Performance Measure 4.15: Seasonal Inundation

Performance Measure (PM) Component Attributes

Type: Outcome Performance Measure

Description

Restoring land-water connections to increase hydrologic connectivity and seasonal floodplain inundation.

Expectations

Increased hydrologic surface water connectivity and increased frequency of seasonal inundation contributes to achieving a healthy Delta ecosystem and viable populations of native species.

Metric

Acres within the Sacramento-San Joaquin Delta and Suisun Marsh that are:

1. Hydrologically connected to fluvial and tidally influenced waterways.
2. A nontidal floodplain[1] area that inundates[2] at least once every two years.

Metric will be evaluated annually.

Baseline

As of the year 2018:

1. An estimated 75,000 acres of land physically connected to the fluvial river and tidal system.

[1] Area that is inundated on a two-year recurrence frequency and is connected via surface water to the fluvial river or tidal system.
[2] There is no depth threshold for the inundation analysis, as inundation occurs at any depth. While depth of inundation is important for ecological processes, the available data do not include depth measurements.

2. Approximately 15,000 acres of the connected land inundated at a two-year interval, calculated as a long-term average for 1985-2018.

Target

By 2050:

1. Additional 51,000 acres added to the 75,000-acre baseline that are physically connected to the fluvial river and tidal system, for a total of 126,000 acres.
2. At least an additional 19,000 acres of nontidal floodplain area is inundated on a two-year recurrence interval, for a total of 34,000 acres.

Basis for Selection

Since the 1800s, 91 percent of historical wetland habitat in California has been lost (Dahl 1990), including 95 percent of Central Valley floodplain habitat (Opperman et al. 2010, Whipple et al. 2012). In the Delta, most of these wetlands and floodplains have been drained and converted to agricultural land use (SFEI-ASC 2014). Although most of the natural wetlands no longer remain, some agricultural land, floodways, and floodplains can provide similar functions, including greatly increased aquatic food production and transfer of nutrients to the fluvial system compared to other converted land uses (Moyle and Mount 2007, Corline et al. 2017, Katz et al. 2017). However, in order for these functions to be maintained or restored, areas must be hydrologically connected via surface water, and inundated for at least part of the year (Sommer et al. 2001a, Jeffres et al. 2008, Opperman et al. 2010, Katz et al. 2017).

The ecological health of the Delta is fundamentally dependent on the reestablishment of more natural inundation patterns and land-water connections. It is expected that increased area and frequency of floodplain inundation will result in enhanced primary productivity, an improved food web and flow of nutrients that better support a healthy and functioning ecosystem (Ahearn et al. 2006, Cloern et al. 2016). Floodplain inundation occurs when rivers or waterways exceed their channel capacity and flow onto adjacent lands. In the Delta, this most often occurs during winter and spring months.

Restoration of land-water connections to provide the biological benefits of floodplain inundation requires two components: 1) physical or hydraulic surface water connectivity for water to flow onto land; and 2) sufficient flow of water to inundate these connected areas (Merenlender and Matella 2013).

Connectivity

Surface water connectivity between areas of fresh and saline water, riverine, riparian, floodplain, and other aquatic and terrestrial transitions is critical for the health and productivity of aquatic ecosystems (Opperman 2012, SFEI-ASC 2014, Cloern et al. 2016, SFEI-ASC 2016). The aquatic food web benefits from an exchange between land and water habitats (Polis et al. 1997, Ahearn et al. 2006, Opperman et al. 2010). However, transformation of the Delta from its mid-1800s condition has also increased connectivity of some waterways in manners that may negatively affect ecosystem functions, such as through construction of water conveyance structures and channels that cross the Delta (Whipple et al. 2012). In some areas, limiting connectivity of waterways from such structures could improve ecosystem function (SFEI-ASC 2016). For example, closure of the Delta Cross Channel leaves additional flow in the mainstem Sacramento River and helps prevent entrainment of native fish species such as migration juvenile Chinook salmon.

