Bay Area Clean Water Agencies

Nutrient Reduction Study

Potential Nutrient Reduction
by Treatment Optimization, Sidestream Treatment, Treatment Upgrades, and Other Means

Draft Report

May 16, 2018

BACWA
BAY AREA
CLEAN WATER
AGENCIES

Nutrient Reduction Study

Potential Nutrient Reduction by Treatment Optimization,
Sidestream Treatment, Treatment Upgrades, and Other Means

Bay Area Clean Water Agencies

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1. Executive Summary

On April 9, 2014 the San Francisco Bay Regional Water Quality Control Board (RWQCB) issued Order No. R2-2014-0014, *Waste Discharge Requirements for Nutrients from Municipal Wastewater Discharges to San Francisco Bay* (Watershed Permit). The Watershed Permit became effective on July 1, 2014 and covers each municipal Publicly Owned Treatment Works (POTW) that discharges to the San Francisco Bay (SF Bay) and its tributaries. The purpose of the Watershed Permit is to track and evaluate treatment plant performance, fund nutrient monitoring programs, support load response modeling, and conduct studies to better understand treatment plant optimization opportunities and upgrade needs to achieve nutrient removal.

This Nutrient Reduction Study was prepared in response to the requirements outlined in the Watershed Permit to conduct studies to evaluate potential nutrient discharge reduction by treatment optimization and sidestream treatment and by treatment upgrades or other means.

1.1 Background

Nutrients in the SF Bay are a growing concern for the Bay Area water quality community. Historically, the SF Bay has not been adversely impacted by nutrient loading, although there are indications that its historic resilience to the effects of nutrient enrichment may be weakening.[1,2] While the definition of impairment has not been reached, there is concern that the SF Bay has reached a tipping point that might lead to impairment. Numerous scientific studies are being conducted to understand the impact of nutrients on the SF Bay. As a result, it may be necessary to limit the availability of essential nutrients, by implementing some form of wastewater treatment nutrient removal to address three potential challenges:

1. Ammonia toxicity and/or inhibition of phytoplankton growth. Full or partial nitrification may be required.
2. Eutrophication. Denitrification may be required where total inorganic nitrogen is the limiting nutrient.
3. Undesirable phytoplankton assemblage changes due to the ratio of nitrogen to phosphorus. Phosphorus reduction may be required.

The Watershed Permit sets forth a regional framework to facilitate collaboration on studies that will inform future management decisions and regulatory strategies. The permit includes three special provisions to support the further understanding of nutrient loads and their impacts in the SF Bay:

1. Evaluation of Potential Nutrient Discharge Reduction by Treatment Optimization and Sidestream Treatment
2. Evaluation of Potential Nutrient Discharge Reduction by Treatment Upgrades or Other Means

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[1] Cloern, J.E. and Jassby, A.D. (2012) Drivers of change in estuarine-coastal ecosystems: Discoveries from four decades of study in San Francisco Bay. Reviews of Geophysics, 50, RG4001, page 21.
[2] San Francisco Estuary Institute (SFEI) (2013) Nutrient Conceptual Model Draft, May 1, 2013, page 14. San Francisco Estuary Institute, Richmond, CA.

3. Monitoring, Modeling, and Embayment Studies

This Nutrient Reduction Study was prepared in response to the first two special provisions listed above. As envisioned by the Watershed Permit, the POTWs are working collectively under the joint powers agency, Bay Area Clean Water Agencies (BACWA), to submit one coordinated study.

The third special provision, Monitoring, Modeling, and Embayment Studies, is being addressed through a separate, parallel effort, being undertaken by the San Francisco Estuary Institute (SFEI).

1.2 Participating Agencies

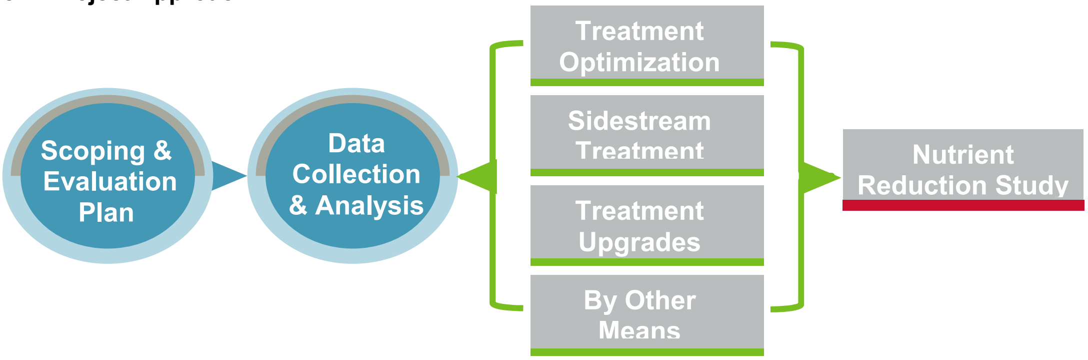
The Watershed Permit requires major POTW dischargers to participate in the Nutrient Reduction Study. The participating agencies are illustrated in Figure 1.

Figure 1. Participating Agencies and Major Dischargers to SF Bay

1.3 Project Approach

Figure 2 illustrates the approach employed for conducting this study, including the four major components which comprise this Nutrient Reduction Study: Treatment Optimization; Sidestream Treatment; Treatment Upgrades; and Nutrient Removal by Other Means.

Figure 2. Project Approach



The Scoping and Evaluation Plan established a range of nutrient removal levels, shown in Table 1, which became the basis for the study.

Table 1. Nutrient Removal Levels

Level	Ammonia	Total Nitrogen	Total Phosphorus
Level 1	Varies by Facility	Varies by Facility	Varies by Facility
Level 2	2 mg N/L	15 mg N/L	1.0 mg P/L
Level 3	2 mg N/L	6 mg N/L	0.3 mg P/L

Level 1 does not have established numerical targets, but was established to represent the optimization opportunities where nutrient loads could be reduced as much as possible with relatively minimal capital investment to improve existing facilities.

Levels 2 and 3 were selected based on the typical tipping point for treatment technologies to achieve the respective effluent water quality benchmarks. For most plant configurations, the less stringent Level 2 benchmark can be achieved with conventional nutrient removal processes without adding an external carbon source or effluent filtration. The more stringent Level 3 benchmark typically requires an external carbon source for nitrogen removal and metal salt coagulant addition with filtration for most plant configurations. These factors contribute to a tipping point due to the increase in cost, operational and safety burdens, energy demand, additional solids production, and GHG emissions.

Ammonia levels were established to provide stable ammonia reduction (typically through nitrification). The total nitrogen benchmark of 6.0 mg N/L was selected based on an assessment of the capabilities of conventional nitrogen reduction technologies in the Northern California climate. It is expected that a lower effluent nitrogen concentration would require additional treatment and associated costs.

Total nitrogen and phosphorus typically have seasonal impacts on receiving waters. Thus, the analysis considered both dry season and year round averaging periods.

Following completion of the Scoping and Evaluation Plan, each of the 37 participating agencies was evaluated individually. The evaluation included data collection and synthesis, a site visit and interviews with plant staff, and desktop analyses to develop treatment concepts for the treatment optimization, sidestream treatment and treatment upgrades components of the study. In addition, existing and planned, future methods of reducing nutrients by other means were identified. Appendix D includes the reports that were prepared for each of the 37 participating agencies.

For the purposes of this Nutrient Reduction Study, the recommended upgrades to meet the Level 2 and 3 benchmarks are based on established technologies. Established technologies were used because there is a wealth of information related to facilities costs and sizing which are important for planning purposes. However, there are many emerging technologies that may achieve lower levels of nutrient discharges, be more cost-effective, and/or have other benefits. As a result, innovative and/or emerging technologies were also considered, and at least 2 were identified for plant for future consideration (refer to Appendix D).

1.4 Study Results

A summary of the load reduction that can be achieved with each treatment strategy, including the implementation of treatment optimization, sidestream treatment, and plant upgrades to meet the Level 2 and Level 3 water quality benchmarks, is presented in Table 2. These load reductions, and their associated costs, are based on year round operation of the treatment strategies, where facilities are sized to treat year round flows and loads. For comparison, the estimated total nitrogen reduction that is anticipated through existing and planned recycled water use is approximately 8,900 lb N/d by 2040, which is most comparable to the load reductions achievable through treatment optimization. The associated costs and incremental increase of greenhouse gas emissions are also presented in Table 2.

Overall, the estimated load reductions increase with increasing degrees of treatment, from optimization through Level 3. Implementation of the optimization strategies could result in a load reduction of approximately seven percent for total nitrogen for a short term (approximately 10 years) capital investment of approximately $120M, whereas implementation of sidestream treatment could result in a total nitrogen load reduction of nearly 20 percent for a longer period (approximately 30 years) at a capital cost of nearly $380M. While the load reductions that could be achieved with implementation of the upgrades to meet the Level 2 and 3 benchmarks are substantially more than that for optimization or sidestream treatment, the capital costs are also substantially higher (as illustrated in Figure 3B).

Table 2 also presents three unit cost metrics. The first is the unit present value per gallon of treated capacity ($/gpd), which can be useful in comparing the relative magnitude of present value costs for the wide range of plant capacities (the plants in the study range in capacity from 1.1 to 167 mgd design capacity). Similar to capital costs, the unit present value per gallon of treated capacity increases from optimization through Level 3 (as illustrated in Figure 3C).

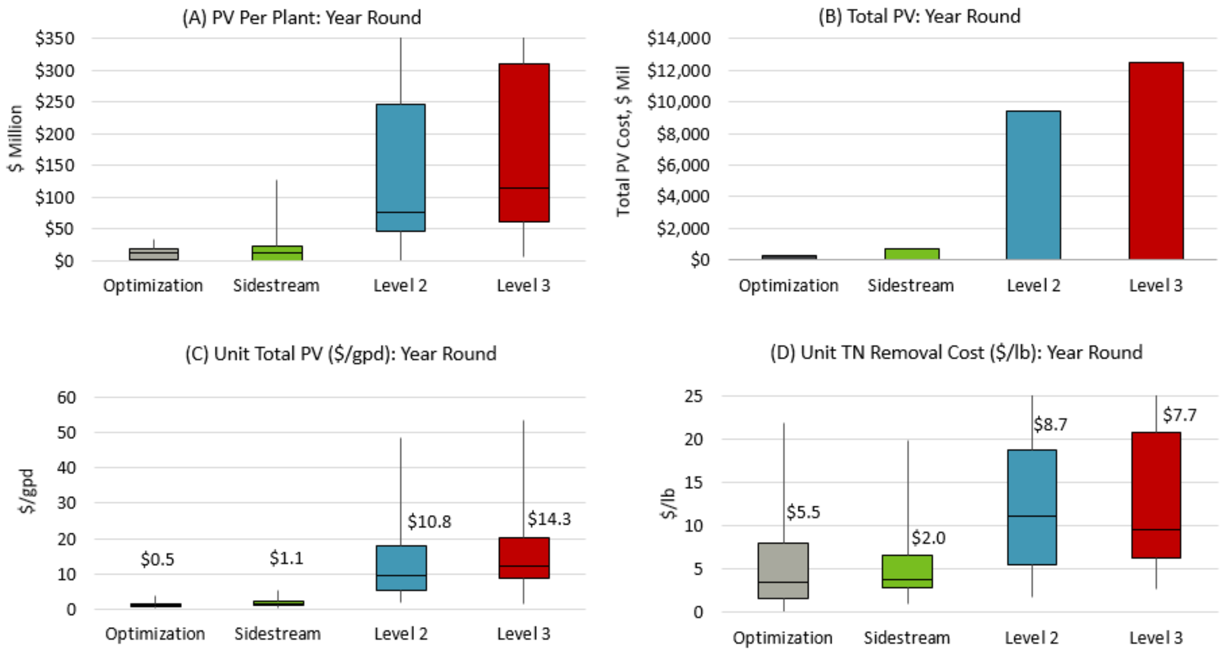
Table 2. Summary of Nutrient Load Reduction and Associated Costs, Year Round Operation

Parameter	Unit	Current Discharge[1]	Treatment Strategy			
			Optimization[2]	Sidestream[2]	Level 2[2]	Level 3[2]
Design Flow	mgd	--	546	633	869	869
Load Reduction						
Ammonia	lb N/d	86,510	12,290	27,439	106,900	106,900
TN	lb N/d	129,670	8,559	31,827	95,00	136,300
TP	lb P/d	9,240	3,139	1,404	7,000	10,500
Costs[3,4]						
Capital	$M	--	119	377	6,976	8,517
O&M PV	$M	--	147	345	2,443	3,888
Total PV	$M	--	266	722	9,419	12,405
Average Unit Costs						
Per gpd[5]	$/gpd	--	0.5	1.1	10.8	14.3
Per lb N[6]	$/lb N	--	5.6	2.0	8.7	7.7
Per lb P[6]	$/lb P	--	8.6	2.7	43	59
Greenhouse Gas Emissions						
Total Increase[7]	MT CO_2/yr	--	63,100	257,400	306,900	257,400

1. Current discharge loads are based on the 2015 BACWA Nutrient Reduction Study Group Annual Report (data from 7/2012-6/2015). The reported flows and loads for optimization, sidestream, and upgrades represent average projected load reduction for the period of analysis (10-yr for optimization and 30-yr for upgrades and sidestream). Sidestream design flow reflects only the candidate plants.
2. Facilities were sized for year round loads and year round operation.
3. Costs are referenced to the ENR SF CCI for January 2018 at 12,015. Costs do not include changes in solids handling or changes in energy requirements in other unit processes. Level 3 costs are inclusive of facilities needed to meet Level 2.
4. The present value is calculated based on a 2 percent discount rate for 10 years (optimization) and 30 years (sidestream and upgrades).
5. Unit cost ($/gpd) was calculated by dividing the total present value by the design flow.
6. Unit cost ($/lb) was calculated by dividing the total present value for the nutrient of interest by the nutrient load reduction over the projection duration (e.g., for upgrades: Total PV for TN Removal facilities divided by (Average Annual TN Removed times 30-years)).
7. Values are average projected incremental increase over the respective period of analysis.

The second unit cost is the cost to remove one pound of total nitrogen ($/lb N removed) and includes only those treatment facilities needed to remove nitrogen (i.e., does not include the capital or O&M costs for treatment elements that are only required for phosphorus removal). Similarly, the third unit cost is the cost to remove one pound of total phosphorus ($/lb P removed). These latter two unit cost metrics can be thought of as a measure of efficiency and used in comparing the cost to remove total nitrogen (or total phosphorus) between plants. This metric could also be useful in identifying the best plant(s) for a regional solution(s) under a nutrient trading scenario. Those plants with the lowest unit cost for nitrogen (or phosphorus) removal would be more desirable than plants with higher unit costs.

Figure 3. Summary of PV Cost per Plant, Total PV, and Unit Costs, Year Round Operation


(A) PV Per Plant: Year Round

(B) Total PV: Year Round

(C) Unit Total PV ($/gpd): Year Round

(D) Unit TN Removal Cost ($/lb): Year Round

Notes:

1. Graphs A, C and D are presented as box and whisker plots, where the boxes represents the range of costs falling within the 25th to 75th percentiles, the horizontal bar within the box represents the median cost, and the ends of the whiskers represent the minimum and maximum present value costs, respectively.
2. The maximum value for Level 2 and Level 3 are not illustrated in the box and whisker plots in A and D due to scale. For Figure A, the maximums are $2.7B and $2.9B for Levels 2 and 3, respectively. For Figure D, the maximums are $145 and $41 for Levels 2 and 3, respectively.

As shown in Table 2, sidestream treatment is the most cost-effective means of reducing both total nitrogen (see also Figure 3D) and total phosphorus, when comparing the cost per pound removed. However, sidestream treatment is not feasible at all plants and there may be site-specific optimization opportunities that are more cost-effective and/or would warrant consideration for other reasons. For example, an agency may wish to first pursue optimization if it is the quickest and easiest way to meet a near term no net load increase requirement or if it addresses other process issues or results in a more stable overall process.

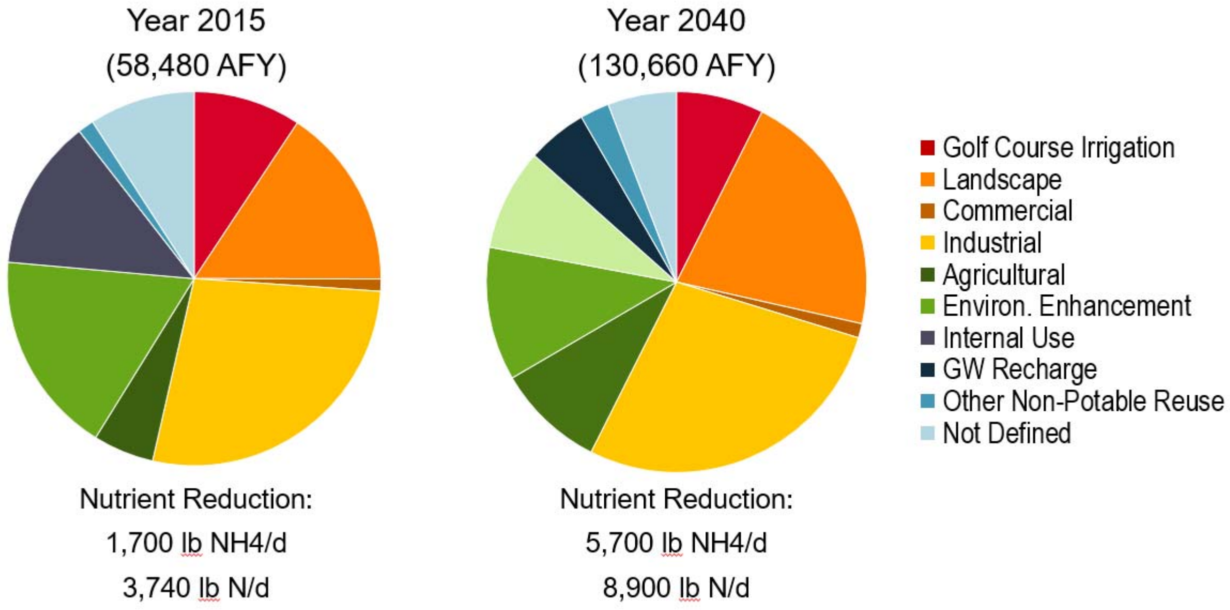
The analysis also evaluated the incremental increase in greenhouse gas (GHG) emissions due changes in energy and chemical demands with the transition from existing secondary treatment to the additional treatment required for nutrient removal. Table 2 shows that GHG emissions increase with more advanced treatment.

Figure 3A illustrates the range of present value costs for the individual plants. The treatment optimization strategies range from less than $1M for some plants to over $40M for San Jose. For sidestream treatment, the range is larger, with some plants having a present value cost of less than $1M compared to over $120M for EBMUD (for total nitrogen removal). The range in costs for the Level 2 and Level 3 upgrades is stark. The present value costs range from as low as $1.3M at American Canyon to achieve the Level 2 benchmark, to as high as $2.6B at

EBMUD. To meet the Level 3 benchmark, the present value costs range from $8.9M at the Sonoma Valley plant to nearly $2.9B at the EBMUD plant.

In addition to the treatment optimization, sidestream treatment, and treatment upgrades analyses, the potential nutrient load reduction that could be achieved through other means was also considered. Several potential methods were anticipated, including effluent management (e.g., recycled water use), effluent polishing (e.g., wetlands treatment), source control, and non-point source reduction. For the agencies participating in this Nutrient Reduction Study, the primary method of reducing nutrient effluent loads by other means is through the use of recycled water. Figure 4 illustrates the distribution of existing and future recycled water by use category as well as the estimated nutrient reduction for ammonia and total nitrogen due to recycled water use.

Figure 4. Recycled Water Projections by Use Category



It is notable that some recycled water use categories do not result in a reduction in nutrient loads discharged to SF Bay. In fact, some uses, such as potable reuse, could increase concentrations discharged to the bay due to the concentrated brine streams created during the advanced treatment processes. Generally, irrigation uses (i.e., landscape, golf course, and agricultural) result in a decrease of nutrient loads since the water is completely consumed at the application site. However, uses such as potable reuse and often times industrial uses, will have a concentrated stream that is either returned to the plant for discharge or otherwise discharged to SF Bay. Thus, with respect to identifying the nutrient reductions associated with future recycled water uses, it is important to understand the type of use anticipated and whether there will be a concentrated return stream that ultimately needs to be discharged.

The estimated total nitrogen reduction that is anticipated through existing and planned recycled water use is approximately 8,900 lb N/d by 2040, which is most comparable to the load reduction achievable through treatment optimization, estimated at approximately 8,600 lb N/d.

1.5 Key Findings and Next Steps

Ultimately, the costs to upgrade treatment plants to achieve the Level 2 and 3 effluent quality benchmarks are substantial. As a result, it is recommended that the other ongoing scientific studies be further developed or completed to provide a better understanding of nutrient processing and confirm whether or not the SF Bay is impaired, and if so, to determine the specific nutrients (and speciation) causing impairment. As that is better understood, appropriate water quality objectives can be established.

It is important to emphasize the impact that permit limits can have on technology selection and facility sizing, and their associated costs, footprint requirements, and GHG emissions. Traditional permit structures for POTWs generally include both monthly and weekly limits on both a concentration and mass basis. This may inadvertently eliminate the most effective watershed solutions to nutrient management by creating disincentives to wastewater dischargers to explore combinations of advanced wastewater treatment and other watershed management practices, such as reuse. Flexible permits, with longer averaging periods and mass-based limits (as opposed to concentration-based limits) will foster innovation and create opportunities for the most creative and economical approaches to managing nutrients.

When the relationship between nutrient loading and water quality responses is not well defined, it is advisable to avoid overly restrictive effluent limits at the outset, since they may later prove unnecessary to meeting actual receiving water needs when they eventually become better understood. Preserving an opportunity for adaptive management approaches to guide the process of nutrient management over time may improve water quality incrementally, without overly restrictive discharge permits that result in over investment in advanced treatment. Permits structured around no net increase in existing loadings, or simple seasonal or annual loading reductions, may provide a foundation for adaptive management.

Once permit requirements are defined, and for the avoidance of doubt, each agency should conduct a thorough facilities planning study to determine the best way to achieve the limits at their respective facility prior to initiating preliminary design, design, and construction. As previously described, the findings presented in this study are based on conservative, well-established technologies for the purpose of providing reasonable costs and space requirements for long-term planning. There are many emerging technologies that could be more cost-effective and/or have other benefits that should also be considered.

2. Introduction

On April 9, 2014 the RWQCB issued Order No. R2-2014-0014, *Waste Discharge Requirements for Nutrients from Municipal Wastewater Discharges to San Francisco Bay* (Watershed Permit). The Watershed Permit became effective on July 1, 2014 and covers each municipal POTW that discharges to SF Bay and its tributaries. The purpose of the Watershed Permit is to track and evaluate treatment plant performance, fund nutrient monitoring programs, support load response modeling, and conduct studies to better understand treatment plant optimization opportunities and upgrade needs to achieve nutrient removal.

This Nutrient Reduction Study was prepared in response to the requirements outlined in the Watershed Permit to conduct studies to evaluate potential nutrient discharge reduction by treatment optimization and sidestream treatment and by treatment upgrades or other means. The following sections describe the study background, the participating agencies, and other permit-required nutrient-related activities, and presents the report organization.

2.1 Background

Nutrients in the SF Bay are a growing concern for the Bay Area water quality community. Historically, the SF Bay has not been adversely impacted by nutrient loading, although there are indications that its historic resilience to the effects of nutrient enrichment may be weakening.[3,4] While the definition of impairment has not been reached, there is concern that the SF Bay has reached a tipping point that might lead to impairment. Numerous scientific studies are being conducted to understand the impact of nutrients on the SF Bay. As a result, it may be necessary to limit the availability of essential nutrients, by implementing some form of wastewater treatment nutrient removal to address three potential challenges:

1. Ammonia toxicity and/or inhibition of phytoplankton growth. Full or partial nitrification may be required.
2. Eutrophication. Denitrification may be required where total inorganic nitrogen is the limiting nutrient.
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The Watershed Permit sets forth a regional framework to facilitate collaboration on studies that will inform future management decisions and regulatory strategies. The permit includes three special provisions to support the further understanding of nutrient loads and their impacts in the SF Bay:

1. Evaluation of Potential Nutrient Discharge Reduction by Treatment Optimization and Sidestream Treatment
2. Evaluation of Potential Nutrient Discharge Reduction by Treatment Upgrades or Other Means
3. Monitoring, Modeling, and Embayment Studies

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[3] Cloern, J.E. and Jassby, A.D. (2012).
[4] SFEI (2013).

This Nutrient Reduction Study was prepared in response to the first two special provisions listed above. As envisioned by the Watershed Permit, the POTWs are working collectively under the joint powers agency, Bay Area Clean Water Agencies (BACWA), to submit one coordinated study.

The third special provision, Monitoring, Modeling, and Embayment Studies, is being addressed through a separate, parallel effort, being undertaken by the San Francisco Estuary Institute (SFEI).

2.1.1 Nutrients and SF Bay

The SF Bay is the largest estuary along the US Pacific coast and its watershed drainage includes about 40 percent of California's land (over 60,000 square miles) and 47 percent of the state's total runoff. The land surrounding SF Bay is home to approximately 7.5 million people while Central Valley supports an additional 6.5 million people

While commonly referred to as "the Bay", SF Bay is better characterized as a series of connected subembayments having distinct physical, chemical, and biological characteristics.[5] Approximately 90 percent of SF Bay's annual freshwater supply enters through the Sacramento-San Joaquin Delta, causing Suisun and San Pablo Bays to (generally) experience the lowest salinities and also have the shortest residence times (days to weeks).[6] Central Bay, the deepest subembayment, receives little direct freshwater input, but exchanges readily with the Pacific Ocean. The Lower South Bay and South Bay receive considerably less freshwater than northern SF Bay and have the longest residences times (weeks to months).[7]

SF Bay receives large inputs of the nutrients nitrogen and phosphorus from anthropogenic sources.[8,9] On a Bay-wide and annual-average basis, effluent from POTWs accounts for over 60 percent of nitrogen loads to SF Bay. In Lower South Bay, South Bay, and Central Bay, POTWs account for over 90 percent of nitrogen loads.

Nitrogen and phosphorus are essential components of a healthy estuary, supporting primary production at the base of the food web. However, ambient nitrogen and phosphorus concentrations in SF Bay exceed those in many other estuarine ecosystems[10], including those that experience nutrient-related impairment, such as excessive phytoplankton blooms and prolonged periods of low dissolved oxygen (DO). Unlike those other nutrient-enriched estuaries, though, SF Bay has exhibited resistance to classic eutrophication symptoms. High turbidity and

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[5] Kimmerer, W. (2004) Open Water Processes of the San Francisco Estuary: From Physical Forcing to Biological Responses. San Francisco Estuary and Watershed Science, 2(1). Retrieved from https://escholarship.org/uc/item/9bp499mv

[6] Smith S and Hollibough JT. (2006) Water, salt, and nutrient exchanges in San Francisco Bay. Limnology and Oceanography. 51. 504-517. 10.4319/lo.2006.51.1_part_2.0504.

[7] Kimmerer 2004; Smith and Hollibaugh, 2006

[8] Cloern, J. E., and A. D. Jassby (2012) Drivers of change in estuarine-coastal ecosystems: Discoveries from four decades of study in San Francisco Bay, *Rev. Geophys.*, 50, RG4001, doi:10.1029/2012RG000397.

