APPENDIX Q1. Methods Used to Update Ecosystem Restoration Maps Using New Digital Elevation Model and Tidal Data

Delta Plan Amendments

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Methods Used to Map Elevation Bands

Introduction

Part 1 of this appendix documents the methods employed by Siegel and Gillenwater (2020) to develop the *Map of Elevation Bands for the Protection, Restoration, and Enhancement of Different Classes of Natural Communities* (Map) (Figure 4-5 in Chapter 4 of the Delta Plan) to replace the *Map of Habitat Types Based on Elevation, Shown with Developed Areas in the Delta and Suisun Marsh* (Figure 4-6 in Chapter 4 of the Delta Plan, as adopted in 2013). The new Map reflects current land elevation data, tidal datum data, and sea level rise projections. Two layouts were prepared: one with three intervals of sea level rise shown (Figure 1) and the other combining the sea level rise intervals into a single area (Figure 2).

All input data, analytical steps, and output data sets are described. This includes discussion of:

- Digital Elevation Models (DEM) used for land elevations, derived from recent Light Detection and Ranging (LiDAR) data
- Modeled tidal datums and interpolation methods used to establish tidal elevations across the diked and nontidal landscapes of the Delta and Suisun Marsh
- Sea level rise values applied to show accommodation space
- Setting of shallow subtidal elevations boundary restoration opportunities
- Habitat map units
- Resulting compiled Geographic Information Systems (GIS) data sets

Figure 3 outlines the steps used in preparing the Map of *Elevation Bands for the Protection, Restoration, and Enhancement of Different Classes of Natural Communities* (Figure 4-5 in Chapter 4 of the Delta Plan) and the sections where these steps are described.

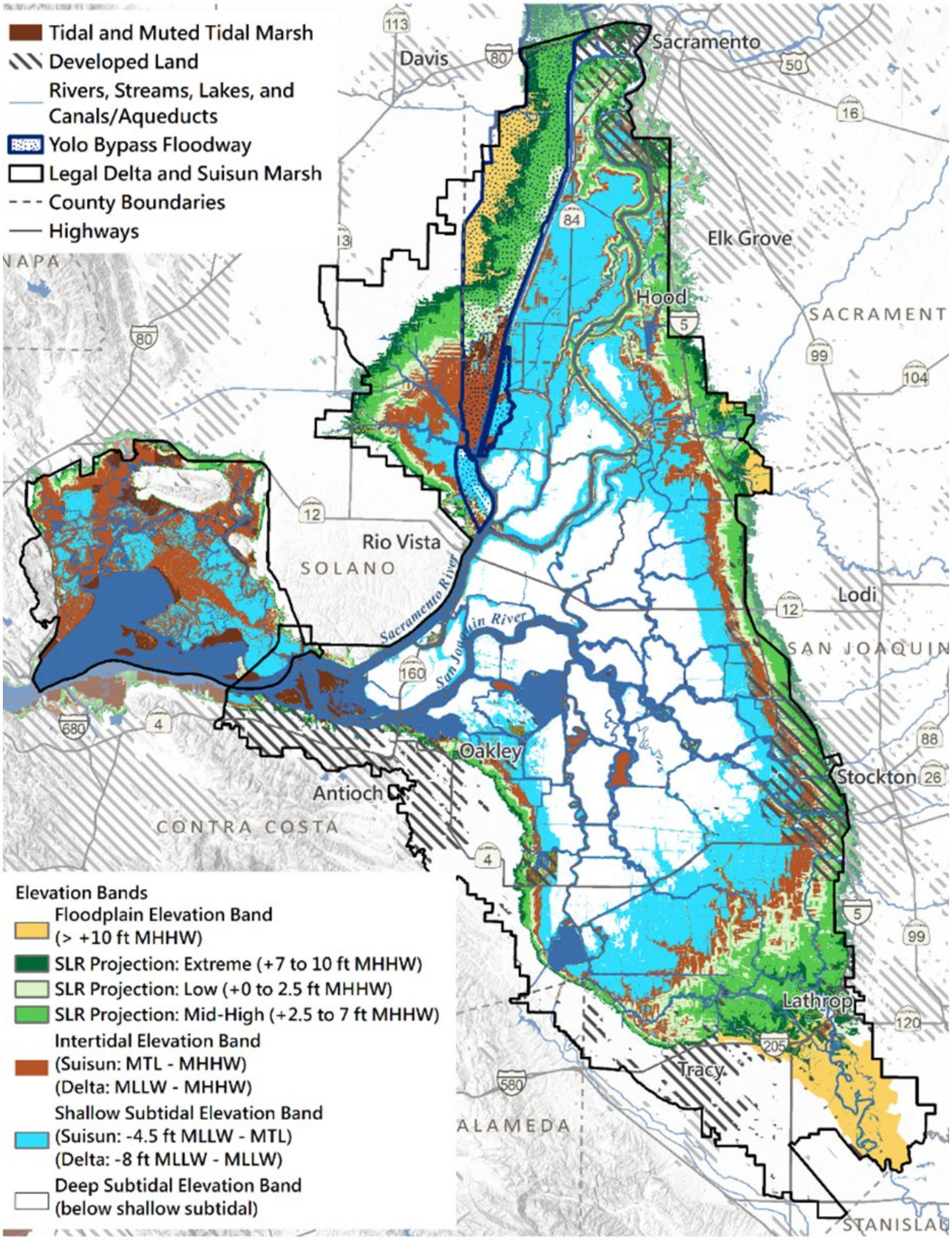

Figure 1. Elevation Bands, Shown with Developed Areas in the Delta and Suisun Marsh – Multiple Sea Level Rise Projections

Figure 1. Elevation Bands, Shown with Developed Areas in the Delta and Suisun Marsh – Multiple Sea Level Rise Projections (contd.)

This map illustrates the detailed results of the analysis described in this appendix. The map shows the tidal elevation bands resulting from various projections of sea level rise, including extreme sea level rise (7 feet to over 10 feet mean higher high water), medium to high sea level rise (over 2.5 feet to 7 feet mean higher high water), and low sea level rise (0 to 2.5 feet mean higher high water).

The map also shows topography of diked lands, grouped into habitat types based on elevation. These habitat types and elevation bands include floodplain (greater than 10 feet mean higher high water), intertidal potential emergent marsh (in Suisun Marsh: between mean tide to mean higher high water; in the Delta: between mean lower low water to mean higher high water), shallow tidal aquatic (in Suisun Marsh: between 4.5 feet below mean lower low water to mean tide; in the Delta: between 8 feet below mean lower low water to mean lower low water), and deep subtidal (below shallow tidal aquatic).

