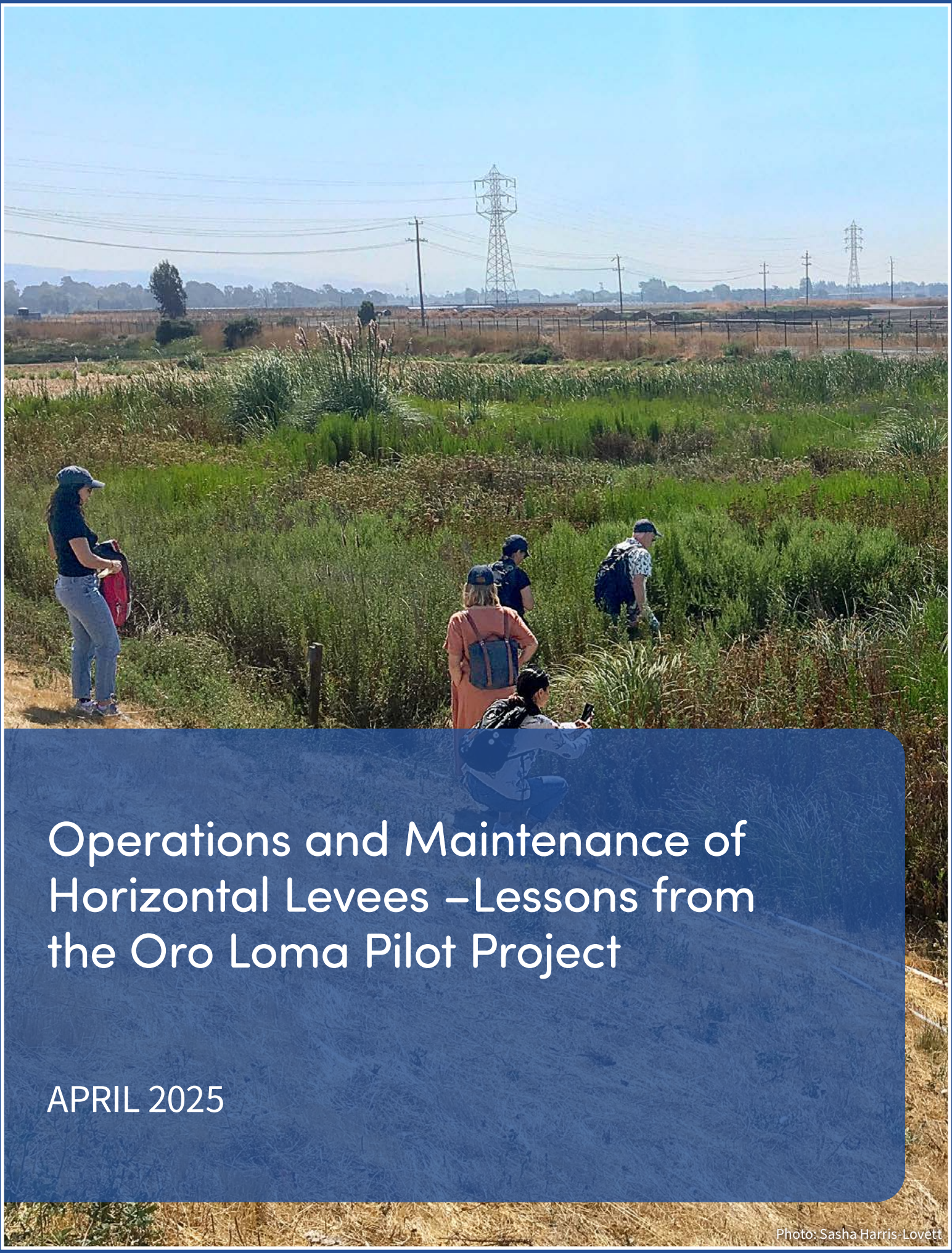

Operations and Maintenance of Horizontal Levees –Lessons from the Oro Loma Pilot Project

APRIL 2025

Photo: Sasha Harris-Lovett

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Note:
Aidan Cecchetti contributed to this document in a personal capacity. The views expressed are Aidan's and do not reflect the views of the San Francisco Bay Regional Water Quality Control Board.

