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Appendix D

Ecosystem Benefit Modeling Appendix

Watsonville Slough Ecosystem Restoration Project
San Francisco District

Continuing Authorities Program (CAP), Section 1135

TABLE OF CONTENTS

List of Abbreviations & Acronyms

AAHU	Average Annualized Habitat Units
CAP	Continuing Authorities Program
CE/ICA	Cost Effectiveness/Incremental Cost Analysis
CRAM	California Rapid Assessment Method
CCWG	Central Coast Wetlands Group
ECO-PCX	Ecosystem Restoration Planning Center of Expertise
ESA	Environmental Science Associates
FID	Federal Interest Determination
FWOP	Future without project
GIS	Geographic Information Systems
HEC	Hydrologic Engineering Center
H&H	Hydrology and Hydraulics
HH&C	Hydrology, Hydraulics, and Climate
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HSI	Habitat Suitability Index
HU	Habitat Units
IWR	Institute for Water Resources
MFR	Memorandum For Record
NAVD	North American Vertical Datum
POC	Point of Contact
PDT	Project Delivery Team
PTI	Percent Time Inundated
SPD	South Pacific Division
USACE	US Army Corps of Engineers

1. Study Description

1.1. Purpose and Scope

The goal of the Watsonville Slough CAP study is to enhance existing marsh habitat by restoring tidal/hydrologic connectivity within the study area. The scope of the Ecosystem Benefit Modeling analysis for this study was primarily to quantify the ecosystem restoration benefits from proposed project alternatives over the course of the project design life, based on the changes to hydrology described in the HH&C Appendix. Ecosystem restoration benefits in this study are tied to increases in hydroperiod (or percent time inundated). Thus, the primary objective of the ecosystem benefit modeling was to interpret the simulated percent time inundated throughout the marsh plain contained within the study area under various present and future scenarios, as described in the HH&C Appendix.

1.2. Study Area

The Watsonville Slough CAP study area is located at the confluence of the Watsonville Slough with the Pajaro River, in southern Santa Cruz County. The study area is bordered inland by low-lying, active agricultural fields and on the ocean side by the Pajaro Dunes Community. The project area is bounded by Shell Road at the upstream end, and the Pajaro River and Lagoon at the downstream end (Figure 1).

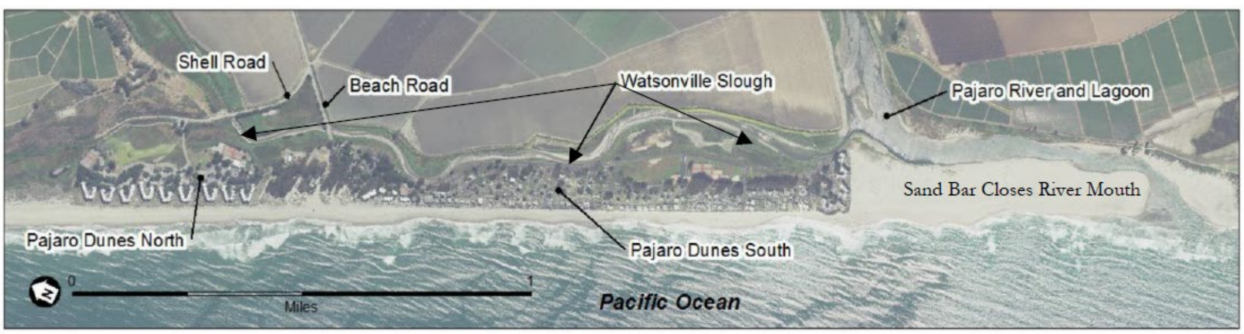

Figure 1: Map of the project area extents, showing the confluence of the Watsonville Slough and the Pajaro River at the Pajaro Lagoon (Source: Technical Memo from ESA, 2018).

The mouth of the Pajaro River watershed includes a lagoon and can be characterized as a bar-built estuary system, which experiences intermittent closures caused by the interplay of wave action and sediment transport. Wave runup deposits sand transported onshore and builds up a beach berm, which rises in elevation over time and “closes” the lagoon mouth. Closure events typically occur in the summer and fall. The lagoon stage can increase from wave run-up overtopping the beach or from watershed runoff and breach the berm, thus creating a new channel outlet to the ocean (Figure 2). While closed, lagoon water levels can spike rapidly with fluvial inputs and create a backwatering effect.

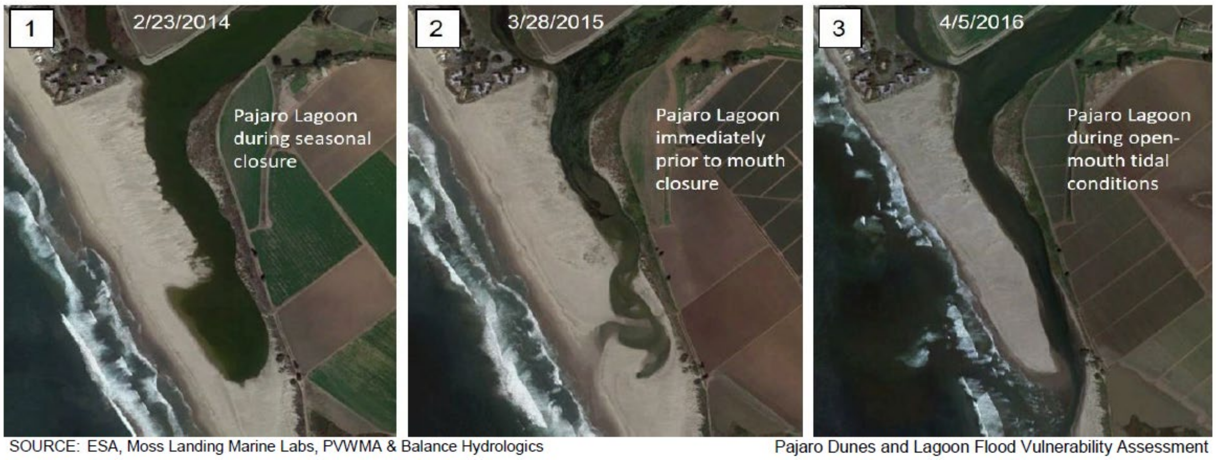

Figure 2: Pajaro Lagoon under open and closed conditions (Source: Technical Memo from ESA, 2018).

This system (and its closure/breaching patterns) influences the upstream hydrology and water quality of Watsonville Slough and lower Pajaro River. When the lagoon mouth is open, water levels in Watsonville Slough and Pajaro River (up to Highway 101) are subject to tidal influence. When the lagoon is closed, the project area is effectively disconnected from tidal forcing, and water levels in the project area are determined predominantly by streamflow inputs and losses due to evapotranspiration and seepage/infiltration.

1.3. Modeling Workflow Overview

The primary objective of the ecomodel analysis described herein is to quantify the ecosystem restoration benefits of the proposed project alternatives. Given the complicated hydrologic nature of an intermittently closed estuary system, a multi-step modeling approach was employed. The approach aims to link the changes to the annual hydroperiod that result from the proposed project alternatives in a “typical” hydrologic year as described in the HH&C Appendix to the ecology of the marsh and generate “Habitat Units” that can be entered into CE/ICA for plan formulation. The modeling workflow steps are summarized as follows:

1) *Investigate Background of Bar-Built Estuaries (Chapter 2):* Conduct a literature review to develop a background understanding of how bar-built estuaries function under natural conditions, including the interplay of hydrology and marsh vegetation. Examine how hydrologic modifications such as those at Watsonville Slough and the Pajaro River Lagoon can affect marshes associated with bar-built estuaries. Link findings to conditions at Watsonville Slough.

2) *Conceptual Ecological Model (Chapter 3):* Based on the understanding of how bar-built estuaries are meant to function under natural hydrologic conditions and conditions at Watsonville Slough, develop an ecological conceptual model of the Watsonville Slough as part of the Pajaro River bar-built estuary.

3) *Review Measures for Hydrologic Restoration Measures and overview of modeling approach (Chapter 4)*: Based on the understanding of the conceptual ecological model for Watsonville Slough, a number of potential restoration measures were devised to address the truncated hydrology that was degrading the marsh quality. These were

assessed by H&H (Appendix B-1) to determine the effects of the measures on marsh plain hydrology.

4) *Interpret Hydraulic Modeling (Chapter 5):* Review the Annual Percent Time Inundated (PTI) rasters generated by the H&H team (described in detail in the HH&C Appendix) and compare them to the vegetation mapped by Watsonville Wetlands Watch to determine brackets of inundation associated with open water, healthy marsh, and upland/stressed marsh. Use this information to develop a Habitat Suitability Index (HSI) curve for generating Habitat Units (HUs).

5) *Assess the HUs Associated with Alternative Plans (Chapter 5)*: Apply the HSI curve to Annual PTI rasters for each parcel (County, State, and Lower Mile) for each alternative (FWOP, Earthwork Only, Crossing Improvements Only, Crossing Improvements and Earthwork) at each time step (Years 0, 25, and 50), to generate the HUs associated with each.

6) *Annualize the HUs (Chapter 5)*: Use IWR Planning Suite, a certified planning model, to annualize the HUs for each parcel alternative over the life of the project. Subtract the FWOP HUs from the HUs associated with each of the other plans to derive the annualized benefits at each parcel for each alternative. These are handed off to the economist for use in CE/ICA (Appendix E).

2. Background on Bar-built Estuaries in California

Roughly half of California's 577 coastal confluences can be described as bar-built estuaries (Clark and O'Connor 2019). As described in the Section 1 above, these river mouths naturally close for a period of time, typically in the summer, when river flows are low and wave action from the ocean builds up the beach sufficiently to block the river outlet, leading to backwater flooding some distance upstream. These seasonal closures are a major driver of the evolution of these estuarine systems, and as a result the marsh plains of bar-built estuaries are typically perched above the elevation of marshes in strictly tidal systems.

Bar-built estuaries exhibit three natural lagoon mouth states. When open, water levels in the lagoon are driven by the tides and water stays primarily in the slough channels, and immediately adjacent low marsh (Figure 3, top lagoon mouth condition, blue cross section). When the sand bar has been partially built up and the lagoon mouth is in a partially open, muted tidal condition, water levels are somewhat elevated, backing up onto the marsh plain via microtopographic relief and side channels (Figure 3, middle lagoon mouth condition, red cross section). The majority of the marsh plain is only inundated when the lagoon mouth is closed, and the backwater flooding at its highest levels (Figure 3, bottom lagoon mouth condition, orange cross section).

