Introduction

Ocean or bay water elevations define the groundwater level (or head) boundary for coastal aquifers and influence the adjacent groundwater elevations. With sea level rise (SLR), these elevations are predicted to increase resulting in an increase in coastal groundwater elevations. The primary impact of these increasing elevations is a higher water table, possibly causing groundwater to rise above the land surface. There are many possible impacts resulting from elevated groundwater levels besides saturated or submerged land area, including:

- Reduced infiltration to the subsurface resulting in higher volumes of surface runoff
- Loss of access to land and pasture area
- Decrease in or changes to habitat and habitat types
- Possible acceleration of contaminant transport rates if contaminated sites are present
- Reduced sewer and septic drainage
- Increased roadway rutting and fatigue failure due to wetting and drying of the road base
- Foundation damage to buildings and other infrastructure

Higher sea levels may also promote salt water intrusion, or the replacement of fresh groundwater with brackish or salt water, as higher sea levels create a gradient that moves salt water inland.

This memo describes the current understanding of potential impacts of SLR on the groundwater in and adjacent to the Highway 101 Eureka-Arcata corridor and presents evaluation of the groundwater conditions and hazards. The information presented is a combination of assessments by government agencies, primarily the United States Geologic Survey (USGS), and analyses completed specifically for this assessment to better evaluate local conditions and processes. The specific content presented includes:

1. A description and summary of the USGS Coastal Storm Modeling System groundwater analysis (CoSMoS-GW) for the project area
2. Results from local groundwater models developed to further refine groundwater response to SLR predictions incorporating more local detail and processes
3. Analysis of the risk due to known contaminated sites in the project area
4. Description of the hazards of elevated groundwater to roads and summary of the expected elevations within the existing road base
5. Conclusions and recommendations
6. Appendix A - Project Area Well Log Data
7. Appendix B – Response to review comments

CoSMoS-GW Groundwater Analysis Summary

In coastal regions, the groundwater gradient is typically, in the absence of significant groundwater extraction by pumping, towards the coast with net discharge of groundwater to the ocean or coastal surface water bodies. With rising sea level, the gradient becomes reduced by higher ocean or bay water elevations at the coast, reducing the net discharge to the ocean and slowing drainage of groundwater to coastal surface water channels. To evaluate the possible magnitude of SLR on coastal groundwater conditions, the USGS developed regional groundwater models along the entire California coast, then merged these models to create a continuous state-wide analysis. Their simulations applied a coastal groundwater head boundary that matched sea level and analyzed 12 different SLR values from 0.00 to 5.00 m (0.0 – 16.4 ft) of increase. These SLR values were added to both the local mean sea level (LMSL) and maximum higher high water (MHHW) for a total of 24 different modeling scenarios analyzed. All results and products prepared from additional analysis of these results are available for download from the USGS ScienceBase data catalog (Befus et al. 2020). The data are packaged as shapefiles covering the modeled region of each California coastal county.

To conduct this assessment over such a large geographical region, the groundwater models developed by the USGS were necessarily simplified using the following assumptions:

- The coastal aquifer was simulated as a single layer, homogeneous and unconfined aquifer with bottom elevation of -50 m NAVD88.
- All analyses were steady state.
- Annual average values were assumed for net recharge (precipitation – evapotranspiration).
- The presence of drainage networks such as sloughs and stream channels were ignored.

In addition to the 24 tidal datum/SLR scenarios analyzed, three hydraulic conductivities (0.1, 1.0 and 10 m/day) were assumed and results compared to well data from the California State Water Resources Control Board GeoTracker database (CA SWRCB, n.d.). A hydraulic conductivity of 1.0 m/day best matched water table elevations available from observed well data.

The results from the USGS CoSMoS-GW groundwater modeling provide an estimate of groundwater elevation response to various SLR scenarios. The predictions are conservative, steady-state annual average values that do not account for the possible extremes experienced in California’s Mediterranean climate with its distinct wet and dry seasons. These simulations also did not account for the presence of sloughs or coastal stream channels that can promote drainage or infiltration to and from adjacent land. The results of this study do predict that low elevation coastal regions will generally be submerged by rising SLR so that overall, the total area of shallow, coastal areas with high groundwater will decrease. For the project area, this means that areas that currently experience groundwater elevations at the ground surface for most of the wet season (~December through March) will likely become inundated by increasing SLR rather than submerged by rising groundwater elevations.

In the next two subsections, CoSMoS-GW predictions for groundwater shoaling (groundwater elevations approaching or exceeding the land surface) and saltwater intrusion are presented and interpreted. These results illustrate the major trends predicted and the SLR scenarios presented bound likely near-term and longer-term expectations for SLR impacts on groundwater elevations.

Predicted Shoaling and Groundwater Elevations

One of the most informative CoSMoS-GW results is the prediction of groundwater shoaling or the groundwater elevation increasing and approaching the ground surface with SLR. These predictions are reported as areas that are submerged (groundwater already at the surface), emergent (groundwater within 1 m or 3.1 ft of the ground surface) and in additional groundwater depth increments indicating potential vulnerability. Figure 1 compares these predictions for the simulations adding SLR to the mean higher high water (MHHW) level and assuming a hydraulic conductivity of 1.0 m/day. MHHW is a commonly used tidal datum that is the mean of the highest high tide per day over a tidal epoch. As expected, these results show that for current conditions (SLR = 0.0 m/ft, Figure 1a), most of the project area is low elevation with a predicted annual average depth to groundwater of less than 1 m (3.1 ft). As SLR increases to 0.25 m (0.8 ft, Figure 1b), the primary change is an expansion of area with emergent (at or above the land surface) groundwater in the northern part of the project area along Gannon Slough. A SLR of 0.8 ft (0.25 m) is categorized as the Intermediate scenario level by 2050 according to the latest California Ocean Protection Council (OPC) guidelines (OPC 2024).

The other two scenarios presented are more extreme with SLR of 1.0 m (3.1 ft, Figure 1c) and 2.5 m (8.2 ft, Figure 1d), respectively. These results illustrate the changes predicted with greater SLR and into the future. These two SLR values are categorized as the 2100 Intermediate and 2150 Intermediate-High scenarios in the current OPC guidelines (OPC 2024), respectively. With an increase in sea level of 1.0 m (3.1 ft), the remaining low-lying areas within the project region are predicted to be submerged by rising sea level. Due to the local topography with ridges and hills to the east, once all the low-lying areas are submerged by rising sea level, the change in groundwater elevations with additional SLR is minimal. The difference between groundwater levels predicted for SLR of 1.0 m (3.1 ft) and 2.5 m (8.2 ft) is small with only an additional region of the project area submerged by elevated groundwater predicted to occur moving upstream along the Jacoby Creek channel (compare Figure 1c and Figure 1d). The 2.5 m (8.2 ft) scenario is a very extreme and unlikely case but illustrates that once low-lying regions are inundated by SLR, the impacts to groundwater are expected to be minimal.

