Nature-based Solutions for Nutrient Management – Applying the Adaptation Toolkit

State of the Estuary // Oct 28, 2025

BACWA BAY AREA CLEAN WATER AGENCIES

SFEI AQUATIC SCIENCE CENTER
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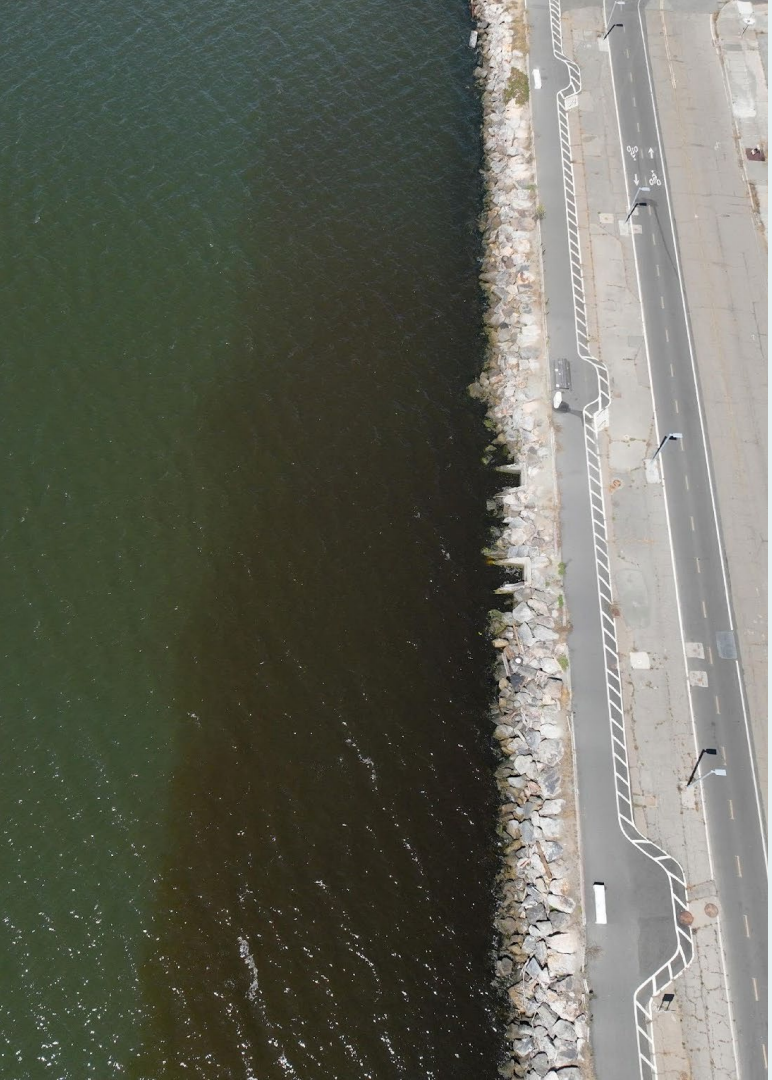


The Project

- Requirement of Provision VI.C of the 2019 Nutrient Watershed Permit
- Estimate nutrient reduction potential, on a regional scale, via treatment wetlands (open water & horizontal levees)
- Secondary objective to address barriers to implementation and encourage multi-agency coordination

The New York Times

Toxic Red Tide Kills 'Uncountable' Numbers of Fish in the Bay Area

A harmful algal bloom in the San Francisco Bay is killing fish, sharks and stingrays. Some are washing ashore.

Give this article

A harmful algal bloom in the San Francisco Bay Area has killed numerous fish, sharks and stingrays. Justin Sullivan/Getty Images

By Livia Albeck-Ripka

Aug. 30, 2022

A harmful algal bloom known as a red tide is killing off

New Urgency Post-2022

- 2022 harmful algae bloom of *Heterosigma akashiwo* killed an unknown number of white and green sturgeon, along others
- 2024 Nutrient Watershed permit requires a 40% Bay-wide reduction in total inorganic nitrogen loads from wastewater

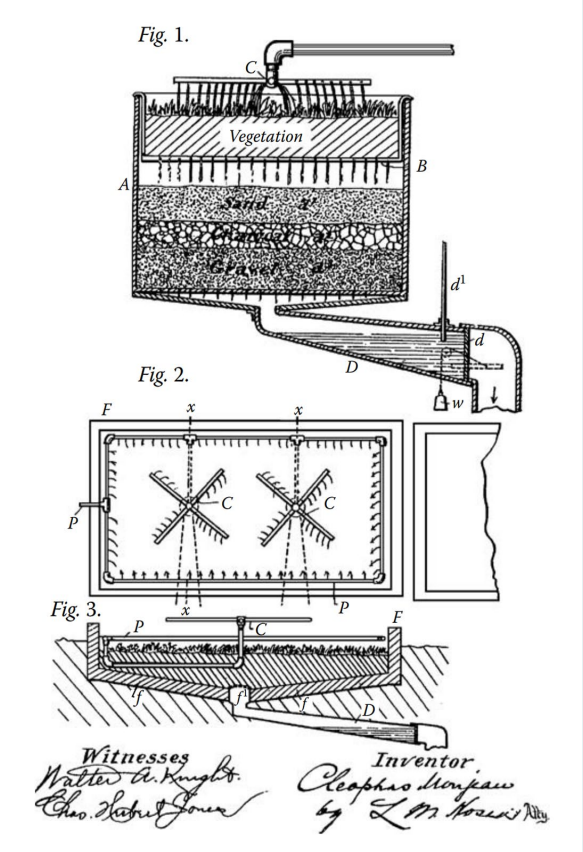
What are Nature-based Solutions?

Engineered interventions that exploit natural processes to foster urban resilience and sustainability.

- Variant of several definitions

Back to the Future

- Wastewater treatment is based upon natural systems and is constantly iterating



1901 U.S. patent for a treatment wetland system. (From U.S. Patent 681,884.) Courtesy Kadlec and Wallace 2009.

Drivers of Nature-based Solutions for Wastewater

1. **Sea level rise adaptation** - horizontal levees/living shorelines, tidal marsh restoration, oyster reefs,
2. **Reduction in nutrients & other pollutants**- horizontal levees/living shorelines, open water treatment wetlands, horizontal or vertical flow (subsurface) wetlands, floating wetlands
3. **Wet weather retention** - open water wetlands
4. **Recycled water & dry-weather discharge prohibitions** - land application & irrigation, ROC treatment

Horizontal Levees

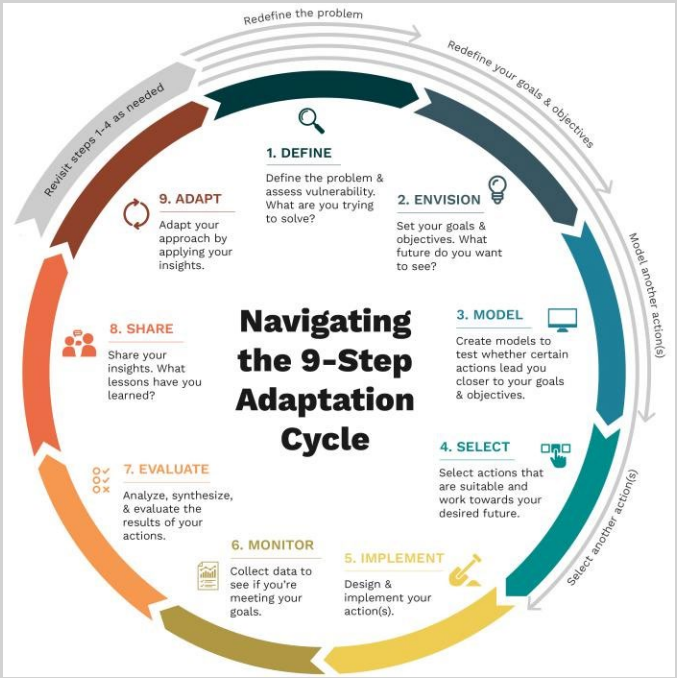
Oro Loma horizontal levee. Photo: SFEP

Open Water Wetlands

Photo: David Sedlak

Adaptation Toolkit - A framework for shoreline resilience

Evolution of the GreenPlanIT and Adaptation Atlas models to inform NbS for wastewater treatment + shoreline resilience



