This technical memorandum (TM) presents the Sea Level Rise (SLR) Impact Assessment for the California Department of Transportation’s (Caltrans’) proposed Miner Slough Bridge Replacement Project. In addition, it includes information and guidance for planning and design.

1.0 Summary

Caltrans is considering the following three alternatives for the Miner Slough Bridge Replacement Project:

1. no project (e.g., leave the existing bridge as-is),
2. rehabilitate the existing bridge (Alternative 7C), and
3. a new bridge (Alternative 7B), to be built about 100 feet west of the existing bridge.

Because the project site is located in an area vulnerable to SLR and the design life of bridge alternatives is estimated beyond the year 2030, according to Caltrans’s SLR guidance (Caltrans, 2011), an assessment of impacts to SLR is required.

The assessment of SLR impacts on the Miner Slough Bridge Replacement Project presented in this TM included vulnerability and risk assessments, as well as an adaptation assessment and planning. In agreement with Caltrans’ SLR guidance (Caltrans, 2011), SLR projections developed by National Research Council (NRC, 2012) were used in the assessment. A design life of 20 years was assumed for the existing and rehabilitated bridges, and 75 years for new bridge. Assuming the start of the project in 2015, these design lives would result in end lives by the years 2035 and 2090, respectively.

Water levels (river stage) and currents were considered to be the main drivers of processes, which, depending on their severity, could be hazardous to the Miner Slough Bridge. Processes (generally referred herein as hazards) driven by water levels and currents that were preliminary identified were flooding, inundation, bridge clearance, bank erosion, and pier scour.

As a first step in the vulnerability assessment, the effect of SLR on river stage at the Miner Slough Bridge was assessed, given that the river stage is the main driver of most of the hazards identified. CH2M HILL reviewed preexisting California State Department of Water Resources’ Delta Simulation Model II (DSM2) hydraulic numerical model simulations to determine the expected increase in peak stages at the Miner Slough Bridge for a range of SLR conditions. The results indicated that peak stages at the project site would be between 0.1 and 0.9 feet higher than present in 2035, and 0.9 and 3.9 feet in 2090.

Guidance provided by the U.S. Army Corps of Engineers (USACE) to Caltrans references the Sacramento River Flood Control Project and the design hydraulic conditions in USACE (1957) as required for hydraulic analysis, and to receive encroachment permit (Caltrans, 2015a). USACE (1957) provides design flood
conditions, levee and channel profiles for Miner Slough and others including the Sacramento River, Yolo Bypass, etc. The design flood conditions at Miner Slough according to USACE (1957) are a flow of 10,000 cfs and a peak stage of 19.8 feet U.S. Corps of Engineers Datum (USED), which equates to 16.8 feet National Geodetic Vertical Datum of 1929 (NGVD29) or 19.24 feet North American Vertical Datum of 1988 (NAVD88). Caltrans instructed CH2M HILL to use the USACE (1957) design peak stage of 19.24 feet NAVD88 in this SLR impact assessment (Caltrans, 2015b).

For the USACE (1957) design peak stage, the range of stages accounting for SLR is expected to be between 19.4 and 20.2 feet NAVD88 in 2035 for the existing and rehabilitated bridge, and 20.2 and 23.1 feet NAVD88 in 2090 for the new bridge.

Stage and flow drive currents; therefore, as a second step, the impact of SLR on currents was analyzed. On the basis of the hydraulic numerical simulations, it was determined that in SLR conditions, the average current velocity will remain unchanged or slightly decrease for the higher sea level conditions.

The vulnerability assessment indicated that flooding, inundation, bank erosion and pier scour are not hazards for consideration in the SLR impact assessment. The bridges would not be impacted by these hazards as a consequence of SLR. However, flooding is a hazard for north levee and adjacent landward areas.