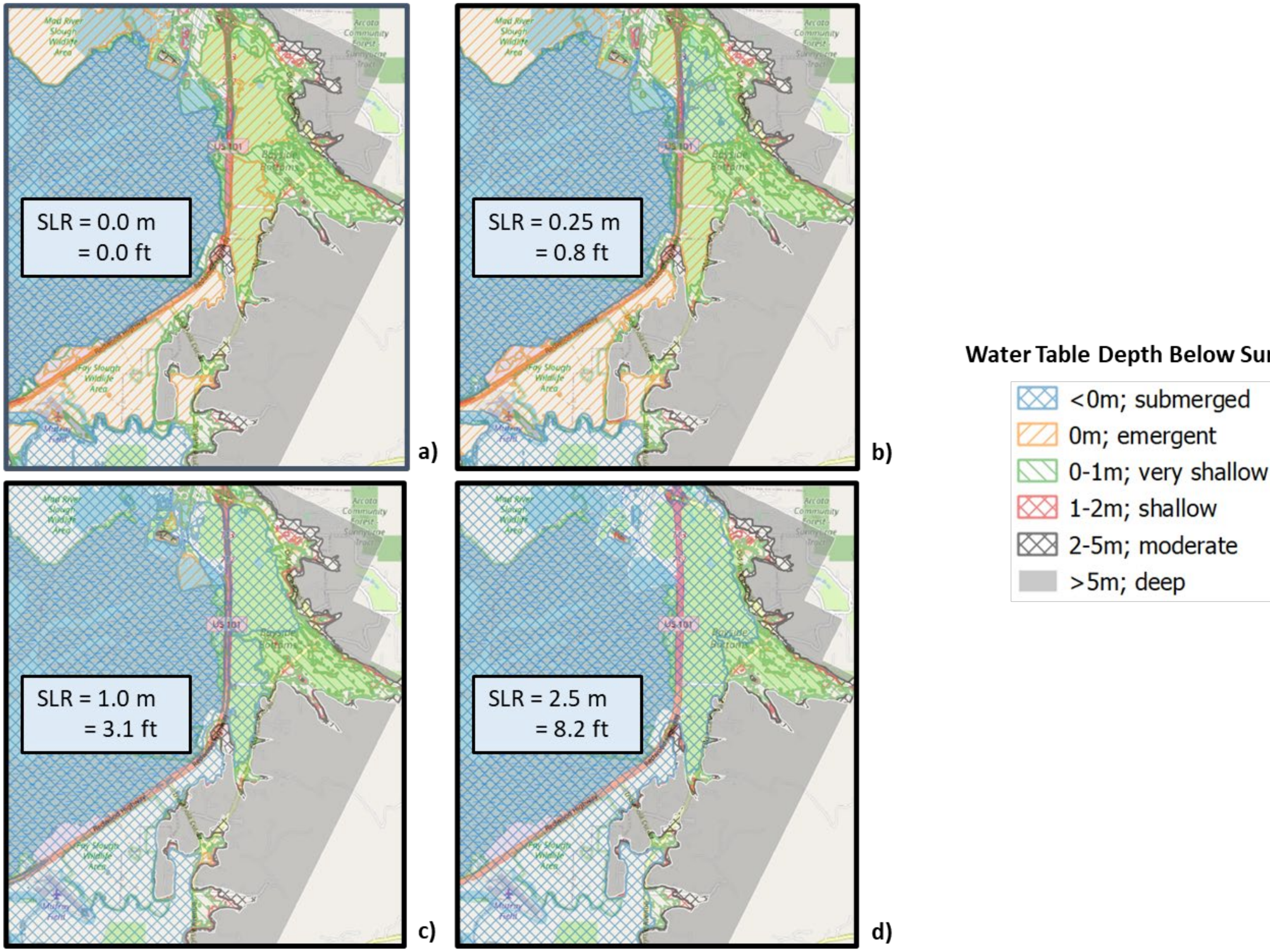

Figure 1. USGS CoSMoS-GW predictions of shoaling and near surface groundwater for the simulations adding SLR to the MHHW and assuming a hydraulic conductivity of 1.0 m/day (data downloaded from Befus et al. 2020).

Saltwater Intrusion

The USGS CoSMoS-GW modeling effort also assessed the potential for saltwater intrusion into coastal aquifers. This assessment was done by coupling their groundwater models with a chemical transport model that accounts for the density difference between salt and fresh water and dispersion of saltwater into the aquifer. Figure 2 shows these results for the same simulation cases presented for groundwater shoaling in Figure 1. As Figure 2 shows, the fresh groundwater zone remains essentially the same even with SLR increasing to 2.5 m (8.2 ft). The area of the saltwater interface, which defines the region where the near-surface groundwater aquifer would become brackish or saline, decreases as the lower elevation land surface is converted to marine/tidal by rising sea level.

In all cases, the area predicted to be affected by saltwater intrusion into the groundwater is much smaller than the area predicted to be submerged from rising sea level. These predictions match expectations that saltwater intrusion into groundwater around Humboldt Bay would be minimal. The primary reasons for this expectation are that groundwater recharge on to the coastal plain from the surrounding hillslopes to the east maintains a high groundwater head gradient with dominant groundwater flow from east-to-west. Additionally, and unlike many other regions in California, there are no large capacity groundwater extraction wells in the project area capable of helping to draw saltwater into the coastal aquifer.

Potential impacts to the few domestic and irrigation wells in this area should also be negligible because these wells are generally screened at depths greater than 80 ft below the ground surface. These depths are lower than the maximum depths of Humboldt Bay of ~XX feet near the bay outlet. The well completion reports available for the few wells in the project area show that the wells are screened in confined aquifers under pressure with many of these wells are reported to be artesian or at least seasonally artesian (CA-DWR 2024). Appendix A – Project Area Well Log Data summarizes the available information about the subsurface and measured groundwater elevations.

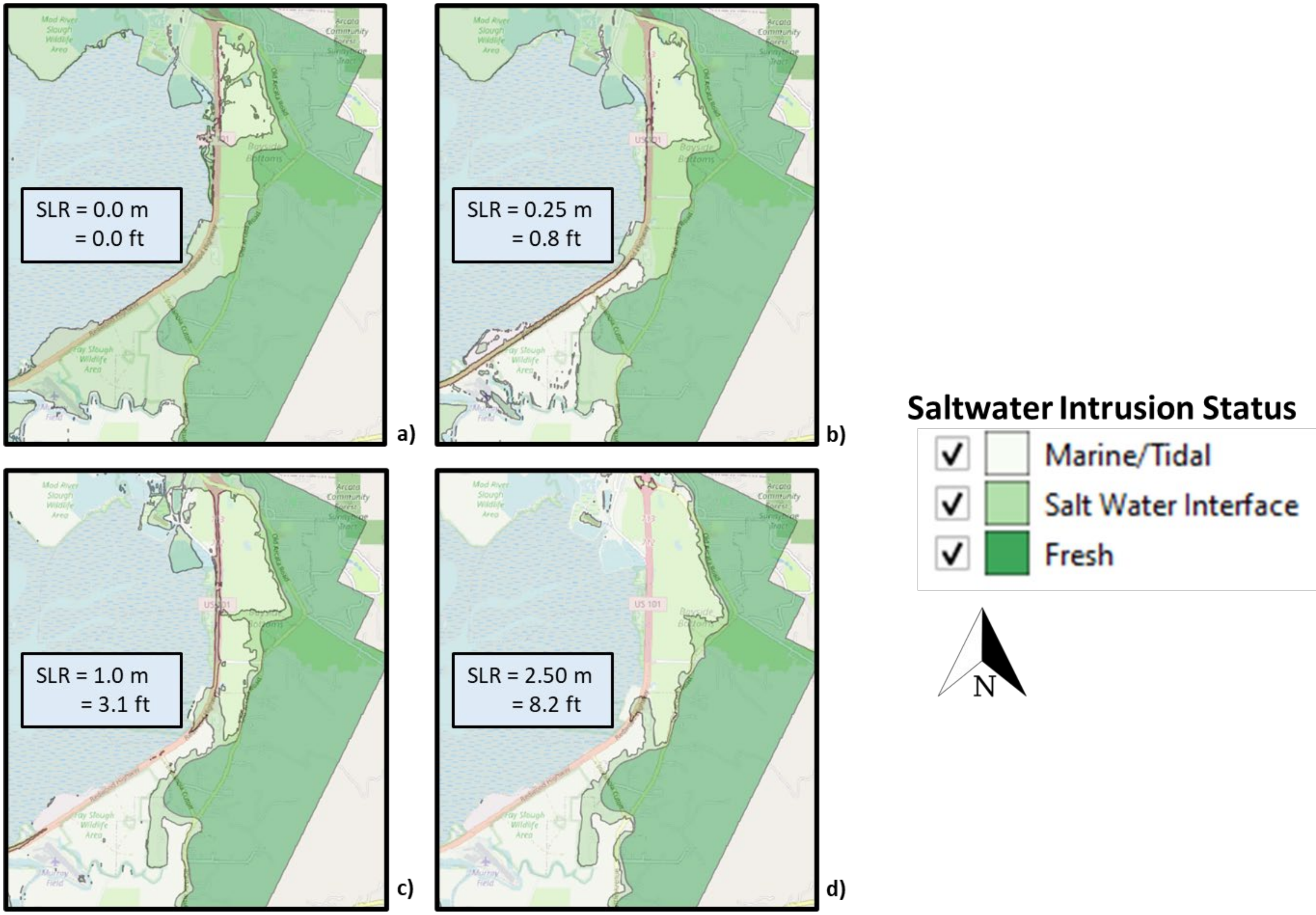

Figure 2. USGS CoSMoS-GW predictions of saltwater intrusion adding SLR to the MHHW and assuming a hydraulic conductivity of 1.0 m/day (data downloaded from Befus et al. 2020).

Detailed, Local Groundwater Analysis

For much of the wet season (~December through March), saturated conditions with groundwater elevations at or very close to the ground surface already exist within the project area. As rainfall decreases and evapotranspiration increases in the spring, the groundwater elevation drops. The USGS CoSMoS-GW analysis evaluated only the average annual condition and not those during the wettest and driest months. Their analysis also did not include impacts of stream and slough channels and how these might modify exfiltration from or infiltration to groundwater. To assess how SLR might impact land use and habitat conditions within and adjacent to the project area, two local groundwater models were developed. Similar to the CoSMoS-GW simulations, these models were created using Modflow 6 (Langevin, et al., 2017).

The local models are capable of illustrating the influence of important processes not accounted for in the CoSMoS-GW simulations but there is insufficient observed data to calibrate these models. Thus, their results are useful for identifying the magnitude of these process impacts but the groundwater elevations predicted cannot be verified. Additionally, the sea level rise impacts to dry season groundwater elevations will be strongly influenced by tidal incursion into slough and creek channels. The level of tidal inundation depends on operation and maintenance of tide gates, levees and similar structures. Any changes to these components of local infrastructure will alter the areas and extents of inundation and their influence on groundwater elevations.