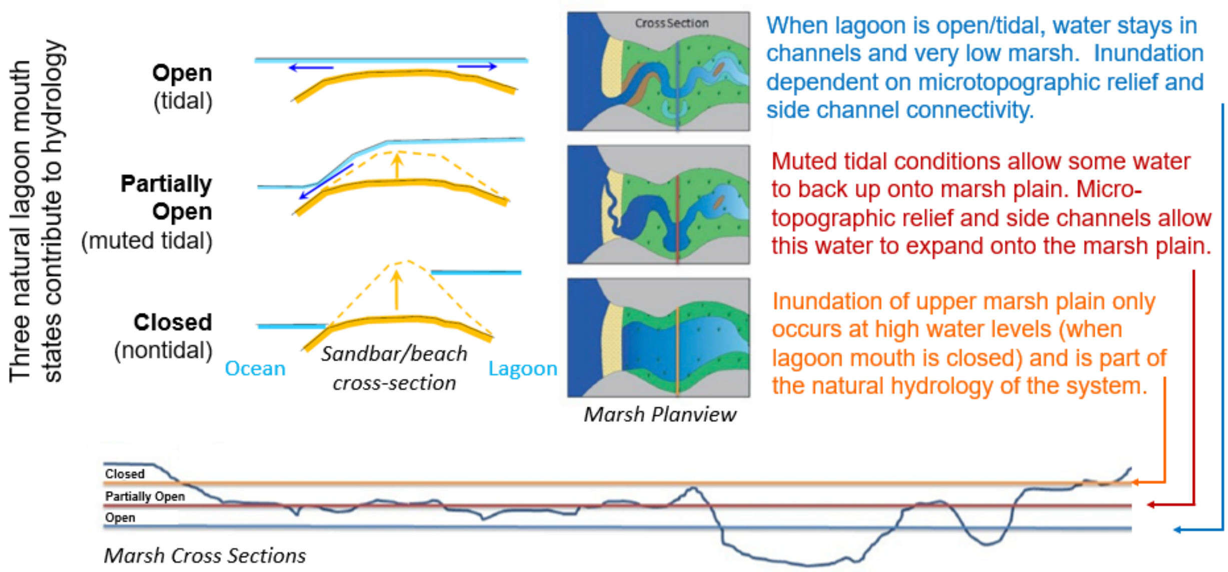

Figure 3. Effect of lagoon mouth state on bar-built estuary marsh hydrology. Adapted from Clark and O'Connor 2019 and ESA 2022.

The closures are natural components of the hydrology of the perched marsh plains associated with these bar-built estuaries. like that at the mouth of the Pajaro River and the lower Watsonville Slough. These backwater events inundate the perched marsh plain, not only contributing to the hydrology necessary for marsh plants, but making the habitat accessible to young fish and other epibenthic species during critical lifecycles.

This complex hydrology leads to diverse annual inundation regimes and consequently diverse plant communities. However, many coastal bar-built estuaries are managed to prevent the high water events associated with the lagoon closures, often to protect communities or infrastructure built on the former marsh plains (Clark and O'Connor 2019, Largier et al. 2019). Such “truncated” hydrology has been shown to impact the quality of existing marsh. A study at Scott’s Creek Estuary, another central coast bar-built estuary approximately 25 miles northwest of Watsonville Slough, highlights the differences in inundation between a healthy, natural marsh and one subjected to artificial breaching (Largier et al. 2019). In this study, dataloggers were left in the marsh for more than three years, and an annual percent of time inundated was calculated with empirical data across a broad region of the marsh (Figure 4). The natural inundation periods, including natural lagoon closures, resulted in a diverse range of annual inundation ranges (Figure 4A). The researchers then modeled the impact of a mechanical breaching program typical of managed bar-built estuaries (Figure 4B), and showed that not only did the area of inundation decrease, but the complexity of the habitat is reduced from a broad range of inundation patterns to essentially two: areas inundated 80-100% of the time, and areas inundated less than 20% of the time (i.e., upland conditions) (Largier et al. 2019). This lack of heterogeneity is seen by comparing the percent area of marsh within various marsh flooding regimes under natural and forced-breaching hydrology (Figure 5).

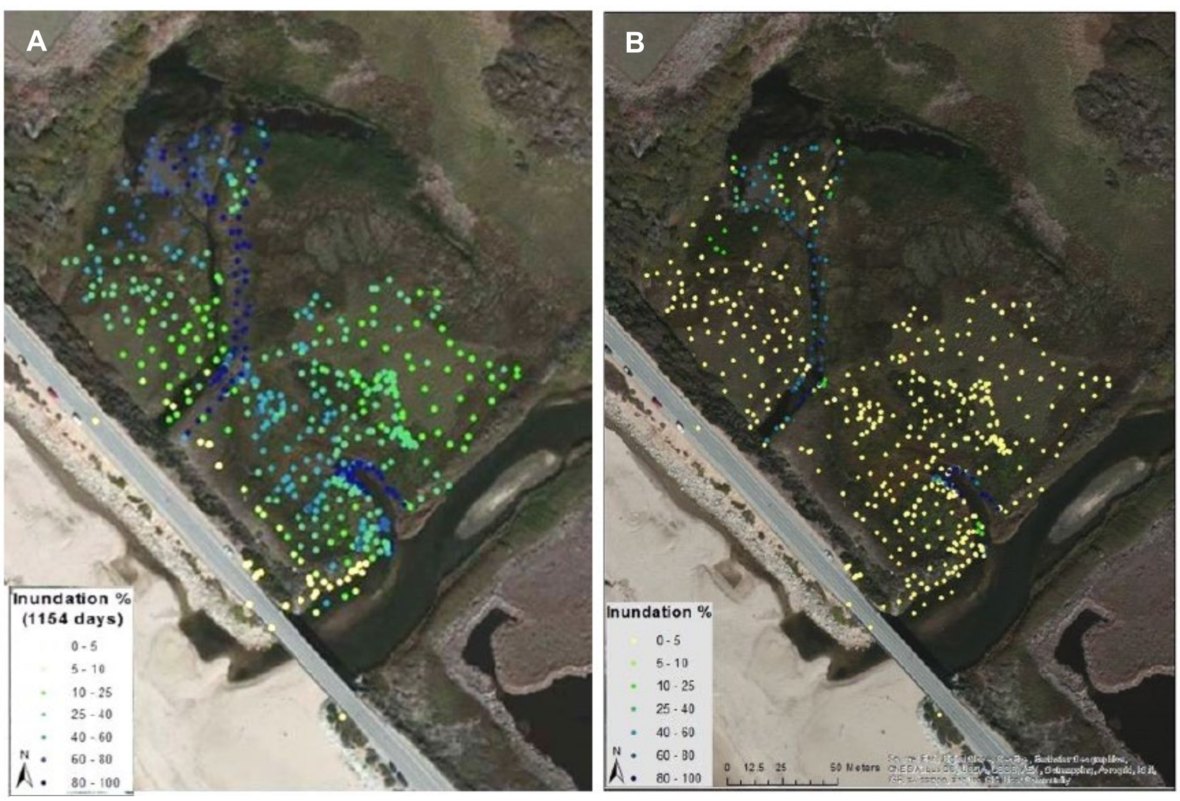

Figure 4. A: The percent of time that points on the marsh plain are inundated in Scott Creek Estuary over a 1164 day period from 2013 to 2016. B: Percent of time points would be inundated if a hypothetical managed breaching regime limited water level to 1.45 meter above mean sea level (MSL). From Largier et al. 2019.

These shorter inundation periods affect the plant community on the marsh plain. Different marsh species prefer different inundation regimes (Figure 6). A shift to drier conditions can also lead to community shift to high marsh and even upland species (Largier et al. 2019).

However, seasonality of the flooding may also play an important role. Clark and O'Connor (2019) indicate that flooding of the marsh plain in summer months is correlated with increased plant diversity. Figure 7 illustrates this summer flooding in the Matole River, Salmon Creek, and Gaviota Creek estuaries, all of which had CRAM scores reflecting

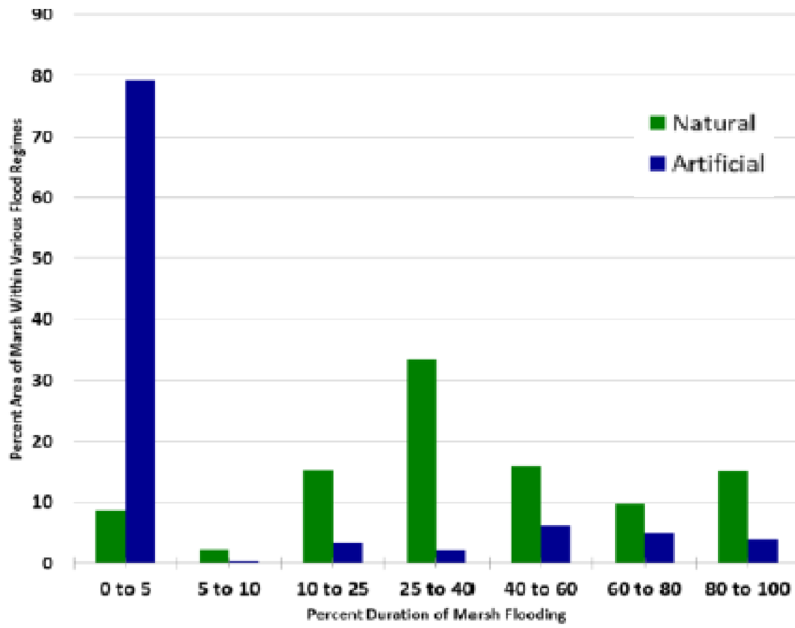

Figure 5. Percent of the marsh plain flooded under natural conditions (green bars) and under a hypothetical 1.45 m maximum water elevation breaching regime (blue bars). From Largier et al. 2019.

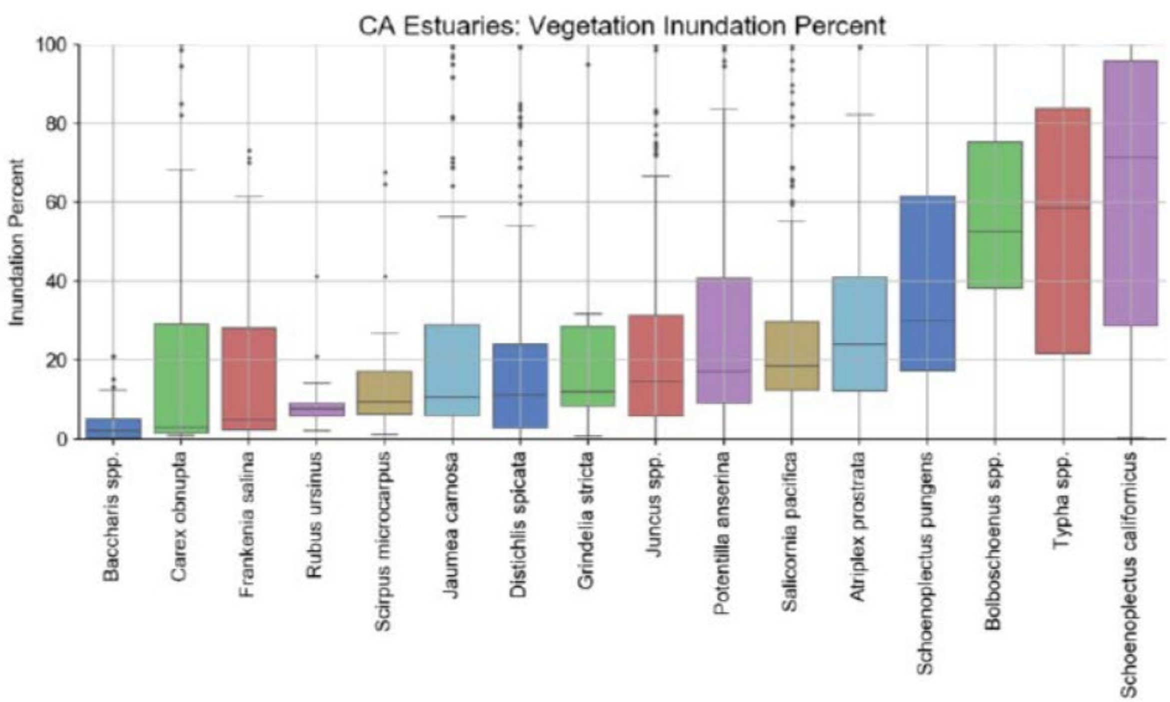

Figure 6. Plant species commonly found in bar-built estuaries organized by the amount of time they were inundated at 30 estuaries along the California coastline. The box represents the quartiles of the data. The mid-line of each box is the median, lower end of the box is the mid-value between the lowest value and the median. The higher end of the box is the mid-value between the highest value and the median. The whiskers show the extremes (max & min) values, while the dots are outliers. (Data provided by CCWG). From Largier et al. 2019.