Adaptation Toolkit - A framework for shoreline resilience

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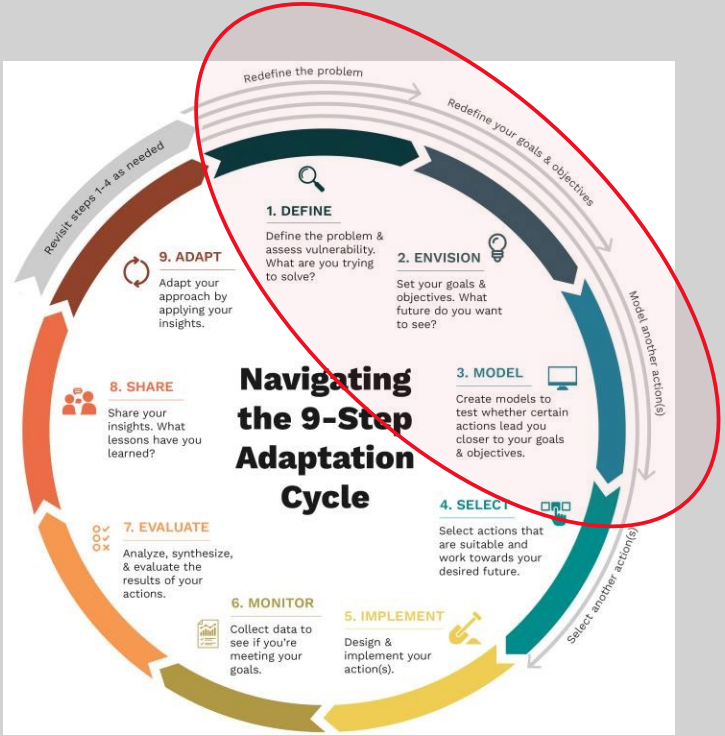
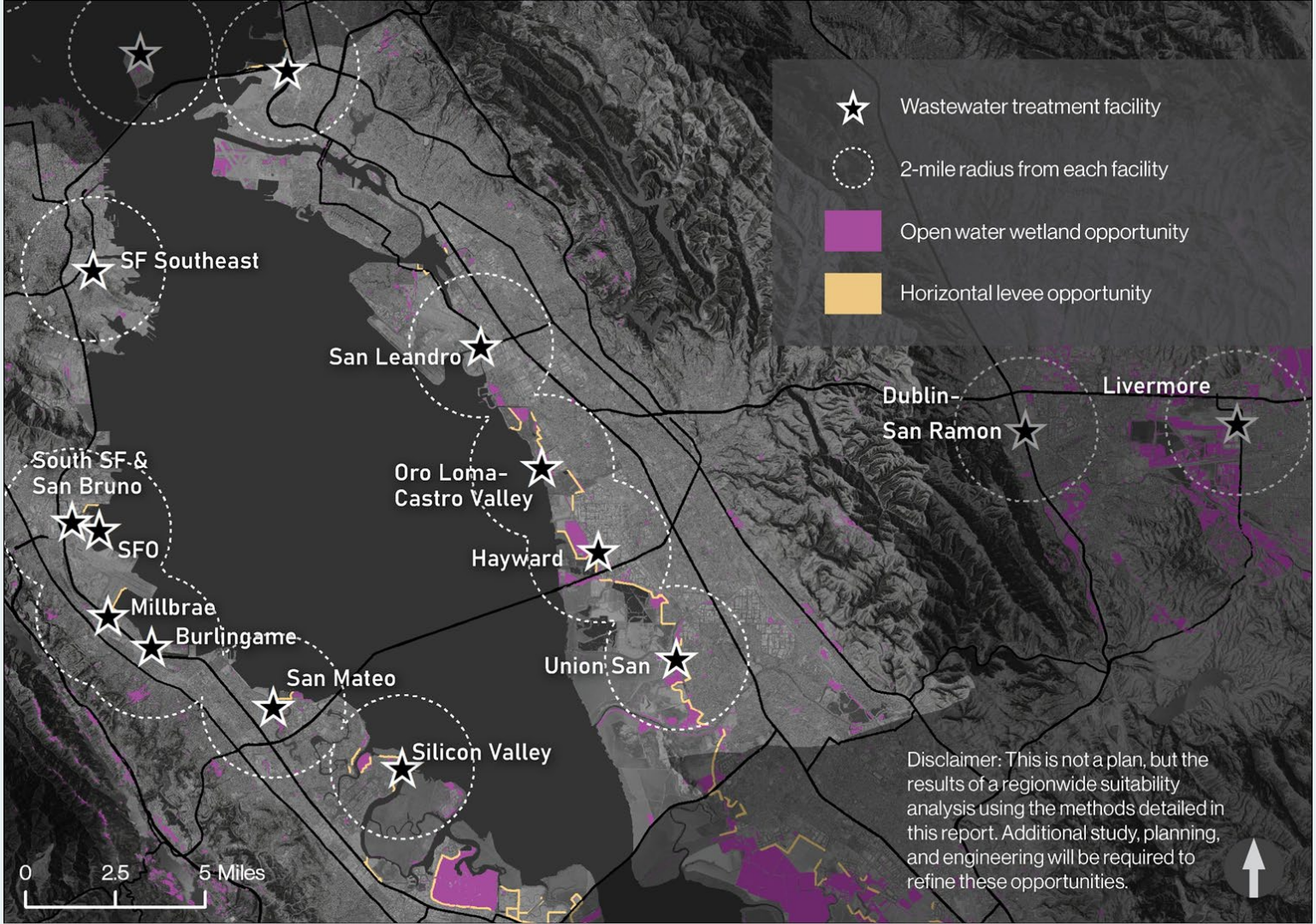


Desktop screening

GIS suitability analysis, including factors like:

- Land cover
- Elevation
- Slope
- Ownership
- Adjacency (e.g. to tidal marshes and development)


Wastewater treatment facility
2-mile radius from each facility
Open water wetland opportunity
Horizontal levee opportunity
SF Southeast
San Leandro
Dublin-
San Ramon
Livermore
South SF &
San Bruno
Oro Loma-
Castro Valley
SFO
Hayward
Millbrae
Burlingame
San Mateo
Union San
Silicon Valley
0
2.5
5 Miles
Disclaimer: This is not a plan, but the results of a regionwide suitability analysis using the methods detailed in this report. Additional study, planning, and engineering will be required to refine these opportunities.

CITY OF PALO ALTO

NATURE-BASED TREATMENT SOLUTIONS

The Palo Alto Wastewater Treatment Plant discharges nitrified effluent to Lower SF Bay. The facility serves a population of ~220,000 - with a dry weather permitted capacity of 39 mgd and average dry weather flow of ~20 mgd. The facility's existing 14-ac freshwater marsh receives treated effluent. Palo Alto has expressed interest in expanding NbS and recycled water deliveries to meet sustainability objectives.

Preliminary Findings

Several opportunities for both treatment types were identified, including some in close proximity to the Palo Alto facility. Together, the three highlighted open water wetland opportunities could reduce the nitrified TIN load by about 45%. The nearest horizontal levee opportunity could reduce TIN loads by about 19%.

Opportunities & Constraints

As a nitrifying facility with a high degree of future flood vulnerability, potential exists to partner on horizontal levees. Constraints include the adjacent airport, the dense urban landscape, and need for cooperation among diverse stakeholders and landowners. Lessons being learned through the current levee project will aid in future planning.

Photo courtesy of Google Earth

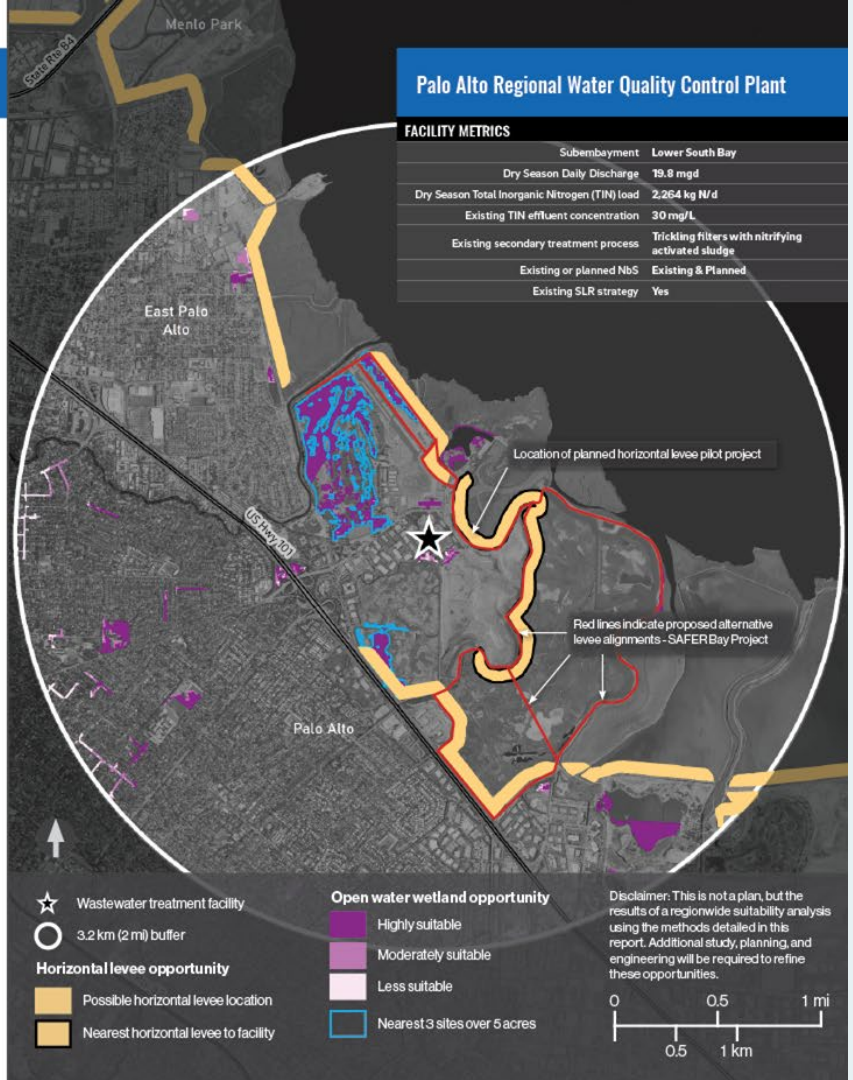
Refer to pages 14-15 for a key to interpreting the metrics in the following tables:

Overall suitability for nature-based treatment solutions	
Measure	**Suitability**
Open water wetlands	Moderate
Horizontal levees	High

Open water wetland opportunities	*open water wetlands on map*
Within 2 miles of facility	
Total Potentially Suitable Area	182 acres
Nearby sites over 5 acres (highlighted in blue on map)	
Potentially Suitable Area	8 - 111 acres
Total Potential Flow Capacity	0.7 - 9.9 mgd
Total TIN Reduction Potential	80 - 1,130 kg/day
Facility-Specific TIN Reduction	3% - 45%

Horizontal levee opportunities	*horizontal levees on map*
Potentially Suitable Length	3.3 - 12.8 km
Total Potential Flow Capacity	5.6 - 21.8 mgd
Total TIN Reduction Potential	430 - 1,660 kg/day
Facility-Specific TIN Reduction	19% - 73%

Site opportunities and constraints	
Consideration	**Relative Magnitude**
Excess Treatment Capacity	Moderate
Land Use/Regulatory Conflicts	High



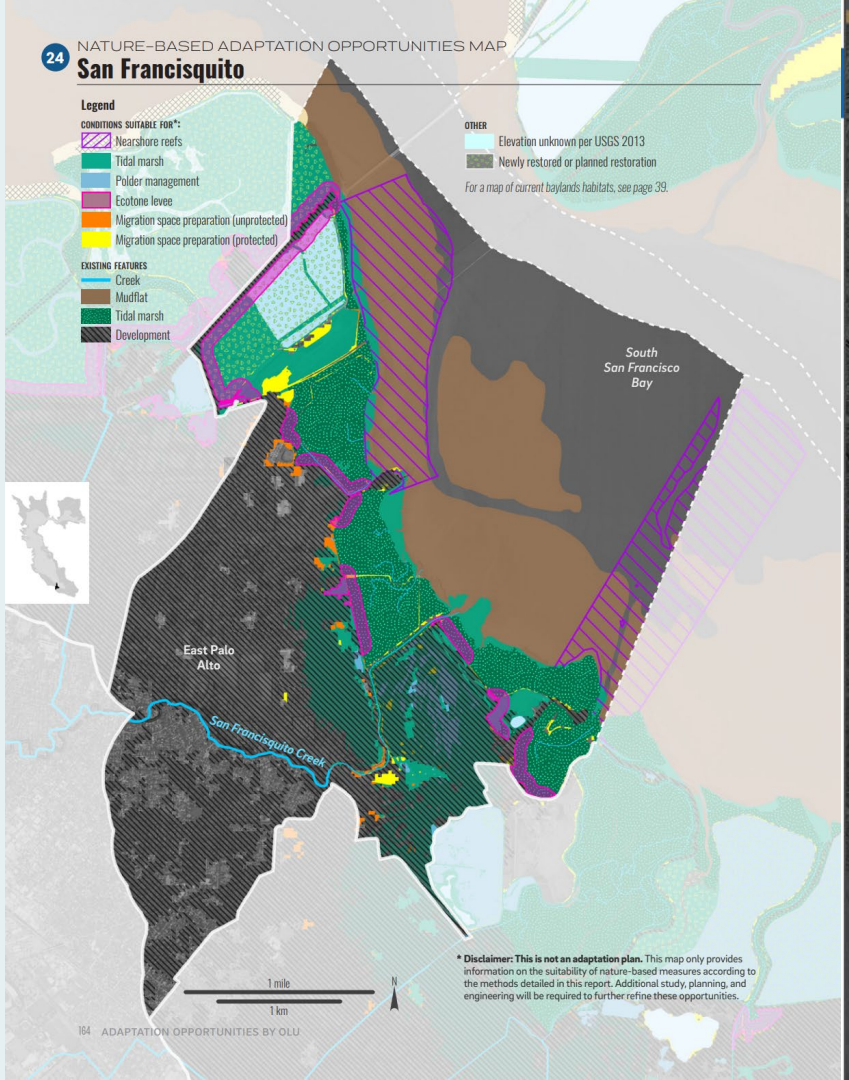
Palo Alto Regional Water Quality Control Plant

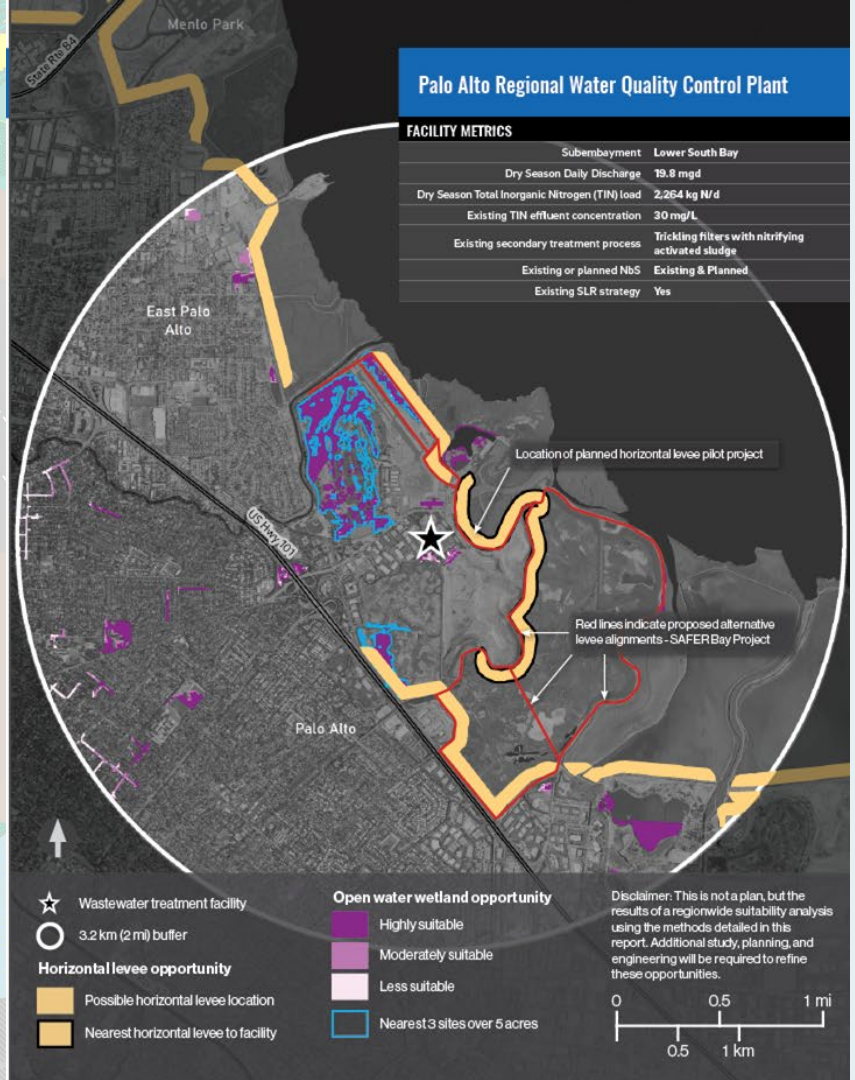
FACILITY METRICS

Subembayment	Lower South Bay
Dry Season Daily Discharge	19.8 mgd
Dry Season Total Inorganic Nitrogen (TIN) load	2,264 kg N/d
Existing TIN effluent concentration	30 mg/L
Existing secondary treatment process	Trickling filters with nitrifying activated sludge
Existing or planned NbS	Existing & Planned
Existing SLR strategy	Yes

