INTEGRATED MASTER PLAN *for the* MAIN WASTEWATER TREATMENT PLANT

C80: Nutrient Reduction Alternatives

May 2021

EBMUD

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TABLE OF CONTENTS

APPENDIX

FIGURES

TABLES

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EXECUTIVE SUMMARY

The goal of the East Bay Municipal Utility District (District) Integrated Main Wastewater Treatment Plant (MWWTP) Master Plan Project (Master Plan) is to provide a 30-year roadmap for the MWWTP. The roadmap will serve as a guide for prioritizing projects to address future regulations, capacity constraints, and rehabilitation and renewal needs. Potential future regulations regarding nutrient discharges to the San Francisco Bay (SF Bay or Bay) and biosolids management could impact future upgrades at the MWWTP.

As part of the Master Plan, an evaluation of nutrient reduction alternatives was performed to identify a long-term approach for meeting anticipated nutrient reduction regulations. The selected alternative will be refined and further developed into a phased implementation plan and included in the Master Plan 30-year roadmap.

The purpose of this report is to review the:

- Universe of nutrient reduction alternatives that were considered and screened in order to select seven distinct alternatives to carry forward for further analysis;
- Development and evaluation of the seven nutrient reduction alternatives;
- Selection of a long-term nutrient reduction alternative to carry forward and develop into a phased implementation plan.

Overview of Nutrient Reduction Regulations

The primary driver to implement nutrient reduction improvements at the MWWTP is compliance with potential future regulatory requirements. Current regulations do not require the MWWTP to remove nutrients from the wastewater; however, it is anticipated that future regulations may require reductions in nitrogen for the health of the SF Bay. There has been some discussion of phosphorus too, although reductions are not expected at this time.

The San Francisco Regional Water Quality Board (Regional Board) is the primary regulatory agency for the MWWTP. In 2014, the Regional Board developed the San Francisco Bay Nutrient Management Strategy (NMS) Science Program to study the impact of nutrients on the health of the Bay and to develop a scientific foundation for nutrient management decisions. Since its establishment, the NMS has conducted investigative studies to determine safe levels of nutrient loads to the Bay. The District is a member of the NMS and works collectively with other SF Bay wastewater agencies, under the Bay Area Clean Water Agencies (BACWA) joint powers authority, to support ongoing efforts related to nutrient studies and management decisions.

To establish a regional framework for assessing nutrient impacts on the Bay, as well as nutrient reduction strategies that could be implemented by wastewater agencies, the Regional Board issued a regional order (Order No. R2-2014-0014, *Waste Discharge Requirements for Nutrients from Municipal Wastewater Discharges to San Francisco Bay*) on April 9, 2014, to the 37 SF Bay municipal dischargers, including the District. The regional order, which is commonly referred to as the Watershed Permit, required effluent monitoring and reporting, the evaluation of potential nutrient reduction upgrades that could be implemented, and funding of ongoing scientific studies of nutrient impacts. To comply with the Watershed Permit requirements, the District worked collectively with other SF Bay wastewater agencies under BACWA to develop the 2018 Nutrient Reduction Study. The 2018 Nutrient Reduction Study included development of Level 2 and Level 3 nutrient reduction targets for total nitrogen (TN) and total phosphorus (TP) to serve as the basis for the study, and identified nutrient load reduction opportunities for the various wastewater agencies identified in the Watershed Permit.

On May 8, 2019, the Regional Board issued the second Watershed Permit (2019 Watershed Permit), which is effective through June 30, 2024 and requires continued effluent monitoring, reporting, and funding of ongoing scientific studies. At the time the 2019 Watershed Permit was issued, there was insufficient evidence to conclude that nutrients are adversely impacting the water quality of the Bay. As such, it does not include water-quality based numeric effluent limits for nutrients. However, the 2019 Watershed Permit does include estimated total inorganic nitrogen (TIN) load targets that major dischargers may be required to meet by 2024. These load targets were estimated for each discharger using the highest effluent dry weather load from 2014 through 2017 and an additional 15 percent allowance for growth.

There is uncertainty as to the future of nutrient regulations, both when they will take effect, and what constituent (or form) will be regulated. This uncertainty is largely due to the lack of conclusive evidence that current loads are a problem and lack of agreement on what future load reductions should be implemented to protect the health of SF Bay. Based on the District's discussions with the Regional Board, it is uncertain if the load cap targets will be implemented in 2024, and it may be some time (if ever) before the Watershed Permit includes more stringent numeric limits similar to those described in the 2018 Nutrient Reduction Study. In addition, it appears that future potential regulations would be based on TIN instead of TN, and it is unlikely that phosphorus will be included in Watershed Permits within the planning period of the Master Plan.

Lacking clear direction on future regulation, for the purposes of this planning effort, regulatory endpoints or targets were developed based on the current regulations and ongoing efforts. Table ES-1 summarizes the assumed nutrient reduction targets and how they are used in planning.

- **Master Plan Target:** The Master Plan Target is a seasonal load target based on the potential load cap target noted in the 2019 Watershed Permit.
- **Level 2 Off-Ramp:** The Level 2 Off-Ramp is based on the Level 2 Target in the 2018 Nutrient Reduction Study except it is based on TIN instead of TN and does not include a phosphorus limit. This target is anticipated to be the most stringent potential endpoint that may occur within the 30-year planning period. The Level 2 Off-Ramp was used to develop and evaluate the nutrient reduction alternatives in terms of sizing, detailed site layouts, and life cycle costs.
- **Level 3 Off-Ramp:** The Level 3 Off-Ramp is based on the Level 3 Target in the 2018 Nutrient Reduction Study and is not anticipated to occur within the planning period and may

never occur. As such, it was only considered at a high-level with respect to identifying the site space potentially required for nutrient removal and to screen out alternatives that do not fit within the plant boundaries. The Level 3 Off-Ramp is considered the limit of technology (LOT).

The Master Plan Target and Level 2 Off-Ramp could potentially occur within the planning period and will be considered when developing the phased implementation plan for the selected nutrient removal alternative. The Level 3 Off-Ramp is not anticipated within the planning period and may never be implemented. As such, the Level 3 Off-Ramp was only considered to identify the potential site space requirements and screen out alternatives that cannot fit within the plant boundaries.

Table ES-1. Nutrient Reduction Targets Assumed for the MWWTP Master Plan Nutrient Reduction Alternatives Analysis

Nutrient Reduction Target	Total Inorganic Nitrogen (TIN) and Total Nitrogen (TN)	Total Phosphorus (TP)	Estimated Year Included in Permit [(a)]	Estimated Year for Compliance [(a)]	Used for CIP Cash Flows?	Used for Site Planning?
Master Plan Target [(b)]	TIN Seasonal Load Target = 11,000 kg/day [(b)]	No target anticipated	2024±	2029±	Yes	Yes
Level 2 Off-Ramp	TIN = 15 mg-N/L TIN at 2050 = 3,750 kg/day (average annual load) [(c)]	No target anticipated	2045±	2055±	No	Yes
Level 3 Off-Ramp **(d)**	**Level 2 with HSW** [(e)] TN = 15 mg-N/L TIN = 5 mg-N/L **Level 3 without HSW** [(f)] TN = 6 mg-N/L TIN = 3 mg-N/L	0.3 – 1 mg-P/L	Outside of Master Plan Horizon	Outside of Master Plan Horizon	No	Yes

a. Timing is uncertain and contingent on findings of ongoing scientific studies.

b. As identified in the 2019 Watershed Permit. Based on performance during the dry weather period (May 1 – September 30).

c. Based on performance over the entire year (i.e., average annual load). Assume nitrogen target will be based on TIN because the 2024 nutrient load targets in the 2019 Watershed Permit are expressed in terms of TIN. The permit also states nitrogen is the growth-limiting nutrient for phytoplankton in San Francisco Bay, and TIN is the bioavailable form of nitrogen.

d. Based on the Nutrient Removal Level assumptions included in the 2018 Nutrient Reduction Study.

e. Achievable by conventional nutrient removal processes without effluent filtration, but will likely require supplemental carbon. The MWWTP could continue to accept/treat high strength waste (HSW) as part of the District's Resource Recovery Program. The analysis considered the impact of HSW because it contains soluble unbiodegradable nitrogen that is not removed in the treatment process and contributes to the effluent TN.

f. Filters and additional external carbon required. HSW could no longer be accepted and treated at the MWWTP as HSW nutrient load would result in effluent TN greater than 6 mg/L.

Alternatives Analysis Overview

As discussed above, the nutrient reduction targets were established to guide the development and evaluation of reduction alternatives to meet those targets. The following steps outline the approach taken to develop and evaluate the nutrient reduction alternatives:

1. Identify alternatives
2. Screen alternatives
3. Develop and evaluate screened alternatives

The alternatives evaluation process is described in detail in the C50-Evaluation Process and Criteria Report.

Alternatives Identification

During a workshop conducted on September 19, 2019, District Staff and the Consultant Team identified six types of long-term nutrient reduction alternatives, as well as specific treatment technologies/process configurations (technologies) that could be implemented for each type of alternative. The alternatives are based on meeting the Level 2 Off-Ramp instead of the Master Plan Target for the following reasons:

- The Master Plan Target would likely not require significant mainstream improvements and can be met with sidestream treatment or other means that are more cost-effective.

- The Level 2 Off-Ramp will require mainstream improvements, and could occur at the end of the planning period. Since the scope of this evaluation are the main stream nutrient reduction alternatives, the Level 2 Off-Ramp reflects a reasonable and conservative long-term planning target.

The six types of long-term alternatives are summarized in Table ES-2. A total of 20 technologies were identified.

Each alternative was identified with the understanding that the existing secondary treatment of high-purity oxygen activated sludge (HPOAS) cannot reduce nutrients due to its low solids retention time (SRT). Options considered included additions to the HPOAS process, modifications to the HPOAS process, or replacement of the HPOAS process with different a process or technology.

Note that for Alternative Type 1 – HPOAS + Post Secondary, multiple processes for nitrification, denitrification, and phosphorus removal are required, so technologies were identified for each of these processes.

Table ES-2. Summary of Types of Long-Term Nutrient Reduction Alternatives

Type of Alternative		Description
1	**HPOAS + Post-Secondary**	The existing HPOAS process would remove BOD and TSS and would be followed by post-secondary treatment processes that would remove nutrients. Post-secondary treatment process would include nitrification, denitrification and phosphorus removal.
2	**Activated Sludge Biological Nutrient Removal (AS BNR)**	The existing HPOAS process would be modified and expanded to an Activated Sludge Biological Nutrient Removal (AS BNR) process.
3	**Established Intensification Technology**	The existing HPOAS process would be modified and expanded to an established intensification process, such as membrane bioreactors (MBRs). The intensification technology, by definition, would require less site space compared to a conventional treatment process.
4	**Emerging Intensification Technology**	The existing HPOAS process would be modified and expanded to an emerging intensification process, such as aerobic granular sludge (AGS). The intensification technology, by definition, would require less site space compared to a conventional treatment process.
5	**Top Ranked Technology at MWWTP + Decentralized Treatment**	In addition to modifying the existing HPOAS process to the top-ranked technology/process configuration determined for the MWWTP (e.g., Alt. 1 through 4), separate treatment would be sited upstream to relieve loading at the MWWTP and to better facilitate nutrient reduction. Decentralized nutrient reduction facilities could be implemented at the District's existing Pt. Isabel and Oakport Wet Weather Facilities (WWFs) using the emerging intensification process configuration selected for Alternative 4. The primary driver to consider this alternative is to determine if distributed treatment would be cost effective.
6	**Split Treatment**	Two different processes would be implemented to operate in parallel (e.g., AS BNR + AGS). To determine the size and technology for each process, the evaluation results of Alternatives 1 – 4 would be used. Key factors for selection of the split treatment processes include site footprint, flexibility, and net present value.

Alternatives Screening

The technologies identified for each type of alternative were screened using criteria developed by the District and Consultant Team. The screening criteria establish the minimum criteria that a technology must meet to be considered viable, thereby eliminating any technologies with fatal flaws early on in the evaluation process. The screening criteria included the following:

- **Ability to Meet Regulations –** Can the technology comply with near-term regulations and be adapted to meet anticipated future regulations?
- **Technology Maturity and Risk –** Is there at least one installation with a capacity of 20 mgd or greater with at least one year of successful operation (within the last 10 years) at 90 percent of capacity?
- **Ease of Permitting –** Can the technology be permitted at the MWWTP?
- **Site Constraints –** Can the technology fit within the MWWTP property lines?
- **Independent Operations –** Can the facility be operated fully by District Staff (without contract operations by private entities)?

The technology screening was performed with the District Staff and Consultant Team at a workshop conducted on December 19, 2019. At least one technology passed the screening criteria for each of the six types of alternatives. In several cases, more than one technology passed, so the technology that was most aligned with the evaluation criteria was selected for further evaluation. The most aligned technology was selected to avoid evaluating similar alternatives. Other similar technologies were noted as alternates that could be considered in the future during implementation. A total of seven alternatives passed the screening process and were carried forward for further evaluation, as summarized in Table ES-3. For Alternative 3 (Established Intensification Process), two technologies were carried forward: MBR and IFAS. IFAS is potentially more cost effective than MBR, but MBR was considered in detail in the 2018 BACWA Nutrient Reduction Study. Therefore, it was determined that both technologies could be viable long-term solutions and warrant further development and evaluation.

Table ES-3. Summary of Screened Nutrient Reduction Alternatives for Further Development

Alternative		Description (Type of Alternative)	Technology/ Configuration
1	**HPOAS**	HPOAS + Post-Secondary	High Purity Oxygen Activated Sludge (HPOAS) + Biologically Aerated Filters (BAF) and Denitrification Filters
2	**AS BNR**	Activated Sludge Biological Nutrient Removal (AS BNR)	Activated Sludge Biological Nutrient Removal (AS BNR)
3	**MBR**	Established Intensification Technology	Membrane Bioreactors (MBR)
4	**IFAS**	Established Intensification Technology	Integrated Fixed Film Activated Sludge (IFAS)
5	**AGS**	Emerging Intensification Technology	Aerobic Granular Sludge (AGS)
6	**Decentralized**	Top Ranked Technology at MWWTP + Decentralized Treatment	IFAS at the MWWTP (a) + AGS at Pt. Isabel and Oakport WWFs (b)
7	**Split Flow**	Split Treatment	AS BNR + AGS (c)

Based on the evaluation results for Alternatives 1 – 4, IFAS was selected because it has the lowest expected lifecycle cost (net present value) and the primary driver to consider decentralized treatment is to determine if it is significantly more cost effective than the other alternatives. AGS was selected as the optimum technology because it is anticipated to minimize footprint and cost. Based on the evaluation results of Alternatives 1 – 4, AS BNR and AGS were selected as the two treatment processes because: AS BNR maximizes the nutrient reduction that can be achieved within the existing tankage; and AGS is compact enough that it fits within the remaining site space available for secondary treatment.

Alternatives Development and Evaluation

The alternatives were developed using the following primary assumptions:

- Sizing, detailed site layouts, and estimated costs were based on meeting the Level 2 Off-Ramp at 2050 flows and loads with all process units in service and the peak wet weather flow through the secondary process limited to 168 mgd.
- Annual operations and maintenance costs were based on anticipated flows and loads during the planning period (2021 – 2050).

- High-level site layouts were based on meeting the Level 3 Off-Ramp, in order to identify/reserve the potential site space needed for additional nutrient reduction.

The alternatives were evaluated using a process and criteria established for this Master Plan and described in detail in the in the C50-Evaluation Process and Criteria Report. Through a series of workshops, District Staff and the Consultant Team developed the economic and non-economic evaluation criteria and weighting. The economic criteria include capital cost, annual operation and maintenance (O&M) cost, and rehabilitation and replacement (R&R) cost in a life cycle cost (or net present value (NPV)) analysis. The non-economic criteria include 13 criteria that fall into three major categories: social, environmental, and technical. Appendix A presents a summary of the evaluation criteria and weighting.

For the economic evaluation, both capital and annual operating costs were used to determine the NPV of each alternative. The capital cost estimates are Class 5 conceptual estimates as defined by the Association for the Advancement of Cost Engineering International (AACE International) and are based the assumptions described in the C40-Basis of Cost Estimating Report. The NPV was developed over a 30-year period assuming a 2 percent discount rate and 3 percent inflation rate. Figure ES-1 provides a summary of the NPV for each alternative. Appendix B includes additional details on the NPV cost estimates and assumptions.

For the non-economic evaluation, a score of 1 to 5 was assigned for each criterion for each alternative. The criterion weighting was then considered to determine the overall weighted score for the alternative. Facility safety, flexibility to meet current/future regulations, and technology maturity/reliability are the three criteria that have the highest weighting and the largest impact on the non-economic score.

Figure ES-2 provides a summary of the non-economic evaluation and includes the non-economic score that was determined for each alternative. Appendix C provides the detailed scoring and scoring justification for each alternative and criterion.

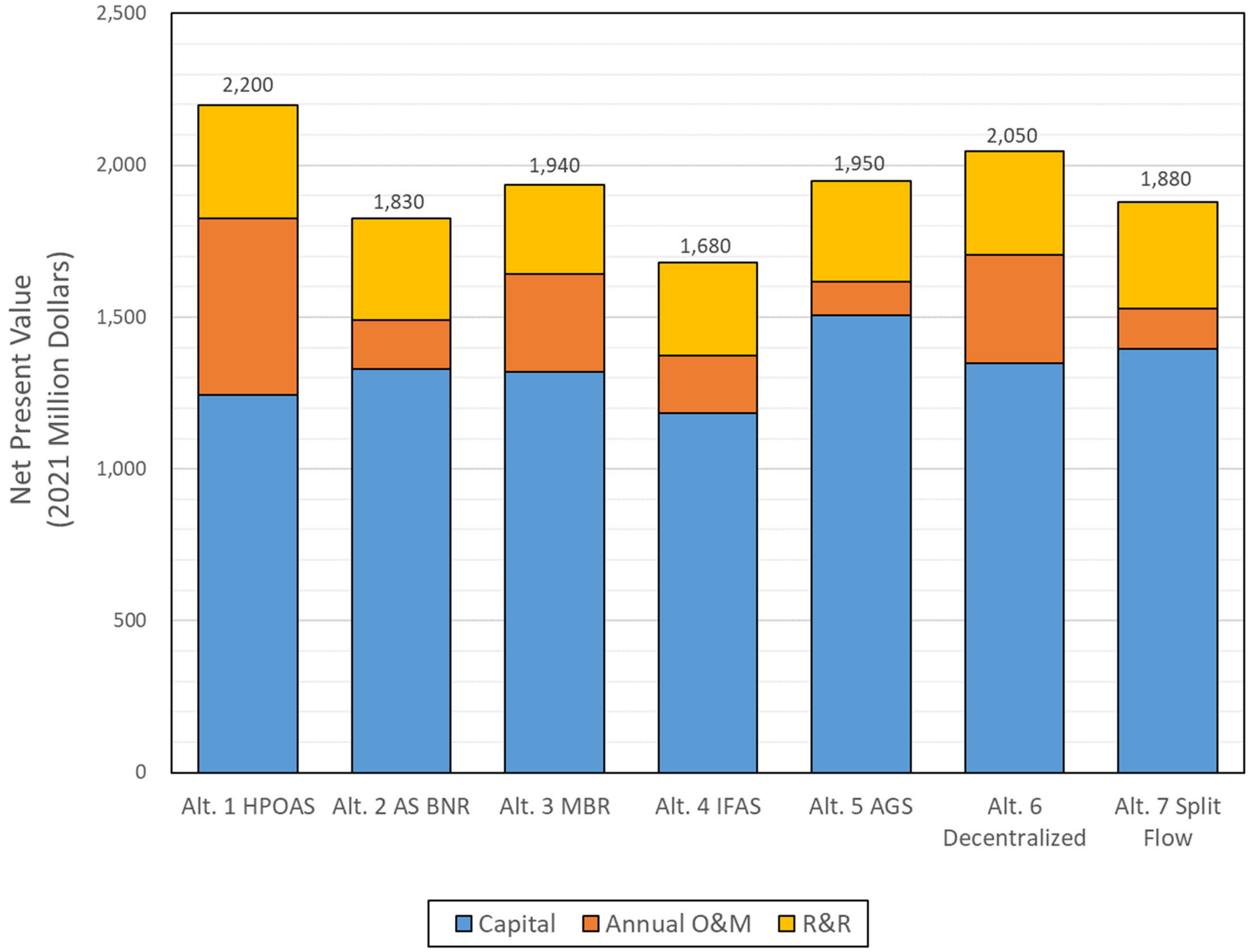

Figure ES-1. Summary of the Net Present Value for Each Alternative

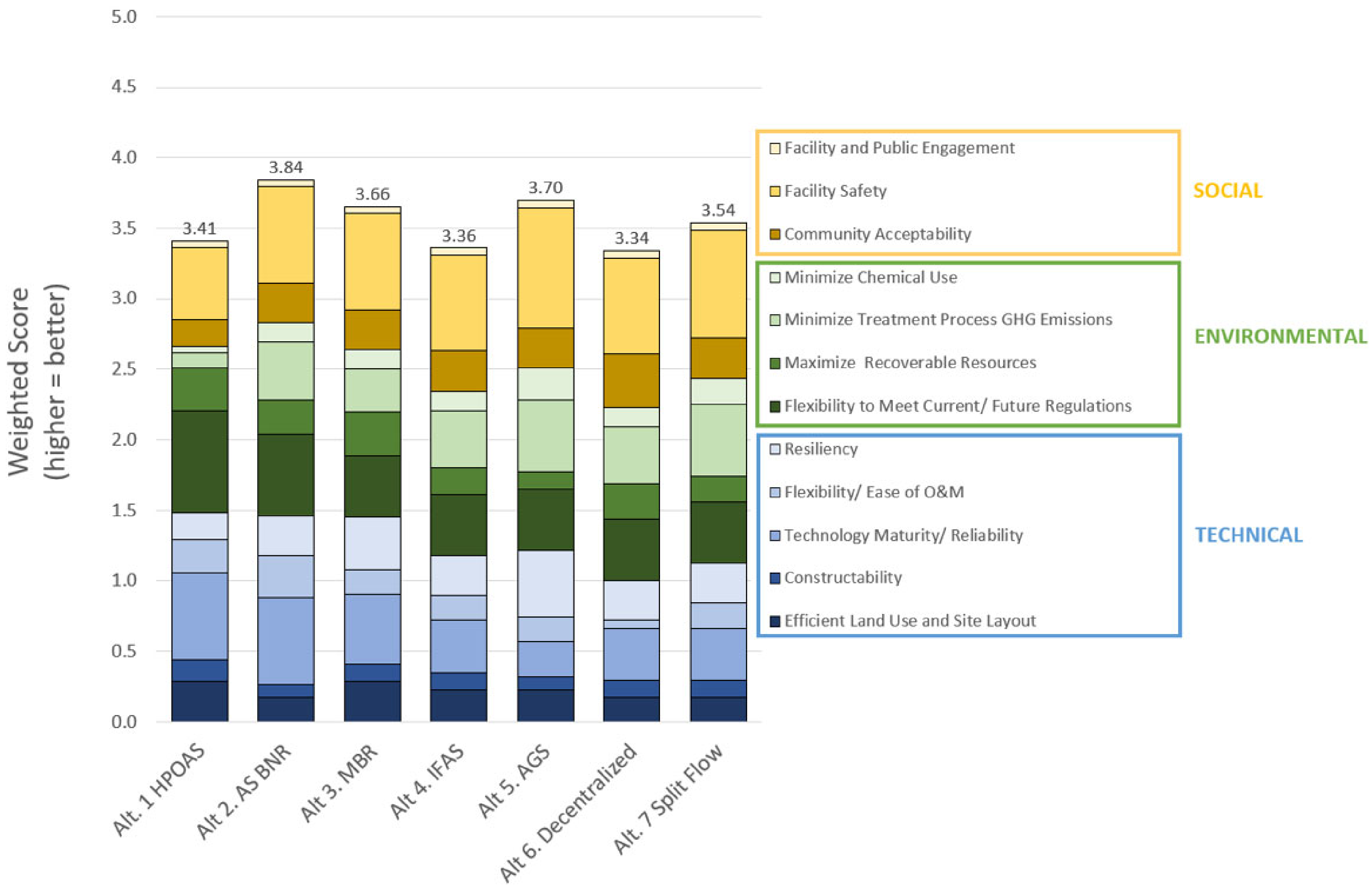

Figure ES-2. Summary of Non-Economic Scores for Each Alternative.

Through a series of meetings and a workshop, District Staff and the Consultant Team discussed the economic and non-economic evaluation and the following conclusions were drawn:

- **Low-Ranking Alternatives** – The following alternatives were considered low ranking alternatives and were eliminated from further consideration as the basis for planning.
    - Alternative 1 HPOAS – Due to its high NPV and low non-economic score.
    - Alternative 6 Decentralized – Due to its moderate NPV and low non-economic score.
- **Mid-Ranking Alternatives –** The following alternatives were determined to be mid-ranking alternatives due to their similar NPVs and non-economic scores.
    - Alternative 3 MBR – This alternative may become favorable in the future should regulations require significant reduction of effluent discharged to the Bay. Reducing bay discharge would require a significant increase in water reuse. Therefore, MBR may offer a greater benefit than the other technologies.
    - Alternative 5 AGS – This alternative may become more favorable in the future as the technology matures and its reliability and sizing is better established. As the technology matures and is implemented on a larger scale, the cost of the technology may also decrease to make it more cost competitive with the other technologies.
    - Alternative 6 Split Flow – This alternative may become more favorable in the future depending on the timing and magnitude of the nutrient regulations. It is very likely the first phase of nutrient reduction improvements implemented at the MWWTP will operate in parallel with the existing HPOAS process (i.e., in a split flow configuration). This may be the case for subsequent phases, and the secondary treatment facilities may continue with a split flow configuration throughout the planning period. The benefits of operating in a split flow configuration can be taken into consideration when developing the phasing plan for the nutrient reduction improvements included in the roadmap.
- **High-Ranking Alternatives –** The following alternatives were determined to be high ranking alternatives.
    - Alternative 2 AS BNR – This alternative is considered high ranking due to its low NPV and high non-economic score. This alternative was viewed as especially favorable for planning because it provides the most flexibility for transitioning to a different technology in the future, should another technology become more cost effective due to advances in emerging technologies or changing drivers (such as the need for increased water reuse).
    - Alternative 3 IFAS – This alternative is considered high ranking due to its low NPV.

Recommendations and Next Steps

Through the evaluation process, it was determined that that maintaining flexibility and the ability to implement nutrient reduction improvements in phases, on an as-needed basis, is very important. Given that the earliest anticipated timing for the Level 2 Off-Ramp is 2045 to 2055, there is considerable time before the District needs to decide on the specific nutrient reduction technology/process configuration.

Given this and the results of the alternatives evaluation, it was determined that that Alternative 2 AS BNR should be carried forward as the basis for the roadmap. In addition to having a low NPV and high non-economic score, Alternative 2 was selected because it is conservative with respect to site planning and offers the most flexibility with respect to long-term planning, as described below:

- AS BNR requires the largest site footprint of the alternatives considered. As such, the Master Plan would reserve a conservative amount of site space for nutrient reduction. Should other alternatives become more favorable in the future, it is anticipated that they would fit with the site space reserved.
- AS BNR provides the most flexibility in that the major upgrades include additional bioreactors. The bioreactors could be implemented in phases over time on an as-needed basis.

AS BNR could be configured to accommodate an intensification technology in the future in order to optimize the site footprint to capitalize on other economic/non-economic benefits. Compared to the other alternatives, the AS BNR bioreactors provide more flexibility for reconfiguration to accommodate other intensification technologies/process in the future such as MBR, IFAS, AGS, or another emerging technology. At this time, IFAS appears favorable compared to the other intensification technologies, although that may change as the technologies develop further or mature. Alternative 2 AS BNR will be carried forward for further refinement and integration into the roadmap. A phased implementation plan will be developed to serve as the basis of the roadmap. The phased implementation plan will indicate which level of nutrient reduction will trigger major decisions on the mainstream technology/process configuration, how it will be coordinated with sidestream treatment, and how the AS BNR configuration can be modified to accommodate an intensification technology (i.e., IFAS, MBR, or AGS) in the future.

While the focus of this report is evaluating mainstream treatment improvements for meeting the Level 2 Off-Ramp, the roadmap must also consider how to best meet the Master Plan Target which is anticipated to occur earlier in the planning period. The roadmap will evaluate several approaches for meeting the Master Plan Target, one of which is sidestream treatment.

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CHAPTER 1 - INTRODUCTION

The goal of the East Bay Municipal Utility District's (District) Integrated Main Wastewater Treatment Plant (MWWTP) Master Plan Project (Master Plan) is to provide a 30-year roadmap for the MWWTP. Potential future regulations regarding nutrient discharges to the San Francisco Bay (SF Bay or Bay) and biosolids diversion from landfills may drive upgrades at the MWWTP. The roadmap will serve as a guide to prioritize projects that are necessary to meet future regulations, capacity constraints, and/or to address rehabilitation and renewal needs.

As part of the Master Plan, an evaluation of nutrient reduction alternatives was performed to select a long-term alternative that can meet the potential regulatory endpoints considered for the basis of planning. The purpose of this report is to review the:

- Universe of nutrient reduction alternatives (referred to as the "universe of alternatives") that were considered and screened in order to select seven viable and distinct alternatives to carry forward for further analysis;
- Development and evaluation of the seven nutrient reduction alternatives;
- Selection of a long-term nutrient reduction alternative to carry forward for further refinement and development into a phased implementation plan.

This report is organized as follows:

- Executive Summary
- Chapter 1: Introduction
- Chapter 2: Background
- Chapter 3: Nutrient Reduction Regulations
- Chapter 4: Alternatives Analysis Approach
- Chapter 5: Alternatives Analysis
- Chapter 6: Conclusions and Next Steps
- Chapter 7: References

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CHAPTER 2 - BACKGROUND

2.1 Driver for Nutrient Reduction Improvements

The primary driver to implement nutrient reduction improvements at the MWWTP would be to comply with a regulatory requirement to do so. Current regulations do not require the MWWTP to remove nutrients, such as nitrogen and phosphorous, from the wastewater effluent treated at the plant; however, it is anticipated that future regulations may require nutrient removal in order to maintain the health of the Bay.

2.1.1 Nutrients and San Francisco Bay Water Quality

Stakeholders in the SF Bay Area are concerned about the impact of nutrients on the water quality of the SF Bay. If a body of water is enriched with excess nutrients, such as nitrogen and phosphorus, then excessive growth of phytoplankton (or algae) may occur, which in turn may deplete the dissolved oxygen (DO) present in the water. Zones where oxygen levels are depleted (dead zones or hypoxic zones) can cause fish kills, harm to other aquatic life, and reduction of marine habitat. Excessive growth of phytoplankton can lead to harmful algal blooms (HABs), which can be toxic to people, fish, birds, and other marine life (East Bay Municipal Utility District [EBMUD], 2018) (NOAA, 2020).

The SF Bay has long been recognized as a nutrient-enriched estuary; however, historically, it has been resilient to the adverse effects of nutrient enrichment. Dissolved oxygen concentrations within the Bay are higher and phytoplankton biomass and productivity are lower than typically occur with such high nutrient loads. Studies indicate other factors such as tidal mixing, light limitation due to high turbidity, and algae-filtering clams are contributing to the resilience of the Bay to eutrophication (San Francisco Estuary Institute, 2018).

Recent monitoring of the SF Bay water quality indicates the Bay’s resilience to the negative effects of nutrient enrichment may be weakening. Some regions of the Bay have experienced increased phytoplankton growth and decreased DO concentrations. To better understand the impacts of nutrient loads on the Bay, several agencies are working together to develop a scientific basis for nutrient management decisions.

In 2014, the San Francisco Regional Water Quality Control Board (Regional Board) developed the San Francisco Bay Nutrient Management Strategy (NMS) Science Program, to develop a scientific foundation to support nutrient management decisions (San Francisco Estuary Institute, 2016). The NMS is led by the San Francisco Estuary Institute (SFEI) and is comprised of several stakeholder groups, including state and regional regulators, SF Bay wastewater agencies, water purveyors, NGOs, and others. Since its establishment, the NMS has continued to conduct investigative studies to determine safe levels of nutrient loads to the Bay.

To establish a regional framework for assessing nutrient impacts on the Bay, as well as nutrient reduction strategies that could be implemented by wastewater agencies, the San Francisco Water Quality Control Board (SFWQCB) issued a Watershed Permit on April 9, 2014 (Order No. R2-2014-0014, *Waste Discharge Requirements for Nutrients from Municipal Wastewater Discharges to San Francisco Bay*). The Watershed Permit required effluent monitoring and reporting, and the evaluation of potential nutrient reduction that could be achieved with plant optimization, sidestream treatment, plant upgrades, and by other means. On May 8, 2019, the Regional Board issued the second Watershed Permit, which includes continued effluent monitoring and reporting, funding of scientific studies, and support of special studies. Both permits are discussed in further detail in Chapter 3.

While the impacts of nutrients are still being studied, depending on future findings, the Regional Board may impose nutrient limits for wastewater dischargers, including the District. Should nutrient limits be included in the MWWTP’s future discharge permits, the treatment process facilities would need to be upgraded to reduce nutrient loads in the effluent.

2.2 Influent Nutrient Load to the MWWTP

Nutrients such as nitrogen and phosphorus are naturally present in the residential, commercial, and industrial wastewater flow received at the MWWTP through the collection system. These nutrients are also present in the low-strength and high-strength waste that is trucked to the MWWTP as part of the resource recovery (R2) Program.

The low-strength waste, which typically includes water treatment sludge, septage, and brine waste streams, is accepted at the plant headworks and combined with the influent flow to the plant. As such, the nutrient load in the low-strength waste directly contributes to the nutrient load to the MWWTP liquid treatment process.

The high-strength waste (HSW) typically includes protein; fats, oils, grease (FOG); and winery wastes. High strength waste is accepted at two receiving stations and digested with the solids generated by the MWWTP liquid treatment process. The digested sludge is dewatered and the excess water (or centrate) is returned to the primary sedimentation basins for additional treatment in the liquid process. This centrate stream is highly concentrated with nutrients. The centrate is only 1 percent of the MWWTP flow, but comprises nearly 35 percent of the ammonia load to the liquid treatment process. The HSW likely contributes to approximately half of the centrate load as most wastewater plants that do not import HSW see the centrate ammonia load ranging from 15 to 25 percent of the total influent ammonia load, rather than the 35 percent seen at MWWTP.

2.3 MWWTP Treatment Process Overview

A process flow diagram of the District's MWWTP is provided as Figure 2-1. A complete description of the District's treatment facilities is included in the Wastewater System Overview Report (EBMUD, 2019). The liquid treatment process includes influent screening and pumping, grit removal, primary treatment, secondary treatment, effluent pumping, disinfection, and dechlorination. The primary treatment wet weather capacity is 320 million gallons per day (mgd), and the secondary treatment wet weather capacity is 168 mgd. When the secondary influent flow exceeds 150 mgd, EBMUD is permitted to blend primary effluent with secondary effluent prior to disinfection for discharge.

2.4 Secondary Treatment Facilities

The MWWTP is not currently designed and operated to reduce nutrients in the wastewater. To reduce nutrients, modifications and upgrades would need to be made to the secondary treatment facilities.

The secondary treatment facilities are currently operated to remove dissolved organic waste, specifically five-day carbonaceous biological oxygen demand ($cBOD_5$ or BOD) and total suspended solids (TSS). The secondary treatment facilities include eight, four-stage high purity oxygen reactors (HPOAS reactors or HPOAS tanks) and 12 secondary clarifiers.

High purity oxygen is added to the HPOAS tanks to support the growth of microorganisms (biomass) that break down the organic matter present in the wastewater. The high purity oxygen is generated and stored onsite by a cryogenic oxygen generating plant and liquid oxygen storage system.

The effluent from the HPOAS reactors, which is referred to as mixed liquor suspended solids (MLSS), flows to the secondary clarifiers. In the secondary clarifiers, the biomass in the MLSS separates from the wastewater and settles as sludge. A portion of the sludge, referred to as return activated sludge (RAS), is pumped to the HPOAS reactors to replenish the biomass available to provide treatment. The remaining RAS, referred to as waste active sludge (WAS), is wasted from the treatment process and pumped to the dewatering building to be thickened and treated in the anaerobic digesters. WAS is wasted from the secondary process to control the solids retention time (SRT), which is the average time that solids remain in the secondary process, or the average age of the microorganisms in the biomass. Controlling the SRT impacts the type of microorganisms present and level of treatment achieved (e.g., reduction of $cBOD_5$, nitrogen, and/or phosphorous).

A complete description of the District's solids facilities and historical performance is provided in the Wastewater System Overview Report (EBMUD, 2019).

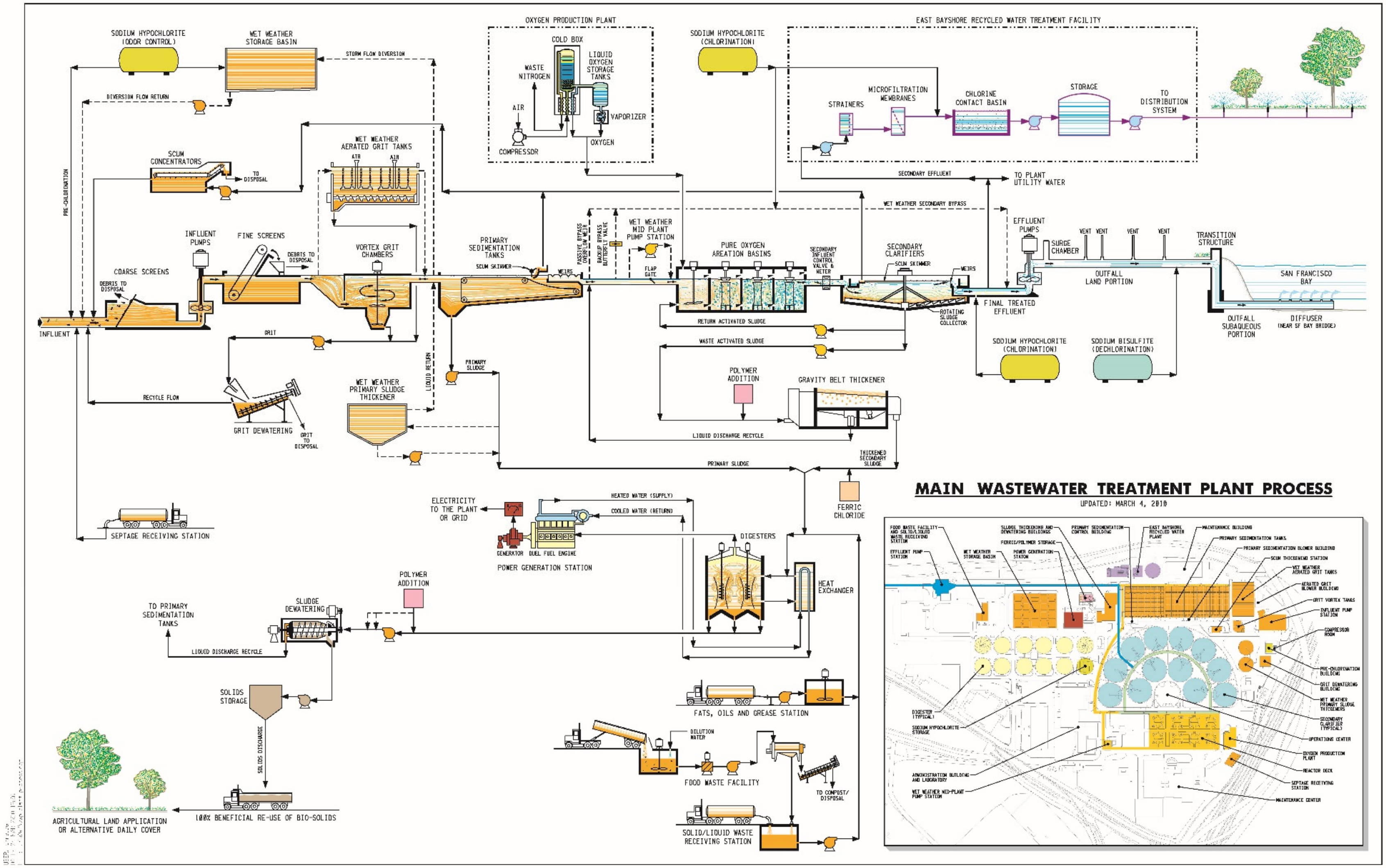

Figure 2-1. MWWTP Process Flow Diagram

CHAPTER 3 - NUTRIENT REGULATIONS

This section provides an overview of current and anticipated future regulations that were considered for the development of the nutrient reduction alternatives.

3.1 Current Regulations

Discharges from the MWWTP are permitted by the San Francisco Bay Regional Water Quality Control Board (Regional Board) under the National Pollutant Discharge Elimination System (NPDES) program. The MWWTP is currently regulated under the individual NPDES permit no. CA0037702 and discharges are currently regulated under Order No. R2-2020-0018, which expires on June 30, 2025. This permit is renewed and updated every five years by the issuance of a new Order unless a major change requires a faster renewal schedule (EBMUD, 2018).

Discharges are also regulated by several other Regional Orders including those for nutrients, mercury and polychlorinated biphenyls (PCBs), alternate monitoring and reporting requirements, and regional monitoring and reporting requirements. A complete description of the current and anticipated regulations for wastewater discharges is included in the Current and Future Regulations Report (EBMUD, 2018).

With respect to nutrients, the permit includes toxic pollutant effluent limits for ammonia, which is a form of nitrogen. The average monthly limit is 84 mg/L, and the average daily limit is 110 mg/L.

3.1.1 Watershed Permit

Nutrient discharges are primarily regulated by the Regional Order for nutrients, which is also referred to as the Watershed Permit. The initial Watershed Permit was issued in 2014. The current Watershed Permit (Order No. R2-2019-0017, NPDES No. CA 0038873, *Waste Discharge Requirements for Nutrients from Municipal Wastewater Discharges to San Francisco Bay*), was issued on May 8, 2019 and is a renewal of the initial 2014 Watershed Permit. Both permits are discussed below.

3.1.1.1 2014 Watershed Permit

The SFRWQB issued the initial Watershed Permit (Order No. Order No. R2-2014-0014, *Waste Discharge Requirements for Nutrients from Municipal Wastewater Discharges to San Francisco Bay*), to establish a regional framework for assessing nutrient impacts on the Bay, as well as nutrient reduction strategies that could be implemented by wastewater agencies. The permit was issued on April 9, 2014 and was effective from June 1, 2014 to June 20, 2019.

The major permit requirements included:

- Routine effluent monitoring and reporting, including submission of an Annual Nutrients Report
- Evaluation of potential nutrient load reduction opportunities at the MWWTP including:
    - Treatment plant optimization
    - Sidestream treatment
    - Treatment plant upgrades
    - Other methods including natural treatment systems (wetlands and horizontal levees) and water recycling
- Submission of a Nutrient Reduction Study summarizing the treatment optimization and upgrade opportunities
- Conducting monitoring, modeling, and subembayment studies

3.1.1.1.1 Monitoring, Modeling, and Subembayment Studies

To conduct the required monitoring, modeling, and subembayment studies, the District collaborated with other SF Bay wastewater agencies and stakeholders under the Nutrient Management Strategy (NMS) Science Program. As described in Chapter 2, the Regional Board formed the NMS in 2014 so that various SF Bay stakeholders could work collaboratively to develop a scientific foundation to support nutrient management decisions. The NMS is led by the San Francisco Estuary Institute (SFEI) and is comprised of several stakeholder groups. To address the permit requirements, the District funded a portion of the $880,000 provided annually by the SF Bay wastewater agencies to NMS to support the required monitoring, modeling, and study efforts.

3.1.1.1.2 Nutrient Reduction Study

To complete the Nutrient Reduction Study, the District worked collectively with other SF Bay wastewater agencies under the Bay Area Clean Water Agencies (BACWA) joint powers authority to conduct a regional study to evaluate nutrient load reduction opportunities. Through this collective effort, Individual Facility Reports were developed and included in the Final Nutrient Reduction Study which was submitted to the SFRWCB on June 22, 2018.

As part of this effort, the group developed and submitted a Scoping and Evaluation Plan to describe the approach and assumptions used to conduct the Nutrient Reduction Study. While the Watershed Permit did not include specific nutrient reduction goals, the Scoping and Evaluation Plan effort included development of Level 2 and Level 3 nutrient reduction levels (targets) to serve as the basis for the Nutrient Reduction Study.

The nutrient reduction levels developed are summarized in Table 3-1.

Table 3-1. Nutrient Reduction Levels Assumed for the 2018 Nutrient Reduction Study

Nutrient Reduction Levels (a) (b)	**Ammonia mg-N/L**	**Total Nitrogen mg-N/L**	**Total Phosphorus mg-P/L**
Level 1	Varies by Facility (c)	Varies by Facility (c)	Varies by Facility (c)
Level 2 (d)	2	15	1
Level 3 (e)	2	6	0.3

a. Nutrient Reduction Level assumed for the 2018 Final Nutrient Reduction Study developed by Bay Area Clean Water Agencies (BACWA).
b. Seasonal impacts were considered for all three treatment levels.
c. Varies based on optimization opportunities where nutrient loads are reduced as much as possible with minimal capital investment to improve existing facilities.
d. Achievable by conventional nutrient reduction processes without effluent filtration and without adding external carbon, although some plant configurations and technologies may require chemical addition.
e. Filters and additional of external carbon required.

The District's Individual Facility Report (included in the 2018 Nutrient Reduction Study) identified the following major nutrient reduction opportunities:

- To meet Level 1:
    - No new process optimization strategies were identified; however, the report noted the District had already implemented an optimization strategy to reduce the total phosphorus load across the plant by optimizing the operation of the HPOAS facilities and implementing metal salt coagulant dosing at the anaerobic digesters.
- To meet Level 2:
    - Add sidestream treatment to reduce ammonia, total nitrogen, and total phosphorus loads from the dewatering centrate produced by the solids treatment process. As described in Chapter 2, the centrate flow is returned to the secondary treatment process for treatment, and thus contributes to the total nutrient load to the secondary treatment process.
    - Replace the HPOAS facilities with an MBR facility.
- To meet Level 3:
    - Add additional aeration basins and ancillary facilities and increase chemical usage (methanol and metal salts) to provide additional nitrogen and phosphorus removal.

3.1.1.2 2019 Watershed Permit

The current Watershed Permit, adopted May 2019, is effective from July 1, 2019 to June 30, 2024, and is anticipated to be renewed in 2024. The major permit requirements include:

- Routine effluent monitoring and reporting, including submission of an Annual Nutrients Report.
- Support for scientific studies associated with the NMS, including monitoring, modeling, and subembayment studies.
- Special studies including:
    - Regional evaluation of potential nutrient reduction by natural systems (e.g., horizontal levees and wetland enhancement)
    - Regional evaluation of potential nutrient reduction by water recycling

To meet the monitoring and reporting requirements, the District is continuing to collaborate with BACWA and its member agencies. Each BACWA member agency conducts its own effluent monitoring and BACWA prepares a Group Annual Report each year on February 1. The District is also collaborating with BACWA to complete the special studies. To support the scientific studies, the District funds a portion of the $2.2 million provided annually by SF Bay wastewater agencies to NMS.

3.1.1.2.1 2024 Nutrient Load Cap Target

When the 2019 Watershed Permit was issued, there was insufficient evidence to conclude that nutrients are adversely impacting the water quality of the Bay. Therefore, it does not include water quality-based effluent limitations for nutrients or additional limitations beyond those included in the Discharger’s individual NPDES permits. The 2019 Watershed Permit does include estimated nutrient load targets that major dischargers may be required to meet by 2024 based on their current nutrient discharge performance and future population growth.

The 2024 nutrient load target, which is also referred to as the “load-cap”, is intended to notify dischargers of potential future nutrient limitations so they can implement necessary nutrient reduction improvements in a timely manner. The load target is expressed in terms of total inorganic nitrogen (TIN) because nitrogen is the growth-limiting nutrient for phytoplankton in the SF Bay (Order No. R2-2019-0017, NPDES No. CA 0038873, *Waste Discharge Requirements for Nutrients from Municipal Wastewater Discharges to San Francisco Bay*).

2024 nutrient load targets were developed for each wastewater discharger was based on the maximum dry season average of the total inorganic nitrogen data collected between May 1, 2014 and September 30, 2017. The District’s maximum dry season average during this period was 9,800 kg/day. To account for population growth, the 2024 nutrient load target was calculated by adding an additional 15 percent buffer to the current maximum dry season average. As a result, the District’s 2024 Dry Season Average Load Target in the 2019 Watershed Permit is 11,000 kg/day.

3.2 Anticipated Nutrient Regulations

Based on the District's ongoing participation with BACWA's nutrient-related efforts and discussions with the SFRWQB, it is understood that nutrient limits will be determined and implemented if the findings of the scientific studies indicate they are necessary to maintain the health and water quality of the SF Bay. The 2019 Watershed Permit indicates the District may be required to meet the 2024 Dry Season Average Load Target included in the permit. If effluent limits are required in 2024 and based on performance, the limits would be based on performance during the dry weather period (May 1 – September 30).

Based on discussions with the Regional Board, more time may be required to complete the scientific studies to confirm the need for the 2024 Load Cap Target. The next Watershed Permit, which is expected to take effect in 2024, may be an extension of the 2019 Watershed Permit and may not include a load target.

Due to this lack of evidence and clear regulatory direction, it may be some time (if ever) before the Watershed Permit requires meeting a Level 2 target as defined in the 2018 Nutrient Reduction Study. It is very unlikely that phosphorus limits and Level 3 nutrient removal altogether would need to be implemented within the planning period of the Master Plan.

As stated in the 2019 Watershed Permit, nitrogen is the growth-limiting nutrient for phytoplankton in San Francisco Bay; therefore, the 2024 nutrient load targets in the 2019 Watershed Permit are expressed in terms of total inorganic nitrogen, the bioavailable form of nitrogen. It is anticipated that future nutrient limits will also be based on total inorganic nitrogen as opposed to total nitrogen, which was assumed in the 2018 Nutrient Reduction Study. Total nitrogen and total inorganic nitrogen include the following forms of nitrogen:

$$\begin{aligned}Total\ Nitrogen \\ &= nitrate\ (NO_3 - N) + nitrite\ (NO_2 - N) + ammonia\ (NH_3 - N) \\ &+ organically\ bound\ nitrogen\end{aligned}$$

$$Total\ Inorganic\ Nitrogen = nitrate\ (NO_3 - N) + nitrite\ (NO_2 - N)$$

3.3 Nutrient Management Endpoints

Based on the current regulations and ongoing efforts, regulatory endpoints (or targets) were developed to serve as the basis for the current Master Planning effort. Table 3-2 summarizes the nutrient reduction targets assumed and how they are used to support the planning effort:

- **Master Plan Target:** The Master Plan Target is a seasonal load target based on the potential load cap target noted in the 2019 Watershed Permit. In the roadmap report, cash flows will be based on the Master Plan Target.

- **Level 2 Off-Ramp:** The Level 2 Off-Ramp is based on the Level 2 Target in the 2018 Nutrient Reduction Study with two exceptions – it is based on TIN instead of TN, and does not include a phosphorus limit. This target is anticipated to be the most stringent potential endpoint that may occur within the 30-year planning period. The Level 2 Off-Ramp was used to develop and evaluate the nutrient reduction alternatives in terms of sizing, detailed site layouts, and life cycle costs.
- **Level 3 Off-Ramp:** The Level 3 Off-Ramp is based on the Level 3 Target in the 2018 Nutrient Reduction Study and is not anticipated to occur within the planning period and may never occur. As such, it was only considered at a high-level with respect to identifying the site space potentially required for nutrient removal and to screen out alternatives that do not fit within the plant boundaries. The Level 3 Off-Ramp is considered the limit of technology (LOT).

The Master Plan Target and the Level 2 Off-Ramp could all potentially occur within the planning period, and will be taken into consideration when developing the phased implementation plan for the selected nutrient removal alternative.

Table 3-2. Nutrient Reduction Targets Assumed for the MWWTP Master Plan Nutrient Reduction Alternatives Analysis

Nutrient Reduction Target	Total Inorganic Nitrogen (TIN) and Total Nitrogen (TN)	Total Phosphorus (TP)	Estimated Year Included in Permit [(a)]	Estimated Year for Compliance [(a)]	Used for CIP Cash Flows?	Used for Site Planning?
Master Plan Target (b)	TIN Seasonal Load Target = 11,000 kg/day (b)	No target anticipated	2024±	2029±	Yes	Yes
Level 2 Off-Ramp	TIN = 15 mg-N/L TIN at 2050 = 3,750 kg/day (average annual load) (c)	No target anticipated	2045±	2060±	No	Yes
Level 3 Off-Ramp (d)	**Level 2 with HSW** (e) TN = 15 mg-N/L TIN = 5 mg-N/L **Level 3 without HSW** (f) TN = 6 mg-N/L TIN = 3 mg-N/L	0.3 – 1 mg-P/L	2065+	2075+	No	Yes

a. Timing is uncertain and contingent on findings of ongoing scientific studies.

b. As identified in the 2019 Watershed Permit. Based on performance during the dry weather period (May 1 – September 30).

c. Based on performance over the entire year (i.e., average annual load). Assume nitrogen target will be based on TIN because the 2024 nutrient load targets in the 2019 Watershed Permit are expressed in terms of TIN. The permit also states nitrogen is the growth-limiting nutrient for phytoplankton in San Francisco Bay, and TIN is the bioavailable form of nitrogen.

d. Based on the Nutrient Removal Level assumptions included in the 2018 Nutrient Reduction Study.

e. Achievable by conventional nutrient removal processes without effluent filtration, but will likely require supplemental carbon. The MWWTP could continue to accept/treat high strength waste (HSW) as part of the District's Resource Recovery Program. The analysis considered the impact of HSW because it contains soluble unbiodegradable nitrogen that is not removed in the treatment process and contributes to the effluent TN.

f. Filters and additional external carbon required. HSW could no longer be accepted and treated at the MWWTP as HSW nutrient load would result in effluent TN greater than 6 mg/L.

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CHAPTER 4 - ALTERNATIVES EVALUATION APPROACH

As discussed in the previous section, a range of nutrient reduction targets were established to guide the assessment of alternative treatment to meet future regulatory requirements. The development and evaluation of treatment alternatives followed a process established for this Master Plan and described in C50 Draft Evaluation Criteria and Process Report (Carollo, 2020). Steps include:

1. Identify potential alternatives.
2. Screen alternatives.
3. Develop and evaluate seven short-listed alternatives.

The alternatives described in this report represent possible ways to implement a long-term solution for nutrient reduction. Based on the selected long-term alternative, a detailed roadmap of interim solutions will be developed that fit with the long-term vision.

4.1 Identify Alternatives

During a workshop conducted on September 19, 2020, District Staff and the Consultant Team identified a range of nutrient reduction alternatives/technologies to be considered for anticipated nutrient removal requirements. This range of alternatives is referred to as the “universe of alternatives.” Six types of nutrient reduction alternatives were identified, as shown in Table 4-1. Following identification of these types of alternatives, specific treatment technologies or process configurations (technologies) were then identified for each type of alternative.

Table 4-1. Summary of Types of Long-Term Nutrient Reduction Alternatives

Type of Alternative		Description
1	**HPOAS + Post-Secondary**	The existing HPOAS process would remove BOD and TSS, and would be followed by post-secondary treatment processes that would remove nutrients. Post-secondary treatment process would include nitrification, denitrification and phosphorus removal.
2	**Activated Sludge Biological Nutrient Removal (AS BNR)**	The existing HPOAS process would be modified and expanded to an Activated Sludge Biological Nutrient Removal (AS BNR) process.
3	**Established Intensification Technology**	The existing HPOAS process would be modified and expanded to an established intensification process, such as membrane bioreactors (MBRs). The intensification technology, by definition, would require less site space compared to a conventional treatment process.
4	**Emerging Intensification Technology**	The existing HPOAS process would be modified and expanded to an emerging intensification process, such as aerobic granular sludge (AGS). The intensification technology, by definition, would require less site space compared to a conventional treatment process.
5	**Top Ranked Technology at MWWTP + Decentralized Treatment**	In addition to modifying the existing HPOAS process to the top-ranked technology/process configuration determined for the MWWTP (e.g., Alt. 1 through 4), separate treatment would be sited upstream to relieve loading at the MWWTP and to better facilitate nutrient reduction. Decentralized nutrient reduction facilities could be implemented at the Districts existing Pt. Isabel and Oakport Wet Weather Facilities (WWFs) using the emerging intensification process configuration selected for Alternative 4. The primary driver to consider this alternative is to determine if distributed treatment would be cost effective.
6	**Split Treatment**	Two different processes would be implemented to operate in parallel (e.g., AS BNR + AGS). To determine the size and technology for each process, the evaluation results of Alternatives 1 – 4 would be used. Key factors for selection of the split treatment processes include site footprint, flexibility, and net present value.

4.2 Screen Alternatives

Through a series of workshops, District Staff developed criteria to screen alternatives to carry forward for development and further evaluation. The screening criteria, summarized in Table 4-2 below, establish the minimum criteria that all alternatives must meet in order to be considered viable and evaluated further.

Table 4-2. Screening Criteria

Criteria	Description	Metric [(a)]
Ability to Meet Regulations	Complies with near term water, air, and land related regulations, and can be adapted to meet anticipated regulations.	Pass/Fail
Technology Maturity & Risk[(b)]	Proposed technology/approach has at least one installation with a capacity of 20 mgd or greater, with at least one year of successful operation (within the last 10 years) at 90 percent capacity.	Pass/Fail
Ease of Permitting	Technology has been permitted at a WWTP.	Pass/Fail
Site Constraints	Structures, equipment, etc., fit within the existing WWTP boundaries.	Pass/Fail
Independent Operations	Facilities can be fully operated by EBMUD staff (i.e., contract operations by independent entities is not required).	Pass/Fail

a. The screening criteria were applied on a pass/fail basis – the alternative either meets the criteria (Passes); or it does not (Fails). Alternatives must meet all criteria to be considered viable and evaluated further.

b. To facilitate screening, technologies were grouped into three categories of technology maturity: embryonic, emerging, and established.

District staff and the Consultant Team applied the criteria to screen each technology and to determine which alternative types and associated technologies were viable for further evaluation. A total of seven alternatives passed the screening process and were carried forward.

4.3 Evaluate Alternatives

The seven nutrient reduction alternatives selected through the screening process were developed and evaluated using quantitative, qualitative, and pairwise comparison elements. Over a series of workshops, District staff developed the evaluation criteria used to evaluate the alternatives. The evaluation criteria were developed to support each Master Plan goal and objective. District staff used the pairwise comparison method to determine the relative importance (i.e., weighting) of each evaluation criterion. The resulting evaluation criteria and weighting is summarized in Appendix A.

The evaluation criteria are either quantitative (based on a measurable/estimated metric) or qualitative (based on professional judgement). Using a combination of quantitative and qualitative scoring for each criterion allowed the District to consider multiple criteria in an efficient manner and to a level of detail necessary to determine which alternatives are best aligned with the Master Plan goals and objectives.

The nutrient reduction alternatives were evaluated with the District in a workshop on April 30, 2020. Based on the results, the top nutrient reduction alternative was identified to carry forward for further refinement and for the development into a phased implementation plan.

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CHAPTER 5 - ALTERNATIVES ANALYSIS

This section provides a summary of the nutrient reduction alternatives that were identified, screened, developed, and evaluated.

5.1 Alternatives Identification

Table 5-1 summarizes the six types of nutrient reduction alternatives that were identified, as well as the specific technologies that could be implemented for each type of alternative. A total of 20 technologies were identified.

As shown in Table 5-1, the status (i.e., maturity) of each technology was determined using the following industry accepted definitions:

- **Embryonic:** Technology in its early development state that has been demonstrated at bench or small pilot scale. In some cases, the technology may not have been proven or operated at full scale.
- **Emerging:** Technology that is commercially viable and has been proven at full-scale in one or more installations. Emerging technologies have a shorter track record than established technologies (typically less than 5 years).
- **Established:** Technology that is well established in the industry for nutrient reduction applications. These technologies have been implemented and operated at full scale for a minimum of 10 years.

5.2 Alternatives Screening

5.2.1 Screening Assumptions

The following assumptions were made to screen the alternatives:

- All treatment facilities must fit within the existing MWWTP and/or WWF boundaries:
    - The MWWTP is not moving to an alternative location, and therefore always serves as the base treatment for any alternative.
    - The Pt. Isabel and Oakport WWF properties can be used for decentralized treatment, but their core function of wet weather storage and treatment must be maintained.
- To ensure the screened alternatives would be feasible for the long-term (i.e., beyond the planning period), the screened alternatives need to be able to fit on the site assuming 2050 medium growth conditions and be able to achieve the Level 3 Off-Ramp (conditions beyond this Master Planning horizon):
    - Total Nitrogen = 6 mg/L (equivalent average annual load)
    - Total Inorganic Nitrogen = 3 mg/L (equivalent average annual load)
    - Total Phosphorus = 0.3 mg/L (equivalent average annual load)

- High strength waste (HSW) streams were not included to avoid eliminating a technology due to HSW contributions. HSW contributions are considered in the development of the phasing plan for the selected alternative.
- For the decentralized treatment alternatives, the following assumptions were used for the nutrient reduction facilities at the Pt. Isabel and Oakport WWFs:
    - The nutrient reduction facilities would provide treatment year-round.
    - Raw wastewater flow would be pumped from the sewer system interceptor to the decentralized nutrient reduction facilities, which would remove the nutrients from the flow. The treated effluent, as well as the solids generated from the treatment process, would then be discharged back into the sewer system interceptor and conveyed to the MWWTP for further treatment and disposal.
    - The nutrient reduction facilities at the Pt. Isabel and Oakport WWF would treat an average annual flow of 3 mgd and 10 mgd, respectively. These flows are based on projected flows to Pump Station N, and the hydraulic capacity of the line draining Oakport WWF back to Pump Station H.
    - Potential future recycled water demand at the Pt. Isabel WWF depends on the time frame:
        - 2020-2030: The potential dry season recycled water demand is status quo, i.e. 1.5 mgd for use at Chevron cooling towers.
        - Beyond 2030: The potential year-round recycled water demand is 3.5 mgd total. This includes the existing 1.5 mgd for use at Chevron cooling towers, as well as an addition 2 mgd for new customers.

5.2.2 Screening Results

The screening results were developed with District staff and presented at a workshop on December 19, 2019. The detailed screening results, presentation materials, and minutes from the workshop are included in Appendix D.

As summarized in Table 5-1, at least one technology passed the screening criteria for each of the six types of alternatives considered. In several cases more than one technology passed, and in those cases the technology most aligned with the evaluation criteria was selected for further evaluation. The most aligned technology was selected to avoid evaluating similar alternatives. Other similar technologies were noted as alternates that could be considered in the future during implementation.

Table 5-1. Summary of Screening Effort Results

Alternative Type	Technology No.	Technology/ Configuration	Technology Status (Maturity)	Result	Basis for Fail or Selected for Further Evaluation
Alternative Type 1: HPOAS + Post-Secondary					
		Post-Secondary Nitrification Process (One to be selected for further evaluation)			
	1	Nitrifying Trickling Filter (NTF)	Established	**Fail**	Will not nitrify as reliably and consistently as other technologies
	2	Biologically Aerated Filter (BAF)	Established	**SELECTED**	• Smallest footprint. • Doesn't preclude from implementing MBBR's in future.
	3	Moving Bed Biofilm Reactor (MBBR)	Established	**ALTERNATE**	• Slightly larger footprint than BAFs. • Less industry experience in U.S. than BAF.
	4	Activated Sludge	Established	**Fail**	Large footprint for clarification and more complex operation
		Post-Secondary Denitrification Process (One to be selected for further evaluation)			
	5	Denitrification Filters	Established	**SELECTED**	Most common technology; provides opportunity to also perform chemical P polishing with filtration.
	2	Biologically Active Filter (BAF)	Established	**ALTERNATE**	Smallest footprint. Can be implemented as an alternate to denitrification filters, but would require filtration downstream to meet Level 3 P removal.

Alternative Type	Technology No.	Technology/ Configuration	Technology Status (Maturity)	Result	Basis for Fail or Selected for Further Evaluation
	3	Moving Bed Biofilm Reactor (MBBR)	Established	**Fail**	Not carrying forward, because not implementing for nitrification, and would still require downstream filtration.
	4	Activated Sludge	Established	**Fail**	Large footprint and complex operation compared to other technologies in this group.
		Post-Secondary Phosphorus Removal Process (One to be selected for further evaluation)			
	6	Chemical Addition in Primary Clarifiers	Established	**ALTERNATE**	Can achieve significant P reduction with chemical addition to primary clarifiers.
	7	Chemical Addition in Secondary Process	Established	**Fail**	Feasible, but not recommended as chemical addition to secondary process may pose operational challenges and not be as efficient as other means of phosphorus removal.
	8	Chemical Addition in Tertiary Clarifiers	Established	**SELECTED**	• Uses the least chemicals. • Easier to control. • Intermediate clarification step will reduce solids loading on denitrification process and improve performance.

Alternative Type	Technology No.	Technology/ Configuration	Technology Status (Maturity)	Result	Basis for Fail or Selected for Further Evaluation
Alternative 2: Activated Sludge Biological Nutrient Removal (AS BNR)					
	9	Conventional AS BNR • Modified Ludzak Ettinger (MLE) • Anaerobic, Anoxic, Oxic (A2O) • 4-Stage Bardenpho (with supplemental carbon) • 5-Stage Bardenpho (with supplemental carbon)	Established	**SELECTED**	• Provides the most flexibility and highest water quality. • All listed technologies are variants of conventional AS BNR, that provide varying levels of N and P removal. 5-Stage Bardenpho provides the highest level of N and P removal, while MLE provides the lowest level of N removal and no P removal. The actual configuration required is dependent on the final N and P discharge criteria.
	10	Step Feed	Established	**Fail**	Would achieve limited P removal. Would not achieve Level 3 N removal without additional treatment processes.
	11	Simultaneous Nitrification/Denitrification	Emerging	**Fail**	• Complex operation, and more difficult to control than other processes. • Could be implemented as part of an operational strategy with any of the alternatives. • Susceptible to poor settleability.

Alternative Type	Technology No.	Technology/ Configuration	Technology Status (Maturity)	Result	Basis for Fail or Selected for Further Evaluation
Alternative 3: Established Intensification Process					
	12	Ballasted Activated Sludge (BAS)	Established	**Fail**	• Limited installations. • Significant mechanical equipment and supply of external ballast for this size of installation, which represent potential points of failure and risk.
	13	Integrated Fixed Film Activated Sludge (IFAS)	Established	**SELECTED**	Not broadly applied across the industry (especially in the West Coast) but several installations in successful use.
	14	Membrane Bioreactor (MBR)	Established	**SELECTED**	• Significant industry experience, smallest footprint, and basis for BACWA evaluation. • Filtration is inherent to process if P-removal is needed. • Well-aligned with Recycled Water Master Plan and future reuse due to use of membranes that will provide Title 22 water quality.

Alternative Type	Technology No.	Technology/ Configuration	Technology Status (Maturity)	Result	Basis for Fail or Selected for Further Evaluation
Alternative 4: Emerging Intensification Technology					
	15	Anaerobic Granular Sludge (AGS)	Emerging	**SELECTED**	Most mature technology of those listed in this category.
	16	Membrane Aerated Biofilm Reactor (MABR)	Emerging	**Fail**	• Insufficient full-scale operating experience. • Two facilities (less than 5 mgd) in operation.
	17	High Rate A-Stage/B-Stage (A/B)	Emerging	**Fail**	• Large footprint for clarification. • Additional operational complexity. • More industry experience than other technologies in this group, but still not common.
	18	Mainstream Deammonification	Emerging	**Fail**	• 4 full scale facilities and 4 pilot scale facilities. • WERF studies indicate technology is “viable” but results are “lacking.”
	19	Nitrate Shunt	Emerging	**Fail**	• Some success at full scale, but less industry experience. • Complex process controls. • Risk of poor settleability.
	20	Anaerobic MBR	Emerging	**Fail**	• Insufficient full-scale operating experience. • Unable to meet Level 3 unless additional processes are added.

Alternative Type	Technology No.	Technology/ Configuration	Technology Status (Maturity)	Result	Basis for Fail or Selected for Further Evaluation
Alternative 5: Top Ranked Technology at MWWTP + Decentralized Treatment					
		Top Ranked MWWTP Technology (To be selected as part of the alternatives evaluation)			
	-				All technologies selected for Alternative Types 1 – 4 are suitable for consideration.
		Decentralized (WWF) Treatment Technology (To be selected as part of the alternatives evaluation)			
	12	Ballasted Activated Sludge (BAS)	Established	**Fail**	• Limited installations. • Significant mechanical equipment and supply of external ballast for this size of installation, which represent potential points of failure and risk.
	13	Integrated Fixed Film Activated Sludge (IFAS)	Established	**ALTERNATE**	IFAS could be cost effective, but would require more site space and more facilities
	14	Membrane Bioreactor (MBR)	Established	**ALTERNATE**	MBR would be more costly, but would generate better quality water that could be used for reuse.

Alternative Type	Technology No.	Technology/ Configuration	Technology Status (Maturity)	Result	Basis for Fail or Selected for Further Evaluation
	15	Aerobic Granular Sludge (AGS)	Emerging	**SELECTED**	• Compact and fewer facilities. • Expected to be more cost-effective than MBR and more resilient for handling wet weather flows, if desired. Does not preclude implementing MBR (e.g. for reuse).
Alternative 6: Split Treatment					
	-	**Top Ranked MWWTP Technologies** (A combination of two technologies to be selected for further evaluation)			All technologies selected for Alternative Types 1 – 4 are suitable for consideration. A combination of two technologies to be selected based on evaluation results. Key factors to be optimized including: site footprint, flexibility, and net present value.

A total of seven alternatives passed the screening process and were carried forward for further evaluation, as summarized in Table 5-2. For Alternative Type 3-Established Intensification Process, it was determined that two technologies should be carried forward, including MBR and IFAS. Both MBR and IFAS passed the screening criteria. IFAS is potentially more cost effective than MBR, but MBR was considered in detail in the 2018 BACWA Nutrient Reduction Study. Therefore, it was determined that that both technologies could be viable long-term solutions and warrant further development and evaluation.

Table 5-2. Summary of Screened Nutrient Reduction Alternatives for Further Development

Long-Term Alternative		Description	Technology/ Configuration
1	**HPOAS**	HPOAS + Post-Secondary	High Purity Oxygen Activated Sludge (HPOAS) + Biologically Aerated and Denite Filters (BAF)
2	**AS BNR**	Activated Sludge Biological Nutrient Removal (AS BNR)	Activated Sludge Biological Nutrient Removal (AS BNR)
3	**MBR**	Established Intensification Technology	Membrane Bioreactors (MBR)
4	**IFAS**	Established Intensification Technology	Integrated Fixed Activated Sludge (IFAS)
5	**AGS**	Emerging Intensification Technology	Aerobic Granular Sludge (AGS)
6	**Decentralized**	Top Ranked Technology at MWWTP + Decentralized Treatment	Top Ranked Technology at MWWTP (TBD) (a) + AGS at Pt. Isabel and Oakport
7	**Split Flow**	Split Treatment	Combination of two technologies at MWWTP (TBD) (a)

a. To be determined based on evaluation results developed for Alternatives 1 – 4.

5.3 Alternatives Development

This section provides a description of the planning assumptions that were used to develop and evaluate the long-term nutrient reduction alternatives, as well as a description of each alternative.

5.3.1 Assumptions

Each of the selected nutrient reduction alternatives were developed for the 2050 planning conditions. After selection of a preferred alternative, project phasing plans will be developed that consider the interim upgrades.

5.3.1.1 Influent Conditions

Flow and loading projections were developed by the District for influent wastewater and trucked waste streams in 2020, 2030, 2040, and 2050. Projections include average dry weather (ADW), the peak 30-day (or maximum month), the peak 10-day, the peak 7-day (or maximum week), the peak 3-day, the peak day, and the peak hour wet weather flow (PHWWF). These projections are available in Appendix E and summarized in Table 5-3 for the 2050 condition.

There are several driving factors for developing the sizing of each nutrient reduction alternative. Potential future limits are anticipated to be based on a yearly averaging period, so the facility must be able to meet annual average effluent targets. Sizing for the treatment processes was based on the peak 30-day conditions, or maximum month (MM) to ensure that every month can meet reduction targets. Although there will be periods where the daily load would exceed the MM (such as the maximum week, peak 3-day, or peak day), these are shorter term events and it would only affect performance if it coincided with other limiting conditions such as the peak wet weather flow, minimum temperature, or poor settleability. It is unlikely that all of these limiting conditions will coincide; therefore, it is sufficiently conservative to size the alternatives for MM conditions, which should provide robust treatment year-round. ADW conditions were used to estimate operating costs for the economic analysis of the alternatives. Table 5-3 below summarizes the ADW and MM influent flow, load, and HSW projections for 2050 used for alternative sizing as well as the assumed wastewater temperature. The assumed temperature was developed as part of the capacity assessment and is used for establishing the minimum SRT needed to achieve the necessary level of treatment.

Table 5-3. Influent Conditions

Parameter	Units	2050 ADW Projection	2050 MM Projection
Raw Influent plus Low-Strength Waste			
Flow	mgd	66	146
TSS Loading	lb/d	278,400	406,000
COD Loading	lb/d	574,700	701,400
cBOD Loading	lb/d	246,000	300,300
TKN Loading	lb/d	38,100	45,800
Ammonia Loading	lb/d	23,800	26,100
Nitrate Loading	lb/d	1,500	6,300
Nitrite Loading	lb/d	700	1,200
ortho-Phosphate Loading	lb/d	3,200	3,800
Total Phosphorus Loading	lb/d	6,200	7,800
Temperature	Deg C	21.3	16.6
High Strength Waste			
Flow	gpd	244,600	293,400
TS Loading	lb/d	153,600	184,300
VS Loading	lb/d	127,300	152,700
(Filtered) COD Loading	lb/d	200,700	240,800
Total Nitrogen Loading	lb/d	7,300	8,700

5.3.1.2 Level of Treatment

The nutrient removal target assumed for the development and evaluation of the alternatives is the Level 2 Off-Ramp described in Table 3-2. The Level 2 Off-Ramp was used instead of the Master Plan Target for the following reasons:

- The Master Plan Target would likely not require significant mainstream improvements and can be met with sidestream treatment or other means that are more cost-effective.
- The Level 2 Off-Ramp will require mainstream improvements, and could occur at the end of the planning period. Since the scope of this evaluation are the main stream nutrient reduction alternatives, the Level 2 Off-Ramp reflects a reasonable and conservative long-term planning target.

5.3.1.3 Siting

As shown in Figure 5-1, the assumed location for the future nutrient reduction facilities is the area occupied by the existing secondary treatment facilities as well as the area south of the existing HPOAS bioreactors. This location will be refined as the Master Plan and roadmap is developed.

Figure 5-1. Siting Location for New Nutrient Removal Facilities

This location was chosen because it was assumed that that the existing secondary treatment facilities would be modified and repurposed to provide nutrient reduction. From the perspective of hydraulic design and O&M, it is generally preferred to have all secondary facilities in a common location. Furthermore, there is significant open space south of the existing secondary treatment facilities, with the exception of the existing Maintenance Building facilities. These facilities could more easily be relocated than other existing facilities (e.g., treatment process tankage, digesters, etc.).

The site layouts were developed to assess how well each alternative fits within the plant boundaries. The site layouts depict how facilities required to meet the Level 2 Off-Ramp could be oriented with respect to the existing facilities. To show the long-term potential site space that may be required for nutrient removal, the site layout also outlines additional space needed for facilities that would be required to meet the Level 3 Off-Ramp.

5.4 Alternatives

Table 5-4 summarizes the major elements and key planning level sizing criteria that was developed for each of the alternatives. Appendix F contains detailed planning level sizing criteria. Each alternative is described in further detail in the sections below.

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Table 5-4. Planning Level Sizing Criteria for the Nutrient Reduction Alternatives

Parameter	Units	Alt. 1: HPOAS	Alt. 2: AS BNR	Alt. 3: MBR	Alt. 4: IFAS	Alt. 5: AGS	Alt. 6: De-centralized			Alt. 7: Split Flow	
							AGS at Oakport	AGS at Pt. Isabel	IFAS at MWWTP	40 percent AS BNR	60 percent AGS
Influent Flow and WW Characteristics (Includes Low Strength Waste)											
Average Dry Weather Flow	mgd	66	66	66	66	66	6.0	3.0	66	66	66
Maximum Month Flow	mgd	146	146	146	146	146	12.7	6.3	146	146	146
Primary Effluent Screening											
Type	-	N/A	N/A	2 mm spacing	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Number of Duty Screens	Number	0	0	4	0	0	0	0	0	0	0
Number of Standby Screens	Number	0	0	1	0	0	0	0	0	0	0
Primary Effluent Pumping											
Number of Duty Pumps	Number	0	0	3	0	0	0	0	0	0	0
Number of Standby Pumps	Number	0	0	1	0	0	0	0	0	0	0
Capacity per Pump	mgd	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Firm Capacity	mgd	N/A	N/A	168	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Primary Effluent (Secondary Influent)											
Average Dry Weather Flow	mgd	78	68	68	70	68	N/A	N/A	70	27	41
Maximum Month Flow	mgd	168	148	148	149	148	N/A	N/A	149	59	89
Bioreactors											
Number of Tanks	Number	8	12	5	10	24	4	4	9	4	14
Volume per Tank	MG	1.6	4.75	5.59	4.75	2.38	1.30	0.65	4.75	4.75	2.36
Total Volume	MG	12.7	57	28	48	57	5.2	2.6	42.7	19	33
Average Dry Weather											
Suspended MLSS	mg/L	2,334	2,086	4,524	1,399	1,317	1,076	1,076	1,399	2,503	1,354
MLSS Membrane	mg/L	N/A	N/A	5,648	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Aerobic SRT	days	1.1	5.5	5.5	5.5	N/A	N/A	N/A	5.5	5.5	N/A
Total SRT	days	1.5	8.3	8.79	6.9	32	10 to 12	10 to 12	6.9	8.3	32
Maximum Month											
Suspended MLSS	mg/L	3,085	2,919	6,345	2,624	2,470	2,018	2,018	2,624	3,503	2,540
MLSS Membrane	mg/L	N/A	N/A	8,022	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Parameter	Units	Alt. 1: HPOAS	Alt. 2: AS BNR	Alt. 3: MBR	Alt. 4: IFAS	Alt. 5: AGS	Alt. 6: De-centralized			Alt. 7: Split Flow	
							AGS at Oakport	AGS at Pt. Isabel	IFAS at MWWTP	40 percent AS BNR	60 percent AGS
Bioreactor Aeration											
Typical DO in Aerobic Zones	mg/L	6 to 8	2	2	3	0.5 to 2.0	0.5 to 2.0	0.5 to 2.0	3	2	0.5 to 2.0
Average Dry Weather											
OTR	lb/d	122,245	259,132	258,149	244,411	425,804	26,887	13,443	222,529	103,653	255,482
Air Flow	scfm	N/A	56,321	109,334	85,469	97,402	9,400	4,700	77,817	22,528	74,167
Maximum Month											
OTR	lb/d	123,120	309,336	306,305	298,687	550,851	34,800	17,400	271,946	123,735	330,511
Air Flow	scfm	N/A	68,887	157,124	98,753	127,939	11,500	5,750	89,912	27,555	90,833
Diffusers											
Number	Number	0	34,533	48,370	54,394	69,308	6,000	3,000	49,524	13,813	41,585
Type		High Purity Oxygen Activated Sludge (HPOAS)	Fine Bubble	Fine Bubble (Coarse in Membrane Tanks)	Medium Bubble	Fine Bubble	Fine Bubble	Fine Bubble	Medium Bubble	Fine Bubble	Fine Bubble
Bioreactor MLR Pumping											
Average Dry Weather MLR Flow	mgd	0	99	330	99	0	0	0	99	40	0
Maximum Month MLR Flow	mgd	0	219	696	219	0	0	0	219	88	0
Solids Separation											
Type	-	Secondary Clarifiers	Secondary Clarifiers	Membrane Filtration	Secondary Clarifiers	Settling in AGS Reactors	Settling in AGS Reactors	Settling in AGS Reactors	Secondary Clarifiers	Secondary Clarifiers	Settling in AGS Reactors
Secondary Clarification											
Number of Clarifiers	Number	12	12	0	12	0	0	0	12	11	0
Surface Area, each	sf	15,394	15,394	N/A	15,394	N/A	N/A	N/A	15,394	15,394	N/A
Settling in AGS Reactors											
Effective Surface Overflow Rate at ADWF	gpd/sf	N/A	N/A	N/A	N/A	877	758	758	N/A	N/A	877
Effective Surface Overflow Rate at MMF	gpd/sf	N/A	N/A	N/A	N/A	1,900	1,600	1,600	862	955	1,900
Membrane Filtration											
Number of Tanks	Number	0	0	32	0	0	0	0	0	0	0
Tank Volume, each	MG	N/A	N/A	0.07	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Tank Volume	MG	N/A	N/A	2.13	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Parameter	Units	Alt. 1: HPOAS	Alt. 2: AS BNR	Alt. 3: MBR	Alt. 4: IFAS	Alt. 5: AGS	Alt. 6: De-centralized			Alt. 7: Split Flow	
							AGS at Oakport	AGS at Pt. Isabel	IFAS at MWWTP	40 percent AS BNR	60 percent AGS
Membrane Area per Tank	million sf	N/A	N/A	0.331	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Membrane Area	million sf	N/A	N/A	10.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Net Flux at ADWF	gfd	N/A	N/A	8.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Net Flux at MMF	gfd	N/A	N/A	16.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
RAS Pumping											
Average Dry Weather RAS Flow	mgd	31	31	262	29	0	0	0	29	12	0
Maximum Month RAS Flow	mgd	70	71	548	70	0	0	0	70	28	0
Waste Activated Sludge (WAS)											
Average Dry Weather											
Flow	mgd	2.50	2.24	2.15	3.76	0.86	0.45	0.22	3.76	0.9	0.5
TSS	mg/L	7,529	6,227	6,630	4,159	9,969	5,308	5,308	4,189	6,231	5,763
VSS	mg/L	6,377	5,111	5,438	3,449	7,712	4,170	4,170	3,475	5,114	4,458
Maximum Month											
Flow	mgd	2.45	2.17	2.13	2.58	0.83	0.43	0.22	2.58	0.9	0.5
TSS	mg/L	10,024	8,728	9,417	7,838	13,975	7,440	7,440	7,895	8,430	7,797
VSS	mg/L	7,977	6,554	7,056	5,954	9,890	5,348	5,348	5,997	6,330	5,518
Post Secondary Nitrification											
Feed Pumping											
Number of Duty Pumps	Number	3	0	0	0	0	0	0	0	0	0
Number of Standby Pumps	Number	1	0	0	0	0	0	0	0	0	0
Capacity per Pump	mgd	55.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Firm Capacity	mgd	165.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Type		Biologically Aerated Filter (BAF)	None	None	None	None	None	None	None	None	None
Duty Units	Number	20	0	0	0	0	0	0	0	0	0
Standby Units	Number	2	0	0	0	0	0	0	0	0	0
Surface Area, each	sf	2,582	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Capacity Surface Area	sf	56,804	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Dry Weather											
Flow	mgd	75	0	0	0	0	0	0	0	0	0
Maximum Month											
Flow	mgd	166	0	0	0	0	0	0	0	0	0

Parameter	Units	Alt. 1: HPOAS	Alt. 2: AS BNR	Alt. 3: MBR	Alt. 4: IFAS	Alt. 5: AGS	Alt. 6: De-centralized			Alt. 7: Split Flow	
							AGS at Oakport	AGS at Pt. Isabel	IFAS at MWWTP	40 percent AS BNR	60 percent AGS
Post Secondary Denitrification											
Feed Pumping											
Number of Duty Pumps	Number	3	0	0	0	0	0	0	0	0	0
Number of Standby Pumps	Number	1	0	0	0	0	0	0	0	0	0
Capacity per Pump	mgd	55.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Firm Capacity	mgd	165.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Type		Denitrification Filters	None	None	None	None	None	None	None	None	None
Number of Duty Units	Number	17	0	0	0	0	0	0	0	0	0
Number of Standby Units	Number	1	0	0	0	0	0	0	0	0	0
Surface Area, each	sf	2,565	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Capacity Surface Area	sf	46,170	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Process Chemical Usage											
Methanol (100 percent Solution)	gpd	9,800	3,000	3,000	3,000	0	0	0	2,700	1,200	0
Alkalinity (45 percent NaOH Solution)	gpd	2,500	0	0	0	0	0	0	0	0	0

5.4.1 Alternative 1: HPOAS

5.4.1.1 Description

The HPOAS alternative is comprised of the existing HPOAS treatment process followed by biologically aerated filters (BAFs) and denitrification filters. Figure 5-2 provides a process flow schematic of this alternative. The existing HPOAS facilities and secondary clarifiers would be operated as they currently are to remove BOD and TSS.

The BAFs and denitrification filters would be operated to remove TIN. The BAFs would be operated to provide nitrification – converting the ammonia present in the wastewater to nitrate and nitrite. The denitrification filters would be operated to provide denitrification – converting the nitrate and nitrite to elemental nitrogen gas which then off-gases or diffuses into the atmosphere and is removed from the wastewater.

The BAF is a submerged media aerated filter. The media are typically plastic or polystyrene ranging in size from 3-5 mm, and provide a surface for nitrifying biofilm to grow. The media bed depth is 10-12 feet. Wastewater passes through the media in either an upflow or downflow configuration, and air is introduced at the bottom to create aerobic conditions, which is necessary for nitrification. Throughout a typical day, the media is backwashed to remove excess solids. Since nitrification consumes alkalinity, a chemical storage and feed system is needed to ensure reliable nitrification.

BAFs can also be operated without aeration to promote denitrification; however, it was decided to perform denitrification in a denitrification filter so that filtration would already be installed in the event that more stringent water quality or phosphorus limits were ever required. A denitrification filter is similar to a conventional sand filter, and also requires frequent backwashes to clean the media and maintain a healthy biomass. Media size is 2-3 mm and depth is 6-8 feet. The media in a denitrification filter grows biomass that converts nitrate to nitrogen gas. A carbon source is needed for this process, and it was assumed that methanol would be used, as it is most common for this type of application. Other sources of carbon are available and could be used instead.

Dedicated pump stations are anticipated to be required for both the BAF and denitrification filters to pump the full secondary process flow through the filters.

5.4.1.2 Site Layout

The site layout for this alternative is shown in Figure 5-3. This site layout meets the Level 2 and the Level 3 Off-Ramp. This layout would require demolition and relocation of the following existing facilities:

- Maintenance Building and Maintenance Warehouse.
- Fueling Station.