This map also shows the extent of tidal and muted tidal marsh habitat and modern tidal waters and tributaries, and the Yolo Bypass floodway. Major cities, rivers, and other features of interest are included for reference purposes.

Alternative formats of this map are available upon request.

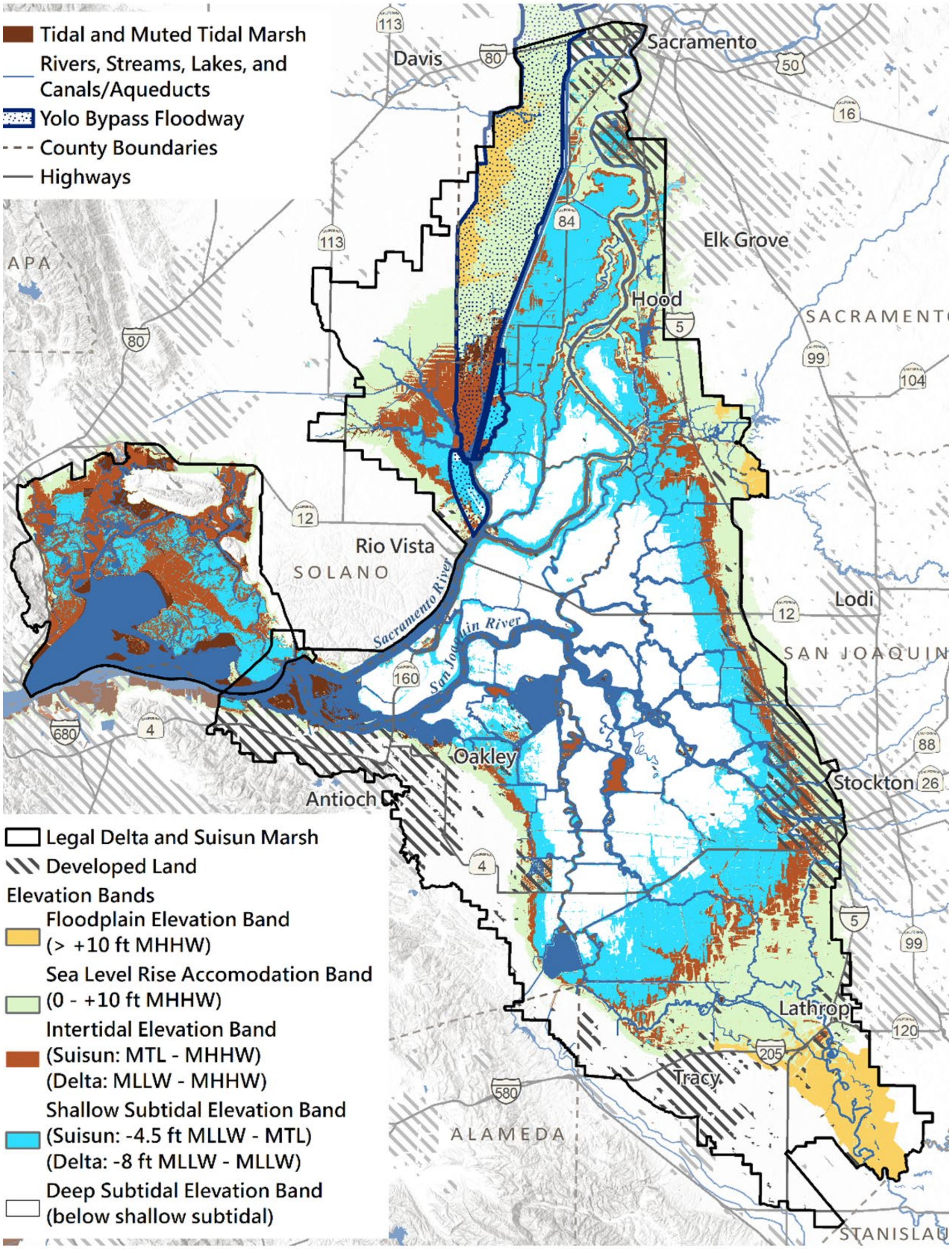

Figure 2. Elevation Bands, Shown with Developed Areas in the Delta and Suisun Marsh – Merged Sea Level Rise Projections

Figure 2. Elevation Bands, Shown with Developed Areas in the Delta and Suisun Marsh – Merged Sea Level Rise Projections (contd.)

This map illustrates the consolidated results of the analysis described in this appendix. The map shows the tidal elevations band resulting from various projections of sea level rise between 0 to 10 feet mean higher high water.

The map also shows topography of diked lands, grouped into habitat types based on elevation. These habitat types and elevation bands include floodplain (greater than 10 feet mean higher high water), intertidal potential emergent marsh (in Suisun Marsh: between mean tide to mean higher high water; in the Delta: between mean lower low water to mean higher high water), shallow tidal aquatic (in Suisun Marsh: between 4.5 feet below mean lower low water to mean tide; in the Delta: between 8 feet below mean lower low water to mean lower low water), and deep subtidal (below shallow tidal aquatic).

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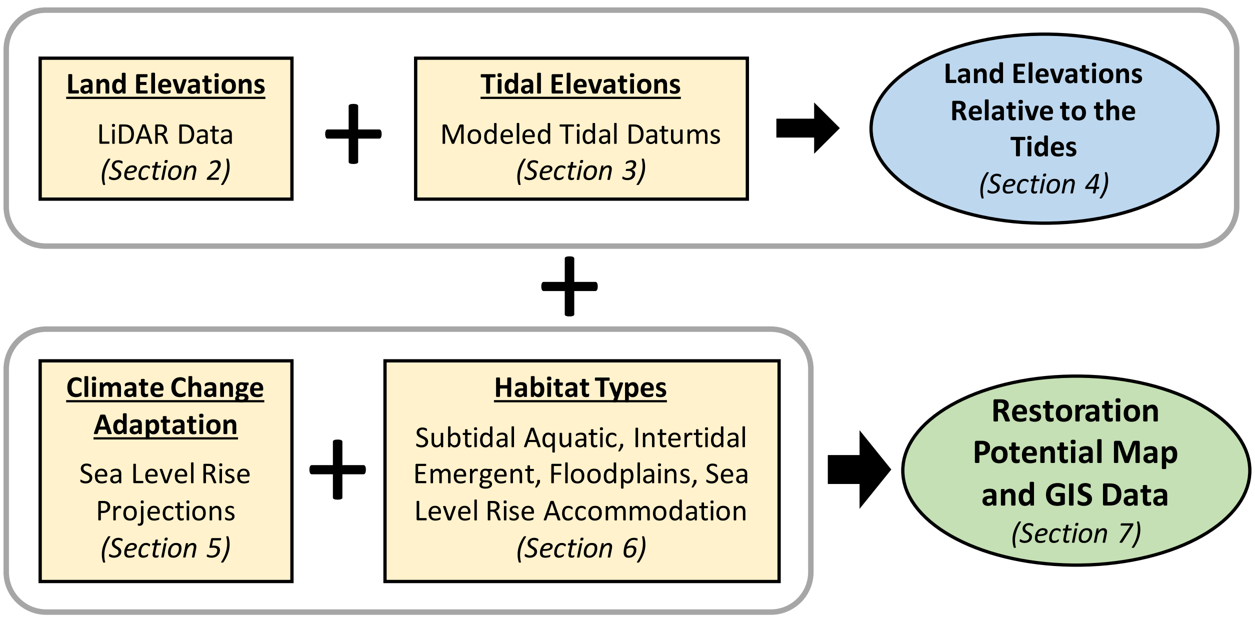

