5-2019

# Caltrans Eureka-Arcata Corridor: Sea Level Rise Vulnerabilities and Adaptation Solutions

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May 21, 2019

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## INTRODUCTION

Caltrans is proposing to improve unsafe portions of the Highway 101 Eureka-Arcata Corridor (the Corridor). This includes the Indianola Road / Highway 101 Intersection, Jacoby Creek Bridge, and four tide gates. Further details on the Corridor project can be referenced in the Caltrans Project Information document as part of the Coastal Development Permit application. Figure 1 shows the location of the proposed developments analyzed in this report within the project area.[1]

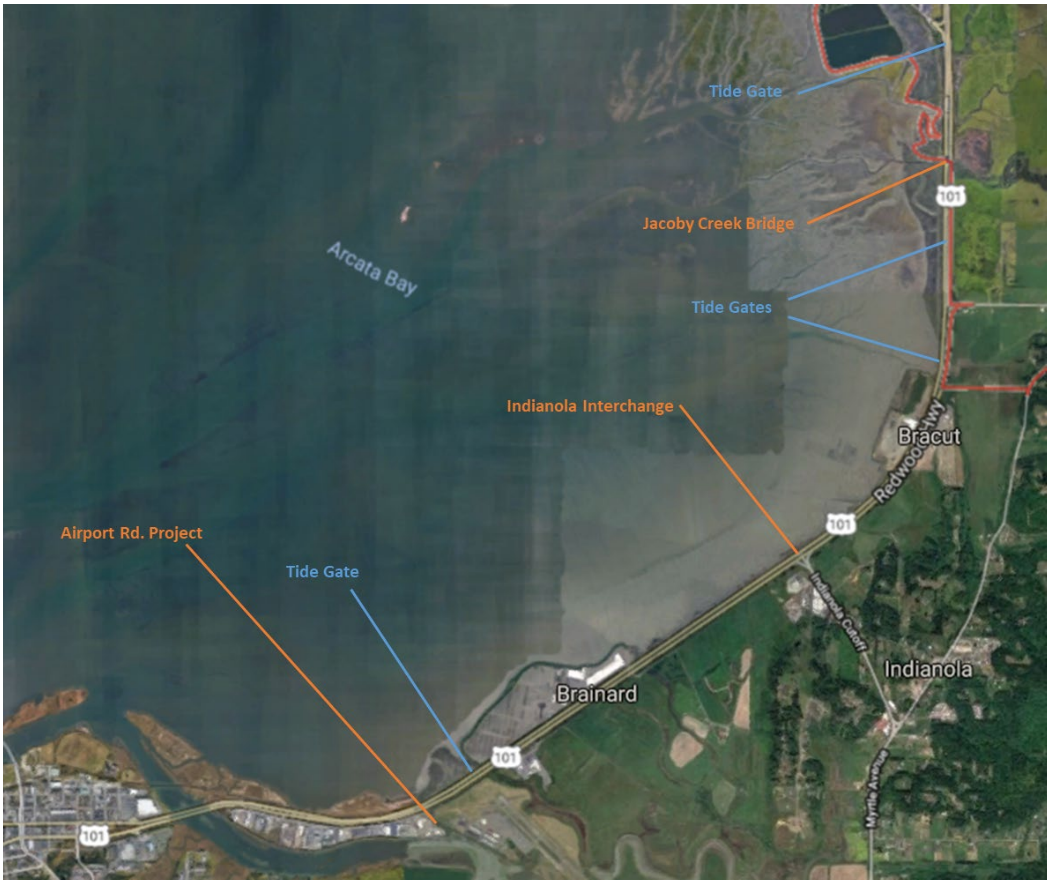

*Figure 1. Locations of the proposed developments analyzed in this report within Highway 101 Eureka-Arcata Corridor.*

Recent studies in the Humboldt Bay region have found this specific area is potentially vulnerable to inundation from projected sea level rise (SLR) (Anderson and Laird 2018, Laird 2018). California Coastal Commission (CCC) staff has recommended that Caltrans consider vulnerabilities and potential adaptation measures for new developments in accordance with the most recent CCC SLR guidance for Coastal Development Permits (CCC 2018).

In this report, the vulnerability of the proposed Caltrans projects to SLR and other coastal hazards is analyzed. The analysis enables identification of a range of adaptation options for the proposed projects. The analysis addresses the following planning needs.

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[1] Note that not all assets in the CDP package are included in this assessment. We only assess the proposed developments that will be significantly impacted by SLR in the future.

- Projected SLR range for the project site area.

- Projected SLR hazard impacts to Corridor service, incorporating storm surge, wave run up, and erosion.

- Projected impacts from the combination of the proposed Corridor projects and SLR hazards to local coastal resources.

- Project adaptation solutions that avoid these impacts and minimize risks to the projects and coastal resources.

- Considerations for long-term Caltrans adaptation planning efforts for the project area and broader Humboldt Bay region.

In the SLR and adaptation assessment, the research team only considered impacts directly related to the proposed developments using the CCC guidance. Beyond those project elements, the report cursorily discusses potential impacts and adaptation needs for other community and Caltrans assets (e.g., lower-lying adjacent roads leading to the project elements) as part of the broader regional adaptation effort, but does not explicitly address risks and adaptation needs for those assets outside the development scope. As a result, the proposed projects analyzed in this assessment represent an initial stage in Caltrans's overall rehabilitation and adaptation goals for the Corridor and Humboldt Bay region at large. Throughout this document, and particularly in the Adaptation Planning section, the findings fit within this ongoing long-term adaptation strategy development. The following sections detail the approach and results from the SLR vulnerability and adaptation solution assessments.

## SEA LEVEL RISE VULNERABILITY ANALYSIS

### Sea Level Rise Projections from Existing Reports

This analysis uses the previously mentioned guidance from the CCC's Sea Level Rise Policy Guidance, adopted in 2018. Based on that guidance and CCC staff feedback to Caltrans (CCC 2019), this report evaluated vulnerabilities under the CCC low, medium-high, and extreme risk aversion scenarios for the project lifetimes out to 2100 (end of century).

The analysis draws on several recent reports that provide detailed analyses of risks and vulnerabilities for the Corridor and are based on local SLR projections that are drawn from CCC guidance published prior to the latest 2018 CCC report. All of these previous SLR studies evaluated scenarios lower than the latest CCC medium-high and extreme risk aversion scenarios, but nonetheless provide useful information in the context of higher SLR projections. These three previous assessments include the following.

- **Humboldt Bay Area Plan – Sea Level Rise Vulnerability Assessment (Laird 2018):** Using a 5.4-feet of SLR by 2100 scenario at the Mad River Slough to Hookton Slough tide gauge, this assessment projects significant inundation of the Highway 101 Corridor segments.

- **City of Arcata Sea Level Rise Risk Assessment (Anderson and Laird 2018):** This assessment uses a 6.5-feet of SLR by 2100 scenario at the Arcata Wharf tide gauge. The report's vulnerability assessment is limited to risks to local groundwater resources from SLR.

- **District 1 Climate Change Vulnerability Assessment and Pilot Studies (Caltrans 2014):** This report assesses infrastructure vulnerabilities to climate hazards along the Highway 101 Corridor in the Humboldt Bay region. The SLR assessment includes vulnerability scores and potential adaptation solutions for local transportation assets and uses a SLR scenario of 5.8 feet by 2100 at the Mad River Slough to Hookton Slough tide gauges.

Based on the 2018 CCC SLR guidance and using the North Spit tide gauge, the analysis in this report uses a low risk SLR scenario of 4.1 feet by 2100, a medium-high of 7.6 feet, and an extreme risk of 10.9 feet.

Table 1 compares the SLR scenarios of the three local studies and the CCC guidance scenarios considered in this study.

