Performance Measure 4.12: Subsidence Reversal for Tidal Reconnection

Performance Measure (PM) Component Attributes

Type: Output Performance Measure

Description

Subsidence reversal[1] activities are located at shallow subtidal elevations to prevent net loss of future opportunities to restore intertidal wetlands through tidal reconnection 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. Tracking will continue until a project is tidally reconnected.

Baseline

1. In 2019, zero acres of subsidence reversal on islands with large areas at shallow subtidal elevations.
2. Soils in the Delta are subsiding at a rate of between 0 cm/year and 1.8 cm/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 at least 1,235 acres at shallow subtidal elevations.
2. For each project, an average elevation accretion of at least 4 centimeters per year until the project is tidally reconnected.

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 (Council 2018). In addition to sea level rise, most of the land in the Delta is subsiding due to microbial oxidation and areas in the central Delta are already below sea level (Deverel et al. 2016). The areas at subtidal elevations offer limited ecological value if reconnected to a stream because species native to the Delta are not well adapted to lake-like deep water habitats (Durand 2017). Only a thin band of land is at appropriate elevations suitable for tidal restoration through hydrologic reconnection (Delta Plan, Appendix Q2) 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 historic subsidence, and maintain or increase land elevation. Recovering lost land will also preserve the opportunities for tidal reconnection. Subsidence reversal activities in locations with current shallow subtidal elevations could recover land for tidal restoration and prevent further losses

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

from sea level rise. To recover tidal restoration opportunities, islands identified in this performance measure should initiate subsidence reversal projects by at least 2030, and then continue long-term until the land reaches the desired intertidal elevation—becoming available for tidal reconnection and subsequent tidal wetland restoration.

The Council's landscape model (see Methods section below) indicates that from 2008 to 2019 (the decade following the passage of the Delta Reform Act of 2009), the Delta and Suisun Marsh lost 3,500 acres and 3,000 acres of land, respectively, at intertidal elevations due to subsidence and sea level rise. By initiating subsidence reversal activities on 3,500 Delta acres and 3,000 acres in Suisun Marsh, land that was once at intertidal elevations can be recovered, and subsequently, maintaining opportunities for future tidal reconnection and restoration. 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 multibenefit projects that support native species and natural communities. Subsidence reversal projects that are managed wetlands 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. PM 5.2 has a target of 30,000 acres of subsidence reversal and carbon sequestration in the Delta to be achieved by 2030. Managed wetlands or rice production 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 on islands with shallow subtidal elevations, whereas PM 5.2 tracks both shallow and deeply subsided areas. Shallow subtidal elevations have a reasonable chance of achieving intertidal elevations through subsidence reversal in the timeframe from 2020 to about 2100, preventing the net loss of future opportunities to restore tidal wetlands. Deeply subsided areas may need more than 80 years to be restored to intertidal elevations making such projects unlikely to result in intertidal habitat within a planning horizon of 2100.

Relationship to the Performance Measure Acres of Natural Communities Restored Performance Measure (PM 4.16)

The performance measure PM 4.16, “Acres of Natural Communities Restored Performance Measure” targets the creation of 32,500 acres of tidal wetlands. Actions that support the landscape potential for tidal wetland restoration will also support the achievement of that target. If the target is achieved, this performance measure would result in 6,500 acres of wetlands tidally reconnected to the system in Suisun Marsh and the Delta. The 6,500 acres suitable for tidal restoration that would result from successful achievement of this performance measure (PM 4.12) target would account for 20 percent of the PM 4.16 target acreage. However, depending on the location and subsidence rates, some of the acreage tracked by this performance measure may not be suitable for reconnection by the 2050 target of PM 4.16.