These two models focused on the Jacoby Creek/Bayside Bottoms and Fay Slough areas on the north and south end of the project area, respectively (Figure 3). The project area is already known to have groundwater at or near the ground surface during most of the wet season and this would be expected to become worse with SLR. Thus, this modeling analysis evaluated potential SLR impacts on groundwater elevations during dry weather conditions with little to no precipitation and maximum evapotranspiration. The simulations also included the network of stream and slough channels present within the project area as these can both infiltrate and drain surface water into or out of the groundwater. As sea level rises, the water level in these channels could potentially become deeper promoting more infiltration into the groundwater during the dry season and maintaining higher year-round groundwater elevations.

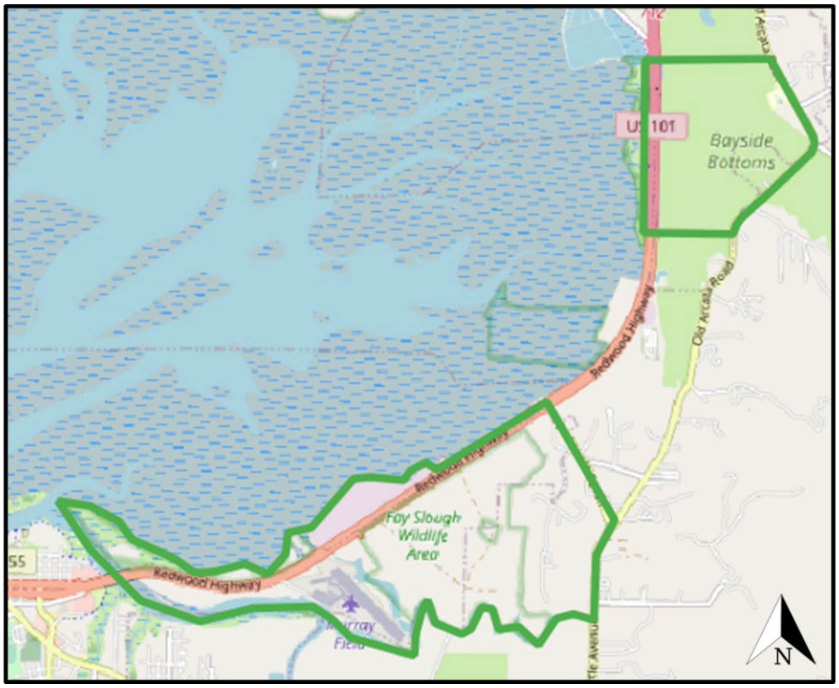

Figure 3. The two model domain boundaries (in green) for the Jacoby Creek/Bayside Bottoms region and the Fay Slough region used for local groundwater analysis.

To develop the local, smaller-scale groundwater models, the approach retained many of the same simplifying assumptions as the USGS CoSMoS-GW analysis. The model focused on the shallow surface aquifer and this aquifer was assumed to be homogeneous and unconfined with a hydraulic conductivity of 0.137 ft/hr (1.0 m/day). This hydraulic conductivity was the value that the CoSMoS-GW analysis showed best matched observed groundwater elevations. The models assumed no precipitation and incorporated the local monthly evapotranspiration rate for June, 4.50 inches/month, obtained from the California Irrigation Management Information System (CIMIS) (CA-DWR 2024). Unlike the CoSMoS-GW models, these models also include the presence of stream and slough channels, and groundwater can be influenced by both infiltration from the channels and drainage to the channels depending on the local water elevation gradients.

The physical structure for the groundwater model was built using the same digital elevation model (DEM) used for this project's surface water hydraulics modeling but clipped to the two regions of interest. This DEM was created from the 2020 USGS Coastal National Elevation Database Applications (CoNED) 1m LiDAR topobathymetric DEM (mostly 2019 LiDAR) with stream channels added to correct for hydroflattened areas in the LiDAR data. The channels were defined using available datasets from the City of Arcata GIS stream layer (City of Arcata 2024) and USGS National Hydrography Dataset (USGS 2024). A grid with cell size of 50-ft by 50-ft was used throughout both model domains.

Most simulations were steady state and assumed constant head groundwater boundary conditions. For the Jacoby Creek/Bayside Bottoms model, these were defined on the west using the MHHW tidal datum from direct measurements collected in Humboldt Bay just outside Gannon Slough from 2019 through 2021 (CPH and MLA 2022). For SLR scenario simulations, the specific sea level increase for each scenario was added to the current condition MHHW values. On the east side of the model, the groundwater elevation was set to a constant elevation of 10 feet below the ground surface which matches the limited groundwater data available from well logs in this area (CA-DWR 2024). The north and south boundaries were defined as no flow boundaries.

The Fay Slough area model has tidally influenced water levels along both the Humboldt Bay and the Freshwater Slough boundaries. The water level at these boundaries was set to MHHW tidal datums observed in Humboldt Bay from 2019 through 2021 just outside of Brainard Slough and in Freshwater Slough just outside of the tide gate near Jacobs Avenue and Murray Field (CPH and MLA 2022). Expected sea level rise was added to these observed MHHW values to simulate the different SLR scenarios. The eastern boundary groundwater elevation was set to 10 feet below the ground surface. The Jacoby Creek/Bayside Bottoms and the northern boundary along Indianola Road was defined as no flow.

To simulate the infiltration and drainage of groundwater to and from channels, the water level in the channels was set by comparing the channel bottom elevation to the sea level along the model boundaries. If the channel bottom elevation was lower than the sea level, then the water elevation in the channel was set to sea level. If the channel bottom elevation was higher than sea level, then the water level in the channel was set equal to the channel bottom elevation. Thus, as sea level increases for the various SLR scenarios, the water elevation in the channels was able to penetrate further upstream into the channel network.

Results

The results for selected sea level rise scenarios for the two local, sub-area models are presented here as plots of groundwater head or elevation along cross sections through the areas and as plan maps of depth to groundwater. The current condition simulations (SLR = 0.0 ft) are also compared to the CoSMoS-GW simulation results. Results for three SLR scenarios are presented here, and their likelihoods as defined by the latest OPC guidelines (OPC 2024) are indicated:

1. SLR of 0.8 ft – the Intermediate likelihood for 2050
2. SLR of 3.1 ft – the Intermediate likelihood for 2100
3. SLR of 4.9 ft (1.5 m) – the Intermediate-High likelihood for 2100

Expected groundwater elevations for SLR values between those simulated can be extrapolated from these results. Most of the region modeled in this analysis is predicted, without the implementation of significant infrastructure or physical modification, to convert to marine/tidal conditions and be inundated with SLR of 3.1 ft (1.0 m) or higher.

Unfortunately, there is currently insufficient data to calibrate these models so the results are primarily intended to show interactions between processes that influence groundwater elevations during the dry (summer) season and how these might change with rising sea level.

The simulations also do not account for future physical structures that might alter the tidal flow into and out of the existing stream and slough channels.

Jacoby Creek/Bayside Bottoms

The groundwater elevations across the modeled area were compared by extracting the values from the models, including the CoSMoS-GW model, along the red line shown in Figure 4. This cross section intersects channels identified in the City of Arcata GIS stream layer (City of Arcata 2024) in four locations as indicated by the red circles and labeled in the cross-section plots (Figure 5 - Figure 7).

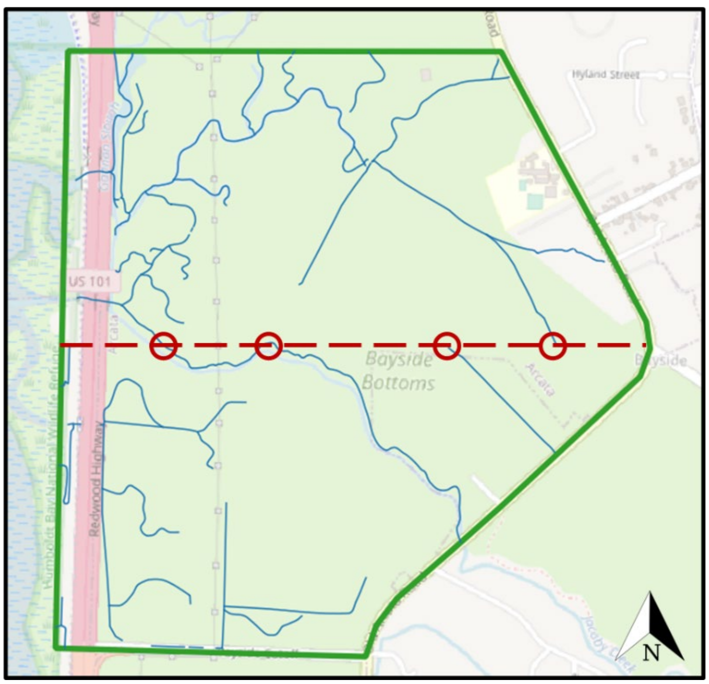

Figure 4. Jacoby Creek/Bayside Bottoms model domain showing the cross section used to extract groundwater elevations for model comparisons. The red circles indicate locations where the cross section intersects blue line channels present in the City of Arcata stream channel GIS layer (City of Arcata 2024). The channel layer has been clipped to the model domain.