“Optimal” condition (Clark and O’Connor 2019). In contrast, estuaries with flooding primarily in the late fall and winter exhibited a range of conditions as defined by CRAM scores: Alter Creek (Good), Pajaro River (Fair), Jalama Creek (Good).

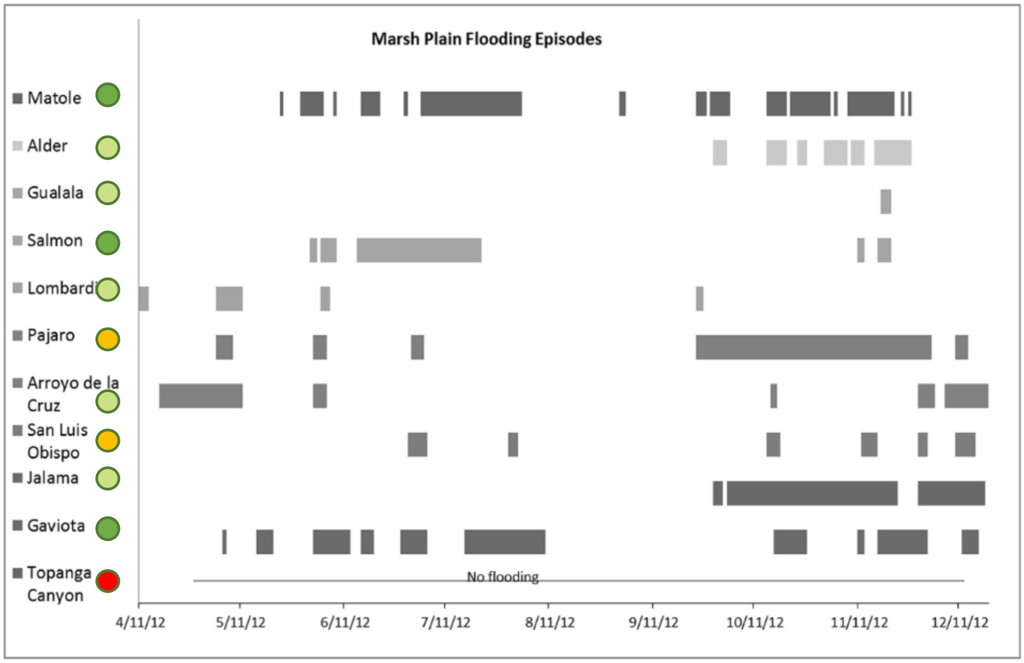

Figure 7. Periods of marsh plain inundation for 10 BBEs during 2012. Summer flooding in Matole, Salmon Creek, and Gaviota were correlated with higher CRAM scores and presence of sensitive plant species. Ponding in the winter occurred in estuaries with a range of CRAM scores. Colored dots beside the estuary name reflect the overall CRAM score for the estuary: green is “Optimal”, chartreuse is “Good”, amber is “Fair”, and red is “Poor”. Adapted from Clark and O’Connor 2019.

Largier et al. (2019) also describes other impacts to the ecosystem associated with premature mechanical breaching of lagoons. When the sand barrier is breached, high discharge velocities can scour sand, flush algae and other biota from the lagoon. When the sand barrier is breached prematurely and repeatedly, sand accumulates in the flood-tide shoal, reducing tidal prism and making the shoal less susceptible to natural breaching. Finally, a comparison of more than bar-built estuaries in California showed that those with natural hydrology also scored higher in California Rapid Assessment Method (CRAM) scores than estuaries with managed bar-built estuaries (Figure 8). Some of these may be mere correlations (e.g., buffer width and conditions), but in light of the information above the lower scores for attributes of the vegetative community are likely caused by the decreased or truncated hydrology. Species richness, patch richness, number of plant layers, and vertical biotic structure are all lower in managed bar-built estuaries with low hydroperiods. Largier et al. (2019) concludes that the altered hydrology reduces the complexity, quality, and health of the marsh ecosystem.

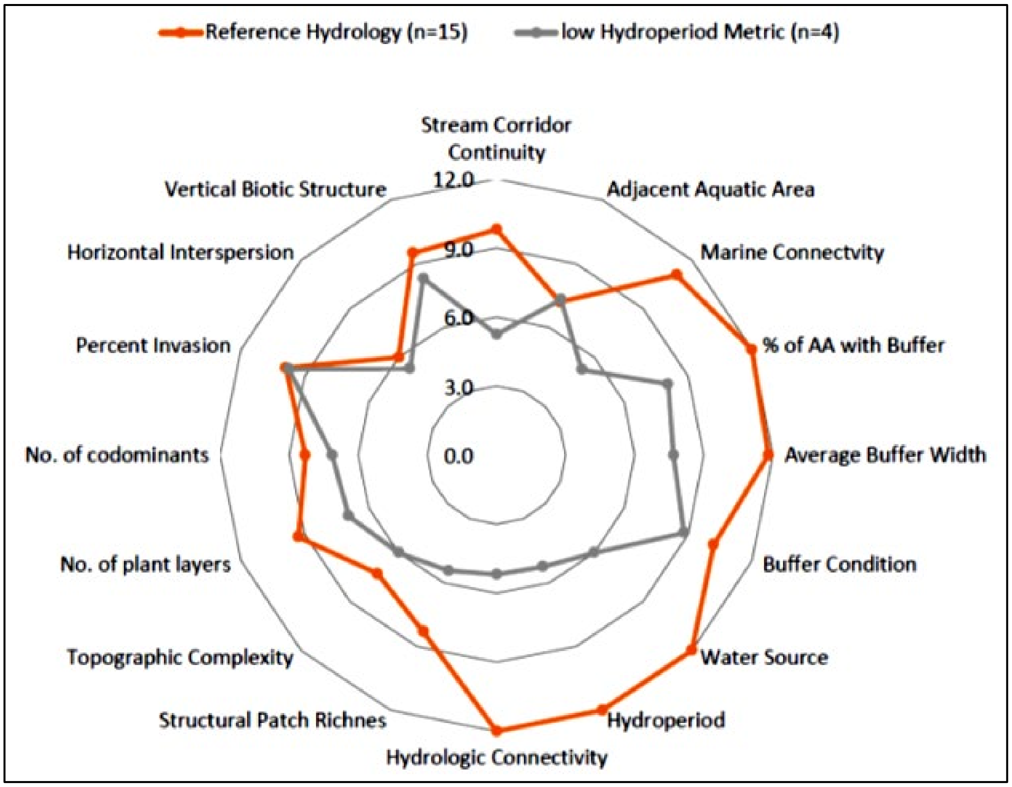

Figure 8. Comparison between CRAM metrics of bar-built estuaries with reference condition hydrology, and those with managed hydrology due to mechanical breaching. From Largier et al. 2019.

3. Development of an Ecological Conceptual Model for Watsonville Slough

Watsonville Slough is a tributary to the Pajaro River's bar-built estuary. Historically, the marsh extended up into the area north of the bend near Camp Goodall, though intertidal channels are not extensively shown on the 1853 USCS T Sheets (Figure 9). Much of the dune areas has been developed, and the historic "side slough" and tidal marsh between it and Watsonville Slough is currently used for agriculture, confining the marsh plain to areas between the federal levees on the main stem of the Pajaro River, and between the farm levees and built infrastructures along Watsonville Slough, drastically reducing the area in which the lagoon may flood during closure backwater events.

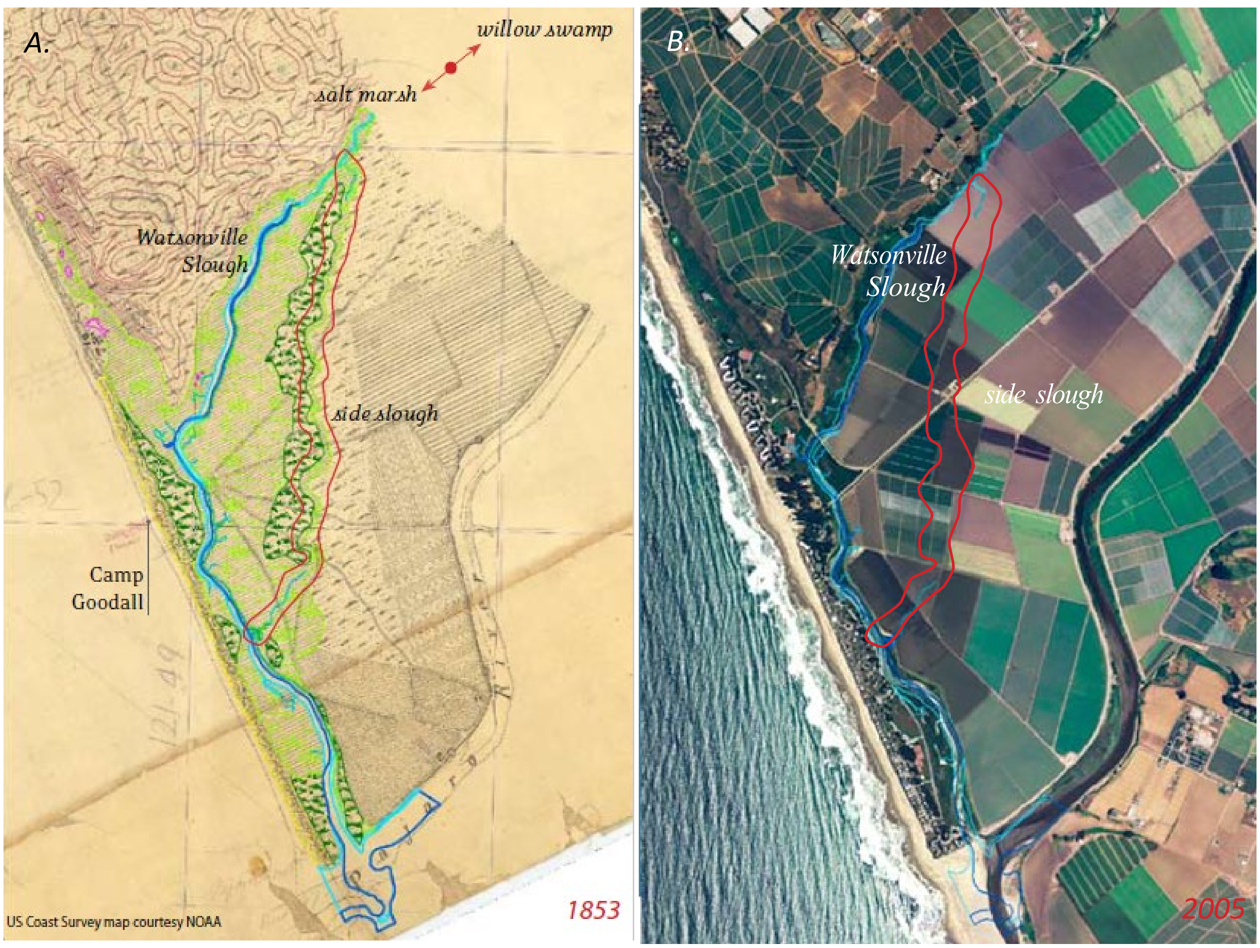

Figure 9. A. 1853 USCS T-sheet of Watsonville Slough showing mapped habitats: yellow dunes, chartruese tidal marsh, green grassland, and magenta marsh pannes. B. T-Sheet features overlain on 2005 aerial photography. Adapted from Whipple and Grossinger 2008.