The connectivity metric in this performance measure tracks the landscape in which physical dynamics, supported by geomorphic land-water interaction, can take place. This interaction requires two components: 1) physical or hydraulic connectivity that allows water to flow onto land; and 2) sufficient flow of water to inundate these connected areas (Merenlender and Matella 2013). Within the Delta, the terrestrial system has been largely disconnected from fluvial and tidal connectivity, even during periods of high flows. Restoring physical connectivity to the fluvial river and tidal system can help restore ecosystem processes and support many native species.

It should also be noted that hydrologic connectivity through surface waters can include more than floodplain areas. This is especially true in the Suisun Marsh and areas of the greater San Francisco Estuary. At this time this performance measure does not include areas such as riparian zones, because the focus is more on aquatic ecosystem functions in areas that can be inundated for extended periods and also due to limited habitat types within the Delta itself outside of floodplains or floodways. However, this could be explored further in the future, for example, by assessing the riparian area and upland transition zones, especially in Suisun Marsh (Goals Project 2015, Appendix E). While areas that function as riparian or intermittent floodplain are important, most of this habitat type is upstream or downstream of the Delta, where levees heavily constrain riparian function.

Inundation

Seasonal nontidal floodplain inundation is critical for providing a range of ecosystem benefits such as freeing and transformation of nutrients, increasing primary productivity, and creation of habitat that can serve as a migratory pathway, rearing habitat, and refuge for juvenile salmonids (Junk et al. 1989, Sommer et al. 2001b). Such areas promote wetland ecosystem functions and are a high-value area for rearing and spawning of fish species such as Sacramento splittail and Chinook salmon, leading to increased survival rates. Food production (phytoplankton and zooplankton biomass) requires sufficient duration of inundation to develop, thus food-web processes and habitat provision increase with duration of inundation (Sommer et al. 2001b, Moyle et al. 2008, Katz et al. 2017). Illustrative areas within or near the Delta include the Yolo Bypass, Sutter Bypass, agricultural and other vegetated lands that are regularly inundated, and areas of the Cosumnes River Preserve.

The hydrologically connected metric component tracks the area of land available to tidal and freshwater inundation, and the floodplain metric tracks nontidal, seasonal water surface area that inundates these connected areas.

Linkages to Delta Reform Act and the Coequal Goals

Delta Reform Act

The Delta Reform Act mandates that the Delta Plan include measures that promote specified characteristics of a healthy Delta ecosystem (Water Code section 85302(c)). Increased hydrologic connectivity and seasonal inundation of floodplains contribute to achieving “diverse and biologically appropriate habitats and ecosystem processes” (Water Code section 85302(c)(3)) and support “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 85803(c)(5)).

Native resident and migratory fish species rely on habitat connectivity and floodplain inundation for their life cycle and the ecosystem functions they provide, aligning with “Viable populations of native and resident and migratory species” (Water Code section 85302(c)(1)). Restored land-water connectivity will provide diverse habitats and ecosystem processes such as primary production and energy transfer which supports “diverse and biologically appropriate habitats and ecosystem processes” (Water Code section 85302(c)(3)).

Delta Plan Core Strategy

4.2 Restore Ecosystem Function

Methods

Baseline Methods

Connectivity

Council staff developed a hydrologically connected spatial dataset by combining data for levee locations (to identify in-channel areas), bypasses, and floodways. Levee locations were compiled from multiple levee data sources, and from aerial imagery. Levee data sources included the following data sets. Data is listed in priority of use, with items first on the list being used in place of items later in the list when there is spatial overlap:

1. **DWR 2012:** i7 Delta Levee Centerline Classifications. Available online.
2. **URS 2007:** Delta Vision. Draft dataset provided by DWR and compiled by the consulting firm Arcadis in 2014 as part of the Council's Delta Levee Investment Strategy (DLIS) process. Not available online. DLIS feature class name: *DeltaVision_Levee_Reach_by_Hydro*
3. **DWR and URS 2007:** Delta Risk Management Strategy (DRMS) – Developed for DWR by URS Corporation in 2007; last updated 2013. Version used compiled by the consulting firm Arcadis in 2014 as part of the DLIS process. Not publicly available. DLIS feature class name: *levee_delta_centerlines_DRMS*
4. **Groves et al. 2019:** Decision Support Tool for the San Francisco Bay-Delta Levees Investment Strategy. Available online.
5. **DWR 2015:** Nonproject Levees. Part of a database intended to assist public agencies in assessing public safety needs for areas protected by levees. Compiled by the consulting firm Arcadis in 2014 as part of the DLIS process. Not publicly available. feature class name: *DWR_Levees_AllRDs*