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About This Report

The following report contains information, lessons learned, and tips from the team that has managed and studied the Oro Loma horizontal levee pilot project over the past decade, including Aidan Cecchetti (San Francisco Bay Regional Water Quality Control Board), Jimmy Dang (Oro Loma Sanitary District), Anthony DeSalvo (UC Berkeley), David Sedlak (UC Berkeley), Angela Stiegler (Hazen and Sawyer), Jonothan Uhler (UC Berkeley), and Jason Warner (Pacific Optimization). These tips were compiled and transcribed by Sasha Harris-Lovett (San Francisco Estuary Partnership). Intended audiences for this report include wastewater treatment professionals, shoreline planners, and others involved in the planning, design and implementation of horizontal levees in the San Francisco Bay Area.

Photo: San Francisco EstuaryPartnership Archive

Introduction

As San Francisco Bay Area communities confront the varied regional challenges of sea level rise, water pollution in San Francisco Bay, and loss of wetland habitat at the shoreline, horizontal levees are emerging as a compelling nature-based technology to address these concerns. Horizontal levees are engineered treatment wetlands built on a slope between coastal levees and tidal marshes, through which water is piped below the surface of the ground, where microbes help improve the water quality. This report defines horizontal levees as ecotone levees that incorporate nature-based water treatment[1], including for wastewater effluent, reverse osmosis (RO) concentrate, and/or stormwater.

Diagram Credit: Angelo Stiegler

1 Sasha Harris-Lovett et al., "Nature Based Solutions for Coastal Resilience, Habitat Enhancement, and Water Quality Improvement at the San Francisco Bay Shoreline: Challenges, Solutions, and Next Steps." (San Francisco Bay Estuary Partnership and Bay Area One Water Network, November 2021).

2 Aidan R. Cecchetti et al., "The Horizontal Levee: A Multi-Benefit Nature-Based Treatment System That Improves Water Quality and Protects Coastal Levees from the Effects of Sea Level Rise," Water Research X 7 (May 1, 2020): 100052, https://doi.org/10.1016/j.wroa.2020.100052; Aidan R. Cecchetti et al., "Fate of Dissolved Nitrogen in a Horizontal Levee: Seasonal Fluctuations in Nitrate Removal Processes," Environmental Science & Technology 56, no. 4 (2022): 2770–82; Angela N. Stiegler et al., "Persistent Trace Organic Contaminants Are Transformed Rapidly under Sulfate- and Fe(III)-Reducing Conditions in a Nature-Based Subsurface Water Treatment System," Environmental Science & Technology 57, no. 43 (October 31, 2023): 16616–27, https://doi.org/10.1021/acs.est.3c03719; Adam R. Brady et al., "Pharmaceutical Attenuation Differs within Woodchip-Based Lignocellulose Bioreactors across Nitrate- and Sulfate-Reducing Conditions," ACS ES&T Water 3, no. 5 (May 12, 2023): 1352–63, https://doi.org/10.1021/acsestwater.3c00030.

Oro Loma Sanitary District, in partnership with University of California Berkeley, San Francisco Estuary Partnership, and other project partners, developed a pilot-scale horizontal levee to test this innovative nature-based system for providing additional wastewater treatment, flood protection, and habitat at the shoreline. Scientists have recorded the Oro Loma horizontal levee's success in removing nutrients, pharmaceuticals, and other contaminants of concern[2]

The Oro Loma horizontal levee pilot has a 30:1 slope in most areas and a 15:1 slope in a few experimental areas. It is divided into 12 different experimental areas referred to as "cells", which contain different substrates and vegetation/habitat types to test the efficiency of each for water quality