[9] SFEI (2014) Scientific Foundation for the San Francisco Bay Nutrient Management Strategy. SFEI Contribution #731.

[10] Cloern and Jassby (2012).

strong tidal mixing in SF Bay cap light levels available to phytoplankton, leading to low growth rates, and allowing only a small portion of available nutrients to be converted into phytoplankton biomass.[11] During some years and in some regions, large populations of filter-feeding clams also limit phytoplankton accumulation.[12]

Observations over the past decade, though, suggest that SF Bay's resistance to nutrient enrichment is weakening, or that SF Bay is more prone to nutrient-related impacts than previously thought.[13] These observations include:

- A two-fold increase in summer-fall phytoplankton biomass in South Bay since 1999;[14]
- Frequent detections of algal species that form harmful algal blooms (HABs), and frequent detection of the toxins they produce.[15,16,17]
- Evidence of low dissolved oxygen in some sloughs and tidal creeks.[18]

The combination of SF Bay's high nutrient concentrations and potential changes in the environmental factors that regulate nutrient-related responses has generated concern about whether some SF Bay habitats are moving toward experiencing nutrient-related impairment. To address this concern, the RWQCB worked collaboratively with stakeholders to develop the San Francisco Bay Nutrient Management Strategy, which lays out an approach for gathering and applying information to inform major nutrient management decisions.

2.1.2 Nutrient Loads

Nutrient loads arise from point and nonpoint sources. Point sources are typically from POTWs, which treat municipal wastewater, and treated industrial wastewater resulting from industrial operations, processing, cleaning, and cooling. Municipal Separate Storm Sewer Systems (MS4s) permitted under Phase I and Phase II stormwater National Pollutant Discharge Elimination System (NPDES) are also considered point sources.

Nonpoint sources are essentially everything that is not a point source including diffuse agricultural pollutant runoff, as well as urban sources, stormwater runoff from areas not covered

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[11] Cloern JE (1999) The relative importance of light and nutrient limitation of phytoplankton growth - a simple index of coastal ecosystem sensitivity to nutrient enrichment: Aquatic Ecology 33(1): 3-16.

[12] Cloern, J.E., (1982) Does the benthos control phytoplankton biomass in south San Francisco Bay? Marine Ecology Progress Series, 9:191-202.

[13] Cloern, J.E., A.D. Jassby, J.K. Thompson, K.A. Hieb, (2007) A cold phase of the East Pacific triggers new phytoplankton blooms in San Francisco Bay, Proceedings of the National Academy of Sciences of the United States of America, 104 (47): 18561-18565.

[14] Cloern et al, (2007).

[15] Sutula M, Kudela, RM, Hagy JD, Harding LW, Senn DB, Cloern JE, Bricker S, Berg, GM, Beck M (2017) Novel analyses of long-term data provide a scientific basis for chlorophyll-a thresholds in San Francisco Bay, *Estuarine, Coastal and Shelf Science* 196:1-12.
Peacock MB, Gibble CM, Senn DB, Cloern JE, Kudela RM (2018) Blurred lines: Multiple freshwater and marine algal toxins at the land-sea interface of San Francisco Bay, California, *Harmful Algae*, 73:138-147.

[16] SFEI (2016) Nutrient Management Strategy Science Program FY16 Annual Report. SFEI Contribution #791.

[17] Peacock MB, Gibble CM, Senn DB, Cloern JE, Kudela RM (2018) Blurred lines: Multiple freshwater and marine algal toxins at the land-sea interface of San Francisco Bay, California, *Harmful Algae*, 73:138-147.

[18] SFEI 2016, 2017.

by MS4 stormwater permits, groundwater discharges, and atmospheric deposition. “Nonpoint source pollution is considered one of the top threats to the Bay’s ecological health and may account for a considerable proportion of the Bay’s total pollutant load. The Bay receives 90 percent of its freshwater from the Sacramento and San Joaquin Rivers and 10 percent from the watershed surrounding San Francisco Bay[19]”. Since most of the flow is from the Delta, most of the nonpoint source load is also from upstream. “Nonpoint source pollutants transported to the Bay come from Sacramento and San Joaquin Rivers, the Delta and the surrounding watersheds” (SFBCDC, 2003).

Municipal wastewater treatment plants were significantly improved in the late 1970s, reducing the pollutant loads from POTWs. Today, the minimum level of performance is secondary treatment to remove organic matter and solids, but little reduction is made in nutrients as most plants were not designed to remove nutrients. At the secondary treatment level, effluent nutrient discharges are typically about 30 to 35 mg/L total nitrogen and 2 to 3 mg/L total phosphorus. Lower effluent concentrations are possible with the addition of more advanced treatment.

Table 3 presents a summary of the nutrient concentrations discharged to SF Bay from the agencies included in the Watershed Permit.

Table 3. Average POTW Flow and Nutrient Concentrations Discharged to SF Bay

Constituent	2012/13	2013/14	2014/15	2015/2016	2016/2017
Flow, mgd	453	434	421	425	510
Ammonia, mg N/L	20	22	23	23	21
TKN, mg N/L	22	25	26	26	23
NOx, mg N/L	8.7	8.8	8.9	8.7	7.4
TN, mg N/L	31	33	35	34	31
Orthophosphate, mg P/L	2.8	2.8	1.9	2.0	1.7
TP, mg P/L	2.3	2.3	2.3	2.4	2.1

1. Data is from the 2017 Group Annual Report, required as part of the Watershed Permit. Data is from July 1 – June 30.

The 2017 Group Annual Report[20] reported the five year annual average total daily nitrogen load discharged by the participating POTWs was approximately 55,600 kg N/d and the total daily phosphorus load was 3,900 kg P/d. A study conducted by Smith and Hollibough in 2006[21] found that, “Effluent from sewage treatment plants accounts for approximately 50 percent of the nutrient loading to the bay in winter and 80 percent of the summer loading”.

2.1.3 Watershed Permit

As described above, this Nutrient Reduction Study was prepared to address two special provisions in the Watershed Permit requiring the evaluation of potential nutrient discharge

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[19] SFBCDC (2003) Water Quality Protection and Nonpoint Source Pollution Control in San Francisco Bay. San Francisco Bay Conservation and Development Commission, San Francisco, CA.

[20] BACWA (2017) Group Annual Report, Nutrient Watershed Permit Annual Report, 2017

[21] Smith, S and J.T. Hollibough (2006).

reduction. The first was to include an evaluation of potential nutrient reduction by treatment optimization and sidestream treatment. The second was to include an evaluation of potential nutrient reduction by treatment upgrades or other means.

For the purpose of preparing this report, the evaluations required by these two special provisions have been combined. The following subsections present a brief summary of the key elements of the special provisions.

OPTIMIZATION OF CURRENT TREATMENT WORKS

This element includes a plant-specific evaluation of alternatives to reduce nutrient discharges through methods such as operational adjustments to existing treatment systems, process changes, or minor upgrades. For example, a plant could implement chemically enhanced primary treatment (CEPT) as means to remove total phosphorus and increase aeration basin capacity for ammonia removal. Optimization strategies are intended to be relatively low- or no-cost improvements that can be implemented quickly. Additional examples include: use of existing, offline tankage to provide additional treatment; modification of operational mode, such as raising the solids residence time (SRT); or operation in split treatment mode.

This element includes consideration of beneficial and adverse ancillary impacts, development of planning level costs, and evaluation of nutrient load reduction.

SIDESTREAM TREATMENT

The sidestream refers to the return streams from biosolids processing, with particular emphasis on the mechanical dewatering return stream for plants with anaerobic digesters. Despite their small flows (typically less than a few percent of plant influent flow), the sidestream typically represents approximately 15 to 25 percent of the total ammonia and total nitrogen from an individual plant.[22] This element of the study includes an evaluation of sidestream treatment opportunities and associated ammonia, total nitrogen, and total phosphorus load reductions, and capital and O&M costs.

TREATMENT UPGRADES

This element of the study considers potential upgrade technologies to reduce effluent nitrogen and phosphorus for each plant. To facilitate this analysis, the Scoping and Evaluation Plan identified nutrient removal levels such that facilities needs could be identified and sized, costs could be evaluated, and greenhouse gas emissions could be quantified. The nutrient removal levels are described in Section 3.1.

This element of the study also includes consideration of beneficial and adverse ancillary impacts, development of planning level capital and operating costs, and evaluation of nutrient load reduction.

REDUCTION BY OTHER MEANS

The Watershed Permit includes a provision to consider other ways to reduce nutrient loading through alternative discharge scenarios, such as water recycling or use of wetlands, in

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[22] Fux, C and Siegrist, H. (2004) Nitrogen removal from sludge digester liquids by nitrification/denitrification or partial nitritation/anammox: environmental and economical considerations. Water Science & Technology. 50(10):19-26.

combination with, or in-lieu of, the upgrades to achieve similar levels of nutrient load reductions at the treatment plants. As a result, this study summarizes the results of a survey that was conducted to characterize current and future plans by the participating agencies for water reuse.

SEA LEVEL RISE

In addition to the above described nutrient reduction elements, the Watershed Permit also includes an element related to sea level rise. In accordance with the Scoping and Evaluation Plan (Appendix A), this study identifies participating agencies that are vulnerable to the impacts of sea level rise. For each agency, the impacts of sea level rise were analyzed with respect to the potential for inundation of facilities needed to achieve nutrient reduction.

2.2 Participating Agencies

The Watershed Permit requires major POTW dischargers to conduct a Nutrient Reduction Study. A list of major dischargers identified in the Watershed Permit is provided in Table 4 and the location of each discharger is shown in Figure 5.

Table 4. Major Dischargers Included in the SF Bay Watershed Permit

Discharger (Abbreviation)	POTW Facility Name
American Canyon, City of (American Canyon)	Wastewater Treatment and Reclamation Facility
Benicia, City of (Benicia)	Benicia Wastewater Treatment Plant
Burlingame, City of (Burlingame)	Burlingame Wastewater Treatment Plant
Central Contra Costa Sanitary District (CCCSD)	Central Contra Costa Sanitary District Wastewater Treatment Plant
Central Marin Sanitation Agency (CMSA)	Central Marin Sanitation Agency Wastewater Treatment Plant
Delta Diablo (Delta Diablo)	Wastewater Treatment Plant
East Bay Dischargers Authority (EBDA) [City of Hayward (Hayward), City of San Leandro (San Leandro), Oro Loma Sanitary District (OLSD), Castro Valley Sanitary District, Union Sanitary District (Union San), Livermore-Amador Valley Water Management Agency (LAVWMA), Dublin San Ramon Services District (DSRSD), and City of Livermore (Livermore)]	EBDA Common Outfall
	Hayward Water Pollution Control Facility
	San Leandro Water Pollution Control Plant
	Oro Loma/Castro Valley Sanitary Districts Water Pollution Control Plant
	Raymond A. Boege Alvarado Wastewater Treatment Plant
	Livermore-Amador Valley Water Management Agency Export and Storage Facilities
	Dublin San Ramon Services District Wastewater Treatment Plant
	City of Livermore Water Reclamation Plant
East Bay Municipal Utility District (EBMUD)	East Bay Municipal Utility District, Special District No. 1 Wastewater Treatment Plant

Discharger (Abbreviation)	POTW Facility Name
Fairfield-Suisun Sewer District (FSSD)	Fairfield-Suisun Wastewater Treatment Plant
Las Gallinas Valley Sanitary District (Las Gallinas)	Las Gallinas Valley Sanitary District Sewage Treatment Plant
Millbrae, City of (Millbrae)	Water Pollution Control Plant
Mt. View Sanitary District (Mt View)	Mt View Sanitary District Wastewater Treatment Plant
Napa Sanitation District (Napa)	Soscol Water Recycling Facility
Novato Sanitary District (Novato)	Novato Sanitary District Wastewater Treatment Plant
Palo Alto, City of (Palo Alto)	Palo Alto Regional Water Quality Control Plant
Petaluma, City of (Petaluma)	Ellis Creek Water Recycling Facility
Pinole, City of (Pinole)	Pinole-Hercules Water Pollution Control Plant
Rodeo Sanitary District (Rodeo)	Rodeo Sanitary District Water Pollution Control Facility
San Francisco (San Francisco International Airport), City and County of (SFO Airport)	Mel Leong Treatment Plant, Sanitary Plant
San Francisco (Southeast Plant), City and County of (SFPUC Southeast)	Southeast Water Pollution Control Plant
San Jose/Santa Clara Water Pollution Control Plant and Cities of San Jose and Santa Clara (San Jose)	San Jose/Santa Clara Water Pollution Control Plant
San Mateo, City of (San Mateo)	City of San Mateo Wastewater Treatment Plant
Sausalito-Marin City Sanitary District (SMCSD)	Sausalito-Marin City Sanitary District Wastewater Treatment Plant
Sewerage Agency of Southern Marin (SASM)	Sewerage Agency of Southern Marin Wastewater Treatment Plant
Sonoma Valley County Sanitary District (Sonoma Valley)	Municipal Wastewater Treatment Plant
Silicon Valley Clean Water (SVCW)	SVCW Wastewater Treatment Plant
South San Francisco and San Bruno, Cities of (South SF)	South San Francisco and San Bruno Water Quality Control Plant
Sunnyvale, City of (Sunnyvale)	Sunnyvale Water Pollution Control Plant
U.S. Department of Navy (Treasure Island)	Wastewater Treatment Plant
Vallejo Sanitation and Flood Control District (Vallejo)	Vallejo Sanitation and Flood Control District Wastewater Treatment Plant

Discharger (Abbreviation)	POTW Facility Name
West County Agency (West County) (West County Wastewater District and City of Richmond Municipal Sewer District)	West County Agency Combined Outfall

1. As defined in the Watershed Permit.

Figure 5. Participating Agencies and Major Dischargers to SF Bay

2.3 Related Activities

The San Francisco Bay Nutrient Management Strategy (NMS) Science Program was launched in 2014 to build the scientific foundation to support nutrient management decisions. The NMS Steering Committee, representing 13 stakeholder groups (regulators, dischargers, water purveyors, non-governmental organizations, resource agencies) oversees the NMS' implementation, including financial oversight and alignment of NMS science activities with high priority management questions. SFEI serves as the technical lead on implementing the NMS Science Program (sfbaynutrients.sfei.org), and collaborates with researchers from academia, USGS, and other agencies to carry out NMS projects, including field investigations, monitoring, and data interpretation.

NMS Science Program activities are guided by management questions (shown in Table 5) that tie back to identifying protective nutrient loads for SF Bay habitats and that target priorities laid out in the NMS multi-year Science Plan (SFEI 2016) and related technical reports. The primary technical program areas explored include: nutrient loads and cycling; phytoplankton blooms and DO in deep subtidal habitats; DO in shallow margin habitats; HAB abundance, toxin abundance, and phytoplankton assemblage; and coastal ocean impacts.

Table 5. Nutrient Management Strategy – Management Questions

1. What conditions would be considered adverse impacts or impairments that would require management actions?
2. Monitoring and condition assessment: Are adverse impacts or impairment currently occurring?
3. How do SF Bay habitats respond to nutrient inputs -- dose:response? Are nutrients causing or contributing to current impacts or impairment?
4. What potential future impacts or impairments warrant pre-emptive management actions?
5. What change in conditions (e.g., nutrient loads or nutrient concentrations) would mitigate impacts or impairment in questions 3 or 4?
6. How do individual nutrient sources contribute to ambient concentrations throughout SF Bay as a function of space and time?
7. What management actions or load reductions are needed to prevent or mitigate current or future impairment?

Major NMS focus areas over the past few years include:

- Building and refining the NMS Observation Program
- Developing and applying biogeochemical models
- Developing an assessment framework
- Synthesis and Interpretation of long-term and new datasets

The NMS 2017 Annual Report and 2016 Annual Report provide overviews of recent work. All NMS related work products can be found at sfbaynutrients.sfei.org.

2.4 Report Organization

This Nutrient Reduction Study is organized into eight chapters and five appendices, as follows:

Chapter 1 – Executive Summary

Chapter 2 – Introduction. This chapter describes the study background, the participating agencies and other Watershed Permit-required nutrient-related activities.

Chapter 3 – Basis of Evaluation. This chapter presents the project approach used to develop the strategies and concepts for nutrient reduction through treatment optimization, sidestream treatment, and treatment upgrades. This chapter also presents the common approach for preparing cost estimate and evaluating greenhouse gas emissions. The methodology for evaluating sea level rise is introduced and study limitations are described.

Chapter 4 – Nutrient Reduction Findings. This chapter presents a summary of the findings for the treatment optimization, sidestream treatment and treatment upgrades analyses, as well as a comparison of the three.

Chapter 5 – Nutrient Reduction by Other Means. This chapter describes the assessment of nutrient reduction by other means assessment.

Chapter 6 – Sea Level Rise. This chapter presents the results of the sea level rise analysis that was conducted to identify plants that may be vulnerable to the impacts of sea level rise.

Chapter 7 – Discussion and Observations. This chapter summarizes the key observations of this Nutrient Reduction Study with respect to water quality objectives, averaging periods, permit structures, constrained sites, technology selection, GHG emissions, and factors influencing capital costs.

Chapter 8 – Summary and Next Steps. This chapter summarizes the results and findings of the study and describes next steps that agencies should take.

Appendices

A. Scoping and Evaluation Plan
B. Basis of Cost Estimates
C. Sea Level Rise Methodology
D. Individual Plant Reports
E. Agency Acceptance Letters

2.5 Acknowledgements

During the development of this Nutrient Reduction Study, the project team received invaluable assistance and cooperation from each of the participating agencies and their respective staff. We gratefully acknowledge the members of the Contract Management Group, for their guidance and active participation, as well as the BACWA Executive Board. In addition, the study was conducted in close collaboration with the EPA Regional Sidestream Grant Project executed by EBMUD.

2.6 Abbreviations

AA	average annual
ADWF	average dry weather flow
AFY	acre-feet per year
AOB	ammonia-oxidizing bacteria
BACC	Bay Area Chemical Consortium
BACWA	Bay Area Clean Water Agencies
BAF	biological aerated filter
BNR	biological nutrient removal
BOD	biological oxygen demand
$CaCO_3$	calcium carbonate
CARB	California Air Resources Board
CBOD	Carbonaceous Biochemical Oxygen Demand
CCCSD	Central Contra Costa Sanitary District
CEC	cation exchange capacity
CEPT	chemically enhanced primary treatment
CFR	Code of Federal Regulations
CIP	capital improvement program or plan
CMG	contract management group
CMSA	Central Marin Sanitation Agency
DO	dissolved oxygen
DSRSD	Dublin San Ramon Services District
EBDA	East Bay Dischargers Authority
EBMUD	East Bay Municipal Utilities District
ENR SF CCI	Engineering News Record San Francisco Construction Cost Index
EPA	US Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FSSD	Fairfield-Suisun Sewer District
GHG	greenhouse gas
gpd	gallon per day
HAB	harmful algal bloom

IFAS	integrated fixed film activated sludge
IPCC	Intergovernmental Panel on Climate Change
kWh	kilowatt hour
lb/d	pounds per day
LAVMA	Livermore-Amador Valley Water Management Agency
MABR	membrane aerated biofilm reactor
MBBR	moving bed biofilm reactor
MBR	membrane bioreactor
mg/L	milligrams per liter
mgd	million gallons per day
MLE	Modified Ludzack-Ettinger
MM	maximum month
N	nitrogen
NMS	San Francisco Bay Nutrient Management Strategy
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NTF	nitrifying trickling filter
O&M	operation and maintenance
OLSD	Oro Loma Sanitary District
P	phosphorus
PG&E	Pacific Gas & Electric
PV	present value
POTW	publicly owned treatment works
RWQCB	Regional Water Quality Control Board
SASM	Sewerage Agency of Southern Marin
SBR	sequencing batch reactor
SF Bay	San Francisco Bay
SFEI	San Francisco Estuary Institute
SFPUC	San Francisco Public Utilities Commission
SMCSD	Sausalito-Marin City Sanitary District
SND	simultaneous nitrification and denitrification

SON	soluble organic nitrogen
SOP	soluble organic phosphorus
SRT	solids retention time
SVCW	Silicon Valley Clean Water
TKN	Total Kjeldahl Nitrogen
TMDL	total maximum daily load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	total suspended solids
Union San	Union Sanitary District
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UV	ultraviolet
WCSD	West County Wastewater District
WERF	Water Environment Research Foundation
WPCP	water pollution control plant
WRRF	water resource recovery facility
WWTP	wastewater treatment plant
y	year

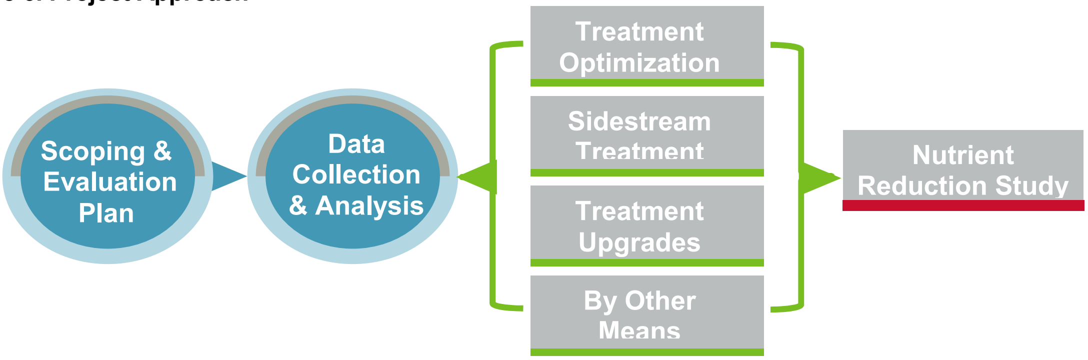
3. Basis of Evaluation

This chapter presents the project approach used to develop the strategies and concepts for nutrient reduction through treatment optimization, sidestream treatment, and treatment upgrades. The approach to documenting nutrient reduction by other means is also described. In addition, the basis of evaluation includes assumptions with respect to the computation of greenhouse gas (GHG) emissions, cost estimates, and sea level rise. Through the application of a uniform set of planning assumptions, strategies and concepts were developed in a consistent manner for all POTWs to allow comparison and evaluation of the resulting load reductions and costs.

3.1 Project Approach

The general approach to the Nutrient Reduction Study is presented in Figure 6 and along with the scoping and evaluation plan, and data collection and analysis, includes preparation of four major components to comprise this Nutrient Reduction Study: Optimization; Sidestream Treatment; Upgrades; and By Other Means. The following subsections describe the major elements of the approach.

Figure 6. Project Approach



3.1.1 Scoping and Evaluation Plan

The Scoping and Evaluation Plan, submitted to the RWQCB in February 2015 and included as Appendix A, describes the approach for conducting the study. A key component of the plan was the establishment of a range of nutrient removal levels that would become the basis for the study. The nutrient removal levels are presented in Table 6.

Table 6. Nutrient Removal Levels

Level	Ammonia	Total Nitrogen	Total Phosphorus
Level 1	Varies by Facility	Varies by Facility	Varies by Facility
Level 2	2 mg N/L	15 mg N/L	1.0 mg P/L
Level 3	2 mg N/L	6 mg N/L	0.3 mg P/L

Level 1 does not have established numerical targets, but was established to represent the optimization opportunities where nutrient loads are reduced as much as possible with minimal capital investment to improve existing facilities.

Levels 2 and 3 were selected based on the typical tipping point for treatment technologies to achieve the respective effluent water quality benchmarks. For most plant configurations, the less stringent Level 2 benchmark can be achieved with conventional nutrient removal processes without adding an external carbon source or effluent filtration. The more stringent Level 3 benchmark typically requires an external carbon source for nitrogen removal and metal salt coagulant addition with filtration for most plant configurations. These factors contribute to a tipping point due to the increase in cost, operational and safety burdens, energy demand, additional solids production, and GHG emissions.

Ammonia levels were established to provide stable ammonia reduction (typically through nitrification). The total nitrogen benchmark of 6.0 mg N/L was selected based on an assessment of the capabilities of conventional nitrogen reduction technologies in the Northern California climate. It is expected that a lower effluent nitrogen concentration would require additional treatment and associated costs.

Total nitrogen and phosphorus typically have seasonal impacts on receiving waters. Thus, the analysis considered both dry season and year round averaging periods. The dry season is defined as May 1 to September 30.

3.1.2 Data Collection and Analysis

Following completion of the Scoping and Evaluation Plan, the data collection and analysis phase of the study began, which included four questionnaires for the utilities, as well as site visits at each plant.

QUESTIONNAIRE 1 – PLANT PERFORMANCE

The first questionnaire focused on gathering information related to plant wide performance, including influent and effluent water quality, plant process and site layout, major unit processes, annual energy and chemical usage, and existing permit requirements.

QUESTIONNAIRE 2 – SIDESTREAM TREATMENT

The purpose of the sidestream treatment questionnaire was to identify which plants were potential candidates for sidestream treatment and specifically sought information related to existing solids handling facilities and their operation.

QUESTIONNAIRE 3 – RECYCLED WATER

The recycled water questionnaire was used to summarize existing and planned future recycled water use to better estimate nutrient loads diverted from SF Bay through water recycling. Consistent with existing state requirements to project future recycled water use, the questionnaire requested estimates of future recycled water production/use through 2040 in five year increments as well as the anticipated type of use (e.g., landscape, industrial, etc.).

QUESTIONNAIRE 4 – CAPITAL IMPROVEMENT PLANS

The capital improvement questionnaire was used to gather information about planned capital improvement projects and costs related to nutrient removal, including secondary treatment and recycled water projects. The objective was to identify planned projects that could reduce nutrient discharge loads.

PLANT SITE VISITS

Following the review and synthesis of the data collected from the questionnaires, two-person teams conducted site visits to each participating plant. The purpose of the site visits was to confirm the understanding of existing plant operations, validate chemical usage, discuss data gaps, and review potential concepts for optimizing plant operation to achieve greater nutrient removal. The optimization strategies were discussed with plant operations staff, and often included alternate flow routing, chemical dosing, and aeration strategies.

A facility evaluation memorandum was prepared to summarize basic facility information, current conditions, site layout, major unit processes, and potential optimization strategies and upgrade requirements to meet the Level 2 and 3 benchmarks. Then, following review by each agency, respectively, the detailed analyses for treatment optimization, sidestream treatment, and treatment upgrades were initiated.

3.1.3 Treatment Optimization

The objective of this element of the Nutrient Reduction Study was to review the current facilities and operations at each POTW and, in collaboration with plant staff, identify potential strategies to optimize current operations to achieve nutrient removal, to the extent possible.

The treatment optimization strategies are based on each individual plant's documented plans for future growth for the 10-year period between 2015 and 2025. For plants without documented growth projections, a 15 percent increase in BOD and nutrient loadings was assumed for the 10-year period with no increase in flows. A 10-year planning period was selected because optimization strategies are considered an interim solution because most strategies require the use of existing, yet-to-be required treatment capacity (i.e., facilities not needed to meet the current load but which may be required to treat the future design load).

The following treatment optimization strategies were considered for each plant:

- Use offline tankage
- Operate in split treatment mode
- Modify operational mode (e.g., raise SRT)
- Modify blower operating set points
- Shut down aeration to create anoxic zones
- Process control instrumentation (e.g., for ammonia based aeration control)
- Add additional chemicals (e.g., add coagulant for phosphorus removal, or to reduce load and unlock downstream capacity)
- Add anoxic and/or anaerobic zones for biological nutrient removal (BNR)
- Add internal recycle for denitrification
- Add mixers for un-aerated zones

The potential feasibility of these strategies was discussed with facility staff during the site visits and those with the greatest potential for success were further evaluated. The evaluation considered potential capital investments and complexity of operation, among other factors. Based on the evaluation, the best strategy, or combination thereof, was further developed. Facility changes and layouts were prepared and nutrient load reductions were estimated. In addition, capital and O&M costs were developed, ancillary benefits and impacts were identified, and the incremental increase (if any) in GHG emissions was quantified.

