

Performance Measure 4.12: Subsidence Reversal for Tidal Reconnection

Performance Measure (PM) Component Attributes

Type: Output Performance Measure

Description

Subsidence reversal¹ activities are located at shallow subtidal elevations to prevent net loss of future opportunities to restore tidal wetlands in the Delta and Suisun Marsh.

Expectations

Preventing long-term net loss of land at intertidal elevations in the Delta and Suisun Marsh from impacts of sea level rise and land subsidence.

Metric

1. Acres of Delta and Suisun Marsh land with subsidence reversal activity located on islands with large areas at shallow subtidal elevations. This metric will be reported annually.
2. Average elevation accretion at each project site presented in centimeters per year. This metric will be reported every five years.

Baseline

1. In 2019, zero acres of subsidence reversal on islands with large areas at shallow subtidal elevations.
2. Short-term elevation accretion in the Delta at 4 centimeters per year.

¹ Subsidence reversal is a process that halts soil oxidation and accumulates new soil material in order to increase land elevations. Examples of subsidence reversal activities are rice cultivation, managed wetlands, and tidal marsh restoration.

Target

1. By 2030, 3,500 acres in the Delta and 3,000 acres in Suisun Marsh with subsidence reversal activities on islands, with at least 50 percent of the area or with at least 1,235 acres at shallow subtidal elevations.
2. An average elevation accretion of subsidence reversal is at least 4 centimeters per year up to 2050.

Basis for Selection

General Purpose

California will experience sea level rise over the next century. The Ocean Protection Council's guidance estimates that sea level rise at San Francisco Bay, the nearest forecasted area to the Delta, could range from an increase of 1.6 feet to 10.2 feet by 2100 (OPC 2018). Anticipated sea level rise will increase pressure on already stressed Delta ecosystems (DSC 2018). In addition to sea level rise, the land in the Delta is subsiding due to microbial oxidation and most of the central Delta is already below sea level (Deverel et al. 2016). The areas at subtidal elevations offer limited ecological value if reconnected to a stream (Durand 2017). Only a thin band of land is at appropriate elevations suitable for tidal restoration through hydrologic reconnection (DSC 2019) and that band is getting smaller as the landscape subsides and sea level rises. Hence, the potential for future tidal restoration is being lost.

Many of the existing areas suitable for tidal wetland restoration are already being targeted for restoration as part of the California EcoRestore initiative.² Finding additional areas suitable for tidal wetland restoration will become increasingly difficult. Many of the most suitable areas already have tidal wetland restoration projects planned, and other areas in the Delta are becoming incapable of supporting intertidal restoration due to sea level rise and subsidence. One way to preserve the potential for future intertidal restoration on the landscape is through subsidence reversal.

If subsidence reversal activities are located at suitable locations, the accumulated land can counteract effects of sea level rise and subsidence, and maintain or increase land elevation. Preventing the loss of land will also preserve the opportunity for the land to be restored for tidal reconnection. Subsidence reversal activities in locations with current shallow subtidal elevations could prevent the net loss of opportunities for tidal restoration that is due to sea level rise. To prevent this net loss of tidal restoration opportunities, subsidence reversal on islands identified in this performance measure

² California EcoRestore is a California Natural Resources Agency initiative (<http://resources.ca.gov/ecorestore>).

must be initiated by 2030, and then continue long-term until the land reaches the desired intertidal elevation—becoming available for tidal reconnection and subsequent tidal wetland restoration.

A 50th percentile outcome elevation model, accounting for 2.6 feet of sea level rise (OPC 2018, see methods section below), indicates that 3,500 acres of land at intertidal elevation in the Legal Delta, and 3,000 acres in Suisun Marsh, may be lost during the next ten years. By initiating subsidence reversal activities on 3,500 Delta acres and 3,000 acres in Suisun Marsh, the net loss of land at intertidal elevation can be prevented, and subsequently, the opportunities for future tidal reconnection and restoration can be maintained. In order to accrete sufficient elevation at the identified locations, projects would need to accrete at least 4 centimeters per year.

Subsidence reversal is a process that increases land elevation by halting soil oxidation and accumulating new soil material. Subsidence reversal activities are conservation actions that can be implemented as multi-benefit projects that support native species and natural communities. Subsidence reversal projects can provide habitat for migratory bird species (Shuford and Dybala 2017; Shuford et al. 2019) and support native vegetation communities. After suitable land elevation is reached, locations can become available for tidal reconnection and tidal wetland restoration, that in turn benefits aquatic species and native fish populations, while restoring natural geomorphic processes.

Relationship to the Subsidence Reversal and Carbon Sequestration Performance Measure (PM 5.2)

Delta Plan performance measure PM 5.2, “Subsidence Reversal and Carbon Sequestration,” tracks carbon sequestration projects and acres of subsidence reversal projects across the entire Delta and Suisun Marsh. The PM 5.2 has the target of 30,000 acres of subsidence reversal and carbon sequestration in the Delta to be achieved by 2030. Managed wetlands, on deeply subsided areas operated for subsidence reversal, sequester carbon in the organic material they accrete. This decreases carbon emissions for organic soils. Subsidence reversal projects to sequester carbon can take advantage of carbon credit markets while also helping California meet its greenhouse gas reduction targets.