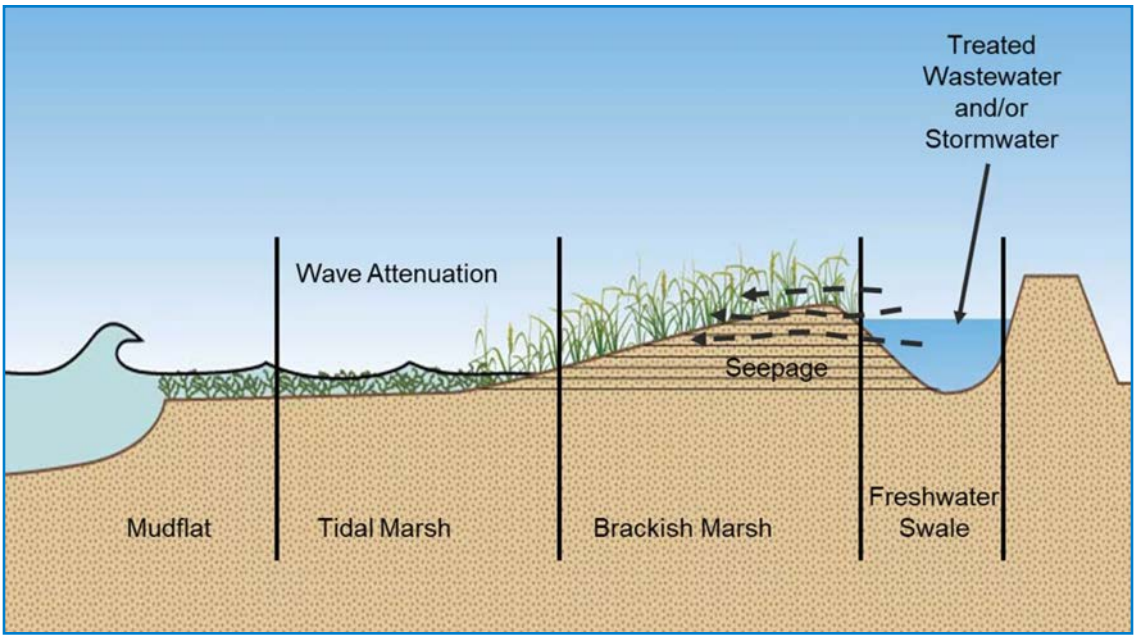
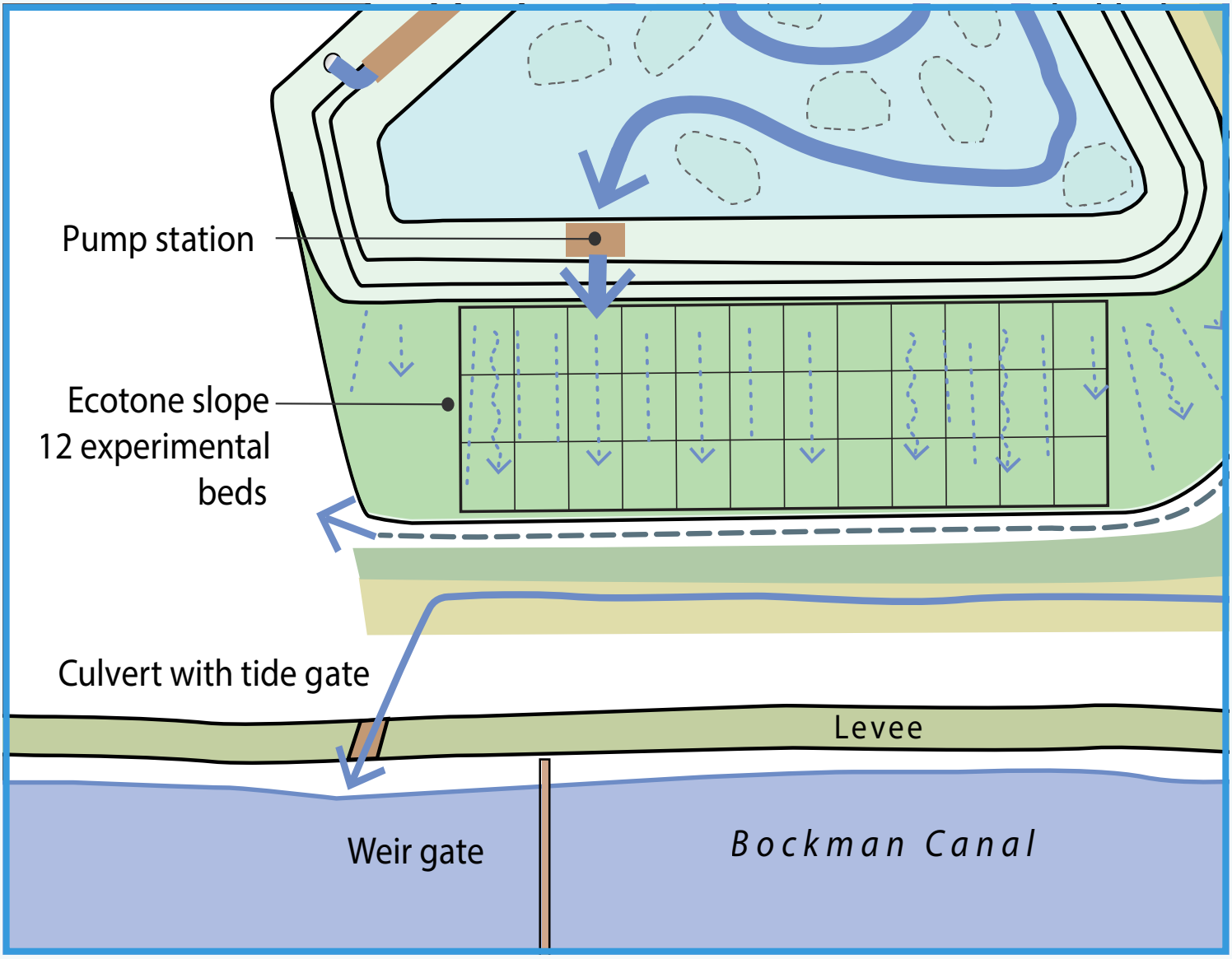