Figure 3. Steps Used in Updating Elevation Band Maps

This diagram illustrates the methods used to develop updated elevation band maps. The diagram shows the different data sets used and how they are combined to develop a restoration potential map. The top of the diagram includes a section with two data sets: (1) land elevations (LiDAR data, discussed in Land Elevations section and (2) tidal elevations (modeled tidal datums, discussed in Tidal Datums Used section. These data sets are used to determine land elevations relative to the tides (discussed in Creation of Tide Range Zones and the Classified DEM section. The bottom half of the diagram includes two additional data sets: (1) climate change adaptation (sea level rise projections discussed in Sea Level Rise Values section and habitat types (subtidal aquatic, intertidal emergent, floodplains, sea level rise accommodation discussed in Section 6). This diagram indicates that the two data sets in the top half and bottom half are combined to develop a restoration potential map and GIS data (discussed in Section 7).

This appendix describes the methods utilized to develop the updated version of the Map utilizing newly available 2017-2018 Delta and 2018 Suisun Marsh source LiDAR ground elevation data.

Land Elevations

There are multiple data sets currently available that collectively provide the full geographic extent needed for the Delta Plan Map. These data sets are described in Section 2.1, and the process for creating a single combined data set is detailed in Section 2.2

Digital Elevation Models

Key to producing the new Map is the land elevation data used in the analysis. Each of these data sets and rationale for their selection are described below.

1. **Legal Suisun Marsh** (new data): September 2018 LiDAR flown for and processed by the U.S. Geological Survey (USGS) and available online[1] (the "**USGS 2018 LEAN DEM**" released in 2019). USGS applied a new method, LiDAR Elevation Adjustment with NDVI (LEAN) (Buffington and Thorne 2019). This method utilizes extensive ground-based surveying data and machine learning to correct for the dense, tall emergent vegetation of the diked and tidal marshes that comprise the bulk of lands in Suisun Marsh. This vegetation cover is well-known to obscure ground surface elevations. USGS removed all the tidal waters (bays and sloughs) of Suisun Marsh for its DEM. As part of its DEM generation, USGS carried out validation of the corrected DEM with ground-based topographic data, which indicated that the LEAN correction resulted in a 66 percent improvement in the mean elevation error and a 45 percent reduction in the standard deviation of those errors.

   One question that remained open with this new data set was whether areas of standing water that were present within diked marshes at the time of the September 2018 LiDAR acquisition may have inaccurate ground elevations in the DEM. To address this question, elevations in these areas were compared against the DWR 2017-2018 DEM (see next item). Our initial assumption was that the DEM containing the lower elevation within the flooded areas would be more accurate, which may or may not be entirely valid (Buffington and Thorne 2019). The USGS 2018 LEAN DEM contained the lower elevation in the majority of flooded areas, and when it was higher, it was typically within 0.5 feet (ft) of the DWR 2017-2018 DEM, which is negligible at the scale of land subsidence in the region. It was determined that no adjustments to the USGS 2018 LEAN DEM were warranted for this regional-scale analysis. As has long been known for site-specific restoration planning in diked marshes with extensive cover of tall

[1] https://www.sciencebase.gov/catalog/item/5d140b8ae4b0941bde59934a

emergent vegetation, ground topographic surveys to validate DEM elevations are essential.

2. **Legal Delta** (new data): December 2017 to January 2018 LiDAR flown for the California Department of Water Resources (DWR) (the "**DWR 2017-2018 DEM,**" Woolpert 2019). These data covered the Delta and Suisun Marsh, but here, only data within the Delta data are used, with Suisun replaced by the USGS 2018 LEAN DEM data described above. A LEAN correction has not been applied to the DWR 2017-2018 DEM. Delta lands behind levees are predominantly in agricultural use. In addition, LiDAR flights for this data set were conducted in the winter, when vegetation is less prominent. As such, the value of the LEAN method to correct for tall emergent marsh vegetation is assumed low for this data set.
3. **Lands Outside the Suisun Marsh and Legal Delta** (prior data): In 2017, DWR prepared a Delta-wide DEM from a variety of best available datasets at the time, reflecting various years of data collection. This combined DEM is identified as the "**DWR 2017 Seamless DEM.**" This data set combines a variety of LiDAR data sources for land elevations, incorporates the best available data (at the time of compilation) for the Delta and surrounding uplands, and is the basis for several ongoing planning and analysis efforts in the Delta. This dataset is used for all lands *outside* the extent of the USGS 2018 LEAN DEM and DWR 2017-2018 DEM (essentially outside of the Delta and Suisun Marsh).

Creation of Mosaicked DEM for Analysis

The three DEMs described in Section 2.1 were mosaicked together to create the single DEM used for this analysis. The methods used to create this mosaicked DEM are as follows, with all spatial analyses performed in ArcGIS 10.7.1.