5.4.1.3 Key Assumptions

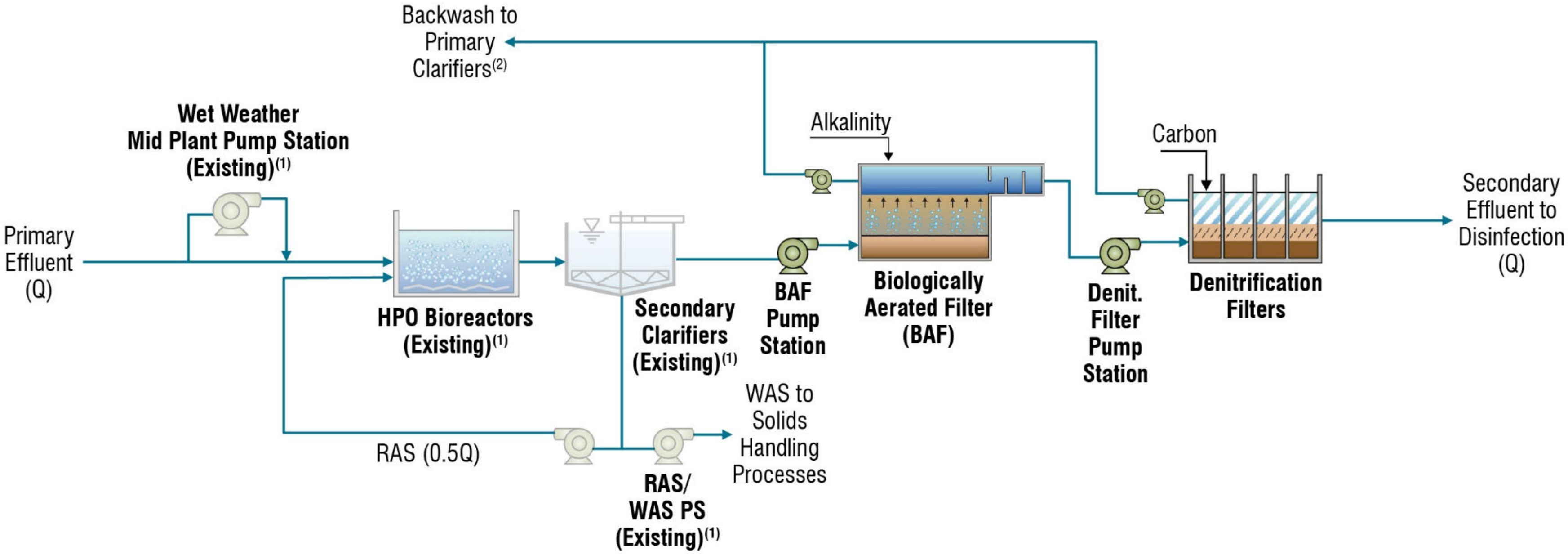
5.4.1.3.1 Rehabilitation of Existing Facilities

With this alternative, the existing secondary treatment facilities would be rehabilitated as needed to extend their useful life through the planning period. These facilities include:

- HPOAS Reactors
- High purity oxygen facilities including the cryogenic oxygen generating plant and liquid oxygen storage system
- Secondary Clarifiers
    - RAS and WAS Pump Stations
    - The RAS pump stations would be upgraded to address capacity needs related to increasing influent flow and load due to growth.

5.4.1.3.2 Upgrades to Meet Level 3 Off-Ramp

To upgrade this alternative to meet the Level 3 Off-Ramp, 25 to 50 percent more supplemental carbon would need to be applied at the denitrification filters to increase the level of denitrification achieved. If phosphorus limits are in place, chemical addition (such as ferric or alum) will be needed at the denitrification filters. If more than a few milligrams per liter of phosphorus removal is required, tertiary clarifiers may be needed between the BAF and denitrification filters so that the filters are not overloaded with respect to solids.



NOTES:

1. Existing facilities to be rehabilitated, and expanded as needed.
2. Alternatively, backwash can be thickened and fed directly to the anaerobic digesters.
3. Q = Flow

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Figure 5-2. Alternative 1 HPOAS – Process Flow Schematic

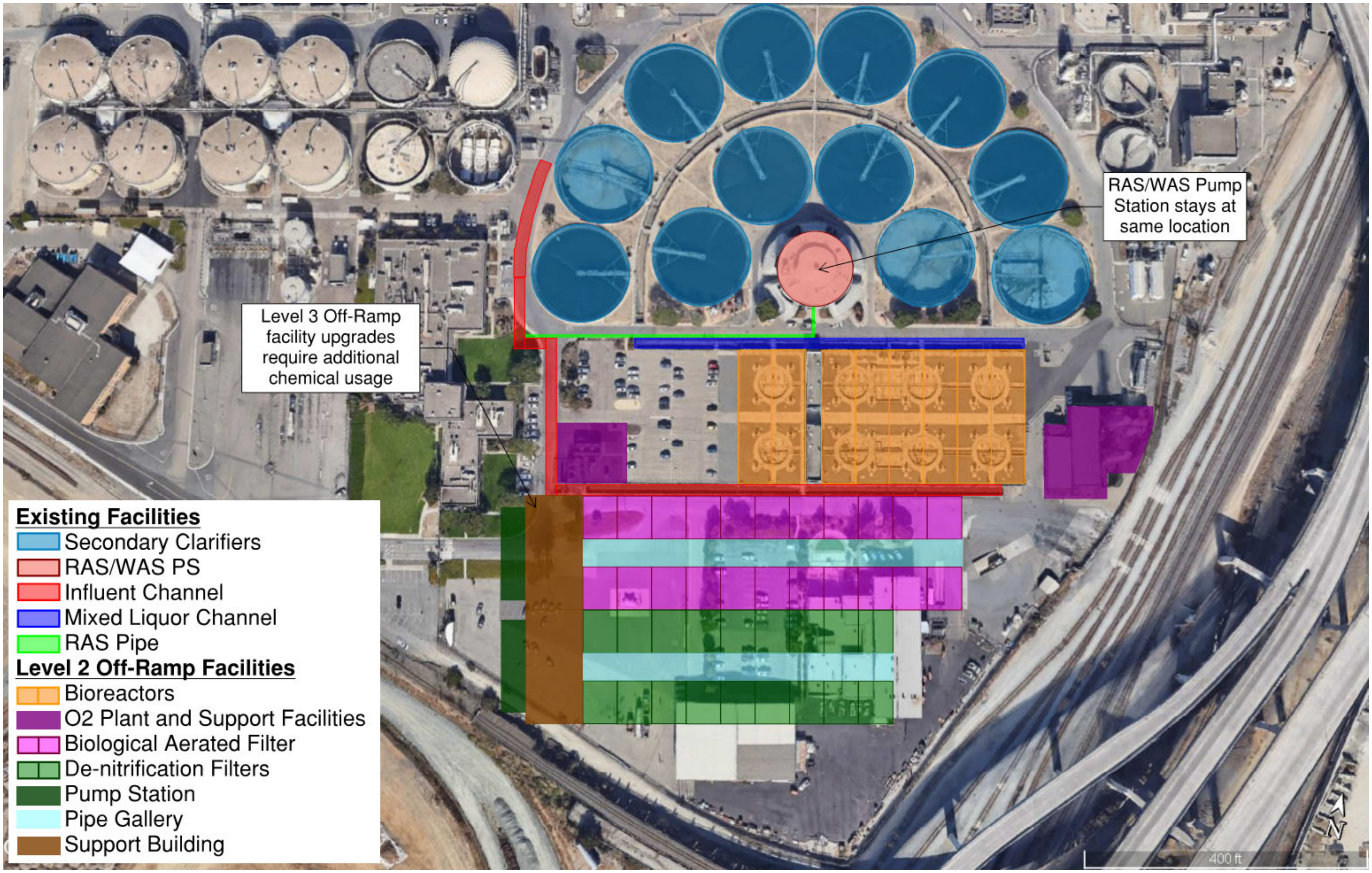


Figure 5-3. Alternative 1 HPOAS – Conceptual Site Layout

5.4.2 Alternative 2: AS BNR

5.4.2.1 Description

The AS BNR alternative is comprised of bioreactors followed by secondary clarifiers. Figure 5-4 provides a process flow schematic of this alternative. The configuration of the bioreactors will largely depend on the level of nutrient reduction required. Since the Level 2 Off-Ramp TIN limit is 15 mg/L with no phosphorus limit, the bioreactors would have a Modified Ludzak-Ettinger (MLE) configuration, which is a common process configuration implemented across the industry for nutrient reduction. With an MLE configuration, the bioreactors are divided into separate anoxic and aerobic zones. Nitrification occurs in the aerobic zone and denitrification occurs in the anoxic zone. Mixed liquor recirculation pumps bring nitrate from the aerobic zone back to the anoxic zone where denitrification occurs. Since primary effluent is also introduced in the anoxic zone, most of the carbon demand for denitrification can be satisfied with the wastewater. However, some supplemental carbon would still be needed, especially during dry weather periods when influent ammonia concentrations are higher than the rest of the year.

The existing HPOAS bioreactors would be utilized and reconfigured, and additional bioreactors would be constructed to provide additional SRT. It was assumed that that the bioreactors would be three-pass bioreactors. The bioreactors would be supplied with air from a new aeration system, which would replace the existing high purity oxygen generation and storage facilities. The new aeration system would be comprised of blowers, which would supply pressurized air to fine bubble diffusers located at the bottom of the bioreactors.

The existing secondary clarifiers would be utilized and would be operated very similarly to how they are operated now. The key difference is that the solids loading rate to the secondary clarifiers would be higher given that the bioreactors would be operated at a higher MLSS concentration. To accommodate the higher volume of sludge, the existing RAS pumps would need to be replaced with higher capacity pumps. Since there is no historical settleability information for this process at the MWWTP, a typical worst case settleability of 150 mL/g was assumed, which is typical for an MLE process. Based on this condition and a PHWWF of 168 mgd, the maximum allowable MLSS during wet weather is approximately 2,750 mg/L based on CFD modeling performed by Hazen and Sawyer (EBMUD Secondary Clarifier Master Plan, Secondary Clarifiers Scenarios, 2020). As part of the CFD modeling, it was assumed that the RAS capacity would be upgraded as well as the clarifier internals and baffling. The bioreactor sizing for this alternative is based on maintaining a minimum aerobic SRT of 5.5 days at 2,750 mg/L during maximum month load conditions. A 5.5 day aerobic SRT was selected based on the minimum month temperature of 16.6 ℃. A 5.5 day aerobic SRT results in a total SRT of approximately 8 days.

5.4.2.2 Site Layout

The site layout for this alternative is shown in Figure 5-5. This site layout meets the Level 2 Off-Ramp and the Level 3 Off-Ramp. This layout would require demolition and relocation of the following existing facilities:

- Administration Building
- Maintenance Building and Maintenance Warehouse.
- Fueling Station
- High purity oxygen generation and storage facilities

5.4.2.3 Key Assumptions

5.4.2.3.1 Rehabilitation of Existing Facilities

With this alternative the following existing secondary treatment facilities would be rehabilitated as-needed to extend their useful life through the planning period:

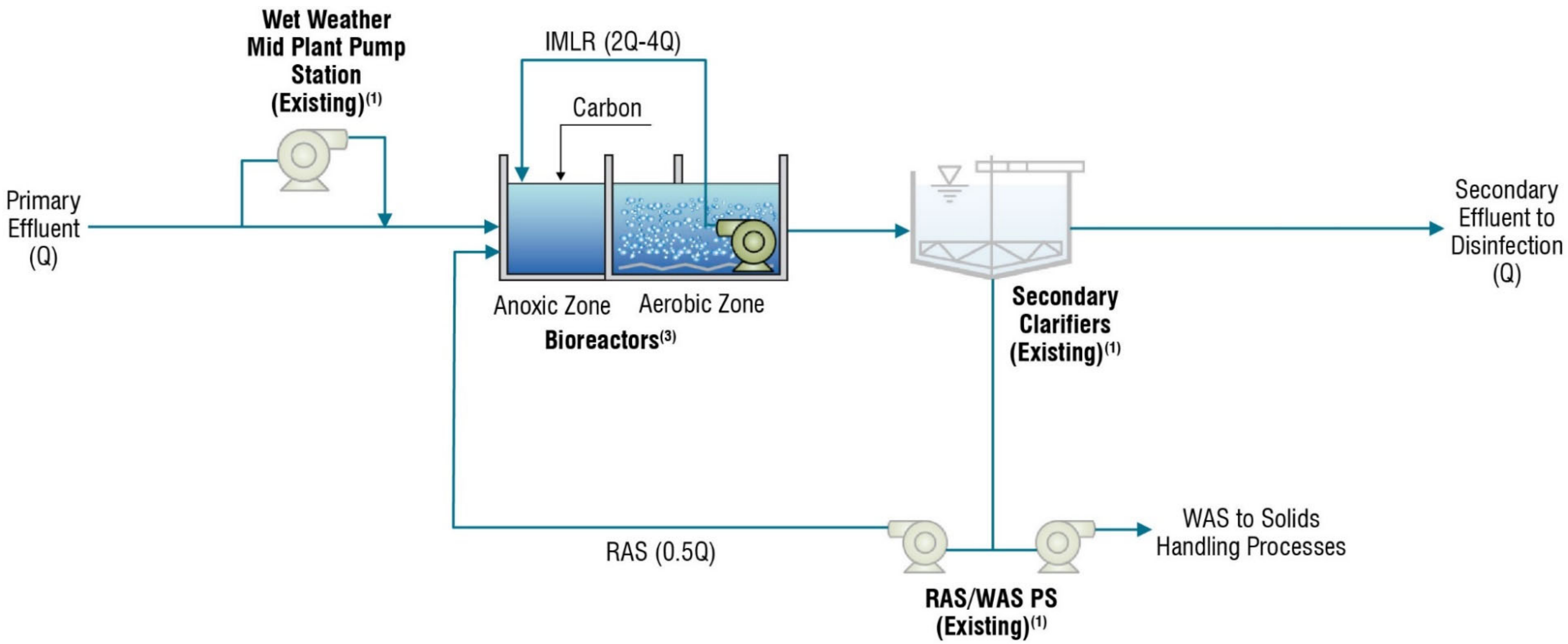
- HPOAS Reactors (retrofitted for MLE)
- Secondary Clarifiers
- RAS and WAS Pump Stations
    - The RAS pump station would be upgraded to increase the RAS pumping capacity to accommodate the higher solids loading in the secondary clarifiers.

5.4.2.3.2 Upgrades to Meet Level 3 Off-Ramp

To upgrade this alternative to meet the Level 3 Off-Ramp, the following improvements would be needed:

- Modify the MLE process to a 5-Stage Bardenpho. This would require re-partitioning the bioreactor zones to include an anaerobic zone to facilitate biological phosphorus removal, and a post-anoxic zone with more supplemental carbon to increase the level of denitrification achieved. A small post-aerobic zone will also be needed as a polishing step prior to clarification. The 5-Stage Bardenpho will be able to achieve effluent TIN levels less than 3 mg/L and a TP of 1 mg/L.
- The overall SRT would need to be increased from 8 to approximately 10-12 days, and more supplemental carbon would be needed. The additional carbon and biological phosphorus removal will increase the sludge production. All of these items will increase the bioreactor volume needed. However, it is anticipated that only one additional aeration basin will be needed because biological phosphorus removal is expected to improve the mixed liquor settleability from 150 mL/g to 125 mL/g. This means the allowable MLSS in the bioreactors could be increased from 2,750 to 3,750 mg/L based on CFD modeling performed by Hazen and Sawyer (EBMUD Secondary Clarifier Master Plan, Secondary Clarifiers Scenarios, 2020).

- If a total phosphorus limit of < 1 mg/L is required, effluent filters will be needed. The filters will need some chemical addition with alum or ferric to remove the small amount of phosphorus remaining in the effluent.



NOTES:

1. Existing facilities to be rehabilitated, and expanded as needed.
2. Phosphorus polishing. Only required for maximum month flow to meet anticipated limits.
3. Existing bioreactors to be rehabilitated and expanded as needed.
4. Q = Flow

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Figure 5-4. Alternative 2 AS BNR – Process Flow Schematic

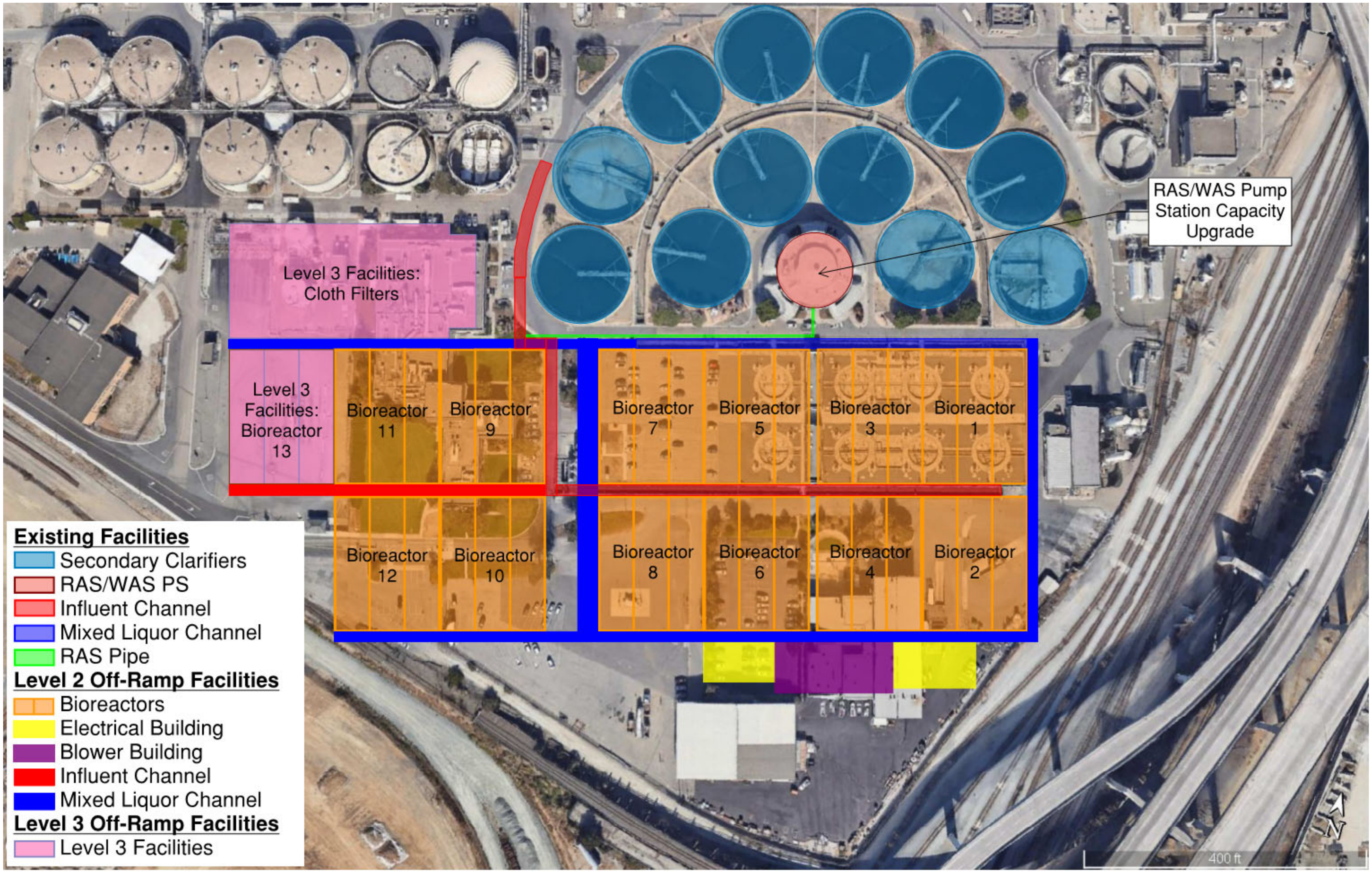


Figure 5-5. Alternative 2 AS BNR – Conceptual Site Layout

5.4.3 Alternative 3: MBR

5.4.3.1 Description

The MBR alternative is comprised of bioreactors followed by membrane filters. Figure 5-6 provides a process flow schematic of this alternative. This alternative is similar to the AS BNR in that it is an MLE configuration with internal mixed liquor recirculation, except solids separation is achieved with membrane filters instead of secondary clarifiers. The same amount of biological inventory (i.e. biomass in the bioreactors) is needed in this alternative as the AS BNR alternative. However, since the membrane filters don't rely on solids settling properties (which are hindered at higher concentrations), the bioreactors can be operated at much higher MLSS concentrations than in activated sludge. This alternative is sized based on maintaining an MLSS concentration less than 10,000 mg/L in the membrane tanks, although some manufacturers are capable of operating with concentrations almost twice that. Given this, the bioreactors can be operated at a higher MLSS concentration and significantly less bioreactor volume is required. As such, it is considered an intensification process.

Similar to Alternative 2, the existing bioreactors would be utilized and reconfigured, and additional bioreactors would be implemented. It was assumed that that the bioreactors would be three-pass bioreactors. The bioreactors would be supplied with air from a new aeration system, which would replace the existing high purity oxygen generation and storage facilities. The new aeration system would be comprised of blowers, which would supply pressurized air to fine bubble diffusers located at the bottom of the bioreactors.

From the bioreactors, the mixed liquor would flow to the MBR tanks containing the membrane filters. Permeate pumps would pump the mixed liquor through microfilter or ultrafilter membranes. With porous openings ranging from 0.01 – 0.4 µm in diameter, the filters would physically separate the solids from the liquid to remove BOD, TSS, and nitrogen present in the biomass in the wastewater.

As shown in Figure 5-7, the membrane filters require the following ancillary facilities:

- **Primary Effluent Fine Screens.** The fine screens would be located upstream of the bioreactors and would filter out debris and solids that could damage the membrane filters.
- **Primary Effluent Pump Station.** The primary effluent pump station would pump primary effluent either upstream of downstream of the fine screens to make up for headloss that occurs across the fine screens.
- **Permeate Pumps.** The permeate pumps would pump flow through the membrane filters.
- **Backpulse and Clean-in-Place Pumps.** These pumps would pump flow backwards through the membrane filters and/or pump chemicals through the filters to clear solids that accumulate on the surface of the filter over time. This cleaning increases the overall throughput of the filters and optimizes the amount of pumping required by the permeate pumps.

- **Clean-in-Place Chemical Storage and Feed Facilities.** These facilities store and supply the chemicals needed to routinely clean the membrane filters. The chemicals used include sodium hypochlorite and citric acid.
- **Air Scour Blowers.** In addition to backpulsing the membrane filters and cleaning them in place with chemicals, air scour blowers regularly supply air to the surface of the filters to scour solids that have accumulated on the filter surface. MBR suppliers have historically used coarse bubble diffusers mounted beneath the membranes to achieve this, but other more efficient configurations are now available.

Since the membrane filters would replace the function of the secondary clarifiers, the secondary clarifiers would no longer be used for secondary treatment.

Since the bioreactors would be operated at a higher mixed liquor concentration, the RAS flow for this alternative would be significantly higher than the existing HPOAS process or the AS BNR alternative. Accordingly, it was assumed that that new RAS and WAS pump stations would be required, and that they would be collocated for more efficient hydraulics and O&M.

The new RAS and WAS pump station would be constructed adjacent to the bioreactors and membrane filters. The RAS pump station would pump mixed liquor flow from the membrane filter tanks to the bioreactors to replenish the biomass available in the bioreactors to provide treatment. Like Alternatives 1 and 2, the new WAS pump station would be used to waste a portion of the RAS flow from the secondary process to control the SRT. The new WAS pump station would pump WAS from the secondary process to the solids handling facilities for treatment and disposal.

5.4.3.2 Site Layout

The site layout for this alternative is shown in Figure 5-7. This site layout meets the Level 2 and the Level 3 Off-Ramp. This layout would require demolition and relocation of the following existing facilities:

- Maintenance Building and Maintenance Warehouse.
- Fueling Station
- High purity oxygen generation and storage facilities

Since the secondary clarifiers would no longer be needed for secondary treatment, they could potentially be used for other purposes or demolished to create space for new facilities. For the purpose of this analysis, it was assumed that that they would be abandoned in place. Note that the economic evaluation does not include costs to decommission the secondary clarifiers.

5.4.3.3 Key Assumptions

5.4.3.3.1 Rehabilitation of Existing Facilities

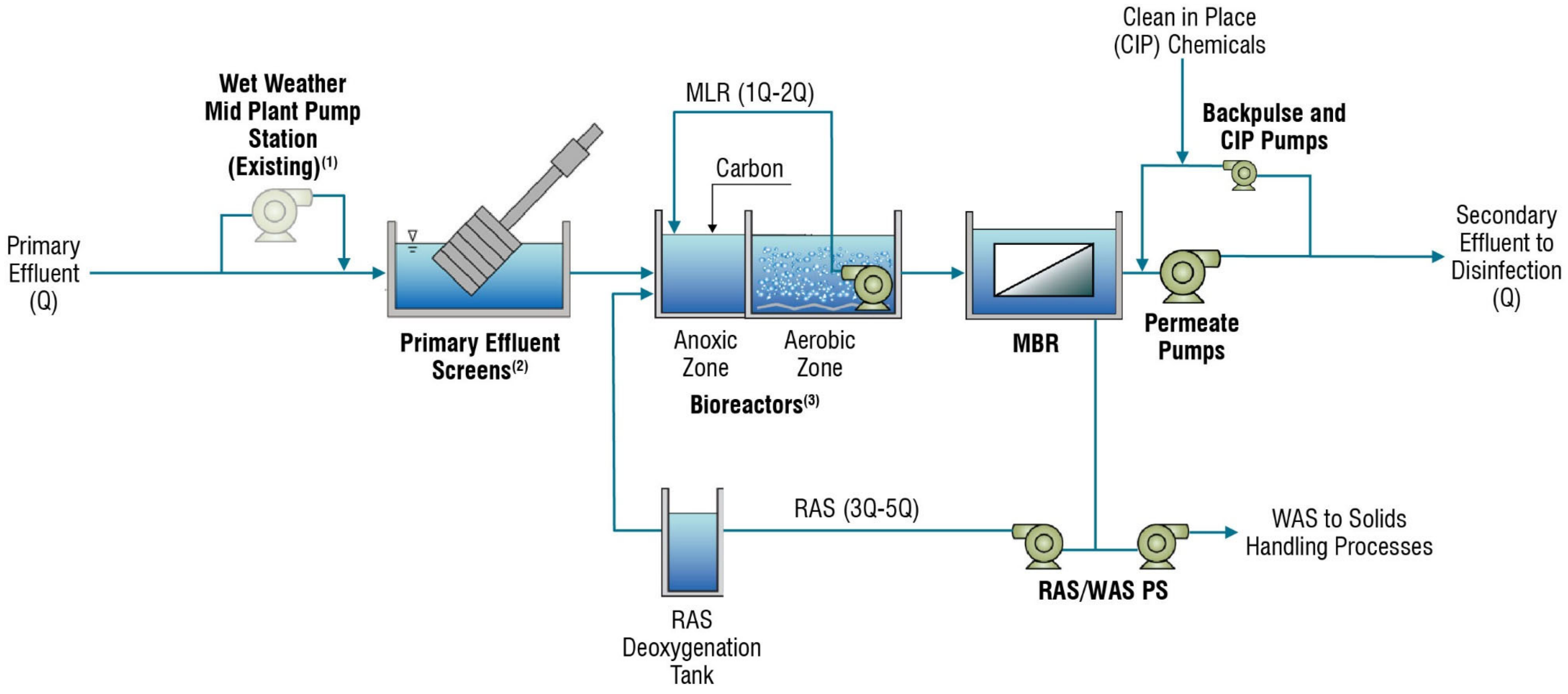
With this alternative the following existing secondary treatment facilities would be rehabilitated as-needed to extend their useful life through the planning period:

- HPOAS Reactors

5.4.3.3.2 Upgrades to Meet Level 3 Off-Ramp

To upgrade this alternative to meet the Level 3 Off-Ramp, the following improvements would be needed:

- As described in Alternative 2, modify the process configuration to a 5-Stage Bardenpho. This would require re-partitioning the bioreactor zones to include an anaerobic zone to facilitate biological phosphorus removal, and a post-anoxic zone with more supplemental carbon to increase the level of denitrification achieved. A small post-aerobic zone will also be needed as a polishing step prior to clarification. The 5-Stage Bardenpho will be able to achieve effluent TIN levels less than 3 mg/L and a TP of 1 mg/L.
- As described in Alternative 2, the overall SRT would need to be increased from 8 to approximately 10-12 days, and more supplemental carbon would be needed. The additional carbon and biological phosphorus removal would increase the sludge production. All of these items would increase the bioreactor volume needed and one additional aeration basin would need to be added.
- If a total phosphorus limit of < 1 mg/L is required, some chemical addition (alum or ferric) upstream of the filters would be needed to remove the small amount of phosphorus remaining in the effluent.



NOTES:
1. Existing facilities to be rehabilitated and expanded as needed.
2. 2mm perforated plate screens.
3. Existing bioreactors to be rehabilitated and expanded as needed.
4. Q = Flow

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Figure 5-6. Alternative 3 MBR – Process Flow Schematic

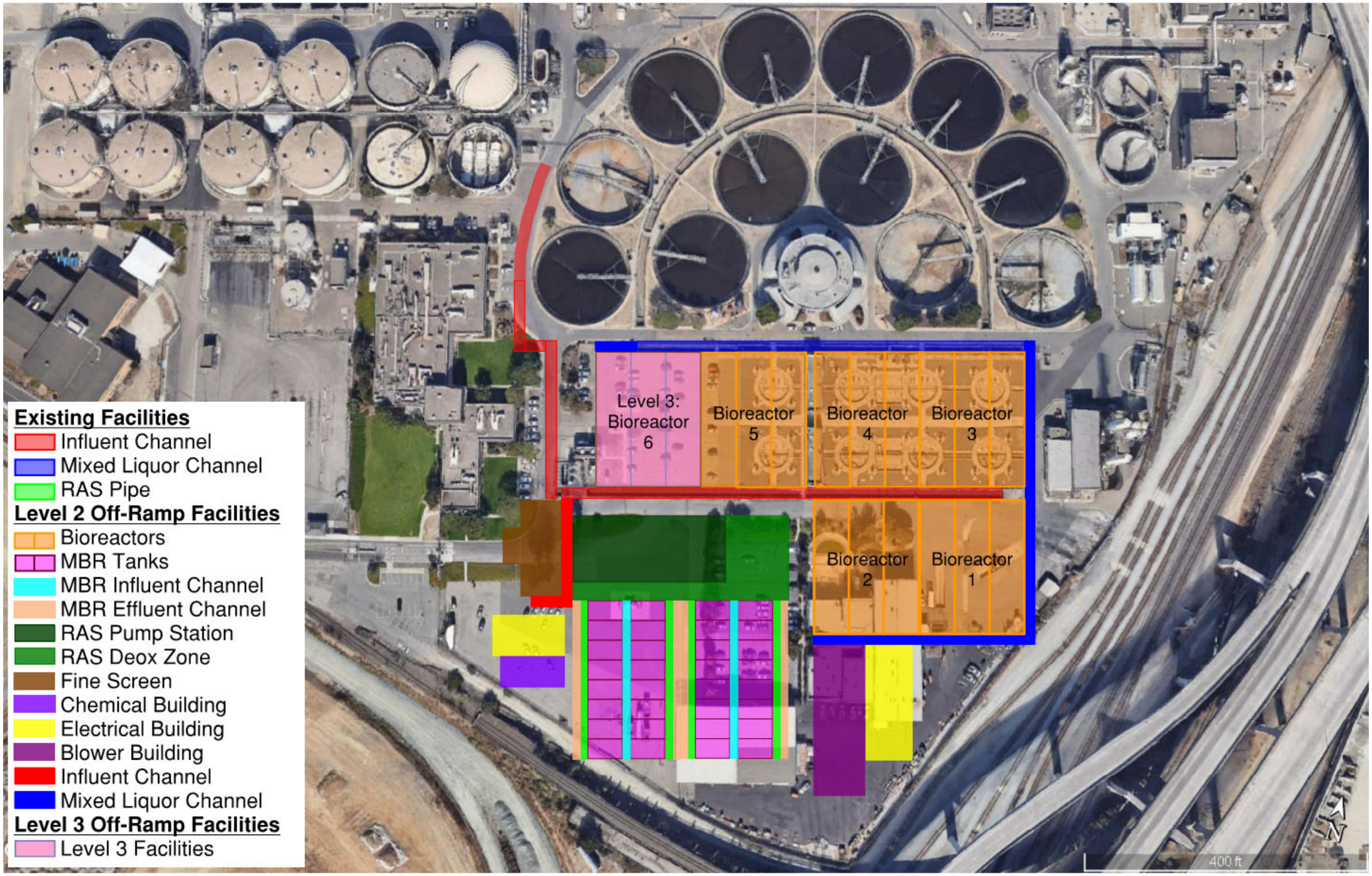


Figure 5-7. Alternative 3 MBR – Conceptual Site Layout

5.4.4 Alternative 4: IFAS

5.4.4.1 Description

The integrated fixed film activated sludge (IFAS) alternative is similar to the AS BNR alternative in that it contains a suspended growth MLE activated sludge process followed by secondary clarifiers. The same amount of biological inventory (i.e. biomass in the bioreactor) is needed for IFAS as is for AS BNR. The main difference, however, is that the IFAS process also includes media in the bioreactor that facilitates fixed (or attached) growth biomass. The media can be fixed or floating, but the most common in use today is floating media. Retention screens keep the floating media in the bioreactor while mixed liquor passes to the secondary clarifiers for solids separation. Figure 5-8 provides a process flow schematic of this alternative.

Since a portion of the required biological inventory can be provided with the attached growth biomass, less suspended growth biomass and bioreactor volume is needed than in a conventional AS BNR process. For this reason, the IFAS process is considered an intensification process.

5.4.4.2 Site Layout

The site layout for this alternative is shown in Figure 5-9. This site layout meets the Level 2 and the Level 3 Off-Ramp. This layout would require demolition and relocation of the following existing facilities:

- Administration Building (Approximately 25 percent of the existing building would need to be demolished and relocated.)
- Maintenance Building and Maintenance Warehouse.
- Fueling Station
- High purity oxygen generation and storage facilities

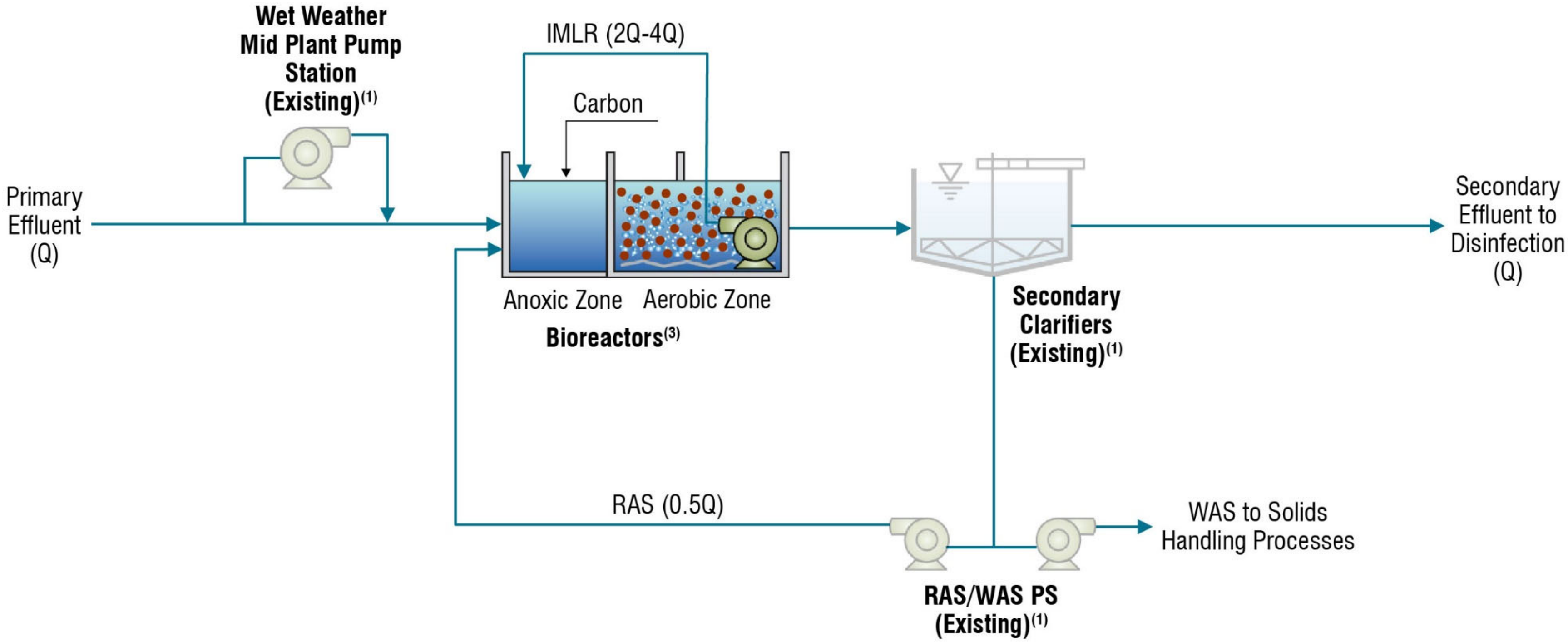
5.4.4.2.1 Rehabilitation of Existing Facilities

With this alternative the following existing secondary treatment facilities would be rehabilitated as-needed to extend their useful life through the planning period:

- HPOAS Reactors
- Secondary Clarifiers
- RAS and WAS Pump Stations
    - The RAS pump station would be upgraded to increase the RAS pumping capacity to accommodate the higher rate of sludge production in the secondary clarifiers.

5.4.4.2.2 Upgrades to Meet Level 3 Off-Ramp

To upgrade this alternative to meet the Level 3 Off-Ramp, the same improvements as what was described for the AS BNR alternative are needed.



NOTES:

1. Existing facilities to be rehabilitated and modified as needed.
2. Phosphorus polishing. Only required for maximum month flow to meet anticipated limits.
3. Existing bioreactors to be rehabilitated and expanded as needed.
4. Q = Flow

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Figure 5-8. Alternative 4 IFAS – Process Flow Schematic

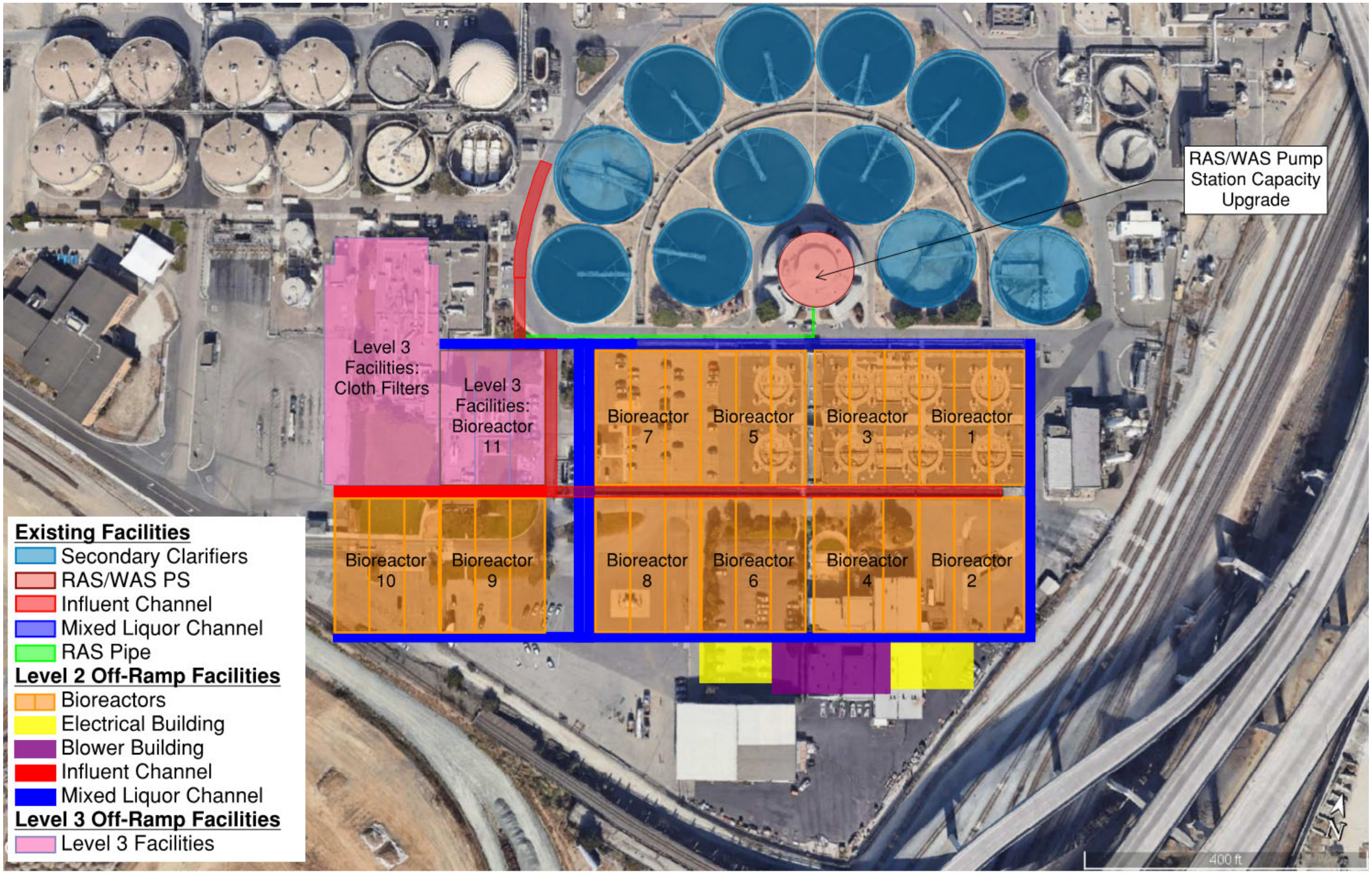


Figure 5-9. Alternative 4 IFAS – Conceptual Site Layout

5.4.5 Alternative 5: AGS

5.4.5.1 Description

Aerobic granular sludge (AGS) has been developed over the last 10-15 years as a nutrient removal alternative with a smaller footprint than activated sludge BNR systems. AGS incorporates the same bacteria (i.e. heterotrophs, ammonia and nitrite oxidizing bacteria, and phosphorus accumulating organisms) found in activated sludge, except the biomass grows as heterogeneous granules rather than as individual flocs.

Another significant difference is that the engineered conditions to promote the growth of different bacteria is accomplished with sequencing batch reactors instead of a flow-through reactor with multiple partitions and recirculation flows (such as MLE, A2O, or Bardenpho activated sludge). Typical cycle times for the reactor range from 3-8 hours. For this alternative a 4- hour cycle time was assumed and includes a mix/aeration period (approximately 60% of cycle time) followed by a settle period (40% of cycle time) during which sludge is first wasted and then influent is fed to the bottom of the reactor. The feed cycle displaces the settled effluent over effluent weirs at the top.

By controlling when and where sludge is wasted from the reactor, slowly settling flocculent biomass is selectively wasted from the system while the more rapidly settling, denser biomass (or granules) are retained. By selecting for rapidly setting biomass, the bioreactor can be operated at much higher effective mixed liquor concentrations and SRT compared to conventional activated sludge. Typical design criteria is 20-40 day SRT and an effective MLSS of 8,000 mg/L. The bioreactor volume for an AGS process is similar to a conventional AS BNR process, but secondary clarifiers are not needed since settling is achieved in the AGS bioreactors. For this reason, the AGS process is considered an intensification process. Figure 5-10 provides a process flow schematic of this alternative.

5.4.5.1.1 AGS Facilities

For this alternative, there would be 4 separate trains and each train would have 6 reactors, for a total of 24 reactors. Similar to Alternative 2 AS BNR, the existing bioreactors would be utilized and reconfigured, and additional bioreactors would be implemented. It was assumed that that the bioreactors would be modified to the required sequencing batch reactor configuration. The bioreactors would include a new fine bubble diffused aeration system, which would replace the existing high purity oxygen generation and storage facilities. New blowers would be located in a new building and would supply pressurized air to the bioreactors.

Since sludge is wasted intermittently, storage or equalization of the waste sludge would be provided to optimize WAS thickening operation. The secondary clarifiers and RAS pumping are no longer needed, so it was assumed that that one secondary clarifier would be retrofitted to be a WAS sludge equalization or buffer tank. It may be possible to reuse the existing WAS pumping infrastructure, although it is likely more practical to implement new WAS pumping that is optimized for the new bioreactor configuration.

5.4.5.2 Site Layout

The site layout for this alternative is shown in Figure 5-11. This site layout meets the Level 2 and the Level 3 Off-Ramp. This layout would require demolition and relocation of the following existing facilities:

- Administration Building
- Maintenance Building and Maintenance Warehouse.
- Fueling Station
- High purity oxygen generation and storage facilities

Since the secondary clarifiers and RAS pumping infrastructure would no longer be needed for secondary treatment, they could potentially be used for other purposes or demolished to create space for new facilities. For the purpose of this analysis it was assumed that they would be abandoned in place. Note that the economic evaluation does not include costs to decommission the secondary clarifiers.

5.4.5.2.1 Rehabilitation of Existing Facilities

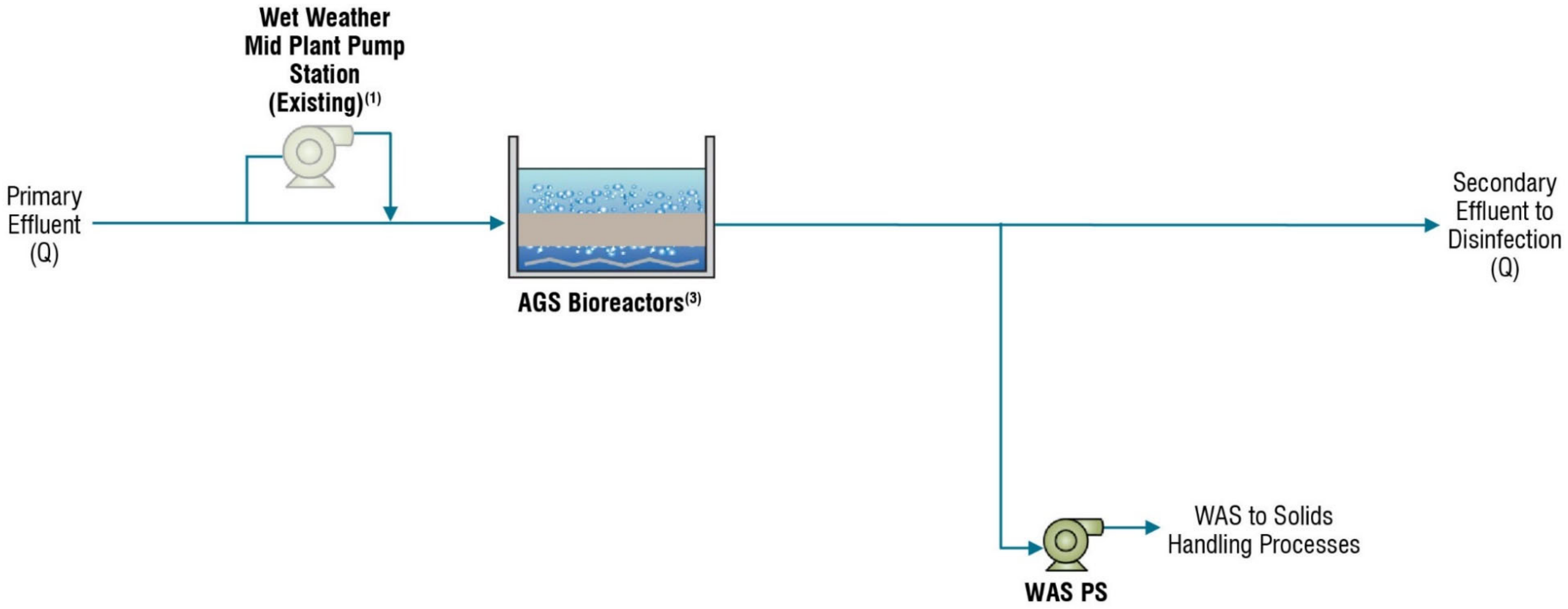
With this alternative the following existing secondary treatment facilities would be rehabilitated as-needed to extend their useful life through the planning period:

- HPOAS Reactors
- WAS Pump Station

5.4.5.2.2 Upgrades to Meet Level 3 Off-Ramp

To upgrade this alternative to meet the Level 3 Off-Ramp, the following improvements would be needed:

- Approximately 20 to 25 percent more bioreactors. This is due to the need to increase cycle times and achieve a higher level of nitrogen and phosphorus removal.
- Supplemental carbon. While supplemental carbon does not appear to be necessary for meeting the Level 2 Off-Ramp, it would be needed for the Level 3 Off-Ramp.
- If a total phosphorus limits of < 1 mg/L is required, effluent filters would be needed. The filters would need some chemical addition with alum or ferric to remove the small amount of phosphorus remaining in the effluent.



NOTES:

1. Existing facilities to be rehabilitated and modified as needed.
2. Phosphorus polishing. Only required for maximum month flow to meet anticipated limits.
3. Existing bioreactors to be rehabilitated and expanded as needed.
4. Q = Flow

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Figure 5-10. Alternative 5 AGS – Process Flow Schematic

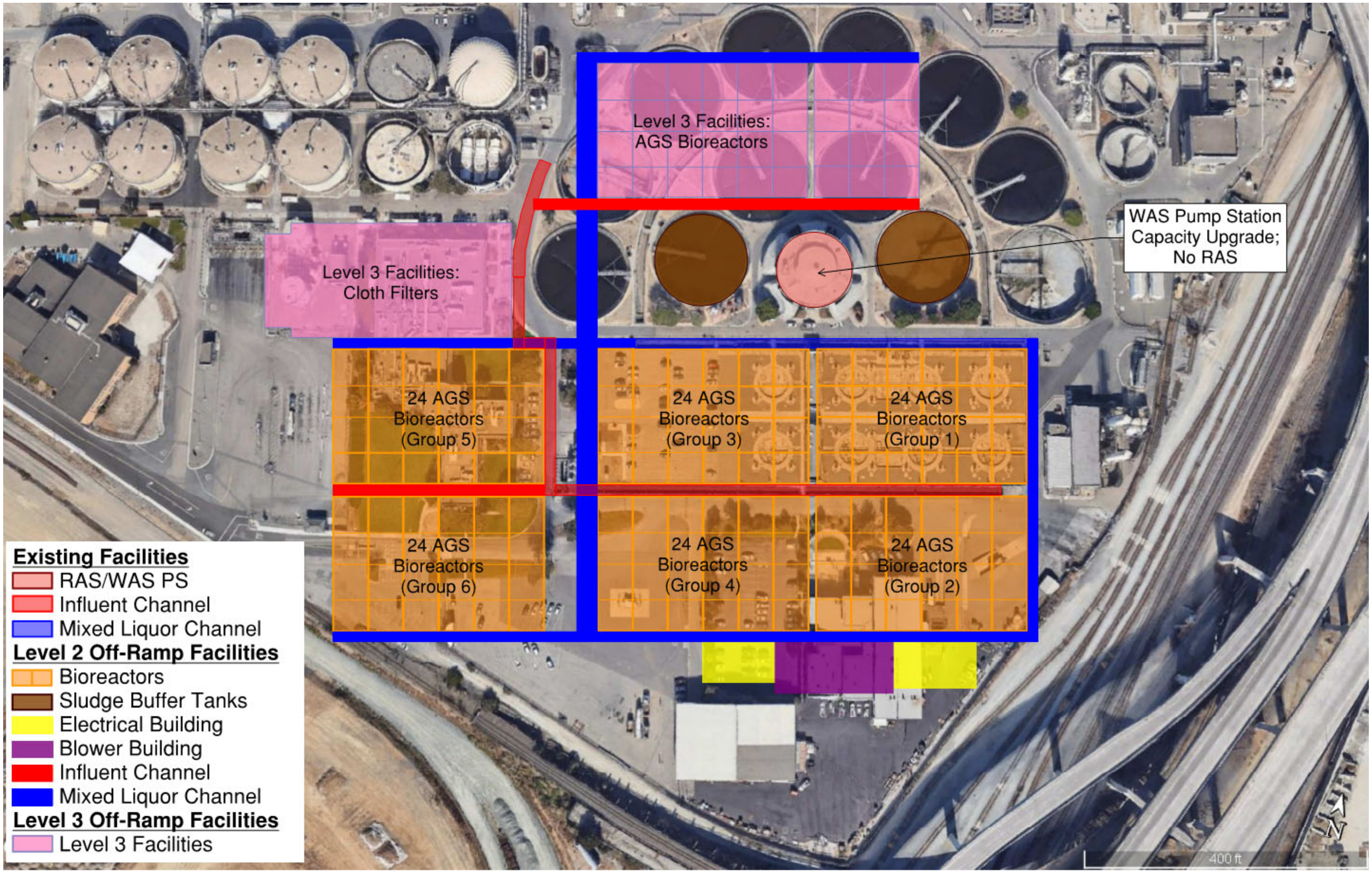


Figure 5-11. Alternative 5 AGS – Conceptual Site Layout

5.4.6 Alternative 6: Decentralized

5.4.6.1 Description

The Decentralized alternative is comprised of nutrient reduction facilities at the MWWTP and at the Pt. Isabel and Oakport WWFs. Effluent and solids from the WWFs would be discharged to the EBMUD interceptor for conveyance to the MWWTP. Figure 5-12 provides a process flow schematic of this alternative.

At the MWWTP, IFAS facilities would be implemented similar to Alternative 4. An IFAS process configuration was selected for this alternative because IFAS has the lowest expected lifecycle costs of the technologies considered and the primary driver to consider decentralized treatment was to determine if it was significantly more cost effective than the other alternatives.

At the WWFs, AGS treatment facilities would be implemented because it is a compact technology (similar to MBRs), so it could most easily fit within the existing plant boundaries. AGS and MBR have similar lifecycle costs, but AGS requires fewer facilities and components, so AGS was selected to maximize the non-economic benefits of this alternative. It is important to note that MBR facilities could still be implemented instead of AGS facilities at the WWFs in the future. A primary driver to do so could be increased demand for recycled water. MBR produces effluent suitable for reuse, whereas AGS would require additional treatment (filtration) facilities and likely wouldn’t be as cost effective.

The treatment provided by the AGS facilities would reduce the overall load to the MWWTP by about 10 percent. This would allow the MWWTP facilities to be a slightly smaller. For this alternative, one less IFAS aeration basin would be needed in comparison to Alternative 3.

5.4.6.2 Site Layout

One site layout was developed for the MWWTP and each of the WWFs. The site layouts are shown in Figures 5-13, 5-14, and 5-15. This site layout meets the Level 2 and the Level 3 Off-Ramp.

The MWWTP layout would require demolition and relocation of the following existing facilities:

- Administration Building (Approximately 25 percent of the existing building would need to be demolished and relocated.)
- Maintenance Building and Maintenance Warehouse.
- Fueling Station
- High purity oxygen generation and storage facilities

No demolition of major facilities is anticipated to be required at the WWFs to accommodate the new nutrient reduction facilities.

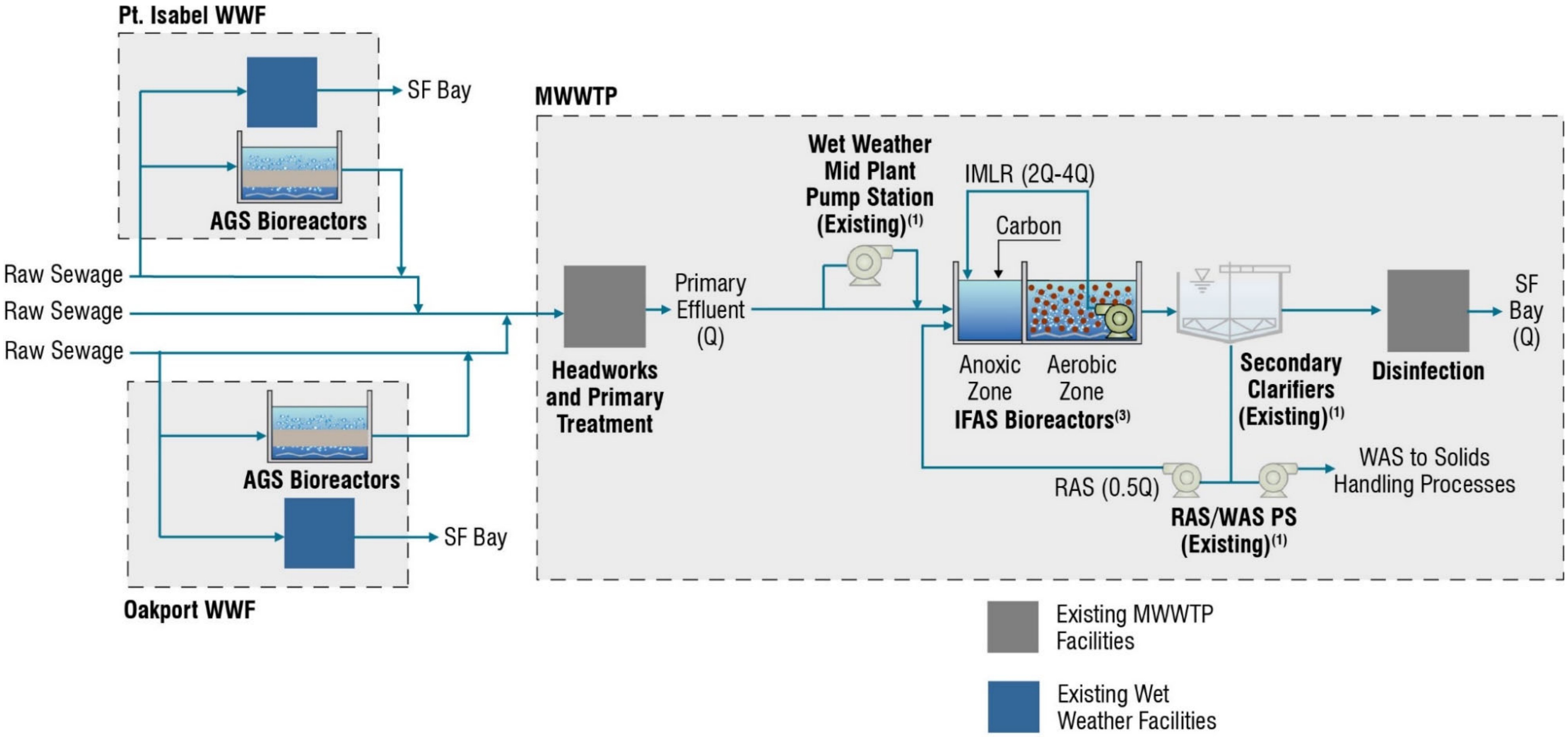
5.4.6.2.1 Rehabilitation of Existing Facilities

With this alternative the following existing secondary treatment facilities at the MWWTP would be rehabilitated as-needed to extend their useful life through the planning period:

- HPOAS Reactors
- Secondary Clarifiers
- RAS and WAS Pump Stations
    - The RAS pump station would be upgraded to increase the RAS pumping capacity to accommodate the higher rate of sludge production in the secondary clarifiers.

5.4.6.2.2 Upgrades to Meet Level 3 Off-Ramp

To upgrade this alternative to meet the Level 3 Off-Ramp, the same improvements as described for Alternatives 2 and 4 would be needed at the MWWTP only.



NOTES:
1. Existing facilities to be rehabilitated and modified as needed.
2. Phosphorus polishing. Only required for maximum month flow to meet anticipated limits.
3. Existing bioreactors to be rehabilitated and expanded as needed.
4. Q = Flow

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Figure 5-12. Alternative 6 Decentralized – Process Flow Schematic

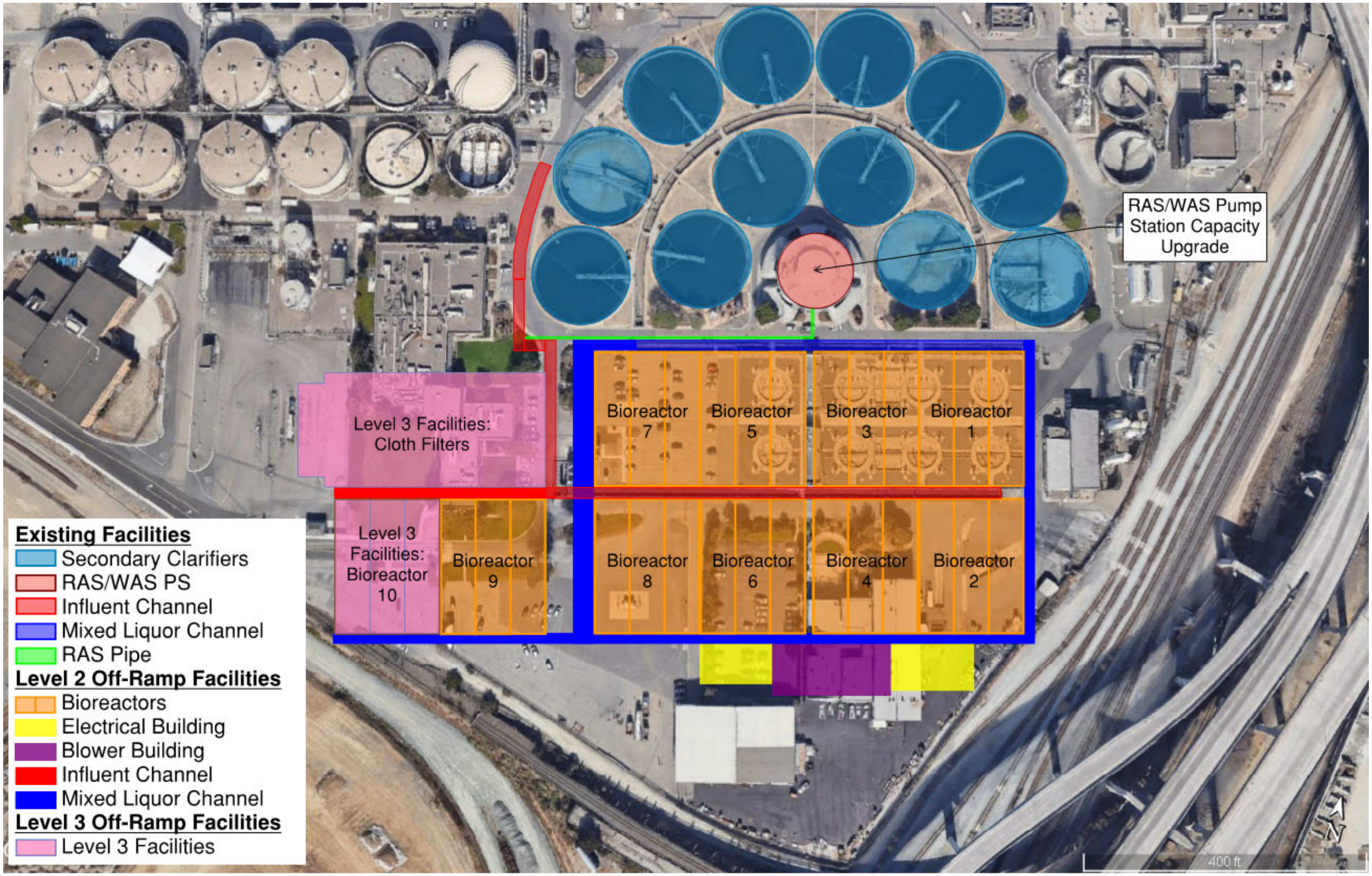


Figure 5-13. Alternative 6 Decentralized – Conceptual Site Layout for MWWTP

Figure 5-14. Alternative 6 Decentralized – Conceptual Site Layout for Oakport WWF

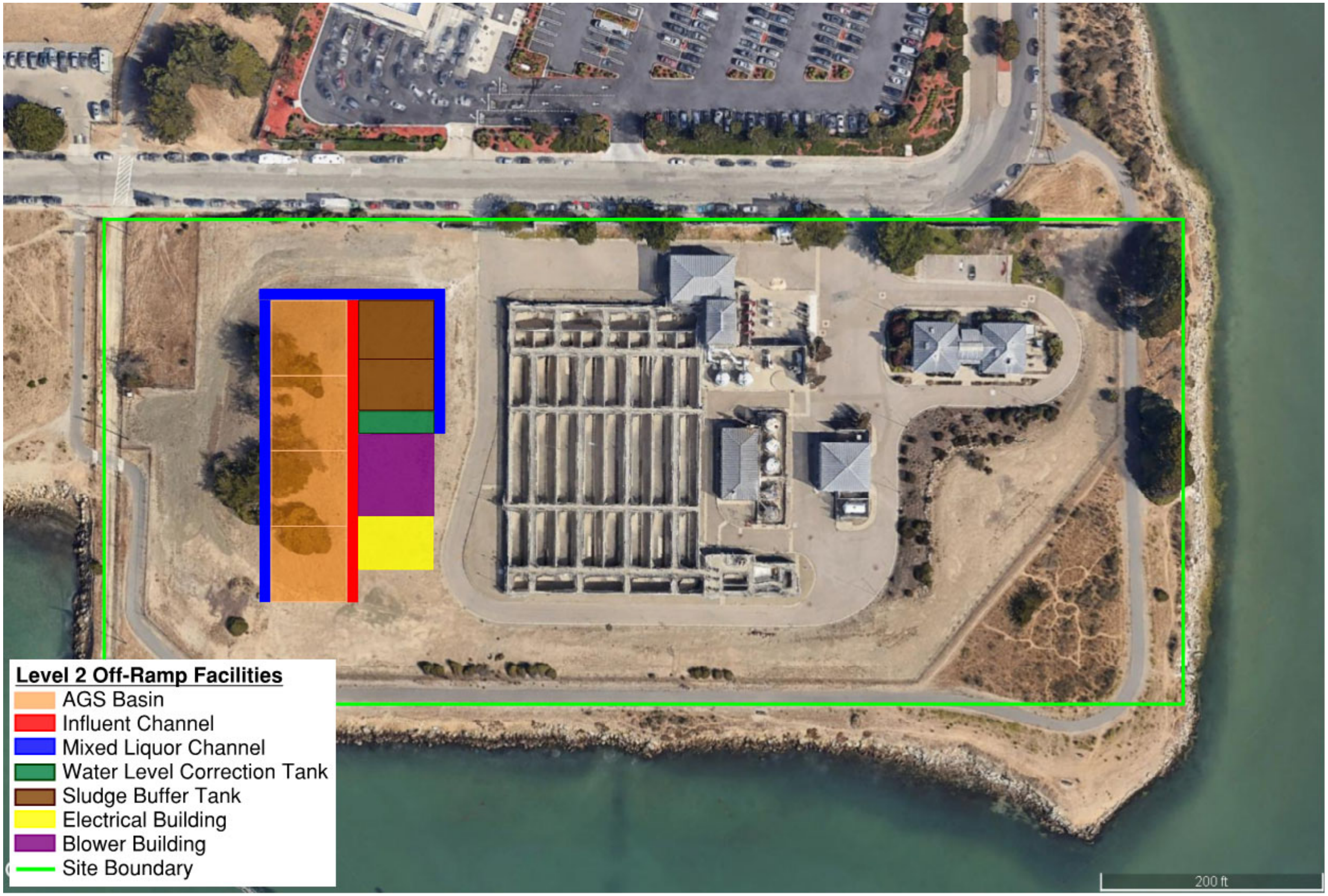


Figure 5-15. Alternative 6 Decentralized – Conceptual Site Layout for Pt. Isabel WWF

5.4.7 Alternative 7: Split Flow

5.4.7.1 Description

The Split Flow alternative is comprised of two different treatment processes (AS BNR and AGS) that would operate in parallel with one another. With this configuration, the AS BNR process would treat 40 percent of the flow, and the AGS process would treat 60 percent of the flow. The secondary effluent from both processes would combine and flow to the downstream treatment facilities for disinfection, dechlorination, and discharge. Figure 5-16 provides a process flow schematic of this alternative.

Of the process technologies considered, the AS BNR and AGS process technologies were selected because they minimize the overall footprint required for nutrient reduction and maximize anticipated non-economic benefits. The AS BNR process maximizes the nutrient reduction that can be achieved within the existing bioreactor and secondary clarifier tankage, which reduces the need for new tankage and site space. The AGS process is compact enough that it can provide the additional nutrient reduction within the remaining site space available for secondary treatment. An MBR process could also fit within the remaining site space, and could be implemented in lieu of an AGS process for a similar life cycle cost. However, the AGS process was selected due to a slightly higher scoring for non-economic benefits (see Sections 5.5. and 5.6 for a discussion of the economic and non-economic evaluation results).

5.4.7.1.1 AS BNR Facilities

The AS BNR facilities would be very similar to those included in Alternative 2 AS BNR, and would include bioreactors with a Modified Ludzak-Ettinger (MLE) configuration followed by secondary clarifiers. The existing bioreactors would be utilized and reconfigured, and additional bioreactors would be implemented. It was assumed that that the bioreactors would be three-pass bioreactors. The bioreactors would be supplied with air from a new aeration system, similar to that included in Alternative 2 AS BNR.

The existing secondary clarifiers would be utilized and would be operated similarly to how they are operated now. The key difference is the solids loading rate to the secondary clarifiers would be higher given the bioreactors would be operated at a higher MLSS concentration. This would result in a higher rate of sludge settling in the clarifiers. Given the AS BNR bioreactors would only treat about 40 percent of the flow, the existing RAS pump stations are expected to provide sufficient RAS pumping capacity. However, it was assumed that some modifications to the pumps would be needed to extend their useful life.

5.4.7.1.2 AGS Facilities

The AS BNR facilities would be very similar to those included in Alternative 5 AGS and would include new bioreactors that utilize aeration granular sludge (AGS) for treatment. It was assumed that the bioreactors would be sequencing batch bioreactors. The bioreactors would be supplied with air from a new aeration system, similar to that included in Alternative 5 AGS.

5.4.7.2 Site Layout

The site layout for this alternative is shown in Figure 5-17. This site layout meets the Level 2 and the Level 3 Off-Ramp. This layout would require demolition and relocation of the following existing facilities:

- Administration Building
- Maintenance Building and Maintenance Warehouse.
- Fueling Station
- High purity oxygen generation and storage facilities

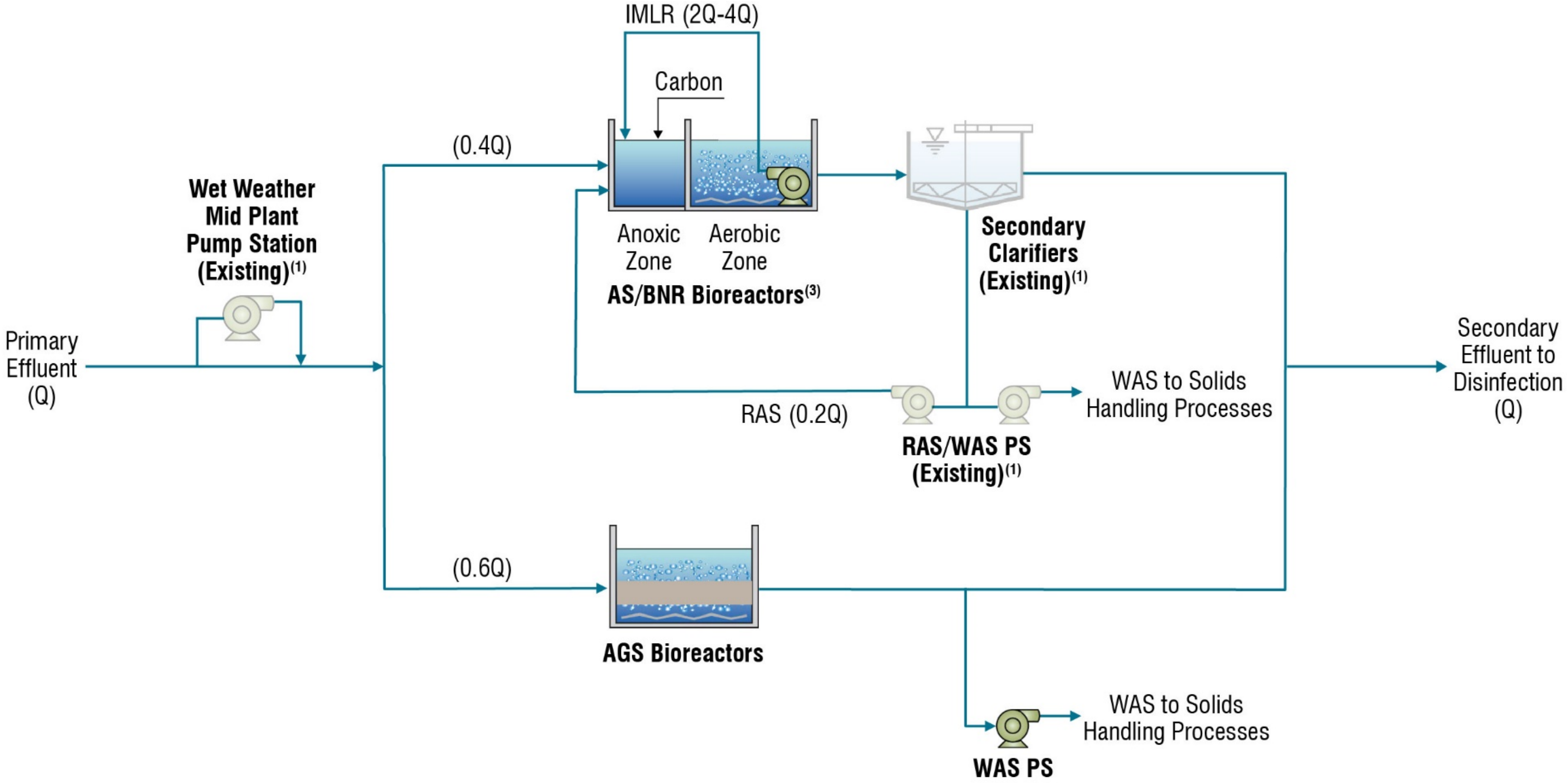
5.4.7.2.1 Rehabilitation of Existing Facilities

With this alternative the following existing secondary treatment facilities would be rehabilitated as-needed to extend their useful life through the planning period:

- HPOAS Reactors
- Secondary Clarifiers
- RAS and WAS Pump Stations
    - Modifications to the existing pumps will be made to extend the useful life of the existing facility.

5.4.7.2.2 Upgrades to Meet Level 3 Off-Ramp

To upgrade this alternative to meet the Level 3 Off-Ramp, the same improvements as described for Alternative 2 and 5 would be needed.



NOTES:
1. Existing facilities to be rehabilitated and modified as needed.
2. Phosphorus polishing. Only required for maximum month flow to meet anticipated limits.
3. Existing bioreactors to be rehabilitated and expanded as needed.
4. Q = Flow

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Figure 5-16. Alternative 7 Split Flow – Process Flow Schematic

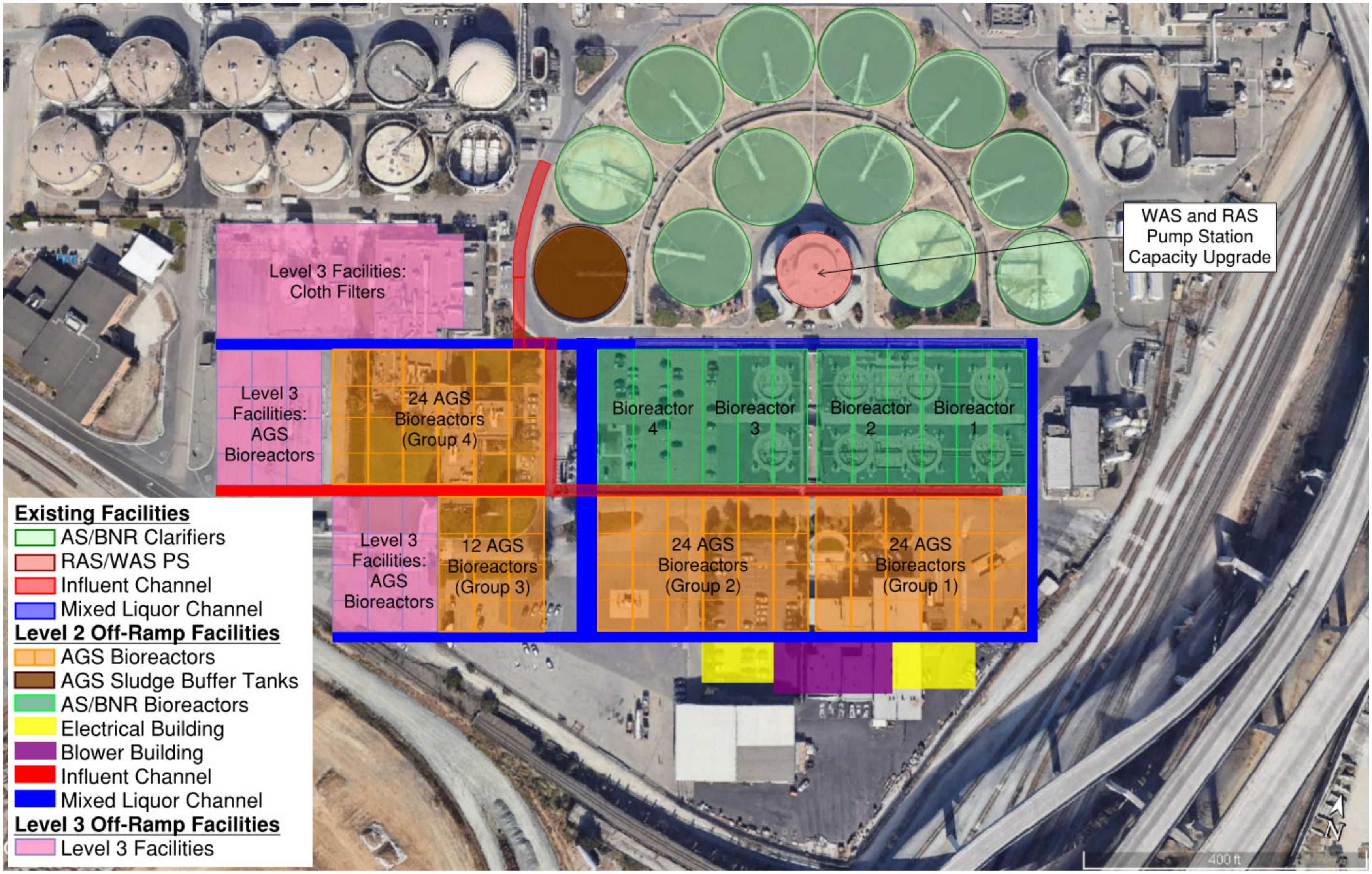

Figure 5-17. Alternative 7 Split Flow – Conceptual Site Layout

5.5 Economic Evaluation

5.5.1 Assumptions

Both capital and annual operating costs were developed to determine the net present value (NPV) of each alternative. The cost estimates developed are Class 5 conceptual cost estimates per the Association for the Advancement of Cost Engineering International (AACE), and are based on facilities sized for 2050 conditions that meet the Level 2 Off-Ramp, as well as the assumptions described in the C40-Basis of Cost Estimating Report. The NPV was developed over a 30-year period assuming a 2 percent discount rate and 3 percent inflation rate.

The capital costs developed include total project costs which include construction, planning and permitting, engineering, and construction management. The annual operating costs developed include:

- Energy usage
- Chemical usage
- The relative difference in additional labor required for the new facilities
- Rehabilitation and replacement (R&R) costs

Across all of the alternatives, it was assumed that the labor costs would be about the same for the new nutrient reduction facilities located at the MWWTP, given that those facilities would treat the same amount of flow and would have a similar level of complexity. It was assumed that Alternative 6 would have a higher labor cost compared to the other alternatives, because it would require additional staff to operate and maintain the new facilities at the Pt. Isabel and Oakport WWFs.

Annual R&R costs for existing facilities were estimated based on R&R costs included in the 10-year Wastewater Treatment Capital Improvement Plan (CIP) for fiscal years 2020 – 2029. It was assumed that R&R costs planned for existing facilities would be similar over the next 30 years. If existing facilities were not included in the Alternative, then the R&R costs for those facilities were not included (e.g., Alternative 3 does not include R&R costs for the secondary clarifiers).

Annual R&R costs for future facilities were estimated as a percentage of the capital cost. It was assumed that facilities that require regular rehabilitation and replacement accounted for about 30 percent of the capital cost. Of that portion, it was assumed that about 2 percent of the facilities would need to be replaced each year.

5.5.2 Results Summary

Table 5-5 includes a summary of the economic evaluation and includes the estimated capital cost, annual operating cost, and NPV of each alternative. Figure 5-18 provides a summary of the NPV for each alternative (Appendix B includes additional details on the NPV cost estimates and assumptions used).

The NPVs for each alternative were considered to be similar to each other, with the relative difference falling within the accuracy of Class 5 estimate. That said, some general observations can be made regarding the NPV. Alternative 1 HPOAS is higher cost, largely due to significant chemical usage (both methanol and alkalinity). Alternative 2 AS BNR and Alternative 4 IFAS are lower cost. The other alternatives are moderate cost. It is feasible that one of the moderate cost alternatives could potentially be optimized to be cost competitive with Alternatives 2 and 4, especially considering that both established and emerging intensification technologies may continue to mature. As the technologies mature over the planning period, the number of installations may increase and technology/equipment costs may decrease.

Table 5-5. Economic Evaluation Summary

	Alt. 1: HPOAS	**Alt. 2: AS BNR**	**Alt. 3: MBR**	**Alt. 4: IFAS**	**Alt. 5: AGS**	**Alt. 6: De-centralized**	**Alt. 7: Split Flow**
Total Capital Cost	**$ 1,240**	**$ 1,330**	**$ 1,320**	**$ 1,180**	**$ 1,510**	**$ 1,350**	**$ 1,400**
Total Annual Operating Costs (Year 1)	**$ 25.9**	**$ 13.8**	**$ 17.0**	**$ 13.7**	**$ 12.4**	**$ 19.5**	**$ 13.5**
Power	$ 5.4	$ 2.3	$ 4.2	$ 3.1	$ 2.7	$ 3.5	$ 2.5
Chemical	$ 9.7	$ 1.7	$ 1.9	$ 1.7	$ -	$ 1.6	$ 0.7
Labor	$ -	$ -	$ -	$ -	$ -	$ 4.6	$ -
Equipment Replacement [b]	$ -	$ 0.1	$ 2.4	$ -	$ 0.2	$ 0.1	$ 0.1
Rehabilitation and Replacement (R&R)	$ 10.8	$ 9.7	$ 8.5	$ 8.8	$ 9.6	$ 9.8	$ 10.1
Net Present Value ($ millions)	**$ 2,200**	**$ 1,830**	**$ 1,940**	**$ 1,680**	**$ 1,950**	**$ 2,050**	**$ 1,880**

a. All costs are presented in 2021 dollars and rounded.

b. Equipment replacement includes membrane diffusers and membrane modules.

c. R&R costs to replace aging infrastructure.

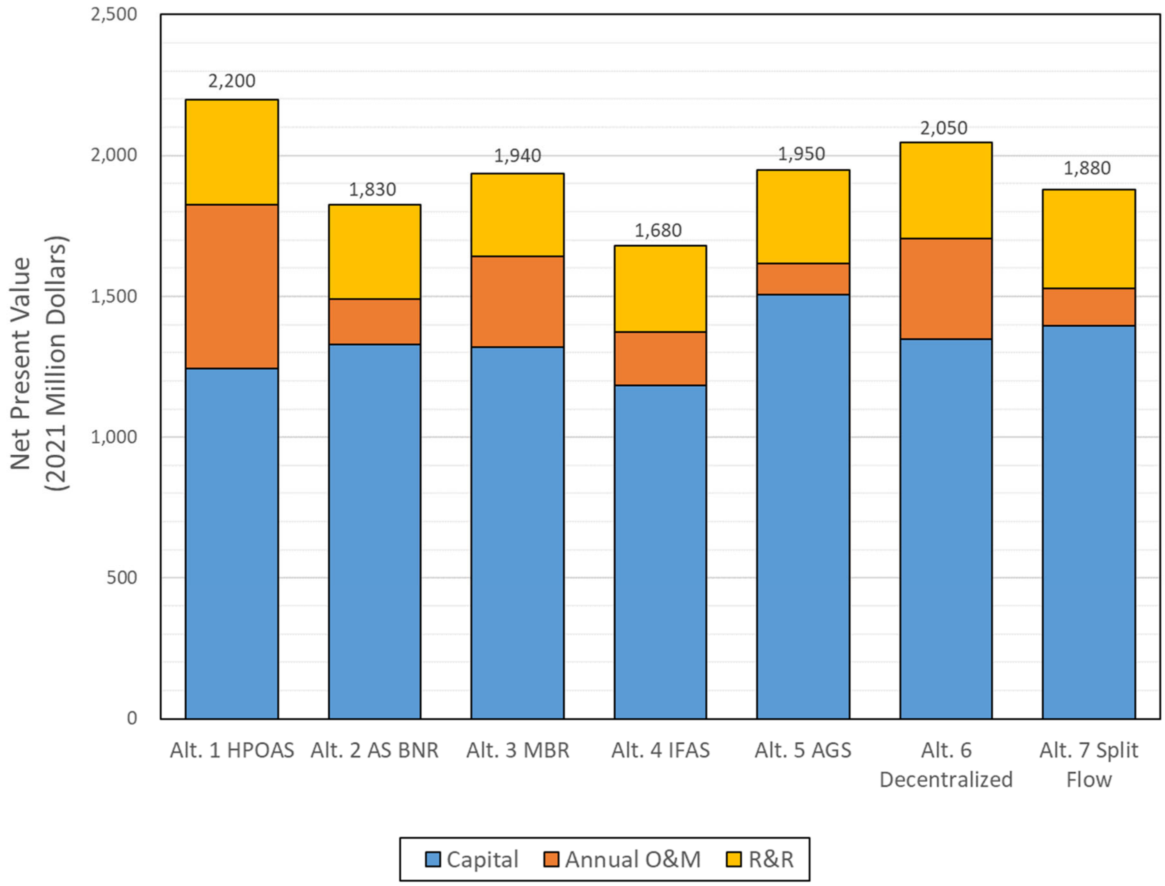

Figure 5-18. Summary of the Net Present Values for Each Alternative

5.5.3 Non-Economic Evaluation

The alternatives were evaluated using the non-economic criteria summarized in Appendix C. A score of 1 – 5 was assigned to each criterion for each alternative -- a 5 indicated best alignment with the criterion, while a 1 indicated least alignment. The criteria weighting was then used to determine the overall weighted score for the alternative.

The non-economic criteria include a combination of qualitative and quantitative criteria, and were categorized in three major groups including: Social, Environmental, and Technical. The following criteria are the top-weighted criteria and thus have the largest impact on the overall non-economic score:

- Facility Safety (Social)
- Flexibility to Meet Current and Future Regulations (Environmental)
- Technology Maturity and Reliability (Technical)

- Minimize Greenhouse Gas (GHG) Emissions (Environmental)

The “Minimize GHG Emissions” criterion is a quantitative criterion. GHG emissions were estimated for each alternative and included: treatment process emissions (energy demand for treatment); and nitrous oxide emissions from the treatment process and at the SF Bay (due to the treated effluent discharged). The GHG emissions assumptions and calculations are detailed in Appendix G. Based on the estimated GHG emissions, each alternative was assigned a score of 1 – 5 to summarize the relative difference in GHG emissions.

