EAST BAY DISCHARGERS AUTHORITY NATURE-BASED SOLUTIONS

Hayward Feasibility Study

Prepared for
East Bay Dischargers Authority (EBDA)

July 2022

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CHAPTER 1
Project Background and Introduction

This Nature-Based Solutions Feasibility Study for the Hayward Water Pollution Control Facility (WPCF) was prepared for the East Bay Dischargers Authority (EBDA) and the City of Hayward. The purpose of the Nature-Based Solutions Feasibility Study (Study) is to evaluate the potential for nature-based treatment systems to reduce nitrogen in wastewater effluent from the Hayward Water Pollution Control Facility (WPCF). The proposed nature-based treatment systems would be located within Hayward WPCF's former oxidation ponds that were built in the mid-1900s and are currently used for wet weather storage of treated effluent. The Hayward WPCF currently discharges effluent to San Francisco Bay via the EBDA pipeline. With the implementation of a nature-based solution, Hayward could reduce both nutrient loading and discharges to the EBDA pipeline in dry weather while also preserving the utility of the former oxidation ponds as wet weather storage.

The Hayward Area Regional Shoreline Planning Agency (HASPA) recently commissioned the Regional Shoreline Adaptation Master Plan (SCAPE 2021) that evaluated the risks of coastal flooding and sea level rise to Hayward shoreline and developed alternative adaptation approaches. The Plan evaluated potential risks with up to 7 feet of sea level rise considering regular high tides as well as 100-year storm surge. With 2 feet of sea level rise, the WPCF is potentially impacted by groundwater emergence while the WPCF effluent pump station, sludge decant pump stations, solar fields, and WPCF itself were found to be potentially impacted by tides and 100-year storm surge. The preferred mitigation alternative to sea level rise identified in the Master Plan includes a flood protection levee that extends from the West Winton Landfill northwest of the WPCF oxidation ponds to the Diked Baylands and Salt Ponds southeast of the oxidation ponds designed to protect the shoreline from up to 4 feet of sea level rise concurrent with a 100-year (1% annual chance of occurrence) Bay water level. The levee segment along the ponds includes a horizontal levee facing the bay with a wastewater treatment marsh in the former oxidation ponds area. A new Bay Trail alignment would also be routed along the top of the new flood protection levee. The proposed concept evaluated in this feasibility study is compatible with the HASPA Master Plan preferred alternative for this segment of shoreline.

The elevation of the perimeter levees around the former oxidation ponds is below the current 100-year flooding water level for SF Bay in some areas (Section 3.2), such that the ponds could be subject to extreme coastal flooding as mapped by FEMA (Section 3.5). Flood risk to the WPCF and adjacent shores will increase with sea level rise (Section 3.6, also see SCAPE 2021). A horizontal levee would raise the elevation of the perimeter levee between the oxidation ponds and Cogswell Marsh to provide more resilience to flooding and sea level rise.

The proposed nature-based solutions concept utilizes a combination of unit-process open water (UPOW) wetlands and a horizontal ecotone levee to improve flood protection and provide sea level rise resiliency / adaption while polishing wastewater effluent within the footprint of former oxidation ponds at the WPCF.

Hayward is currently planning a nutrient upgrade project for the WPCF. The nature-based concept proposed in this study could augment or reduce the need for certain upgrades by addressing a portion of the denitrification goals of the proposed treatment plant upgrade.

This report documents the concept for nature-based treatment at Hayward WPCF including background information on the WPCF and nature-based wastewater treatment methods. An evaluation of the concept feasibility is also provided, including estimates of treatment potential and cost.

CHAPTER 2
Project Goals & Objectives

Project goals and objectives were developed in coordination with EBDA and Hayward WPCF staff. The project goals (numbered 1, 2, 3, etc.) and related objectives (labeled a, b, c, etc.) are listed below.

3. **Increase Resilience of Hayward Shoreline to Sea Level Rise (SLR)**

    a. Develop design criteria for nature-based system (NBS) that increases SLR resilience of the Hayward shoreline fronting the WPCF.

    b. Identify additional areas in the vicinity of the former oxidation ponds that require upgrades to improve overall SLR resilience along Hayward WPCF.

4. **Maintain wet weather storage function in former oxidation ponds**

    c. Develop design criteria for NBS that maintains the wet weather storage function of the oxidation ponds (see Section 5.6)

5. **Examine the potential for nature-based treatment options at Hayward WPCF**

    d. Provide examples of existing functional NBS.

    e. Determine treatment levels possible with NBS within former oxidation ponds.

    f. Compare treatment potential of different NBS configurations (i.e. open water treatment wetland, vegetated treatment wetland, horizontal ecotone levee, combination) with proposed WPCF nutrient removal upgrades to determine potential for NBS to replace or reduce upgrade needed.

    g. Determine requirements for nitrification upstream of NBS.

    h. Develop estimate of probable engineering costs to construct and maintain NBS.

CHAPTER 3
Site Conditions

This chapter summarizes the information and data gathered to characterize existing conditions at the WPCF and potential future conditions with sea level rise. The first sections document site history, existing conditions, topography, property and utilities, and soil conditions at the nature-based treatment site. Following sections describe the range of water levels in the adjacent Cogswell Marsh and SF Bay including future projections for sea level rise at the site, and wastewater influent and effluent characteristics at Hayward WPCF.

3.1 Site History and Layout

Figure 1 shows aerial imagery taken in June 2018 at the site with property boundaries and streets in the vicinity of the former oxidation ponds. The site considered for nature-based treatment feasibility at Hayward WPCF consists of former oxidation ponds 3 through 7. Ponds 1 and 2 have been largely filled in with imported soils to provide for storage and handling of biosolids and for solar power generation. The remaining ponds (3 through 7) periodically receive secondary treated wastewater effluent during wet weather events when Hayward's daily limit of 15 million gallons per day (mgd) is exceeded, or when requested by EBDA to relieve hydraulic pressure on the effluent pipeline (Hayward pers. comm. 2021). Under extreme wet weather events when the capacity of the on-site equalization basin is exceeded, primary effluent may be combined with secondary effluent and discharged to ponds 3 and 4 only, however this is an extremely rare event and will be corrected during the WPCF Stage II Improvements Project. The ponds are accessible from the end of Depot Road through a locked gate at the southeast side of the ponds or from the WPCF just east of the sludge drying beds. The WPCF effluent channel flows northwest along the eastern boundary of the ponds, with the hypochlorite treatment facility located along the effluent channel between Ponds 4 and 5, and the Hayward Effluent Pump Station (HEPS) that discharges to the EBDA pipeline is located at the northeast corner of Pond 7.

SOURCE: City of Hayward, EBDA, NOAA, ESA

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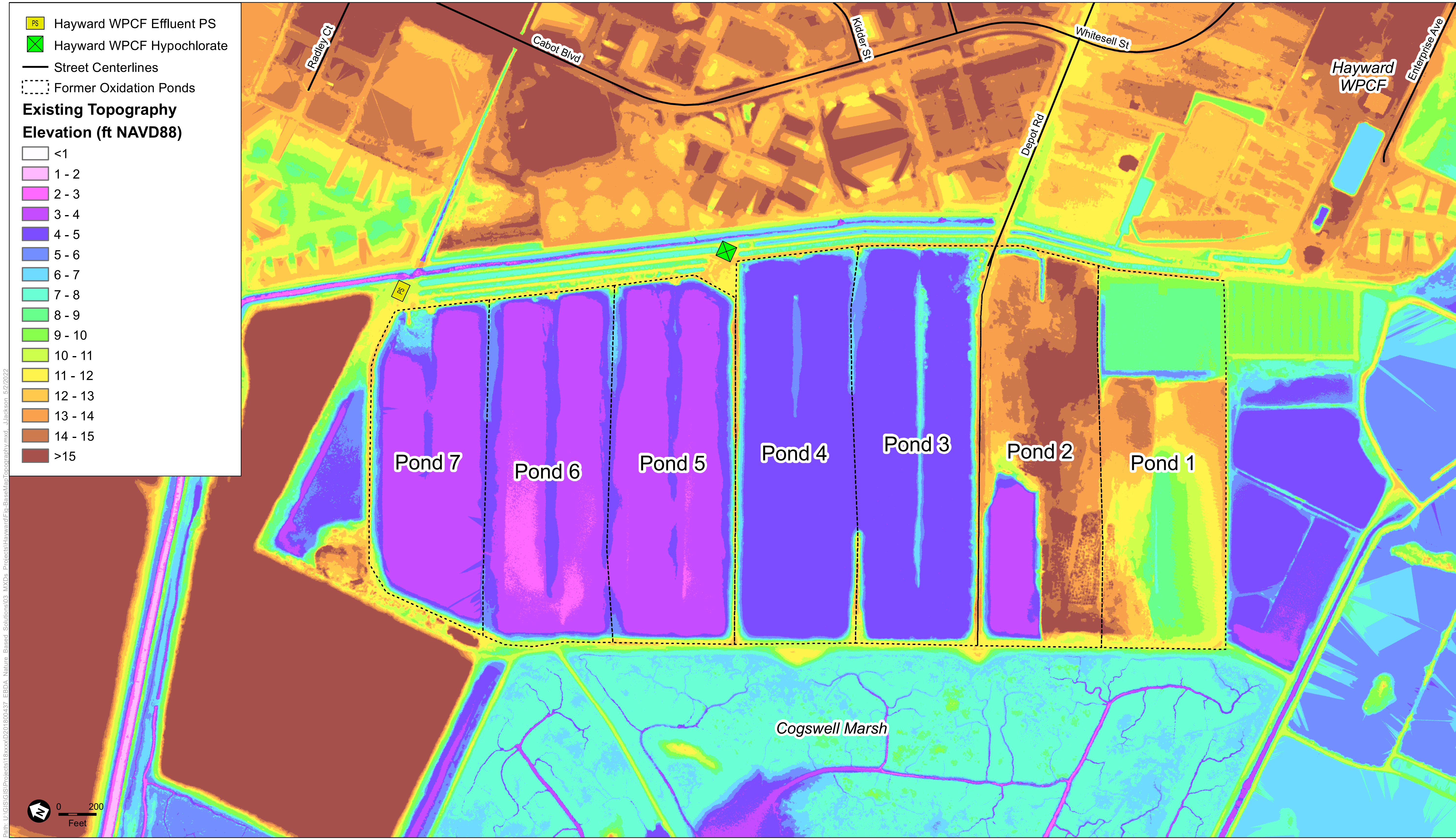
Figure 1
Project Basemap with Aerial Imagery

ESA



SOURCE: City of Hayward, ESA

NOTE: Elevations in Ponds 3, 4 and 7 are approximate, it appears water may have been present in these ponds during the early summer 2020 LiDAR flight.

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Figure 2
Project Basemap with Site Topography

ESA

3.2 Site Topography

Site topography including existing perimeter levee and pond bottom elevations were reviewed to determine existing coastal flooding potential, related flooding design criteria, wet weather storage capacity, and estimates of earthwork required for the conceptual nature-based treatment design alternatives. LiDAR flown in early summer 2020 was provided by the City of Hayward for use as existing ground topographic base map for the site, see Figure 2 above.

The existing ponds are approximately 1,800 feet long by 650 feet wide on average. Degraded internal berms divide each pond along the long axis. Pond bottom elevations range from 2 to 4 feet NAVD. Ponds 3 & 4 appear incrementally higher than Ponds 5, 6 & 7 in Figure 2 likely due to water in the ponds when the LiDAR was flown. However, the pond bottom elevations are expected to be fairly similar between the ponds. The levee separating the ponds from Cogswell Marsh has a crest elevation ranging from 10.2 feet to 13 feet NAVD, with numerous areas below the 100-year base flood elevation of 11 feet to 12 feet NAVD in the Bay and marsh. The levee along the north side of the ponds ranges in elevation from 11 feet to 12.5 feet NAVD, beyond which is a triangular pond and former sanitary landfill with max elevation approximately 35 feet NAVD. The east levee along the ponds ranges in elevation from 11.5 feet to 13 feet NAVD, with the WPCF effluent channel(s) east of the levee. The south perimeter levee abuts the mostly filled Pond 2 with crest elevation ranging 11.5 to 14.4 feet NAVD. See Section 4.5.2 for discussion on storage volumes in the ponds with respect to the nature-based treatment concept.

3.3 Utilities and Property Boundaries

Parcel and roadway data are presented in Figure 1. These data were downloaded from the City of Hayward's Open Data website to characterize the surrounding area and to develop the project basemap (data accessed at https://opendata.hayward-ca.gov/search?collection=Dataset). Approximate location information for the EBDA pipeline was provided by EBDA (see Figure 1 above), which generally runs along Depot Road northeast of the site. Other utilities data in the vicinity of the ponds are limited, however the following utilities are located around the ponds per Hayward input:

- A Shell oil pipeline and electrical duct banks are located in the levee road on the east side of the ponds.
- A landfill leachate line runs along the west access road that turns at the property corner and goes to between winter and summer sludge drying beds where it discharges to a CB.
- An air line for air pumps on the landfill that goes to HEPS.

Information for these facilities should be obtained for further study of the nature based concept in this report. In addition, there are some abandoned electrical facilities in at least two of the pond divider berms. There are also abandoned steel pipes for discharge of water and other concrete structures that are visible.

3.4 Soils

Soil type and quality within the former oxidation ponds is pertinent to the feasibility of treatment wetlands for Hayward WPCF. Soils in the ponds appear to be largely comprised of (Organic) Silty Clay, Silty Sandy Clay, Clayey silts and sands (Cooper & Associates 1963). Historically, primary and secondary effluent has been sent to the ponds.