Diagram Credit: Angelo Stiegler

improvement. Wastewater from Oro Loma Sanitary District and reverse osmosis concentrate from Valley Water are pumped and trucked, respectively, to the horizontal levee to flow through the cells. The substrate of the horizontal levee cells consists of layers of clay, porous gravel, bay mud, woodchips, sand and soil.



Source: ESA

The experiment is divided into 12 beds and will test for different combinations of soil types, plant, species, and water regimes, as well as provide three replicates.

Oro Loma is permitted as a pilot-scale project, so after passing through the Oro Loma horizontal levee, the water is returned to the Oro Loma Wastewater Treatment Plant before being discharged to the Bay. In a full-scale horizontal levee, treated wastewater would likely be discharged directly to the Bay after passing through the horizontal levee and reaching water quality standards for permitting compliance. For more information about the Oro Loma horizontal levee design, please see the informational press release developed by the project partners in 2015, "Oro Loma and Castro Valley Sanitary Districts to Test Experimental Levee" as well as a report on reconfiguring the cells in 2024, "Oro Loma Horizontal Levee: Cell Reconfiguration Project."

Vegetation is planted in different configurations along the Oro Loma horizontal levee cells, with the intention of learning about which plants do best in this environment, which ones promote the greatest improvement in water quality, and what kind of maintenance they need over time. The Oro Loma horizontal levee was planted with native plants to optimize the site's habitat value. To learn more about the plants on the Oro Loma horizontal levee, please see the Oro Loma Horizontal Levee Vegetation Report, prepared by Save The Bay in 2017.

As of this report's completion in 2024, the pilot horizontal levee at Oro Loma has been in operation for more than ten years. Although Oro Loma's horizontal levee is a small, experimental, closed-loop system, it can provide many lessons about the operations and maintenance of full-scale horizontal levee systems, as well as illuminate what is still unknown about long-term operations and maintenance of horizontal levees.