5.5.4 Results Summary

Table 5-6 and Figure 5-19 provide a summary of the non-economic evaluation. Appendix C provides the detailed scoring and scoring justification for each alternative and criterion.

Table 5-6. Non-Economic Scoring Summary

Evaluation Criteria	Relative Weight	Unweighted Scores (a)						
		Alt. 1 HPOAS	Alt. 2 AS BNR	Alt. 3 MBR	Alt. 4 IFAS	Alt. 5 AGS	Alt. 6 Decentralized IFAS at MWWTP + AGS	Alt. 7 Split Flow AS BNR + AGS
Technical								
Efficient Land Use and Site Layout	6 percent	5	3	5	4	4	3	3
Constructability	3 percent	5	3	4	4	3	4	4
Technology Maturity/ Reliability	12 percent	5	5	4	3	2	3	3
Flexibility/ Ease of O&M	6 percent	4	5	3	3	3	1	3
Resiliency	9 percent	2	3	4	3	5	3	3
Environmental								
Flexibility to Meet Current/ Future Regulations	14 percent	5	4	3	3	3	3	3
Maximize Recoverable Resources	6 percent	5	4	5	3	2	4	3
Minimize Treatment Process GHG Emissions	10 percent	1	4	3	4	5	4	5
Minimize Chemical Use	5 percent	1	3	3	3	5	3	4

		Unweighted Scores (a)						
Evaluation Criteria	**Relative Weight**	**Alt. 1 HPOAS**	**Alt. 2 AS BNR**	**Alt. 3 MBR**	**Alt. 4 IFAS**	**Alt. 5 AGS**	**Alt. 6 Decentralized IFAS at MWWTP + AGS**	**Alt. 7 Split Flow AS BNR + AGS**
Social								
Community Acceptability	9 percent	2	3	3	3	3	4	3
Facility Safety	17 percent	3	4	4	4	5	4	4.5
Facility and Public Engagement	2 percent	3	3	3	3	3	3	3
Total								
Total Unweighted Score		**41**	**44**	**44**	**40**	**43**	**39**	**41.5**
Total Weighted Normalized Score		**3.41**	**3.84**	**3.66**	**3.36**	**3.70**	**3.34**	**3.54**
Percentage of Maximum Score of 5		**68**	**77**	**73**	**67**	**74**	**67**	**71**

a. Scores assigned on scale of 1-5.
1 = alternative is LEAST aligned with criteria
5 = alternative is MOST aligned with criteria

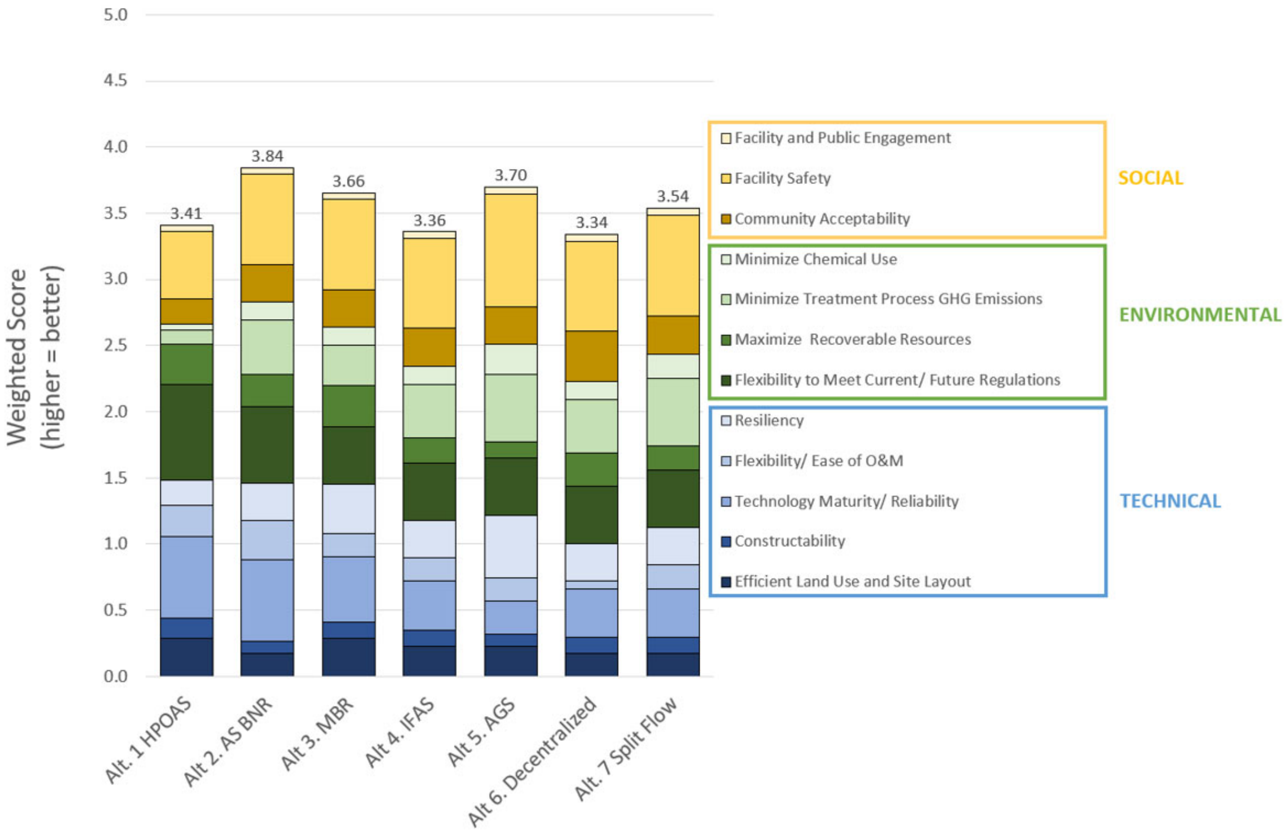

Figure 5-19. Summary of Non-Economic Scores for Each Alternative

The non-economic scores for each alternative were considered to be somewhat similar to each other. Alternative 2 AS BNR and Alternative 5 AGS were considered the highest scoring alternatives. Alternative 1 HPOAS, Alternative 4 IFAS, and Alternative 6 Decentralized were considered low scoring alternatives. Alternative 3 MBR and Alternative 7 Split Flow were considered to be moderate scoring alternatives.

Alternative 2 AS BNR largely received a high non-economic score due to its:

- High scoring across each of the top-weighted categories.
- High scoring for Facility Safety because it uses a moderate amount of chemicals.
- High scoring for "Flexibility to Meet Current and Future Regulations" because it can easily be modified in the future to integrate established or emerging intensification technologies such as MBR, IFAS, or AGS. This is particularly beneficial because it maximizes the District's ability to capitalize on emerging technologies that may mature and prove to be reliable and more cost-effective than established technologies.

- High scoring for "Technology Maturity/Reliability" because it is a well-established and reliable technology.
- High scoring for "Minimize Process GHG Emissions" because it requires moderately low energy and chemical usage.

Alternative 5 AGS received a high non-economic score due to its:

- High scoring for "Facility Safety" due to its low chemical and energy usage.
- High scoring for "Minimize Greenhouse Gas Emissions" due to its low chemical and energy usage

Alternative 1 HPOAS received a lower non-economic score due to its:

- Low scoring for "Facility Safety" due to its high chemical usage
- Low scoring for "Minimize Greenhouse Gas Emissions" due to its high chemical usage

Alternative 4 IFAS received a lower non-economic score due to its:

- Moderate scoring for "Flexibility to Meet Current and Future Regulations" and "Technology Maturity/Reliability." This alternative is considered less flexible because once the secondary treatment facilities are configured for an IFAS treatment process, the facilities cannot as easily be modified to a different technology. This wouldn't allow the District to pivot in the future to a different technology (such as an emerging technology that matures over the planning period and provides significant benefits over IFAS).
- Moderate scoring for "Technology Maturity/Reliability" because, although it is an established intensification technology, it has fewer installations compared to the other alternatives considered. Although there are fewer installations, the technology is similar in performance and reliability as Alternative 2 AS BNR.

Alternative 6 Decentralized Treatment received a lower non-economic score due to its:

- Moderate scoring for "Flexibility to Meet Current and Future Regulations" and "Technology Maturity/Reliability." This alternative is considered less flexible because once new nutrient reduction facilities are implemented at the WWFs, it would be the most cost effective to continue using them for the long term. Also, once the secondary treatment facilities are configured for an IFAS treatment process (at the MWWTP) and an AGS treatment process (at the WWFs), they cannot as easily be modified to integrate a different/emerging intensification technology.
- Moderate scoring for "Technology Maturity/Reliability" because it is largely comprised of an IFAS treatment process (so received similar scoring to Alternative 4 IFAS).

Alternative 3 MBR received a moderate score due to its:

- High scoring for "Facility Safety" due to moderate chemical usage
- High scoring for "Technology Maturity/Reliablity" due to several installations and reliable operating history
- Low scoring for "Minimize Greenhouse Gas Emissions" due to high energy usage
- Low scoring for "Flexibility to Meet Current and Future Regulations." Similar to Alternative 4 IFAS, once the secondary treatment facilities are configured for an MBR process, they cannot easily be modified to accommodate emerging technologies.

Alternative 7 Split Flow received a moderate score due to its:

- High scoring for "Facility Safety" due to low chemical usage
- High scoring for "Minimize Greenhouse Gas Emissions" due to no chemical usage and low energy usage
- Low scoring "Technology Maturity/Reliability" given AGS is an emerging technology with fewer installations that are all considerably smaller than the MWWTP.
- Low scoring for "Flexibility to Meet Current and Future Regulations." Once a large portion of the secondary treatment facilities are configured for an AGS process, they cannot easily be modified to accommodate other emerging technologies.

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CHAPTER 6 - CONCLUSIONS AND NEXT STEPS

At the workshop on April 30, 2020, the following conclusions were drawn from the economic and non-economic evaluation of the alternatives. The presentation materials and minutes from the workshop are included in Appendix H.

6.1 Low-Ranking Alternatives

The following alternatives were determined to be low-ranking alternatives. It was decided they should not be evaluated further as the basis for planning.

- **Alternative 1 HPOAS.** due to its high NPV and low non-economic score.
- **Alternative 6 Decentralized.** due to its moderate NPV and low non-economic score.

6.2 Middle-Ranking Alternatives

The following alternatives were determined to be mid-ranking alternatives due to their similar NPVs and non-economic scores.

- **Alternative 3 MBR.** This alternative may become favorable in the future should regulations require significant reduction of effluent discharged to the Bay. Reducing bay discharge would require a significant increase in water reuse. Therefore, MBR may offer a greater benefit than the other technologies.
- **Alternative 5 AGS.** This alternative may become more favorable in the future as the technology matures and its reliability and sizing is better established. As the technology matures and is implemented on a larger scale, the cost of the technology may also decrease to make it more cost competitive with the other technologies.
- **Alternative 6 Split Flow.** This alternative may become more favorable in the future depending on the timing and magnitude of the nutrient regulations. It is very likely the first phase of nutrient reduction improvements implemented at the MWWTP will operate in parallel with the existing HPOAS process (i.e., in a split flow configuration). This may be the case for subsequent phases, and the secondary treatment facilities may continue with a split flow configuration throughout the planning period. The benefits of operating in a split flow configuration can be taken into consideration when developing the phasing plan for the nutrient reduction improvements included in the roadmap.

6.3 High-Ranking Alternatives

The following alternatives were determined to be high-ranking alternatives.

- **Alternative 2 AS BNR.** This alternative is considered high ranking due to its low NPV and high non-economic score. This alternative was viewed as especially favorable for planning because it provides the most flexibility for transitioning to a different technology in the future, should another technology become more cost effective due to advances in emerging technologies or changing drivers (such as the need for increased water reuse).

- Alternative 3 IFAS. This alternative is considered high ranking due to its low NPV, which indicates that intensification is potentially cost effective, and that at this time IFAS is favorable compared to the other intensification technologies.

6.4 Selected Alternative for Basis of Roadmap

Through the evaluation process, it was determined that maintaining flexibility and the ability to implement nutrient reduction improvements in phases on an as-needed basis is very important. Given the earliest the Level 2 Off-Ramp is anticipated to take effect until 2045-2055, there is considerable time before the District needs to decide on the specific nutrient reduction technology/process configuration.

Given this and the results of the alternatives evaluation, it was determined that Alternative 2 AS BNR should be carried forward as the basis for the roadmap. In addition to having a low NPV and high non-economic score, AS BNR was selected because it is conservative with respect to site planning offers the most flexibility with respect to long-term planning.

- AS BNR requires the largest site footprint of the alternatives considered. As such, the Master Plan would reserve a conservative amount of site space for nutrient reduction. Should other alternatives become more favorable in the future, it is anticipated that they would fit with the site space reserved.
- AS BNR provides the most flexibility in that the major upgrades include additional bioreactors. The bioreactors could be implemented in phases over time, on an as-needed basis.
- The AS BNR could be configured to accommodate an intensification technology in the future in order to optimize the site footprint to capitalize on other economic/non-economic benefits. Compared to the other alternatives, the AS BNR bioreactors provide more flexibility for reconfiguration to accommodate other intensification technologies/process in the future such as MBR, IFAS, AGS, or another emerging technology. At this time, IFAS appears favorable compared to the other intensification technologies, although that may change as the technologies develop further or mature.

6.5 Implementation and Next Steps

Alternative 2 AS BNR will be carried forward for further refinement and integration into the roadmap. A phased implementation plan will be developed to serve as the basis of the roadmap. The phased implementation plan will indicate which level of nutrient reduction will trigger major decisions on the mainstream technology/process configuration, how it will be coordinated with sidestream treatment, and how the AS BNR configuration can be modified to accommodate an intensification technology (i.e., IFAS, MBR, or AGS) in the future.

While the focus of this report is evaluating mainstream treatment improvements for meeting the Level 2 Off-Ramp, the roadmap must also consider how to best meet the Master Plan Target which is anticipated to occur earlier in the planning period. The roadmap will evaluate several approaches for meeting the Master Plan Target, one of which is sidestream treatment.

If sidestream treatment is implemented first, the sizing of mainstream facilities for meeting a potential future Level 2 Off-Ramp would be slightly reduced. Specifically, the bioreactor volume can be decreased due to a reduction in the nutrient load. To support development of the roadmap, this sizing reduction was quantified for the AS BNR, IFAS, MBR, and AGS alternatives. Table 6-1 summarizes the bioreactor number and volume required for meeting the Level 2 Off-Ramp with and without sidestream treatment.

Table 6-1. Bioreactor Sizing for meeting Level 2 Off-Ramp

Item	Without Sidestream Treatment	With Sidestream Treatment
AS BNR		
Number of Bioreactors	12	11
Volume, each, MG	4.75	4.75
Total Volume, MG	57	52
IFAS		
Number of Bioreactors	10	9
Volume, each, MG	4.75	4.75
Total Volume, MG	48	43
MBR		
Number of Bioreactors	5	4
Volume, each, MG	5.59	5.59
Total Volume, MG	28	22
AGS		
Number of Bioreactors	24	22
Volume, each, MG	2.38	2.38
Total Volume, MG	57	52

Figures 6-1 and 6-2 are site plans for meeting the potential future Level 2 and Level 3 Off-Ramps assuming sidestream treatment is implemented for the Master Plan Target.

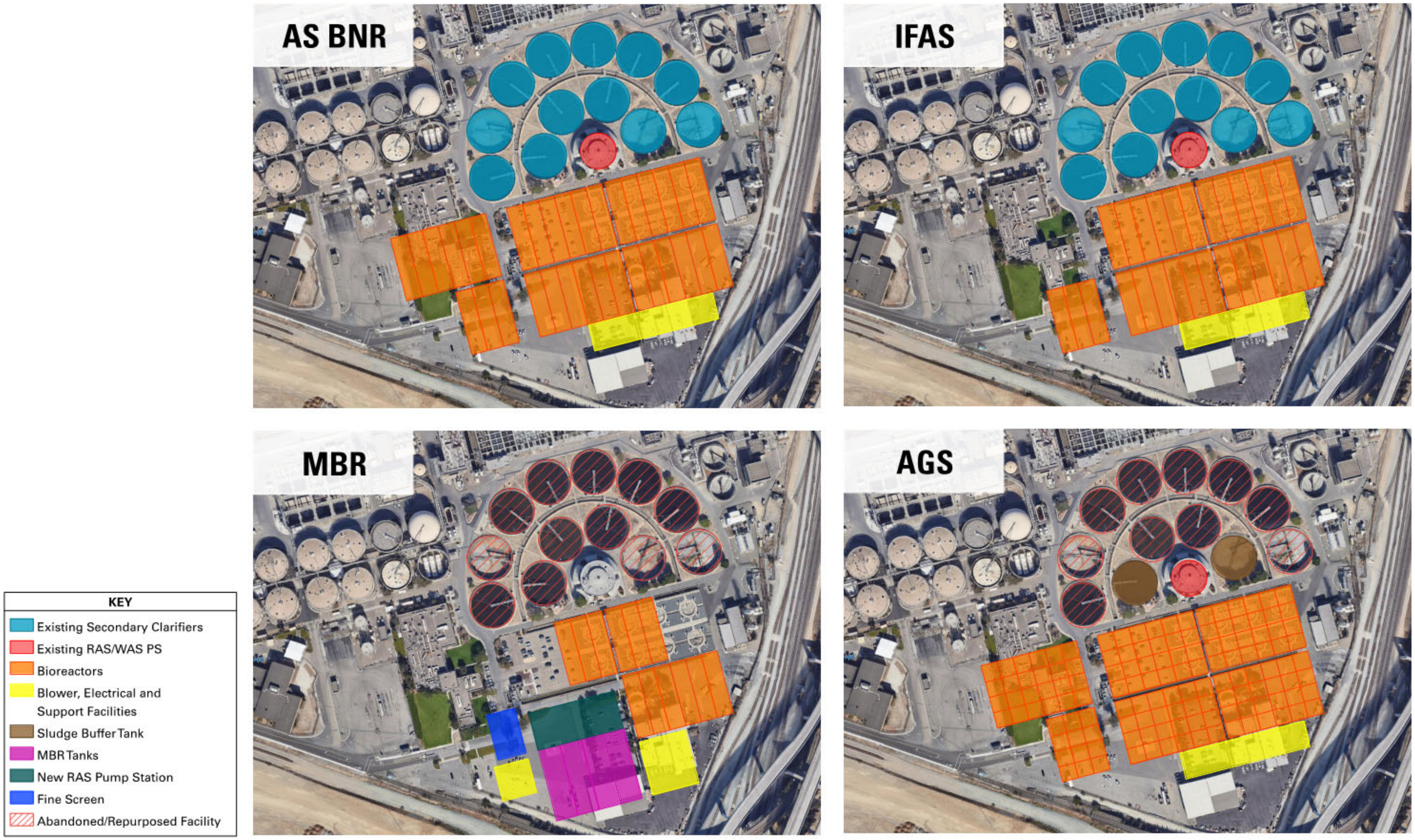

Figure 6-1. Level 2 Off-Ramp Facilities

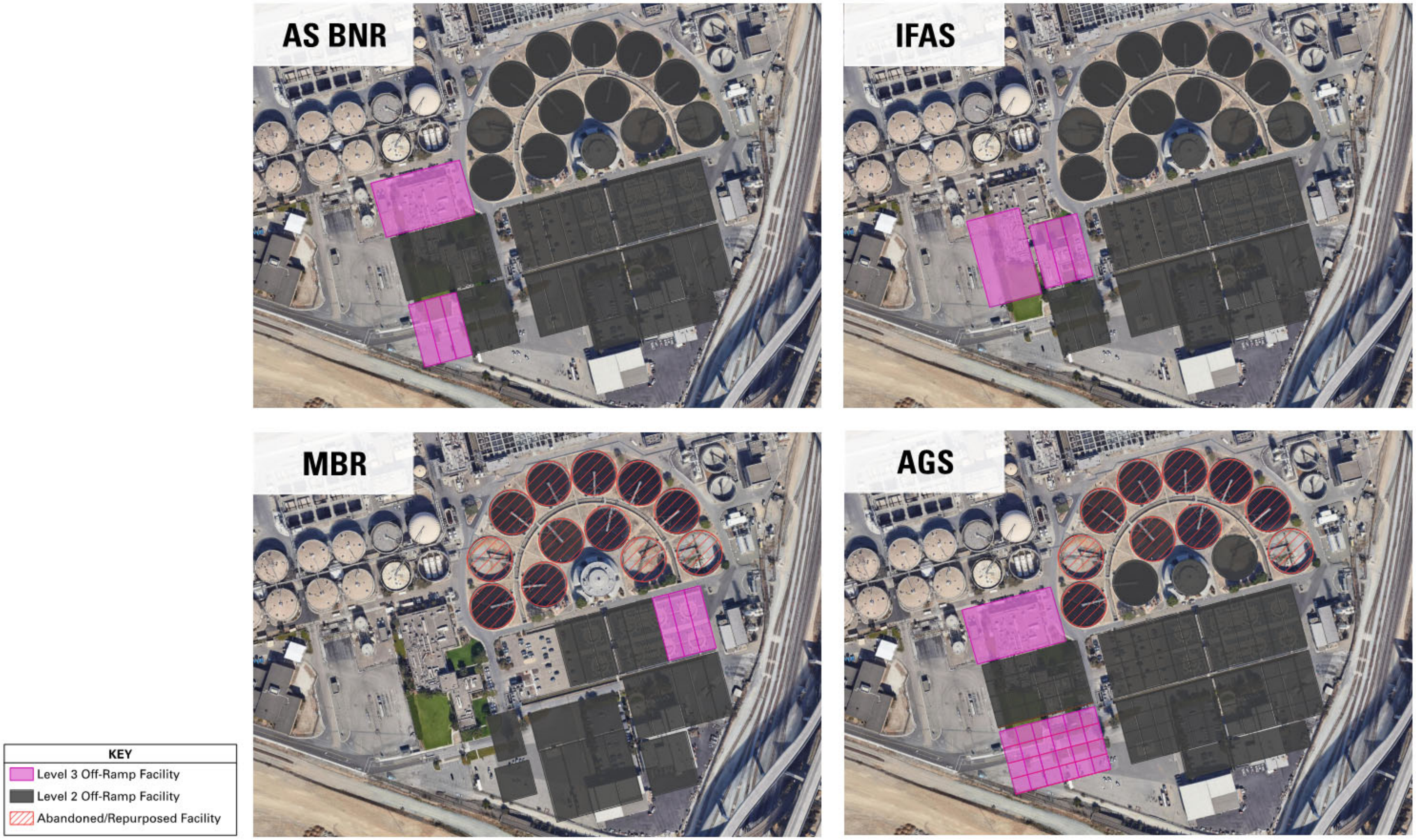

Figure 6-2. Level 3 Off-Ramp Facilities

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CHAPTER 7 - REFERENCES

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APPENDIX A – Evaluation Criteria

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Table A-1. Master Plan Evaluation Criteria and Metrics by Master Plan Goal and Objective

Guiding Principles/Goals	Objectives	Evaluation Criteria					
		Criteria	Weight	Considerations	Metric(s)	Basis for Score[(a)]	
						Initial Evaluation[(b)]	Detailed Evaluation[(c)]
TECHNICAL							
Maintain reliable wastewater treatment by preserving, implementing, and utilizing assets that provide sufficient treatment capacity and are resilient to changing conditions, both imminent and gradual (e.g., seismic events and sea-level rise).	Preserve/replace assets, maintain an efficient site layout, and optimize land utilization to facilitate reliable wastewater treatment operations and maintenance.	Efficient Land use and Site Layout	6 %	• Does it minimize the footprint required per mgd of influent? • Does it leave space for future improvements, expansion, or upgrades? • How well do future facilities integrate with existing facilities?	• Acreage of treatment facilities (low, medium, high) • Synergies in facility placement and logical flow (high, medium, low)	Qualitative	Quantitative score scaled based on least acres of land used
		Ease of Constructability	3 %	• How easily can the future facilities be constructed? • How easy will it be to continue operating the existing processes during construction?	• Simplicity of construction phasing	Qualitative (simple, moderate, or complex)	No Change
	Provide reliable capacity to manage and treat wastewater flows within the existing wastewater service area, such that regulations are met under a variety of operating conditions.	Technology Maturity/ Reliability	12 %	• How many existing WWTPs have the proposed technology/approach? • How large are they and how long have they been operating successfully? • Will the treatment process be reliable and robust with respect to meeting current and future regulations under a variety of flow/load conditions? • Does this alternative have flexibility to handle high peaking factors/wet weather flows?	• Operating history (significant, moderate, minimal) based on: ○ Number of installations ○ Size of installations ○ Years of successful, reliable operation meeting similar regulations • Effluent quality consistently meets potential effluent limits under variable flow/load conditions (high, medium, low consistency)	Qualitative	No Change

Guiding Principles/Goals	**Objectives**	**Evaluation Criteria**					
		Criteria	**Weight**	**Considerations**	**Metric(s)**	**Basis for Score(a)**	
						Initial Evaluation(b)	**Detailed Evaluation(c)**
		Flexibility/ Ease of O&M	6 %	• Will O&M labor hours be minimized? • Is staff already familiar with the process or will it require substantial staff training? • Is the technology serviceable in the United States, or does it require parts from outside the country? • Will reliance on third parties be minimized (e.g., for special maintenance, management /marketing the product(s), etc.)? • Will a third party manage or market the product?	• O&M effort based on: ○ O&M labor hours ○ O&M training ○ Monitoring/ instrumentation ○ Wait time for parts/support ○ Specialized staff required and reliance on third parties ○ Complexity/difficulty of O&M activities	Qualitative (low, medium, high)	No Change
	Maintain and improve resiliency of MWWTP and wastewater infrastructure such that interruptions of service are minimized and it can retain its essential function (i.e., protect life safety and convey wastewater flows to San Francisco Bay) under imminent changing conditions (e.g., seismic event, flooding) and gradual changing conditions (e.g., sea-level rise.	Resiliency	9 %	• Does it maximize the ability to protect life safety and convey wastewater flows to the SF Bay during the following events? • Seismic event (It is assumed new construction will have greater ability.) • Storm surge/flood event • Does it maximize the ability to maintain typical function under latest projected changes in sea/tide levels? • Does it enhance the ability to meet regulations and safety goals by providing resiliency?	• Relative change in cost to protect life safety and convey wastewater flows to the SF Bay • Relative change in cost to maintain typical function	Qualitative (decrease, minimal change, increase)	No Change

Guiding Principles/Goals	Objectives	Evaluation Criteria					
		Criteria	Weight	Considerations	Metric(s)	Basis for Score(a)	
						Initial Evaluation(b)	Detailed Evaluation(c)
ENVIRONMENTAL							
Protect the environment, public health, and safety through reliable wastewater treatment that can proactively meet future regulations and minimize impacts to the local (San Francisco Bay) and global environment.	Continue to meet increasingly stringent water quality and environmental regulations and upgrade wastewater facilities to address future regulatory requirements.	Reliability and Flexibility to Meet Current and Potential Future Regulations	14 %	• Can it reliably meet current regulations? • Does the alternative have flexibility to be modified to meet increasingly stringent regulations (including water quality, biosolids, and air regulations)?	• Flexibility to easily implement alternate configurations/future technologies over time	Qualitative (low, medium, high)	No Change
Promote resource recovery as a sustainable enterprise benefitting the region through responsible waste management and renewable energy generation.	Support sustainability goals by maximizing resource recovery and energy production, and minimizing energy consumption, greenhouse gas emissions, and use of non-renewable resources	Maximize Recoverable Resources	6 %	• Does it maximize utilization of the R2 Program? • Does it support beneficial use of biosolids? • Does it support nutrient recovery? • Does it support water reuse?	• Change in R2 Program (increase, minimal change, decrease) • Beneficial use of biosolids (high, medium, low) • Utilization of recoverable resources (treatment byproducts) (high, medium, low)	Qualitative	Qualitative score based on mass for all categories (R2, biosolids, nutrient recovery, water reuse)
		Minimize Treatment Process GHG Emissions 3a. Minimize energy purchases (electricity and natural gas) 3b. Minimize N_2O emissions (under consideration)	10 %	• Will it result in a change in GHG emissions?	• GHG emissions	Qualitative (low, medium, high)	No Change
				• Will it minimize flaring of biogas? • Will it increase the biogas/energy generation potential? • Is this Master Plan alternative energy efficient?	• Energy purchase	Quantitative (metric tons carbon dioxide equivalent per year based on kWh or Btu purchased per year)	No Change
				• Will it decrease the N2O at the plant and the receiving water (San Francisco Bay)?	• GHGs from N2O emissions both at the MWWTP and at San Francisco Bay	Quantitative (metric tons carbon dioxide equivalent per year based on N_2O emissions)	No Change

Guiding Principles/Goals	Objectives	Evaluation Criteria					
		Criteria	Weight	Considerations	Metric(s)	Basis for Score(a)	
						Initial Evaluation(b)	Detailed Evaluation(c)
		Minimize Chemical Use	5 %	• Does it minimize chemical addition for treatment?	• Chemical usage	Qualitative (low, medium, high)	No Change
SOCIAL							
Maintain positive relationships with community groups and minimize adverse community impacts through improved aesthetics, noise abatement, reduced truck traffic, and odor controls.	Minimize adverse visual, noise, truck traffic, and odor impacts from the MWWTP operations to neighbors to the extent practicable.	Community Acceptability	9 %	• Will the alternative introduce a source of odors, noise, and/or other emissions? • Will the alternative result in adverse visual impacts? • Will the alternative increase or decrease local truck traffic? • Will the alternative provide a community benefit (e.g., product the community can use)?	• Change in negative community impacts based on: o Noise o Odor emissions o Number of structures negatively impacting views or visual aesthetics o Truck traffic • Change in positive community impacts based on: o Community benefits	Qualitative (decrease, minimal change, increase)	No Change
Maintain safe and engaging work environment at EBMUD facilities.	Prioritize worker safety and maintain an engaging work environment at EBMUD facilities.	Facility Safety	17 %	• Does the alternative promote staff safety	• Change in the safety of the facilities/ work environment	Qualitative (decrease, minimal change, increase)	No Change
		Facility and Public Engagement	2 %	• Does the MWWTP promote staff and public engagement (e.g., functional and aesthetic site layout, adequate space for staff collaboration and public visitors)?	• Change in factors/ amenities promoting staff and public engagement • Change in potential for highly functional and aesthetic site layout/facilities	Qualitative (decrease, minimal change, increase)	No Change

Guiding Principles/Goals	Objectives	Evaluation Criteria					
		Criteria	Weight	Considerations	Metric(s)	Basis for Score[(a)]	
						Initial Evaluation[(b)]	Detailed Evaluation[(c)]
ECONOMIC							
Maintain fair and reasonable rates for customers by maximizing economic benefits through operating efficiencies and cost-effective alternatives.	Maintain fair and reasonable rates, including determining the role of resource recovery and beneficial use of treatment byproducts. Maintain transparent and accurate cost accounting and financial reporting. After meeting service area needs, utilize additional capacity for ratepayer benefit (i.e., to reduce ratepayer costs). Maintain cost-effective, "no-regrets" investments in wastewater facilities (e.g., through asset management, system upgrades, efficient operations, land utilization, assimilation of new technologies, etc.).	Life Cycle Cost	NA	• Does it minimize life cycle cost (capital and O&M cost) at Build-Out in 2020 U.S. dollars?	• Life cycle cost (capital and O&M cost) at Build-Out in 2020 U.S. dollars	Quantitative score scaled based on least life cycle cost at Build-Out	No Change

a. Scoring to be assigned where 5 is the highest (best alignment with criteria) and 1 is the lowest (least alignment with criteria).
b. Initial Evaluation of alternatives to occur in Nutrient Reduction and Biosolids Workshop No. 2. 12 alternatives to be evaluated and 4 to be selected (2 nutrient reduction alternatives and 2 biosolids alternatives).
c. Detailed Evaluation of alternatives to occur in Nutrient Reduction and Biosolids Workshop No. 3. 2 alternatives to be evaluated and 1 to be selected (1 nutrient reduction and 1 biosolids).

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APPENDIX B – NPV Cost Estimates and Assumptions

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TABLE B.1 - SUMMARY OF OPERATION AND MAINTENANCE UNIT COSTS

Item	Cost	Units	Notes
Annual Operating Costs			
Energy Costs			
at MWWTP (WAPA)	$ 0.10	kWh	Existing with demand charges rolled in
PG&E at Pt. Isabel	$ 0.22	kWh	Existing with demand charges rolled in
Chemicals			
Ferric chloride (43% solution)	$ 2.37	$/gallon	Billed at $0.4375 per dry lb
Sodium hypochlorite (12.5% solution)	$0.525 (For MWWTP); or $0.696 (For WWFs)	$/gallon	Use high value for wet weather facilitiies. Low number for MWWTP
Methanol	$ 2.00	$/gallon	historical peak price from Methanex website
Sodium hydroxide (NaOH) – 50% solution	$ 0.34	$/lb	Purchase order for RARE dated February 2020; 1,500,000 lbs purchased
Citric acid (50% solution)	$ 7.00	$/gallon	from Bay Area Consortium
Replacement and Rehab			
Diffuser Membranes (9-inch disc)	$ 10	$/diffuser	To be confirmed with vendor proposals for Master Plan
Membranes (MBR)	$ 955	$/module	To be confirmed with vendor proposals for Master Plan
Labor			
Hourly O&M Rate	$ 147	/hour	
Net Present Value Assumptions			
Time period	30	years	Time period TBD
Inflation rate	3%		Biosolids management, electricity and R2 tipping fees will escalate at different rates - TBD
Nominal Discount Rate	5%		
Real Discount Rate	2%		
Salvage Value for Equipment	---	Not included	
Equipment Useful Life	30	years	
Escalation Rate for Construction Costs (Midpoint)	4%	per year	

TABLE B.2 SUMMARY OF ALTERNATIVE CAPITAL COSTS

	Alt. 1: HPO	Alt. 2: AS BNR	Alt. 3: MBR	Alt. 4: IFAS	Alt. 5: AGS	Alt. 6: De-centralized	Alt. 7: Split Flow
New Administration Building	$ -	$ 42,968,000	$ -	$ 10,742,000	$ 42,968,000	$ 10,742,000	$ 42,968,000
Maintenance Building	$ 34,468,000	$ 34,468,000	$ 34,468,000	$ 34,468,000	$ 34,468,000	$ 34,468,000	$ 34,468,000
Fueling Station	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000
Aeration Basins	$ -	$ 285,856,000	$ 89,431,000	$ 271,495,000	$ 337,385,000	$ 239,258,000	$ 287,854,000
AGS - Sludge Holding Tank	$ -	$ -	$ -	$ -	$ 1,000,000	$ -	$ 500,000
Existing HPO System Demolition	$ -	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000
Blower Building	$ -	$ 15,621,000	$ 30,773,000	$ 18,801,000	$ 26,426,000	$ 18,152,000	$ 33,065,000
Fine Screens	$ -	$ -	$ 44,644,000	$ -	$ -	$ -	$ -
MBR Tanks	$ -	$ -	$ 151,064,000	$ -	$ -	$ -	$ -
RAS/WAS Pump Station Modifications	$ 10,761,000	$ 10,761,000	$ 36,719,000	$ 10,761,000	$ -	$ 10,761,000	$ 10,761,000
BAF/Denite Filters	$ 321,901,000	$ -	$ -	$ -	$ -	$ -	$ -
Oakport - AGS							
Influent PS and Screening	$ -	$ -	$ -	$ -	$ -	$ 12,613,000	$ -
Aeration Basins	$ -	$ -	$ -	$ -	$ -	$ 39,251,000	$ -
Blower Building	$ -	$ -	$ -	$ -	$ -	$ 3,710,000	$ -
Sludge Buffer Tank	$ -	$ -	$ -	$ -	$ -	$ 1,332,000	$ -
Pt. Isabel - AGS							
Influent PS and Screening	$ -	$ -	$ -	$ -	$ -	$ 6,367,000	$ -
Aeration Basins	$ -	$ -	$ -	$ -	$ -	$ 16,580,000	$ -
Blower Building	$ -	$ -	$ -	$ -	$ -	$ 1,859,000	$ -
Sludge Buffer Tank	$ -	$ -	$ -	$ -	$ -	$ 390,000	$ -
Subtotal A	$ 368,629,000	$ 393,671,000	$ 391,097,000	$ 350,265,000	$ 446,245,000	$ 399,477,000	$ 413,614,000
0.5% Misc. Demolition	$ 1,844,000	$ 1,969,000	$ 1,956,000	$ 1,659,000	$ 2,232,000	$ 1,998,000	$ 2,069,000
6% Civil	$ 22,118,000	$ 23,621,000	$ 23,466,000	$ 19,897,000	$ 26,775,000	$ 23,969,000	$ 24,817,000
10% Yard Piping	$ 36,863,000	$ 39,368,000	$ 39,110,000	$ 39,793,000	$ 44,625,000	$ 39,948,000	$ 41,362,000
10% Electrical, Instrumentation & Controls	$ 36,863,000	$ 39,368,000	$ 39,110,000	$ 33,161,000	$ 44,625,000	$ 39,948,000	$ 41,362,000
3% Hazardous Materials and Handling	$ 11,059,000	$ 11,811,000	$ 11,733,000	$ 9,949,000	$ 13,388,000	$ 11,985,000	$ 12,409,000
Subtotal B	$ 477,400,000	$ 509,800,000	$ 506,500,000	$ 436,100,000	$ 577,900,000	$ 517,300,000	$ 535,600,000
12% Startup and Construction Sequencing	$ 57,288,000	$ 61,176,000	$ 60,780,000	$ 52,332,000	$ 69,348,000	$ 62,076,000	$ 64,272,000
5% Construction Easements	$ 23,870,000	$ 25,490,000	$ 25,325,000	$ 21,805,000	$ 28,895,000	$ 25,865,000	$ 26,780,000
10% General Conditions	$ 47,740,000	$ 50,980,000	$ 50,650,000	$ 43,610,000	$ 57,790,000	$ 51,730,000	$ 53,560,000
10% Contractor Overhead and Profit	$ 47,740,000	$ 50,980,000	$ 50,650,000	$ 43,610,000	$ 57,790,000	$ 51,730,000	$ 53,560,000
9% Sales Tax (1/2 of B)	$ 21,483,000	$ 22,941,000	$ 22,793,000	$ 19,625,000	$ 26,006,000	$ 23,279,000	$ 24,102,000
Subtotal C Construction Costs	$ 675,500,000	$ 721,400,000	$ 716,700,000	$ 617,100,000	$ 817,700,000	$ 732,000,000	$ 757,900,000
0% Market Factor	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Construction Costs with Market Factor	$ 675,500,000	$ 721,400,000	$ 716,700,000	$ 617,100,000	$ 817,700,000	$ 732,000,000	$ 757,900,000
5% Change Order Contingency (10% if less than $50M)	$ 33,775,000	$ 36,070,000	$ 35,835,000	$ 30,855,000	$ 40,885,000	$ 36,600,000	$ 37,895,000
Total Construction Costs	$ 709,275,000	$ 757,470,000	$ 752,535,000	$ 647,955,000	$ 858,585,000	$ 768,600,000	$ 795,795,000
5% Planning and Permitting	$ 35,464,000	$ 37,874,000	$ 37,627,000	$ 32,398,000	$ 42,930,000	$ 38,430,000	$ 39,790,000
15% Engineering	$ 106,392,000	$ 113,621,000	$ 112,881,000	$ 97,194,000	$ 128,788,000	$ 115,290,000	$ 119,370,000
15% Construction Management	$ 106,392,000	$ 113,621,000	$ 112,881,000	$ 97,194,000	$ 128,788,000	$ 115,290,000	$ 119,370,000
Subtotal Project Costs	$ 957,500,000	$ 1,022,600,000	$ 1,015,900,000	$ 874,700,000	$ 1,159,100,000	$ 1,037,600,000	$ 1,074,300,000
30% Estimating Contingency (includes market factor contingency)	$ 287,250,000	$ 306,780,000	$ 304,770,000	$ 262,410,000	$ 347,730,000	$ 311,280,000	$ 322,290,000
Total Project Costs	$ 1,244,800,000	$ 1,329,400,000	$ 1,320,700,000	$ 1,137,100,000	$ 1,506,800,000	$ 1,348,900,000	$ 1,396,600,000

TABLE B.3 SUMMARY OF ECONOMIC EVALUATION OF NUTRIENT REDUCTION ALTERNATIVES

	Alt. 1: HPO	Alt. 2: AS BNR	Alt. 3: MBR	Alt. 4: IFAS	Alt. 5: AGS	Alt. 6: De-centralized	Alt. 7: Split Flow
Total Capital Cost ($ millions) [(a)]	**$ 1,240**	**$ 1,330**	**$ 1,320**	**$ 1,180**	**$ 1,510**	**$ 1,350**	**$ 1,400**
Total Annual Operating Costs (Year 1) ($ millions) [(a)]	**$ 25.9**	**$ 13.8**	**$ 17.0**	**$ 13.7**	**$ 12.4**	**$ 19.5**	**$ 13.5**
Power	$ 5.4	$ 2.3	$ 4.2	$ 3.1	$ 2.7	$ 3.5	$ 2.5
Chemical	$ 9.7	$ 1.7	$ 1.9	$ 1.7	$ -	$ 1.6	$ 0.7
Labor	$ -	$ -	$ -	$ -	$ -	$ 4.6	$ -
Equipment Replacement [(b)]	$ -	$ 0.1	$ 2.4	$ 0.0	$ 0.2	$ 0.1	$ 0.1
Rehabilitation and Replacement (R&R) [(c)]	$ 10.8	$ 9.7	$ 8.5	$ 8.8	$ 9.6	$ 9.8	$ 10.1
Net Present Value ($ millions) [(a)]	**$ 2,200**	**$ 1,830**	**$ 1,940**	**$ 1,680**	**$ 1,950**	**$ 2,050**	**$ 1,880**
TN Reduction (million lbs/30 yrs)	284	284	284	284	284	284	284
Nutrient Reduction Unit Cost, $/lb TN	$ 7.7	$ 6.4	$ 6.8	$ 5.9	$ 6.9	$ 7.2	$ 6.6

Notes:

a. All costs are presented in 2021 dollars and rounded. Costs are Class 5 estimates. Costs were developed to determine differences between alternatives and do not include elements expected to be common to all alternatives (e.g., annual labor costs).

b. Equipment replacement includes membrane diffusers and membrane modules.

c. R&R costs to replace aging infrastructure.

APPENDIX C – Detailed Non-Economic Alternative Scoring

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Table C.1 - Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores [a]						
				Alt. 1 HPOAS	Alt. 2 AS BNR	Alt. 3 MBR	Alt. 4 IFAS	Alt. 5 AGS	Alt. 6 Decentralized IFAS at MWWTP + AGS	Alt. 7 Split Flow AS BNR + AGS
Technical										
Efficient Land Use and Site Layout	Does it minimize the footprint required per mgd of influent? Does it leave space for future improvements, expansion, or upgrades? How well do future facilities integrate with existing facilities?	Acreage of treatment facilities (Qualitative: low, medium, high) Synergies in facility placement and logical flow (Qualitative: high, medium, low)	**Score and Justification**	5	3	5	4	4	3	3
				High synergy and logical flow. Integrates well with existing facilities. Requires few modifications to existing secondary process.	Largest footprint of all alternatives. Requires relocation of several facilities including administration and maintenance buildings.	Although it is the most compact footprint of all the alternatives, it does not leverage the infrastructure and space currently taken by the secondary clarifiers. Maintenance building still requires relocation.	Although this is not the most compact alternative, it fully leverages the existing secondary process infrastructure and requires the least additional space for new facilities. Maintenance building still requires relocation.	Although it is more compact than the AS BNR process when considering the entire secondary process, AGS requires a similar amount of new bioreactor volume. In addition, it does not leverage the existing secondary clarifiers. That space and infrastructure is available for other uses. Many existing facilities require relocation.	Facilities at the MWWTP will be 5-10% smaller due to reduced load from the nutrient removal facilities at Oakport and Pt. Isabel. This reduction will reduce site constraints, but requires construction of new facilities at wet weather facilities and taking up space there.	Although existing secondary process will be leveraged by conversion to AS BNR, new infrastructure will still take up significant space and require relocation of the administration and maintenance buildings.
Construct-ability	How easily can the future facilities be constructed? How easy will it be to continue operating the existing processes during construction?	Simplicity of construction phasing (Qualitative: simple, moderate, or complex)	**Score and Justification**	5	3	4	4	3	4	4
				Requires least amount of work and impact to existing process and operation.	Takes most space and requires relocation of several facilities including administration and maintenance buildings.	Most compact alternative. Secondary clarifiers are not used, although that space is available for other future facilities, if needed.	Not as compact as MBR, although more compact and easily sequenced than AS BNR.	More than 2/3rd of the process capacity can be installed before HPO reactors need to be taken off-line and upgraded. However, layout requires relocating administration and maintenance buildings.	Similar to IFAS. Fewer space constraints for construction at Wet Weather Facilities.	Easily integrates with existing HPO system. New process can be built first, then HPO system can be converted after.

Table C.1 - Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores [a]						
				Alt. 1 HPOAS	Alt. 2 AS BNR	Alt. 3 MBR	Alt. 4 IFAS	Alt. 5 AGS	Alt. 6 Decentralized IFAS at MWWTP + AGS	Alt. 7 Split Flow AS BNR + AGS
Technology Maturity/ Reliability	How many existing WWTPs have the proposed technology/approach? How large are they and how long have they been operating successfully? Will the treatment process be reliable and robust with respect to meeting current and future regulations under a variety of flow/load conditions? Does this alternative have flexibility to handle high peaking factors/wet weather flows?	Operating history (Qualitative: significant, moderate, minimal) based on: - Number of installations - Size of installations - Years of successful, reliable operation meeting similar regulations Effluent quality consistently meets potential effluent limits under variable flow/load conditions (Qualitative: high, medium, low consistency)	**Score and Justification**	5	5	4	3	2	3	3
				Hundreds of operating BAF and Denitrification filter installations with proven track record in removing nutrients and achieving low effluent solids. First BAF installation was in 1981. This alternative can also accommodate lower nitrogen limits with the addition of more carbon and some phosphorus removal with the addition of chemicals upstream of the denitrification filters.	The most common nitrogen removal process in the municipal industry. The first MLE process was implemented in the early 1970's and is the most common nitrogen removal process for reducing effluent nitrogen down to TN of 10 mg/L. Process can achieve lower effluent nitrogen with additional stages and conversion to a 4-stage Bardenpho process with supplemental carbon. Phosphorus removal can be achieved with the addition of an anaerobic zone.	Technology has been in use for 20+ years and there are hundreds of installations worldwide. Largest installation is 40 mgd. Although not as common as conventional activated sludge systems, systems perform very well and produce filtered effluent that is very low in TSS and BOD. Effluent is suitable for reuse in CA with additional disinfection. The controls for MBR will be more complex and will likely become less reliable with age.g.	The first IFAS installation was in 1984 in Northern Europe where the technology was initially developed and advanced. Technology was initially developed for cold-weather nitrification and has grown to over 200 installations worldwide. There are nearly 100 installations in the U.S. Although there are fewer installations, the technology is similar in performance and reliability as AS BNR.	Emerging technology (<10 years) with 30+ operating facilities worldwide and 2 being in the U.S. (0.2 and 3.6 mgd). There are 4 facilities larger than 20 mgd; 1 in the Netherlands and 3 in Brazil. Process performance track record is good so far, with some susceptibility to effluent TSS conc. being higher than what is seen from an activated sludge process. This is believed to be due to poor capture and settling of fine particles due to granular nature of biomass (as opposed to flocculent nature of a suspended growth system).	Similar to IFAS and AGS.	Average of AS BNR and AGS.

Table C.1 - Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores (a)						
				Alt. 1 HPOAS	Alt. 2 AS BNR	Alt. 3 MBR	Alt. 4 IFAS	Alt. 5 AGS	Alt. 6 Decentralized IFAS at MWWTP + AGS	Alt. 7 Split Flow AS BNR + AGS
Flexibility/ Ease of O&M	Will O&M labor hours be minimized? Is staff already familiar with the process or will it require substantial staff training? Is the technology serviceable in the United States, or does it require parts from outside the country? Will reliance on third parties be minimized (e.g., for special maintenance, management /marketing the product(s), etc.)? Will a third party manage or market the product?	O&M effort (Qualitative: low, medium, high) based on: - O&M labor hours - O&M training - Monitoring/ instrumentation - Wait time for parts/support - Specialized staff required and reliance on third parties - Complexity/ difficulty of O&M activities	**Score and Justification**	4	5	3	3	3	1	3
				Existing process remains the same and District would add the operation of a new post-secondary nitrification and denitrifying facilities. Some specialty parts will be needed as well as additional training.	Least amount of proprietary parts. Although operation of a nutrient removal activated sludge process is different than HPOAS, retraining for new process is not anticipated to be overly complicated.	Although process will be appropriately automated, MBR systems require more complicated controls and many specialty parts including the membranes themselves.	Process is similar to the AS BNR, but with added complexity of the media and screens in the IFAS reactor zones. Requires a more precise control of operating parameters (compared to AS BNR) to maintain proper distribution of suspended and biofilm growth. Some specialty parts are required.	Since this process is like a sequencing batch reactor, it is highly automated to control the feed, wasting, withdrawal, and cycling of all the different reactor phases. The automation reduces manual labor, but does not replace the need to monitor the operation and performance, make necessary adjustments, and maintain the instrumentation and equipment. Specialty parts are needed as well as training for the new process.	Highest labor effort because additional staff needed at wet weather facilities and AGS process has higher O&M (see AGS alternative).	More complex to operated two facilities instead of 1.

Table C.1 - Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores (a)						
				Alt. 1 HPOAS	Alt. 2 AS BNR	Alt. 3 MBR	Alt. 4 IFAS	Alt. 5 AGS	Alt. 6 Decentralized IFAS at MWWTP + AGS	Alt. 7 Split Flow AS BNR + AGS
Resiliency	Does it maximize the ability to protect life safety and convey wastewater flows to SF Bay during the following events? - Seismic event (It is assumed new construction will have greater ability.) - Storm surge/flood event Does it maximize the ability to maintain typical function under latest projected changes in sea/tide levels? Does it enhance the ability to meet regulations and safety goals by providing resiliency?	Relative change in cost to protect life safety and convey wastewater flows to SF Bay (Qualitative: decrease, minimal change, increase) Relative change in cost to maintain typical function (Qualitative: decrease, minimal change, increase)	Score and Justification	2	3	4	3	5	3	3
				Existing secondary process will remain and new facilities will be constructed to higher standards of seismic and storm reliability.	Most of bioreactor tank capacity will be new and constructed to higher standards of seismic and storm reliability.	After AGS alternative, least reliance on existing facilities and new facilities will be constructed to higher standards of seismic and storm reliability.	Most of bioreactor tank capacity will be new and constructed to higher standards of seismic and storm reliability.	Least reliance on existing facilities and new facilities will be constructed to higher standards of seismic and storm reliability.	Similar to IFAS.	Similar to AS BNR.

Table C.1 - Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores (a)						
				Alt. 1 HPOAS	Alt. 2 AS BNR	Alt. 3 MBR	Alt. 4 IFAS	Alt. 5 AGS	Alt. 6 Decentralized IFAS at MWWTP + AGS	Alt. 7 Split Flow AS BNR + AGS
Environmental										
Flexibility to Meet Current/ Future Regulations	Can it reliably meet current regulations? Does the alternative have flexibility to be modified to meet increasingly stringent regulations (including water quality, biosolids, and air regulations)?	Flexibility to easily implement alternate configurations/ future technologies over time (Qualitative: high, medium, low)	**Score and Justification**	5	4	3	3	3	3	3
				This alternative can also accommodate lower nitrogen limits with the addition of more carbon and some phosphorus removal with the addition of chemicals upstream of the denitrification filters. BAF/Denite filters can be added in phases as needed. Process can not easily be modified in the future to integrate emerging, intensification technologies.	Process can achieve lower effluent nitrogen with additional stages and conversion to a 4-stage Bardenpho process with supplemental carbon. Phosphorus removal can be achieved with the addition of an anaerobic zone. Process can easily be modified in the future to integrate emerging, intensification technologies (e.g., IFAS, AGS).	System is similar to AS BNR for nutrient removal and produces filtered effluent that is very low in TSS and BOD. Effluent is suitable for reuse in CA with additional disinfection. Chemicals can be added upstream of membranes for some phosphorus removal. Once configured, MBR process is not easily be modified in the future to integrate emerging, intensification technologies.	Process can achieve similar limits to AS BNR. Once configured, IFAS process is not as easily modified as AS BNR is to integrate emerging intensification technologies (e.g., AGS).	Process is capable of achieving low effluent limits and some phosphorus removal, though this would require additional bioreactor volume. Filtration would need to be added to achieve very low phosphorus limits. Aeration basins can easily be added in phases to operated in parallel with HPOAS system.	Similar to IFAS and AGS.	Similar to AGS.
Maximize Recoverable Resources	Does it maximize utilization of the R2 Program? Does it support beneficial use of biosolids? Does it support nutrient recovery? Does it support water reuse?	Change in R2 Program (Qualitative: increase, minimal change, decrease) Beneficial use of biosolids (Qualitative: high, medium, low) Utilization of recoverable resources (treatment byproducts) (Qualitative: high, medium, low)	**Score and Justification**	5	4	5	3	2	4	3
				Can generate Title 22 quality water with respect to turbidity.	Produces effluent that is very suitable for filtration.	Achieves Title 22 quality water (with respect to turbidity).	Produces effluent that is suitable for filtration, but likely needs more chemical than for AS BNR as fixed film processes tend to produce small particles that are not as filterable as suspended growth only systems.	Granular biomass likely does not capture fine solids as well as AS BNR (or IFAS). Anticipate effluent would require more chemicals for filter conditioning.	Having satellite facilities away from the MWWTP supports implementing recycled water distribution in those locations.	Average of AS BNR and AGS

Table C.1 - Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores (a)						
				Alt. 1 HPOAS	Alt. 2 AS BNR	Alt. 3 MBR	Alt. 4 IFAS	Alt. 5 AGS	Alt. 6 Decentralized IFAS at MWWTP + AGS	Alt. 7 Split Flow AS BNR + AGS
Minimize Treatment Process GHG Emissions	Will it result in a change in GHG emissions?	GHG emissions (Qualitative: low, medium, high)	Score and Justification	1	4	3	4	5	4	5
				Estimated 11,400 metric tons CO2e/yr (based on power and N2O calculated from population equivalents).	Estimated 7,200 metric tons CO2e/yr (based on power and N2O calculated from population equivalents).	Estimated 12,100 metric tons CO2e/yr (based on power and N2O calculated from population equivalents).	Estimated 9,600 metric tons CO2e/yr (based on power and N2O calculated from population equivalents).	Estimated 8,200 metric tons CO2e/yr (based on power and N2O calculated from population equivalents).	Estimated 9,300 metric tons CO2e/yr (based on power and N2O calculated from population equivalents).	Estimated 7,800 metric tons CO2e/yr (based on power and N2O calculated from population equivalents).
a. Minimize energy purchases (electricity and natural gas)	Will it minimize flaring of biogas? Will it increase the biogas/energy generation potential? Is this Master Plan alternative energy efficient?	Energy purchase (Quantitative: metric tons carbon dioxide equivalent per year based on kWh or Btu purchased per year)	Justification	Average power demand of 5,000 kW (in 2050). High chemical usage.	Average power demand of 2,900 kW (in 2050). Moderate chemical usage.	Average power demand of 5,400 kW (in 2050). Moderate chemical usage.	Average power demand of 4,000 kW (in 2050). Moderate chemical usage.	Average power demand of 3,400 kW (in 2050). No chemical usage.	Average power demand of 4,000 kW (in 2050). Moderate chemical usage.	Average power demand of 3,200 kW (in 2050). Moderate chemical usage.
b. Minimize nitrous oxide (N2O) emissions (under consideration)	Will it decrease the N2O at the plant and the receiving water (San Francisco Bay)?	GHGs from N2O emissions both at the MWWTP and at San Francisco Bay (Quantitative: metric tons carbon dioxide equivalent per year based on N2O emissions)	Justification	Industry accepted calculation approach based on population for nitrogen removal processes, no differentiation based on technology at this time.	Industry accepted calculation approach based on population for nitrogen removal processes, no differentiation based on technology at this time.	Industry accepted calculation approach based on population for nitrogen removal processes, no differentiation based on technology at this time.	Industry accepted calculation approach based on population for nitrogen removal processes, no differentiation based on technology at this time.	Industry accepted calculation approach based on population for nitrogen removal processes, no differentiation based on technology at this time.	Industry accepted calculation approach based on population for nitrogen removal processes, no differentiation based on technology at this time.	Industry accepted calculation approach based on population for nitrogen removal processes, no differentiation based on technology at this time.
Minimize Chemical Use	Does it minimize chemical addition for treatment?	Chemical usage (Qualitative: low, medium, high)	Score and Justification	1	3	3	3	5	3	4
				Nearly 15,000 gpd of methanol and 2,500 gpd of caustic. Significantly higher chemical usage than other alternatives.	Approximately 3,000 gpd of methanol needed to meet target nitrogen reduction.	Approximately 3,000 gpd of methanol needed to meet target nitrogen reduction. In addition, some chemical needed for membrane cleanings.	Approximately 3,000 gpd of methanol needed to meet target nitrogen reduction.	No supplemental carbon required.	Similar to IFAS.	Average of AS BNR and IFAS.

Table C.1 - Alternative Scoring for Non-Economic Evaluation Criteria

				Unweighted Scores [a]						
Criteria	**Considerations**	**Metrics (Qualitative/ Quantitative)**		**Alt. 1 HPOAS**	**Alt. 2 AS BNR**	**Alt. 3 MBR**	**Alt. 4 IFAS**	**Alt. 5 AGS**	**Alt. 6 Decentralized IFAS at MWWTP + AGS**	**Alt. 7 Split Flow AS BNR + AGS**
Social										
Community Acceptability	Will the alternative introduce a source of odors, noise, and/or other emissions? Will the alternative result in adverse visual impacts? Will the alternative increase or decrease local truck traffic? Will the alternative provide a community benefit (e.g., product the community can use)?	Change in negative community impacts (Qualitative: decrease, minimal change, increase) based on: - Noise - Odor emissions - Number of structures negatively impacting views or visual aesthetics - Truck traffic Change in positive community impacts (Qualitative: decrease, minimal change, increase) based on: - Community benefits	Score and Justification	2	3	3	3	3	4	3
				Alternative will increase truck traffic due to additional chemical deliveries (approximately 4 more trucks per day).	Negligible change from current acceptability.	Negligible change from current acceptability.	Negligible change from current acceptability.	Negligible change from current acceptability.	Reducing load at MWWTP may have effect of reducing truck traffic and odors very slightly.	Negligible change from current acceptability.
Facility Safety	Does the alternative promote staff safety	Change in the safety of the facilities/ work environment (Qualitative: increase, minimal change, or decrease)	Score and Justification	3	4	4	4	5	4	4.5
				HPOAS still in use and significant amount of supplemental carbon needed for denit filters (15,000 gpd methanol). The production, handling, and storage of liquid oxygen for HPOAS process poses some risk.	Eliminates need for HPO production and use, although some chemical needed for supplemental carbon. (3,000 gpd methanol).	Eliminates need for HPO production and use, although some chemical needed for supplemental carbon. (3,000 gpd methanol).	Eliminates need for HPO production and use, although some chemical needed for supplemental carbon. (3,000 gpd methanol).	Eliminates need for HPO production and chemical use.	Similar to IFAS.	Average of AS-BNR and AGS

Table C.1 - Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	**Considerations**	**Metrics (Qualitative/ Quantitative)**		**Unweighted Scores (a)**						
				Alt. 1 **HPOAS**	**Alt. 2** **AS BNR**	**Alt. 3** **MBR**	**Alt. 4** **IFAS**	**Alt. 5** **AGS**	**Alt. 6** **Decentralized IFAS at MWWTP + AGS**	**Alt. 7** **Split Flow AS BNR + AGS**
Facility and Public Engagement	Does the MWWTP promote staff and public engagement (e.g., functional and aesthetic site layout, adequate space for staff collaboration and public visitors)?	Change in factors/ amenities promoting staff and public engagement (Qualitative: increase, minimal change, decrease) Change in potential for highly functional and aesthetic site layout/facilities (Qualitative: increase, minimal change, decrease)	**Score and Justification**	3	3	3	3	3	3	3
				Negligible difference among alternatives.	Negligible difference among alternatives.	Negligible difference among alternatives.	Negligible difference among alternatives.	Negligible difference among alternatives.	Negligible difference among alternatives.	Negligible difference among alternatives.
		Total								
		Total Unweighted Score		**41**	**44**	**44**	**40**	**43**	**39**	**41.5**

Notes:
a) Score assigned on scale of 1 - 5.
1 = alternative is **LEAST** aligned with the criteria
5 = alternative is **MOST** aligned with the criteria

APPENDIX D – Screening Results Workshop Materials

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Workshop materials removed to reduce file size. Key assumptions, drivers, and decisions are documented within task report.

APPENDIX E – Flow and Load Projections

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TABLE E.1 FLOW AND LOAD OVERVIEW

	Peaking Factors					2020							2030						
	Peak 30-d	Peak 10-d	Peak 7-d	Peak 3-d	Peak Day	Average Dry Weather	PHWWF	Peak 30-d	Peak 10-d	Peak 7-d	Peak 3-d	Peak Day	Average Dry Weather	PHWWF	Peak 30-d	Peak 10-d	Peak 7-d	Peak 3-d	Peak Day
Raw Influent plus Low-Strength Waste																			
Flow, mgd	2.2	3.0	2.9	3.6	4.4	52	415	115	156	153	187	281	56	415	124	167	164	200	284
TSS Loading, lb/d	1.5	1.9	1.9	3.1	3.1	193,566	---	282,201	366,726	366,726	601,370	601,370	218,478	---	318,521	413,924	413,924	678,767	678,767
COD Loading, lb/d	1.2	1.4	1.4	2.1	2.1	401,241	---	489,662	555,253	566,546	861,987	861,987	452,168	---	551,811	625,727	638,454	971,393	971,393
cBOD Loading, lb/d	1.2	1.4	1.4	2.1	2.1	170,197	---	207,703	235,525	240,315	365,634	365,634	192,464	---	234,876	266,338	271,755	413,469	413,469
TKN Loading, lb/d	1.2	1.3	1.3	1.3	1.3	26,455	---	31,787	35,002	35,002	35,002	35,002	29,983	---	36,025	39,669	39,669	39,669	39,669
Ammonia Loading, lb-N/d	1.1	1.3	1.3	1.3	1.3	16,535	---	18,133	21,145	21,145	21,145	21,145	18,739	---	20,551	23,964	23,964	23,964	23,964
Nitrate Loading, lb-N/d	4.1	7.3	7.3	7.3	7.3	1,080	---	4,467	7,932	7,932	7,932	7,932	1,213	---	5,014	8,904	8,904	8,904	8,904
Nitrite Loading, lb-N/d	1.8	2.5	2.5	2.5	2.5	485	---	884	1,211	1,211	1,211	1,211	551	---	1,004	1,376	1,376	1,376	1,376
ortho-Phosphate Loading, lb-P/d	1.2	1.8	1.8	1.8	1.8	2,271	---	2,661	4,018	4,018	4,018	4,018	2,557	---	2,997	4,526	4,526	4,526	4,526
Total Phosphorus Loading, lb/d	1.2	1.4	1.4	1.4	1.4	4,299	---	5,369	6,037	6,037	6,037	6,037	4,872	---	6,084	6,842	6,842	6,842	6,842
Raw Influent plus Low-Strength Waste																			
TSS, mg/L						444	---	293	282	287	386	257	468	---	308	297	302	407	286
COD, mg/L						921	---	508	426	444	554	368	968	---	534	448	466	582	410
cBOD, mg/L						391	---	216	181	188	235	156	412	---	227	191	198	248	174
TKN, mg/L						60.72	---	33.00	26.88	27.41	22.48	14.96	64.20	---	34.89	28.42	28.97	23.77	16.74
Ammonia, mg/L						37.95	---	18.83	16.24	16.56	13.58	9.04	40.12	---	19.90	17.17	17.50	14.36	10.11
Nitrate, mg/L						2.48	---	4.64	6.09	6.21	5.09	3.39	2.60	---	4.86	6.38	6.50	5.33	3.76
Nitrite, mg/L						1.11	---	0.92	0.93	0.95	0.78	0.52	1.18	---	0.97	0.99	1.00	0.82	0.58
ortho-Phosphate, mg/L						5.21	---	2.76	3.09	3.15	2.58	1.72	5.48	---	2.90	3.24	3.31	2.71	1.91
Total Phosphorus, mg/L						9.87	---	5.57	4.64	4.73	3.88	2.58	10.43	---	5.89	4.90	5.00	4.10	2.89
High-Strength Waste																			
Flow, gpd	1.2	1.3	1.3	1.6	1.7	240,587	---	288,705	312,763	312,763	384,939	408,998	235,000	---	282,000	305,500	305,500	376,000	399,500
TS Loading, lb/d	1.2	1.3	1.3	1.6	1.7	141,400	---	169,680	183,820	183,820	226,240	240,380	147,550	---	177,060	191,815	191,815	236,080	250,835
VS Loading, lb/d	1.2	1.3	1.3	1.6	1.7	114,737	---	137,685	149,158	149,158	183,579	195,053	122,298	---	146,758	158,988	158,988	195,677	207,907
(Filtered) COD Loading, lb/d	1.2	1.3	1.3	1.6	1.7	177,939	---	213,527	231,321	231,321	284,703	302,496	192,790	---	231,348	250,627	250,627	308,464	327,743
TKN Loading, lb/d	1.2	1.3	1.3	1.6	1.7		---	-	-	-	-	-		---	-	-	-	-	-
Ammonia Loading, lb-N/d	1.2	1.3	1.3	1.6	1.7		---	-	-	-	-	-		---	-	-	-	-	-
Nitrate Loading, lb-N/d	1.2	1.3	1.3	1.6	1.7		---	-	-	-	-	-		---	-	-	-	-	-
Nitrite Loading, lb-N/d	1.2	1.3	1.3	1.6	1.7		---	-	-	-	-	-		---	-	-	-	-	-
Total Nitrogen Loading, lb/d	1.2	1.3	1.3	1.6	1.7	6,858	---	8,229	8,915	8,915	10,972	11,658	6,983	---	8,380	9,078	9,078	11,173	11,871
ortho-Phosphate Loading, lb-P/d	1.2	1.3	1.3	1.6	1.7		---	-	-	-	-	-		---	-	-	-	-	-
Alkalinity Loading, lb/d	1.2	1.3	1.3	1.6	1.7		---	-	-	-	-	-		---	-	-	-	-	-
High-Strength Waste																			
TS, mg/L						70,471	---	70,471	70,471	70,471	70,471	70,471	75,284	---	75,284	75,284	75,284	75,284	75,284
VS, mg/L						57,183	---	57,183	57,183	57,183	57,183	57,183	62,400	---	62,400	62,400	62,400	62,400	62,400
Filtered COD, mg/L						88,681	---	88,681	88,681	88,681	88,681	88,681	98,367	---	98,367	98,367	98,367	98,367	98,367
TKN, mg/L							---							---					
Ammonia, mg/L							---							---					
Nitrate, mg/L							---							---					
Nitrite, mg/L							---							---					
Total Nitrogen, mg/L						3,418	---	3,418	3,418	3,418	3,418	3,418	3,563	---	3,563	3,563	3,563	3,563	3,563
ortho-Phosphate, mg/L							---	-	-	-	-	-		---	-	-	-	-	-
Alkalinity, mg/L							---	-	-	-	-	-		---	-	-	-	-	-

TABLE E.1 FLOW AND LOAD OVERVIEW

	Peaking Factors					2040							2050						
	Peak 30-d	Peak 10-d	Peak 7-d	Peak 3-d	Peak Day	Average Dry Weather	PHWWF	Peak 30-d	Peak 10-d	Peak 7-d	Peak 3-d	Peak Day	Average Dry Weather	PHWWF	Peak 30-d	Peak 10-d	Peak 7-d	Peak 3-d	Peak Day
Raw Influent plus Low-Strength Waste																			
Flow, mgd	2.2	3.0	2.9	3.6	4.4	61	415	134	181	177	216	289	66	415	146	197	193	236	294
TSS Loading, lb/d	1.5	1.9	1.9	3.1	3.1	246,697	---	359,662	467,387	467,387	766,439	766,439	278,444	---	405,946	527,534	527,534	865,069	865,069
COD Loading, lb/d	1.2	1.4	1.4	2.1	2.1	509,709	---	622,032	705,354	719,700	1,095,007	1,095,007	574,745	---	701,400	795,354	811,531	1,234,725	1,234,725
cBOD Loading, lb/d	1.2	1.4	1.4	2.1	2.1	217,596	---	265,547	301,118	307,242	467,462	467,462	246,036	---	300,254	340,474	347,399	528,559	528,559
TKN Loading, lb/d	1.2	1.3	1.3	1.3	1.3	33,731	---	40,529	44,628	44,628	44,628	44,628	38,140	---	45,826	50,461	50,461	50,461	50,461
Ammonia Loading, lb-N/d	1.1	1.3	1.3	1.3	1.3	21,164	---	23,210	27,065	27,065	27,065	27,065	23,810	---	26,112	30,448	30,448	30,448	30,448
Nitrate Loading, lb-N/d	4.1	7.3	7.3	7.3	7.3	1,367	---	5,652	10,037	10,037	10,037	10,037	1,521	---	6,290	11,170	11,170	11,170	11,170
Nitrite Loading, lb-N/d	1.8	2.5	2.5	2.5	2.5	617	---	1,125	1,541	1,541	1,541	1,541	683	---	1,245	1,706	1,706	1,706	1,706
ortho-Phosphate Loading, lb-P/d	1.2	1.8	1.8	1.8	1.8	2,888	---	3,385	5,111	5,111	5,111	5,111	3,241	---	3,798	5,735	5,735	5,735	5,735
Total Phosphorus Loading, lb/d	1.2	1.4	1.4	1.4	1.4	5,512	---	6,883	7,740	7,740	7,740	7,740	6,217	---	7,764	8,730	8,730	8,730	8,730
Raw Influent plus Low-Strength Waste																			
TSS, mg/L						489	---	322	310	316	425	318	506	---	334	321	327	440	353
COD, mg/L						1,009	---	557	467	486	607	455	1,045	---	577	484	503	628	504
cBOD, mg/L						431	---	238	200	208	259	194	447	---	247	207	215	269	216
TKN, mg/L						66.80	---	36.30	29.57	30.15	24.73	18.53	69.33	---	37.68	30.69	31.29	25.67	20.58
Ammonia, mg/L						41.91	---	20.79	17.94	18.28	15.00	11.24	43.28	---	21.47	18.52	18.88	15.49	12.42
Nitrate, mg/L						2.71	---	5.06	6.65	6.78	5.56	4.17	2.77	---	5.17	6.79	6.93	5.68	4.56
Nitrite, mg/L						1.22	---	1.01	1.02	1.04	0.85	0.64	1.24	---	1.02	1.04	1.06	0.87	0.70
ortho-Phosphate, mg/L						5.72	---	3.03	3.39	3.45	2.83	2.12	5.89	---	3.12	3.49	3.56	2.92	2.34
Total Phosphorus, mg/L						10.91	---	6.17	5.13	5.23	4.29	3.21	11.30	---	6.38	5.31	5.41	4.44	3.56
High-Strength Waste																			
Flow, gpd	1.2	1.3	1.3	1.6	1.7	239,743	---	287,691	311,665	311,665	383,588	407,562	244,581	---	293,497	317,955	317,955	391,329	415,787
TS Loading, lb/d	1.2	1.3	1.3	1.6	1.7	150,527	---	180,633	195,686	195,686	240,844	255,897	153,565	---	184,278	199,635	199,635	245,704	261,061
VS Loading, lb/d	1.2	1.3	1.3	1.6	1.7	124,766	---	149,719	162,196	162,196	199,626	212,103	127,284	---	152,741	165,469	165,469	203,655	216,383
(Filtered) COD Loading, lb/d	1.2	1.3	1.3	1.6	1.7	196,680	---	236,017	255,685	255,685	314,689	334,357	200,650	---	240,780	260,845	260,845	321,039	341,104
TKN Loading, lb/d	1.2	1.3	1.3	1.6	1.7		---	-	-	-	-	-		---	-	-	-	-	-
Ammonia Loading, lb-N/d	1.2	1.3	1.3	1.6	1.7		---	-	-	-	-	-		---	-	-	-	-	-
Nitrate Loading, lb-N/d	1.2	1.3	1.3	1.6	1.7		---	-	-	-	-	-		---	-	-	-	-	-
Nitrite Loading, lb-N/d	1.2	1.3	1.3	1.6	1.7		---	-	-	-	-	-		---	-	-	-	-	-
Total Nitrogen Loading, lb/d	1.2	1.3	1.3	1.6	1.7	7,124	---	8,549	9,261	9,261	11,399	12,111	7,268	---	8,722	9,448	9,448	11,629	12,355
ortho-Phosphate Loading, lb-P/d	1.2	1.3	1.3	1.6	1.7		---	-	-	-	-	-		---	-	-	-	-	-
Alkalinity Loading, lb/d	1.2	1.3	1.3	1.6	1.7		---	-	-	-	-	-		---	-	-	-	-	-
High-Strength Waste																			
TS, mg/L						75,284	---	75,284	75,284	75,284	75,284	75,284	75,284	---	75,284	75,284	75,284	75,284	75,284
VS, mg/L						62,400	---	62,400	62,400	62,400	62,400	62,400	62,400	---	62,400	62,400	62,400	62,400	62,400
Filtered COD, mg/L						98,367	---	98,367	98,367	98,367	98,367	98,367	98,367	---	98,367	98,367	98,367	98,367	98,367
TKN, mg/L							---							---					
Ammonia, mg/L							---							---					
Nitrate, mg/L							---							---					
Nitrite, mg/L							---							---					
Total Nitrogen, mg/L						3,563	---	3,563	3,563	3,563	3,563	3,563	3,563	---	3,563	3,563	3,563	3,563	3,563
ortho-Phosphate, mg/L							---	-	-	-	-	-		---	-	-	-	-	-
Alkalinity, mg/L							---	-	-	-	-	-		---	-	-	-	-	-

TABLE E.2 LOADING PROJECTIONS

Loading to IPS (kg/d)

Year	TSS			CBOD			VSS			COD			sCOD			TKN		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
2020	87,700	87,800	88,000	77,200	77,200	77,200	70,900	70,900	71,000	181,400	182,000	182,500	46,100	46,300	46,400	12,000	12,000	12,000
2030	96,100	99,100	112,100	85,300	87,300	98,800	78,100	80,100	90,700	197,800	205,100	231,600	50,200	52,200	58,900	13,200	13,600	15,300
2040	105,400	111,900	142,700	94,200	98,700	126,500	86,000	90,600	115,900	215,800	231,200	294,000	54,800	58,800	74,700	14,500	15,300	19,600
2050	115,700	126,300	181,900	104,000	111,600	161,900	94,800	102,300	148,100	235,700	260,700	373,400	59,700	66,300	94,800	15,900	17,300	25,000

Year	NH3			Alkalinity			TP			Ortho-P			Nitrate			Nitrite		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
2020	7,500	7,500	7,500	59,500	59,500	59,500	1,950	1,950	1,950	1,030	1,030	1,040	490	490	500	220	220	230
2030	8,200	8,500	9,600	65,600	67,300	76,100	2,160	2,210	2,500	1,110	1,160	1,310	510	550	620	230	250	280
2040	9,100	9,600	12,200	72,300	76,000	97,300	2,380	2,500	3,200	1,190	1,310	1,650	540	620	760	230	280	340
2050	10,000	10,800	15,600	79,700	85,900	124,400	2,630	2,820	4,100	1,290	1,470	2,080	560	690	950	240	310	410

	Low				Medium				High			
Parameter (kg/day)	2020	2030	2040	2050	2020	2030	2040	2050	2020	2030	2040	2050
TSS Loading, lb/d	87,700	96,100	105,400	115,700	87,800	99,100	111,900	126,300	88,000	112,100	142,700	181,900
COD Loading, lb/d	181,400	197,800	215,800	235,700	182,000	205,100	231,200	260,700	182,500	231,600	294,000	373,400
cBOD Loading, lb/d	77,200	85,300	94,200	104,000	77,200	87,300	98,700	111,600	77,200	98,800	126,500	161,900
TKN Loading, lb/d	12,000	13,200	14,500	15,900	12,000	13,600	15,300	17,300	12,000	15,300	19,600	25,000
Ammonia Loading, lb-N/d	7,500	8,200	9,100	10,000	7,500	8,500	9,600	10,800	7,500	9,600	12,200	15,600
Nitrate Loading, lb-N/d	490	510	540	560	490	550	620	690	500	620	760	950
Nitrite Loading, lb-N/d	220	230	230	240	220	250	280	310	230	280	340	410
ortho-Phosphate Loading, lb-P/d	1,030	1,110	1,190	1,290	1,030	1,160	1,310	1,470	1,040	1,310	1,650	2,080
Total Phosphorus Loading, lb/d	1,950	2,160	2,380	2,630	1,950	2,210	2,500	2,820	1,950	2,500	3,200	4,100

	Low				Medium				High			
Parameter	2020	2030	2040	2050	2020	2030	2040	2050	2020	2030	2040	2050
TSS Loading, lb/d	193,345	211,864	232,367	255,075	193,566	218,478	246,697	278,444	194,007	247,138	314,600	401,021
COD Loading, lb/d	399,919	436,074	475,758	519,630	401,241	452,168	509,709	574,745	402,344	510,591	648,159	823,206
cBOD Loading, lb/d	170,197	188,054	207,675	229,281	170,197	192,464	217,596	246,036	170,197	217,817	278,885	356,928
TKN Loading, lb/d	26,455	29,101	31,967	35,053	26,455	29,983	33,731	38,140	26,455	33,731	43,211	55,116
Ammonia Loading, lb-N/d	16,535	18,078	20,062	22,046	16,535	18,739	21,164	23,810	16,535	21,164	26,896	34,392
Nitrate Loading, lb-N/d	1,080	1,124	1,190	1,235	1,080	1,213	1,367	1,521	1,102	1,367	1,676	2,094
Nitrite Loading, lb-N/d	485	507	507	529	485	551	617	683	507	617	750	904
ortho-Phosphate Loading, lb-P/d	2,271	2,447	2,624	2,844	2,271	2,557	2,888	3,241	2,293	2,888	3,638	4,586
Total Phosphorus Loading, lb/d	4,299	4,762	5,247	5,798	4,299	4,872	5,512	6,217	4,299	5,512	7,055	9,039

TABLE E.3 FLOW PROJECTIONS

Year	Flow Rate (MGD)		
	Low	Medium	High
2020	51.7	52.2	52.7
2030	52.5	56.0	64.1
2040	54.3	60.5	78.4
2050	56.7	66.0	96.6

APPENDIX F– Planning Level Sizing Criteria

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Table F.1 - Planning Level Criteria for the Nutrient Reduction Alternatives

		Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alternative 6 Decentralized			Alternative 7 Split Flow	
Parameter	**Units**	**HPO**	**AS BNR**	**MBR**	**IFAS**	**AGS**	**AGS at Oakport**	**AGS at Pt Isabel**	**IFAS at MWWTP**	**40% AS BNR**	**60% AGS**
Influent Flow and WW Characteristics (Includes Low Strength Waste)											
Average Dry Weather											
Flow	mgd	66	66	66	66	66	6.0	3.0	66	66	
COD	mg/L	1,045	1,045	1,045	1,045	1,045	1,045	1,045	987	1,046	
cBOD	mg/L	449	449	449	449	449	449	449	409	449	
TSS	mg/L	462	462	462	462	462	468	468	465	462	
NH4-N	mg/L	39.5	39.5	39.5	39.5	39.5	39.5	39.5	34.4	39.5	
TKN	mg/L	69.3	69.3	69.3	69.3	69.3	69.3	69.3	64.3	69.3	
PO4-P	mg/L	5.6	5.6	5.6	5.6	5.6	5.6	5.6	4.9	5.6	
TP	mg/L	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	
Liquid Temperature	deg C	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	
Maximum Month											
Flow	mgd	146	146	146	146	146	12.7	6.3	146	146	
COD	mg/L	577	577	577	577	577	577	577	545	577	
cBOD	mg/L	248	248	248	248	248	248	248	226	248	
TSS	mg/L	282	282	282	282	282	286	286	284	282	
NH4-N	mg/L	21.5	21.5	21.5	21.5	21.5	21.5	21.5	18.7	21.5	
TKN	mg/L	37.7	37.7	37.7	37.7	37.7	37.7	37.7	35.0	37.7	
PO4-P	mg/L	3.2	3.2	3.2	3.2	3.2	3.2	3.2	2.8	3.2	
TP	mg/L	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	
Liquid Temperature	deg C	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	
Recycle Streams											
Average Dry Weather											
WAS Thickening											
Flow	mgd	2.16	1.99	1.89	3.47	0.77	0.00	0.00	3.47	1.25	
TSS	mg/L	436	351	377	225	562	N/A	N/A	227	429	
TKN	mg/L	79	34	35	25	51	N/A	N/A	23	40	
Dewatering											
Flow	mgd	0.86	0.75	0.76	0.79	0.67	0	0	0.79	0.71	
TSS	mg/L	1,154	1,224	1,230	1,189	1,273	N/A	N/A	1,189	1,252	
TKN	mg/L	2,408	2,312	2,298	2,333	2,230	N/A	N/A	2,333	2,266	
BAF											
Flow	mgd	6	0	0	0	0	0	0	0	0	
TSS	mg/L	92	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
TKN	mg/L	15.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Denitrification Filters											
Flow	mgd	3	0	0	0	0	0	0	0	0	
TSS	mg/L	684	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
TKN	mg/L	68.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Total Recycle											
Flow	mgd	11.89	2.74	2.65	4.25	1.44	0	0	4.25	1.96	
TSS	mg/L	396	591	622	404	895	N/A	N/A	405	725	
TKN	mg/L	215	660	684	453	1,071	N/A	N/A	451	841	
Maximum Month											
WAS Thickening											
Flow	mgd	2.00	1.82	1.77	2.20	0.70	0	0	2.20	1.15	
TSS	mg/L	614	521	567	459	833	N/A	N/A	462	636	
TKN	mg/L	66	39	42	35	59	N/A	N/A	33	47	
Dewatering											
Flow	mgd	1.10	0.96	0.97	0.99	0.86	0	0	0.99	0.90	
TSS	mg/L	1,251	1,328	1,359	1,310	1,380	N/A	N/A	1,310	1,733	
TKN	mg/L	2,136	2,084	2,079	2,102	2,010	N/A	N/A	2,102	2,606	
BAF											
Flow	mgd	12	0	0	0	0	0	0	0	0	
TSS	mg/L	129	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
TKN	mg/L	14.4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Denitrification Filters											
Flow	mgd	7	0	0	0	0	0	0	0	0	
TSS	mg/L	397	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
TKN	mg/L	37.4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Total Recycle											
Flow	mgd	22.66	2.78	2.73	3.19	1.56	0	0	3.19	2.05	
TSS	mg/L	312	800	847	722	1,135	N/A	N/A	724	1,119	
TKN	mg/L	129	747	763	674	1,136	N/A	N/A	673	1,173	

Table F.1 - Planning Level Criteria for the Nutrient Reduction Alternatives

		Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alternative 6 Decentralized			Alternative 7 Split Flow	
Parameter	**Units**	**HPO**	**AS BNR**	**MBR**	**IFAS**	**AGS**	**AGS at Oakport**	**AGS at Pt Isabel**	**IFAS at MWWTP**	**40% AS BNR**	**60% AGS**
Primary Sedimentation Tanks											
Number of Duty Tanks in Service	Number	14	14	14	14	14	0	0	14	14	
Number of Standby Tanks	Number	2	2	2	2	2	0	0	2	2	
Total Area In Service	sf	87,500	87,500	87,500	87,500	87,500	N/A	N/A	87,500	87,500	
Average Dry Weather											
Overflow Rate	gpd/sf	886	782	781	799	779	N/A	N/A	799	799	
% TSS Removal	%	64	64	64	64	64	N/A	N/A	64	64	
Primary Sludge Flow	mgd	0.37	0.34	0.34	0.34	0.34			0.34	0.34	
Primary Sludge % TS	mg/L	5.9	5.9	5.9	5.9	5.9			5.9	5.9	
Primary Sludge % VS	mg/L	5.1	5.1	5.1	5.1	5.1			5.1	5.1	
Maximum Month											
Overflow Rate	gpd/sf	1,920	1,693	1,692	1,698	1,688	N/A	N/A	1,698	1,690	
% TSS Removal	%	61	61	61	61	61	N/A	N/A	61	61	
Primary Sludge Flow	mgd	0.485	0.44	0.44	0.44	0.44			0.44	0.44	
Primary Sludge % TS	mg/L	5.9	5.9	5.9	5.9	5.9			5.9	5.9	
Primary Sludge % VS	mg/L	4.6	4.6	4.6	4.6	4.6			4.6	4.6	
Primary Effluent Screening											
Type		N/A	N/A	2 mm spacing	N/A	N/A	N/A	N/A	N/A	N/A	
Number of Duty Screens	Number	0	0	4	0	0	0	0	0	0	
Number of Standby Screens	Number	0	0	1	0	0	0	0	0	0	
Primary Effluent Pumping											
Number of Duty Pumps	Number	0	0	3	0	0	0	0	0	0	
Number of Standby Pumps	Number	0	0	1	0	0	0	0	0	0	
Capacity per Pump	mgd	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A	
Firm Capacity	mgd	N/A	N/A	168	N/A	N/A	N/A	N/A	N/A	N/A	
Existing Mid Plant Pumping											
Number of Duty Pumps	Number	2	2	2	2	2	N/A	N/A	2	2	
Number of Standby Pumps	Number	1	1	1	1	1	N/A	N/A	1	1	
Capacity per Pump	mgd	84	84	84	84	84	N/A	N/A	84	84	
Firm Capacity	mgd	168	168	168	168	168	N/A	N/A	168	168	
Primary Effluent (Secondary Influent)											
Average Dry Weather											
Flow	mgd	78	68	68	70	68	N/A	N/A	70	27	41
COD	mg/L	593	635	636	625	632	N/A	N/A	591	633	
cBOD	mg/L	259	281	281	276	279	N/A	N/A	251	280	
TSS	mg/L	171	175	176	173	173	N/A	N/A	174	174	
NH4-N	mg/L	55	56	56	56	53	N/A	N/A	49	54	
TKN	mg/L	79	81	81	81	78	N/A	N/A	75	79	
PO4-P	mg/L	8	8	8	8	7	N/A	N/A	7	7	
TP	mg/L	10	10	10	10	9	N/A	N/A	10	10	
Maximum Month											
Flow	mgd	168	148	148	149	148	N/A	N/A	149	59	89
COD	mg/L	347	368	369	368	366	N/A	N/A	348	367	
cBOD	mg/L	151	163	163	163	162	N/A	N/A	148	162	
TSS	mg/L	116	118	118	118	116	N/A	N/A	119	117	
NH4-N	mg/L	29	31	31	31	29	N/A	N/A	27	30	
TKN	mg/L	43	45	45	45	43	N/A	N/A	42	44	
PO4-P	mg/L	4	4	4	4	4	N/A	N/A	4	4	
TP	mg/L	6	6	6	6	5	N/A	N/A	6	5	
Bioreactors											
Number of Tanks	Number	8	12	5	10	24	4	4	9	4	14
Volume per Tank	MG	1.6	4.75	5.59	4.75	2.38	1.30	0.65	4.75	4.75	2.36
Total Volume	MG	12.7	57	27	47	57	5.2	2.6	42.7	19	33
Volume Distribution											
Anaerobic	%	25%	0%	0%	0%	N/A	N/A	N/A	0%	0%	N/A
Anoxic	%	0%	33%	23%	33%	N/A	N/A	N/A	33%	33%	N/A
RAS Deox	%	0%	0%	7%	0%	N/A	N/A	N/A	0%	0%	N/A
Aerobic	%	75%	67%	62%	67%	N/A	N/A	N/A	67%	67%	N/A
Aerobic/Membrane Tanks	%	0%	0%	7%	0%	N/A	N/A	N/A	0%	0%	N/A