There are different sediment quality standards for base and cover material for treatment wetlands (SFBRWQCB 2000). While these guidelines are geared toward beneficial reuse of dredged materials in wetlands, they provide important background information on key metals and chemicals that the Regional Water Quality Control Board (RWQCB) considers for wetland soil quality including required testing frequency for soils placed within wetland areas. Thus, understanding the sediment quality in the ponds will help the team determine what additional actions may be needed to create treatment wetlands. Specific analytical testing would answer the following questions:

- Geotechnical properties of the soil; can the soil be used to construct horizontal levee and/or internal berms?
- Presence of contaminants; are there contaminants that would preclude use of pond soils for cover or foundation material on the horizontal levee or leave as bed material in the ponds (albeit lined with geosynthetic liner)?

To better understand potential soils issues at the feasibility level, ESA developed recommendations for soil sampling and testing within the ponds see **Appendix A: Sediment Testing Memo** (ESA 2022).

3.5 Water Level Datums in San Francisco Bay

Understanding the range of coastal water levels at the Hayward site is important to inform planning for habitat function, wastewater treatment and flood protection of the treatment facilities. Coastal water levels were evaluated for the site using the most current and proximate estimates for extreme water levels to the Hayward WPCF ponds provided in San Francisco Bay Tidal Datums and Extreme Tides Study (AECOM 2016). Table 1 lists tidal inundation and flooding datums representative of the Hayward site that were extracted from Location Alameda-636 (Figure 3) located near the mouth of Cogswell Marsh. Mean higher high water (MHHW) is the average of the higher high water elevation of each tidal day observed over the 19-year tidal epoch (the present epoch used is 1983 to 2001). The other datums represent statistical water levels for San Francisco Bay adjacent to the Cogswell marsh ranging from the annual maximum water level (i.e. 1-year recurrence) to the 1% annual likelihood of occurrence (i.e. 100-year recurrence).

TABLE 1
TIDAL INUNDATION AND FLOODING ELEVATIONS AT HAYWARD WPCF PONDS (COGSWELL MARSH)

Datum	Elevation (feet NAVD88)
100-year	10.34
10-year	9.23
1-year	8.32
MHHW	6.99
Source: AECOM 2016, Location 636	

The datums in Table 1 are relevant to the study for several reasons:

1. To identify the most ecologically important elevation bands for transitional ecotone on a horizontal levee considered along the Cogswell Marsh-Pond levee alignment.
    a. e.g. MHHW up to the 1-year or 10-year (10%) recurrence Bay water level (i.e. annual storm or 10-year storm).
2. To identify the lowest elevation for the treatment seepage slope to allow for drainage and to prevent inundation of the treatment zone with saline waters.
    a. E.g. the average annual maximum (1-year) tide elevation is a conservative datum to design the treatment zone above, such that the treatment zone is not impacted by the highest tides of the year. Sea level rise over the design life of the treatment zone should be considered in advanced stages of the design.
3. To determine the minimum crest elevation of the horizontal levee based on the 100-year Bay flooding water level with accommodation for some extent of Sea Level Rise.

The ponds are currently mapped within the FEMA 100-year floodplain (11 feet Zone AE, Figure 4).

SOURCE: AECOM 2016

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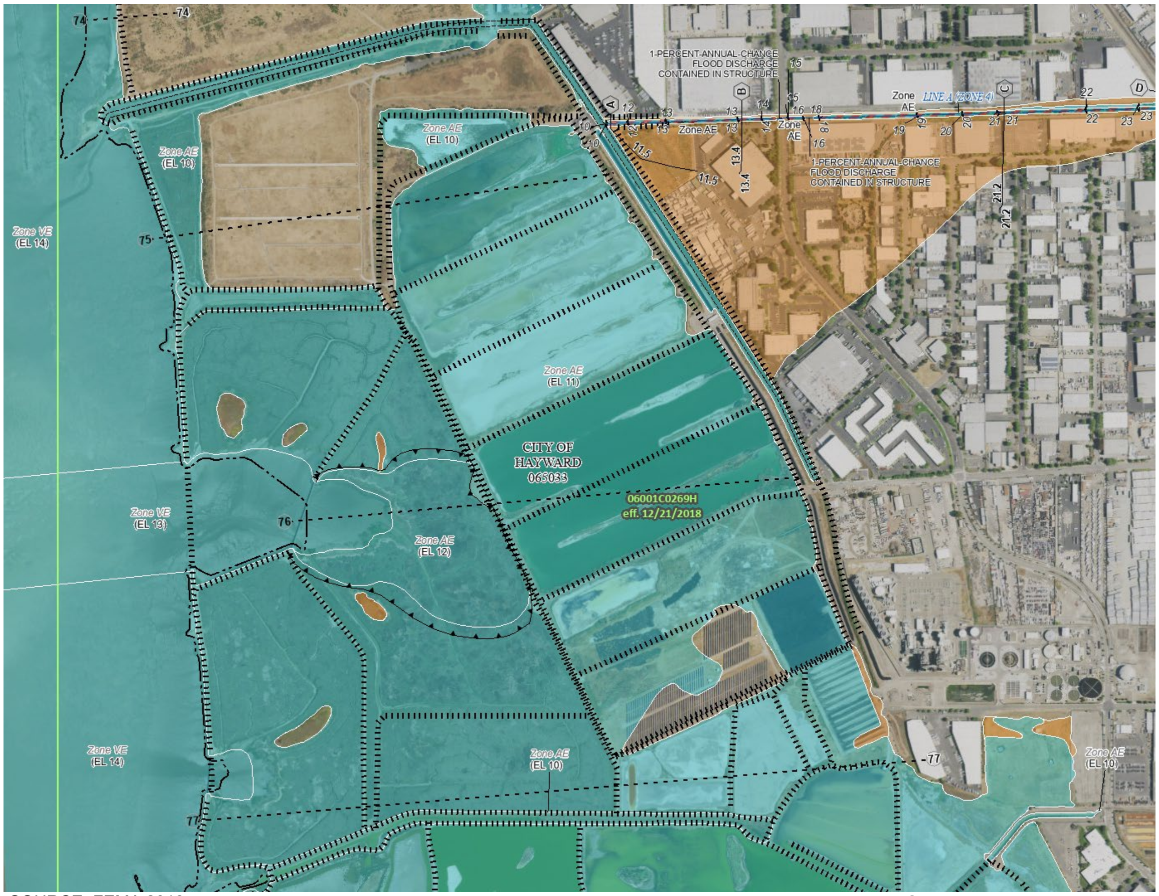
Figure 3
Modeling Output Locations for Tidal Statistics from San Francisco Bay Tidal Datums and Extreme Tides Study



SOURCE: FEMA 2018

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Figure 4
FEMA Hazard Zones at Hayward WPCF for existing 100-year (blue) and 500-year (orange) flood (without sea level rise)

3.6 Sea level rise projections in San Francisco Bay

Sea level rise poses a threat to much of the Hayward shoreline and specifically the Hayward WPCF. In particular, the WPCF may become exposed to coastal flooding with rising seas. Hayward Area Shoreline Sea-level rise projections were used to develop the horizontal ecotone levee design. The HASPA Master Plan (SCAPE 2021) was developed considering a projection of 4 feet sea level rise within 50-60 years. The latest state guidance on sea level rise from the CA Ocean Protection Council (CA OPC 2018) and the California Coastal Commission (CCC 2021) recommends probabilistic scenarios for planning with different levels of risk aversion and different emissions scenarios, see Table 2 below for projections of sea level rise at San Francisco for low, medium-high and extreme risk aversion. The CA OPC guidance recommends planning around four feet of sea level rise through 2075 based on the medium-high risk aversion projection (0.5%), or through about 2060 on the extreme risk aversion projection (considered for critical infrastructure such as wastewater treatment facilities[1]). To accommodate future sea level rise and differential settlement along the new ecotone levee, the levee will likely require periodic raises in the future. Levee geometry including initial height and future raising for sea level rise accommodation are described in Chapter 5.

TABLE 2
OPC (2018) STATE GUIDANCE: PROJECTED SEA LEVEL RISE FOR SAN FRANCISCO IN FEET

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)						*H++ scenario (Sweet et al. 2017) *Single scenario*
		MEDIAN	LIKELY RANGE			1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds…	*66% probability sea-level rise is between…*			*5% probability sea-level rise meets or exceeds…*	*0.5% probability sea-level rise meets or exceeds…*	
					Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.4	0.3	-	0.5	0.6	0.8	1.0
	2040	0.6	0.5	-	0.8	1.0	1.3	1.8
	2050	0.9	0.6	-	1.1	1.4	1.9	2.7
Low emissions	2060	1.0	0.6	-	1.3	1.6	2.4	
High emissions	2060	1.1	0.8	-	1.5	1.8	2.6	3.9
Low emissions	2070	1.1	0.8	-	1.5	1.9	3.1	
High emissions	2070	1.4	1.0	-	1.9	2.4	3.5	5.2
Low emissions	2080	1.3	0.9	-	1.8	2.3	3.9	
High emissions	2080	1.7	1.2	-	2.4	3.0	4.5	6.6
Low emissions	2090	1.4	1.0	-	2.1	2.8	4.7	
High emissions	2090	2.1	1.4	-	2.9	3.6	5.6	8.3
Low emissions	2100	1.6	1.0	-	2.4	3.2	5.7	
High emissions	2100	2.5	1.6	-	3.4	4.4	6.9	10.2
Low emissions	2110*	1.7	1.2	-	2.5	3.4	6.3	
High emissions	2110*	2.6	1.9	-	3.5	4.5	7.3	11.9
Low emissions	2120	1.9	1.2	-	2.8	3.9	7.4	
High emissions	2120	3	2.2	-	4.1	5.2	8.6	14.2
Low emissions	2130	2.1	1.3	-	3.1	4.4	8.5	
High emissions	2130	3.3	2.4	-	4.6	6.0	10.0	16.6
Low emissions	2140	2.2	1.3	-	3.4	4.9	9.7	
High emissions	2140	3.7	2.6	-	5.2	6.8	11.4	19.1
Low emissions	2150	2.4	1.3	-	3.8	5.5	11.0	
High emissions	2150	4.1	2.8	-	5.8	7.7	13.0	21.9

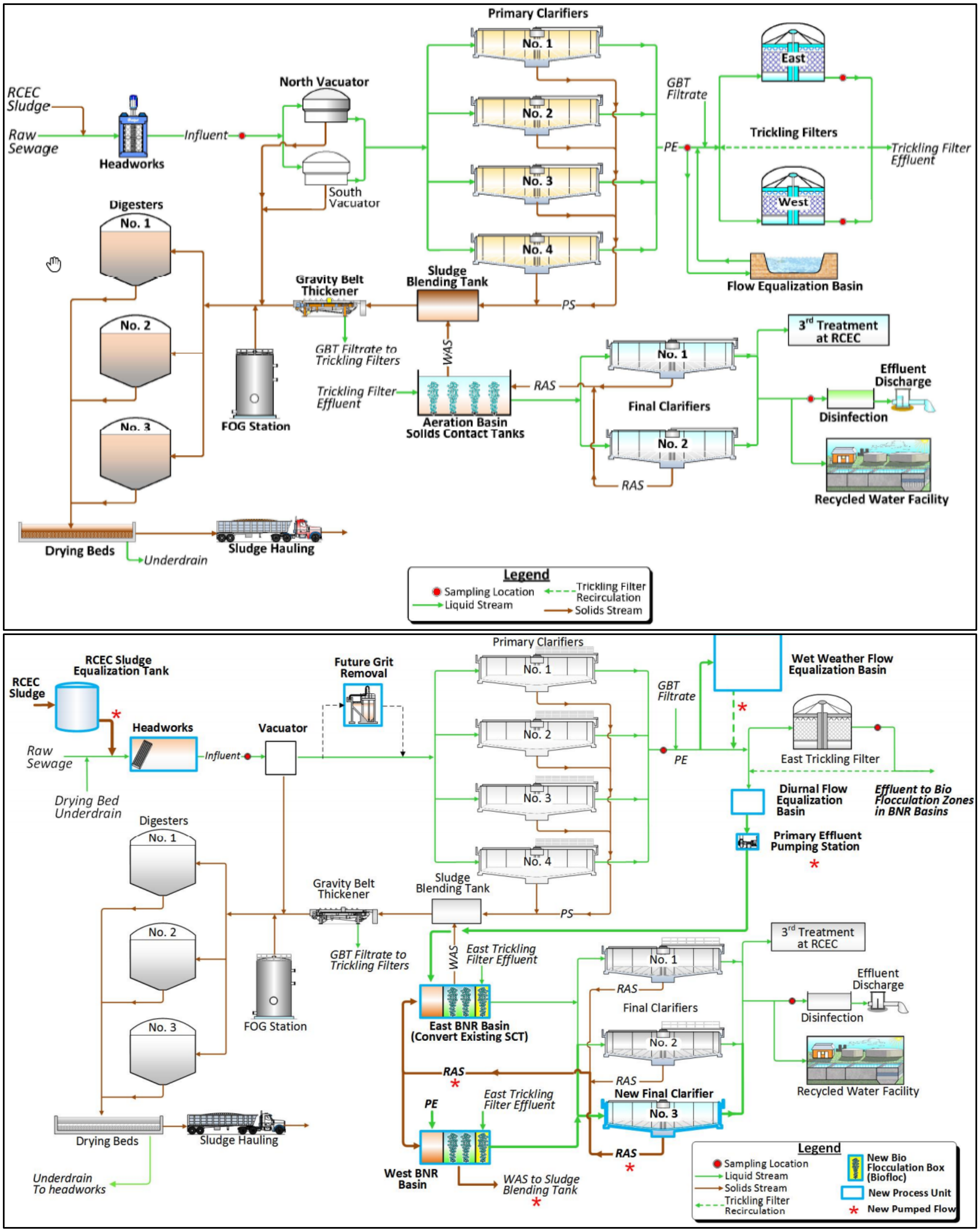
Source: OPC (2018),
Note: *Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates. Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.