Using the software program ArcGIS (version 10.4.1), these data were merged and clipped to the boundaries of the Delta and Suisun Marsh. Council staff removed areas when satellite imagery (NAIP 2016) indicated that the areas were unconnected, for example, when located on the landside of a levee. The connected areas were then compared to Global Surface Water Extent (GSWE) data to confirm if at least part of the contiguous area had been inundated at any point within the last 30 years. The baseline was then calculated as the entire hydrologically connected area, regardless of the area actually inundated during this period.

The hydrologically-connected area currently does not capture several tidal marsh areas. If and as restoration projects create newly connected tidal marsh areas in the future, these areas could be added in the future, and the entire layer updated.

Inundation

To calculate the baseline, the 1984-2018 GSWE data (Pekel et al. 2016) was used to identify areas that were inundated at least once every two years, but not inundated all of the time (i.e., inundation recurrence between 50 and 90 percent). The inundation dataset (GSWE, recurrence layer) was clipped to hydrologically connected surface areas within the Delta (Liberty Island was removed because it is now open water). For the baseline period for inundation, this analysis identified approximately 15,000 acres of inundated area matching these criteria. However, this represents a long-term average over more than 20 years. In addition, much of this area can be found within channel margins (bounded by levees) and along riparian areas/levee-water interfaces and is not limited to floodplains. Due to this and other limitations with the currently available data (see below), the baseline was set at approximately 15,000 acres as of the year 2018. This baseline date was selected to align with the period of data availability.

There are some limitations associated with the GSWE data. First, recurrence is calculated as a percentage of time that water appears at the same location from year to year. This means that an area could show 100 percent recurrence even if it is dry for periods of the year, and would be excluded by the less than 90 percent filter used in this analysis. Second, the GWSE appears not to include valid observations for the months of November, December, and January and this could affect the accuracy of the data. Third, there is no depth threshold for the inundation analysis since the data sources do not include this information.

Target Methods

Connectivity

The connectivity target is based on quantitative goals provided in the 2016 Central Valley Flood Protection Plan (CVFPP) Conservation Strategy, Appendix H (DWR 2016a, pp. H-4-6 to H-4-8) which identified numeric floodplain and tidal marsh area targets. These targets were based on the area modeled to help recover spring and fall-run Chinook salmon to meet the Central Valley Project Improvement Act (CVPIA) of 1992 salmon doubling goal. The area modeled to achieve this goal is reported in the 2016 CVFPP Conservation Strategy, Appendices H (DWR 2016a) and L (DWR 2016b) as follows: 11,000 acres for the Sacramento River Basin, and 4,500 acres for the lower San Joaquin River Basin. Analysis for the CVFPP identified that on average, only 17 percent of floodplains are considered suitable for salmonid species (DWR 2016a). To account for this, the areas required were divided by 17 percent to generate 64,705 acres needed for the Sacramento River Basin and 26,471 acres for the San Joaquin River Basin. Council staff then scaled these areas by the relative proportion of the Conservation Planning Areas (CPA) for the CVFPP within the Delta and Suisun Marsh as determined by a spatial analysis: approximately 52 percent of the Lower Sacramento CPA and 67 percent of the Lower San Joaquin CPA fall within this area. Multiplying by these respective factors (see equations below) results in 33,647 acres in the Lower Sacramento CPA and 17,735 acres in the Lower San Joaquin CPA, for a sum of 51,382 acres of floodplain habitat (see below). After rounding, the connectivity target is set to 51,000 acres. Here are the equations to set the targets:

- Sacramento CPA: 64,705 acres x 52% = 33,647 acres
- San Joaquin CPA: 26,471 acres x 67% = 17,735 acres

In addition to the connectivity approach described above, connectivity considerations are also illustrated in Appendix Q3, Figures 4-3 and 4-5.