Figure 5 compares the current condition (SLR=0.0 ft) groundwater elevation prediction of CoSMoS-GW to the local model results for the average annual conditions and dry season groundwater elevations predicted by the local model. For the average annual conditions, the results from both models compare well with the major differences seen at the locations of channels whose influence were not included in the USGS CoSMoS-GW analyses. As expected, the dry season simulations predict lower groundwater elevations driven by a combination of increased evapotranspiration and movement of groundwater into the channels. It should also be noted that the groundwater head boundary on the eastern edge of the model domain for the dry season simulation is defined as 10 ft below the ground surface which matches observations but is different (10-ft lower) than the CoSMoS-GW and average annual simulation boundary conditions which assumed a groundwater elevation at the land surface. Sensitivity analysis on this boundary condition assumption (not presented) showed that the effect of this head boundary value only minimally influences groundwater elevations between approximately 4000 ft and eastward on Figure 5.

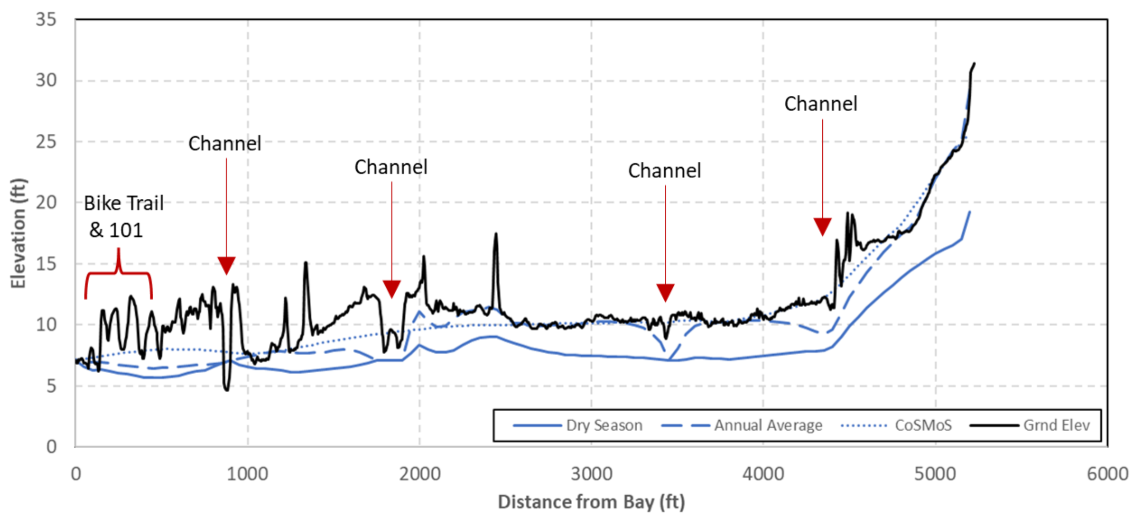

Figure 5. Comparison of local model predictions for annual average and dry condition with the USGS CoSMoS-GW results for the Jacoby Creek/Bayside Bottom region for current conditions (SLR 0.0 ft).

To illustrate the influence of different processes and assumptions on current condition (SLR = 0.0 ft) groundwater elevations, four simulations were evaluated (Figure 6):

- A sea level boundary condition at current MHHW (7.12 ft) that includes channels and evapotranspiration
- A sea level boundary condition at current LMSL (3.80 ft) that includes channels and evapotranspiration
- A sea level boundary condition at current MHHW (7.12 ft) that excludes channels but includes evapotranspiration
- A sea level boundary condition at current MHHW (7.12 ft) that includes channels but excludes evapotranspiration

Comparing the results with evapotranspiration and no channels (short-dash line) to the case with both processes active (solid line), clearly shows the role of the channels in maintaining higher groundwater elevations during the dry season. The channels closer to the bay (the first two channels labeled at ~900 and 1800 ft, respectively) and at lower elevation have greater incursion of tidal water so infiltration from these channels to groundwater creates higher groundwater elevations. The simulation excluding the influence of tidal excursion and higher surface water elevations in the channels (short-dash line) represents a situation where tide gates or similar structures would completely block tidal water from the channels. The case without evapotranspiration (long-dash line) is not realistic but important for understanding the influence of this process on lowering the groundwater elevations through the summer months.

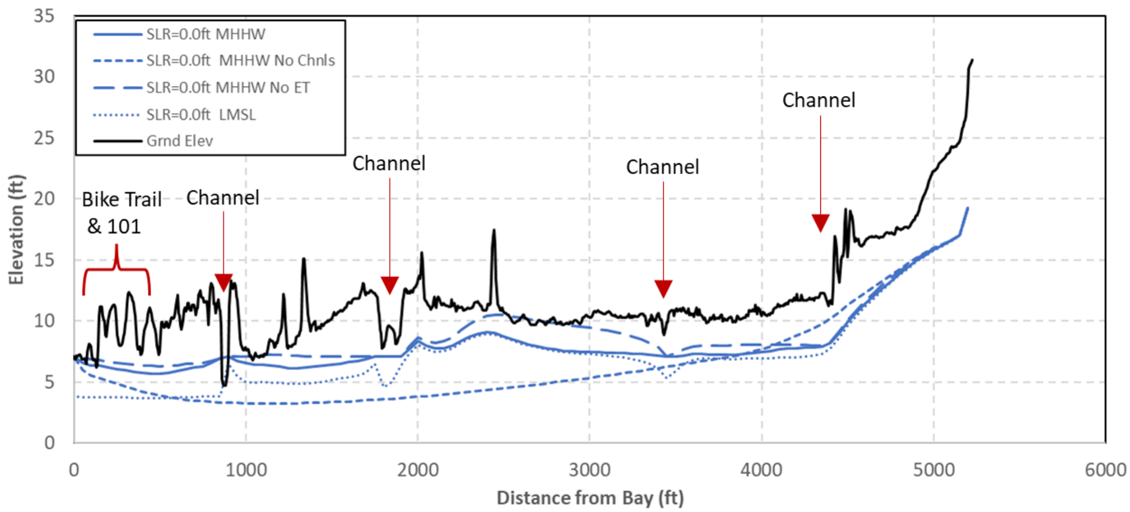

Figure 6. Comparison of local, steady-state model results for current conditions (SLR=0.0 ft) and different process and boundary condition assumptions for the Jacoby Creek/Bayside Bottoms area.

Figure 7 shows the results for the current condition and the three SLR scenarios. The rate of evapotranspiration assumed was the same for all simulations. The primary change as sea level rises is that groundwater elevations are predicted to increase due to additional infiltration from the channels into the subsurface with higher and more persistent in-channel, surface water elevations. The groundwater elevations expected for SLR values between those simulated can be interpolated from these results.

The results presented in Figure 7 assume that higher tidal elevations move into the project area primarily via the slough and stream channels. Also shown in Figure 7 are the static water levels (orange lines) associated with the estimated MHHW for each scenario. Comparing these elevations to the LiDAR ground surface elevations shows that for a SLR of 4.9 ft (1.5 m) most of the land surface on this cross section is fully submerged. At SLR of 3.1 ft (1.0 m), the water elevation is coincident with much of the land surface. These results are consistent with the USGS CoSMoS-GW predictions presented above shows the majority of this area converting to marine/tidal at SLR of approximately 1.0 m (3.1 ft). Under these conditions, the groundwater elevation within the project area would be at the land surface and the mechanisms promoting a dry season drop in groundwater elevations would no longer function.

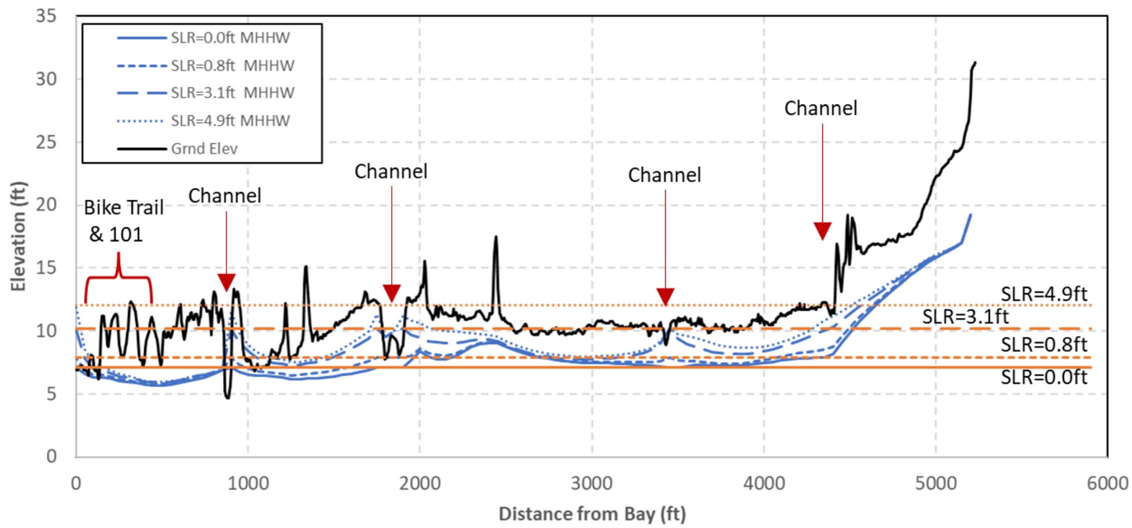

Figure 7. Comparison of local, steady-state model results for current conditions (SLR=0.0 ft) and three higher sea level scenarios for the Jacoby Creek/Bayside Bottoms area. The orange lines show the static water elevations for each of the scenarios.