24 NATURE-BASED ADAPTATION OPPORTUNITIES MAP

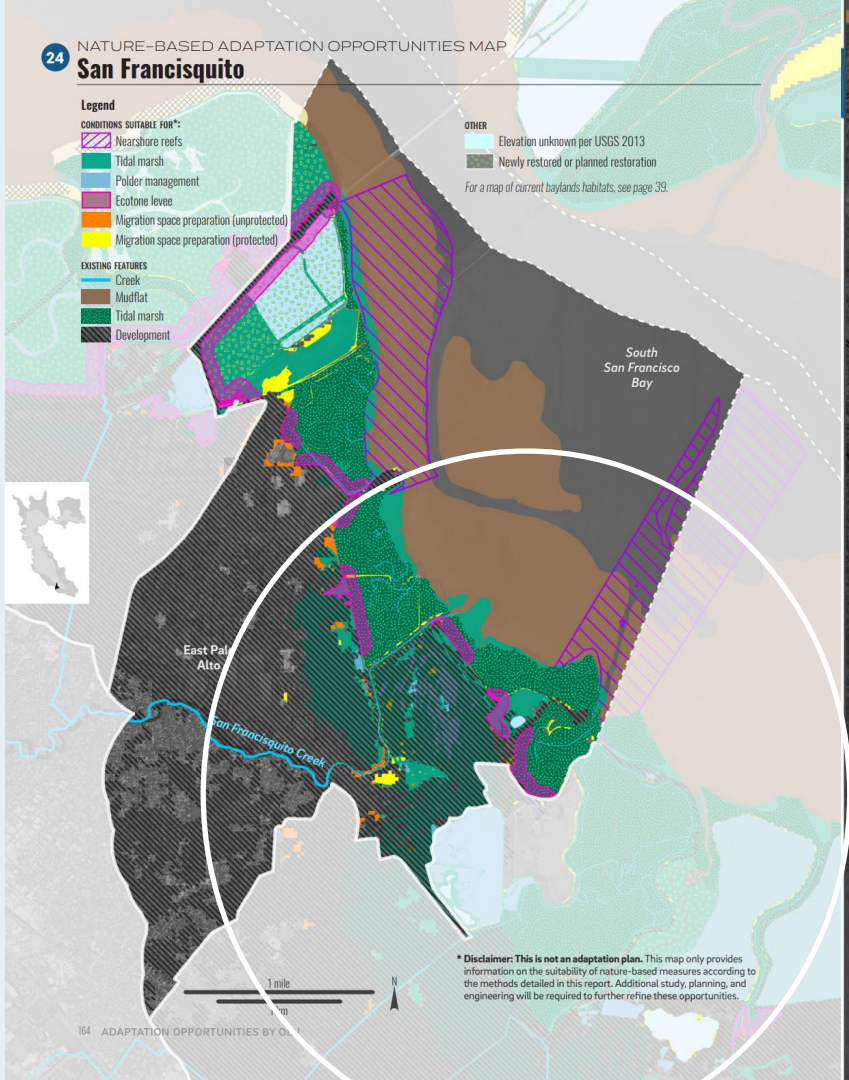
San Francisquito

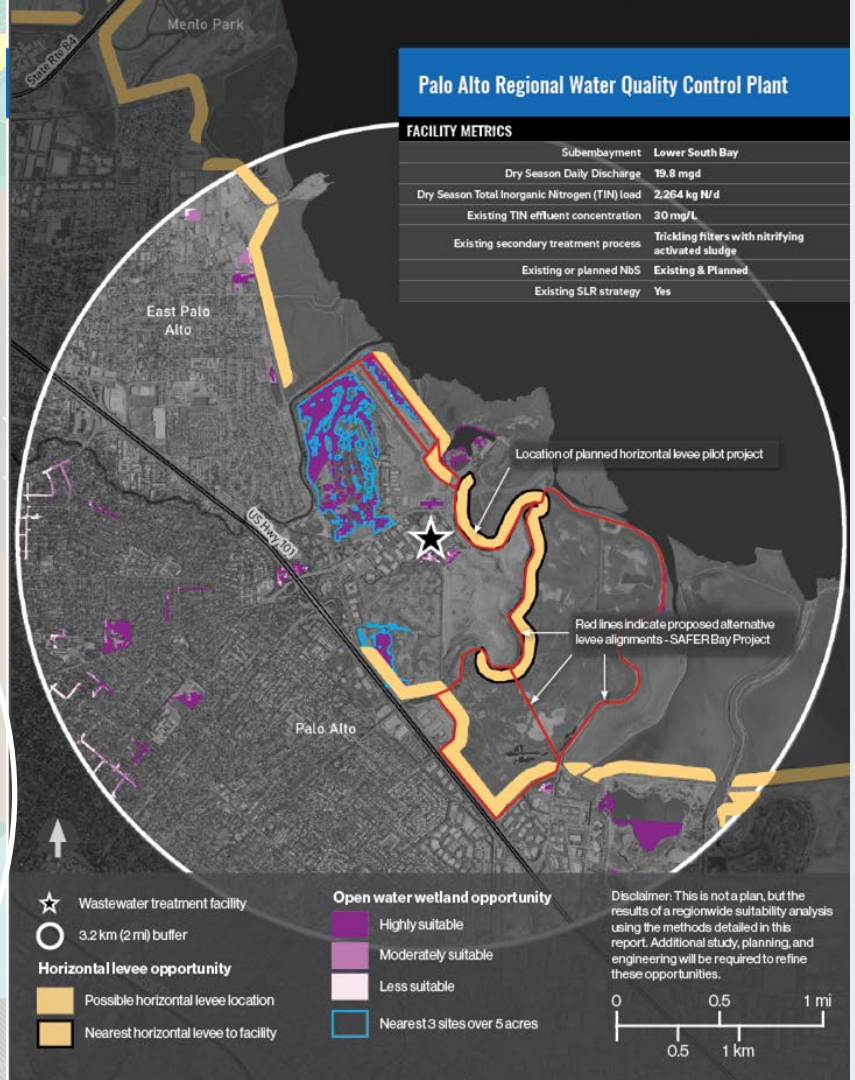




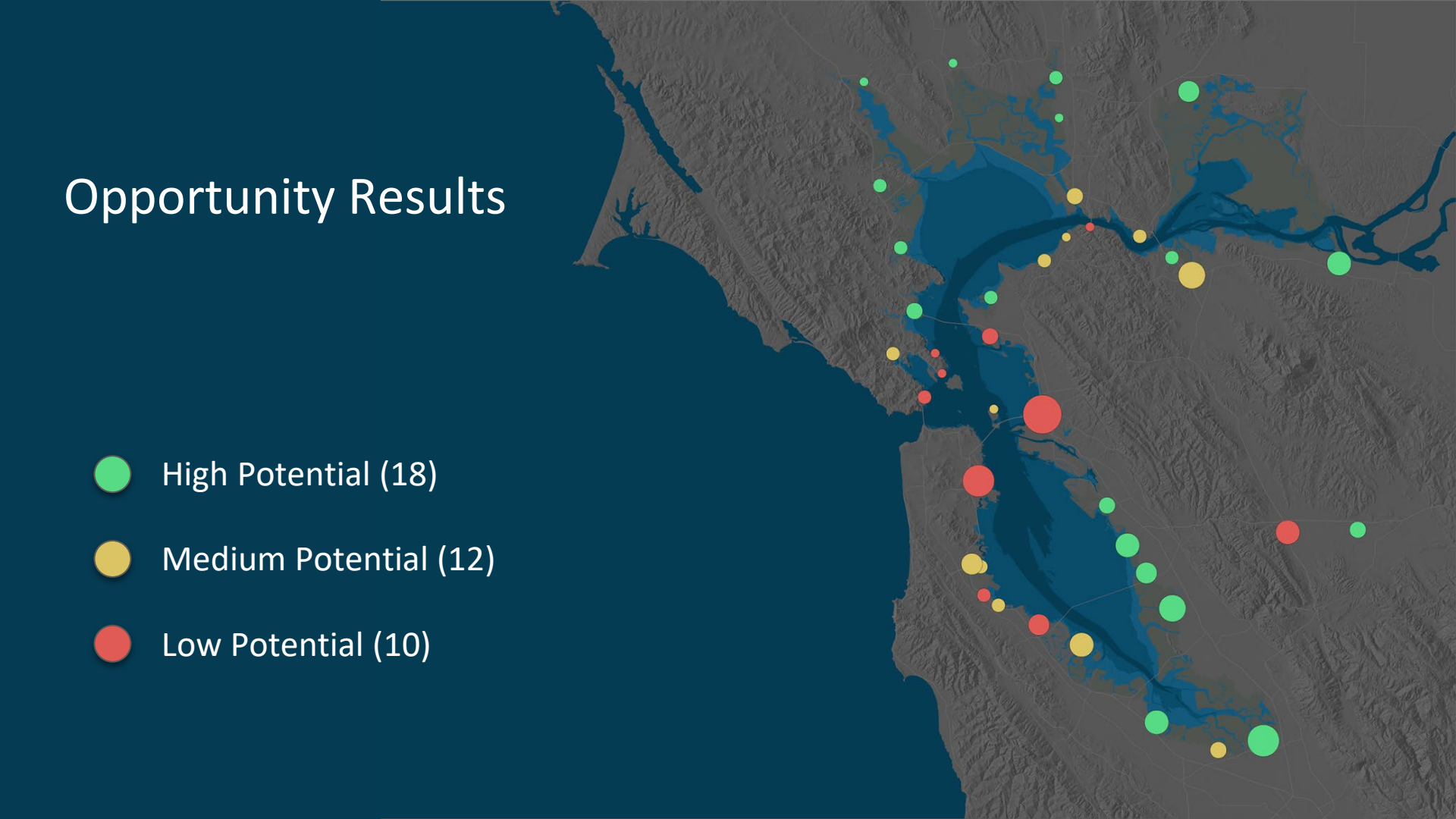
24 NATURE-BASED ADAPTATION OPPORTUNITIES MAP

San Francisquito

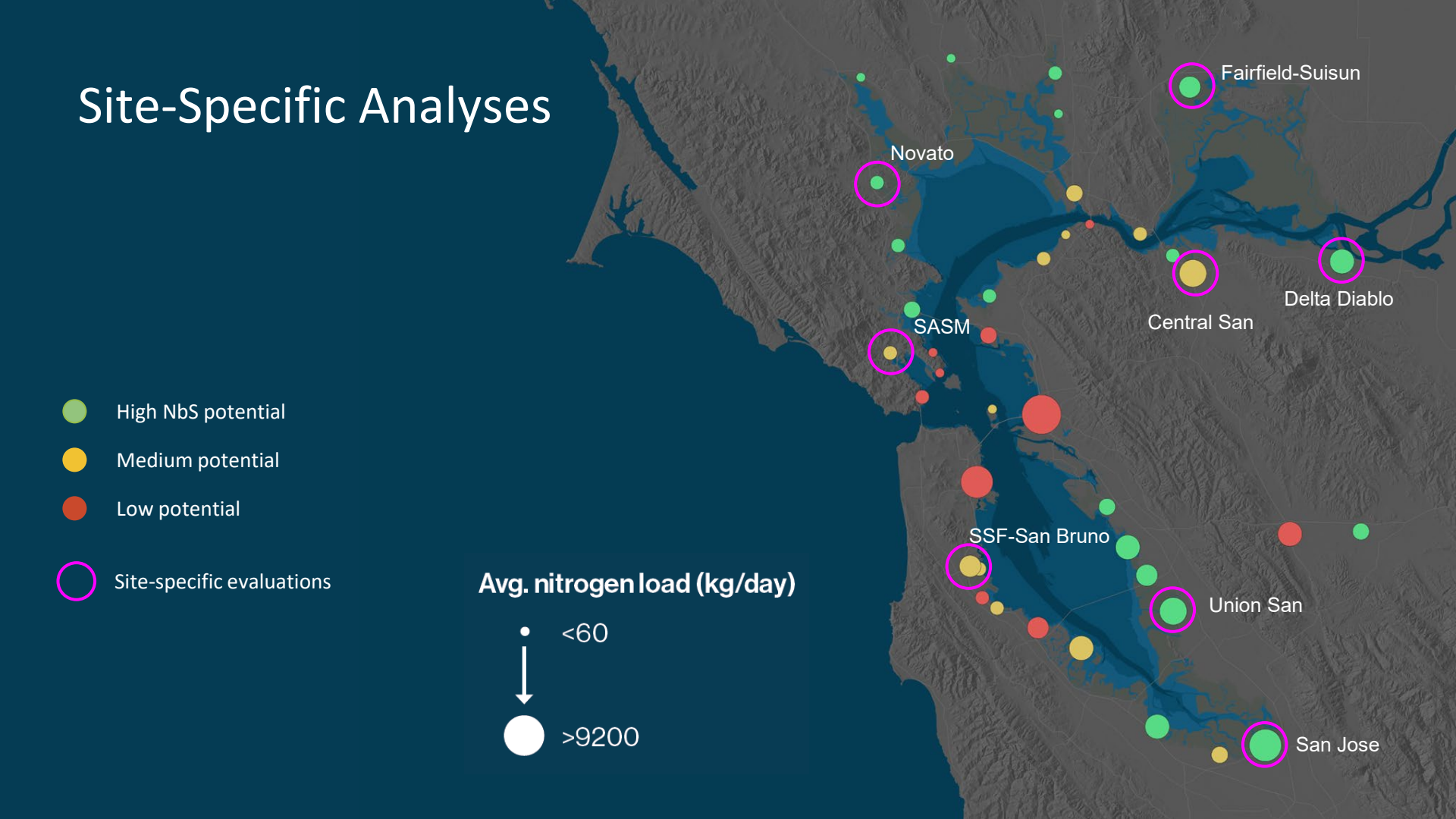




Opportunity Results

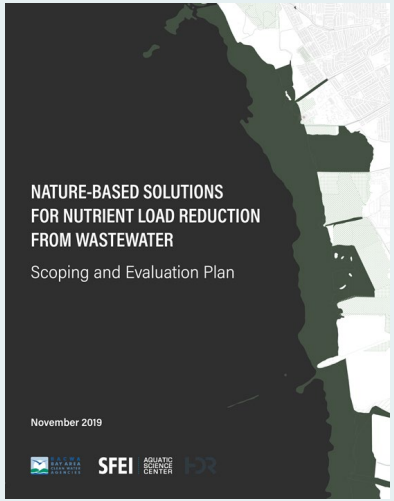


Site-Specific Analyses

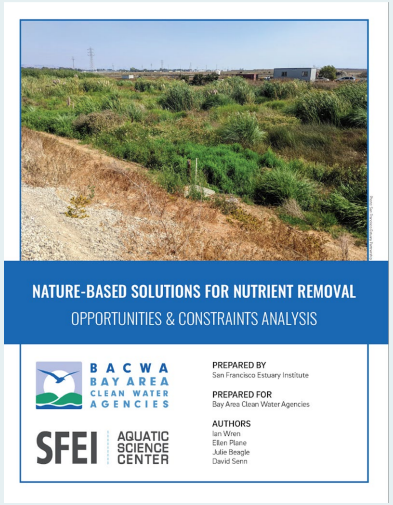