Table F.1 - Planning Level Criteria for the Nutrient Reduction Alternatives

		Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alternative 6 Decentralized			Alternative 7 Split Flow	
Parameter	**Units**	**HPO**	**AS BNR**	**MBR**	**IFAS**	**AGS**	**AGS at Oakport**	**AGS at Pt Isabel**	**IFAS at MWWTP**	**40% AS BNR**	**60% AGS**
Total	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Average Dry Weather											
Suspended MLSS	mg/L	2,334	2,086	4,524	1,399	1,317	1,076	1,076	1,399	2,503	1,354
MLSS Membrane	mg/L	N/A	N/A	5,648	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Suspended Growth Inventory	lbs	244,948	991,846	1,044,816	459,062	552,800	41,333	20,667	413,156	396,601	331,680
Suspended Growth Aerobic SRT	days	1.1	5.5	5.5	2.8	N/A	N/A	N/A	2.8	5.5	N/A
Suspended Growth SRT	days	1.5	8.3	8.79	3.5	N/A	N/A	N/A	3.5	8.3	N/A
Biofilm Total Media Surface Area	million sf	0	0	0	204	N/A	N/A	N/A	184	0	N/A
Biofilm or Granular Sludge (GS) Inventory	lbs	0	0	0	458,375	3,171,060	233,333	116,667	412,538	0	1,849,785
Total Inventory (Including Biofilm and GS)	lbs	244,948	991,846	1,044,816	917,437	3,723,859	274,667	137,333	825,693	396,601	2,181,465
Aerobic SRT	days	1.1	5.5	5.5	5.5	N/A	N/A	N/A	5.5	5.5	N/A
Total SRT	days	1.5	8.3	8.79	6.9	32	10 to 12	10 to 12	6.9	8.3	32
Maximum Month											
Suspended MLSS	mg/L	3,085	2,919	6,345	2,624	2,470	2,018	2,018	2,624	3,503	2,540
MLSS Membrane	mg/L	N/A	N/A	8,022	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Suspended Growth Inventory	lbs	325,054	1,388,470	1,469,054	872,639	1,036,848	76,667	38,333	785,375	555,136	622,109
Suspended Growth Aerobic SRT	days	1.1	5.5	5.5	3.6	N/A	N/A	N/A	3.6	5.5	N/A
Suspended Growth SRT	days	1.5	8.3	8.8	4.9	N/A	N/A	N/A	4.9	8.3	N/A
Biofilm Total Media Surface Area	million sf	0	0	0	204	N/A	N/A	N/A	184	0	N/A
Biofilm or Granular Sludge (GS) Inventory	lbs	0	0	0	445,668	3,083,152	227,333	113,667	401,101	0	1,798,505
Total Inventory (Including Biofilm and GS)	lbs	325,054	1,388,470	1,469,054	1,318,307	4,120,000	304,000	152,000	1,186,476	555,388	2,420,614
Aerobic SRT	days	1.1	5.5	5.5	5.5	N/A	N/A	N/A	5.5	5.5	N/A
Total SRT	days	1.5	8.3	8.8	7.4	34	10 to 12	10 to 12	7.4	8.3	34
Bioreactor Aeration											
Typical DO in Aerobic Zones	mg/L	6 to 8	2	2	3	0.5 to 2.0	0.5 to 2.0	0.5 to 2.0	3	2	0.5 to 2.0
Average Dry Weather											
OTR	lb/d	122,245	259,132	258,149	244,411	425,804	26,887	13,443	222,529	103,653	255,482
Air Flow	scfm	N/A	56,321	109,334	85,469	97,402	9,400	4,700	77,817	22,528	74,167
Maximum Month											
OTR	lb/d	123,120	309,336	306,305	298,687	550,851	34,800	17,400	271,946	123,735	330,511
Air Flow	scfm	N/A	68,887	157,124	98,753	127,939	11,500	5,750	89,912	27,555	90,833
Diffusers											
Number	Number	0	34,533	48,370	54,394	69,308	6,000	3,000	49,524	13,813	41,585
Type		High Purity Oxygen (HPO)	Fine Bubble	Fine Bubble (Coarse in Membrane Tanks)	Medium Bubble	Fine Bubble	Fine Bubble	Fine Bubble	Medium Bubble	Fine Bubble	Fine Bubble
Blowers											
Number of Duty Units	Number	1	4	6	4	5	1	1	4	5	
Number of Standby Units	Number	1	1	1	1	1	1	1	1	1	
Capacity, each	scfm	Per Capacity Assessment	22,388	34,043	32,095	33,264	14,950	7,475	29,221	30,781	
Firm Capacity	scfm	Per Capacity Assessment	89,553	204,261	128,379	166,320	14,950	7,475	116,886	116,886	
Bioreactor MLR Pumping											
ADW MLR Flow	mgd	0	99	330	99	0	0	0	99	40	0
MM MLR Flow	mgd	0	219	696	219	0	0	0	219	88	0
Number of Duty Pumps	Number	0	12	30	10	0	0	0	9	4	0
Number of Standby Pumps	Number	0	12	5	10	0	0	0	9	4	0
Pump Capacity, each	mgd	N/A	18.2	23.2	21.9	N/A	N/A	N/A	24.3	21.9	N/A
Firm Pumping Capacity	mgd	N/A	219	696	219	N/A	N/A	N/A	219	88	N/A
Solids Separation											
Type		Secondary Clarifiers	Secondary Clarifiers	Membrane Filtration	Secondary Clarifiers	Settling in AGS Reactors	Settling in AGS Reactors	Settling in AGS Reactors	Secondary Clarifiers	Secondary Clarifiers	Settling in AGS Reactors
Secondary Clarification											
Number of Clarifiers	Number	12	12	0	12	0	0	0	12	11	0
Surface Area, each	sf	15,394	15,394	N/A	15,394	N/A	N/A	N/A	15,394	15,394	N/A
Average Dry Weather (w/1 UOOS)											
Surface Overflow Rate	gpd/sf	443	391	N/A	391	N/A	N/A	N/A	391	438	N/A
Solids Loading Rate	lb/d/sf	12	10	N/A	7	N/A	N/A	N/A	7	11	N/A
Maximum Month (w/1 UOOS)											
Surface Overflow Rate	gpd/sf	978	862	N/A	862	N/A	N/A	N/A	862	955	N/A
Solids Loading Rate	lb/d/sf	36	31	N/A	28	N/A	N/A	N/A	28	33	N/A
Settling in AGS Reactors											

Table F.1 - Planning Level Criteria for the Nutrient Reduction Alternatives

		Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alternative 6 Decentralized			Alternative 7 Split Flow	
Parameter	**Units**	**HPO**	**AS BNR**	**MBR**	**IFAS**	**AGS**	**AGS at Oakport**	**AGS at Pt Isabel**	**IFAS at MWWTP**	**40% AS BNR**	**60% AGS**
Effective Surface Overflow Rate at ADWF	gpd/sf	N/A	N/A	N/A	N/A	877	758	758	N/A	N/A	877
Effective Surface Overflow Rate at MMF	gpd/sf	N/A	N/A	N/A	N/A	1,900	1,600	1,600	N/A	N/A	1,900
Membrane Filtration											
Number of Tanks	Number	0	0	32	0	0	0	0	0	0	0
Tank Volume, each	MG	N/A	N/A	0.07	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Tank Volume	MG	N/A	N/A	2.13	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Membrane Area per Tank	million sf	N/A	N/A	0.331	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Membrane Area	million sf	N/A	N/A	10.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Net Flux at ADWF	gfd	N/A	N/A	8.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Net Flux at MMF	gfd	N/A	N/A	16.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
RAS Pumping											
Average Dry Weather RAS Flow	mgd	31	31	262	29	0	0	0	29	12	0
Maximum Month RAS Flow	mgd	70	71	548	70	0	0	0	70	28	0
Number of Duty Pumps	Number	3	3	9	3	0	0	0	3	3	0
Number of Standby Pumps	Number	1	1	1	1	0	0	0	1	1	0
Capacity per Pump	mgd	23	24	61	23	NA	NA	NA	23	9	N/A
Firm Capacity	mgd	70	71	548	70	0	0	0	70	28	0
Waste Activated Sludge (WAS)											
Average Dry Weather											
Flow	mgd	2.50	2.24	2.15	3.76	0.86	0.45	0.22	3.76	0.9	0.5
TSS	mg/L	7,529	6,227	6,630	4,159	9,969	5,308	5,308	4,189	6,231	5,763
VSS	mg/L	6,377	5,111	5,438	3,449	7,712	4,170	4,170	3,475	5,114	4,458
Maximum Month											
Flow	mgd	2.45	2.17	2.13	2.58	0.83	0.43	0.22	2.58	0.9	0.5
TSS	mg/L	10,024	8,728	9,417	7,838	13,975	7,440	7,440	7,895	8,430	7,797
VSS	mg/L	7,977	6,554	7,056	5,954	9,890	5,348	5,348	5,997	6,330	5,518
WAS Pumping											
Number of Duty Pumps	Number	2	2	2	2	2	2	2	2	2	2
Number of Standby Pumps	Number	1	1	1	1	1	1	1	1	1	1
Capacity per Pump	mgd	1.3	1.1	1.1	1.9	0.4	0.2	0.1	1.9	0.4	0.3
Firm Capacity	mgd	2.5	2.2	2.1	3.8	0.9	0.4	0.2	3.8	0.9	0.5
WAS Equalization Tanks											
Number of Tanks	Number	0	0	0	0	1	0	0	0	0	1
Volume	MG	0	0	0	0	6.4	0	0	0	0	3.2
Surface Area	sf	0	0	0	0	30,787	0	0	0	0	15,394
Post Secondary Nitrification											
Feed Pumping											
Number of Duty Pumps	Number	3	0	0	0	0	0	0	0	0	0
Number of Standby Pumps	Number	1	0	0	0	0	0	0	0	0	0
Capacity per Pump	mgd	55.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Firm Capacity	mgd	165.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Type		Biologically Aerated Filter (BAF)	None	None	None	None	None	None	None	None	None
Duty Units	Number	20	0	0	0	0	0	0	0	0	0
Standby Units	Number	2	0	0	0	0	0	0	0	0	0
Surface Area, each	sf	2,582	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Capacity Surface Area	sf	56,804	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Media Depth	ft	11.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Side water depth	ft	18.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Media Volume, each	kcf	30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Capacity Media Volume	kcf	653	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Dry Weather											
Flow	mgd	75	0	0	0	0	0	0	0	0	0
Ammonia Load	lb NH3/kcf/d	42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TKN Load	lb TKN/kcf/d	52	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Load	gpm/sf	0.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Process Aeration	scfm	31,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Maximum Month											
Flow	mgd	166	0	0	0	0	0	0	0	0	0
Ammonia Load	lb NH3/kcf/d	49	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TKN Load	lb TKN/kcf/d	62	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Load	gpm/sf	2.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Process Aeration	scfm	36,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table F.1 - Planning Level Criteria for the Nutrient Reduction Alternatives

		Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alternative 6 Decentralized			Alternative 7 Split Flow	
Parameter	**Units**	**HPO**	**AS BNR**	**MBR**	**IFAS**	**AGS**	**AGS at Oakport**	**AGS at Pt Isabel**	**IFAS at MWWTP**	**40% AS BNR**	**60% AGS**
Post Secondary Denitrification											
Feed Pumping											
Number of Duty Pumps	Number	3	0	0	0	0	0	0	0	0	0
Number of Standby Pumps	Number	1	0	0	0	0	0	0	0	0	0
Capacity per Pump	mgd	51.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Firm Capacity	mgd	153.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Type		Denitrification Filters	None	None	None	None	None	None	None	None	None
Number of Duty Units	Number	17	0	0	0	0	0	0	0	0	0
Number of Standby Units	Number	1	0	0	0	0	0	0	0	0	0
Surface Area, each	sf	2,565	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Capacity Surface Area	sf	46,170	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Media Depth	ft	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Media Volume, each	kcf	26	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Capacity Media Volume	kcf	462	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Dry Weather											
Flow	mgd	69	0	0	0	0	0	0	0	0	0
Nitrate Load	lb NO3/kcf/d	56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Load	gpm/sf	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Maximum Month											
Flow	mgd	153	0	0	0	0	0	0	0	0	0
Nitrate Load	lb NO3/kcf/d	65	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydraulic Load	gpm/sf	2.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Final Effluent											
Average Dry Weather Flow	mgd	66	66	66	66	67	Effluent and WAS to MWWTP	Effluent and WAS to MWWTP	66	66	
Maximum Month Flow	mgd	146	146	146	146	147	Effluent and WAS to MWWTP	Effluent and WAS to MWWTP	146	147	
Final Effluent (Monthly Average)											
cBOD	mg/L	30.0	30.0	10.0	30.0	30.0	N/A	N/A	30.0	30.0	
TSS	mg/L	30.0	30.0	10.0	30.0	30.0	N/A	N/A	30.0	30.0	
NH4-N	mg/L	0.5	0.5	0.5	0.5	0.5	N/A	N/A	0.5	0.5	
TIN	mg/L	10.0	10.0	10.0	10.0	10.0	N/A	N/A	10.0	10.0	
TN	mg/L	15 to 20	20.0	20.0	20.0	20.0	N/A	N/A	20.0	20.0	
Process Chemical Usage											
Methanol (100% Solution)	gpd	9,800	3,000	3,000	3,000	0	0	0	2,700	1,200	0
Alkalinity (45% NaOH Solution)	gpd	2,500	0	0	0	0	0	0	0	0	0

APPENDIX G– GHG Assumptions and Calculations

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This appendix summaries the greenhouse gas (GHG) emissions and offset calculations. Table G-1 summaries the factors used in the calculations. Table G-2 summarizes the inputs and GHG calculations.

Table G-1. Greenhouse gas factors and assumptions

Factor	Units	Value	Sources
Electricity, CAMX - WECC California	Lb CO_2e/MWh	499	US EPA, eGRID Summary Tables 2018; Table 1. Subregion Output Emission Rates
Electricity, CAMX - WECC California	kg CO_2e/MWh	226	Calculated
POTW with nitrification/denitrification	g N_2O/ person-year	7	Based on population served
POTW without nitrification/denitrification	g N_2O/ person-year	3	Based on population served
Factor for industrial/commercial co-discharge waste in the sewer system		1.25	
Service Population	Population	950,000	
Global Warming Potential - CO_2	mass CO_2/mass CO_2	1	IPCC Fourth Assessment Report
Global Warming Potential - CH_4	mass CO_2/mass CH_4	25	IPCC Fourth Assessment Report
Global Warming Potential - N_2O	mass CO_2/mass N_2O	298	IPCC Fourth Assessment Report
Methanol	kg CO_2e/lb methanol	0.9561	Energy to produce 1 lb of methanol (Owen 1982): 18,000 Btu (natural gas based)/lb methanol
Sodium Hydroxide (NaOH)	kg CO_2e/lb NaOH	0.2262	1.0 kWh/lb * Electricity Factor CO_2e/kWh
Ferric Chloride ($FeCl_3$)	kg CO_2e/lb Ferric	0.0113	0.05 kWh/lb * Electricity Factor CO_2e/kWh

Table G-2. Summary of Greenhouse Gas emissions and offset calculations

Parameter	**Units**	**Alt. 1**	**Alt. 2**	**Alt. 3**	**Alt. 4**	**Alt. 5**	**Alt. 6**	**Alt. 7**	**Notes**
		HPO	**AS BNR**	**MBR**	**IFAS**	**AGS**	**De-centralized**	**Split Flow**	
Alternative Inputs									
Power Usage	kWh/yr	44,039,005	25,665,831	47,370,380	35,103,102	29,955,595	34,765,869	28,239,689	O&M Cost
Power Usage	MWh/yr	44,039	25,666	47,370	35,103	29,956	34,766	28,240	O&M Cost
Methanol	lb methanol (active)/yr	31,223,560	6,439,695	6,439,695	6,439,695	0	5,795,835	2,575,805	
Sodium Hydroxide	lb NaOH (active)/yr	4,071,210	0	0	0	0	0	0	
Ferric Chloride	lb Ferric Chloride (active)/yr	3,076,220	0	0	0	0	0	0	
GHG Emissions									
Purchased Power Usage	metric tons CO_2e/yr	9,962	5,806	10,716	7,941	6,776	7,864	6,388	
Methanol	metric tons CO_2e/yr	29,853	6,157	6,157	6,157	0	5,541	2,463	
Sodium Hydroxide	metric tons CO_2e/yr	921	0	0	0	0	0	0	
Ferric Chloride	metric tons CO_2e/yr	35	0	0	0	0	0	0	
Nitrous Oxide (N2O) Treatment Process Emissions at MWWTP and in SF Bay	metric tons CO_2e/yr	1,982	1,982	1,982	1,982	1,982	1,982	1,982	Per IPCC and EPA standards, includes N_2O emissions from nitrification and denitrification processes.
GHG Offsets									
None									
Totals									
Total Emissions	**metric tons CO_2e/yr**	42,752	13,944	18,854	16,079	8,758	15,387	10,832	
Purchased Power Usage	metric tons CO_2e/yr	9,962	5,806	10,716	7,941	6,776	7,864	6,388	
Chemicals	metric tons CO_2e/yr	30,809	6,157	6,157	6,157	0	5,541	2,463	
N_2O Process Emissions	metric tons CO_2e/yr	1,982	1,982	1,982	1,982	1,982	1,982	1,982	
Total Offsets	**metric tons CO_2e/yr**	0	0	0	0	0	0	0	
Net Emissions	**metric tons CO_2e/yr**	42,752	13,944	18,854	16,079	8,758	15,387	10,832	
Normalized Score of 1 - 5		1	4	3	4	5	4	5	

APPENDIX H– Nutrient Alternatives Workshop Materials

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Workshop materials removed to reduce file size. Key assumptions, drivers, and decisions are documented within task report.

<<

INTEGRATED MASTER PLAN *for the* MAIN WASTEWATER TREATMENT PLANT

C80.1: Sidestream Treatment Alternatives Analysis

June 2021

EBMUD

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TABLE OF CONTENTS

APPENDIX

FIGURES

TABLES

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EXECUTIVE SUMMARY

The goal of the East Bay Municipal Utility District's (District) Integrated Main Wastewater Treatment Plant (MWWTP) Master Plan Project (Master Plan) is to provide a 30-year roadmap that identifies capital improvement program (CIP) projects that address aging infrastructure, new regulations, capacity constraints and climate change resiliency.

As part of the Master Plan, treatment of the dewatering centrate stream was considered as an option for reducing nutrient discharges to the San Francisco Bay (Bay). The dewatering centrate stream (herein referred to as sidestream) contains high ammonia and phosphorus loads that are currently returned to the primary sedimentation tanks (PST) for treatment prior to discharge to the Bay. This report summarizes the evaluation of sidestream nitrogen removal and sidestream phosphorus removal alternatives. A placeholder technology was selected to carry forward for further analysis and development of the Master Plan. The Nutrient Reduction Alternatives Report and Integrated Roadmap Report further detail the regulatory, implementation and phasing considerations of sidestream treatment.

Sidestream Flow and Load Projection

Table ES-1 summarizes the projected sidestream flow and load conditions that were used for the analyses presented in this report. The plant-wide process model was used to project 2050 centrate flows and loads assuming medium growth in the District's service area (EBMUD, March 2020) and medium growth of the resource recovery (R2) program (EBMUD, May 2019).

Table ES-1. Sidestream flow and load projection

Parameter	2050 Projection[a]
Flow	0.9 mgd
Temperature[b]	45 degrees Celsius (°C)
Total suspended solids (TSS)	1,000 milligrams per liter (mg/L) 7,800 pounds per day (lb/d)
Chemical oxygen demand (COD)	1,900 mg/L 14,400 lb/d
Ammonia-nitrogen (NH_3-N)	1,600 mg/L 11,900 lb/d
Phosphate as phosphorus (PO_4-P)[c]	170 mg/L 1,300 lb/d
Alkalinity (as calcium carbonate [$CaCO_3$])	6,000 mg/L 45,300 lb/d

All values are rounded.

a. Sidestream flow and loads were developed using the plant-wide process model assuming medium growth in the service area and medium growth of the R2 program.

b. Centrate temperature was assumed to be equal to the historical temperature in the second stage digesters.

c. Assumes ferric chloride addition for hydrogen sulfide control at the blend tanks.

Sidestream Nitrogen Treatment

Three types of sidestream nitrogen removal were considered: (1) conventional biological system, (2) deammonification biological system, and (3) physical-chemical system. Figures ES-1 through ES-3 present process schematics of these systems. A summary of the technologies, total inorganic nitrogen (TIN) reduction, land requirements and project costs is presented in Table ES-2.

Key considerations of the technologies include:

- The biological deammonification systems (Alternatives 2N through 5N) require seeding the reactors with anammox bacteria. The anammox bacteria reduce the aeration/energy demand and chemical use compared to a conventional biological system (Alternative N1).
- The four deammonification systems that were evaluated have a range of installations across the world and the United States; the number of installations and operational history of deammonification for sidestream treatment has increased over the past 20 years and is considered an established process.
- The physical-chemical alternatives rely on chemical addition to strip ammonia from the sidestream so that an ammonia-rich product is formed that can be marketed as a fertilizer product. Locally, the market for a recovered ammonia product (of human waste origin) is not well established and presents the challenge of creating a product that the District would need to manage and market.

As shown on Figures ES-1 through ES-3, equalization and pre-treatment of the dewatering centrate is included for each alternative. The purpose of the equalization tank is to minimize flow and load variations directed to the sidestream treatment system (i.e., provides for a more stable operation) and to reduce the concentration of ammonia and COD to the biological systems. Additionally, for the deammonification treatment alternatives, the equalization tank provides a location to cool the sidestream flow (target temperature of less than 35 °C), which is a design criterion. Pre-treatment is also included to reduce the solids and phosphorus loads (and struvite formation) directed to the sidestream treatment reactors.

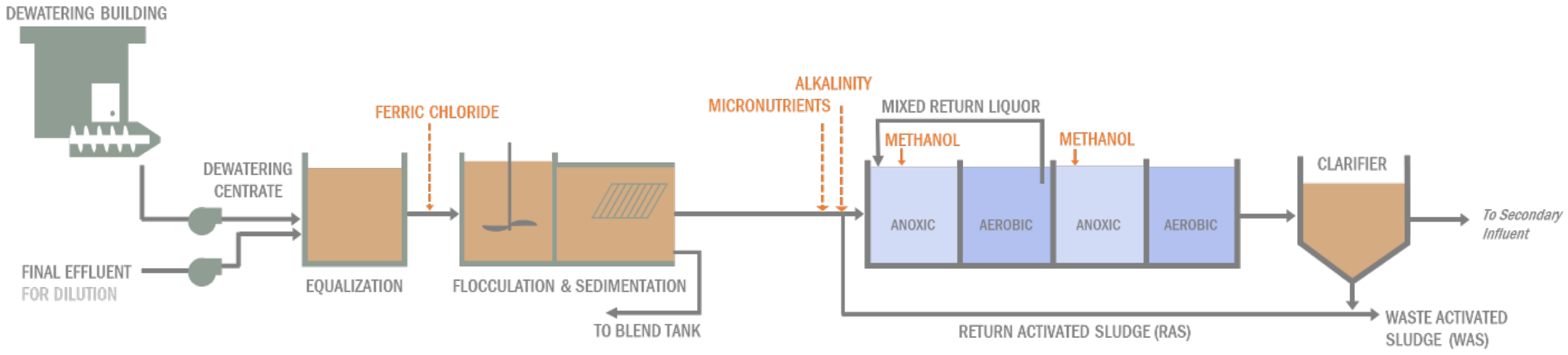

Figure ES-1. Process flow diagrams of sidestream nitrogen treatment Alternative N1: Conventional biological treatment

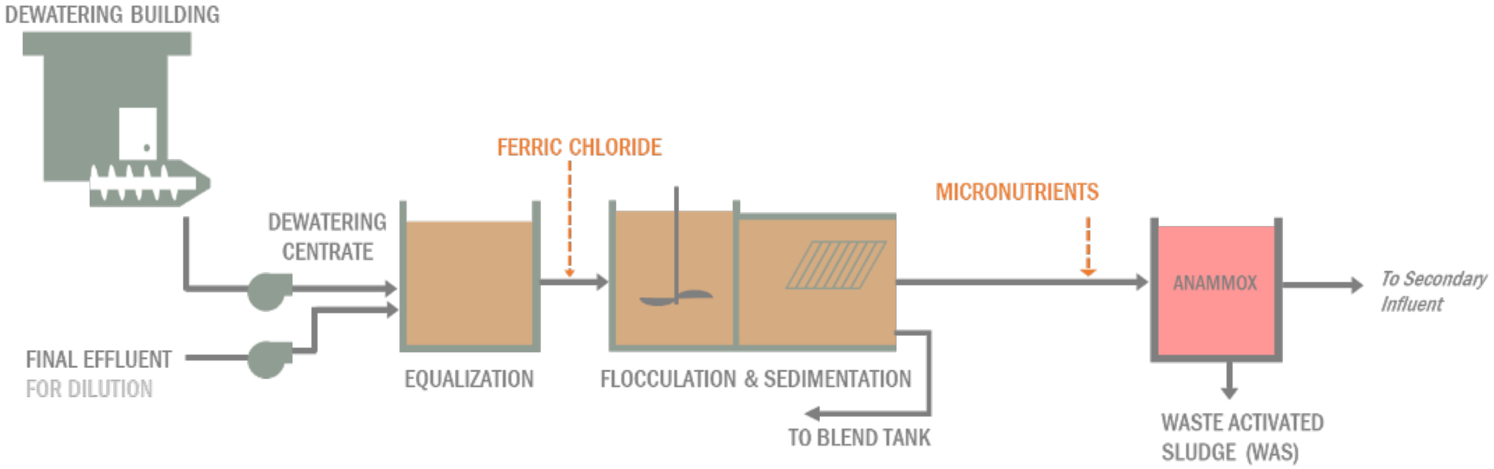

Figure ES-2. Process flow diagrams of sidestream nitrogen treatment Alternatives N2 - N5: Deammonification biological treatment

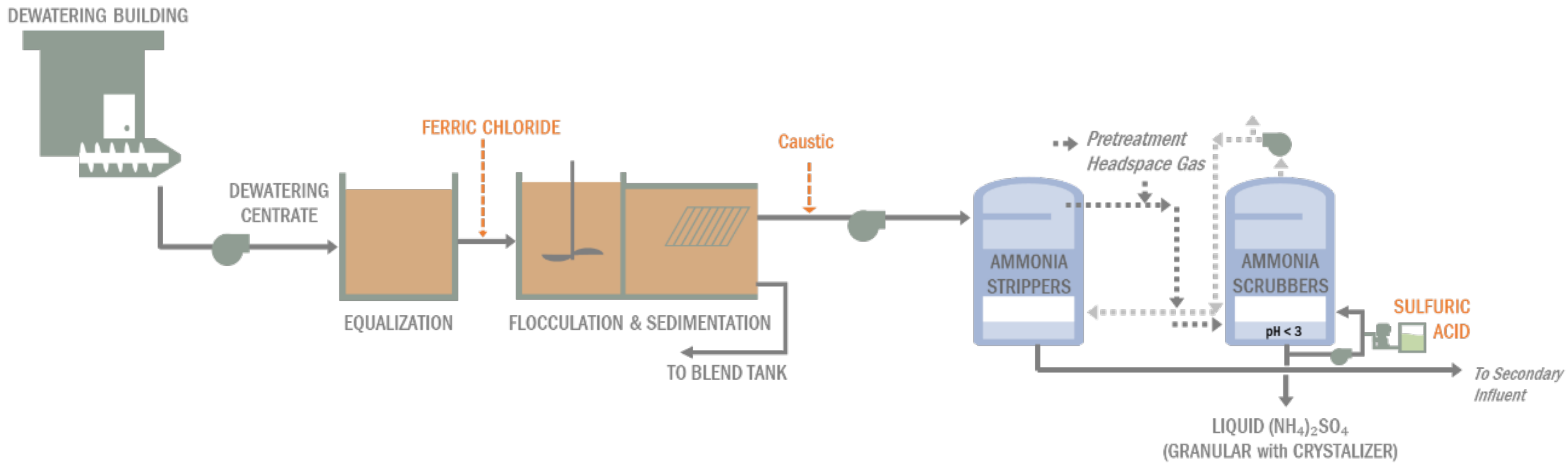

Figure ES-3. Process flow diagrams of sidestream nitrogen treatment Alternatives N6 and N7: Physical-chemical ammonia recovery

Table ES-2. Summary of sidestream nitrogen alternatives

Parameter	Biological N Removal					Physical-chemical N Recovery	
	Alternative N1: Conventional Biological	**Alternative N2: DEMON**	**Alternative N3: ANITAMox**	**Alternative N4: AnammoPAQ**	**Alternative N5: ZeeNAMMOX**	**Alternative N6: Ammonia Recovery (AMR) with Liquid Ammonium Sulfate (LAS)**	**Alternative N7: AMR with Granular Ammonium Sulfate (GAS)**
Effluent TIN reduction (tons/year)[a]	1,700	1,700	1,600	1,700	1,800	1,800	1,800
Capital cost, $ million[b]	$133.4	$84.4	$91.8	$99.3	$145.2	$77.2	$105.6
Operating cost, $ million[c]	$126.4	$27.7	$28.8	$32.0	$33.5	$92.5	$105.0
Labor PV, $ million	$18.6	$18.6	$18.6	$18.6	$18.6	$21.2	$21.2
Chemical PV, $ million	$84.5	$0.0	$0.0	$0.0	$0.0	$62.8	$63.6
Energy PV, $ million	$18.2	$4.8	$5.6	$6.8	$3.2	$2.4	$11.9
Repair and rehabilitation PV, $ million	$5.1	$4.3	$4.6	$6.6	$11.7	$6.0	$8.3
Revenue PV,[c] $ million	No revenue	No revenue	No revenue	No revenue	No revenue	$9.8	$44.6
Net present value (NPV), $ million	$259.8	$112.1	$120.6	$131.3	$178.7	$159.8	$166.0
Unit cost,[d] $/TIN lb removed	$2.75	$1.20	$1.35	$1.40	$1.80	$1.60	$1.65
Land requirements, acres	1.0 3 Reactors (at 1 MG each)	0.6 2 reactors (at 0.5 MG each)	0.6 2 reactors (at 0.54 MG each)	0.6 2 reactors (at 0.39 MG each)	0.4 2 reactors (at 0.65 MG each)	0.5 5 trains	0.5 5 trains
Technology maturity (or full-scale installations)	Established	Established More than 92 global installations and 7 United States installations	Established 28 global and 8 United States installations	Established More than 54 global installations and 1 United States installations	Emerging 0 full-scale installations	Established More than 24 full-scale installations	Established technology Limited installation with similar application

All values are rounded.

a. TIN reduction for Year 2050 is presented. TIN reduction is calculated based on sidestream influent ammonia (11,900 lb/day) minus sidestream effluent TIN.

b. Capital costs assume equalization and pre-treatment of centrate upstream of the sidestream treatment reactors. New tankage is assumed for all alternatives. The gravity sludge thickeners (GST) could be repurposed as sidestream reactors for Alternatives 2 and 4 for a capital cost savings on the order of $15 to $17 million; the savings is dependent on GST rehabilitation that is needed, which is uncertain at this time. Capital costs are presented as 2021 dollars.

c. Operating costs are presented as the PV of energy, labor, chemical use and renovation and repair (R&R) costs over a 30-year operating period. Annual revenue is sale of recovered ammonia based on the market assessment findings. Operating costs and benefits (defined as revenue and avoided costs) are presented as the PV in 2021 dollars.

d. Unit cost is based on the NPV over the 30-year period divided by the pounds of TIN removed over the 30-year period.

$ = dollars
MG = million gallon(s)
PV = present value

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The economic evaluation of the sidestream nitrogen alternatives are presented as Figure ES-4. The DEMON (Alternative N2) and ANITAMox (Alternative N3) have the lowest NPV. The ammonia recovery (AMR) alternatives (Alternatives N6 through N7), along with conventional biological (Alternative N1) have higher NPVs. The high chemical use associated with the AMR technologies (Alternatives N6 and N7) contribute to the higher NPV. The AMR with GAS (Alternative N7) has higher capital and operating costs due to the additional steps required for producing the GAS.

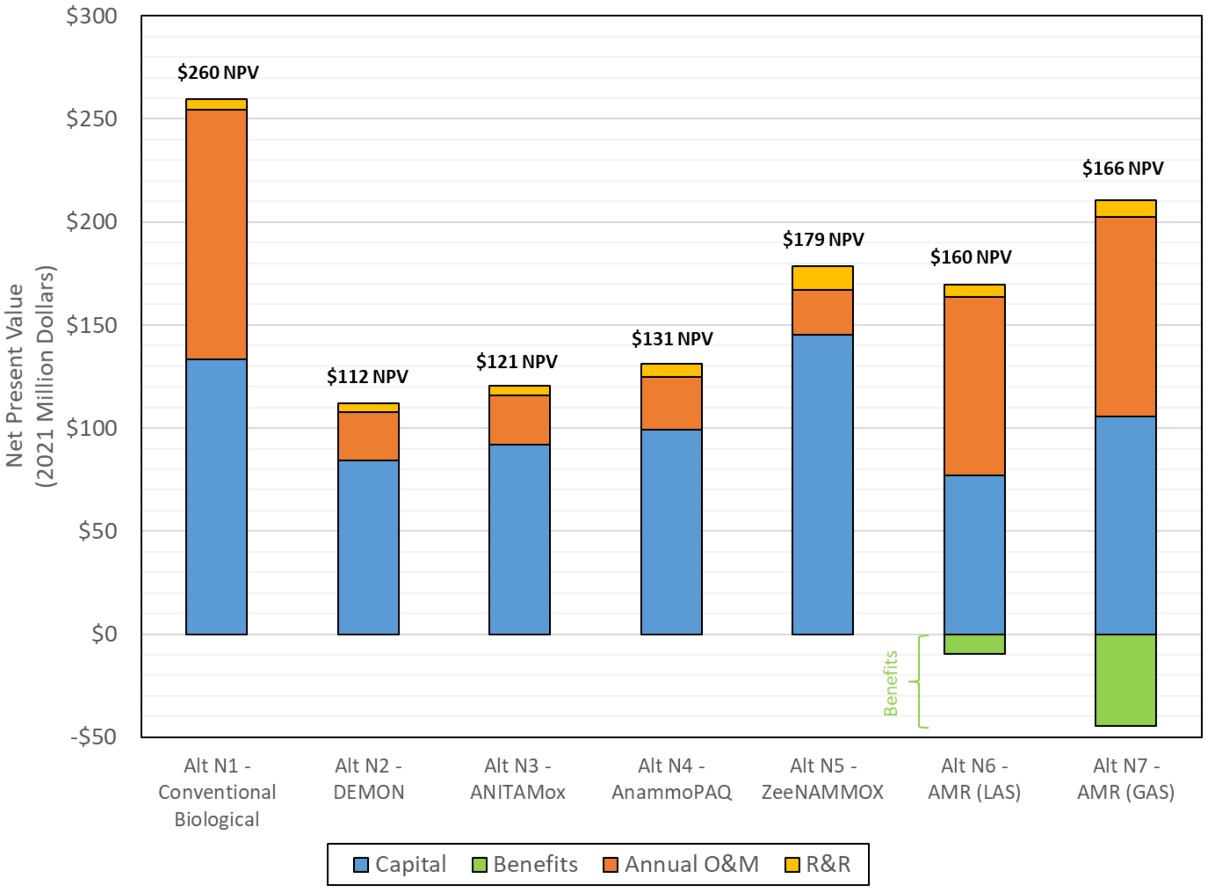

Figure ES-4. Economic evaluation of sidestream nitrogen alternatives

The non-economic evaluation of sidestream nitrogen alternatives is presented on Figure ES-5. The deammonification technologies have the highest non-economic score, which can be primarily attributed to the benefits of a process that is not heavily dependent on chemical use and that has lower energy use. The ZeeNAmmox alternative (Alternative N5) does not have installations in the United States and, therefore, was considered a less established deammonification technology. It should be noted that the DEMON and ANITAMox alternatives (Alternatives N2 and N3) are shown as a single bar on Figure ES-5 because the score for both alternatives was the same.

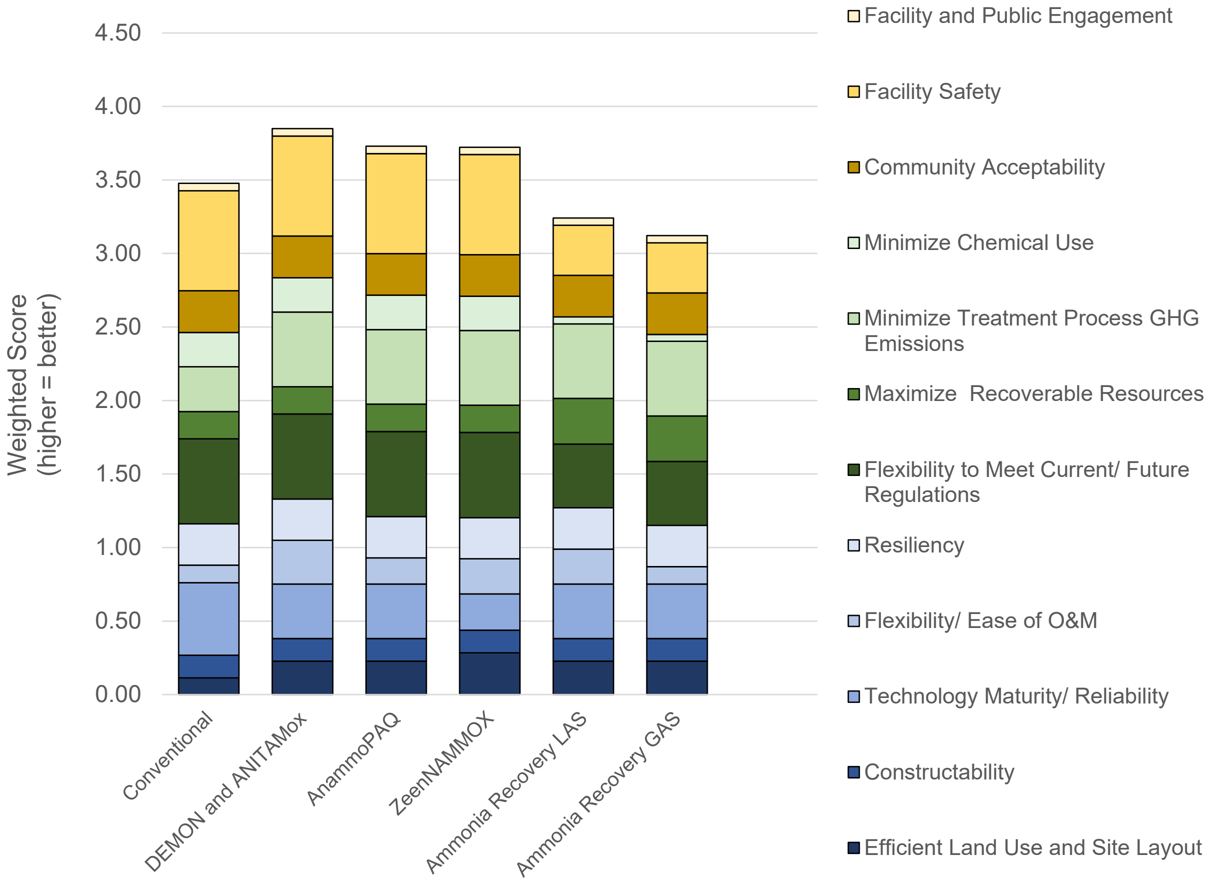

Figure ES-5. Non-economic evaluation of sidestream nitrogen alternatives

Based on an evaluation of the alternatives, deammonification was selected to carry forward into the Master Plan. The ANITAMox technology (Alternative N3) will serve as the basis for the Master Plan project costs and land requirements. The District will still have the flexibility (and land) to implement any of the deammonification technologies. Conventional biological treatment was not selected as the placeholder technology for the Master Plan due to the larger footprint and higher NPV. AMR with liquid (Alternative N6) or granular (Alternative N7) products were also not selected because the alternatives have a higher NPV and require significant chemical use. The AMR alternatives also require development of a local market for the distribution of the recovered ammonia product; the local market and product value present a risk for the District compared to the biological treatment alternatives, which are not dependent on a product market.

Pilot testing deammonification at the MWWTP is recommended to confirm performance, define design criteria and provide operational experience. Due to the R2 program, the centrate quality at the MWWTP varies, and the impact of the variability on the deammonification system should be confirmed with pilot testing. If pilot testing demonstrates that deammonification does not meet the District's goals and expectations, AMR with LAS (Alternative N6) could be further considered for sidestream treatment.

Sidestream Phosphorus Treatment

Sidestream phosphorus alternatives were developed for 2050 flows and loads (Table ES-1). As further described in the Nutrient Reduction Alternatives Report and the Integrated Roadmap Report, discharge regulations are not expected to include total phosphorus (TP) load or concentration-based limits. Sidestream phosphorus removal was reviewed as part of the Master Plan to consider alternatives that would help alleviate operations and maintenance issues related to struvite formation in the digesters and dewatering equipment. Figure ES-6 provides a flow schematic of the different sidestream phosphorus alternatives that were evaluated:

- Chemical addition (Alternative P1) assumes ferric chloride addition; ferric chloride could be added at the digesters as shown on Figure ES-6 or could be added at the PSTs. The alternative would not result in a recovered phosphorus product.
- Alternatives P2 through P4 consider different technologies designed to recover phosphorus as a product that could be marketed as a fertilizer product.

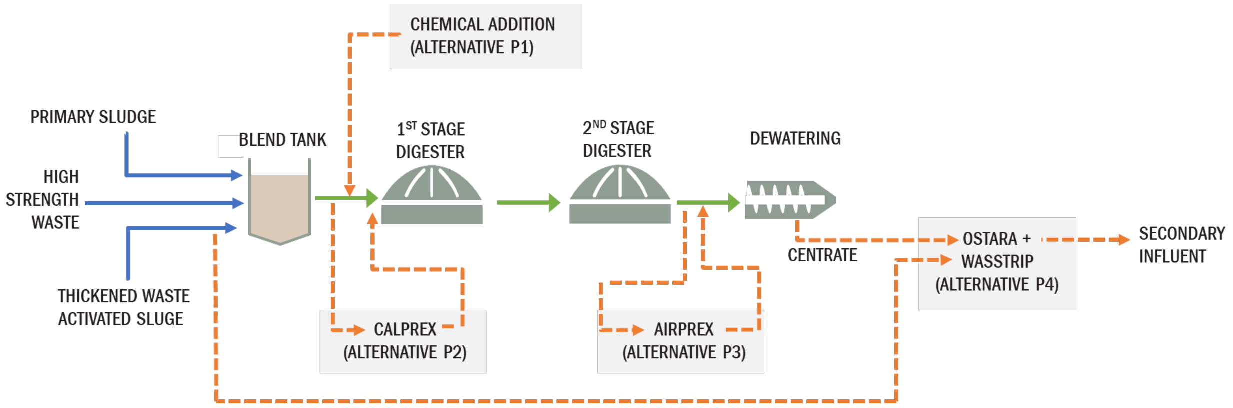

Figure ES-6. Flow schematic of sidestream phosphorus treatment alternatives

Table ES-3 summarizes the considerations and costs of the of the alternatives. As noted in Table ES-3, two options were considered with the CalPrex alternative. CalPrex typically relies on a fermentation step (acid-phase digestion step) upstream of the CalPrex system; the fermentation step increases the orthophosphate (OP) load directed to CalPrex, thereby maximizing phosphorus recovery. Due to the R2 program, the OP levels in the blend tank are currently higher than typical publicly owned treatment works (POTW) This means the fermentation step could be eliminated; therefore, the CalPrex system was evaluated with and without a fermentation step.

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Table ES-3. Summary of sidestream phosphorus treatment alternatives

Parameter	**P-removal**	**P-Recovery**		
	Alternative P1 Chemical Addition	**Alternative P2 CalPrex (without and with fermentation)**	**Alternative P3 AirPrex**	**Alternative P4 Ostara + WASSTRIP**
Phosphorus reduction (lb/d)	1,700 lb/d [a]	600 - 2,100 lb/d [b]	1,200 lb/d [c]	1,400 lb/d [d]
Capital cost, $ millions	$2.6	$52.7 - $104.9 [f]	$48.9	$106.9
Operating cost, $ millions	$86.9[g]	$22.9 - $28.8	$82.8	$43.2
Labor PV, $ million	$0.0	$15.9	$15.9	$15.9
Chemical PV, $ million	$86.9	$0.9 - $3.3	$60.6	$19.6
Energy PV, $ million	$0.0	$1.3 - $4.8	$2.7	$4.5
R&R PV, $ million	$0.0	$4.8	$3.6	$3.2
Revenue PV, $ millions [g]	No revenue	$0.5 - $1.7	$11.5	$12.7
NPV, $ millions	$89.5	$75.1 - $132.0	$120.2	$137.4
Unit cost, $/TP lb removed	$5.50	$3.80 - $6.60	$11.00	$10.40
Land requirements, acres	--	0.4 - 0.6	0.3	0.5
Addresses location struvite issue	Digesters and dewatering	Digesters	Dewatering	Digesters and dewatering

All values are rounded.

a. Based on estimated performance from the Struvite Control Investigation Report (Hazen and Sawyer 2016) for Alternative P1. Estimated reduction presented for 2050.

b. A range of phosphorus reduction was considered to reflect CalPrex installation with and without a fermenter/acid-phase digester. The range of TP removal is based on manufacturer estimate with 60% reduction of OP from digester feed; testing to confirm performance is recommended. This alternative requires ferric chloride addition to be relocated so that it is not added at the blend tank.

c. Estimated performance according to manufacturer estimate of 90% of OP load resulting in dewatering centrate.

d. Estimated performance from manufacturer. Lab and pilot testing required to confirm estimated performances.

e. Low range of capital cost assumes acid phase digester /fermenter is not needed and phosphorus reduction can be achieved. High-range of capital cost assumes that new acid phase digester/fermenter is constructed.

f. Annual cost is based on additional ferric chloride dose needed for struvite control, as identified in the 2016 Struvite Investigation Report. The dose identified in the report was increased to account for impacts of changes in received R2. In the 2016 report, a total dose of 1,000 milligrams iron per liter (mgFe/L) and baseline dose of 360 mg Fe/L were identified (or an increase in ferric chloride addition by an equivalent dose of 640 mgFe/L).

g. Based on estimated value of recovered phosphorus product (refer to Final Draft Market Assessment Report for estimated struvite value). Brushite (produced with Alternative P2 – CalPrex) estimated value was assumed at $150/ton based on manufacturer information. It should be noted the local value for brushite was estimated at roughly 50% of this value ($75/ton).

h. Unit cost is based on the NPV over the 30-year period divided by the pounds of TP removed over the 30-year period.

$ = dollars
MG = million gallon(s)
PV = present value
TP = total phosphorus
WASSTRIP = waste activated sludge stripping to remove internal phosphorus

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Figure ES-7 provides a summary of the economic evaluation of the sidestream phosphorus alternatives. Chemical addition (Alternative P1) and Calprex without a new fermentation/acid-phase digestion step have the lowest NPVs. Alternative P1 has a low capital investment but increases chemical use at the MWWTP. CalPrex (without fermentation) requires a larger capital investment because new tankage for an acid-phase digester was assumed in the project costs. CalPrex with fermentation (Alternative P2), AirPrex (Alternative P3) and Ostara + Waste Activated Sludge Stripping to Remove Internal Phosphorus (WASSTRIP) (Alternative P4) have the highest NPVs due to the high capital investment. CalPrex, AirPrex and Ostara + WASSTRIP (Alternatives P2 through P4) offer the benefit of recovering phosphorus and producing a product that could be sold as a fertilizer product, but the product value is not expected to cover system capital and operating costs.

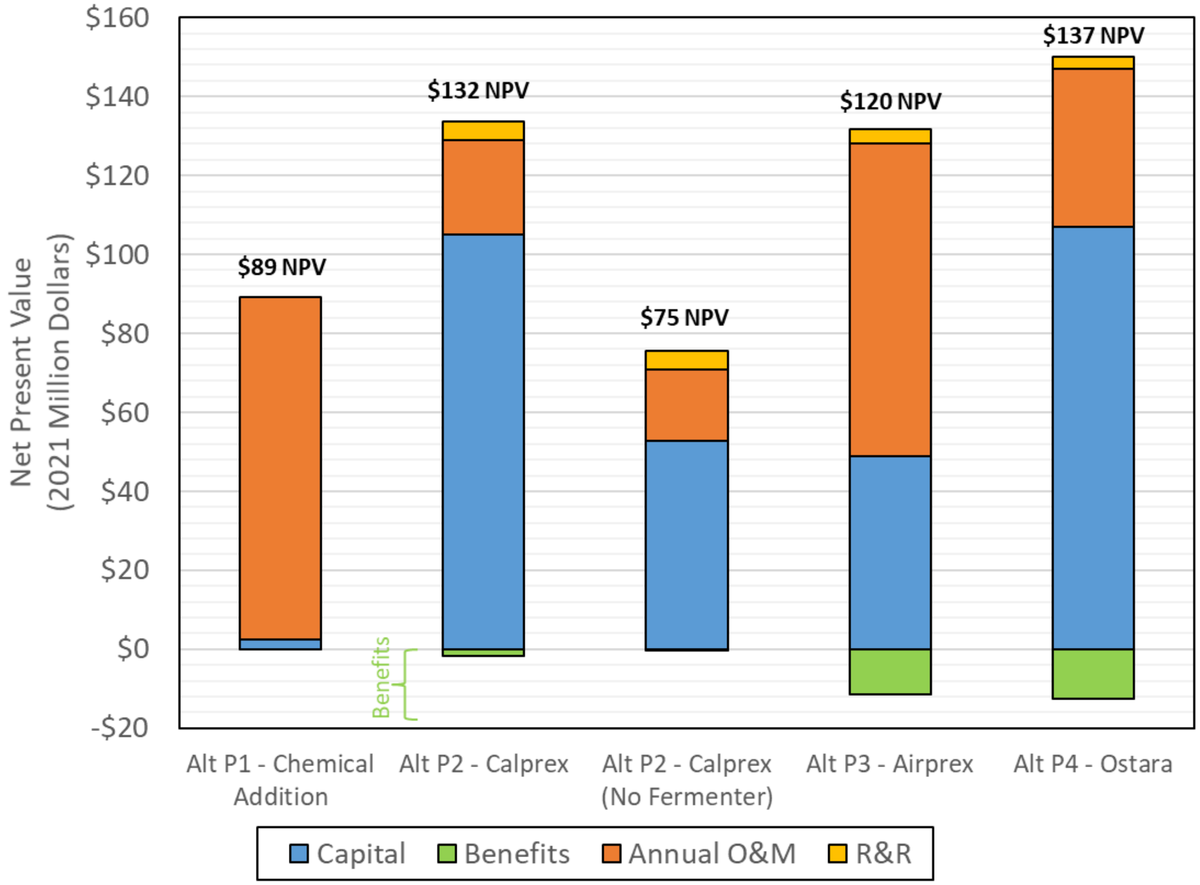

Figure ES-7. NPV for phosphorus treatment alternatives economic analysis

Figure ES-8 presents the non-economic evaluation of the sidestream phosphorus alternatives. The alternatives have similar non-economic scores. The phosphorus recovery alternatives (P2 through P4) offer the benefit of recovering a product that can be distributed as a fertilizer product; these options do require the District to develop a market for product distribution. It should also be noted that if the R2 waste stream characteristics change in the future, the economics of the phosphorus recovery alternatives may change due to lower OP and total TP loads entering the MWWTP.

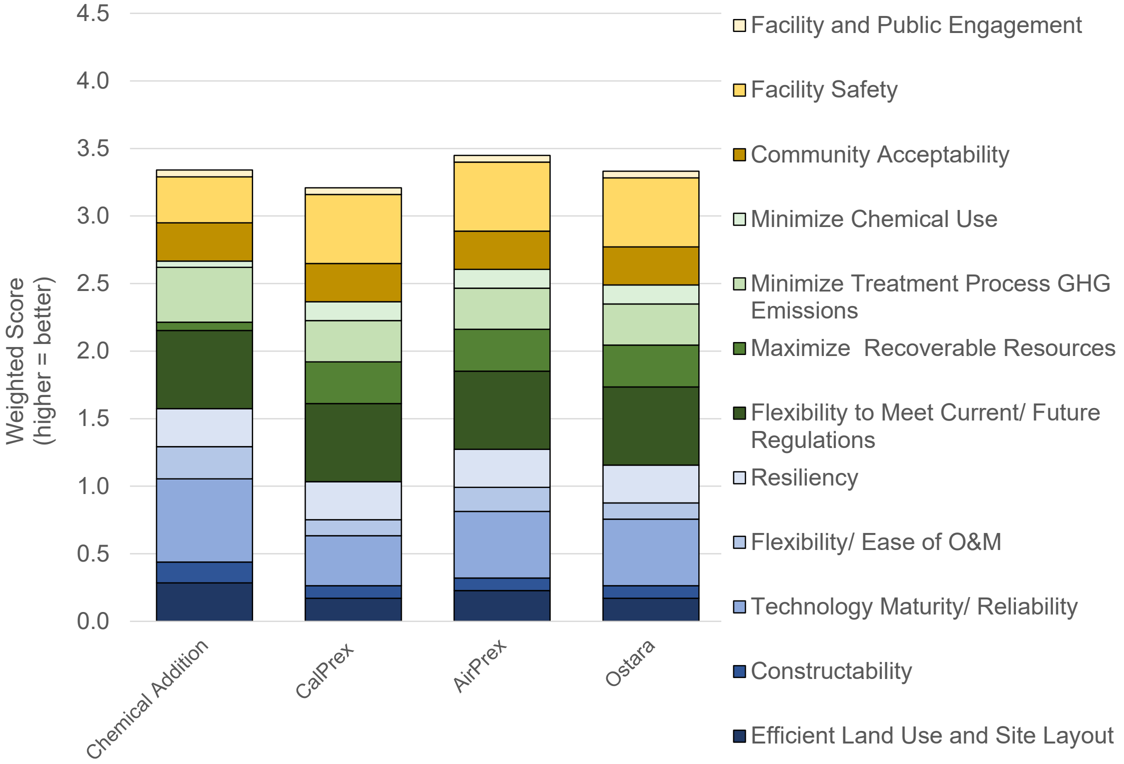

Figure ES-8. Non-economic evaluation of sidestream phosphorus alternatives

Chemical addition (Alternative P1) offers flexibility to accommodate phosphorus load variations that could occur if the makeup of R2 waste streams changes. This alternative has the disadvantage of increasing chemical use at the MWWTP. Chemical addition (i.e., ferric chloride addition) has the potential to offer the following plant-wide benefits:

- Increased TSS and biochemical oxygen demand (BOD) removal across the PSTs, which reduces the load to the secondary system and increases secondary system capacity
- Operation at higher PST surface overflow rates (SOR), which may allow for up to three PSTs to be dedicated for other uses.

For the development of the Master Plan, chemical addition (Alternative P1) was carried forward as a placeholder technology to address struvite precipitation in the solids handling facilities for the following reasons:

- The alternative offers plant-wide benefits that could benefit the secondary treatment system capacity and could allow for up to three PSTs to be repurposed for other uses.
- The alternative offers operational flexibility and can easily be adjusted to accommodate variations in TP and OP loads that may occur with changes in R2 waste streams entering the MWWTP.

- The alternative requires a low capital investment. The District has a number of near-term, regulatory and aging infrastructure projects at the MWWTP that require significant capital investment. As a result, an investment in phosphorus recovery is not economically feasible in the near-term.

Additional testing is recommended to confirm the chemical dosage needed for struvite control, increased TSS and BOD removal, as well as operation of the PSTs at higher SORs.

It is also recommended that the District continue to monitor the phosphorus recovery technologies (Alternatives P2 through P4) to confirm the capital costs and local product value. In parallel, it is recommended that the District consider the future R2 waste stream characteristics and confirm if the economics of the phosphorus recovery alternatives shift and become more favorable.

Conclusions

Based on the sidestream treatment analyses summarized above, next steps for integrating sidestream treatment into the Master Plan roadmap are:

- Incorporate sidestream deammonification into the nutrient reduction alternatives and develop phasing plans for sidestream and mainstream nutrient removal. ANITAMox (Alternative N3) will be used as a placeholder technology for the purposes of developing site plans and capital improvement program (CIP) project costs for the Master Plan.
- Conduct additional sidestream characterization and pilot testing of deammonification technologies to confirm performance and design criteria, and to provide operational experience. Due to the variable nature of the MWWTP's sidestream quality, pilot testing is recommended. Furthermore, this is a new technology for the District and is less established than conventional biological nitrogen removal.
- Consider including chemical addition (Alternative P1) into the Master Plan roadmap for near-term struvite mitigation. The chemical addition (i.e., ferric chloride addition at the PSTs) can provide plant-wide benefits of increasing secondary system capacity and could allow for up to three PSTs to be repurposed for other uses. Bench-scale and full-scale testing is recommended to confirm chemical dosage, performance and benefits of ferric chloride addition at the PSTs.
- Continue to monitor the market and product value of recovered ammonia and phosphorus products. As appropriate, the placeholder technologies should be modified or updated.

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CHAPTER 1 - INTRODUCTION

The goal of the East Bay Municipal Utility District's (District) Integrated Main Wastewater Treatment Plant (MWWTP) Master Plan Project (Master Plan) is to provide a 30-year roadmap that identifies capital improvement program (CIP) projects that address aging infrastructure, new regulations, capacity constraints, and climate change resiliency.

As part of the Master Plan, treatment of the dewatering centrate stream was considered an option for reducing nutrient discharges to the San Francisco Bay (Bay). The dewatering centrate stream (herein referred to as sidestream) at the MWWTP contains high ammonia and phosphorus loads. The sidestream is returned to the primary sedimentation tanks (PST) for treatment prior to discharge to the Bay. Because of the concentrated nutrient load in dewatering centrate, sidestream treatment can be a cost-effective solution for nutrient reduction.

The purpose of this report is to evaluate alternatives for sidestream nitrogen and phosphorus removal, and to identify placeholder technologies that can be integrated into the nutrient reduction alternatives. The Nutrient Reduction Alternatives Report and the Integrated Roadmap Report further develop the placeholder technologies for sidestream treatment to address project implementation, timing and project costs.

This report is organized as follows:

- Executive Summary
- Chapter 1: Introduction
- Chapter 2: Sidestream Nitrogen Removal
- Chapter 3: Sidestream Phosphorus Removal
- Chapter 4: Conclusions
- Chapter 5: References

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CHAPTER 2 - SIDESTREAM NITROGEN REMOVAL

Sidestream nitrogen treatment technologies can be categorized either as biological treatment or physical-chemical treatment. The following section provides an overview of technologies considered, followed by the alternatives evaluation.

2.1 Planning Assumptions

The District developed flow and loading projections for influent wastewater and resource recovery (R2) waste streams. The plant-wide process model was used to estimate dewatering centrate flows and loads in future years. The sidestream nitrogen treatment system was sized to treat 2050 average dry weather (ADW) loads (Table 2-1).

The 2050 ADW centrate ammonia load is approximately 30 to 35 percent of the influent wastewater total Kjeldahl nitrogen (TKN) load (i.e., dewatering centrate load is 11,900 pounds of ammonia-nitrogen per day [lb-NH_3-N/d]. The influent wastewater TKN load is 38,140 lbs-N/d). Appendix A provides the influent wastewater and the dewatering centrate flows and loads by decade from 2020 through 2050. There is approximately a 15 percent increase in the ADW ammonia load from 2020 to 2050.

Table 2-1. Sidestream treatment nitrogen flow and load basis

Parameter	2050 Projection [a]
Flow	0.9 million gallons per day (mgd)
Temperature [b]	45 degrees Celsius (°C)
Total suspended solids (TSS)	1,000 milligrams per liter (mg/L) 7,800 pounds per day (lb/d)
Chemical oxygen demand (COD)	1,900 mg/L 14,400 lb/d
Ammonia as nitrogen (NH_3-N)	1,600 mg/L 11,900 lb/d
Phosphate as phosphorus (PO_4-P)	170 mg/L 1,300 lb/d
Alkalinity (as $CaCO_3$)	6,000 mg/L 45,300 lb/d

All values are rounded.

a. Sidestream nitrogen removal alternatives were sized for 2050 ADW flows and loads.

b. Centrate temperature was assumed to be equal to the current temperature in the second-stage digesters.

As noted in Table 2-1, the temperature of the dewatering centrate was assumed to equal the temperature in the second-stage digesters (or approximately 45 °C). The desired feed temperature to the deammonification treatment systems is 35 °C; herefore, the biological sidestream treatment alternatives assume that secondary effluent (temperature ranging from 15 to

25 °C) would be blended with centrate and used as cooling water. At 2050 conditions, a secondary effluent flow ranging from 50 to 100 percent of the sidestream flow (i.e., 0.45 to 0.9 mgd) would be needed to sufficiently reduce the feed temperature of centrate. The dilution of centrate with secondary effluent has the additional benefit of reducing the ammonia and COD concentrations in the feed stream, which can help mitigate the potential for ammonia oxidizing bacteria (AOB) inhibition with the biological treatment alternatives.

2.2 Siting

The assumed location for the nitrogen sidestream treatment and the pre-treatment system is west of the solids-liquid waste (SLW) receiving station, as shown on Figure 2-1. This location will be refined as the Master Plan and roadmap is developed and be incorporated with siting of biosolids and mainstream nutrient removal facilities. The location shown on Figure 2-1 was selected because it is currently open land near the dewatering building, blend tanks and the final effluent channel, which minimizes the need for meaning new yard piping. Yard piping for sidestream treatment is assumed to include: (1) a new dewatering centrate pipeline from the dewatering building to the sidestream treatment system, (2) a new pipeline from the final effluent channel to the sidestream equalization tank, and (3) a new pipeline from the sidestream pre-treatment system to convey solids to the blend tanks.

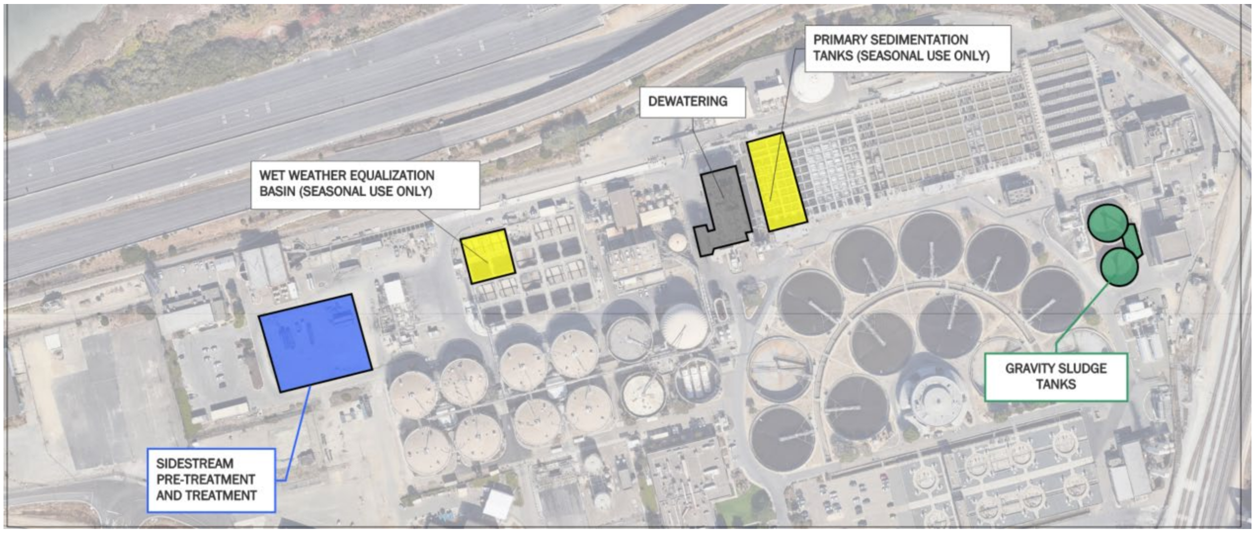

Figure 2-1. Sidestream nitrogen treatment siting locations

Use of existing tankage was considered for the biological treatment alternatives. Table 2-2 summarizes the advantages and disadvantages associated with using existing tankage at the MWWTP. The gravity sludge thickeners (GST) are the only existing tanks currently available on a year-round basis. The wet weather equalization basin is not available year-round, and it was determined that annually starting up a biological sidestream system would be labor intensive and operationally challenging, and would result in higher costs.

Under current operation, the PSTs are not available on a year-round basis. If chemically enhanced primary treatment (CEPT) was implemented at the MWWTP, up to three PSTs could be dedicated year-round for biological sidestream treatment. Additional testing would be required to confirm the benefits that CEPT would have on the PST operation and to confirm the number of PSTs that could be dedicated year-round for sidestream treatment. Additional details are included in the Integrated Roadmap Report on the potential for repurposing the PSTs for sidestream treatment.

For the purposes of this report, the GSTs were the only existing tanks that were considered for biological sidestream treatment. It should be noted that there is limited space next to the GSTs to site pre-treatment facilities, and conveying dewatering centrate to the GSTs will be challenging due to site constraints and present the potential for struvite precipitation in the pipeline.

Table 2-2. Siting considerations for biological sidestream nitrogen removal

Location	Advantages	Disadvantages
Land west of the SLW receiving station	• Open land (currently used for construction staging area) • Proximity to existing dewatering building and blend tanks	• Does not repurpose existing and unused tankage • Land is currently designated as construction staging area; a new staging area would be needed
GSTs	• Available year-round • Adequate volume for select deammonification technologies • Repurposes existing and unused tankage	• Not close to existing dewatering building • Limited land adjacent to tanks for pre-treatment system • Unknown condition; cost of tank rehabilitation needs to be confirmed
Wet weather equalization basins	• Portion of basins could be dedicated for sidestream treatment • Adequate volume for select deammonification technologies • Repurposes existing and tankage that is not used during dry weather conditions • Proximity to dewatering building and solids blend tanks	• Tanks are not available year-round (only available in dry-weather conditions) • Challenging to startup biological sidestream treatment system annually
PSTs	• Adequate volume for select deammonification technologies • Repurposes existing and tankage that is not used during dry weather conditions • Proximity to dewatering building and centrate flow is already routed to PSTs • CEPT could be implemented to provide up to 3 PSTs on a year-round basis	• Under current operation, the PSTs are not available year-round (only available in dry-weather conditions). • Challenging to startup biological sidestream treatment system annually • CEPT testing is required to confirm the number of PSTs that could be dedicated year-round for sidestream treatment

2.3 Overview of Technologies

One conventional and five deammonification biological technologies were evaluated in addition to two physical-chemical technologies. This section provides a brief overview of each alternative. Details for application specific to the MWWTP are provided in section 2.4.

2.3.1 Conventional Biological Sidestream Nitrogen Removal

Conventional biological treatment consists of achieving nitrogen reduction with biological nitrification and denitrification. During nitrification, ammonia is oxidized to nitrite and then to nitrate by AOB and nitrite oxidizing bacteria (NOB), respectively, in aerobic conditions. Nitrate is then denitrified to nitrogen gas under anoxic conditions by heterotrophic bacteria (Figure 2-2). This process requires 4.57 pounds of oxygen per pound of ammonia removed, 7.14 pounds of alkalinity per pound of ammonia removed, and 6 pounds of carbon as COD per pound of nitrate removed through heterotrophic denitrification.

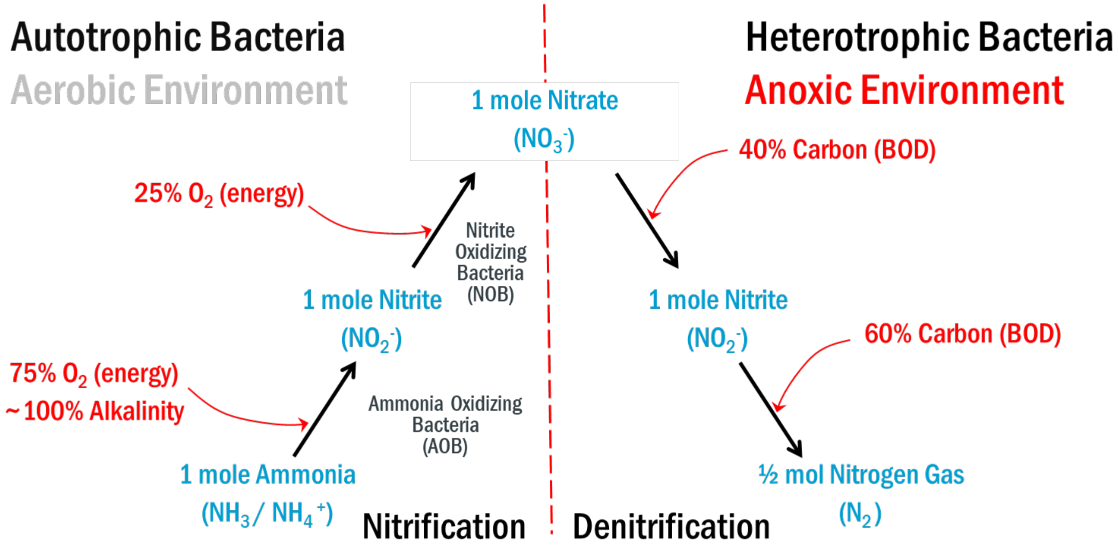

Figure 2-2. Conventional biological treatment process

A 4-stage Bardenpho process configuration was assumed for sidestream treatment at the MWWTP. This configuration was selected over a Modified Ludzack Ettinger (MLE) or sequencing batch reactor (SBR) configuration because it provides a higher level of nitrogen removal, similar to the levels that deammonification can achieve with a smaller footprint. Figure 2-3 provides a flow schematic of the system, including a pretreatment step. The reactor configuration includes anoxic and aerobic zones followed by a clarification step where return activated sludge (RAS) is returned to the reactors and waste activated sludge (WAS) is pumped to the solids handling system. Alkalinity addition (as caustic) and methanol addition are added to the reactor and provisions for micronutrients are included. At the MWWTP, additional testing and characterization is needed to confirm if micronutrient addition is needed.

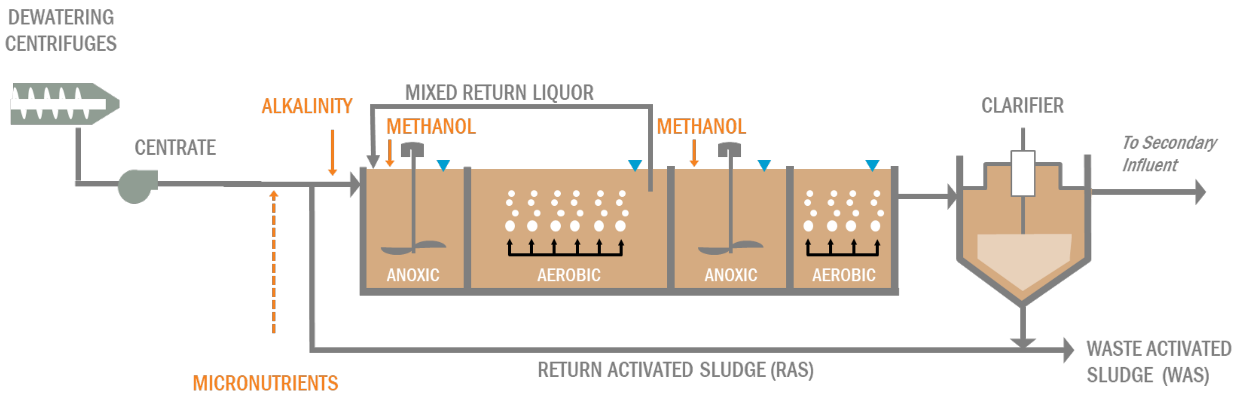

Figure 2-3. Process schematic, conventional, 4-stage Bardenpho

2.3.2 Deammonification Biological Sidestream Treatment

Deammonification or shortcut nitrogen removal is considered the most efficient biological pathway for nitrogen removal. The deammonification process converts approximately half of the influent ammonia into nitrite by AOBs, followed by the simultaneous removal of ammonia and nitrite by the anammox bacteria. Deammonification results in approximately a 67 percent savings in aeration, 50 percent savings in alkalinity, and 100 percent savings in external carbon addition per pound of nitrogen removed (Figure 2-4).

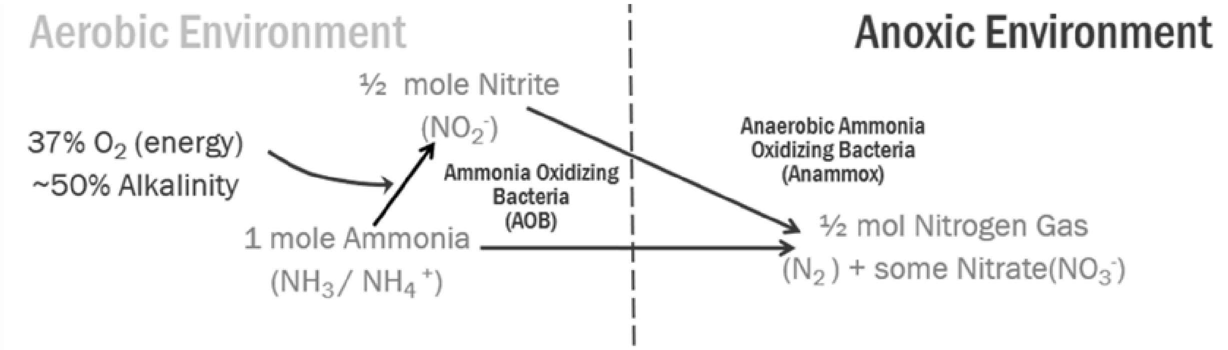

Figure 2-4. Overview of deammonification process

There are various manufacturers that have developed proprietary deammonification systems to treat high-temperature and high-strength sidestream flows. The success of the operation relies on converting ammonia to nitrite, which is usually the limiting step. For this reason, nitrite concentrations typically remain small, and nitrite that is produced is quickly used by the anammox. This is a critical aspect, because high concentrations of nitrite can be toxic to the anammox bacteria.

The anammox bacteria are slow growing, which means a high solids retention time (SRT) is needed. Seed anammox from operating facilities is used to start-up new installations. The first generation of deammonification reactors struggled with long reactor start-up periods (up to several years) due to the slow growth rate of anammox. More recent installations have relied on seeding the reactors to reduce startup times; the growing number of US installations provides a benefit of having a local source of anammox bacteria.

There are close to 200 installations of deammonification processes world wide, and there are currently 16 in the United States. The adoption of deammonification technologies for sidestream treatment has continued to climb over the past two decades, reaching early majority status on the technology S-curve (Figure 2-5).

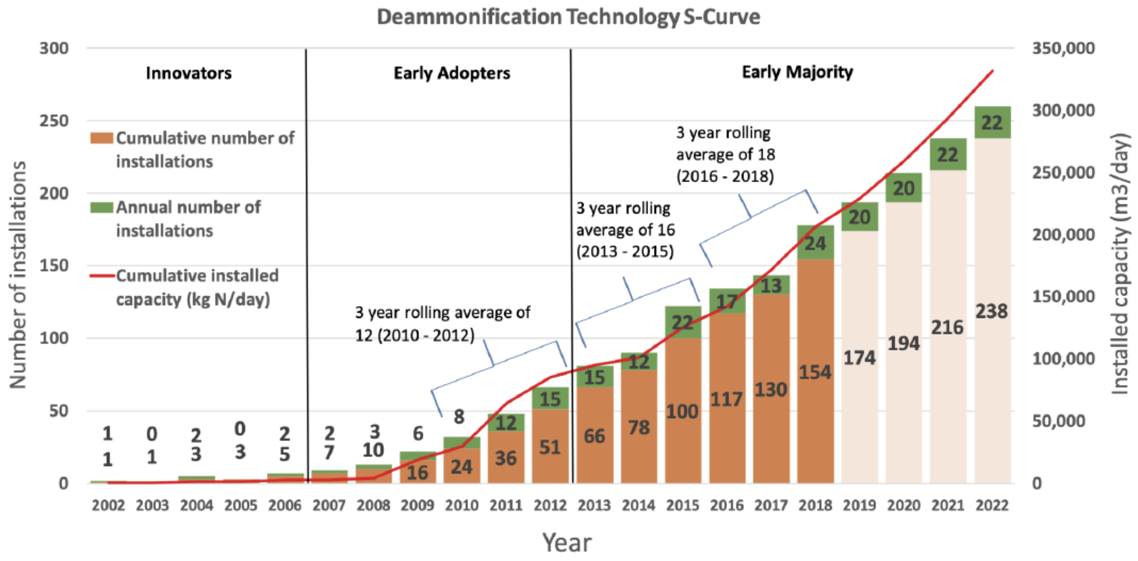

Figure 2-5. Global deammonification technologies between 2002–18, with predictions made for 2019–22

(adopted from 2018 Bluetech deammonification market update)

The more prevalent deammonification technologies that are available in the US are summarized in Table 2-3 and are the basis for the alternatives evaluated for the MWWTP. For the noted deammonification technologies, ZeeNAMMOX is the only system with no operating facilities and is, therefore, considered to be an emerging sidestream technology. ZeeNAMMOX was evaluated as Alternative 5 because it offers the benefit of a compact footprint (high ammonia loading rate) relative to the other deammonification technologies.

There is only one AnammoPAQ facility in the US; however, there are a sizeable number of worldwide installations, which is why the AnammoPAQ was considered. Both ANITAMox and DEMON have multiple full-scale facilities operating in the US. For this reason, information on the reliability and robustness for these technologies is more readily available. The following subsections provide additional details on the process improvements, optimizations and expected reliability of these technologies. Pilot testing would be needed to gain additional, site-specific experience.

Table 2-3. Deammonification Technologies in the US

Feature	DEMON	ANITAMox	AnammoPAQ	ZeeNAMMOX
Biomass	Suspended growth (granules)	Suspended and attached growth	Suspended growth (granules)	Attached growth
Flow	Continuous/flow-through	Continuous/flow-through	Continuous/flow-through	Continuous/flow-through
Anammox retention	Micro-screen	Biofilm plastic media and screen	Internal Settler	Membrane aerated bioreactor (MABR)
Process control	pH/dissolved oxygen (DO)	pH/DO	DO	Airflow
Installations	>92 worldwide; 7 in United States	>28 worldwide; 8 in United States	>54 worldwide; 1 in United States	None; only pilots
Aeration system	Messner aeration panel	Medium bubble aeration grids	Aerostrip® diffusers	Zeelung MABR

Deammonification has become a more robust and reliable process for sidestream treatment; however, operational upsets can still occur from the inhibition of AOBs, equipment failure, shock pH changes and high influent solids concentration. Modifications and advancements to sidestream deammonification systems have been made that have increased the reliability and improved system operation as follows:

- Simplified aeration control strategies have resulted in easier-to-operate systems that limit and out-select the NOB population.
- The use of screens and micro-screens to select and retain the anammox bacteria are more effective than hydrocyclones. The change from hydrocyclones to screens has led to fewer process upsets and/or loss of anammox bacteria. This has the added benefit of being able to treat higher ammonia loading rates.
- The volumetric requirements for sidestream treatment are reduced with a continuous flow system compared to an SBR, which requires a settling and decant step.

More operating experience has led to a better understanding of pre-treatment that is needed to mitigate the impact of high temperatures, high TSS and COD concentrations, and high phosphate and/or nitrogen fractions. For this reason, it is assumed that dewatering centrate at the MWWTP would be diluted to reduce feed temperature, ammonia and COD concentrations. The dewatering centrate would also be pre-treated to reduce TSS, COD and struvite precipitation in the feed.

2.3.2.1 DEMON

The DEMON process is a continuous flow-through suspended-growth system that uses an internal clarification process to capture settled biomass to return to the biological process. In this system, anammox bacteria are part of the suspended solids but remain in granular fraction, while the AOB are part of the flocculant fraction. Anammox bacteria retention is managed by a micro-screen (~200 micron [µm]) separation device that captures and returns the annamox granules to the biological reactor, allowing a much longer SRT compared to the floccular fraction, which is selectively wasted (Figure 2-6). Earlier DEMON configurations were designed as SBRs with hydrocyclones for anammox bacteria retention.

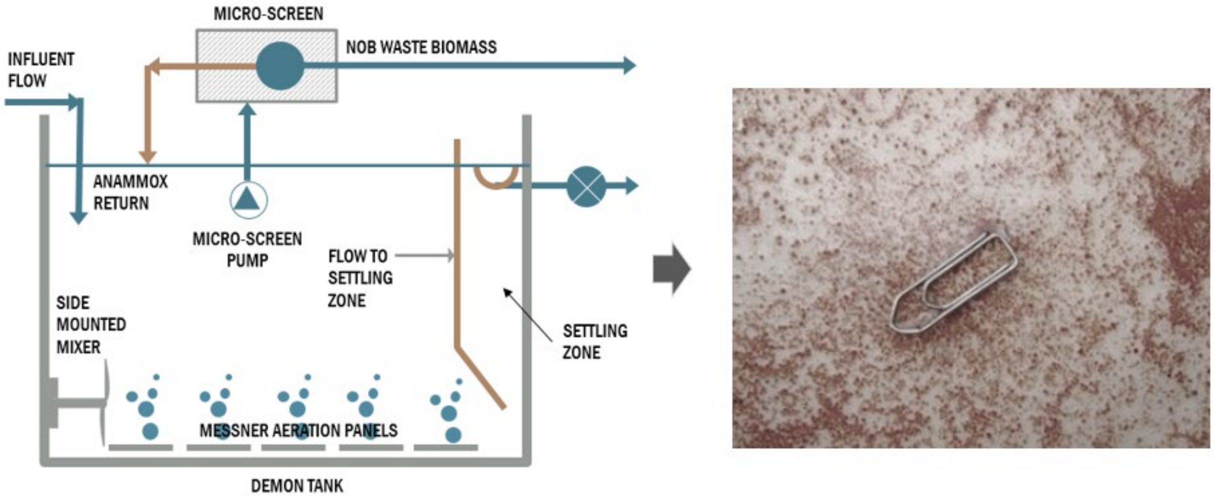

Figure 2-6. Schematic of DEMON system and anammox granules

The DEMON reactor is aerated using Messner panels while submersible mixers are used to maintain mixed liquor suspended solids (MLSS) in suspension during unaerated periods (Figure 2-6). Aeration and mixing are controlled using pH and DO sensors (typical DO setpoint of 0.3 mg/L). The aeration blowers are typically operated within a narrow pH control range of 0.02 pH units. Nitrate, nitrite and ammonia probes are also typically used to monitor process performance.

There are six operating systems that treat dewatering sidestream from thermophilic digesters and thermal hydrolysis process (THP) systems and more than five systems that treat centrate from codigestion facilities (codigestion of fats, oils and grease [FOG] and food waste with municipal sludge). The continuous flow DEMON system at the Amersfoort, Netherlands, was installed in 2012 as one of the earliest continuous flow DEMON systems. The Amersfoort facility treats high-strength sidestream from a THP and mesophilic anaerobic digestion process. The facility can process up to 14,400 dry tons of biosolids per year, of which trucked waste streams account for approximately 40 percent of total solids.

2.3.2.2 ANITAMox

ANITAMox can be configured as a flow-through process using the integrated fixed-film activated sludge (IFAS) configuration. The IFAS configuration is a hybrid attached-growth (on plastic media) and suspended-growth system that provides a higher SRT so that higher ammonia loads can be treated with a smaller tank volume. The anammox bacteria will attach to the plastic media, which is retained with screens at the exit of the reactor. The suspended growth organisms pass through the screen and settle in a clarifier that is equipped with a RAS and WAS system (Figure 2-7).

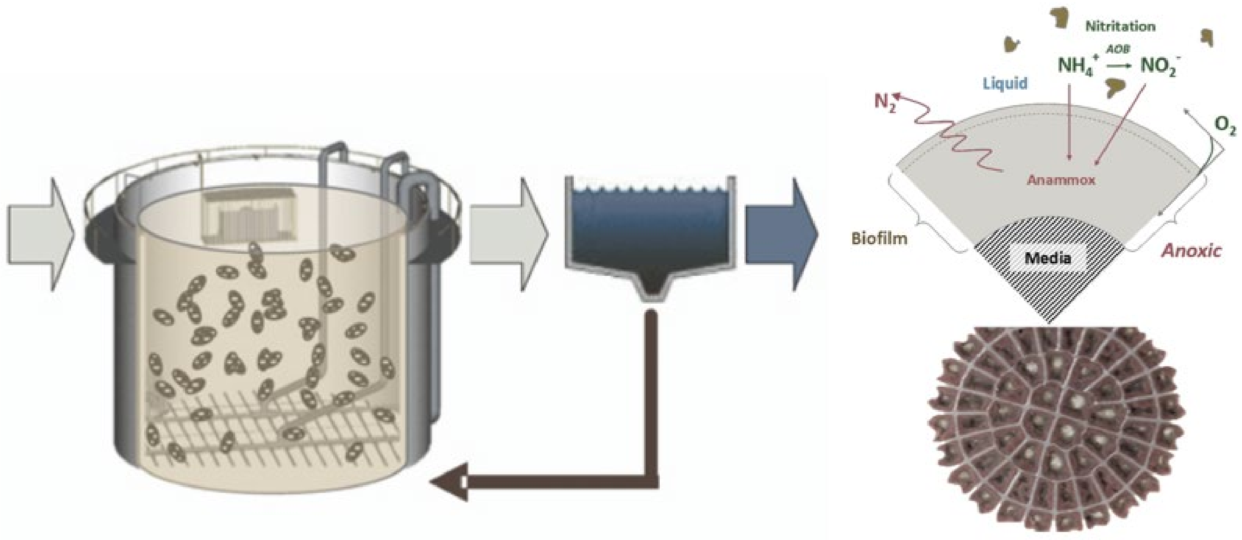

Figure 2-7. Schematic of ANITAMox system configuration

The process reactor is equipped with submersible mixers and medium-bubble aeration grids. Similar to the DEMON system, pH and DO is typically used for control of the aeration blowers. Nitrite/nitrate and ammonia instrumentation would also be installed in the reactors for process monitoring and control.