Shallow subsided areas (shallow subtidal elevations) tend to not emit high amounts of carbon dioxide compared to the deeply subsided areas, therefore, it is unlikely that carbon markets will incentivize projects in these areas.

This performance measure PM 4.12, “Subsidence Reversal for Tidal Reconnection,” is different from PM 5.2 because it only tracks subsidence reversal located in islands with shallow subtidal elevations. Shallow subtidal elevations have a reasonable chance of achieving intertidal elevations through subsidence reversal in the timeframe from 2030

to about 2100, preventing the net loss of future opportunities to restore tidal wetlands. Deeply subsided areas will require longer timelines to reach the intertidal elevation.

Linkages to Delta Reform Act and the Coequal Goals

Delta Reform Act

The loss of land elevation is a major stressor on the ecosystem that makes restoration of the Delta more difficult. The Sacramento-San Joaquin Delta Reform Act of 2009 (Delta Reform Act) defines a number of strategies for restoring a healthy Delta ecosystem. Achieving the target in this performance measure would support the following subgoals and strategies for restoring a healthy ecosystem:

- **“Restore large areas of interconnected habitats within the Delta and its watershed by 2100.” (Water Code section 85302(e)(1)).** Due to sea level rise and subsidence on land at current intertidal elevation, the potential for habitat reconnection is being lost. In the 10-year period (2020 to 2030) of modeled elevation change (see methods section below), 3,500 acres are estimated to be lost in the Legal Delta and 3,000 acres in Suisun Marsh. Applying subsidence reversal activities on the same amount of land will prevent the net loss of opportunities to restore tidal wetlands due to subsidence and sea level rise.
- **“Restore Delta flows and channels to support a healthy estuary and other ecosystems.” (Water Code section 85302(e)(4)).** Delta geometry has been radically simplified from the complex channel systems that were common in the pre-reclamation Delta (SFEI-ASC 2016). With large-scale wetland restoration, the formation of complex dendritic channels is possible. This measure tracks projects that could create new spaces for restoring those geomorphic formations. Those new spaces would offset the loss of elevation occurring elsewhere.
- **“Restore habitat necessary to avoid a net loss of migratory bird habitat and, where feasible, increase migratory bird habitat to promote viable populations of migratory birds.” (Water Code § 85302(e)(6)).** Both managed wetlands—for subsidence reversal in deeply subsided and shallow subsided areas—provide habitat for migratory bird species (Shuford and Dybala 2017; Shuford et al. 2019).

In addition to providing subgoals and strategies for restoring a healthy Delta ecosystem, the Delta Reform Act also mandates that the Delta Plan include measures that promote specified characteristics of a healthy Delta ecosystem (Water Code section 85302(c)). Achieving the target in this performance measure would promote the following characteristics of a healthy Delta, as identified in the Delta Reform Act:

- **“Viable populations of native resident and migratory species.” (Water Code section 85302(c)(1)).** Prior to reclamation, native and migratory species thrived in a dynamically inundated tidal marsh system (SFEI-ASC 2016). In the last 150 years, more than 95 percent of wetlands in the Delta have been lost; those wetlands were habitat for many native species (SFEI-ASC 2016). Without opportunities on the landscape to restore lost tidal wetlands, it will be difficult to support viable populations of native resident and migratory species. PM 4.16, “Natural Communities Restored,” sets targets for the number of acres of natural wetlands to be restored. Achieving that goal will require significant space on the landscape. Meeting the target of this measure will ensure that the Delta landscape maintains opportunities for natural wetland restoration, as opposed to losing suitable landscapes due to sea level rise and subsidence.
- **“Diverse and biologically appropriate habitats and ecosystem processes.” (Water Code section 85302(c)(3)).** The pre-reclamation Delta was characterized by a diverse series of seasonally inundated tidal wetlands that provided complex and variable hydrology and landscape patterns (SFEI-ASC 2016). Restoring these processes will require space on the landscape that is not deeply subtidal. The intertidal space is being lost to subsidence and sea level rise. Meeting the target of this measure will ensure that the Delta landscape maintains opportunities to restore seasonally inundated tidal wetlands and fluvial and geomorphic patterns.
- **“Reduced threats and stresses on the Delta ecosystem.” (Water Code section 85302(c)(4)).** Land loss is a stress on the ecosystem. Deeply subsided islands offer less potential habitat value than those of intertidal elevations (Durand 2017). Meeting the target of this measure will ensure no net loss of the land at intertidal elevation.
- **“Conditions conducive to meeting or exceeding the goals in existing species recovery plans, and state and federal goals with respect to doubling salmon populations.” (Water Code section 85302(c)(5)).** Loss of land at intertidal elevations prohibits opportunities for restoring large areas of tidally connected wetlands that support native fish species and the doubling of salmon populations. Meeting the target of this measure will ensure that the Delta landscape maintains opportunities for natural wetland restoration.

Delta Plan Core Strategy

4.3 Protect Land for Restoration and Safeguard Against Land Loss.

Methods

Baseline Methods

Islands in the Delta and Suisun Marsh, with large enough areas at shallow subtidal elevations, were identified as capable of reaching intertidal elevations with subsidence reversal ongoing from 2030 to 2100 (see method below).