The remaining marsh areas, found between the levees, has been by Watsonville Wetland Watch. Although the vast majority of the area between the levees supports marsh vegetation, it is not all healthy and robust. Portions of the marsh plain are co-dominated by upland weeds or exhibit stressed and stunted marsh vegetation. Figure 10 illustrates the difference between healthy marsh, as shown in Insert B, and stressed marsh, as shown in Inserts A and C. After reviewing the literature and conferring with experts on bar-built estuaries Ross Clark and Kevin O'Connor of the Central Coast Wetlands Group at Moss Landing Research Station, associated with the California State University system, the PDT determined that the presence of stunted marsh vegetation and invasion of the marsh plain by xeric non-native species suggests a truncation of marsh hydrology. The project area was then investigated for potential stressors leading to this truncated hydrology.

Figure 10. Vegetation mapping of marsh near Beach Road crossing. Areas with red asterisks show areas of stressed marsh (inserts A and C) compared to areas exhibiting healthy marsh (insert B).

The parcels immediately adjacent to the slough have been laser-leveled in the past and are largely devoid of tidal channels or microtopographic heterogeneity (Figure 11, green asterisks). As such, water in the slough has limited access to the marsh plain during open-lagoon, low (i.e. tidal) water conditions. Complicating matters, a series of berms exist immediately adjacent to the slough, between the open water and the marsh plain. These appear to be side-cast berms associated with dredging the slough, but their origin is uncertain. These berms may also hinder water from entering the marsh plain during open-lagoon conditions (Figure 11, cyan ovals).

As a result of these factors and the general perched elevation of much of the marsh plain, the marsh areas currently have "all or nothing" hydrology depending on the water level in the slough

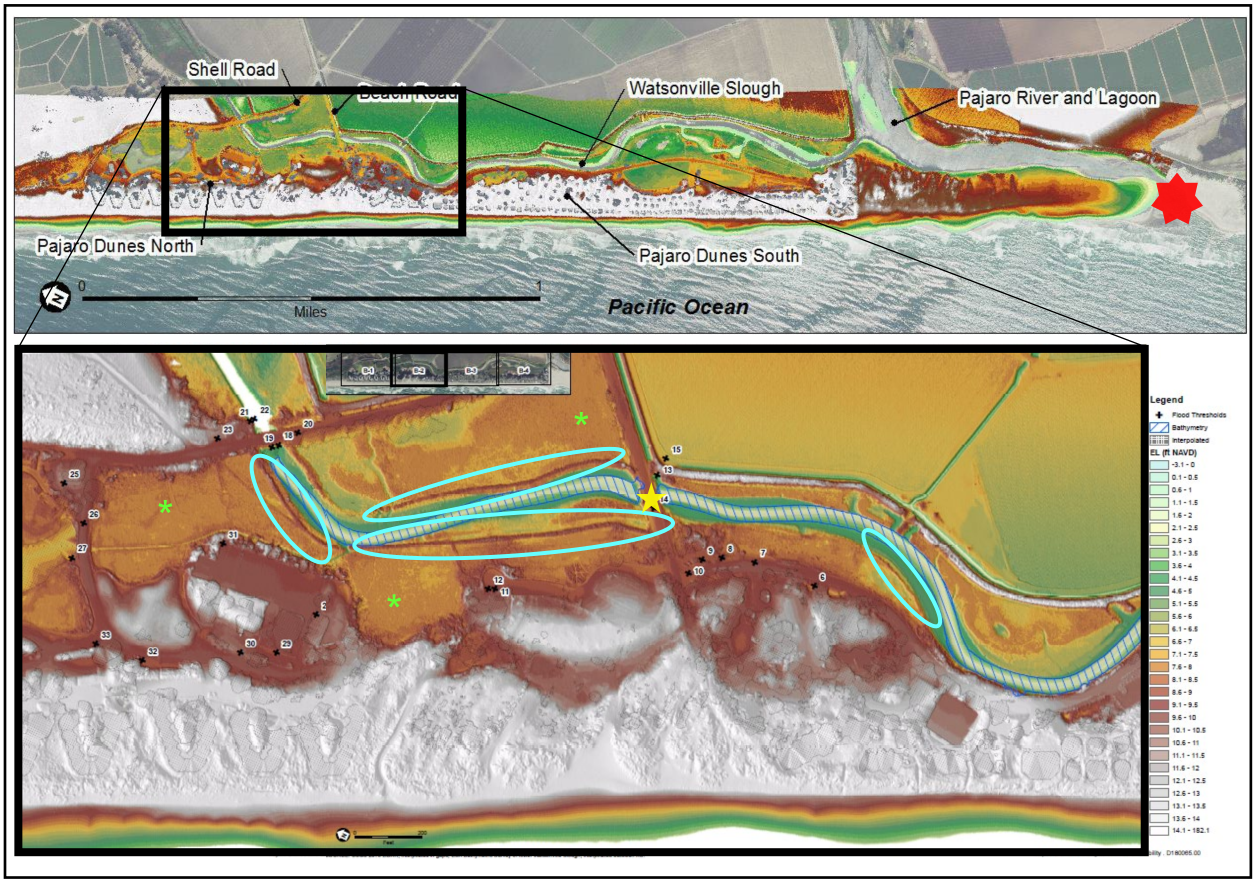

Figure 11. Elevation map of marsh areas of Watsonville Slough showing factors that may truncate natural marsh hydrology: berms between slough and marsh plain (outlined in cyan ovals), a lack of channels on the marsh plain (green asterisks), and the undersized culverts and low crossing of Beach Road which gets flooded during natural lagoon closures (small yellow star), triggering the mechanical breaching of the lagoon at the mouth (large red star).

and whether it can penetrate the breaches in the historic berms spread onto the perched elevation. This typically only happens during closed-lagoon, backwater flooding events.

However, the Pajaro lagoon is managed, and the crossing of Watsonville Slough at W. Beach Road currently triggers lagoon breaching during high-water, closed-lagoon conditions (Figure 11, yellow star). The crossing consists of six small culverts that are sufficient to carry flows during open-lagoon conditions (Figure 12 A and B), but become overtopped and insufficient to carry flows during closed lagoon conditions (Figure 12 C and D), forcing water up and over the road and creating hazardous driving conditions. When the water gets to this point, at roughly 8.0 NAVD88, the county breaches the lagoon at the mouth of the Pajaro River (Figure 11, red star), draining the backwater flooding off the road and marsh plain, as described in more detail in Chapter 1 of the report.

The mechanical breaches have environmental impacts beyond potentially truncating the hydrology of the marsh. Rapid changes in water velocities at a time when young fish may be present impacts potential fish habitat. Maintaining the lagoon in an open state increases the percent of the year the lagoon experiences higher salinities, shifting marshes from diverse brackish communities to more saline ones and potentially allowing saltwater intrusion into adjacent farms.

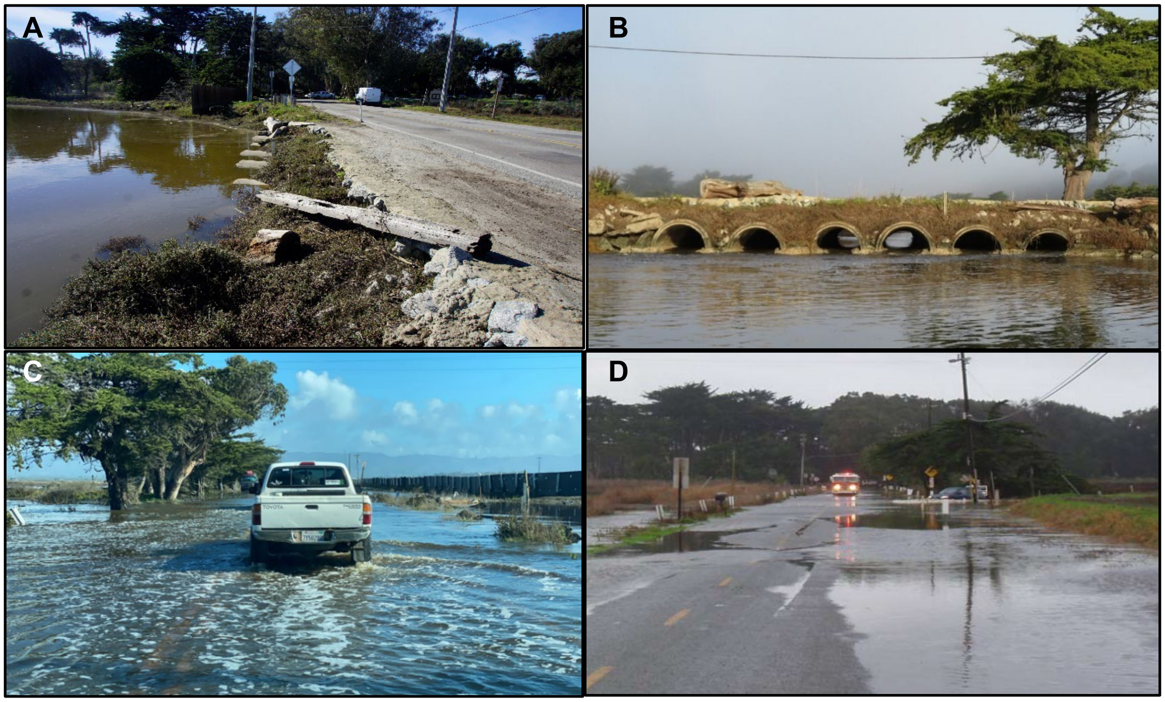

Figure 12. West Beach Road Crossing of Watsonville Slough. A. Looking west during high-tide, open lagoon conditions. B. Looking west during open lagoon conditions. C. Looking east during closed-lagoon conditions. D. Looking east during closed-lagoon conditions when a local firetruck had to traverse a flooded road. Note that in C and D, the culverts are completely overtopped and water in the lagoon and on the road are at the same level.

Figure 13 illustrates a comprehensive ecological conceptual model for the Watsonville Slough lagoon and marshes. Multiple drivers are acting on the system, including changes in stream flows and sea level rise, both stemming from climate change. These combine with anthropogenic drivers, including the reduction of marsh acreage and the isolation of the lagoon from its floodplain by the federal levees and farm levees, to change the water levels in the lagoon and the pattern of lagoon closures, as well as the speed with which lagoon water levels rise during natural closures. These water levels during closures combine with another anthropogenic stressor, undersized culverts and low-elevation infrastructure, to create a public safety risk associated with the flooding of roads and lack of emergency access, which prompts the mechanical breaching of the lagoon and leads to a cascade of effects, including the truncation of marsh hydrology during high water affecting the quality of marsh habitat.