In general, the Oro Loma wastewater plant manager considers the horizontal levee to be very low maintenance, compared with other parts of the treatment plant. Horizontal levees represent a nature-based solution for sea level rise adaptation that can also have multiple benefits for water quality and habitat. While some routine maintenance is required to keep them operational, there are large long-term potential benefits associated with their implementation around the San Francisco Bay.

The report is organized in the following categories:

Photo: Sasha Harris-Lovett

1. Maintaining the vegetation on the horizontal levee

Key lessons:

- Start with an effective vegetation design and plant palette.
- Maintain a robust native plant community on the horizontal levee slope.
- Remove invasive plants if they become established.
- Be aware of operational considerations or concerns related to specific plants.

The planting design and execution at the Oro Loma horizontal levee, by Save The Bay, Peter Baye, and others, established a robust native plant community. Due to this foundational native vegetation, the levee slope was not as susceptible to encroachment by invasive species, as evidenced by the fact that encroachment by cattails on the horizontal levee lessened over time. It seems likely that the meadows in the middle of the Oro Loma horizontal levee will reach some steady state (a mat of plants) that might not need routine maintenance. In general, the vegetation at Oro Loma is very hardy. You can walk over the plants without harming them. For more information on the plant palette evolution over time at the Oro Loma horizontal levee, please see the report, "Fragmentation Drives Dominant Plant Encroachment on a Horizontal Wastewater Treatment Levee" (2022, Master Theses) offers insight into how the plant palette had evolved over time at the Oro Loma horizontal levee.

The native plants on the horizontal levee generally require low maintenance. At the edge of the horizontal levee, where the wetland interfaces with paths or property, there has to be routine maintenance (trimming or mowing) of the vegetation.

Despite starting with a robust and vigorous native plant palate, there may be concerns about invasive vegetation, like pampas grass, taking root on the horizontal levee slope over time. Horizontal levees might need annual or semi-annual vegetation surveys to see if invasive plants

Photo: Darcie Luce

are taking over. This early detection would enable a quick response. If pampas grass were to take over a shoreline, the scale of the problem might get so big that it would be hard to manage. At the Oro Loma horizontal levee, pampas grass was very localized in the gravel trenches and along the berms. It did not tend to colonize the wetland treatment areas. If it did show up in the treatment area, it was usually somewhere the soil had been disturbed and was quickly removed.

If invasive plants take root on the horizontal levee slope, early action is recommended. Oro Loma staff went in once a year and removed all the pampas grass on the horizontal levee by cutting the plants back and putting Roundup on the roots. However, application of herbicides to a horizontal levee system that drains directly to the Bay would not be recommended, and manual removal of invasive plants may be required.

Note that if the vegetated slope of the horizontal levee becomes good habitat for an endangered species, it may make it difficult for the wastewater agency to do what is needed for maintenance of the vegetation (i.e., using weed whackers). For example, Union Sanitary District had a treatment wetland, and it became a rich habitat for many birds, including endangered species. As a result, Union Sanitary District had to do the vegetation maintenance work "from stilts with chopsticks" because there were so many regulatory considerations around disturbing the birds. While more costly, these special conditions around endangered species habitat can be managed with careful maintenance.

Photo: San Francisco Estuary Partnership archive

Specific native plants on the horizontal levee slope can require different levels of maintenance. In particular, willow trees planted on the horizontal levee can cause issues with the system function and require ongoing maintenance. While willows may provide several benefits including cultural uses, wildlife habitat and resistance to storm surges, it is worth careful consideration about whether willows are appropriate for the horizontal levee site.

For example, the willow trees at the Oro Loma horizontal levee grew so much over several years (20-25 feet tall) that they shaded all other vegetation out. They had to be cut down, and the crew that cut them down chipped the branches and spread the woodchips on the ground. Those woodchips made it so that no other vegetation would grow except the willow stumps that were there.