The 4 centimeters per year metric for the vertical accretion baseline is based on empirical data from Twitchell Island (Miller et al. 2008). This data was derived over a short interval. Long-term subsidence reversal may be lower than this without technical improvements to the process, such as with the use of metal coagulants (Stumpner et al. 2018).

Target Methods

Acres of Intertidal Land Lost by 2030

Areas at current intertidal elevation were derived from the Delta and Suisun Marsh 2007-2008 digital elevation model (DEM) and 2017 DEM revisions by the Department of Water Resources (DWR) (Tolentino 2017). The estimated intertidal land loss is calculated for 10 years of elevation change based on the projected subsidence and sea level rise (method described in Appendix 1). The resulting 3,500 Delta acres and 3,000 acres in Suisun Marsh is the estimated area of land loss.

The land loss is calculated for 2020-2030 because projections of sea level rise and rates of subsidence reversal after 2030 have a high uncertainty. A longer-term target date requires more foreknowledge of sea level rise and the future development of subsidence reversal technology. Subsidence reversal technology in the Delta is in the early stages of development. Currently, there are only few subsidence reversal projects in the Delta and none in Suisun Marsh. By 2030, more subsidence reversal projects are expected to be implemented and evaluated, contributing to the state of the science and the adaptive management. The 2030 target date is consistent with the existing performance measure PM 5.2, "Subsidence Reversal and Carbon Sequestration."

Identifying Islands with Large Areas of Land Capable of Reaching Intertidal Elevations Suitable for Potential Future Restoration by 2100

The Delta and Suisun Marsh islands were analyzed by Council staff to determine which islands contain significant opportunities to achieve intertidal elevations (needed for tidal reconnection and tidal wetland restoration) through soil accretion from subsidence reversal (technical details are described in Appendix 1). For each island in the Delta and

Suisun Marsh, Council staff estimated the amount of vertical soil accretion that could potentially be gained through subsidence reversal based on empirical data from existing subsidence reversal projects. Staff then used GIS to count, for each island, the number of acres that could reach intertidal elevations by 2100 or sooner.

Staff reviewed the elevations at each island and included any island with at least 50 percent of its area or at least 1,235 acres at current shallow subtidal elevations as being able to reach intertidal elevations by 2100 with subsidence reversal and therefore provide future opportunities for tidal reconnection. The 1,235-acre threshold was selected because it is the minimum area needed for complex intertidal channel systems to develop in a wetland complex (SFEI-ASC 2016) and would therefore allow for large-scale intertidal wetland restoration. This 1,235-acre threshold is also used in the Delta Plan Ecosystem Amendment Appendix 2 to determine if a tidal wetland project is large-scale. An island list (Appendix 2) and map (Figure 1) were manually corrected to exclude islands that included large acreage but little connectivity to support channel formation such as Brannan-Andrus Island.