3.1.4 Sidestream Treatment

Sidestream treatment is a cost effective way to reduce effluent nutrient loads because the sidestream is typically a nutrient rich, low flow stream that can be treated with relatively small sized treatment processes. However, not all plants are candidates for sidestream treatment.

The sidestream treatment strategies are based on each individual plant's ADWF permitted capacity for a 30 year period. A 30 year planning period was selected because sidestream treatment is viewed as a capital improvement project.

Sidestream data collection occurred in two parts. First, a questionnaire was submitted to participating BACWA members that requested historical plant data and relevant operational information. The initial questionnaire was distributed to all 37 participating POTWs that requested historical plant performance data, a description of discharge requirements and general POTW information, and a list of existing assets. This information was used to identify potential candidate POTWs for sidestream treatment using a structured approach.

Following compilation of information, a subsequent sampling request and questionnaire was issued to POTWs initially identified as potential candidates for sidestream treatment (32 out of 37 POTWs). The sampling request included three separate sampling events in July 2015 to better understand sidestream flows and loads. In addition to sampling, information was gathered about existing solids handling operations (e.g., dewatering frequency) to further identify suitable POTWs for sidestream treatment.

The suitability of a sidestream flow for nitrogen removal and the types of treatment available are heavily dependent on solids handling, particularly with regard to dewatering equipment and operation. The following information was considered in determining suitability:

- Dewatering equipment type and size
- Biosolids dewatering feed rate
- Washwater added, if applicable (for belt filter press)
- Digester feed flow for plants that add washwater to the dewatering equipment
- Dewatering operation schedule for selecting an appropriate sidestream treatment technology and the corresponding facility needs
- Sidestream temperature

For sidestream treatment to be viable, the following criteria were required:

- Year round sidestream flow: Biological nitrogen removal requires a steady, nutrient-rich flow to maintain the microbial population necessary for treatment. A seasonal sidestream flow is not appropriate as it disrupts the biological process.
- A dewatering frequency of at least four days per week: Dewatering operation must be frequent enough to limit the amount of equalization volume needed to produce a steady flow.

Two nitrogen removal technologies were considered for sidestream treatment, including deammonification and conventional nitrification. Deammonification was the preferred method of sidestream treatment due to its well documented energy and chemical savings. However, the deammonification process requires a relatively high temperature in the feed flow (e.g., 25 to 35 degrees C preferred). Thus, conventional nitrification was recommended when sidestream water temperatures were comparable to ambient air temperatures, where dewatering operation is limited to four or five days per week, or where the dewatering technology uses considerable backwash water. In all other cases, deammonification was selected as the recommended technology.

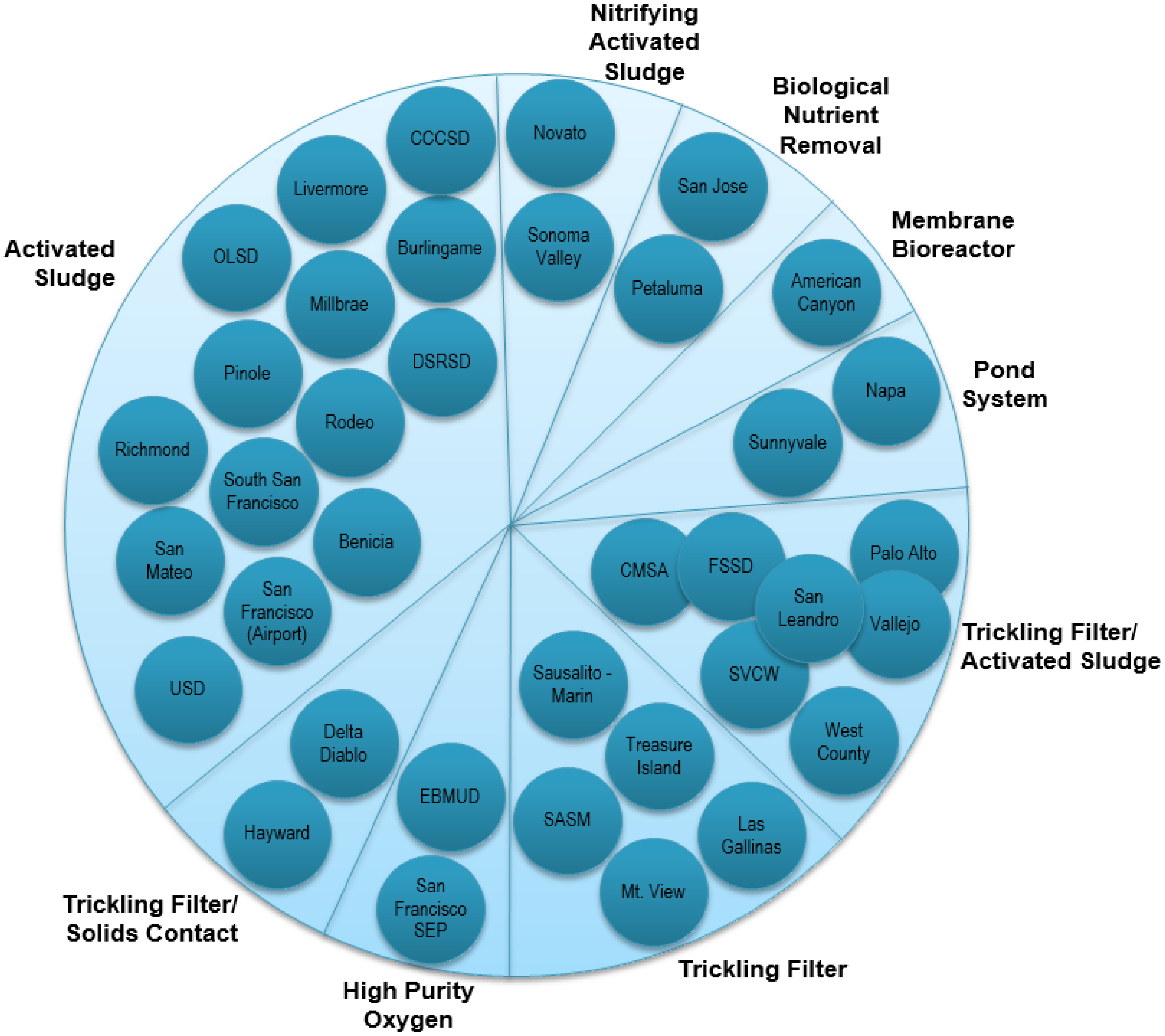
The sidestream treatment of phosphorus typically relies on either chemical precipitation using metal salts or phosphorus recovery through struvite precipitation. There are two commonly used phosphorus removal and recovery technologies for sidestream phosphorus reduction. For candidate plants, the evaluation considered either conventional phosphorus removal by metal salts and settling, or phosphorus recovery (typically struvite precipitation technology) for plants using biological phosphorus removal.

Once the appropriate technology was selected for each of the candidate plants, facilities needs and layouts were prepared and nutrient load reductions were estimated. In addition, capital and O&M costs were developed, ancillary impacts and benefits were identified, and the incremental increase in GHG emissions was quantified.

3.1.5 Treatment Upgrades

The objective of this element of the study was to identify an appropriate treatment technology and the associated facilities required to meet the Level 2 and 3 water quality benchmarks described in Table 6. To facilitate conservative, long-range planning, the treatment technologies considered for this study were based on conventional nutrient removal technologies that would work well with each plant's existing secondary treatment process. A summary of the existing secondary treatment process for each plant is presented in Figure 7 and the list of treatment technologies that were considered to meet the Level 2 and 3 water quality benchmarks is presented in Table 7.

Figure 7. Classification of Existing Secondary Processes for Participating POTWs



In determining upgrade requirements, each plant was evaluated based on existing infrastructure and plant site space constraints, and new facilities were sized to treat the plant's design condition (i.e., design flow and load). Existing infrastructure was incorporated into the recommended upgrade strategies as much as possible. Available space was a key factor in technology selection. For example, a membrane bioreactor (MBR) would be required for a facility with limited available space, whereas a facility with ample available space could entertain a wider variety of larger footprint technology options.

Table 7. Technologies Considered for Ammonia, Nitrogen, and Phosphorus Removal

Level 2 Technologies	Level 3 Technologies[1]
Nitrifying Technologies	
Nitrifying air activated sludge	Level 2 meets Level 3 ammonia benchmarks
Integrated fixed film activated sludge (IFAS)	
Membrane bioreactor (MBR)	
Nitrifying trickling filter (NTF)	
Biological aerated filter (BAF)	
Oxidation ditch	
Nitrogen Removal Technologies	
Modified Ludzack-Ettinger (MLE)	4-stage Bardenpho[2]
Denitrification filter[2]	Denitrification filter[2]
Moving bed biofilm reactor (MBBR)[2]	MBBR[2]
Step feed activated sludge	Oxidation ditch
Oxidation ditch	
Phosphorus Removal Technologies	
Oxidation ditch	Direct filtration[3]
2-stage Phoredox (P only)	Sedimentation/filtration[3]
3-stage Phoredox	Membrane filtration[3]
5-stage Bardenpho (both N and P)	
Chemical[3] addition to primary clarifiers	
Chemical[3] addition to aeration basin	
Tertiary chemical[3] addition/solids removal	

1. Level 3 technologies are considered in addition to or expansion of Level 2 technologies.
2. Carbon source may be required (e.g. methanol)
3. Metal salt or other chemical added

Upgrade strategies were devised such that the technology and associated facilities recommended to meet the Level 2 water quality benchmark could be expanded upon to meet the Level 3 benchmark. This approach avoids situations where infrastructure constructed to meet a Level 2 benchmark would subsequently become stranded assets if a future Level 3 benchmark was later required within the facility’s lifespan. While this can add some additional cost for the Level 2 facilities, it is a more conservative approach and is consistent with typical engineering practice to stage improvements in logical increments.

Once an appropriate technology was selected to achieve the Level 3 benchmarks, the required facilities and layouts were prepared for both Level 2 and 3 and nutrient load reductions were estimated. Then capital and O&M cost estimates were prepared for each. In addition, ancillary impacts and benefits were identified and the incremental increase in GHG emissions was quantified.

3.1.6 By Other Means

While the treatment optimization, sidestream treatment and treatment upgrade analyses focus on concepts that would be implemented within the plant, there are other ways to reduce the effluent nutrient loads discharged to SF Bay. Other means of nutrient reduction include:

- Effluent Management: Nutrient trading, water recycling and reuse
- Effluent Polishing: Wetlands treatment (e.g., Hayward Marsh. Horizontal Levee or Ecotone Project, etc.)
- Source Control: Septic source abatement, urine separation, elimination of phosphorus from some consumer products (e.g., phosphorus bans in lawn fertilizer and dish detergent because of state legislation, etc.)
- Non-Point Sources: Non-point source reduction programs, load trading and offsets, etc.

The approach for this element of the study relied on feedback from each of the participating agencies. As previously described, questionnaires were used to solicit information regarding planned capital improvement projects that could impact nutrient removal as well as existing and future recycled water use. The information gathered from these questionnaires formed the basis for the information presented in this Nutrient Reduction Study.

3.1.7 Greenhouse Gas (GHG) Emissions

GHG emissions were evaluated for the recommended treatment optimization, sidestream treatment, and treatment upgrades. The GHG emissions evaluation is focused on the incremental increase in GHG emissions associated with the recommendations (i.e., does not include current emissions).

The GHG emissions accounting methodology considers the operating energy and chemical demand for the recommended treatment strategies. The approach relies on the USEPA eGRID values[23] for the regional energy production and the GHG emissions associated with chemical mining/fabrication. For example, converting energy demand to GHG emissions is based on additional energy demand (kWh/y) associated with plant optimization and/or upgrade strategies, followed by a conversion from energy to GHG emissions. The process and fugitive emissions associated with nitrous oxide emissions were not quantified. It is anticipated that nitrous oxide emissions would increase as a plant transitions from secondary treatment to nitrogen removal due to cycling between oxic and anoxic conditions.

3.1.8 Sea Level Rise

The Watershed Permit also requires consideration of the potential impacts of sea level rise on nutrient removal facilities. The intent of the requirement was to avoid identifying nutrient removal options that would be infeasible due to actions implemented or planned to address sea level rise. As a result, the plants that are vulnerable to the impacts of sea level rise were identified. The methodology, described in detail in Appendix C, is based on publicly available data from the United States Army Corps of Engineers (USACE), the Federal Emergency Management Agency (FEMA), and publicly available topography data.

The location of each POTW was determined and a representative ground surface elevation was identified and used to compare against water surface elevations. FEMA’s Flood Insurance Rate Maps (FIRMs) were used to determine if the POTW is already within the one-percent annual

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[23] http://www.epa.gov/cleanenergy/energy-resources/egrid/

chance (100-year) floodplain. Then, the USACE Sea Level Change Curve Calculator[24] was used to determine the projected water surface elevation due to sea level rise for low, intermediate, and high rise scenarios over the next 30, 50, and 100 years. The water surface elevations were then compared to the ground surface elevation to identify those POTWs that could be impacted by sea level rise.

Recognizing that there are many related studies, opinions, and ongoing work related to sea level rise, the USACE calculator was selected, and employed consistently for each of the 37 POTWs, because the USACE is a highly recognized federal agency responsible for designing and constructing flood control structures throughout the United States, including throughout the SF Bay.

The methodology employed in this study has certain limitations. For example, one point elevation was used to represent the respective elevation for each plant and some areas of the plant could be at higher or lower elevations. The methodology does not account for other, non-certified flood protection structures, such as existing embankments or coastal dikes. Nor does the methodology consider the future protection that would be provided by flood protection projects currently in the planning or design phase. Thus, it is important to note that while many agencies have identified their vulnerabilities with respect to coastal flooding and sea level rise, and may have projects underway to address it, those projects are not necessarily reflected in the findings of this study.

In addition, the analysis performed for this Nutrient Reduction Study is focused on the potential impacts to the treatment plant sites. There are many other wastewater-related facilities that could be impacted by sea level rise, such as piping and sewage lift stations within the collection system (particularly those in low lying areas which could become more susceptible to sea water intrusion) and effluent discharge facilities. With respect to the latter, sea level rise could impact the hydraulics and capacity of effluent pump stations and pipelines. Sea level rise could potentially result in additional pumping requirements to discharge effluent, increasing both energy requirements and associated costs.

3.2 Basis of Cost Estimates

The approach to developing the estimated capital and O&M costs for treatment optimization, sidestream treatment, and treatment upgrades was consistent for each of the 37 POTWs included in this Nutrient Reduction Study, as described further in Appendix B.

A parametric cost analysis was used to estimate the construction costs for each facility. Allowances were included for undefined facilities, site conditions, and contractor's costs and profit. An allowance for engineering, construction management, legal and other administrative costs was then applied to develop a total estimated capital cost. An additional 15 percent contingency was added to the capital cost to reflect the current bidding climate in the SF Bay Area.

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[24] http://www.corpsclimate.us/ccaceslcurves.cfm

The incremental increase in O&M costs for power, chemicals, and labor were also estimated using a parametric cost analysis. Unit chemical costs were developed using information from the Bay Area Chemical Consortium (BACC). The same unit costs were used for all the BACWA treatment plants to simplify the analysis. In addition, equipment replacement costs were included for major equipment items that would require replacement during the planning period, such as membranes for membrane bioreactors.

The capital and O&M costs are presented in current dollars, referenced to the ENR SF CCI for January 2018 at 12,014.72. Present value costs were developed based on the discount rate and respective period for each scenario, as shown in Table 8.

Table 8. Assumptions for Life Cycle Cost Analysis

Scenario	Discount Rate	Period (yr)
Optimization	2%	10
Sidestream Treatment	2%	30
Level 2	2%	30
Level 3	2%	30

In order to understand the relative costs for each of the 37 POTWs, the present value costs are also expressed as unit costs:

- Unit present value cost per gallon ($/gpd) includes the present value capital and O&M costs for the treatment strategy to remove ammonia, nitrogen and phosphorus. The cost per gallon is based on the design flow and is calculated as the total present value divided by design flow.
- Unit cost for total nitrogen and total phosphorus reductions ($ per pound nutrient removed) include both capital and O&M costs for the life of the project. The nutrient reduction is calculated based on the average removal over the life cycle period. The unit cost calculation is then based on the present value divided by the average nutrient load reduction over the design period.
  - Unit costs for total nitrogen reduction were estimated based only on the cost elements that contribute to total nitrogen removal (e.g., expansion of activated sludge basins). The unit cost is calculated as the total present for total nitrogen removal facilities divided by the average annual total nitrogen removed times 30-years.
  - Unit costs for phosphorus reduction were estimated based on the cost elements needed to remove phosphorus (e.g., metal salt coagulant at primary clarifiers). The unit cost is calculated as the total present for total phosphorus removal facilities divided by the average annual total phosphorus removed times 30-years.

Unless specifically noted with a table or figure, all cost information presented in this Nutrient Reduction Study is based on year round facility design parameters and year round operation.

3.3 Study Limitations

This Nutrient Reduction Study presents high level concepts for implementing nutrient removal at the 37 participating agencies which discharge effluent to the SF Bay. It is a useful tool for gaining a region-wide and subembayment perspective on the relative impacts of treatment options, but should not be used without further study on an individual plant basis. These planning-level concepts were developed to quantify the potential load reduction possible and the associated order of magnitude costs required to implement nutrient removal. The use of parametric cost estimating tools limits site-specific factors. For example, construction with congested sites can often have a cost premium. Such premiums were not captured in this analysis.

Due to the high-level nature of the findings presented herein, if nutrient effluent limits are defined in the future, each agency should undertake its own site-specific study to further evaluate its options, considering both conventional and emerging technologies, and develop more detailed recommendations and costs. The analysis should also include further refinement of influent loads, more plant performance data, condition assessment of existing facilities, more detailed consideration of plant hydraulics, plant-specific process modeling, and future growth within the service area, among other plant-specific factors.

4. Nutrient Reduction Findings

The following sections present a summary of the findings for the treatment optimization, sidestream treatment and treatment upgrades analyses, as well as a comparison of the three.

4.1 Treatment Optimization

The optimization of existing facilities could be a potential first step toward nutrient reduction by taking advantage of existing facilities and/or capacity on site, changing process approaches, or improving instrumentation.

Many plants are already achieving some effluent nutrient removal. In some cases, the treatment is intentional; for example, all three plants in the Lower South Bay each have ammonia effluent limits and have a nitrification process in place to achieve those limits. More interestingly, there are plants that are achieving some nutrient reduction due to existing treatment processes that may have been implemented for other reasons (i.e., the nutrient removal is an unintended ancillary benefit).

Eleven plants already have full nitrification. Of those, seven plants currently meet the Level 2 total nitrogen benchmark (15 mg N/L) and two meet the Level 3 total nitrogen benchmark (6 mg N/L). In addition, approximately two-thirds of the raw influent total phosphorus loads are being removed. Three plants reliably meet the Level 2 effluent benchmark (1 mg P/L) and an additional six nearly meet the Level 2 total phosphorus benchmark, with values ranging between 1 and 2 mg P/L.

As previously mentioned, there are also situations where nutrients are being removed “opportunistically”. For example, some plants employ metal salt coagulants that opportunistically precipitate soluble reactive phosphorus, others have anaerobic selectors for enhanced settling in their secondary clarification process that opportunistically foster biological phosphorus removal. The optimization analysis considered ways to enhance existing performance, regardless of whether nutrient removal was already being achieved.

While not possible at all plants, optimization strategies were identified for 32 of the 37 participating plants. In each case, the strategies were formulated to achieve as much nutrient reduction as possible, with the assumption that there would be no numerical effluent limits, and as such, a safety factor was not included when preparing facility needs and estimating resulting effluent loads. In addition, it is important to note that the proposed optimization strategies are considered interim or short-term solutions because they may rely on currently unused capacity (i.e. facilities not needed to meet the current wastewater load but which may be required to treat the design load in the future).

The most common optimization strategies are summarized below for nitrogen and phosphorus removal, respectively:

- Common Optimization Strategies for Nitrogen Removal
  - Increase SRT for plants with activated sludge to encourage nitrification
  - Operate trickling filters as nitrifying trickling filters

- Common Optimization Strategies for Phosphorus Removal
  - Metal salt coagulant addition
  - CEPT, including a metal salt and polymer

In most cases, optimization would result in marginal increases in energy and GHG emissions. Additional chemicals were commonly recommended which have the disadvantage of adding process complexity and can often impact solids production and dewatering performance. Where CEPT is recommended for phosphorus removal, additional organics would be diverted to the digesters which could enhance biogas production (where applicable), but could also generate additional solids.

Table 9 summarizes the annual nutrient load reductions for each of the participating agencies. As shown, optimization strategies were identified to reduce ammonia at 12 plants, total nitrogen at 15 plants, and 29 plants had optimization strategies to reduce total phosphorus. The total potential load reduction is also presented, as well as the percentage reduction. Phosphorus removal is often easier to implement, since many plants already have metal salt coagulant chemical feed facilities on site, so it follows that the percentage reduction would be greater.

Table 9. Average Daily Nutrient Load Reduction with Treatment Optimization

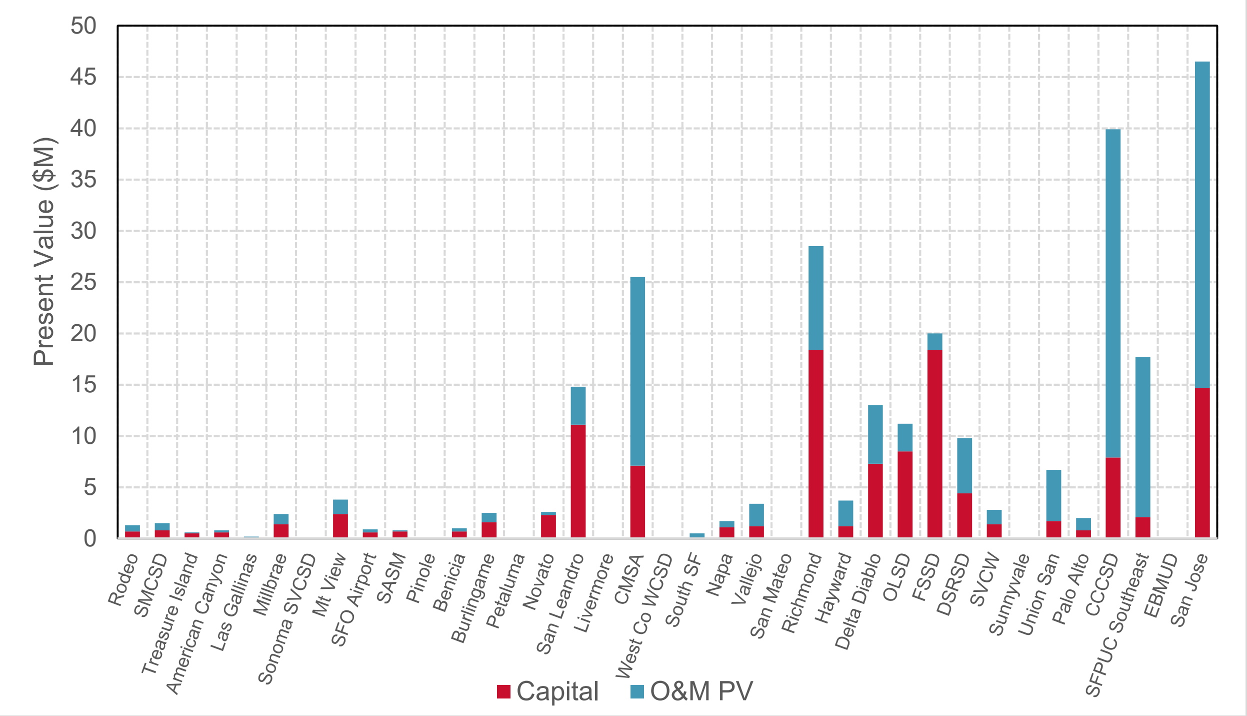
Plant[1]	Permitted ADWF Capacity (mgd)	Projected Nutrient Load Reduction[2,3]		
		NH3 (lb N/d)	TN (lb N/d)	TP (lb P/d)
Rodeo	1.1	0	19	14
SMCSD	1.8	30	0	23
Treasure Island	2.0	0	0	3.7
American Canyon	2.5	0	0	52
Las Gallinas	2.9	0	0	28
Millbrae	3.0	340	150	20
Sonoma SVCSD	3.0	0	0	0
Mt View	3.2	0	130	29.3
SFO Airport	3.4	0	0	27
SASM	3.6	50	0	60
Pinole	4.1	0	0	0
Benicia	4.5	0	0	47
Burlingame	5.5	230	230	170
Petaluma	6.7	0	0	0
Novato	7.0	0	0	13
San Leandro	7.6	1,150	370	8
Livermore	8.5	0	0	17
CMSA	10.0	670	0	80
West Co WCSD	12.5	0	0	0
South SF	13.0	0	0	270
Napa	15.4	0	0	6

Plant[1]	Permitted ADWF Capacity (mgd)	Projected Nutrient Load Reduction[2,3]		
		NH3 (lb N/d)	TN (lb N/d)	TP (lb P/d)
Vallejo	15.5	0	0	220
San Mateo	15.7	0	0	0
Richmond	16.0	1,300	600	50
Hayward	18.5	0	0	161
Delta Diablo	19.5	760	750	20
OLSD	20.0	2,860	1,490	130
FSSD	23.7	0	950	100
DSRSD	23.9	2,310	970	30
SVCW	29.0	0	0	320
Sunnyvale	29.5	0	0	0
Union San	33.0	0	0	380
Palo Alto	39.0	0	0	720
CCCSD	53.8	2,590	930	0
SFPUC Southeast	85.0	0	0	140
EBMUD	120	0	0	0
San Jose	167	0	1,970	0
Total Nutrient Load Reduction with Optimization Strategies[2,3]	--	12,290	8,559	3,139
Nutrient Discharge Loads Projected with Existing Treatment Facilities[2]	--	87,860	129,670	9,240
Nutrient Discharge Loads Projected with Opt. Strategies Implemented[2,3]	--	75,570	121,111	6,101
Percent Reduction in Nutrient Discharge Loads[2,3]	--	14%	7%	34%

1. Plants are organized in ascending order of permitted ADWF capacity.
2. Values are average projected loads/reductions to SF Bay over the 10 year period of analysis for treatment optimization.
3. Values are based on operating with the optimization strategy in place on a year round basis.

Figure 8 presents a summary of the present value costs for each plant as well as the associated average annual load reductions for ammonia, total nitrogen, and total phosphorus. Note that the plants are organized, left to right, in increasing permitted capacity, with Rodeo having the smallest permitted capacity flow (1.1 mgd ADWF), while the San Jose WPCP has the largest permitted capacity flow (167 mgd ADWF).

Figure 8. Treatment Optimization PV Cost, Year Round Operation



As shown in Figure 8, the present value costs to implement optimization range from less than $1M for some plants to over $45M for San Jose. With the exception of FSSD and Richmond, it is notable that for those plants with total present value greater than $15M, more than half of the present value cost is attributed to operating costs.

The total present value to implement the optimization strategies at all of the facilities is approximately $270M, of which the total capital cost is $120M (approximately 45 percent of total) and the O&M PV cost is approximately $150M (approximately 55 percent of total). These results are consistent with the intent of the optimization strategies, which was to modify the operation of existing facilities, with minimal capital investment.