Title 23 of the California Code of Regulations (CCR) states, in Section 128, that the soffit elevation of the bridge must be 3 feet above the floodplain (design peak stage). Bridge clearance would be a hazard for the bridge alternatives because the clearance required by the CCR would not be satisfied in any of the NRC (2012) SLR scenarios.

To provide initial guidance for planning and design, the following areas, elements and structures were identified as vulnerable in NRC (2012) SLR scenarios:

- **Bridge clearance for the existing, rehabilitated and new bridges**, as required by the CCR, would not be satisfied.
- **The north levee adjacent landward areas** would be vulnerable to flooding.

A risk assessment consisted of assessing the likelihood of an event occurring in the future and assessing the magnitude of the consequences if the event were to occur. The assessment was performed in qualitative manner and indicated that the risk of not meeting the CCR’s bridge clearance requirements was high, and that flooding was a hazard of medium risk for the north levee adjacent landward areas.

Using the results of the risk assessment, the capacity of the Miner Slough Bridge alternatives and north levee adjacent landward areas to adapt to SLR and associated hazards were assessed, and preliminary adaptation measures identified. The following was considered in the adaptation assessment:

- A bridge is a large monolithic structure at a fixed elevation with essentially no adaptation capacity.

For the existing bridge, the risk associated with not complying with the CCR’s 3-foot clearance was assessed as high, and because the bridge is already built its adaptation capacity was assessed as low.

For the rehabilitated bridge, the soffit elevation would not comply with the CCR requirement in the NRC (2012) SLR scenarios in 2035. Its soffit elevation could simply be revised to comply with the CCR requirement, and this would imply a high adaptation capacity. However, because constructability, cost, site characteristics, and environmental implications of raising its soffit elevation are unknown at this time its adaptation capacity was assessed as medium.

For the new bridge, the soffit elevation would not comply with the CCR requirement in the NRC (2012) SLR scenarios in 2090. Its soffit elevation could simply be revised to comply with the CCR requirement, and this would imply a high adaptation capacity. However, because constructability, cost, site
characteristics, and environmental implications of raising its soffit elevation are unknown at this time its adaptation capacity was assessed as medium.

- For the north levee adjacent landward areas, the risk associated with the flooding hazard was assessed as medium. The adaptation capacity of these areas is tied to the adaptation capacity of the levee. Because in 2090 the USACE (1957) design peak stage in the high NRC (2012) SLR scenario is estimated at 23.1 feet NAVD88, only 0.2-foot higher than the levee elevation (22.9 feet NAVD88), the adaptation capacity of the levee, and consequently of the adjacent landward areas, could be assessed as high given the relative ease of increasing the elevation of the levee that small amount. However, given the uncertainties in long-term SLR projections and the unknown length of the stretch of the levee that would require a higher elevation, its adaptation capacity was assessed as medium.

The following adaptation measures are suggested, prioritizing the structures with low adaptation capacity and hazards with high risk:

1. Compliance with the CCR’s 3-foot bridge clearance appears to be the most significant issue for the existing bridge alternative. The possibility relaxing the CCR bridge clearance requirement should be investigated given that its construction date likely precedes the date of the CCR requirement.

2. Similarly, compliance with the CCR’s 3-foot bridge clearance appears to be the most significant issue for the rehabilitated and new bridges. The possibility of increasing their soffit elevations should be evaluated, in addition to exploring the possibility of relaxing the CCR bridge clearance requirement to 2 feet (applicable to minor streams at sites where significant amounts of stream debris are unlikely).

3. SLR monitoring is recommended to determine if climate change and corresponding SLR projections materialize and the need to increasing the north levee elevation.

4. While not derived from the SLR impact assessment presented herein, it is recommended to provide bank and pier scour protection, or monitor these and provide remedial action when needed.