Other anthropogenic stressors include the historic removal of marsh side channels and the placement of berms between the slough and marsh platform, both of which have the potential to truncate hydrology during low water, open lagoon conditions. These stressors also combine with others to have the effect of low-quality fish habitat (Figure 13).

Many of the stressors identified by the ecological conceptual model are not matters a CAP study can reasonably address (e.g. agricultural runoff or groundwater overdraft). The PDT focused first on identifying areas where marsh could be expanded, and then on addressing the truncation of marsh hydrology.

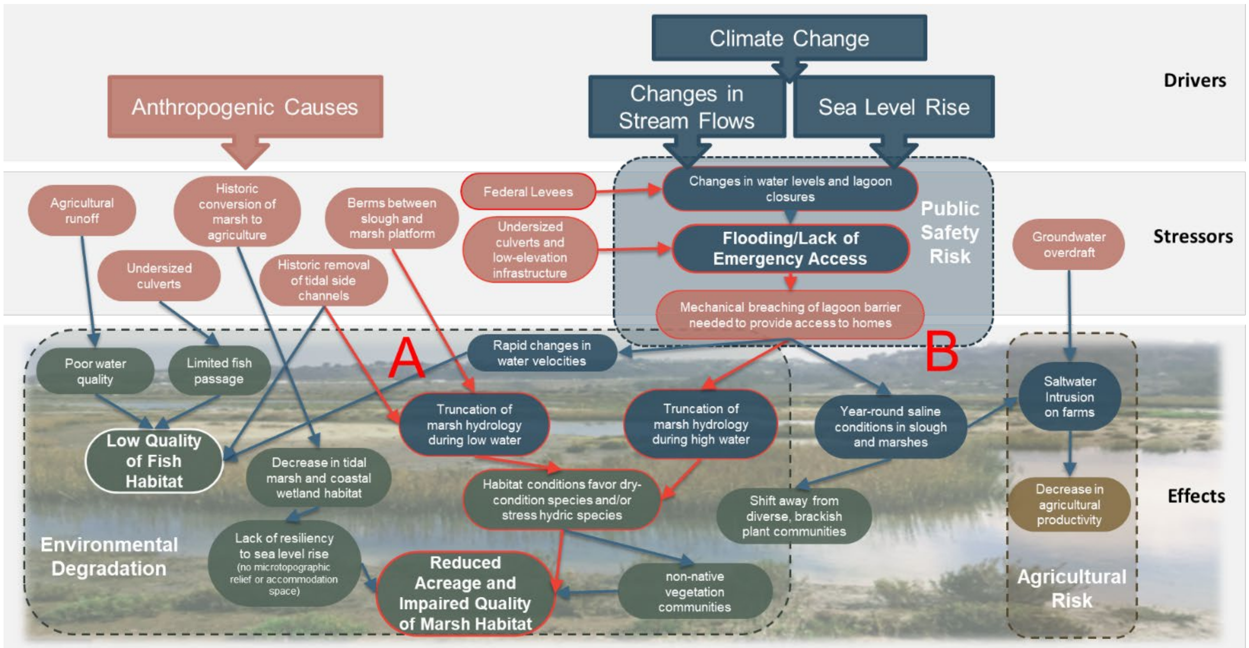

Figure 13. Comprehensive conceptual ecological model of the lagoon and marsh habitat associated with Watsonville Slough. While many stressors and effects are identified, the PDT focused on the stressors contributing to the truncated hydrology of the existing marsh plain and causing reduced quality of the marsh habitat. Two potential pathways were identified. Pathway A identifies stressors that may be responsible for truncating marsh hydrology in open-lagoon, tidal conditions. Pathway B identifies the interaction of the stressors affecting water levels, including the federal levees, and low, undersized infrastructure requiring the breaching of the lagoon during natural closures, and thereby truncating the marsh hydrology during high water events.

As Figure 13 shows, there are two primary pathways by which marsh hydrology may be truncated. The first, Pathway A, identifies potential impediments to marsh hydrology during open-lagoon, low water conditions that truncate marsh hydrology and reduce marsh vegetation and habitat quality. The second, Pathway B, identifies the truncating effects of manual breaching on marsh hydrology during high water, closed-lagoon conditions.

Either pathway may be responsible for stunted and stressed marsh vegetation and invasion by upland weeds identified in the marsh plain of Watsonville Slough. While any restoration will include the removal of exotics and interplanting with native species, there’s no point in doing this until the marsh hydrology is improved. The PDT undertook developing measures that would have an effect on either Pathway A or Pathway B (Figure 13).

4. Overview of Measures for Restoring Marsh Hydrology and the Novel Approach for Modeling Annual Percent Inundation

4.1. Restoration Measures to Improve Marsh Hydrology

There are two types of measures to improve hydrology of the marsh plain in any parcel targeted for restoration:1) those that improve hydrologic connectivity between the slough and marsh plain during normal, tidal flows, referred to hereafter as “earthwork”, and 2) those that allow high flows, especially during lagoon mouth closures to persist on the marsh plain for natural durations, rather than being truncated by manual breaches.

Earthwork measures that rectify the historic leveling of the marsh plain and placement of berms between the slough and the marsh plain that currently impacts many parts of the marsh plain adjacent to Watsonville Slough include the following:

- Creating multiple breaches in the berms where they haven’t yet been eroded.
- Excavating side tidal channels into the marsh plain to facilitate the movement of water into the marsh plain during the tidal cycle.
- Utilizing the excavated material to create microtopographic relief within the marsh plain to reintroduce heterogeneity.

After initial screening of restoration locations (See Chapter 3), three restoration locations remained: County Parcel, State Parcel, and the Lower Mile, which consists of the larger parcels on the west side of the slough between Beach Road and the confluence of Watsonville Slough with the Pajar River. For each of the restoration locations, parcel-specific Earthwork measures were designed based on the existing locations of berms (Figure 14). These measures would have a positive impact on Pathway A in the conceptual ecological model (Figure 15).

Measures that rectify the truncation of high-flow inundation events include the modification of hydrologic constrictions and raising of critical infrastructure so that flood risk and safety concerns don’t force premature lagoon breaching. The most relevant includes changes to the W. Beach Road crossing of Watsonville Slough by replacing the culverts to allow the conveyance of closed-lagoon water levels within them, rather than forcing the water up and onto the road. This would raise the level of the Beach Road crossing to at Watsonville Slough from 8.0’ to 9.2’ NAVD88, and likewise change the County’s breaching threshold for Pajaro River Lagoon to 9.2’ NAVD88. These measures, hereafter referred to as “Crossing Improvements”, affect Pathway B of the conceptual ecological model (Figure 16).

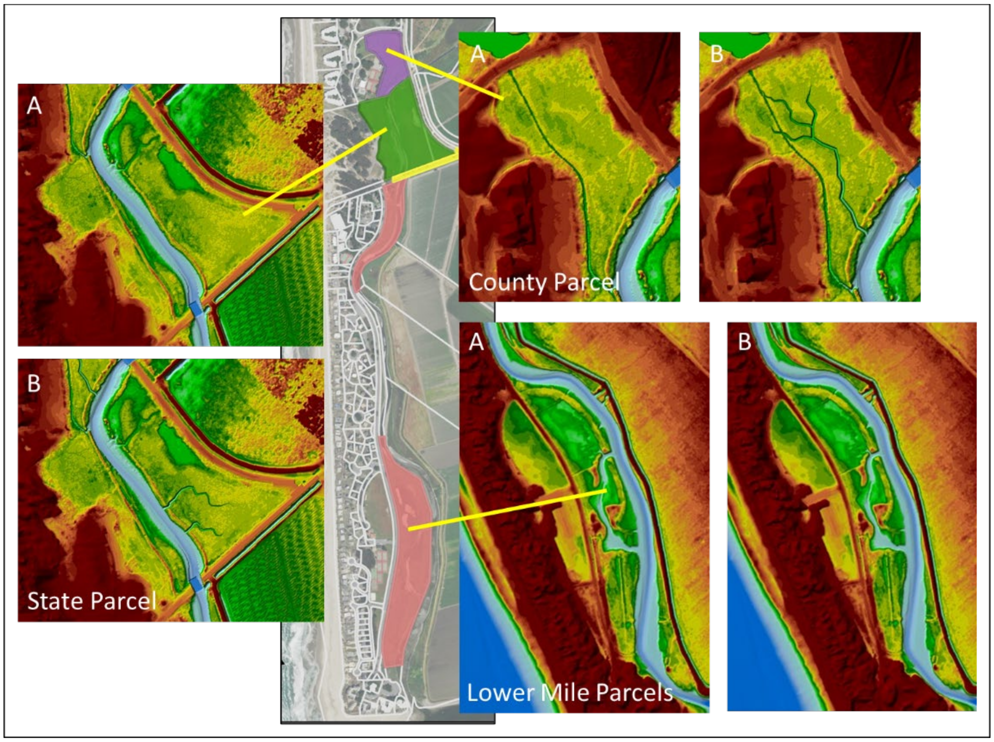

Figure 14. For each parcel in the final array of locations, earthwork measures were designed to improve the terrain from existing conditions (A labels) to a terrain that included "earthwork" measures in the form of berm breaches and the excavation of side channels designed to improve marsh hydrology (B labels). More details can be found in the HH&C Appendix.

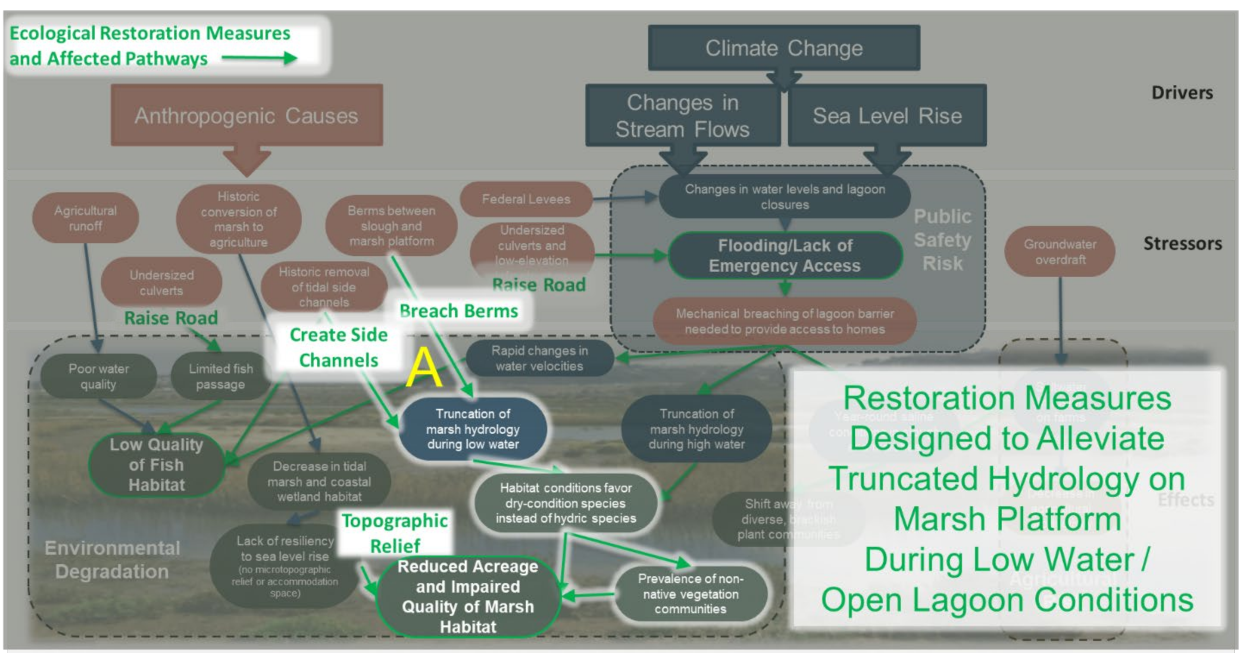

Figure 15. Earthwork measures, including breaching existing berms between the slough and marsh plain and excavating new side channels into the marsh plain, and using the material to create microtopographic relief, all address Pathway A of potential marsh hydrology truncation in the conceptual ecological model. Details can be found in the HH&C and Civil Appendices.