Figure 9 illustrates the daily average load reduction for year round operation at each plant for total nitrogen and total phosphorus. The total nutrient load reduction for all plants is approximately 8,600 lb total nitrogen-N/d, and 3,100 lb total phosphorus-P/d. Figure 9 illustrates that the majority of the total nitrogen load reduction is coming from about five plants while phosphorus load reduction is more widely distributed across many of the utilities.

Figure 9. Treatment Optimization Daily Average TN and TP Load Reduction

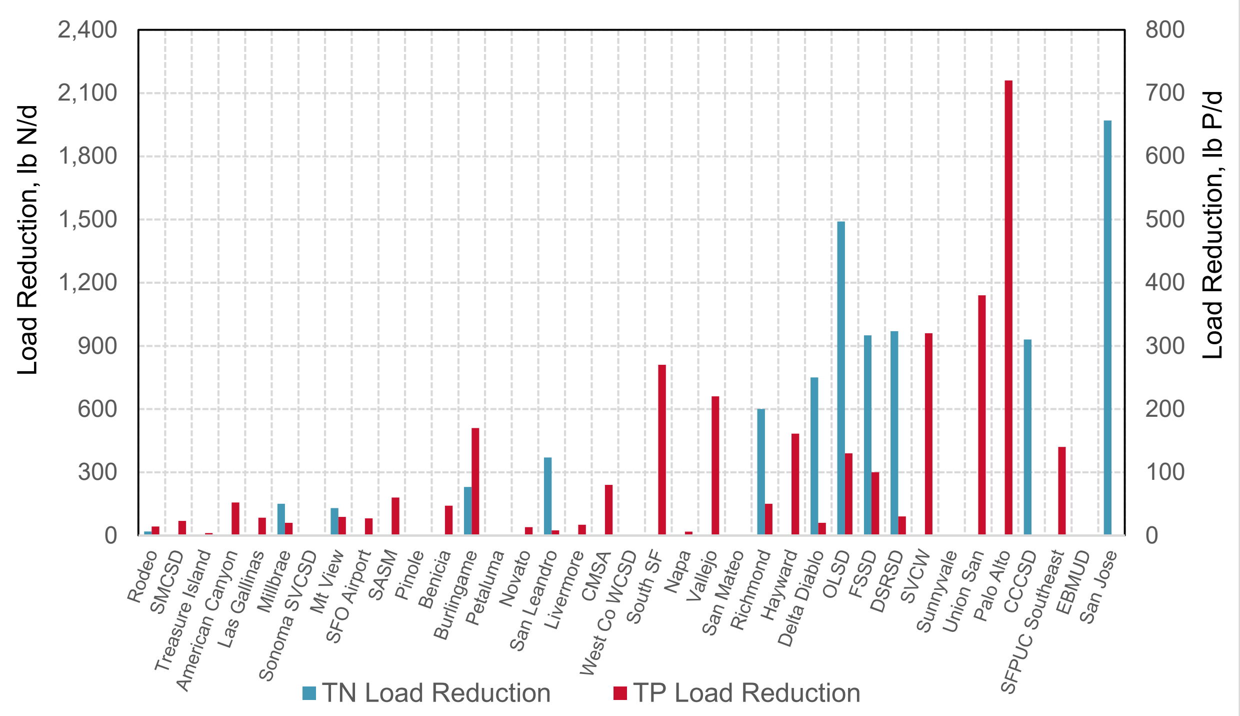
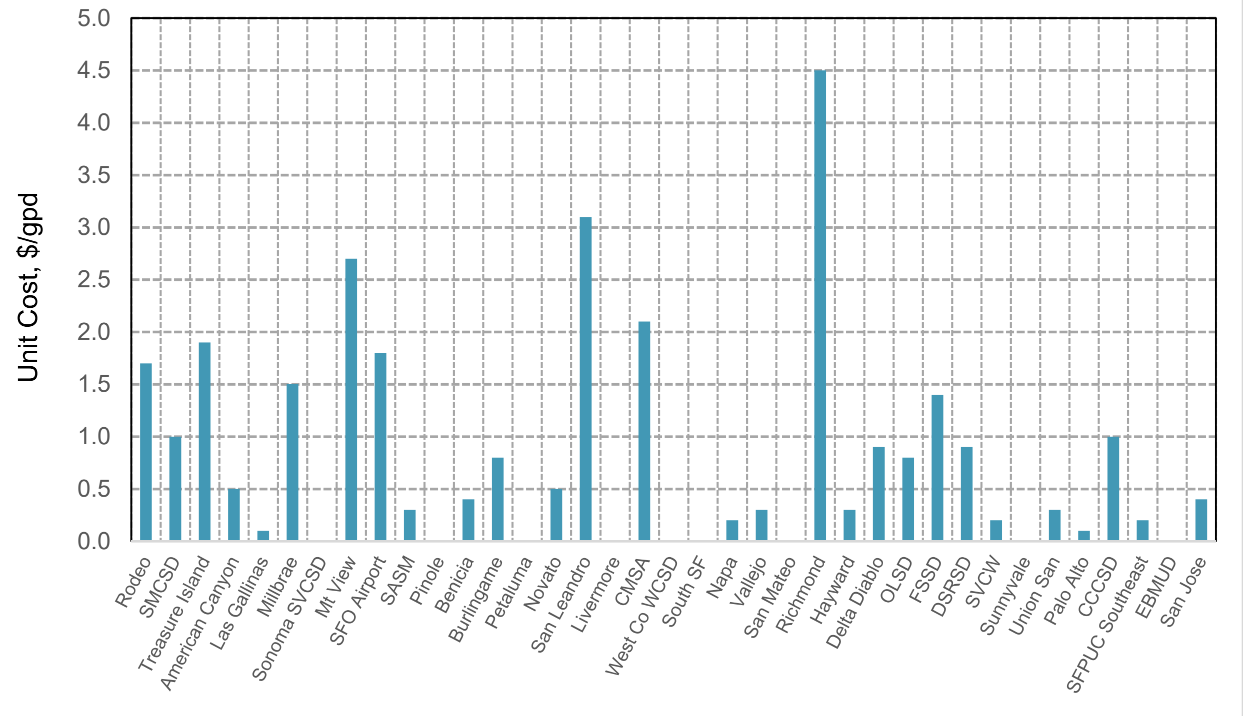


Figure 10 introduces the present value as a unit cost for each plant based on design flow (i.e., total PV divided by the optimization design flow). The unit cost is used to better compare the relative magnitude of the costs for the wide range of plants.

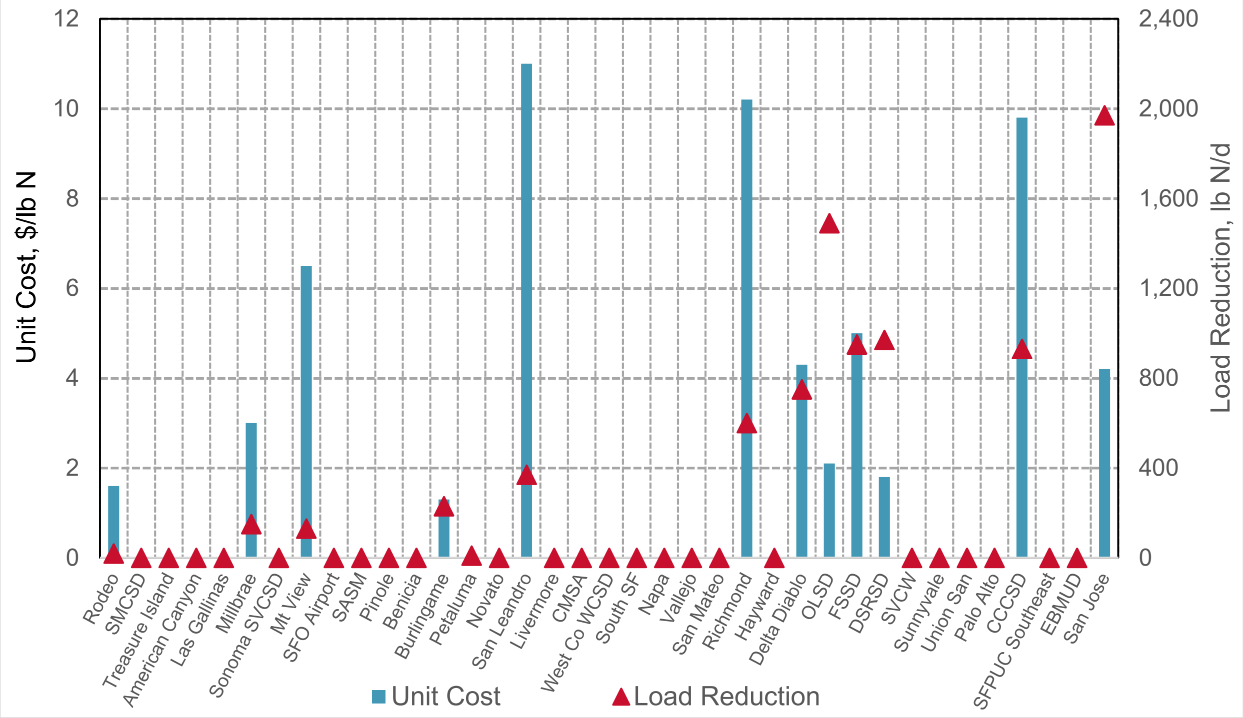
Figure 10. Treatment Optimization PV Unit Cost per Gallon Treatment Capacity



The average unit present value cost is approximately $0.5/gpd based on the plants for which a nutrient load reduction optimization strategy was identified. Most of the larger plants have a unit cost lower than the average, while many of the smaller plants have a unit cost higher than the average, which reflects the savings associated with economies of scale introduced at the larger plants.

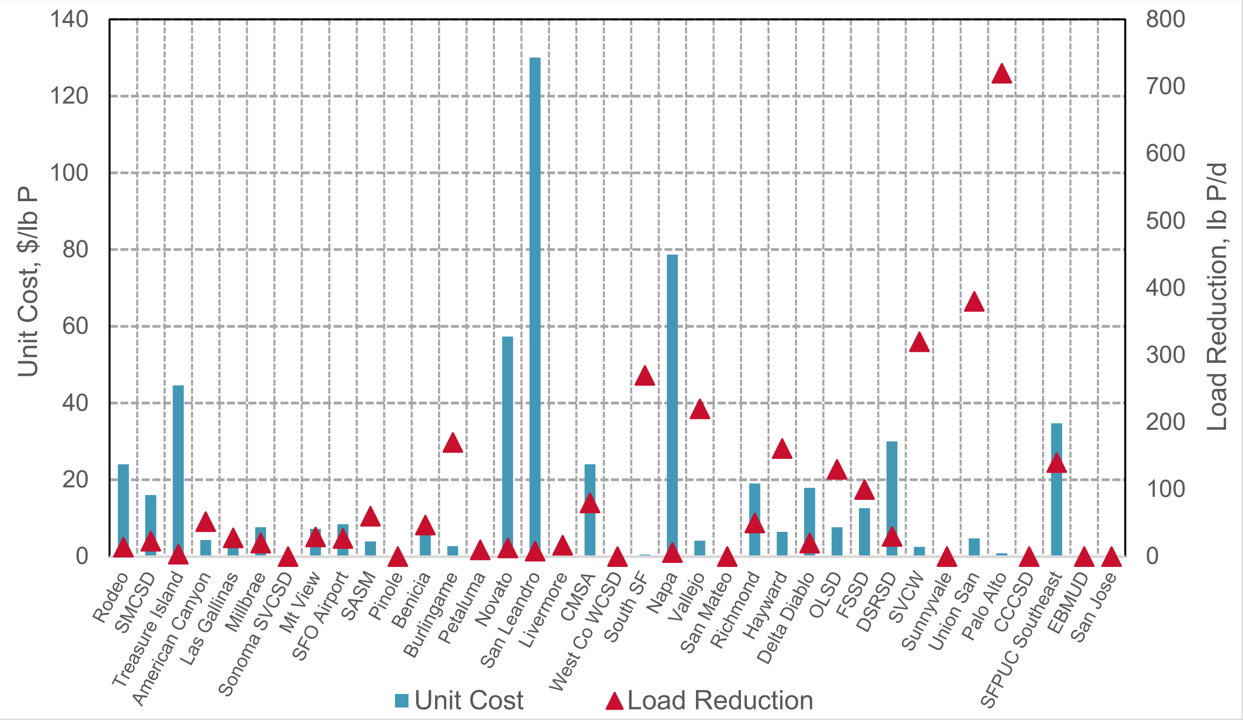
Figure 11 and Figure 12 show the total present value cost per average load reduction over the 10-year optimization period for both total nitrogen and total phosphorus, respectively. The cost per pound removed is used as a measure of efficiency to compare the implementation of a project at one plant compared to that of another plant. For example, as shown, the cost per pound of total nitrogen removed at OLSD is $2.1/lb N as compared to FSSD with a cost of $5.0/lb N. In this case, the cost per pound of nitrogen removed is lower at OLSD.

Figure 11. Treatment Optimization PV Unit Cost per Pound TN Removed



The average unit cost for total nitrogen removal is approximately $5.6/lb N removed, whereas total phosphorus removal is approximately $8.6/lb P removed. As shown in Figure 11, SMCSD has the highest cost per pound of nitrogen removed and as shown in Figure 12, San Leandro has the high cost per pound of phosphorus removed at just under $130/lb P removed.

Figure 12. Treatment Optimization PV Unit Cost per Pound TP Removed



4.2 Sidestream Treatment

As described in Chapter 3, a screening process was conducted to identify which plants were candidates for sidestream treatment. The key criteria of the screening process included the production of a sidestream throughout the year, effluent discharge throughout the year, and sufficient dewatering frequency, which was defined as four or more days per week.

The screening process identified 15 plants as candidates for ammonia reduction and 23 plants as candidates for total nitrogen reduction as shown in Table 10. Depending on the water temperature, one of two processes were recommended, including conventional nitrification technology for sidestreams with temperatures below 20 degrees Celsius or deammonification technology for sidestreams with temperatures above 20 degrees Celsius.

Table 10. Plants Eligible for Sidestream Treatment by Subembayment, Ammonia and TN

Subembayment	Initial Screening for Ammonia Reduction	Refined Analysis	
		Ammonia Reduction	Total Nitrogen Reduction
Suisun Bay	4	1	2
San Pablo Bay	9	1	5
Central Bay	5	3	4
South Bay	12	10	10
Lower South Bay	2	0	2
Total	32	15	23

The initial screening process identified 32 candidate plants for total phosphorus reduction and through additional analysis, that number was refined to 15.

Table 11. Plants Eligible for Sidestream Treatment by Subembayment, TP

Subembayment	Total Phosphorus Reduction
Suisun Bay	1
San Pablo Bay	4
Central Bay	3
South Bay	6
Lower South Bay	1
Total	15

Table 12 summarizes the annual average daily nutrient load reductions for ammonia, total nitrogen and total phosphorus for each plant. The total load reduction is also presented, as well as the percentage reduction.

Table 12. Average Daily Load Reduction with Sidestream Treatment

Plant[1]	Permitted ADWF Capacity (mgd)	Projected Nutrient Load Reduction[2,3]		
		NH3 (lb N/d)	TN (lb N/d)	TP (lb P/d)
Rodeo	1.1	--	46	4
SMCSD	1.8	20	20	--
Treasure Island	2.0	--	--	--
American Canyon	2.5	--	--	--
Las Gallinas	2.9	--	--	--
Millbrae	3.0	120	110	10
Sonoma SVCSD	3.0	--	--	--
Mt View	3.2	--	--	--
SFO Airport	3.4	--	--	--
SASM	3.6	--	--	--
Pinole	4.1	--	170	11
Benicia	4.5	80	70	16
Burlingame	5.5	240	210	30
Petaluma	6.7	--	--	37
Novato	7.0	--	--	--
San Leandro	7.6	330	300	24
Livermore	8.5	480	430	--
CMSA	10.0	430	380	--
West Co WCSD	12.5	--	180	22
South SF	13.0	610	540	60

Plant[1]	Permitted ADWF Capacity (mgd)	Projected Nutrient Load Reduction[2,3]		
		NH3 (lb N/d)	TN (lb N/d)	TP (lb P/d)
Napa	15.4	--	--	--
Vallejo	15.5	--	--	--
San Mateo	15.7	--	240	--
Richmond	16.0	--	--	--
Hayward	18.5	730	640	--
Delta Diablo	19.5	770	690	--
OLSD	20.0	1,070	1,070	--
FSSD	23.7	--	600	40
DSRSD	23.9	--	--	--
SVCW	29.0	1,400	1,300	100
Sunnyvale	29.5	--	630	160
Union San	33.0	2,400	2,200	130
Palo Alto	39.0	--	--	--
CCCSD	53.8	--	--	--
SFPUC Southeast	85.0	5,000	4,500	--
EBMUD	120	13,700	12,100	750
San Jose	167	--	5,600	--
Total Nutrient Load Reduction with Sidestream Treatment[2,3]	--	27,380	32,026	1,394
Nutrient Discharge Loads Projected with Existing Treatment Facilities[2]	--	113,100	166,300	11,900
Nutrient Discharge Loads Projected with Sidestream Treatment[2,3]	--	85,720	134,274	10,506
Percent Reduction in Nutrient Discharge Loads[2,3]	--	24%	19%	12%

1. Plants are organized in ascending order of permitted ADWF capacity.
2. Values are average projected loads/reductions to SF Bay over the 30-year period of analysis for sidestream treatment.
3. Values are based on operating with sidestream treatment on a year round basis.

As shown in Table 12, implementation of sidestream treatment at the candidate facilities has the potential to remove approximately 24 percent of the effluent ammonia load, and about 19 and 12 percent of the effluent total nitrogen and total phosphorus loads, respectively.

Figure 13 and Figure 14 present the total present value cost distribution between capital and O&M at each candidate plant for total nitrogen and total phosphorus load reduction, respectively. The plants without cost shown in the figure were not candidates for sidestream treatment. As shown, the present value costs for candidate plants range from less than $1.0M to over $120M at EBMUD for total nitrogen. The present value costs for total phosphorus removal are much lower and O&M costs make up a substantially larger portion of the total present value.

Figure 13. Sidestream Treatment PV Costs for TN Load Reduction

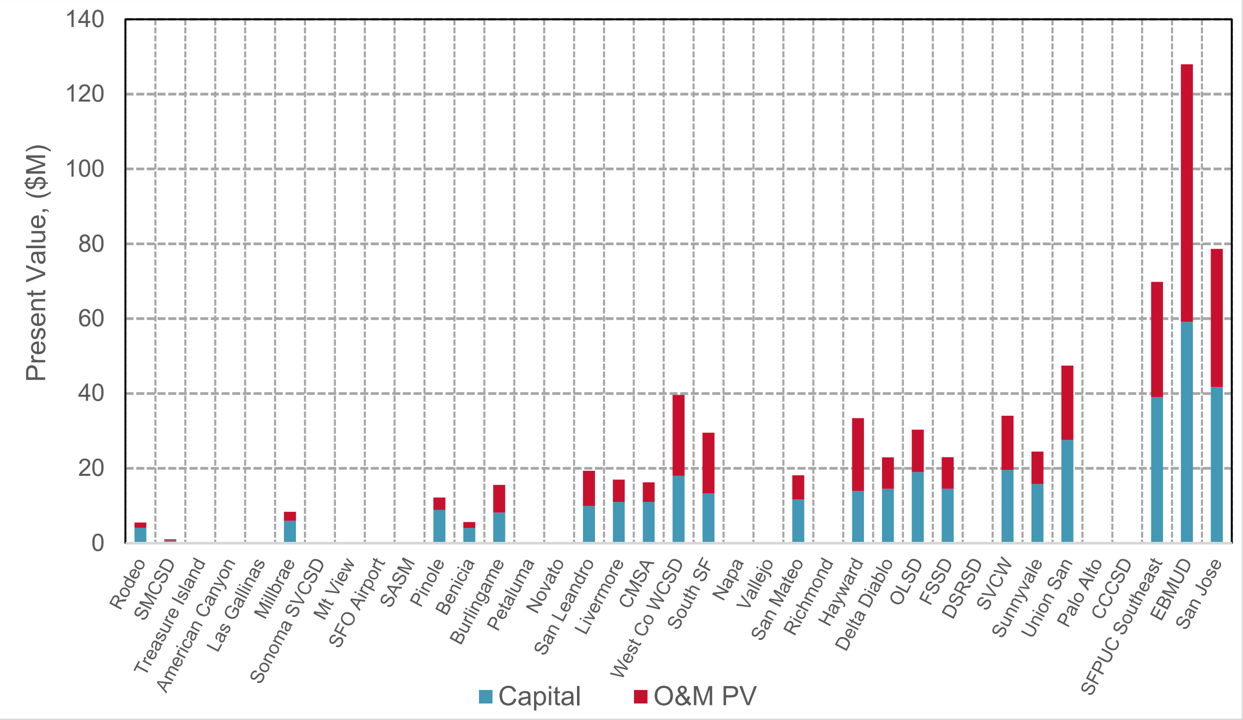
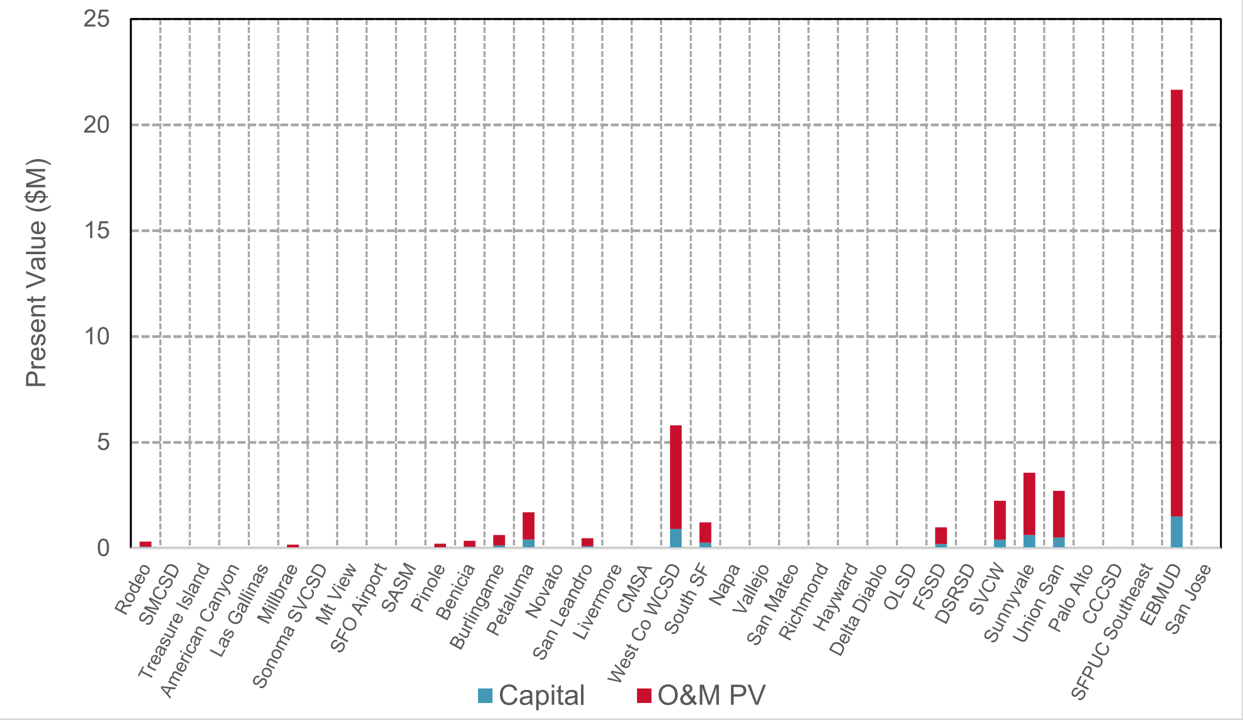


Figure 14. Sidestream Treatment PV Costs for TP Load Reduction



The total present value to implement total nitrogen sidestream treatment is approximately $680M, of which the total capital cost is $371M (approximately 55 percent of total) and the O&M

PV cost is approximately $308M (approximately 45 percent of total). The total present value to implement total phosphorus sidestream treatment is approximately $43M for all eligible facilities.

Figure 15 illustrates the daily average load reduction for sidestream treatment at each plant for total nitrogen and total phosphorus. The total nutrient load reduction for all plants is approximately 32,250 lb N/d, and 1,560lb P/d, respectively. Figure 15 demonstrates that the majority of the load reduction would be achieved from the three largest plants, representing approximately 65 percent for total nitrogen and 74 percent for total phosphorus load reduction.

Figure 15. Sidestream Treatment Daily Average TN and TP Load Reduction

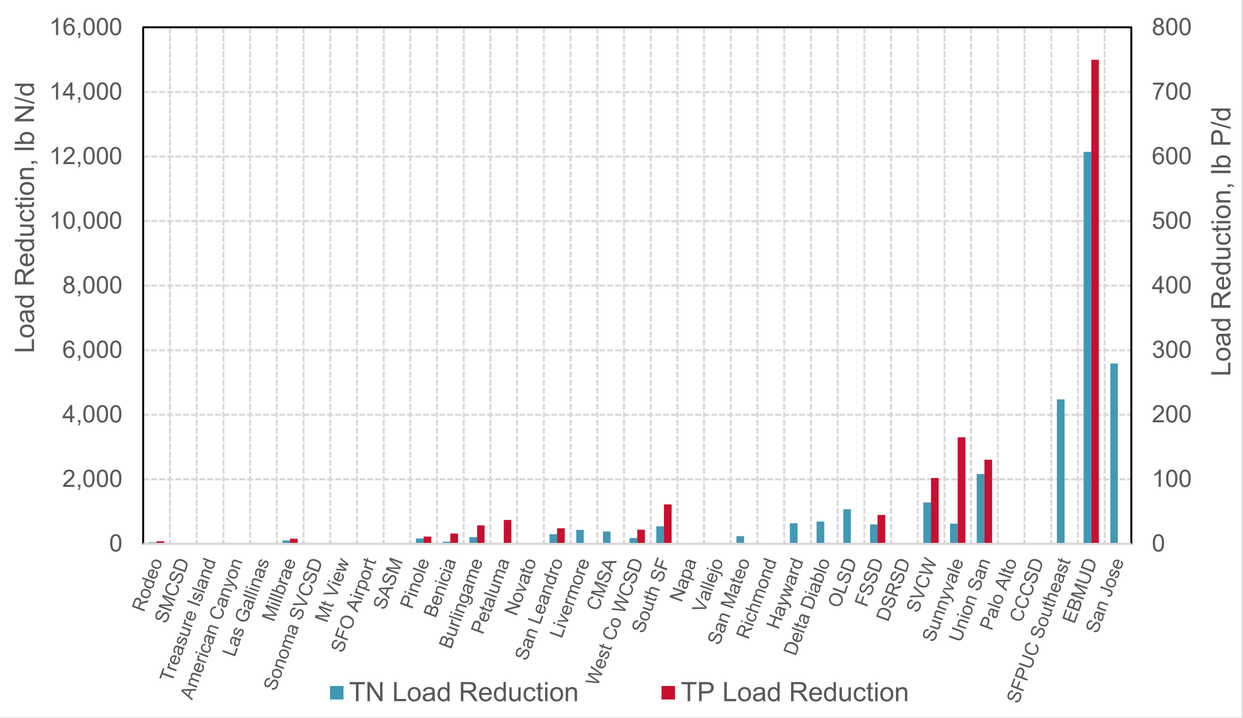


Figure 16 presents the present value as a unit cost for each plant based on design flow (i.e., total PV divided by the plant design capacity). The average unit present value cost of the plants for which sidestream treatment is feasible is approximately $1.1/gpd.