Phases of analysis

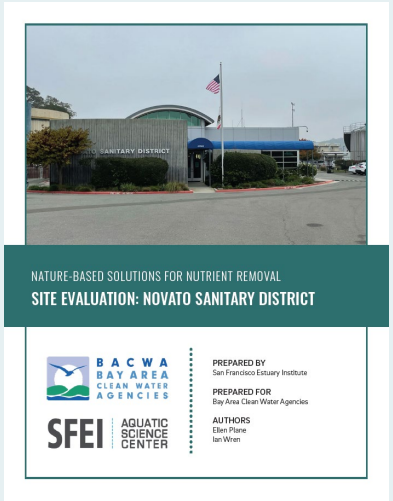
Scoping & Evaluation



Desktop screening (factsheets for 37 facilities)



Site evaluations for 8 high opportunity facilities



Cost estimates and concept designs for 3 facilities

Figure 5. Infrastructure, recreation, & disadvantaged communities

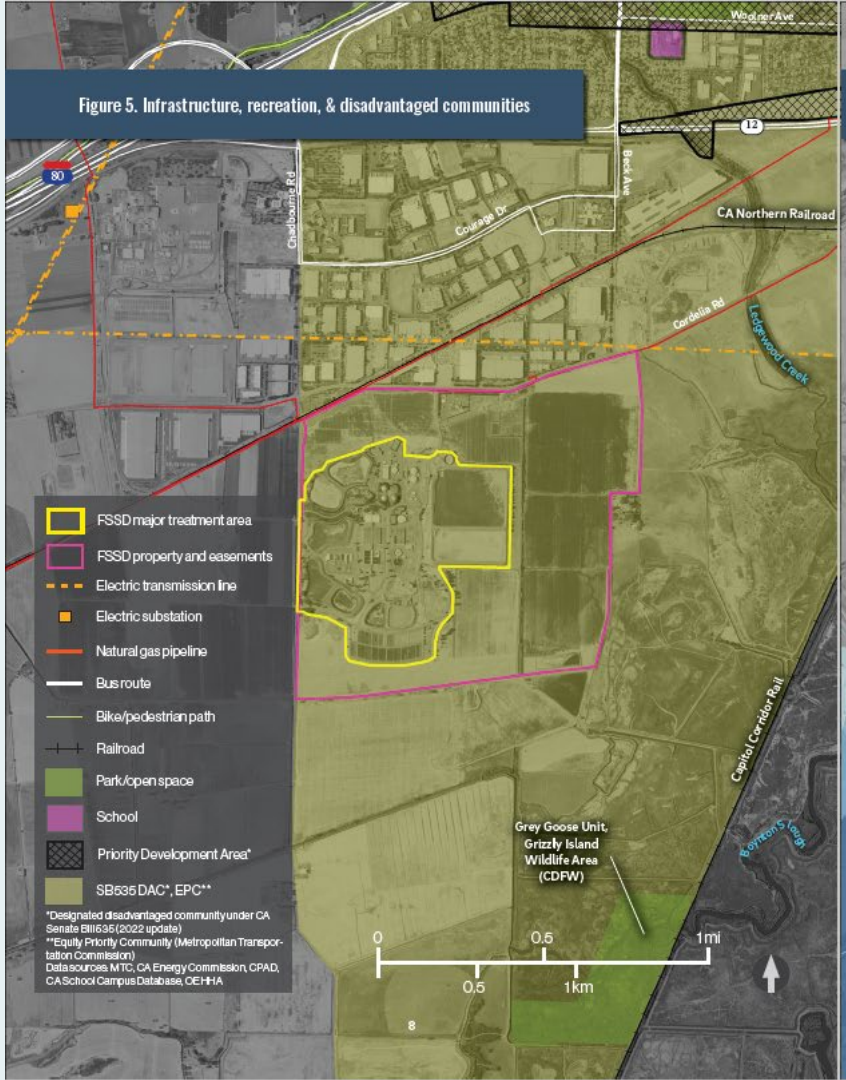
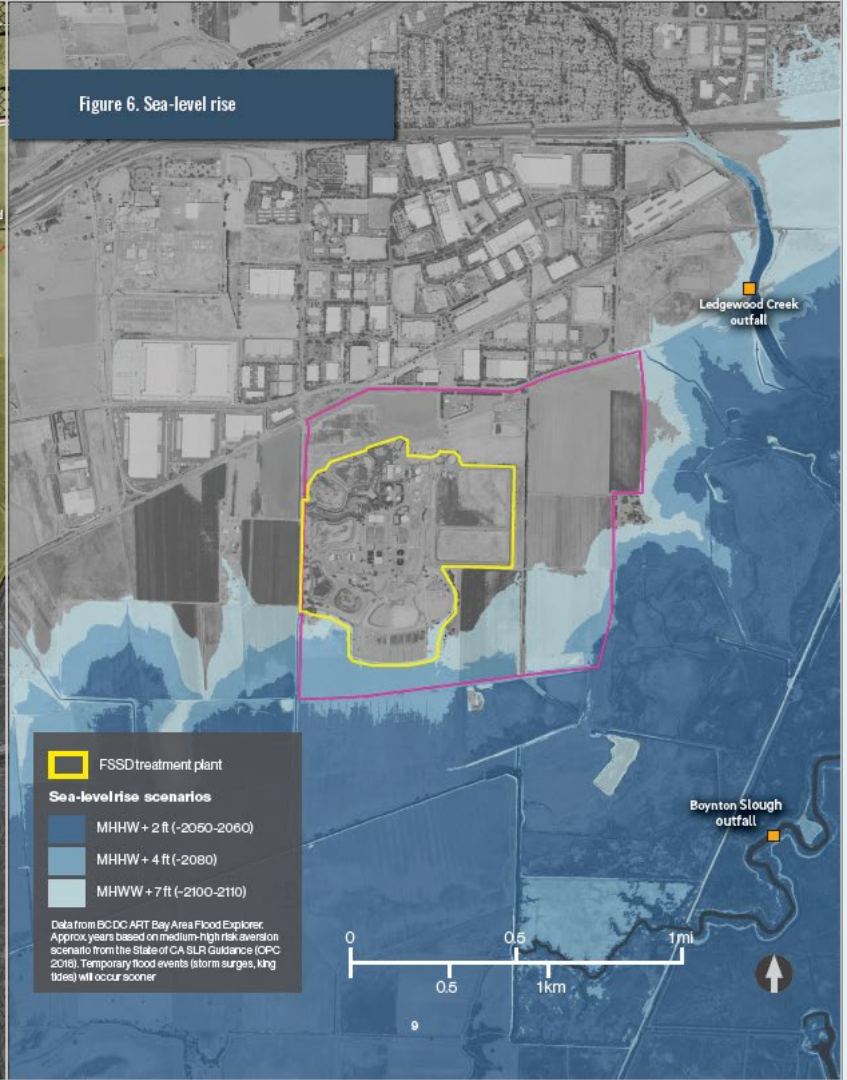