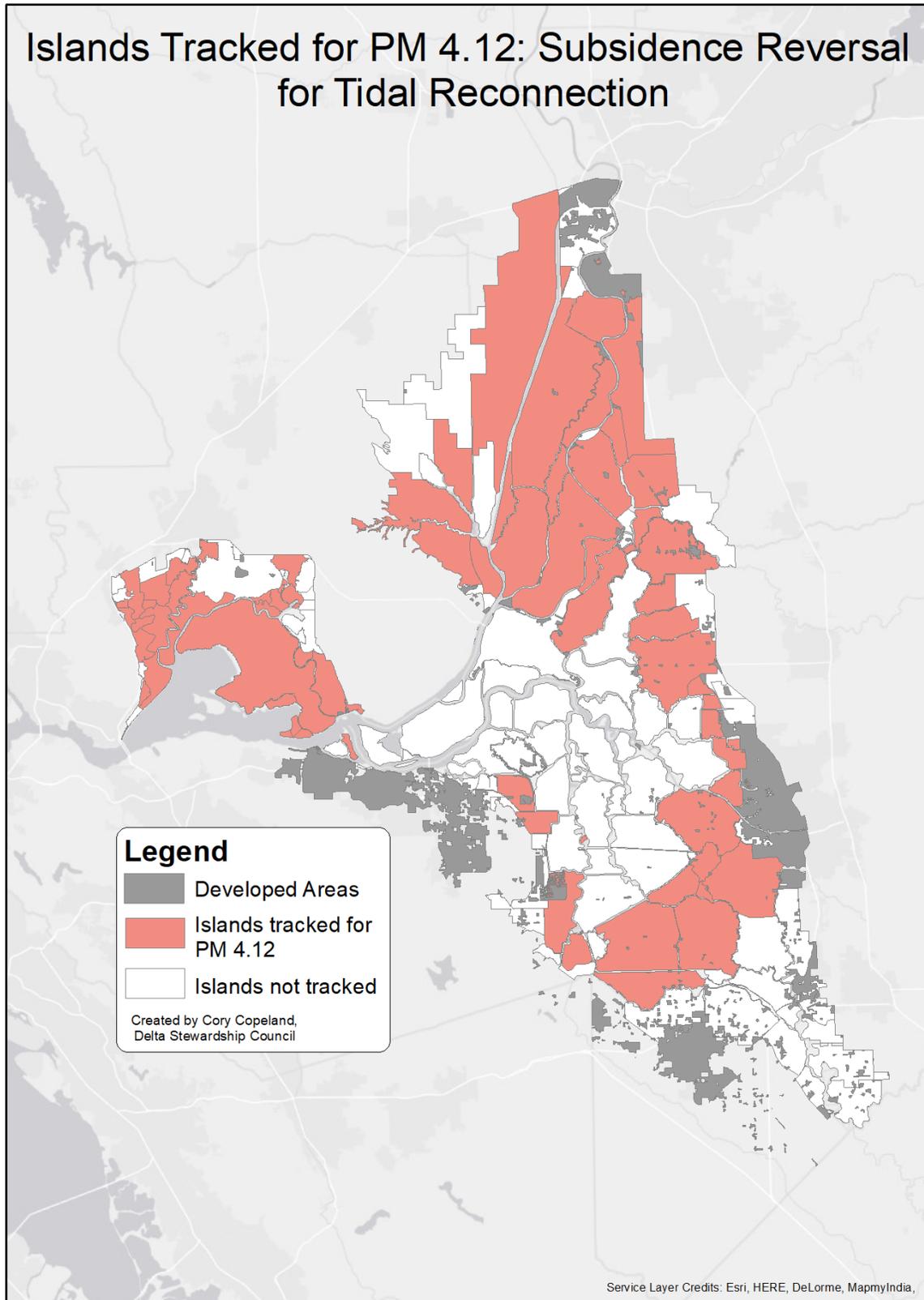


Figure 1. Islands Tracked in this Performance Measures

Figure 1. Islands Tracked in this Performance Measures (contd.)

Within the boundaries of Suisun Marsh and the Legal Delta, this map shows the islands that are tracked for this performance measure and the islands that are not tracked. The islands are not labeled. The map shows: Developed Areas in solid gray, the Islands Tracked for PM 4.12 in solid pink, and Islands Not Tracked in white. Islands that are tracked for this performance measure include areas where subsidence reversal activities ongoing from 2030 to 2100 can produce intertidal elevations by 2100.

Islands that are tracked for this performance measure are concentrated in Suisun Marsh, Cache Slough, Yolo Bypass, the north Delta along the Sacramento River, the eastern Delta near the Cosumnes/Mokelumne confluence, adjacent to the City of Stockton, and in the south Delta north of Tracy and Lathrop. Hotchkiss Tract and Veale Tract (in East Contra Costa County) are also shown as islands tracked for this performance measure. Islands that are not tracked for this performance measure are concentrated in the central Delta where land is too deeply subsided to be reconnected to tidal inundation; and at the edges of the Legal Delta and Suisun Marsh, where land is above the tidal range. The names of the individual islands that are tracked for this performance measure are listed in Appendix 3 of this document. Please contact the Delta Stewardship Council with any questions regarding this figure.

Accretion Metric and Target Selection

This measure identifies that projects would need to accrete at least 4 centimeters per year (cm/yr) over a long-term project life. The rate of 4 cm/yr has been shown to be possible over the short-term in the Delta based on empirical data from Twitchell Island (Miller et al. 2008). Subsidence reversal activities must continue to accrete elevation at an average 4 cm/yr rate to reach intertidal elevations suitable for tidal reconnection and tidal wetland by 2100.

Data Sources

Primary Data Sources

The listed primary data sources below will be used for tracking this performance measure. If subsidence reversal project-implementers choose to report project information outside of these listed sources, Council staff will seek to identify additional sources of project information.

1. [The Delta Stewardship Council Covered Actions website](#). Subsidence reversal projects are likely to meet the definition of a covered action and will need to establish consistency with the Delta Plan before implementation.
 - a. Content: Covered actions project description provides details about types of subsidence reversal activities, acreages, and locations.
 - b. Update frequency: As covered actions are submitted.

2. DWR. DWR has the lead role in implementing subsidence reversal projects through the [West Delta Program](#). Initially data will be collected by DWR until other organizations, landowners, and stakeholders begin implementing subsidence reversal projects.
 - a. Content: Project specific information.
 - b. Update frequency: On a project-by-project basis.
3. [CA Wetland Protocol Group](#). Consists of multiple organizations and/or agencies (e.g., Sacramento-San Joaquin Delta Conservancy (Delta Conservancy), California Department of Fish and Wildlife (CDFW), Sacramento Municipal Utilities District (SMUD), Metropolitan Water District of Southern California (MWD), and the California Coastal Conservancy).
 - a. Content: Project specific information.
 - b. Update frequency: Variable.
4. [California Department of Fish and Wildlife Wetlands Restoration for Greenhouse Gas Reduction Program](#). Uses Cap-and-Trade money to fund greenhouse gas emissions. Delta wetlands are a potential future target for this program.
 - a. Content: Project specific information.
 - b. Update frequency: Based on funding cycles, usually annual or shorter.
5. [AmeriFlux Network](#). U.S. Department of Energy initiative. A network of monitoring stations measuring ecosystem CO₂, water, and energy fluxes in North, Central, and South America. For example, the [Twitchell Wetland \(Twitchell Island East End Habitat Restoration Project\) project has a page that](#) includes project-related publications.
 - a. Content: Project and related research information.
 - b. Update frequency: Variable.
6. [San Francisco Bay and Sacramento-San Joaquin Delta Digital Elevation Model \(DEM\)](#). U.S. Geological Survey DEM is developed based on synthesizing LiDAR, single- and multi-beam sonar soundings, and existing integrated maps collated from multiple sources. It is possible to calculate site-specific changes in land elevation from revisions and updates to DEM.
 - a. Content: Elevation data.
 - b. Update frequency: About every 10 years.

