



King County

Department of

Natural Resources and Parks

Wastewater Treatment Division

King County Wastewater Treatment Division Puget Sound Nutrient General Permit: 2022 Annual Report

BRIGHTWATER, SOUTH PLANT, AND WEST POINT TREATMENT
PLANTS

March 2023

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Appendix A Declaration of Nitrogen Removal Optimization Selection

Abbreviations

ABAC	ammonia-based aeration control
AVN	ammonia vs. nitrite plus nitrate
BOD	biochemical oxygen demand
Brightwater	Brightwater Treatment Plant
BWABO	Brightwater Aeration Basin Optimization
County	King County
DO	dissolved oxygen
Ecology	Washington State Department of Ecology
g	gram(s)
HPO	high-purity oxygen
L	liter(s)
lb	pound(s)
LE	Ludzack-Ettinger
MBR	membrane bioreactor
mg	milligram(s)
mgd	million gallons per day
mL	milliliter(s)
MLE	modified Ludzack-Ettinger
N	nitrogen
NO ₃	nitrate
NPDES	National Pollutant Discharge Elimination System
OGADS	Oxygen Generation and Dissolution System
PAO	phosphorus-accumulating organism
PSNGP	Puget Sound Nutrient General Permit
RAS	return activated sludge
SND	simultaneous nitrification and denitrification
SIU	significant industrial user
South Plant	South Treatment Plant
SRT	solids retention time
SVI	sludge volume index
TIN	total inorganic nitrogen
TN	total nitrogen
TSS	total suspended solids
VFA	volatile fatty acid
WAS	waste activated sludge
West Point	West Point Treatment Plant
WRF	Water Research Foundation
WRRF	water resource recovery facility

WTD	(King County) Wastewater Treatment Division
WWTP	wastewater treatment plant
yr	year(s)

1.0 Introduction

This report fulfills the Washington State Department of Ecology's (Ecology) [Puget Sound Nutrient General Permit](#) (PSNGP) annual reporting requirements for the King County Wastewater Treatment Division's (WTD) wastewater treatment plants (WWTPs) with dominant total inorganic nitrogen (TIN) loads. WTD operates three treatment plants with dominant TIN loads: South Treatment Plant (South Plant), Brightwater Treatment Plant (Brightwater), and West Point Treatment Plant (West Point), which are covered by the PSNGP under a bubbled action level. Table 1-1 presents a crosswalk indicating where the annual report information required by the PSNGP can be found.

Table 1-1. PSNGP annual report requirements crosswalk for dominant TIN loads

Question No. ^a	PSNGP Section	PSNGP Appendix C Question ^a	WTD Response ^b	WTD 2022 Annual Report section
1.	S4.C.2.b.i	Did your facility stay below the Action Level in S4.b, Table 5 or Table 6 for the jurisdiction with a bubbled action level?	Yes	Sub-section 3.3, Table 3-2, Figure 3-1
1a.		Attach a document listing the contribution of each of your individual facilities to the total bubble allocation for the reporting period	Attachment	
2.	S4.C.2.b.i	Did your facility stay below a 10 mg/L annual average TIN concentration?	No	N/A
3.	S4.C.1.a	Attach a document describing the assessment method applied to evaluate the existing treatment process.	Attachment	Section 2.0 (Sub-section 2.1–2.2)
4.	S4.c.1.a.i	What is your pre-optimization TIN removal rate, expressed as a percentage?	-1.0%	Sub-section 2.2, Table 2-2
5.	S4.C.1.a	Attach a document explaining your initial approach for optimization.	Attachment	Section 2.0 (Sub-section 2.3)
6.	S4.C.1.a.ii	Did you maintain and/or update your assessment approach after year 1?	N/A	N/A
7.	S4.C.1.b	Do viable optimization strategies exist for your current treatment process?	Yes	Sub-section 2.4
7a.	S4.C.1.a.ii	Attach a document listing and prioritizing the potential optimization strategies capable of meeting your action level that were developed for S4.C.1.a.ii.	Attachment	
8.	S4.C.1.b	Did all of the potential optimization strategies you identified and evaluated for S4.C.1.b have a reasonable implementation cost and timeframe?	No	
9.	S4.C.1.c	Attach a document describing your preferred optimization strategy for implementation in 2022 (due July 1).	Attachment	Appendix A

Question No. ^a	PSNGP Section	PSNGP Appendix C Question ^a	WTD Response ^b	WTD 2022 Annual Report section
10.	S4.C.1.c	What is the expected performance for the selected optimization strategy?	Removal of 720,000 lb TIN	Sub-section 2.5, Table 2-8
11.	S4.C.2.a	Attach a document describing optimization plan implementation including start date, schedule for full implementation, initial costs, and challenges including impacts to other measures of treatment plant performance.	Attachment	Section 3.0
12.	S4.C.2.b.ii	What TIN removal rate was observed during the reporting period?	2.5% TIN removal	Sub-section 3.3, Table 3-3 and 3-4
13.	S4.C.3.a, S4.C.3.b	Attach a document describing your ongoing investigations to reduce influent TIN loads from septage handling practices, commercial, dense residential and industrial sources.	Attachment	Section 4.0
14.	S4.D.1.a and S4.D.1.b	(If Q1=No and Q7 = Yes) N/A	N/A	N/A
15.	S4.D.2	(If Q1 = No and Q7 = No) N/A	N/A	
16.	S4.D.2.a	(If Q1 = No in two prior years) N/A	N/A	
17.	S4.E	N/A	N/A	
18.	S7, S9.A	Did you submit discharge monitoring reports according to the required schedule? If no, attach a document describing/listing the missing records and corrective actions taken/or planned.	Yes	N/A
19.	S9.F	Are you retaining all applicable records? If no, attach a document describing/listing the missing records and corrective actions taken and/or planned.	Yes	N/A
20.	S9.G	Did you follow non-compliance notification requirements? If no, attach a document describing the non-compliance and the corrective actions taken and/or planned.	Yes	N/A

N/A = not applicable; light grey text indicates tasks that are included in the PSNGP Appendix C list of questions, but do not appear in Ecology's WQWebPortal this year.

a. As it appears in Ecology's WQWebPortal.

b. Per response options available in the online form via Ecology's WQWebPortal.

2.0 Optimization Planning

The PSNGP became effective January 1st, 2022. WTD's permit coverage began April 1, 2022. WTD's optimization planning efforts for South Plant, Brightwater, and West Point were undertaken to identify available optimization strategies, focusing analysis on the strategies that could be implemented within existing facility design. This section describes the treatment process performance of the existing facilities, the approach used to identify nitrogen (N) removal optimization strategies, and initial selection of optimization strategies for implementation.

2.1 Treatment Process Performance Assessment

The nitrogen removal potential of the current treatment processes at WTD's facilities was evaluated with process modeling software, GPS-x, from Hatch Hydromantis. A plant-specific GPS-x process model was calibrated and used for evaluating both baseline (existing 2020 and 2021 operation) and optimization (ongoing and future process changes) strategies at each facility.

2.2 Treatment Process Background

This section presents background on the three treatment plant processes that are relevant to nitrogen removal optimization. Table 2-1 provides a link to general process descriptions for each of the treatment plants.

Table 2-1. General process descriptions

Treatment plant	Treatment plant process: https://kingcounty.gov/depts/dnrp/wtd/system/treatment-process.aspx
South Plant	Conventional activated sludge secondary treatment
Brightwater	Advanced treatment with membrane bioreactor (MBR)
West Point	High-rate pure-oxygen activated sludge secondary treatment

2.2.1 South Plant Process

South Plant's treatment process was assessed for potential optimization opportunities. South Plant enables potential optimization through several design features:

- South Plant is a conventional air-activated sludge high rate, low cell residence time secondary treatment system that was designed for operation with an anaerobic selector. The anaerobic selector supports the growth of phosphorus-accumulating organisms (PAOs) that provide enhanced settleability in the secondary clarifiers. Though not the intended process, the design of the facility has allowed South Plant to partially nitrify and denitrify seasonally in a Ludzack-Ettinger (LE) mode.