Inundation

The 2016 CVFPP Conservation Strategy (Appendix H, p. H3-H7) calculated the amount of new floodplain needed in the Sacramento and San Joaquin watersheds to support doubling salmon populations, and it suggested that floodplains should be inundated in two-year intervals to support salmon life cycles (DWR 2016a). To calculate the area required for inundation targets, the connectivity target of 51,000 acres was proportionally split into nontidal (fluvial) and tidal areas based on estimation of historical habitats. San Francisco Estuary Institute's (SFEI) historical ecology spatial data estimates 63 percent of the Delta as tidal, and 37 percent as nontidal (Whipple et al. 2012). Multiplying the nontidal estimate of 37 percent by the target of 51,000 acres of connectivity represents the floodplain inundation target of 19,000 acres (number rounded).

Data Sources

Primary Data Sources

The primary data sources listed below will be used for tracking this performance measure:

Connectivity

1. The Delta Stewardship Council Covered Actions Website. On-the-ground projects that restore surface water connectivity (such as levee breach, levee notch, weir modification, and tidal marsh restoration) 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 and supporting documentation provide details on project restoration activities and acres of land opened for hydrologic connectivity.
    b. Update Frequency: As covered actions are submitted and hydrologic connectivity is implemented.
2. San Francisco Estuary Institute (SFEI) Project Tracker. The Project Tracker is a tool that supports regional tracking of restoration projects and includes acres and locations of habitat types restored for hydrologic connectivity.
    a. Content: Project monitoring region wide.
    b. Update Frequency: As projects are implemented.

Inundation

1. GSWE from the European Commission Joint Research Center (JRC).
    a. Content: Global water surface areas (water extent, duration, and seasonality derived from remote sensing data).
    b. Update Frequency: Annually.

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 depending on best available science and the availability of the primary sources.

Connectivity

1. Two-dimensional hydrologic model and digital elevation model to identify the area that would physically allow fluvial or tidal surface water to flow onto land during events below the 1-in-100 recurrence interval flood flow, without pumping or modification of physical landforms. These areas may be dry in most conditions, but they could be hydrologically connected during high flows.

a. Content: Data to be developed based on two-dimensional hydrologic model (for example, SCHISM), high-resolution digital elevation model (based on 2017 or most up to date LiDAR-derived elevation).

b. Update Frequency: Updates are based on alternative methodology described above, when new elevation data or recurrence interval updates are available.

Inundation

1. Landsat Dynamic Surface Water Extent (DSWE) map. NASA makes available a Landsat-derived product that could be used to help monitor inundated surface water areas. Landsat satellite data has the longest historic record available and is anticipated to remain available far into the future with new satellite launches. However, because this is based on optical data it is affected by cloud cover and cloud shadow, making it less useful in winter months.

    a. Content: Estimate of surface water extent per pixel, derived from Landsat data and developed into interpreted layer of surface water extent.

    b. Update Frequency: Every 14 days; however, data may not be usable at this interval due to cloud cover.

2. National Aeronautics and Space Administration (NASA) and Indian Space Research Organisation (ISRO) Synethetic Aperature Radar (NiSAR) Mission. This mission will make active observations of surface water for at least three years, starting in early 2022. NiSAR data would help avoid an issue with the primary data source, where cloud cover affects imagery during periods of the year, limiting the ability to track inundation duration.

    a. Content: Data to be derived from imagery overlapping the Delta and Suisun Marsh.

    b. Update Frequency: Every 12 days.