Figure 8 compares the depth to groundwater from the land surface for current conditions and the three SLR scenarios. Except for the higher elevation locations on the eastern edge, most of the area has groundwater within 2 feet of the surface. The total area with very shallow groundwater is predicted to expand most significantly with a change in SLR from 3.1 ft to 4.9 ft.

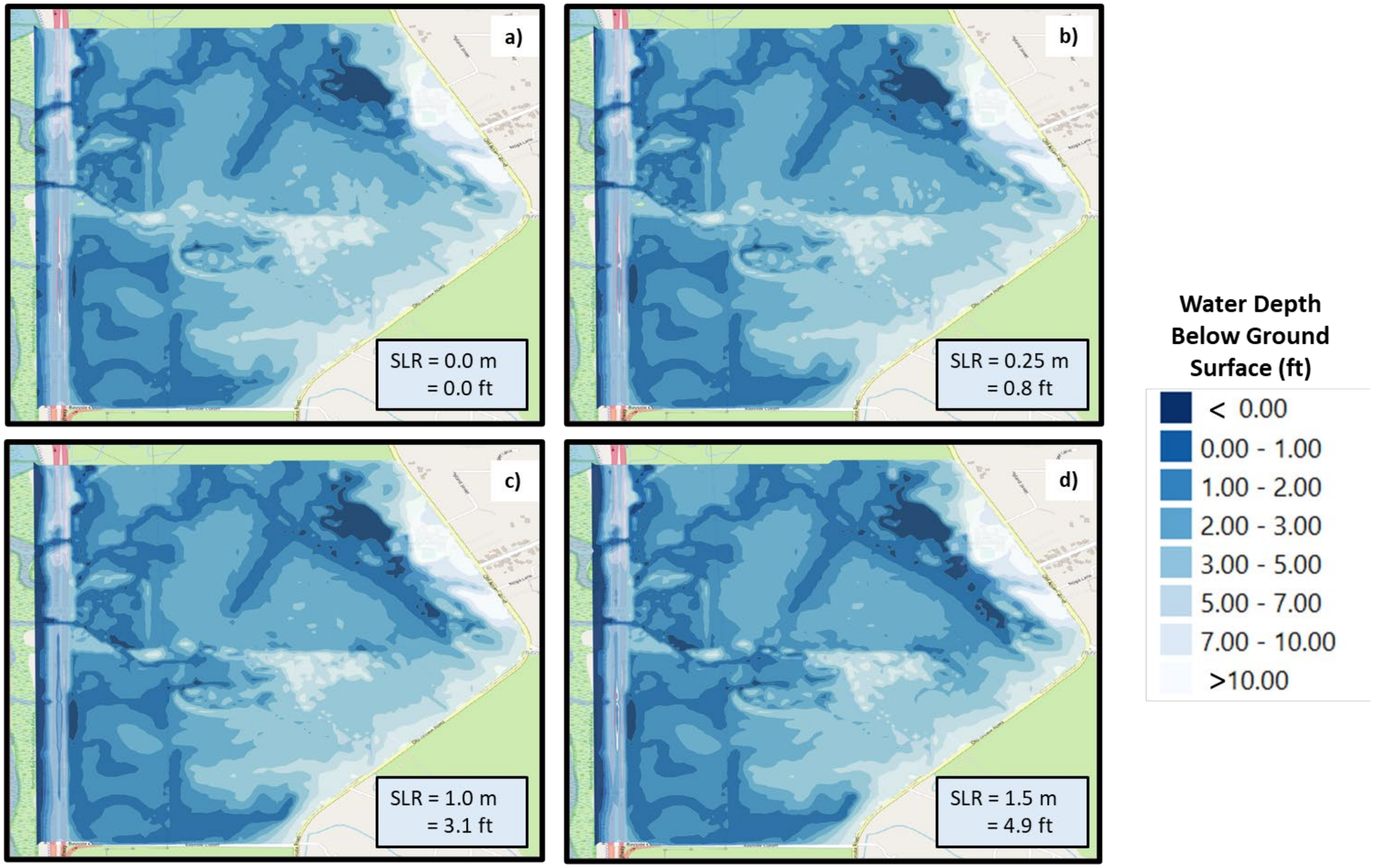

Figure 8. Comparison of local, steady-state model results showing water depth below the land surface for current conditions (SLR=0.0 ft) and three higher sea level scenarios for the Jacoby Creek/Bayside Bottoms area.

Fay Slough

The model for the Fay Slough area was developed using the same data sets and parameters as for the Jacoby Creek/Bayside Bottoms area and simulations were run for the same SLR scenarios. The groundwater elevation predictions across the modeled area were compared at two cross sections by extracting the values from the models, including the CoSMoS-GW model, along the red lines (A and B, Figure 9). Cross section A crosses only one defined channel, the slough along Highway 101 and cross section B crosses the 101 Slough and one of Fay Slough's channels at several locations (red circles).

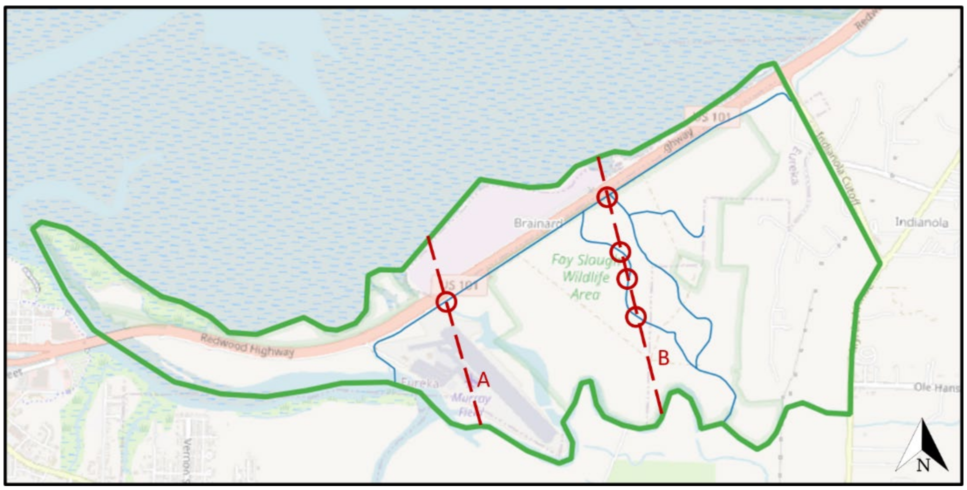

Figure 9. Fay Slough model domain showing the cross section used to extract groundwater elevations for model comparisons. The red circles indicate locations where the cross section intersects blue line channels present in the USGS National Hydrography Dataset (USGS 2024). The channel layer has been clipped to the model domain.

Figure 10 and Figure 11 show the local and CoSMoS-GW results for cross sections A and B, respectively. The MHHW boundary elevations for current conditions agree for all simulations but the CoSMoS-GW groundwater elevation predictions are much higher than the local model's for average annual conditions. In addition to not simulating the influence of channels in the landscape, the CoSMoS-GW simulations used a different surface elevation data set that was smoothed to remove depressions and this might explain the differences in predictions. The predicted groundwater elevations match better for cross section A (Figure 10) which has a more elevated and less undulating topography than cross section B (Figure 11) which supports this explanation.

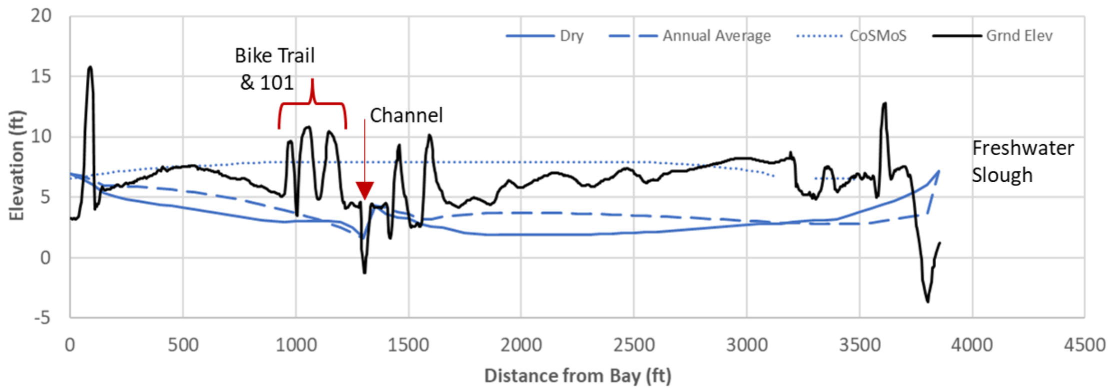

Figure 10. Comparison of local model predictions for annual average and dry condition with the USGS CoSMoS results for cross section A in the Fay Slough area for current conditions (SLR 0.0 ft).