- South Plant can isolate aeration basin 1 and secondary clarifiers 1 through 4 (referred to as “pod 1”) to operate as a separate and independent process train. This ability is relevant because it would allow for one process train to be operated with an anaerobic selector to promote the growth of PAOs, while allowing the other aeration basins and secondary clarifiers to operate in an LE mode for nitrogen removal optimization. Furthermore, the solids from the isolated train containing PAOs could be seeded into the other three aeration basins to prepare for wet weather operation.
- Aeration basins at South Plant are configured with flexibility to manually adjust feed to different locations within the tanks during high flows (known as step-feed), though significant capital modifications would be needed to optimize this configuration for nitrification/denitrification operation on a seasonal basis.

2.2.2 Brightwater Process

Brightwater, which began operations in 2011, is a membrane bioreactor (MBR) facility that uses a diffused-air aeration biological process. During peak flow events at Brightwater, base flow is treated through the MBR process; flows in excess of the MBR capacity can be treated through chemically enhanced primary treatment and combined with the MBR treated flow. Currently, if Brightwater secondary treatment capacity were to be exceeded, excess flow would be redirected to South Plant, if capacity is available, or stored, before chemically enhanced primary treatment operation would be used.

Brightwater’s treatment process was assessed for potential optimization opportunities:

- The MBR process at Brightwater is designed for a sufficiently long solids retention time (SRT) for full biological nitrification, but only limited denitrification. Although the Brightwater biological reactors are configured as a modified Ludzack-Ettinger (MLE) process (i.e., anoxic and aerobic zones with internal mixed liquor return from the end of the aeration zones to the front of the anoxic zone), the small anoxic zone volume limits the extent of denitrification that is possible with the existing configuration.
- A capital project, the Brightwater Aeration Basin Optimization (BWABO) project, is currently being implemented. The two key project enhancements are: (1) new automated aeration valves and controls to allow more precise control of dissolved oxygen (DO) levels and (2) a classifying selector to improve surface wasting and foam removal from the aeration basins to improve and automate SRT control. The BWABO project will improve denitrification, thereby decreasing air use and decrease chemical addition for pH control and improving the operation of the aeration basins. Improvements to be implemented with zone control include control of DO in all four zones in the aeration basins, and ammonia-based aeration control (ABAC). Substantial completion and full transition to the ABAC strategy is expected to occur by 2024. Future trials using

simultaneous nitrification and denitrification (SND) are planned. Both ABAC and SND operation will also allow increased nitrogen removal (through enhanced denitrification) relative to current process operations.

2.2.3 West Point Process

West Point is a high-purity oxygen (HPO) activated sludge secondary treatment plant currently rated for 215-mgd maximum month flow under the National Pollutant Discharge Elimination System (NPDES) permit. The secondary biological treatment facilities commenced operation in 1995. West Point receives combined sewer flows (wastewater and stormwater) and was designed to provide secondary treatment up to a peak flow of 300 mgd. West Point wastewater flows exceeding 300 mgd (up to 440 mgd) receive primary treatment only. West Point's process provides limited nitrogen removal optimization opportunities.

2.2.4 Pre-optimization Effluent TIN Removal Rate

Table 2-2 summarizes previous effluent TIN performance data (observed prior to optimization). The coefficient of variation values for annual loading indicate that effluent TIN loading varied significantly from year to year at each WWTP, but that the bubbled values for the entire system varied significantly less. Standard deviation values are based on 3 years of record.

Influent TIN loading (and subsequent effluent TIN) for each plant is subject to the effect of flow swaps between plants, increase or decrease in inflow and infiltration, population growth, and the lower distribution of population in downtown Seattle due to Covid-19 pandemic impacts on work locations and residency.

Modeling results, as opposed to data from previous years, were used to identify anticipated pre-optimization results for several reasons: (1) modest amounts of optimization were tested at South Plant in previous years, so previous data do not strictly represent preoptimization conditions; (2) influent loadings in 2022 varied slightly from previous years; and (3) using modeled results for the current year establishes a procedure for assessing optimization performance in future annual reports.

Table 2-2. Observed effluent TIN loadings and pre-optimization TIN removal rate

Parameter	South Plant	Brightwater	West Point	Bubbled ^a
PSNGP action level, lb TIN/yr	7,340,000	1,810,000	6,670,000	15,820,000
Measured effluent TIN				
2019 data, lb TIN/yr	6,410,000	1,840,000	6,660,000	14,910,000
2020 data, lb TIN/yr	8,080,000	1,750,000	5,980,000	15,800,000
2021 data, lb TIN/yr	7,300,000	2,030,000	6,100,000	15,430,000
Mean (2019–2021), lb TIN/yr	6,850,000	1,830,000	6,460,000	15,350,000

Parameter	South Plant	Brightwater	West Point	Bubbled ^a
Standard deviation (2019–2021), lb TIN/yr	1,000,000	120,000	290,000	420,000
Coefficient of variation (standard deviation/mean), percent	14.6%	6.6%	4.5%	2.7%
2022 modeled pre-optimization TIN removal rate (%)^b	14.2%	4.0%	-23.4%	-1.0%

a. Compliance is based on bubbled values.

b. Modeled pre-optimization TIN removal rate, % =
$$\frac{\text{Total Infl TIN}_{\text{All Plants, projected}} \left(\frac{\text{lb}}{\text{yr}} \right) - \text{Total Eff TIN}_{\text{All Plants, projected}} \left(\frac{\text{lb}}{\text{yr}} \right)}{\text{Total Infl TIN}_{\text{All Plants, projected}} \left(\frac{\text{lb}}{\text{yr}} \right)} \quad \text{Eq. 1}$$

2.3 Identification of Potential Optimization Strategies

WTD used the tools described in Water Research Foundation (WRF) Project 4973, *Guidelines for Optimizing Nutrient Removal Plant Performance*

(<https://www.waterrf.org/research/projects/guidelines-optimizing-nutrient-removal-plant-performance>) to identify potential optimization strategies.

The stated goal for WRF 4973 is to “provide guidance for optimizing Water Resource Recovery Facilities/Wastewater Treatment Plants to reduce nutrient loads discharged to receiving water bodies.” The report describes a process to identify strategies that can be used by facilities to achieve one or more of three optimization objectives for the target nutrient(s): (1) increase the mass of nutrients removed in treatment, (2) improve treatment reliability, and (3) reduce cost (capital and operations and maintenance).

The document includes 28 decision trees to guide users through a series of decision points, ending with a list of potential strategies that a utility can evaluate further for their specific needs. The outcome from the WRF 4973 guidance is a series of potential optimization strategies to reduce discharged nitrogen. The WRF 4973 strategy list was developed to cover a broad range of treatment processes and configurations, and not all available strategies may apply to a specific facility. General guidance fact sheets provide additional information for the potential optimization strategies identified.

To apply the WRF 4973 method to WTD’s regional treatment plants, site-specific decision analysis was used to create a list of potential optimization strategies for the specific application and conditions, tailored to the unique characteristics and operating conditions at each individual WTD facility, to identify the most attractive strategies. These potential strategies were evaluated, eliminated or selected, and then prioritized, as detailed in Sections 2.4 and 2.5.

2.3.1 South Plant Potential Optimization Strategies

A list of potential optimization strategies developed from the site-specific decision analysis for South Plant was created. Not all strategies were viable, as detailed in Sections 2.4 and 2.5. The potential strategies for South Plant were as follows:

- **Full plant in LE mode:** This strategy would operate the entire secondary biological process in the LE mode. SRT would be increased to initiate nitrification. Nitrate (NO_3) in the return activated sludge (RAS) would be recycled to the first pass of the aeration basin, which would operate as an anoxic zone to denitrify the mixed liquor.
- **Full plant in MLE mode:** This strategy is a modification of the prior strategy, full plant in LE Mode, which emerged during discussions with WTD staff. This strategy would require capital investment to add internal recycle to the biological process so that nitrates can be recycled to the anoxic zone for denitrification.
- **Aeration basin 1/clarifier pod 1 only in LE mode:** This strategy would operate only aeration basin 1/pod 1 in LE mode. This would reduce operating risks, but would also reduce the nitrogen removal rate compared to full plant in LE mode.
- **Aeration basin 1/clarifier pod 1 in PAO configuration, remaining trains in LE mode:** For this strategy, aeration basin 1/pod 1 would be separated and operated independently to grow PAOs. The remaining process would operate in LE mode to optimize nitrogen removal. Waste activated sludge (WAS) from aeration basin 1/pod 1 would be used to “seed” or bioaugment the remainder of the biological process with PAOs to improve settleability.
- **Step feed:** For this strategy, primary effluent would be distributed to both pass 1 and pass 3. Denitrification would occur in the anoxic zones immediately following primary effluent addition. Nitrification would occur in aerated zones, consisting of the second half of pass 1, pass 2, the second half of pass 3, and all of pass 4. Unlike the LE strategy described above, this strategy consists of two denitrification zones, both with carbon addition.
- **Contact stabilization:** For this strategy, the biological process would be operated in a modified contact stabilization mode. RAS, containing ammonia, would be routed to pass 1 for nitrification. Denitrification would occur in pass 2, where primary effluent is added. Passes 3 and 4 would be configured as aerated zones for nitrification.
- **Simultaneous nitrification and denitrification:** This strategy would operate the biological process at low DO levels to promote SND. A high SRT would be maintained to promote nitrification.