*Table 1. SLR scenario comparison for this study and local vulnerability studies.*

| Study | SLR Scenarios (2100 Reference Year) | Tide Gauge Scope | Geographic Scope |
|---|---|---|---|
| Highway 101 Corridor Vulnerability and Adaptation Solutions (this Report) | Low: 4.1 ft<br>Medium-High: 7.6 ft<br>Extreme: 10.9 ft | Mad River Slough to Arcata Wharf | Highway 101 Corridor |
| Humboldt Bay Area Plan | 5.4 ft | Mad River Slough to Hookton Slough | Humboldt Bay |
| City of Arcata Vulnerability Study - NHE SLR Report | 6.5 ft | Arcata Wharf | City of Arcata - Groundwater Supply |
| City of Arcata Vulnerability Study - Trinity Consultants Report | 4.9 ft | Mad River Slough, Arcata Wharf | City of Arcata |
| Caltrans District 1 Climate Change Vulnerability | 5.8 ft | Mad River Slough to Hookton Slough | Highway 101 Corridor |

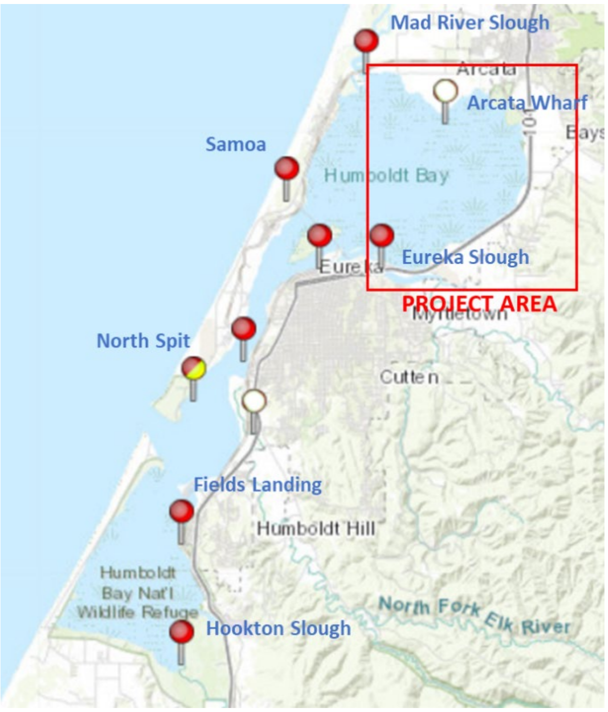

*Figure 2. Local tide gauges used in this study and other vulnerability studies adjacent to the Highway 101 Corridor Project Area (NOAA 2019)[2].*

While the studies previous undertaken in area do not meet the CCC guidance scenarios for total SLR by 2100, those studies offer key insights for "trigger levels" where the Corridor may experience significant impacts from SLR hazards.

The recent Humboldt Bay Area Plan's vulnerability assessment scope is similar to this assessment. The author modeled the Corridor's current vulnerability to projected SLR (Laird 2018).  shows the tidal inundation resulting from 4.9 ft of SLR by 2100 combined with the mean monthly maximum water level (MMMW), where both north and south lanes of the Corridor are inundated. The study does not consider adaptation options for Corridor to prevent service disruptions from SLR.

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[2] Map key for tide gauges:

- Red and yellow – water level, meteorological, and harmonic tide prediction data available
- Red only – water level and harmonic tide prediction data available
- White only – subordinate tide prediction data available

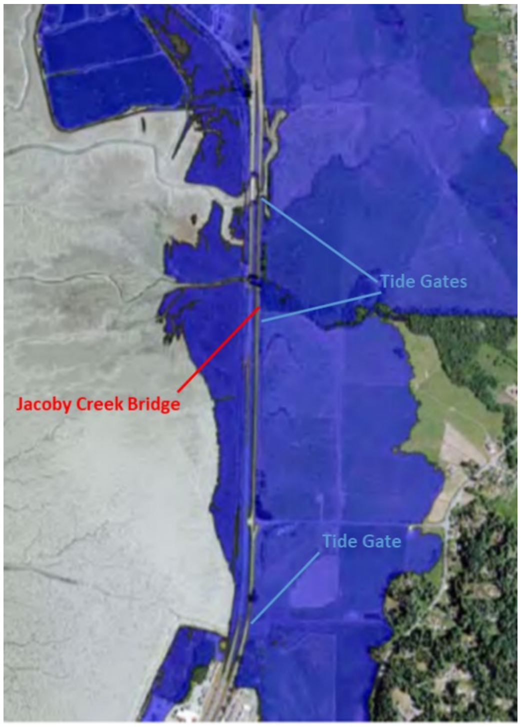

*Figure 3. Tidal inundation in the northern portion of the Corridor with 4.9 ft of SLR by 2100 (Laird 2018).*

## Existing Conditions

The previously discussed reports have documented the existing vulnerabilities and coastal protection measures associated with SLR and other coastal hazards. Anderson and Laird (2018) documented the historical increase in annual maximum high tide elevations (i.e., king tides) at the North Spit gauge (Figure 4). The 2005 high tide event shown in Figure 4 was coupled with storm surge to create the highest recorded tidal elevation in Humboldt Bay at over 9.5 ft.

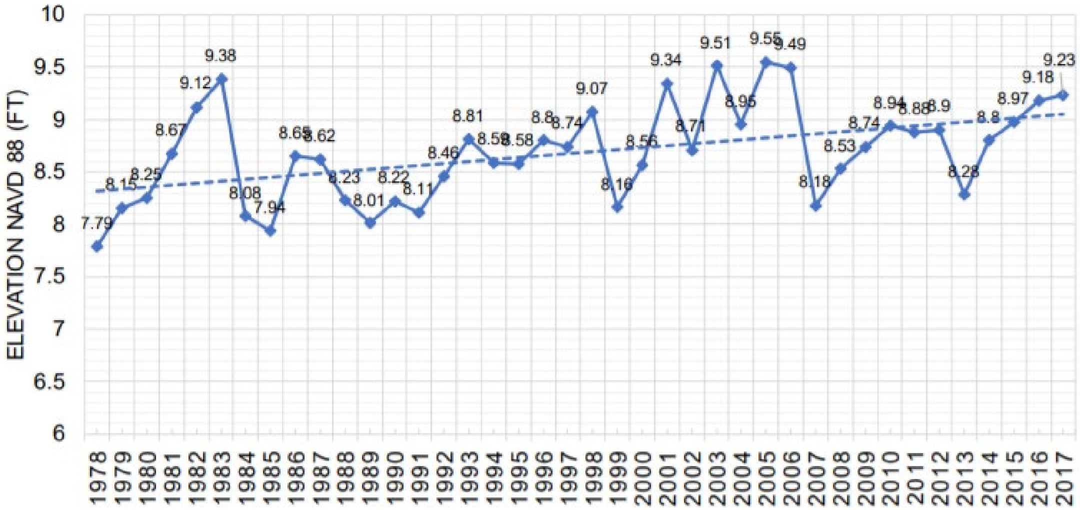

*Figure 4. Annual maximum high tide elevations (Laird 2018).*

Dikes protect much of the project area, most of which were built over 100 years ago (Laird 2018). However, these structures can be susceptible to overtopping, as occurred in the 2005 event. Along the Corridor, these dikes and the Highway 101 road grade provide protection for the community and Caltrans assets against high tide, storm surge, and wave impacts. Figure 5 shows an existing dike (in the form of a railroad grade) adjacent to the proposed Indianola Interchange.

*Figure 5. Existing dike (as a railroad grade) near proposed Indianola Interchange.*

Many of the dikes in the project area are controlled by private land owners, such as the North Coast Rail Authority (NCRA) and the California Department of Fish and Wildlife (CDFW). These dikes are not of uniform height and, as a result, there will likely be different levels of flooding along the Corridor, given that some locations will experience overtopping first. Figure 6 and Figure 7 show the recent Humboldt Bay Area Plan's vulnerability ratings for the shoreline segments along the Corridor. The most vulnerable segments have the lowest elevation dikes in red, which are less two feet higher than MMMW (Laird 2019).