[1] Critical infrastructure guidance from the CA Coastal Commission can be found at https://documents.coastal.ca.gov/assets/slr/SLR%20Guidance_Critical%20Infrastructure_12.6.2021.pdf

3.8 Wastewater Process, Influent and Effluent Characteristics at Hayward WPCF

This section summarizes the existing wastewater processes at Hayward WPCF. A benefit of a nature-based treatment system at Hayward is that it may reduce the need or capacity of a future nutrient removal project

A schematic of the current wastewater treatment process including planned Phase 2 upgrades is provided in the Hayward WPCF Phase II Facilities Plan (Black and Veatch 2020), reproduced in Figure 5 below. The specific implementation of the natural treatment systems within the existing WPCF process are discussed in Chapter 5.



SOURCE: Black and Veatch 2020

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Figure 5
Existing Hayward WPCF Treatment Process (top) and Proposed Phase 2 Improvements (bottom)

Effluent characteristics of dry weather flow rates and Total Inorganic Nitrogen (sTIN) concentrations are the key parameters for the feasibility analysis as a primary goal of the nature-based treatment systems is to provide advanced treatment of WPCF effluent during dry months when nitrogen loading to SF Bay is an issue of concern. The following details and assumptions for wastewater effluent were provided by Hayward WPCF staff:

- The treatment wetland and horizontal levee will receive wastewater that has not passed through the disinfection (sodium hypochlorite) process. Disinfection occurs approximately halfway down the mile-long effluent channel that runs SE-NW along the NE side of the ponds, between ponds 4 and 5. While not a driving parameter for analysis in this case, natural treatment systems can provide a level of disinfection (Silverman et al 2019a). The potential level of disinfection is not analyzed in detail in this feasibility study.
- Typical inflow rates, projected influent loads and concentrations and design planning effluent targets following implementation of the Phase 2 upgrades are outlined in Table 3 below. Current **average dry weather flow rate is 11.2 MGD.**
- The City plans to divert ~1 MGD of its treated effluent for recycled water by 2028. (David Donovan, personal communication, March 25, 2022). **Thus, the target discharge rate evaluated for this study is 10 MGD.**
- Nutrient loading rates in Hayward WPCF secondary and blended effluent are listed in Table 4 (2020 Facilities Plan, Figure 8-12). **Target effluent concentration for soluble total inorganic nitrogen (sTIN) is less than 20 mg/L following the planned Phase 2 upgrades.**
- Dry weather effluent loading record summary for 2014-2018 at Hayward WPCF with the current treatment process is listed in Table 5. (pers. comm. Suzan England, 2021)

TABLE 3
HAYWARD WPCF INFLUENT AND EFFLUENT CHARACTERISTICS (FROM BLACK AND VEATCH 2020)

CURRENT AND FUTURE INFLOW

YEAR	UNIT	AVERAGE DRY WEATHER	ANNUAL AVERAGE	MAXIMUM MONTH	PEAK DAY	PEAK HOUR
Average of 2007-2018	mgd	11.2	11.7	14.0	20.9	31.6
Projected for 2040	mgd	14.5	16.1	22.8	36.0	53.0

SUMMARY OF PROJECTED INFLUENT LOADS AND CONCENTRATIONS

PARAMETER	UNIT	AVERAGE DRY WEATHER	ANNUAL AVERAGE	MAXIMUM MONTH	PEAK DAY
$cBOD_5$	lb/day	48,586	50,942	57,627	81,549
	mg/L	402	379	303	271
TSS	lb/day	38,312	39,951	51,288	97,430
	mg/L	317	297	270	324
NH_3-N	lb/day	4,192	4,376	4,866	6,798
	mg/L	34.6	32.6	25.6	22.6
PO_4-P	lb/day	345	392	596	960
	mg/L	2.9	2.9	3.1	3.2

*lb/day=pounds per day, mg/L=milligrams per liter

PHASE 2 UPGRADES PLANNING LEVEL EFFLUENT TARGETS

EFFLUENT PARAMETER	TARGET CONCENTRATION
sTIN	<20 mg/L (dry weather average)
$cBOD_5$ *	<20 mg/L
TSS *	<20 mg/L

*The design basis is to achieve the target sTIN limits in accordance with the 2nd Watershed Permit. The TSS and CBOD5 targets presented in the table above are integral to achieving the sTIN objective.

TABLE 4
SECONDARY AND BLENDED EFFLUENT LOADING RATES AT HAYWARD WPCF

Constituent	Trickling Filter Effluent (mg/L)	Blended Effluent[1] (mg/L)	Note
sTIN	34	20	soluble Total Inorganic Nitrogen
NOx-N	< 0.5	7	Nitrate/nitrite
NHx-N	34	13	Ammonia

Source: Black and Veatch WPCF Phase II Facilities Plan, Figure 8-12.

1. Phase 2 Biological Nutrient system blended with secondary effluent

TABLE 5
DRY-WEATHER EFFLUENT LOADING RECORDS AT HAYWARD WPCF FOR THE PERIOD 2014-2018 (HAYWARD 2021)

	COH INFLUENT Flow		NH3-N Eff (COH)	Nitrate Eff (COH)	COH TIN
			2053	14144	
	MGD	LPD	mg/L	mg/l	mg-N/L
May '14	11.47	4.34E+07			
Jun '14	11.48	4.35E+07	29	2.85	31.85
Jul '14	10.76	4.07E+07	28.30	2.95	31.25
Aug '14	10.39	3.93E+07	29.67	2.24	31.91
Sep '14	10.33	3.91E+07	29.78	1.76	31.54
May '15	10.39	3.93E+07	25	7.52	32.52
Jun '15	10.27	3.89E+07	33.67	3.08	36.75
Jul '15	10.12	3.83E+07	29.56	5.52	35.08
Aug '15	10.41	3.94E+07	28	4.45	32.45
Sep '15	10.03	3.80E+07	26.3	4.87	31.17
May '16	9.20	3.48E+07	19.88	8.09	27.97
Jun '16	10.52	3.98E+07	22.7	6.73	29.43
Jul '16	10.24	3.88E+07	22.13	6.89	29.02
Aug '16	9.79	3.71E+07	24.11	6.24	30.35
Sep '16	10.01	3.79E+07			
May '17	11.74	4.44E+07	22.7	3.28	25.98
Jun '17	11.22	4.25E+07	23.5	4.96	28.46
Jul '17	10.47	3.96E+07	22.13	7.44	29.57
Aug '17	10.72	4.06E+07	24.88	4.65	29.53
Sep '17	10.89	4.12E+07	26.75	2.4	29.15
May '18	11.06	4.19E+07	23.4	5.04	28.44
Jun '18	10.74	4.07E+07	27.25	3.99	31.24

CHAPTER 4
Nature-based Treatment Systems Background

This chapter summarizes the typical natural treatment systems used for wastewater, conceptual alternatives development for the Hayward site and evaluation of the concept alternatives to address the project goals and objectives.

Wetland treatment systems are used around the world for wastewater treatment from municipal, mining, and other sources. Wetlands are some of the most biologically productive ecosystems on earth that provide habitat to a range of plants and animals. Due to the high rate of biologic activity in wetlands, they can transform wastewater pollutants into harmless byproducts and nutrients for additional biologic productivity at a relatively low cost compared to conventional wastewater treatment technologies.

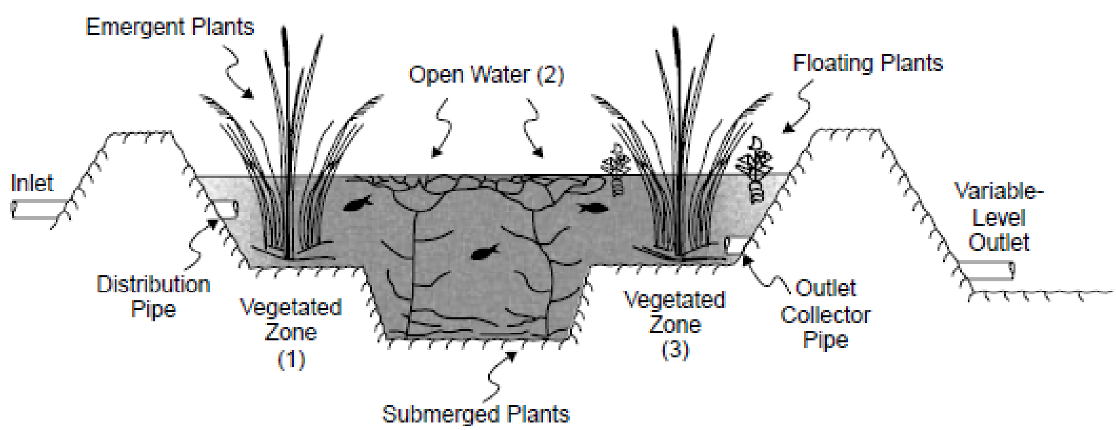
Relevant nature-based systems for wastewater treatment include the following:

- **Free water surface** (FWS) wetlands with a mix of open water and vegetated zones of submerged, emergent aquatic plants and floating plants, lined or unlined
- **Unit-process open-water** (UPOW) wetland ponds with a shallow, vegetation-free water column that are typically lined to prevent emergent vegetation growth
- **Vegetated submerged bed** (VSB) systems that utilize a bed of material (e.g. gravel) planted with wetland vegetation, also referred to as Horizontal subsurface flow (HSSF) wetlands and include the horizontal levee concept which incorporates a gently sloped vegetated submerged bed
- **Vertical flow** (VF) wetlands that distribute water on the surface of porous medium planted with wetland vegetation with treatment provided as water infiltrates the medium into the root zone. VF are not applicable at Hayward given site conditions.

This feasibility study considers FWS, UPOW and VSB systems. Treatment potential is summarized for each of these three systems in terms of Nitrate (NO_3^-) reduction, the primary wastewater constituent of concern for this feasibility study. Treatment potential of natural treatment systems is documented in peer reviewed journal articles on case studies as well as academic and government-authored design manuals. Treatment efficacy is reported in these studies as the k20 value. The k20 value is the treatment potential at 20 degrees Celsius that studies report to facilitate comparison of results to different temperature regimes (treatment processes are temperature dependent).

4.1 Free Water Surface Wetlands

Free water surface (FWS) wetlands include open water areas, floating aquatic vegetation, emergent vegetation or submerged vegetation and may be contained by berms and liners. Treatment processes provided in FWS wetlands include sedimentation, filtration, oxidation, reduction, sorption and precipitation (dilution) as water flows through the wetland. FWS wetlands are not typically used for secondary treatment because of the potential human exposure to pathogens in the wetlands and are thus typically used for the advanced treatment (or "polishing") of effluent from secondary or tertiary treatment processes. In addition to water quality treatment functions, FWS wetlands provide added benefits of wildlife habitat and recreational value for humans. Figure 6 shows a typical profile view schematic for a FWS wetland. FWS wetlands are commonly constructed as cells in series and can be graded and vegetated in various configurations. Two example FWS wetland units are shown in Figure 7 at two sites in the Imperial Valley, CA that treat surface water that is polluted by nutrients, pesticides, heavy metals, pathogens, and suspended sediments from agricultural runoff. These two systems employ sedimentation ponds upstream of the FWS wetland cells that use different configurations of open water and vegetated areas within the cells. Sedimentation is needed in this example since flows diverted from surface water sources contain sediments. Sinuous cells have vegetated bands stemming from alternating sides of the cell similar to baffles to create a sinuous open water flow path. Cross-banded cells consists of alternating bands of shallow vegetation and deeper open water zones that span the entire width of the cell. Pond-island cells have a natural appearance consisting of vegetation fringes and islands with open water.