2.3.2 Brightwater Potential Optimization Strategies

A list of potential optimization strategies was developed for Brightwater. Some of the potential strategies at Brightwater can be combined and some have already been implemented. Not all

strategies were viable, as detailed in Sections 2.4 and 2.5. The potential strategies for Brightwater were as follows:

- **All-zone control at low DO without classifying selector:** This strategy would implement low-DO set points across all aeration zones to promote SND prior to the classifying selector in the BWABO project being constructed.
- **Zone 1 control at low DO without classifying selector:** This strategy would operate zone 1 at a low-DO set point in an effort to “extend” the anoxic zone and aim to achieve some degree of SND prior to the classifying selector being constructed.
- **Cyclic aeration:** This strategy would configure the aeration system controls so that aeration cycles on and off between the existing aerated zones, creating additional anoxic zones for denitrification.
- **Reduced primary sedimentation tanks in service:** This strategy would increase carbon supply to the biological process, with the goal of increasing anoxic zone denitrification.
- **Magnesium hydroxide addition for filterability optimization:** This strategy would be to continue the pilot use of magnesium hydroxide for alkalinity addition (and ultimately construct a permanent installation) to enhance membrane filterability, thus allowing more flow to be treated through Brightwater, particularly during winter, versus prior conditions with caustic addition.
- **Primary sludge blanket fermentation testing for increased volatile fatty acid (VFA) production:** As a first step, testing could be done to inform the potential benefits and/or viability of this strategy prior to proceeding with any physical plant modifications required for implementation. Ultimately, if selected, a permanent version of this strategy would increase readily degradable carbon supply to the biological process required for enhanced denitrification, or decrease the need for carbon addition for denitrification.
- **Reduced RAS channel aeration:** This strategy would be to continue and further reduce the air agitation rate in the RAS channel to reduce the amount of oxygen recycled to the first aerobic zone, which may be necessary to achieve low-DO aeration strategies particularly aimed at SND.
- **Reduced membrane scouring aeration:** This strategy would be to (continue) to reduce the membrane air scouring rate to reduce the amount of oxygen recycled to the first aerobic zone, which may be necessary to achieve low-DO aeration strategies particularly aimed at SND.
- **Reduced RAS rate:** This strategy would be to reduce the RAS pumping rate to reduce the amount of oxygen recycled to the first aerobic zone, which may be necessary to achieve certain low-DO aeration strategies particularly aimed at SND. The reduced RAS rate may need to be coupled with changes in the mixed liquor return rate and membrane performance.

- **Testing of supplemental carbon addition to anoxic zone with manual dose set point:** This strategy would add a temporary, readily degradable carbon supply to the anoxic zone to test the degree of enhanced denitrification that is achievable.
- **All zone control at low DO with classifying selector:** This strategy would implement low-DO set points across all aeration zones to promote SND once the BWABO project construction is complete.
- **ABAC at low DO with classifying selector:** This strategy would implement ABAC once the BWABO project construction is complete. ABAC can improve denitrification when combined with operation at low DO concentrations to select for low-DO-adapted nitrifying organisms.
- **Anoxic zone hydraulic improvements:** This strategy would modify the anoxic zone configuration (piping and/or mixers) to potentially improve mixing and denitrification.
- **Primary scum collection improvements:** This strategy would improve primary scum removal to reduce fats, oils, and grease carryover into aeration basins and the associated growth of filamentous organisms. This, along with the classifying selector, would improve the chances of mitigating the buildup of filamentous bacteria that typically are present at low DO concentrations.
- **Supplemental carbon addition to anoxic zone with automated nitrate-based control:** This strategy would increase the readily degradable carbon supply to the existing anoxic zone with a permanent system to enhance denitrification.
- **Baffling between aeration zones:** This strategy would install baffles between the aeration zones to optimize new zone DO control capability and create distinct well-controlled DO zones.
- **Increased internal mixed liquor recirculation:** This strategy would increase internal mixed liquor recirculation to enhance denitrification.
- **Ammonia vs. nitrite plus nitrate (AVN) aeration control:** AVN-based aeration control is a strategy that can be used to reduce energy demand and improve denitrification via low DO concentrations once the BWABO project construction is complete.
- **Partial granulation testing and implementation:** Partial granulation using WAS hydrocyclones (InDense by World Water Works) may improve sludge filterability and/or floc structure, leading to various process benefits and optimization opportunities.
- **Conversion of unused primary sedimentation tanks to anoxic reactors:** This strategy would modify two primary sedimentation tanks for use as anoxic biological reactors to increase denitrification capacity.
- **Sidestream equalization:** This strategy would modify a primary sedimentation tank to equalize centrate loading to the biological process to improve nitrogen removal.

- **Zone 4 as post-anoxic zone with supplemental carbon addition:** This strategy would create more anoxic volume and increase denitrification and thus TIN removal by converting zone 4 to a swing post-anoxic zone with supplemental carbon addition.
- **Primary sedimentation blanket fermentation and elutriation:** This strategy would increase readily degradable carbon supply to the biological process to enhance denitrification by fermenting primary sludge and introducing the VFAs produced into the secondary influent.

2.3.3 West Point Potential Optimization Strategies

A list of potential optimization strategies was developed for West Point. Not all strategies were viable, as detailed in Sections 2.4 and 2.5. The potential strategies for West Point were as follows:

- **Reduced biomass wasting to raise SRT:** This strategy would increase the SRT by reducing wasting and operating the secondary biological process to nitrify wastewater.
- **Conversion of biological process to LE-HPO:** This strategy would increase the SRT to initiate nitrification and to configure the biological process to an LE mode. The RAS rate would be increased to return nitrates to the first zone, which would be converted to an anoxic (unaerated) configuration, for denitrification.
- **Conversion of biological process to MLE-HPO:** This strategy would be similar to the LE-HPO strategy, with the addition of internal mixed liquor recirculation to transfer nitrates from the final stage to the first anoxic stage and increase total nitrogen (TN) removal.
- **Conversion to MLE-HPO with modification to in situ oxygenation:** This strategy would be similar to the MLE-HPO strategy except that one or more HPO stages would be converted from closed to open configuration and the existing mixers would be replaced with in-situ oxygenation (by Praxair) equipment.
- **Reduced biomass wasting and operating in step-feed mode:** This strategy would increase SRT to initiate nitrification and to operate in a step-feed mode by dedicating at least one stage to anoxic operation and the other three stages to HPO operation. A portion of the primary effluent would be fed to the anoxic zone to supply carbon for denitrification.
- **Chemically enhanced primary treatment:** This strategy would add chemicals to enhance primary treatment total suspended solids (TSS) and biochemical oxygen demand (BOD) removal efficiency to free up treatment capacity in the secondary bioreactors and increase the potential to nitrify. Chemically enhanced primary treatment impacts to the digestion process would have to be considered.

2.3.4 System-wide Potential Optimization Strategies

During the development of the site-specific optimization analysis for each treatment plant, several system-wide potential optimization strategies were also developed that were based on optimization outside of the individual plant boundaries. Similar to the site-specific analysis for each treatment plant, not all strategies were viable, as detailed in Sections 2.4 and 2.5.