### 2.0 Introduction

The Miner Slough bridge (No. 23-0035) on State Route 84 in Solano County about 30 miles southwest of Sacramento, California, is a swing bridge with nonstandard geometry connecting Ryer Island in the Sacramento River Delta to the mainland over Miner Slough. At the bridge location, the slough is flanked by a 22.9-foot NAVD88 elevation levee to the north, and a 26.6-foot NAVD88 elevation levee to the south (Caltrans, 2015c). It consists of a 55-foot long approach span supported by an abutment and piers on the south side, an approximately 190-foot long truss swing span supported by a central pivot pier, and an approximately 112-foot approach span supported by an abutment and piers on the north side.

For the Miner Slough Bridge Replacement Project, Caltrans is considering the following three alternatives:

1. no project (e.g., leave the existing bridge as-is),
2. rehabilitate the existing bridge (Alternative 7C), and
3. a new bridge (Alternative 7B), to be built about 100 feet west of the existing bridge, featuring approach spans supported on abutments and piers to the north and south of a steel swing span supported by a central pivot pier.

Table 1 shows the bridge elevations (Caltrans, 2015d) and assumed design lives for each alternative. The soffit elevations of the approach spans were used in this SLR impact assessment since these are the lowest. Figure 1 shows an elevation drawing of the existing bridge, Figure 2 shows the rehabilitation alternative (7C), and Figure 3 the new bridge alternative (7B).
TABLE 1
Elevation and Design Life of Miner Slough Bridge Alternatives

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Elevation (feet) NAVD88</th>
<th>Design Life (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Approach Span Soffit*</td>
<td>Swing Span Soffit</td>
</tr>
<tr>
<td>Existing Bridge</td>
<td>20.3 (Abutment 12)</td>
<td>25.01</td>
</tr>
<tr>
<td>Rehabilitation (Alternative 7C)</td>
<td>20.22 (Abutment 6)</td>
<td>25.01</td>
</tr>
<tr>
<td>New Bridge (Alternative 7B)</td>
<td>24.09 (Abutment 5)</td>
<td>24.28</td>
</tr>
</tbody>
</table>
*
soffit elevation used in this SLR impact assessment.

FIGURE 1
Miner Slough Existing Bridge (Caltrans, 2014)

FIGURE 2
Miner Slough Bridge Rehabilitation (Alternative 7C) (Caltrans, 2015e)
The project site is located in an area vulnerable to SLR and the design life of the bridge alternatives is estimated beyond the year 2030. Consequently, and in agreement with Caltrans (2011), the impacts of SLR on the Miner Slough Bridge Replacement Project need to be assessed.

The assessment of SLR impacts on the Miner Slough Bridge Replacement Project consisted of the following:

1. **Vulnerability assessment**
   - Selection of SLR projection
   - Identification of hazards
   - Identification of vulnerabilities
2. **Risk assessment**
3. **Adaptation assessment and planning**

The **vulnerability assessment** involved the selection of SLR projections; definition of the hazards and processes that affect and/or could affect the project site; and identification of areas, components, and/or assets of the project that would be vulnerable to SLR.

The **risk assessment** combined the likelihood that future hazards associated with SLR would occur, with the magnitude or severity of the consequences of those hazards taking place.

The **adaptation assessment and planning** used the results of the risk assessment to identify, assess, and plan measures so that potential impacts and consequences are mitigated.

### 3.0 Vulnerability Assessment

#### 3.1 SLR Projections

Caltrans (2011) provided interim SLR projections developed by Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT) so that the impacts of SLR on State projects could be assessed while SLR projections for the states of California, Oregon, and Washington were developed by the NRC (2012) as mandated by Governor Arnold Schwarzenegger’s Executive Order (EO) S-13-08.