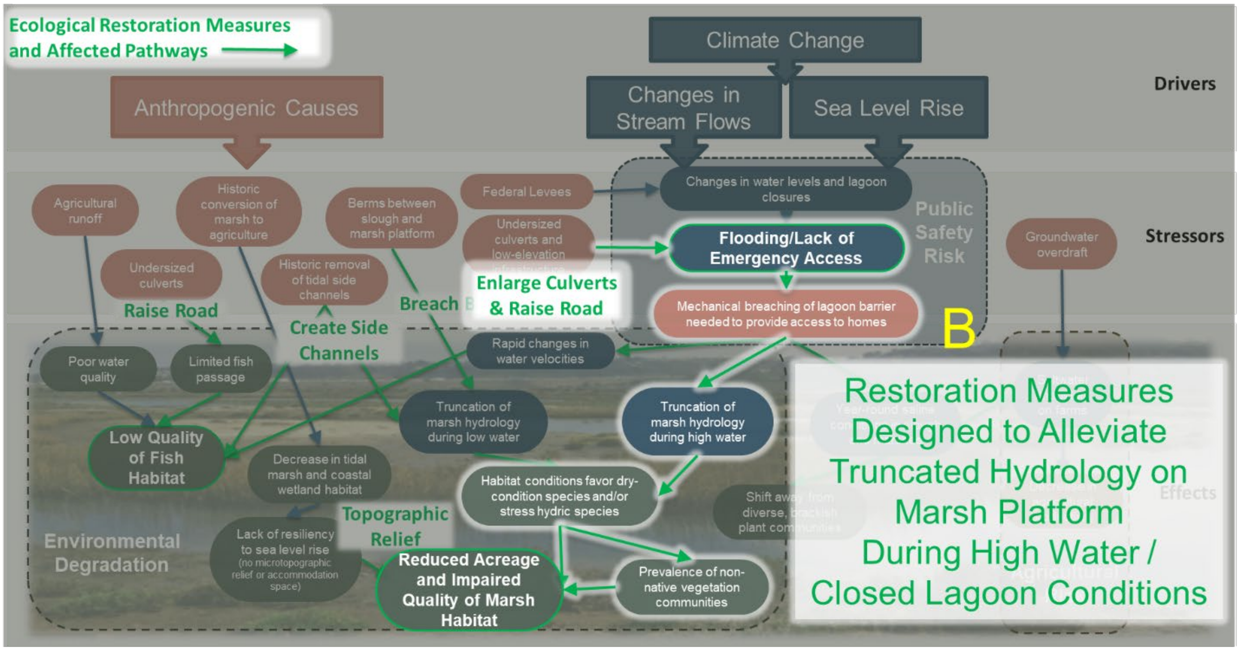

Figure 16. Enlarging the culverts at the Beach Road crossing of Watsonville Slough so that they can convey the closed-lagoon water levels, and adjusting the road height to accommodate them (i.e., Crossing Improvements) would raise the County's lagoon breaching threshold from approximately 8.0 NAVD88 to 9.2 feet NAVD88, and would positively affect Pathway B of potential marsh hydrology truncation in the conceptual ecological model.

4.2. Ecological Modeling Overview

Through the Federal Interest Determination (FID) and early feasibility phase, PDT members, Ecosystem Restoration Planning Center of Expertise (ECO-PCX), USACE's Hydrologic Engineering Center (HEC), resource agencies, national POCs and SPD determined that there is no existing representative species model nor wetland model appropriate for lagoon restoration, particularly where the primary stressor is hydrology. The PDT coordinated with a wetland scientist from the USACE Engineering Research and Development Center's Environmental Laboratory to confirm the findings and to develop a Hydrology and Hydraulics (H&H)-based model that could link H&H outputs with restoration objectives and outputs. Only through an H&H-based ecomodel could it be shown that the measures proposed for restoration of the truncated hydrology were actually improving the conditions on the marsh plain. The PDT coordinated with Eco-PCX on novel approach to calculate ecosystem benefits based on modeled annual Percent Time Inundated (PTI) rates on marsh plain, similar to the empirical data generated by the data logger inundation studies of Scott's Creek described in Section 2 of this appendix. The PDT received vertical team alignment on a hydrology-based novel approach to ecological modeling in June 2022.

The conceptualization of the model was relatively straightforward.

1. Use a combination of HEC-RAS, GIS, and other hydrology models to model the PTI across the marsh plain for the Future Without Project, Earthwork measures, Crossing Improvement measures, and combined Earthwork and Crossing Improvement Measures (Detailed in HH&C Appendix).
2. Compare the modeled "heat maps" of PTI for existing conditions (i.e. FWOP year 0) and the vegetation mapping conducted by Watsonville Wetlands Watch to determine

brackets of inundation associated with open water, healthy marsh, and upland/stressed marsh. Use this information to develop a Habitat Suitability Index (HSI) curve for generating Habitat Units (HUs). These modeled inundation rates may or may not be similar to the observed PTI rates measured empirically in bar-built estuaries, since H&H models focus on surface water processes.

3. Derive benefits by comparing “with project” versus “without project” conditions for each of the project scenarios.

Because Watsonville Slough is part of a bar-built estuary, Step 1 above involved a set of 2-month model runs for each of four lagoon states, which were then combined into an annual PTI heat map by a weighted average, using a separate model to forecast the percent of the year the lagoon is in each state in future time steps (Figure 17). Many more details on this process are discussed in the HH&C Appendix, including the Memorandum for Record (MFR), dated 7 November 2022, describing the detailed hydrologic assessment for the Watsonville Slough CAP study, which underwent District Quality Control and Agency Technical Review as part of USACE South Pacific Division’s (SPD) requirement for Hydrology Certification. The SPD-certified Hydrologic Assessment MFR is included as an attachment to HH&C Appendix.

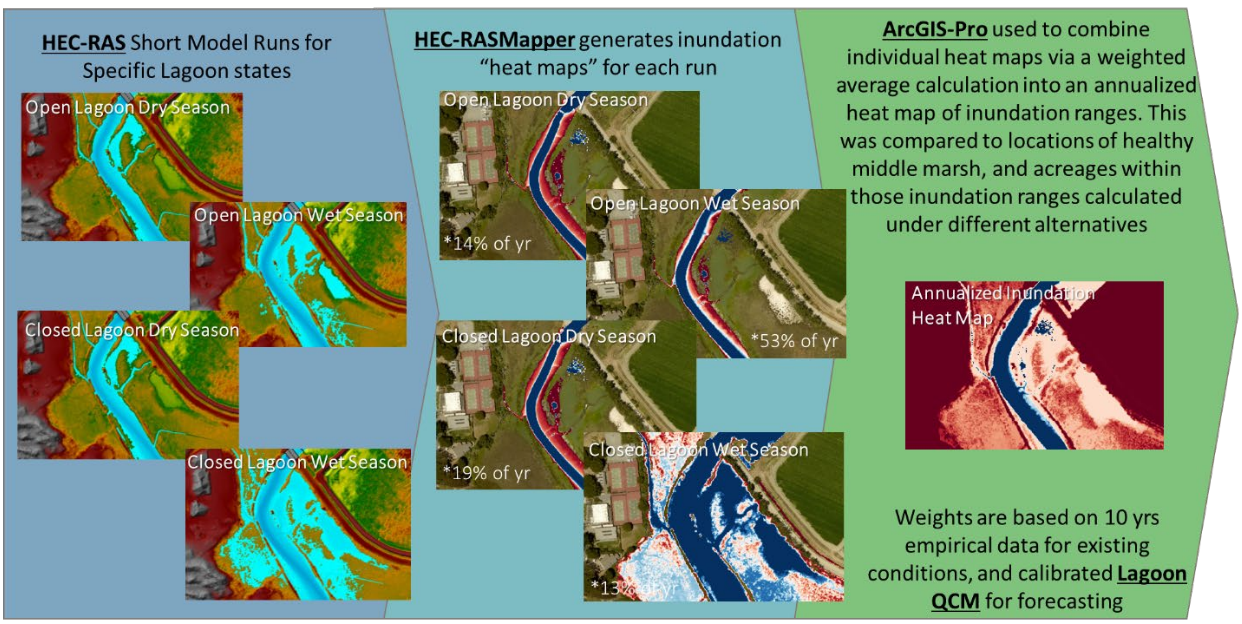

Figure 17. An overview of the hydrology-based ecosystem benefit modeling for determining acres of "marsh hydrology" on the marsh plain. Separate short (2-month) HEC-RAS model runs were done for each of four separate lagoon states, generating four separate inundation heatmaps. These were combined using a weighted averages determined based on 10 years of empirical data for existing conditions, and Lagoon Quantified Conceptual Model to forecast the percent of time the lagoon is in each state in the future time steps.

5. Ecological Interpretation of Hydraulic Modeling

The H&H modeling in support of the ecobenefits of restoration resulted in annualized Percent Time Inundated heat maps for each of the following scenarios: No Action (Future without Project), Crossing Improvements, Earthwork, and Crossing Improvements + Earthwork. These heatmaps were binned into annual inundation ranges (0-1%, 1-5%, and 5% increments from 5-100%) to ease analysis and visualization of the data. An example of one of the annual PTI maps for the No Action project alternative is provided in Figure 18.