Figure 6. Sea-level rise



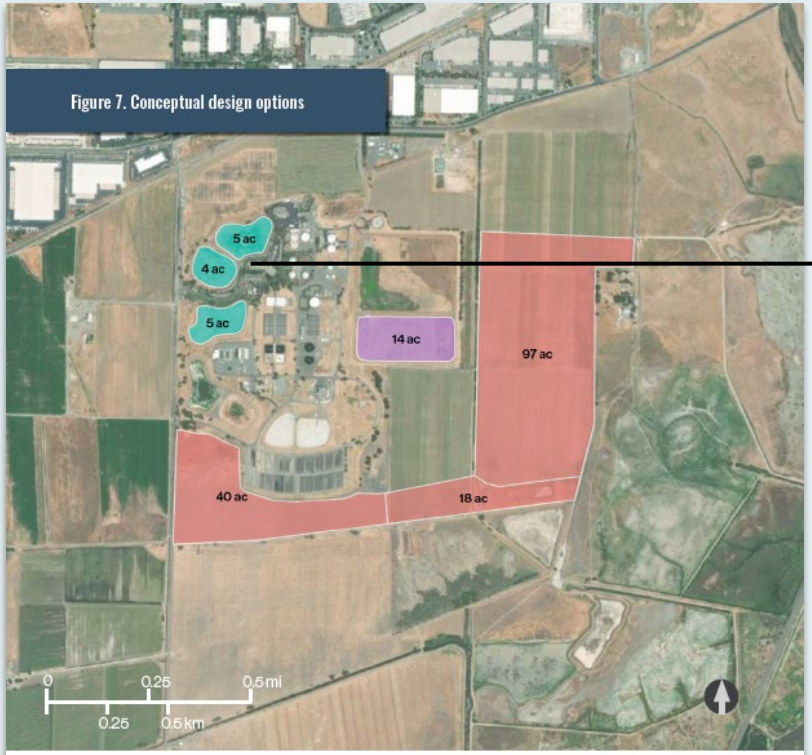


Figure 7. Conceptual design options

Option 1: Convert former final effluent ponds into train of open water wetlands optimized for various purposes

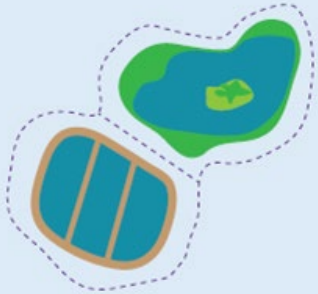
Option 2: Dual-purpose wet-weather equalization / open water treatment cell with seepage slope sides

Option 3: Construct perimeter horizontal levee in phases. Eventually reconnect to restored tidal marsh (Option 4)

Option 4: Convert the 97-acre parcel to a multi-benefit wastewater polishing wetland. Future phases may include construction of polishing wetlands in the parcels the south of the plant and partnerships with duck clubs to construct temporary freshwater wetlands to build peat (elevation) and prepare for future tidal restoration.

OPTION 1

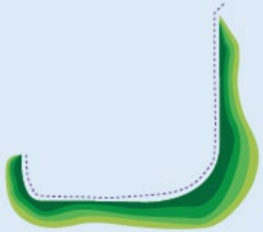
Convert one or more of the effluent holding ponds in the northwest area of the plant to a train of ponds or segmented sections optimized separately for ecological enhancement and nutrient removal. These holding ponds are currently underutilized and could be repurposed to achieve multiple benefits. The train of ponds could provide a valuable recreational opportunity in an underserved area with minimal access to parks. This could include wildlife viewing opportunities as well as educational components including signage describing the design and purpose of each pond. The series could include 1-2 unvegetated ponds optimized for nutrient and contaminants of emerging concern (CEC) removal and 1-2 vegetated ponds optimized for waterbird habitat.



Example concept sketch demonstrating Option 1.
The open water treatment cell on the left is optimized for denitrification - with woodchip seepage slopes and baffles to minimize hydraulic short-circuiting. The pond on the right is a vegetated open water wetland with a habitat island. A trail with educational signage (purple dotted line) surrounds the two ponds.

OPTION 3

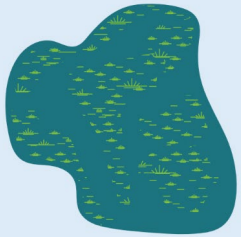
Build a horizontal levee around the treatment plant on the farmed parcels to the south and east. The levee could be developed in phases, with the first phase on the parcels to the east or south of the plant, and later phases completing the ring with a levee on the edge of the southeast parcel. Initially, the purpose of the horizontal levee would be nutrient removal, with additional co-benefits if tidal marsh is restored bayward of the levee. The horizontal levee could be designed to include trails for public access, recreation, and education. Figure 7 shows the parcels where the horizontal levee could be constructed. The actual construction footprint would be smaller than these parcels and can be determined in later design stages. The design would need to be integrated with the design of future flood risk management infrastructure needed to protect the plant.



Example concept sketch demonstrating option 3.
A horizontal levee/seepage slope is located to the south and east of the plant. An option includes adding recreational access at the top of the flood levee behind the seepage slope for public access and educational/wildlife viewing opportunities.

OPTION 4

Convert the 97-acre agricultural parcel to the east of the treatment plant to a treatment wetland for wastewater polishing, education, and possible recreation. Other areas potentially suitable for conversion to freshwater marsh include the 40- and 18-acre parcels south of the plant and nearby duck clubs. Based on management priorities, the area could serve long-term wastewater treatment purposes or be encouraged to build a peat layer to increase land elevation and sea-level rise resilience. As maintenance of perimeter dikes becomes more challenging with sea-level rise, strategic breaches may connect the area to tidal influence via Suisun Marsh sloughs. Eventually, the marsh could migrate upland toward a horizontal levee, if incorporated with Option 3, and freshwater flowing through the horizontal levee could be discharged in a diffuse manner to the tidal marsh. This option would enhance the connectivity of the landscape to Suisun Marsh and increase the resilience of the wastewater plant and surrounding lands to sea-level rise.



Example concept sketch demonstrating option 4.
Treated wastewater is used to create a temporary freshwater wetland to build up organic matter for increasing elevation and resilience to sea-level rise.

Table 1. Comparison of each option's relative contribution to achieving goals of NbS implementation.

● = Achieves. ◑ = Partially achieves. ○ = Does not achieve.

For TIN removal, 'Achieves' is>30% removal, 'Partially achieves' is 5-20% removal, and "Does not achieve is <5% removal.