The first generation of ANITAMox systems were installed as a moving bed bioreactor (MBBR) configuration, which does not include the RAS stream in Figure 2-7. More recent installations have used the IFAS configuration, which has been an improvement to the system because it provides more process control of the suspended-growth system. The plant in Boras, Sweden, was the first ANITAMox installation in the IFAS configuration. The sidestream system at Boras treats sidestream from anaerobic digesters and leachate from a neighboring landfill. The design nitrogen load to the reactor is approximately 1,800 pounds of nitrogen per day (lb-N/d) without equalization.

Some notable benefits of the ANITAMox system that contribute to process stability and reliability include:

- The aeration control strategy is straightforward and simple to operate.
- The risk of washout and upsets is low; anammox is retained as a biofilm on the carrier media.
- The attached growth system responds quickly after process interruptions related to aeration and feed.

2.3.2.3 AnammoPAQ

AnammoPAQ is a fully granular system that operates in continuous-flow and suspended-growth mode. The AOB and annamox organisms co-exist inside granules, with the AOB organisms located on the outer layer of the granule and the annamox located within the inner granule structure. The granules developed in this process are typically 1 to 5 millimeter (mm) in diameter, which is much larger in size compared with the granules in the DEMON process (1 mm observed). Figure 2-8 provides a schematic of the AnammoPAQ system. The specific feed and settling system to the reactor is proprietary and is attributed for the large granule size. The proprietary outlet structure retains large, dense anammox granules in the reactor while lighter suspended solids and non-granulated bacteria are washed out through an overflow weir. The aeration blowers are controlled using DO in combination with ammonia, nitrite and pH sensors. To manage the granule inventory, excess sludge is occasionally wasted from the AnammoPAQ reactor.

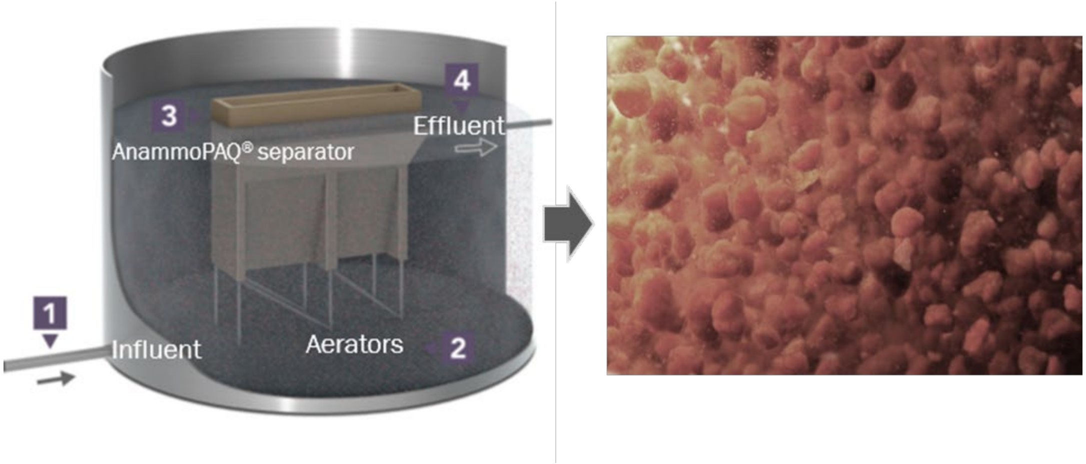

Figure 2-8. Main components of the AnammoPAQ system (provided by Ovivo)

The AnammoPAQ system has less mechanical equipment in the process reactors and, therefore, has some reduced operation and maintenance (O&M) requirements. As noted earlier, the inlet and outlet configuration in the reactors is proprietary because it is critical for granule formation; the mechanisms are not understood and require manufacturer assistance during startup and/or process troubleshooting. The aeration and process control system has not yet been standardized by the manufacturer and is specific to each facility, which may increase the need for manufacturer input during startup and operation.

2.3.2.4 ZeeNAMMOX

ZeeNAMMOX is the newest deammonification technology in the United States, which currently has no full-scale installations; however, there are several pilot-scale facilities. ZeeNAMMOX builds on the emerging MABR technology for mainstream treatment. The MABR employs a gas-permeable membrane to deliver oxygen to a biofilm attached to the surface of the membrane, which allows bacteria to consume oxygen more readily and significantly reduces energy use ZeeNAMMOX is a continuous flow system where partial nitritation takes place on the biofilm closest to the media, which is oxygen rich. Ammonia and nitrite removal by anammox take place in the outer layer of biofilm where no bulk oxygen is the reactor. Anammox retention is achieved by attachment to the MABR media. Figure 2-9 shows the main components of the ZeeNAMMOX system.

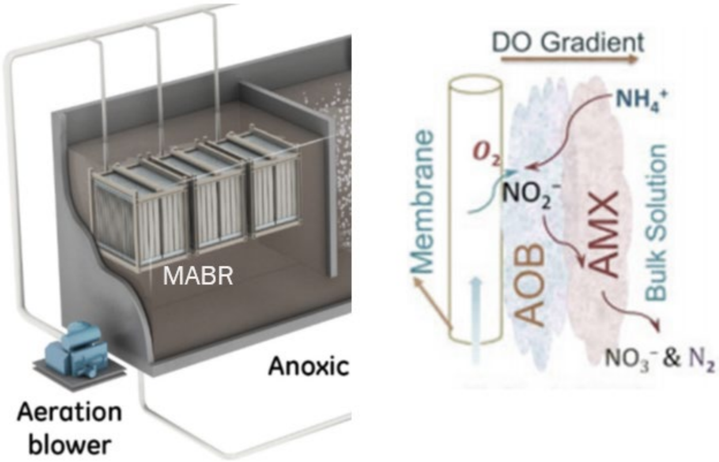

Figure 2-9. Main components of the ZeeNAMMOX system

2.3.3 Physical-Chemical Ammonia Recovery (AMR)

Physical-chemical treatment does not require biological activity to reduce ammonia in the dewatering centrate but instead relies on stripping ammonia from the liquid phase to the gas phase. A two-step process is typically used with the first step consisting of raising the pH of the dewatering centrate stream to 10 pH units and stripping ammonia to a gas stream in a column filled with plastic media. Fans or low-pressure blowers are used to provide a counter-current stream of air through the packed media. The liquid stream is returned to the plant drain with a low ammonia and nitrogen concentration. The ammonia-rich gas stream is directed to a second column where it is passed counter-current through a stream of sulfuric acid that is sprayed from the top of the tower. The acid converts the ammonia to liquid ammonium sulfate (LAS), which can be sold as a fertilizer. Figure 2-10 provides a schematic of the AMR process. The AMR process is an established technology, and there are various manufacturers that can provide package AMR systems, including Anaergia. A non-proprietary system was assumed for the alternative (refer to Appendix B).

As shown on Figure 2-10, the process produces LAS, which can be further processed to evaporate water and form granular ammonium sulfate (GAS). A crystallizer can be used for granule production. GAS can also be sold as a fertilizer and typically has a higher value than LAS. A key consideration with the AMR systems is that a market or outlet is needed for the ammonia-rich product. A benefit of AMR is that the process would be less sensitive to influent ammonia load variations and/or other dissolved constituents since it does not rely on microbiology, which can be more susceptible to process upsets due to feed water quality.

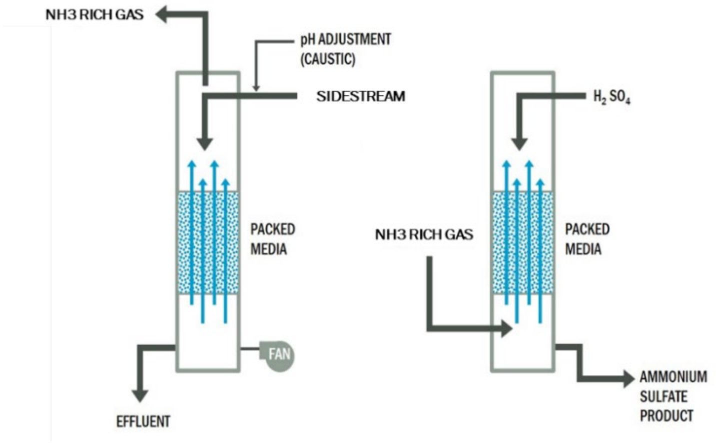

Figure 2-10. AMR process schematic

2.4 Alternative Development

A total of seven sidestream nitrogen removal alternatives were developed and evaluated (refer to Table 2-4) and are described in more detail in the subsequent sections. Alternatives N1 through N5 are biological removal processes that convert ammonia to nitrogen gas, thereby reducing nitrogen levels in the centrate. Alternatives N6 and N7 are physical-chemical processes that rely on removing ammonia from the centrate and recovering it as a product that can be used as a fertilizer. This evaluation compares land requirements andcapital and operational requirements of the alternatives.

Table 2-4. Sidestream nitrogen removal alternatives

Alternative	Description
Alternative N1: Biological	Conventional, 4-stage Bardenpho configuration Flow-through, suspended-growth system Provides 80 percent TIN reduction
Alternative N2: Biological	Deammonification using the DEMON system Flow-through, suspended-growth system Provides 70 to 75 percent TIN reduction
Alternative N3: Biological	Deammonification using the ANITAMox system Flow-through, IFAS configuration Provides 80 percent TIN reduction
Alternative N4: Biological	Deammonification using the AnammoPAQ system Flow-through, suspended-growth, granule-based system Provides 80 percent TIN reduction
Alternative N5: Biological	Deammonification using the ZeeNAmmox system Attached growth, granule-based system Provides 80 to 85 percent TIN reduction
Alternative N6: Physical-Chemical	AMR to produce LAS Provides 85 percent TIN removal
Alternative N7: Physical-Chemical	AMR to produce GAS Provides 85 percent TIN removal

2.4.1 Flow Equalization

Flow equalization of dewatering centrate is included for all alternatives to decouple the sidestream treatment from the dewatering operation and to minimize variability in sidestream feed flows and loads. The flow equalization was sized for approximately 3 to 4 hours of detention time, which is sufficient to accommodate variation of dewatering performance. The equalization tank for the biological alternatives includes volume so that dilution water can be added to the tank while still maintaining the target detention time. The physical-chemical alternatives do not require dilution water and, therefore, have a slightly smaller equalization tank (refer to Table 2-5).

Table 2-5. Flow equalization

Parameter	Value
Approximate holding time	3 to 4 hours[a]
Equalization volume [a]	0.15 million gallons (MG) (physical-chemical processes), 4-hour holding time for 0.9 mgd sidestream 0.225 MG (biological processes), 3- or 4-hour holding time for 1.8- or 1.35-mgd diluted sidestream
Ancillary facilities	Covered tank with odor control Discharge pumping station included

All values are rounded.

a. The smaller volume is for the physical-chemical alternatives to provide 4 hours of detention time. The larger volume is for biological alternatives and assumes 0.90 mgd of dewatering centrate is combined with 0.45 to 0.90 mgd of secondary effluent as cooling water. For the biological alternatives, 3 hours of detention is provided in 2050 when 100 percent dilution water is required.

2.4.2 Pre-Treatment

Pre-treatment is included for all sidestream nitrogen alternatives to reduce TSS and COD concentrations and to minimize the potential for struvite formation. For the biological alternatives, a high TSS in the centrate feed will result in more solids in the reactor, which increases reactor volume. In addition, it can lead to a mixed liquor that is less specific to desired organisms (i.e., anammox and AOBs). The higher TSS levels can also result in fouling of process instrumentation in the reactor. Similarly, high TSS levels in the centrate can foul process instrumentation and the plastic media in the physical-chemical reactors, ultimately leading to higher O&M costs. For these reasons, the pre-treatment system is considered critical for operating nitrogen sidestream treatment.

The pre-treatment step includes chemical addition (ferric chloride) for flocculation and for struvite control, followed by sedimentation. High phosphorus concentrations in sidestream feed can cause struvite formation in the sidestream reactors, which can foul equipment and instrumentation as well as create micronutrient deficiencies in the biological systems. Tube settler clarifiers were assumed as noted in Table 2-6 (refer to Attachment B for manufacturer information), with the exception of DEMON (Alternative N2), where the manufacturer includes lamella plate settlers upstream of the reactors. Scum removal is also assumed in the pre-treatment step. Removed scum and solids would be sent to the blend tanks.

Table 2-6. Pre-treatment system

Parameter	Value
Coagulant addition	Ferric chloride
Sedimentation system	Lamella plate settler for Demon (Alternative N2) tube settlers (all other alternatives)[a]
No. of sedimentation tanks	2 (1 duty, 1 standby)
Sedimentation tank dimensions[b]	16 feet (ft) 11-inch diameter 20 ft, 4-inch high (Volume 0.1 MG each)
Ancillary facilities	Tanks are covered with odor-control system Sludge pumping to blend tanks

a. Alternative 2 assumes lamella plate settlers for the pre-treatment sedimentation step. All other alternatives assume tube settlers. Refer to Appendix B for manufacturer information.

b. Dimensions provided for tube settler sedimentation tanks.

Ferric chloride addition was not included in the annual operating costs and net present value (NPV) calculation because it is assumed to be the same for all alternatives. Capital costs do include provisions for a dedicated ferric chloride chemical storage and dosing system at the pre-treatment/sidestream treatment location. Ferric chloride addition for sidestream treatment will be further considered in the Integrated Roadmap Report so as to provide an estimate of future operating costs.

2.4.3 Alternative N1: 4-Stage Bardenpho – Conventional Biological

Figure 2-11 provides a process flow schematic of the conventional (4-stage Bardenpho) biological system developed for sidestream treatment at the MWWTP. The conventional system was assumed to operate as a flow-through system. This configuration was selected because it was determined to be a reliable configuration that could achieve TIN reduction similar to the deammonification alternatives. If Alternative N1 is carried forward, an SBR could be further considered/developed to determine if new tankage could be optimized and capital costs could be reduced. The operating costs of an SBR are not anticipated to be significantly different from those of the 4-stage Bardenpho system.

Table 2-7 provides a summary of main process performance parameters as well as the capital and operating costs for Alternative N1. The reactor volumes required for this alternative are greater than the volumes of the two GSTs; therefore, this alternative requires new tankage as well as new aeration blowers and new clarifiers. The capital costs for this alternative include a new building for the aeration blowers and electrical facilities, odor control for the pretreatment tanks and the equalization tank as well as yard piping to route centrate and waste streams to the solids blend tanks. Appendix D includes the detailed capital and operating cost estimates and the NPV calculation. Appendix C provides a site layout for conventional biological treatment.

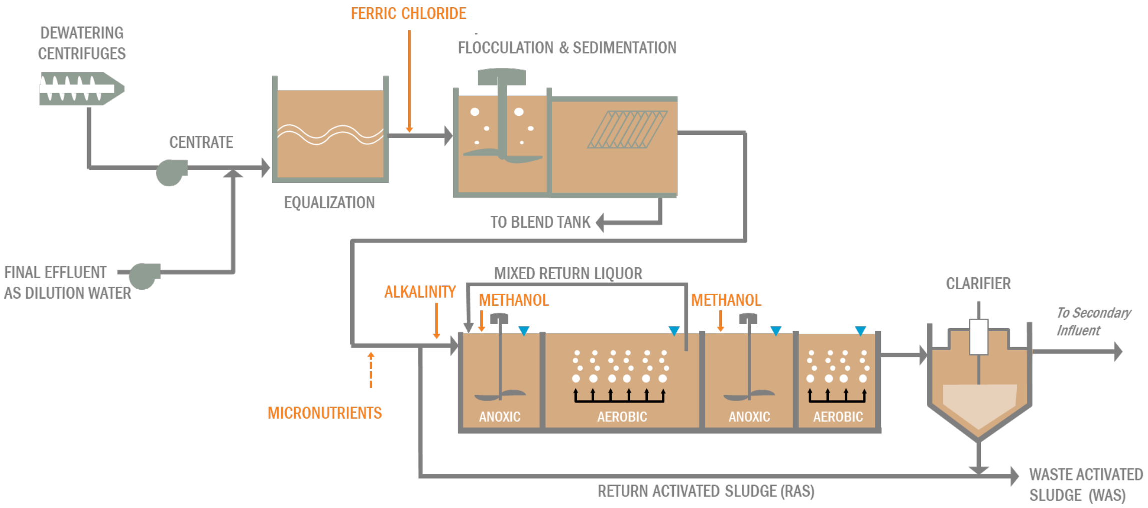

Figure 2-11. Alternative N1: conventional biological process schematic

The conventional biological system is an established process however, it is a biological process that can be subject to process upsets. The feed characteristics of the sidestream are critical to biological system performance. Additional characterization of the dewatering centrate is recommended to confirm if micronutrient addition is needed and if there are dissolved constituents that could inhibit nitrification in the dewatering centrate.

Table 2-7. Alternative N1: Conventional biological planning assumptions

Parameter[a]	Value
Sidestream process reactors	
No. of reactors	3
Volume per reactor	1 MG
Total reactor volume	3 MG
Dimensions per reactor (length x width x side water depth)	120 ft x 56 ft x 20 ft
Sidestream secondary clarifiers	
No. of clarifiers	2
Diameter	38 ft
Surface area per clarifier	600 square ft (ft^2)
Performance	
Ammonia reduction	95 percent removal
TIN reduction	80 percent removal
Ammonia loading rate	0.5 kg-N/m^3/day
ADW operating conditions:	
Process aeration demands	16,000 standard cubic ft per minute (scfm)
Methanol addition	2,700 gallons per day (gpd)
Alkalinity addition	850 gpd
Land requirements for Alternative N1	1 acre
Capital costs – Alternative N1[b]	$133.4 million
Total annual operating costs – Alternative N1 (PV) [b]	$126.4 million
Annual energy cost (PV)	$18.2 million
Annual chemical cost (PV)	$84.5 million
Annual labor cost (PV)[c]	$18.6 million
Annual replacement and repair (R&R)[d] (PV)	$5.1 million
NPV	$259.8 million
Unit cost per pound of TIN removed [e]	$2.75/lb TIN removed

a. Equalization and pre-treatment are included with this alternative as described in Tables 2-5 and 2-6.

b. Refer to Attachment D for capital and operating cost details. Capital costs assume new tanks are constructed west of the SLW receiving station. Chemical use includes caustic and methanol addition. Ferric chloride addition is not included in the chemical operating costs; ferric chloride dose is assumed to be the same for all alternatives and was not included in operating costs for this analysis.

c. Labor assumes that 1.75 full-time equivalents (FTE) are added to the O&M staff (in addition to current staffing plan)

d. R&R costs include general equipment maintenance and replacement. Fine-bubble diffusers are included in the R&R with an assumed replacement frequency of 7 years.

e. Unit cost calculated as NPV divided by total pounds of TIN reduced over 30-year life cycle.

kg-N/m^3/day = kilograms nitrogen per cubic meter per day

2.4.4 Alternative N2: Deammonification – DEMON Configuration

Figure 2-12 provides a process flow schematic of the DEMON system at the MWWTP. The tank volume required for the DEMON system is approximately 1 MG, which is the equal to the volume of the GSTs. It was confirmed with the manufacturer that the GSTs could be repurposed and used with the DEMON process. For conservatism, the capital costs included in Table 2-8 assume that new tankage is constructed west of the SLW receiving station. Attachment C provides a detailed site plan for the DEMON system. Attachment D provides the detailed capital, operating and NPV costs. It is estimated that repurposing the GSTs could reduce capital costs by approximately $15 to $17 million, but this assumes no seismic repairs to the GSTs are needed. The cost savings of repurposing the GSTs is dependent on the rehabilitation that is needed with the tanks. If the GSTs are used for sidestream treatment, the equalization and pre-treatment would likely need to be located west of the SLW receiving station such that centrate would be pumped across the plant after pre-treatment.

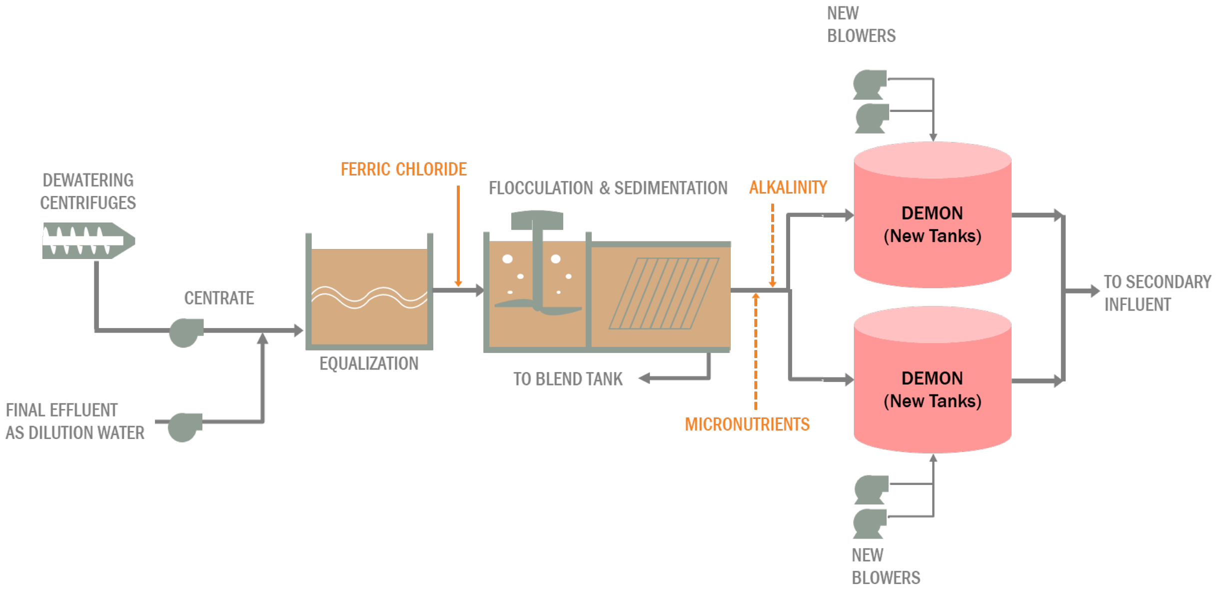

Figure 2-12. Alternative N2: DEMON flow schematic

As noted in section 2.3, the DEMON system is considered an established technology for sidestream treatment. Improvements to the system have been made to increase system reliability. Because the system is biological, it can be prone to process upsets. As with the conventional biological alternative (Alternative N1), additional characterization of the sidestream is needed to confirm the need for micronutrient addition and to confirm that there are no substances that could inhibit or impact performance of the deammonification system.

Table 2-8. Alternative N2: DEMON assumptions

Parameter[a]	Value
DEMON process reactors No. of reactors Volume per reactor Total reactor volume Dimensions per reactor (diameter x side water depth)	 2 0.5 MG 1 MG 70 ft x 14 ft
Performance Ammonia reduction TIN reduction Ammonia loading rate	 90 percent removal 80 percent removal 1.5 kg-N/m^3/day
ADW operating conditions: Process aeration demands	 5,800 scfm
Land requirements for Alternative N2	0.6 acre
Capital costs – Alternative N2[b]	$84.4 million
Total annual operating costs – Alternative N2 (PV) [b]	$27.7 million
Annual energy cost (PV)	$4.8 million
Annual chemical cost (PV) [b]	$0.0 million
Annual labor cost (PV) [c]	$18.6 million
Annual R&R (PV) [d]	$4.3 million
NPV	$112.1 million
Unit cost per pound of TIN removed [e]	$1.20/lb TIN removed

a. Equalization and pre-treatment are included with this Alternative as described in Tables 2-5 and 2-6.
b. Refer to Attachment D for capital and operating cost details. Capital costs assume new tanks are constructed west of the SLW receiving station. Ferric chloride addition is not included in the chemical operating costs; ferric chloride dose is assumed to be the same for all alternatives and was not included in operating costs for this analysis.
c. Labor assumes that 1.75 FTEs are added to the O&M staff (in addition to current staffing plan)
d. R&R costs include general equipment maintenance and replacement. Aeration panels are included in the R&R with an assumed replacement frequency of 7 years.
e. Unit cost calculated as NPV divided by total pounds of TIN reduced over 30-year life cycle.

2.4.5 Alternative N3: Deammonification – ANITAMox Configuration

Figure 2-13 provides a flow schematic of the ANITAMox system at the MWWTP and Table 2-9 summarizes the system configuration. Appendices C and D provide site plans, along with capital, operating and NPV estimates for this alternative. It should be noted that the ANITAMox ammonia and TIN reduction is lower than DEMON because the manufacturer applied additional factors of safety to account for variability due to the R2 waste streams.

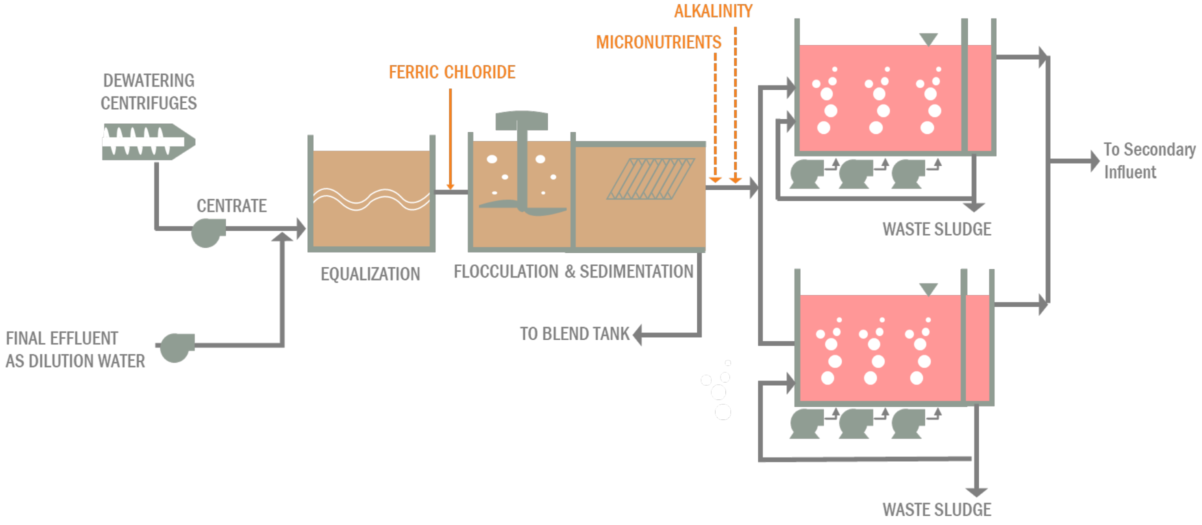

Figure 2-13. Alternative N3: ANITAMox process flow schematic

The ANITAMox system is considered an established technology for sidestream treatment. As noted with the DEMON system (Alternative N2), a biological system can be prone to process upsets. As with the conventional biological alternative (Alternative N1), additional characterization of the sidestream is needed to confirm the need for micronutrient addition and that there are no substances that could inhibit or impact performance of the deammonification system.

Table 2-9. Alternative N3: ANITAMox planning assumptions

Parameter[a]	Value
ANITAMox Process Reactors	
No. of reactors	2
Volume per reactor	0.54 MG
Total Reactor volume	1.08 MG
Dimensions per reactor (length x width x side water depth)	60 ft x 60 ft x 20 ft
Performance	
Ammonia reduction	80 - 85 percent removal
TIN reduction	70 – 75 percent removal
Ammonia loading rate	1.3 kg-N/m^3/day
ADW operating conditions:	
Process aeration demands	5,800 scfm
Methanol addition	--
Alkalinity addition	--
Land requirements for Alternative N3	0.6 acre
Capital costs – Alternative N3[b]	$91.8 million
Total annual operating costs – Alternative N3 (PV) [b]	$28.8 million
Annual energy cost (PV)	$5.6 million
Annual chemical cost (PV) [b]	$0.0 million
Annual labor cost (PV) [c]	$18.6 million
Annual R&R (PV) [d]	$4.6 million
NPV	$120.6 million
Unit cost per pound of TIN removed [e]	$1.35/lb TIN removed

a. Equalization and pre-treatment are included with this Alternative as described in Tables 2-5 and 2-6.

b. Refer to Attachment D for capital and operating cost details. Capital costs assume new tanks are constructed west of the SLW receiving station. Ferric chloride addition is not included in the chemical operating costs; ferric chloride dose is assumed to be the same for all alternatives and was not included in operating costs for this analysis.

c. Labor assumes that 1.75 FTEs are added to the O&M staff (in addition to current staffing plan)

d. R&R costs include general equipment maintenance and replacement. Aeration panels are included in the R&R with an assumed replacement frequency of 7 years.

e. Unit cost calculated as NPV divided by total pounds of TIN reduced over 30-year life cycle.

2.4.6 Alternative N4: Deammonification – AnammoPAQ Configuration

Figure 2-14 provides the process schematic for AnammoPAQ at the MWWTP and Table 2-10 summarizes the details of this alternative. The AnammoPAQ tank volume requirements are such that the GSTs could be repurposed as reactors. As with the Conventional Biological alternative, the capital costs presented in Table 2-10 assume new tankage.

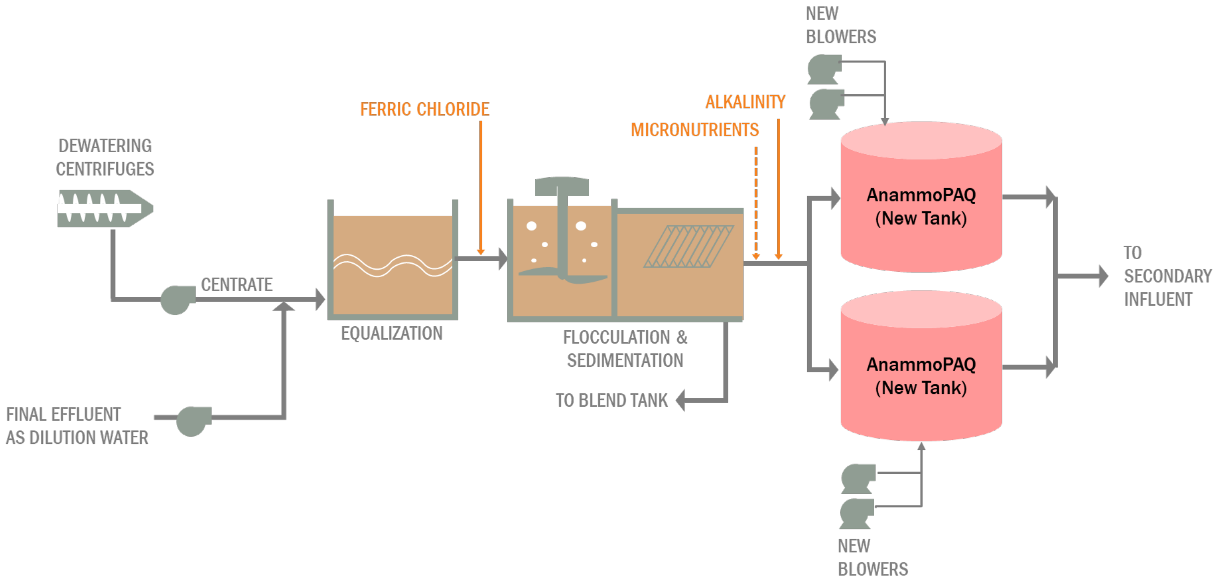

Figure 2-14. Alternative N4: AnammoPAQ process schematic

As noted in Section 2.3, the AnammoPAQ system has fewer installations in the United States; however, there are a number of installations worldwide. For this reason, it was considered an established technology, though the District would likely want to pilot test to confirm the operational requirements and system performance. As noted above with the other biological alternatives, the AnammoPAQ system could be prone to process upsets, and the influent feed characteristics should be confirmed to determine the need for micronutrient addition and/or to confirm if there is potential for inhibition.

Table 2-10. Alternative N4: AnammoPAQ assumptions

Parameter[a]	Value
AnammoPAQ process reactors	
No. of reactors	2
Volume per reactor	0.39 MG
Total reactor volume	0.78 MG
Dimensions per reactor (length x width x side water depth)	51 ft x 51 ft x 20 ft
Performance	
Ammonia reduction	90 percent removal
TIN reduction	80 percent removal
Ammonia loading rate	1.8 kg-N/m^3/day
ADW operating conditions:	
Process aeration demands	6,800 scfm
Methanol addition	--
Alkalinity addition	--
Land requirements for Alternative N4	0.6 acre
Capital costs – Alternative N4[b]	$99.3 million
Total annual operating costs – Alternative N4 (PV) [b]	$32.0 million
Annual energy cost (PV)	$6.8 million
Annual chemical cost (PV) [b]	$0.0 million
Annual labor cost (PV) [c]	$18.6 million
Annual R&R (PV) [d]	$6.6 million
NPV	$131.3 million
Unit cost per pound of TIN removed[e]	$1.40/lb TIN removed

a. Equalization and pre-treatment are included with this Alternative as described in Tables 2-5 and 2-6.

b. Refer to Attachment D for capital and operating cost details. Capital costs assume new tanks are constructed west of the SLW receiving station. Ferric chloride addition is not included in the chemical operating costs; ferric chloride dose is assumed to be the same for all alternatives and was not included in operating costs for this analysis.

c. Labor assumes that 1.75 FTEs are added to the O&M staff (in addition to current staffing plan)

d. R&R costs include general equipment maintenance and replacement. Aeration panels are included in the R&R with an assumed replacement frequency of 7 years.

e. Unit cost calculated as NPV divided by total pounds of TIN reduced over 30-year life cycle.

2.4.7 Alternative N5: Deammonification – ZeeNAMMOX Configuration

Figure 2-15 provides a process schematic at the MWWTP and Table 2-11 summarizes the alternative. The high energy savings makes the alternative attractive, but is tempered by the high cost of the MABR system.

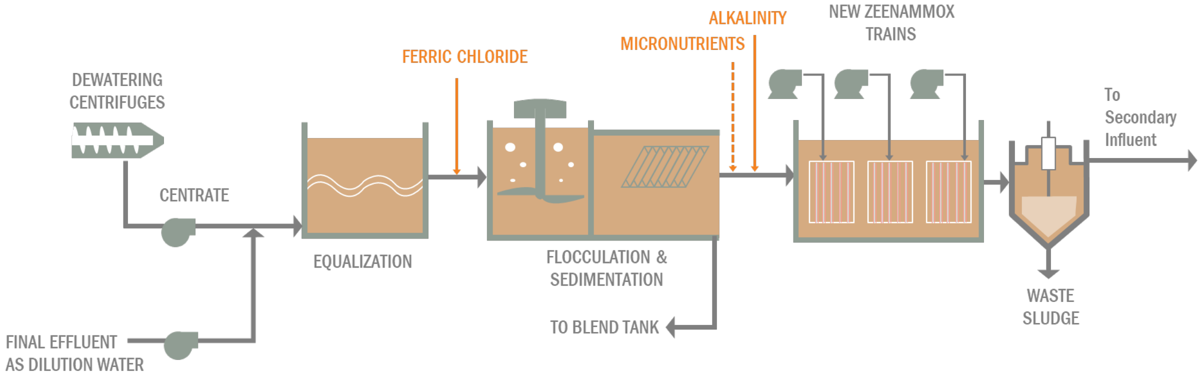

Figure 2-15. Alternative N5: ZeeNAMMOX process schematic

The ZeeNAMMOX system was considered emerging because there are no full-scale operational facilities. Due to the lack of full-scale installations, there is no operational history, and system reliability is unknown. If the District moves forward with pilot testing, ZeeNAMMOX system performance could be considered at that time. As with the biological alternatives listed above, system performance will also depend on the feed characteristics.

Table 2-11. Alternative N5: ZeeNAMMOX planning assumptions

Parameter[a]	Value
ZeeNAMMOX process reactors	
No. of reactors	2
Volume per reactor	0.65 MG
Total reactor volume	1.30 MG
Dimensions per reactor (length x width x side water depth)	66 ft x 66 ft x 20 ft
Performance	
Ammonia reduction	90 percent removal
TIN reduction	80 - 85 percent removal
Ammonia loading rate	1.09 kg-N/m^3/day
ADW operating conditions:	
Process aeration demands	2,100 scfm
Land requirements for Alternative N5	0.4 acre
Capital costs – Alternative N5[b]	$145.2 million
Total annual operating costs – Alternative N5 (PV) [b]	$33.5 million
Annual energy cost (PV)	$3.2 million
Annual chemical cost (PV)[b]	$0.0 million
Annual labor cost (PV)[c]	$18.6 million
Annual R&R (PV)[d]	$11.7 million
NPV	$178.7 million
Unit cost per pound of TIN removed [e]	$1.80/lb TIN removed

a. Equalization and pre-treatment are included with this Alternative as described in Tables 2-5 and 2-6.

b, Refer to Attachment D for capital and operating cost details. Capital costs assume new tanks are constructed west of the SLW receiving station. Ferric chloride addition is not included in the chemical operating costs; ferric chloride dose is assumed to be the same for all alternatives and was not included in operating costs for this analysis.

c. Labor assumes that 1.75 FTEs are added to the O&M staff (in addition to current staffing plan)

d. R&R costs include general equipment maintenance and replacement. Aeration panels are included in the R&R with an assumed replacement frequency of 7 years.

e. Unit cost calculated as NPV divided by total pounds of TIN reduced over 30-year life cycle.

2.4.8 Alternative N6: AMR with LAS

Alternative N6 consists of the AMR process shown on Figure 2-16. Equalization of dewatering centrate is assumed to provide the ability to feed a constant flow rate to the AMR. Cooling water is not needed because temperature reduction is not needed with the process. Pre-treatment is included upstream of the AMR system to reduce TSS in the feed and struvite precipitation, which can foul the packed media columns and increase O&M.

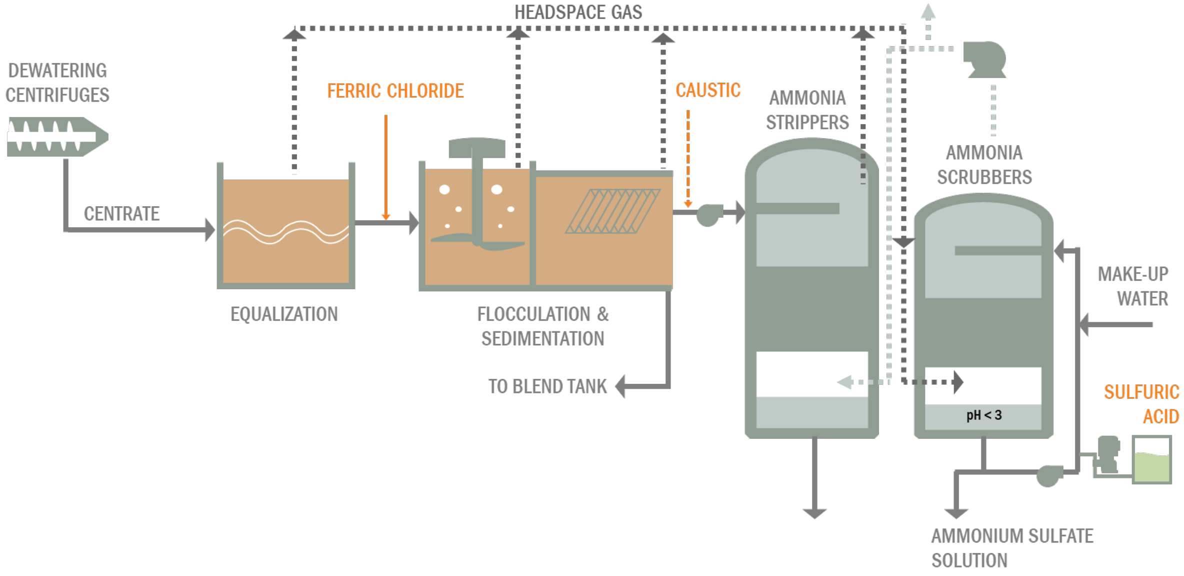

Figure 2-16. Alternative N6: AMR with LAS process schematic

The AMR process is dependent on chemical addition to raise the pH and subsequently lower it. For this reason, it is not susceptible to the process upsets and/or toxic or inhibitory substances that can impact performance of a biological system. The AMR system can accommodate changes in flows, loads and centrate quality provided there is sufficient hydraulic capacity in the system. Caustic soda addition for pH adjustment in the first step of the AMR process was estimated using historical data. The actual amount of caustic needed to raise the pH may be higher due to the high alkalinity of the centrate stream. Table 2-12 summarizes the alternative. The capital costs included in Table 2-12 do not include costs for storage and truck loadout facilities for LAS. The LAS is not a hazardous material and can be stored onsite and transported without special regulatory or safety measures. There are multiple manufacturers of AMR systems, and Appendix B includes more detailed information on the system assumed for this alternative.

It should be noted that the AMR with LAS was sized to treat all sidestream flow. As noted in the Market Assessment Report (Brown and Caldwell, 2021), there may not be a local market for the volume of LAS that would be produced. The AMR system offers the benefit of being a fairly modular system that could be sized to produce LAS that matches the local demand of the product. This option would increase operational complexity and would increase the number of unit processes that Staff would need to operate.

Table 2-12. Alternative N6: AMR with LAS planning assumptions

Parameter[a]	Value
Ammonia stripping columns No. of reactors Reactor dimensions (diameter x height) Hydraulic capacity per reactor	 5 (4 duty, 1 standby) 11 ft x 25 ft 0.23 mgd
Ammonia scrubber columns No. of reactors Reactor dimensions (diameter x height) Hydraulic capacity per reactor	 5 (4 duty, 1 standby) 11 ft x 10 ft 0.23 mgd
Ammonia removal from dewatering centrate	85 percent
Caustic addition	120 gpd
Sulfuric acid addition	2,500 gpd
ADW low-pressure air demand for ammonia strippers	54,000 scfm
Land requirements for Alternative N6	0.5 acre
Capital costs – Alternative N6[b]	$77.2 million
Total annual operating costs – Alternative N6 (PV) [b]	$92.4 million
Annual energy cost (PV)	$2.4 million
Annual chemical cost (PV) [b]	$62.8 million
Annual labor cost (PV) [c]	$21.2 million
Annual R&R (PV) [d]	$6.0 million
Annual revenue – Alternative N6 (PV)[e]	$9.8 million
NPV	$159.8 million
Unit cost per pound of TIN removed [f]	$1.60/lb TIN removed

a. Equalization and pre-treatment are included with this Alternative as described in Tables 2-5 and 2-6.
b. Refer to Attachment D for capital and operating cost details. Capital costs assume new tanks are west of the SLW receiving station. Chemicals costs include caustic and sulfuric acid use. Ferric chloride addition is not included in the chemical operating costs; ferric chloride dose is assumed to be the same for all alternatives and was not included in operating costs for this analysis.
c. Labor assumes that 2 FTEs are added to the O&M staff (in addition to current staffing plan)
d. R&R costs include general equipment maintenance and replacement. Additional R&R allowance is included for chemical feed facility maintenance and repair due to the corrosive nature of the chemicals.
e. Revenue is based on the net value of $36/ton of LAS identified in the Market Assessment report.
f. Unit cost calculated as NPV divided by total pounds of TIN reduced over 30-year life cycle.

2.4.9 Alternative N7: AMR with GAS

This alternative builds off the AMR with LAS alternative (Alternative N6) and adds a crystallization step for GAS production. Table 2-13 summarizes the capital and annual operating costs of the alternative. The crystallizer system requires natural gas at startup, but then is able to recirculate excess heat to minimize electrical and natural gas demands during operation. Appendix B includes more detailed information on the systems assumed for this alternative.

Table 2-13. Alternative N7: AMR with GAS planning assumptions

Parameter[a]	Value
AMR system[b]	Refer to Table 13 for details. AMR system is identical to Alternative N6.
Crystallizer system	1 crystallizer and 1 belt filter press for dewatering crystals
Ammonia removal from dewatering centrate[b]	85 percent
Caustic addition[b]	120 gpd
Sulfuric acid addition[b]	2,500 gpd
ADW low-pressure air demand for ammonia strippers[b]	54,000 scfm
Land requirements for Alternative N7	0.6 acre
Capital costs – Alternative N7[c]	$105.6 million
Total annual operating costs – Alternative N7 (PV)[c]	$105.0 million
Annual energy cost (PV)	$11.9 million
Annual chemical cost (PV)[c]	$63.6 million
Annual labor cost (PV)[d]	$21.2 million
Annual R&R (PV)[e]	$8.3 million
Annual revenue – Alternative N7 (PV)[f]	$44.6 million
NPV	$166.0 million
Unit Cost per pound of TIN removed[g]	$1.65/lb TIN removed

a. Equalization and pre-treatment are included with this Alternative as described in Tables 2-5 and 2-6.
b. AMR system, which is identical to Alternative 6- refer to Table 13 for details.
c. Refer to Attachment D for capital and operating cost details. Capital costs assume new tanks are constructed west of the SLW receiving station. Chemicals costs include caustic and sulfuric acid use. Ferric chloride addition is not included in the chemical operating costs; ferric chloride dose is assumed to be the same for all alternatives and was not included in operating costs for this analysis.
d. Labor assumes that 2 FTEs are added to the O&M staff (in addition to current staffing plan)
e. R&R costs include general equipment maintenance and replacement. Additional R&R allowance is included for chemical feed facility maintenance and repair due to the corrosive nature of the chemicals.
f. Revenue is based on the net value of $228/ton of GAS identified in the Market Assessment report.
g. Unit cost calculated as NPV divided by total pounds of TIN reduced over 30-year life cycle.

2.5 Sidestream Nitrogen Treatment Evaluation

Table 2-14 summarizes the sidestream nitrogen removal alternatives. The results of the economic and non-economic evaluation are presented on Figure 2-17 and Figure 2-18, respectively. Appendix E provides additional details for the non-economic analysis. The following are conclusions from the analysis:

- The deammonification alternatives (Alternative N2 through N5) have lower NPVs and higher non-economic scores compared to the physical-chemical alternatives (Alternative N6 and N7) and the conventional biological system (Alternative N1).
- In general, biological sidestream nitrogen removal is subject to process upsets, and the feed quality can impact system performance. The physical chemical alternatives (Alternatives N6 and N7) have a lower potential for process upsets.
- The conventional biological system is not a proprietary system and does not require seeding with anammox bacteria. The deammonification systems are proprietary and require seeding with the anammox bacteria.
- Conventional biological (Alternative N1) treatment requires more land than the other alternatives and has a high NPV. The capital costs and chemical and energy requirements of the alternative are higher than the deammonification alternatives.
- DEMON (Alternative N2) and ANITAMox (Alternative N3) are the deammonification technologies with more operational history in the United States. The number of US installations increases the ability to easily reseed the reactors with anammox bacteria if needed due to a process upset. AnammoPAQ has limited operational history in the US but does have international operating experience. ZeeNAMMOX has no full-scale installations and was, therefore, considered an emerging technology.
- The NPV and land requirements for DEMON (Alternative N2), ANITAMox (Alternative N3) and AnammoPAQ (Alternative N4) are similar. The GSTs could be repurposed and used as the DEMON and AnammoPAQ reactors.
- ZeeNAMMOX has the highest NPV and capital cost of the deammonification alternatives.
- ANITAMox (Alternative N3) offers advantages of increased system reliability due to the attached growth system. The attached growth system reduces the risk of washout because anammox is retained as a biofilm on the carrier media. The attached growth system can also quickly respond to changes in the feed, thereby reducing the potential for process upsets.
- The NPV for the AMR with LAS alternative (Alternative N6) has a similar order of magnitude to the deammonification alternatives. The alternative would increase chemical use at the MWWTP, and the high operating costs are the result of the system's high chemical use.
- The AMR systems (Alternatives N6 and N7) produce an ammonia-rich product that could be used as fertilizer. Either alternative would require the District to develop a market and distribute the product offsite. The estimated revenue stream generated from the sale of LAS or GAS would not cover system operating costs.

Based on the conclusions noted above, it was determined that the Master Plan would use ANITAMox as a placeholder technology for sidestream nitrogen removal. Additional characterization of the sidestream quality, along with pilot testing, is recommended to confirm design criteria, performance and the potential presence of constituents that may impact performance of the biological system. The District would still have the flexibility to accommodate the other deammonification alternatives, based on the pilot testing results. If testing of the deammonification alternatives does not produce results that meet the District's goals, there would also be flexibility to accommodate the AMR alternatives (N6 and N7).

Table 2-14. Summary of sidestream nitrogen alternatives

Parameter	**Biological N Removal**					**Physical-chemical N Recovery**	
	Alternative N1: Conventional Biological	**Alternative N2: DEMON**	**Alternative N3: ANITAMox**	**Alternative N4: AnammoPAQ**	**Alternative N5: ZeeNAMMOX**	**Alternative N6: Ammonia Recovery (AMR) with Liquid Ammonium Sulfate (LAS)**	**Alternative N7: AMR with Granular Ammonium Sulfate (GAS)**
Effluent TIN reduction (tons/year)[a]	1,700	1,700	1,600	1,700	1,800	1,800	1,800
Capital cost, $million[b]	$133.4	$84.4	$91.8	$99.3	$145.2	$77.2	$105.6
Operating cost, $million[c]	$126.4	$27.7	$28.8	$32.0	$33.5	$92.5	$105.0
Labor PV, $million	$18.6	$18.6	$18.6	$18.6	$18.6	$21.2	$21.2
Chemical PV, $million	$84.5	$0.0	$0.0	$0.0	$0.0	$62.8	$63.6
Energy PV, $million	$18.2	$4.8	$5.6	$6.8	$3.2	$2.4	$11.9
Repair and rehabilitation PV, $million	$5.1	$4.3	$4.6	$6.6	$11.7	$6.0	$8.3
Revenue PV, $million[c]	No revenue	No revenue	No revenue	No revenue	No revenue	$9.8	$44.6
NPV, $million	$259.8	$112.1	$120.6	$131.3	$178.7	$159.8	$166.0
Unit cost[d], $/TIN lb removed	$2.75	$1.20	$1.35	$1.40	$1.80	$1.60	$1.65
Land requirements, acres	1.0 3 reactors (at 1 MG each)	0.6 2 reactors (at 0.5 MG each)	0.6 2 reactors (at 0.54 MG each)	0.6 2 reactors (at 0.39 MG each)	0.4 2 reactors (at 0.65 MG each)	0.5 5 trains	0.5 5 trains
Technology maturity (or full-scale installations)	Established	Established More than 92 global installations and 7 United States Installations	Established 28 global and 8 United States installations	Established More than 54 global installations and 1 United States installation	Emerging 0 full-scale installations	Established More than 24 full-scale installations	Established technology Limited installation with similar application

All values are rounded.

a. TIN reduction for Year 2050 is presented. TIN reduction is calculated based on sidestream influent ammonia (11,900 lb/day) minus sidestream effluent TIN.

b. Capital costs assume equalization and pre-treatment of centrate upstream of the sidestream treatment reactors. New tankage is assumed for all alternatives. The GSTs could be repurposed as sidestream reactors for Alternatives 2 and 4 for a capital cost savings on the order of $15 to $17 million; the savings is dependent on GST rehabilitation that is needed, which is uncertain at this time. Capital costs are presented as 2021 dollars.

c. Operating costs are presented as the PV of energy, labor, chemical use and R&R costs over a 30-year operating period. Annual revenue is sale of recovered ammonia based on the market assessment findings. Operating and benefits are presented as the PV in 2021 dollars.

d. Unit cost is based on the NPV over the 30-year period divided by the pounds of TIN removed over the 30-year period.

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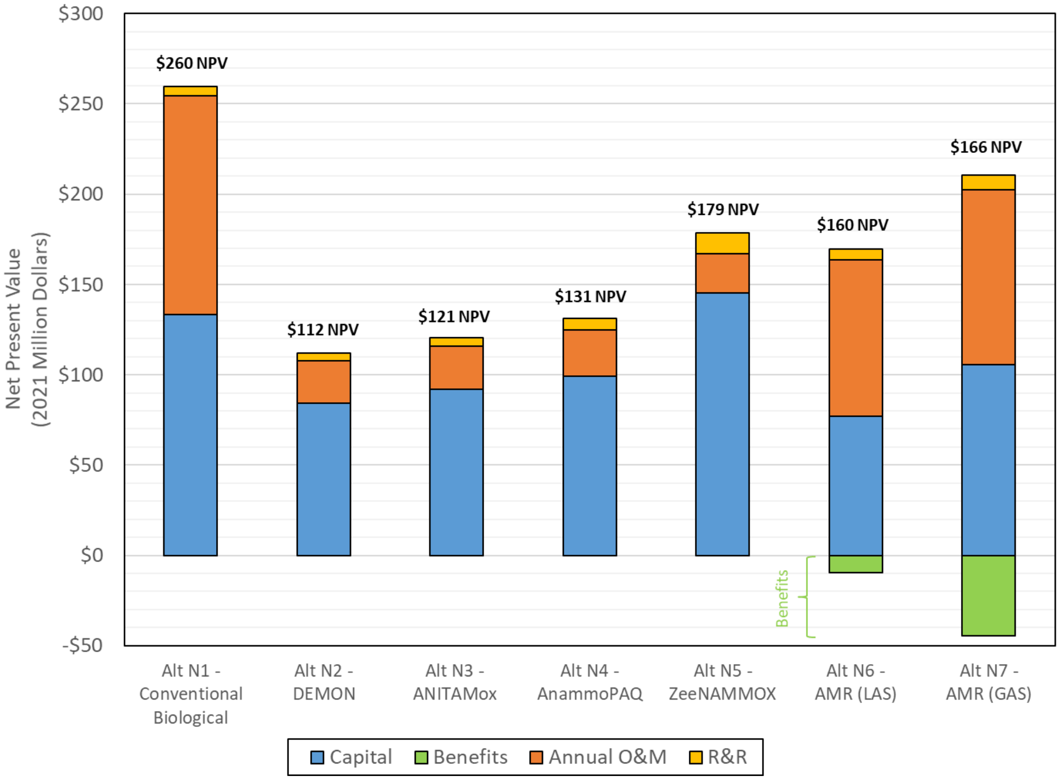

Figure 2-17. Nitrogen sidestream treatment alternatives economic analysis

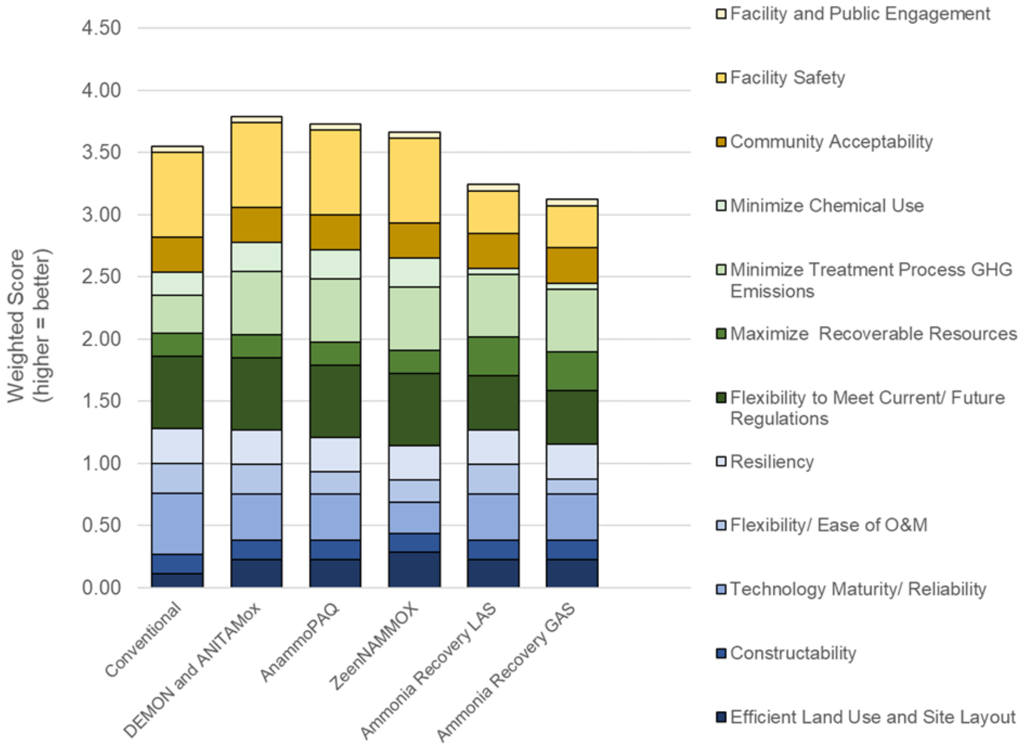

Figure 2-18. Non-economic evaluation of sidestream nitrogen alternatives

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CHAPTER 3 - SIDESTREAM PHOSPHORUS REMOVAL

As noted in chapter 1, nutrient discharge regulations are not anticipated to include phosphorus limits. For this reason, the focus of sidestream phosphorus removal is to minimize struvite precipitation in the solids handling facilities and pipelines, thereby reducing O&M costs associated with struvite mitigation. The following section provides a summary of the alternatives considered for the Master Plan.

3.1 Planning Assumptions

Table 3-1 summarizes the 2050 flow and load conditions for sidestream phosphorus removal (refer to Appendix A for a complete summary of conditions by decade).

Table 3-1. Sidestream phosphorus removal flow and load basis

Parameter	Projected 2050 Value
Digester feed flow, mgd	1.0
Digester feed TP load lb-P/day [a]	7,000 (850 mg/L)
Digester feed OP load (with ferric chloride addition at the blend tanks) lb-P/day [b]	440 (53 mg/L)
Digested sludge flow, mgd	1.0
Digested sludge, TP load, lb-P/day	7,000 (850 mg/L)
Digested sudge, OP load, lb-P/day	1,400 (170 mg/L)
Centrate flow, mgd	0.9
Centrate TP load, lb-P/day	1,500 (200 mg/L)
Centrate OP load, lb-P/day	1,300 (170 mg/L)

All values are rounded.

a. In 2050, the TP from high-strength waste (HSW) is estimated to be 21% (or 1,500 lbs-P/day) of the total TP load in digester feed.

b. The OP load from HSW in 2050 is projected to be approximately 1,100 lbs-P/day. Current operation includes ferric chloride addition to the blend tanks. The digester feed OP load reflects the continued addition of ferric chloride to the blend tanks, which decreases the OP load in the digester feed.

lb-P/day = pounds of phosphorus per day

OP = orthophosphate

TP = total phosphorus

3.2 Siting for Sidestream Phosphorus Removal

For the purposes of evaluating technologies, it was assumed that sidestream phosphorus treatment facilities would be located on the land available west of the SLW receiving station (refer to Figure 2-1). As the Master Plan is further developed, the siting of sidestream phosphorus removal will be refined and coordinated with other Master Plan projects.

3.3 Sidestream Phosphorus Removal Technology Overview and Alternatives

In 2016, the District prepared a Struvite Control Investigation Report (Hazen and Sawyer, 2016). The 2016 report considered various alternatives for struvite mitigation. As part of the Master Plan, alternatives from the 2016 report were updated to reflect future flow and load conditions, capital and operating costs, as well as potential revenue from the sale of a struvite product. CalPrex (Alternative P2) was not considered in the 2016 study and has been added to this evaluation. Table 3-2 summarizes the alternatives for sidestream phosphorus removal.

Table 3-2. Sidestream phosphorus removal/recovery alternatives

Alternative	Description
Alternative P1: Chemical Addition	Ferric chloride addition upstream of the anaerobic digesters to bind phosphorus and minimize struvite formation in and downstream of the digesters.
Alternative P2: CalPrex	Pre-digestion P-recovery: Proprietary system that is downstream of a fermentation step (acid-phase digester) and precipitates phosphorus as calcium phosphate or brushite, which can be sold as a fertilizer. A sub-alternative was also considered that eliminates the fermentation step and treats digester feed; because the R2 waste streams are projected to contribute a high OP load, the fermentation step could be eliminated if an alternate ferric chloride dosing location is identified (i.e., addition at the PSTs for CEPT)
Alternative P3: AirPrex	Post digestion P-removal or recovery: Proprietary system that precipitates struvite with the biosolids in a controlled reactor to minimize formation on dewatering equipment and centrate lines.
Alternative P4: Ostara (Struvite Recovery) with WASSTRIP (waste activated sludge stripping to remove internal phosphorous)	Proprietary system that precipitates and pelletizes struvite in a reactor and minimizes formation in the digesters and downstream of the digesters. Struvite pellets can be marketed as a fertilizer.

It should be noted that as mainstream nitrogen removal technologies are developed for the MWWTP, struvite precipitation in the digesters may be reduced if the secondary system no longer operates with enhanced biological phosphorus removal (EBPR) when the anaerobic selector is eliminated. Additionally, if R2 waste streams are changed in the future, TP and OP loads directed to the digesters could be reduced, which could further reduce struvite precipitation.

3.3.1 Alternative P1: Chemical Addition

The addition of iron salts is frequently used to control struvite. At the MWWTP, ferric chloride is currently added to the digester feed (at the blend tanks) to control hydrogen sulfide in the digester gas. Increasing the ferric chloride dosage could minimize struvite precipitation by binding OP and precipitating it as ferric phosphate (vivianite). A higher ratio of ferric chloride to solids may be needed due to the contribution of OP from HSW streams. Typically, ferric chloride rates for struvite control can be in the range of 30 to 50 lbs of ferric/dry ton of solids (Hazen and Sawyer, 2016). Multipoint addition of ferric chloride can be used by increasing the dosage at the blend tanks, and/or adding ferric chloride at the PSTs (CEPT), the digesters and the centrate lines. Alternative P1 assumes a 43 percent ferric chloride solution added upstream of the anaerobic digesters as shown on Figure 3-1. The current ferric chloride dosage for hydrogen sulfide control is 360 milligrams iron per liter (mg Fe/L). An additional 590 mg Fe/L dose could be used to reduce struvite in the centrate lines (Hazen and Sawyer, 2016). This increased dose equates to approximately 3,100 gpd of ferric chloride addition.

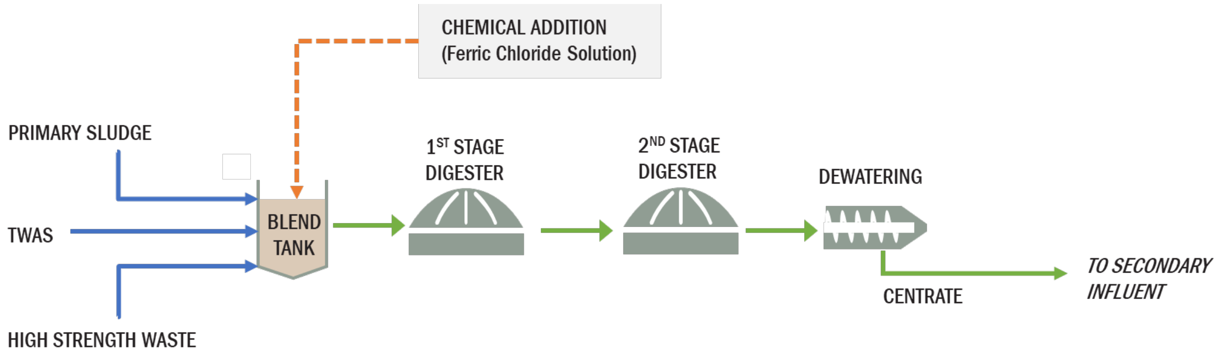

Figure 3-1. Chemical addition process flow diagram

Table 3-3 summarizes the main assumptions and costs of this alternative. This alternative assumes that a dose of 1,000 mg Fe/L of ferric chloride is sufficient for struvite control and is based on the modeling that was done as part of the 2016 Struvite Investigation Report (Hazen and Sawyer, 2016). The operating cost for this alternative includes the ferric chloride use needed for struvite control is 640 mg Fe/L (i.e., 1,000 mg Fe/L minus 360 mg Fe/L). An allowance for ferric chloride metering and piping is assumed to provide for the flexibility of multi-point addition. It is assumed that additional chemical storage is not needed. Ferric chloride at the PSTs could provide multiple benefits because it could reduce loading to the secondary system (refer to findings in Integrated MWWTP Roadmap Report), could allow for repurposing the PSTs for sidestream nitrogen removal, and could provide struvite mitigation.

This alternative offers the benefit of being easy to adjust if future conditions change. For example, if mainstream nitrogen removal is implemented and EBPR no longer performed, the phosphorus content in the digesters will likely be lower and ferric chloride use may be reduced. Similarly, if HSW streams are reduced in the future, the phosphorus content in the digesters may also be lower, thereby reducing ferric chloride addition and lowering struvite formation in the solids handling facilities.

Table 3-3. Alternative P1: Chemical addition phosphorus sidestream planning assumptions

Parameter	Value
Ferric chloride system	Assumes that storage is adequate. Allowance for piping and new metering pumps.
Ferric chloride addition (Year 2050)[a]	3,100 gpd
Capital cost – Alternative P1	$2.6 million
Annual operating cost (chemical use only) – Alternative P1 (PV) [b]	$86.9 million
NPV	$89.5 million

a. Assumes 43% iron chloride ($FeCl_3$) by weight solution with 1.38 specific gravity. Volume is the additional amount of 43% ferric chloride solution added relative to the baseline dose of 640 mgFe/L.

b. Presented as PV for 30-year project life cycle.

3.3.2 Alternative P2: CalPrex

CalPrex is a phosphorus recovery technology that can be implemented upstream of digestion. The system is most effective at higher OP concentrations (OP greater than 250 milligrams as phosphorus per liter (mg-P/L). A typical CalPrex system includes a fermentation or acid-phase digestion upstream of the CalPrex system. The target hydraulic retention time (HRT) in the fermentation tank is 1 to 1.5 days, which provides adequate time to release OP. The fermented sludge is dewatered, the centrate or filtrate is routed to the CalPrex reactor and solids are directed to the anaerobic digester. Figure 3-2 provides a process schematic of the CalPrex system at the MWWTP. Calcium hydroxide is added to the CalPrex reactor (see Figure 3-2) to raise the pH and precipitate calcium phosphate ($CaHPO_4 \cdot 2H_2O$) or brushite. The brushite crystals settle in a clarifier. The composition of pure brushite is 18 percent phosphorus and 23.3 percent calcium. The CalPrex system also includes a drying step. Brushite can be marketed as a fertilizer product by the manufacturer or by the District.

The main benefits of the CalPrex system include:

- Reduced struvite formation in the digesters
- Production of brushite product that can be marketed as a fertilizer product
- Use of brushite to remove grit in the digester feed sludge.

If long-term discharge regulations include phosphorus limits, CalPrex can typically recover 40 percent of phosphorus that is fed to the digesters. Table 3-4 summarizes the key considerations of the CalPrex alternative (Alternative P2).

As shown in Table 3-4, a new, 1.5-MG acid-phase digester or fermentation tank is assumed upstream of the CalPrex system; the acid-phase digester would maximize the brushite recovered in the CalPrex system. The existing blend tanks do not have adequate volume to provide a target 1 to 1.5-day HRT; therefore, new tankage would be needed.

An alternative to constructing a new acid-phase digester is to implement CalPrex to recover the OP that is in the HSW streams. The HSW streams currently have a high OP load (estimated load in 2050 is 1,100 lb/day); however, the OP is likely precipitated in the blend tanks due to ferric chloride addition. Thus, this option would require moving the ferric chloride addition point to an alternate location that would still reduce hydrogen sulfide in the digester gas without precipitating OP in the HSW. One potential alternate location for ferric chloride addition would be at the PSTs; if CEPT were implemented, the ferric chloride addition could reduce loading to the secondary system and also reduce the number of PSTs that are required for wet weather treatment.

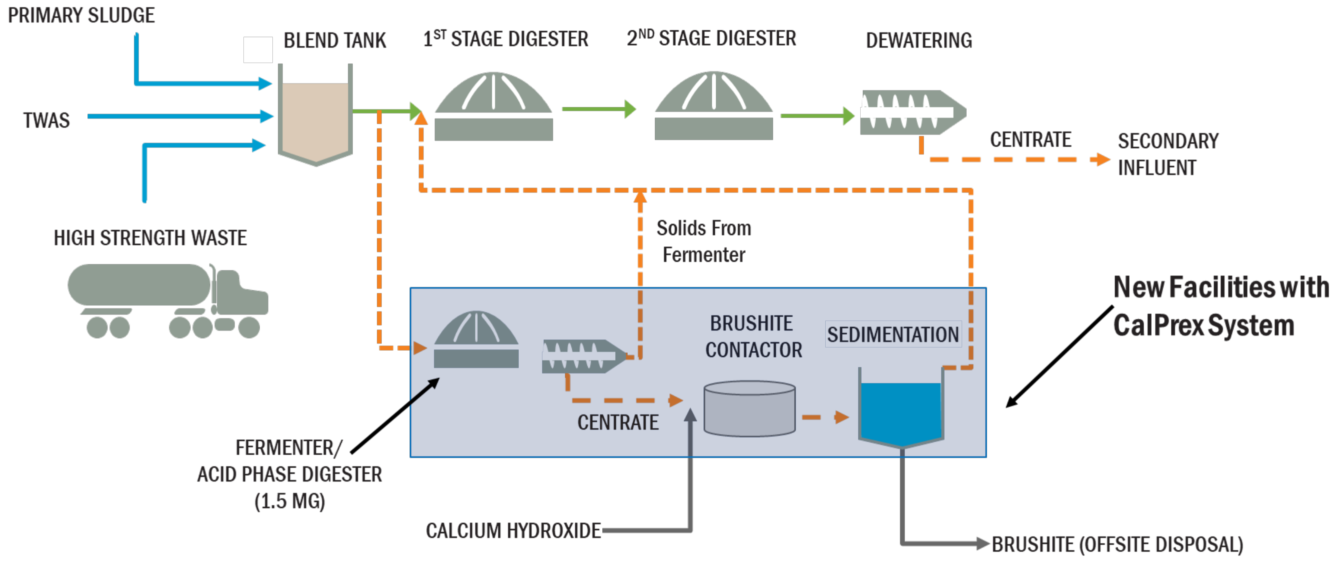

Figure 3-2. Alternative P2: CalPrex process flow schematic

Table 3-4. Alternative P2: CalPrex planning assumptions

Parameter	With Acid-Phase Digester	Without Acid Phase Digester
Acid-phase digester volume	1.5 MG	NA
Dewatering upstream of CalPrex	Centrifuge (2 duty, 1 standby) (designed to treat acid-phase digestate)	Centrifuge (2 duty, 1 standby) (designed to treat blend tank effluent)
CalPrex system components	• Calcium hydroxide storage and dosing system (silos, slurry tanks, feed pumps) • Two Calprex reactors • One clarifier • Reactor feed pumps • Brushite dewatering and drying system • Brushite storage • Dewatered sludge holding tank	• Calcium hydroxide storage and dosing system (silos, slurry tanks, feed pumps) • Two Calprex reactors • One clarifier • Reactor feed pumps • Brushite dewatering and drying system • Brushite storage • Dewatered sludge holding tank
Land requirement, acres[a]	0.6	0.4
Brushite produced (Year 2050) lbs-P/day	2,100	700
Capital cost – Alternative P2	$104.9 million	$52.7 million
Total annual operating cost – Alternative P2 (PV)[a]	$28.8 million	$22.9 million
Annual energy (PV)[a]	$4.8 million	$1.3 million
Annual chemical use (PV)[a]	$3.3 million	$0.9 million
Annual labor (PV)[a,b]	$15.9 million	$15.9 million
Annual R&R(PV)	$4.8 million	$4.8 million
Annual revenue (PV)[a, c]	$1.7 million	$0.5 million
NPV[a]	$132.0 million	$75.1 million

a. Presented as PV for 30-years
b. Assumes 1.5 additional FTEs
c. Assumes $150/ton gross revenue for brushite revenue

Discussions with the CalPrex manufacturer indicate that the gross value of brushite is in the range of $150/ton. Additional outreach was performed to confirm the local brushite market. Based on discussions with fertilizer blending operations and animal feed operations, the value of brushite locally is narrow and could be lower by 50 percent (i.e., $75/ton). The brushite value may be greater in other parts of the country, but delivery costs would rise and reduce or eliminate revenue potential. If the District were to move forward with a CalPrex system, entering into an agreement with the manufacturer for brushite distribution/marketing is recommended to maximize revenue potential.

3.3.3 Alternative P3: AirPrex

The AirPrex system is a proprietary process that is located between digestion and dewatering and uses a reactor to form and remove struvite crystals. It can minimize struvite formation in dewatering, digested sludge piping and pumps, and in centrate lines. The AirPrex system uses air to circulate sludge in the reactor; the air strips carbon dioxide from solution, thereby increasing pH, which aids in struvite precipitation. Magnesium chloride is also dosed into the reactor to aid in the precipitation of the struvite crystals. The AirPrex system can remove up to 90 percent of OP in the digested sludge and 10 to 20 percent of ammonia through the precipitation of struvite. The HRT of the reactor typically ranges from 4 to 5 hours, and the struvite crystals can be sent out with the dewatered cake. Struvite crystals can also be separated from the cake and marketed as fertilizer; however, a longer HRT is needed in the reactor (8 to 10 hours is recommended) and the crystals need additional washing. Figure 3-3 provides a schematic of a typical AirPrex reactor with the crystal washing step.

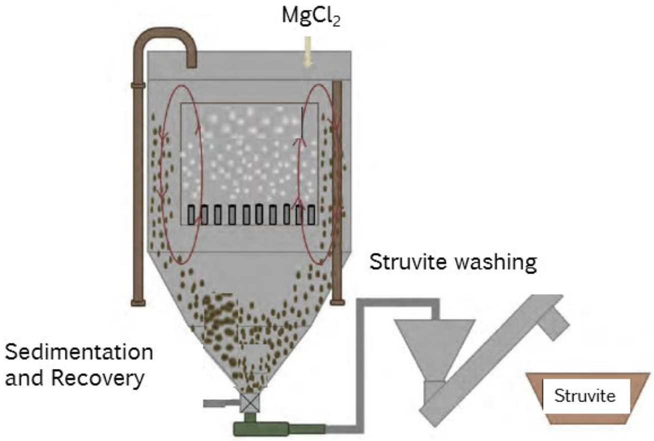

Figure 3-3. Process schematic - AirPrex

The key advantages to the AirPrex system are that it is simple to operate and can achieve a high recovery of OP. The dewaterability of the digested sludge is also improved; operational facilities have observed a 20 to 30 percent reduction in polymer use, together with a 2 to 3 percent increase in cake solids content. A key consideration is that other alternatives target minimizing struvite precipitation in the digesters, whereas AirPrex does not. AirPrex is expected to mitigate struvite precipitation in and downstream of the digesters by reducing overall phosphorus in the system.

Figure 3-4 provides a process schematic of the AirPrex system at the MWWTP. Table 3-5 summarizes the key considerations. The AirPrex system could be located between the first and second stage digesters to reduce struvite accumulation in the second-stage digesters and dewatering system. The alternative costs would not significantly change if the system were located upstream of the second-stage digesters. The alternative assumes that the struvite crystals remain in the dewatered cake and are not separated out. The economic benefits of this alternative are based on assumed improvements to dewaterability and polymer dose. This alternative was considered in the 2016 Struvite Investigation Report and has been updated with planning-level flows and loads, vendor proposals and costing methodology.

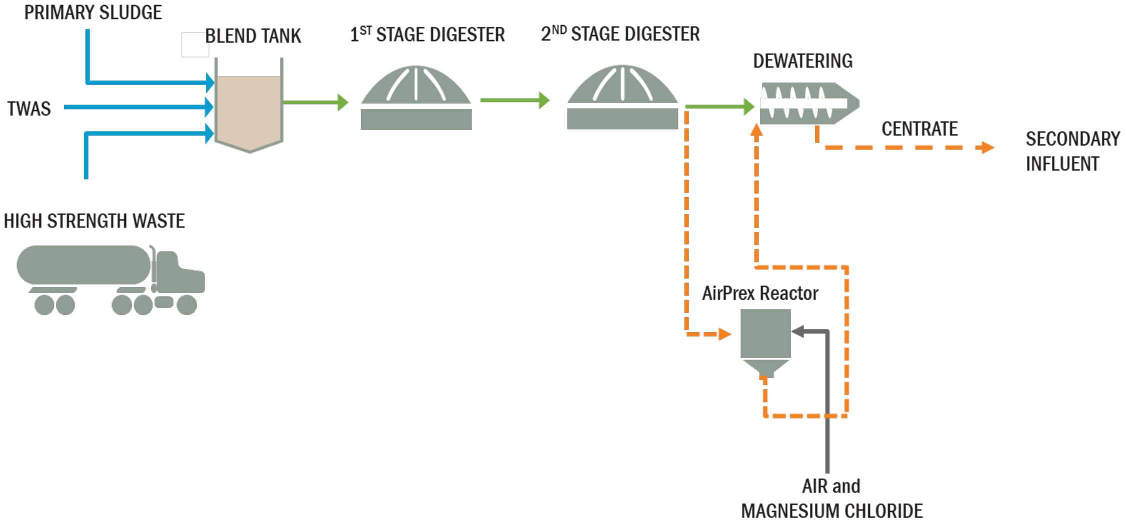

Figure 3-4. Alternative P3: AirPrex process flow schematic

Note: AirPrex system can be located in between first-stage and second-stage digesters to minimize struvite precipitation in the second-stage digestion and dewatering systems

Table 3-5. Alternative P3: AirPrex planning assumptions

Parameter	Value
AirPrex system components	• 4 AirPrex Reactors (14-ft diameter, 55 ft. high) • 4 blowers • Magnesium chloride storage and dosing system
Magnesium chloride use, gpd	4,300
Land requirement, acres	0.3
Capital cost – Alternative P3	$48.9 million
Annual operating cost – Alternative P3 (PV)[a]	$82.8 million
Annual energy (PV) [a]	$2.7 million
Annual chemical use (PV) [a]	$60.6 million
Annual labor (PV) [a,b]	$15.9 million
Annual R&R (PV) [a]	$3.6 million
Annual revenue (PV) [c]	$11.5 million
NPV	$120.2 million

a. Presented as PV for 30-year project life cycle
b. Assumes 1.5 additional FTEs
c. Based on polymer and increased dewaterability. Alternative benefits were quantified in the 2016 Struvite Investigation Report and were escalated into 2021 dollars.

The key advantages of the AirPrex system are that it addresses struvite precipitation downstream of the digesters and it is simple to operate. Sludge dewaterability can be improved, which provides operational benefits.

3.3.4 Alternative P4: Ostara and WASSTRIP

The Ostara Pearl process recovers phosphorus from post-digestion centrate. The WASSTRIP system ferments WAS to release OP; the WAS is then thickened, and the filtrate (high in OP) is routed to the Ostara Pearl reactor and the thickened WAS is routed to the digesters. The two reactors paired together control struvite formation in as well as downstream of the digesters. Magnesium chloride and sodium hydroxide or magnesium oxide are added to the Pearl reactor to raise pH and precipitate struvite. Struvite pellets are dried and stored prior to distribution as a fertilizer (Crystal Green fertilizer). Struvite pellets formed with magnesium chloride (higher cost) tend to have a higher value, while pellets formed with magnesium oxide (lower cost) tend to have a slightly lower value due to the size and quality of the pellet. The Ostara and WASSTRIP process are most effective when the secondary process includes EBPR; without EBPR the process is not cost effective. A process schematic of the Ostara and WASSTRIP system is shown on Figure 3-5.

Key advantages to the Ostara + WASSTRIP process are that struvite is minimized in and downstream of the digesters, and the pellet can be marketed with a higher value for fertilizer use. This alternative was considered in the 2016 Struvite Investigation Report and has been updated with planning-level flows and loads, vendor proposals and costing methodology.

Table 3-6 summarizes key features of the alternative. Based on discussions with the manufacturer, magnesium oxide is recommended in the Bay Area in lieu of magnesium chloride. Magnesium oxide has a lower cost compared to magnesium chloride, thereby reducing operating costs. The pellets produced with magnesium oxide are smaller, which can impact the market value. It should be noted that if the District goes to mainstream nitrogen removal, EBPR could be eliminated, which would reduce the OP diverted to the Ostara process.

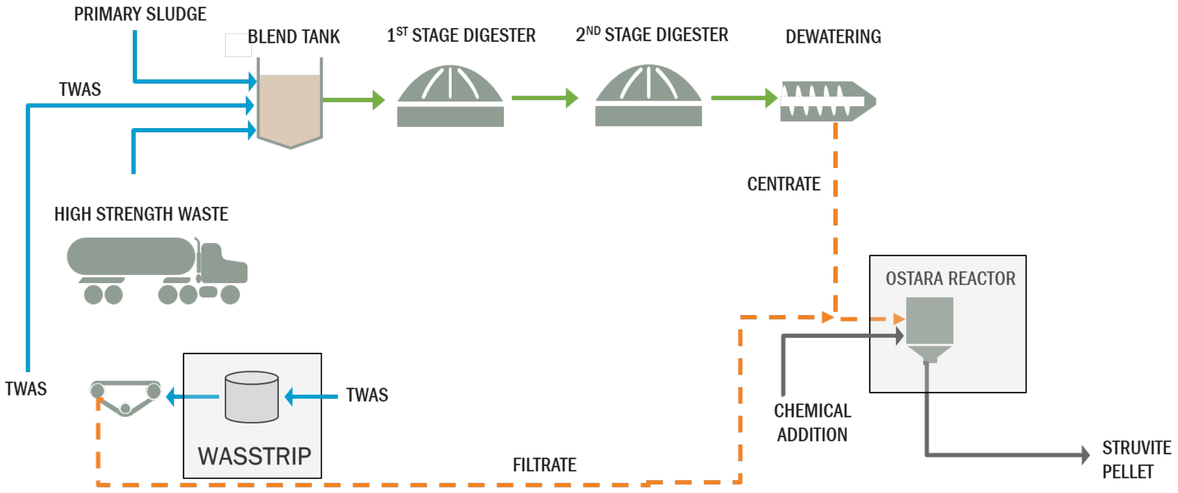

Figure 3-5. Process flow diagram for Ostara and WASSTRIP at MWWTP

Table 3-6. Alternative P4: Ostara and WASSTRIP planning assumptions

Parameter	Value
Ostara and WASSTRIP System components	• 1 Pearl 10K reactor and bagging system • 2 15,000-gallon $MgCl_2$ tanks and dosing system • 1 12,000-gallon NaOH tank and dosing system • Dryer and heater assembly
Magnesium oxide use, dry tons/d	1.2
Land requirement, acres	0.5
Struvite pellet production (Crystal Green product) in Year 2050, tons/year	1,550
Capital cost – Alternative P4	$106.9 million
Total annual operating cost – Alternative P4 (PV)[a]	$43.2 million
Annual energy (PV) [a]	$4.5 million
Annual chemical Use (PV) [a]	$19.6 million
Annual labor (PV) [a,b]	$15.9 million
Annual R&R (PV) [a]	$3.2 million
Annual revenue (PV) [c]	$12.7 million
NPV	$137.4 million

a. Presented in PV for 30-year project life cycle
b. Assumes 1.5 additional FTEs
c. Based on improved dewaterability and sale of struvite pellet. The struvite pellet value was assumed to be $150/ton based on Ostara's proposal for the value of Crystal Green product.
$MgCl_2$ = magnesium chloride
NaOH = sodium hydroxide

The WASSTRIP reactor was sized for the TWAS flows. HSW has a significant contribution of phosphorus to the digesters; the OP fraction is estimated based on historical sampling of the trucked wastes. Due to the variable nature of the trucked waste streams, additional characterization of the HSW and/or the digester feed streams should be performed. The additional characterization would confirm if there were a benefit to diverting HSW streams to the WASSTRIP tank for increased struvite recovery.

It should be noted that Ostara indicated the typical net value to the District for the Crystal Green product (Ostara's proprietary brand of struvite pellet) is $150/ton. This is lower than the Market Assessment Report findings ($900/ton gross value; $720/ton revenue). For the NPV analysis, the value of $150/ton from the manufacturer was assumed because it is more conservative.

3.4 Sidestream Phosphorus Treatment Conclusions

Table 3-7 presents a summary of the phosphorus alternatives evaluated. The results of the economic and non-economic evaluations are presented on Figure 3-6 and Figure 3-7, respectively. The following summarizes the conclusions from the alternatives analysis:

- The chemical addition (Alternative P1) and CalPrex – No fermenter (Alternative P2) have the lowest NPVs. The AirPrex (Alternative P3), CalPrex – With fermenter (Alternative P2) and Ostara (Alternative P4) have higher NPVs.
- Chemical addition (Alternative P1) increases the District's reliance on chemical use at the MWWTP. The alternative is flexible and can easily accommodate changes in flow and load conditions. The alternative can also provide plantwide benefits, including increased secondary system capacity and a reduced number of PSTs that are needed year-round.
- Alternatives P2 through P4 provide nutrient recovery, but all require a large capital investment. The revenue generated from the distribution of the recovered phosphorus products does not offset the annual operating costs.
- Alternatives P2 and P4 produce a product that the District would need to manage. The District would need to develop a local market for the product or rely on the manufacturer to distribute it. Storage at the MWWTP may be required if the product cannot be distributed; increased storage would require more land and increase capital costs.
- CalPrex – with fermenter (Alternative P2) would maximize phosphorus recovery but would require construction of new tankage (1.5 MG acid-phase digester). CalPrex—with and without the fermenter—also require a new dewatering step upstream of the anaerobic digesters. The new tankage and dewatering step are needed for the CalPrex system only; they are not needed for solids handling capacity.
- AirPrex (Alternative P3) is a simple-to-operate system with lower project costs; however, the AirPrex system does not address struvite accumulation in the digesters and only addresses struvite downstream of the first-stage digesters.
- Ostara + WASSTRIP (Alternative P4) addresses struvite in and downstream of the digesters. Alternative P4 has the highest NPV and would be a significant investment for the District.
- If mainstream nitrogen removal is implemented in the future, the secondary system would likely not operate with an anaerobic selector, and phosphorus loading to the digesters would be reduced. Similarly, if HSW streams are reduced, phosphorus loading to the digesters may decrease, which would change the operating conditions of the CalPrex, AirPrex and Ostara+WASSTRIP systems. The economics and need for the systems may change with reduced phosphorus loading to the digesters. Thus, there is a potential risk of these systems becoming stranded assets.

Based on the conclusions noted above, chemical additional (Alternative P1) is recommended to carry forward as a placeholder technology for the Master Plan Roadmap. Although the alternative increases chemical use at the MWWTP, it provides flexibility to accommodate potential future changes in phosphorus loading to the digesters, provides plantwide benefits and minimizes capital investment. The alternative would also address the O&M challenges associated with struvite precipitation in the digesters and dewatering equipment.