Figure 16. Sidestream Treatment PV Unit Cost per Gallon Treatment Capacity

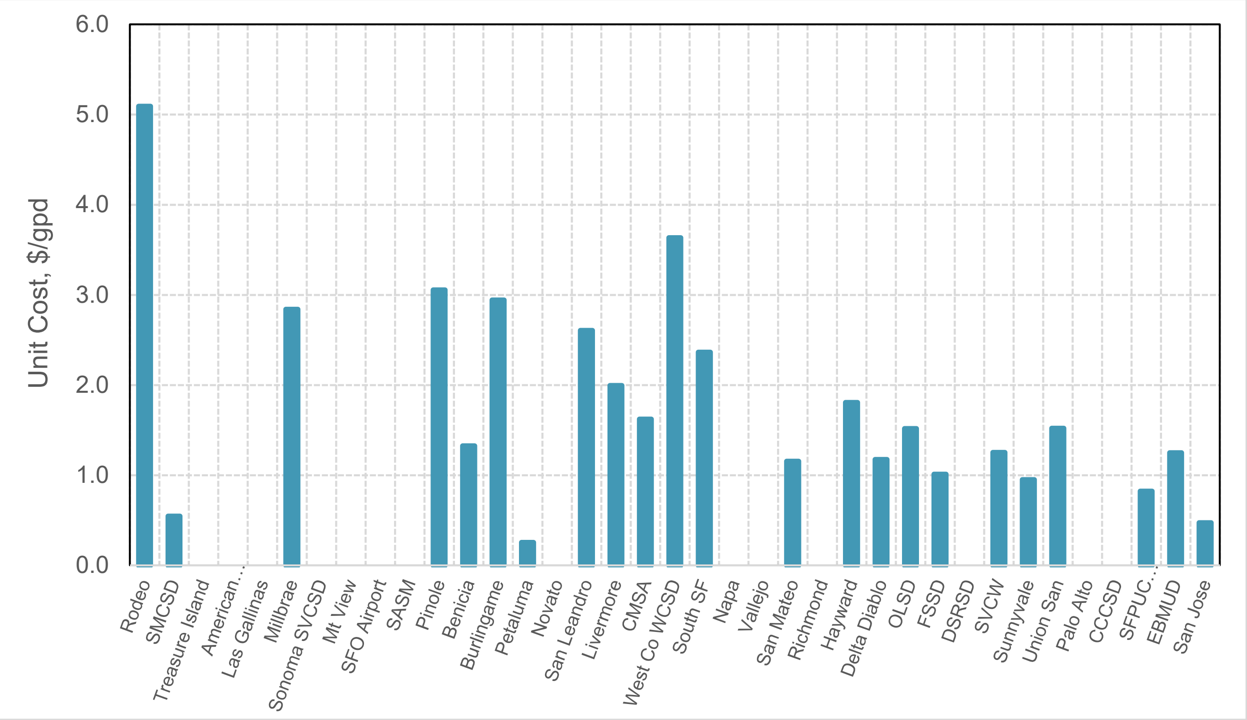


Figure 17 and Figure 18 show the total present value cost per average load reduction over the 30-year design period for both total nitrogen and total phosphorus, respectively. The cost per pound removed is used as a measure of efficiency to compare the implementation of a project at one plant to that of another plant. As shown, West County has the highest cost per pound of total nitrogen removed at approximately $20/lb N, compared to the average for all plants at approximately $2.0/lb N. Similarly, West County has the highest unit cost for sidestream phosphorus removal also, at nearly $25/lb P, compared to an average of only $2.7/lb P.

Figure 17. Sidestream Treatment PV Unit Cost per Pound TN Removed

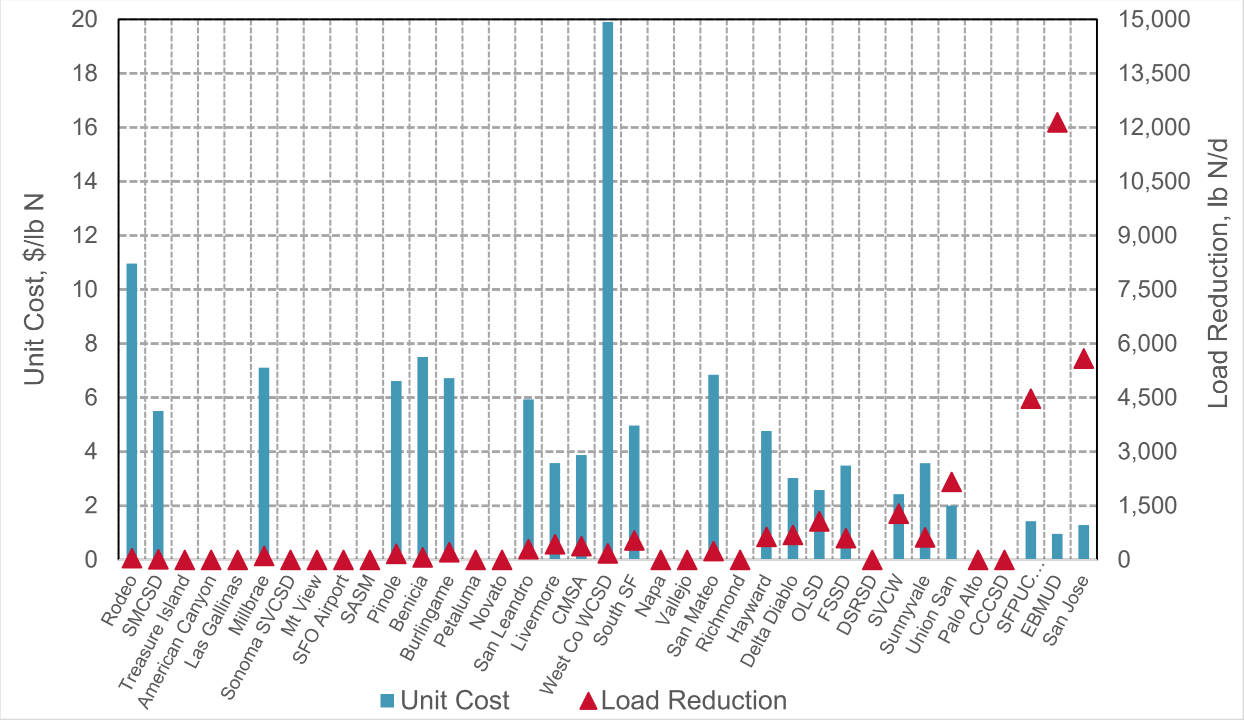
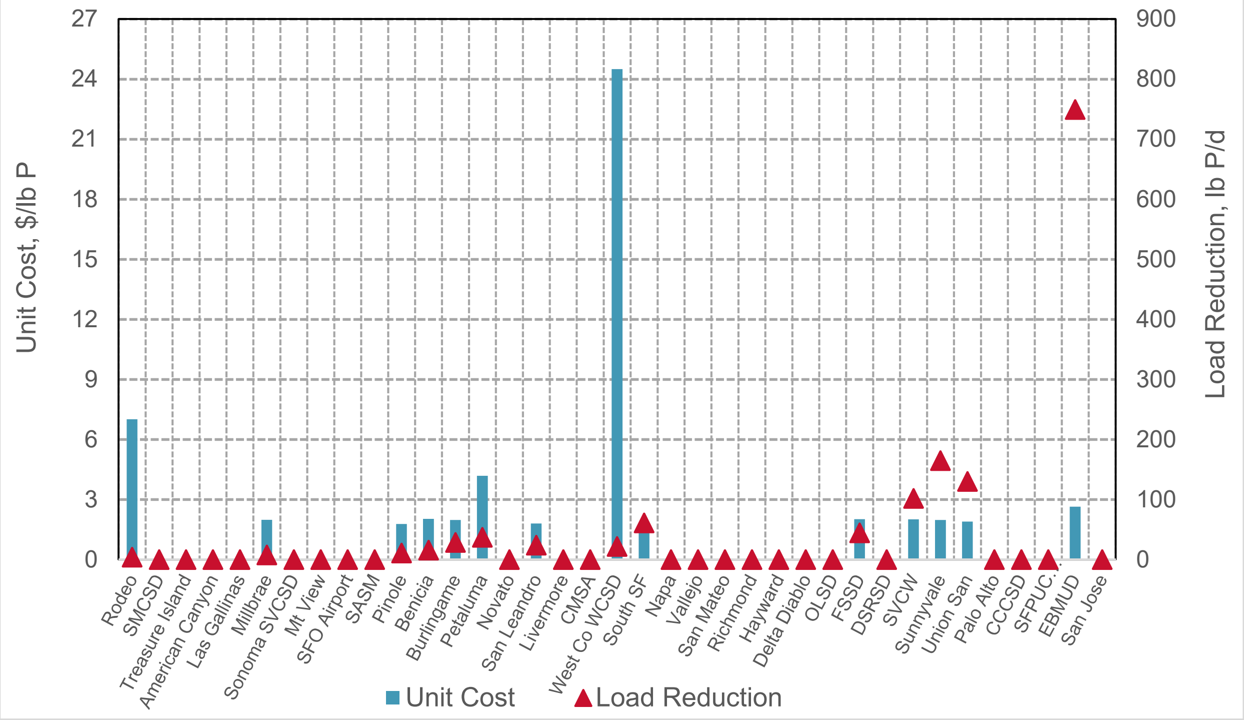


Figure 18. Sidestream Treatment PV Unit Cost per Pound TP Removed



4.3 Treatment Upgrades

As described in Chapter 3, treatment targets were identified to facilitate the evaluation of facilities needs for each plant. The targets for treatment upgrades are referred to as Levels 2 and 3. These levels were selected based on the typical tipping point for treatment technologies to achieve the respective effluent levels. For most plant configurations, the less stringent Level 2 can be achieved with conventional nutrient removal processes, without adding an external carbon source and without adding effluent filtration. The more stringent Level 3 would typically require an external carbon source for nitrogen removal and metal salt coagulant addition with filtration for phosphorus removal for most plant configurations. It is also notable that both levels included an effluent ammonia target of 2 mg N/L. Since established treatment technologies (each with a nitrification step) were used to determine cost estimates, the upgrades identified for each plant will meet the effluent ammonia target of 2 mg N/L.

As previously described, many plants already have some form of nutrient removal. American Canyon and Petaluma currently meet the Level 2 ammonia and total nitrogen targets. Sunnyvale typically meets the ammonia target and occasionally meets the Level 2 total nitrogen target in the dry season. In addition, the Pinole WWTP is currently under construction, and once complete, will also be capable of meeting the Level 2 targets.

Common upgrades to achieve the Level 2 effluent quality target include conventional nitrification/denitrification or the addition of a membrane bioreactor (MBR) for nitrogen removal, while Level 3 commonly required the addition of an effluent filter, or denitrification filter, an external carbon source, alkalinity, and metal salt coagulant addition.

Overall, the core recommendation for most plants was to expand or modify existing activated sludge reactor basins (or trickling filters) to accommodate biological nutrient removal. However, due to space constraints, or other constraints, the addition of an MBR was recommended for eight plants.

Implementation of the Level 2 and Level 3 treatment upgrades would increase both energy consumption and GHG emissions. In most cases, more chemicals are required and additional solids are also created. Other impacts include the increased complexity to operate the new facilities and potential safety concerns if methanol is selected as an external carbon source. For those plants with an MBR, the effluent is likely to be of a higher quality and more desirable for recycled water uses (particularly for future potable reuse applications).

Table 13 summarizes the annual average daily nutrient load reductions for each plant for nutrient reduction Levels 2 and 3. The total load reduction is also presented, as well as the percentage reduction in nutrient loadings from POTWs.

Table 13. Daily Average Load Reduction with Treatment Upgrades

Plant[1]	Permitted ADWF Capacity (mgd)	Projected Nutrient Load Reduction[2,3]					
		Ammonia (lb N/d)		TN (lb N/d)		TP (lb P/d)	
		Level 2	Level 3	Level 2	Level 3	Level 2	Level 3
Rodeo	1.1	1	1	7	75	18	23
SMCSD	1.8	100	100	160	280	40	50
Treasure Island	2	30	30	120	160	28	33
American Canyon	2.5	--	--	--	80	64	73
Las Gallinas	2.9	10	10	120	240	30	40
Millbrae	3	750	750	600	780	30	43
Sonoma SVCSD	3	--	--	--	--	15	21
Mt View	3.2	--	--	120	220	28	36
SFO Airport	3.4	640	640	480	600	32	41
SASM	3.6	80	80	250	490	100	120
Pinole	4.1	530	530	550	720	30	50
Benicia	4.5	590	590	360	620	65	85
Burlingame	5.5	810	810	890	1,230	230	250
Petaluma	6.7	--	--	--	--	40	60
Novato	7	--	--	--	230	8.8	32
San Leandro	7.6	1,490	1,490	950	1,270	92	130
Livermore	8.5	2,060	2,060	1,430	1,870	14	41
CMSA	10	1,930	1,930	1,600	2,300	180	240
West Co WCSD	12.5	--	--	250	420	40	50
South SF	13	2,180	2,180	1,820	2,660	350	420
Napa	15.4	0	0	--	260	6	38
Vallejo	15.5	1,570	1,570	1,200	2,200	260	340
San Mateo	15.7	2,960	2,960	2,450	3,110	190	260
Richmond	16	2,530	2,530	1,700	2,300	40	110
Hayward	18.5	2,300	2,300	1,500	2,490	180	260
Delta Diablo	19.5	3,640	3,640	3,060	3,820	5	64
OLSD	20	4,040	4,040	2,460	3,750	60	160
FSSD	23.7	--	--	2,100	3,100	480	590
DSRSD	23.9	3,120	3,120	2,200	2,800	30	90
SVCW	29	6,860	6,860	5,180	6,800	460	590
Sunnyvale	29.5	220	220	440	1,460	400	480
Union San	33	10,300	10,300	8,400	10,900	490	690
Palo Alto	39	--	--	2,770	4,810	740	900
CCCSD	53.8	8,870	8,870	6,800	9,200	--	220
SFPUC Southeast	85	21,700	21,700	18,100	22,800	170	536
EBMUD	120	27,600	27,600	25,100	32,200	2,100	2,700

Plant[1]	Permitted ADWF Capacity (mgd)	Projected Nutrient Load Reduction[2,3]					
		Ammonia (lb N/d)		TN (lb N/d)		TP (lb P/d)	
		Level 2	Level 3	Level 2	Level 3	Level 2	Level 3
San Jose	167	30	30	1,800	10,100	--	600
Total Load Reduction[2,3]	--	106,900	106,900	95,000	136,300	7,000	10,500
Nutrient Discharge Loads Project with Existing Facilities[2]	--	114,700	114,700	166,300	166,300	11,900	11,900
Nutrient Discharge Loads Project with Upgrades[2,3]	--	7,800	7,800	71,300	30,000	4,900	1,400
Percent Reduction in Nutrient Discharge Loads[2,3]	--	93%	93%	57%	82%	59%	88%

1. Plants are organized in ascending order by plant permitted ADWF capacity.
2. Values are average projected loads/reductions to SF Bay over the 30-year period of analysis for upgrades.
3. Values are based on meeting the Level 2 and 3 benchmarks on a year round basis.

As shown in Table 13, implementation of the recommended upgrades to meet the Level 2 targets would result in the reduction of POTW loads of approximately 93 percent of the effluent ammonia load, and about 60 percent for both effluent total nitrogen and total phosphorus loads. With additional treatment processes added to achieve the Level 3 benchmarks, approximately 80 percent of the effluent POTW total nitrogen loads and nearly 90 percent of the total phosphorus loads would be removed.

Figure 19 presents a summary of the present value costs to achieve the Level 2 effluent quality benchmarks on an annual basis. Similarly, Figure 20 shows the present value cost to meet the Level 3 effluent benchmarks.

As shown in Figure 19, the present value costs range from as low as $1.3M at American Canyon to achieve the Level 2 benchmark, to as high as $2.6B at EBMUD. To meet the Level 3 benchmark, the present value costs range from $8.9M at the Sonoma Valley plant to nearly $2.9B at the EBMUD plant.

The total present value cost to achieve the Level 2 target is approximately $9.4B, while the cost to achieve the Level 3 target is an additional $3B, for a total of approximately $12.4B. It is notable that the plants with an MBR process typically have a lower marginal increase from Level 2 to Level 3 because the membrane tank volume does not increase. For the MBR options, the increase in cost is due to the carbon addition and larger aeration basins.

In contrast to the treatment optimization cost analysis, the treatment upgrade capital costs generally make up a larger proportion of the present value for each plant. For Level 2, the capital costs make up nearly 75 percent of the total present value. For Level 3, the capital costs make up nearly 70 percent of the total present value. It is logical that the capital proportion of total costs would drop slightly from Level 2 to Level 3 due to the additional chemicals and energy that are typically required to meet the lower effluent limits.

Figure 19. PV Cost for Treatment Upgrades for Level 2

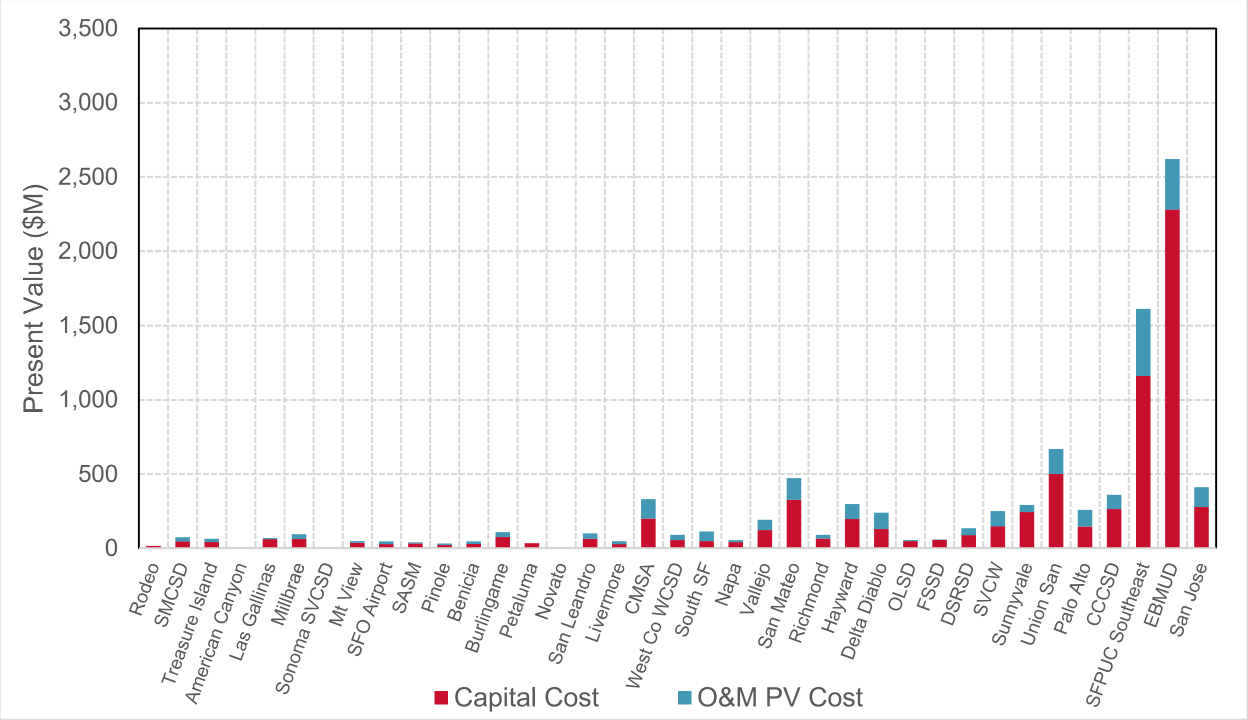


Figure 20. PV Cost for Treatment Upgrades for Level 3

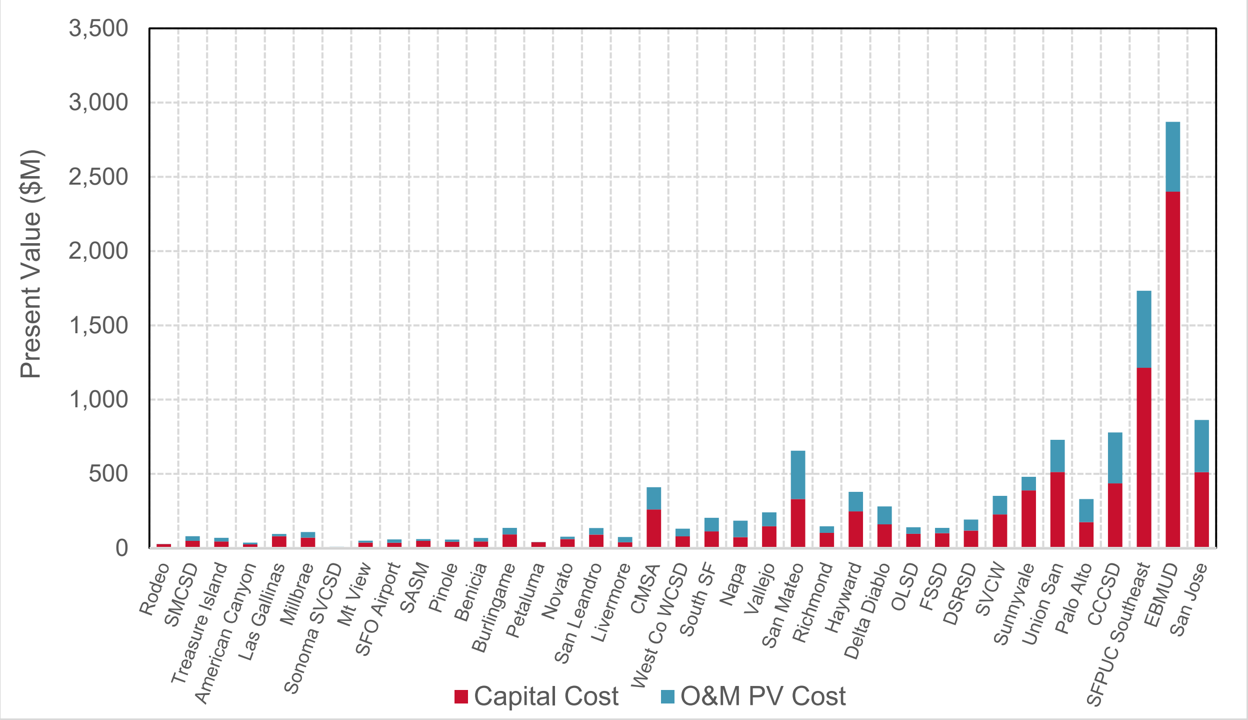


Figure 21 and Figure 22 illustrate the present value as a unit cost for each plant based on permitted capacity for Level 2 and Level 3, respectively. In addition, annual average daily total nitrogen load reduction is also presented.

Figure 21. PV Unit Cost per Gallon Capacity for Level 2 Treatment Upgrades

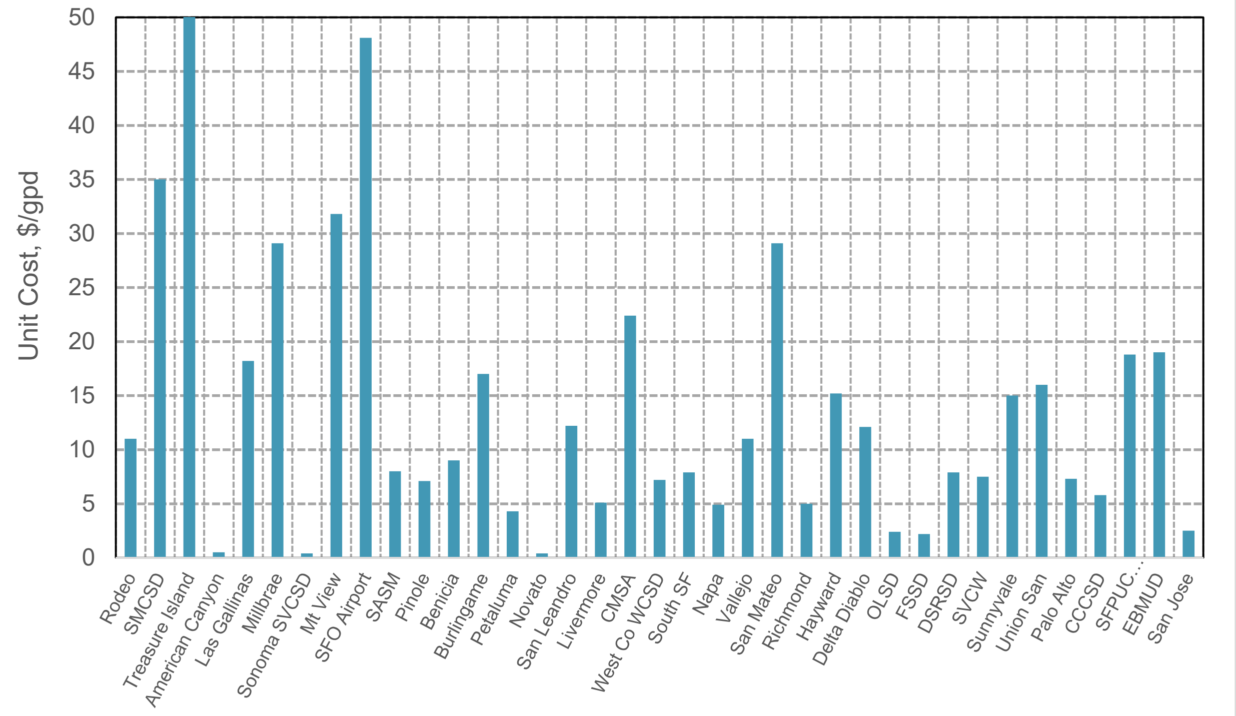
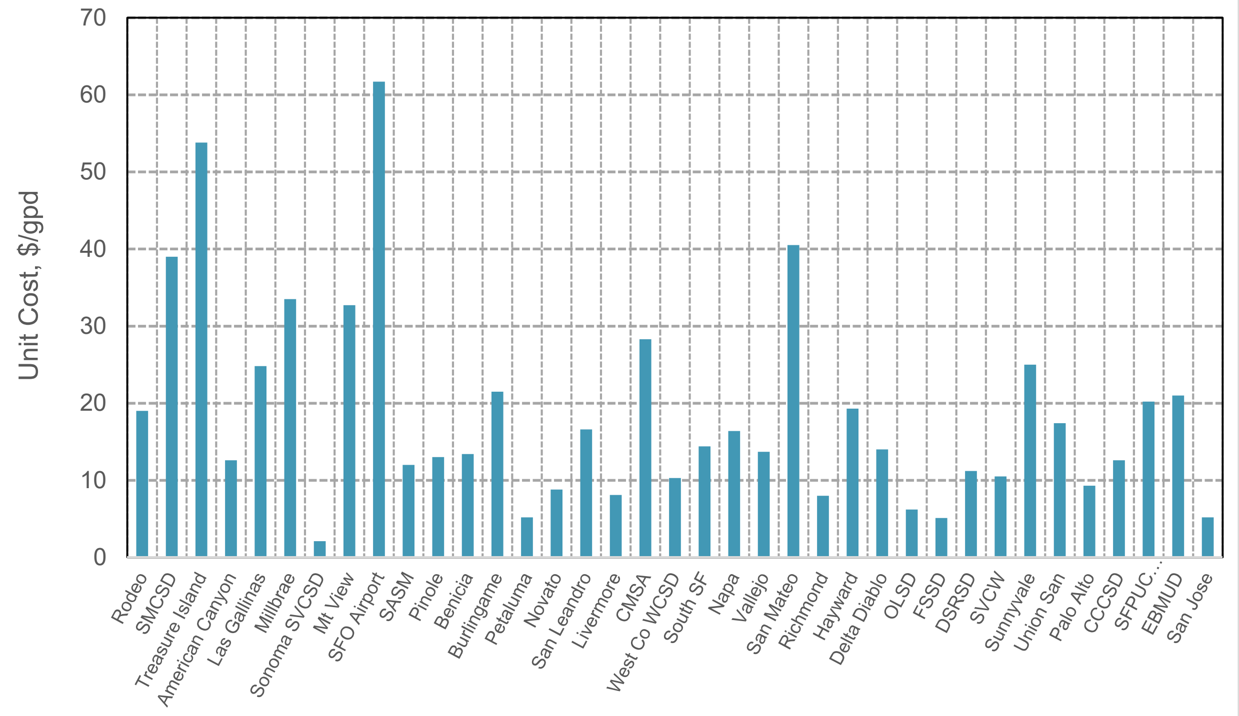


Figure 22. PV Unit Cost per Gallon Capacity for Level 3 Treatment Upgrades



As expected, there are economies of scale. Typically, the unit costs are higher for the smaller plants and lower for the larger plants. The average unit cost to achieve the Level 2 target is $10.8/gpd compared to $14.3/gpd to achieve the Level 3 target.