At the time of this SLR impact assessment for the Miner Slough Bridge Replacement Project, the NRC (2012) report had already been released. Table 2 shows the NRC (2012) SLR projections for San Francisco (referred to the year 2000) for low (B1), medium (A1B), and high (A1FI) greenhouse gas emissions scenarios and for years 2030, 2050, and 2100. Figure 4 presents interpolated curves of these projections between the years 2000 and 2100. The projections are based on ice loss rates for glaciers and ice caps except Alaska, Greenland, and Antarctica.
3.2 Identification of Hazards

Water levels (river stage) and currents are considered to be the main drivers of processes, which, depending on their severity, could be hazardous to the Miner Slough Bridge. In addition, the following processes (generally referred herein as hazards), driven by water levels and currents, were preliminarily identified for analysis:

- **Flooding** (the process of a dry area becoming periodically or episodically submerged)
- **Inundation** (the process of a dry area becoming permanently submerged)
- **Bridge clearance** (the vertical distance between the water level and the bottom of the bridge)
- **Bank erosion** (the process of removal of sediment from the slough banks)
- **Pier scour** (the process of removal of sediment from around the piers at the bottom)

As a first step in the identification of hazards, the effect of SLR on river stage at the Miner Slough Bridge was assessed, given that the river stage is the main driver of most of the hazards identified. Estimations were
performed with numerical hydraulic simulations previously performed by CH2M HILL throughout the Delta. Estimates of peak daily stage for a range of SLR conditions were computed with the latest version of the DSM2 model. The latest version of the DSM2 model—a one-dimensional hydraulic model that is used extensively to model flows, stage, and salinity in the Delta—updated the vertical datum to NAVD88. CH2M HILL are recognized experts in the application of the DSM2 model and have previously applied it to support large regional planning projects, such as the Bay Delta Conservation Plan (BDCP). The model accurately represents Miner Slough, which is a subsidiary channel of the main Sacramento River connected through Sutter Slough.

A historic simulation spanning from 1996 to 2006 was performed as a validation exercise to demonstrate the performance of the model. This time period covers the largest flows on record in several portions of the Delta, which are considered representative of the 100-year flood event. Results from this simulation provide the best available estimates of river stage at Miner Slough during extreme flow events.

The 10-year-long DSM2 hydraulic simulation covered a wide range of hydrologic conditions, from dry years to record-breaking wet years (e.g., 1997). Figure 4 shows a time series of the peak daily stage and flow at Miner Slough Bridge as predicted by the DSM2 model. The circles represent three distinct periods where high resolution stage data was available through the Department of Water Resources’ (DWR’s) Water Data Library website to allow a comparison of model predictions to field measurements.

FIGURE 4
DSM2-Predicted Peak Daily Stage and Flow at Miner Slough Bridge

Figure 5 through Figure 7 show the predicted and measured stages for the three periods noted in Figure 4. The agreement is very good and demonstrates the good performance and confidence in the predictions of the DSM2 model. Measured data was obtained from the U.S. Geological Survey (USGS) website, Station 11455165 (USGS, 2015). Data collected prior to October 1, 2005, were corrected to the NAVD88 datum by subtracting 6.34 feet from the gage datum, based on a personal communication with Patricia Orlando at the California Water Science Center/USGS Sacramento Office. Figure 8 provides more detail of the predicted
stage at the Miner Slough Bridge during the January 1997 flood event, the largest on record for many rivers in the Delta. The predicted peak stage during that flood event is 15.8 feet NAVD88.

FIGURE 5
DSM2-predicted and USGS-measured Stage and Miner Slough Bridge, February/March 2004

FIGURE 6
DSM2-predicted and USGS-measured Stage and Miner Slough Bridge, May 2005

FIGURE 7
DSM2-predicted and USGS-measured Stage and Miner Slough Bridge, December 2005/January 2006
As part of the BDCP analysis, CH2M HILL performed simulations of a set of potential future SLR conditions represented by increases at the downstream boundary (San Francisco Bay) of 15, 45, 60, and 140 cm. Peak stages at the Miner Slough Bridge for each of these conditions were extracted from existing model simulations and used to develop curves that show how the SLR is expected to change peak stage at the Miner Slough Bridge between the years 2000 and 2100, the time range of reference for the NRC (2012) projections. From these curves, results can be extracted to quantify expected future stage conditions in 2035 and 2090, for the corresponding assumed 20 and 75-year design lives of the bridge alternatives.