1. Mosaic the three DEMs into a single DEM
    a. The Mosaic to New Raster tool was used to mosaic the three DEMs together. The mosaic priority order was set as follows to ensure that the appropriate dataset was utilized in the final mosaic DEM:
        i. USGS 2018 LEAN DEM (first priority, overwrites all other datasets)
        ii. DWR 2017-2018 DEM (second priority, overwrites DWR 2017 Seamless DEM)
        iii. DWR 2017 Seamless DEM (third priority, used outside areas of overlap)

    b. The cell size of the mosaicked raster was set to 10 ft (3.05 meters). *Future site-specific restoration planning efforts in the Delta or Suisun Marsh are* *better served by utilizing the appropriate full-resolution DEM, as opposed to this down-sampled mosaic.*

2. Clip the mosaicked DEM down to the analysis extent to create the input DEM for subsequent spatial analyses.

    a. A polygon was drawn along the approximate 30 ft NAVD88 contour line around the perimeter of the Suisun Marsh and Delta study area. This polygon represents the maximum extent of topographic analysis in this effort, plus a 10-ft vertical buffer.

    b. This polygon was used in the Extract by Mask tool to clip out the extent of the mosaicked DEM for use in subsequent spatial analyses. This data set represents the *Input DEM* for this project. This data has been archived in an ESRI file geodatabase: Merged_DEM_Feb2020_Clip_Analysis_Extent.fgdbr

Tidal Datums Used

A tidal datum is a set of elevations describing tide heights (e.g., mean high or mean low water) at a point location in an estuary. The tidal datum differs from place to place depending on how tidal energy is dissipated across the geometry of the estuary and how tidal forcing is influenced by river flow inputs. The *spatial* tidal datum is a three-dimensional surface of interpolated point tidal datums that quantified the tidal range and height changes around the estuary. Delta hydrodynamic geometry changes in three general ways: intentional tidal marsh restoration actions, unintentional levee breaches, and direct and indirect modifications to state and federal water project facilities. Delta flows change seasonally, interannually, and from water operations, dam operations, diversions, and exports within and above the Delta. River flows that can be more than double tidal flows in wet years and a fraction of tidal flows in drought years, combined with the effects of all the water operations and in-Delta agricultural diversions, makes the concept of tidal datums inherently more complex than in the tidally dominated lower estuary.

This section describes how tidal datums are calculated (Section 3.1), the preliminary effort to compute them for the Delta in 2007 (Section 3.2), the next improvement in 2008 and 2009 (Section 3.3), the uncertainty remaining today in tidal datums for the Delta (Section 3.4), and a recommended approach to updating tidal datums for the region (Section 3.5).

How Tidal Datums Are Calculated

The National Ocean Service (NOS) is the federal entity charged with promulgating methods for computing tidal datums in the United States and for computing them throughout the nation in support of interstate commerce. NOS utilizes two methods for computing tidal datums:

1. **Reference or Harmonic Station Tidal Datums.** The first method applies to locations where NOS has installed and operated a tide gauge of suitable technical specification for at least 19 years. This duration captures the full 18.6-year cycle of solar and lunar gravitational forces generating tides, known as the *Metonic cycle*. NOS directly calculates datums from these data for periods of time it designates as the National Tidal Datum Epoch (NOS 2001). These tidal datum locations are called *reference* or *harmonic* sites.
2. **Local or Subordinate Station Tidal Datums.** The second method applies where NOS (or any other party) has a shorter record of tides. For those locations, NOS utilizes the Method of Corresponding Tides (MoCT) (NOS 2003). This method compares short-term records at the *local* or *subordinate* station to the synoptic records at the closest NOS reference station, computes the differences for each high and low tide during the short time period, and applies those differences to the reference station datums to establish the local station datums.

Port Chicago, located on the Contra Costa shoreline in Suisun Bay, roughly midway between the Delta to the east and Carquinez Strait to the west, is the nearest NOS reference station to the Delta and Suisun Marsh. There are four other NOS tidal datum reference stations lower in the San Francisco Estuary (San Francisco at the Golden Gate, Alameda, Redwood City, and Richmond). There are no NOS tidal datum reference stations in the Delta, though NOS did install short-term local stations in the past.

First Delta-Wide Tidal Datums Analysis: Initial 2007 Coarse Estimate

The first effort to compile tidal datums across the Delta was done in 2007 by Stuart Siegel for Governor Schwarzenegger's Delta Vision Blue Ribbon Task Force (Siegel 2007). That effort involved compiling all the NOS *local/subordinate* tide stations operated in the Delta up to that point in time, converting the reported tidal datums to a common vertical geodetic datum where possible, assessing the relative quality of the reported datums based largely on their geodetic accuracy, and identifying broad regions of similar tidal datums (the data supported three regions: south, central, and north Delta). That effort made two key findings. First, the available data—12 stations, located mostly in the central interior Delta—were inadequate to represent tidal datums throughout the Delta and did not capture the significant tidal effects of the large and small rivers flowing into the Delta. Thus, the three tidal range zones were very rough approximations. Second, the absence or low stability ratings of geodetic benchmarks translated to low vertical certainty in much of the data, and thus poor ability to compare across the Delta. The result of this effort was identification of the need to improve estimates of Delta tidal datums. That effort took place in 2008 and 2009 and is described in the next section.

Currently Best Available Data, Used Here: 2009 DWR Tidal Datums Computations

Following completion of the initial 2007 coarse tidal datum estimates, Stuart Siegel worked with Chris Enright and Brad Tom at DWR in 2008 and 2009 to develop a comprehensive tidal datum data set for the Delta that data available at that time could support, as the first step to remedy these problems. At the time, this group identified that the effort itself, while a major improvement, still had limitations. These data are used here, as no suitable improvements have yet been made to it.

That analysis used hydrodynamic modeling to calculate tidal datums (utilizing the NOS 2003 MoCT methodology) throughout the Delta and up each river and stream at a high node density. It calibrated and verified model results with about five years of verified field observational water level data (from 2000 to 2005) for dozens of long-term DWR and USGS Delta stage data stations distributed far more widely across the Delta than the twelve NOS stations.

The DWR modeling effort calculated tidal datums for the entirety of the multiyear modeling period (“all data” tidal datums) and for subannual time periods (“subannual” tidal datums) reflecting Delta Cross Channel closure (closed February through mid-May; a portion of mid-May through June; and a portion of November and December), and the annual installations of the south-Delta temporary barriers at Head of Old River (closed from mid-September to end of November), Old River near Tracy, Middle River, and Grant Line Canal (all closed mid-April to the end of September). These subannual subsets of the data reveal seasonal variability in the tidal datums, resulting in variations in local tide ranges of up to 2 feet in some locations. This Delta Plan map uses the “all data” tidal datums. When planning actions such as restoration projects where the tidal datums at certain times of year are critical, it may be appropriate to utilize the subannual tidal datums specific to that time period.