	Option 1. Convert former final effluent ponds into train of wetlands optimized for various purposes (14-ac total)[1]	**Option 2.** Dual purpose wet weather equalization / open water treatment cell with seepage slope sides (155-ac total)	**Option 3.** 2.4-km horizontal levee along the interior portions of the three potential freshwater wetland cells[2]	**Option 4.** Convert the 97-acre parcel to a multi-benefit wastewater polishing wetland
Goal 1: Reduces nutrient loads to the Bay and improves overall water quality.				
Reduces TIN *Estimated dry-season reduction (kg d-1 / % reduction of daily TIN load)*	● *100 kg d-1 / 10%*	● *1,200 kg d-1 potential / 100%*	◑ *310 kg d-1 / 30%*	● *730 kg d-1 / 70%*
Reduces CECs	●	●	●	●
Goal 2: Reduces flood risk for the plant and/or associated infrastructure.				
Attenuates waves and provides erosion resistance	○	○	●	●
Facilitates marsh accretion	○	○	○	●
Goal 3: Create and/or enhance habitat				
Provides marsh-upland transition zone habitat and marsh migration space	○	○	●	○
Provides high tide refuge habitat for wildlife	○	○	●	○
Increases habitat complexity	●	◑	●	●
Provides freshwater pond/marsh habitat	●	◑	●	●
Goal 4: Enhances recreational opportunities.				
Provides opportunity for public trails and wildlife viewing	●	○	●	●
Goal 5: Provides additional co-benefits.				
Reduces use of potable water for irrigation	○	○	○	○
Supports goals of partner organizations (e.g. facilitates neighboring restoration projects)	N/A	N/A	N/A	N/A

Conceptual Designs & Cost Estimates

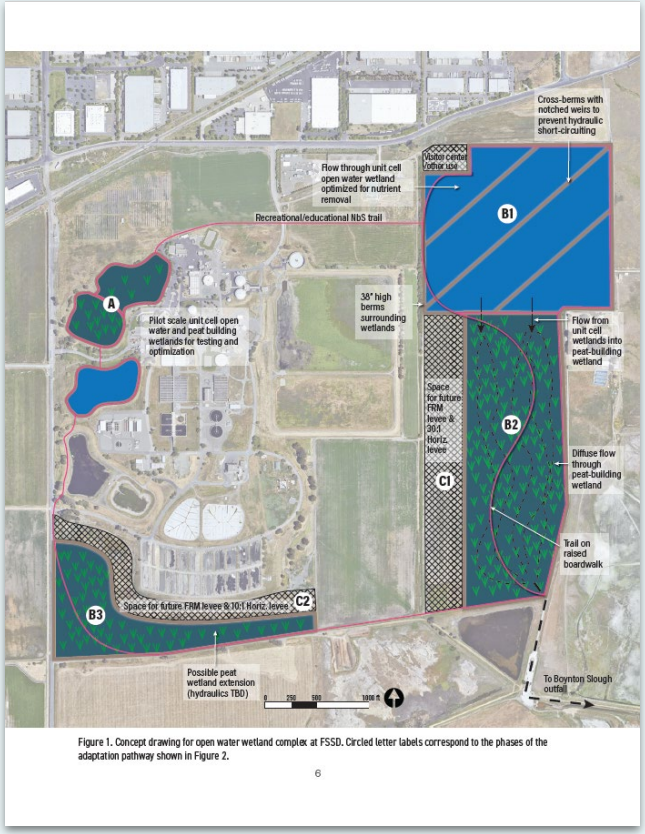


Figure 1. Concept drawing for open water wetland complex at FSSD. Circled letter labels correspond to the phases of the adaptation pathway shown in Figure 2.

6

Table 1. Planning level cost estimates for various nature-based solutions considered in Appendix A.

Option	Footprint Size (acres)	Construction Cost ($ Milions)
Unit Cell Wetland (B1 - Figure 1)	68	$35 Mil
Peat Building wetland (B2 - Figure 1)	64	$34 Mil
Extended Peat Building Wetland (B3 - Figure 1)	31	$19 Mil
30:1 Horizontal Levee (C1 - Figure 1)	17	$11 - 26 Mil
10:1 Horizontal Levee (C2 - Figure 1)	7	$6-12 Mil

Figure 7. Conceptual design options

Option 1: Coordinate with Bothin Marsh Evolving Shorelines project on a horizontal levee at North Bothin Marsh.

Option 2: Construct a horizontal levee between the South Equalization Basin and Mill Valley Marsh.

Option 3: Retrofit one or both equalization basins as dual-purpose treatment wetlands / wet weather equalization basins.

CONCEPTUAL DESIGN OPTIONS

To date, this project identified three main nature-based options for a multi-benefit nutrient load management strategy for SASM (Figure 7). These could be standalone options or could be combined as elements of a larger strategy. Option 3 represents the most viable stand-alone alternative, involving conversion of the North and/or South Equalization Basins to some form of open water treatment wetland. Options 1 and 2 involve a footprint outside the treatment plant and would require additional partnerships and regulatory processes.

The next step in this process involves additional engagement with SASM to identify the preferred alternative and appropriate near-term planning efforts.

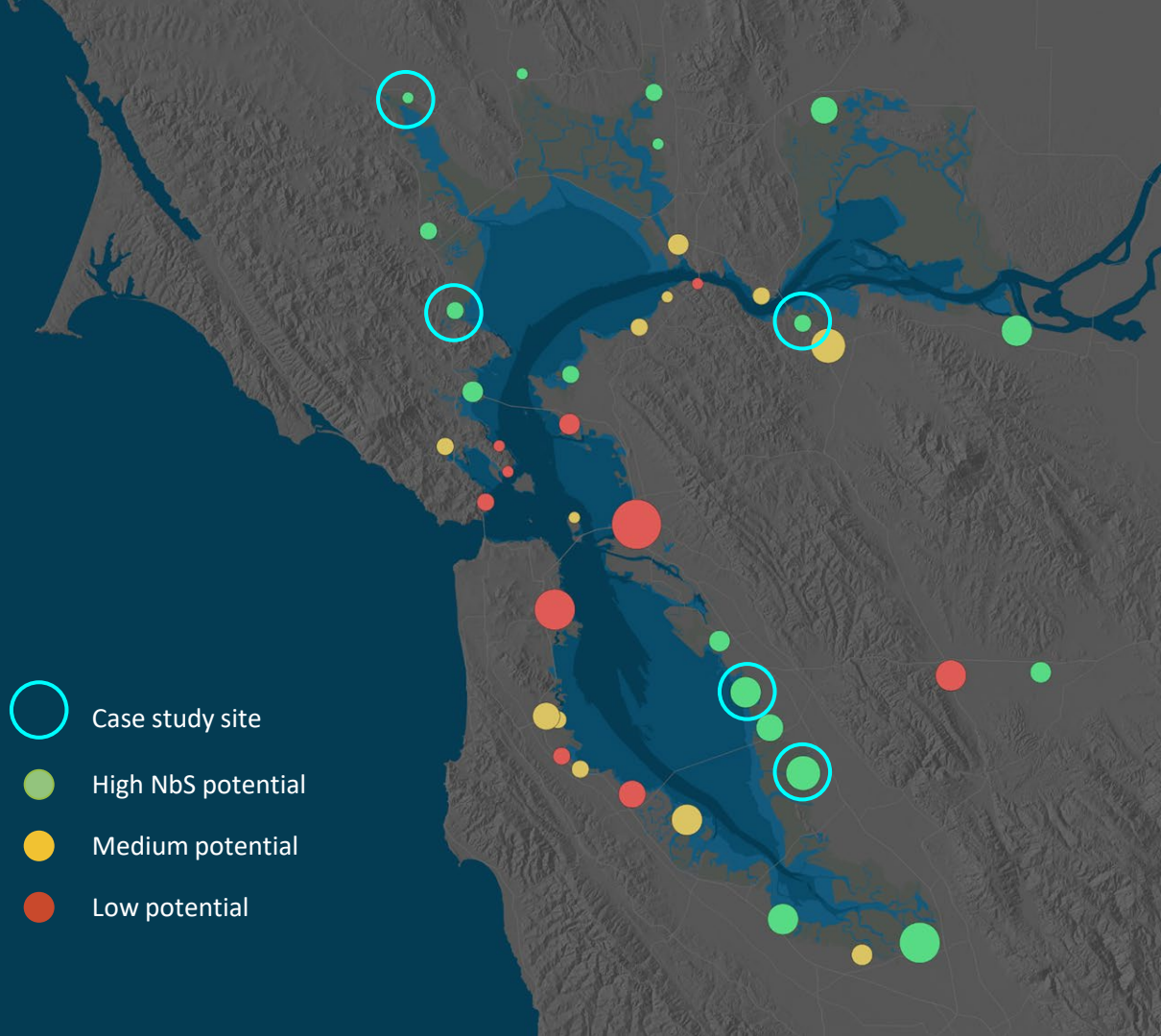
OPTION 1

Option 1 requires partnership with the Bothin Marsh Evolving Shorelines project and the Bothin Marsh Open Space Preserve to route treated effluent to a horizontal levee at the back of North Bothin Marsh. The levee could be constructed as part of a habitat resilience and flood protection effort, making it lower risk and lower cost for SASM. The horizontal levee would be integrated with Bay Trail and habitat adaptation planning for Bothin Marsh. Water would need to be piped from the SASM plant along the Bay Trail and across the bridge at Arroyo Corte Madera del Presidio to the horizontal levee site. It would then seep through a subsurface layer in the horizontal levee and discharge to North Bothin Marsh.

Example concept sketch demonstrating Option 1. Treated wastewater from SASM is polished in a horizontal levee seepage slope integrated into an ecotone levee at the back of Bothin Marsh.