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 (2009 to 2019) of modeled elevation change (see methods section below), 3,500 acres are estimated to have been lost in the Delta and 3,000 acres in Suisun Marsh since the passage of the Delta Reform Act. 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 recovers 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

Subsidence Reversal Activity

This performance measure tracks "subsidence reversal activity." Subsidence reversal is a process that both halts subsidence caused by organic soil oxidation and leads to increases in land elevation through accumulation of new soil material. Subsidence reversal results in land elevations that are higher than land elevations prior to subsidence reversal; the process does not necessarily result in land elevations at or above mean sea level, however, because this depends on the initial elevation and the rate of subsidence reversal over time. Examples of subsidence reversal management actions include, but are not limited to, increasing land elevation by accreting organic material in managed wetlands, and placement of fill and levee breaching to reestablish hydrological connection with a river or bay.

For the purposes of this performance measure, subsidence reversal activity is defined as projects that include landscape interventions that increased land elevation in nontidally connected locations whose elevations are below nearby water levels. There are two common forms of subsidence reversal in the Delta. The first form is vegetation-based, in which managed wetlands (Miller et al. 2008), or a rice and wetland mosaic landscape (Deverel et al. 2017) are used to accrete organic material on an area that increases elevation. The other form of subsidence reversal is through the application of sediment on a landscape. For example, prior to tidal reconnection elevations in areas of the Montezuma Wetlands had dredge material deposited on them to raise their elevations. Due to limited availability of dredge spoils and other sediment, this form of subsidence reversal is likely to be less common and more limited in its geographic scope.

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 subsidence rates for soils in the Delta of between 0 cm/year and 1.8 cm/year are based on soil composition models from subsidence rates (Deverel et al. 2016).

Target Methods

Acres of Intertidal Land Lost Since the Delta Reform Act

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). Because the DEM was produced based on (mostly) conditions on the ground in 2008 (Tolentino 2017), the baseline is 2008 and the analysis tracks intertidal elevation loss of the following ten years. 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 lost following the passage of the Delta Reform Act.

The land loss is calculated for ten years based on the Tolentino (2017) DEM, most of which is based on 2008 LiDAR survey, because at the time of development of the model it was the best available data. Projected sea level rise and subsidence indicate that more intertidal land could be lost if action is not taken.

Implementation by 2030

The target date for project implementation is for 2030 because rates of sea level rise and subsidence reversal 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 a 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 Delta Plan, Appendix Q2 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.