Figure 23 and Figure 24 show the present value cost per pound of total nitrogen and total phosphorus removed for Level 2. Similarly, Figure 25 and Figure 28 show the present value cost per pound of total nitrogen and total phosphorus removed for Level 3.

Figure 23. PV Unit Cost per Pound TN Removed for Level 2 Treatment Upgrades

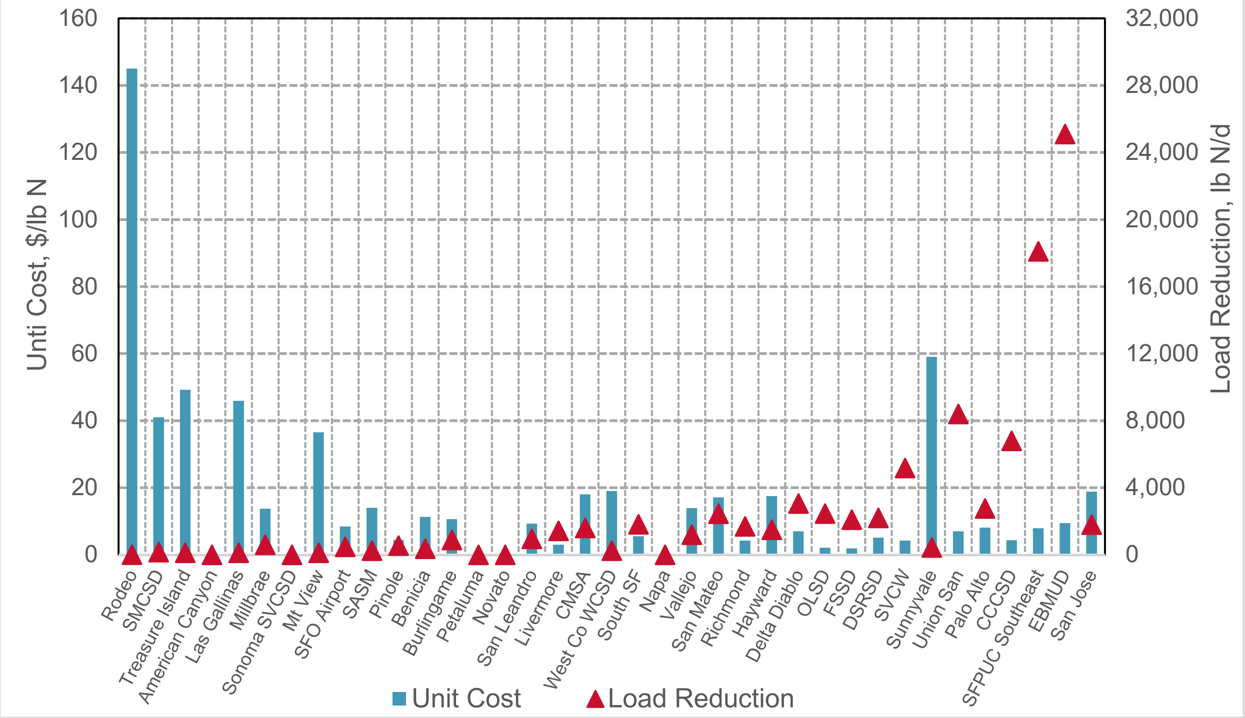


Figure 24. PV Unit Cost per Pound TP Removed for Level 2 Treatment Upgrades

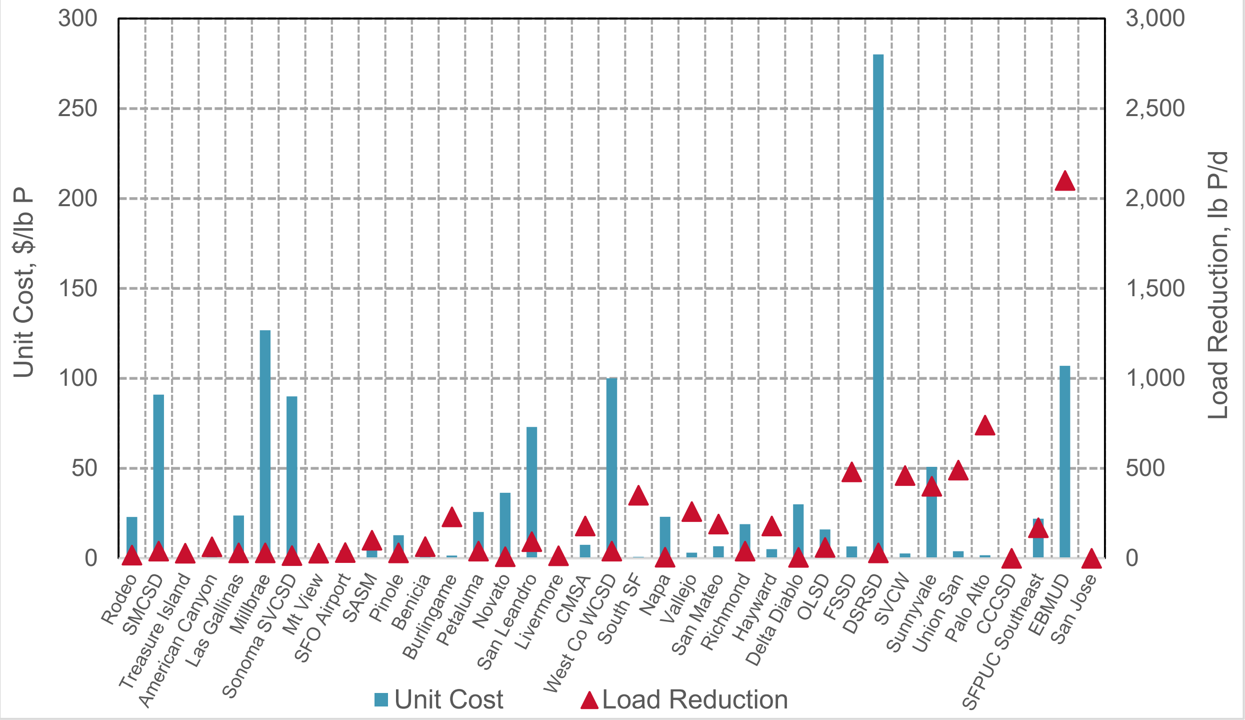


Figure 25. PV Unit Cost per Pound TN Removed for Level 3 Treatment Upgrades

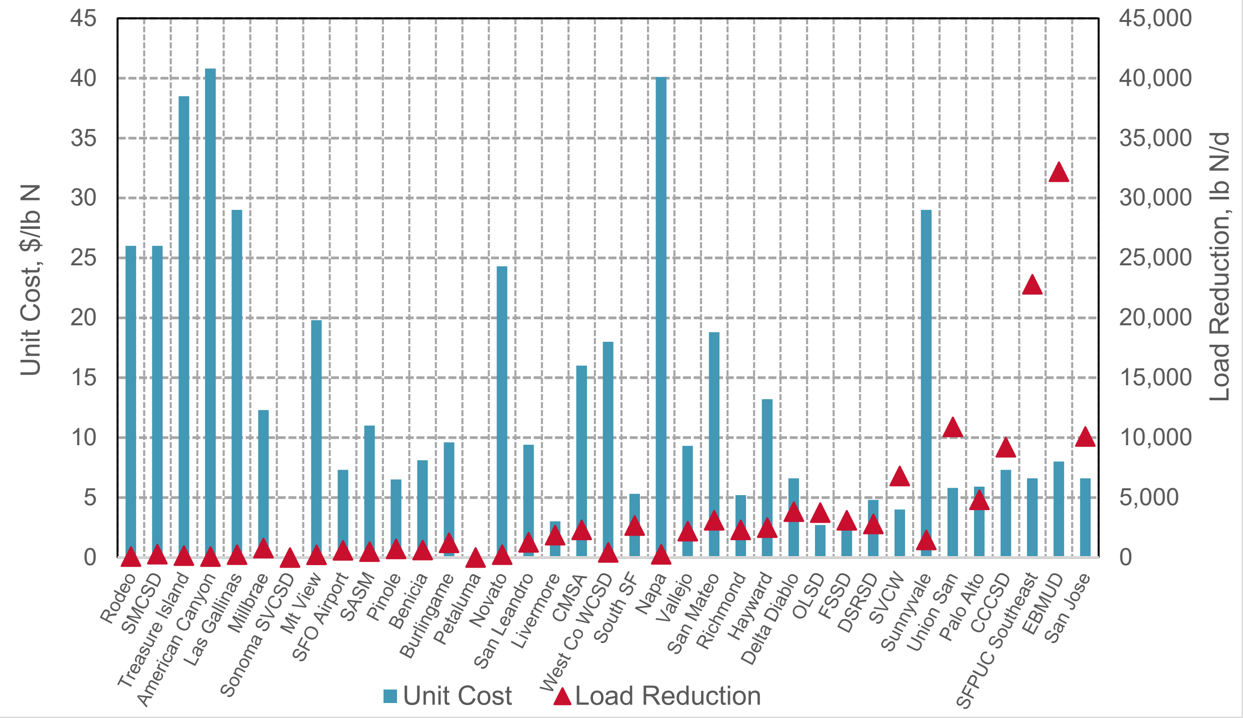
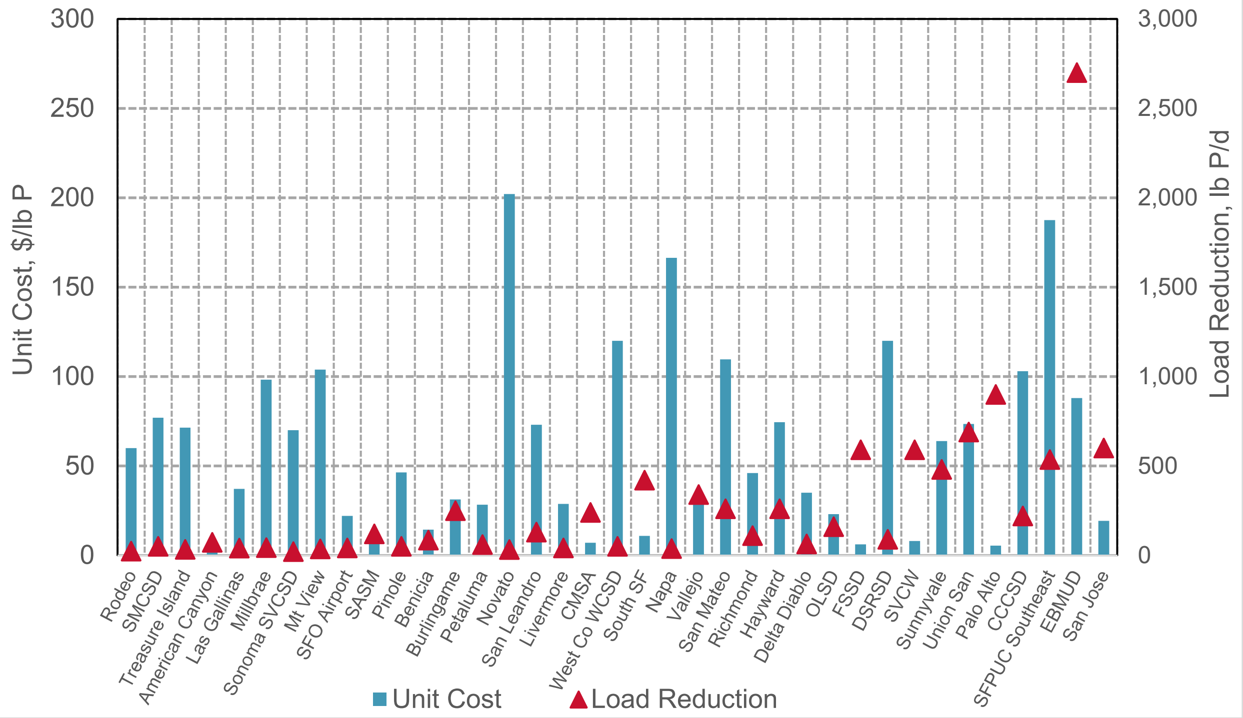


Figure 26. PV Unit Cost per Pound TP Removed for Level 3 Treatment Upgrades



The average unit cost for total nitrogen removal is approximately $8.7/lb N to meet the Level 2 target and $7.7/lb N to meet the Level 3 target. The average unit cost for total phosphorus removal is approximately $43/lb P to meet the Level 2 target and nearly $59/lb P to meet the Level 3 target. The plants with the highest unit costs per pound remove are typically those that are currently meeting or almost meeting the respective water quality benchmarks, because there is a significant investment required to achieve the marginal reduction on a reliable basis.

As previously described, the recommended upgrades to meet the Level 2 and 3 benchmarks, and the associated costs described above, are based on established technologies. These established technologies were used because there is a wealth of information related to facilities costs and sizing which are important for planning purposes. However, there are many emerging technologies that may achieve lower levels of nutrient discharges and/or be more cost-effective. As such, innovative and/or emerging technologies were also considered.

For each of the participating agencies, at least 2 emerging technologies were identified for future consideration. Emerging technologies that were considered include:

- Granular Activated Sludge
- Simultaneous nitrification / denitrification
- Nitrite Shunt
- Zeolite-Anammox
- Treatment Wetlands
- Membrane Aerated Biofilm Reactor (MABR)
- Ballasted Activated Sludge

Many of these technologies are early in their development. Bench-, pilot-, and/or demonstration-scale testing would be prudent to confirm design and sizing criteria, potential process benefits and further define potential cost and plant site footprint space savings. For planning purposes, pilot studies can commonly represent approximately one percent of anticipated project costs, or more, and provide a positive return on investment.

4.4 Summary Comparison

A summary of the load reduction that can be achieved with each treatment strategy, including the implementation of treatment optimization, sidestream treatment, and plant upgrades to meet the Level 2 and Level 3 water quality benchmarks, is presented in Table 14. These load reductions, and their associated costs, are based on year round operation of the treatment strategies, where facilities are sized to treat year round flows and loads. Similar information is presented in Table 15 for dry season conditions. As previously described, the dry season represents the period between May 1 and September 30, and facilities were sized to meet the loads during that period. However, it was assumed that facilities would operate on a year round basis. In all cases, it was assumed that sidestream treatment would be operated on a year round basis.

Table 14. Summary of Nutrient Load Reduction and Associated Costs, Year Round Operation

Parameter	Unit	Current Discharge[1]	Treatment Strategy			
			Optimization[2]	Sidestream[2]	Level 2[2]	Level 3[2]
Design Flow	mgd	--	546	633	869	869
Load Reduction						
Ammonia	lb N/d	86,510	12,290	27,439	106,900	106,900
TN	lb N/d	129,670	8,559	31,827	95,00	136,300
TP	lb P/d	9,240	3,139	1,404	7,000	10,500
Costs[3,4]						
Capital	$M	--	119	377	6,976	8,517
O&M PV	$M	--	147	345	2,443	3,888
Total PV	$M	--	266	722	9,419	12,405
Average Unit Costs						
Per gpd[5]	$/gpd	--	0.5	1.1	10.8	14.3
Per lb N[6]	$/lb N	--	5.6	2.0	8.7	7.7
Per lb P[6]	$/lb P	--	8.6	2.7	43	59

1. The current discharge loads are based on the 2015 BACWA Nutrient Reduction Study Group Annual Report (data from 7/2012-6/2015). The reported flows and loads for optimization, upgrades, and sidestream represent average projected load reduction for the period of analysis (10-yr for optimization and 30-yr for upgrades and sidestream). Sidestream design flow reflects only the candidate plants.
2. Facilities were sized for year round loads and operated year round.
3. Costs are referenced to the ENR SF CCI for January 2018 at 12,015. Costs do not include changes in solids handling or changes in energy requirements in other unit processes. Level 3 costs are inclusive of facilities needed to meet Level 2.
4. PV is calculated based on a 2 percent discount rate for 10 years (optimization) and 30 years (sidestream and upgrades).
5. Unit cost ($/gpd) was calculated by dividing the total present value by the design flow.
6. Unit cost ($/lb) was calculated by dividing the total present value for the nutrient of interest by the nutrient load reduction over the projection duration (e.g., for upgrades: Total PV for TN Removal facilities divided by (Average Annual TN Removed times 30-years)).

As illustrated in both Table 14 and Table 15, the load reductions increase with increasing degrees of treatment, from optimization through Level 3. Implementation of the optimization strategies could result in a load reduction of approximately seven percent for total nitrogen for a short term (approximately 10 years) capital cost investment of approximately $120M, whereas implementation of sidestream treatment could result in a total nitrogen load reduction of over 19 percent for a longer period (approximately 30 years) at a capital cost of nearly $380M. The cost per pound of nitrogen removed is lower for sidestream treatment than that for optimization, it also has a longer term benefit and is expected to be a more reliable nutrient reduction strategy. The results are similar for total phosphorus when comparing the cost per pound removed for optimization and sidestream treatment.

Table 15. Summary of Nutrient Load Reduction and Associated Costs, Dry Season Operation

Parameter	Unit	Current[1]	Treatment Strategy			
			Optimization[2]	Sidestream[2]	Level 2[2]	Level 3[2]
Design Flow	mgd	--	494	633	788	788
Load Reduction[1]						
Ammonia	lb N/d	82,020	11,910	27,439	106,400	106,400
TN	lb N/d	121,570	7,035	31,827	90,300	110,800
TP	lb P/d	8,590	2,950	1,404	6,800	8,300
Costs[3,4]						
Capital	$M	--	107	377	6,544	7,866
O&M PV	$M	--	134	345	2,226	2,945
Total PV	$M	--	241	722	8,770	10,811
Average Unit Costs[5,6]						
Per gpd	$/gpd	--	0.5	1.1	11.1	13.7
Per lb N	$/lb N	--	6.0	2.0	8.5	8.4
Per lb P	$/lb P	--	6.0	2.7	44	66

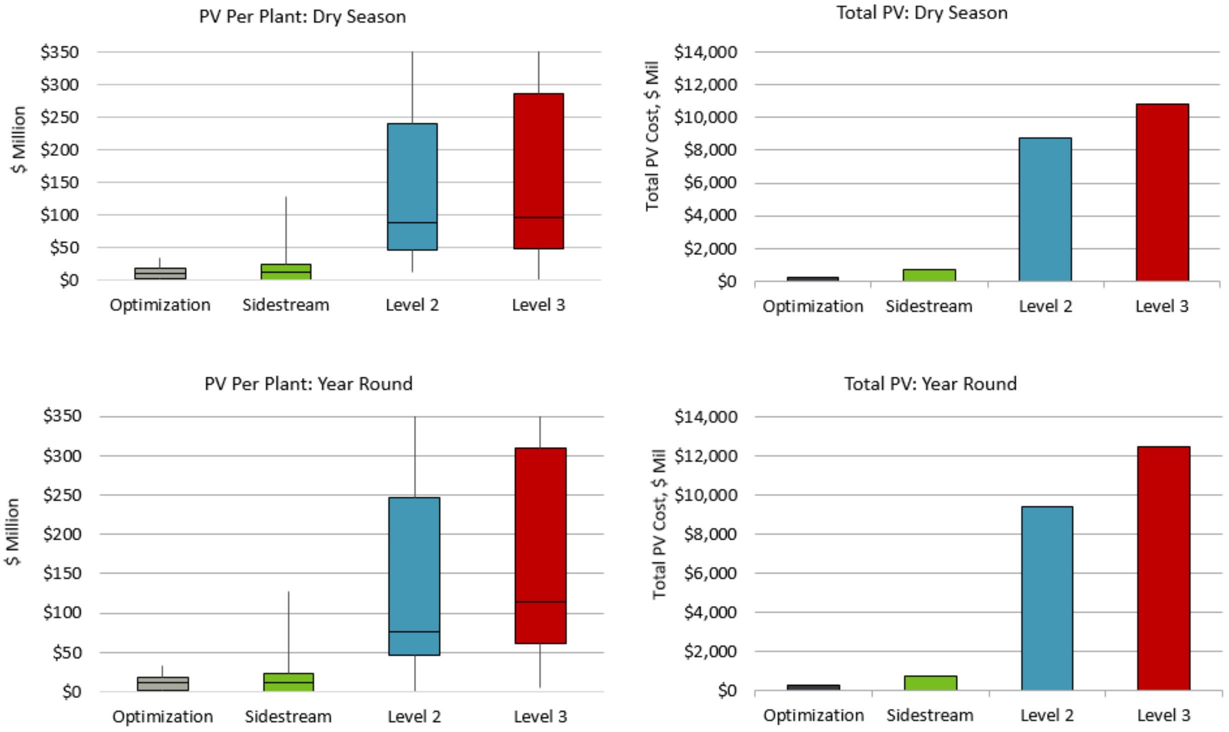
1. The current discharge loads are based on the 2015 BACWA Nutrient Reduction Study Group Annual Report (data from 7/2012-6/2015). The reported flows and loads for optimization, upgrades, and sidestream represent average projected load reduction for the period of analysis (10-yr for optimization and 30-yr for upgrades and sidestream). Sidestream design flow reflects only the candidate plants.
2. Facilities were sized for dry season (May 1 through September 30) loads and are assumed to operate year round. The sidestream facilities are sized for a year round loads and operated year round.
3. Costs are referenced to the ENR SF CCI for January 2018 at 12,015. Costs do not include changes in solids handling or changes in energy requirements in other unit processes. Level 3 costs are inclusive of facilities needed to meet Level 2.
4. PV is calculated based on a 2 percent discount rate for 10 years (optimization) and 30 years (sidestream and upgrades).
5. Unit cost ($/gpd) was calculated by dividing the total present value by the design flow.
6. Unit cost ($/lb) was calculated by dividing the total present value for the nutrient of interest by the nutrient load reduction over the projection duration (e.g., for upgrades: Total PV for TN Removal facilities divided by (Average Annual TN Removed times 30-years)).

The incremental present value cost to go from Level 2 to 3 upgrades is approximately $2B for upgrades based on dry season loads and $3B for upgrades based on year round loads. The major factor causing the large cost differential is the need for additional facilities to reliably achieve the lower benchmarks (e.g., additional denitrifying filter and ancillary equipment). This incremental increase is reflected in the unit cost per gallon capacity ($/gpd). The unit cost for total nitrogen removal efficiency ($/lb TN removed) are comparable for Levels 2 and 3, regardless of season (all approximately $8/lb TN removed). In contrast, the unit cost for total phosphorus removal efficiency ($/lb TP removed) has a pronounced increase from Levels 2 and 3 and a marginal increase from dry season to year round limits.

Overall, the present value costs increase with increasing treatment, ranging from $241M to implement dry season optimization up to $12.5B to implement treatment upgrades to meet

Level 3 effluent quality benchmarks year round. This substantial increase in present value costs is illustrated in Figure 27, which also illustrates the range of present value costs for each plant to implement the treatment strategies. These range from less than $1M to implement optimization strategies at several plants to well over $1B to implement upgrades at some of the larger plants, including EBMUD and SFPUC's Southeast plant.

Figure 27. Summary of Present Value Costs



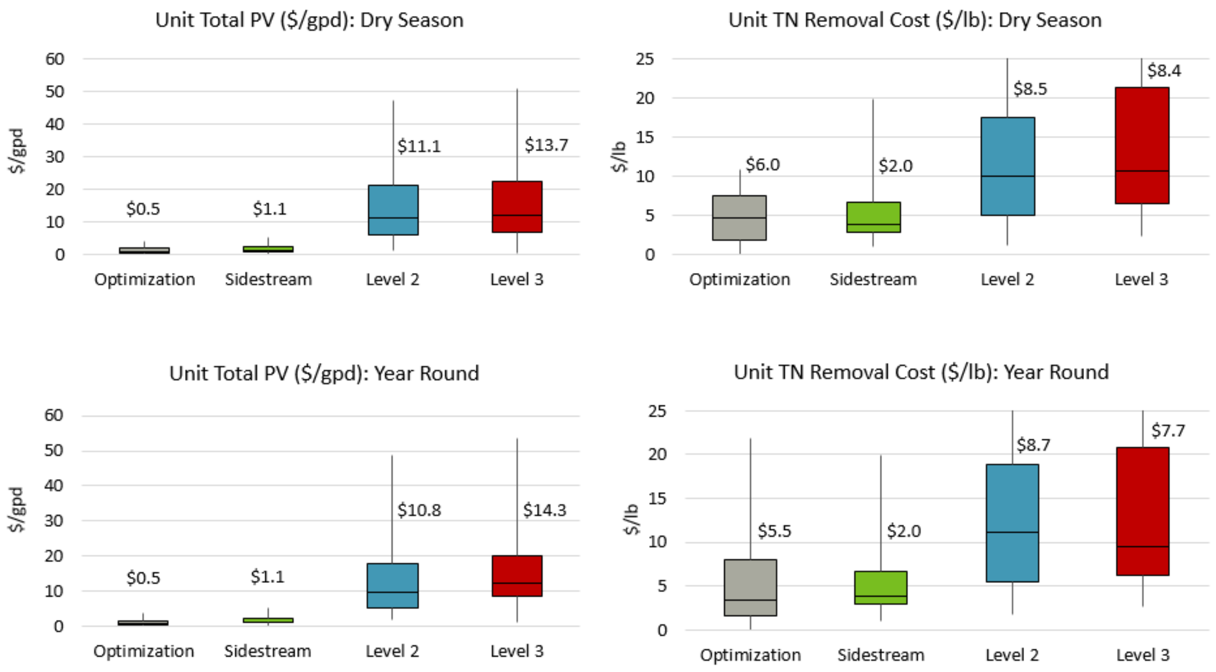
Notes:

1. The PV Per Plant graphs are presented as box and whisker plots, where the boxes represents the range of costs falling within the 25th to 75th percentiles, the horizontal bar within the box represents the median cost, and the ends of the whiskers represent the minimum and maximum present value costs, respectively.
2. The maximum value for Level 2 and Level 3 are not illustrated in the box and whisker plots due to scale. For dry season conditions, the maximums are $2.5B and $2.6B for Levels 2 and 3, respectively. For year round conditions, the maximums are $2.7B and $2.9B for Levels 2 and 3, respectively.