Currently, there are active reclaimed water programs at both Brightwater and South Plant. Potential optimization strategies involving reclaimed water were identified during the development of system-wide potential strategies. WTD will continue to serve existing reclaimed water customers and add new customers where feasible.

Reclaimed water flow and TN, total Kjeldahl nitrogen, nitrate-nitrites, and ammonia concentration sampling are reported monthly for Brightwater (Reclaimed Water Permit ST0045498) and South Plant (Reclaimed Water Permit ST007445). Annual reclaimed water use volume from each customer is reported in the Brightwater Annual Summary Report, per requirement R.3.B of the Brightwater Reclaimed Water Permit. South Plant's annual reclaimed water use summary plan, per requirement R4.C, includes estimates of reclaimed water use for each customer.

Limited nitrogen reduction is anticipated because customer use is outside of WTD's control. However, expanded use of reclaimed water will be explored further in the Nutrient Reduction Evaluation as an alternative effluent management strategy.

The list of other system-wide potential optimization strategies developed are as follows:

- **System-wide Bioxide use reduction:** Bioxide (calcium nitrate) is used in the conveyance system to control odor and corrosion by reducing sulfides. Limiting Bioxide use may reduce WWTP influent nitrogen loadings, but the effect is minimal. Bioxide addition is already controlled to minimize nitrate discharged from the force mains it is applied to, and thus has limited to no impact on influent and effluent of facilities because nitrate is consumed in the process. WTD has three dose set points for summer, winter, and spring/fall. This strategy could cause increased odor and corrosion in the collection system and a substitute chemical may require more complicated chemical handling or mechanical systems.
- **Control odor and corrosion in Hollywood force main through use of nitrified Brightwater effluent (reclaimed water):** This strategy would convey up to 2 mgd of Brightwater reclaimed water, which has a high nitrate content, to the Hollywood Pump Station. This strategy modifies the prior strategy, substituting Bioxide with reclaimed water. Hollywood is a preferred location because (1) a reclaimed water pipeline exists and (2) Bioxide consumption is high there. Nitrates in reclaimed water will function in the same manner as nitrates in Bioxide to minimize odors and corrosion in the force main

and downstream piping, with reduced chemical costs. This strategy is preferable to the prior strategy, but involves piping modifications (capital costs) and potential impacts on the reclaimed water supply for other reclaimed water customers with only minimal reduction in effluent nitrogen loading.

- **Increase winter flow to Brightwater from East Section:** Brightwater has historically achieved greater nitrogen removal in the winter than WTD's other two regional WWTPs. This strategy would develop a flow management strategy and operation to prioritize Brightwater maximizing its winter flows. Implementing flow diversion capital projects is required to make this strategy possible.
- **Increase flow to Brightwater from West Section:** The Kenmore Pump Station normally discharges to the West Section. By manually adjusting flow control gates, 2 to 4 mgd of wastewater can be backed up to flow to Brightwater. Brightwater has more nitrogen removal potential than West Point, particularly during winter conditions. Feasibility, odor control, and operational complexity are barriers for this strategy.
- **Incentivize industrial users to increase carbon supply for denitrification:** Significant industrial users (SIUs) are currently assessed a surcharge for high-strength organic wastes. This strategy would involve relaxing the requirement to pay this fee and incentivizing industrial users to divert their carbon supply directly to the WWTP to increase wastewater carbon content. This will be a more attractive option if an industrial source with high carbon content can be isolated, concentrated, conveyed, and stored at the WWTPs. Seasonal timing and delivery of a carbon source may dictate feasibility of this strategy. Currently, there are no readily available industrial wastewater sources that meet the above criteria. WTD surcharge treatment fees are low compared to other West Coast utilities and thus may not provide sufficient economic incentive for this strategy.

2.4 Evaluation of Optimization Strategies and Prioritization

Once potential optimization strategies were identified, analyses were conducted to further refine the strategies, and evaluation criteria were developed. Where the potential optimization strategy involved a process change (i.e., either a modification of operational procedure or addition of a capital improvement), process modeling with GPS-x was conducted to assess the impact on effluent TIN.

To identify viable optimization strategies, cost and implementation timeframe criteria were developed. The timeline to select and begin implementing an optimization strategy by July 1, 2022, restricted potential initial optimization strategies to those that had a "reasonable implementation cost and timeframe," per PSNGP S4.C.1.b.

WTD defined "reasonable" as potential optimization strategies that met the following criteria:

- **Action level:** Anticipated to reduce effluent TIN load to avoid exceeding the bubbled action level.
- **Timeframe:** Could be implemented immediately, without operational testing and without capital improvements.
- **Cost:** Without capital improvements, meaning in the cost category of “none” to “very low” (\$0–\$100,000) displayed in Table 2-2 and could be achieved with existing budget allocation.

Immediate implementation and low cost significantly limited viable initial optimization strategies and, together, became the primary evaluation criterion. Potential optimization strategies in the “high,” “very high,” and “extremely high” cost categories would require significant investment and are not practical optimization strategies, but may be evaluated in future nutrient reduction planning efforts. Future optimization may consider whether pilot testing or other development activities of high-cost potential optimization strategies should be conducted.

Rough order-of-magnitude opinions of capital costs were developed for optimization strategies, and were assigned a capital cost category, as shown in Table 2-2. Detailed cost analysis per the Association for the Advancement of Cost Engineering was not performed.

Table 2-3. Capital cost category for optimization

Category*	Range upper limit
None	\$0
Extremely low	\$20,000
Very low	\$100,000
Low	\$500,000
Moderate	\$5,000,000
Moderately high	\$10,000,000
High	\$50,000,000
Very high	\$100,000,000
Extremely high	\$200,000,000+

*Green denotes viable cost categories; red denotes cost categories that exceed optimization and would require further evaluation in a long-term planning effort, such as the Nutrient Reduction Evaluation.

A series of workshops was conducted with WTD staff using the aforementioned criteria to select optimization strategies for implementation. At the workshops, WTD staff also identified potential optimization strategies that may be feasible but would require further development and, therefore, may be re-evaluated in future years as part of adaptive management.

Tables 2-4 through Table 2-7 document the potential optimization strategies for South Plant, Brightwater, and West Point as well as system-wide. Strategies that were eliminated do not meet the above criteria action level, timeframe, or cost and will not be considered further in optimization planning. Eliminated strategies may be reconsidered in the future if planning

assumptions change. If planning assumptions hold, eliminated strategies will not be considered further.

Table 2-4. South Plant nitrogen removal potential optimization strategies

Strategy	Capable of meeting bubbled action level?	Construction cost estimate	Implementation time	Viable to meet bubbled action level in 2022? If not, why?	Next steps
Prioritized strategies					
1. Full plant in LE mode	Yes	Very low	Immediate	Yes	Implement for 8 months per year or more
2. Aeration basin 1/pod 1 in PAO configuration, remaining trains in LE mode	Yes	Low	Immediate	Yes	Re-evaluate as part of adaptive management
3. Step-feed mode	Yes	Moderate	5–8 years	No (time)	Re-evaluate as part of adaptive management
4. Full plant in MLE mode	Yes	Moderately high	5–8 years	No (time, cost)	Re-evaluate as part of adaptive management
Eliminated strategies					
Aeration basin 1/pod 1 only in LE mode	No	Very Low	Immediate	No (low TIN reduction)	Eliminated
Contact stabilization mode	Yes	Moderate	5–8 years	No (time, cost)	Eliminated
SND	Yes	Moderately high	5–8 years	No (time, cost)	Eliminated