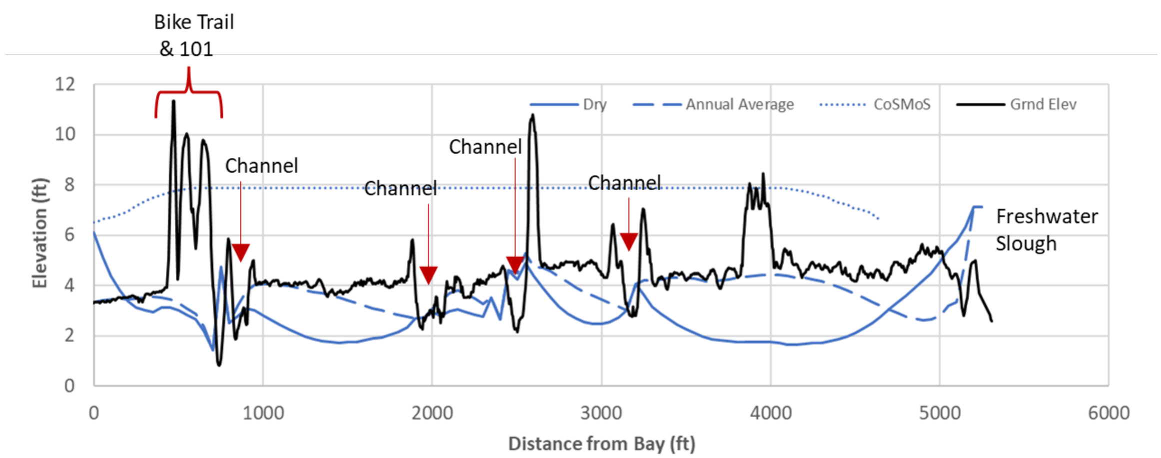

Figure 11. Comparison of local model predictions for annual average and dry condition with the USGS CoSMoS results for cross section B in the Fay Slough area for current conditions (SLR 0.0 ft).

Figure 12 and Figure 13 show the influence of the different processes and assumptions under current conditions (SLR = 0.0 ft) on groundwater elevations for four simulations along cross sections A and B, respectively:

- A sea level boundary condition at current observed MHHW (7.13 ft in Freshwater Slough and 6.95 ft in the bay at Brainard Slough) that includes channels and evapotranspiration
- A sea level boundary condition at current LMSL (3.61 ft in Freshwater Slough and 3.86 ft in the bay at Brainard Slough) that includes channels and evapotranspiration
- A sea level boundary condition at current MHHW (7.13 ft in Freshwater Slough and 6.95 ft in the bay at Brainard Slough) that excludes channels but includes evapotranspiration
- A sea level boundary condition at current MHHW (7.13 ft in Freshwater Slough and 6.95 ft in the bay at Brainard Slough) that includes channels but excludes evapotranspiration

Comparing the results with evapotranspiration and no channels (short-dash line) to the case with both processes active (solid line), clearly shows the role of the channels, both internal and on the boundaries, in maintaining higher groundwater elevations during the dry season. The simulation excluding the influence of tidal excursion into the channels and higher surface water elevations in the channels (short-dash line) represents a scenario where tide gates or similar structures would completely block tidal water from the channels. If this scenario existed and was maintained through the dry season, evaporation would be able to depress groundwater elevations at approximately four feet below the ground surface. The case without evapotranspiration (long-dash line) is instructive for understanding the influence of evapotranspiration on lowering the groundwater elevations through the summer months but is not realistic.

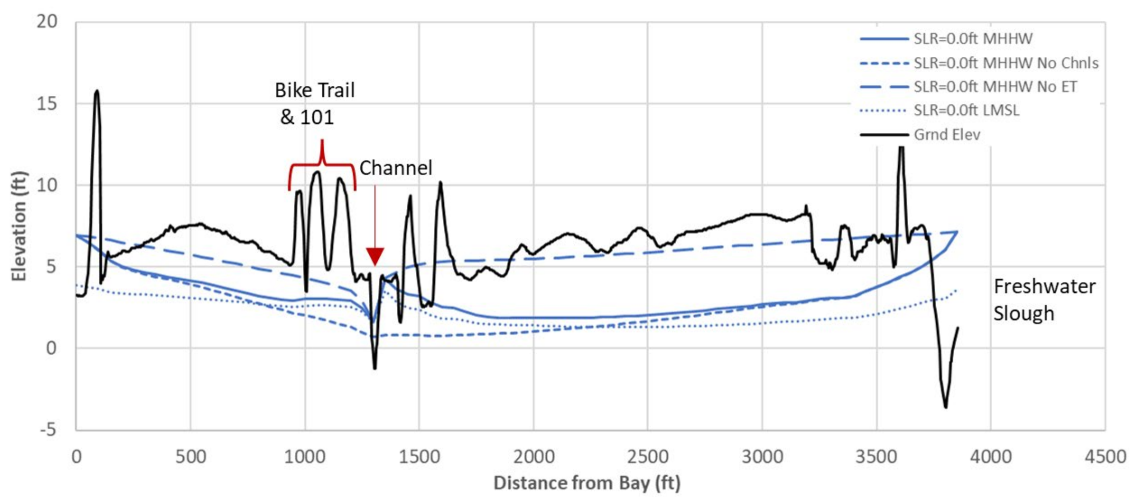

Figure 12. Comparison of local, steady-state model results for current conditions (SLR=0.0 ft) and different process and boundary condition assumptions for cross section A in the Fay Slough area.

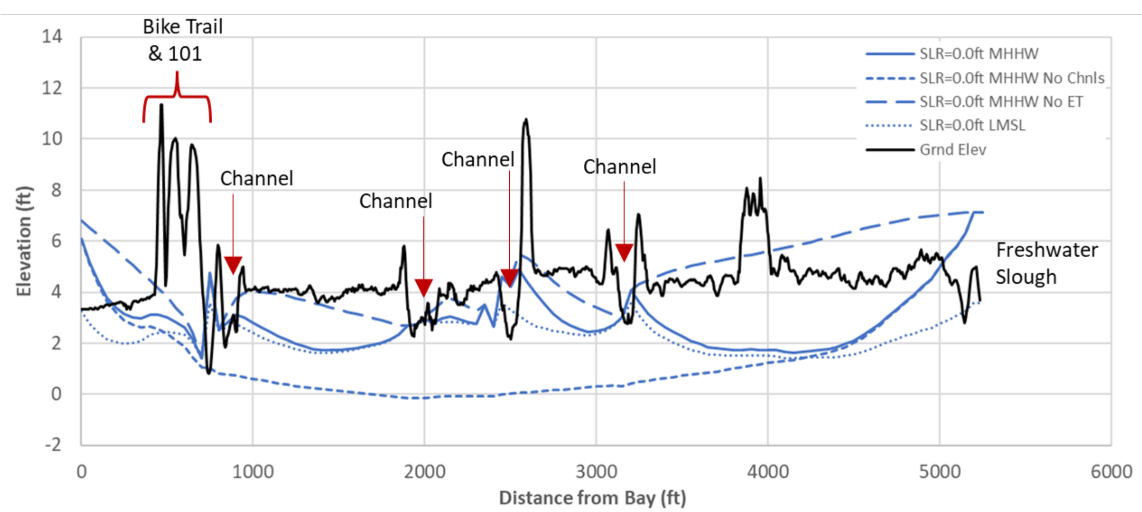

Figure 13. Comparison of local, steady-state model results for current conditions (SLR=0.0 ft) and different process and boundary condition assumptions for cross section B in the Fay Slough area.

The groundwater elevations along cross sections A and B for the current condition and three SLR scenarios are shown in Figure 14 and Figure 15, respectively. The rate of evapotranspiration used was the same for all simulations. Thus, the only change as sea level rises is that groundwater elevations are predicted to increase due to additional infiltration from the channels into the subsurface with higher and more persistent in-channel, surface water elevations. The groundwater elevations expected for SLR values between those simulated can be interpolated from these results.

The results presented in Figure 14 and Figure 15 account for higher tidal elevations to move into the project area as sea level rises and migrates further upstream via the slough and stream channel network. Also shown in these figures are the static water levels (orange lines) associated with the estimated MHHW for each scenario. Comparing these elevations to the LiDAR ground surface elevations shows that for even current conditions the sea level elevation would inundate much of the land surface, especially for cross section B. The presence of levees surrounding most of the area covered by this model and tide gates at the channel and slough outlets currently limit this inundation.