Completion and publication of that effort has not yet occurred due to absence of funding support. The work completed to date is referenced as Enright et al. (2009). The suggested approach to its completion is described below in Section 3.5.

Disclosure on Uncertainty of Tidal Datums Used

It is important to disclose two key limitations of the tidal datums used in this effort:

1. All Delta tidal datum computations utilizing the Method of Corresponding Tides (NOS 2003) have no choice but to use the Port Chicago NOS tidal datum reference station, as there are no such NOS stations within the Delta. The tidal hydrology of Suisun Bay where Port Chicago is located is very strongly

influenced by tides through the Golden Gate. In contrast, the tidal hydrology of the 750,000-acre Delta is very strongly influenced by river flows, water operations within and above the Delta, and so forth, and these processes have strong geographic variability around the Delta. Consequently, utilizing Port Chicago as the reference station introduces uncertainty into the computations, and the amount of that uncertainty has not been calculated, nor is it a simple task to calculate.

2. The results of the effort described in Section 3.3 are calibrated and verified using a roughly five-year data set of water level observation stations in the Delta and Suisun Bay. These time periods are well below the 18.6-year tidal epoch time period. This is less of a concern for Suisun Marsh as Port Chicago is reasonably reflective of tides in Suisun Bay. It is more of a concern in the Delta given the above discussion about there being no Delta NOS reference stations to utilize for the computations.

Recommendation for Developing Newly Updated Tidal Datums

The best tidal datum calculations follow the NOS approach of having an 18.6-year continuous data record or longer at water level recording stations with high geodetic accuracy (see Section 3.1 above). Such data sets now exist, as sufficient time has passed for a large number of geographically dispersed water level recording stations that have been operated by DWR and USGS. The basic approach to compute data-derived tidal datums is to compile the most recent 18.6 years of data from each of these stations, validate both sensor functionality and geodetic basis for each station to ensure suitable data quality or at a minimum to be able to assess uncertainty for each data station, directly calculate the tidal datums for each station, use these data as calibration and verification data for hydrodynamic modeling across the entire Delta and Suisun Bay, update the tidal datum zones for the Delta and Suisun Bay, and apply these updates to the topographic data. Given the complexity of this effort and its policy importance, submitting this work through a scientific peer-reviewed journal would provide the highest level of confidence in tidal datums for this region. A partial draft manuscript has been developed (Siegel et al., in preparation).

Creation of Tide Range Zones and the Classified DEM

The Suisun Marsh and Delta diked and nontidal lands study areas require division into a series of tide range zones, which are used to segment (classify) the underlaying terrestrial topography (represented by DEM described in Section 2) for visualization and analysis of the various elevation classes of interest to this effort (i.e., subtidal, intertidal, sea level rise accommodation space). As described in the previous section, this analysis uses the “all data” hydrodynamic model results (Enright et al. 2009) for determination of regional tidal datums. The methods used to create the tide range zones and classified DEM are as follows, with all spatial analyses performed using ArcGIS 10.7.1.

Creation of Tide Range Zones

1. Import the Enright et al. (2009) hydraulic model nodes for mean lower low water (MLLW) and mean higher high water (MHHW) in the waterways
2. Interpolate grids of MHHW and MLLW across the diked lands between tidal waterways, using the modeled water surface elevation at hydraulic model nodes
   - Digitize the interpolation boundary polygon at the ~30 ft NAVD88 contour around the study area, incorporating the split between the Yolo Bypass and Clarksburg Agricultural District along the Sacramento Deep Water Ship Channel (see discussion below)
   - Use the Inverse Distance-Weighted (IDW) interpolation tool to create the diked and nontidal lands tidal datum grids
     - 300-meter (m) output grid resolution
     - Variable search radius (minimum 12 interpolation points)
     - Interpolation boundary set as described above
3. Reclassify the resulting MHHW and MLLW diked and nontidal lands grids into elevation bands using the Reclassify tool
   - 1 ft bands centered on 1 ft intervals (e.g., 5.5 to 6.5 ft)
4. Convert the reclassified MHHW/MLLW diked and nontidal lands grids to polygons using the Raster to Polygon tool
   - Assign the mean elevation of each band to the resulting polygons (e.g., 5.5 to 6.5 ft is assigned an elevation of 6 ft)
   - Edit the polygons to remove slivers and other anomalies
5. Perform a spatial union of the MLLW and MHHW polygons to create the diked and nontidal lands tide range zone polygons using the Union tool
   - e.g., overlap of the 1 ft NAVD88 MLLW polygon with the 6 ft NAVD88 MHHW polygon is assigned a tide range class of 1 to 6 ft NAVD88
   - Edit the resulting polygons to remove slivers and other anomalies

- *Final tide range zone shapefile: Tide_range_ALL_polys_IDW1_1ft_bin_simplify.shp*

Clarksburg Agricultural District and Yolo Bypass Tidal Datums

The Clarksburg Agricultural District in the Netherlands area of the northern Delta and the Yolo Bypass present a setting that required selecting which tidal datums to use, given relatively large tidal datum differences between the Sacramento River, Sacramento Deep Water Ship Channel, and Yolo Bypass Toe Drain.

Clarksburg Agricultural District. This area is bordered on the west by the tidal, dead-end Sacramento Deep Water Ship Channel and on the east by the tidal Sacramento River. To determine how to apply the waterways tidal datum data to this area, the connection of potential restoration efforts to tidal sources was considered. Early planning of the DWR Prospect Island restoration project made clear that the Bar Pilots Association advocates for no breaches to the Ship Channel in order to avoid introducing cross-current navigation challenges. Based on that knowledge, and in consultation with Council staff, this effort applies Sacramento River tidal datums to the entirety of the Clarksburg Agricultural District.

Yolo Bypass. The Yolo Bypass Toe Drain runs along the east side of the Yolo Bypass along the western toe of the levee that functions as both the western Ship Channel and eastern Yolo Bypass hydraulic boundaries. The Toe Drain is subject to tidal action along much of its length, receives inflows from local tributaries (e,g., Putah Creek) as well as major winter flood conveyance, and is hydrologically isolated from the Ship Channel by the levee. Tidal datums for Yolo Bypass have been set based on modeled Toe Drain tidal datums, based on the same assumption for not breaching into the Ship Channel applied for Clarksburg and that Ship Channel levee breaches might affect the flood conveyance functions of the Yolo Bypass. The validity of these assumptions could change in the future, but for the present, they are deemed appropriate.