Figure 9 presents a scatter plot showing the relationship between flow and stage at the Miner Slough Bridge for four SLR conditions and a baseline condition consisting of no SLR (e.g., current sea level). The scatter in the plots shows the influence of the tide on predicted stage at the Miner Slough Bridge. Linear regressions of the data show that for larger instances of SLR, there is a reduction in the slope of the relationship between stage and flow. In other words, the difference in peak daily stage between any two of the linear regressions is larger for low than for high flows.
Figure 10 presents an alternate view of the results presented in Figure 9, showing the model predictions in terms of the change in peak daily stage for the four SLR conditions. It is clear that as flow increases, the change in peak stage for a given SLR decreases. During low flow conditions (less than 2,000 cfs), the full SLR increase projected in San Francisco Bay (the downstream boundary) is propagated through the Delta channels to Miner Slough. There is no damping of the SLR with distance up the Delta to this location during low flow conditions. During high flow conditions (greater than 11,500 cfs), however, there is significant damping, such that the projected increase in peak stage at the Miner Slough Bridge associated with SLR is 64 to 72 percent of what would be seen in San Francisco Bay. These statistics are summarized in Table 3 where, in addition, results for the 10,000 cfs design flow condition required for hydraulic analysis by the USACE (1957) are included. Results for all days with flows within 5% of 10,000 cfs were reviewed and the highest value was selected to maintain a degree of conservatism in the analysis.
FIGURE 10
Change in Peak Daily Stage versus Flow for Various SLR Conditions

TABLE 3
Summary Predicted Changes in Stage at the Miner Slough Bridge as a Function of SLR Conditions for Low, USACE (1957) Design and High Flows

<table>
<thead>
<tr>
<th>SLR at San Francisco Bay, cm (feet)</th>
<th>15 (0.49)</th>
<th>45 (1.48)</th>
<th>60 (1.97)</th>
<th>140 (4.59)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Flow (&lt;2,000 cfs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in Stage, cm (feet)</td>
<td>15 (0.49)</td>
<td>45 (1.48)</td>
<td>60.3 (1.98)</td>
<td>140.4 (4.61)</td>
</tr>
<tr>
<td>Percent of Rise at Boundary</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>USACE (1957) Design Flow (10,000 cfs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in Stage, cm (feet)</td>
<td>11 (0.37)</td>
<td>34.3 (1.12)</td>
<td>46.7 (1.53)</td>
<td>115.7 (3.80)</td>
</tr>
<tr>
<td>Percent of Rise at Boundary</td>
<td>74%</td>
<td>76%</td>
<td>78%</td>
<td>83%</td>
</tr>
<tr>
<td>High Flow (&gt;11,500 cfs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in Stage, cm (feet)</td>
<td>9.6 (0.31)</td>
<td>29.9 (0.98)</td>
<td>41.0 (1.34)</td>
<td>100.6 (3.30)</td>
</tr>
<tr>
<td>Percent of Rise at Boundary</td>
<td>64%</td>
<td>67%</td>
<td>68%</td>
<td>72%</td>
</tr>
</tbody>
</table>

Figure 11 presents the estimated absolute peak stage at the Miner Slough Bridge for the 19.24 feet NAVD88 USACE (1957) design peak stage and the NRC (2012) SLR scenarios. Each curve is a fit to the predicted peak stage estimated with the DSM2 model for the four SLR conditions (e.g., 15, 45, 60, and 140 cm) simulated with the model.

For each SLR condition, the results were plotted in the year in which the SLR was projected to occur for each of the three NRC (2012) projections. For example, the 15-cm SLR condition yielded 10 cm (or 0.3 foot) of SLR during peak flows at Miner Slough Bridge. When added to the 19.24-foot NAVD88 design peak stage, this
yields a 19.54-foot NAVD88 peak stage. This result was projected to occur in 2055 for the low scenario, in 2031 for the medium, and 2018 for the high scenario. Thus, there are three points in Figure 11 at the 19.54-foot NAVD88 peak stage occurring in 2018, 2031, and 2055. Similar points were added for the 45, 60, and 140-cm SLR conditions. Polynomial curves were then fit to the points, and values for 2090 were extracted from the curves.