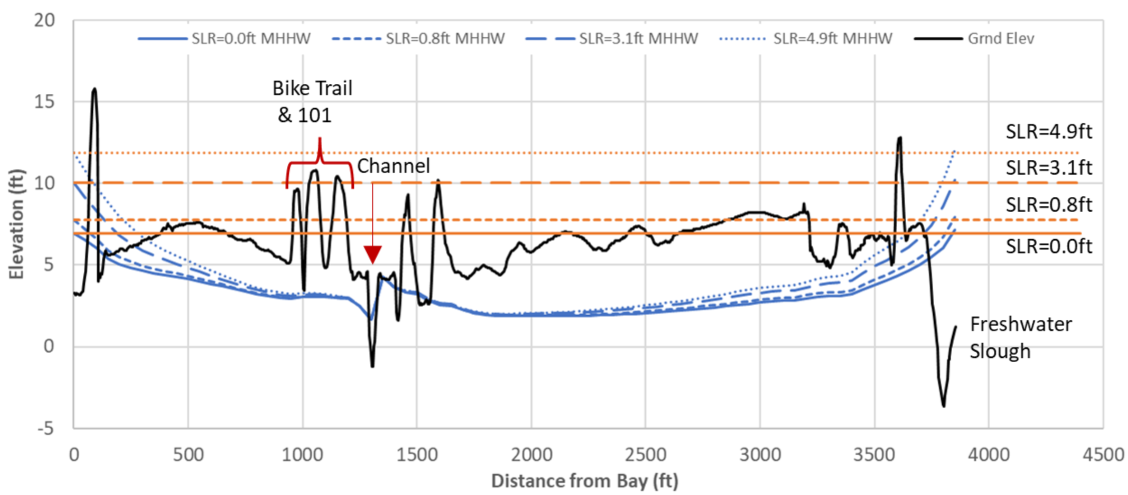

Figure 14. Comparison of local, steady-state model results for current conditions (SLR=0.0 ft) and three higher sea level scenarios for cross section A in the Fay Slough area. The orange lines show the static water elevations for each of the scenarios.

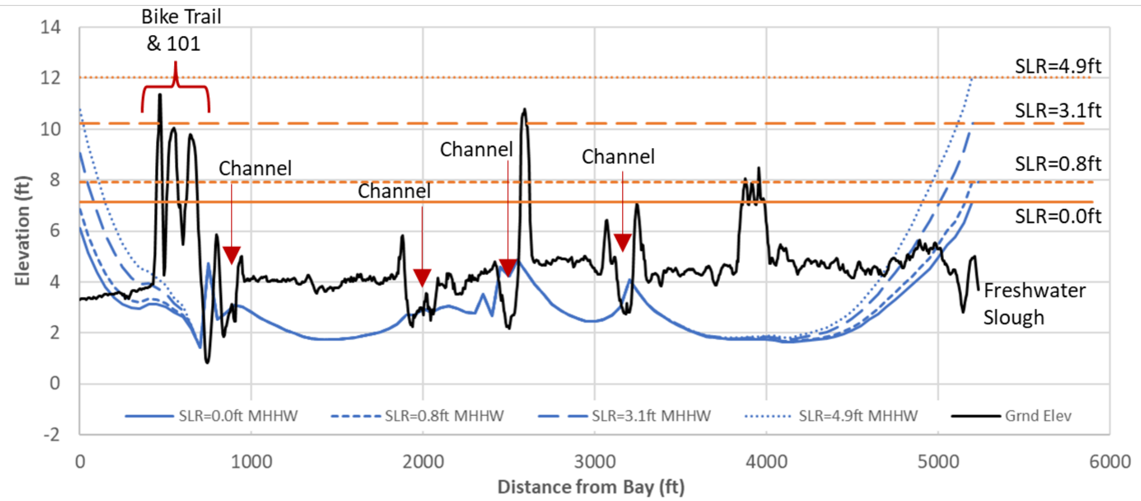

Figure 15. Comparison of local, steady-state model results for current conditions (SLR=0.0 ft) and three higher sea level scenarios for cross section B in the Fay Slough area. The orange lines show the static water elevations for each of the scenarios.

Figure 16 shows the depth to groundwater from the land surface for current conditions and the three SLR scenarios. Except for the higher elevation locations on the eastern edge, most of the area has groundwater within 2 feet of the surface under all scenarios. The Jacobs Avenue area and into Fay Slough are predicted to experience the greatest rise in dry season groundwater elevations.

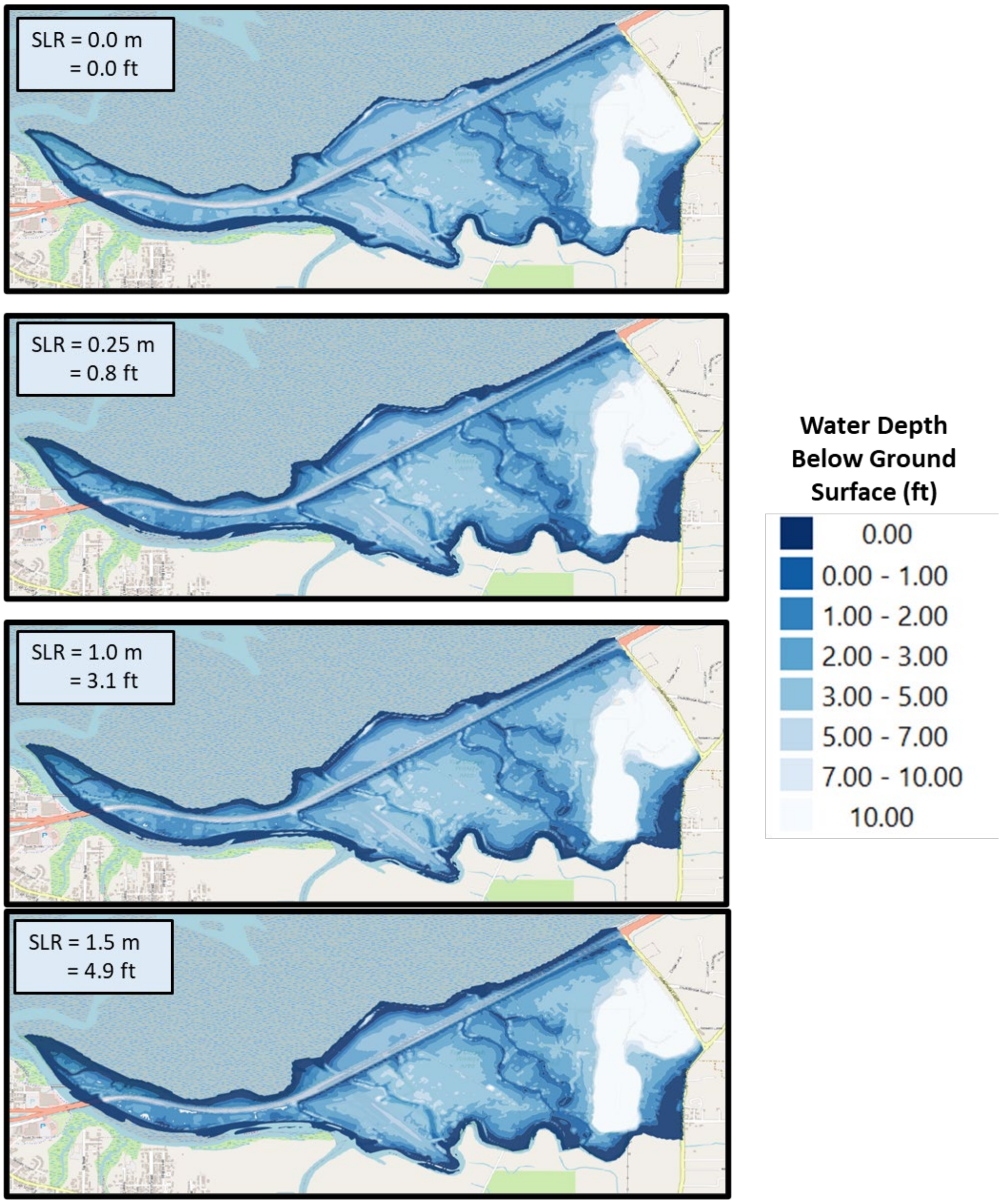

Figure 16. Comparison of local, steady-state model results showing water depth below the land surface for current conditions (SLR=0.0 ft) and three higher sea level scenarios for the Fay Slough area.

Contaminated Sites in Project Area

Contaminated sites and their status within the project area were identified using the State of California's Geotracker database (CA SWRCB, n.d.). Most of the sites are remediated leaky, underground storage tanks (LUSTs) indicated as red squares in Figure 17. Remediated sites are those that have had the contaminant source removed, monitoring shows that contaminant levels are below regulatory concerns and that have been officially closed. These sites are indicated with an X in Figure 17. The sites that are not LUST sites are indicated as green squares and most of these were fuel spills which have also been remediated and closed.

Three active sites exist in or near the project area and these are indicated by three green squares without an "X". These three sites are Trinity Diesel (fuel spills, BTEX, MTBE), Humboldt Aviation (fuel spills, diesel) and Roger's Garage (heavy metals found in surface soils). All of these sites have had the contaminant sources removed and been remediated but are listed as "Open" because they are still being monitored.

The impact of groundwater elevation changes due to SLR does not appear to pose a significant threat of interacting with known contaminated sites within the project area. Identified sites have all been fully remediated or have had the contaminant source removed and are being monitored. The known sites are concentrated in the southern portion of the project area, mostly along Jacobs Avenue, and this location remains an active industrial area with the potential for additional releases.