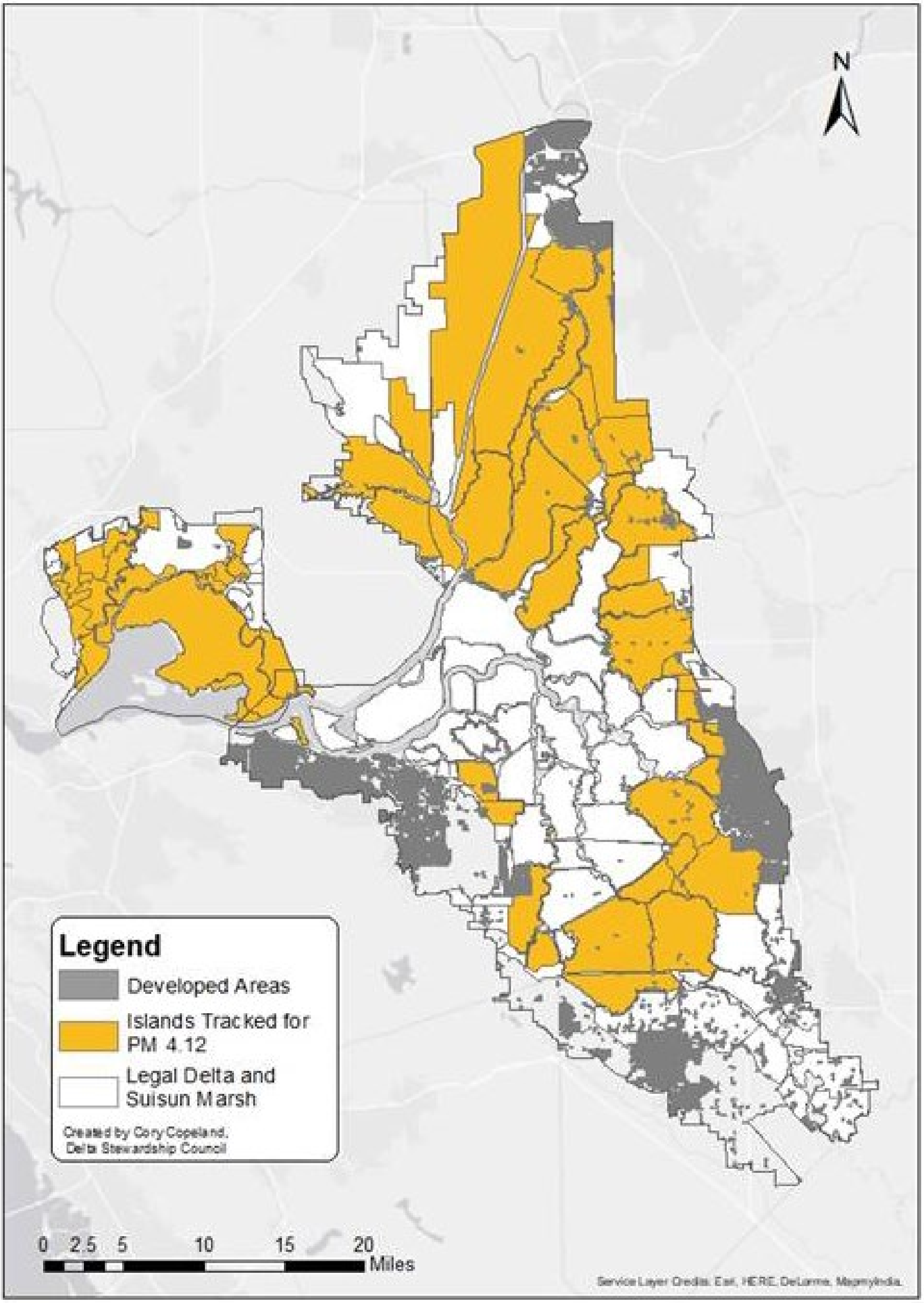

Figure 1. Islands Tracked in this Performance Measure

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

This map shows the areas where subsidence reversal activities ongoing through 2100 can produce intertidal elevations on or before 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. 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 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 2 of this document.

Alternative formats of this map are available upon request.

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. San Francisco Estuary Institute (SFEI) Project Tracker. The SFEI project tracker is a tool that supports regional tracking of restoration projects. Restoration

projects, including subsidence reversal projects created for the purpose of future intertidal reconnection are anticipated to be tracked on Project Tracker.

   a. Content: Project monitoring region wide.
   b. Update frequency: As projects are implemented.

3. DWR. This agency 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.
4. 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.
5. California Department of Fish and Wildlife Wetlands Restoration for Greenhouse Gas Reduction Program. Uses Cap-and-Trade money to fund greenhouse gas reduction of 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.
6. 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.
7. 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, Council staff will update the status of this performance measure by:

- Reviewing 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.
- Reviewing projects to determine if they reached intertidal elevations and have become tidally connected. Once that occurs, staff will no longer track vertical accretion in that project.

Process Risks and Uncertainties

The four major risks 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. As a part of the Council's adaptive management process, staff will regularly review uncertainties related to the amount of sea level rise, effects of sea level rise, rates of subsidence, subsidence reversal rates, elevations, and project implementation (Table 1).

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; therefore, such adjustments are being explored. Metal-based coagulants sometimes used in wastewater 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 study, however, notes 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 0.49 meters (1.6 feet) and 3.1 meters (10.2 feet) through 2100 (OPC 2018, p. 18). For the landscape model, the median sea level rise projection of 0.76 meters (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; therefore, likely impacts from sea level rise in the Delta will be experienced at a lower rate. If sea level rise occurs more slowly than the median projection, and affects 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 subisland 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 capable of being accomplished by means 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. Subsidence reversal projects implemented by a state or local agency in the Delta are likely to be subject to Council's process for potential covered actions to determine consistency with the Delta Plan. However, Council staff will review the identified sources for information on projects.