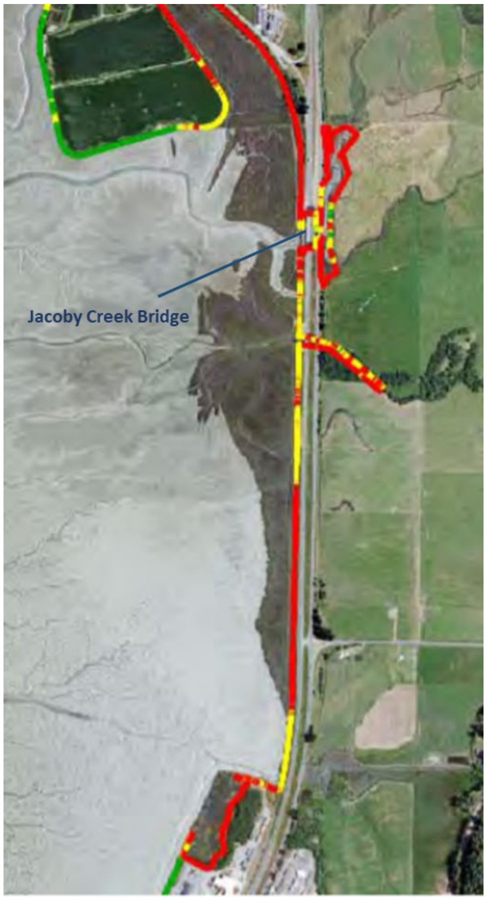

*Figure 6. Vulnerability ratings for the upper portion of the Corridor shoreline: high (red), moderate (yellow), and low (green) (Laird 2018).*

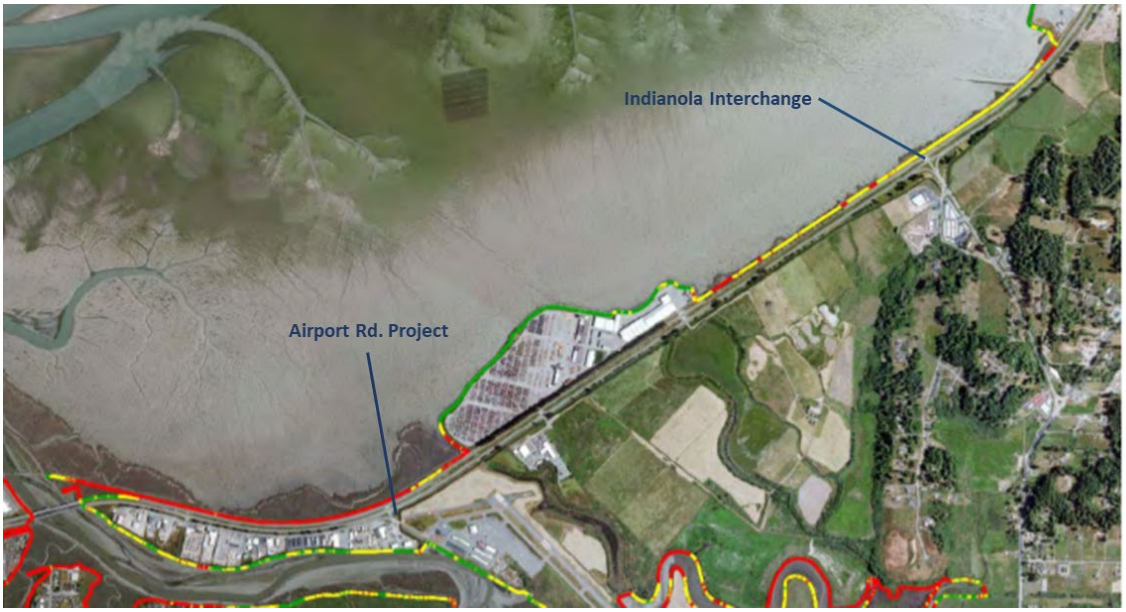

*Figure 7. Vulnerability ratings for the lower portion of the Corridor shoreline (Laird 2018).*

Note that in the previous Figures the Jacoby Creek Bridge does not have a dike providing protection from overtopping, but the Indianola Interchange does have moderate protection. For the proposed Corridor developments, we assess scenarios for SLR creating overtopping events in the following section.

## Highway 101 Corridor Proposed Development Vulnerability

For this proposed project, the research team assessed the vulnerabilities for tide gate replacements, the Jacoby Creek Bridge rehabilitation, and the construction of the Indianola interchange. The impacts of SLR and other coastal hazards to each proposed project are examined using results from existing local vulnerability studies, CCC guidance, and design specifications.

### *Analysis Timelines*

SLR vulnerabilities to the proposed project are evaluated over each asset's design lifetime. Table 2 shows these asset design lifetimes, and includes a general timeline for Caltrans's broader, long-term adaptation planning effort for the project area and broader Humboldt Bay region.

***Table 2. Timelines considered in this analysis.***

| **Asset/Planning Effort** | **Design Lifetime/ Analysis Period** |
|---|---|
| Tide Gates (four in total) | 25 years (2045) |
| Guardrails[3] | 30 years (2050) |
| Indianola Interchange | 80 years (2100) |
| Jacoby Creek Bridge | |
| Long-Term Regional Caltrans Adaptation Planning | Beyond 2100 |

### *Sea Level Rise Thresholds*

Caltrans has proposed to adopt an adaptive management approach to integrate SLR risk into the project design and operations. For both the proposed Highway 101 Indianola Interchange and Jacoby Creek Bridge, the structures will be raised to protect against future inundation from SLR and other hazards. In the current design, the Highway 101 grade separation at Indianola Cut-off will be raised 2.4 feet to 12 feet (currently 9.6 feet) in the construction of the Interchange, and Jacoby Creek Bridge will be raised to 2.3 feet to 13.8 feet (currently 11.5 feet).[4] These new design elevations are higher than the existing dike protections (see Table 6). The bottom elevations for the new bridges are only slightly higher (less than 0.5 feet) than the current bridge bottom elevations. However, Caltrans designed the new bridges to

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[3] Guardrails are not explicitly considered in this assessment, but will be incorporated into any future adaptation plans in the proposed developments or Corridor as a whole.

[4] Elevations in NAVD88 vertical datum (Lark 2019).

have a greater weight than buoyant forces to prevent any potential damage from uplift. Additional measures are integrated into the design to allow future adaptation in the long term that are outlined in the Adaptation Planning section.

In Table 3 methods from the Adapting to Rising Tides program are applied to identify when these design elevations will be overtopped in CCC's current scenario guidance (ART 2019). These elevations add the risk aversion scenario SLR values from the CCC guidance scenarios to the North Spit tide gauge mean annual maximum water (MAMW) height of 8.8 feet (Laird 2018).[5] MAMW occurs approximately four times per year in Humboldt Bay (Laird 2019). To adjust for local tidal elevations at the project site, 0.89 ft has been added to the MAMW based on feedback from Caltrans design engineers (Lark 2019). The following equation details how each elevation relative to NAVD88 was calculated using North Spit MAMW levels.

$$E_{Corridor} = MAMW_{NS} + SLR_{NS} + E_{Adj}$$

Where:

- $E_{Corridor}$ = Projected water level at Highway 101 Corridor for a given year relative to NAVD88
- $MAMW_{NS}$ = Mean annual maximum water level at North Spit tide gauge (8.8 ft)
- $SLR_{NS}$ = Projected SLR using the risk aversion scenarios from CCC for a given year
- $E_{adj}$ = Elevation adjustment from North Spit tide gauge to Corridor (0.89 ft)

Table 3 shows the proposed elevations of the Highway 101 Indianola Interchange and Jacoby Creek Bridge against expected tidal elevations under the risk aversion scenarios to identify when these structures might be overtopped under each water-level scenario.

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[5] Elevations in NAVD88 vertical datum.