Table 2-5. Brightwater nitrogen removal potential optimization strategies

Strategy	Capable of meeting bubbled action level?	Construction cost estimate	Implementation time	Viable to meet bubbled action level in 2022? If not, why?	Next steps
Prioritized strategies					
1. All-zone control at low DO with classifying selector (BWABO project)	No	High	2 years (underway)	No (time)	Being implemented
2. ABAC at low DO with classifying selector (BWABO project)	No	High	2 years (underway)	No (time)	Being implemented
3. All-zone control at low DO without classifying selector	No	Very Low	Immediate	No (low TIN reduction)	Trial. Re-evaluate as part of adaptive management
4. Primary scum collection improvements	No	Low	5–8 years	No (time, low TIN reduction)	Re-evaluate as part of adaptive management
5. Anoxic zone hydraulic improvements	No	Moderate	8+ years	No (time, cost, low TIN reduction)	Re-evaluate as part of adaptive management
6. Sidestream equalization	No	Moderate	8+ years	No (time, cost)	Re-evaluate as part of adaptive management
Previously implemented strategies					
Reduced primary sedimentation tanks in service	No	Extremely low (implemented)	Immediate	No (low TIN reduction)	Already implemented
Magnesium hydroxide addition for filterability optimization	No	Very low (implemented)	Immediate	No (low TIN reduction)	Already implemented, and installation of a permanent system has been recommended for capital implementation
Reduced RAS channel aeration	No	Very Low (implemented)	Immediate	No (low TIN reduction)	Already implemented
Reduced membrane scouring aeration	No	Low (implemented)	Immediate	No (low TIN reduction)	Already implemented
Eliminated strategies					
AVN aeration control with classifying selector	No	Low	5-8 years	No (time)	Eliminated
Zone 1 control at low DO without classifying selector	No	Low	Immediate	No (low TIN reduction)	Eliminated
Cyclic aeration	No	Low	5–8 years	No	Eliminated

Strategy	Capable of meeting bubbled action level?	Construction cost estimate	Implementation time	Viable to meet bubbled action level in 2022? If not, why?	Next steps
				(time, low TIN reduction)	
Primary sludge blanket fermentation testing for increased VFA production	No	Very low	Immediate	No (low TIN reduction)	Eliminated
Reduced RAS rate	No	Very low	Immediate	No (low TIN Reduction)	Eliminated
Supplemental carbon addition to anoxic zone with manual dose set point (testing)	No	Low	3–5 years	No (time, low TIN reduction)	Eliminated
Supplemental carbon addition to anoxic zone with automated NO ₃ -based control	No	Moderate	5–8 years	No (time, cost, low TIN reduction)	Eliminated
Baffling between aeration zones	No	Moderate	5–8 years	No (time, cost, low TIN reduction)	Eliminated
Increased internal mixed liquor recirculation	No	Moderate	5–8 years	No (time, cost, low TIN reduction)	Eliminated
Partial granulation testing and implementation	No	Moderate	5–8 years	No (Time, Cost, Low TIN Reduction)	Eliminated
Conversion of unused primary sedimentation tanks to anoxic reactors	No	Moderately high	5–8 years	No (time, cost, low TIN reduction)	Eliminated
Zone 4 as post-anoxic zone with supplemental carbon addition	No	Moderate	5–8 years	No (time, cost)	Eliminated
Primary sludge blanket fermentation and elutriation	No	Moderate	5–8 years	No (time, cost, low TIN reduction)	Eliminated

Table 2-6. West Point nitrogen removal potential optimization strategies

Strategy	Capable of meeting bubbled action level?	Construction cost estimate	Implementation time	Viable to meet bubbled action level in 2022? If not, why?	Next steps
Prioritized strategies					
None					
Potential strategies					
Reduced biomass wasting to raise SRT	No	Low	3–5 years	No (time, low TIN reduction)	Potentially re-evaluate as part of adaptive management
Eliminated strategies					
Conversion of biological process to LE-HPO	Unknown	High	10–20 years	No (time, cost)	Eliminated
Conversion of biological process to MLE-HPO	Unknown	Very high	10–20 years	No (time, cost)	Eliminated
Conversion to MLE-HPO with modification to in situ oxygenation	Unknown	Very high	10–20 years	No (time, cost)	Eliminated
Reduced biomass wasting and operate in step-feed mode	Unknown	High	10–20 years	No (time, cost)	Eliminated
Chemically enhanced primary treatment	No	Moderately high	10–20 years	No (time, cost, low TIN reduction)	Eliminated
Sidestream treatment	No	Very high	8–10 years	No (time, cost, low TIN reduction)	Eliminated

Table 2-7. System-wide nitrogen removal potential optimization strategies

Strategy	Capable of meeting bubbled action level?	Construction cost estimate	Implementation time	Viable to meet bubbled action level in 2022? If not, why?	Next steps
Prioritized strategies					
Continue to serve existing reclaimed water customers					
Eliminated strategies					
Control odor and corrosion in Hollywood force main through use of nitrified Brightwater effluent (reclaimed water)	No	Moderate	5–8 years	No (time, cost, low TIN reduction)	Potentially re-evaluate as part of adaptive management
System-wide Bioxide use reduction	No	Very low	1 year	No (low TIN reduction)	Eliminated
Increase winter flow to Brightwater from East Section	No	Extremely high	10–20 years	No (time, cost)	Eliminated
Increase winter flow to Brightwater from West Section	No	Very low	1–2 years	No (cost, feasibility)	Eliminated
Incentivize industrial users to increase carbon supply for denitrification	No	Low	3–5 years	No (cost, no carbon sources available)	Eliminated

2.5 Selected Optimization Strategies

Appendix A describes the selected optimization strategies for implementation in 2022. They are summarized here as follows:

- **South Plant:** Immediately implement full-plant LE mode to partially nitrify and denitrify wastewater. Operating in this mode all year would be challenging. Therefore, during the wet months (generally November through February), South Plant will be operated with limited or no nitrification and with an anaerobic selector to encourage growth of PAOs to enhance biological sludge settleability. South Plant has identified several potential capital projects required to support continued implementation of this and other potential optimization strategies. Capital budget was requested for the 2023 to 2024 biennium. In addition, priority and schedule of projects, such as the RAS piping replacement project, were accelerated. ***Operating in full-plant LE mode was the focus of 2022 activities at South Plant.***
- **Brightwater:** Sustain current operations and monitoring. Continue implementing the BWABO project, including trialing of low-DO control. ***Construction of the BWABO project was the focus of 2022 activities at Brightwater.***
- **West Point:** Sustain current operations and monitoring. During this stage, implementation of asset renewal and reliability projects, such as the Raw Sewage Pump Improvements and rehabilitation of the Oxygen Generation and Dissolution System (OGADS), will continue. These projects are necessary to improve WWTP redundancy and reliability to support potential future nitrogen removal optimization. ***Sustaining current operations, monitoring, and asset and reliability capital project implementation were the focus of 2022 activities at West Point.***
- **System-wide:** WTD will continue to serve existing reclaimed water customer connections at Brightwater and South Plant and add new users where feasible.

Preliminary estimates of anticipated nitrogen removal resulting from the optimization strategies adopted for implementation in 2022 were developed using GPS-X software. The estimates were informed by both past WWTP operating data as well as process modeling results.

Table 2-8 presents a summary of the simulated performance estimates for 2022, with and without optimization. Maximum and minimum values were determined by multiplying the coefficient of variation values in Table 2-3 by 2 and applying this factor to the mean values determined from process modeling. The maximum is then the mean plus 2 standard deviations and the minimum is the mean minus 2 standard deviations. Optimization is estimated to reduce bubbled TIN loading by 8 percent.

Table 2-8. Simulated (expected) 2022 performance for the selected optimization strategy/nitrogen optimization plan

Parameter	South Plant	Brightwater	West Point	Bubbled ^a
PSNGP action level, lb TIN/yr	7,340,000	1,810,000	6,670,000	15,820,000
Projected 2022 without optimization, lb TIN/yr				
Mean	6,636,000	1,909,000	7,015,000	17,000,000
Projected 2022 with optimization, lb TIN/yr				
Mean	5,767,000	1,909,000	7,015,000	14,690,000
Projected 2022 TIN removal rate ^d	25.5%	4.0%	-23.4%	4.7%

a. Compliance is based on bubbled value.

b. Maximum values are modeled mean values plus 2 times the coefficient of variation. Coefficient of variation was determined from Table 2-2.

c. Minimum values are modeled mean values minus 2 times the coefficient of variation. Coefficient of variation was determined from Table 2-2.

d. Projected actual TIN removal rate, % =
$$\frac{\text{Total Inf} TIN_{All\ Plants, projected} \left(\frac{lb}{yr} \right) - \text{Total Eff} TIN_{All\ Plants, projected} \left(\frac{lb}{yr} \right)}{\text{Total Inf} TIN_{All\ Plants, projected} \left(\frac{lb}{yr} \right)} \quad \text{Eq. 3}$$

3.0 Optimization Strategy Implementation

This section summarizes implementation of the selected optimization strategies during 2022, including an assessment of optimization performance.