**FIGURE 11**
Peak Stage at the Miner Slough Bridge for the USACE (1957) design peak stage (19.24 feet NAVD88) and NRC (2012) SLR Scenarios

Stage and flow drive currents; therefore, as a second step in the identification of hazards, the impact of SLR on currents was analyzed. The DSM2 model provides channel average current velocities in addition to stage and flow. Velocities at the Miner Slough Bridge were extracted from model simulations to determine the influence of SLR on peak current velocities. Figure 12 presents the frequency distribution of the peak daily velocity at the project site for four SLR conditions, and a baseline condition consisting of no SLR (e.g., current sea level), covering a 16-year period. Results show that in SLR conditions the average current velocity will remain unchanged or slightly decrease for the higher sea level regimes. This is attributable to the increase in cross-sectional area available for the flow that comes with SLR.
The effects of SLR on stage and current velocity for the low, medium and high NRC (2012) SLR scenarios at the Miner Slough Bridge (bridge and levees) were used to determine the relevance of the following preliminarily identified hazards:

- **Flooding** (the process of a dry area becoming periodically or episodically submerged)
  
  i) for the existing bridge, with a soffit elevation of 20.3 feet NAVD88, flooding is *not considered a hazard* because in 2035 the USACE (1957) design peak stages in all NRC (2012) SLR scenarios would be lower than the bridge soffit (19.4 (low), 19.7 (medium) and 20.2 feet NAVD88 (high) < 20.3 feet NAVD88).
  
  ii) for the rehabilitated bridge (Alternative 7C), with a soffit elevation of 20.22 feet NAVD88, flooding is *not considered a hazard* because in 2035 the USACE (1957) design peak stages in all NRC (2012) SLR scenarios would be lower than the bridge soffit (19.4 (low), 19.7 (medium) and 20.2 feet NAVD88 (high) < 20.22 feet NAVD88).
  
  iii) for the new bridge (Alternative 7B), with a soffit elevation of 24.09 feet NAVD88, flooding is *not considered a hazard* because in 2090 the USACE (1957) design peak stage in all NRC (2012) SLR scenarios would be lower than the bridge soffit (20.2 (low), 21.1 (medium) and 23.1 feet NAVD88 (high) < 24.09 feet NAVD88).
  
  iv) for the north levee adjacent landward areas, flooding is *considered a hazard* because in 2090 the USACE (1957) design peak stages in the high NRC (2012) SLR scenarios would be higher than the levee (23.1 feet NAVD88 > 22.9 feet NAVD88).
  
  v) for the south levee adjacent landward areas, flooding is *not considered a hazard* because in 2090 the USACE (1957) design peak stages in all NRC (2012) SLR scenarios would be lower than the levee (20.2 (low), 21.1 (medium) and 23.1 (high) feet NAVD88 < 26.6 feet NAVD88).

- **Inundation** (the process of a dry area becoming permanently submerged). For the existing, rehabilitated and new bridges with soffit elevations of 20.3, 20.22 and 24.09 feet NAVD88, respectively, inundation is
not considered a hazard because peak stages are episodic events of relatively short duration, and the bridge soffits are sufficiently high to prevent inundation.

For the north levee adjacent landward areas, inundation is not considered a hazard because, while the levee would be overtopped, the land would be flooded but not inundated.

For the south levee adjacent landward areas, inundation is not considered a hazard because the levee would not be overtopped.