*Table 3. Projected MAMW, MHHW, and MMMW elevations in project area (ft. above NAVD88) under the CCC risk aversion SLR scenarios, versus critical infrastructure thresholds for the Highway 101 Indianola Interchange and Jacoby Creek Bridge.*

| | Low Risk Aversion (ft.) | | | | Medium-High Risk Aversion (ft.) | | | | Extreme Risk Aversion (ft.) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **SLR Value** | **MAMW** | **MMMW** | **MHHW** | **SLR Value** | **MAMW** | **MMMW** | **MHHW** | **SLR Value** | **MAMW** | **MMMW** | **MHHW** |
| 2030 | 0.7 | 10.4 | 9.3 | 8.1 | 1.0 | 10.7 | 9.6 | 8.4 | 1.2 | 10.9 | 9.8 | 8.6 |
| 2040 | 1.1 | 10.8 | 9.7 | 8.5 | 1.6 | 11.3 | 10.2 | 9.0 | 2.0 | 11.7 | 10.6 | 9.4 |
| 2050 | 1.5 | 11.2 | 10.1 | 8.9 | 2.3 | 12.0 | 10.9 | 9.7 | 3.1 | 12.8 | 11.7 | 10.5 |
| 2060 | 1.9 | 11.6 | 10.5 | 9.3 | 3.1 | 12.8 | 11.7 | 10.5 | 4.3 | 14.0 | 12.9 | 11.7 |
| 2070 | 2.4 | 12.1 | 11.0 | 9.8 | 4.0 | 13.7 | 12.6 | 11.4 | 5.6 | 15.3 | 14.2 | 13.0 |
| 2080 | 2.9 | 12.6 | 11.5 | 10.3 | 5.1 | 14.8 | 13.7 | 12.5 | 7.2 | 16.9 | 15.8 | 14.6 |
| 2090 | 3.5 | 13.2 | 12.1 | 10.9 | 6.2 | 15.9 | 14.8 | 13.6 | 8.9 | 18.6 | 17.5 | 16.3 |
| 2100 | 4.1 | 13.8 | 12.7 | 11.5 | 7.6 | 17.3 | 16.2 | 15.0 | 10.9 | 20.6 | 19.5 | 18.3 |
| 2110 | 4.3 | 14.0 | 12.9 | 11.7 | 8.0 | 17.7 | 16.6 | 15.4 | 12.7 | 22.4 | 21.3 | 20.1 |
| 2120 | 4.9 | 14.6 | 13.5 | 12.3 | 9.4 | 19.1 | 18.0 | 16.8 | 15.0 | 24.7 | 23.6 | 22.4 |

| | |
|---|---|
| 🟥 | Indianola Interchange design elevation (12 ft. NAVD88) |
| 🟨 | Jacoby Creek Bridge design elevation (13.8 ft. NAVD88) |
| ▨ | Assets' design lifetime |

While the proposed structures will reduce risks to inundation under current conditions and in the next few decades, Table 3 shows that with MAMW the proposed Highway 101 Indianola Interchange would experience tidal inundation several times per year by 2050 under the medium-high and extreme risk aversion scenarios (MAMW elevations). The Jacoby Creek Bridge may experience inundation within its proposed lifetime by 2070 under these same scenarios and MAMW elevations. For both the Interchange and the Bridge, annual high tides will overtop each structure before the end of the design lifetimes, expected around 2100.

This report's analysis of projected MAMW risks to the proposed developments in Table 3 only shows inundation risks for approximately four times each year. Table 3 also shows the North Spit mean high-higher water (MHHW) elevation (6.5 ft, NAVD88) to determine inundation risks on a more frequent basis, occurring approximately every other day (Anderson and Laird 2018). MHHW from North Spit to the project area has been adjusted using the same method as with MAMW. We have elected to expand on those assessments by examining higher (MAMW) and more frequent (MHHW) water levels. Both proposed structures will experience inundation at MHHW every other day within their lifetimes, although this is not projected until at least 2070 under CCC's scenarios. Adaptation options for these structures are discussed in the Adaptation Planning section over the analysis period and beyond.

The most recent Humboldt Bay vulnerability assessment used the mean monthly maximum water level (MMMW) in examining inundation vulnerabilities. The MMMW is a monthly datum (7.7 at North Spit, above NAVD88), and does not reflect tidal events like MAMW (i.e., king tides). Local researchers have found MMMW useful as it correlates well with the vegetative boundary between local salt and freshwater environments (Laird 2018). The MMMW also provides an elevation frequency between the

MAMW and MHHW to further inform adaptation needs. Table 3 shows MMMW elevation thresholds for inundation of the proposed developments. Under the medium-high risk aversion scenario, overtopping occurs by 2070 and 2080 for the proposed developments.

SLR projections are uncertain due to potential changes in global greenhouse gas emissions, local vertical land motion, and other factors. The elevations in Table 3 could be reached sooner or later, but CCC's scenario-based approach allows Caltrans to account for this uncertainty in adaptation planning.

In Table 3 and this sea level rise vulnerability assessment, the proposed tide gate elevations were not considered. Tide gate elevations will not change, and they are currently below MAMW. The tide gates are critical in maintaining the hydraulic connectivity of the local watersheds and ecosystems. Increasing the elevations of tide gates currently would disrupt this continued connectivity. Caltrans plans to redesign and replace the culverts that house the tide gates in 2050 and will reevaluate the tide gate elevations and impacts of sea level rise at that time. The Adaptation Planning section discusses further potential adaptation needs for the tide gates for Caltrans to continually monitor and evaluate the risks to tide gates.

### *Inundation Impacts to the Proposed Developments*

The SLR inundation timelines determined in the analysis above will have varying impacts depending on the depth and duration of inundation. For the time periods in Table 3 where the tidal elevation is only slightly higher than the Interchange or Jacoby Creek Bridge design elevations (such as 2050 for MAMW), inundation may last several hours creating a closure of the 101 Corridor for those areas. Those closures would occur four times a year with MAMW, but would occur every month with MMMW and every other day with MHHW, potentially permanently closing portions of the Corridor. As SLR progresses, inundation will last longer unless adaptation planning is put into action. For the Jacoby Creek Bridge, inundation can also create uplift forces and corrosion risks. Determining the critical threshold whereby the number of inundations per year are acceptable to Caltrans and the community will be an important step in the long-range planning necessary to adapt to SLR along Humboldt Bay.

### *Impacts from Sea Level Rise and Other Coastal Hazards*

Tidal inundation from the SLR projections used in this report, would create road closures for the proposed structures and the Corridor as a whole in the second half of the 21st Century. In the past, road closures from inundation has only occurred once in 2005 (this event is described below). Rising tidal elevations at tide gates will prevent the gates from opening with increasing frequency. This will prevent the gates from allowing upstream freshwater areas to drain, increasing the frequency and duration of local flooding events (Walsh and Miskewitz 2013).

#### *Storm Surge*

The SLR impacts to the proposed developments will be compounded by other coastal hazards. Storm surge can increase inundation levels in the project area through rising freshwater levels in groundwater basins and surface water resources (i.e., creeks, rivers) combining with tidal elevations. To model this, the *Humboldt Bay Area Plan – Sea Level Rise Vulnerability Assessment* examined the Corridor's exposure to the 100-year flooding event with different levels of projected SLR (Laird 2018). The report found that the southern portion of the Corridor (Bracut to Eureka) will be fully inundated (north and southbound lanes) in a 100-year storm event if such an event occurred today. As evidence, the 2005 storm and king tide event inundated the southbound Corridor lanes. This has been the only recorded event of road closure from inundation on the Corridor.

***Figure 8. 2005 storm impacts to the Corridor just north of proposed Indianola Interchange (Caltrans 2016).***

This southern portion of the Corridor is also exposed to wave action during winter storms. Dikes currently protect the Corridor from wave impacts (Figure 5), but the dikes are vulnerable to wave-induced erosion. See the *Erosion* section below for more detail.