3.1 Strategy Implementation

Section 2.5 identified the strategies selected for implementation during 2022 at South Plant, Brightwater, and West Point and in relation to system-wide considerations. This section summarizes how these strategies were implemented, including identification of operational challenges and information to guide future optimization efforts.

3.1.1 South Plant

South Plant implemented the optimization plan, which involved operating the full plant in an LE configuration. An LE configuration for South Plant includes the following:

- Increasing the SRT (by reducing WAS pounds) and mixed liquor suspended solids concentration to grow and maintain nitrifier and denitrifier biological populations
- Increasing the DO set points to provide oxygen for nitrification of ammonia to nitrate (significantly higher initially to grow up the nitrifier population)

- Increasing the RAS flow rate to return nitrate from the clarifiers to the front of the aeration basin to enhance denitrification (sometimes requiring both RAS pumps to operate instead of one being maintained in standby)
- Operating pass 1A in the aeration basins as an anoxic or anoxic/anaerobic selector to denitrify the recycled nitrate

The objective of this optimization strategy at South Plant was to maximize partial nitrification/denitrification and, hence, nitrogen removal, while maintaining required process operating conditions—in particular, sustaining the PAO population for enhanced settleability and keeping pH within NPDES permit limits.

In preparation for testing these optimization requirements, South Plant began operation in the LE configuration in late November 2021. Since then, it operated in the LE configuration through 2022 while making small and moderate adjustments to the secondary process along the way.

Below is a summary of key operational adjustments made at South Plant throughout 2022, in an adaptive management fashion, to examine the impacts of various process changes.

Observations of these key operational adjustments are summarized according to nutrient removal performance as well as operational challenges and impacts to other operating conditions. These observations are documented to inform subsequent phases of optimization.

- **November/December 2021:** South Plant began operating in an LE configuration. Within about 2 weeks of operating in this manner, nitrification and denitrification were relatively successful, resulting in an 8-mg/L effluent TIN reduction (an increase of 10 to 20 percent in TN removal) by early December.
- **Late December 2021:** The nitrification rate continued to increase into December, which resulted in depressed effluent pH values and the need for South Plant staff to adjust operation to stay in compliance with the pH limit in its NPDES permit. The DO set points were decreased to reduce nitrification. This reduced the alkalinity consumption and the resulting effluent pH depression.
- **January 2022:** South Plant returned to normal operation for a brief period to support other operational needs.
- **Late January–early April 2022:** South Plant returned to operating in LE configuration. Nitrogen removal performance in February was good (the TIN load was 21 percent below the PSNGP action level) and sludge volume indices (SVIs) remained good as well, generally in the 70- to 100-mL/g range, through early March. In addition, South Plant was not experiencing floating sludge in the secondary clarifiers or gas entrainment in the

digesters and digesting sludge. The effluent pH was still a constraint on nitrification and had dropped to as low as 6.28. The DO set points were adjusted according to laboratory results and effluent pH values. At this time, the mixed liquor SVIs began to climb (with a few results above 200 mL/g) even though phosphorus removal was relatively high, indicating a robust population of PAOs. Because flows were low during this time and most of the secondary clarifier tanks were in service, the impact of high SVIs on clarifier capacity was less of a concern and South Plant staff did not modify operation. The monthly TIN loads for South Plant for March and April were well below historical averages for these months, and the total nitrogen removal rate averaged 54 percent.

- **Late April 2022:** South Plant staff began reducing the DO set point for passes 3 and 4. Sampling around the secondary system had identified fermentation occurring in the mixed liquor channels and secondary clarifiers. The fermentation led to denitrification in these areas. It was thought that a reduction in the DO set point for passes 3 and 4 might encourage fermentation and denitrification earlier in the process (e.g., pass 4) and avoid denitrification in the secondary clarifiers, thus avoiding the potential for floating sludge. In conjunction, the DO set point for passes 1B and 2 was increased to encourage higher nitrification rates in these passes of the aeration basins. The TN removal rate stayed fairly constant through May and into early June, and the DO in passes 3 and 4 was steadily reduced. The mixed liquor SVIs also started to decrease in early June.
- **Late June 2022:** South Plant staff reduced aeration rates into pass 4 of the aeration basin even further to promote fermentation and denitrification in pass 4 and the mixed liquor channels. The aeration downcomers beyond DO probe 10 were throttled to restrict airflow to most of the pass. The airflow was adjusted to be just enough for minimal mixing to occur. Again, South Plant staff hoped to avoid denitrification in the secondary clarifiers and, if full denitrification occurred prior to the secondary clarifiers, to potentially reduce RAS flow rates to save on wear of the RAS pumps and piping (the RAS piping has failed in several locations). This adjustment was not successful. With the reduction in aerated volume caused by the DO set point adjustments in passes 3 and 4 and the throttling of the downcomers in pass 4, nitrification rates began to drop off significantly. This adjustment to the optimization strategy was abandoned after about 4 weeks.
- **Early October 2022:** After achieving high nitrogen removal rates in August coupled with very low effluent pH, South Plant staff decided to lower the DO set points and SRT in September to try to reduce nitrification and increase the effluent pH. A balance of nitrogen removal and effluent pH management was achieved through September by continuing to adjust DO and SRT, but in the beginning of October, a thick and persistent

filamentous foam quickly developed on top of the mixed liquor in all the aeration basins. Plant staff had to use water sprays and hoses to knock down the foam on the aeration basin and clarifier surfaces for about a week. In addition, WAS carrying the filamentous organisms was sent through thickening and to the digesters where it had a moderate impact on the digester operation. The digesters began to “hold up” digester gas within the digesting sludge causing the density in the digesters to drop dramatically. Fortunately, the aeration basin foam and digester gas entrainment problems were not as significant as in years past during nitrogen removal trials. The DO set points in all aeration passes were increased because it was hypothesized the filamentous organisms were thriving in the lower DO conditions. The RAS rate was also reduced. By the end of October, the mixed liquor SVI measurements had fallen from as high as 195 mL/g in late September to below 100 mL/g, and the foam was under control.

- **Late October through December 2022:** Because the nitrogen removal rate had also fallen significantly by the end of October, South Plant staff increased the SRT to increase nitrification rates again. The DO set points in all basins as well as the RAS rates were reduced to try to simultaneously create some denitrification while creating at least partially anaerobic conditions in aeration basin pass 1a to maintain lower mixed liquor SVI values. Throughout November and December, the DO settings, SRT, and RAS rate were adjusted to attempt to achieve a modest nitrogen removal rate while maintaining good SVI values in preparation for wet weather.

Although partial nitrification is typically a difficult condition to maintain continuously, South Plant staff appear to be succeeding in achieving this condition for much of the time. Sometimes, the process operated near full nitrification and ammonia dropped below 5 mg/L (e.g., early April); during these times, the effluent pH dropped as the alkalinity was consumed during nitrification. At other times, nitrification was significantly reduced, and the nitrate/nitrite concentration dropped to near zero. The orthophosphate concentration in the effluent was low into July and then increased above historical values in the second half of 2022, indicating an active PAO population for the first 7 months and reduced activity in the last half of the year. It is not until the nitrate/nitrite concentration rises above about 10 mg/L that the orthophosphate increases above 0.5 mg/L. Presumably, at higher nitrate concentrations eventually being recycled to the anoxic/anaerobic zone, the PAOs are not able to compete for soluble chemical oxygen demand as well.