Creation of the Classified DEM

1. Use the tide range zone polygons to clip out individual sub-DEMs for each zone (17 DEMs total) from the Input DEM using the Extract by Mask tool
2. Classify each of the sub-DEMs into the elevation classes of interest based on the assigned tide range using the Reclassify tool. The elevation classes are described in detail in the “Habitat Map Units” section, below.
3. Merge the 17 classified sub-DEMs into a complete classified DEM of the Delta and Suisun Marsh using the Mosaic to New Raster tool.
4. Delineate the extent of “floodplain” habitat within the Yolo Bypass, Mokelumne-Cosumnes, and south-Delta regions (see discussion in the “Floodplain

Delineation" section, below). Merge the "floodplain" habitat class into the classified DEM using the Mosaic to New Raster tool.

5. Remove tidal waters and tidal marshes from the classified DEM so that all computational analyses consider only diked lands with tidal or floodplain (nontidal) restoration potential. USGS removed the tidal waters in its 2018 LEAN DEM.

    - **Removing tidal marshlands**. A GIS dataset of all natural and restored tidal marshes throughout the San Francisco Estuary was used. This data set is founded on the EcoAtlas developed by the San Francisco Estuary Institute and improved by Stuart Siegel and his collaborators over many years as part of a variety Final classified DEM: Merged_DEM_Feb2020_Clip_Analysis_Extent_Reclass_FINAL.tif
    - This classified DEM retains data within the currently mapped extent of tidal waters, tidal/muted tidal wetlands, and developed/urban areas. These areas will need to be removed from the DEM before any quantitative analysis of the DEM is performed.

Sea Level Rise Values

This map update utilizes the most recent Ocean Protection Council (OPC 2018) values for three ranges of projected sea level rise at the Golden Gate (outer coast) for the year 2100 (Table 1). The degree of sea level rise within Suisun Marsh and the Delta associated with these predictions for the outer coast is difficult to forecast due to interactions with river flows, tidal restoration efforts, and potential future human sea level rise adaptation efforts (e.g., salinity barriers, wetland restoration, levee setbacks, sea walls). Therefore, the sea level rise values shown on the map are merely contour lines of higher water associated with the outer-coast sea level rise values, and do not reflect physical transmission of sea level at the Golden Gate into the Delta, nor the effects of sea level rise adaptation efforts. This effort also rounded sea level rise projections to the nearest half-foot, so as not to reflect the inherent uncertainties across all the data when together.

Table 1. Sea Level Rise Projections for 2100 Used in Mapping

OPC SLR Scenarios [1]	OPC 2100 SLR Values [2]	Adopted SLR Values for Delta Plan Map [3]
Low	**RCP 2.6 = 2.4 feet** RCP 8.5 = 3.4 feet	2.5 feet
Medium to high	RCP 2.6 = 5.7 feet **RCP 8.5 = 6.9 feet**	7.0 feet
Extreme	**H++ = 10.2 feet**	10.0 feet

Notes:

[1] OPC lists sea level rise scenarios in terms of "risk aversion." OPC states "Risk tolerance is the level of comfort associated with the consequences of sea level rise and associated hazards in project planning and design. Risk aversion is the strong inclination to avoid taking risks in the face of uncertainty." Thus, low risk aversion equates to scenarios of lower sea level rise, high risk aversion equates to scenarios of higher sea level rise.

[2] Sea level rise scenarios utilized in and described by OPC (2018):

a RCP 2.6 is the "low end" sea level rise scenario that requires significant global emissions reductions to achieve.
b RCP 8.5 is the "high end" business-as-usual, fossil-fuel intensive emissions scenario.
c H++ is the extreme sea level rise scenario reflecting uncertain projections of high rates of Antarctic and Greenland land ice-sheet loss to the ocean.

[3] For purposes of the Delta Plan map preparation:

a SLR values rounded to nearest 0.5-foot in consideration of multiple sources of uncertainty.
b "Low" uses RCP 2.6 (low risk and low emissions) to reflect optimistic SLR projections.
c "Medium-high" uses RCP 8.5 as it represents current emissions levels and trends globally.

Map Units

The units used to symbolize topography in the map of elevation bands (Figures 1 and 2) are provided in Table 2.

Table 2. Mapping Units Elevation Ranges and Habitat Types

Mapping Elevation Unit	Elevation Range		Habitat Types
	Delta	Suisun Marsh	
Uplands	Lands above sea level rise accommodation elevations		Dry land habitats, seasonal wetland complexes, riparian corridors, etc.
Floodplains			
Floodplain	Lands above the “extreme” sea level rise accommodation class within the Yolo Bypass and the lower Mokelumne-Cosumnes River and lower San Joaquin River corridors. Overlap exists between today’s floodplain areas and their associated sea level rise accommodation space.		Existing and potential future floodplain habitat above the potential sea level rise elevations
Sea Level Rise Accommodation			
Extreme	+7 ft MHHW to +10 ft MHHW		Potential future emergent tidal marsh, currently lands not subject to tidal action
Medium-high	+2.5 ft MHHW to +7 ft MHHW		
Low	MHHW to +2.5 ft MHHW		
Intertidal Emergent Tidal Marsh			
Emergent marsh potential	MLLW to MHHW	MTL[1] to MHHW	Tidal marsh supporting emergent vegetation
Intertidal and Subtidal Open Water			
Intertidal open water[2]	NA	MLLW to MTL	Tidal aquatic – daily submerged/exposed without emergent vegetation
Shallow subtidal[2]	-8 ft MLLW to MLLW	-4.5 ft MLLW to MLLW	Diked lands suitable for subsidence reversal[3] then tidal restoration by 2100
Deep subtidal	Below -8 ft MLLW	Below -4.5 ft MLLW	Diked lands too low for subsidence reversal to emergent tidal marsh elevation by 2100

Notes

[1] MTL: mean tide level (arithmetic mean of MHW and MLW per NOS 2000)

[2] Intertidal open water and shallow subtidal units are combined on the map as “Shallow Tidal Aquatic” and are retained as separate polygons in the GIS data set to support subsequent analyses.

[3] Subsidence reversal thresholds were calculated by Council staff based on OPC (2018) sea level rise estimates and published organic matter accretion rates throughout the estuary (see Methods Used for Setting Subtidal Subsidence Reversal Elevations section).

Subtidal Habitat Delineation

The threshold used to delineate between shallow subtidal and deep subtidal was developed using methods described in Methods Used for Setting Subtidal Subsidence Reversal Elevations section of this appendix.