For the northern portion of the Corridor (Arcata to Bracut), the Humboldt Bay Area Plan found that storm surge in the 100-year flood event (surge depth of 1.3 ft.) combined with 1.6 ft. of SLR (0.5 m) would fully inundate the Corridor (Laird 2018). Table 4 and Table 5 show when inundation may occur for the Highway 101 Indianola Interchange and Jacoby Creek Bridge for 10-year (surge depth of 0.6 ft.) and 100-year flooding events using elevation estimates from Anderson and Laird (2018) near Arcata Wharf. The 10- and 100-year events have 10% (1 in 10) and 1% (1 in 100) probability of occurring annually, respectively.

*Table 4. 10-year flood event elevation (raising tidal elevations from Table 3 by 0.6 ft.) estimates for the CCC scenarios.*

| Year | Low Risk Aversion | Medium-High Risk Aversion | Extreme Risk Aversion |
|---|---|---|---|
| 2030 | 10.7 | 11.0 | 11.2 |
| 2040 | 11.1 | 11.6 | 12.0 |
| 2050 | 11.5 | 12.3 | 13.1 |
| 2060 | 11.9 | 13.1 | 14.3 |
| 2070 | 12.4 | 14.0 | 15.6 |
| 2080 | 12.9 | 15.1 | 17.2 |
| 2090 | 13.5 | 16.2 | 18.9 |
| 2100 | 14.1 | 17.6 | 20.9 |

*Table 5. 100-year flood event elevation (raising tidal elevations from Table 3 by 1.3 ft.) estimates for the CCC scenarios.*

| Year | Low Risk Aversion | Medium-High Risk Aversion | Extreme Risk Aversion |
|---|---|---|---|
| 2030 | 11.4 | 11.7 | 11.9 |
| 2040 | 11.8 | 12.3 | 12.7 |
| 2050 | 12.2 | 13.0 | 13.8 |
| 2060 | 12.6 | 13.8 | 15.0 |
| 2070 | 13.1 | 14.7 | 16.3 |
| 2080 | 13.6 | 15.8 | 17.9 |
| 2090 | 14.2 | 16.9 | 19.6 |
| 2100 | 14.8 | 18.3 | 21.6 |

| | |
|---|---|
| 🟥 | Indianola Interchange design elevation (12 ft. NAVD88) |
| 🟧 | Jacoby Creek Bridge design elevation (13.8 ft. NAVD88) |
| ▨ | Assets' design lifetime |

In both 10- and 100-year events, the Interchange and Bridge will be exposed to temporary inundation from flooding before the end of the design lifetimes. Since the analyses in Table 4 and Table 5 use MAMW (frequency of four times per year), the estimates are conservative given they assume that the storm coincides with MAMW levels. However, recent research has shown that in the California North Coast region, these intense storms may occur with increasing frequency in the future due to climate change (Grantham 2018). This conservative approach is warranted as a result.

*Erosion*

Dikes currently provide protection to the Corridor from SLR, storm surge, wave impacts, and other coastal hazards (Figure 5). However, wave-induced erosion from tides and storm surge can damage and weaken these embankments over time (Laird 2018). In addition, erosion of sediments adjacent to dikes could increase the incident energy of waves along these dikes. With higher tides and more frequent storms in the future from climate change, these dikes will face greater risks from erosion in the future.

If the dikes are not regularly maintained against erosion impacts, they could risk structural failure and expose the road grades, bridge structures, and culverts to tides, storm surge, and erosion. If the dikes are raised in the future (see the Adaptation Planning section for more details on this action), dike failure from erosion would risk inundation to the proposed developments. These risks are considered in the assessment of adaptation solutions (see Adaptation Planning).

#### *Groundwater Changes*

Sea level rise will impact local aquifers by raising elevations and creating salt-water intrusion to freshwater resources. Higher groundwater levels will reduce the local area's ability to capture and store freshwater flows during precipitation events. This will increase the risk of impacts to the proposed development and Corridor from inland flooding. The rise in groundwater levels from SLR will be compounded by an increase in the severity and frequency of extreme precipitation events from climate change (Grantham 2018).

## Highway 101 Corridor Vulnerability

This report's SLR vulnerability assessment above considered only the proposed Caltrans developments and not impacts to the Corridor as a whole. We assess the Corridor's vulnerability to SLR as a whole in the following section.

### *Sea Level Rise Thresholds*

Figure 9 shows where the segment post miles (PMs) are located related to the proposed Indianola Interchange and Jacoby Creek Bridge for the Corridor. We used the same vulnerability approach to analyze the impacts to 101 Corridor shown in Table 6.

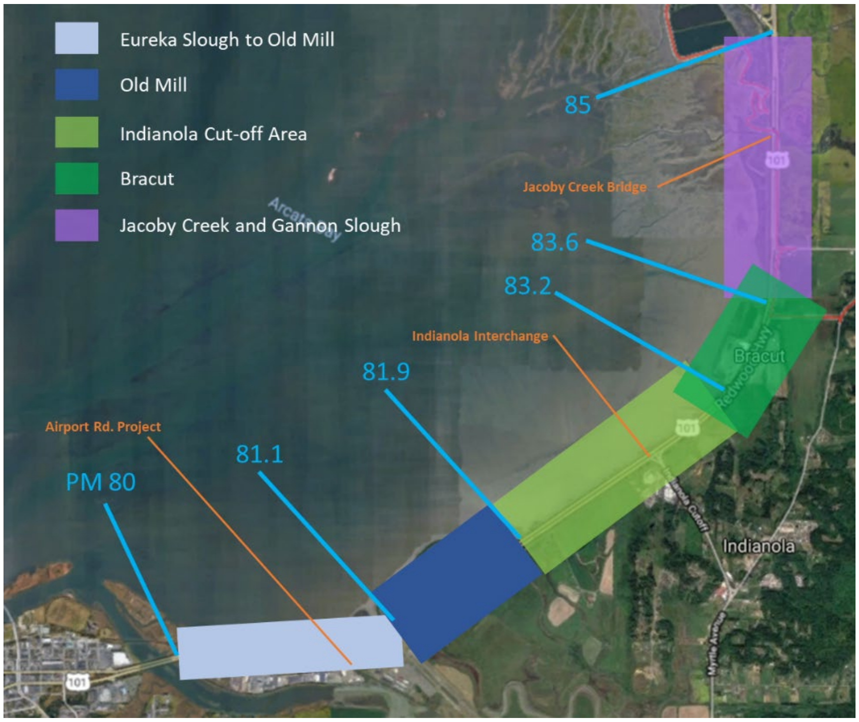

***Figure 9. PM locations (in blue) and Corridor segment names from Table 6 in relation to the Indianola Interchange and the Jacoby Creek Bridge.***

***Table 6. Highway 101 Corridor segments with corresponding PM, elevation ranges, and dike elevation ranges.***

| Segment | Post Mile Range | Elevation Range (ft. above NAVD88) | Dike Elevation Range (ft. above NAVD88) |
|---|---|---|---|
| Eureka Slough to the Old Mill | 80 - 81.1 | 9.1 - 14.5 | 9.4 – 10.8 |
| Old Mill | 81.1 - 81.9 | 9.0 - 11.4 | 11 – 12 |
| Indianola Cut-off Area | 81.9 - 83.2 | 9.1 - 10.8 | 10.5 – 10.6 |
| Bracut | 83.2 - 83.6 | 21.9 | N/A |
| Jacoby Creek and Gannon Slough | 83.6 - 85 | 10.8 - 13.0 | 10.6 – 11.1 |

Using the elevations ranges for each section, this analysis took the same approach for the 101 Corridor as the proposed development SLR assessment. Table 7 shows the projected inundation scenarios for the Corridor segments from the CCC SLR risk aversion scenarios, using existing road and dike elevations as thresholds for the different Corridor segments. Whereas the proposed developments (101 Indianola Interchange and Jacoby Creek Bridge) were higher than the adjacent dikes, almost all of the Corridor segments (outside of Bracut) have elevations below the dike elevations. For reference, MAMW elevations are reached approximately four times per year, and MHHW elevations are reached every other day (Laird 2018, Anderson and Laird 2018).