Additionally, the willow roots clogged the intakes of water into the Oro Loma horizontal levee (one time in 10 years of operation). The roots had to be manually removed. When roots grew into the piping, Oro Loma Sanitary District shut off the flow to the horizontal levee, pulled out the willow root mat, then reconnected the system hydrologically. If this were a recurring problem, the wastewater agency could think about feeding water into the horizontal levee system in different ways, for example by using a gravel distribution trench.

At a wetland in Belgium that followed Oro Loma's lead and uses willow in an engineered wetland to treat reverse osmosis concentrate, they cut the trees down to the stumps every few years and send the wood to a bioenergy facility. However, if the willows are intended to build wildlife habitat, cutting them down would be counterproductive.

Photo: San Francisco Estuary Partnership archive

2. Maintaining the horizontal levee's water treatment system

Key lessons:

- Monitor the site's hydrological conditions over time and have a plan if the system clogs or if there is overland flow (meaning water is bypassing treatment).
- If pre-treatment filters or pumps are used in the horizontal levee system, these will have to be cleaned or replaced periodically.
- Scientists do not know yet if the substrate of the horizontal levee will need to be replaced over time to maintain effective water treatment.
- Scientists do not know how interaction with salt water from the Bay in a full-scale horizontal levee will affect water treatment.

If contaminant removal from wastewater is a goal of the horizontal levee, it is imperative to understand the hydrological conditions of the site. There is an ongoing need to track if the water is going through the subsurface of the horizontal levee (where treatment happens), or if it is going over the surface and bypassing treatment. To track this activity, a network of online sensors at different locations around the site can provide ongoing monitoring of conductivity or chloride, because these parameters shift dramatically if the water is getting treated in the subsurface or not. This kind of ongoing monitoring will be important for the wastewater agencies implementing the horizontal levee systems to work with regulatory agencies to get treatment credit for removal of contaminants.

The horizontal levee water treatment system requires standard maintenance on any pumps or filters that bring water into the horizontal levee. In its decade of operation, the Oro Loma horizontal levee has experienced only a few instances of decreased flow or clogging. The exception to this is when running reverse osmosis concentrate through the horizontal levee, Oro Loma employed a pre-treatment filter to screen out larger particles. This pre-screen got clogged with biological growth, causing overland flow over the surface of the wetland. To remedy this, Oro Loma staff periodically pulled out and cleaned the pre-screen filters (once every five months).

The Oro Loma horizontal levee did not experience much clogging with Oro Loma Sanitary District's treated effluent, however, a full-scale system could receive wastewater of significantly more variable quality than what was seen at Oro Loma. The variability of wastewater increases the potential for clogging at different sites. It is possible to mitigate clogging in subsurface flow treatment wetlands, as practiced in Europe. The wastewater agency should have a plan in place of what to do if the horizontal levee water system starts to clog.

Scientists do not know yet if the substrate in the horizontal levee, including wood chips, will need to be replaced or renewed in situ to enable effective water treatment over time. The Oro Loma project scientists hope that over time the organic matter from the surface of the wetland will move downward into the soil substrate to provide ongoing water treatment capacity, because the carbon in the organic matter is essential for the microbial communities underground to do the work of improving waterquality. If the organic matter does not move into the soil substrate over time, horizontal levee managers may need to add more woodchips to the treatment zone over time to enable ongoing water treatment. Scientists still do not understand the long-term water treatment role of the plants in the horizontal levee, and if the plants can substitute for the woodchips over time. After the first 10 years of operation, without any kind of replacement or renewal of the subsurface materials in the treatment zone, there has not been a decline in water quality improvement capacity in the Oro Loma horizontal levee.

The Oro Loma horizontal levee mixed the woodchips in the substrate with granular activated carbon and Fluoro-Sorb to experiment with using these materials to remove metals and chemicals of emerging concern, including per- and polyfluoroalkyl substances (PFAS), from the water. The Fluoro-Sorb and activated carbon may accumulate contaminants over time, eventually becoming saturated and reducing their treatment capacity. Scientists are currently working to determine how long these systems will be able to operate before the geomedia sorbents need to be replaced.