Floodplain Delineation

Existing and potentially restorable floodplain habitat is present within the Yolo Bypass and along the lower Mokelumne-Cosumnes and San Joaquin (South Delta) river corridors. For the purposes of this analysis, the “floodplain” elevation class is defined as all lands above the highest sea level rise class (> + 10 ft MHHW) that fall within the floodplain footprint in each of these geographic areas. The floodplain footprint in each area was defined as follows:

- **Yolo Bypass**: All areas within the Yolo Bypass footprint with elevations above the highest sea level rise class, clipped to the Delta boundary.
- **Mokelumne-Cosumnes**: All areas within the Mokelumne-Cosumnes watershed polygons (from CalWater GIS data) cross-checked with the 100-year FEMA floodplain extent, with elevations above the highest sea level rise (SLR) class, clipped to the Delta boundary.
- **South Delta**: All areas within the FEMA 100-year floodplain extent, with elevation above the highest SLR class, clipped to the Delta boundary. The northwest extent of floodplain shown (along the axis of the Delta) was terminated at the approximate extent of floodplain shown on the previous version of the map (*Map of Habitat Types Based on Elevation, Shown with Developed Areas in the Delta and Suisun Marsh [Figure 4-6 in Chapter 4 of the Delta Plan, as adopted in 2013]*).

The individual floodplain class DEMs were created as follows:

1. Use the digitized floodplain bounding polygons to clip out sub-DEMs from the classified DEM (see Section 4.3) using the Extract by Mask tool.
2. Convert all lands classified as “uplands” in these sub-DEMs into a new “floodplain” class using the Reclassify tool.

These new floodplain class rasters were merged back into the overall classified DEM, as described in Section 4.3.

Generation of the Final Elevation Band Maps

The input datasets used in the preparation of the final maps are detailed in Table 3. The final map is presented in Figure 1 showing sea level rise accommodation in the three categories described in Table 2, and in Figure 2 with those three categories merged into a single category.

Table 3. Input Datasets to Final Map

Data Type	Filename	Citation[1]	Use Summary
Elevations and Land Uses			
Diked Lands Topography (DEMs)	Merged_DEM_Feb2020_Clip_Analysis_Extent_Reclass_FINAL.tif	GillenH$_2$O and SF Bay NERR, 2020; *built from DWR (2017, 2019) and USGS (2019) datasets*	The classified DEM is symbolized based on the habitat map units described above
Developed Land	2014_2016_DeltaCountiesMerge.shp	DSC, 2018; *built from California FMMP land cover data for Delta counties (2014-2016)*	Landcover types "D" (urban and built-up land), "R" (rural residential land), and "V" (vacant or disturbed land) were symbolized as "developed" and excluded from the analysis
	Legacy_Communities.shp	DSC, 2013: *built from Yolo, Sacramento, and Contra Costa Counties' land use data*	This file was used to show the development footprint of legacy communities within the Delta, which may not be adequately captured by the FMMP dataset
Waterways and Marshes			
Tidal and Muted Tidal Marsh	Current_modern_baylands_June2014_ tidalmarsh_only.shp	WWR, 2014; *built from SFEI EcoAtlas (1998) with periodic updates to keep current*	This layer contains all tidal and muted tidal wetlands within San Francisco Bay and Suisun Marsh, and was used to symbolize their extent within Suisun Marsh
	CacheSuisunDelta_NaturalCommunities_ Hydro_20140108.shp	WWR, 2014; *compiled from various existing natural community datasets (primarily CDFW 2007 Delta natural communities' dataset) and updated to distinguish tidal and nontidal settings*	This layer contains a complete classification of the natural communities within the Delta and some areas of Suisun Marsh. The layer was symbolized to show the extent of tidal and muted tidal marshes within the Delta

Table 3. Input Datasets to Final Map (contd.)

Data Type	Filename	Citation[1]	Use Summary
Tidal and Muted Tidal Marsh (contd.)	Flooded_Island-Aquatic.shp	WWR, 2008; *built from 2007 CDFW vegetation data*	This layer was used to symbolize the extent of tidal marsh in the Browns Island-Sherman Lake area, as it was not adequately depicted by the other two datasets
Tidal Waters	CSCCA_CDFG_DeltaSuisun_TidalHyrology_ WWR20130724.shp	WWR, 2013; *built from CDFW (2000) and BDCP (2010) hydrology data*	This layer was used to symbolize the tidal waterways within Suisun Marsh and the Delta
	Current_modern_baylands.shp	WWR, 2014; *built from SFEI EcoAtlas (1998) with periodic updates to keep current*	This layer was used to symbolize the tidal waterways at the extreme western end of Suisun Marsh, which was not captured by the above layer
Tributaries	Delta_River_input.shp	WWR, 2008; *built from various input datasets*	This layer contains the alignments of the major rivers and creeks flowing into the Delta
	Major_suisun_creeks.shp	WWR, 2008; *built from various input datasets*	This layer contains the alignments of the major creeks flowing into Suisun Marsh
	DP_Waterway_additions_Lines.shp	CH2M Hill (no date provided)	This layer contains the alignments of major rivers and creeks flowing into Suisun Marsh and the Delta. It was used to supplement the Delta_River_input.shp file, which did not have complete coverage of the Cosumnes River and Dry Creek alignments within the map extent

Table 3. Input Datasets to Final Map (contd.)

Data Type	Filename	Citation[1]	Use Summary
Legal Boundaries, Roads, Hillshade Relief			
Yolo Bypass Floodway	Yolo_baypass_complete.shp	WWR, 2010; *built from DWR and URS data (2007)*	This layer contains the complete extent of the Yolo Bypass floodway
Legal Delta Boundary	Legal_delta_UTM.shp	DWR, 2002	Represents the boundary of the Delta established under the 1992 Delta Protection Act (primary and secondary zones)
Suisun Marsh Boundary	SMPP_total_outline_Mar2011_diss.shp	WWR, 2011; updated in collaboration with BCDC	Represents the boundary of Suisun Marsh under the 1977 Suisun Marsh Protection Plan (primary and secondary management areas)
Hillshade (background)	HS_Regional_topo_az315.fgbdr	URS, 2008	Regional topographic hillshade layer used as the map background

Key:
BCDC = San Francisco Bay Conservation and Development Commission
BDCP = Bay-Delta Conservation Plan
CDFW = California Department of Fish and Wildlife
DSC = Delta Stewardship Council
DWR = California Department of Water Resources
FMMP = Farmland Mapping and Monitoring Program
GillenH_2O = Gillenwater Consulting, LLC
NERR = National Estuarine Research Reserve
SFEI = San Francisco Estuary Institute
USGS = United States Geologic Survey
WWR = Wetlands and Water Resources, Inc.