*Table 7. Projected MAMW, MHHW, and MMMW elevations in project area (above NAVD88) under the CCC SLR scenarios, versus Highway 101 Corridor segment thresholds. Note that in MAMW elevations the Eureka Slough to Old Mill segment dike and road will be inundated before 2030.*

| | Low Risk Aversion | | | | Medium-High Risk Aversion | | | | Extreme Risk Aversion | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **SLR Value** | **MAMW** | **MMMW** | **MHHW** | **SLR Value** | **MAMW** | **MMMW** | **MHHW** | **SLR Value** | **MAMW** | **MMMW** | **MHHW** |
| 2030 | 0.7 | 10.4 | 9.3 | 8.1 | 1.0 | 10.7 | 9.6 | 8.4 | 1.2 | 10.9 | 9.8 | 8.6 |
| 2040 | 1.1 | 10.8 | 9.7 | 8.5 | 1.6 | 11.3 | 10.2 | 9.0 | 2.0 | 11.7 | 10.6 | 9.4 |
| 2050 | 1.5 | 11.2 | 10.1 | 8.9 | 2.3 | 12.0 | 10.9 | 9.7 | 3.1 | 12.8 | 11.7 | 10.5 |
| 2060 | 1.9 | 11.6 | 10.5 | 9.3 | 3.1 | 12.8 | 11.7 | 10.5 | 4.3 | 14.0 | 12.9 | 11.7 |
| 2070 | 2.4 | 12.1 | 11.0 | 9.8 | 4.0 | 13.7 | 12.6 | 11.4 | 5.6 | 15.3 | 14.2 | 13.0 |
| 2080 | 2.9 | 12.6 | 11.5 | 10.3 | 5.1 | 14.8 | 13.7 | 12.5 | 7.2 | 16.9 | 15.8 | 14.6 |
| 2090 | 3.5 | 13.2 | 12.1 | 10.9 | 6.2 | 15.9 | 14.8 | 13.6 | 8.9 | 18.6 | 17.5 | 16.3 |
| 2100 | 4.1 | 13.8 | 12.7 | 11.5 | 7.6 | 17.3 | 16.2 | 15.0 | 10.9 | 20.6 | 19.5 | 18.3 |
| 2110 | 4.3 | 14.0 | 12.9 | 11.7 | 8.0 | 17.7 | 16.6 | 15.4 | 12.7 | 22.4 | 21.3 | 20.1 |
| 2120 | 4.9 | 14.6 | 13.5 | 12.3 | 9.4 | 19.1 | 18.0 | 16.8 | 15.0 | 24.7 | 23.6 | 22.4 |

| | |
|---|---|
| 🟥 | Eureka Slough segment dike low point (9.4 ft. above NAVD88) |
| 🟧 | Jacoby Creek and Indianola segments dike low points (10.5 ft) |
| 🟨 | Old Mill segment dike low point (11.0 ft) |
| 🟩 | Bracut segment road low point (21.9 ft) |

In all CCC scenarios, all Corridor segments outside of the Bracut segment will have dike protections and roadways inundated by 2050 during MAMW events, creating roadway closures multiple times per year. By 2070 in the medium-high and extreme risk aversion scenarios, these segments will be inundated every other day at MHHW elevations. Inundation will occur monthly by 2060 during MMMW events in the medium-high and extreme scenarios.

Figure 10 shows a visualization of the Table 7 results. The Figure shows when the CCC's medium-high risk aversion scenario projects inundation for the different Corridor segments using the MMMW elevation (NAVD88). The Figure shows that the majority of the Corridor will experience inundation every other day by 2070 in the medium-high risk aversion scenario, with the southernmost segment (Eureka Slough) inundated by 2050.

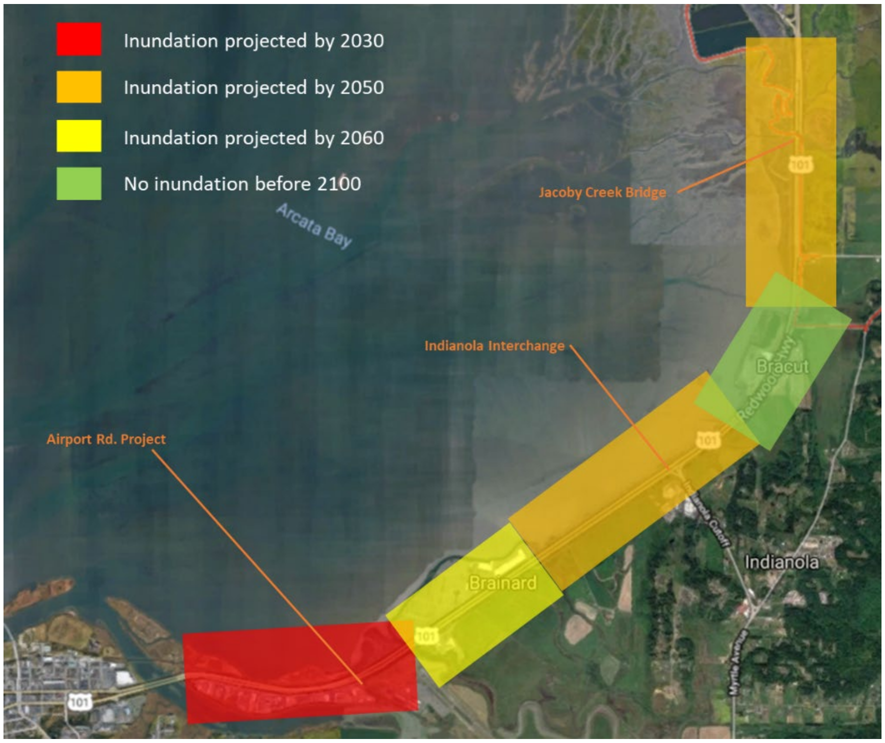

*Figure 10. Projected inundation timelines for Highway 101 Corridor segments based on Table 7 results for the medium-high risk aversion scenario and MMMW elevation (NAVD88).*

### *Inundation Impacts to the Corridor*

The SLR inundation impacts to the Corridor as a whole will have the same implications on highway closure as the proposed developments (see Inundation Impacts to the Proposed Developments). Closures may only last several hours for the years where elevations are projected to be slightly higher than the Corridor segments (such as 2030 for the Jacoby Creek and Indianola segments in Table 7 MAMW), but closures will become longer as SLR progresses over time and inundation depth increases. This could result in permanent closure for some segments if adaptation actions are not taken.

### *Impacts from Sea Level Rise and Other Coastal Hazards*

The Corridor will also be vulnerable to the same coastal hazards as the proposed developments. While impacts from erosion will be the same as detailed for the proposed development, storm surge combined with SLR will create different timelines for inundation than the proposed developments. Using the same methodology for assessing storm surge as the proposed developments, we found in the medium-high risk aversion scenario that all Corridor segments (outside of Bracut) will experience flooding in both the 10 and 100-year events. Bracut will not experience flooding from storm surge combined with SLR before 2100. The risk of closure from inundation to both the proposed developments and the Corridor as a whole are considered in the Adaptation Planning section below.

## ADAPTATION PLANNING

The proposed developments on the 101 Corridor are designed to address the immediate highway safety needs of the Corridor. While the proposed developments may be exposed to climate hazards in the future based on the CCC SLR scenario, we have crafted a tailored adaptation plan for the proposed developments using the results from the SLR vulnerability assessment.

This adaptation planning builds on the previous adaptation assessment performed by Caltrans as part of the original SLR analysis required by the consistency certification. That report created two primary categories for adaptation: protect in place, and relocation/retreat. The protect in place options included raising the Corridor structures as a causeway or a levee, raising the existing levee, and increasing maintenance and inspection intervals. The relocation/retreat option was rejected due to extensive costs, environmental impacts, and community impacts. We expanded on the protect in place options in this section by assessing the implications of uncertainty, and how the different adaptation options can work in conjunction to address SLR vulnerabilities.