The unit costs are also revealing (illustrated in Figure 28). While optimization has the lowest unit cost per gallon treated, sidestream treatment has the most efficient unit removal cost for both total nitrogen and total phosphorus ($/lb TN or TP).

While there is a significant increase in the average unit cost per pound of phosphorus removed between Level 2 to Level 3 treatment (refer to Table 14 and Table 15), there is a reduction in the average unit cost per pound of nitrogen removed. The former is due to the relatively small increment in pounds removed required to reduce from an effluent total phosphorus of 1.0 mg P/L to 0.3 mg P/L, yet a substantial cost to achieve that increment. On the other hand, there is considerable reduction in total nitrogen load with the reduction from 15 mg N/L to only 6 mg N/L which balances with the additional costs required to achieve that reduction.

Figure 28. Summary of Unit Costs



Notes:

1. The unit cost graphs are presented as box and whisker plots, where the boxes represent the range of costs falling within the 25th to 75th percentiles, the horizontal bar within the box represents the median cost, and the ends of the whiskers represent the minimum and maximum unit costs, respectively.

Finally, the consideration of the impact of new unit processes on GHG emissions is a requirement of the Watershed Permit. The analysis is not intended to be a plant-wide GHG analysis with indirect and direct emissions reporting. Rather, the analysis was limited to the identification of potential changes in energy and chemical demands with the transition from secondary treatment to nutrient removal. It is well documented that transitioning from secondary treatment to advanced treatment with nutrient removal will increase the plant-wide GHG emissions in most cases. The increase is attributed to a combination of additional energy required to oxidize and reduce the various nitrogen species, filtration requirements, chemical demands for alkalinity and phosphorus precipitation, and others.

A summary of the relative increase in GHG emissions with respect to current emissions is provided in Table 16. In general, the GHG emissions increase with more advanced treatment. Chemicals are the predominant contributor to GHG emissions, regardless of treatment level. The increase in GHG emissions associated with the most stringent Level 3 targets is primarily due to additional electrical energy required to reduce both TN and TP, compounded with additional chemicals. The predominant GHG emission increase is indirect, resulting from electrical power generation.

Table 16. Incremental Increase in Greenhouse Gas Emissions

Parameter	Unit	Annual Increase in GHG Emissions			
		Optimization	Sidestream	Level 2	Level 3
Due to Energy	MT CO_2/yr	14,400	4,500	119,000	138,500
Due to Chemicals	MT CO_2/yr	48,700	600	138,400	168,400
Total Increase	MT CO_2/yr	63,100	5,100	257,400	306,900

1. Values are average projected incremental increase in GHG emissions over the respective period of analysis for each treatment type.
2. Values are based on operating with the treatment strategy in place on a year round basis.

As shown in Table 16, with each successive step of treatment (except for sidestream treatment), the average annual increase in GHG emissions increases.

5. Nutrient Reduction by Other Means

The analyses and results described in Chapter 4 are based on improvements that can be achieved through optimization and upgrade of the respective treatment plants. The focus of the nutrient reduction by other means assessment is to identify other ways to reduce the nutrient loads discharged to SF Bay.

As described in Chapter 3, several potential methods were anticipated, including effluent management (e.g., recycled water use), effluent polishing (e.g., wetlands treatment), source control, and non-point source reduction. For the agencies participating in this Nutrient Reduction Study, the primary method of reducing nutrient effluent loads by other means is through the use of recycled water.

A survey was conducted to collect information about existing recycled water usage and plans for the future. The survey requested forecasted use in five year increments through 2040 as well as the type of use. The following categories were included in the questionnaire:

- Golf Course Irrigation
- Landscape Irrigation
- Commercial Use
- Industrial Use
- Agricultural Use
- Environmental Enhancement
- Internal Use
- Groundwater Recharge for Indirect Potable Reuse
- Surface Water Augmentation
- Direct Potable Use
- Other Non-Potable Uses

Recognizing that some of the use categories listed above may have return streams that are high in nutrient concentration, the projected concentrate from advanced treatment and/or other return streams (e.g., cooling tower blow down) was also requested.

Table 17 presents a summary of existing and future recycled water use for each of the five subembayments. Values are presented as acre-feet per year and do not include concentrated return streams that are discharged to the SF Bay.

Approximately six percent of the current effluent volume is being diverted for recycled water use on an annual basis. Recycled water use is expected to more than double by 2040. Suisun Bay is currently using the highest volume of recycled water; however, over time, the other subembayments are projecting greater growth. By 2040, the South Bay is anticipating having the highest volume of recycled water use.

Table 17. Recycled Water Projections by Subembayment (AFY)

Subembayment	2015	2020	2030	2040
Suisun Bay	20,040	24,070	25,980	27,050
San Pablo Bay	8,010	13,350	15,450	17,250
Central Bay	10,680	14,620	25,120	28,880
South Bay	12,020	24,160	29,450	30,970
Lower South Bay	7,730	16,130	21,360	26,500
Total	58,480	92,330	117,360	130,660

1. Values are acre-feet per year and do not include concentrate and other streams that are returned to the plant and discharged with plant effluent.

Figure 29 illustrates the distribution of existing and future recycled water by use category. As shown, industrial use is currently the largest use type, making up approximately 28 percent of the total use, followed by irrigation at approximately 27 percent when combining golf course irrigation with general landscape irrigation. By 2045, irrigation is anticipated to make up a larger portion of recycled water use. Environmental enhancement, such as the water diverted to the Hayward Marsh, currently makes up approximately 21 percent of total recycled water use and this annual volume is projected to be stable over the planning period. While no potable reuse was reported for 2015, ground water recharge, a form of potable reuse, is anticipated to make up approximately seven percent of the total use in 2040.

Figure 29. Recycled Water Projections by Use Category

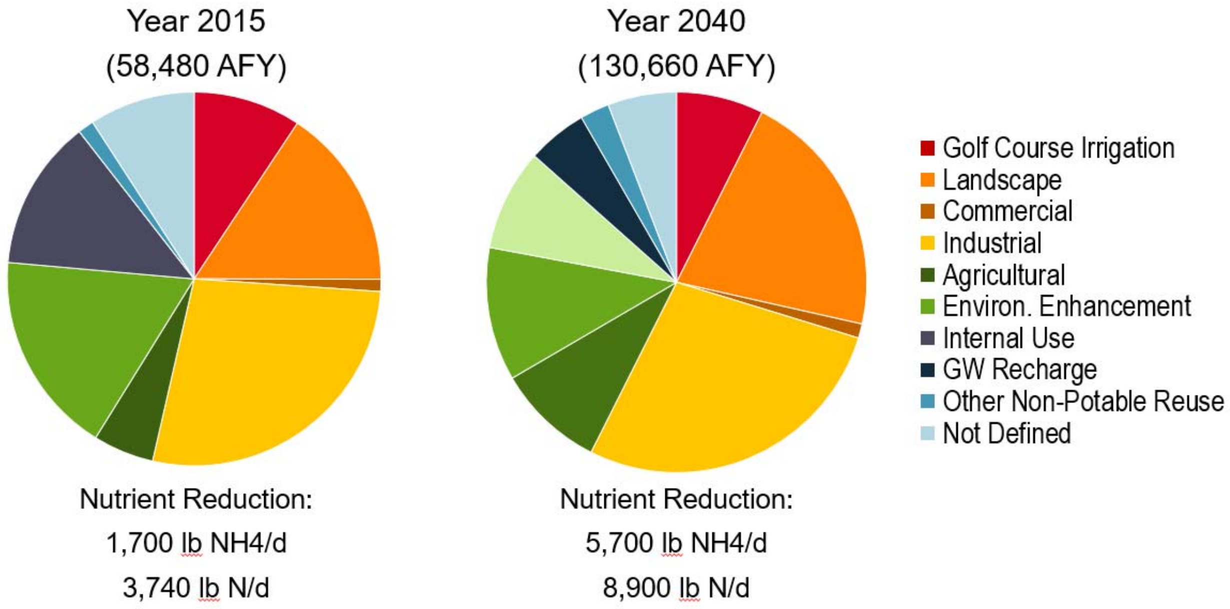


Figure 29 also presents the estimated nutrient reduction for ammonia and total nitrogen due to recycled water use. It is notable that some recycled water use categories do not result in a reduction in nutrient loads discharged to SF Bay. In fact, some uses, such as potable reuse, could increase concentrations discharged to the bay due to the concentrated reject brine streams created during the advanced treatment processes. Generally, irrigation uses (i.e., landscape, golf course, and agricultural) result in a decrease of nutrient loads since the water is completely consumed at the application site. However, uses such as potable reuse and often times industrial uses, will have a concentrated stream that is either returned to the POTW for discharge or otherwise discharged to SF Bay. Thus, with respect to identifying the nutrient reductions associated with future recycled water uses, it is important to understand the type of use anticipated and whether there will be a concentrated return stream that ultimately needs to be discharged.

In addition to recycled water, another potential opportunity to reduce nutrients by means other than treatment within the fenceline is the horizontal levee project. OLSD recently constructed a horizontal levee, known as the Ecotone Project. It is the first of its kind in the Bay Area. The horizontal levee has several anticipated benefits to the OLSD WWTP:

- Protection against sea level rise
- Reduction in nutrient loads to the Bay by polishing in the levees wetland system
- Equalization of wet weather flows
- Protection against flooding and habitat loss

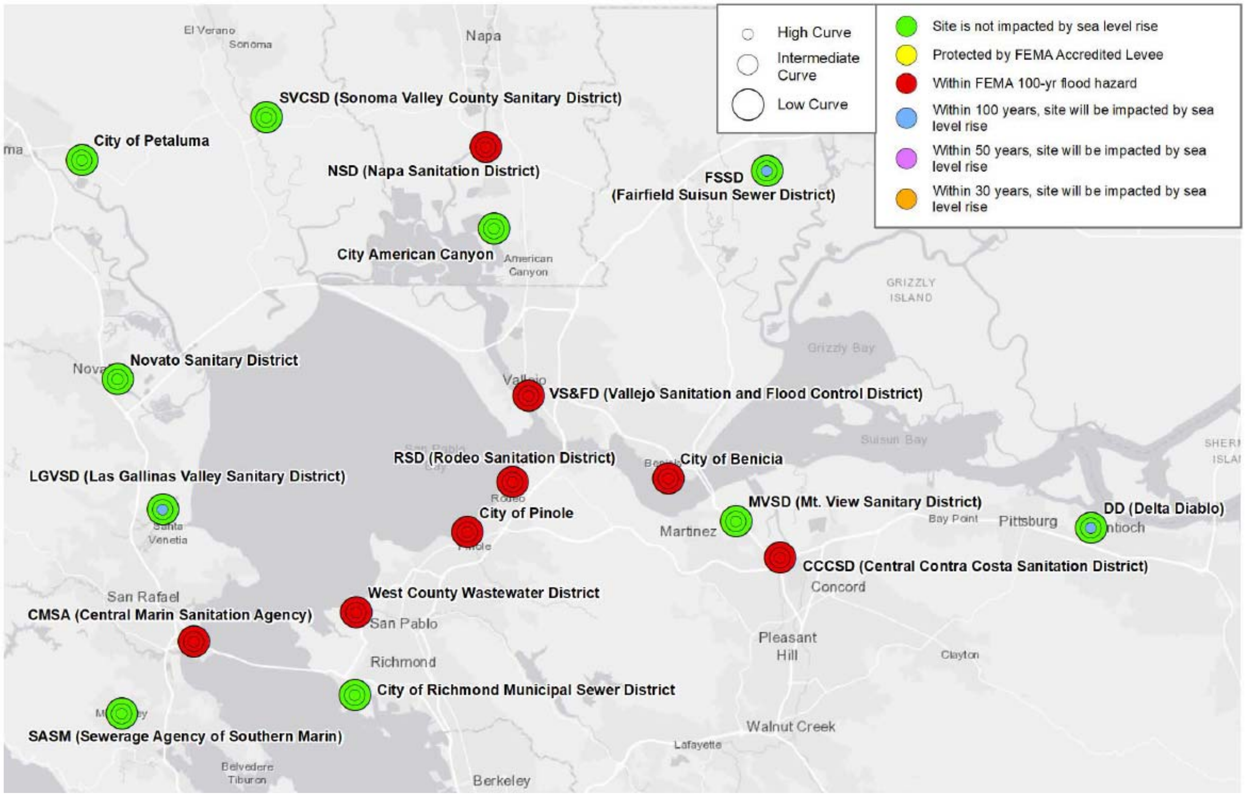
Tracking the Ecotone Project performance will provide valuable information to assist other agencies in determining whether such a project is appropriate for other sites.

6. Sea Level Rise

As described in Chapter 3, the Watershed Permit requires consideration of the potential impacts on facilities due to sea level rise. The intent of the requirement was to avoid identifying nutrient removal options that would be infeasible due to actions implemented or planned to address sea level rise. Thus, the plants that are vulnerable to the impacts of sea level rise were identified. The methodology, described in detail in Appendix C, is based on publicly available data from the USACE, FEMA, and publicly available topography data.

The results of the analysis are illustrated in Figure 30 and Figure 31 for the north and south bay, respectively, and presented in detail in Appendix C. The figures present the results of the analysis under three rates of sea level rise conditions, as defined by the USACE:[25] low, intermediate, and high. The low rate of sea level rise reflects the historical rate of sea level change. The intermediate rate of rise is based on the modified National Research Council (NRC) Curve I considering both the most recent Intergovernmental Panel on Climate Change (IPCC) projections and modified NRC projections with the local rate of vertical land movement added. The high rate of rise is based on the modified NRC Curve III considering both the most recent IPCC projections and modified NRC projections with the local rate of vertical land movement.

Figure 30. Sea Level Rise Assessment, North Bay



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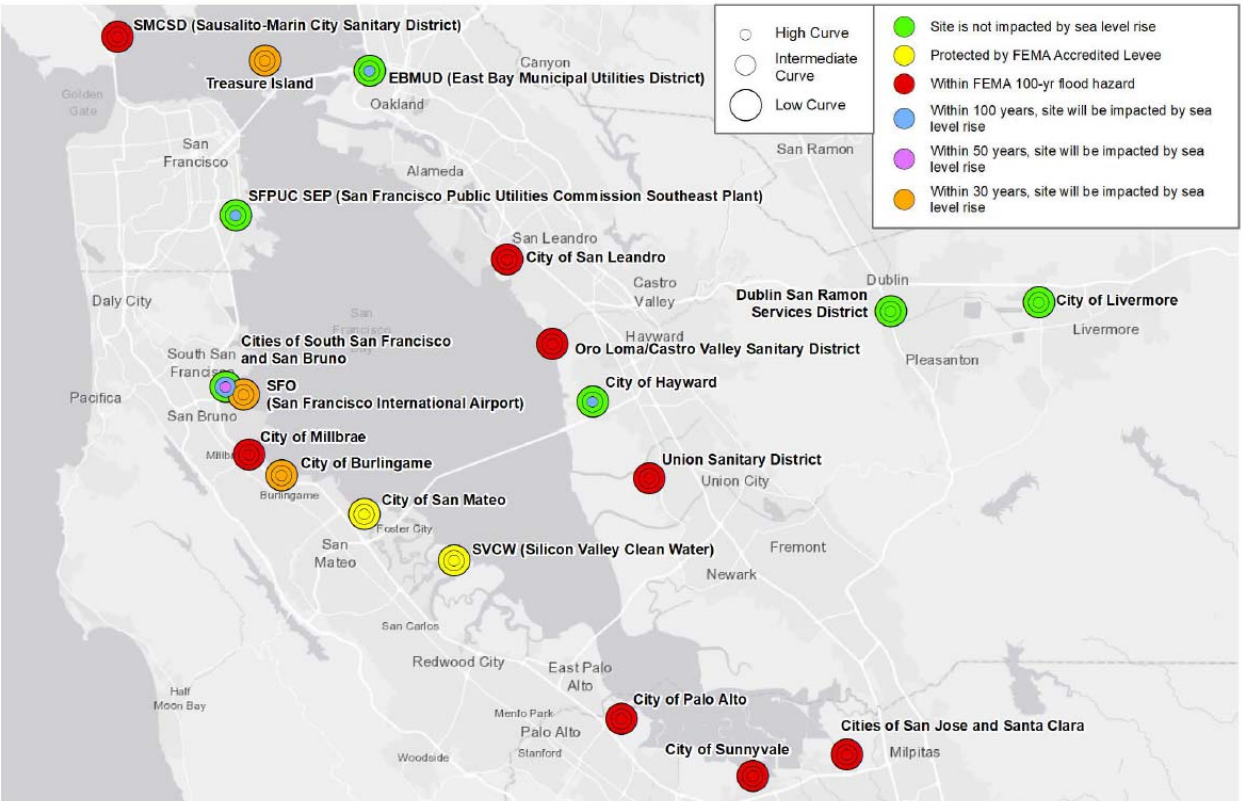
[25] http://www.corpsclimate.us/ccaceslcurves.cfm

Figure 31. Sea Level Rise Assessment, South Bay



Sixteen plants are currently within the FEMA 100-yr flood hazard, which indicates that they are currently vulnerable to sea level rise and other flooding conditions. Nine plants are not vulnerable to sea level rise under the low, medium, or high rate of rise conditions. Two plants are protected by existing FEMA accredited levees. The remaining ten plants are vulnerable to the effects of future sea level rise, particularly under the high level rise condition forecast. Many agencies are aware of their vulnerability and have already begun planning for future flood protection facilities. For example, the City of Sunnyvale is constructing a flood wall to protect its plant as part of an on-going upgrade of the headworks and primary treatment facilities.

As previously described, in addition to the 37 plants, there are many other wastewater-related facilities that could be impacted by sea level rise, such as piping and sewage lift stations within the collection system (particularly those in low lying areas which could become more susceptible to sea water intrusion) and effluent discharge facilities. With respect to the latter, sea level rise could impact the hydraulics and capacity of effluent pump stations and pipelines. Sea level rise could potentially result in additional pumping requirements to discharge effluent, increasing both energy requirements and associated costs.

7. Discussion and Observations

The following sections summarize the key observations of this study with respect to water quality objectives, averaging periods, permit structures, constrained sites, technology selection, GHG emissions, and factors influencing capital costs.

7.1 Water Quality Objectives Influence Technology Selection

As previously described, there are ongoing studies to evaluate the impact of nutrients, nitrogen and phosphorus, on the health of SF Bay. The outcome of those studies will determine whether nutrients are impacting the bay, and if so, which nutrient (nitrogen, phosphorus, or both) and which species (organic, inorganic, soluble, particulate, etc.) impact the bay. It is anticipated that future water quality objectives (i.e., numeric effluent limits, species, averaging periods, etc.) would be established based on those results, and those objectives will have a strong influence on the selected nutrient technology and the resulting cost of nutrient removal.

LOWER LIMITS DICTATE ADDITIONAL TREATMENT

The Water Environment Research Foundation (WERF) Nutrient Removal Challenge[26] research program found that inorganic nutrients are readily used by algae while organic nutrients are typically slow to stimulate algal growth. The research also concluded that inorganic nutrients (nitrogen and phosphorus) are readily removable through conventional treatment methods, while soluble organic nutrient species (SON and SOP) resist conventional and even advanced treatment methods.

The Level 2 benchmarks are sufficiently high such that conventional nutrient removal technologies could be employed without the need for chemical addition (e.g., additional carbon for total nitrogen removal and metal salts for total phosphorus removal) or filtration. Conversely, the Level 3 benchmarks were selected to capture the lower range wherein chemical addition and filtration would be needed to remove particulate nutrients while reliably meeting water quality objectives and allowing for SON and SOP in the effluent.

AMMONIA LIMITS MAY PRECLUDE EMERGING TECHNOLOGIES

A requirement to achieve complete ammonia reduction (i.e., through nitrification) could constrain the ability to implement emerging technologies. With a few exceptions, near complete nitrification is unavoidable with conventional biological processes. Fixed film processes (trickling filters, MBBR, BAF, etc.) or split treatment strategies can avoid complete nitrification. However, emerging technologies such as shortcut nitrogen removal processes, have the major benefit of reduced energy and footprint requirements, but do not achieve complete ammonia removal. With incomplete nitrification, ammonia remains in the effluent. As a result, the establishment of a low water quality objective for ammonia would inhibit the use of some emerging technologies.

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[26] Jeong, J.; Liu, H.; Sedlak, D.L. (2013) Uptake by Algae of Dissolved Organic Nitrogen from BNR Treatment Plant Effluents. Water Environment Research Federation, Alexandria, VA. NUTR1R06e.
Li, Bo and Brett, M. (2015). The Bioavailable Phosphorus (BAP) Fraction in Effluent from Advanced Secondary and Tertiary Treatment. Water Environment Research Federation, Alexandria, VA. NUTR1R06m.

PERMITTING UNCERTAINTY INCREASES CAPITAL COSTS

A typical consideration in the selection of nutrient removal treatment technologies is to plan for future flexibility if future permitted effluent limits change. Specifically, facilities planners often prefer process technologies that do not complicate future changes in nutrient removal requirements or which would not result in stranded assets. For this Nutrient Reduction Study, technologies were selected to facilitate phased implementation of facilities without stranding assets. First, the existing facilities were incorporated, or modified to be incorporated, into process needs for optimization, then that was expanded for Level 2, and ultimately to achieve the Level 3 benchmarks. While the potential for leaving an asset stranded is reduced with this approach, it may not result in the optimal solution for the first phase of improvements if future, lower nutrient objectives never materialize. Thus, long-term nutrient discharge permit certainty could result in more cost-effective solutions from the outset.

7.2 Averaging Periods Influence Footprint and Cost

The appropriate averaging period for nutrient discharges depends on the sensitivity of the water body to nutrient enrichment and water quality degradation, and the location of the discharge in the watershed. The federal NPDES regulations in 40 CFR 122.45(d) require that effluent limits be expressed as monthly and weekly limits for municipal permits “unless impracticable.” Maximum daily limits focused on an effluent mixing zone are appropriate for protection of aquatic life from toxicity. In general, longer averaging periods for nutrient discharges are appropriate due to slower growth responses for algae and time for enrichment to result in water quality degradation on a broader watershed scale. For larger water bodies, such as bays, estuaries, reservoirs, and lakes, monthly, seasonal, or yearly averaging periods are more appropriate.[27]

Nitrogen and phosphorus typically have seasonal impacts on receiving waters. Thus, water quality objectives for total nitrogen and phosphorus removal should be based on long averaging periods linked to the specific water body response to nutrient enrichment. Short averaging periods based on protection of aquatic life from toxics would result in unnecessarily restrictive nutrient limits that would, in turn, lead to overly conservative designs for nutrient removal facilities with little, or no, additional water quality benefit. However, the incremental reduction in nutrient effluent loads would be minor.

Longer averaging permit periods and median limits maintain the average loading below water quality targets, such as waste load allocations in TMDLs, while accommodating the variability in effluent quality and occasionally higher discharge concentrations that are offset by lower effluent concentrations during normal operation. For example, EPA determined that annual nutrient effluent limits were appropriate for the Chesapeake Bay because it is impracticable to express

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[27] EPA (2003) Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll for the Chesapeake Bay and Its Tidal Tributaries. Office of Water. Washington, D.C.

limits on a shorter time scale.[28] For the Spokane River[29], it was determined that it is impracticable to calculate appropriate average monthly and average weekly limits for total phosphorus, ammonia, and carbonaceous biochemical oxygen demand (CBOD). Future variability of the key TMDL constituents, total phosphorus, ammonia, and CBOD, are likely to be highly variable at the low concentration levels targeted in the TMDL. This makes it difficult to calculate appropriate monthly average and weekly limits with any degree of certainty, and may result in artificially stringent limits which are unnecessary for protection of water quality. Further, water quality modeling of the Spokane River demonstrated that Lake Spokane is insensitive to short-term increases in loading of oxygen-demanding pollutants from point source discharges. The effluent limits for total phosphorus, ammonia, and CBOD for the Spokane River are based on far-field, as opposed to near-field, water quality concerns. Seasonal average mass loadings result in water quality protection equivalent to the TMDL. Clean Water Services of Washington County, south of Portland, OR, has challenging monthly limits (previously 0.07 mg/L and currently 0.1 mg/L TP) based on a median effluent concentration. By using the median concentration, occasional higher discharge concentrations do not threaten permit compliance.

The permit averaging period determines both the design criteria and loading used to size the treatment process for nutrient removal. The structure of effluent discharge limits can govern the cost and size of treatment facilities, as illustrated in the following example.

Table 18 contains the design of a hypothetical total nitrogen load reduction facility if the permit conditions change from average, to monthly, and to daily limits. The design loading increases as the averaging period decreases; the maximum month loading is 12 percent higher than the average loading and the maximum day loading is 45 percent higher. The design temperature for the shorter period results in a higher sludge age. All of these factors combine to increase the reactor volume and footprint space requirements by 30 percent and 65 percent, respectively. The capital costs increase by 7 percent and 30 percent respectively, as the averaging period is shortened to monthly and to daily.

This example illustrates the additional cost and footprint space requirements as the averaging period decreases from annual to monthly, and to daily. The estimated additional total nitrogen load reduction over an entire year is just over 10 percent.

In addition to the above considerations, longer averaging periods could support the implementation of emerging and innovative technologies.

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[28] Hanlon, J. H., Director Office of Wastewater Management. (2004) Memorandum to Jon Capacasa, Director Water Permits Division, EPA Region and Rebecca Hammer, Director Chesapeake Bay Program Office, “Annual Permit Limits for Nitrogen and Phosphorus for Permits Designed to Protect Chesapeake Bay and its tidal tributaries from Excess Nutrient Loading under the National Pollutant Discharge Elimination System.” http://www.epa.gov/reg3wapd/npdes/pdf/ches_bay_nutrients_hanlon.pdf

[29] Spokane County (2011) National Pollutant Discharge Elimination System Waste Discharge Permit No. WA-0093317, Spokane County Division of Utilities.

Table 18. Impact of Averaging Period on Facility Sizing for Hypothetical Loading Scenario

Parameter	Unit	Permit Averaging Period		
		Annual Average	Maximum Month	Maximum Day
Total Nitrogen Design Load	lb N/d	44,000	49,300	64,200
Design Temperature	deg C	20	15	12
Design SRT	d	8	10	15
Footprint Requirement	Relative	100%	133%	167%
Capital Cost	$	200	214	260
Estimated Annual Total Nitrogen Removal[1]	Million lb/yr	9.4	10.3	10.4
Additional removal[2]	%	Base	10%	11%

1. Estimated removal operating for 10 days at Maximum Day, 60 days at Maximum Month, and 295 days at average conditions.
2. Additional removal compared to Annual Average condition

7.3 Flexible Permit Structures Facilitate Innovation

Emphasis in nutrient discharge permitting should focus on providing the maximum flexibility possible in the structure of nutrient limits in order to preserve the opportunity for the most creative and economical approaches to managing nutrients. Traditional permit structures for POTWs generally include both monthly and weekly limits on both a concentration and mass basis. This may inadvertently eliminate the most effective watershed solutions to nutrient management by creating disincentives to wastewater dischargers to explore combinations of advanced wastewater treatment and other watershed management practices, such as reuse.

It is important to structure nutrient discharge permits in a manner that avoids inadvertent disincentives to watershed management, nutrient trading and offsets, and other approaches to optimization. Combinations of both effluent concentration and mass effluent limits for nutrients may constrain the development of trades, or increase the complexity in accounting for trades. Watershed permits formulated with loading exchanges and optimization in mind may facilitate the implementation of water quality trading. Effluent limits based on total mass loadings combined with long averaging periods, such as seasonal or annual limits, facilitate compliance and provide an opportunity for optimal combinations of advanced treatment and water quality offsets and trading.