SOURCE: USEPA 2000

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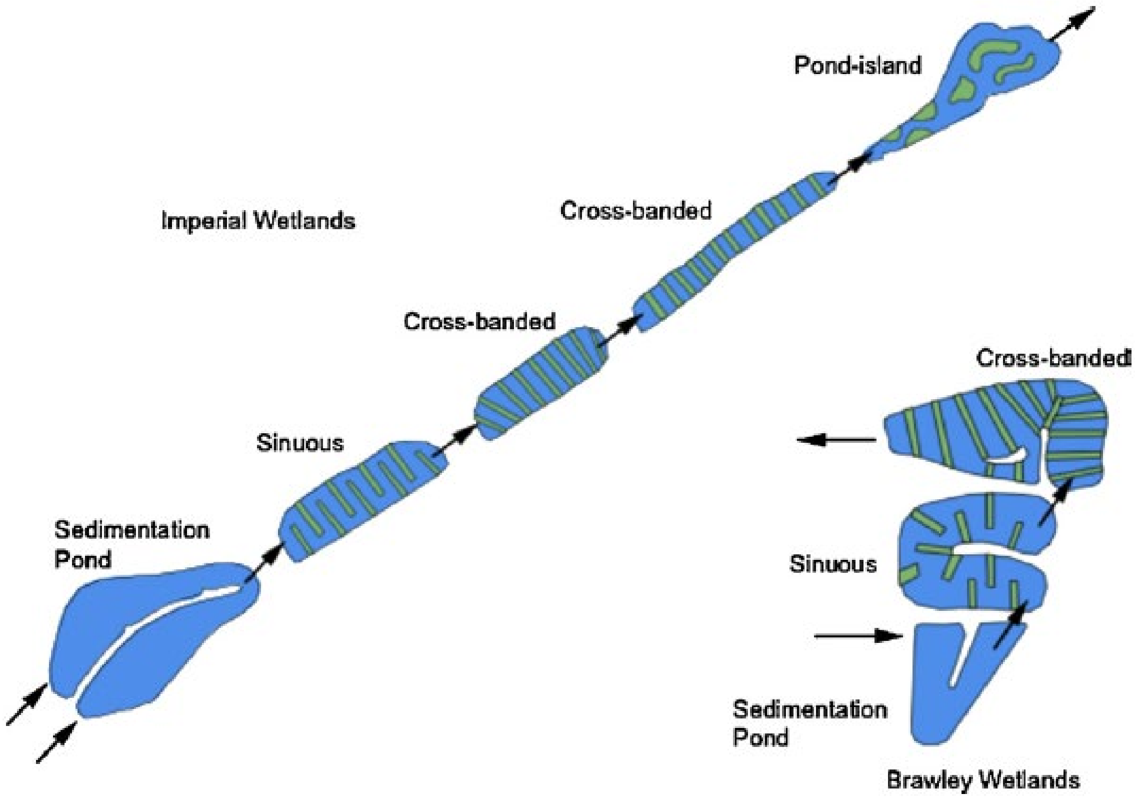
Figure 6
Profile Schematic of a Three-Zone FWS wetland cell



SOURCE: Kadlec et al 2010

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Figure 7
Schematic layouts of the Imperial and Brawley wetlands

Design and operations of FWS wetlands is well documented in a technology assessment by EPA (2000) that includes the following recommendations to optimize performance as part of wastewater treatment systems:

- Use distributed inflow and outflow structures. Design outlet to allow complete draining of wetland if needed.
- Use berms with 3:1 side slope with at least 2 feet of freeboard. Perimeter/external berms should be 10 feet wide at crest, internal berms can be narrower. Berms should be tall enough to contain design flows and account for deposition of solids and organics, and consider protection from animals and root penetration.
- Configure wetland cells in series of 2-3 at a minimum.
- Utilize emergent plants such as Scirpus and Typha.
- Existing natural site soils with permeability less than approximately 10^{-6} cm/s are generally adequate as an infiltration barrier. For site soils with higher permeability, some type of liner material is required.
- Routine operation and maintenance requirements for wetland systems are similar to those for oxidation pond systems, and include hydraulic and water depth control, inlet/ outlet structure cleaning, grass mowing of berms, inspections of berm integrity, wetland vegetation management, vector control, and accumulated solids management if required.
- Vegetation and detritus removal every 15-20 years is typical.

Additionally, FWS wetlands require nitrified effluent to allow for the use of mosquito fish to help limit mosquito production within the wetlands.

4.1.1 Treatment potential in FWS wetlands

Treatment potential for FWS wetlands is summarized below from select publications.

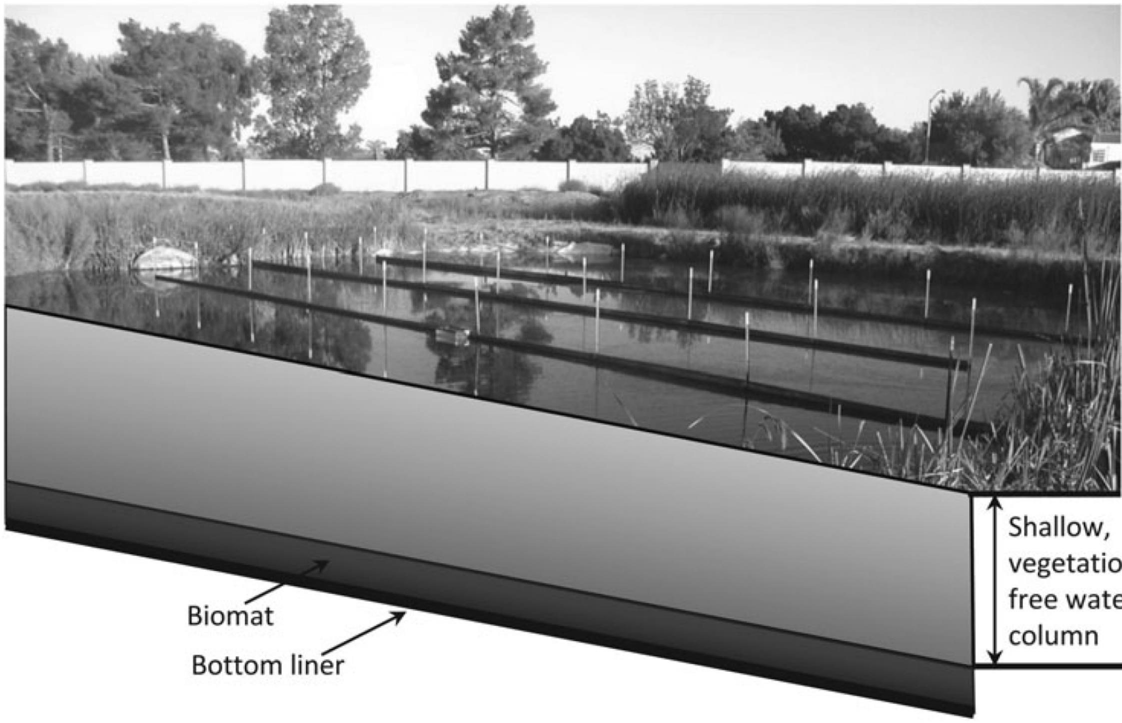
Treatment Wetlands (Second Ed.) (Kadlec and Wallace 2009). This book presents a synthesis of treatment wetland science and design. In a review of 66 studies of nitrate-dominated treatment wetlands, nitrate was reduced by 52% on average (ranging from 11% to 97%), with an average k20-value of 44.3 m/yr for nitrogen reduction.

Water quality performance of treatment wetlands in the Imperial Valley, California (Kadlec et al 2010). Two demonstration wetland systems were studied for over four years, tracking treatment processes for wastewater constituents resulting in total nitrogen concentration reductions ranging 50% to 73% between the two systems. Although these systems treated surface waters polluted by agricultural runoff, the treatment processes for nitrogen reduction are the same for wastewater.

Constructed Wetlands Treatment of Municipal Wastewaters (US EPA 2000). This manual describes constructed wetland types, treatment capabilities (but not specific rates), design approach, operation and management requirements and case studies for FWS wetlands and VSB systems.

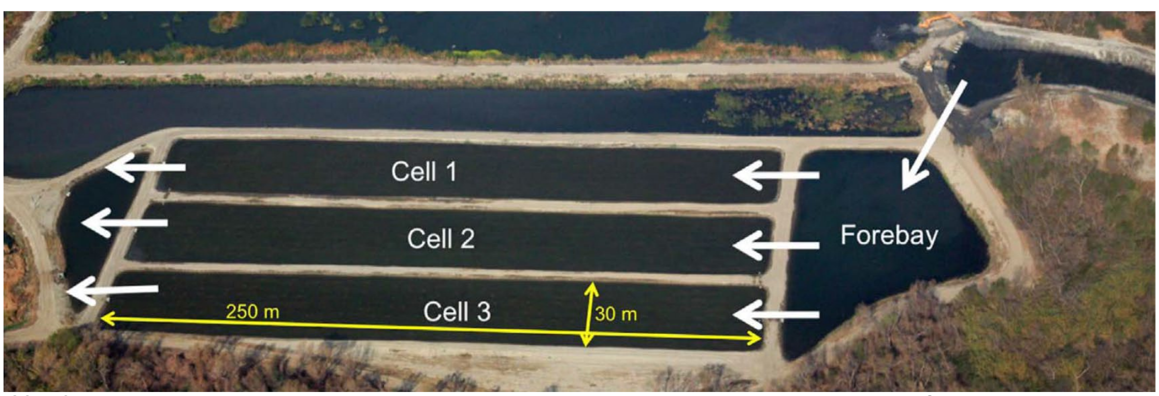
4.2 Unit-process open-water (UPOW) Wetlands

Unit-process open-water wetlands are designed to promote sunlight and biological water treatment processes. Treatment processes promoted in UPOW wetlands include photolysis and biotransformation of chemical contaminants (including trace organic compounds), photo-inactivation of microbial contaminants, and biological removal of nitrate (e.g., denitrification and anammox) (Silverman et al 2019b). UPOW wetlands are designed for shallow (~1 foot deep) and low flow velocities (~1 cm/s) to create near plug-flow conditions with a vegetation free water column that results in higher light penetration and increased hydraulic performance compared to typical vegetated wetlands. Bed liners are used in UPOW wetlands to prevent the growth of emergent vegetation. The definitive biologic component of shallow open-water wetlands is the biomat, a diffuse, porous, periphyton layer that naturally accumulates on the bottom of these systems and functions for nitrogen removal and biotransformation of trace organic contaminants (Silverman et al 2019b). These design features are shown in Figure 8 sketched on a photo of a pilot UPOW system in Discovery Bay, CA. Another example UPOW wetland system constructed in Corona, CA is shown in Figure 9.



SOURCE: Silverman et al 2019a D201800437.02 . EBDA Nature-Based Solutions Hayward Feasibility

Figure 8
Profile view showing features of a UPOW wetland system in Discovery Bay, CA



SOURCE: Bear et al 2017 D201800437.02 . EBDA Nature-Based Solutions Hayward Feasibility

Figure 9
Aerial Photo showing flow through the Prado Wetlands UPOW Cells in Corona, CA

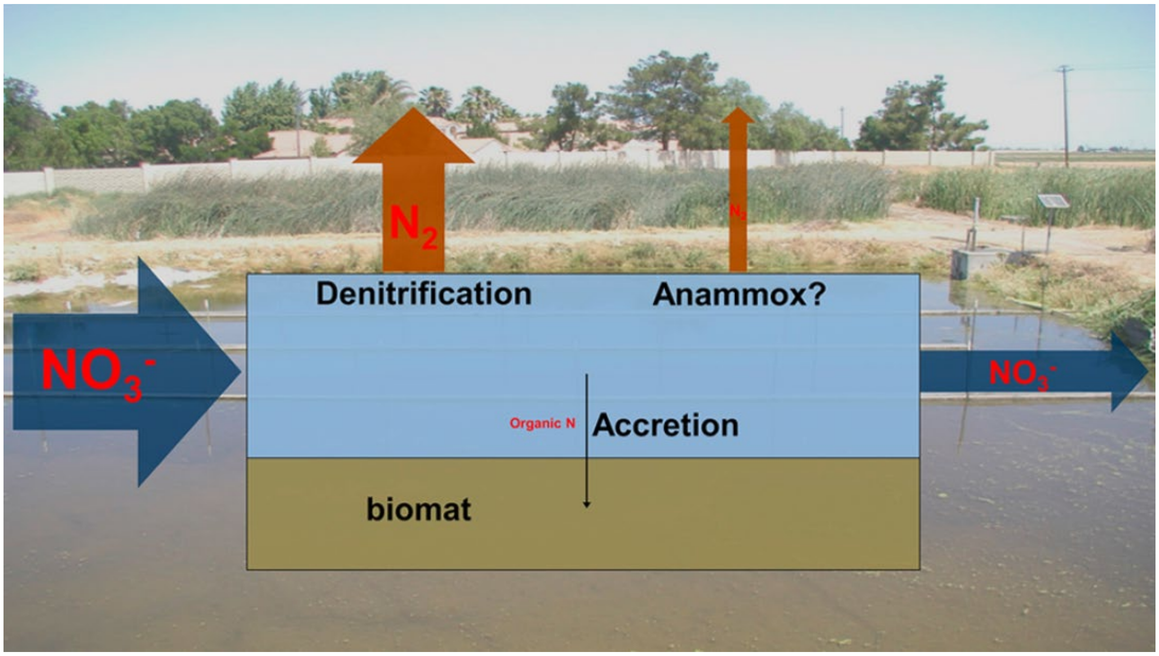
Design and operations of UPOW wetlands is documented in guidelines by Silverman and others (2019b) which include the following recommendations to optimize performance:

- Use distributed inflow structures spanning entire width of cells to reduce hydraulic short-circuiting and maximize treatment performance.
- Use long length-to-width aspect ratios of treatment cells.
- Set operational flow depth at 20-40 cm.
- Use multiple cells in series when possible to improve hydraulic performance.
- Reduce/manage vegetation on shores to prevent shading/vector issues.
- Remove duckweed immediately.
- Harvest biomat periodically (5-10 years), (approximately 2-3 months is needed to accumulate effective biomat thickness following removal).
- Modulate residence times (inflows) to reduce risk of algal blooms by minimizing residence time while meeting treatment objectives.
- Improve hydraulic performance with baffles (70% of cell width perform best), long aspect ratios, or sub-cells in series.

Similar to FWS wetlands, UPOW wetlands require nitrified effluent to allow for the use of mosquito fish to help limit mosquito production within the wetlands.

4.2.1 Treatment potential in UPOW wetlands

Guidelines for the Design and Operation of Unit-process, Open-water Wetlands (Silverman et al 2019b) provides a discussion on treatment potential in UPOW wetlands. The guidelines describe the characteristics of unit-process open water wetlands with case studies, details on mechanisms of contaminant removal and transformation, sizing and other design criteria for UPOW wetlands and operations and maintenance information. Two California UPOW case studies at wetlands in Discovery Bay and Corona are summarized in the guidelines. At the Discovery Bay UPOW wetland (Jasper et al 2014), average nitrate removal was 95% during summer and 30% during winter, with k20-value of 59.4 m/yr. At the Prado Wetlands (Bear et al 2017), nitrate removal was similar to the Discovery Bay wetlands throughout the year (>90% in summer, 30% in winter) with a k20-value of 65 m/yr. Overall, these guidelines and referenced studies have shown UPOW wetlands have higher nitrogen removal than constructed vegetated wetlands that receive nitrate-dominated wastewater effluent or agricultural runoff. Figure 10 illustrates the nitrogen removal processes that take place in a UPOW wetland, including denitrification, minor accretion (accumulation) and some annamox within the biomat (Jasper et al 2014).