3. European Space Agency SENTINEL Program. Sentinel-1 and Sentinel-2 platforms with combined overpass frequency of approximately every five days for a given location on Earth, including the Delta. Sentinel data would help avoid an issue with the primary data source, where cloud cover affects imagery during periods of the year. In addition, the update frequency of this dataset could allow for more accurate quantification of inundation duration. As part of this alternative, the duration of inundation (e.g., acre-days) could also be reported as supporting information.

    a. Content: Water surface extent, change, and seasonality derived from remote sensing data.

   b. Update Frequency: Approximately every five days. Sentinel water surface areas are anticipated to be incorporated into the base JRC GSWE data (Pekel 2019).

4. NASA Surface Water and Ocean Topography Mission (SWOT). Data from this mission should be available for at least three years after successful deployment and calibration, anticipated in 2022. The SWOT mission sensor includes the ability to measure water surface elevation. This means that it could be used to estimate water depth when used in conjunction with a known ground surface, such as LiDAR-derived terrain.
   a. Content: Water surface extent, elevation, change, and seasonality derived from remote sensing data.
   b. Update Frequency: Anticipate updates at a frequency equal to or better than 21 days.

Process

Data Collection and Analysis

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

Connectivity

1. Reviewing Council Covered Actions website for projects that restore hydrologic connectivity (tidal marsh and floodplain restoration), and if necessary, contact project manager for clarifications on project status (construction status).
2. Adding project locations to the connected-land dataset and calculate acres open to hydrologic surface water connectivity.
3. Calculating annual change in hydrologically connected areas. Acres connected will be then calculated as the entire hydrologically connected area, regardless of the area actually inundated during this period.
4. If alternative or additional data sources are used, these sources will be disclosed on the Performance Measures Dashboard.

Inundation

1. GSWE data for surface water extent occurrence (primary data) will be downloaded in GeoTIFF format at~98 feet resolution (30 meters) in October of each year.

2. Data will be clipped to the boundaries of the Delta and Suisun Marsh, and converted to a projected coordinate system.
3. Council staff will analyze GSWE data primarily on the Google Earth Engine platform. Surface water area will be analyzed to determine maximum water extent during each water year (October 1 to September 31) for areas inundated 50-90 percent of the year.

Interim Performance Assessment

In order to provide a short-term assessment of progress toward the inundation and connectivity targets, intermediate milestones are set for evaluation every decade. The interim milestones are established on an assumed linear progression towards the 2050 target date:

Metric	Baseline (acres)	Total Area (Baseline Acres Plus Net Increase)		
		2030	2040	2050
Hydrologic Tidal and Fluvial Connectivity	75,000	92,000	109,000	126,000
Nontidal Inundation	15,000	21,400	27,700	34,000

Although linear progression is presumed for setting interim milestones, many management and environmental uncertainties exist, such as climate change and frequency of drought in implementing restoration projects and achieving the target acres of inundation and connectivity. Interim assessments of the performance measure will consider the existing state of the restoration in the Delta and disclose conditions impacting the rate of restoration interim progress.

Process Risks and Uncertainties

Assessments of the performance measure and the evaluation of interim milestones will account for issues within and outside of management actions and the long-term periods required to implement large-scale, on-the-ground projects.

Restoration of land-water connections to increase the areas with hydrologic connectivity that allow for increase in seasonal inundation depends on:

- Activities and effects within human management control (e.g., breaching or notching levees).
- Effects outside management control (e.g., peak flood flows, near- and medium-term sea level rise).

While areas outside of direct management control must be considered, the opportunities for reaching the target acreage require a concerted focus on modifications to the physical geometry of the Delta and Suisun Marsh.

Five-year averages will be used as interim milestones. However, a linear trajectory of annual acreage increases may not be a reasonable expectation. Rather, long lead times of restoration projects may cause a nonlinear increase in restored areas based on type and size of restoration projects completed.

Reporting

Reporting of this performance measure will include maps of connected areas and seasonally inundated areas, together with project locations that restore hydrologic surface water connectivity. Restoration project details will be displayed (e.g., year of restoration, type of connectivity restoration, acreages).

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 the 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.

Five-year averages will be used as interim milestones for assessments towards the target over the 30-year time period of 2020-2050 (i.e., every five years, to increase connected land by 8,500 acres and inundated areas by 3,000 acres).

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