Climate change impacts often unfold over a long period of time and can be difficult to predict with certainty. Because of this, implementing a suite of adaptation options that respond to all inundation scenarios can end up being very costly if they go beyond the necessary level of protection. However, under-adapting could also become an issue as this may leave assets vulnerable to risk, while waiting to adapt can result in difficult and expensive changes in the future.

For these reasons, flexible adaptation pathways have been developed to assess adaptation options for the Corridor. This method, which includes multiple adaptation actions that can be switched out for other viable actions when sea levels reach pre-determined thresholds, keeps options open throughout the project timeline.

Five actions were applied to the three locations assessed: the Indianola Interchange, Jacoby Creek Bridge, and the four tide gates. These five actions include:

*Short-term adaptation actions*: The following adaptation actions can be implemented in the short-term (10-20 years).

A. **Address low points in dikes**. Some of the dikes currently in place have low points that allow for higher rates of overtopping. Caltrans can work with local partners to address these specific sections and raise them to the same height as the rest of the dikes. To achieve this, Caltrans and local partners may need to conduct a detailed survey of dike heights beyond what is publicly available from the Humboldt Bay Area Plan (Laird 2018). This action may encroach on existing wetlands when raising dike sections, and may impact tidal ecosystems. This action and Action C will also protect against increased inland flooding risks from higher groundwater levels from SLR and increased severity and frequency of precipitation events.

B. **Increase maintenance and inspection intervals**. By enhancing maintenance and inspection for both the Corridor and dike protections, Caltrans can enhance its monitoring capabilities. This will allow Caltrans to determine at what point in the timeline it becomes necessary to implement more robust adaptation actions. Caltrans can work with its staff to ensure crews are aware of climate hazards that will impact assets. Maintenance and inspection of dikes may require collaboration with local partners. While this adaptation action can be implemented in the short term, this is ongoing throughout the adaptation timeline in the figures below.

C. **Raise dikes.** Caltrans can work with local partners to raise dikes. Higher dikes will better protect the Corridor from inundation due to overtopping from additional sea level rise and storm surge in the future. This action may encroach on existing wetlands when raising dike sections, and may impact tidal ecosystems.

*Longer-term adaptation actions:* The following adaptation actions can be implemented in the longer-term (20+ years).

D. **Raise elevation of structures.** Raising the structures themselves can also protect from inundation. The Jacoby Creek Bridge's foundation and drainage structures are designed to accommodate for future increases in bridge height. The Interchange utilizes a prism design and can be raised in the future as needed. The culverts that house the tide gates will need to be replaced in 2050, and Caltrans will reevaluate the tide gate performance and design elevation needs during inspection intervals. Raising the elevation of structures will also protect against increased inland flooding risks from higher groundwater levels from SLR and increased severity and frequency of precipitation events.

E. **Integrate project adaptation planning into long-term adaptation planning.** In this action, Caltrans would integrate adaptation needs for the proposed project into upcoming long-term adaptation planning for the Humboldt Bay region. This action would align the adaptation needs of the proposed project with other vulnerabilities the Corridor is experience at lower-lying highway segments. To achieve this, Caltrans would need to closely collaborate with local government agencies and other partners (e.g., private land owners). Local partnerships would ensure that Caltrans does not generate its plan in isolation, and integrates the long-term plan with other local adaptation plans and the Local Coastal Plan. This option reflects a holistic approach for the Corridor that includes all segments and proposed developments. Caltrans anticipates to have this plan completed by 2030. Caltrans has already initiated local collaboration through a grant awarded to Humboldt County for studying SLR impacts and adaptation options for the southern Corridor, and is encouraging the county to apply for a grant to assess the northern Corridor.

Figure 11, Figure 12, and Figure 13 illustrate these five actions as adaptation pathways under the medium-high risk aversion scenario. The three pathways differ in their timelines based on the asset lifetime. The tide gates have a lifetime of 25 years, while the design lifetimes for the Indianola Interchange and Jacoby Creek Bridge are 80 years (2100). The timelines used for Actions C and D for the interchange and bridge (shown in Figure 11 and Figure 12) on the inundation thresholds determined in Table 3. After the project lifespan ends, sea levels may surpass new inundation thresholds created by adaptation actions, so further adaptation beyond that point will be required.

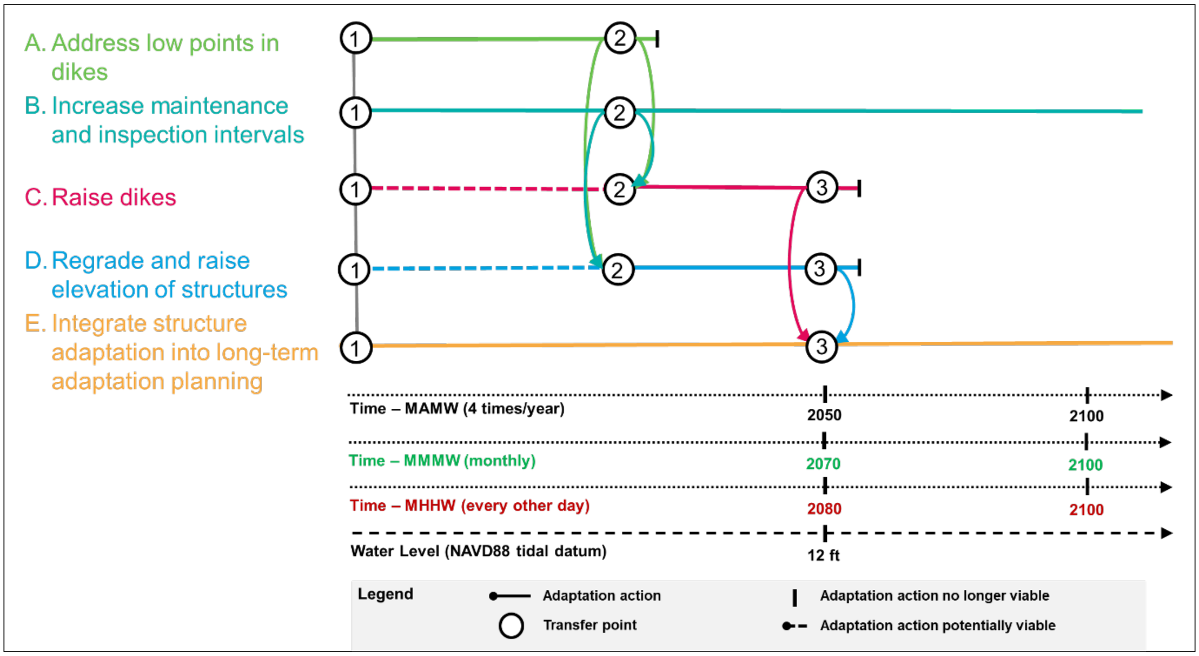

*Figure 11: Adaptation pathway for Highway 101 Indianola Interchange using the medium-high risk aversion scenario*