Table 3-7. Summary of sidestream phosphorus treatment alternatives

Parameter	**P-removal**	**P-Recovery**		
	Alternative P1 **Chemical Addition**	**Alternative P2** **CalPrex** **(without and with fermentation)**	**Alternative P3** **AirPrex**	**Alternative P4** **Ostara + WASSTRIP**
Phosphorus reduction (lb/d)	1,700 lb/d [a]	600 - 2,100 lb/d [b]	1,200 lb/d [c]	1,400 lb/d [d]
Capital cost, $millions	$2.6	$52.7 - $104.9 [e]	$48.9	$106.9
Operating cost, $millions	$86.9	$22.9 - $28.8	$82.8	$43.2
Labor PV, $million	$0.0	$15.9	$15.9	$15.9
Chemical PV, $million	$86.9[f]	$0.9 - $3.3	$60.6	$19.6
Energy PV, $million	$0.0	$1.3 - $4.8	$2.7	$4.5
R&R PV, $million	$0.0	$4.8	$3.6	$3.2
Revenue PV, $millions [h]	*No revenue*	$0.5 - $1.7	$11.5	$12.7
NPV, $millions	$89.5	$75.1 - $132.0	$120.2	$137.4
Unit cost, $/TP lb removed	$5.5	$3.80 - $6.6	$11.0	$10.4
Land requirements, acres	--	0.4 - 0.6	0.3	0.5
Location struvite issue is addressed	Digesters and dewatering	Digesters	Dewatering	Digesters and dewatering

All values are rounded.

a. Based on estimated performance from the Struvite Control Investigation Report (Hazen and Sawyer 2016) for Alternative P1. Estimated reduction presented for year 2050.

b. A range of phosphorus reduction was considered to reflect CalPrex installation with and without a fermenter/acid-phase digester. The range of TP removal is based on manufacturer estimate with 60% reduction of OP from digester feed; testing to confirm estimated performance is recommended. Ferric chloride addition is assumed to be relocated to an alternate location and not added at the blend tanks.

c. Estimated performance according to manufacturer estimate of 90% of OP load resulting in dewatering centrate.

d. Estimated performance from manufacturer. Lab and pilot testing required to confirm estimated performances.

e. Low range of capital cost assumes acid phase digester /fermenter is not needed and phosphorus reduction can be achieved. High-range of capital cost assumes that new acid phase digester/fermenter is constructed.

f. Annual cost is based on additional ferric chloride dose needed for struvite control, as identified in the 2016 Struvite Investigation Report. The dose identified in the report was increased to account for impacts of changes in received R2. In the 2016 report, a total dose of 1,000 mgFe/L and baseline dose of 360 mg Fe/L were identified (or an increase in ferric chloride addition by an equivalent dose of 640 mgFe/L).

g. Based on estimated value of recovered phosphorus product (refer to Final Draft Market Assessment Report for estimated struvite value). Brushite (produced with Alternative P2 – CalPrex) estimated value was assumed at $150/ton based on manufacturer information. It should be noted the local value for brushite was estimated at roughly 50% of this value ($75/ton).

h. Unit cost is based on the NPV over the 30-year period divided by the pounds of TP removed over the 30-year period.

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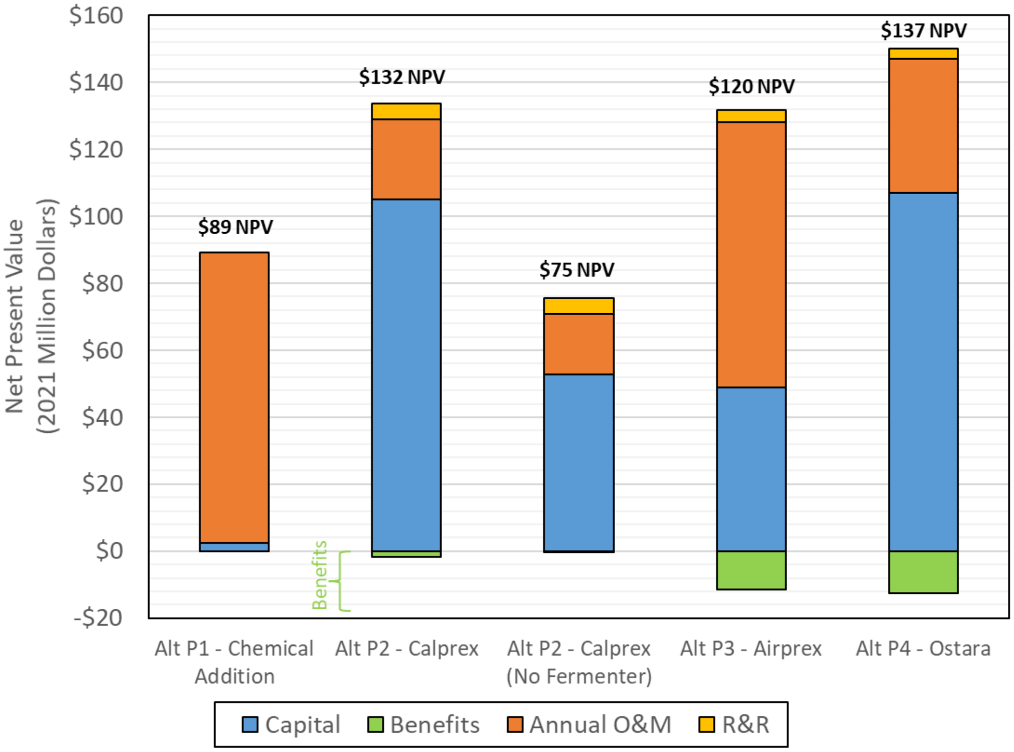

Figure 3-6. NPV for phosphorus treatment alternatives economic analysis

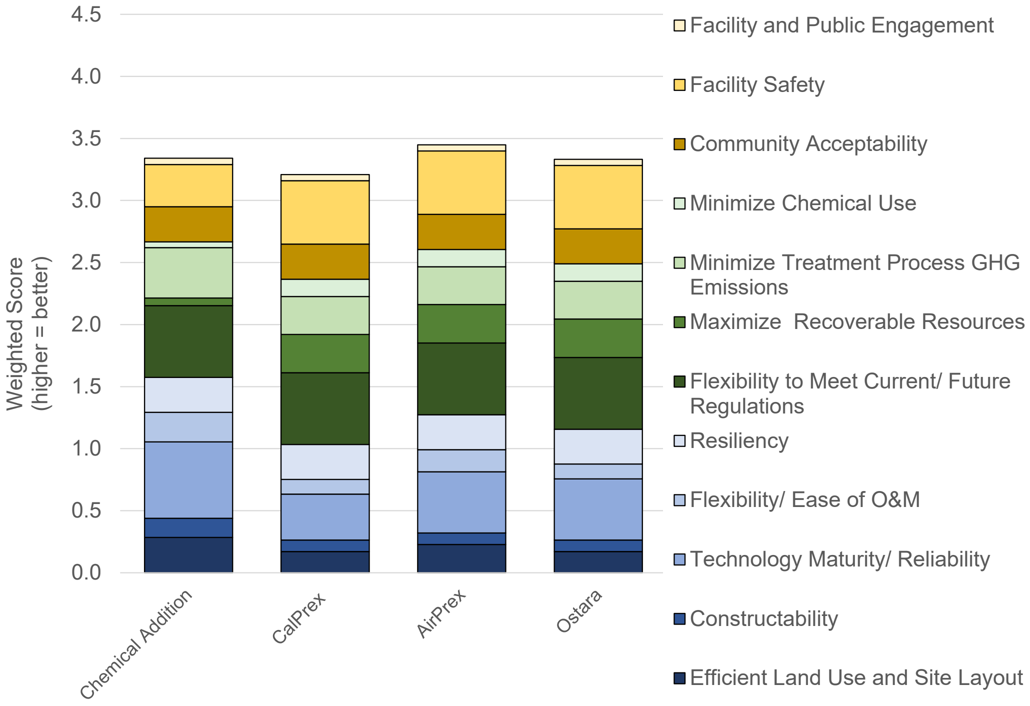

Figure 3-7. Non-economic evaluation of sidestream phosphorus alternatives

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CHAPTER 4 - SIDESTREAM TREATMENT CONCLUSIONS

Based on the sidestream treatment analysis, the following summarizes the recommended approach for integrating sidestream treatment into the nutrient management alternatives and ultimately into the master plan roadmap:

- Incorporate ANITAMox (Alternative N3) into nitrogen-reduction alternatives and develop phasing plans for sidestream and mainstream treatment. ANITAMox would serve as a placeholder technology and provide adequate land to accommodate any of the deammonification technologies.
- Identify in the phasing plan and roadmap time for additional sidestream characterization and pilot testing to confirm design criteria and performance and to provide operational experience with deammonification technologies. Pilot testing deammonification (ANITAMox or others) is recommended to confirm performance and design criteria, and to provide operational experience. This is a new technology for the District and is less established than conventional biological nitrogen removal. Additionally, pilot testing is also recommended due to the variable nature of the centrate characteristics resulting from the R2 program. Through pilot testing, if deammonification is demonstrated to not meet the District's goals and expectations, AMR with LAS (Alternative N6) could be constructed within the land and budget allocations of ANITAMox.
- Consider Alternative P1 as an interim struvite mitigation strategy that could provide the additional benefit of addressing secondary system capacity constraints. The addition of ferric chloride at the PSTs also has the potential to reduce the number of PSTs that are needed during wet weather, which could free up PSTs for other uses, such as sidestream nitrogen removal.

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CHAPTER 5 - REFERENCES

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APPENDIX A - SIDESTREAM FLOW AND LOAD PROJECTIONS

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Attachment A

		Average Dry Weather (ADW) Model Runs at Firm Capacity			
Parameter	**Units**	**2020**	**2030**	**2040**	**2050**
Centrate					
Centrate Flow	mgd	0.70	0.75	0.82	0.90
Centrate Alkalinity	meq/L	132	129	125	121
COD Concentration	mg/L	1,890	1,950	1,931	1,920
COD Loading	lb/d	11,001	12,219	13,236	14,394
fCOD Concentration	mg/L	969	980	929	882
fCOD Loading	lb/d	5,640	6,138	6,368	6,609
TSS Concentration	mg/L	963	1,000	1,019	1,043
TSS Loading	lb/d	5,607	6,264	6,985	7,818
VSS Concentration	mg/L	597	630	651	674
VSS Loading	lb/d	3,477	3,946	4,459	5,056
BOD Concentration	mg/L	89	99	108	119
BOD Loading	lb/d	518	618	742	891
Nitrogen Concentration	mg/L	1,762	1,734	1,683	1,635
Nitrogen Loading	lb/d	10,252	10,862	11,536	12,258
Ammonia Concentration	mg N/L	1,714	1,684	1,631	1,581
Ammonia Loading	lb/d	9,975	10,548	11,181	11,855
Total Phosphorus Concentration	mg P/L	193	194	199	202
Total Phosphorus Loading	lb/d	1,126	1,215	1,361	1,515
Soluble Ortho-Phosphate Concentration	mg P/L	164	164	169	172
Soluble Ortho-Phosphate Loading	lb/d	955	1,030	1,158	1,292
2nd Stage Digester Discharge (Feed to Centrifuges)					
2nd Stg Dig flow	mgd	0.76	0.83	0.90	0.99
2nd Stg Dig Alkalinity	meq/L	132	129	125	121
COD Concentration	mg/L	21,969	23,037	23,665	24,379
COD Loading	lb/d	140,203	158,777	178,713	201,927
fCOD Concentration	mg/L	969	980	929	882
fCOD Loading	lb/d	6,185	6,753	7,016	7,303
TSS Concentration	mg/L	21,963	22,720	23,123	23,598
TSS Loading	lb/d	140,168	156,590	174,618	195,462
VSS Concentration	mg/L	13,621	14,314	14,760	15,261
VSS Loading	lb/d	86,925	98,658	111,465	126,406
BOD Concentration	mg/L	1,782	1,992	2,199	2,426
BOD Loading	lb/d	11,371	13,730	16,609	20,095
Nitrogen Concentration	mg/L	2,776	2,799	2,780	2,769
Nitrogen Loading	lb/d	17,716	19,289	20,997	22,937
Ammonia Concentration	mg N/L	1,714	1,684	1,631	1,581
Ammonia Loading	lb/d	10,939	11,605	12,320	13,099
Total Phosphorus Concentration	mg P/L	834	837	841	845
Total Phosphorus Loading	lb/d	5,321	5,772	6,350	6,995
Soluble Ortho-Phosphate Concentration	mg P/L	164	164	169	172
Soluble Ortho-Phosphate Loading	lb/d	1,047	1,133	1,276	1,428

Attachment A

		Average Dry Weather (ADW) Model Runs at Firm Capacity			
Parameter	**Units**	**2020**	**2030**	**2040**	**2050**
Blend Tank Discharge (Feed to Digesters)					
Digester Feed Flow	mgd	0.76	0.83	0.90	0.99
Digester Feed Alkalinity	meq/L	33	31	29	27
COD Concentration	mg/L	82,226	83,953	82,653	81,530
COD Loading	lb/d	524,754	578,622	624,180	675,307
fCOD Concentration	mg/L	27,454	27,596	25,704	23,920
fCOD Loading	lb/d	175,206	190,197	194,109	198,125
TSS Concentration	mg/L	42,361	43,494	43,892	44,352
TSS Loading	lb/d	270,339	299,771	331,464	367,362
VSS Concentration	mg/L	34,788	35,807	36,199	36,635
VSS Loading	lb/d	222,015	246,787	273,366	303,447
BOD Concentration	mg/L	41,782	42,433	41,253	40,159
BOD Loading	lb/d	266,650	292,459	311,536	332,632
Nitrogen Concentration	mg/L	2,777	2,799	2,780	2,769
Nitrogen Loading	lb/d	17,722	19,289	20,997	22,937
Ammonia Concentration	mg N/L	379	364	343	324
Ammonia Loading	lb/d	2,420	2,506	2,591	2,683
Total Phosphorus Concentration	mg P/L	834	837	841	845
Total Phosphorus Loading	lb/d	5,323	5,772	6,350	6,995
Soluble Ortho-Phosphate Concentration	mg P/L	64	58	55	53
Soluble Ortho-Phosphate Loading	lb/d	408	399	419	439

APPENDIX B - VENDOR PROPOSALS AND INSTALLATION LISTS

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Proposals removed to reduce file size.
Key cost and sizing information is
documented within task report.

APPENDIX C - SITE LAYOUTS

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Attachment C: Site Layouts

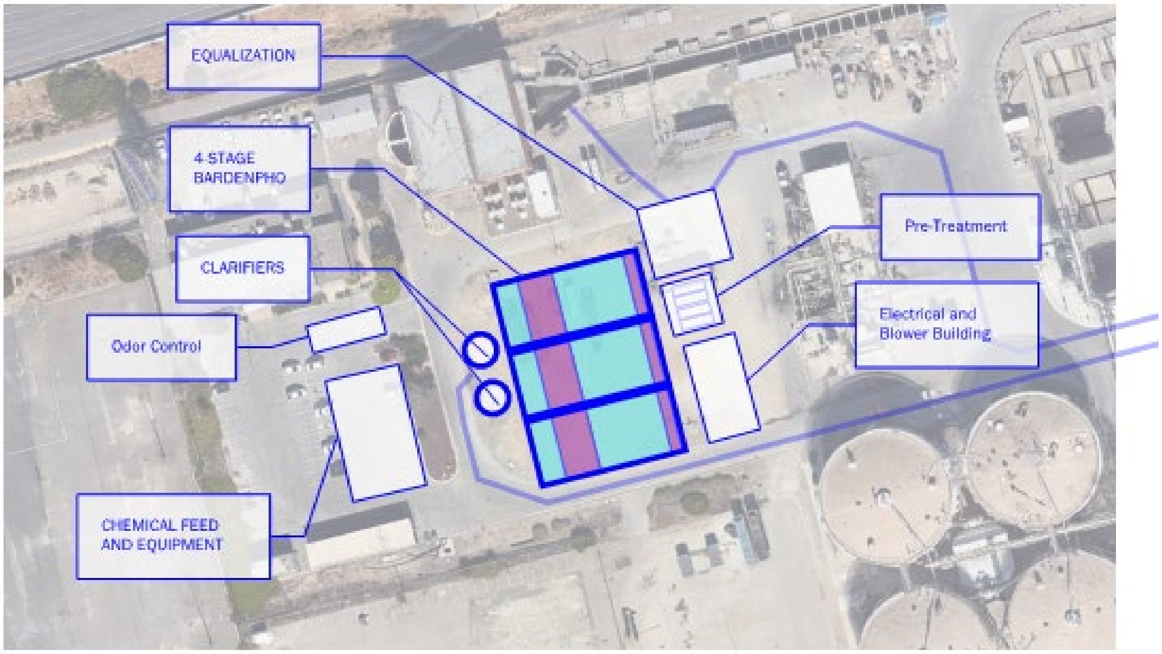

Figure C-1. Alternative N1 – 4-Stage Bardenpho (West of SLW Receiving Station)

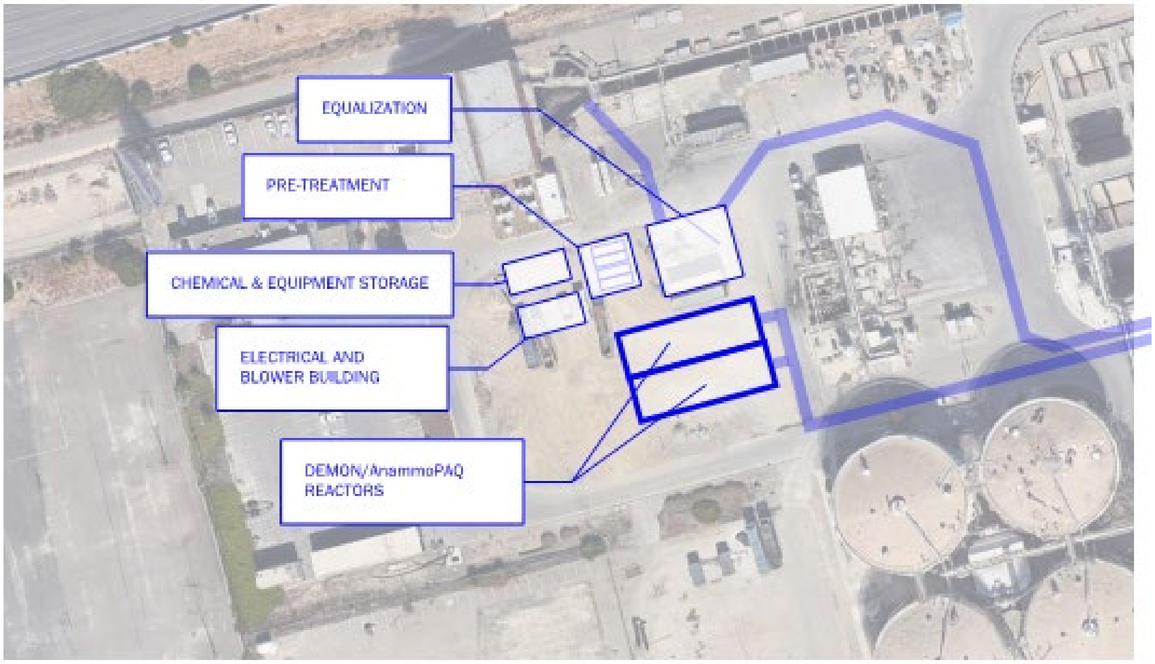

Figure C-2. Alternative N2 – DEMON/AnammoPAQ (West of SLW Receiving Station)

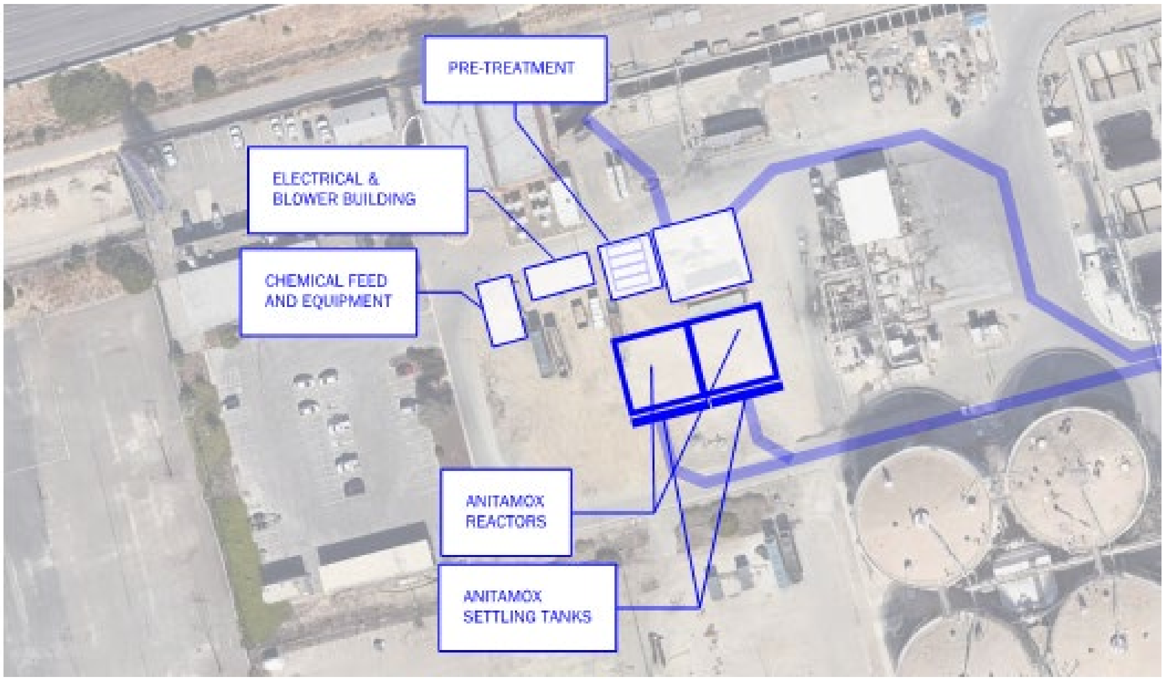

Figure C-3. Alternative N3 – ANITAMox (West of SLW Receiving Station)

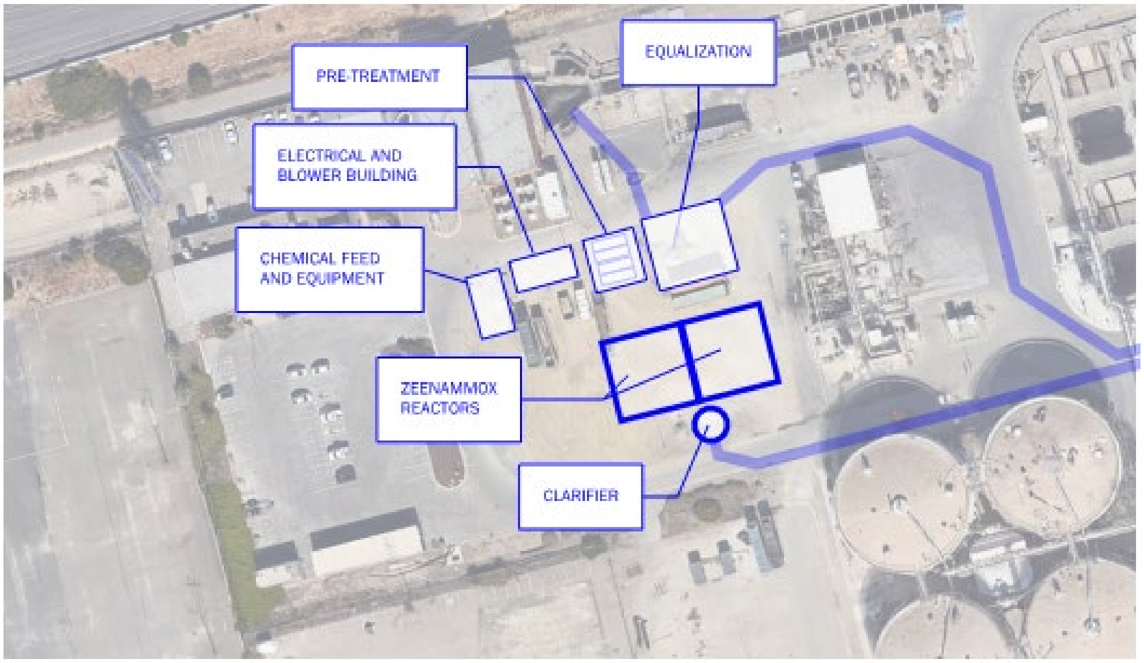

Figure C-4. Alternative N5 – ZeeNAmmox (West of SLW Receiving Station)

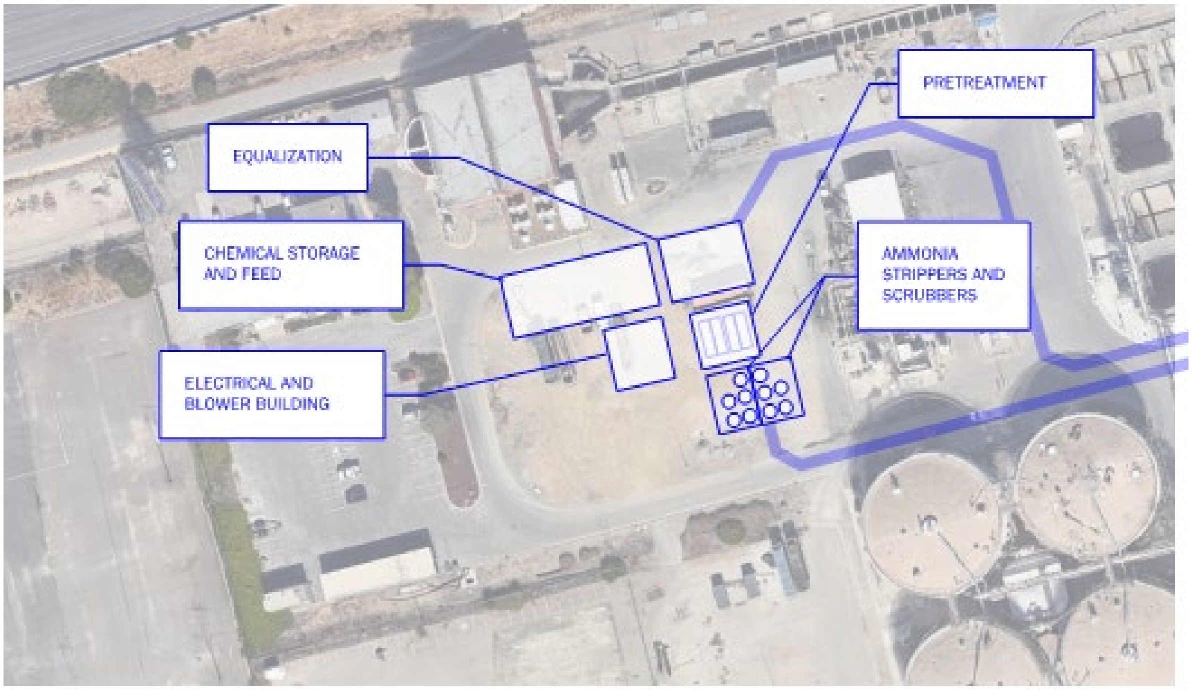

Figure C-6. Alternative N6 – AMR - LAS (West of SLW Receiving Station)

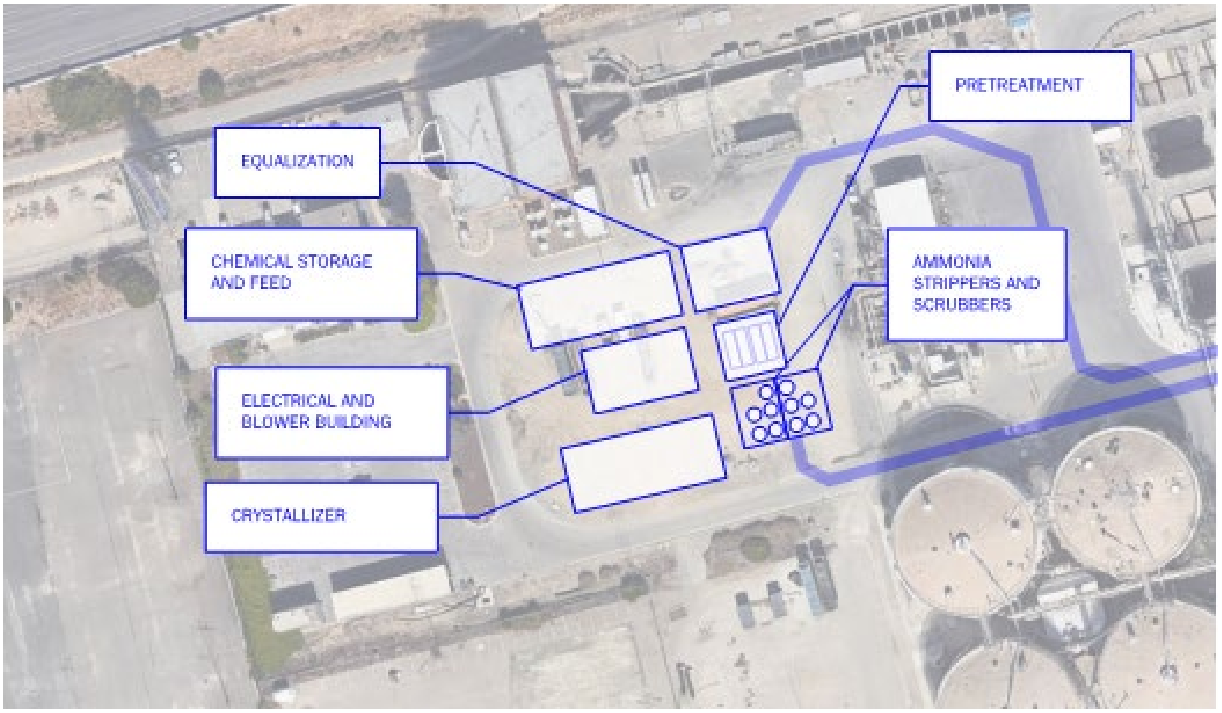

Figure C-7. Alternative N7 – AMR - GAS (West of SLW Receiving Station)

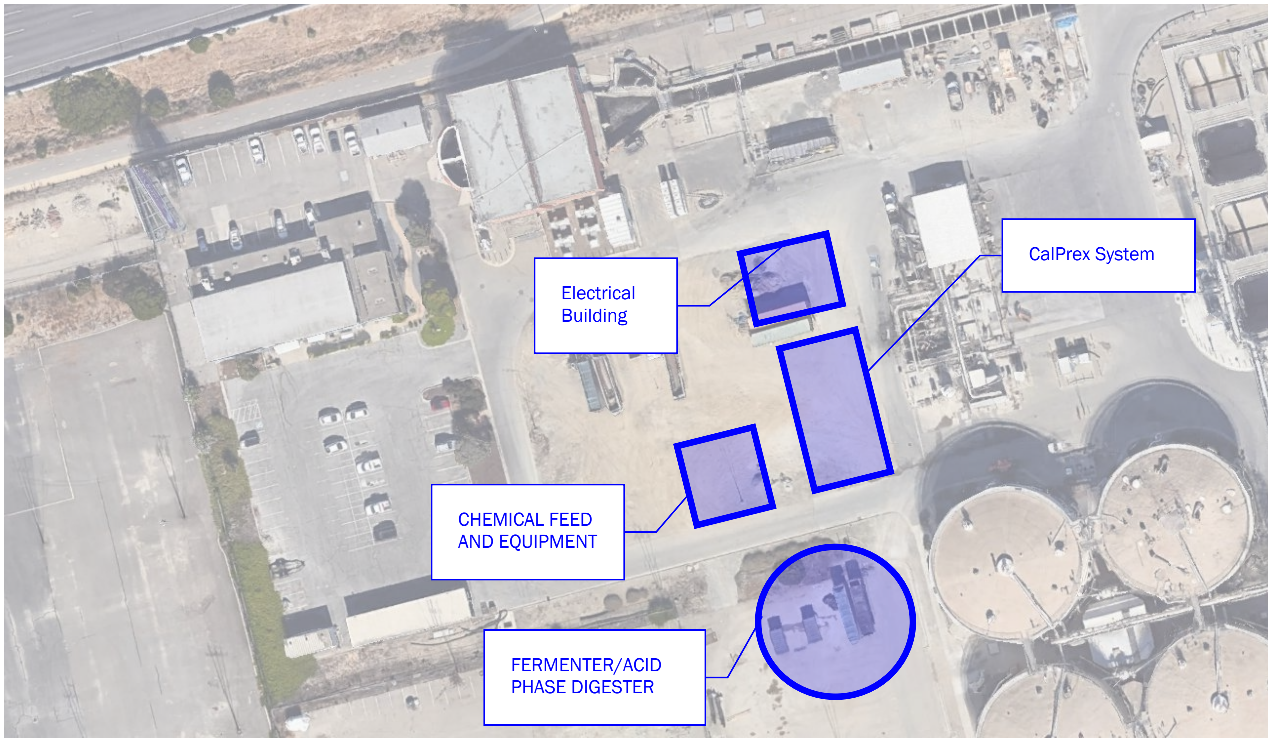

Figure C-8. Alternative P2 – CalPrex (West of SLW Receiving Station)

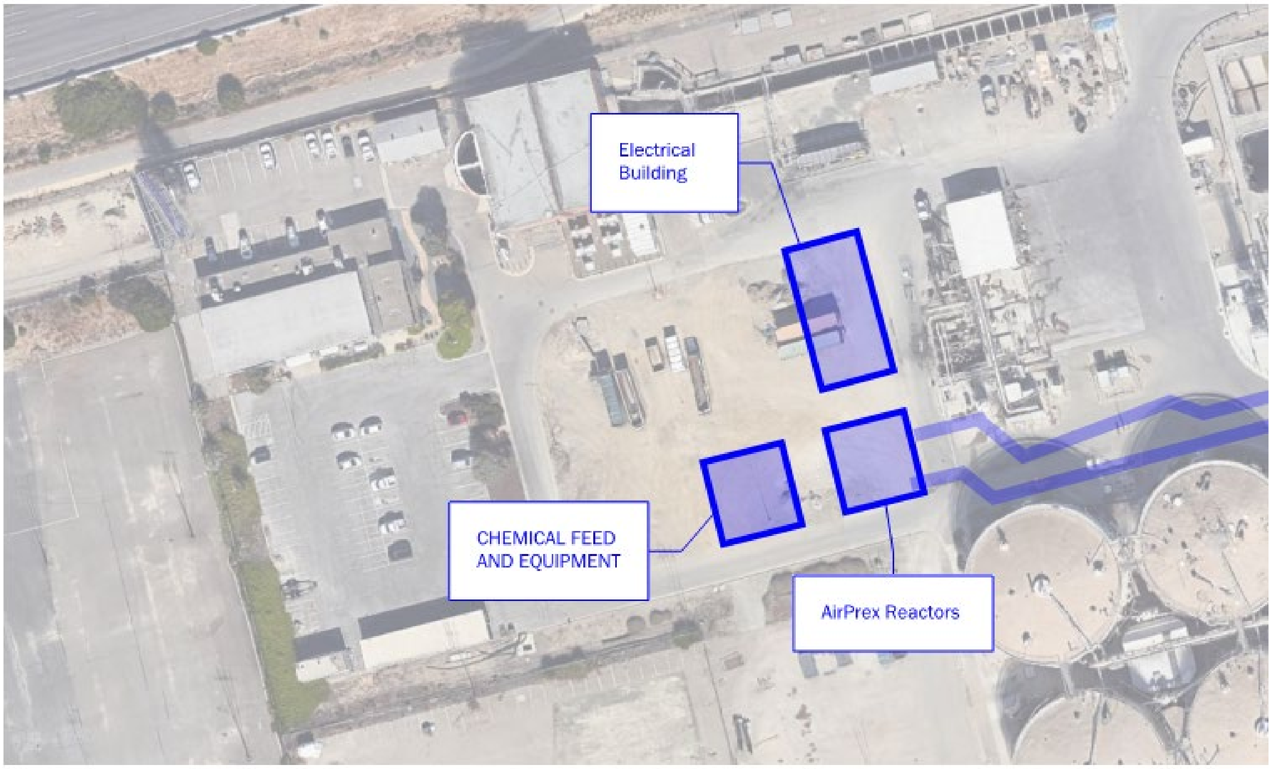

Figure C-9. Alternative P3 – AirPrex (West of SLW Receiving Station)

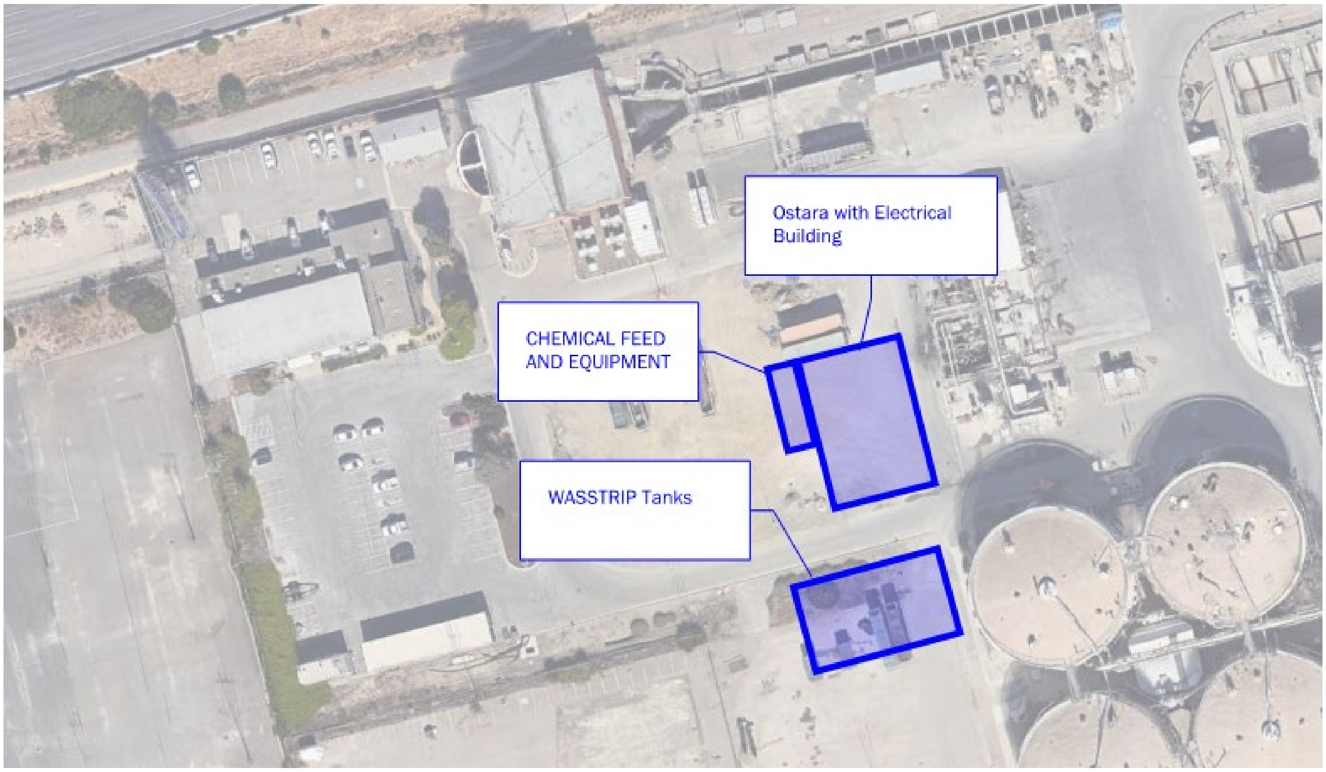

Figure C-10. Alternative P4 – Ostara + WASSTRIP

APPENDIX D - CAPITAL AND OPERATING COSTS

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D.1 - CAPITAL COSTS

Item	Alt N1 - 4-Stage Bardenpho	Alt N2 - DEMON	Alt N3 - ANITAMox	Alt N4 - AnammoPAQ	Alt N5 - ZeeNAmmox	Alt N6 - AMR with LAS	Alt N7 - AMR with GAS
Construction Cost							
Equalization with Odor Control	$ 675,000	$ 675,000	$ 675,000	$ 675,000	$ 675,000	$ 450,000	$ 450,000
Pre-Treatment System	$ 2,500,000	$ 1,100,000	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000
Reactor Tanks and Foundation	$ 7,800,000	$ 6,200,000	$ 4,400,000	$ 4,800,000	$ 4,500,000	$ 1,100,000	$ 1,100,000
Reactor Equipment and Process Blowers	$ 2,400,000	$ 6,800,000	$ 8,900,000	$ 10,200,000	$ 21,000,000	$ 5,400,000	$ 11,600,000
Secondary Clarifiers	$ 10,300,000	$ -	$ -	$ -	$ -	$ -	$ -
Blower and Electrical Building	$ 1,800,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 2,500,000	$ 2,900,000
Chemical Feed Facilities	$ 4,400,000	$ 2,100,000	$ 2,100,000	$ 2,100,000	$ 2,100,000	$ 4,300,000	$ 4,300,000
Ancillary Facilities	$ 800,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,400,000	$ 1,400,000
Subtotal "A" Construction Elements	$ 30,700,000	$ 19,400,000	$ 21,100,000	$ 22,800,000	$ 33,300,000	$ 17,700,000	$ 24,300,000
Misc. Demolition - 5% of A	$ 1,500,000	$ 1,000,000	$ 1,050,000	$ 1,150,000	$ 1,700,000	$ 900,000	$ 1,200,000
Civil - 5% of A	$ 1,500,000	$ 1,000,000	$ 1,050,000	$ 1,150,000	$ 1,700,000	$ 900,000	$ 1,200,000
Yard Piping - 12% of A	$ 3,700,000	$ 2,300,000	$ 2,500,000	$ 2,700,000	$ 4,000,000	$ 2,100,000	$ 2,900,000
HVAC - 5% of A	$ 1,500,000	$ 1,000,000	$ 1,050,000	$ 1,150,000	$ 1,700,000	$ 900,000	$ 1,200,000
Shoring and Dewatering - 10% of A	$ 3,100,000	$ 1,900,000	$ 2,100,000	$ 2,300,000	$ 3,300,000	$ 1,800,000	$ 2,400,000
Electrical, Instrumentation & Controls - 25% of A	$ 7,700,000	$ 4,800,000	$ 5,300,000	$ 5,700,000	$ 8,300,000	$ 4,400,000	$ 6,100,000
Hazardous Materials and Handling - 5% of A	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Misc. Excavated Soil Disposal- 5% of A	$ 1,500,000	$ 1,000,000	$ 1,050,000	$ 1,150,000	$ 1,700,000	$ 900,000	$ 1,200,000
Subtotal "B" Construction Elements	$ 51,200,000	$ 32,400,000	$ 35,200,000	$ 38,100,000	$ 55,700,000	$ 29,600,000	$ 40,500,000
Startup and Construction Sequencing - 12% of B	$ 6,100,000	$ 3,900,000	$ 4,200,000	$ 4,600,000	$ 6,700,000	$ 3,600,000	$ 4,900,000
Construction Easements - 5% of B	$ 2,600,000	$ 1,600,000	$ 1,800,000	$ 1,900,000	$ 2,800,000	$ 1,500,000	$ 2,000,000
General Conditions - 10% of B	$ 5,100,000	$ 3,200,000	$ 3,500,000	$ 3,800,000	$ 5,550,000	$ 2,950,000	$ 4,050,000
Contractor Overhead and Profit - 10% of B	$ 5,100,000	$ 3,200,000	$ 3,500,000	$ 3,800,000	$ 5,550,000	$ 2,950,000	$ 4,050,000
Sales Tax - 9% - 1/2 of B	$ 2,300,000	$ 1,500,000	$ 1,600,000	$ 1,700,000	$ 2,500,000	$ 1,300,000	$ 1,800,000
Subtotal "C" Construction Cost	$ 72,400,000	$ 45,800,000	$ 49,800,000	$ 53,900,000	$ 78,800,000	$ 41,900,000	$ 57,300,000
Market Factor - 0%	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Construction Costs with Market Factor	$ 72,400,000	$ 45,800,000	$ 49,800,000	$ 53,900,000	$ 78,800,000	$ 41,900,000	$ 57,300,000
Change Order Contingency (5% of construction cost w/Market Factor)	$ 3,600,000	$ 2,300,000	$ 2,500,000	$ 2,700,000	$ 3,900,000	$ 2,100,000	$ 2,900,000
Total Construction Costs	**$ 76,000,000**	**$ 48,100,000**	**$ 52,300,000**	**$ 56,600,000**	**$ 82,700,000**	**$ 44,000,000**	**$ 60,200,000**
Planning and Permitting - 5% of Total Construction Cost	$ 3,800,000	$ 2,400,000	$ 2,600,000	$ 2,800,000	$ 4,200,000	$ 2,200,000	$ 3,000,000
Engineering - 15% of Total Construction Cost	$ 11,400,000	$ 7,200,000	$ 7,800,000	$ 8,500,000	$ 12,400,000	$ 6,600,000	$ 9,000,000
Construction Management - 15% of Total Construction Cost	$ 11,400,000	$ 7,200,000	$ 7,800,000	$ 8,500,000	$ 12,400,000	$ 6,600,000	$ 9,000,000
Subtotal Project Cost	**$ 102,600,000**	**$ 64,900,000**	**$ 70,500,000**	**$ 76,400,000**	**$ 111,700,000**	**$ 59,400,000**	**$ 81,200,000**
Estimating Contingency - 30%	$ 30,800,000	$ 19,500,000	$ 21,300,000	$ 22,900,000	$ 33,500,000	$ 17,800,000	$ 24,400,000
Total Project Costs	**$ 133,400,000**	**$ 84,400,000**	**$ 91,800,000**	**$ 99,300,000**	**$ 145,200,000**	**$ 77,200,000**	**$ 105,600,000**

a. All values are rounded and presented in 2019 dollars

b. Alternative 2 pretreatment costs are included with vendor proposal for DEMON system

c. Excavated soils were assumed to be Non-RCRA waste soils. Costs include disposal for excavated soils.

d. Hazardous materials allowance was included for alternatives that reuse/repurpose existing structures.

Item	Alt P1 - Chemical	Alt P2- CalPrex	Alt P2- CalPrex (no fermenter)	Alt P3 - AirPrex	Alt 4 - Ostara + WASSTRIP
Fermenter/Acid Phase Digester and Dewatering	$ -	$ 12,300,000	$ 300,000	$ -	$ -
Struvite Recovery Reactors	$ -	$ 11,200,000	$ 11,200,000	$ 10,600,000	$ 23,900,000
Chemical Feed Facilities	$ -	$ 600,000	$ 600,000	$ 600,000	$ 600,000
Ancillary Facilities	$ 600,000	$ -		$ -	$ -
Subtotal "A" Construction Elements	$ 600,000	$ 24,100,000	$ 12,100,000	$ 11,200,000	$ 24,500,000
Misc. Demolition - 5% of A	$ 30,000	$ 1,200,000	$ 600,000	$ 600,000	$ 1,200,000
Civil - 5% of A	$ 30,000	$ 1,200,000	$ 600,000	$ 600,000	$ 1,200,000
Yard Piping - 12% of A	$ 70,000	$ 2,900,000	$ 1,500,000	$ 1,300,000	$ 3,000,000
HVAC - 5% of A	$ 30,000	$ 1,200,000	$ 600,000	$ 600,000	$ 1,200,000
Shoring and Dewatering - 10% of A	$ 60,000	$ 2,400,000	$ 1,200,000	$ 1,100,000	$ 2,500,000
Electrical, Instrumentation & Controls - 25% of A	$ 150,000	$ 6,000,000	$ 3,000,000	$ 2,800,000	$ 6,200,000
Hazardous Materials and Handling - 5% of A	$ -	$ -	$ -	$ -	$ -
Misc. Excavated Soil Disposal- 5% of A	$ 30,000	$ 1,200,000	$ 600,000	$ 600,000	$ 1,200,000
Subtotal "B" Construction Elements	$ 1,000,000	$ 40,200,000	$ 20,200,000	$ 18,800,000	$ 41,000,000
Startup and Construction Sequencing - 12% of B	$ 120,000	$ 4,800,000	$ 2,400,000	$ 2,200,000	$ 4,900,000
Construction Easements - 5% of B	$ 50,000	$ 2,000,000	$ 1,000,000	$ 900,000	$ 2,100,000
General Conditions - 10% of B	$ 100,000	$ 4,000,000	$ 2,000,000	$ 1,900,000	$ 4,100,000
Contractor Overhead and Profit - 10% of B	$ 100,000	$ 4,000,000	$ 2,000,000	$ 1,900,000	$ 4,100,000
Sales Tax - 9% - 1/2 of B	$ 50,000	$ 1,800,000	$ 900,000	$ 800,000	$ 1,800,000
Subtotal "C" Construction Cost	$ 1,400,000	$ 56,800,000	$ 28,500,000	$ 26,500,000	$ 58,000,000
Market Factor - 0%	$ -	$ -	$ -	$ -	$ -
Construction Costs with Market Factor	$ 1,400,000	$ 56,800,000	$ 28,500,000	$ 26,500,000	$ 58,000,000
Change Order Contingency (5% of construction cost w/Market Factor)	$ 100,000	$ 2,800,000	$ 1,400,000	$ 1,300,000	$ 2,900,000
Total Construction Costs	**$ 1,500,000**	**$ 59,600,000**	**$ 29,900,000**	**$ 27,800,000**	**$ 60,900,000**
Planning and Permitting - 5% of Total Construction Cost	$ 100,000	$ 3,000,000	$ 1,500,000	$ 1,400,000	$ 3,000,000
Engineering - 15% of Total Construction Cost	$ 200,000	$ 9,000,000	$ 4,500,000	$ 4,200,000	$ 9,100,000
Construction Management - 15% of Total Construction Cost	$ 200,000	$ 9,000,000	$ 4,500,000	$ 4,200,000	$ 9,100,000
Subtotal Project Cost	**$ 2,000,000**	**$ 80,600,000**	**$ 40,400,000**	**$ 37,600,000**	**$ 82,100,000**
Estimating Contingency - 30%	$ 600,000	$ 24,300,000	$ 12,300,000	$ 11,300,000	$ 24,800,000
Total Project Costs	**$ 2,600,000**	**$ 104,900,000**	**$ 52,700,000**	**$ 48,900,000**	**$ 106,900,000**

a. All values are rounded and presented in 2019 dollars
b. Excavated soils were assumed to be Non-RCRA waste soils. Costs include disposal for excavated soils.
c. Hazardous materials allowance was included for alternatives that reuse/repurpose existing structures.

D.2 - NET PRESENT VALUE ANALYSIS

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 1 - Conventional Bardenpho

From Summary Sheet:		**Risk adjustments (+/- percent):**	
Year of analysis	**2021**	**Benefits**	
Escalation rate	**3.00%**	**Capital costs**	
Discount rate	**2.00%**	**Running costs**	

	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Expressed in 2021 dollars, unescalated														
Capital Outlays														
Capital Costs	133,400,000													
Total capital outlays	**133,400,000**													
Benefits:														
Total benefits														
Annual Running Costs:														
Energy	478,673	481,432	484,191	486,950	489,709	492,469	495,228	497,987	500,746	503,505	506,592	509,678	512,764	515,850
Methanol + Caustic	2,230,687	2,243,428	2,256,169	2,268,909	2,281,650	2,294,391	2,307,132	2,319,872	2,332,613	2,345,354	2,359,428	2,373,503	2,387,578	2,401,653
Labor	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080
Total running costs	**3,244,440**	**3,259,940**	**3,275,440**	**3,290,940**	**3,306,440**	**3,321,939**	**3,337,439**	**3,352,939**	**3,368,439**	**3,383,939**	**3,401,100**	**3,418,261**	**3,435,422**	**3,452,583**
R&R Costs:														
Diffusers	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400
Other Equipment	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000
Total refurbishments	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**
Net Benefit/(cost)	**(136,792,840)**	**(3,408,340)**	**(3,423,840)**	**(3,439,340)**	**(3,454,840)**	**(3,470,339)**	**(3,485,839)**	**(3,501,339)**	**(3,516,839)**	**(3,532,339)**	**(3,549,500)**	**(3,566,661)**	**(3,583,822)**	**(3,600,983)**
Expressed in escalated dollars with sensitivity adjustments														
Capital Outlays														
Capital Costs	133,400,000													
Other														
Other														
Other														
Other														
Other														
Total capital outlays	**133,400,000**													
Benefits:														
Total benefits														
Annual Running Costs:														
Energy	478,673	495,875	513,678	532,104	551,172	570,906	591,328	612,461	634,330	656,960	680,817	705,513	731,079	757,544
Methanol + Caustic	2,230,687	2,310,731	2,393,569	2,479,299	2,568,017	2,659,828	2,754,836	2,853,150	2,954,884	3,060,154	3,170,874	3,285,483	3,404,115	3,526,908
Labor	535,080	551,132	567,666	584,696	602,237	620,304	638,914	658,081	677,823	698,158	719,103	740,676	762,896	785,783
Total running costs	**3,244,440**	**3,357,738**	**3,474,914**	**3,596,099**	**3,721,427**	**3,851,038**	**3,985,077**	**4,123,692**	**4,267,038**	**4,415,273**	**4,570,794**	**4,731,673**	**4,898,091**	**5,070,235**
R&R Costs:														
Diffusers	32,400	33,372	34,373	35,404	36,466	37,560	38,687	39,848	41,043	42,275	43,543	44,849	46,195	47,580
Other Equipment	116,000	119,480	123,064	126,756	130,559	134,476	138,510	142,665	146,945	151,354	155,894	160,571	165,388	170,350
Total refurbishments	**148,400**	**152,852**	**157,438**	**162,161**	**167,026**	**172,036**	**177,197**	**182,513**	**187,989**	**193,628**	**199,437**	**205,420**	**211,583**	**217,930**
Net escalated benefit/(cost)	**(136,792,840)**	**(3,510,590)**	**(3,632,352)**	**(3,758,259)**	**(3,888,452)**	**(4,023,075)**	**(4,162,274)**	**(4,306,206)**	**(4,455,026)**	**(4,608,901)**	**(4,770,231)**	**(4,937,093)**	**(5,109,673)**	**(5,288,165)**
Life cycle cost analysis														
PVs in 2021	(136,792,840)	(3,441,755)	(3,491,303)	(3,541,492)	(3,592,329)	(3,643,823)	(3,695,981)	(3,748,811)	(3,802,322)	(3,856,522)	(3,913,251)	(3,970,721)	(4,028,943)	(4,087,924)
NPV as of 2021	**(259,775,361)**													

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 1 - Conventional Bardenpho

<-- See Rows on Previous Page

Year															
2035	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
518,937	522,023	525,109	528,196	531,282	534,368	537,695	541,021	544,347	547,673	551,000	554,326	557,652	560,978	564,305	567,631
2,415,728	2,429,802	2,443,877	2,457,952	2,472,027	2,486,101	2,501,088	2,516,074	2,531,061	2,546,047	2,561,034	2,576,020	2,591,006	2,605,993	2,620,979	2,635,966
535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080
3,469,744	**3,486,905**	**3,504,067**	**3,521,228**	**3,538,389**	**3,555,550**	**3,573,863**	**3,592,175**	**3,610,488**	**3,628,801**	**3,647,113**	**3,665,426**	**3,683,739**	**3,702,051**	**3,720,364**	**3,738,677**
32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400
116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000
148,400	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**	**148,400**
(3,618,144)	**(3,635,305)**	**(3,652,467)**	**(3,669,628)**	**(3,686,789)**	**(3,703,950)**	**(3,722,263)**	**(3,740,575)**	**(3,758,888)**	**(3,777,201)**	**(3,795,513)**	**(3,813,826)**	**(3,832,139)**	**(3,850,451)**	**(3,868,764)**	**(3,887,077)**
784,938	813,295	842,646	873,027	904,472	937,018	971,136	1,006,458	1,043,025	1,080,881	1,120,069	1,160,635	1,202,628	1,246,095	1,291,088	1,337,659
3,654,005	3,785,553	3,921,705	4,062,620	4,208,460	4,359,394	4,517,243	4,680,639	4,849,774	5,024,844	5,206,054	5,393,614	5,587,742	5,788,663	5,996,611	6,211,826
809,357	833,637	858,646	884,406	910,938	938,266	966,414	995,406	1,025,269	1,056,027	1,087,707	1,120,339	1,153,949	1,188,567	1,224,224	1,260,951
5,248,300	**5,432,485**	**5,622,998**	**5,820,053**	**6,023,870**	**6,234,678**	**6,454,793**	**6,682,504**	**6,918,068**	**7,161,752**	**7,413,830**	**7,674,588**	**7,944,319**	**8,223,326**	**8,511,924**	**8,810,436**
49,008	50,478	51,992	53,552	55,159	56,814	58,518	60,274	62,082	63,944	65,863	67,838	69,874	71,970	74,129	76,353
175,460	180,724	186,146	191,730	197,482	203,407	209,509	215,794	222,268	228,936	235,804	242,878	250,165	257,670	265,400	273,362
224,468	**231,202**	**238,138**	**245,283**	**252,641**	**260,220**	**268,027**	**276,068**	**284,350**	**292,880**	**301,667**	**310,717**	**320,038**	**329,639**	**339,528**	**349,714**
(5,472,768)	**(5,663,687)**	**(5,861,137)**	**(6,065,335)**	**(6,276,511)**	**(6,494,898)**	**(6,722,820)**	**(6,958,572)**	**(7,202,418)**	**(7,454,632)**	**(7,715,497)**	**(7,985,305)**	**(8,264,357)**	**(8,552,965)**	**(8,851,452)**	**(9,160,151)**
(4,147,674)	(4,208,203)	(4,269,520)	(4,331,635)	(4,394,558)	(4,458,298)	(4,524,265)	(4,591,097)	(4,658,805)	(4,727,399)	(4,796,890)	(4,867,290)	(4,938,608)	(5,010,858)	(5,084,049)	(5,158,194)

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 2 - DEMON

From Summary Sheet:		**Risk adjustments (+/- percent):**	
Year of analysis	**2021**	**Benefits**	
Escalation rate	**3.00%**	**Capital costs**	
Discount rate	**2.00%**	**Running costs**	

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Expressed in 2021 dollars, unescalated														
Capital Outlays														
Capital Costs	84,400,000													
Total capital outlays	**84,400,000**													
Benefits:														
Total benefits														
Annual Running Costs:														
Energy	125,945	126,684	127,423	128,162	128,901	129,640	130,379	131,118	131,857	132,596	133,442	134,288	135,134	135,980
Labor	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080
Total running costs	**661,025**	**661,764**	**662,503**	**663,242**	**663,981**	**664,720**	**665,459**	**666,198**	**666,937**	**667,676**	**668,522**	**669,368**	**670,214**	**671,060**
R&R Costs:														
Diffusers	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934
Other Equipment	104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000
Total refurbishments	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**
Net Benefit/(cost)	**(85,183,959)**	**(784,698)**	**(785,437)**	**(786,176)**	**(786,915)**	**(787,654)**	**(788,393)**	**(789,132)**	**(789,871)**	**(790,609)**	**(791,456)**	**(792,302)**	**(793,148)**	**(793,994)**
Expressed in escalated dollars with sensitivity adjustments														
Capital Outlays														
Capital Costs	84,400,000													
Total capital outlays	**84,400,000**													
Benefits:														
Total benefits														
Annual Running Costs:														
Energy	125,945	130,485	135,183	140,046	145,079	150,288	155,679	161,258	167,032	173,007	179,335	185,886	192,669	199,691
Labor	535,080	551,132	567,666	584,696	602,237	620,304	638,914	658,081	677,823	698,158	719,103	740,676	762,896	785,783
Total running costs	**661,025**	**681,617**	**702,850**	**724,743**	**747,317**	**770,593**	**794,593**	**819,339**	**844,856**	**871,165**	**898,437**	**926,562**	**955,565**	**985,474**
R&R Costs:														
Diffusers	18,934	19,502	20,087	20,689	21,310	21,949	22,608	23,286	23,985	24,704	25,445	26,209	26,995	27,805
Other Equipment	104,000	107,120	110,334	113,644	117,053	120,565	124,181	127,907	131,744	135,696	139,767	143,960	148,279	152,728
Total refurbishments	**122,934**	**126,622**	**130,420**	**134,333**	**138,363**	**142,514**	**146,789**	**151,193**	**155,729**	**160,401**	**165,213**	**170,169**	**175,274**	**180,532**
Net escalated benefit/(cost)	**(85,183,959)**	**(808,239)**	**(833,270)**	**(859,076)**	**(885,680)**	**(913,107)**	**(941,382)**	**(970,532)**	**(1,000,584)**	**(1,031,566)**	**(1,063,650)**	**(1,096,731)**	**(1,130,839)**	**(1,166,006)**
Life cycle cost analysis														
PVs in 2021	(85,183,959)	(792,391)	(800,913)	(809,526)	(818,231)	(827,029)	(835,920)	(844,907)	(853,989)	(863,168)	(872,564)	(882,060)	(891,659)	(901,361)
NPV as of 2021	**(112,013,866)**													

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 2 - DEMON

<-- See Rows on Previous Page

Year															
2035	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
136,826	137,672	138,518	139,364	140,210	141,056	141,988	142,920	143,852	144,784	145,716	146,648	147,580	148,512	149,444	150,376
535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080
671,906	**672,752**	**673,598**	**674,444**	**675,290**	**676,136**	**677,068**	**678,000**	**678,932**	**679,864**	**680,796**	**681,728**	**682,660**	**683,592**	**684,524**	**685,456**
18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934
104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000	104,000
122,934	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**	**122,934**
(794,840)	**(795,686)**	**(796,532)**	**(797,378)**	**(798,224)**	**(799,070)**	**(800,002)**	**(800,934)**	**(801,866)**	**(802,798)**	**(803,730)**	**(804,662)**	**(805,594)**	**(806,526)**	**(807,458)**	**(808,390)**
206,962	214,488	222,281	230,348	238,698	247,343	256,446	265,873	275,635	285,744	296,211	307,048	318,270	329,888	341,917	354,371
809,357	833,637	858,646	884,406	910,938	938,266	966,414	995,406	1,025,269	1,056,027	1,087,707	1,120,339	1,153,949	1,188,567	1,224,224	1,260,951
1,016,318	**1,048,126**	**1,080,927**	**1,114,753**	**1,149,636**	**1,185,609**	**1,222,860**	**1,261,280**	**1,300,904**	**1,341,771**	**1,383,918**	**1,427,387**	**1,472,219**	**1,518,455**	**1,566,141**	**1,615,322**
28,639	29,498	30,383	31,295	32,233	33,200	34,196	35,222	36,279	37,367	38,488	39,643	40,832	42,057	43,319	44,619
157,309	162,029	166,889	171,896	177,053	182,365	187,836	193,471	199,275	205,253	211,411	217,753	224,285	231,014	237,944	245,083
185,948	**191,527**	**197,273**	**203,191**	**209,286**	**215,565**	**222,032**	**228,693**	**235,554**	**242,620**	**249,899**	**257,396**	**265,118**	**273,071**	**281,263**	**289,701**
(1,202,266)	**(1,239,652)**	**(1,278,200)**	**(1,317,944)**	**(1,358,923)**	**(1,401,174)**	**(1,444,892)**	**(1,489,973)**	**(1,536,458)**	**(1,584,391)**	**(1,633,817)**	**(1,684,783)**	**(1,737,336)**	**(1,791,527)**	**(1,847,405)**	**(1,905,023)**
(911,168)	(921,080)	(931,099)	(941,226)	(951,462)	(961,809)	(972,371)	(983,048)	(993,841)	(1,004,751)	(1,015,779)	(1,026,927)	(1,038,196)	(1,049,587)	(1,061,102)	(1,072,742)

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 3 - AnitaMox

From Summary Sheet:		Risk adjustments (+/- percent):	
Year of analysis	2021	Benefits	
Escalation rate	3.00%	Capital costs	
Discount rate	2.00%	Running costs	

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Expressed in 2021 dollars, unescalated														
Capital Outlays														
Capital Costs	91,800,000													
Total capital outlays	**91,800,000**													
Benefits:														
Total benefits														
Annual Running Costs:														
Energy	148,439	149,305	150,172	151,039	151,906	152,773	153,640	154,507	155,374	156,241	157,228	158,214	159,201	160,188
Labor	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080
Total running costs	**683,519**	**684,385**	**685,252**	**686,119**	**686,986**	**687,853**	**688,720**	**689,587**	**690,454**	**691,321**	**692,308**	**693,294**	**694,281**	**695,268**
R&R Costs:														
Diffusers	15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429
Other Equipment	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000
Total refurbishments	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**
Net Benefit/(cost)	**(92,614,947)**	**(815,814)**	**(816,681)**	**(817,548)**	**(818,415)**	**(819,282)**	**(820,149)**	**(821,016)**	**(821,883)**	**(822,750)**	**(823,736)**	**(824,723)**	**(825,710)**	**(826,696)**
Expressed in escalated dollars with sensitivity adjustments														
Capital Outlays														
Capital Costs	91,800,000													
Total capital outlays	**91,800,000**													
Benefits:														
Total benefits														
Annual Running Costs:														
Energy	148,439	153,785	159,318	165,045	170,972	177,106	183,454	190,024	196,823	203,859	211,301	219,006	226,983	235,241
Labor	535,080	551,132	567,666	584,696	602,237	620,304	638,914	658,081	677,823	698,158	719,103	740,676	762,896	785,783
Total running costs	**683,519**	**704,917**	**726,984**	**749,741**	**773,209**	**797,410**	**822,368**	**848,105**	**874,646**	**902,017**	**930,404**	**959,682**	**989,879**	**1,021,024**
R&R Costs:														
Diffusers	15,429	15,891	16,368	16,859	17,365	17,886	18,423	18,975	19,544	20,131	20,735	21,357	21,997	22,657
Other Equipment	116,000	119,480	123,064	126,756	130,559	134,476	138,510	142,665	146,945	151,354	155,894	160,571	165,388	170,350
Total refurbishments	**131,429**	**135,371**	**139,433**	**143,616**	**147,924**	**152,362**	**156,933**	**161,641**	**166,490**	**171,484**	**176,629**	**181,928**	**187,386**	**193,007**
Net escalated benefit/(cost)	**(92,614,947)**	**(840,288)**	**(866,417)**	**(893,357)**	**(921,133)**	**(949,772)**	**(979,300)**	**(1,009,746)**	**(1,041,136)**	**(1,073,502)**	**(1,107,033)**	**(1,141,609)**	**(1,177,265)**	**(1,214,032)**
Life cycle cost analysis														
PVs in 2021	(92,614,947)	(823,812)	(832,773)	(841,830)	(850,985)	(860,238)	(869,591)	(879,044)	(888,600)	(898,258)	(908,152)	(918,154)	(928,265)	(938,486)
NPV as of 2021	**(120,560,126)**													

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 3 - AnitaMox

<-- See Rows on Previous Page

Year															
2035	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
161,175	162,161	163,148	164,135	165,121	166,108	167,189	168,270	169,351	170,432	171,513	172,594	173,675	174,756	175,837	176,918
535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080
696,255	**697,241**	**698,228**	**699,215**	**700,201**	**701,188**	**702,269**	**703,350**	**704,431**	**705,512**	**706,593**	**707,674**	**708,755**	**709,836**	**710,917**	**711,998**
15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429	15,429
116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000	116,000
131,429	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**	**131,429**
(827,683)	**(828,670)**	**(829,657)**	**(830,643)**	**(831,630)**	**(832,617)**	**(833,698)**	**(834,779)**	**(835,860)**	**(836,941)**	**(838,022)**	**(839,103)**	**(840,184)**	**(841,265)**	**(842,346)**	**(843,427)**
243,791	252,642	261,805	271,290	281,108	291,272	301,962	313,032	324,494	336,363	348,651	361,374	374,547	388,184	402,303	416,920
809,357	833,637	858,646	884,406	910,938	938,266	966,414	995,406	1,025,269	1,056,027	1,087,707	1,120,339	1,153,949	1,188,567	1,224,224	1,260,951
1,053,147	**1,086,279**	**1,120,451**	**1,155,695**	**1,192,046**	**1,229,538**	**1,268,376**	**1,308,439**	**1,349,763**	**1,392,389**	**1,436,359**	**1,481,713**	**1,528,495**	**1,576,751**	**1,626,527**	**1,677,871**
23,337	24,037	24,758	25,501	26,266	27,054	27,866	28,702	29,563	30,450	31,363	32,304	33,273	34,271	35,299	36,358
175,460	180,724	186,146	191,730	197,482	203,407	209,509	215,794	222,268	228,936	235,804	242,878	250,165	257,670	265,400	273,362
198,798	**204,761**	**210,904**	**217,231**	**223,748**	**230,461**	**237,375**	**244,496**	**251,831**	**259,386**	**267,167**	**275,182**	**283,438**	**291,941**	**300,699**	**309,720**
(1,251,945)	**(1,291,041)**	**(1,331,355)**	**(1,372,927)**	**(1,415,794)**	**(1,459,998)**	**(1,505,751)**	**(1,552,934)**	**(1,601,594)**	**(1,651,775)**	**(1,703,526)**	**(1,756,895)**	**(1,811,933)**	**(1,868,692)**	**(1,927,226)**	**(1,987,591)**
(948,818)	(959,262)	(969,820)	(980,493)	(991,282)	(1,002,188)	(1,013,327)	(1,024,589)	(1,035,973)	(1,047,483)	(1,059,119)	(1,070,882)	(1,082,774)	(1,094,796)	(1,106,950)	(1,119,237)

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 4 - AnammoPAQ

From Summary Sheet:		**Risk adjustments (+/- percent):**	
Year of analysis	**2021**	**Benefits**	
Escalation rate	**3.00%**	**Capital costs**	
Discount rate	**2.00%**	**Running costs**	

	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Expressed in 2021 dollars, unescalated														
Capital Outlays														
Capital Costs	99,300,000													
Total capital outlays	**99,300,000**													
Benefits:														
Total benefits														
Annual Running Costs:														
Energy	178,286	179,323	180,360	181,398	182,435	183,473	184,510	185,548	186,585	187,622	188,797	189,972	191,147	192,323
Labor	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080
Total running costs	**713,366**	**714,403**	**715,440**	**716,478**	**717,515**	**718,553**	**719,590**	**720,628**	**721,665**	**722,702**	**723,877**	**725,052**	**726,227**	**727,403**
R&R Costs:														
Diffusers	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934
Other Equipment	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000
Total refurbishments	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**
Net Benefit/(cost)	**(100,202,299)**	**(903,337)**	**(904,374)**	**(905,412)**	**(906,449)**	**(907,486)**	**(908,524)**	**(909,561)**	**(910,599)**	**(911,636)**	**(912,811)**	**(913,986)**	**(915,161)**	**(916,336)**
Expressed in escalated dollars with sensitivity adjustments														
Capital Outlays														
Capital Costs	99,300,000													
Total capital outlays	**99,300,000**													
Benefits:														
Total benefits														
Annual Running Costs:														
Energy	178,286	184,703	191,344	198,218	205,333	212,695	220,315	228,200	236,360	244,805	253,728	262,966	272,531	282,432
Labor	535,080	551,132	567,666	584,696	602,237	620,304	638,914	658,081	677,823	698,158	719,103	740,676	762,896	785,783
Total running costs	**713,366**	**735,835**	**759,011**	**782,915**	**807,570**	**833,000**	**859,228**	**886,281**	**914,184**	**942,963**	**972,831**	**1,003,642**	**1,035,427**	**1,068,215**
R&R Costs:														
Diffusers	18,934	19,502	20,087	20,689	21,310	21,949	22,608	23,286	23,985	24,704	25,445	26,209	26,995	27,805
Other Equipment	170,000	175,100	180,353	185,764	191,336	197,077	202,989	209,079	215,351	221,811	228,466	235,320	242,379	249,651
Total refurbishments	**188,934**	**194,602**	**200,440**	**206,453**	**212,647**	**219,026**	**225,597**	**232,365**	**239,336**	**246,516**	**253,911**	**261,528**	**269,374**	**277,456**
Net escalated benefit/(cost)	**(100,202,299)**	**(930,437)**	**(959,451)**	**(989,368)**	**(1,020,216)**	**(1,052,025)**	**(1,084,825)**	**(1,118,646)**	**(1,153,519)**	**(1,189,478)**	**(1,226,742)**	**(1,265,171)**	**(1,304,801)**	**(1,345,671)**
Life cycle cost analysis														
PVs in 2021	(100,202,299)	(912,193)	(922,194)	(932,303)	(942,522)	(952,852)	(963,294)	(973,848)	(984,517)	(995,302)	(1,006,356)	(1,017,530)	(1,028,827)	(1,040,247)
NPV as of 2021	**(131,185,281)**													

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 4 - AnammoPAQ

<-- See Rows on Previous Page

Year															
2035	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
193,498	194,673	195,848	197,023	198,198	199,373	200,654	201,936	203,217	204,499	205,780	207,062	208,344	209,625	210,907	212,188
535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080
728,578	**729,753**	**730,928**	**732,103**	**733,278**	**734,453**	**735,734**	**737,016**	**738,297**	**739,579**	**740,860**	**742,142**	**743,424**	**744,705**	**745,987**	**747,268**
18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934	18,934
170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000
188,934	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**	**188,934**
(917,511)	**(918,686)**	**(919,861)**	**(921,036)**	**(922,211)**	**(923,386)**	**(924,668)**	**(925,950)**	**(927,231)**	**(928,513)**	**(929,794)**	**(931,076)**	**(932,357)**	**(933,639)**	**(934,920)**	**(936,202)**
292,682	303,294	314,278	325,649	337,418	349,601	362,404	375,660	389,386	403,596	418,309	433,542	449,312	465,638	482,539	500,035
809,357	833,637	858,646	884,406	910,938	938,266	966,414	995,406	1,025,269	1,056,027	1,087,707	1,120,339	1,153,949	1,188,567	1,224,224	1,260,951
1,102,039	**1,136,931**	**1,172,924**	**1,210,054**	**1,248,356**	**1,287,867**	**1,328,818**	**1,371,067**	**1,414,654**	**1,459,623**	**1,506,017**	**1,553,881**	**1,603,261**	**1,654,205**	**1,706,763**	**1,760,986**
28,639	29,498	30,383	31,295	32,233	33,200	34,196	35,222	36,279	37,367	38,488	39,643	40,832	42,057	43,319	44,619
257,140	264,854	272,800	280,984	289,414	298,096	307,039	316,250	325,738	335,510	345,575	355,942	366,621	377,619	388,948	400,616
285,779	**294,353**	**303,183**	**312,279**	**321,647**	**331,296**	**341,235**	**351,472**	**362,017**	**372,877**	**384,063**	**395,585**	**407,453**	**419,676**	**432,267**	**445,235**
(1,387,818)	**(1,431,283)**	**(1,476,107)**	**(1,522,333)**	**(1,570,003)**	**(1,619,164)**	**(1,670,053)**	**(1,722,539)**	**(1,776,671)**	**(1,832,500)**	**(1,890,080)**	**(1,949,466)**	**(2,010,714)**	**(2,073,882)**	**(2,139,030)**	**(2,206,221)**
(1,051,793)	(1,063,465)	(1,075,264)	(1,087,193)	(1,099,253)	(1,111,444)	(1,123,898)	(1,136,490)	(1,149,220)	(1,162,091)	(1,175,103)	(1,188,260)	(1,201,561)	(1,215,008)	(1,228,604)	(1,242,350)

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 5 - ZeenAmmox

From Summary Sheet:		**Risk adjustments (+/- percent):**	
Year of analysis	**2021**	**Benefits**	
Escalation rate	**3.00%**	**Capital costs**	
Discount rate	**2.00%**	**Running costs**	

	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Expressed in 2021 dollars, unescalated														
Capital Outlays														
Capital Costs	145,200,000													
Total capital outlays	**145,200,000**													
Benefits:														
Total benefits														
Annual Running Costs:														
Energy	84,568	85,070	85,572	86,074	86,576	87,078	87,580	88,083	88,585	89,087	89,670	90,254	90,838	91,422
Labor	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080
Total running costs	**619,648**	**620,150**	**620,652**	**621,154**	**621,656**	**622,158**	**622,660**	**623,163**	**623,665**	**624,167**	**624,750**	**625,334**	**625,918**	**626,502**
R&R Costs:														
Diffusers	18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669
Other Equipent (includes casettes)	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000
Total refurbishments	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**
Net Benefit/(cost)	**(146,158,316)**	**(958,818)**	**(959,320)**	**(959,823)**	**(960,325)**	**(960,827)**	**(961,329)**	**(961,831)**	**(962,333)**	**(962,835)**	**(963,419)**	**(964,003)**	**(964,587)**	**(965,170)**
Expressed in escalated dollars with sensitivity adjustments														
Capital Outlays														
Capital Costs	145,200,000													
Total capital outlays	**145,200,000**													
Benefits:														
Total benefits														
Annual Running Costs:														
Energy	84,568	87,622	90,783	94,055	97,442	100,948	104,576	108,330	112,216	116,238	120,510	124,933	129,513	134,256
Labor	535,080	551,132	567,666	584,696	602,237	620,304	638,914	658,081	677,823	698,158	719,103	740,676	762,896	785,783
Total running costs	**619,648**	**638,754**	**658,450**	**678,752**	**699,679**	**721,252**	**743,489**	**766,411**	**790,040**	**814,396**	**839,612**	**865,609**	**892,409**	**920,039**
R&R Costs:														
Diffusers	18,669	19,229	19,805	20,400	21,012	21,642	22,291	22,960	23,649	24,358	25,089	25,842	26,617	27,415
Other Equipent (includes casettes)	320,000	329,600	339,488	349,673	360,163	370,968	382,097	393,560	405,366	417,527	430,053	442,955	456,243	469,931
Total refurbishments	**338,669**	**348,829**	**359,293**	**370,072**	**381,174**	**392,610**	**404,388**	**416,520**	**429,015**	**441,886**	**455,142**	**468,797**	**482,860**	**497,346**
Net escalated benefit/(cost)	**(146,158,316)**	**(987,583)**	**(1,017,743)**	**(1,048,824)**	**(1,080,854)**	**(1,113,862)**	**(1,147,877)**	**(1,182,931)**	**(1,219,055)**	**(1,256,282)**	**(1,294,755)**	**(1,334,405)**	**(1,375,270)**	**(1,417,385)**
Life cycle cost analysis														
PVs in 2021	(146,158,316)	(968,218)	(978,223)	(988,330)	(998,542)	(1,008,859)	(1,019,282)	(1,029,813)	(1,040,452)	(1,051,200)	(1,062,150)	(1,073,213)	(1,084,391)	(1,095,685)
NPV as of 2021	**(178,727,912)**													

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 5 - ZeenAmmox

<-- See Rows on Previous Page

Year															
2035	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
92,005	92,589	93,173	93,757	94,340	94,924	95,576	96,228	96,880	97,532	98,184	98,835	99,487	100,139	100,791	101,443
535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080	535,080
627,085	**627,669**	**628,253**	**628,837**	**629,420**	**630,004**	**630,656**	**631,308**	**631,960**	**632,612**	**633,264**	**633,915**	**634,567**	**635,219**	**635,871**	**636,523**
18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669	18,669
320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000
338,669	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**	**338,669**
(965,754)	**(966,338)**	**(966,921)**	**(967,505)**	**(968,089)**	**(968,673)**	**(969,324)**	**(969,976)**	**(970,628)**	**(971,280)**	**(971,932)**	**(972,584)**	**(973,236)**	**(973,888)**	**(974,540)**	**(975,192)**
139,166	144,251	149,515	154,965	160,608	166,450	172,621	179,012	185,632	192,487	199,587	206,939	214,554	222,438	230,603	239,057
809,357	833,637	858,646	884,406	910,938	938,266	966,414	995,406	1,025,269	1,056,027	1,087,707	1,120,339	1,153,949	1,188,567	1,224,224	1,260,951
948,523	**977,888**	**1,008,161**	**1,039,371**	**1,071,546**	**1,104,716**	**1,139,035**	**1,174,418**	**1,210,900**	**1,248,514**	**1,287,294**	**1,327,278**	**1,368,502**	**1,411,006**	**1,454,827**	**1,500,008**
28,238	29,085	29,958	30,856	31,782	32,735	33,718	34,729	35,771	36,844	37,949	39,088	40,260	41,468	42,712	43,994
484,029	498,550	513,506	528,911	544,779	561,122	577,956	595,294	613,153	631,548	650,494	670,009	690,109	710,812	732,137	754,101
512,267	**527,635**	**543,464**	**559,768**	**576,561**	**593,857**	**611,673**	**630,023**	**648,924**	**668,392**	**688,443**	**709,097**	**730,370**	**752,281**	**774,849**	**798,095**
(1,460,789)	**(1,505,523)**	**(1,551,625)**	**(1,599,139)**	**(1,648,106)**	**(1,698,573)**	**(1,750,708)**	**(1,804,442)**	**(1,859,824)**	**(1,916,905)**	**(1,975,738)**	**(2,036,375)**	**(2,098,872)**	**(2,163,286)**	**(2,229,676)**	**(2,298,103)**
(1,107,096)	(1,118,625)	(1,130,275)	(1,142,045)	(1,153,937)	(1,165,953)	(1,178,176)	(1,190,527)	(1,203,007)	(1,215,617)	(1,228,359)	(1,241,233)	(1,254,242)	(1,267,387)	(1,280,669)	(1,294,090)

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 6 - Ammonia Recovery

From Summary Sheet:		**Risk adjustments (+/- percent):**	
Year of analysis	**2021**	**Benefits**	
Escalation rate	**3.00%**	**Capital costs**	
Discount rate	**2.00%**	**Running costs**	

	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Expressed in 2021 dollars, unescalated														
Capital Outlays														
Capital Costs	77,200,000													
Total capital outlays	**77,200,000**													
Benefits:														
LAS Revenue	248,207	249,968	251,728	253,488	255,249	257,009	258,769	260,530	262,290	264,050	266,515	268,979	271,444	273,908
Total benefits	**248,207**	**249,968**	**251,728**	**253,488**	**255,249**	**257,009**	**258,769**	**260,530**	**262,290**	**264,050**	**266,515**	**268,979**	**271,444**	**273,908**
Annual Running Costs:														
Energy	60,728	61,159	61,590	62,020	62,451	62,882	63,312	63,743	64,174	64,604	65,207	65,810	66,413	67,016
Chemical	1,598,447	1,609,673	1,620,898	1,632,124	1,643,350	1,654,575	1,665,801	1,677,026	1,688,252	1,699,478	1,715,058	1,730,639	1,746,219	1,761,800
Labor	611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520
Total running costs	**2,270,695**	**2,282,352**	**2,294,008**	**2,305,664**	**2,317,321**	**2,328,977**	**2,340,633**	**2,352,290**	**2,363,946**	**2,375,602**	**2,391,786**	**2,407,969**	**2,424,152**	**2,440,336**
R&R Costs:														
Equipment	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000
Total refurbishments	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**
Net Benefit/(cost)	**(79,396,488)**	**(2,206,384)**	**(2,216,280)**	**(2,226,176)**	**(2,236,072)**	**(2,245,968)**	**(2,255,864)**	**(2,265,760)**	**(2,275,656)**	**(2,285,552)**	**(2,299,271)**	**(2,312,990)**	**(2,326,709)**	**(2,340,428)**
Expressed in escalated dollars with sensitivity adjustments														
Capital Outlays														
Capital Costs	77,200,000													
Total capital outlays	**77,200,000**													
Benefits:														
LAS Revenue	248,207	257,467	267,058	276,994	287,285	297,944	308,984	320,419	332,261	344,526	358,174	372,330	387,014	402,244
Total benefits	**248,207**	**257,467**	**267,058**	**276,994**	**287,285**	**297,944**	**308,984**	**320,419**	**332,261**	**344,526**	**358,174**	**372,330**	**387,014**	**402,244**
Annual Running Costs:														
Energy	60,728	62,994	65,340	67,771	70,289	72,897	75,598	78,396	81,293	84,294	87,633	91,097	94,690	98,416
Chemical	1,598,447	1,657,963	1,719,611	1,783,466	1,849,604	1,918,106	1,989,053	2,062,531	2,138,627	2,217,433	2,304,895	2,395,609	2,489,691	2,587,262
Labor	611,520	629,866	648,762	668,224	688,271	708,919	730,187	752,092	774,655	797,895	821,832	846,487	871,881	898,038
Total running costs	**2,270,695**	**2,350,822**	**2,433,713**	**2,519,462**	**2,608,165**	**2,699,922**	**2,794,838**	**2,893,019**	**2,994,576**	**3,099,622**	**3,214,360**	**3,333,192**	**3,456,262**	**3,583,716**
R&R Costs:														
Equipment	174,000	179,220	184,597	190,134	195,839	201,714	207,765	213,998	220,418	227,031	233,841	240,857	248,082	255,525
Total refurbishments	**174,000**	**179,220**	**184,597**	**190,134**	**195,839**	**201,714**	**207,765**	**213,998**	**220,418**	**227,031**	**233,841**	**240,857**	**248,082**	**255,525**
Net escalated benefit/(cost)	**(79,396,488)**	**(2,272,575)**	**(2,351,251)**	**(2,432,602)**	**(2,516,718)**	**(2,603,692)**	**(2,693,619)**	**(2,786,599)**	**(2,882,733)**	**(2,982,127)**	**(3,090,027)**	**(3,201,719)**	**(3,317,330)**	**(3,436,997)**
Life cycle cost analysis														
PVs in 2021	(79,396,488)	(2,228,015)	(2,259,949)	(2,292,295)	(2,325,059)	(2,358,244)	(2,391,857)	(2,425,902)	(2,460,384)	(2,495,310)	(2,534,899)	(2,575,024)	(2,615,692)	(2,656,910)
NPV as of 2021	**(159,879,118)**													