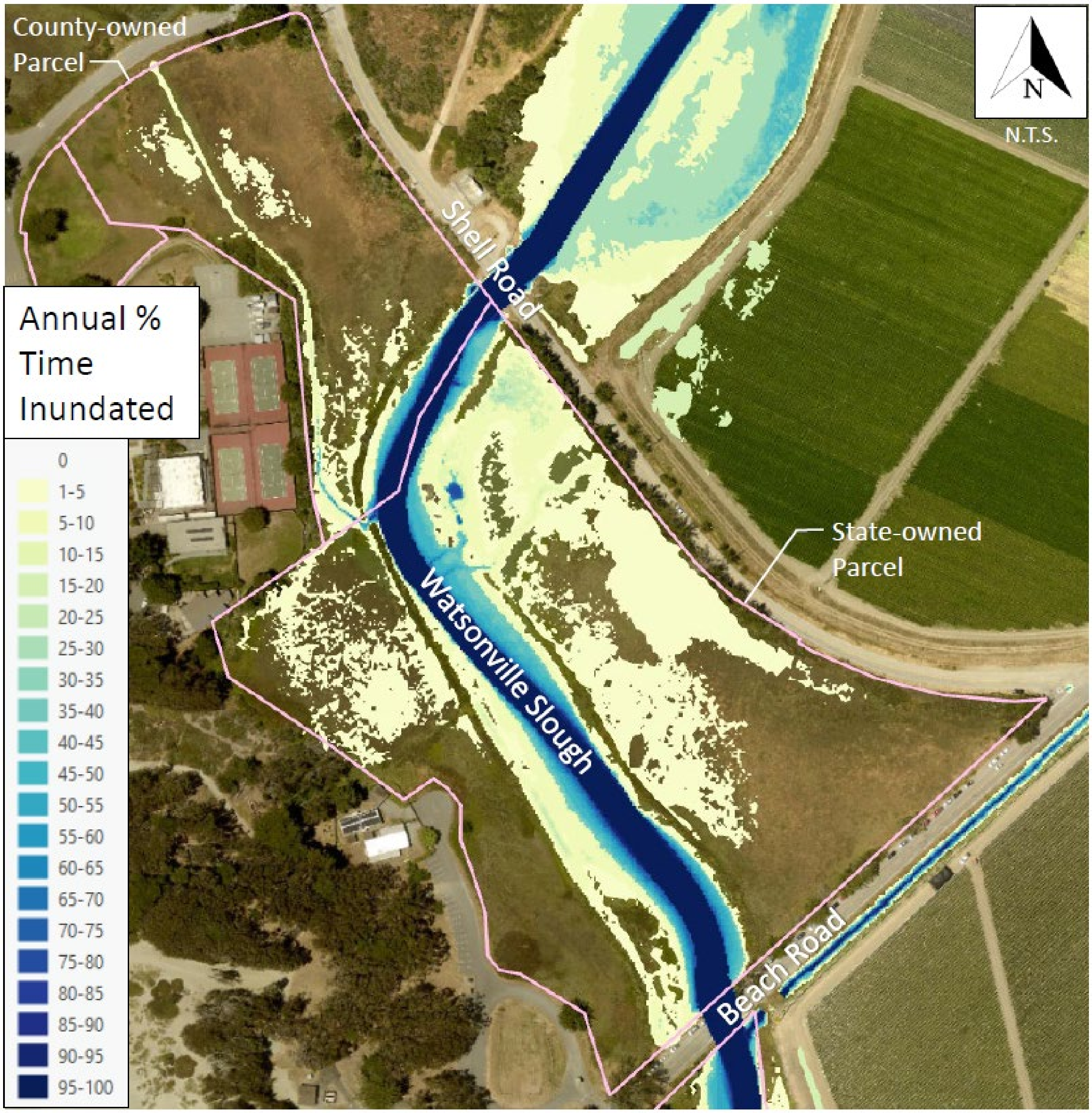

Figure 18: Annual percent time inundated for No Action, Project Year 0.

The binned inundation heat maps were clipped to the three parcels being considered as restoration measures/locations (County-owned, State-owned, and Lower Mile). The results were exported to Excel for analysis.

Figure 19 shows that most of the changes associated with the different restoration scenarios occur in the drier ranges, from 0-15% modeled annual inundation. Very little acreage occurs in inundation ranges between 20 and 95%, particularly in the County and State parcels and in the No Action scenario. This distribution mimics the "Artificial" hydrology pattern shown in Scott's Creek study (Figure 5). The Lower Mile Parcels appear to be less perched than the others and have noticeable acreage across a broad array of PTI ranges, though still most significantly between 0 and 15% annual inundation. The Lower Mile also has the most acreage in the 95-100% inundation range, indicating the presence of existing side-channels.

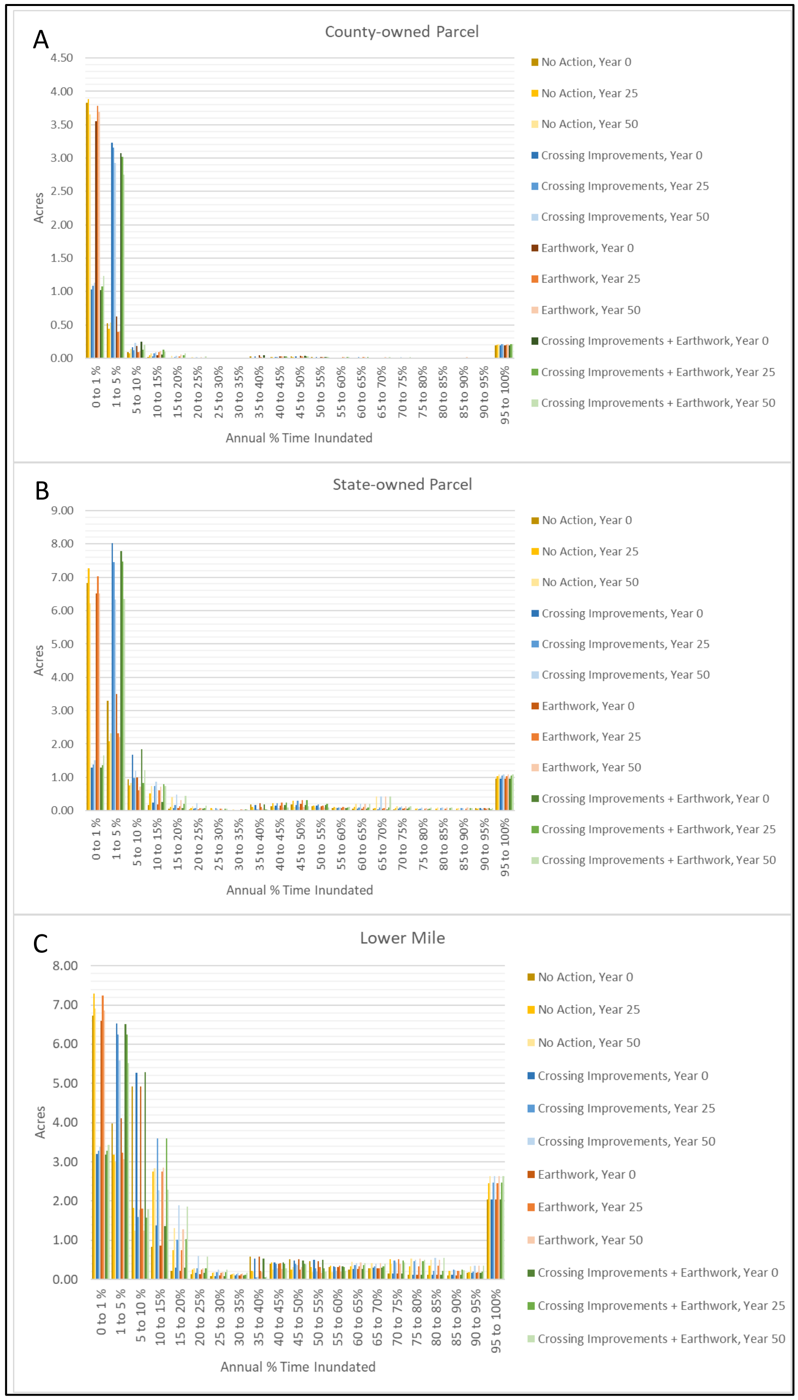

Figure 19. Bar graphs for County-owned Parcel (A), State-owned Parcel (B), and Lower Mile (C) showing acres falling within each inundation range for each restoration scenario at three time steps: Year 0 (immediately after implementation), Year 25, and Year 50.

While seeing the differences in inundation regimes across the three restoration areas under different restoration scenarios and timesteps is interesting, it's difficult to interpret the significance of such narrow PTI bins. Most plants have broad ranges under which they can flourish, with specific thresholds at which conditions are no longer favorable. The modeled PTI ranges that support healthy marsh had to be identified.

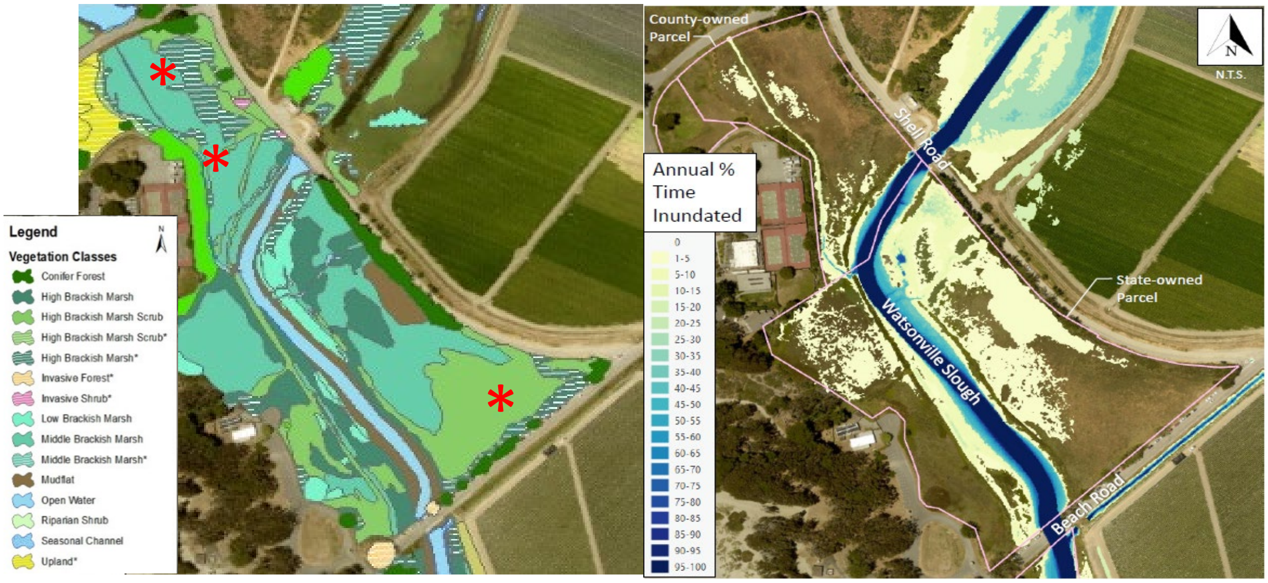

Figure 20. A comparison of mapped existing vegetation and modeled existing (i.e., No Action, Year 0) modeled inundation. Note that hatched vegetation types include exotics and upland species. Red asterisks show areas of stressed, stunted vegetation. Open water and mudflats correspond with 50-100% modeled annual inundation. Low marsh corresponds with 15-50% modeled annual inundation. Middle marsh corresponds with 1-15% modeled annual inundation. Areas mapped as 0-1% support stressed middle marsh, exotics, some stressed high marsh and high marsh scrub.

To correlate the inundation maps with habitat, the inundation heat map for No Action, Year 0 (i.e., existing modeled inundation) was compared with existing vegetation mapping of Watsonville Slough completed by Watsonville Wetlands Watch (Figure 20). Areas modeled as being wetter than 50% inundation were generally mapped as mudflat or open water. Low marsh corresponded with approximately 15-50% modeled annual inundation. Areas of healthy pickleweed middle marsh were closely associated with modeled inundation ranges between 1-15%. Areas modeled as 0-1% annual inundation were mapped as one of the following: upland, high marsh codominant with xeric exotic vegetation, high marsh scrub exhibiting some stress, stressed middle marsh, or middle marsh co-dominant with xeric and exotic species.