Alternative Data Sources

Alternative data sources will be used if the primary data sources become unavailable or are insufficient. Alternative data sources can be used concurrently with the primary data sources as a reference or as supplemental information. For this performance measure, the alternative data sources focus on subsidence reversal project implementation that could technically occur independent of the state interests described above, but it is not likely.

1. University of California research programs. UC Berkeley monitors greenhouse gas fluxes on rice and wetlands, and establishes baselines for typical farming practices. UC Davis is researching carbon stock, agronomy effects, and economics of rice management for carbon sequestration.
 - a. Content: Research results and published references.
 - b. Update frequency: Variable.

Process

Data Collection and Assessment

Every year, Council staff will update the status of this performance measure by:

1. Reviewing the listed primary data sources, and if necessary, contacting the responsible agencies for clarifications on project status.
2. Compiling relevant data and comparing for changes from previous years.
3. Reviewing locations of subsidence reversal projects to assess if they are located on islands listed in this measure (Figure 1 and Appendix 2). Projects on other islands not included in this metric, may be reported under PM 5.2 “Subsidence Reversal and Carbon Sequestration.”
4. Calculating annual acreage of subsidence reversal projects showing a comparison over time, and gathering information about vertical elevation changes if available.
5. Displaying project locations on a map.
6. Disclosing alternative or additional data sources used by including them on the [Performance Measures Dashboard](#).

Every five years through 2050, Council staff will update the status of this performance measure by:

- The Council will review subsidence reversal project publications, reports, and presentations related to project performance for site-specific accretion rates. Vertical land accretion rates will be reported as a long-term average.

Process Risks and Uncertainties

The four major uncertainties related to this measure are the dependence on Delta levees, the sustainability of accretion rates, rates of sea level rise, and timely and comprehensive project reporting.

Delta Levees

Projects below water elevation are dependent on the ongoing maintenance of levees. If a subsided island were to experience levee failures prior to achieving intertidal elevations, and the island was not recovered, it would likely add limited ecological value to native species in the system (Durand 2017). Many islands that may be targets for subsidence reversal are at risk of levee failure (Bates and Lund 2013). While subsidence reversal would decrease the likelihood of levee failures, this remains a persistent risk in the system for subsidence reversal.

Sustainability of Accretion Rates

The identified target of 4 cm/yr of newly accreted elevations is based on a historical statistic. On Twitchell Island, early results for a subsidence reversal project showed that 4 cm/yr was possible (Miller et al. 2008). However, the authors of that report, and subsequent research, indicates that newly accreted organic soils are less dense, and as more soil accretes, the soils compress. This indicates that a long-term accretion rate of 4 cm/yr is unlikely without management adjustments that increase accretion rates—such adjustments are being explored. Metal-based coagulants sometimes used in waste water treatment are being explored as a method for capturing more organic material as soil. Early results from a research project in the Delta indicate that applying polyaluminum chloride could increase short-term accretion rates to 6 cm/yr (Stumpner et al. 2018). The authors of the study, however, note that these new soils are less dense, and may be subject to greater compression, making 6 cm/yr an unlikely long-term vertical accretion rate.

Sea Level Rise

Sea level rise forecasting carries significant uncertainty. The range of sea level rise at San Francisco Bay—recommended for planners to consider by the Ocean Protection Commission—is between 1.6 feet and 10.2 feet through 2100 (OPC 2018, p. 18). For the landscape model, the median sea level rise projection of 2.5 feet was chosen for the high-emission scenario. The Delta, and especially the eastern parts of the Delta where

the least-subsided islands are located, is inland from the San Francisco Bay, its likely impacts from sea level rise will be experienced at a lower rate. If sea level rise occurs more slowly than the median projection, and effects these areas less than projected, this analysis may have ultimately excluded locations capable of reaching intertidal elevation through subsidence reversal. However, if sea level rise occurs more quickly than projections indicate, the analysis may have included areas unlikely to achieve intertidal elevations given the assumptions of the model. This uncertainty is managed two ways. The first way is by aggregating the sub-island scale analysis of appropriate locations to the Island scale. A more rapid rate of sea level rise may lead to a lesser portion of the Island reaching intertidal elevations, but unless there is rapid sea level rise much of the island may still be suitable for future intertidal reconnection. The second way this uncertainty is managed is by offering a short-term target with an acreage target capable of being accomplished via a small number of projects.

Project Reporting

For this performance measure, there is no single data source. Instead, tracking these metrics will require Council staff to stay aware of projects implemented in the Delta. These sources will be tracked at least annually on a recurring basis, but may be updated more frequently as Council staff become aware of projects. Any subsidence reversal project implemented by a state or local agency in the Delta is likely to be subject to Council's early consultation process for potential covered actions, determining consistency with the Delta Plan. However, Council staff will review the identified sources for information on projects.