When the relationship between nutrient loadings and water quality responses is not well defined, it is advisable to avoid overly restrictive effluent limits at the outset, since they may later prove unnecessary to meeting actual receiving water needs when they eventually become better understood. Preserving an opportunity for adaptive management approaches to guide the process of nutrient management over time may improve water quality incrementally, without overly restrictive discharge permits that result in over investment in advanced treatment.

Permits structured around no net increase in existing loadings, or simple seasonal or annual loading reductions, may provide a foundation for adaptive management.

7.4 Constrained Sites Influence Technology Selection

Conventional nutrient removal technologies can require significant plant real estate. Unfortunately, many of the SF Bay plants are located on constrained sites. Not only is space required for new treatment basins and equipment, but allowances must be made to sustain operations during construction, while also setting aside construction staging areas. Constrained sites can also require more complex and costly construction techniques.

Site constraints result from several factors. Plants in densely populated areas such as San Francisco and San Mateo, have little open space available. Other plant sites, such as CMSA or Millbrae, are bounded by major roadways and natural features.

With limited space to add treatment processes, compact technologies such as an MBR become more attractive. While an MBR provides a smaller footprint than conventional nutrient removal techniques, it also has higher capital and operating costs. Some emerging technologies have a small footprint, but their performance is yet to be proven in large scale applications.

An example of a constrained site is illustrated in Figure 32 for the City of Millbrae.

Figure 32. Constrained Site, Millbrae Example

Note: New facilities to achieve the Level 3 water quality benchmarks would include: (1) optimization of ferric addition for phosphorus removal, (2) new polymer chemical feed facilities, (3) conversion of the activated sludge to an MBR by converting secondary clarifiers to membrane tanks, (4) expansion of the aeration basins to create a third train (requires moving the blower building), (5) new alkalinity chemical feed facilities, (6) new external carbon source chemical feed facilities, (7) decommissioning of the chlorination disinfection system and use this footprint for additional aeration basin volume, and (8) add an ultraviolet disinfection system.

The only viable treatment solution for nutrient removal on the Millbrae site was to rearrange existing facilities and convert to a compact MBR process. As shown, the plant is located within a triangular parcel of land bounded by Highway 101 to the southwest, the on-ramp to the north, and the Millbrae Avenue overpass to the southeast. In addition, there is a buried 24-inch gas pipeline, owned by PG&E, which runs adjacent to the existing aeration basin. These site constraints severely limit the options available for adding new facilities. To achieve the Level 3 effluent water quality benchmarks, the space currently occupied by the existing chlorine contact basin would be used to expand the biological reactor and a new, compact ultraviolet (UV) system is proposed for disinfection. In addition, the blower building would be relocated to make site space available.

Overall, MBRs were recommended for eight plants due to site constraints.

7.5 Technology Selection Influences Effluent Quality, Footprint, GHGs, and Costs

As previously described, conventional nutrient removal technologies were used as the basis of analysis in this study because the costs, space requirements, and performance are well established. However, emerging technologies have the potential to significantly reduce capital and/or operating costs in comparison to the well-established technologies that were used as the basis of this study. In addition, some emerging technologies could also reduce the plant site space footprint required for nutrient removal.

The following subsections describe some of the emerging technologies that may be useful to reduce nutrient discharges to SF Bay.

7.5.1 Shortcut Nitrogen Removal

Shortcut nitrogen removal refers to a range of processes that reduce the operating cost, footprint, and carbon needs for total nitrogen reduction. This group of processes aims to halt the nitrification reactions at nitrite, and then denitrify the nitrite directly to nitrogen gas by nitrite reducing heterotrophs using carbon, or by anammox bacteria that produce nitrogen gas from ammonia and nitrite. In other cases, simultaneous nitrification and denitrification (SND) can be achieved by operating at reduced dissolved oxygen (DO) concentrations.

Even though the design to achieve shortcut nitrogen removal is still evolving, the use of shortcut nitrogen removal has been demonstrated at many pilot-scale and some full-scale treatment plants. It offers a modest reduction in footprint, but could significantly improve total nitrogen reduction and reduce both aeration requirements and the need for supplemental carbon.

7.5.2 Granular Activated Sludge

The ability to grow activated sludge bacteria to form granules is a significant improvement in the activated sludge process. By growth and waste selection, the activated sludge form granules and each granule has an anaerobic core, an anoxic inner zone, and aerobic outer shell to achieve BOD removal, nitrification/denitrification, and phosphorus removal. Research is ongoing (led by Professor McSwain Sturm at the University of Kansas) to investigate the process requirements, selection mechanisms, and design features needed for mainstream granular activated sludge. This research is still in the emerging stage, but granules have been detected in full-scale applications.

The emerging AquaNereda® process is the only commercially available, full-scale proven granular activated sludge technology. It operates in a sequencing batch reactor (SBR) mode at a mixed liquor concentration of about three times a conventional BNR and requires no additional clarifiers for solids separation. Additional flow buffering tanks may be required to accommodate continuous treatment. As a result of these reduced reactor requirements, the footprint for an AquaNereda® process could be less than 40 percent of a conventional process. The Aqua Nereda® process can achieve the Level 2 water quality benchmarks, but requires additional process elements to meet Level 3 benchmarks.

7.5.3 Zeolite Anammox

Zeolite/Anammox is an emerging technology that was developed in Northern California by Dr. Robert Collison. It is a hybrid technology that leverages the benefits of zeolite and Anammox bacteria. The technology performs nitrogen removal with applications for sidestream treatment, liquid stream treatment, and water reuse.

Zeolite (clinoptilolite) is a microporous, aluminosilicate mineral that has a high cation exchange capacity (CEC). This high CEC preferentially adsorbs ammonium which is immobilized on the ion exchange sites. The immobilization step also concentrates ammonium for advantageous growth of a bacterial biofilm.

The use of zeolite for ammonium removal from wastewater using CEC has been in practice for decades. Truckee Meadows Water Reclamation Facility used zeolite to remove ammonium following secondary treatment for approximately 30 years. While effective, zeolite media has to be regenerated (i.e., ammonium removed) once all the zeolite ion exchange sites are saturated. Typically, regeneration uses high strength brine which has its own challenges.

The Zeolite/Anammox Technology avoids the disadvantages of earlier zeolite-based ammonium removal systems by using continuous biological regeneration of the zeolite media. The technology relies on zeolite serving as a medium to adsorb ammonium and biofilm growth. A biofilm rich with anammox and ammonia-oxidizing bacteria (AOB) coats the zeolite, and as the zeolite adsorbs ammonium, the biofilm continuously regenerates the zeolite by converting the adsorbed ammonium to nitrogen gas. The end products in the process are nitrogen gas and water.

7.5.4 Membrane Aerated Biofilm Reactors (MABR)

The Membrane Aerated Biofilm Reactor (MABR) is a fixed film process that uses a hollow fiber membrane as a surface to grow biofilm on the outside of the fiber while also providing aeration from the inside of the fiber. By supplying aeration to the inside of the biofilm and placing the wastewater on the outside of the biofilm, the resulting biology provides nitrification on the inside of the film and denitrification on the outside of the biofilm. This arrangement allows for highly efficient aeration, a small footprint, and effective nitrification and denitrification.

There are no full-scale MABR plants in the US at this time; however, several pilot studies are ongoing, including a study at Hayward. The results from these studies can further define the design requirements, facility needs, and potential performance of the process.

7.5.5 BioMag® Activated Sludge

The BioMag® activated sludge process introduces magnetite into the biological process to serve as a nucleus for biological growth. Small magnetite particles are introduced to impregnate the biological flocs, making them heavier and easy to separate by gravity in a secondary clarifier. The rapid settling floc facilitates a higher mixed liquor concentration in the biological reactor, which reduces the footprint of the reactor and also accommodates higher peak flows through the process. The magnetite is recovered from the waste sludge and returned to the main biological process. Due to the heavy floc, mixing energy is increased in this process to keep the solids in suspension.

The BioMag® process has been proven in several facilities, mainly smaller plants (e.g., less than 5 mgd). The biological process can be designed as a classic BNR process with similar performance expectations, but with the advantage of a smaller footprint.

7.5.6 High Rate Primary Treatment

Primary treatment is not required for nutrient removal but does reduce the loading to the biological process, resulting in lower biological growth, smaller reactors, but potentially insufficient carbon to achieve nitrogen removal. Primary treatment also diverts organics to solids processing where anaerobic digestion can produce methane that can be used to reduce energy demand or other beneficial uses.

High rate primary treatment options include microscreens (e.g., Salsnes filter), cloth media filters (e.g., AquaPrime), Densadeg® ballasted sedimentation, or CEPT. The first two processes are emerging, whereas the latter two have been used in full-scale plants. The benefit of high rate primary treatment would be to free up site space or improve particulate BOD removal in the primary treatment process.

7.5.7 Sidestream Treatment

As previously described, the sidestream generated from anaerobic digested sludge dewatering is nutrient rich. By eliminating the nitrogen and phosphorus from these streams, the effluent from the plant nutrient load can be reduced accordingly. There are several technologies available to reduce sidestream loading.

Nitrogen can be removed through physical and biological processes. Biological ammonia removal using a deammonification (Anammox®) process such as DEMON®, AnitaMox^{TM}, or Paques®, has been proven to be about 85 to 90 percent efficient and cost effective to reduce the ammonia recycle load. Recovery of ammonia (e.g., ammonium sulfate) via stripping and condensation is an emerging technology that is gaining traction. Most of the current full-scale installations are located outside of the US and typically focus on industrial loads. Nonetheless, this market is anticipated to grow in upcoming years and should be monitored.

Phosphorus can be harvested from the sidestream by precipitating struvite into granules (using Ostara, Phospaques, Airprex or similar technologies) and beneficially used as a fertilizer. The high phosphorus recycle can also be arrested by adding a metal salt (alum or ferric) before dewatering to precipitate the phosphorus and capture it in the dewatered cake.

7.5.8 Summary, Emerging Technologies

Many other new technologies are still emerging and it is likely that many more will come. It takes a long time for a new technology to enter full-scale treatment at a substantial (e.g., over 5 mgd) capacity (granular sludge took about 15 years to come to full-scale and remains unproven in the United States). A longer period is needed to “work out the kinks” in the technology and improve the control and efficiency of the process.

The risks associated with a new technology can be substantial. Unforeseen process problems can emerge, process control needs time to mature, and performance may be highly variable until the process has been in full-scale operation for a number of years. For example, while enhanced biological phosphorus removal was discovered and implemented in the early 1970’s, the process performance remained variable with substantial improvements in early 2000’s. Even after 30 years, there remains new discoveries to further improve the process stability, particularly to achieve low effluent phosphorus concentrations.

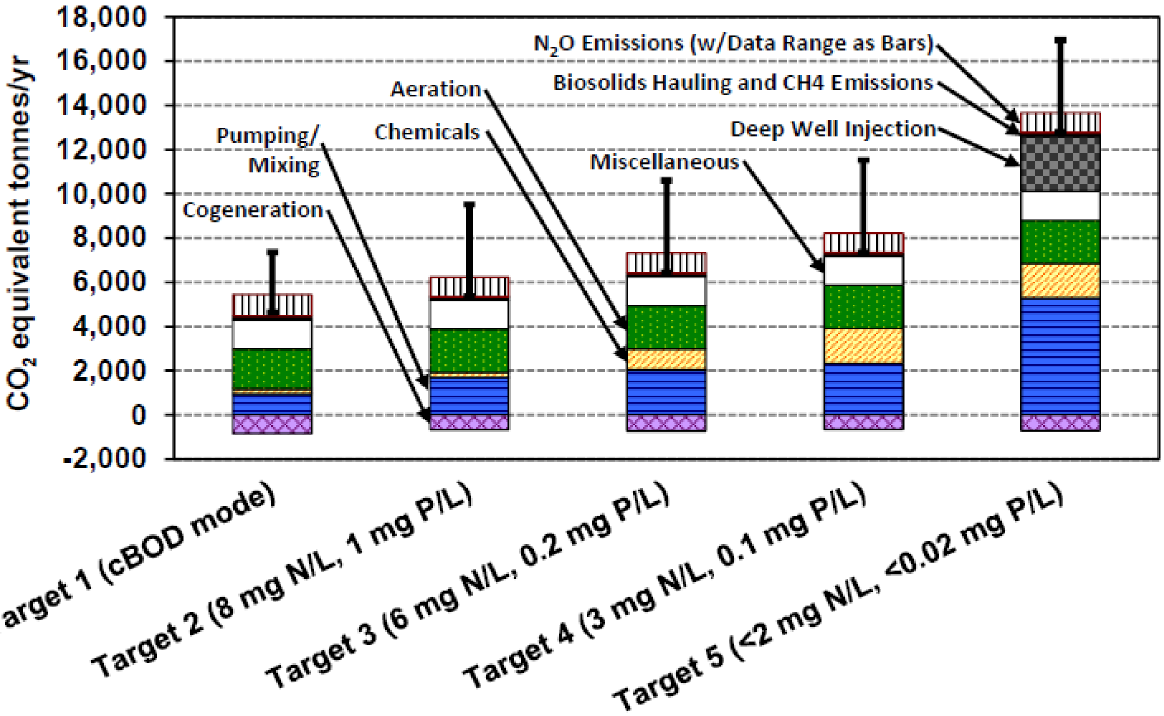
Utilities should remain active in evaluating and potentially pilot testing and even demonstration scale testing promising technologies. Regulatory cooperation could further accelerate implementation of new technologies by allowing full-scale testing and time to optimize the technology.

7.6 GHG Emissions Impacted By Water Quality Objectives

More stringent water quality objectives will result in an increase in GHG emissions with the transition from secondary treatment to advanced treatment with nutrient removal. The increase is attributed to a combination of additional energy required to oxidize and reduce the various nitrogen species, filtration requirements, and chemical demands for alkalinity and phosphorus precipitation, among others.

The increase in energy, chemicals, and GHG emissions while transitioning from secondary treatment to nutrient removal is plant specific due to varying water characteristics, technology selection, chemical type, electrical power generation, fuel type (e.g., coal versus natural gas), and location. Research by Falk et al. (2013) is presented in Figure 33 that illustrates the potential plant wide increase in GHG emissions for various nutrient targets for a nominal 10 mgd plant. Target 1 represents secondary treatment, while Targets 2 through 5 represent nutrient targets with Target 5 being the most stringent. The Level 2 target established for this Nutrient Reduction Study is between Falk’s Targets 1 and 2, while the Level 3 target is comparable to Falk’s Target 3.

Figure 33. GHG Emissions for a Nominal 10 mgd Plant for Various Treatment Targets[30]



The gradual increase in GHG emissions demonstrated in Figure 33 from Target 1 to the higher levels is attributed to additional biological treatment facilities, increased energy and chemical use, and additional tertiary nitrogen and phosphorus removal processes. The study revealed that a point of diminishing return is reached as nutrient removal objectives approach the limit of technology where GHG emissions and the cost of treatment both increase rapidly, while the potential for algal growth in the receiving water is only marginally reduced. Note, the point of diminishing returns is watershed specific.

The increased energy demands are assumed to be satisfied with imported electricity; therefore, the GHG emissions associated with the imported electricity would not impact plantwide anthropogenic greenhouse gas emissions counted towards the California Air Resources Board (CARB) Cap and Trade Threshold (i.e. these would be emissions associated with the electric utility provider).

Similarly, the increase in GHG emissions from chemicals is associated with the production of those chemicals and would not impact plantwide anthropogenic greenhouse gas emissions counted towards the CARB Cap and Trade Threshold (i.e. these would be emissions associated with the chemical manufacturer/supplier).

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[30] Falk, M.W.; Reardon, D.J.; Neethling, J.B.; Clark, D.L.; Pramanik, A. (2013) Striking the Balance between Nutrient Removal, GHG Emissions, Receiving Water Quality, and Costs. Wat. Environ. Res., 85(12):2307-2316.

Although fugitive N_2O emissions can be significant while performing nitrification/denitrification, these emissions are not currently reportable to CARB and are not part of the anthropogenic emissions total that determines Cap and Trade inclusion applicability.

7.7 Capital Costs are Substantial

Capital costs make up approximately 60 to 70 percent of the total present value costs for facilities required to meet the Level 2 and 3 benchmarks. It is notable that construction costs for large infrastructure projects in the SF Bay region, as measured by the CCI, have been escalating at a rate of 3 to 4 percent in recent years. If this trend continues, the construction cost for future projects could be significantly impacted. Moreover, the recent trade tariffs on steel and other items, announced in late March 2018, have created volatility in construction costs, which could have further impacts on future construction costs.

Another factor that could impact future costs is the relative timing of projects. That is, if each of the 37 POTWs were to undergo a major upgrade simultaneously, there could be significant cost impacts due to constraints in construction capacity in the local Bay Area marketplace.

8. Summary and Next Steps

The purpose of this Nutrient Reduction Study is to evaluate opportunities to reduce effluent nutrient loading to SF Bay through treatment optimization, sidestream treatment, and treatment upgrades. In addition, this study considers opportunities to reduce effluent nutrient loading through other, non-treatment means.

Table 19 summarizes the potential nutrient load reductions for treatment optimization, sidestream treatment, and treatment upgrades. The associated costs are also presented. For comparison, the estimated total nitrogen reduction that is anticipated through planned recycled water use is approximately 8,900 lb N/d by 2040, which is most comparable to the load reductions achievable through treatment optimization.

Table 19. Summary of Nutrient Load Reduction and Associated Costs, Year Round Operation

Parameter	Unit	Current Discharge[1]	Treatment Strategy			
			Optimization[2]	Sidestream[2]	Level 2[2]	Level 3[2]
Design Flow	mgd	--	546	633	869	869
Load Reduction						
Ammonia	lb N/d	12,290	27,439	106,900	106,900	12,290
TN	lb N/d	8,559	31,827	95,00	136,300	8,559
TP	lb P/d	3,139	1,404	7,000	10,500	3,139
Costs[3,4]						
Capital	$M	119	377	6,976	8,517	119
O&M PV	$M	147	345	2,443	3,888	147
Total PV	$M	266	722	9,419	12,405	266
Average Unit Costs						
Per gpd[5]	$/gpd	--	0.5	1.1	10.8	14.3
Per lb N[6]	$/lb N	--	5.6	2.0	8.7	7.7
Per lb P[6]	$/lb P	--	8.6	2.7	43	59

1. The current discharge loads are based on the 2015 BACWA Nutrient Reduction Study Group Annual Report (data from 7/2012-6/2015). The reported flows and loads for optimization, upgrades, and sidestream represent average projected load reduction for the period of analysis (10-yr for optimization and 30-yr for upgrades and sidestream). Sidestream design flow reflects only the candidate plants.
2. Facilities were sized for year round loads and operated year round.
3. Costs are referenced to the ENR SF CCI for January 2018 at 12,015. Costs do not include changes in solids handling or changes in energy requirements in other unit processes. Level 3 costs are inclusive of facilities needed to meet Level 2.
4. PV is calculated based on a 2 percent discount rate for 10 years (optimization) and 30 years (sidestream and upgrades).
5. Unit cost ($/gpd) was calculated by dividing the total present value by the design flow.
6. Unit cost ($/lb) was calculated by dividing the total present value for the nutrient of interest by the nutrient load reduction over the projection duration (e.g., for upgrades: Total PV for TN Removal facilities divided by (Average Annual TN Removed times 30-years)).

Overall, load reductions increase with increasing degrees of treatment, from optimization through Level 3. Implementation of the optimization strategies could result in a load reduction of approximately seven percent for total nitrogen for a short term (approximately 10 years) capital investment of approximately $120M, whereas implementation of sidestream treatment could result in a total nitrogen load reduction of nearly 20 percent for a longer period (approximately 30 years) at a capital cost of nearly $380M. On the whole, the cost per pound of nitrogen removed is lower for sidestream treatment than that for optimization. However, there may be site-specific optimization opportunities that are more cost-effective and/or would warrant consideration for other reasons. For example, an agency may wish to first pursue optimization if it is the quickest and easiest way to meet a near term no net load increase requirement or if it addresses other process issues or results in a more stable overall process.

Sidestream treatment is the most cost-effective means of reducing both total nitrogen and total phosphorus, when comparing the cost per pound removed. However, sidestream treatment is not feasible at all plants. Of the 37 participating plants, only 23 facilities are candidates for total nitrogen reduction and 15 facilities for total phosphorus reduction. A total load reduction of nearly 20 percent for total nitrogen and over 10 percent for total phosphorus could be achieved with the implementation of sidestream treatment at all the feasible plants.

Ultimately, the costs to upgrade treatment plants to achieve the Level 2 and 3 effluent quality benchmarks are substantial. As a result, it is recommended that the other ongoing scientific studies be further developed or completed to provide a better understanding of nutrient processing and confirm whether or not the SF Bay is impaired, and if so, to determine the specific nutrients (and speciation) causing impairment. As that is better understood, appropriate water quality objectives can be established.

It is important to emphasize the impact that permit limits can have on technology selection and facility sizing, and their associated costs, footprint requirements, and GHG emissions. Traditional permit structures for POTWs generally include both monthly and weekly limits on both a concentration and mass basis. This may inadvertently eliminate the most effective watershed solutions to nutrient management by creating disincentives to wastewater dischargers to explore combinations of advanced wastewater treatment and other watershed management practices, such as reuse. Flexible permits, with longer averaging periods and mass-based limits (as opposed to concentration-based limits) will foster innovation and create opportunities for the most creative and economical approaches to managing nutrients.

When the relationship between nutrient loadings and water quality responses is not well defined, it is advisable to avoid overly restrictive effluent limits at the outset, since they may later prove unnecessary to meeting actual receiving water needs when they eventually become better understood. Preserving an opportunity for adaptive management approaches to guide the process of nutrient management over time may improve water quality incrementally, without overly restrictive discharge permits that result in over investment in advanced treatment. Permits structured around no net increase in existing loadings, or simple seasonal or annual loading reductions, may provide a foundation for adaptive management.

Once permit requirements are defined, and for the avoidance of doubt, each agency should conduct a thorough facilities planning study to determine the best way to achieve the limits at their respective facility prior to initiating preliminary design, design, and construction. As previously described, the findings presented in this study were based on conservative, well-established technologies for the purpose of providing reasonable costs and space requirements for long-term planning. There are many emerging technologies that could be more cost-effective and/or have other benefits that should also be considered.

A

Scoping and Evaluation Plan

B

Basis of Cost Estimates

Basis of Cost Estimates

The approach to developing the estimated capital and O&M costs for the optimization strategies and facilities upgrades was consistent for each of the 37 POTWs included in the study.

First, treatment options were analyzed to determine their feasibility and facility needs and the major process facilities were identified on a site plan to show their respective footprint and location. The need for additional major facilities such as pumping stations, significant transfer piping, chemical feed facilities, and blowers were identified and the footprint for these facilities was located on the site plan. Once the major facilities were defined, a parametric cost analysis was used to estimate the construction costs for each facility. Allowances were included for undefined facilities, site conditions, and contractor's costs and profit. An allowance for engineering, construction management, legal and other administrative costs was then applied to develop a total estimated capital cost. Table 1 presents the various allowances that were included to estimate the capital cost. An additional 15 percent contingency was added to the capital cost to reflect the current bidding climate in the SF Bay Area.

The O&M costs for power, chemicals, and labor were also estimated using a parametric cost analysis. Unit chemical costs were developed using information from the Bay Area Chemical Consortium (BACC). The same unit costs were used for all the BACWA treatment plants to simplify the analysis. The unit costs used in developing the cost opinions are shown in Table 2.

The capital and O&M costs are presented in current dollars, referenced to the ENR SF CCI for January 2018 at 12,014.72. In order to understand the relative costs for each of the 37 POTWs included in the watershed permit, the capital and O&M costs are also expressed as unit costs:

- Unit capital cost per gallon ($/gpd) includes the capital cost for the treatment strategy to remove ammonia, nitrogen and phosphorus.
- Unit present value cost per gallon ($/gpd) includes the present value capital and O&M costs for the treatment strategy to remove ammonia, nitrogen and phosphorus.
- Unit cost for TN and TP reductions ($ per pound nutrient removed) include both capital and O&M costs for the life of the project.
    - Unit costs for TN reduction were estimated based only on the cost elements that contribute to TN removal.
    - Unit costs for phosphorus reduction were estimated based on the cost elements needed to remove phosphorus.

The nutrient reduction is calculated based on the average removal over the life cycle period. The unit cost calculation is then based on the present value (capital and O&M over the project duration) divided by the average nutrient load reduction over the period. Table 3 shows the discount rate and period used for the different scenarios.

Table 1. Allowanced used in developing the Opinion of Probably Cost.

Undefined Items	Value
Undefined Unit Processes	20%
Miscellaneous Site Structures	15%
Site Conditions	
Sitework	10%
Yard Piping	5%
Soil Conditions	7%
Site Electrical Power Distribution	1%
Contractor's Costs	
Field General Conditions, Mobilization, Demobilization	12%
Sales Tax (Allowance)	8%
General Contractor Overhead and Profit	10%
Bonds and Insurance	1.5%
Construction Contingency - Change Orders	4%
Additional Project Costs	
Engineering	10%
Construction Management	10%
Legal, Fiscal, Administration, Environmental	5%
Contingency to Reflect Bidding Climate in the Bay Area	15%

Table 2. Unit Costs

Unit	Unit Cost
Power	$0.17 per kWh
Labor	$150 per hour
50% Sodium Hydroxide	$350 per ton
Sodium Hypochlorite	$0.43/gal for 12.5%
Ferric Chloride	$619/dry ton
Hydrated Lime	$396/wet ton (45% alkali lime)
Liquid Alum	$0.80/gal
Methanol	$1.25/gal
Citric Acid	$6.38/gal or $1.15/lb
Polymer (Emulsion)	$9.10/gal which is $1.07/lb

Table 3. Assumptions for Life Cycle Analysis

Scenario	Discount Rate	Period (yr)
Optimization	2%	10
Side Stream Treatment	2%	30
Level 2	2%	30
Level 3	2%	30

C

Sea Level Rise Methodology

D

Individual Plant Reports

Contents of Appendix D (Need a divider page for each agency)

1. American Canyon, City of
2. Benicia, City of
3. Burlingame, City of
4. Central Contra Costa Sanitary District
5. Central Marin Sanitation Agency
6. Delta Diablo
7. Dublin San Ramon Services District
8. East Bay Municipal Utility District
9. Fairfield-Suisun Sewer District
10. Hayward, City of
11. Las Gallinas Valley Sanitary District
12. Livermore, City of
13. Millbrae, City of
14. Mt. View Sanitary District
15. Napa Sanitation District
16. Novato Sanitary District
17. Oro Loma / Castro Valley Sanitary Districts
18. Palo Alto, City of
19. Petaluma, City of
20. Pinole, City of
21. Richmond, City of
22. Rodeo Sanitary District
23. San Francisco International Airport
24. San Francisco Public Utilities Commission Southeast Plant
25. San Jose-Santa Clara Regional Wastewater Facility
26. San Leandro, City of
27. San Mateo, City of
28. Sausalito-Marin City Sanitary District
29. Sewerage Agency of Southern Marin
30. Silicon Valley Clean Water
31. Sonoma Valley County Sanitation District
32. South San Francisco and San Bruno
33. Sunnyvale, City of
34. Treasure Island
35. Union Sanitary District
36. Vallejo Sanitation and Flood Control District
37. West County Wastewater District

E

Agency Acceptance Letters

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