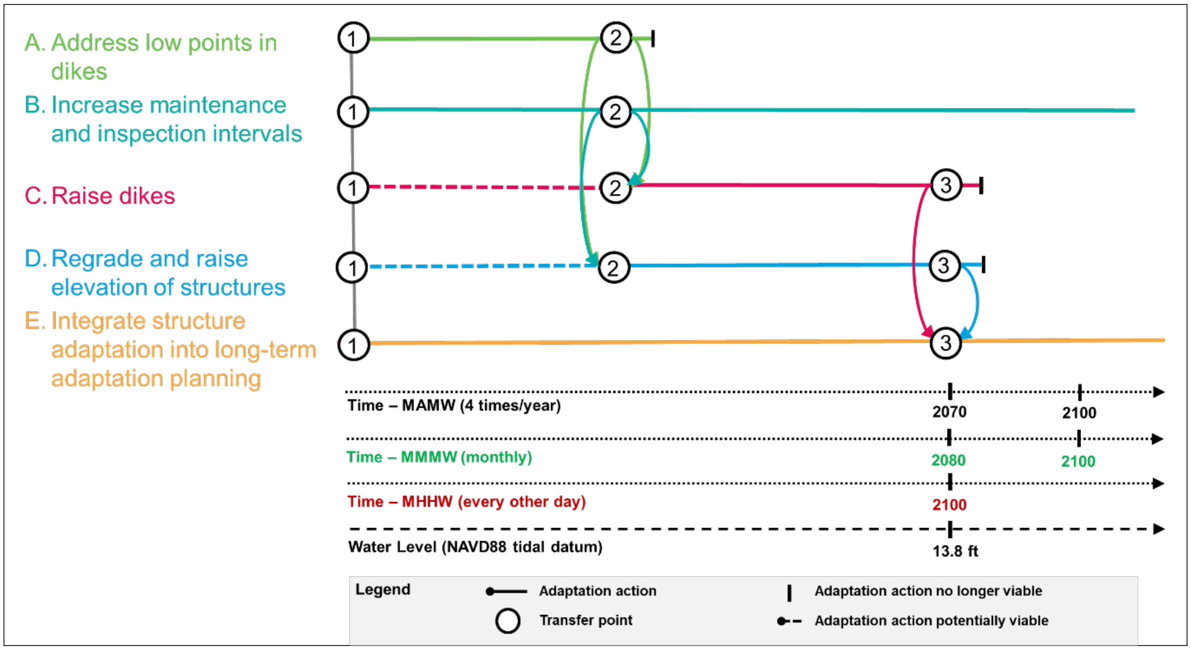

*Figure 12: Adaptation pathway for Jacoby Creek Bridge using the medium-high risk aversion scenario*

The Interchange (Figure 11) and Bridge (Figure 12) would follow similar flows for adaptation decision-making over time. The different elevations axes (MAMW, MMMW, MHHW) show different timelines for when Caltrans can expect varying frequencies of inundation, and how that impacts adaptation decision making. For example, under the medium-high risk aversion scenario, if Caltrans wants to avoid inundation four times a year at MAMW elevations (2050), they would need to regrade and raise the proposed structures 20 years before MMMW elevations (2070), and 30 years before MHHW elevations (2080).

Caltrans's first priority will be to carry out Action A and Action B. After those actions have been in place for some time, Caltrans will observe through monitoring whether existing dike protections have become insufficient and increasing protections or raising structures is necessary (e.g., Transfer Point #2 in the figures). Caltrans can determine a year for this Transfer Point by monitoring and projecting when projected SLR will surpass current dike heights. Thus, Caltrans will reevaluate project needs and risks, and will choose to implement either Action C or Action D. The Jacoby Creek Bridge's drainage system and foundation are currently designed to accommodate for additional height, and the Indianola Interchange can be raised by adding height to the prism structure in the future.

For tide gates (shown in Figure 13), Caltrans will again prioritize Actions A and B, but increasing protections or raising the structures will not be considered until the end of the culverts' lifetime. As part of that culvert design process, Caltrans will reevaluate needs for increasing the elevation of tide gates. Action B may also inform Caltrans that actions in culvert replacement are needed ahead of the current 2050 timeline.

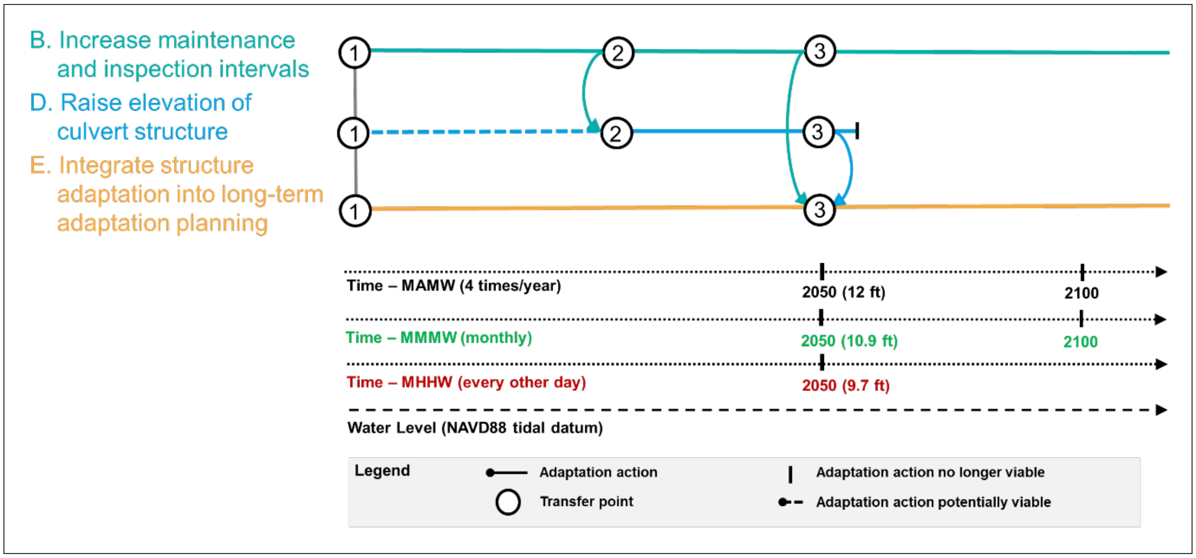

*Figure 13: Adaptation pathway for tide gates using the medium-high risk aversion scenario*

Raising the tide gates could also bring about ecological problems; if the gates are too high, they may interrupt the hydraulic connectivity of local watersheds. If Caltrans decides to implement this adaptation action, they will closely consider impacts to coastal resources and local ecosystems as part of the design process.

### Impacts and Challenges from Adaptation Actions

Each adaptation action presents its own unique benefits and challenges in design and implementation. For example, raising dikes will encroach on adjacent tidal or freshwater wetlands and will require collaboration with multiple authorities, agencies, private landowners, and municipalities as the existing dikes occur outside of Caltrans ROW. Thus, a concerted community-wide effort will be necessary to meet these challenges in the coming decades.

Raising the road will also requires regrading and expanding of the road prism to allow for greater elevations; factors that can also encroach on adjacent wetlands. Caltrans can cause minimal disruption by raising the highway during regular maintenance periods (e.g., re-pavement cycles), but expanding he road footprint would be required. As a reference point, raising the Jacoby Creek Bridge currently requires 1,000 feet of regrading and raising it to 15 feet would require one mile of regrading (however, currently the bridge will only be raised to 13.8 feet). These additional construction needs will add future costs to Caltrans, including that potentially required for mitigation, and may temporarily impact local traffic patterns.

## CONCLUSIONS

For all proposed developments and the entire 101 Corridor, these adaptation solutions and future adaptation needs will be integrated into Caltrans's long-term regional adaptation planning (Action E). Caltrans anticipates completed this long-term plan by 2030. Should further SLR by 2050-2080 make the other adaptation solutions presented in this section no longer viable, Caltrans's long-term planning effort will become the primary planning mechanism for achieving climate resilience (Transfer Point #3).

Since Caltrans has not formally initiated its long-term resilience planning effort, these projects and adaptation solutions have been designed with future adaptation needs in mind. These proposed projects and adaptation solutions have been designed as to not interfere or limit opportunities for future adaptation for the Corridor as a whole. This development proposal also incorporates flexibility in design so the structures can be retrofitted to align with future infrastructure improvements in the Corridor as needed over time. For example, if other lower-lying portions of the Corridor are elevated to reduce inundation risks, the Jacoby Creek Bridge or Highway 101 Indianola Interchange can be raised to as well to accommodate those new elevations.

Providing flexibility to accommodate long-term planning will allow the proposed developments to align with other upcoming regional planning and SLR vulnerability efforts. Humboldt County is planning to release an adaptation plan in 2020, and local USGS CoSMoS models will become available in 2021. Both of these resources will be critical for informing Caltrans's long-term planning.

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