The key challenges encountered throughout the optimization work at South Plant conducted in 2022 can be summarized as follows:

- Lack of pH control
- Lack of real-time data to understand and adjust the process
- Concerns regarding RAS piping failures occurring with the additional stress of high RAS flow rates
- The occurrence of filamentous foam in the mixed liquor and the operational repercussions

3.1.2 Brightwater

Brightwater implemented the initial selected strategy during 2022, which was to sustain current operations, including low-DO control with continued monitoring and continued implementation of the BWABO project, per Brightwater Regional Wastewater Treatment System (Brightwater) Facilities Plan Amendment No. 4 (2021). Testing and tuning of the zone control for DO as part of the BWABO project continued between May and the end of the year. DO set points were lowered for short periods of time during the fall season, with a slight improvement to denitrification. Limitations on the blower controls and wasting strategies will be reduced once the BWABO project is completed and expansion of the Low DO trial will be considered as a strategy in 2023. Substantial completion and full transition to the ammonia-based aeration control strategy of the BWABO project is expected to occur by the end of 2024, with the benefits available for optimization efforts by 2025.

3.1.3 West Point

West Point sustained current operations with continued monitoring. During this time, WTD also focused on asset renewal and reliability projects, such as the Raw Sewage Pump Improvements and rehabilitation of the OGADS. As noted in Section 2.5, these projects are necessary to improve WWTP redundancy and reliability to support potential future nitrogen removal optimization.

3.1.4 System-wide

WTD continued to serve existing reclaimed water customer connections where feasible.

3.2 Annual Costs

The implementation timeframe of the PSNGP did not allow WTD sufficient time to align its accounting systems and projects to accurately track internal staff time. Staff resources were extremely constrained in 2022 and actual staff costs are likely higher than what is reported. Costs for staff time are based on actuals as well as estimates of the number of process changes and process upset events, documents produced, meeting hours and number of attendees, and

budget requests for additional staffing support in 2023. Table 3-1 shows the costs to implement the selected optimization strategies. While the BWABO project will enable nitrogen optimization at Brightwater, the capital project was already in progress to add increased process control and would occur regardless of the PSNGP requirements. Therefore, BWABO project costs are not reported here. Costs for additional operational effort beyond the original scope of the BWABO project, with the primary objective of conducting PSNGP optimization, may be reported in the future, especially after the BWABO project is fully constructed.

Table 3-1. 2022 Summary of optimization implementation costs

Cost category	Amount	Cost \$ ^a
WTD staff labor – Optimization Planning	3 FTEs	\$1,086,300
WTD staff labor – Optimization Monitoring & Implementation	4 FTEs	\$1,448,400
Consultant Costs	N/A	\$460,400
Energy Use	3,840,500 kwh	\$345,600
Asset Management and Repairs	N/A	\$200,000
<i>Total cost</i>		<i>\$3,540,700</i>
<i>Grants awarded (Puget Sound Nutrient Reduction Grant)</i>		<i>(\$290,879)</i>
Net Total		\$3,249,821

a. Cost assumptions: WTD hourly rate \$213, includes \$100/hr labor and indirect burden of 113%. 1 full-time equivalent (FTE) = 1,700 hours. Energy costs are \$0.09 per kwh. Costs have been rounded.

3.3. Optimization Performance

Permit coverage began April 1st, 2022, and the reported data to Ecology via discharge monitoring reports was for April to December only. However, the entire year of performance data is reported here for ease of reporting and for consistency in future years (January to December).

In terms of performance, Table 3-2 summarizes the 2022 contribution of measured effluent TIN load from each of the three treatment plants to the bubbled allocation. Figure 3-1 shows cumulative loading.

Performance for all months of 2022 can be summarized as follows:

- WTD was under the TIN action level by more than 2 million pounds in 2022. Actual performance was better than projected by 877,000 lb of TIN.

Table 3-2. 2022 Influent loading and summary TIN contributions of individual facilities to bubbled allocation for the reporting period

Parameter	South Plant	Brightwater	West Point	Bubbled ^a	Bubbled Action Level
Influent TN loading, lb/yr	11,682,000	3,270,000	9,306,000	24,258,000	N/A
Influent TIN loading, lb/yr	6,832,000	1,930,000	5,409,000	14,172,000	
Effluent TIN loading – contribution to bubbled TIN load, lb/yr	4,965,000	1,929,000	6,920,000	13,814,000	15,820,000

a. Compliance is based on bubbled effluent TIN value in lb/year compared to the bubbled action level.

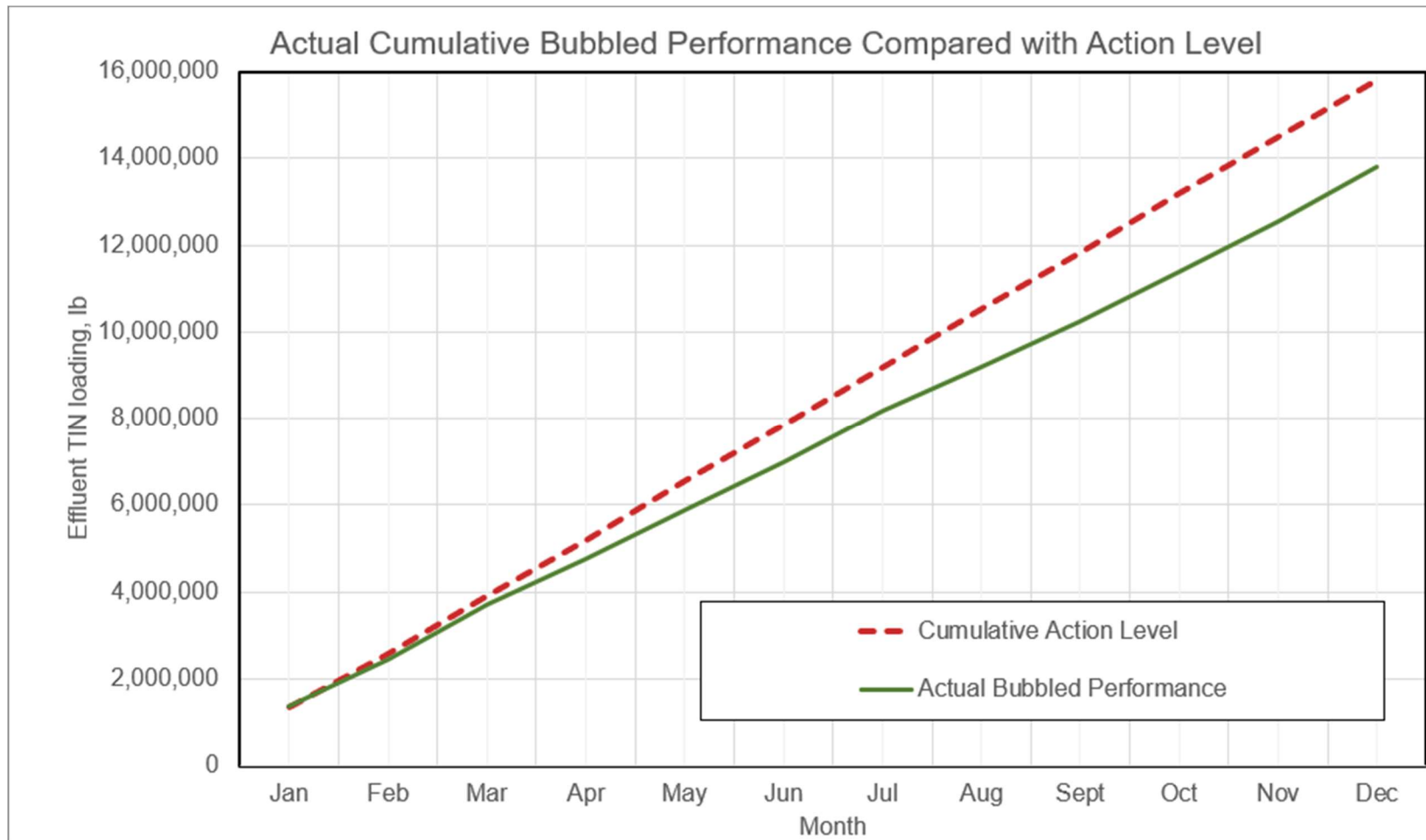


Figure 3-1. Cumulative nitrogen removal performance, January–December 2022

TIN removal rates were calculated and are summarized in Table 3-3 and Table 3-4. Two calculations are presented to show the difference in results depending on which parameters are used, due to conversion of nitrogen in the treatment process. The differences are explained in the subsequent paragraph.