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 6 - Ammonia Recovery

<-- See Rows on Previous Page

Year															
2035	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
276,373	278,837	281,302	283,766	286,231	288,695	291,864	295,032	298,201	301,370	304,538	307,707	310,875	314,044	317,213	320,381
276,373	**278,837**	**281,302**	**283,766**	**286,231**	**288,695**	**291,864**	**295,032**	**298,201**	**301,370**	**304,538**	**307,707**	**310,875**	**314,044**	**317,213**	**320,381**
67,619	68,222	68,825	69,428	70,031	70,634	71,409	72,185	72,960	73,735	74,510	75,286	76,061	76,836	77,611	78,387
1,777,380	1,792,960	1,808,541	1,824,121	1,839,702	1,855,282	1,875,202	1,895,122	1,915,043	1,934,963	1,954,883	1,974,803	1,994,723	2,014,643	2,034,563	2,054,886
611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520	611,520
2,456,519	**2,472,703**	**2,488,886**	**2,505,070**	**2,521,253**	**2,537,437**	**2,558,132**	**2,578,827**	**2,599,523**	**2,620,218**	**2,640,913**	**2,661,609**	**2,682,304**	**2,702,999**	**2,723,695**	**2,744,793**
174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000
174,000	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**	**174,000**
(2,354,147)	**(2,367,865)**	**(2,381,584)**	**(2,395,303)**	**(2,409,022)**	**(2,422,741)**	**(2,440,268)**	**(2,457,795)**	**(2,475,322)**	**(2,492,848)**	**(2,510,375)**	**(2,527,902)**	**(2,545,428)**	**(2,562,955)**	**(2,580,482)**	**(2,598,412)**
418,039	434,419	451,407	469,022	487,289	506,229	527,139	548,847	571,384	594,779	619,064	644,270	670,431	697,583	725,760	754,999
418,039	**434,419**	**451,407**	**469,022**	**487,289**	**506,229**	**527,139**	**548,847**	**571,384**	**594,779**	**619,064**	**644,270**	**670,431**	**697,583**	**725,760**	**754,999**
102,280	106,288	110,444	114,754	119,223	123,858	128,973	134,285	139,799	145,523	151,464	157,632	164,032	170,675	177,569	184,724
2,688,447	2,793,374	2,902,177	3,014,995	3,131,969	3,253,249	3,386,824	3,525,486	3,669,420	3,818,816	3,973,874	4,134,799	4,301,802	4,475,104	4,654,933	4,842,474
924,979	952,728	981,310	1,010,749	1,041,072	1,072,304	1,104,473	1,137,607	1,171,736	1,206,888	1,243,094	1,280,387	1,318,799	1,358,363	1,399,114	1,441,087
3,715,706	**3,852,390**	**3,993,932**	**4,140,498**	**4,292,265**	**4,449,410**	**4,620,271**	**4,797,378**	**4,980,954**	**5,171,227**	**5,368,433**	**5,572,817**	**5,784,633**	**6,004,142**	**6,231,616**	**6,468,284**
263,191	271,086	279,219	287,595	296,223	305,110	314,263	323,691	333,402	343,404	353,706	364,317	375,247	386,504	398,099	410,042
263,191	**271,086**	**279,219**	**287,595**	**296,223**	**305,110**	**314,263**	**323,691**	**333,402**	**343,404**	**353,706**	**364,317**	**375,247**	**386,504**	**398,099**	**410,042**
(3,560,858)	**(3,689,057)**	**(3,821,744)**	**(3,959,072)**	**(4,101,199)**	**(4,248,292)**	**(4,407,396)**	**(4,572,222)**	**(4,742,972)**	**(4,919,852)**	**(5,103,075)**	**(5,292,865)**	**(5,489,449)**	**(5,693,064)**	**(5,903,956)**	**(6,123,327)**
(2,698,685)	(2,741,024)	(2,783,933)	(2,827,421)	(2,871,493)	(2,916,158)	(2,966,051)	(3,016,642)	(3,067,939)	(3,119,953)	(3,172,692)	(3,226,164)	(3,280,381)	(3,335,350)	(3,391,082)	(3,448,121)

From Summary Sheet:		**Risk adjustments (+/- percent):**	
Year of analysis	**2021**	**Benefits**	
Escalation rate	**3.00%**	**Capital costs**	
Discount rate	**2.00%**	**Running costs**	

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 7 - GAS AMR

	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Expressed in 2021 dollars, unescalated														
Capital Outlays														
Capital Costs	105,600,000													
Total capital outlays	**105,600,000**													
Benefits:														
GAS Revenue	1,131,882	1,139,909	1,147,937	1,155,964	1,163,992	1,172,019	1,180,047	1,188,074	1,196,102	1,204,129	1,215,368	1,226,606	1,237,845	1,249,084
Total benefits	**1,131,882**	**1,139,909**	**1,147,937**	**1,155,964**	**1,163,992**	**1,172,019**	**1,180,047**	**1,188,074**	**1,196,102**	**1,204,129**	**1,215,368**	**1,226,606**	**1,237,845**	**1,249,084**
Annual Running Costs:														
Energy	302,331	304,475	306,619	308,763	310,908	313,052	315,196	317,340	319,484	321,629	324,631	327,632	330,634	333,636
Chemical	1,618,790	1,630,160	1,641,530	1,652,900	1,664,270	1,675,640	1,687,010	1,698,380	1,709,750	1,721,120	1,736,902	1,752,685	1,768,467	1,784,250
Total running costs	**2,532,641**	**2,546,156**	**2,559,670**	**2,573,184**	**2,586,698**	**2,600,212**	**2,613,726**	**2,627,240**	**2,640,754**	**2,654,268**	**2,673,053**	**2,691,837**	**2,710,621**	**2,729,406**
R&R Costs:														
Equipment	238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750
Total refurbishments	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**
Net Benefit/(cost)	**(107,239,510)**	**(1,644,996)**	**(1,650,483)**	**(1,655,970)**	**(1,661,456)**	**(1,666,943)**	**(1,672,429)**	**(1,677,916)**	**(1,683,402)**	**(1,688,889)**	**(1,696,435)**	**(1,703,981)**	**(1,711,526)**	**(1,719,072)**
Expressed in escalated dollars with sensitivity adjustments														
Capital Outlays														
Capital Costs	105,600,000													
Total capital outlays	**105,600,000**													
Benefits:														
GAS Revenue	1,131,882	1,174,106	1,217,846	1,263,153	1,310,083	1,358,692	1,409,038	1,461,182	1,515,186	1,571,116	1,633,353	1,697,910	1,764,871	1,834,321
Total benefits	**1,131,882**	**1,174,106**	**1,217,846**	**1,263,153**	**1,310,083**	**1,358,692**	**1,409,038**	**1,461,182**	**1,515,186**	**1,571,116**	**1,633,353**	**1,697,910**	**1,764,871**	**1,834,321**
Annual Running Costs:														
Energy	302,331	313,609	325,292	337,394	349,929	362,913	376,361	390,288	404,713	419,652	436,276	453,520	471,405	489,956
Chemical	1,618,790	1,679,065	1,741,500	1,806,169	1,873,151	1,942,526	2,014,378	2,088,793	2,165,860	2,245,671	2,334,251	2,426,125	2,521,411	2,620,231
Labor	611,520	629,866	648,762	668,224	688,271	708,919	730,187	752,092	774,655	797,895	821,832	846,487	871,881	898,038
Total running costs	**2,532,641**	**2,622,540**	**2,715,554**	**2,811,787**	**2,911,351**	**3,014,358**	**3,120,926**	**3,231,174**	**3,345,229**	**3,463,218**	**3,592,359**	**3,726,132**	**3,864,698**	**4,008,224**
R&R Costs:														
Equipment	238,750	245,913	253,290	260,889	268,715	276,777	285,080	293,632	302,441	311,515	320,860	330,486	340,400	350,612
Total refurbishments	**238,750**	**245,913**	**253,290**	**260,889**	**268,715**	**276,777**	**285,080**	**293,632**	**302,441**	**311,515**	**320,860**	**330,486**	**340,400**	**350,612**
Net escalated benefit/(cost)	**(107,239,510)**	**(1,694,346)**	**(1,750,997)**	**(1,809,523)**	**(1,869,983)**	**(1,932,443)**	**(1,996,968)**	**(2,063,625)**	**(2,132,484)**	**(2,203,617)**	**(2,279,866)**	**(2,358,708)**	**(2,440,227)**	**(2,524,515)**
Life cycle cost analysis														
PVs in 2021	(107,239,510)	(1,661,124)	(1,683,004)	(1,705,154)	(1,727,576)	(1,750,274)	(1,773,250)	(1,796,510)	(1,820,054)	(1,843,888)	(1,870,285)	(1,897,021)	(1,924,103)	(1,951,532)
NPV as of 2021	**(166,045,240)**													

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 7 - GAS AMR

<-- See Rows on Previous Page

Year															
2035	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
1,260,322	1,271,561	1,282,799	1,294,038	1,305,276	1,316,515	1,330,964	1,345,414	1,359,863	1,374,313	1,388,763	1,403,212	1,417,662	1,432,111	1,446,561	1,461,010
1,260,322	**1,271,561**	**1,282,799**	**1,294,038**	**1,305,276**	**1,316,515**	**1,330,964**	**1,345,414**	**1,359,863**	**1,374,313**	**1,388,763**	**1,403,212**	**1,417,662**	**1,432,111**	**1,446,561**	**1,461,010**
336,638	339,640	342,642	345,644	348,645	351,647	355,507	359,366	363,226	367,085	370,945	374,805	378,664	382,524	386,383	390,243
1,800,032	1,815,814	1,831,597	1,847,379	1,863,162	1,878,944	1,899,124	1,919,304	1,939,484	1,959,663	1,979,843	2,000,023	2,020,203	2,040,383	2,060,562	2,081,145
2,748,190	**2,766,974**	**2,785,759**	**2,804,543**	**2,823,327**	**2,842,112**	**2,866,151**	**2,890,190**	**2,914,230**	**2,938,269**	**2,962,308**	**2,986,348**	**3,010,387**	**3,034,426**	**3,058,466**	**3,082,908**
238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750	238,750
238,750	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**	**238,750**
(1,726,618)	**(1,734,164)**	**(1,741,709)**	**(1,749,255)**	**(1,756,801)**	**(1,764,347)**	**(1,773,937)**	**(1,783,526)**	**(1,793,116)**	**(1,802,706)**	**(1,812,296)**	**(1,821,885)**	**(1,831,475)**	**(1,841,065)**	**(1,850,655)**	**(1,860,647)**
1,906,350	1,981,050	2,058,516	2,138,847	2,222,145	2,308,517	2,403,870	2,502,866	2,605,639	2,712,326	2,823,068	2,938,015	3,057,317	3,181,133	3,309,626	3,442,967
1,906,350	**1,981,050**	**2,058,516**	**2,138,847**	**2,222,145**	**2,308,517**	**2,403,870**	**2,502,866**	**2,605,639**	**2,712,326**	**2,823,068**	**2,938,015**	**3,057,317**	**3,181,133**	**3,309,626**	**3,442,967**
509,195	529,148	549,839	571,296	593,546	616,616	642,085	668,527	695,978	724,475	754,055	784,758	816,624	849,696	884,017	919,633
2,722,710	2,828,980	2,939,175	3,053,437	3,171,908	3,294,740	3,430,029	3,570,471	3,716,251	3,867,565	4,024,614	4,187,604	4,356,752	4,532,279	4,714,418	4,904,355
924,979	952,728	981,310	1,010,749	1,041,072	1,072,304	1,104,473	1,137,607	1,171,736	1,206,888	1,243,094	1,280,387	1,318,799	1,358,363	1,399,114	1,441,087
4,156,884	**4,310,856**	**4,470,325**	**4,635,482**	**4,806,526**	**4,983,660**	**5,176,587**	**5,376,605**	**5,583,965**	**5,798,928**	**6,021,763**	**6,252,749**	**6,492,174**	**6,740,338**	**6,997,548**	**7,265,074**
361,131	371,965	383,124	394,617	406,456	418,650	431,209	444,145	457,470	471,194	485,330	499,889	514,886	530,333	546,243	562,630
361,131	**371,965**	**383,124**	**394,617**	**406,456**	**418,650**	**431,209**	**444,145**	**457,470**	**471,194**	**485,330**	**499,889**	**514,886**	**530,333**	**546,243**	**562,630**
(2,611,664)	**(2,701,771)**	**(2,794,932)**	**(2,891,252)**	**(2,990,836)**	**(3,093,793)**	**(3,203,927)**	**(3,317,884)**	**(3,435,796)**	**(3,557,796)**	**(3,684,024)**	**(3,814,624)**	**(3,949,743)**	**(4,089,537)**	**(4,234,164)**	**(4,384,738)**
(1,979,315)	(2,007,455)	(2,035,957)	(2,064,824)	(2,094,062)	(2,123,675)	(2,156,151)	(2,189,060)	(2,222,407)	(2,256,197)	(2,290,437)	(2,325,131)	(2,360,285)	(2,395,905)	(2,431,996)	(2,469,100)

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 1 - Chemical Addition

From Summary Sheet:

Year of analysis	**2021**
Escalation rate	**3.00%**
Discount rate	**2.00%**

Risk adjustments (+/- percent):

Benefits	
Capital costs	
Running costs	

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Expressed in 2021 dollars, unescalated														
Capital Outlays														
Capital Costs	2,600,000													
Total capital outlays	**2,600,000**													
Benefits:														
Total benefits														
Annual Running Costs:														
Ferric Chloride	2,293,249	2,306,347	2,319,445	2,332,543	2,345,641	2,358,739	2,371,837	2,384,935	2,398,033	2,411,131	2,425,601	2,440,070	2,454,540	2,469,009
Total running costs	**2,293,249**	**2,306,347**	**2,319,445**	**2,332,543**	**2,345,641**	**2,358,739**	**2,371,837**	**2,384,935**	**2,398,033**	**2,411,131**	**2,425,601**	**2,440,070**	**2,454,540**	**2,469,009**
R&R Costs:														
Total refurbishments														
Net Benefit/(cost)	**(4,893,249)**	**(2,306,347)**	**(2,319,445)**	**(2,332,543)**	**(2,345,641)**	**(2,358,739)**	**(2,371,837)**	**(2,384,935)**	**(2,398,033)**	**(2,411,131)**	**(2,425,601)**	**(2,440,070)**	**(2,454,540)**	**(2,469,009)**
Expressed in escalated dollars with sensitivity adjustments														
Capital Outlays														
Capital Costs	2,600,000													
Total capital outlays	**2,600,000**													
Benefits:														
Total benefits														
Annual Running Costs:														
Ferric Chloride	2,293,249	2,375,538	2,460,699	2,548,833	2,640,040	2,734,425	2,832,098	2,933,170	3,037,757	3,145,980	3,259,805	3,377,628	3,499,587	3,625,824
Total running costs	**2,293,249**	**2,375,538**	**2,460,699**	**2,548,833**	**2,640,040**	**2,734,425**	**2,832,098**	**2,933,170**	**3,037,757**	**3,145,980**	**3,259,805**	**3,377,628**	**3,499,587**	**3,625,824**
R&R Costs:														
Total refurbishments														
Net escalated benefit/(cost)	**(4,893,249)**	**(2,375,538)**	**(2,460,699)**	**(2,548,833)**	**(2,640,040)**	**(2,734,425)**	**(2,832,098)**	**(2,933,170)**	**(3,037,757)**	**(3,145,980)**	**(3,259,805)**	**(3,377,628)**	**(3,499,587)**	**(3,625,824)**
Life cycle cost analysis														
PVs in 2021	(4,893,249)	(2,328,959)	(2,365,148)	(2,401,822)	(2,438,989)	(2,476,653)	(2,514,822)	(2,553,501)	(2,592,696)	(2,632,415)	(2,674,175)	(2,716,501)	(2,759,401)	(2,802,880)
NPV as of 2021	**(89,479,352)**													

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 1 - Chemical Addition

<--- See Rows on Previous Page

Year															
2035	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
2,483,479	2,497,949	2,512,418	2,526,888	2,541,357	2,555,827	2,571,233	2,586,640	2,602,047	2,617,454	2,632,860	2,648,267	2,663,674	2,679,081	2,694,487	2,709,894
2,483,479	**2,497,949**	**2,512,418**	**2,526,888**	**2,541,357**	**2,555,827**	**2,571,233**	**2,586,640**	**2,602,047**	**2,617,454**	**2,632,860**	**2,648,267**	**2,663,674**	**2,679,081**	**2,694,487**	**2,709,894**
(2,483,479)	**(2,497,949)**	**(2,512,418)**	**(2,526,888)**	**(2,541,357)**	**(2,555,827)**	**(2,571,233)**	**(2,586,640)**	**(2,602,047)**	**(2,617,454)**	**(2,632,860)**	**(2,648,267)**	**(2,663,674)**	**(2,679,081)**	**(2,694,487)**	**(2,709,894)**
3,756,485	3,891,722	4,031,693	4,176,560	4,326,490	4,481,658	4,643,934	4,811,913	4,985,791	5,165,771	5,352,063	5,544,883	5,744,456	5,951,012	6,164,792	6,386,043
3,756,485	**3,891,722**	**4,031,693**	**4,176,560**	**4,326,490**	**4,481,658**	**4,643,934**	**4,811,913**	**4,985,791**	**5,165,771**	**5,352,063**	**5,544,883**	**5,744,456**	**5,951,012**	**6,164,792**	**6,386,043**
(3,756,485)	**(3,891,722)**	**(4,031,693)**	**(4,176,560)**	**(4,326,490)**	**(4,481,658)**	**(4,643,934)**	**(4,811,913)**	**(4,985,791)**	**(5,165,771)**	**(5,352,063)**	**(5,544,883)**	**(5,744,456)**	**(5,951,012)**	**(6,164,792)**	**(6,386,043)**
(2,846,946)	(2,891,607)	(2,936,870)	(2,982,743)	(3,029,233)	(3,076,348)	(3,125,234)	(3,174,784)	(3,225,004)	(3,275,904)	(3,327,493)	(3,379,777)	(3,432,768)	(3,486,472)	(3,540,900)	(3,596,059)

From Summary Sheet:

Year of analysis	**2021**
Escalation rate	**3.00%**
Discount rate	**2.00%**

Risk adjustments (+/- percent):

Benefits	
Capital costs	
Running costs	

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 2 - CalPrex

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Expressed in 2021 dollars, unescalated														
Capital Outlays														
Capital Costs	104,900,000													
Total capital outlays	**104,900,000**													
Benefits:														
Brushite Revenue	42,508	42,866	43,224	43,583	43,941	44,299	44,657	45,016	45,374	45,612	46,187	46,763	47,339	47,914
Total benefits	**42,508**	**42,866**	**43,224**	**43,583**	**43,941**	**44,299**	**44,657**	**45,016**	**45,374**	**45,612**	**46,187**	**46,763**	**47,339**	**47,914**
Annual Running Costs:														
Energy	121,442	122,303	123,165	124,026	124,887	125,748	126,610	127,471	128,332	129,194	130,399	131,605	132,811	134,017
Chemical	80,967	81,650	82,332	83,014	83,697	84,379	85,062	85,744	86,427	86,879	87,976	89,072	90,169	91,265
Labor	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640
Total running costs	**661,049**	**662,593**	**664,137**	**665,680**	**667,224**	**668,768**	**670,312**	**671,855**	**673,399**	**674,713**	**677,015**	**679,318**	**681,620**	**683,922**
R&R Costs:														
Equipment Repair	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198
Total refurbishments	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**
Net Benefit/(cost)	**(105,655,739)**	**(756,925)**	**(758,110)**	**(759,296)**	**(760,481)**	**(761,667)**	**(762,852)**	**(764,038)**	**(765,223)**	**(766,299)**	**(768,026)**	**(769,753)**	**(771,479)**	**(773,206)**
Expressed in escalated dollars with sensitivity adjustments														
Capital Outlays														
Capital Costs	104,900,000													
Total capital outlays	**104,900,000**													
Benefits:														
Brushite Revenue	42,508	44,152	45,857	47,624	49,456	51,355	53,323	55,364	57,479	59,513	62,072	64,731	67,494	70,364
Total benefits	**42,508**	**44,152**	**45,857**	**47,624**	**49,456**	**51,355**	**53,323**	**55,364**	**57,479**	**59,513**	**62,072**	**64,731**	**67,494**	**70,364**
Annual Running Costs:														
Energy	121,442	125,972	130,665	135,526	140,562	145,777	151,179	156,773	162,568	168,568	175,246	182,172	189,357	196,808
Chemical	80,967	84,099	87,346	90,712	94,202	97,819	101,568	105,455	109,483	113,358	118,232	123,297	128,559	134,026
Labor	458,640	472,399	486,571	501,168	516,203	531,689	547,640	564,069	580,991	598,421	616,374	634,865	653,911	673,528
Total running costs	**661,049**	**682,471**	**704,583**	**727,407**	**750,967**	**775,285**	**800,387**	**826,297**	**853,042**	**880,347**	**909,852**	**940,334**	**971,827**	**1,004,363**
R&R Costs:														
Equipment Repair	137,198	141,314	145,553	149,920	154,418	159,050	163,822	168,736	173,798	179,012	184,383	189,914	195,612	201,480
Total refurbishments	**137,198**	**141,314**	**145,553**	**149,920**	**154,418**	**159,050**	**163,822**	**168,736**	**173,798**	**179,012**	**184,383**	**189,914**	**195,612**	**201,480**
Net escalated benefit/(cost)	**(105,655,739)**	**(779,633)**	**(804,279)**	**(829,703)**	**(855,928)**	**(882,980)**	**(910,885)**	**(939,670)**	**(969,362)**	**(999,847)**	**(1,032,163)**	**(1,065,518)**	**(1,099,945)**	**(1,135,479)**
Life cycle cost analysis														
PVs in 2021	(105,655,739)	(764,346)	(773,048)	(781,848)	(790,745)	(799,743)	(808,840)	(818,039)	(827,341)	(836,627)	(846,733)	(856,956)	(867,299)	(877,762)
NPV as of 2021	**(131,902,742)**													

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 2 - CalPrex

<--- See Rows on Previous Page

Year															
2035	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
48,490	49,066	49,641	50,217	50,793	51,368	51,980	52,592	53,204	53,816	54,428	55,040	55,652	56,264	56,876	57,488
48,490	**49,066**	**49,641**	**50,217**	**50,793**	**51,368**	**51,980**	**52,592**	**53,204**	**53,816**	**54,428**	**55,040**	**55,652**	**56,264**	**56,876**	**57,488**
135,223	136,428	137,634	138,840	140,046	141,252	142,802	144,352	145,903	147,453	149,003	150,554	152,104	153,654	155,205	156,755
92,362	93,458	94,555	95,651	96,748	97,845	99,010	100,176	101,341	102,507	103,672	104,838	106,003	107,169	108,334	109,500
458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640
686,225	**688,527**	**690,829**	**693,132**	**695,434**	**697,736**	**700,452**	**703,168**	**705,884**	**708,600**	**711,316**	**714,031**	**716,747**	**719,463**	**722,179**	**724,895**
137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198
137,198	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**
(774,933)	**(776,659)**	**(778,386)**	**(780,113)**	**(781,839)**	**(783,566)**	**(785,670)**	**(787,774)**	**(789,878)**	**(791,982)**	**(794,086)**	**(796,190)**	**(798,294)**	**(800,398)**	**(802,502)**	**(804,605)**
73,345	76,443	79,660	83,001	86,471	90,075	93,882	97,837	101,945	106,211	110,641	115,241	120,018	124,978	130,127	135,473
73,345	**76,443**	**79,660**	**83,001**	**86,471**	**90,075**	**93,882**	**97,837**	**101,945**	**106,211**	**110,641**	**115,241**	**120,018**	**124,978**	**130,127**	**135,473**
204,536	212,551	220,863	229,482	238,419	247,686	257,916	268,538	279,565	291,011	302,893	315,226	328,026	341,311	355,097	369,403
139,706	145,605	151,733	158,097	164,707	171,571	178,823	186,356	194,180	202,306	210,744	219,507	228,606	238,053	247,861	258,044
693,734	714,546	735,983	758,062	780,804	804,228	828,355	853,206	878,802	905,166	932,321	960,290	989,099	1,018,772	1,049,335	1,080,815
1,037,976	**1,072,702**	**1,108,578**	**1,145,641**	**1,183,930**	**1,223,485**	**1,265,094**	**1,308,100**	**1,352,546**	**1,398,483**	**1,445,958**	**1,495,023**	**1,545,731**	**1,598,136**	**1,652,293**	**1,708,262**
207,524	213,750	220,163	226,767	233,570	240,578	247,795	255,229	262,886	270,772	278,895	287,262	295,880	304,756	313,899	323,316
207,524	**213,750**	**220,163**	**226,767**	**233,570**	**240,578**	**247,795**	**255,229**	**262,886**	**270,772**	**278,895**	**287,262**	**295,880**	**304,756**	**313,899**	**323,316**
(1,172,155)	**(1,210,010)**	**(1,249,081)**	**(1,289,407)**	**(1,331,029)**	**(1,373,988)**	**(1,419,007)**	**(1,465,491)**	**(1,513,487)**	**(1,563,044)**	**(1,614,213)**	**(1,667,044)**	**(1,721,593)**	**(1,777,914)**	**(1,836,065)**	**(1,896,105)**
(888,347)	(899,055)	(909,888)	(920,846)	(931,932)	(943,147)	(954,951)	(966,896)	(978,983)	(991,214)	(1,003,591)	(1,016,115)	(1,028,788)	(1,041,612)	(1,054,589)	(1,067,720)

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 2 - CalPrex (No Fermenter)

From Summary Sheet:		**Risk adjustments (+/- percent):**	
Year of analysis	**2021**	**Benefits**	
Escalation rate	**3.00%**	**Capital costs**	
Discount rate	**2.00%**	**Running costs**	

	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Expressed in 2021 dollars, unescalated														
Capital Outlays														
Capital Costs	52,700,000													
Total capital outlays	**52,700,000**													
Benefits:														
Brushite Revenue	11,335	11,431	11,526	11,622	11,718	11,813	11,909	12,004	12,100	12,163	12,317	12,470	12,624	12,777
Total benefits	**11,335**	**11,431**	**11,526**	**11,622**	**11,718**	**11,813**	**11,909**	**12,004**	**12,100**	**12,163**	**12,317**	**12,470**	**12,624**	**12,777**
Annual Running Costs:														
Energy	32,385	32,614	32,844	33,074	33,303	33,533	33,763	33,992	34,222	34,452	34,773	35,095	35,416	35,738
Chemical	21,591	21,773	21,955	22,137	22,319	22,501	22,683	22,865	23,047	23,168	23,460	23,753	24,045	24,337
Labor	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640
Total running costs	**512,616**	**513,027**	**513,439**	**513,851**	**514,262**	**514,674**	**515,086**	**515,497**	**515,909**	**516,259**	**516,873**	**517,487**	**518,101**	**518,715**
R&R Costs:														
Equipment Repair	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198
Total refurbishments	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**
Net Benefit/(cost)	**(53,338,478)**	**(638,795)**	**(639,111)**	**(639,427)**	**(639,743)**	**(640,059)**	**(640,375)**	**(640,691)**	**(641,007)**	**(641,294)**	**(641,755)**	**(642,215)**	**(642,676)**	**(643,136)**
Expressed in escalated dollars with sensitivity adjustments														
Capital Outlays														
Capital Costs	52,700,000													
Total capital outlays	**52,700,000**													
Benefits:														
Brushite Revenue	11,335	11,774	12,228	12,700	13,188	13,695	14,220	14,764	15,328	15,870	16,552	17,262	17,998	18,764
Total benefits	**11,335**	**11,774**	**12,228**	**12,700**	**13,188**	**13,695**	**14,220**	**14,764**	**15,328**	**15,870**	**16,552**	**17,262**	**17,998**	**18,764**
Annual Running Costs:														
Energy	32,385	33,593	34,844	36,140	37,483	38,874	40,314	41,806	43,351	44,952	46,732	48,579	50,495	52,482
Chemical	21,591	22,426	23,292	24,190	25,120	26,085	27,085	28,121	29,195	30,229	31,529	32,879	34,282	35,740
Labor	458,640	472,399	486,571	501,168	516,203	531,689	547,640	564,069	580,991	598,421	616,374	634,865	653,911	673,528
Total running costs	**512,616**	**528,418**	**544,708**	**561,499**	**578,807**	**596,648**	**615,039**	**633,997**	**653,538**	**673,601**	**694,635**	**716,324**	**738,689**	**761,751**
R&R Costs:														
Equipment Repair	137,198	141,314	145,553	149,920	154,418	159,050	163,822	168,736	173,798	179,012	184,383	189,914	195,612	201,480
Total refurbishments	**137,198**	**141,314**	**145,553**	**149,920**	**154,418**	**159,050**	**163,822**	**168,736**	**173,798**	**179,012**	**184,383**	**189,914**	**195,612**	**201,480**
Net escalated benefit/(cost)	**(53,338,478)**	**(657,958)**	**(678,032)**	**(698,719)**	**(720,036)**	**(742,004)**	**(764,641)**	**(787,969)**	**(812,009)**	**(836,744)**	**(862,465)**	**(888,976)**	**(916,302)**	**(944,467)**
Life cycle cost analysis														
PVs in 2021	(53,338,478)	(645,057)	(651,704)	(658,418)	(665,202)	(672,056)	(678,980)	(685,975)	(693,042)	(700,150)	(707,522)	(714,971)	(722,498)	(730,104)
NPV as of 2021	**(75,055,018)**													

<--- See Rows on Previous Page

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 2 - CalPrex (No Fermenter)

Year															
2035	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
12,931	13,084	13,238	13,391	13,545	13,698	13,861	14,025	14,188	14,351	14,514	14,677	14,840	15,004	15,167	15,330
12,931	**13,084**	**13,238**	**13,391**	**13,545**	**13,698**	**13,861**	**14,025**	**14,188**	**14,351**	**14,514**	**14,677**	**14,840**	**15,004**	**15,167**	**15,330**
36,059	36,381	36,702	37,024	37,346	37,667	38,081	38,494	38,907	39,321	39,734	40,148	40,561	40,974	41,388	41,801
24,630	24,922	25,215	25,507	25,799	26,092	26,403	26,714	27,024	27,335	27,646	27,957	28,268	28,578	28,889	29,200
458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640
519,329	**519,943**	**520,557**	**521,171**	**521,785**	**522,399**	**523,123**	**523,847**	**524,572**	**525,296**	**526,020**	**526,744**	**527,469**	**528,193**	**528,917**	**529,641**
137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198	137,198
137,198	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**	**137,198**
(643,597)	**(644,057)**	**(644,517)**	**(644,978)**	**(645,438)**	**(645,899)**	**(646,460)**	**(647,021)**	**(647,582)**	**(648,143)**	**(648,704)**	**(649,265)**	**(649,826)**	**(650,387)**	**(650,948)**	**(651,509)**
19,559	20,385	21,243	22,134	23,059	24,020	25,035	26,090	27,185	28,323	29,504	30,731	32,005	33,327	34,701	36,126
19,559	**20,385**	**21,243**	**22,134**	**23,059**	**24,020**	**25,035**	**26,090**	**27,185**	**28,323**	**29,504**	**30,731**	**32,005**	**33,327**	**34,701**	**36,126**
54,543	56,680	58,897	61,195	63,578	66,050	68,778	71,610	74,551	77,603	80,771	84,060	87,474	91,016	94,693	98,508
37,255	38,828	40,462	42,159	43,922	45,752	47,686	49,695	51,781	53,948	56,199	58,535	60,962	63,481	66,096	68,812
693,734	714,546	735,983	758,062	780,804	804,228	828,355	853,206	878,802	905,166	932,321	960,290	989,099	1,018,772	1,049,335	1,080,815
785,532	**810,055**	**835,341**	**861,416**	**888,304**	**916,030**	**944,819**	**974,511**	**1,005,134**	**1,036,717**	**1,069,291**	**1,102,886**	**1,137,534**	**1,173,269**	**1,210,124**	**1,248,134**
207,524	213,750	220,163	226,767	233,570	240,578	247,795	255,229	262,886	270,772	278,895	287,262	295,880	304,756	313,899	323,316
207,524	**213,750**	**220,163**	**226,767**	**233,570**	**240,578**	**247,795**	**255,229**	**262,886**	**270,772**	**278,895**	**287,262**	**295,880**	**304,756**	**313,899**	**323,316**
(973,498)	**(1,003,420)**	**(1,034,261)**	**(1,066,050)**	**(1,098,816)**	**(1,132,587)**	**(1,167,578)**	**(1,203,649)**	**(1,240,834)**	**(1,279,166)**	**(1,318,682)**	**(1,359,417)**	**(1,401,409)**	**(1,444,698)**	**(1,489,323)**	**(1,535,324)**
(737,789)	(745,556)	(753,403)	(761,333)	(769,346)	(777,443)	(785,747)	(794,139)	(802,620)	(811,191)	(819,853)	(828,607)	(837,453)	(846,394)	(855,429)	(864,560)

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 3 - AirPrex

From Summary Sheet:

Year of analysis	**2021**
Escalation rate	**3.00%**
Discount rate	**2.00%**

Risk adjustments (+/- percent):

Benefits	
Capital costs	
Running costs	

	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Expressed in 2021 dollars, unescalated														
Capital Outlays														
Capital Costs	48,900,000													
Total capital outlays	**48,900,000**													
Benefits:														
Savings; increased dewaterability	284,332	286,729	289,125	291,522	293,918	296,315	298,712	301,108	303,505	305,093	308,944	312,795	316,646	320,496
Total benefits	**284,332**	**286,729**	**289,125**	**291,522**	**293,918**	**296,315**	**298,712**	**301,108**	**303,505**	**305,093**	**308,944**	**312,795**	**316,646**	**320,496**
Annual Running Costs:														
Energy	67,742	68,313	68,884	69,455	70,026	70,597	71,168	71,739	72,310	72,689	73,606	74,524	75,441	76,359
Chemical	1,496,758	1,509,374	1,521,990	1,534,606	1,547,222	1,559,838	1,572,454	1,585,070	1,597,686	1,606,049	1,626,319	1,646,590	1,666,860	1,687,131
Labor	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640
Total running costs	**2,023,141**	**2,036,328**	**2,049,515**	**2,062,701**	**2,075,888**	**2,089,075**	**2,102,262**	**2,115,449**	**2,128,636**	**2,137,378**	**2,158,566**	**2,179,754**	**2,200,942**	**2,222,130**
R&R Costs:														
Equipment Repair	103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758
Total refurbishments	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**
Net Benefit/(cost)	**(50,742,567)**	**(1,853,357)**	**(1,864,147)**	**(1,874,938)**	**(1,885,728)**	**(1,896,518)**	**(1,907,309)**	**(1,918,099)**	**(1,928,889)**	**(1,936,042)**	**(1,953,380)**	**(1,970,717)**	**(1,988,054)**	**(2,005,391)**
Expressed in escalated dollars with sensitivity adjustments														
Capital Outlays														
Capital Costs	48,900,000													
Total capital outlays	**48,900,000**													
Benefits:														
Savings; increased dewaterability	284,332	295,330	306,733	318,554	330,808	343,510	356,677	370,325	384,471	398,078	415,195	432,981	451,461	470,660
Total benefits	**284,332**	**295,330**	**306,733**	**318,554**	**330,808**	**343,510**	**356,677**	**370,325**	**384,471**	**398,078**	**415,195**	**432,981**	**451,461**	**470,660**
Annual Running Costs:														
Energy	67,742	70,363	73,080	75,896	78,815	81,842	84,979	88,230	91,601	94,843	98,921	103,158	107,561	112,135
Chemical	1,496,758	1,554,655	1,614,679	1,676,905	1,741,412	1,808,280	1,877,592	1,949,436	2,023,900	2,095,530	2,185,637	2,279,266	2,376,544	2,477,609
Labor	458,640	472,399	486,571	501,168	516,203	531,689	547,640	564,069	580,991	598,421	616,374	634,865	653,911	673,528
Total running costs	**2,023,141**	**2,097,417**	**2,174,330**	**2,253,970**	**2,336,431**	**2,421,811**	**2,510,211**	**2,601,736**	**2,696,492**	**2,788,793**	**2,900,932**	**3,017,289**	**3,138,017**	**3,263,272**
R&R Costs:														
Equipment Repair	103,758	106,871	110,077	113,379	116,781	120,284	123,892	127,609	131,438	135,381	139,442	143,625	147,934	152,372
Total refurbishments	**103,758**	**106,871**	**110,077**	**113,379**	**116,781**	**120,284**	**123,892**	**127,609**	**131,438**	**135,381**	**139,442**	**143,625**	**147,934**	**152,372**
Net escalated benefit/(cost)	**(50,742,567)**	**(1,908,958)**	**(1,977,674)**	**(2,048,795)**	**(2,122,403)**	**(2,198,584)**	**(2,277,426)**	**(2,359,020)**	**(2,443,459)**	**(2,526,096)**	**(2,625,179)**	**(2,727,933)**	**(2,834,490)**	**(2,944,985)**
Life cycle cost analysis														
PVs in 2021	(50,742,567)	(1,871,527)	(1,900,878)	(1,930,625)	(1,960,773)	(1,991,326)	(2,022,289)	(2,053,669)	(2,085,469)	(2,113,724)	(2,153,561)	(2,193,976)	(2,234,976)	(2,276,569)
NPV as of 2021	**(120,205,918)**													

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 3 - AirPrex

<--- See Rows on Previous Page

Year															
2035	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
324,347	328,198	332,048	335,899	339,750	343,600	347,693	351,787	355,880	359,973	364,066	368,159	372,252	376,345	380,438	384,531
324,347	**328,198**	**332,048**	**335,899**	**339,750**	**343,600**	**347,693**	**351,787**	**355,880**	**359,973**	**364,066**	**368,159**	**372,252**	**376,345**	**380,438**	**384,531**
77,276	78,194	79,111	80,028	80,946	81,863	82,838	83,814	84,789	85,764	86,739	87,714	88,689	89,665	90,640	91,615
1,707,402	1,727,672	1,747,943	1,768,213	1,788,484	1,808,754	1,830,300	1,851,847	1,873,393	1,894,939	1,916,486	1,938,032	1,959,578	1,981,124	2,002,671	2,024,217
458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640
2,243,318	**2,264,506**	**2,285,694**	**2,306,881**	**2,328,069**	**2,349,257**	**2,371,779**	**2,394,300**	**2,416,822**	**2,439,343**	**2,461,865**	**2,484,386**	**2,506,908**	**2,529,429**	**2,551,951**	**2,574,472**
103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758	103,758
103,758	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**	**103,758**
(2,022,729)	**(2,040,066)**	**(2,057,403)**	**(2,074,740)**	**(2,092,078)**	**(2,109,415)**	**(2,127,843)**	**(2,146,272)**	**(2,164,700)**	**(2,183,129)**	**(2,201,557)**	**(2,219,985)**	**(2,238,414)**	**(2,256,842)**	**(2,275,271)**	**(2,293,699)**
490,604	511,321	532,840	555,190	578,401	602,505	627,973	654,427	681,902	710,437	740,071	770,843	802,795	835,971	870,414	906,172
490,604	**511,321**	**532,840**	**555,190**	**578,401**	**602,505**	**627,973**	**654,427**	**681,902**	**710,437**	**740,071**	**770,843**	**802,795**	**835,971**	**870,414**	**906,172**
116,887	121,823	126,950	132,275	137,805	143,548	149,615	155,918	162,464	169,263	176,323	183,654	191,267	199,171	207,377	215,897
2,582,598	2,691,657	2,804,935	2,922,587	3,044,774	3,171,661	3,305,726	3,444,980	3,589,615	3,739,827	3,895,821	4,057,808	4,226,009	4,400,650	4,581,966	4,770,200
693,734	714,546	735,983	758,062	780,804	804,228	828,355	853,206	878,802	905,166	932,321	960,290	989,099	1,018,772	1,049,335	1,080,815
3,393,219	**3,528,026**	**3,667,867**	**3,812,924**	**3,963,382**	**4,119,437**	**4,283,696**	**4,454,104**	**4,630,880**	**4,814,255**	**5,004,464**	**5,201,753**	**5,406,375**	**5,618,593**	**5,838,678**	**6,066,912**
156,943	161,652	166,501	171,496	176,641	181,940	187,398	193,020	198,811	204,775	210,919	217,246	223,764	230,477	237,391	244,513
156,943	**161,652**	**166,501**	**171,496**	**176,641**	**181,940**	**187,398**	**193,020**	**198,811**	**204,775**	**210,919**	**217,246**	**223,764**	**230,477**	**237,391**	**244,513**
(3,059,559)	**(3,178,356)**	**(3,301,528)**	**(3,429,230)**	**(3,561,622)**	**(3,698,872)**	**(3,843,122)**	**(3,992,698)**	**(4,147,789)**	**(4,308,593)**	**(4,475,312)**	**(4,648,157)**	**(4,827,344)**	**(5,013,099)**	**(5,205,655)**	**(5,405,252)**
(2,318,763)	(2,361,566)	(2,404,984)	(2,449,028)	(2,493,703)	(2,539,019)	(2,586,311)	(2,634,285)	(2,682,952)	(2,732,320)	(2,782,398)	(2,833,195)	(2,884,721)	(2,936,984)	(2,989,996)	(3,043,764)

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 4 - WASSTRIP + Ostara

From Summary Sheet:		**Risk adjustments (+/- percent):**	
Year of analysis	**2021**	**Benefits**	
Escalation rate	**3.00%**	**Capital costs**	
Discount rate	**2.00%**	**Running costs**	

	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Expressed in 2021 dollars, unescalated														
Capital Outlays														
Capital Costs	106,900,000													
Total capital outlays	**106,900,000**													
Benefits:														
Struvite Pellet + Biosolids Savings	313,056	315,705	318,354	321,003	323,651	326,300	328,949	331,598	334,247	336,407	339,531	343,787	348,043	352,298
Total benefits	**313,056**	**315,705**	**318,354**	**321,003**	**323,651**	**326,300**	**328,949**	**331,598**	**334,247**	**336,407**	**339,531**	**343,787**	**348,043**	**352,298**
Annual Running Costs:														
Energy	111,167	112,091	113,014	113,938	114,861	115,785	116,708	117,632	118,555	119,191	120,660	122,129	123,598	125,067
Chemical	513,949	518,281	522,613	526,945	531,277	535,609	539,941	544,273	548,605	551,477	558,437	565,397	572,358	579,318
Labor	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640
Total running costs	**1,083,756**	**1,089,011**	**1,094,267**	**1,099,522**	**1,104,778**	**1,110,033**	**1,115,289**	**1,120,544**	**1,125,800**	**1,129,308**	**1,137,737**	**1,146,167**	**1,154,596**	**1,163,025**
R&R Costs:														
Equipment Repair	92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000
Total refurbishments	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**
Net Benefit/(cost)	**(107,762,700)**	**(865,306)**	**(867,913)**	**(870,520)**	**(873,126)**	**(875,733)**	**(878,340)**	**(880,946)**	**(883,553)**	**(884,901)**	**(890,207)**	**(894,380)**	**(898,553)**	**(902,727)**
Expressed in escalated dollars with sensitivity adjustments														
Capital Outlays														
Capital Costs	106,900,000													
Total capital outlays	**106,900,000**													
Benefits:														
Struvite Pellet + Biosolids Savings	313,056	325,176	337,742	350,768	364,273	378,271	392,782	407,824	423,414	438,935	456,301	475,881	496,225	517,362
Total benefits	**313,056**	**325,176**	**337,742**	**350,768**	**364,273**	**378,271**	**392,782**	**407,824**	**423,414**	**438,935**	**456,301**	**475,881**	**496,225**	**517,362**
Annual Running Costs:														
Energy	111,167	115,453	119,897	124,503	129,277	134,226	139,355	144,672	150,182	155,518	162,157	169,056	176,222	183,665
Chemical	513,949	533,829	554,440	575,807	597,957	620,917	644,718	669,387	694,956	719,552	750,493	782,642	816,045	850,748
Labor	458,640	472,399	486,571	501,168	516,203	531,689	547,640	564,069	580,991	598,421	616,374	634,865	653,911	673,528
Total running costs	**1,083,756**	**1,121,682**	**1,160,908**	**1,201,478**	**1,243,437**	**1,286,833**	**1,331,713**	**1,378,128**	**1,426,129**	**1,473,491**	**1,529,024**	**1,586,563**	**1,646,178**	**1,707,942**
R&R Costs:														
Equipment Repair	92,000	94,760	97,603	100,531	103,547	106,653	109,853	113,148	116,543	120,039	123,640	127,350	131,170	135,105
Total refurbishments	**92,000**	**94,760**	**97,603**	**100,531**	**103,547**	**106,653**	**109,853**	**113,148**	**116,543**	**120,039**	**123,640**	**127,350**	**131,170**	**135,105**
Net escalated benefit/(cost)	**(107,762,700)**	**(891,266)**	**(920,769)**	**(951,240)**	**(982,712)**	**(1,015,215)**	**(1,048,784)**	**(1,083,453)**	**(1,119,259)**	**(1,154,595)**	**(1,196,363)**	**(1,238,031)**	**(1,281,122)**	**(1,325,685)**
Life cycle cost analysis														
PVs in 2021	(107,762,700)	(873,790)	(885,014)	(896,375)	(907,874)	(919,511)	(931,290)	(943,211)	(955,276)	(966,113)	(981,435)	(995,703)	(1,010,156)	(1,024,797)
NPV as of 2021	**(137,447,742)**													

East Bay Municipal Utility District
MWWTP Master Plan
Life Cycle Alternative Cost Analysis
Alternative 4 - WASSTRIP + Ostara

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Year															
2035	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
356,554	360,810	365,066	369,322	373,578	377,834	382,237	386,761	391,284	395,808	400,332	404,856	409,380	413,903	418,427	422,951
356,554	**360,810**	**365,066**	**369,322**	**373,578**	**377,834**	**382,237**	**386,761**	**391,284**	**395,808**	**400,332**	**404,856**	**409,380**	**413,903**	**418,427**	**422,951**
126,536	128,005	129,474	130,943	132,412	133,881	135,465	137,049	138,632	140,216	141,800	143,384	144,968	146,551	148,135	149,719
586,278	593,239	600,199	607,160	614,120	621,080	628,479	635,877	643,276	650,674	658,073	665,471	672,870	680,268	246,856	244,200
458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640	458,640
1,171,455	**1,179,884**	**1,188,313**	**1,196,743**	**1,205,172**	**1,213,601**	**1,222,584**	**1,231,566**	**1,240,548**	**1,249,530**	**1,258,513**	**1,267,495**	**1,276,477**	**1,285,459**	**853,631**	**852,559**
92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000	92,000
92,000	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**	**92,000**
(906,900)	**(911,074)**	**(915,247)**	**(919,420)**	**(923,594)**	**(927,767)**	**(932,347)**	**(936,805)**	**(941,264)**	**(945,722)**	**(950,181)**	**(954,639)**	**(959,097)**	**(963,556)**	**(527,204)**	**(521,608)**
539,321	562,131	585,824	610,433	635,992	662,535	690,362	719,488	749,741	781,162	813,792	847,678	882,864	919,399	957,331	996,712
539,321	**562,131**	**585,824**	**610,433**	**635,992**	**662,535**	**690,362**	**719,488**	**749,741**	**781,162**	**813,792**	**847,678**	**882,864**	**919,399**	**957,331**	**996,712**
191,397	199,428	207,768	216,429	225,423	234,761	244,664	254,951	265,634	276,729	288,250	300,214	312,636	325,533	338,922	352,822
886,799	924,247	963,144	1,003,542	1,045,498	1,089,068	1,135,103	1,182,919	1,232,583	1,284,162	1,337,726	1,393,349	1,451,105	1,511,072	564,788	575,473
693,734	714,546	735,983	758,062	780,804	804,228	828,355	853,206	878,802	905,166	932,321	960,290	989,099	1,018,772	1,049,335	1,080,815
1,771,930	**1,838,221**	**1,906,894**	**1,978,033**	**2,051,725**	**2,128,057**	**2,208,122**	**2,291,075**	**2,377,018**	**2,466,056**	**2,558,297**	**2,653,853**	**2,752,839**	**2,855,377**	**1,953,046**	**2,009,111**
139,158	143,333	147,633	152,062	156,624	161,323	166,162	171,147	176,282	181,570	187,017	192,628	198,406	204,359	210,489	216,804
139,158	**143,333**	**147,633**	**152,062**	**156,624**	**161,323**	**166,162**	**171,147**	**176,282**	**181,570**	**187,017**	**192,628**	**198,406**	**204,359**	**210,489**	**216,804**
(1,371,768)	**(1,419,423)**	**(1,468,703)**	**(1,519,662)**	**(1,572,356)**	**(1,626,845)**	**(1,683,922)**	**(1,742,734)**	**(1,803,559)**	**(1,866,465)**	**(1,931,522)**	**(1,998,802)**	**(2,068,381)**	**(2,140,336)**	**(1,206,204)**	**(1,229,203)**
(1,039,629)	(1,054,652)	(1,069,870)	(1,085,286)	(1,100,900)	(1,116,717)	(1,133,231)	(1,149,814)	(1,166,612)	(1,183,630)	(1,200,868)	(1,218,332)	(1,236,022)	(1,253,942)	(692,813)	(692,179)

APPENDIX E - NON-ECONOMIC EVALUATION

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E.1 - SIDESTREAM NITROGEN NON-ECONOMIC EVALUATION CRITERIA

Alternative Scoring for Non-Economic Evaluation Criteria

				Unweighted Scores [(a)]					
Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Alt. N1 Conventional	Alt. N2 and N3 DEMON and ANITAMox	Alt. N4 AnammoPAQ	Alt. N5 ZeenNAMMOX	Alt. N6 Ammonia Recovery LAS	Alt. N7 Ammonia Recovery GAS
Technical									
Efficient Land Use and Site Layout	Does it minimize the footprint required per mgd of influent? Does it leave space for future improvements, expansion, or upgrades? How well do future facilities integrate with existing facilities?	Acreage of treatment facilities (Qualitative: low, medium, high) Synergies in facility placement and logical flow (Qualitative: high, medium, low)	Score and Justification	2 Higher land requirement compared with Anammox and ammonia recovery	4 Smaller footprint compared to conventional treatment	4 Smaller footprint compared to conventional treatment	5 Smallest footprint of all N reduction alternatives	4 Smaller footprint compared to conventional biological treatment	4 Smaller footprint compared to conventional biological treatment
Construct-ability	How easily can the future facilities be constructed? How easy will it be to continue operating the existing processes during construction?	Simplicity of construction phasing (Qualitative: simple, moderate, or complex)	Score and Justification	5 Can be constructed on open parcel of land	5 Could be constructed on open parcel of land	5 Could be constructed on open parcel of land	5 Could be constructed on open parcel of land	5 Could be constructed on open parcel of land	5 Could be constructed on open parcel of land

Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores [a]					
				Alt. N1 Conventional	Alt. N2 and N3 DEMON and ANITAMox	Alt. N4 AnammoPAQ	Alt. N5 ZeenNAMMOX	Alt. N6 Ammonia Recovery LAS	Alt. N7 Ammonia Recovery GAS
Technology Maturity/ Reliability	How many existing WWTPs have the proposed technology/approach? How large are they and how long have they been operating successfully? Will the treatment process be reliable and robust with respect to meeting current and future regulations under a variety of flow/load conditions? Does this alternative have flexibility to handle high peaking factors/wet weather flows?	Operating history (Qualitative: significant, moderate, minimal) based on: - Number of installations - Size of installations - Years of successful, reliable operation meeting similar regulations Effluent quality consistently meets potential effluent limits under variable flow/load conditions (Qualitative: high, medium, low consistency)	**Score and Justification**	4	3	3	2	3	3
				Established technology; pilot testing recommended to confirm design criteria due to variability of waste stream characteristics with R2	Established technology for sidestream treatment; pilot testing recommended to confirm design criteria and to provide O&M experience	Established technology for sidestream treatment; pilot testing recommended to confirm design criteria and to provide O&M experience	No installations in the US - emerging for sidestream treatment	Individual systems are established; relatively new with municipal operations.	Individual systems are established; relatively new with municipal operations.

Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores (a)					
				Alt. N1 Conventional	Alt. N2 and N3 DEMON and ANITAMox	Alt. N4 AnammoPAQ	Alt. N5 ZeenNAMMOX	Alt. N6 Ammonia Recovery LAS	Alt. N7 Ammonia Recovery GAS
Flexibility/ Ease of O&M	Will O&M labor hours be minimized? Is staff already familiar with the process or will it require substantial staff training? Is the technology serviceable in the United States, or does it require parts from outside the country? Will reliance on third parties be minimized (e.g., for special maintenance, management /marketing the product(s), etc.)? Will a third party manage or market the product?	O&M effort (Qualitative: low, medium, high) based on: - O&M labor hours - O&M training - Monitoring/ instrumentation - Wait time for parts/support - Specialized staff required and reliance on third parties - Complexity/ difficulty of O&M activities	**Score and Justification**	4	4	3	3	4	2
				Conventional system that is flexible and O&M comparable to Alt N2 and N3	Based on other recent installations, systems have been optimized to reduce potential for upsets and O&M requirements.	Less US based installations so more challenging to reseed reactors, if/when needed	Maintenance of membrane aeration system unknown.	Higher maintenance associated with chemical feed systems (i.e., sulfuric acid).	Higher maintenance associated with chemical feed systems (i.e., sulfuric acid). More unit processes associated with pellet production which increases complexity of O&M and maintenance requirements

Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores (a)					
				Alt. N1 Conventional	Alt. N2 and N3 DEMON and ANITAMox	Alt. N4 AnammoPAQ	Alt. N5 ZeenNAMMOX	Alt. N6 Ammonia Recovery LAS	Alt. N7 Ammonia Recovery GAS
Resiliency	Does it maximize the ability to protect life safety and convey wastewater flows to SF Bay during the following events? - Seismic event (It is assumed new construction will have greater ability.) - Storm surge/flood event Does it maximize the ability to maintain typical function under latest projected changes in sea/tide levels? Does it enhance the ability to meet regulations and safety goals by providing resiliency?	Relative change in cost to protect life safety and convey wastewater flows to SF Bay (Qualitative: decrease, minimal change, increase) Relative change in cost to maintain typical function (Qualitative: decrease, minimal change, increase)	Score and Justification	3	3	3	3	3	3
				Non-differentiator	Non-differentiator	Non-differentiator	Non-differentiator	Non-differentiator	Non-differentiator
Environmental									
Flexibility to Meet Current/ Future Regulations	Can it reliably meet current regulations? Does the alternative have flexibility to be modified to meet increasingly stringent regulations (including water quality, biosolids, and air regulations)?	Flexibility to easily implement alternate configurations/ future technologies over time (Qualitative: high, medium, low)	Score and Justification	4	4	4	4	3	3
				Can provide adequate TIN load reduction; compatible with future regulations	Can provide adequate TIN load reduction; compatible with future regulations	Can provide adequate TIN load reduction; compatible with future regulations	Can provide adequate TIN load reduction; compatible with future regulations	Provides TIN load reduction; produces residual waste stream that needs to be marketed and hauled offsite	Provides TIN load reduction; produces residual waste stream that needs to be marketed and hauled offsite

Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores (a)					
				Alt. N1 Conventional	Alt. N2 and N3 DEMON and ANITAMox	Alt. N4 AnammoPAQ	Alt. N5 ZeenNAMMOX	Alt. N6 Ammonia Recovery LAS	Alt. N7 Ammonia Recovery GAS
Maximize Recoverable Resources	Does it maximize utilization of the R2 Program? Does it support beneficial use of biosolids? Does it support nutrient recovery? Does it support water reuse?	Change in R2 Program (Qualitative: increase, minimal change, decrease) Beneficial use of biosolids (Qualitative: high, medium, low) Utilization of recoverable resources (treatment byproducts) (Qualitative: high, medium, low)	**Score and Justification**	3	3	3	3	5	5
				Potential biogas increase would not be significant. The end use product may not open new markets. THP causes an increase in ammonia and TN to liquid stream, which requires additional treatment. If AMR is used on side stream, more ammonia can be recovered and sold as product.	Not realizing any additional benefits, not directly controlling the direct benefits.	Increased energy (natural gas) usage, but opens additional end use markets.	Unless using lystemize configuration, does not improve biogas production. The resulting end product is meant for agricultural markets. Less liquid returned as centrate so less ammonia to recover in AMR side stream treatment.	Supports nutrient recovery and can be scaled up or down based on trucked waste deliveries	Supports nutrient recovery and can be scaled up or down based on trucked waste deliveries

Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores [(a)]					
				Alt. N1 Conventional	Alt. N2 and N3 DEMON and ANITAMox	Alt. N4 AnammoPAQ	Alt. N5 ZeenNAMMOX	Alt. N6 Ammonia Recovery LAS	Alt. N7 Ammonia Recovery GAS
Minimize Treatment Process GHG Emissions	Will it result in a change in GHG emissions?	GHG emissions (Qualitative: low, medium, high)	Score and Justification	3	5	5	5	5	5
				Higher energy demand than other alternatives; no difference in NOX emissions assumed	Lower energy demand	Lower energy demand	Lower energy demand	Lower energy demand	Lower energy demand
Minimize Chemical Use	Does it minimize chemical addition for treatment?	Chemical usage (Qualitative: low, medium, high)	Score and Justification	4	5	5	5	1	1
				Higher chemical use for alkalinity addition compared to anammox technologies	Minimal chemical addition	Minimal chemical addition	Minimal chemical addition	Chemical intensive process	Chemical intensive process

Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores [(a)]					
				Alt. N1 Conventional	Alt. N2 and N3 DEMON and ANITAMox	Alt. N4 AnammoPAQ	Alt. N5 ZeenNAMMOX	Alt. N6 Ammonia Recovery LAS	Alt. N7 Ammonia Recovery GAS
Social									
Community Acceptability	Will the alternative introduce a source of odors, noise, and/or other emissions? Will the alternative result in adverse visual impacts? Will the alternative increase or decrease local truck traffic? Will the alternative provide a community benefit (e.g., product the community can use)?	Change in negative community impacts (Qualitative: decrease, minimal change, increase) based on: - Noise - Odor emissions - Number of structures negatively impacting views or visual aesthetics - Truck traffic Change in positive community impacts (Qualitative: decrease, minimal change, increase) based on: - Community benefits	Score and Justification	3 Non-differentiator	3 Non-differentiator	3 Non-differentiator	3 Non-differentiator	3 Non-differentiator	3 Non-differentiator
Facility Safety	Does the alternative promote staff safety	Change in the safety of the facilities/ work environment (Qualitative: increase, minimal change, or decrease)	Score and Justification	4 Similar safety for all biological systems	4 Similar safety for all biological systems	4 Similar safety for all biological systems	4 Similar safety for all biological systems	2 Chemical storage and use impacts safety	2 Chemical storage and use impacts safety

Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores [a]					
				Alt. N1 Conventional	Alt. N2 and N3 DEMON and ANITAMox	Alt. N4 AnammoPAQ	Alt. N5 ZeenNAMMOX	Alt. N6 Ammonia Recovery LAS	Alt. N7 Ammonia Recovery GAS
Facility and Public Engagement	Does the MWWTP promote staff and public engagement (e.g., functional and aesthetic site layout, adequate space for staff collaboration and public visitors)?	Change in factors/ amenities promoting staff and public engagement (Qualitative: increase, minimal change, decrease) Change in potential for highly functional and aesthetic site layout/facilities (Qualitative: increase, minimal change, decrease)	Score and Justification	3 Non-differentiator	3 Non-differentiator	3 Non-differentiator	3 Non-differentiator	3 Non-differentiator	3 Non-differentiator
		Total							
		Total Unweighted Score		**42**	**46**	**45**	**45**	**41**	**39**

Notes:

a) Score assigned on scale of 1 - 5.

1 = alternative is **LEAST** aligned with the criteria

5 = alternative is **MOST** aligned with the criteria

E.2 - SIDESTREAM PHOSPHORUS NON-ECONOMIC EVALUATION CRITERIA

Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores (a)			
				Alt. P1 Chemical Addition	Alt. P2 CalPrex	Alt. P3 AirPrex	Alt. P4 Ostara
Technical							
Efficient Land Use and Site Layout	Does it minimize the footprint required per mgd of influent? Does it leave space for future improvements, expansion, or upgrades? How well do future facilities integrate with existing facilities?	Acreage of treatment facilities (Qualitative: low, medium, high) Synergies in facility placement and logical flow (Qualitative: high, medium, low)	Score and Justification	5	3	4	3
				Low land requirements	Larger footprint	Smaller footprint compared with Alt P2 and P4	Larger footprint
Construct-ability	How easily can the future facilities be constructed? How easy will it be to continue operating the existing processes during construction?	Simplicity of construction phasing (Qualitative: simple, moderate, or complex)	Score and Justification	5	3	3	3
				Constructed where existing headworks station exists	Constructed near digesters - more congested or difficult construction	Constructed near digesters - more congested or difficult construction	Constructed near digesters - more congested or difficult construction

Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores (a)			
				Alt. P1 Chemical Addition	Alt. P2 CalPrex	Alt. P3 AirPrex	Alt. P4 Ostara
Technology Maturity/ Reliability	How many existing WWTPs have the proposed technology/approach? How large are they and how long have they been operating successfully? Will the treatment process be reliable and robust with respect to meeting current and future regulations under a variety of flow/load conditions? Does this alternative have flexibility to handle high peaking factors/wet weather flows?	Operating history (Qualitative: significant, moderate, minimal) based on: - Number of installations - Size of installations - Years of successful, reliable operation meeting similar regulations Effluent quality consistently meets potential effluent limits under variable flow/load conditions (Qualitative: high, medium, low consistency)	**Score and Justification**	5	3	4	4
				Established technology	Established technology; limited number of local installations	Established technology; limited local installations	Established technology; limited local installations

Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores [a]			
				Alt. P1 Chemical Addition	Alt. P2 CalPrex	Alt. P3 AirPrex	Alt. P4 Ostara
Flexibility/ Ease of O&M	Will O&M labor hours be minimized? Is staff already familiar with the process or will it require substantial staff training? Is the technology serviceable in the United States, or does it require parts from outside the country? Will reliance on third parties be minimized (e.g., for special maintenance, management /marketing the product(s), etc.)? Will a third party manage or market the product?	O&M effort (Qualitative: low, medium, high) based on: - O&M labor hours - O&M training - Monitoring/ instrumentation - Wait time for parts/support - Specialized staff required and reliance on third parties - Complexity/ difficulty of O&M activities	**Score and Justification**	4	2	3	2
				Flexible and can be easily adjusted based on varying flow and load	More complex operation; new unit processes	Relatively simple operation but new system to operate	More complex operation; new unit processes

Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores [a]			
				Alt. P1 Chemical Addition	Alt. P2 CalPrex	Alt. P3 AirPrex	Alt. P4 Ostara
Resiliency	Does it maximize the ability to protect life safety and convey wastewater flows to SF Bay during the following events? - Seismic event (It is assumed new construction will have greater ability.) - Storm surge/flood event Does it maximize the ability to maintain typical function under latest projected changes in sea/tide levels? Does it enhance the ability to meet regulations and safety goals by providing resiliency?	Relative change in cost to protect life safety and convey wastewater flows to SF Bay (Qualitative: decrease, minimal change, increase) Relative change in cost to maintain typical function (Qualitative: decrease, minimal change, increase)	Score and Justification	3	3	3	3
				Non-differentiator	Non-differentiator	Non-differentiator	Non-differentiator
Environmental							
Flexibility to Meet Current/ Future Regulations	Can it reliably meet current regulations? Does the alternative have flexibility to be modified to meet increasingly stringent regulations (including water quality, biosolids, and air regulations)?	Flexibility to easily implement alternate configurations/ future technologies over time (Qualitative: high, medium, low)	Score and Justification	4	4	4	4
				Reduces TP in discharge if future regulations limit TP	Reduces TP in discharge if future regulations limit TP	Reduces TP in discharge if future regulations limit TP	Reduces TP and will meet future limits, if applicable.

Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores (a)			
				Alt. P1 Chemical Addition	Alt. P2 CalPrex	Alt. P3 AirPrex	Alt. P4 Ostara
Maximize Recoverable Resources	Does it maximize utilization of the R2 Program? Does it support beneficial use of biosolids? Does it support nutrient recovery? Does it support water reuse?	Change in R2 Program (Qualitative: increase, minimal change, decrease) Beneficial use of biosolids (Qualitative: high, medium, low) Utilization of recoverable resources (treatment byproducts) (Qualitative: high, medium, low)	**Score and Justification**	1	5	5	5
				No product produced	Produces product that can be used as fertilizer	Produces product that can be used as fertilizer	Produces product that can be used as fertilizer

Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores [a]			
				Alt. P1	Alt. P2	Alt. P3	Alt. P4
				Chemical Addition	CalPrex	AirPrex	Ostara
Minimize Treatment Process GHG Emissions	Will it result in a change in GHG emissions?	GHG emissions (Qualitative: low, medium, high)	Score and Justification	4	3	3	3
				Potential to reduce energy by reducing load to HPOAS system	Non-differentiator; potential for fertilizer offset credits, increased energy use	Non-differentiator; potential for fertilizer offset credits, increased energy use	Non-differentiator; potential for fertilizer offset credits, increased energy use
a. Minimize energy purchases (electricity and natural gas)	Will it minimize flaring of biogas? Will it increase the biogas/energy generation potential? Is this Master Plan alternative energy efficient?	Energy purchase (Quantitative: metric tons carbon dioxide equivalent per year based on kWh or Btu purchased per year)	Justification				
b. Minimize nitrous oxide (N2O) emissions (under consider-ation)	Will it decrease the N2O at the plant and the receiving water (San Francisco Bay)?	GHGs from N2O emissions both at the MWWTP and at San Francisco Bay (Quantitative: metric tons carbon dioxide equivalent per year based on N2O emissions)	Justification	N/A	N/A	N/A	N/A
Minimize Chemical Use	Does it minimize chemical addition for treatment?	Chemical usage (Qualitative: low, medium, high)	Score and Justification	1	3	3	3
				Minimal chemical addition	Chemical addition	Chemical Addition	Chemical Addition

Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores [(a)]			
				Alt. P1 Chemical Addition	Alt. P2 CalPrex	Alt. P3 AirPrex	Alt. P4 Ostara
Social							
Community Acceptability	Will the alternative introduce a source of odors, noise, and/or other emissions? Will the alternative result in adverse visual impacts? Will the alternative increase or decrease local truck traffic? Will the alternative provide a community benefit (e.g., product the community can use)?	Change in negative community impacts (Qualitative: decrease, minimal change, increase) based on: - Noise - Odor emissions - Number of structures negatively impacting views or visual aesthetics - Truck traffic Change in positive community impacts (Qualitative: decrease, minimal change, increase) based on: - Community benefits	Score and Justification	3	3	3	3
				Increased truck traffic due to additional chemical use	Increased truck traffic for product hauling	Increased truck traffic for product hauling	Increased truck traffic for product hauling
Facility Safety	Does the alternative promote staff safety	Change in the safety of the facilities/ work environment (Qualitative: increase, minimal change, or decrease)	Score and Justification	2	3	3	3
				Increases chemical storage and use at the MWWTP	No change	No change	No change

Alternative Scoring for Non-Economic Evaluation Criteria

Criteria	Considerations	Metrics (Qualitative/ Quantitative)		Unweighted Scores [(a)]			
				Alt. P1 Chemical Addition	Alt. P2 CalPrex	Alt. P3 AirPrex	Alt. P4 Ostara
Facility and Public Engagement	Does the MWWTP promote staff and public engagement (e.g., functional and aesthetic site layout, adequate space for staff collaboration and public visitors)?	Change in factors/ amenities promoting staff and public engagement (Qualitative: increase, minimal change, decrease) Change in potential for highly functional and aesthetic site layout/facilities (Qualitative: increase, minimal change, decrease)	**Score and Justification**	3 Non-differentiator	3 Non-differentiator	3 Non-differentiator	3 Non-differentiator
		Total					
		Total Unweighted Score		**40**	**38**	**41**	**39**

Notes:
a) Score assigned on scale of 1 - 5.
1 = alternative is **LEAST** aligned with the criteria
5 = alternative is **MOST** aligned with the criteria

APPENDIX U – Nitrification in High Purity Oxygen Activated Sludge Analysis

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Background and Approach

Retrofit of the existing high-purity oxygen activated sludge (HPOAS) reactors was evaluated to determine whether existing tanks could be used to achieve total inorganic nitrogen (TIN) removal.

Existing Mainstream High Purity Oxygen Activated Sludge for BOD Removal

Screened and gritted influent wastewater receives primary treatment using primary sedimentation tanks for TSS and particulate BOD removal. Primary effluent, and return activated sludge, is sent to secondary treatment reactors. The EBMUD secondary treatment reactors are a high purity oxygen activated sludge (HPOAS) process (Figure U-1). Oxygen with approximately 95% purity is injected into the headspace of covered tanks. The headspace gas comes into contact with the mixed using surface aerators and draft tubes. This transfers oxygen into the wastewater for utilization by microorganisms for BOD removal. Carbon dioxide is generated by microorganisms and accumulates in later stages of the HPOAS process. There are four stages in EBMUD's HPOAS process: one anaerobic zone and three aerated zones. Off-gas is released only at the end of the fourth stage.

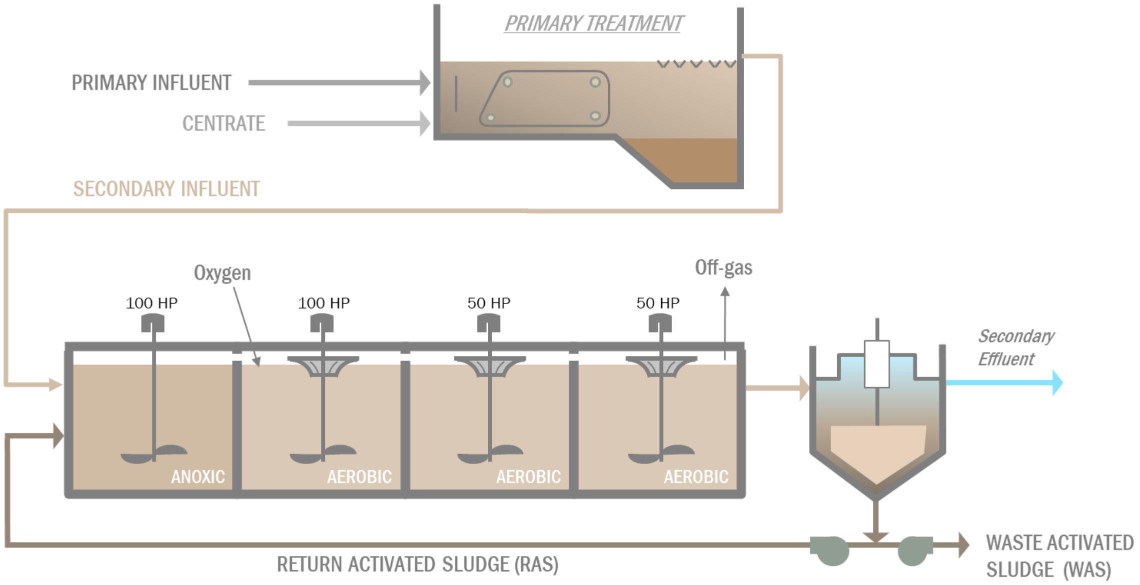

Figure U-1. Process Flow Diagram for Existing EBMUD HPOAS treatment components

As illustrated in Figure U-1, BOD removal is completed with the following existing assets:

- Eight total HPOAS reactors
    - Firm Capacity = 7 HPOAS Reactors in service
    - 4 Stages per Reactor
        - First Stage = Anaerobic Zone (PE + RAS introduction) with 100 HP Mixer
        - Second Stage = Aerobic Zone (HPO introduction) with 100 HP Aerator
        - Third and Fourth Stage = Aerobic Zones with 50 HP Aerators
- Two cryogenic towers
    - 125 tons/d oxygen production capacity per tower
    - Four 1,250 HP air compressors total
- Four total RAS pumps
    - Firm Capacity = 60 mgd (3 pumps)
- 12 total secondary clarifiers
    - Firm Capacity = 11 clarifiers in service
- 16 total primary clarifiers
    - 9 clarifiers in service for ADW flow
    - 64% TSS removal for ADW flow

Typical average dry weather (ADW) operation has the following operational characteristics for BOD removal:

- SRT = 1.7-day,
- Annual 90th Percentile sludge volume index (SVI) = 133 mL/g
- Reactors in Service = 6 or 7 HPOAS Reactors

Nitrification does not typically occur in the existing HPOAS system. The HPOAS reactors MLSS concentration has ranged from about 1,250 to 3,350 mg/L (data from 2010 through 2018) for a range of operation with 4 to 8 tanks in service and SRT of 0.9 to 2.8 days. These historical values represent past performance in the 1st to 99th percentile, respectively.

Existing Mainstream High Purity Activated Sludge for Inorganic Nitrogen Removal

The feasibility of operating the existing system in a nitrifying mode was evaluated. Nitrification requires a higher SRT to support the growth of ammonia and nitrite oxidizing bacteria, and denitrification is required to achieve TIN removal. In nitrification mode, the RAS returns nitrate to the first stage for utilization with influent organic carbon and denitrification. Preliminary BioWin simulations were conducted to determine the minimum SRT to support nitrification (further discussed below). The preliminary simulations also indicate chemically enhanced primary treatment (CEPT) would be required to keep the MLSS to a manageable concentration to avoid overloading the secondary clarifiers.

Several considerations related to nitrification in a HPOAS system are listed below.

- Nitrification consumes alkalinity: The accumulation of carbon dioxide in reactor headspace causes low pH conditions and corrosion in HPOAS systems. The reduction in alkalinity that results from nitrification may further depress the pH.
- Nitrifier inhibition at low pH: Low pH can inhibit nitrifiers, hindering or preventing nitrification at target SRT values. Therefore, additional supplemental alkalinity is required to increase the bulk liquid pH and support adequate nitrification. Alternatively, a longer SRT may be required to support nitrification.
- HPOAS reactors can trap foaming organisms: A higher SRT condition can trap foaming organisms in the HPOAS reactors. Foaming organisms could accumulate in the HPOAS reactors and result in settling issues and accumulation in secondary clarifiers.

The majority of HPOAS systems in the United States are operated in BOD removal only and do not intentionally nitrify. One example of an existing HPOAS reactor used for nitrification is the Rochester Water Reclamation Plant (Rochester, Minnesota, USA). However, this example is operated as a nitrification-only second stage in a two-stage system.

HPOAS Nitrification Alternatives

Four alternatives were considered to achieve nitrification and TIN removal. These are described in detail below.

HPOAS Nitrification Alternative 1: Add Alkalinity

Alternative 1 requires the following upgrades, as shown in Figure U-2:

- Add CEPT (assume 30-40 mg/L $FeCl_3$ and 1 mg/L polymer dose) to reduce organic and solids loading to the HPOAS reactors and manage MLSS concentration
- Add Stage 2 Surface Aerator Upgrade (assuming 3.2 lb O_2/hp-hr standard aeration efficiency [SAE]) to meet increased oxygen demands
- Add quick lime to Stage 2 as an alkalinity source to prevent pH depression
- Upgrade RAS pumps for 90 mgd return flowrate to allow secondary clarifiers to operate at higher MLSS concentration

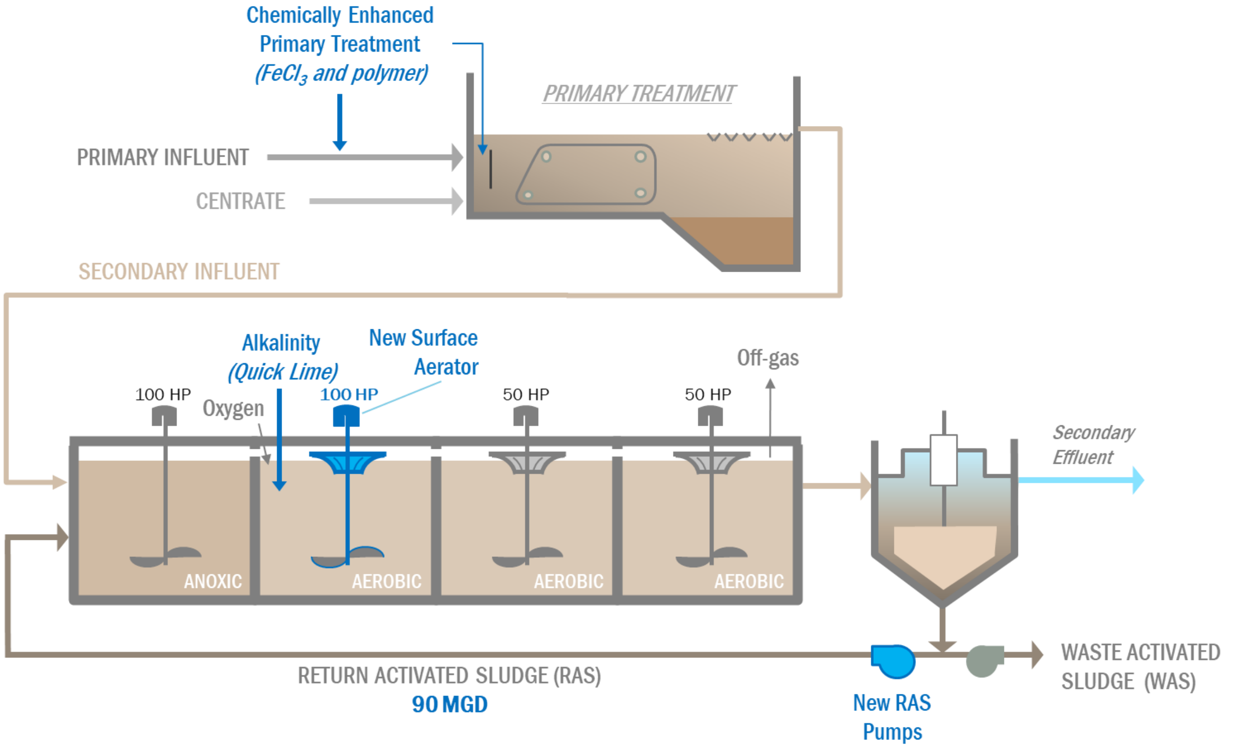

Figure U-2. Process flow diagram for EBMUD HPOAS nitrification alternative 1

HPOAS Nitrification Alternative 2: Add Diffusers

Alternative 2 requires the following upgrades, as shown in Figure U-3:

- Add CEPT (assume 30-40 mg/L $FeCl_3$ and 1 mg/L polymer dose) to reduce organic and solids loading to the HPOAS reactors and manage MLSS concentration
- Remove existing Stage 2, 3, and 4 surface aerators and ventilate aerated reactor zones to mitigate pH depression caused by CO_2 accumulation in reactor headspace and off-gas
- Add diffusers and blowers for Stage 2, 3, and 4 to provide oxygen in lieu of surface aeration
- Add quick lime to Stage 2 as an alkalinity source to prevent pH depression
- Upgrade RAS pumps for 90 mgd return flowrate to allow secondary clarifiers to operate at higher MLSS concentration

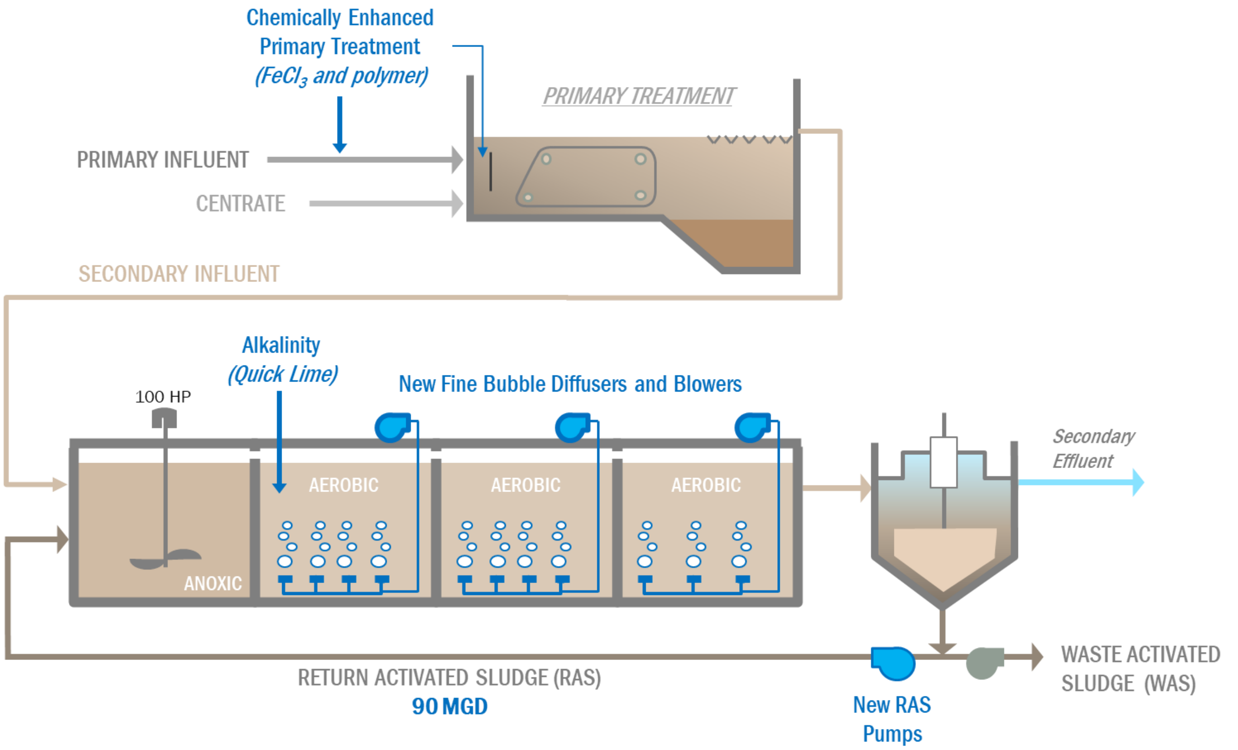

Figure U-3. Process flow diagram for EBMUD HPOAS nitrification Alternative 2

HPOAS Nitrification Alternative 3A: Fourth Stage Ventilation

Alternative 3A requires the following upgrades, as shown in Figure U-4:

- Add CEPT (assume 30-40 mg/L $FeCl_3$ and 1 mg/L polymer dose) to reduce organic and solids loading to the HPOAS reactors and manage MLSS concentration
- Add Stage 2 and Stage 3 Surface Aerator Upgrade (assuming 3.2 lb O_2/hp-hr SAE) to meet increased oxygen demands
- Add quick lime to Stage 2 as an alkalinity source to prevent pH depression
- Upgrade RAS pumps for 90 mgd return flowrate to allow secondary clarifiers to operate at higher MLSS concentration
- Add off-gas ventilation to Stage 3 to mitigate pH depression caused by CO_2 accumulation in reactor headspace and off-gas
- Add surface-mounted blower, upgraded surface aerator, and ventilation stack to Stage 4 to mitigate pH depression caused by CO_2 accumulation in reactor headspace and off-gas while providing additional aeration in final reactor stage

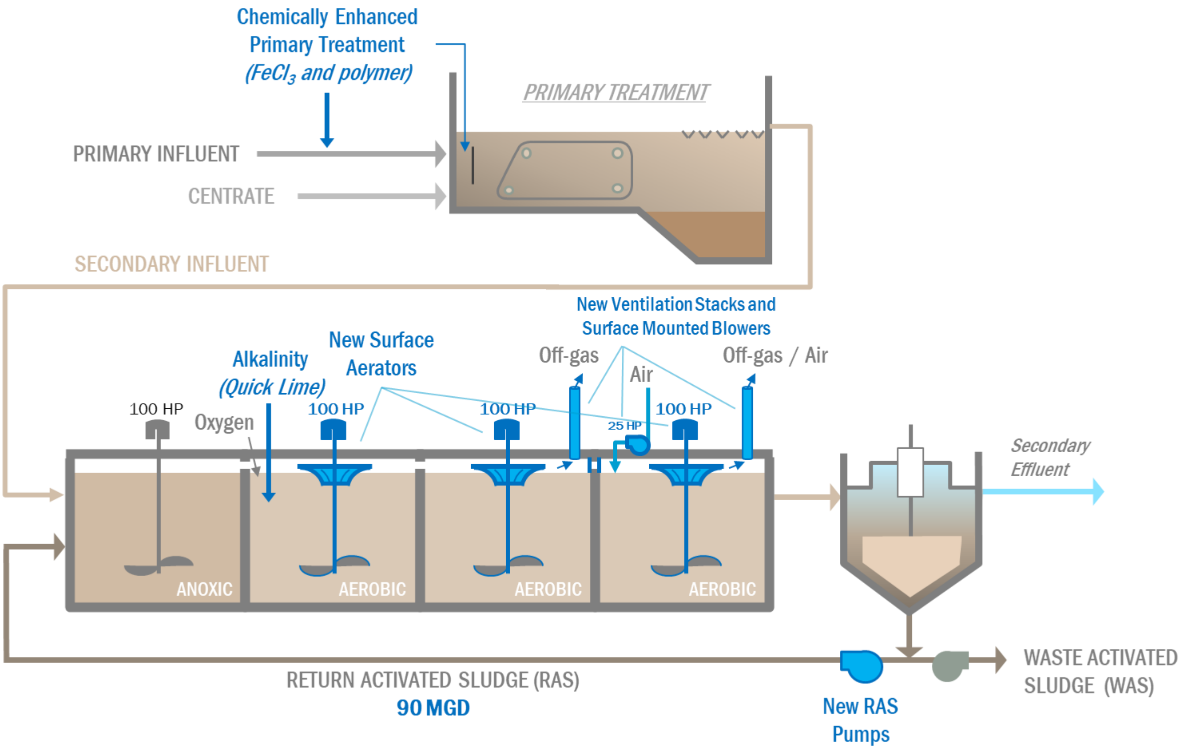

Figure U-4. Process flow diagram for EBMUD HPOAS nitrification Alternative 3A

HPOAS Nitrification Alternative 3B: Fourth Stage Ventilation with INVENT System

Alternative 3A and 3B requires the following upgrades, as shown in Figure U-5:

- Add CEPT (assume 30-40 mg/L $FeCl_3$ and 1 mg/L polymer dose) to reduce organic and solids loading to the HPOAS reactors and manage MLSS concentration
- Add INVENT mixer to Stage 1 for anoxic mixing and denitrification
- Add (2) INVENT mixers/aerators to Stages 2 and 3. Oxygen is added below INVENT mixers/aerators:
    - High purity oxygen is added in Stage 2 to satisfy high oxygen uptake rates in the first aerobic zone
    - Stage 2 head space gas is added in Stage 3 via a blower that compresses headspace gas from Stage 2, which is projected to have oxygen purity above 21%
- Add quick lime to Stage 2 as an alkalinity source to prevent pH depression
- Upgrade RAS pumps for 90 mgd return flowrate to allow secondary clarifiers to operate at higher MLSS concentration
- Add INVENT surface aerator for Stage 4 aeration and ventilation to mitigate pH depression caused by CO_2 accumulation in reactor headspace and off-gas while providing additional aeration in final reactor stage

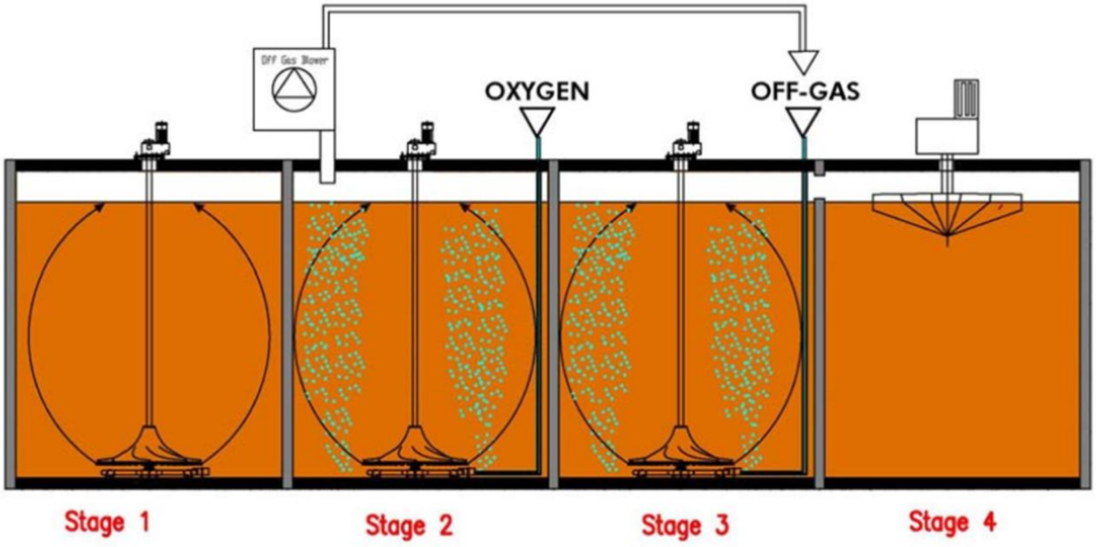

Figure U-5. HPOAS nitrification Alternative 3B: INVENT approach, as provided by INVENT

Mainstream HPOAS Simulation for Alternatives Evaluation

The mainstream HPOAS nitrification alternatives were evaluated using BioWin simulations. Simulations were built from an existing EBMUD MWWTP BioWin model, which was validated using 2017-2018 historical data (C60 Plant-Wide Process Model Report). The MWWTP BioWin reactor aeration parameters were adjusted to simulate pH suppression due to carbon dioxide accumulation in the reactor headspace. BioWin simulations were completed with the following criteria:

- **Maximum MLSS = 4,500 mg/L.** The maximum MLSS criteria was set for adequate settleability. The 4,500 mg/L MLSS criteria was demonstrated as adequate through comparison with the secondary clarifier findings by Hazen and Sawyer. Hazen and Sawyer modeled clarifier performance for an SVI of 150 mL/g. Their results suggested a 4,500 mg/L MLSS will settle adequately for up to 77 mgd with 11 clarifiers in service.
- **Minimum SRT.** The minimum SRT was evaluated based on nitrification results from 0.1 to 1.0-day increment simulations, as shown in Figure U-6. The covered, non-vented alternative (Alternative 1: Add Alkalinity) requires the highest SRT to overcome low pH conditions.
    - Alternative 1 SRT = 6 days
    - Alternative 2 SRT = 5 days
    - Alternative 3A/3B SRT = 5 days
- **Minimum DO Concentration = 2 mg/L.** This was assumed as a criterion for all aerated stages during the oxygen production and transfer capacity evaluation using an Excel-based High Purity Oxygen model. The model was used to evaluate the required tons/day of oxygen

injection to Stage 2 headspace to satisfy minimum DO concentration requirements and also maintain a Stage 4 vent purity of 40% oxygen. The 2 mg/L DO concentration was used as a setpoint in BioWin models as well, which maximizes TIN removal in simulations due to minimizing the RAS oxygen returned to Stage 1.