Reporting

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

1. Posting updates on the Performance Measures Dashboard.

2. Providing results in Council's annual report (published in January).
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. Communicating findings in the five-year review of the Delta Plan.
2. Informing the Council's adaptive management process and other decision-making.
3. Council staff will evaluate six key uncertainties (shown in Table 1) related to the amount of anticipated sea level rise, the heterogeneity of its effects, and the rates of subsidence in the Delta to determine the trigger for reassessment of targets or metrics for this performance measure.

Table 1. Key Uncertainties for Effectiveness Assessment Review

Key Uncertainty	Assumption Made	Trigger for Reassessment
Amount of sea level rise	2.5 feet of sea level rise	Sea level rise occurs faster or slower than projected
Effects of sea level rise	Uniform effects	Improved information on spatially heterogeneous effects of sea level rise in the Delta and Suisun Marsh
Rates of subsidence	Rates occur based on soil composition consistently over time	Improved models or empirical subsidence data that significantly improves estimates
Subsidence reversal rates	4 centimeters per year	Rates change due to site-specific characteristics or new management technologies.
Elevations	Elevations from Tolentino 2017 DEM	Significant change in understanding of Delta landscape elevations.
Project implementation	Projects implemented soon after the adoption of the ecosystem amendment.	If projects are planned but not implemented soon after the adoption of the ecosystem amendment, the appropriate areas may need to be re-evaluated for new implementation scenarios.

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Appendix 1: Detailed Methods

Past 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 Delta and Suisun Marsh.

$$IT = (IT1 \cup IT10) - IT10$$

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:

$$IT1 = MHHW > E < MLLW$$

Where ***E*** is elevation based on the Delta and Suisun Marsh DEM (Tolentino 2017) which was aggregated to $200m^2$. The DEM was aggregated due to computational limitation. Running the landscape model for multiple scenarios on the aggregated DEM required large live memory resources that dramatically slowed the processing. The aggregation to $200m^2$ improved processing. It was determined that local conditions at a smaller scale likely would better suited for a site specific analysis conducted by a project proponent rather than a landscape level analysis. The aggregation level of $200m^2$ was chosen because it is discrete enough to be smaller than any reasonable project, but large enough ease any computational bottlenecks.

MLLW is tidal datum for mean lower low water levels.

MHHW is tidal datum for mean higher high water levels.

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

$$IT10 = MHHW > E - \Delta SLR + \Delta ES > MLLW$$

ΔSLR is the expected sea level rise. This analysis assumes a linear sea level rise of 0.76 meters (2.5 feet) 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 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 Delta and Suisun Marsh DEM (Tolentino 2017) which was aggregated to $200m^2$. The DEM was aggregated due to computational limitation. Running the landscape model for multiple scenarios on the aggregated DEM required large live memory resources that dramatically slowed the processing. The aggregation to $200m^2$ improved processing. It was determined that local conditions at a smaller scale likely would better suited for a site-specific analysis conducted by a project proponent rather than a landscape level analysis. The aggregation level of $200m^2$ was chosen because it is discrete enough to be smaller than any reasonable project, but large enough ease any computational bottlenecks.

MLLW is tidal datum for mean lower low water levels.

MHHW is tidal datum for mean higher high water levels.

ΔSLR is expected sea level rise. This analysis assumes a sea level rise of 0.76 meters (2.5 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).