- **Bridge clearance** (the vertical distance between the water level and the bottom of the bridge)
  
  i) for the existing bridge, with a soffit elevation of 20.3 feet NAVD88 and a CCR required clearance of 3 feet, bridge clearance is considered a hazard because in 2035 the USACE (1957) design peak stages in all NRC (2012) SLR scenarios would be higher than the bridge soffit minus the CCR required clearance (19.4 (low), 19.7 (medium) and 20.2 (high) feet NAVD88 > 20.3 – 3 = 17.3 feet NAVD88). It is noted that for the current sea level, the bridge clearance is a hazard because the soffit elevation minus the CCR required clearance is less than the USACE (1957) design stage (20.3 – 3 = 17.3 feet NAVD88 < 19.24 feet NAVD88).

  ii) for the rehabilitated bridge, with a soffit elevation of 20.22 feet NAVD88 and a CCR required clearance of 3 feet, bridge clearance is considered a hazard because in 2035 the USACE (1957) design peak stages in all NRC (2012) SLR scenarios would be higher than the bridge soffit minus the CCR required clearance (19.4 (low), 19.7 (medium) and 20.2 (high) feet NAVD88 > 20.22 – 3 = 17.22 feet NAVD88).

  iii) for the new bridge, with a soffit elevation of 24.09 feet NAVD88 and a CCR required clearance of 3 feet, bridge clearance is considered a hazard because in 2090 the USACE (1957) design peak stages in the medium and high NRC (2012) SLR scenarios would be higher than the bridge soffit minus the CCR required clearance (21.1 (medium) and 23.1 (high) feet NAVD88 > 24.09 – 3 = 21.09 feet NAVD88).

- **Bank erosion** (the process of removal of sediment from the slough). The analysis of the effect on SLR on current velocity showed that currents would remain unchanged or slightly decrease. Therefore, the bank erosion hazard is not considered relevant.

- **Pier scour** (the process of removal of sediment from around piers at the bottom). Similarly to bank erosion, pier scour is a function of current velocity. For the same reasons outlined for the bank erosion hazard, the pier scour hazard is not considered relevant.

### 3.3 Identification of Vulnerabilities

To provide initial guidance for planning and design, the following areas, elements and structures were identified as vulnerable in NRC (2012) SLR scenarios:

- **Bridge clearance** for the existing, rehabilitated and new bridges, as required by the CCR, would not be satisfied.

- **The north levee adjacent landward areas** would be vulnerable to flooding.

### 4.0 Risk Assessment

A risk assessment consists of assessing the likelihood of an event occurring in the future and assessing the magnitude of the consequences if the event were to occur. The assessment was performed in qualitative manner for three different levels of magnitude of consequences and likelihood of occurrence - low, medium,
and high. The levels used for the likelihood of occurrence, although based upon the SLR projections, are qualitative.

The following summarizes the rationale behind the risk assessment:

- The likelihood of a bridge clearance of less than the 3 feet as required by the CCR is high because, for all bridge alternatives, the soffit elevation minus the CCR required clearance would be less than the USACE (1957) design peak stages in all NRC (2012) SLR scenarios in 2090 for the new bridge, and in 2035 for the existing and rehabilitated bridges. The consequence of not satisfying this requirement was assessed as high because a permit may not be issued.

- The likelihood of occurrence of overtopping the north levee and flooding of adjacent landward areas due to a USACE (1957) design peak stage in a high NRC (2012) SLR scenario in 2090 (23.1 feet NAVD88 > 22.9 feet NAVD88) is assessed as low, given an assumed low likelihood of the high SLR scenario to occur. However, the consequence of such an event could be very damaging and, therefore, the consequence was assessed as high.

Table 4 shows the risk assessment for the bridge alternatives and adjacent landward areas of the north levee. Colors from green to red indicate increasing level of risk, where hazards in red would have the highest priority for adaptation because these will have the highest consequences and will occur more frequently.