Methods Used for Setting Subtidal Subsidence Reversal Elevations

Subsidence Reversal Calculations

The Delta and Suisun Marsh include a gradient of subsided land elevations, with some lands more than 20 feet below current water surface elevations, and others less deeply subsided. A key threshold in restoration planning is the land elevation relative to water surface elevation, where above which, subsidence reversal activities could result in the ability to restore hydrologic connectivity. In deeply subsided areas, current subsidence reversal activities do not increase land elevation at rates which could keep up with sea level rise. In less subsided areas, current subsidence reversal practices could increase land elevations over decadal time frames and ultimately lead to opportunities to create hydrologically connected ecosystems such as tidal marsh. The following section describes the methods and assumptions used to estimate this threshold, which has been used as a criterion to delineate shallow tidal aquatic and deep subtidal on the elevation band maps, and in performance measures related to subsidence reversal.

The methods for calculating the subsidence reversal threshold elevation involves adding elevation change from subsidence reversal (SR) to elevation change from sea level rise (SLR) (Copeland, C. personal communication). This *threshold* is determined by analyzing projected change in sea level rise, an empirically derived subsidence reversal rate, and application over the Delta Reform Act planning horizon. Due to differences in subsidence reversal rates in the Delta and Suisun Marsh, two separate calculations have been carried out.

Delta

Sea level rise for the Delta is expressed as:

$$\Delta SLR = -2.5 \text{ ft}$$

2.5 feet is the median projection for sea level rise in the high emission scenario for San Francisco by 2100 from the Ocean Protection Commission (OPC) guidance (2018).

$$\Delta SR = 4 \text{ cm/year} * 80 \text{ years} * 0.0328 \text{ ft/cm} = 10.98 \text{ ft}$$

The subsidence reversal accretion rate of 4 cm/year comes from the Miller et al. empirical study in the Delta (2008). Based on a start date of 2020, and an end date of 2100 (corresponding to the Delta Reform Act subgoals and strategies for the Delta ecosystem), the change was applied over an 80-year timeframe.

Then: $\Delta SLR+\Delta SR$ = 7.98 ft (rounded to 8 ft)

Subsidence Reversal Threshold = -8 ft MLLW

Suisun Marsh

The following analyses are based on methods developed specifically for Suisun Marsh (Copeland, C., memorandum, February 25, 2019).

Managed wetlands on Twitchell Island have been observed accreting 4 cm/year of elevation (Miller et al. 2008). The majority of this accretion occurs through the deposition of organic material onto the surface. Although similar subsidence reversal is possible in Suisun Marsh, the rates of accumulation will likely be slower due to the saline conditions limiting production of organic material. Currently, no empirical data for subsidence reversal activity in Suisun Marsh exists. In order to estimate how a subsidence reversal project in the western Delta (Twitchell Island) accumulates elevation compared to rates of accumulation in Suisun Marsh, accumulation rates for nonsubsidence reversal wetlands were compared. Proxy locations in Suisun Marsh (Rush Ranch) and the western Delta (Brown Island) were used. A ratio was developed between wetland accumulation at each site of .65 units of accretion in Suisun Marsh per 1 unit in the western Delta (Table 4) based on data for those sites from Callaway et al. 2012.

Table 4. Wetland Accretion at Proxy Sites (based on data in Callaway et al. 2012)

Site (Mid)	Dating Method		
	137 Cs	137 Cs	Mean
Browns Island	.40 cm/year	.32 cm/year	.36 cm/year
Rush Ranch	.26 cm/year	.21 cm/year	.24 cm/year
Rush Ranch to Browns Island ratio	.65 to 1	.66 to 1	.65 to 1

A ratio-adjusted accumulation rate for Suisun Marsh was fed into the formula.

ΔSLR = -2.5 ft

2.5 ft is the median projection for sea level rise in the high global greenhouse gas emission scenario for San Francisco by 2100 from the Ocean Protection Commission (OPC) guidance (2018).

ΔSR = 4 cm/year*80 years*0.0328 ft/cm*.65 (ratio adjustment) = 6.82 ft

Based on a start date of 2020 and an end date of 2100 (corresponding to the Delta Reform Act subgoals and strategies for the Delta ecosystem), the change was applied over an 80-year timeframe.

Then, ΔSLR+ΔSR = 4.32 ft (rounded to 4.5 ft)

Subsidence Reversal Threshold = -4.5 ft MLLW

Methods Used to Update Priority Locations to Evaluate Physical Expansion of Floodplain

This section provides a description of methods employed to update priority locations for Delta Plan Policy ER P4: Expand Floodplains and Riparian Habitats in Levee Projects (23 California Code of Regulations section 5008). The original locations specified for this policy were included as a text description in the 2013 Delta Plan (Appendix 3) and on a map in Appendix 8, Figure 8-1. The updated priority locations for ER P4 are illustrated in Figure 4-4 and Appendix 8A. Priority locations were updated using the new digital elevation models and tidal datums, as described below. Locations were selected based on landscape suitability with respect to tidal or floodplain reconnection, which resulted in removing areas in the subsided central and eastern Delta and adding additional areas in the north and south Delta.

The priority locations were selected based on geomorphic processes and opportunities for ecosystem restoration, using the following steps:

1. Selected levee centerline segments (DWR 2017) within:
    a. priority fish migration pathways (SFEI-ASC 2018, EWG 2008, Blue Ribbon Task Force 2008)
    b. adjacent to lands that were categorized as “shallow,” “intertidal,” “floodplain,” “potential emergent marsh” under current and projected sea level rise scenarios, within the Draft Elevation Band Map (see Methods Used to Map Elevation Bands section, Table 3 and Figures 1 and 2). For a full description of how these elevations were classified and methodology associated with the sea level rise scenarios, see the description in Methods Used to Map Elevation Bands section of this appendix.
2. Removed levee segments that were:
    a. outside of the Delta or Suisun Marsh

b. along the Toe Drain of the Yolo Bypass

c. overlapping with the Freeport Regional Water Project Intake Facility

d. adjacent to currently developed areas, as visible in National Agriculture Imagery Program (NAIP) imagery (USDA 2018) in the cities of Sacramento, West Sacramento, and Delta legacy towns

e. segments adjacent to areas with construction visible in NAIP imagery (USDA 2018)

f. segments adjacent to bridge footings

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