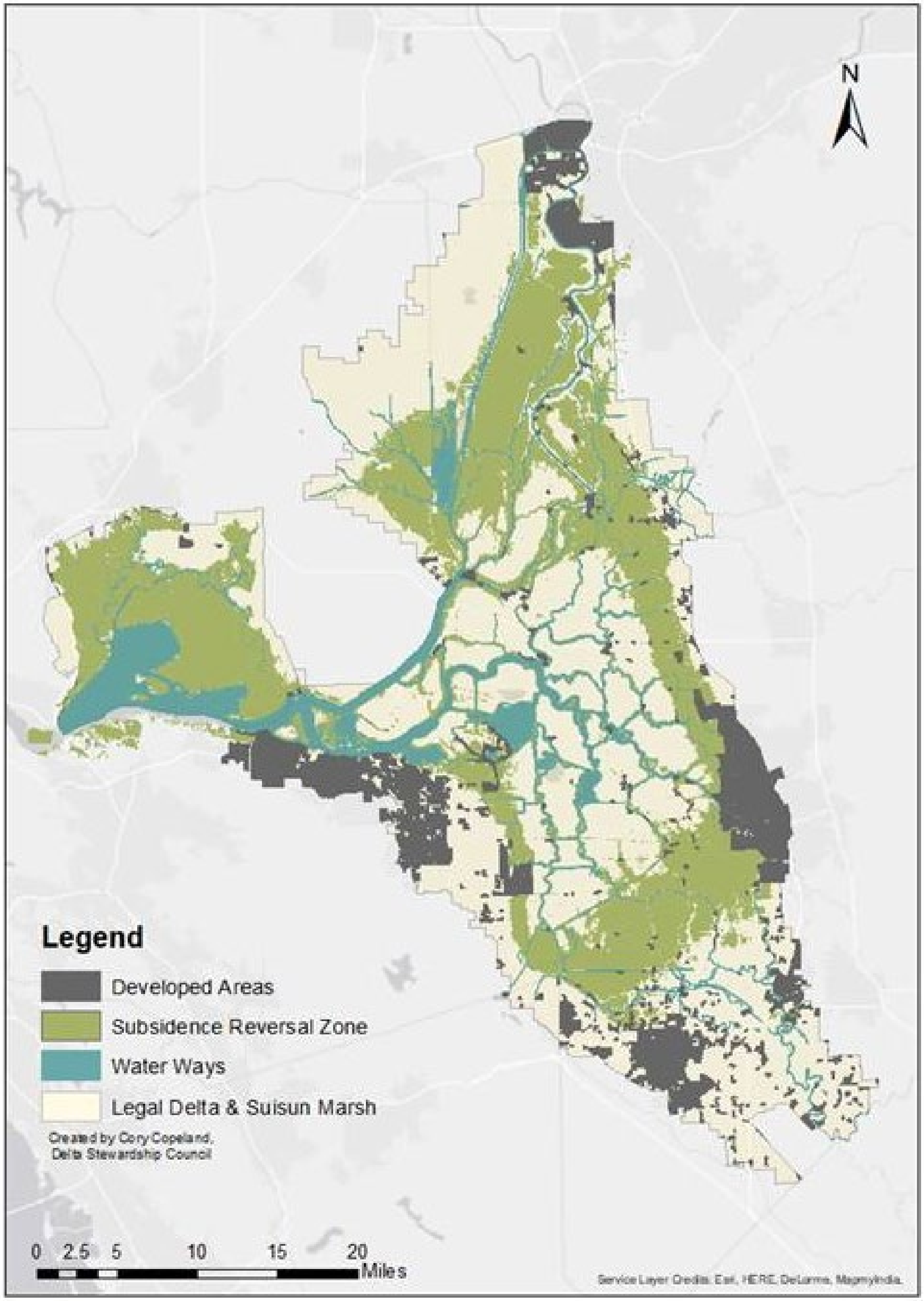

Figure 2. Areas Where Subsidence Reversal Activities, Ongoing from 2030 to 2100, Can Produce Intertidal Elevations by 2100

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 Delta, which are drawn as solid gray lines with a solid tan fill, this map illustrates the subsidence reversal zone. The subsidence reversal zone consists of the areas in the 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 Delta, where land is above the tidal range.

Alternative formats of this map are available upon request.

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, and these activities continue to accrete land elevation, these areas will reach intertidal elevation by 2100 or sooner. 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 Assistance

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

accessibility@deltacouncil.ca.gov

Phone: 916-445-5511