SOURCE: Jasper et al 2014

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Figure 10
Nitrogen removal in UPOW wetland system at Discovery Bay

4.3 Vegetated submerged bed treatment systems

Vegetated submerged bed (VSB) (a.k.a. horizontal sub-surface flow (HSSF)) systems treat wastewater flowing through a planted medium under the ground surface. The primary components of a VSB system are (1) inlet piping, (2) a clay or synthetic membrane lined basin, (3) loose media filling the basin, (4) wetland vegetation planted in the media, and (5) outlet piping with a water level control system (USEPA 2000). Figure 11 shows a typical profile schematic for a VSB system. VSB systems have extra benefits in that they do not pose a vector (primarily mosquito production) or pathogen risk to humans and animals, as compared to systems with open water. The horizontal levee concept pioneered by the Oro Loma Sanitary District is a variation on the VSB/HSSF wetland approach where the system is set on a relatively flat slope (30:1) using gravity to drive hydraulic flows through the permeable medium. The horizontal levee is intended to address three critical issues related to sea level rise along the Bay by:

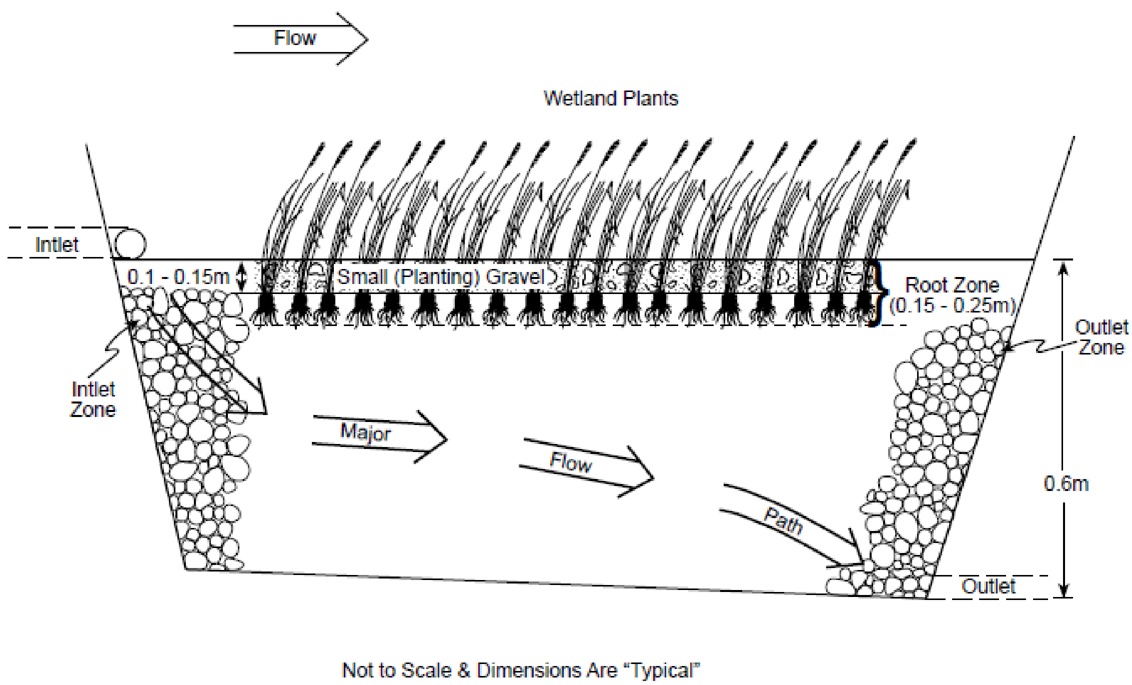
- Providing sea rise resilience by supporting fresh to brackish plant assemblages which can build organic-rich peat soils to keep pace with near-term rates of sea level rise while reducing wind-wave run-up which allows Bay front levees to be constructed with a crest 1 to 2 feet lower than conventional levees.
- Using treated wastewater to mimic the subsurface hydrology that historically supported transitional ecotones where hillslopes met tidal marshes at the Bay's edge while also improving water quality by polishing treated wastewater to remove nutrients and trace pharmaceuticals.
- Providing critical high tide refugia habitat for special status species like the California Ridgway's Rail and Salt Marsh Harvest Mouse while also providing transgression space for marsh habitats to move upslope with sea level rise.

The Oro Loma Horizontal Levee Demonstration project incorporated a relatively thin permeable layer (0.5 feet of gravel overlain by 0.5 feet of sand) and 1.5 to 2 feet layer of soil. The Demonstration Project employed two soil types – a fine grained sandy clay blend and a coarser grained clayey sand blend and three plant assemblages – freshwater marsh, wet meadow, and riparian scrub to test how differing approaches could address the wastewater polishing and sea level rise accommodation goals of the horizontal levee.

The design approach for the Oro Loma Horizontal Levee has been presented at a number of scientific conferences including in a session at the Restore America's Estuaries Conference in 2018 and the State of the Estuary Conference in 2017 where the project was awarded the outstanding environmental project. Additionally, the Oro Loma Horizontal Levee was the subject of Aiden Cecchetti's PhD dissertation **The Removal of Nutrients from Wastewater Effluent in Horizontal Levees** (Cecchetti, 2020) which presented the findings of the UC Berkeley research efforts at the site.

The horizontal levee concept is relatively new, and there are a number of guidelines that are taking shape, which will be further refined as the demonstration project tests new approaches and as the concept is implemented at other sites around the Bay. Key guidelines at this time include:

- Flow through capacity is dependent on the permeability (saturated hydraulic conductivity) & hydraulic slope of the permeable subsurface treatment zone.
- Treatment efficiency is dependent on residence time, with residence times of about 5 to 6 days showing greater than 97% denitrification within the permeable treatment layer.
- Wastewater polishing primarily occurs within the subsurface treatment zone, and surface flows should be limited to the extent possible.
- Incorporate slopes of 15H:1V or flatter.
- The permeable treatment layer should be 12-inches thick minimum and incorporate a permeable material blended with a labile carbon source (such as wood chips).
- The permeable material shall be comprised of primarily gravels and possibly coarse sand with minimal fine-grained material.
- To the extent possible, fines should be prevented from migrating into the permeable treatment layer.



SOURCE: USEPA 2000

D201800437.02 . EBDA Nature-Based Solutions Hayward Feasibility

Figure 11
Profile Schematic of a VSB treatment system

4.3.1 Treatment potential in VSB systems

Treatment potential for the VSB system employed in the horizontal levee was assessed in **The Removal of Nutrients from Wastewater Effluent in Horizontal Levees** (Cecchetti, 2020) which presented the results of over three years of monitoring at the Oro Loma Horizontal Levee Demonstration project. The results indicate that the permeable subsurface treatment zone provides ideal conditions for denitrification and plant uptake of nutrients, and promotes a variety of other processes including adsorption, mineral precipitation and anaerobic processes, that can remove trace metals, trace organic contaminants (e.g. pharmaceuticals), and pathogen indicators (e.g. F+ coliphage). Most contaminants were removed by greater than 90% within the first 16 feet of the subsurface treatment zone (~6-day residence time). Denitrification accounted for about 75% of total nitrogen removal, with about 14% of the nitrogen assimilated into microbial biomass in the subsurface, and the remaining nitrogen (~8%) removed by plant uptake. However, the horizontal levee did not remove phosphorus. Phosphate removal increased from about 11% to greater than 84% during the monitoring period, but production of organic phosphorous likely due to microbial turnover and export phosphorus from the top soil in the ecotone offset the removal of Phosphate from the treated wastewater. **Constructed Wetlands Treatment of Municipal Wastewaters** (US EPA 2000) describes constructed wetland types, treatment capabilities, design considerations, operation and management requirements and case studies for more conventional horizontal (flat) VSB systems.

CHAPTER 5

Nature-based Treatment System Concept Development and Evaluation

This chapter documents the development of a nature-based wastewater treatment concept for Hayward WPCF within the existing ponds footprint. The project team determined a preferred concept by examining the various potential treatment systems (see Chapter 4) including treatment potential and maintenance requirements. The preferred concept includes a combination of a) unit process open water treatment wetlands located within the existing ponds and b) a horizontal levee with vegetated submerged bed treatment system built along the existing levee berm that separates the ponds from the Cogswell Marsh and SF Bay waters. Sections 5.1 and 5.2 describe these two components of the preferred concept with graphics depicting the general conceptual designs of each component followed by discussion of the treatment potential for each component and key design and operational considerations. The treatment potential of the overall nature-based system concept is presented in Section 5.3. Probable engineering costs for construction are presented in Section 5.4. Operation and maintenance considerations are listed in Section 5.5.

5.1 Horizontal Levee

This section describes the development of the horizontal levee component of the nature-based system at Hayward WPCF. The nature-based system includes a horizontal ecotone levee to provide flood protection as well as wastewater treatment and habitat resiliency with sea level rise for the adjacent Cogswell Marsh. The existing levee separating the Hayward ponds from Cogswell Marsh and SF Bay is low (10.5 feet NAVD minimum elevation) compared to the current estimated 100-year tidal flood elevation of 10.34 feet NAVD and could be overtopped during extreme coastal flooding events. Additionally, the low areas in the existing levee limit wet weather storage capacity. The conceptual horizontal levee would be built to reduce existing flood risks and provide sea level rise resiliency for the WPCF as well as adjacent properties along the greater Hayward shoreline. Wastewater treatment/polishing would be provided with a vegetated submerged bed that provides treatment of subsurface flows. The flat, gradual slopes on the horizontal levee ecotone also provide refuge for marsh species during coastal flooding events as well as transgression space for marsh habitat to move upslope with sea level rise. Additionally, these flat slopes significantly reduce wind-wave run-up that could allow the levee crest to be built with incrementally less free board above the still water level.

Two levee configurations were initially developed based on the assumption that the WPCF would like to maximize treatment capacity through the treatment wetlands and horizontal levee natural treatment systems. As such, we anticipate that managing freshwater outflow through the system and out to the Bay will be an important permitting consideration. Delivering large volumes of polished wastewater could convert large areas of Cogswell Marsh from a salt marsh to a brackish marsh, which could negatively impact the existing salt marsh habitat. In order to maximize treatment capacity, we are proposing to incorporate a collection channel within the horizontal levee system to allow conveyance of polished wastewater from the horizontal levee and treatment wetlands to the Bay during low tides to help limit the area within Cogswell marsh that could be converted to brackish marsh. The two alternative configurations of the horizontal levee are described below:

Alternative 1 – Positioned to utilize the existing levee in place as part of the horizontal levee system, minimizing the amount of soil import required. This alignment includes a channel on the outboard side of the existing levee, creating a potential impact to the existing marsh while allowing polished effluent to be collected and routed to the Bay at low tide. Impacts associated with channel excavation would be mitigated by lowering the existing outboard levee to create new marsh habitat along the horizontal levee toe. Discharge of polished wastewater to the adjacent marsh would be limited to spring tides that are above MHHW generally occurring at the highest high tides that occur about 4 to 10 days per month around the full and new moons. During these higher high tides, polished wastewater would mix with saline water from the adjacent tidal marsh, and some of this mixed water would be discharged to the adjacent Cogswell Marsh as the tide recedes.

Alternative 2 – Positioned so that all construction would be within the oxidation ponds and existing levee footprint, minimizing all potential impacts to the existing marsh and providing a more robust separation between polished effluent and Cogswell Marsh. This alignment has a wider overall footprint and would require more imported soil to construct, but is anticipated to result in fewer permitting hurdles with the regulating agencies because the capture channel could be built inboard or within the existing levee and would only interact with the tides at water levels above the 10-year peak Bay water level with current sea level. This approach would limit all earthwork in and nearly all fresh/wastewater input to the adjacent marsh.

Figure 12 shows cross sections of the two potential horizontal levee configurations. For the purposes of this feasibility evaluation, Alternative 2 was selected to be combined with treatment wetlands because it minimizes potential impacts to the existing marsh and provides a conservative estimate of potential construction costs due to the extent of fill required.