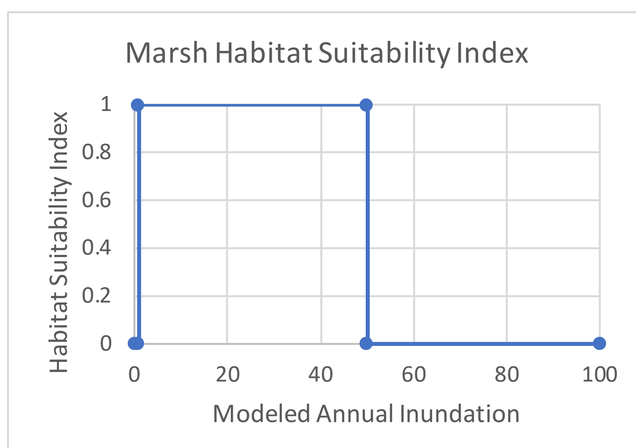

Figure 21. Model Annual Inundation between 1-50% received a "1" in the suitability index, because it correlated with the broad mapping of healthy marsh. Inundation between 0-1% received a 0 because this is where the stressed or invaded marsh occurred. 50-100% inundation also received 0 because it was typically mudflat and open water.

This mapping let to a very simple "Habitat Suitability Index" or HSI to determining ecological benefits. For the purposes of tracking ecological benefits across the restoration measures, target "marsh hydrology" was determined to be 1-50% modeled annual inundation, which received a 1 in this index (Figure 21). This broad range of inundation included the low and healthy middle marsh, and some areas of health high marsh. Despite the fact that some healthy high marsh is mapped in the areas modeled as having 0-1% annual inundation, signification portions of those areas are either stressed or co-dominant with xeric non-native and invasive species, indication that these are the “high and dry” areas affected by the truncated hydrology, as identified by the subject matter experts consulted for the study. These areas received a “0” in the HSI because they are too dry to support healthy marsh (Figure 21). Likewise, inundation ranges from 50-100% receive an HSI of “0” because they are too wet to support healthy marsh, typically being mapped as mudflat or open water (Figure 21).

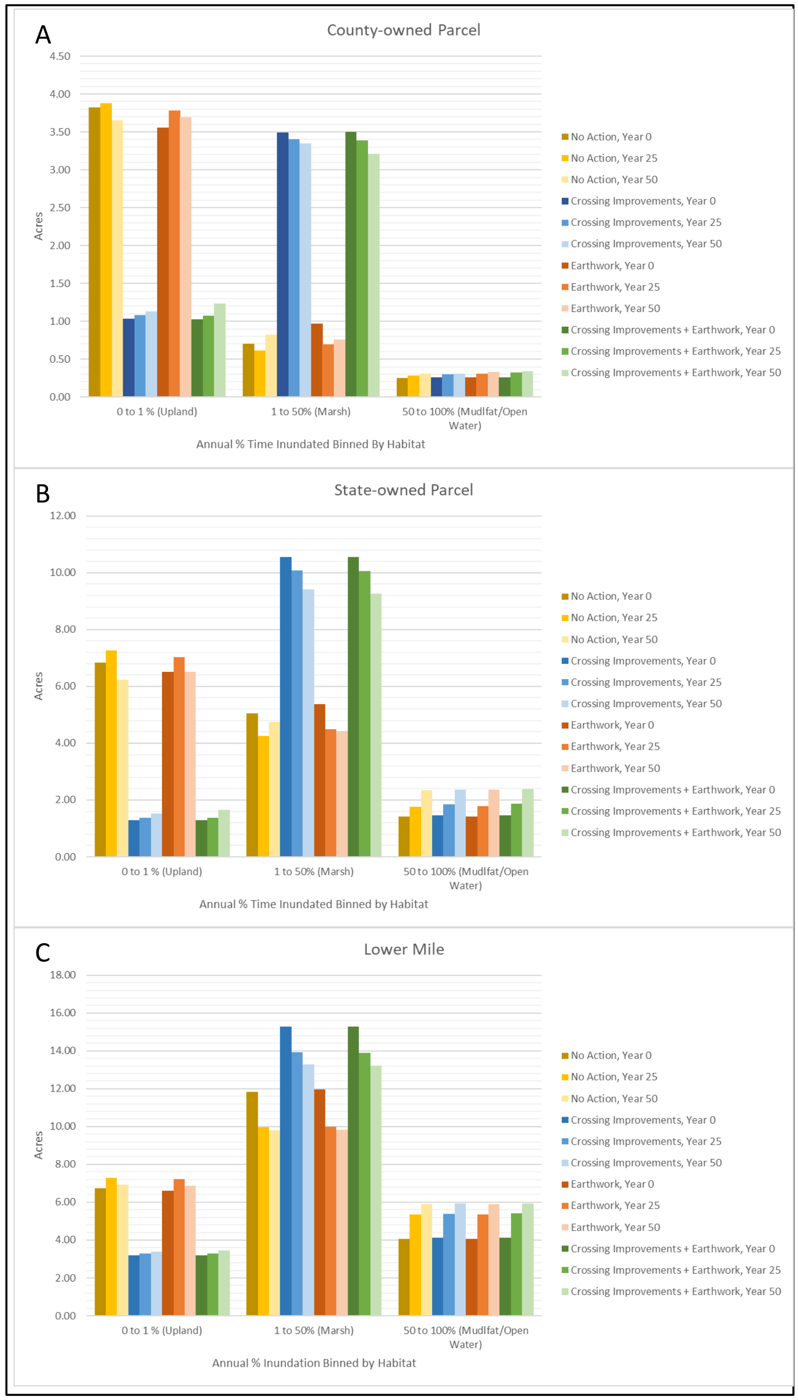

Figure 22. Bar graphs for County-owned Parcel (A), State-owned Parcel (B), and Lower Mile (C) showing acres falling within each habitat-based inundation range for each restoration scenario at three time steps: Year 0 (immediately after implementation), Year 25, and Year 50. Note that the open water inundation ranges are essentially identical across all restoration scenarios in all three parcels, though open water increases over time because of sea level rise.

Figure 22 shows the same information as Figure 19, but now binned into ecologically-significant habitat inundation bins. A few notable patterns can be seen. In the No Action scenario (gold bars), both the County Parcel and State Parcel have significant amounts of upland hydrology, reflecting the stressed vegetation and invasion by xeric non-native species. The Lower Mile parcels are the only restoration location that currently has more wetland hydrology extent than upland hydrology extent. Figure 22 also shows that across all three restoration location, the pattern of upland, marsh, and open water hydrology between the No Action scenario (gold bars) and the Earthwork scenario (orange bars) are nearly identical. The excavating of channels and breaching of sidecast berms had very little effect on the overall extent of marsh hydrology across the marsh plain, indication that Pathway A in Figure 13 was not the primary causal pathway of the truncated hydrology resulting in stressed marsh vegetation and xeric-species invasion. On the other hand, both the Crossing Improvements scenario (blue bars) and the Crossing Improvements + Earthwork scenario (green bars) resulted in major shifts from upland hydrology to marsh hydrology. In both cases, and in all three parcels, the acreage upland hydrology decreased compared to the No Action scenario, and there was a corresponding increase in acreage in the marsh hydrology columns. This shift was most prominent in the County Parcel, somewhat less so in the State Parcel, and still present but least significant in the Lower Mile, where there is the least percent of upland hydrology in the No Action scenario, and therefore the least to convert back to marsh (Figure 22).

The final pattern to note is that across all restoration parcels and all restoration treatment scenarios, the extent of Open Water hydrology is virtually identical to the No Action scenario. While the restoration measures, particularly the measures associated with the Crossing Improvements scenarios, are converting large areas from existing upland to marsh, there is not a similar conversion of existing marsh to open water. The amount of time the lagoon is allowed to remain closed under the new County breaching threshold is not enough to drown the existing marsh. There is an increase in the extent of open water across the timesteps due to sea level rise, and these are most prevalent in the Lower Mile, which is the least perched parcel, and least apparent in the County parcel, which is the most perched. But for a given parcel, the amount of change in open water due to sea level rise is the same in the No Action scenario and all the restoration scenarios (Figure 22).

The purpose of the ecosystem restoration project at Watsonville Slough is to expand marsh hydrology across the marsh plain, especially into the “high and dry” areas hypothesized to be stressed by the truncated hydrology associated with the manual breaching regime. To assess the effectiveness of the restoration measures at each parcel, the acreage of marsh hydrology (i.e., only the middle category in Figure 22) was calculated over the life of the project for each scenario.

Table 1 shows the same data as the center category of Figure 22: the acreages of marsh hydrology between 1-50% modeled annual inundation, referred to as “Habitat Units” to reflect the expected inputs for the economic analysis. Table 2 shows the average annualized Habitat Units (AAHUs), which were determined by calculating the weighted average of acres across the time steps for each parcel and restoration scenario, generating a single number for each parcel and restoration scenario. Finally, the No Action or “Future Without Project” AAHUs are subtracted from each of the restoration scenarios to show the benefits of the restoration measures in Table 3.

These are the ecosystem benefit metrics that were delivered to the economist so they could be compared to costs in Cost Effectiveness/Incremental Cost Analysis (CE/ICA) to determine the suite of cost-effective restoration plans comprising the Preliminary Array of Alternatives.

Table 1. Habitat Units (acres in 1-50% inundation range) by parcel, time step, and restoration measures.

	No Action, Year 0	No Action, Year 25	No Action, Year 50	CI[1] Year 0	CI Year 25	CI Year 50	EW[1] Year 0	EW, Year 25	EW, Year 50	CIEW[1], Year 0	CIEW, Year 25	CIEW Year 50
County	0.71	0.61	0.82	3.49	3.41	3.35	0.97	0.69	0.76	3.50	3.39	3.21
State	5.05	4.26	4.74	10.54	10.08	9.42	5.37	4.49	4.43	10.55	10.07	9.26
Lower Mile	11.82	9.96	9.80	15.29	13.92	13.27	11.95	10.00	9.85	15.29	13.91	13.21

1. CI = Crossing Improvements, EW = Earthwork, CIEW = Crossing Improvements +Earthwork

Table 2. Average Annualized Habitat Units (acres in 1-50% inundation range) per parcel and restoration measure.

	No Action Years 0-50, Annualized	CI[1] Years 0-50, Annualized	EW[1] Years 0-50, Annualized	CIEW[1] Years 0-50, Annualized
County	0.69	3.41	0.78	3.37
State	4.58	10.03	4.69	9.98
Lower Mile	10.39	14.1	10.45	14.08

1. CI = Crossing Improvements, EW = Earthwork, CIEW = Crossing Improvements +Earthwork

Table 3. Average Annualized Habitat Unit Benefits (acres in 1-50% inundation range) per parcel and restoration measure.

	No Action Years 0-50, Annualized Benefits	CI[1] Years 0-50, Annualized Benefits	EW[1] Years 0-50, Annualized Benefits	CIEW[1] Years 0-50, Annualized Benefits
County	0	2.72	0.09	2.68
State	0	5.45	0.11	5.4
Lower Mile	0	3.71	0.06	3.69

1. CI = Crossing Improvements, EW = Earthwork, CIEW = Crossing Improvements +Earthwork

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