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Likelihood of Occurrence</th>
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<tbody>
<tr>
<td>Low</td>
<td>Low, Medium, High</td>
</tr>
<tr>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>High</td>
<td>Flooding\textsuperscript{b}</td>
</tr>
</tbody>
</table>

\textsuperscript{a} – existing, rehabilitated and new bridges
\textsuperscript{b} – north levee adjacent landward areas

5.0 Adaptation Assessment and Planning

Using the results of the risk assessment, the capacity of the Miner Slough Bridge alternatives and north levee adjacent landward areas to adapt to SLR and associated hazards were assessed, and preliminary adaptation measures identified. Table 5 presents the adaptation assessment.

The following summarizes the rationale behind the adaptation assessment:

- A bridge is a large monolithic structure at a fixed elevation with essentially no adaptation capacity.

  For the existing bridge, the risk associated with not complying with the CCR’s 3-foot clearance was assessed as high, and because the bridge is already built its adaptation capacity was assessed as low.

  For the rehabilitated bridge, the soffit elevation would not comply with the CCR requirement in the NRC
(2012) SLR scenarios in 2035. Its soffit elevation could simply be revised to comply with the CCR requirement, and this would imply a high adaptation capacity. However, because constructability, cost, site characteristics, and environmental implications of raising its soffit elevation are unknown at this time its adaptation capacity was assessed as medium.

For the new bridge, the soffit elevation would not comply with the CCR requirement in the NRC (2012) SLR scenarios in 2090. Its soffit elevation could simply be revised to comply with the CCR requirement, and this would imply a high adaptation capacity. However, because constructability, cost, site characteristics, and environmental implications of raising its soffit elevation are unknown at this time its adaptation capacity was assessed as medium.

- For the north levee adjacent landward areas, the risk associated with the flooding hazard was assessed as medium. The adaptation capacity of these areas is tied to the adaptation capacity of the levee. Because in 2090 the USACE (1957) design peak stage in the high NRC (2012) SLR scenario is estimated at 23.1 feet NAVD88, only 0.2-foot higher than the levee elevation (22.9 feet NAVD88), the adaptation capacity of the levee, and consequently of the adjacent landward areas, could be assessed as high given the relative ease of increasing the elevation of the levee that small amount. However, given the uncertainties in long-term SLR projections and the unknown length of the stretch of the levee that would require a higher elevation, its adaptation capacity was assessed as medium.

| TABLE 5 |
|----------------------|----------------------|----------------------|
| **Adaptation Capacity of the Bridge Alternatives and North Levee Adjacent Landward Areas** |
| **Hazard**            | **Risk** | **Adaptation Capacity** |
| Bridge Clearance (existing bridge) | High | Low |
| Bridged Clearance (rehabilitated bridge) | High | Medium |
| Bridge Clearance (new bridge) | High | Medium |
| Flooding (north levee adjacent landward areas) | Medium | Medium |

The following adaptation measures are suggested, prioritizing the structures with low adaptation capacity and hazards with high risk:

1. Compliance with the CCR’s 3-foot bridge clearance appears to be the most significant issue for the existing bridge alternative. The possibility relaxing the CCR bridge clearance requirement should be investigated given that its construction date likely precedes the date of the CCR requirement.

2. Similarly, compliance with the CCR’s 3-foot bridge clearance appears to be the most significant issue for the rehabilitated and new bridges. The possibility of increasing their soffit elevations should be evaluated, in addition to exploring the possibility of relaxing the CCR bridge clearance requirement to 2 feet (applicable to minor streams at sites where significant amounts of stream debris are unlikely).

3. SLR monitoring is recommended to determine if climate change and corresponding SLR projections materialize and the need to increasing the north levee elevation.

4. While not derived from the SLR impact assessment presented herein, it is recommended to provide bank and pier scour protection, or monitor these and provide remedial action when needed.
6.0 References


Caltrans. 2015c. Email from Caltrans’ Pawan Gupta dated April 30, 2015.

Caltrans. 2015d. Email from Caltrans’ Keith Nakaoka dated August 6, 2015.