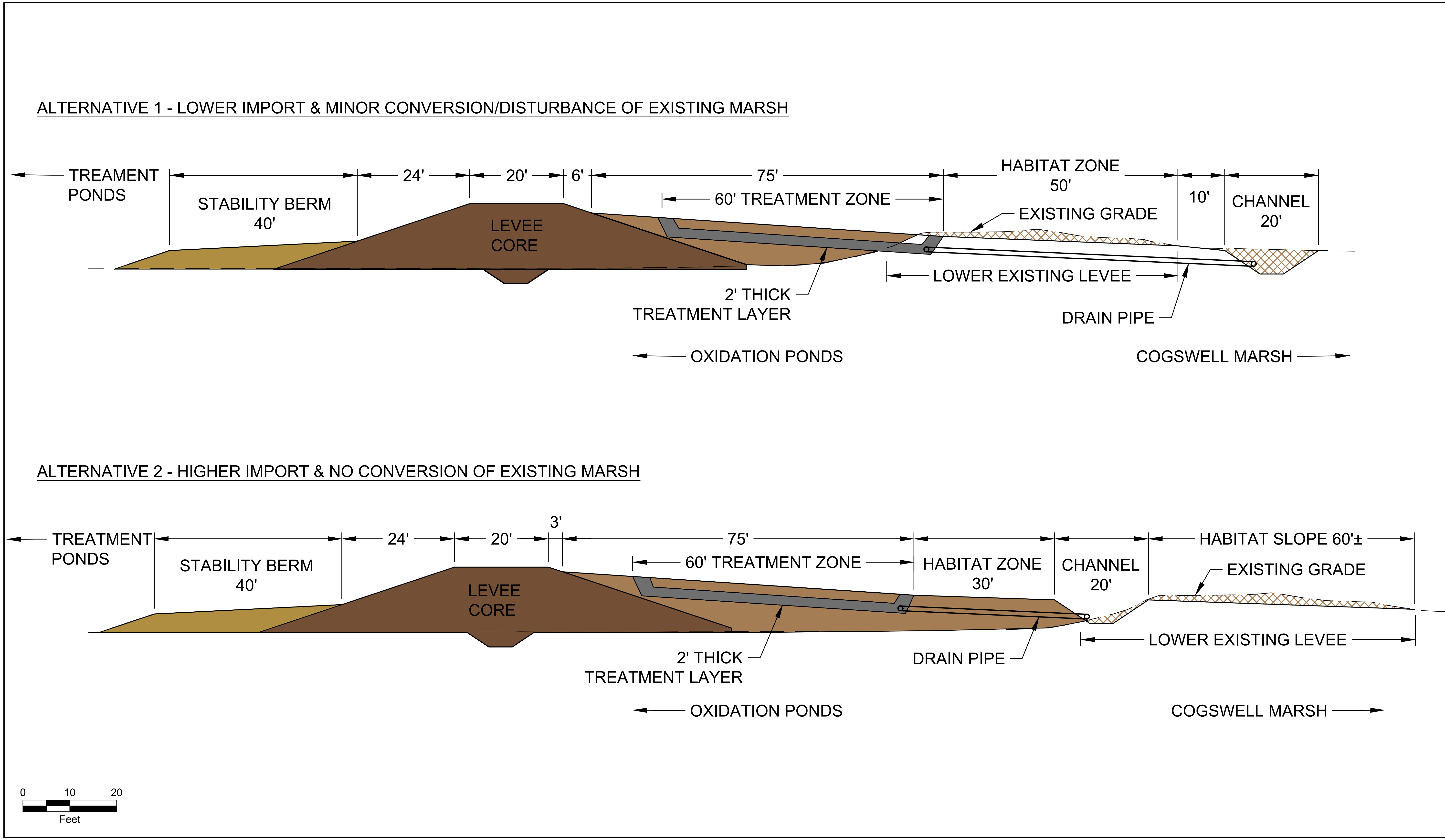


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Figure 12
Cross Section Views of Hayward WPCF
Horizontal Ecotone Levee Concept Alternatives

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The horizontal levee conceptual configuration includes the following components:

- A new ~2,700 LF (linear feet) levee core constructed with imported levee fill material (e.g. clay) built to a crest of ~EL 17' NAVD to accommodate:
  - 100-year tidal flood level (10.34' NAVD), plus
  - 4 feet of sea level rise,
  - 2 feet of freeboard, and
  - up to 0.66' of potential long-term settlement.
- Ecotone slope on the bay side and stability berm on the pond side, constructed with generic fill from the lowered existing levee, the pond bottoms, and/or imported material.
- Vegetated submerged bed (VSB) treatment zone of approximately 2,650 LF, constructed with permeable material (e.g. gravel) blended with wood chips as a labile carbon source to support microbial processes and potentially other materials like activated carbon, bio char, etc. to enhance wastewater polishing. The conceptual treatment zone design includes the following:
  - 2 feet thick permeable submerged bed which should provide a 400% increase in capacity as compared to the Oro Loma Demonstration project
  - 15H:1V slope which should further increase capacity by 200% as compared to the Oro Loma Demonstration project
  - Total anticipated capacity per linear foot – ~800% increase over the Oro Loma Demonstration project
  - 60 feet long submerged bed which is anticipated to provide about a 6.5-day residence time with flows greater than 400,000 GPD which should provide similar treatment efficiencies (>97% nitrogen removal) to those measured at the Oro Loma Demonstration project
  - Submerged bed that extends from ~EL 14' down to ~EL 10' NAVD (Alt 1) or ~EL 15' down to EL 11' NAVD (Alt 2) which sets it above the MHHW (EL 6.99' NAVD) while accommodating 3 to 4 feet of sea level rise before the toe would see regular inundation with salt water. However, it's anticipated that the submerged bed would continue to perform well even as higher high tides regularly inundate the toe of the treatment zone.
- Lowering of the existing levee berm to support transitional ecotone habitat between the treatment zone and the adjacent Cogswell Marsh
- Water control structures to deliver and collect flow:
  - A pump and pipe to convey treated wastewater from the existing effluent channel to the horizontal levee,
  - A series of turnouts with control valves, flow meters, and infiltration pipes that distributes flows along the top of the VSB zone,
  - Discharge pipes at the bottom of the VSB zone that convey polished effluent to a collection channel.
- A pipe/culvert with flap gate that allows flow to discharge from the collection channel through an existing tidal channel to the Bay. The existing culvert to Triangle Marsh would be closed to limit freshwater impacts to this existing marsh (see Figure 15).

- Vegetation planted for cover, treatment and habitat values, including:
    - Upland grasses planted on the stability berm and inboard levee slope as well as above and adjacent to the treatment zone
    - A mix of native plant assemblages along the treatment zone and habitat zone:
        - Riparian Scrub – blend of native willow, shrubs and sedges
        - Perennial Wet Meadow – native herbaceous sedges & rushes
        - Freshwater Marsh – bulrush and tule with sedges and rushes
    - Brackish/Salt High Marsh – gum plant, salt grass, etc.
    - Access road along the top of the levee constructed with aggregate base-rock and potentially surfaced for trail use.

The horizontal levee layout is depicted in plan-view in relation to the UPOW cells in Figure 13.

5.1.1 Treatment Capacity of Horizontal Levee

The potential treatment capacity of the conceptual horizontal levee was estimated using Darcy's Law, with saturated hydraulic conductivities for the proposed VSB treatment zone and ecotone soils measured at the Oro Loma Demonstration project as reported in **The Removal of Nutrients from Wastewater Effluent in Horizontal Levees** (Cecchetti, 2020). The research at the Oro Loma fine-tuned the flow through VSB treatment zone to maintain subsurface flows to maximize treatment efficiency. The research indicated that the hydraulic capacity of the VSB gradually declined over the monitoring period (~four years) as the VSB matured/clogged with fines & decaying plant material by 27% to as much as 50% from the overall average capacity depending on the ecotone soil composition and planting treatment.

For the Hayward Horizontal Levee, we would consider a number of design refinements to increase capacity and to maintain the capacity for a longer period. Key refinements include using more gravel sized permeable material with less medium to coarse sands and employing a separation fabric to limit intrusion of fine-grained material into the VSB treatment layer. We anticipate that these refinements are likely to further increase and extend potential treatment capacity within the VSB. Additionally, the performance of the horizontal levee could be maintained longer by incrementally rebuilding the ecotone subsurface layer. During the permitting process, a maintenance approach could be developed to reconstruct small reaches of the subsurface treatment zone (say 10-20%) each year to limit potential impacts to special status species by maintaining transitional vegetation along the rest of the horizontal levee while gradually rebuilding the treatment zone over a 5- to 10-year period.

However, to be conservative the estimated average and long-term treatment capacity based on measured saturated hydraulic conductivities and the conceptual VSB treatment zone geometry (slope, thickness/flow area, length, and materials) with Darcy's law indicate that potential capacity of the horizontal levee could range from an average of about 410,000 gallons per day and gradually declining down to about 280,000 gallons per day. Total nitrate removal is anticipated to be >97% at those flow rates. While these are conservative estimates, we anticipate that the potential flow through capacity is likely higher as additional design refinements to the permeable medium and separation fabric to limit migration of fines out of the ecotone top soil.

5.2 Treatment Wetlands

This section presents the concept for the treatment wetlands portion of the nature-based system at Hayward WPCF. Treatment wetlands concepts considered for the ponds area include unit-process open-water wetlands and vegetated free water surface wetlands in combination with the horizontal levee. Following discussions on the potential design and maintenance of each treatment wetland type, the project team focused on a preferred concept that utilizes only unit process open water wetlands with a horizontal levee.

The overall layout of the treatment wetlands was developed to minimize earthwork (i.e. cost) as much as possible, and thus was configured to utilize the existing configuration of the rectangular ponds and berms. The primary components required for the treatment wetlands include a distribution channel and water control structures (pipes, valves, and possibly pump(s), etc.), rectangular treatment cells that operate in parallel, outlet structures, a collection channel and discharge water control structure, and required berms that form the channels and treatment cells. The distribution channel would be constructed within the ponds along the existing Hayward effluent channel at the east side of the ponds, while the collection channel would be constructed along the west side of the ponds at the inboard toe of the proposed horizontal ecotone levee described in Section 5.3.

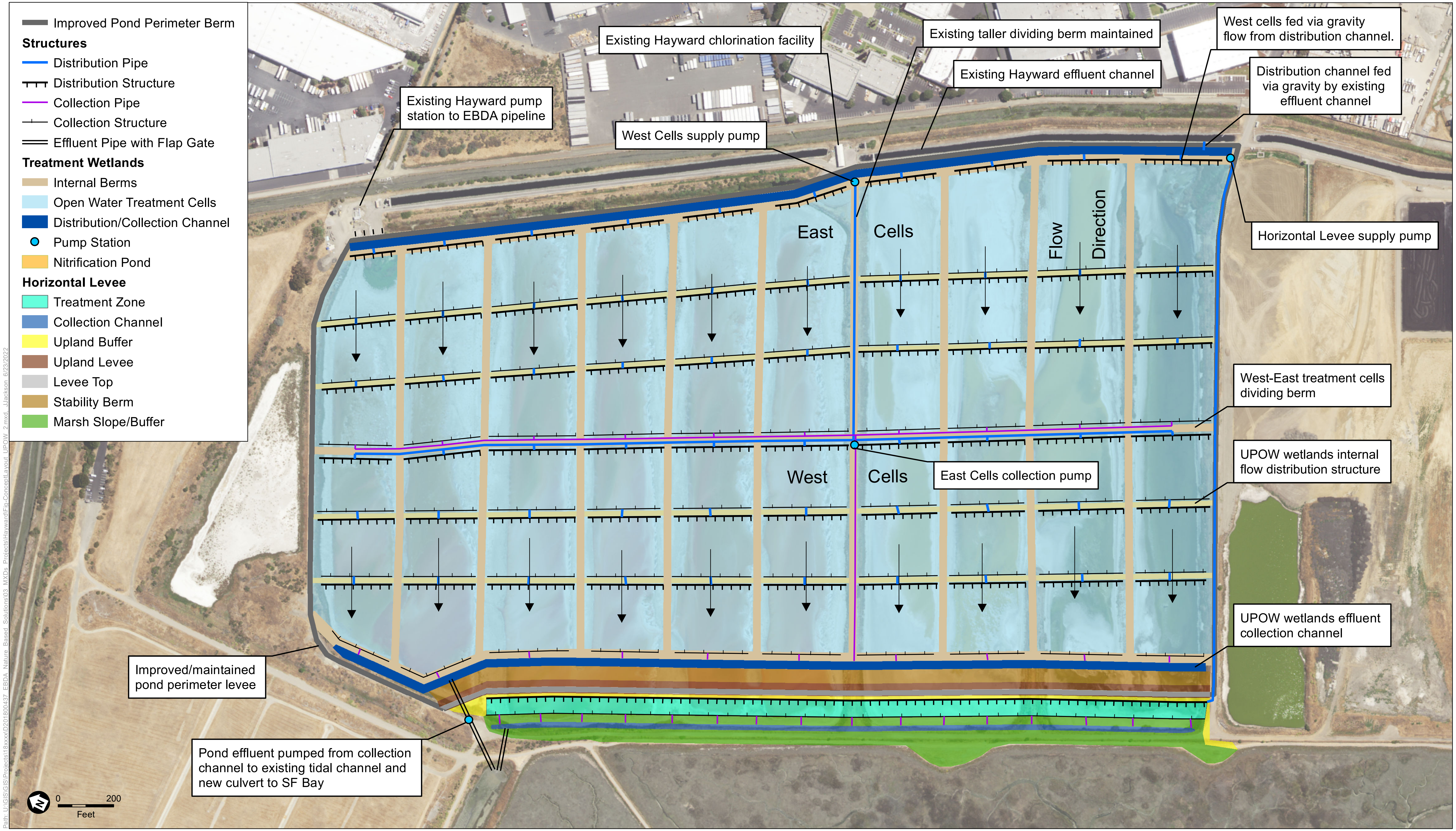
The shape and number of treatment cells was determined to optimize the pond hydraulics (flow) to satisfy conditions recommended by literature on UPOW systems (Jasper et al 2014). Primary criteria for flow through unit process open water treatment cells shall be slow enough to not disturb the accumulated biomat (~1 cm/s) with a short hydraulic residence time (3 days) to prevent emergent vegetation growth. Given an average daily design summer flow of 10 MGD (15.5 cfs) less about 0.35 MGD that would be routed to the horizontal levee VSB, 9.65 MGD of flow would be split into 16 treatment cells to achieve the criteria velocity (average 0.004 ft/s) and residence time (average 2.0 days). The concept layout includes 20 treatment cells in the ponds area to accommodate system maintenance; four of the twenty cells can be offline for maintenance at any given time while the system accommodates full summer flows. Each cell includes two intermediate cross berms that divides the cell into three segments to increase hydraulic performance.