It is still not clear whether the soils in the horizontal levee might someday (far in the future) have to be hauled off to a hazardous waste site because they have accumulated so many contaminants like PFAS. One potential solution is to designate a “PFAS reduction zone” made of pure Fluoro-Sorb or activated carbon in a narrow strip that could be periodically dug out and replaced.

If the horizontal levee water treatment slope is on the Bay side of an actual levee and connected hydrologically to the Bay, it might periodically get inundated with salt water and sediments in a large storm. Hypothetically, this salt water and sediment could come up into the treatment zone and affect the treatment capacity of the horizontal levee. Oro Loma never saw saltwater going into the foot of the levee in the tidal cycle, because it’s a pilot project that isn’t connected to tidal action, and it never experienced sea water flooding. Oro Loma project scientists were not sure what the effects of periodic inundation would be on the horizontal levee’s water treatment capacity.

3. Maintaining the horizontal levee's habitat value

Key lesson:

Apart from maintaining the vegetation, the Oro Loma horizontal levee pilot does not provide much insight about maintaining the site's habitat value.

The Oro Loma horizontal levee is a small pilot project that is not connected hydrologically or geographically to the Bay margins, so it was hard to assess the habitat value of the site. At other water treatment wetlands, different approaches are employed to maintain site's habitat value. Orange County Water District's Prado Wetlands have habitat for sensitive species present on the site. They have developed a practical plan to manage the site by taking advantage of regular nesting windows to do maintenance activities and periodic biological monitoring. However, at the nearby Union Sanitary District treatment wetlands, the high density of birds attracted to the site resulted in the spread of avian diseases.

Photo: Alexandra Thomsen

4. Maintaining public health

Key lessons:

- **Reduce mosquito habitat.**
- **Build early and long-lasting relationships with the local Mosquito Abatement District.**

The Oro Loma horizontal levee was attentive to reducing mosquito habitat. The system is designed for subsurface flow, which alleviates concern about mosquito breeding, since mosquitos breed in open water. If there is any continuously pooled water in the system, operators should ensure there are mosquito fish in those pools to curb mosquito populations.

Horizontal levee project proponents should have relationships with their local Mosquito Abatement District from the design phase all the way through implementation of the project. It is important to have vector control experts, including the staff from local Mosquito Abatement Districts, on board with the horizontal levee design. The design should avoid standing water.

Mosquito breeding is a common concern for many engineered treatment wetlands, including the Oro Loma horizontal levee, the Prado Wetlands in Orange County, and the Discovery Bay open-water treatment wetland in Discovery Bay, CA.

Photo: Darcie Luce

5. Maintaining the horizontal levee slope over time

Key lesson:

- **The Oro Loma horizontal levee pilot does not provide much insight about maintaining the site's slope**

Since the Oro Loma horizontal levee is not connected directly to tidal action, it is not clear how the Bay water and wave action at the Bay margin would affect the slope of a full-scale horizontal levee. It is possible that a full-scale horizontal levee would need ongoing sediment supply to the edge of the levee slope in the Bay over time if the slope gets eroded by the water

Photo: ESA

Conclusion

The Oro Loma Horizontal Levee Pilot project provides valuable insights about operations and maintenance of full-scale horizontal levees. These include lessons about maintaining the vegetation, water quality treatment capacities, and public health value of the site. However, because it is a pilot project that is not connected to the Bay hydrologically or geographically, the Oro Loma horizontal levee does not offer a lot of useful information about maintaining the habitat value or the slope of a full-scale horizontal levee over time. As horizontal levees are built around San Francisco Bay, further study of their habitat value, slope over time, and other operations and maintenance needs will continue to be valuable for informing design and practical implementation of these nature-based solutions for shoreline resilience, water quality improvement, and habitat enhancement.

Imagery: Nate Kauffman