Reporting

Annually, Council staff will report the status of this performance measure by:

1. Posting annual updates on the [Performance Measures Dashboard](#)
2. Using the Council annual report published in January on the following year
3. Communicating management-relevant results at Council and Delta Plan Interagency Implementation Committee (DPIIC) public meetings
4. Presenting findings at technical interagency groups, professional gatherings, and conferences.

Every five years, Council staff will assess and report the status of this performance measure by:

1. Communicate findings in the five-year review of the Delta Plan
2. Informing Council's adaptive management and other relevant decision making

References

- Bates, M.E., and J.R. Lund. 2013. Delta Subsidence Reversal, Levee Failure, and Aquatic Habitat—a Cautionary Tale. *San Francisco Estuary and Watershed Science*, 11(1).
- California Ocean Protection Council (OPC). 2018. State of California Sea Level Rise Guidance 2018 update. Available at: www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf
- Delta Stewardship Council (Council). 2019. Ecosystem Amendment Appendix 2. *Public Review Draft*.
- _____. 2018. Climate Change and the Delta: A Synthesis. *Public Review Draft*.
- Deverel, S.J., et al. 2016. Present-day oxidative subsidence of organic soils and mitigation in the Sacramento-San Joaquin Delta, California, USA. *Hydrogeology Journal*. 24:569-586. doi:10.1007/s10040-016-1391-1. Available at: www.ncbi.nlm.nih.gov/pmc/articles/PMC4944668
- Durand, J.R. 2017. Evaluating the Aquatic Habitat Potential of Flooded Polders in the Sacramento-San Joaquin Delta. *San Francisco Estuary and Watershed Science*, 15(4). Available at: www.escholarship.org/uc/item/6xg3s6v0
- Miller, R.L., et al. 2008. Subsidence Reversal in a Re-established Wetland in the Sacramento-San Joaquin Delta, California, USA. Available at: <https://escholarship.org/uc/item/5j76502x>
- Moyle, P.B., A.D. Manfree, P.L. Fiedler, Editors. 2016. *Suisun Marsh: Ecological History and Possible Futures*. University of California, Berkeley UP.
- San Francisco Estuary Institute-Aquatic Science Center (SFEI-ASC). 2016. A Delta Renewed: A Guide to Science-Based Ecological Restoration in the Sacramento-San Joaquin Delta. Prepared for the California Department of Fish and Wildlife and Ecosystem Restoration Program. A Report of SFEI-ASC's Resilient Landscapes Program, Publication #799, San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA.
- Shuford, W.D., and K.E. Dybala. 2017. Conservation Objectives for Wintering and Breeding Waterbirds in California's Central Valley. *San Francisco Estuary and Watershed Science*, 15(1). Available at: www.escholarship.org/uc/item/5tp5m718

- Shuford, W.D., et al. 2019. The Relative Importance of Agricultural and Wetland Habitats to Waterbirds in the Sacramento–San Joaquin River Delta of California. *San Francisco Estuary and Watershed Science*, 17(1). Available at: www.escholarship.org/uc/item/25f0d6b4
- Smith, K.R., et al. 2018. Toward Salt Marsh Harvest Mouse Recovery: A Review. *San Francisco Estuary and Watershed Science*, 16(2). Available at: www.escholarship.org/uc/item/2w06369x
- Tolentino, K. 2017. Legal Delta and Suisun Marsh DEM. Update to Wang, R. & Ateljevich, E. 2012. California Department of Water Resources, Delta Levees Office.
- Wang, R., and E. Ateljevich. 2012. A Continuous Surface Elevation Map for Modeling (Chapter 6). In Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Mars, 23rd Annual Progress Report to the State Water Resources Control Board. California Department of Water Resources, Bay-Delta Office, Delta Modeling Section.

Appendix 1: Detailed Methods

2020-2030 Elevation Change Formula

The formula below is the set of intertidal elevations that meet the condition of being within the difference between current intertidal elevation and intertidal elevation 10 years from now (see Figure 1 for an illustrated explanation of the methods). These methods are applied to a 200 m-cell size raster grid covering the Legal Delta and Suisun Marsh.

$$IT = (IT_1 \cup IT_{10}) - IT_{10}$$

The acreage area of ***IT*** is an estimate of the number of acres at intertidal elevations today that will not be intertidal after 10 years.

The intertidal zone for the first year (***IT*₁**) is defined using the following formula:

$$IT_1 = MHHW > E < MLLW$$

Where ***E*** is elevation at each pixel in the Delta and Suisun Marsh DEM (Tolentino 2017) which was aggregated to 200m².

MLLW is tidal datum for mean lower low water levels (Ecosystem Amendment Appendix 1).

MHHW is tidal datum for mean higher high water levels (Ecosystem Amendment Appendix 1).

The intertidal zone (IT_{10}) for the tenth year is defined using the following formula:

$$IT_{10} = MHHW > E - \Delta SLR + \Delta ES > MLLW$$

ΔSLR is the expected sea level rise. This analysis assumes a linear sea level rise of 2.6 feet by 2100, with a predicted Golden Gate sea level rise for 50th percentile in RCP 8.5 emission scenario. Only sea level rise over the next 10 years was taken into account.

ΔES is the change in elevation from subsidence within 10 years. For each pixel in the DEM the rate of change is given by the subsidence rates estimated in Deverel et al. (2016) based on organic soil composition.