The unit process open water treatment concept includes the following components:

- Diversion structure and pipe that diverts flow from the existing Hayward effluent channel via gravity to a distribution channel along the east side of the ponds area
- Inlet water control structures set flow rates into each treatment wetland cell. Distributed inflow structures spanning entire width of cells shall be used to reduce hydraulic short-circuiting and maximize treatment performance. These structures are assumed to consist of perforated pipe segments along the upstream and downstream ends of each cell.
- Flow through the treatment wetlands would follow near-plug flow conditions in UPOW cells with a depth of ~1 foot.

- Cells are separated by access berms 3 feet high above the bed elevation, 15 feet top width, 2:1 side slopes. The berm separating the distribution channel from the cells is higher above the bed elevation (~6 feet) to provide head for gravity fed distribution structures.
- Bed liner along the floor of each cell to limit growth of emergent vegetation potentially using a geo-membrane or geo-synthetic separation fabric or concrete base.
- Outlet water control structures should follow a similar design to the inflow structures to facilitate uniform collection of effluent across the entire wetland width. Outlet structures should also be designed such that:
  - the treatment wetland can be drained completely if needed
- Incorporates a self-cleaning fish screen to prevent mosquito fish from escaping the treatment wetlands.
- An outlet water control structure would be constructed at the end of the collection channel southwest through the horizontal ecotone levee to the existing tidal channel.
  - It's possible that the self-cleaning fish screen could be installed in the common outfall.
- To limit potential type conversion of Triangle Marsh (see Figure 15) to brackish conditions, the design team should consider closing the existing culvert that connects the existing channel to Triangle Marsh and constructing a new culvert through the levee berm directly to bay either as part of the proposed project or as an adaptive management measure.

The layout of the UPOW cells are shown in plan-view in relation to the horizontal levee footprint in Figure 13.



SOURCES: NOAA, ESA

EBDA Nature-based Solutions Hayward Feasibility Project

Figure 13
Nature-based Treatment Concept Layout
Unit Process Open Water (UPOW) Wetland Cells with Ecotone Levee

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5.2.1 Treatment potential for UPOW wetlands

Treatment potential for unit process open water cells was estimated using common first order decay equations used in the majority of models on constructed wetlands. These kinetic models use rate coefficients to define the speed of pollutant decay/removal in a system. The following first order decay equation relates inflow and outflow concentrations:

$$\frac{C\ out}{C\ in} = e^{-\mathrm{kA}/q}$$

Where q is the hydraulic loading rate in units of length per time and k_A is the decomposition constant in length per time. Nitrate removal is a temperature dependent biological process. The temperature effect on treatment kinetics is represented by the constant k_A which is determined using the modified Arrhenius equation:

$$kA = k20 * \theta^{T-20}$$

where k20 is the aerial removal rate at 20 degrees Celsius (68 degrees Fahrenheit) and θ is the temperature coefficient (θ = 1.12 +/- 0.02). The k20 and θ constants are typically determined via statistical analysis of study data. The values of k20 and θ used for this feasibility study were calculated by Jasper et al (2014) through monitoring denitrification of nitrified municipal wastewater effluent (typical influent nitrate concentration = 20.7 mg/L-N). Jasper and others (2014) determined k20 values for UPOW systems at Discovery Bay equaled 59.4 +/- 6.2 m/yr, while Bear and others (2017) found k20 equaled 64.9 +/- 3.2 m/yr at Prado Wetlands in southern California once the biomat reached maturity (k20 rates ranged from 32.1 to 39.0 m/yr for the Prado Wetlands cells during the first year of operation when the biomat was getting established and nominal residence time equaled 2 days).

Treatment potential for the UPOW wetlands concept is estimated to be 27% to 43% nitrogen reduction for the temperature range of 50 to 60 degrees Fahrenheit. This treatment reduction can be scaled by area as a ratio of approximately 13.3 acres per 1 MGD of wastewater effluent (including the collection/distribution channels and internal berms required for UPOW system).

Treatment potential for the Horizontal Levee is estimated at about 97% nitrogen reduction with flows ranging from 105 to 155 GPD/LF (77,000 to 112,000 GPD/acre) of subsurface treatment zone. For comparison, the Horizontal Levee requires about 8.9 to 13 acres of subsurface treatment zone to treat 1 MGD of wastewater effluent with an estimated 97% nitrogen reduction.

5.3 Treatment Capacity of Nature-based System Concept

ESA estimated the treatment capacity for the combined system concept at Hayward that utilizes UPOW wetlands and a horizontal levee in terms of nitrate removal. The estimate assumes that all organic nitrogen is nitrified in effluent entering the nature-based system, which could be accomplished with expanded facilities within the WPCF. Assumptions for the treatment capacity include:

- Effluent entering the nature-based system is fully nitrified. The estimate assumes that all organic nitrogen is nitrified in effluent by expanded facilities within the WPCF.
- Effluent average dry weather flow of 10 MGD (D. Donovan, pers. comm. 3/25/2022) with ~0.35 MGD routed to the Horizontal Levee/VSB system.
- WPCF effluent Nitrogen concentration of 34 mg/L as NO_3^- (see Table 4) is fully nitrified prior to entering UPOW wetlands and horizontal levee.
- The range of potential effluent treatment assumes a range of water temperatures in the UPOW ponds from 50 to 60 degrees Fahrenheit during summer months. Average effluent temperature from the Hayward plant is 73 degrees Fahrenheit (Black and Veatch 2020) so there is potential for higher effluent treatment rates than reported here depending on how the wastewater temperatures equilibrate across the treatment cells.

Treatment capacity in the UPOW cells ranges from about 27% average nitrate removal rate at 50 degrees Fahrenheit (which is expected to approximate removal over the fall through early spring months) to as high as 43% nitrate removal at 60 degrees Fahrenheit (expected to approximate removal over the warmest summer months). When considering that 0.35 MGD is anticipated to be routed through the Horizontal Levee/VSB with an anticipated 97% removal of nitrate, the overall nature-based system treatment capacity ranges from 30% to 45% nitrate removal. Assuming an influent nitrate concentration of 34 mg/L as NO_3^-, the combined system effluent nitrogen concentration may range from 24 mg/L as NO_3^- in colder months to 19 mg/L as NO_3^- in warmer months.

5.4 Cost Estimate of Nature-based Treatment Concept

ESA developed an engineer's estimate of probable construction costs to implement the nature-based solution described above. The cost estimate for anticipated elements of the UPOW treatment wetlands and horizontal levee ecotone are provided in Table 6 below. A detailed cost estimate is provided in **Appendix B**. A full lifecycle cost analysis is recommended for the next steps in the design process.

TABLE 6.
COST ESTIMATE SUMMARY FOR CONSTRUCTION OF NATURE-BASED TREATMENT CONCEPT

Work Item	Cost
Mobilization/Demobilization	$4,050,000
Site Preparation	$968,000
Earthwork	$10,211,000
Structures	$21,137,000
Materials	$7,729,000
Planting	$457,000
Construction Subtotal	**$44,552,000**
Construction Contingency (30%)	$13,366,000
Total Estimate of Probable Construction Cost	**$57,918,000**
Planning, Engineering, Legal, and Administration (15%)	$8,688,000
Owner's Reserve for Change Orders (5%)	$2,896,000
Engineering Support During Construction (3%)	$1,738,000
Total Estimate of Project Cost	**$71,240,000**

Note: Cost does not include operations and maintenance, required upstream nitrification, power costs, disinfection (if needed) and other unknowns.

5.5 Permitting Considerations for Nature-based Treatment Concept

This section presents high-level expectations and considerations regarding the anticipated permitting and environmental approvals for the preferred concept, which consists of unit-process open water (UPOW) wetlands combined with a horizontal ecotone levee.

Based on the anticipated key components of the preferred concept and their potential to require work in or impacts (whether temporary or permanent) to jurisdictional waters, a number of local, state, and federal environmental permits and approvals are likely to be required prior to construction and operation of the nature-based treatment concept. In addition, the project will be required to comply with CEQA, and possibly also NEPA, as briefly discussed below.

The concept evaluated in this report includes the following design elements that would help to minimize impacts to regulated resources:

- the proposed UPOW wetlands would be located in existing oxidation ponds that are not expected to be deemed jurisdictional or subject to regulation as waters/wetlands;
- the proposed horizontal levee would result in either no or minimal impacts to existing jurisdictional waters/wetlands;
- the majority of the proposed project's direct impact footprint is not expected to occur in lands that are occupied by or provide habitat for sensitive species;
- permanent 'loss' or adverse impacts from the project are expected to be minor (quantitatively and qualitatively), and primarily resulting from small water control structures that may be placed in the Bay or its tributary(ies);

- there would be no expected significant adverse environmental effects from the project; and
- the project would likely result in net long-term environmental benefits or 'lift' to a number of ecosystem functions and services (including: water quality, habitat diversity as provided on the levee slope, and sea level rise resiliency).

However, the complexity of the permit process will ultimately depend on the final project design and the resulting location, type, and extent of impacts. In addition, more detailed studies are required to determine the nature and extent of existing resources (for example whether sensitive species are found to be utilizing areas within the project footprint).

Environmental Permits and Approvals Anticipated to be Required: The following permits or approvals would likely be required, based on the anticipated key components of the preferred concept:

- USACE Section 404/10 Permit
- RWQCB Section 401 Certification
- RWQCB NPDES Permit/Permit modification
- CDFW Section 1600 LSAA
- BCDC Permit
- USFWS & NMFS Sec 7 FESA consultation
- CDFW CESA coordination (to confirm measures to avoid potential take)
- SHPO Sec 106 NHPA consultation

Note: This preliminary list of permits is based on the project concept described in this report and is intended for planning purposes only.

5.6 Design and Operational Considerations for Nature-based Treatment Concept at Hayward WPCF

Several design and operational considerations shall be noted for the successful implementation of the preferred nature-based treatment concept presented above. This section describes important considerations about the existing function of the ponds as wet weather storage, operations and maintenance considerations, as well as water quality requirements for WCPF flows entering the nature-based system and effluent discharge pathways.

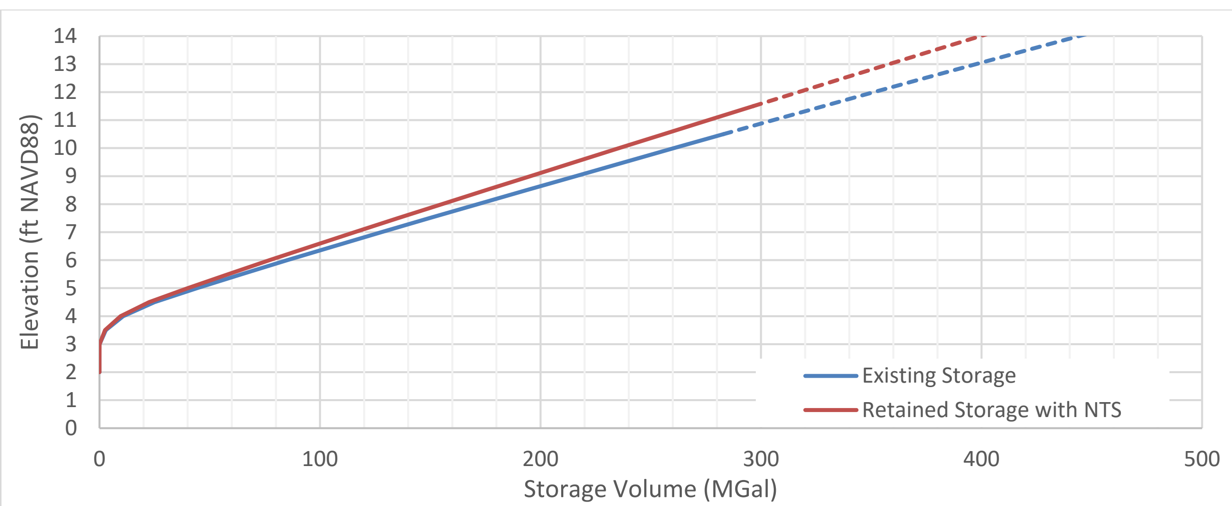
5.6.1 Ponds Wet Weather Storage Capacity

Hayward routinely uses the ponds to hold secondary effluent during the wet season when the EBDA pipeline is fully allocated. As part of EBDA, Hayward is allocated 15 MGD in the pipeline; the ponds are used when effluent discharge is above 15 MGD (David Donovan, personal communication November 2021), channel flushing and for EBDA pump station maintenance. Thus, an objective of the feasibility study is to develop nature-based treatment alternative designs that preserve the wet weather storage capacity provided by the ponds.

Using the LiDAR data (early summer 2020), ESA identified existing low points in the perimeter levees and calculated stage-storage curves for Ponds 3 through 7. Low points around these ponds are located on the southwest berm separating the ponds from Cosgwell Marsh (~10.5 feet NAVD) and along the north and east berms (11.5 feet NAVD). Based on 2020 LiDAR and an operational pond depth of 5 feet (Susan England, pers comm), existing storage capacity in the ponds is approximately 215 MG up to 9 feet NAVD (assuming bottom elevation of 3-4 ft NAVD) which provides 1.5 feet freeboard up to the existing minimum levee crest of 10.5 feet NAVD. Note that there appears to be water present in Ponds 3, 4, and 7 at the time of the 2020 LiDAR flight and thus the actual storage volume in the ponds may be slightly higher than estimated. Potential stage-storage volumes for the ponds are shown in Figure 14. Note that storage volumes shown at elevations above the existing levee crests (10.5 to 12.5 ft NAVD) assume vertical extrapolation above the existing levees.