Case Studies

1. Union San / Hayward Marsh
2. Petaluma
3. Las Gallinas
4. Mt. View
5. Oro Loma

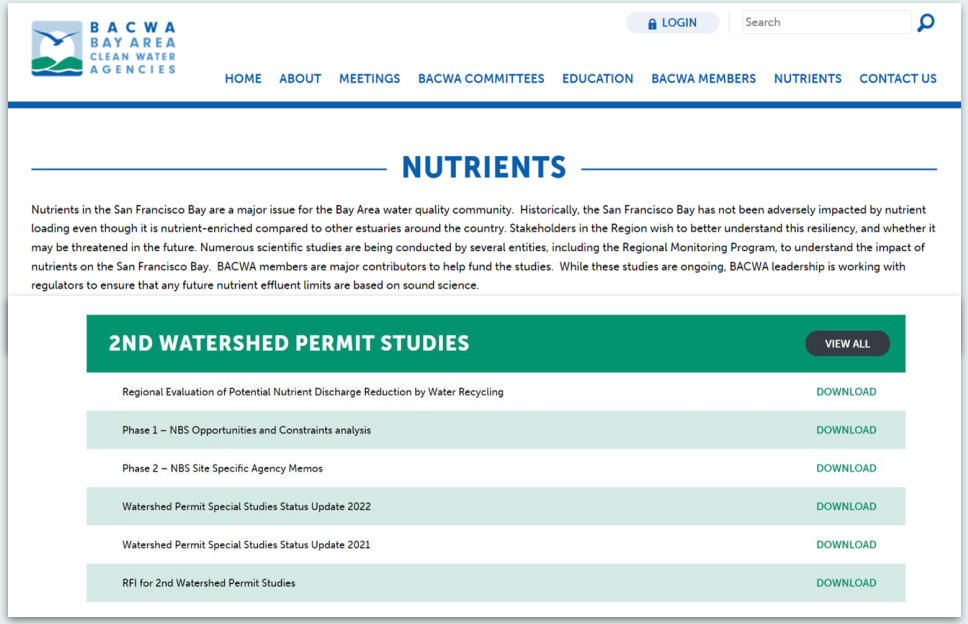


Submittal to the Water Board

Available at

https://bacwa.org/nutrients/

https://www.sfei.org/projects/nature-based-solutions-nutrient-removal

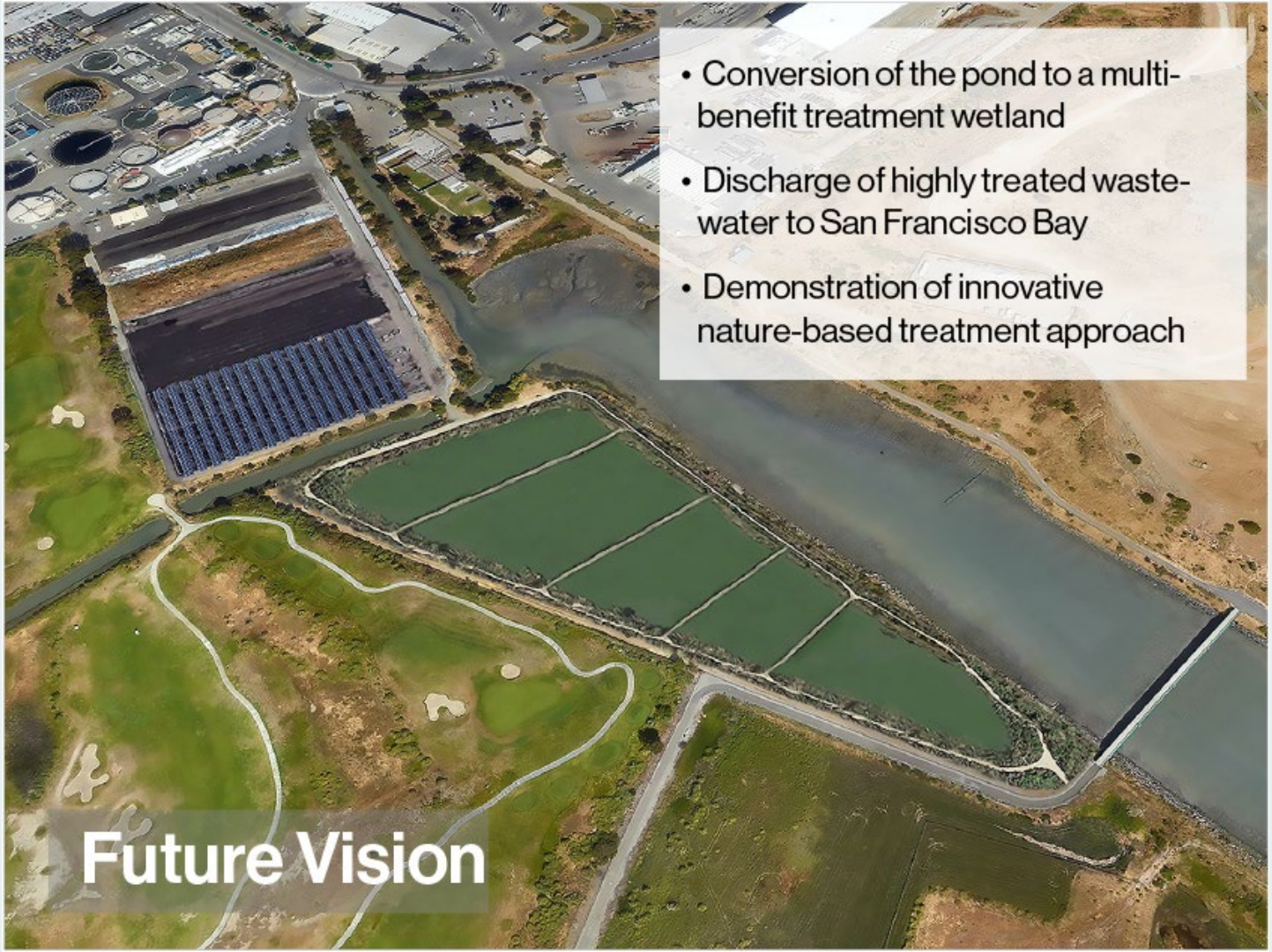


San Leandro WPCP Update

- Seepage slope &open water feature with nitrification, for ~1 mgd via modular MABR nitrification system, liner, fill, woodchip-embedded crates, etc
- ~$3 million for nitrification / $8 million for construction / $1 million contingency
- ~$6 million from Measure AA and EPA Water Quality Improvement Fund

Contact: Hayes Morehouse, San Leandro Water Pollution Control Plant


• 6.9 acre pond built ~1972
• used historically for emergency wet weather storage
• treatment plant subject to future flood risk
Recent Conditions


• Conversion of the pond to a multi-benefit treatment wetland
• Discharge of highly treated waste-water to San Francisco Bay
• Demonstration of innovative nature-based treatment approach
Future Vision


Transforming an Industrial Landscape
The basin in front of you was constructed around 1972 to store treated wastewater before discharging to the Bay. Soon thereafter, San Leandro joined the East Bay Dischargers Authority to dispose its wastewater to the Bay, three miles from the shoreline.
Since then, the pond only operates on an emergency basis. This project aims to partially restore long lost shoreline riparian habitats and improve the water quality discharged from San Leandro's Water Pollution Control Plant, which treats about 5 million gallons of municipal and industrial wastewater each day.
Relying on Nature to Enhance the Shoreline
This project aims to leverage natural processes and engineering to convert this space towards enhancement of the Bay and gain insights into how similar degraded shoreline areas can improve communities and the environment.
Provide advanced treatment of up to one million gallons of wastewater
Wastewater will seep through woodchips embedded along the perimeter of the pond to start the process of removing nitrogen and other pollutants.
The shallow open water portion of the system will be segmented to maximize removal of nutrients and organic contaminants like pharmaceuticals.
Polished wastewater will discharge through an existing pipe.
San Leandro Treatment Wetland Project
With funding from the Measure AA parcel tax, the City of San Leandro plans to transform this area from an underutilized wastewater storage pond to an innovative nature-based treatment system. Following construction in 2022, this basin will polish up to one million gallons of wastewater per day. In the process, San Leandro is testing a system potentially suitable for adoption around the Bay to improve water quality and restore disturbed habitats threatened by sea level rise.
MEASURE AA
Nature-based Solutions to Wastewater Treatment
Overall Treatment Process at San Leandro's Water Pollution Control Plant
Treatment Wetland Project Overview
Seepage Slope Detail
For decades, scientists have recognized San Francisco Bay as a nutrient-enriched estuary, largely due to heavy inputs of nitrogen from the 40 wastewater treatment plants that discharge over 400 million gallons of treated effluent to the Bay every day. Historically, the Bay has shown resistance to symptoms of nutrient over-enrichment due to factors of high turbidity, strong tidal mixing, and phytoplankton-eating clams. More recent studies suggest the need to reduce nitrogen loading to protect the Bay from the potential effects of nutrient over-enrichment, such as toxin-producing algal blooms and low dissolved oxygen.
This project will not only reduce pollution to the Bay, but also improve habitat and help demonstrate whether nature-based treatment strategies can cost effectively rehabilitate damaged shorelines areas such as this, while also improving the health of the Bay.
MEASURE AA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THANK YOU!