The target for acres was calculated by comparing intertidal zone at IT_1 to IT_{10} . The area of the intertidal zones that was in IT_1 but not IT_{10} was calculated. In the Legal Delta, that area was about 3,500 acres. In Suisun Marsh, the area was about 3,000 acres.

Target Methods – Locations Where Ongoing Subsidence Reversal Activities can Reach Intertidal Elevations by 2100

The **subsidence reversal zone** was calculated using the following formula (see Appendix 2 for an illustration of the methods), assuming a beginning date of 2020 and end date of 2100. The formula produces the band of elevation where ongoing subsidence reversal techniques would accrete land to reach intertidal elevations and prevent the net loss of opportunities to restore tidal wetlands to benefit the ecosystem. This analysis assumes that subsidence reversal activity would be halted once the landscape reaches intertidal elevations.

This was calculated using this given equation:

$$SRT = (MLLW > E) \cup (E - \Delta SLR + \Delta E)$$

SRT is the subsidence reversal target zone. It is areas at intertidal elevation by 2100, given subsidence reversal is used during that period to increase elevations.

Where **E** is elevation based on the and Suisun Marsh DEM (Tolentino 2017) which was aggregated to 200m².

MLLW is tidal datum for mean lower low water levels (Ecosystem Amendment Appendix 1).

MHHW is tidal datum for mean higher high water levels (Ecosystem Amendment Appendix 1).

ΔSLR is expected sea level rise. This analysis assumes a sea level rise of 2.6 feet by 2100, with a predicted Golden Gate sea level rise for 50th percentile in RCP 8.5 emission scenario.

ΔE is the change in elevation from subsidence reversal by 2100. The mapped band is based on rates of sediment accretion of 4 cm/yr from Miller et al. 2008.

The target locations identify areas where continued subsidence reversal at 4 cm/yr sediment accretion rate could reach intertidal elevations by 2100. (Figure 2).

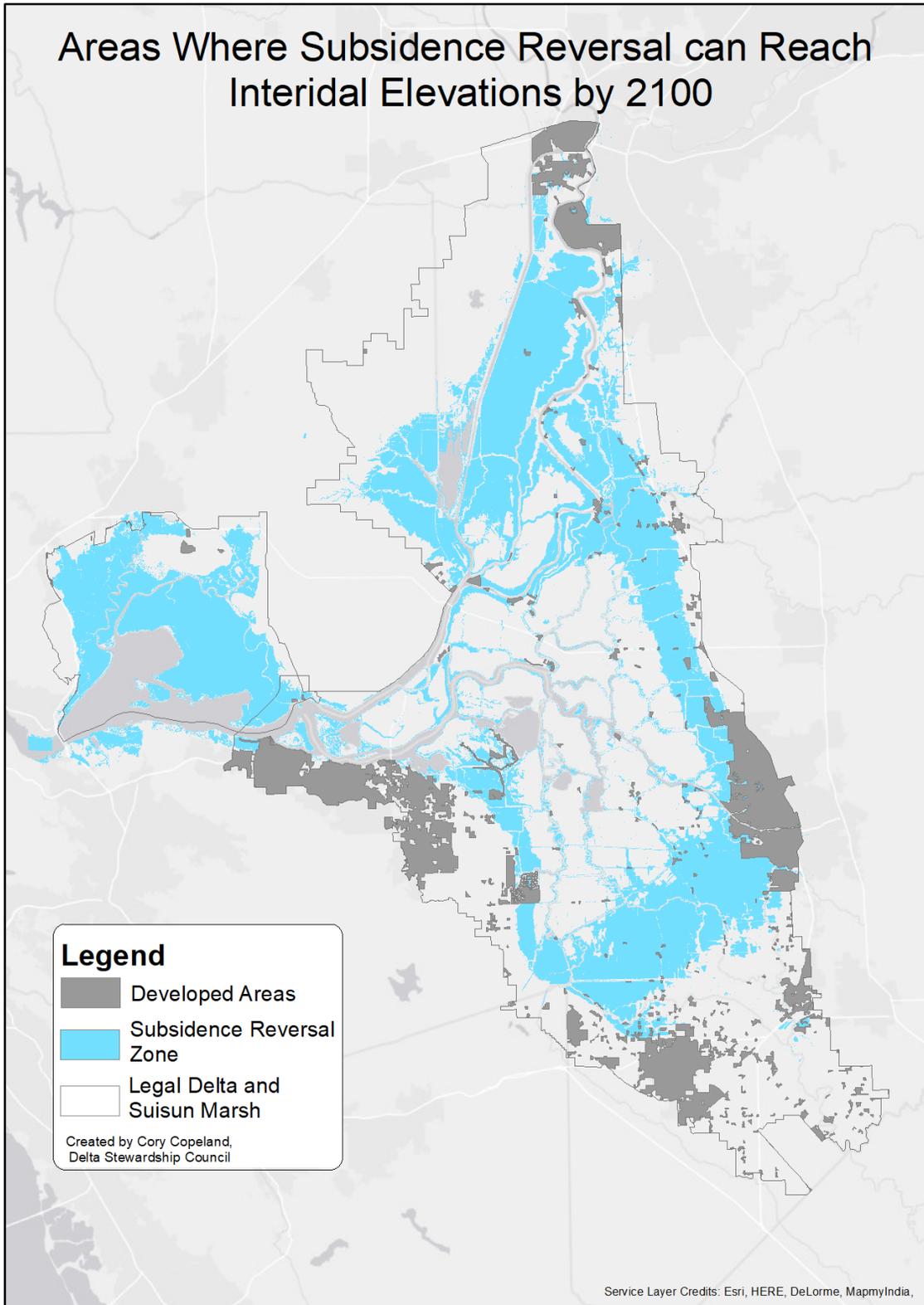


Figure 2. Areas Where Subsidence Reversal Activities, Ongoing from 2030 to 2100, Can Produce Intertidal Elevations by 2100