- **RAS flowrate = 90 mgd.** This was set assuming RAS pumps are upgraded for sustained 90 mgd RAS flowrate.
- **Minimum pH value = 6.0.** This was set to ensure nitrification is supported for complete nitrification and nitrogen removal. pH values below 6.0 may achieve nitrification but start to risk inhibition of nitrification.

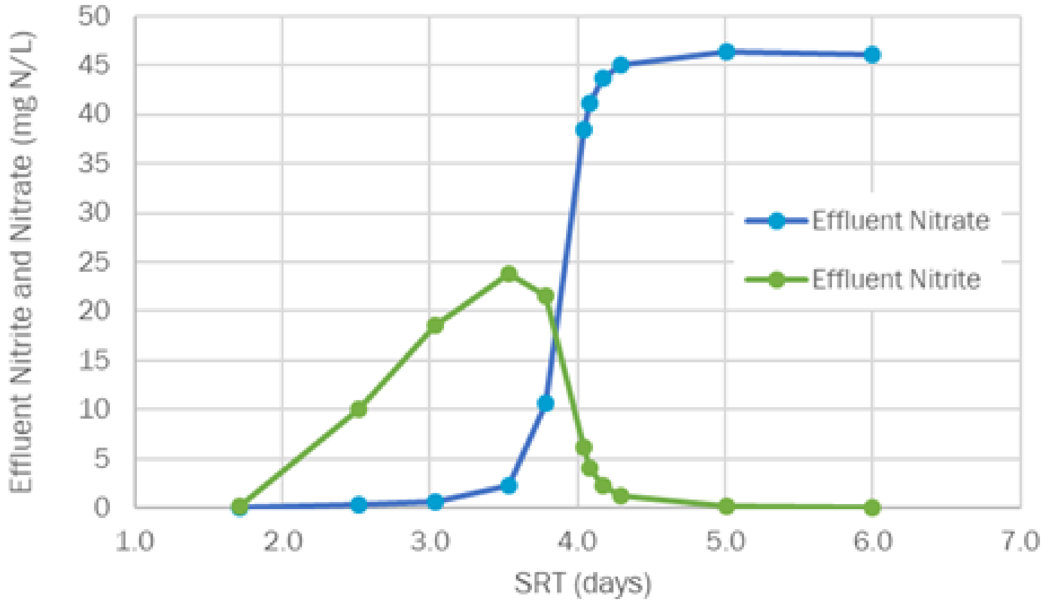

Figure U-6. Impact of SRT on nitrification

Simulations completed to determine minimum SRT had alkalinity added to maintain a minimum pH of 6.7 in HPOAS reactors.

The BioWin simulations were completed as steady-state runs. The steady state results were used to determine oxygen uptake rates (OURs) for each aerated stage, reactor average MLSS concentration, and effluent TIN load. The OURs were used in the HPO model to determine whether the oxygen production requirements were at or below 250 tons/d. The MLSS concentration was compared to the 4,500 mg/L criterion. The effluent TIN load was compared to a baseline effluent TIN load predicted by the BOD-only firm capacity BioWin simulations for corresponding years. Overall, BioWin results demonstrated MLSS was the limiting factor for Alternatives 1 and 3A/3B, and diffuser flux rate was the limiting factor for Alternative 2. Figures U-7 through U-9 show the capacity of each alternative as rated on oxygen-transfer and MLSS criteria. Each simulation was completed with and without CEPT. Figures U-7 through U-9 demonstrate the necessity for CEPT in order to keep MLSS values below 4,500 mg/L and extend capacity.

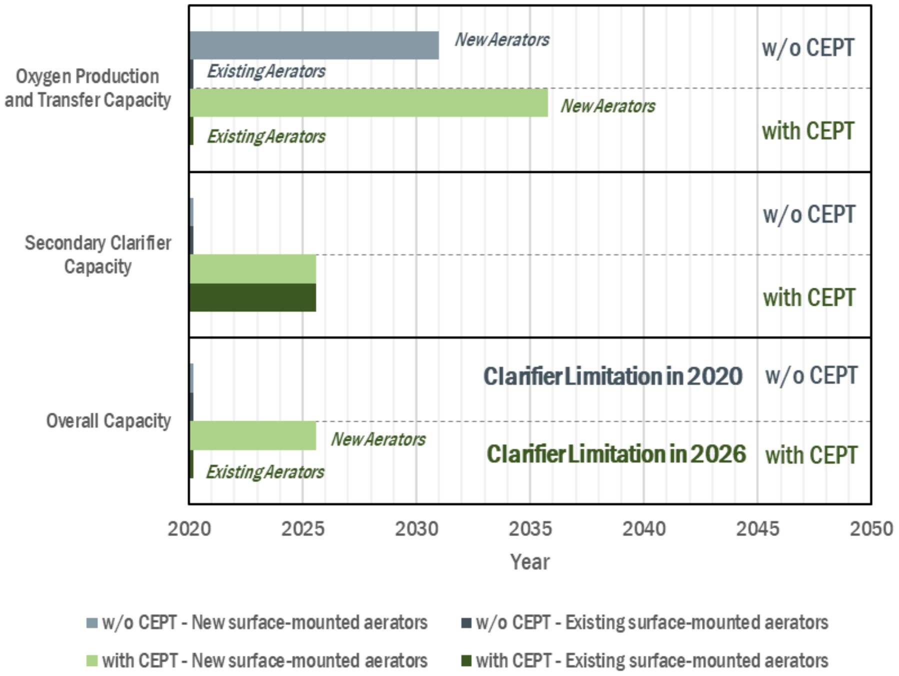

Figure U-7. Alternative 1 (Add Alkalinity) capacity based on oxygen production and transfer capacity and secondary clarifier capacity with and without CEPT implemented.

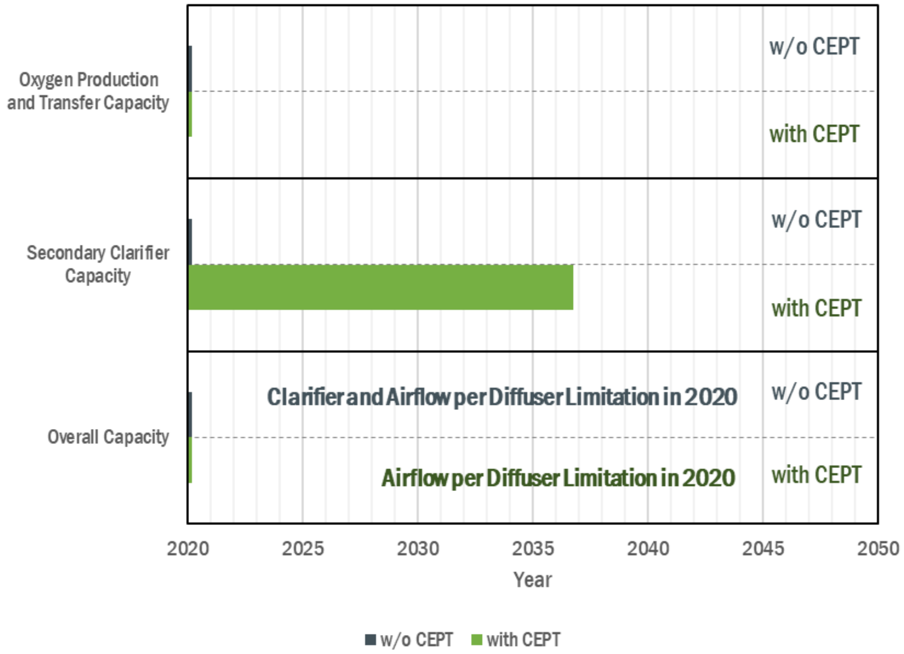

Figure U-8. Alternative 2 (Add Diffusers) capacity based on oxygen production and transfer capacity and secondary clarifier capacity with and without CEPT implemented.

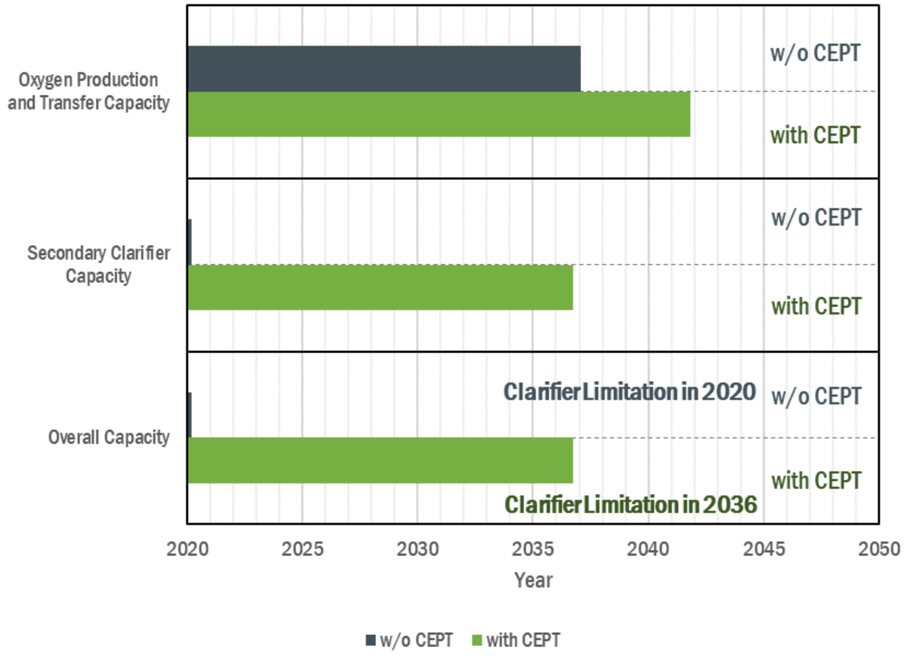

Figure U-9. Alternative 3A/3B (fourth stage ventilation) capacity based on oxygen production and transfer capacity and secondary clarifier capacity with and without CEPT implemented

The TIN removal performance between alternatives was similar. Implementing Alternatives 1 or 3A/3B is expected to reduce effluent TIN loading by 46% for ADW flow and loading conditions. The effluent TIN removal performance was proportional to available organic carbon and inversely proportional to Stage 4 DO concentration.

RESULTS

Capital and Operating Costs

Alternative 3A and 3B provide the longest nutrient reduction capacity. Alternatives 3A and 3B were progressed to a capital cost estimate and net present value evaluation. The capital and operating costs for Alternative 3A was based on a similar approach for fourth stage ventilation completed by the Los Angeles County Sanitation Districts (LACSD) at the Joint Wastewater Treatment Plant to increase reactor pH values in their BOD-only removal operation. The capital and operating costs for the INVENT alternative (Alternative 3B) were based directly from a proposal compiled by INVENT.

Overall, the INVENT design had higher capital costs and lower annual operating costs. The lower operating costs did not overcome the high capital investment for a 2022 through 2036 operational period, and thus Alternative 3A had the lowest net present value. However, if capacity were extended for these alternatives and they were operated for a longer duration, then the net present value results could invert.

A comparison of the capital costs and total net present value for Alternatives 3A and 3B are presented in Figure U-10. Each alternative assumes secondary effluent is routed to the influent pump station (IPS) for odor control and to offset sodium hypochlorite use, as shown in Figure U-11. The values presented in Figure U-10 also include capital and operating costs for sidestream treatment.

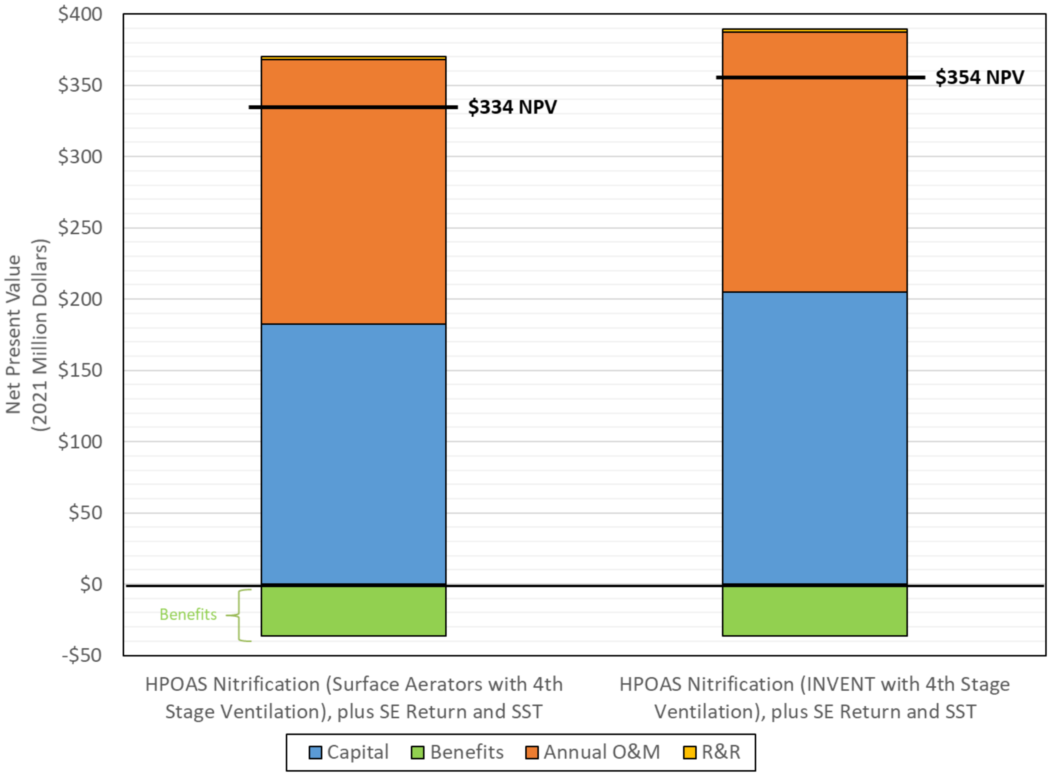

Figure U-10. Alternative 3A and 3B net present values.

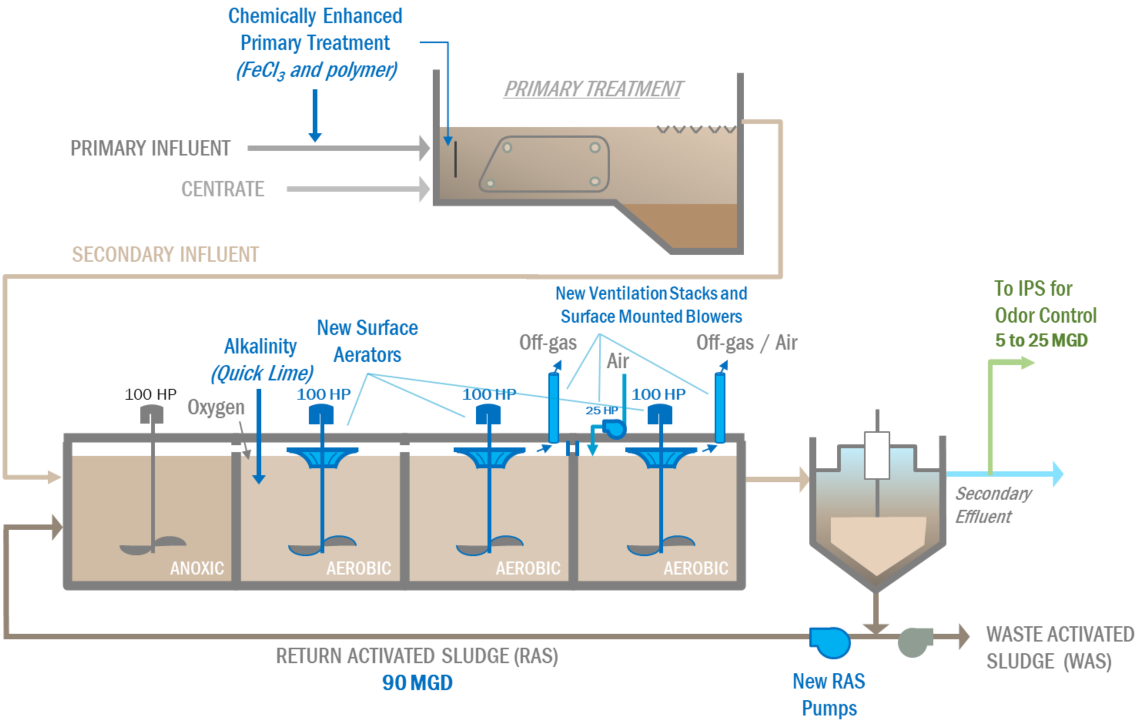

Figure U-11. Alternative 3A with Secondary Effluent routed to IPS for Odor Control

As shown in the net present value comparison, sidestream treatment is still required in operation by 2037. Therefore, mainstream HPOAS nitrification is not a long-term solution. However, as shown in in Figure U-12, the HPOAS nitrification alternative could be used to delay when sidestream treatment is required. The predicted effluent TIN load is shown in Figure U-12, demonstrating that MLSS capacity is exceeded prior to the effluent nutrient load being in excess.

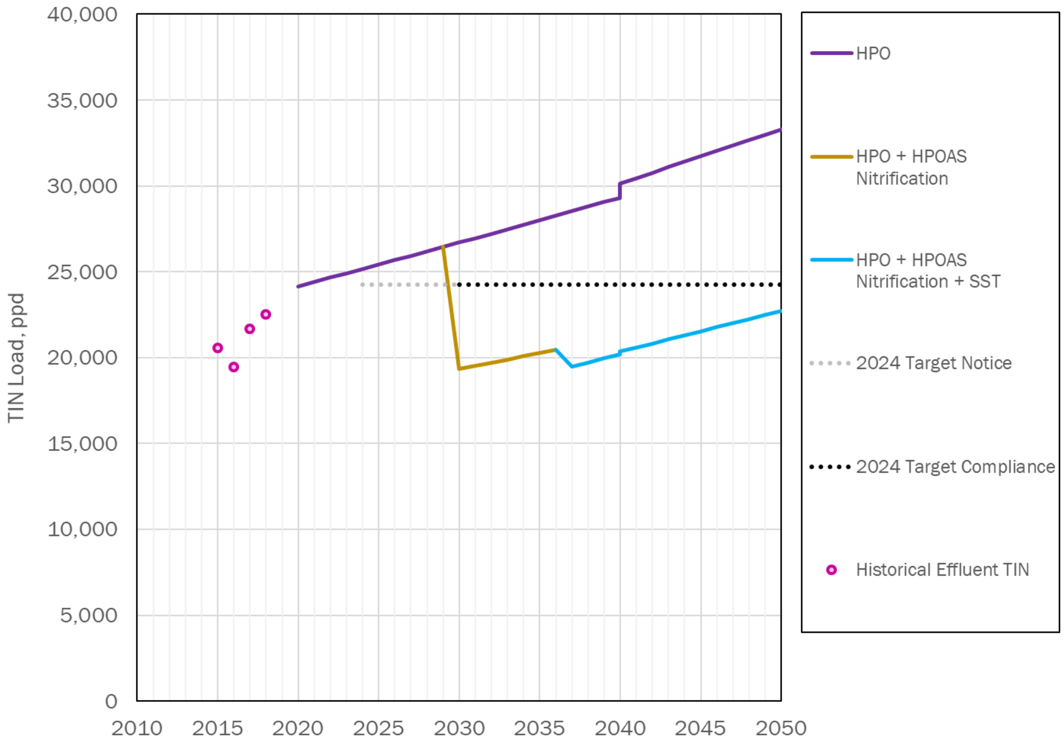

Figure U-12. Nutrient load roadmap for mainstream HPOAS nitrification

Operating Considerations

It is assumed that the mainstream HPOAS nitrification will only reliably provide three months of nitrification and nitrogen removal performance. The two shoulder months of the dry weather period, May and September, should be reserved for transitioning to and from nitrification mode, respectively. A review of historical data suggested significant rain events during May and September are rare. However, rain events during these shoulder months are possible. Therefore, providing shoulder months to transition the process from BOD-only to BOD and TIN removal provides flexibly and reliability in this process.

It should be noted that operating costs in the net present value assumed five months of operations in terms of costs, as CEPT should be implemented at the on-set and during the transition from mainstream HPOAS nitrification in order to maintain a MLSS concentration below 4,500 mg/L. Split treatment was evaluated via BioWin simulations; however, ultimately the complexity for split treatment was determined as prohibitive for this level of analysis and split treatment results were not progressed into the net present value or nutrient load graph evaluations.

In addition to the assumptions and results presented above, the following items should be considered prior to advancing these alternatives into further planning stages:

1. Simulations are modeled with a single point of alkalinity addition at the stage 2 influent. In reality, two points of alkalinity addition may be required to meet permit requirements for discharge pH – one at reactors and one at discharge location - if nitrification is attempted with existing tanks in order to increase effluent pH.
2. Results are based on assumption that SVI is 150 mL/g. Increased SRT could adversely affect settling properties of activated sludge. If a higher SVI is experienced, capacity could be limited at an earlier date based on secondary clarifier performance.
3. Lime slaking facility is used in cost estimation due to high supplemental alkalinity requirement to support nitrification. Lime slaking is expected to increase effort and may pose difficulty for daily EBMUD operations when the HPOAS mainstream is operated in nitrification mode.

The following recommendations should also be implemented prior to selection and design of a mainstream HPOAS nitrification alternative.

1. The use of lime could result in formation of a precipitate (e.g. $Ca_3(PO_4)_2$) that will increase sludge production. If recommended that dewatering equipment and cake hopper storage capacity is reviewed in the context of potential increased sludge production if HPOAS nitrification is implemented with the use of lime for supplemental alkalinity.
2. The analysis herein assumed no inhibition in the influent wastewater. The presence of inhibitory substances may increase minimum SRT required for nitrification. Bench scale testing could be performed to confirm minimum SRT results. High F/M Nitrifying testing (per 2003 WERF protocol) could be used for this analysis. Testing is recommended with two feed sources: 1) raw influent and 2) raw influent mixed with return stream centrate. Comparing nitrification rates between the two feed sources may help identify whether inhibitory substances exist in centrate or the HSW.
3. Further investigation of nitrifier kinetic parameters for the unique HPO system is recommended. For instance, the default BioWin KDO value for AOB kinetics was used. A higher number of 1.0 mg/L may also be justified and may require higher MLSS values.
4. Modeling of chemical phosphorus removal in primary treatment model with CEPT was not calibrated in detail. Further review of chemical phosphorus removal is recommended if design alternatives are sensitive to changes in primary phosphorus removal.

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Attachment U.1 – INVENT Proposal

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Offer-No.:	**IET-1706013-HCMA-Rev04**
Date:	**July 13 2020**
Submitted to:	**MISCOwater**
Project:	**EB-MUD –Brown & Caldwell**
	Budget proposal

INVENT Environmental Technologies Inc.
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Contents

1 Design Basis

1.1 Application

This proposal is following discussions with Brown & Caldwell and following the send information. This proposal includes a design for the anoxic zone mixer (Zone 1) and the Mixer/Aerator for zone 2,3 and 4 of the plant. The is proposal is set up for all train, so 8 parallel trains

1.2 Wastewater Properties

- Origin of wastewater:		municipal	
- Medium:		activated sludge	
- MLSS:	≤	5,000	ppm
- Sludge Volume Index (SVI)	≥	80	ml/g
- Temperature:		68	°F
- Total Dissolved Solids (TDS):	≤	2,000	ppm
- pH-value:		7	
- Plant altitude:		0	ft

1.3 Plant Data , Anoxic STAGE 1

- Number of basins:	8	
- Basin shape:	rectangular	
- Length:	46.0	ft
- Width:	46.0	ft
- Water depth:	25.0	ft
- Basin volume:	0.396	Mgal
- Freeboard:	6.0	ft
- Required operation Mode:	Mixing only	
- Oxygen Uptake Rate Maximum:	0	$mgO_2/L/h$
- Oxygen Uptake Rate Minimum:	0	$mgO_2/L/h$

1.4 Plant Data , Aeration STAGE 2

- Number of basins:	8	
- Basin shape:	rectangular	
- Length:	46.0	ft
- Width:	46.0	ft
- Water depth:	25.0	ft
- Basin volume:	0.396	Mgal
- Freeboard:	6.0	ft
- Required operation Mode:	Aeration only	
- Oxygen Uptake Rate Maximum:	215	mgO_2/L/h
- Oxygen Uptake Rate Minimum:	195	mgO_2/L/h

1.5 Plant Data , Aeration STAGE 3

- Number of basins:	8	
- Basin shape:	rectangular	
- Length:	46.0	ft
- Width:	46.0	ft
- Water depth:	25.0	ft
- Basin volume:	0.396	Mgal
- Freeboard:	6.0	ft
- Required operation Mode:	Aeration only	
- Oxygen Uptake Rate Maximum:	125	mgO_2/L/h
- Oxygen Uptake Rate Minimum:	110	mgO_2/L/h

1.6 Plant Data , Aeration STAGE 4

- Number of basins:	8	
- Basin shape:	rectangular	
- Length:	46.0	ft
- Width:	46.0	ft
- Water depth:	25.0	ft
- Basin volume:	0.396	Mgal
- Freeboard:	6.0	ft
- Required operation Mode:	Aeration only	
- Oxygen Uptake Rate Maximum:	50	mgO_2/L/h
- Oxygen Uptake Rate Minimum:	45	mgO_2/L/h

1.7 Oxygen Requirements based on OUR data

Based on the OUR data provided by Brown & Caldwell we generated the following SOTR data,

Measured OUR maximum Stage 2	215	$mgO_2/L/h$
Volume of the Zone 2 tank	1,498	m^3
Required AOR/h	322	kgO_2/hr
Applied Oxygen percentage in Oxygen feed:	98	%

We convert the AOR to SOTR with the following formula

$$SOTR_{20} = \frac{1}{\alpha} \cdot \frac{C^*_{\infty,20}}{\beta \cdot C^*_{\infty} - C_L} \cdot \theta^{20-T} \cdot AOR \cdot \frac{1}{24}$$

Equation 1: AOR to SOTR conversion

Parameter	Definition	Values used
SOTR	Standard Oxygen Transfer Rate in clean water (+20°C, 14.7 PSI)	
α	alpha coefficient	0.70
β	beta coefficient	0.98
$C^*_{\infty, 20}$	Steady state dissolved oxygen saturation concentration in clean water under standard conditions (+20°C, 14.7 PSI) at aeration depth for Pure Oxygen use	53.67 mg/L
$C^*_{\infty,}$	steady state dissolved oxygen saturation concentration in clean water under field conditions (process temp., field atmospheric pressure) at aeration depth	50.61 mg/L
C_L	actual oxygen concentration in the aeration basin (process conditions)	1.5 mg/L
θ	temperature correction coefficient	1.024
T	process temperature in aeration basin	77 °F
AOR	Actual Oxygen Requirement	322 kg O_2/h

Table 1: Data for Stage 2 Maximum SOTR calculation

This leads to a maximum SOTR value for use with Pure Oxygen per Zone 2 of 1,055 lbs O_2/h. All other calculations where performed are listed in the overview table attached to this proposal.

2 Technical Description of the HYPERCLASSIC® Mixer/Aerator

2.1 General Description

The **HYPERCLASSIC**® Mixer/Aerator (HCMA) is a unique mixing and aeration system which provides excellent mixing and homogenization as well as high oxygen transfer efficiency. The HCMA is a rugged and versatile device that can be used in water and wastewater treatment as well as numerous industrial applications.

Figure 1 shows how the HCMA works. This diagram shows the dry mounted drive in a typical application (rectangular or round tank). The characteristic features of the **HYPERCLASSIC**® system are the hyperboloid form of the mixer body, the option of aeration through an **INVENT** provided sparge ring (from a separate compressed air supply – by others) and the position of the drive. In this illustration, the Hyperboloid Mixer is powered a dry mounted drive with a vertical shaft.

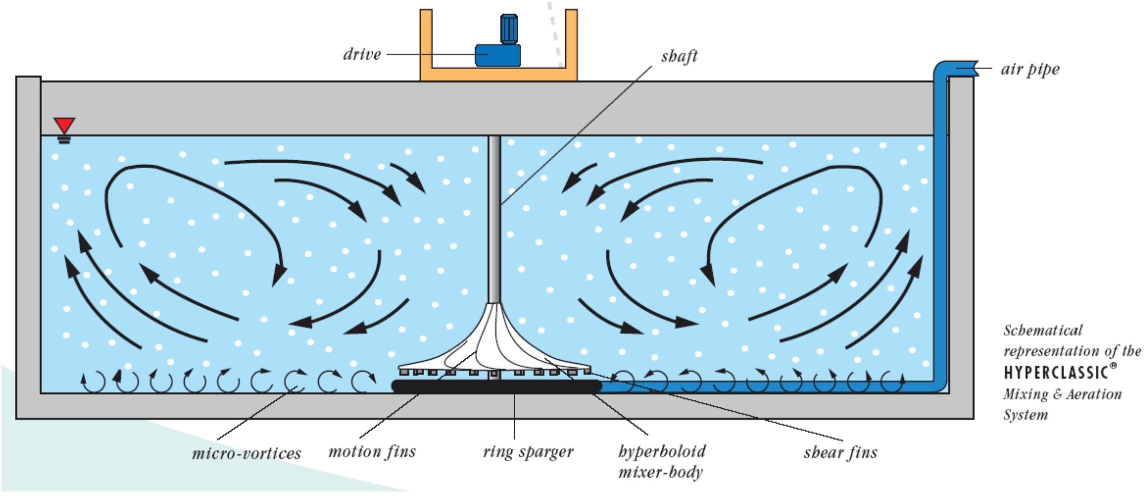


Figure 1: HyperClassic - Mixer / Aerator System Operation with dry mounted drive

2.2 INVENT System approach

For the EBMUD design the COD removal and nitrification require the aeration system to be able to entrain a large amount of oxygen. The system design is though such that every step per aeration train has its own aeration requirements. As there are,

- Stage 1 Anoxic zone no aeration required, mixing only
- Stage 2 First aeration zone, very high aeration demand required
- Stage 3 Second aeration zone, high aeration demand required
- Stage 4 Third aeration zone, medium to low aeration demand

The **INVENT** approach for the EBMUD installation is therefore to determine the optimum solution per STAGE. As every STAGE has a very unique process requirement the optimum equipment selection might differ per STAGE.

Anoxic STAGE 1
For the STAGE 1 an **INVENT HYPERCLASSIC**® Mixer is selected, this mixer will be able to homogenize the incoming flow with the RAS and internal recycle flows. As the retention time is only short a sufficient homogenization is crucial in order to achieve optimum Denitrification. The **HYPERCLASSIC**® Mixer has a very high pumping ratio which can homogenize the contents of the STAGE 1 in a very short period of time. The baffle walls inside the basin where taken into account for the design.

In the current situation the High Purity Oxygen (HPO) is released with low pressure in the headspace of STAGE 1. With the **INVENT** design the headspace of the STAGE 1 would be filled with ambient air, the openings above the waterline to STAGE 2 would be closed.

Aeration STAGE 2
For the STAGE 2 a very high OUR has been calculated, this required the use of HPO gas in this zone. The capacity requirement can be achieved by using two (2) **INVENT HYPERCLASSIC**® Mixer/Aerators for STAGE 2. The two units will operate in parallel with identical speeds though in opposite rotational directions. The HPO flow will be fed underneath each of the Mixer/Aerators, the off-gas is collected in the headspace of STAGE 2.

In the current situation the HPO is released with low pressure in the headspace of STAGE 1 and then flows to STAGE 2. With the **INVENT** design the HPO will be provided with a pressure of app. 11.7 PSI, two droplegs will feed the HPO underneath the Mixer/Aerators. The off-gas of the Mixer/Aerators will flow into headspace of the STAGE 2, the openings above the waterline to STAGE 3 would be closed.

Aeration STAGE 3
For the STAGE 3 the OUR calculated is lower as for the STAGE 2, this does not require the use of only HPO gas in this zone. The capacity requirement can be achieved by using the off gas of STAGE 2 in combination with HPO gas. One (1) **INVENT HYPERCLASSIC**® Mixer/Aerator will be sufficient for STAGE 3 to provide the required oxygen. The off gas of STAGE 2 will be pressurized and will be fed underneath the Mixer/Aerator together with a HPO flow, the off-gas is collected in the headspace of STAGE 3.

In the current situation the off gas of STAGE 2 will flow freely to STAGE 3. With the **INVENT** design the off gas of STAGE 2 is pressurized by means of a gas booster and will be fed underneath the **HYPERCLASSIC**® Mixer/Aerator. A separate dropleg will be provided to feed additional HPO gas underneath the same Mixer/Aerator in order to achieve the required maximum OUR. The off-gas of the Mixer/Aerator will flow into headspace of the STAGE 3, the openings above the waterline to STAGE 4 will remain open.

Aeration STAGE 4
For the STAGE 4 the OUR calculated is lower as for the STAGE 3. As the off-gas of the STAGE 3 still contains an oxygen concentration that is higher as 21% it makes sense to re-use this off gas flow together with ambient air. An **INVENT Rotox**® Surface Aerator is the optimum proposed aeration device for STAGE 4.

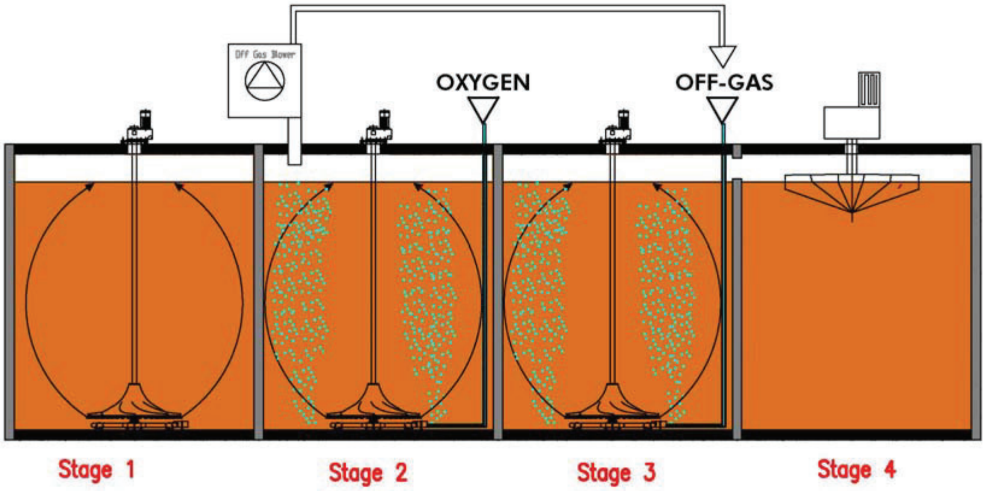


Figure 1: Systematic side view of one train with the INVENT approach

2.3 INVENT System approach Oxygen Consumption

For the **INVENT** System approach the required oxygen requirements can be achieved with the available HPO production capacity. The design combines and efficient aeration with energy efficient mixing which reflects in the listed oxygen and power consumption tables.

The full details are listed in the Attachment D and the separate attached summery table.

Total Oxygen Consumption			Max	Ave
Required Fresh Oxygen/ train	lbsO_2 /h		2352	1820
Operating trains	No.		8	8
Operating hours per day	Hours		24	24
Total required Oxygen	lbsO_2 /day		451584	349440
	tonsO_2 /day		**226**	**175**

Total Power Consumption			Max	Ave
HP Installed per train	HP		272.5	272.5
HP Required per train	HP		247.7	241.3
Operating trains	No.		8	8
Total HP consumed	HP		1981.6	1930.4

Table 2: Oxygen and Power consumption details

3 System Design

3.1 Design HCM for Anoxic Mixer, Zone 1

The **HyperClassic**® Mixer consists of a non-clogging Hyperboloid-body, a shaft and a motor with a mounting base. The mixer is supplied including all necessary parts for the assembly on either a steel or a concrete bridge. The individual parts are easy to install and guarantee quick installation. Figure 2 shows the design in detail.

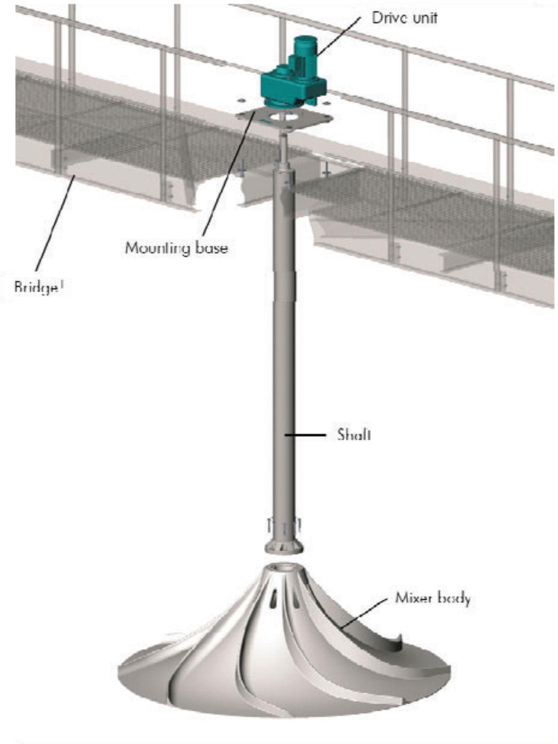


Figure 2: Exploded view on a Hyperboloid Mixer with top mounted drive

HyperClassic® Mixers are stable and designed in such a way that a bottom bearing is not required. This means that all serviceable parts are located above the water surface and are easily accessible for maintenance.

3.2 Design Mixer/Aerator for aeration Stage 2 and 3

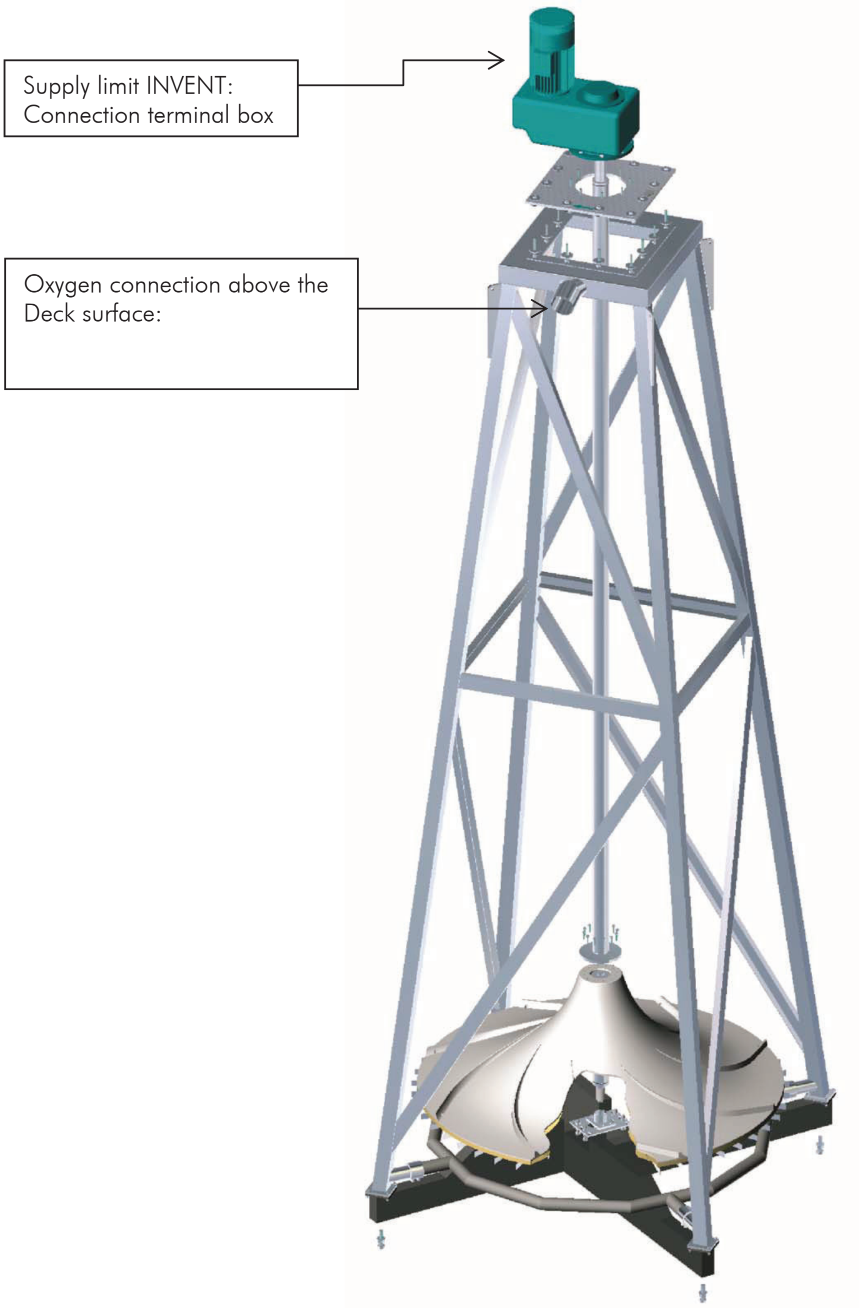
The **HYPERCLASSIC**® Mixer/Aerator consists of:

- Non clogging Hyperboloid body including
  - integrated transport fins
  - stainless steel shear ribs
- Vertical shaft with a motor and mounting base
- Air sparge ring with connection to air supply (by contractor)
- Bottom stabilizer

The Mixer/Aerator is supplied complete including all necessary parts for assembly on either a steel or a concrete bridge. The individual parts are clearly marked for quick installation. Figure 2 shows the design in detail.

3.2.1 HYPERCAGE for lift ability of he Mixer/Aerator

The cage construction enables the installation and removal of the **HYPERCLASSIC®**-Mixer/Aerator without draining the tank. The construction consists of a massive foot cross with a steel rack which goes above the water level. The drive unit is dry mounted on the mounting base. The process air is guided into the ring sparger, which is integrated in the foot cross. Due to the high weight the **HYPERCLASSIC®**-Mixer/Aerator stays on the intended position without any anchoring.
Considering the given wastewater composition the material of the steel rack is ASTM 316.



Supply limit INVENT:
Connection terminal box

Oxygen connection above the
Deck surface:

Figure 3: Exploded view of HYPERCLASSIC® Mixer/Aerator System with HYPERCAGE

3.3 Design ROTOX Surface Aerator for aeration Stage 4

The **Rotox**® Surface Aerator consists of:

- Non clogging Rotox aeration body
- Aeration body with open channels made from AISI 316
- Heavy duty gearbox with electrical motor
- Rotox Open Channel High Efficient design

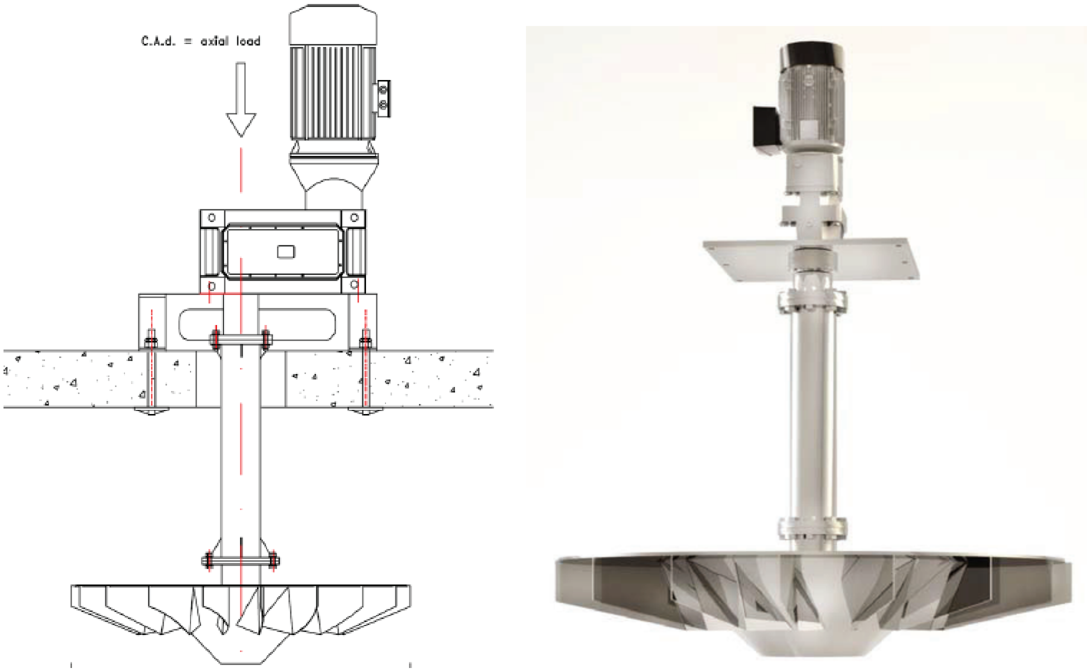


Figure 4: Rotox® Surface Aerator with top mounted drive

4 Equipment Lay Out per STAGE

4.1 Anoxic Mixing System Lay out STAGE 1

We recommend the following hyperboloid mixer configuration for the wastewater and basin properties described in Section 1, with the following technical data:

- Number of basins:	8	
- Number of Mixers per basin:	1	
- Total number of Mixers:	8	
- Model:	HCM/2500-34-10.0hp	
- Diameter:	98.4	in (2,500 mm)
- Speed:	33.7	rpm
- Installed motor power:	10.0	hp
- Power input:	7.0	hp
- Power consumption:	8.1	hp
- Power density:	0.13	hp/1000 cuft
- Power reserve:	≥ 25	%
- Voltage:	460	V
- Nominal current at 460 V, 60 Hz:	12.6	A
- Starting current:	102.1	A
- Total weight:	992	lb
- Average bottom flow velocity:	≥ 26.1	in/s
- Mixer pumping capacity:	≥ 17,677	cuft/min
- Distance from bottom:	4.9	in

Please Note : For this Mixer a Soft start or VFD is required, not included in this proposal..

4.2 Aeration System Layout STAGE 2

As the preferred solution for the aeration requirements described in Section 1, we recommend 2 Hyperboloid Mixer/Aerators with the following technical details:

- Number of basins:	8
- Number of Mixer/Aerators per basin:	2
- Total number of Mixer/Aerators:	16
- Model:	HCMA/2500-45-50.0hp

4.2.1 System design Max Month Loading:

- Oxygen flow per Mixer/Aerator (98% Oxygen):	1,080	lbs O_2 / h
- Total oxygen flow per basin (98% Oxygen):	2,160	lbs O_2 / h
- Total oxygen flow for all eight basins (98% Oxygen):	34,560	lbs O_2 / h
- Pressure required at top of drop pipe (incl. hydr. pressure)[1]:	11.7	PSI
- Standard Oxygen Transfer Efficiency (SOTE):	49	%
- Standard Oxygen Transfer Rate ($SOTR_{20,1000}$)[2]:	527.5	lbO_2/h (per unit)
- Mixer diameter	98.4	in
- Speed:	43.1	rpm
- Installed motor power:	50.0	hp
- Power consumption:	47.1	hp
- Power reserve:	≥ 15	%
- Total weight:	3,505	lb

Please Note : For this Mixer/Aerator a VFD is required, not included in this proposal

---

[1] NOTE: Pressure drop of the piping between blowers and aeration basin as well as losses in the blowers inlet filters are not included..

[2] Standard temperature +20 °C, pressure 14.7 PSI, TDS=1000 ppm. For more information on SOTR please refer to Appendix – Calculation of oxygen demands.

4.3 Aeration System Layout STAGE 3

As the preferred solution for the aeration requirements described in Section 1, we recommend 1 Hyperboloid Mixer/Aerators with the following technical details:

- Number of basins:	8
- Number of Mixer/Aerators per basin:	1
- Total number of Mixer/Aerators:	8
- Model:	HCMA/2500-45-50.0hp

4.3.1 System design Max Month Loading:

- Off Gas flow per Mixer/Aerator (80% Oxygen):	1,118	lbs O_2 / h
- Total Off Gas flow per basin (80% Oxygen):	1,118	lbs O_2 / h
- Total Off Gas flow for all eight basins (80% Oxygen):	8,944	lbs O_2 / h
- Pressure required at top of drop pipe (incl. hydr. pressure)[3]:	11.7	PSI
- Oxygen flow per Mixer/Aerator (98% Oxygen):	192	lbs O_2 / h
- Total oxygen flow per basin (98% Oxygen):	192	lbs O_2 / h
- Total oxygen flow for all eight basins (98% Oxygen):	1,536	lbs O_2 / h
- Pressure required at top of drop pipe (incl. hydr. pressure)[4]:	11.7	PSI
- Standard Oxygen Transfer Efficiency (SOTE):	45	%
- Standard Oxygen Transfer Rate ($SOTR_{20,1000}$)[5]:	580	lbO_2/h (per unit)
- Mixer diameter	98.4	in
- Speed:	43.1	rpm
- Installed motor power:	50.0	hp
- Power consumption:	47.1	hp
- Power reserve:	≥ 15	%
- Total weight:	3,505	lb

Please Note : For this Mixer/Aerator a VFD is required, not included in this proposal

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[3] NOTE: Pressure drop of the piping between blowers and aeration basin as well as losses in the blowers inlet filters are not included..

[4] NOTE: Pressure drop of the piping between blowers and aeration basin as well as losses in the blowers inlet filters are not included..

[5] Standard temperature +20 °C, pressure 14.7 PSI, TDS=1000 ppm. For more information on SOTR please refer to Appendix – Calculation of oxygen demands.

4.4 INVENT Gas-Booster, for off Gas of STAGE 2

In order to reuse the off gas of STAGE 2 for the **HYPERCLASSIC**® Mixer/Aerator the off gas of STAGE 2 will need be pressurized. In order to increase the pressure on the off gas flow a gas booster will be foreseen, the current design incorporates a single gas booster for the two lanes operating with the **INVENT** Mixer/Aerators. The feed to the gas booster will be taken from the STAGE 2 headspace, the suction line and the pressure side will have to be constructed new. A pressurized oxygen line will have to run from the gas booster to the bottom of STAGE 3 of each lane.

The gas booster will be operated by means of a VFD in order to enable the flow adjustment to the oxygen requirement of the biology. The unit will be placed on the deck including a sound enclosure. Piping to and from the gas booster by third parties.

As the preferred solution for the gas booster requirements described in chapter Error! Reference source not found., we recommend 1 Gas-Booster with the following technical details:

- Total number of Gas Boosters:	1 per two (2) lines
- Model:	**INVENT Gas Booster 25S**

4.5 Process conditions:

- Process temperature:	68	°F
- Oxygen concentration:	95-99	%
- Site ambient pressure:	14.7	PSI

4.6 Gas Booster design:

- Off Gas flow Max Month Loading (80% Oxygen):	280	scfm per lane
- Off Gas flow Max Month loading (80% Oxygen):	560	scfm Per Booster
- Pressure required at top of drop pipe (incl. hydr. pressure)[6]:	11.5	PSI
- Speed blower:	1500-4400 rpm	
- Installed motor power:	75.0	hp
- Power consumption:	48	hp
- Power reserve:	≥ 35	%
- Total weight (Excluding sound enclosure) :	1,900	lb

---

[6] NOTE: Pressure drop of the piping between blowers and aeration basin as well as losses in the blowers inlet filters are not included..

The Gas Booster will have a separate oil pressure system and will be using Foblim Oil, especially selecter for applications with high purity oxygen.

Please Note : For this Gas Booster a VFD is required, not included in this proposal

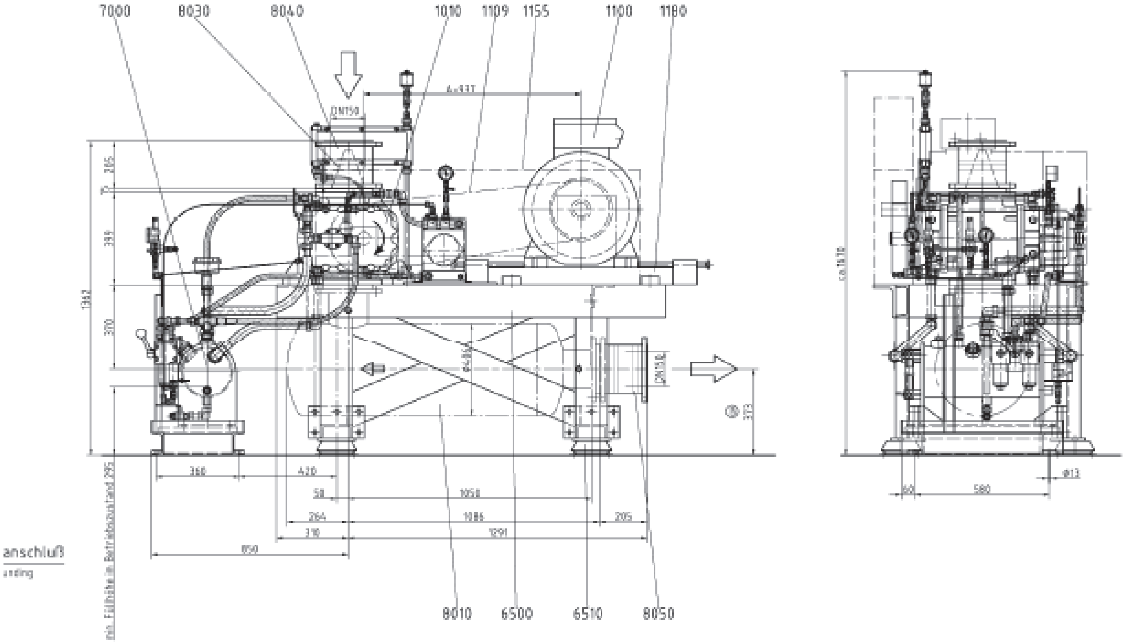

Figure 5: Initial drawing for the Gas Booster

4.7 Aeration System Lay out STAGE 4

As the preferred solution for the aeration requirements for STAGE 4 , we recommend 1 **ROTOX** surface Aerator with the following technical details:

- Number of basins:	8
- Number of **ROTOX** Surface Aerators per basin:	1
- Total number of Surface Aerators:	8
- Model:	**ROTOX S75**

4.7.1 System design Max Month Loading:

- Standard Oxygen Transfer Efficiency (SOTE):	3.2	lbO_2/HP/h
- Standard Oxygen Transfer Rate ($SOTR_{20,1000}$)[7]:	212.5	lbO_2/h (per unit)
- Mixer diameter	90.5	in
- Speed:	47	rpm
- Installed motor power:	75.0	hp
- Power consumption:	66.4	hp
- Power reserve:	≥ 15	%
- Total weight:	2,205	lb

Please Note : For this Mixer/Aerator a VFD is required, not included in this proposal

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[7] Standard temperature +20 °C, pressure 14.7 PSI, TDS=1000 ppm. For more information on SOTR please refer to Appendix – Calculation of oxygen demands.

5 Budget Pricing

For this budget proposal we propose the following items,

Stage 1

HYPERCLASSIC® Mixers HCM/2500-34-10hp	Qty (8)
Liquid gas seal included for all units	included
Support frame to fit the **INVENT** mixers in the existing opening	Included

Stage 2

HYPERCLASSIC® Mixer/Aerators HCMA/2500-44-50hp	Qty (16)
Liftable **HYPERCAGE**® for Mixer/Aerators AISI 316	Qty (16)
Liquid gas seal included for all units	included
Adapt frame to fit the **INVENT HYPERCAGE**® in the existing structure	Included

Stage 3

HYPERCLASSIC® Mixer/Aerators HCMA/2500-44-50hp	Qty (8)
Liftable **HYPERCAGE**® for Mixer/Aerators AISI 316	Qty (8)
Liquid gas seal included for all units	included
Dual ring sparger for aeration with off gas and HPO oxygen	Included
Adapt frame to fit the **INVENT HYPERCAGE**® in the existing structure	Included
GAS BOOSTER ROTOX® S75 – 75HP with sound enclosure	Qty (4)

Stage 4

ROTOX® S75 – 75HP Surface aerators	Qty (8)
Liquid gas seal included for all units	included
Adapt frame to fit the **INVENT HYPERCAGE**® in the existing structure	Included
Transportation and delivery (DDP),	included
Start-up and Training	included

Budget Price INVENT Approach	**$ 8,000,000.-**

6 Excluded items

- Electrical Control Panels
- Air piping on top of the deck
- Civil adjustments to the tank deck in Stage 2
-
- Any frequency drives
- All labor to install the equipment
- The Unloading of the goods, buyer is responsible for unloading the goods. The buyer is responsible for keeping goods safe before assembly.
- Lifting gears for the assembly have to be supplied by the client.
- Electricity and energy must also be supplied by the client free of charge.
- The basins must be empty, cleaned and dry for the assembly.
- The assembly will only be supervised by **INVENT**, not installed.
- The drilling of the wholes for the chemical anchors.
- Any possible required adjustment of the handrails.
- Electrical connecting of the motors
- Scaffolding to enable the access of side of the concrete platform and bridge, if required.

We reserve the right to make technical changes to improve our products.

We appreciate the opportunity to provide the design and details of the **INVENT** mixing / aeration solution for your project. We will contact you in the next few days to discuss any questions that you may have on this offer.

INVENT Environmental Technologies Inc.

Ing. Marcel Huijboom

7 Payment conditions

The offer is for budgetary purposes only.

7.1 Guarantee

- The guarantee period is 12 months after start up of the system, but not later than 6 months after delivery.

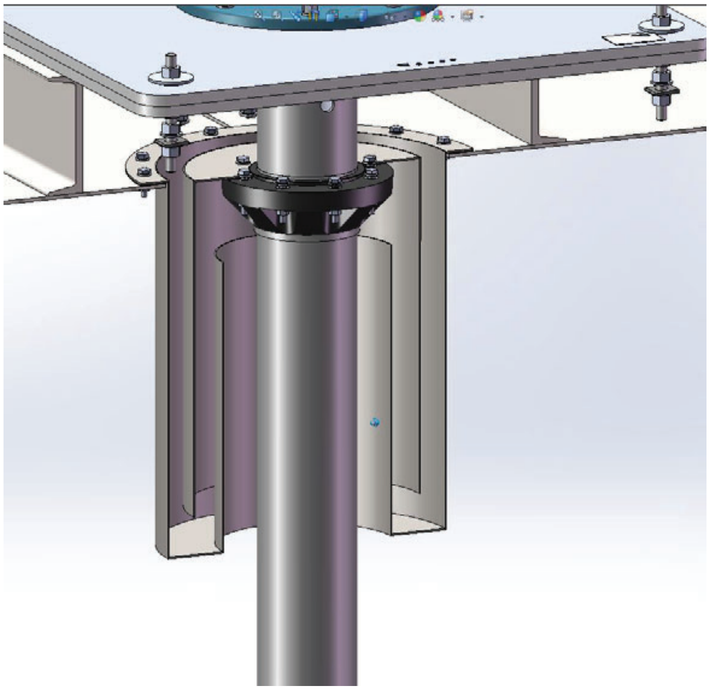
7.2 Delivery Time

The equipment will be ready to ship approximately 16 –18 weeks after approval of submittal documents and the receipt of down payment

7.3 Terms of Payment for goods (EXW)

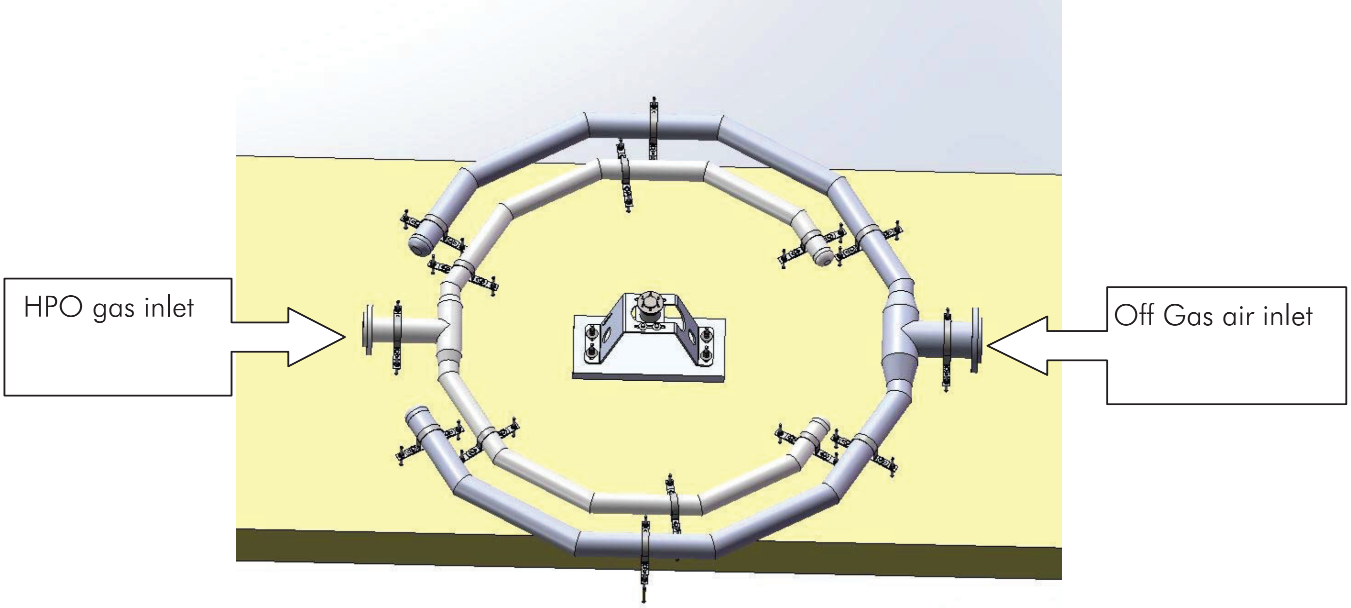
25 %	upon approval of the submittals by the engineer
70 %	upon delivery or announcement readiness for shipping
5 %	upon substantial completion or latest 8 weeks after delivery

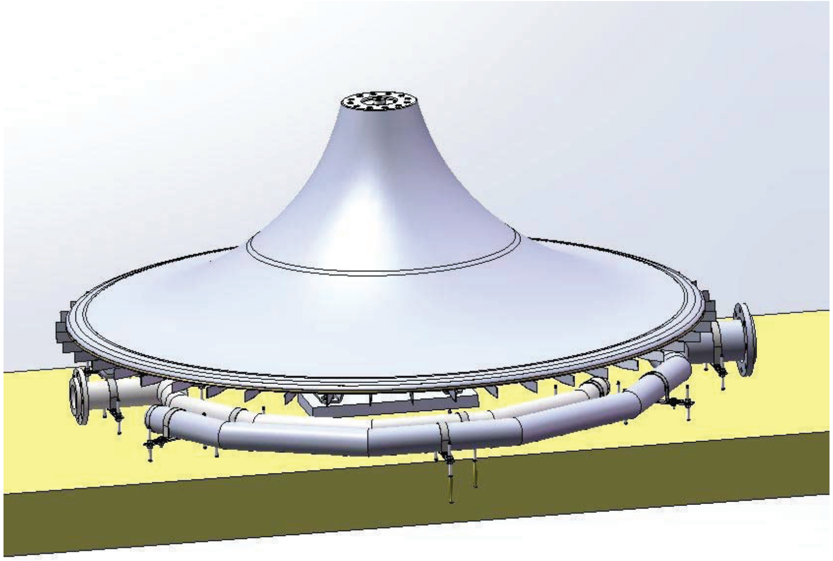
Attachment A – Mixer Liquid Gas Seal



Attachment B – Mixer/Aerator Dual Ring Sparger Stage 3

In order to create the possibility to aerate with either pure oxygen or normal ambient air we have included a Dual Ring Sparger. This enables an Hybrid operation of the unit.



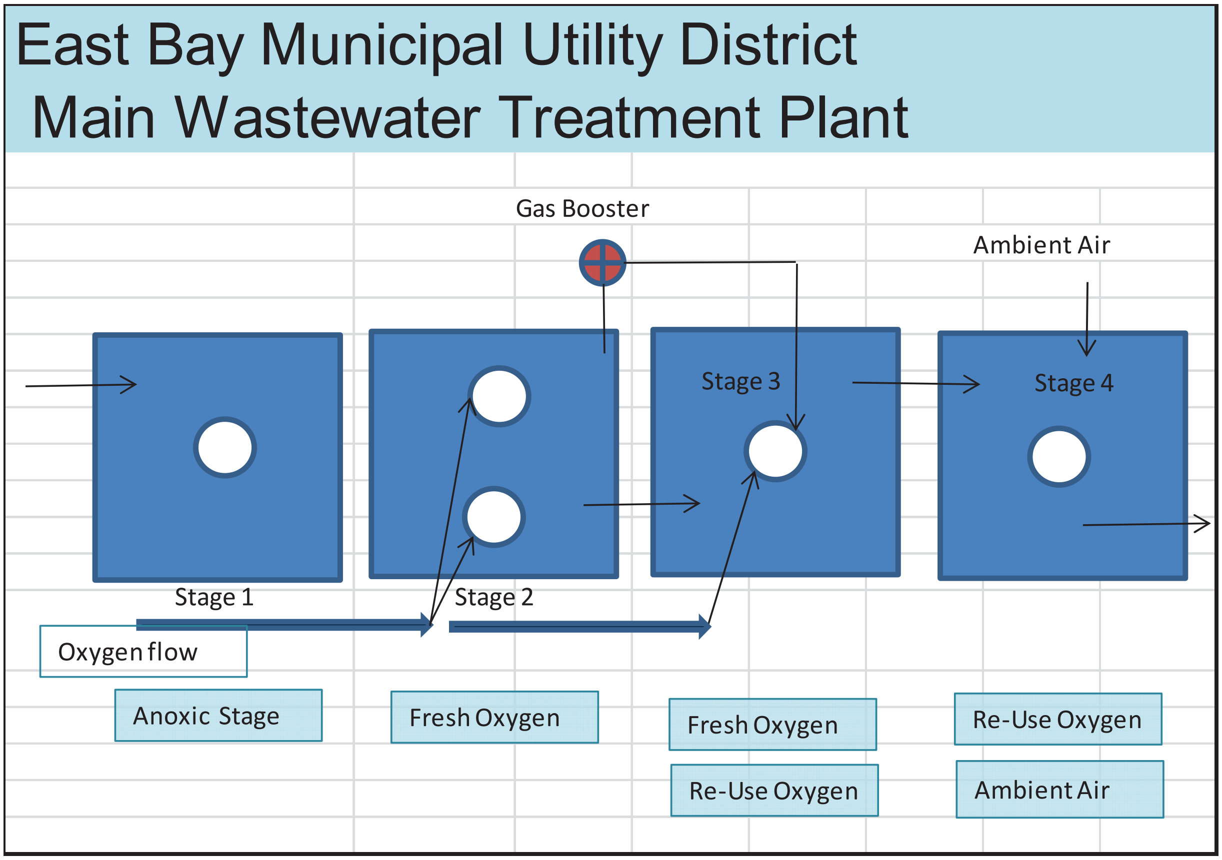


Attachment C – INVENT System Design - Consumption

Max Month Loading and Max Week Temperature

Stage		1	2		3		4
AOR per zone	% AOR	0.0%	55.1%		32.1%		12.8%
AOR per zone	lbs/h AOR	0	710		412.8		165.1
Number of Aerators per Zone	pcs.	1	2		1		1
Used AOR/SOTR	/	/	0.673		0.712		0.777
Required SOTR	lbs/h SOTR	/	1055		579.8		212.5
SOTR per Unit	lbs/h SOTR	/	528		413		165
Installed Unit		HCM	HCMA	Booster	HCMA		ROTOX
Installed Motor Power	HP	10	50	75	50		75
Number of units per Stage	Nr.	1	2	0.5	1		1
Total Installed Motor Power	HP	10	100	37.5	50		75
Total Consumed HP		9.8	93	32	46.5		66.4
Oxygen Conc. Gas feed	% O$_2$	**0**	**98**		**80**	**98**	**50**
Specific weight gas	kg/Nm3	0	1.399		1.142	1.399	1.205
Origin Gas Flow		0	Fresh		Reuse	Fresh	reuse
SOTE	%	0%	49%		45%	45%	3.2 lbs/hp
Required mass O$_2$ / unit	lbsO$_2$ /h	0	1080		1118	192	
Total requred mass frash O$_2$	lbsO$_2$ /h	0	2160		0	192	
Total Oxygen Consumption			Max	Ave			
Required Fresh Oxygen/ train	lbsO$_2$ /h		2352	1820			
Operating trains	No.		8	8			
Operating hours per day	Hours		24	24			
Total required Oxygen	lbsO$_2$ /day		451584	349440			
	tonsO$_2$ /day		**226**	**175**			
Total Power Consumption			Max	Ave			
HP Installed per train	HP		272.5	272.5			
HP Required per train	HP		247.7	241.3			
Operating trains	No.		8	8			
Total HP consumed	HP		1981.6	1930.4			

Attachment D – INVENT System Design – Concept



APPENDIX W – Reduced R2 Scenarios: Flows and Loads and Process Model Results

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Table W-1: 2020 Influent Flows and Loads and Process Model Results Medium Growth Scenario and Reduced R2 Scenarios

Parameter	Units	2020 - MWWTP BioWin Simulation Results							
		Medium Growth Scenario [A]	Right-Size R2 [B]	No HSW	No R2	No LSW	No FOG	No Dairy DAFT	No Protein
Plant Influent (Raw Influent plus Low Strength Waste [LSW])									
Flow	mgd	52.2	52.2	52.2	51.8	51.8	52.2	52.2	52.2
Total Suspended Solids	lb/d	181,300	181,300	181,300	159,200	159,200	181,300	181,300	181,300
Inert Suspended Solids	lb/d	27,200	27,200	27,200	17,600	17,600	27,200	27,200	27,200
Secondary Influent									
Total Suspended Solids	lb/d	72,500	72,300	72,100	62,600	63,000	72,500	72,400	72,400
Inert Suspended Solids	lb/d	11,400	11,300	11,200	7,300	7,600	11,400	11,400	11,400
Total Kjeldahl Nitrogen	lb-N/d	33,500	29,200	28,600	26,700	31,800	33,500	31,100	31,500
Final Effluent									
Total Suspended Solids	lb/d	5,100	5,000	5,000	3,900	4,000	5,100	5,000	5,100
Total Nitrogen	lb-N/d	25,300	21,100	20,600	20,100	25,000	25,300	23,000	23,400
Total Inorganic Nitrogen	lb-N/d	24,200	20,000	19,400	19,100	23,900	24,100	21,900	22,200
Digester Feed (Blend Tank Effluent)									
Total Suspended Solids	lb/d	270,300	254,000	219,100	183,200	233,600	273,000	267,000	262,200
Inert Suspended Solids	lb/d	48,300	42,600	39,300	28,200	37,000	48,000	45,000	46,900
Digester Gas and Potential Phosphate Precipitation Production									
Digester Gas [C]	scfm	2,500	2,200	1,100	1,050	2,450	2,500	2,500	2,250
Struvite + Vivianite + Brushite	lb/d	10,100	8,300	5,800	5,100	9,500	9,900	9,000	9,600
Dewatering Feed									
Flow	mgd	0.76	0.66	0.52	0.47	0.68	0.73	0.68	0.74
Total Suspended Solids	lb/d	140,300	129,400	115,100	87,400	111,200	138,900	134,500	136,000
Inert Suspended Solids (not adjusted for struvite)	lb/d	53,300	47,200	40,900	29,800	42,200	52,700	49,800	51,400
Volatile Suspended Solids	lb/d	87,000	82,200	74,200	57,500	69,000	86,100	84,700	84,600
Dewatered Cake									
Dry Tons per Day [D]	ton/d	52.2	48.7	44.0	33.1	40.9	51.8	50.5	50.8
Wet Tons per Day @ 24 percent Solids	wet ton/d	218	203	183	138	170	216	210	212
Flow	mgd	0.07	0.06	0.05	0.04	0.05	0.07	0.06	0.07
Dewatering Centrate									
Flow	mgd	0.70	0.60	0.47	0.43	0.62	0.66	0.62	0.68
Ammonia	lb-N/d	10,000	5,700	5,200	4,600	9,500	10,000	7,700	8,000

Notes

[A] The medium growth scenario assumes medium population growth for the service area and a medium growth scenario for the resource recovery (R2) program.

[B] The right-size R2 scenario assumes elimination of protein and dairy dissolved air floatation thickening (DAFT) trucked waste streams from the high strength waste (HSW) receiving station.

[C] Dry biogas outputs from BioWin were converted to standard cubic feet per minute by accounting for temperature and pressure: [dry biogas, cfm]*(68+460)/(104+460)*((0.2+14.7)/14.7). This calculation matches the process used in the Plant-Wide Process Model validation task.

[D] Dewatered cake solids were corrected according to findings from the C60 Plant-Wide Process Model task report that cake solids dry solids load was 29 percent higher than the calibration data; BioWin total suspended solids loading values were divided by 1.29 for No Changes to R2, or the [Struvite + Vivianite + Brushite Formation] solids load was subtracted and the resulting load was then divided by 1.19 to correct BioWin overpredictions for scenarios with changes to R2.

Table W-2: 2030 Influent Flows and Loads and Process Model Results Medium Growth Scenario and Reduced R2 Scenarios

Parameter	Units	2030 - MWWTP BioWin Simulations Results							
		Medium Growth Scenario [A]	Right-Size R2 [B]	No HSW	No R2	No LSW	No FOG	No Dairy DAFT	No Protein
Plant Influent (Raw Influent plus Low Strength Waste [LSW])									
Flow	mgd	56.0	56.0	56.0	55.5	55.5	56.0	56.0	56.0
Total Suspended Solids	lb/d	204,400	204,400	204,400	179,900	179,900	204,400	204,400	204,400
Inert Suspended Solids	lb/d	30,700	30,700	30,700	20,000	20,000	30,700	30,700	30,700
Secondary Influent									
Total Suspended Solids	lb/d	81,700	81,500	81,200	70,700	71,100	81,700	81,600	81,600
Inert Suspended Solids	lb/d	12,900	12,800	12,600	8,400	8,600	12,900	12,800	12,800
Total Kjeldahl Nitrogen	lb-N/d	37,200	33,500	32,300	30,100	35,100	37,100	35,700	35,000
Final Effluent									
Total Suspended Solids	lb/d	6,100	6,000	6,000	4,700	4,800	6,100	6,100	6,100
Total Nitrogen	lb-N/d	28,000	24,500	23,300	22,800	27,600	28,000	26,600	25,900
Total Inorganic Nitrogen	lb-N/d	26,700	23,200	22,000	21,500	26,400	26,700	25,300	24,600
Digester Feed (Blend Tank Effluent)									
Total Suspended Solids	lb/d	299,800	287,800	246,500	206,400	258,900	302,600	298,100	291,600
Inert Suspended Solids	lb/d	53,000	47,800	43,600	31,300	40,500	52,600	50,900	51,200
Digester Gas and Potential Phosphate Precipitation Production									
Digester Gas [C]	scfm	2,750	2,500	1,250	1,150	2,700	2,750	2,800	2,500
Struvite + Vivianite + Brushite	lb/d	10,700	9,200	6,500	5,900	10,100	10,400	9,900	10,000
Dewatering Feed									
Flow	mgd	0.83	0.75	0.59	0.49	0.73	0.80	0.78	0.80
Total Suspended Solids	lb/d	156,600	147,500	129,900	98,400	124,000	155,200	153,000	151,700
Inert Suspended Solids (not adjusted for struvite)	lb/d	57,900	53,000	45,400	33,200	45,800	57,300	55,800	55,700
Volatile Suspended Solids	lb/d	98,700	94,500	84,500	65,200	78,200	97,800	97,200	96,000
Dewatered Cake									
Dry Tons per Day [D]	ton/d	58.3	55.6	49.6	37.2	45.8	58.2	57.5	57.0
Wet Tons per Day @ 24 percent Solids	wet ton/d	243	232	207	155	191	243	240	237
Flow	mgd	0.08	0.07	0.06	0.05	0.06	0.07	0.07	0.07
Dewatering Centrate									
Flow	mgd	0.75	0.68	0.53	0.45	0.67	0.72	0.71	0.73
Ammonia	lb-N/d	10,500	7,000	5,800	5,100	10,000	10,500	9,100	8,400

Notes

[A] The medium growth scenario assumes medium population growth for the service area and a medium growth scenario for the resource recovery (R2) program.

[B] The right-size R2 scenario assumes elimination of protein and dairy dissolved air floatation thickening (DAFT) trucked waste streams from the high strength waste (HSW) receiving station.

[C] Dry biogas outputs from BioWin were converted to standard cubic feet per minute by accounting for temperature and pressure: [dry biogas, cfm]*(68+460)/(104+460)*((0.2+14.7)/14.7). This calculation matches the process used in the Plant-Wide Process Model validation task.

[D] Dewatered cake solids were corrected according to findings from the C60 Plant-Wide Process Model task report that cake solids dry solids load was 29 percent higher than the calibration data; BioWin total suspended solids loading values were divided by 1.29 for No Changes to R2, or the [Struvite + Vivianite + Brushite Formation] solids load was subtracted and the resulting load was then divided by 1.19 to correct BioWin overpredictions for scenarios with changes to R2.

Table W-3: 2040 Influent Flows and Loads and Process Model Results Medium Growth Scenario and Reduced R2 Scenarios

Parameter	Units	2040 - MWWTP BioWin Simulations Results							
		Medium Growth Scenario [A]	Right-Size R2 [B]	No HSW	No R2	No LSW	No FOG	No Dairy DAFT	No Protein
Plant Influent (Raw Influent plus Low Strength Waste [LSW])									
Flow	mgd	60.5	60.5	60.5	60.0	60.0	60.5	60.5	60.5
Total Suspended Solids	lb/d	230,200	230,200	230,200	203,600	203,600	230,200	230,200	230,200
Inert Suspended Solids	lb/d	34,500	34,500	34,500	22,700	22,700	34,500	34,500	34,500
Secondary Influent									
Total Suspended Solids	lb/d	92,000	91,800	91,500	80,000	80,500	91,900	91,900	91,900
Inert Suspended Solids	lb/d	14,500	14,300	14,200	9,500	9,700	14,500	14,400	14,400
Total Kjeldahl Nitrogen	lb-N/d	41,000	37,400	36,100	34,000	39,000	41,000	39,600	38,800
Final Effluent									
Total Suspended Solids	lb/d	7,400	7,300	7,300	5,800	5,900	7,400	7,400	7,400
Total Nitrogen	lb-N/d	30,900	27,400	26,100	25,800	30,700	30,900	29,500	28,700
Total Inorganic Nitrogen	lb-N/d	29,300	25,800	24,600	24,400	29,200	29,300	27,900	27,200
Digester Feed (Blend Tank Effluent)									
Total Suspended Solids	lb/d	331,500	319,000	277,000	232,700	286,400	333,400	329,000	322,700
Inert Suspended Solids	lb/d	58,100	52,700	48,400	34,800	44,300	57,700	56,000	56,200
Digester Gas and Potential Phosphate Precipitation Production									
Digester Gas [C]	scfm	2,900	2,650	1,400	1,300	2,850	2,900	2,950	2,650
Struvite + Vivianite + Brushite	lb/d	11,500	9,900	7,200	6,600	10,800	11,200	10,600	10,800
Dewatering Feed									
Flow	mgd	0.90	0.83	0.66	0.56	0.80	0.87	0.86	0.88
Total Suspended Solids	lb/d	174,600	165,200	146,400	111,300	138,300	173,100	170,800	169,500
Inert Suspended Solids (not adjusted for struvite)	lb/d	63,200	58,200	50,300	36,900	49,700	62,500	61,000	60,900
Volatile Suspended Solids	lb/d	111,500	107,000	96,100	74,400	88,600	110,500	109,800	108,600
Dewatered Cake									
Dry Tons per Day [D]	ton/d	65.0	62.5	56.0	42.1	51.2	65.1	64.5	63.8
Wet Tons per Day @ 24 percent Solids	wet ton/d	271	260	233	176	213	271	269	266
Flow	mgd	0.08	0.08	0.07	0.05	0.07	0.08	0.08	0.08
Dewatering Centrate									
Flow	mgd	0.82	0.75	0.59	0.50	0.73	0.79	0.78	0.80
Ammonia	lb-N/d	11,200	7,700	6,400	5,700	10,600	11,200	9,800	9,100

Notes

[A] The medium growth scenario assumes medium population growth for the service area and a medium growth scenario for the resource recovery (R2) program.

[B] The right-size R2 scenario assumes elimination of protein and dairy dissolved air floatation thickening (DAFT) trucked waste streams from the high strength waste (HSW) receiving station.

[C] Dry biogas outputs from BioWin were converted to standard cubic feet per minute by accounting for temperature and pressure: [dry biogas, cfm]*(68+460)/(104+460)*((0.2+14.7)/14.7). This calculation matches the process used in the Plant-Wide Process Model validation task.

[D] Dewatered cake solids were corrected according to findings from the C60 Plant-Wide Process Model task report that cake solids dry solids load was 29 percent higher than the calibration data; BioWin total suspended solids loading values were divided by 1.29 for No Changes to R2, or the [Struvite + Vivianite + Brushite Formation] solids load was subtracted and the resulting load was then divided by 1.19 to correct BioWin overpredictions for scenarios with changes to R2.

Table W-4: 2050 Influent Flows and Loads and Process Model Results Medium Growth Scenario and Reduced R2 Scenarios

Parameter	Units	2050 - MWWTP BioWin Simulations Results							
		Medium Growth Scenario [A]	Right-Size R2 [B]	No HSW	No R2	No LSW	No FOG	No Dairy DAFT	No Protein
Plant Influent (Raw Influent plus Low Strength Waste [LSW])									
Flow	mgd	66.0	66.0	66.0	65.4	65.4	66.0	66.0	66.0
Total Suspended Solids	lb/d	260,000	260,000	260,000	230,400	230,400	260,000	260,000	260,000
Inert Suspended Solids	lb/d	39,000	39,000	39,000	25,900	25,900	39,000	39,000	39,000
Secondary Influent									
Total Suspended Solids	lb/d	103,800	103,600	103,300	90,500	91,000	103,800	103,700	103,700
Inert Suspended Solids	lb/d	16,300	16,200	16,000	10,800	11,000	16,300	16,300	16,300
Total Kjeldahl Nitrogen	lb-N/d	45,500	41,900	40,600	38,100	43,100	45,500	44,100	43,300
Final Effluent									
Total Suspended Solids	lb/d	9,200	9,100	9,000	7,100	7,200	9,200	9,200	9,200
Total Nitrogen	lb-N/d	34,200	30,700	29,500	28,900	33,800	34,200	32,800	32,100
Total Inorganic Nitrogen	lb-N/d	32,400	28,900	27,700	27,300	32,100	32,400	31,100	30,300
Digester Feed (Blend Tank Effluent)									
Total Suspended Solids	lb/d	367,400	354,400	311,600	262,400	317,300	368,400	364,000	357,800
Inert Suspended Solids	lb/d	63,900	58,500	53,800	38,800	48,500	63,500	61,800	62,000
Digester Gas and Potential Phosphate Precipitation Production									
Digester Gas [C]	scfm	3,100	2,850	1,550	1,450	3,000	3,100	3,100	2,850
Struvite + Vivianite + Brushite	lb/d	12,300	10,600	8,000	7,300	11,600	11,900	11,400	11,600
Dewatering Feed									
Flow	mgd	0.99	0.92	0.75	0.63	0.87	0.96	0.94	0.97
Total Suspended Solids	lb/d	195,500	185,800	165,700	126,100	154,500	193,800	191,500	190,100
Inert Suspended Solids (not adjusted for struvite)	lb/d	69,100	64,100	56,000	41,100	54,100	68,400	66,900	66,800
Volatile Suspended Solids	lb/d	126,400	121,700	109,700	85,000	100,400	125,300	124,600	123,300
Dewatered Cake									
Dry Tons per Day [D]	ton/d	72.7	70.5	63.5	47.8	57.4	73.2	72.1	71.8
Wet Tons per Day @ 24 percent Solids	wet ton/d	303	294	264	199	239	305	301	299
Flow	mgd	0.09	0.09	0.08	0.06	0.07	0.09	0.09	0.09
Dewatering Centrate									
Flow	mgd	0.90	0.83	0.67	0.57	0.80	0.87	0.85	0.88
Ammonia	lb-N/d	11,900	8,400	7,100	6,400	11,300	11,900	10,500	9,700

Notes

[A] The medium growth scenario assumes medium population growth for the service area and a medium growth scenario for the resource recovery (R2) program.

[B] The right-size R2 scenario assumes elimination of protein and dairy dissolved air floatation thickening (DAFT) trucked waste streams from the high strength waste (HSW) receiving station.

[C] Dry biogas outputs from BioWin were converted to standard cubic feet per minute by accounting for temperature and pressure: [dry biogas, cfm]*(68+460)/(104+460)*((0.2+14.7)/14.7). This calculation matches the process used in the Plant-Wide Process Model validation task.

[D] Dewatered cake solids were corrected according to findings from the C60 Plant-Wide Process Model task report that cake solids dry solids load was 29 percent higher than the calibration data; BioWin total suspended solids loading values were divided by 1.29 for No Changes to R2, or the [Struvite + Vivianite + Brushite Formation] solids load was subtracted and the resulting load was then divided by 1.19 to correct BioWin overpredictions for scenarios with changes to R2.