With the construction of the wetland treatment system and horizontal levee the minimum levee elevation around the ponds is brought up to 11.5 ft NAVD to increase resilience to the 100-year bay water level (10.34 feet, see Table 1). Assuming an operational freeboard of 1.5 feet, the storage volume within the remaining ponds area could approach approximately 235 MG assuming they are filled to 10 feet NAVD – resulting an in increase in potential wet weather storage volume of up to 20 MG over existing conditions. If desired, storage volumes within the wetland cells/ponds area could be increased by raising the perimeter levees north and south of the ponds and the internal distribution/collection berms. Future study could provide a more detailed assessment of potential storage volumes using a preliminary design surface. Pumping is needed to fill the basins, we assume that the pumps included in the concept could meet this need.

An alternative approach to wet weather operations could be to utilize the ponds for their treatment function (i.e. send the appropriate flows through the ponds during wet season) while sending any flows above the operational capacity of the ponds to the EBDA pipeline.



SOURCE: NOAA Imagery, Hayward LiDAR, ESA

D201800437.02 . EBDA Nature-Based Solutions Hayward Feasibility

Figure 14
Existing Levee Elevations and Storage Volumes at Former Oxidation Ponds

5.6.2 Operations and Maintenance Considerations

Operations and maintenance considerations for the **unit process open water cells** include the following:

- Managing flow delivery to each cell to match individual cell capacity based on area and sampling results.
- Reduce/manage vegetation on shores to prevent shading/vector issues around the perimeter of the ponds.
- Remove duckweed immediately from cells. Duckweed can be managed by having large surface area to promote wind-blown transport to edges, to be removed as it accumulates.
- Harvest biomat periodically (5-10 years), approximately 2-3 months is needed to accumulate effective biomat thickness after disturbance/harvesting. Harvesting can be accomplished by increasing flowrates through the ponds to flush the biomat. Additional considerations include how to dispose of the dried biomat, and whether metals accumulate in the biomat.
- Modulate residence times (inflows) to reduce risk of algal blooms while optimizing residence time to meet treatment objectives.
- Maintain outfall protection for areas to receive wet weather equalization flows. The analyzed concept assumes that the pond areas would be filled during wet weather events utilizing the infrastructure in place to operate the ponds normally. Additional rock or other armoring structures at wet weather outfalls may be needed to facilitate more rapid filling and draining of the ponds areas for wet weather storage.
- Following use for wet weather equalization storage, there may need to be some remedial efforts to clear the internal (lower elevation) access roads and levee/berm slopes of residues from storage of primary or partial secondary treated effluent.

Biomat disturbance: Hydraulics will be a concern for biomat stability in open water treatment cells when the area is used during the wet season to store Hayward effluent. If the biomat is disturbed considerably, there may need to be additional start-up period after flooding the ponds. The pond hydraulic infrastructure should be designed and operated accordingly to minimize disturbance of the biomat. This could include use of outfall protection at each wet weather outlet (e.g. splash pad, rip-rap armoring, or hydraulic diffuser) and considerations on how wet weather flows would be transferred from cell to cell.

Operations and maintenance considerations for the **horizontal ecotone levee** include the following:

- Fine tuning flow balancing across the horizontal levee distribution pipeline which is likely to have ~16 turnouts to distribute flows across the ~2,600 LF horizontal levee.
- Monitoring flows along the levee cells to identify surface flows that exceed the capacity of the VSB treatment zone, and adjusting flowrates to maintain subsurface flow conditions.
- Potentially adjusting flows with the seasons – increasing flows in summer when evapotranspiration is high and decreasing in winter to maintain treatment efficiency.
- Managing discharge pipe valves to adjust how much shallow surface flows to apply to habitat zones below treatment zones.

- Monitoring vegetation establishment and limiting non-native invasive plants along the treatment zone and habitat zones.
- Monitoring of adjacent marsh areas to identify any areas of conversion of existing salt marsh to brackish conditions, and reducing flows and/or increasing discharge through the discharge pipes vs. surface flow to reduce freshwater inputs to the adjacent marsh.
- When flow capacity declines below tolerable levels, remove and reconstruct the VSB treatment zone in select cells. Over time, anticipate that cells might need to be reconstructed after about a decade with reconstruction of alternating cells over number of construction seasons to limit impacts to habitat areas.

5.6.3 Nitrification of effluent prior to nature Based Treatment system

All treated wastewater effluent from Hayward WPCF that flows through the treatment wetlands and likely the horizontal levee will require a nitrification process to convert ammonia prior to discharge into the treatment wetlands. This is critical for the survival of mosquitofish that will aid in reducing vectors in the treatment wetlands. As discussed with the Hayward/EBDA project team, the conceptual designs developed for this project assume that nitrification will require upgrades to the WPCF treatment process.

5.6.4 Freshwater discharge from nature-based treatment systems

Implementation of nature-based systems at Hayward will result in a large volume of freshwater to discharge to SF Bay. To minimize impacts to existing salt marsh habitat in Cogswell Marsh and Triangle Marsh, new and modified water control structures will be needed along the effluent flowpath to SF Bay. Figure 15 below shows the channel and marsh network through which NBS effluent would be directed. The straight channel between Cogswell Marsh and the closed landfill is currently tidally connected to SF Bay via culverts through Triangle Marsh. To support increased flowrates and to limit impacts to Triangle Marsh, new culverts are proposed through the armored access berm at the western end of the channel, shown in orange. The existing culvert between the effluent channel and Triangle Marsh could be closed/blocked or removed to further reduce the potential freshwater influence in Triangle Marsh.

SOURCE: NOAA Imagery, Hayward LiDAR, ESA

D201800437.02 . EBDA Nature-Based Solutions Hayward Feasibility

Figure 15
Freshwater effluent flow path from NBS to SF Bay with proposed improvements

CHAPTER 6
Conclusions and Next Steps

Hayward could feasibly use a combination of unit process open water (UPOW) treatment wetland cells and horizontal ecotone levee to provide additional nutrient reduction (nitrate) for its summer flows with removal rates of 30% to 45%. A horizontal levee would also increase the Hayward WPCF resilience to sea level rise, contributing to the overall vision of the Hayward Shoreline 2021 Master Plan while maintaining wet-weather storage capacity in the pond area. The use of these natural treatment systems primarily to achieve nutrient reduction goals during the dry season would also allow Hayward continued use of the former oxidation ponds for wet weather storage.

Next steps to further advance the nature-based treatment concept presented in this report include:

- Conduct sediment sampling and analysis for Hayward ponds to determine soil characteristics and identify any contaminants of concern. While the UPOW cells will be lined, sediment from within the ponds could be used for internal berms for the cells as well as for material to build the horizontal levee ecotone if it meets suitability criteria.
- Conduct detailed topographic survey of ponds to confirm bed elevations for design development and wet-weather storage analysis.
- Refine the design concept hydraulic assumptions, including:
    - Whether the UPOW cells could be configured to operate via gravity flow.
    - Intermediate cross berm/baffle design
    - Consider a range of operational flowrates. The WPCF is subject to diurnal flow rates ranging from 3.5 to 18 MGD.
    - Consider the need to utilize some ponds for effluent channel flushing (concept assumes 4 cells could be offline at any given time for maintenance or other use)
    - Wet weather operations. What design refinements are needed to facilitate rapid filling of cells if needed? Could flowrates be maintained or modestly increased through the system and a portion of the wet weather flows be sent to the EBDA pipeline to reduce the need to use the area as wet weather storage that is then pumped back to the plant?
- Refine the treatment potential estimate for a preferred nature-based treatment concept, including treatment and fate of metals (in effluent and biomat), pharmaceuticals and pathogens. For example, is effluent disinfection needed prior to the horizontal levee and or UPOW cells, or could either feature potentially provide adequate disinfection?
- Develop design concepts for full nitrification of the WPCF effluent following completion of the Phase II Improvements to allow a nature-based treatment system to be implemented for polishing to meet future more stringent regulatory requirements.
- Develop preliminary designs for a nature-based treatment concept at Hayward WPCF ponds to work out engineering considerations and details and develop more accurate cost estimates. Including coordination with upgrades in the WPCF and required nitrification of effluent upstream of the nature based treatment concept.

- Conduct an aquatic resources delineation, to preliminarily determine which aquatic features are expected to be regulated at the state and/or federal level.
- Conduct a biological resources evaluation to identify and map any potentially sensitive biological resources (species, habitats, movement corridors, etc.) which may be present within the proposed project footprint.
- Refine understanding of regulatory hurdles and associated permitting costs. The next phase of design should include discussions with relevant permitting agencies to further understand the following:
    - Is reconfiguring flow from rectangular channel around triangle marsh an issue.
    - Adding a freshwater discharge through the rectangular channel to SF Bay. (including mixing considerations), and potential conversion of fringe wetland habitats in rectangular channel.
    - Can the ponds be considered treatment units belonging to plant when it comes to regulatory process (or habitat?), if so, then perhaps we could avoid some of the permitting hurdles.
    - Regulatory monitoring/reporting requirements for discharge. Is sampling needed, required locations, frequency, management triggers, etc.
    - Disinfection and TSS monitoring: The San Leandro treatment wetlands permit deals with disinfection and TSS by measuring compliance at the influent to the wetland (effluent of the plant). For disinfection, this means chlorination and dechlorination prior to discharge to the wetland. For TSS, this means solids that may be added in the wetland will not affect compliance. Chlorination process should be evaluated with respect to the nature-based concept design and perhaps diversion structure should be located downstream of the disinfection station along the effluent channel.
- Refine design concept for horizontal levee to specify design life and projected sea level rise scenarios/adaptation plan.
- Develop life cycle costs for the horizontal levee taking into account potential maintenance actions to maintain flow through capacity.
    - Consider permitting periodic horizontal levee maintenance as part of the adaptive management plan, so that remedial actions including required avoidance measures for special status species are permitted ahead of the need for maintenance.

CHAPTER 7
References

AECOM 2016. San Francisco Bay Tidal Datums and Extreme Tides Study. Final Report. February 2016. Accessed online: https://www.adaptingtorisingtides.org/wp-content/uploads/2016/05/20160429.SFBay_Tidal-Datums_and_Extreme_Tides_Study.FINAL_.pdf

Bear, S. E.; Nguyen, M. T.; Jasper, J. T.; Nygrern, S.; Nelson K. L.; Sedlak, D. L., 2017. Removal of nutrients, trace organic contaminants, and bacterial indicator organisms in a demonstration-scale unit process open-water treatment wetland. Ecological Engineering 109 (2017) 76-83. Accessible at http://dx.doi.org/10.1016/j.ecoleng.2017.09.017

Black and Veatch 2020. Water Pollution Control Facility Phase II Facilities Plan. Prepared for the City of Hayward. June 30, 2020.

Cacchetti 2020. The Removal of Nutrients from Wastewater Effluent in Horizontal Levees. PhD Dissertation prepared for UC Berkeley. Summer 2020.

California Coastal Commission (CCC) 2021. Critical Infrastructure at Risk: Sea Level Rise Planning Guidance for California's Coastal Zone. Final Adopted Guidance, November 17 2021. Accessible online: https://documents.coastal.ca.gov/assets/slr/SLR%20Guidance_Critical%20Infrastructure_12.6.2021.pdf

California Ocean Protection Council (OPC), 2018. State of California Sea level Rise Guidance 2018 Update, Prepared by the California Natural Resources Agency and the California Ocean Protection Council, March 2018. Accessible online: https://opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf

City of Hayward, 2021. Open Data website. Accessed May 2021 at https://opendata.hayward-ca.gov/search?collection=Dataset

Federal Emergency Management Agency (FEMA) 2018. Digital Flood Insurance Rate Map, Effective December 2018. Accessed online: https://www.arcgis.com/apps/webappviewer/index.html?id=8b0adb51996444d4879338b5529aa9cd

Jasper, J. T.; Jones, Z. L.; Sharp, J. O.; Sedlak, D. L. 2014. Nitrate Removal in Shallow, Open-Water Treatment Wetlands. Environ. Sci. Technol. 2014, 48, 11512−11520. Accessible at dx.doi.org/10.1021/es502785t

Kadlec, R. H. & Wallace, S. 2009. Treatment Wetlands, Second Edition. CRC Press: Boca Raton, FL, 2009.

Kadelc, R. H.; Roy, S. B.;Munson, D. K.; Charlton, S.; Brownlie, W., 2010. Water quality performance of treatment wetlands in the Imperial Valley, California. Ecological Engineering 36 (2010) 1093–1107. DOI:10.1016/j.ecoleng.2010.04.028

San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) 2000. Beneficial Reuse of Dredged Materials: Sediment Screening and Testing Guidelines. Draft Staff Report prepared May 2000.

SCAPE 2021. Hayward Regional Shoreline Adaptation Master Plan. Prepared for the Hayward Area Shoreline Planning Agency (HASPA). February 2021. Accessible at https://www.hayward-ca.gov/sites/default/files/210510_Hayward%20Shoreline%20Adapatation%20Master%20Plan_Document_Pages.pdf

Silverman, A. I.; Sedlak, D. L.; Nelson, K. L. 2019a. Simplified Process to Determine Rate Constants for Sunlight-Mediated Removal of Trace Organic and Microbial Contaminants in Unit Process Open-Water Treatment Wetlands. Environmental Engineering Science, January 2019, 36 (43-59). Accessed online: http://doi.org/10.1089/ees.2018.0177

Silverman, A. I.; Nelson, K. L.; Sedlak, D. L. 2019b. Guidelines for the Design and Operation of Unit-process, Open-water Wetlands. March 21, 2019.

United States Environmental Protection Agency (USEPA) 1999. FWS Wetlands for Wastewater Treatment: A Technology Assessment. EPA 832/R-99/002. Office of Water, Washington, DC.

United States Environmental Protection Agency (USEPA) 2000. Constructed Wetlands Treatment of Municipal Wastewaters. EPA 625/R-99/010. Office of Research and Development, Cincinnati, OH.

CHAPTER 8
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