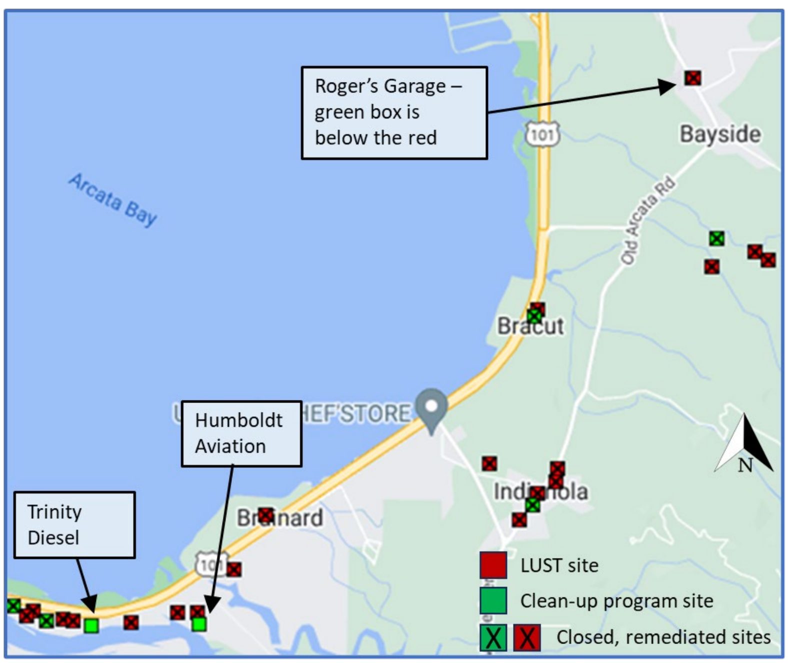

Figure 17. Known contaminated sites within the project boundaries. Most of these sites are former Leaky, Underground Storage Sites (LUST). The clean-up program site contaminants vary but most are fuel components (diesel or BTEX/MTBE). Source https://geotracker.waterboards.ca.gov.

Impact of High or Variable Groundwater Elevations on Roads

As groundwater rises and soil becomes saturated closer to the land surface, the saturated soil interacts with more infrastructure. Saturated soils have different load bearing behavior and properties than unsaturated soils. Thus, roads, buildings and other structure foundations can experience differential settling and deformation leading to cracking or seepage of groundwater into structures. Groundwater rising into the base layers of road infrastructure can also weaken the pavement structure.

A study conducted by the New Hampshire DOT simulated the effect of rising groundwater on road sublayers and pavement design life (Knott et al. 2017). They applied Multilayer Elastic Analysis using the KENLAYER model to simulate changes to the road and road-base properties as groundwater rose into the road base. The model predicts the number of load application cycles until failure by either fatigue cracking due to horizontal tensile strain or rutting failure resulting from vertical compressive strain. The simulations were all conducted with a constant load (9000-lb, single axle) and using the actual road sublayers for vulnerable roadways. Vulnerable roads were those that already had GW levels within the road base or within 1-ft of the road base. Rutting failure was increased more than fatigue failure. Fatigue failure was predicted to increase 5 – 17% as GW approached the base layer and by 50% as GW entered the base layer. Rutting failure was predicted to increase from 38 to 92% as GW rose from the sublayer to the base layer.

Figure 18 shows the groundwater elevations predicted by both CoSMoS and the local model within a representative cross section of Highway 101 near Fay Slough. The CoSMoS-GW simulations for average annual conditions and no sea level rise predicted the highest groundwater elevations, approximately 4.5 ft below the road crown. The groundwater elevations for the local model for both annual average and dry conditions are lower (9 and 10 ft below the road crown, respectively) for SLR = 0.0 ft. These results differ because the local model accounts for groundwater drainage and infiltration to the slough channels. For increasing sea level scenarios, the groundwater elevations predicted with SLR = 0.8 ft (0.25 m) are essentially the same as shown for all models. At greater sea level increases, the project area is predicted to be submerged under average annual conditions.

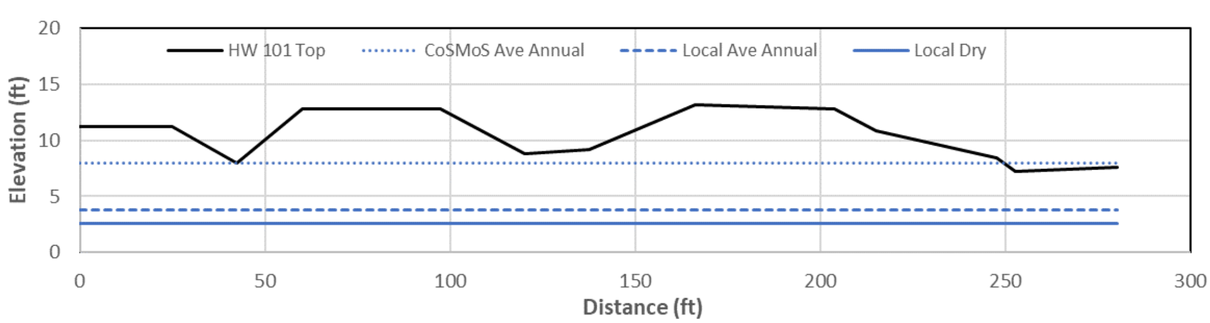

Figure 18. Predicted groundwater elevations for current conditions (SLR = 0.0) under average annual (CoSMoS and local model) and dry conditions (local model only).

Conclusions & Recommendations

As highlighted previously, there is insufficient data to fully calibrate the models constructed and simulations completed to assess the groundwater hazards in the Highway 101 Eureka-Arcata corridor because of sea level rise. The local model results, however, build on the USGS CoSMoS-GW predictions and emphasize the process interactions and likely impacts to groundwater elevations from SLR. Both the USGS CoSMoS-GW and local models were purposely constructed using conservative assumptions, so their predications are likely more pronounced than the actual response of groundwater elevations to SLR. As an example, both models assume homogeneous, unconfined aquifers so do not account for conditions such as fine sediment and bay mud with much lower hydraulic conductivity slowing water infiltration and groundwater drainage at the bay-land and channel-aquifer interfaces.

Groundwater elevations in the project area are also seasonally dynamic and SLR will likely impact these dynamics. The sloughs and stream channels within the project area can strongly influence these dynamics through both infiltration into the groundwater aquifer and drainage from the aquifer. Thus, these are important processes to include in assessment and predictions, and to account for changes to the conditions in these channels as infrastructure is modified to mitigate SLR impacts.

The groundwater elevation in much of the lower lying land in the project area is already subject to complete saturation with groundwater at the surface in an average wet season. Thus, SLR impacts on land use and habitat may be greater during the dry season because higher sea level can maintain year-round higher groundwater elevations.

To better understand the groundwater dynamics and how SLR may impact these conditions, more data is needed to develop a calibrated model. Data needs include installation of a series of small wells, or piezometers, within and adjacent to stream or slough channels to collect observations of the seasonal groundwater elevation dynamics and confirm the magnitude of seasonal groundwater elevation dynamics. Figure 19 and Figure 20 show possible locations for installation of piezometers to collect groundwater elevation observations. These locations are not unique but were selected to collect observations along transects perpendicular to major creek or slough channels which could both confirm the influence of infiltration and exfiltration of groundwater to these channels and provide data to better characterize the local hydraulic conductivity. Placing some observation locations near the highway would also provide insight into the wetting and drying of near the road base and along the drainage ditches.

Figure 19. Possible piezometer placement in the northern section of the project area. Collecting temporal measurements of groundwater elevation at these locations would improve understanding of the seasonal groundwater dynamics within the Highway 101 corridor.

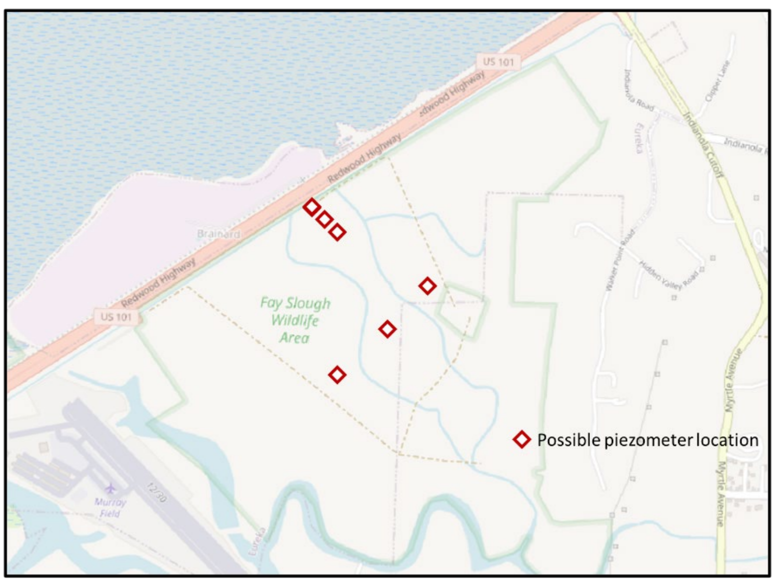

Figure 20. Possible piezometer placement in the southern section of the project area. Collecting temporal measurements of groundwater elevation at these locations would improve understanding of the seasonal groundwater dynamics within the Highway 101 corridor.

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