Figure 2. Areas Where Subsidence Reversal Activities, Ongoing from 2030 to 2100, Can Produce Intertidal Elevations by 2100 (contd.)

Within the boundaries of Suisun Marsh and the Legal Delta, which are drawn as solid gray lines, this map illustrates the subsidence reversal zone. The map shows: Developed Areas in solid gray and the Subsidence Reversal Zone in solid blue. The subsidence reversal zone consists of the areas in the Legal Delta and Suisun Marsh (at a 200-meter resolution) that, according to the elevation model used in this performance measure (described in Appendix 1) could reach intertidal elevations through subsidence reversal by 2100.

The subsidence reversal zone covers most of Suisun Marsh and Cache Slough. Concentrated areas in the north Delta, between the Sacramento Deep Water Ship Channel and the Sacramento River, and in the South Delta, north of Tracy and Lathrop, are within the subsidence reversal zone. A band of land surrounding the central Delta is also included in the subsidence reversal zone. Most of the central Delta is not included in the subsidence reversal zone, except for very small and scattered patches of land along the sloughs and rivers. There is minimal land within the subsidence reversal zone at edges of the Suisun Marsh and Legal Delta, where land is above the tidal range. Please contact the Delta Stewardship Council with any questions regarding this figure.

This map shows all of the areas in the Delta that are presently at intertidal and shallow subtidal elevations. If subsidence reversal activities are implemented by 2030 in these locations, and these activities continue to accrete land elevation, these areas will increase and maintain the intertidal elevation by 2100. The year 2100 serves as a conservative cutoff. Although there are uncertainties, if the best available science indicates that an area cannot reach intertidal by at least 2100, assuming the conservative assumptions built into the model, then the land is likely too deeply subsided to achieve intertidal elevations through subsidence reversal alone. Developed areas are shown on the map for illustrative purposes.

Appendix 2: Islands at Appropriate Locations

List of islands at appropriate locations to reach elevations that would support potential intertidal restoration by 2100:

DREXLER POCKET
 HONKER LAKE TRACT
 BRACK TRACT
 GRAND ISLAND
 TERMINOUS TRACT
 MERRITT ISLAND
 TYLER ISLAND
 PEARSON DISTRICT
 SUTTER ISLAND
 SHIN KEE TRACT
 BISHOP TRACT
 LITTLE EGBERT TRACT
 EHRHEARDT CLUB
 RYER ISLAND
 UPPER ANDRUS ISLAND
 DEAD HORSE ISLAND
 FAY ISLAND
 FABIAN TRACT
 SHIMA TRACT
 SMITH TRACT (LINCOLN VILLAGE)
 BYRON TRACT
 LISBON DISTRICT
 CACHE HAAS AREA
 RIO BLANCO TRACT
 DREXLER TRACT
 WRIGHT-ELMWOOD TRACT
 NEW HOPE TRACT
 CANAL RANCH TRACT
 HOTCHKISS TRACT
 WINTER ISLAND
 ATLAS TRACT
 EGBERT TRACT
 NETHERLANDS
 PROSPECT ISLAND
 GLANVILLE
 MCCORMACK-WILLIAMSON TRACT
 MAINTENANCE AREA 9
 DLIS-11

DLIS-20 (YOLO BYPASS)
 CHIPPS ISLAND
 MEIN'S LANDING
 DLIS-26 (MORROW ISLAND)
 DLIS-63 (GRIZZLY ISLAND AREA)
 DLIS-48
 SUNRISE CLUB
 DLIS-52
 HONKER BAY
 DLIS-62
 DLIS-40
 DLIS-41 (JOICE ISLAND AREA)
 CHIPPS ISLAND SOUTH
 DLIS-55
 DLIS-47
 DLIS-46
 DLIS-30
 DLIS-36
 DLIS-25
 DLIS-28
 DLIS-29
 DLIS-39
 DLIS-31 (GARABALDI UNIT)
 DLIS-32
 DLIS-33
 DLIS-44 (HILL SLOUGH UNIT)
 DLIS-37 (CHADBOURNE AREA)
 DLIS-5
 DLIS-49
 DLIS-50
 UNION ISLAND EAST
 UNION ISLAND WEST
 MIDDLE ROBERTS ISLAND
 LOWER ROBERTS ISLAND
 VEALE TRACT
 HASTINGS TRACT

Island identifications are those used in the Delta Levee Investment Strategy.

For Further Assistance

For further assistance interpreting the content of this document, please contact Delta Stewardship Council staff.

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