Table 3-3. Ecology-required calculation: 2022 summary of actual TIN removal rates, as required by Q4 and Q12

Parameter	Bubbled
Projected 2022 actual TIN removal without optimization, % ^b	-1.0%
Projected 2022 actual TIN removal with optimization, % ^b	4.7%
Actual 2022 TIN removal with optimization, %	2.5%

b. Estimated at mean value. Refer to Table 2-2 and Table 2-8.

$$\text{Projected actual TIN removal rate, \%} = \frac{\text{Total Inf TIN}_{\text{All Plants, projected}} \left(\frac{\text{lb}}{\text{yr}} \right) - \text{Total Eff TIN}_{\text{All Plants, projected}} \left(\frac{\text{lb}}{\text{yr}} \right)}{\text{Total Infl TIN}_{\text{All Plants, projected}} \left(\frac{\text{lb}}{\text{yr}} \right)} \quad \text{Eq. 1}$$

$$\text{Actual TIN removal rate, \%} = \frac{\text{Total Inf TIN}_{\text{All Plants, actual}} \left(\frac{\text{lb}}{\text{yr}} \right) - \text{Total Eff TIN}_{\text{All Plants, actual}} \left(\frac{\text{lb}}{\text{yr}} \right)}{\text{Total Infl TIN}_{\text{All Plants, actual}} \left(\frac{\text{lb}}{\text{yr}} \right)} \quad \text{Eq. 2}$$

Table 3-4. 2022 WTD proposed calculation: summary of effective TIN removal rates

Parameter	Bubbled
Projected 2022 effective TIN removal without optimization, % ^b	38.2 %
Projected 2022 effective TIN removal with optimization, % ^b	41.7 %
Actual 2022 effective TIN removal with optimization, %	43.1 %

b. Estimated at mean value. Refer to Table 2-2 and Table 2-8.

$$\text{Projected effective TIN removal rate, \%} = \frac{\text{Total Inf Nitrogen}_{\text{All Plants, projected}} \left(\frac{\text{lb}}{\text{yr}} \right) - \text{Total Eff TIN}_{\text{All Plants, projected}} \left(\frac{\text{lb}}{\text{yr}} \right)}{\text{Total Infl Nitrogen}_{\text{All Plants, projected}} \left(\frac{\text{lb}}{\text{yr}} \right)} \quad \text{Eq. 3}$$

$$\text{Actual effective TIN removal rate, \%} = \frac{\text{Total Inf Nitrogen}_{\text{All Plants, actual}} \left(\frac{\text{lb}}{\text{yr}} \right) - \text{Total Eff TIN}_{\text{All Plants, actual}} \left(\frac{\text{lb}}{\text{yr}} \right)}{\text{Total Infl Nitrogen}_{\text{All Plants, actual}} \left(\frac{\text{lb}}{\text{yr}} \right)} \quad \text{Eq. 4}$$

Influent nitrogen mainly consists of ammonia and organic nitrogen. TN is the sum of organic nitrogen and TIN (ammonia, nitrate, and nitrite). In the influent, the ratio of ammonia to organic nitrogen will vary seasonally, with the proportion of ammonia being higher during wet weather and lower during dry weather. The calculation for the TIN removal rate, as shown below in Equations 1 and 2, does not account for conversion of organic nitrogen to ammonia in the biological treatment process. Because the calculation of TIN removal in Equations 1 and 2 does not reflect the change in nitrogen species from organic nitrogen to ammonia during biological treatment, the calculation substantially underreports the amount of influent TN. Because of this underreporting of influent TN, using influent TIN to calculate nitrogen removal (as in Equations 1 and 2) means the removal rate could appear to be negative in some months, which is a misleading measure of nitrogen removal.

An effective TIN removal rate using influent TN and effluent TIN, as shown in Table 3-4, using Equations 3 and 4, would be a more accurate measure of performance, as it more clearly represents the amount of nitrogen removal occurring at the treatment plant.

In summary:

- Based on the effective TIN removal calculation, which uses influent TN, in Table 3-4, effective TIN removal was projected to be 38.2 percent without optimization and 41.7 percent with optimization. WTD had better than anticipated removal with an observed effective removal rate of 43.1 percent.
- Based on the actual TIN removal rate required by Q4 and Q12 of this annual report, as shown in Table 3-3, projected 2022 removal was –1.0 percent without optimization and 4.7 percent with optimization. Using this calculation, the actual 2022 TIN removal rate was 2.5 percent, less than the projected 4.7 percent. Because the calculation uses influent TIN, the difference between projected and actual is not reflective of actual plant performance in terms of nitrogen removal (which was better than projected as detailed in Table 3-4). Instead, the difference is due to:
 - lower than projected influent loadings in 2022 and
 - differences between influent and effluent nitrogen species due to the conversion of organic nitrogen to inorganic nitrogen in the liquid stream process.

4.0 Influent Nitrogen Reduction Measures

WTD conducted a preliminary investigation of influent nitrogen reduction measures and source control from septage handling practices and commercial, dense residential, and industrial sources. This investigation included a review of non-residential sources of nitrogen and whether it was possible to identify potential pretreatment opportunities as well as potential strategies for reducing TIN from new multi-family/dense residential developments and commercial buildings. Strategies that reduce the volume of septage or influent to the facility, impose building moratoria, or require significant operational changes that would reduce treatment capacity at the facility were not required to be considered.

4.1 Non-residential Sources

WTD reviewed non-residential (industrial and septage) sources of nitrogen.

4.1.1 Industrial

Industrial sources include any collection system wastewater discharger that is involved in industrial wastewater generating activities. SIUs (significant industrial users) are a particular set

of industrial dischargers defined in the Federal Pretreatment Regulations (40 CFR 403) and monitored by WTD under those regulations. The [King County Industrial Waste Program \(KCIW\)](#) is a delegated pretreatment program that has the responsibility to permit, inspect, and sample all SIUs annually. Industrial dischargers that are not classified as SIUs but have higher amounts of BOD and TSS discharges, called high-strength dischargers, are also monitored by the KCIW pretreatment program for surcharge billing, whether they are classified as an SIU or not.

To review non-residential sources, WTD categorized its industrial dischargers who were either SIUs and/or high-strength dischargers by wastewater type, as summarized in Table 4-1. Industrial wastewater characteristics range widely and can be well understood only if sampled over a period representative of industrial operations. However, generally higher nitrogen content in industrial wastewaters is associated with the following production types (Metcalf & Eddy, 2014):

- Protein and/or fat production
- Oil recovery operations
- Facilities in which sanitary cleaning measures are adopted (e.g., food production)
- Landfill leachate

Table 4-1. Number of industrial dischargers by wastewater type discharging to the King County wastewater system

Source	Number of significant industrial users (SIUs)	Number of high-strength surcharge customers
Barrel cleaning	2	
Boat/shipyard	2	
Cement/ready mix	1	
Centralized waste treatment – CFR 437	3	3
Chemical toilet	2	5
Coil coating – CFR 465	1	
Composting – yard waste	1	
Construction dewatering	4	
Container washing	1	1
Electronic components – CFR 469	3	
Electroplating – CFR 413	4	
Food processing	21	49
Fueling facility	1	

Source	Number of significant industrial users (SIUs)	Number of high-strength surcharge customers
General type	1	2
Groundwater remediation – organics	1	
Iron and steel manufacturing – CFR 420	1	
Laundry – linen or industrial	2	4
Machining	1	
Manufacturing – miscellaneous		1
Metal finishing – CFR 433	30	
Metals recycling	1	
Pharmaceutical manufacturing – CFR 439	5	
Rendering	1	2
Soap and detergent manufacturing – CFR 417	2	2
Solid waste – landfill	2	
Solid waste – transfer facility	4	
Transport equipment clean – CFR 442	1	
Transportation facility	2	1
Trucked waste	1	1
Vehicle washing		1
Total	101	72
Total N influent load	6–8%	

*This table excludes industrial dischargers into the Vashon WWTP system. Only dischargers in the West Point, South Plant, and Brightwater sewer service areas are included.

Sampling of nitrogen species in the discharges from industrial users is needed to confidently understand the nitrogen loading from those sources and to identify possible pretreatment opportunities. However, an order-of-magnitude estimate of nitrogen loading from industrial dischargers is possible based on historical wastewater strength (5-day BOD and TSS), combined with assumptions for nitrogen content of various wastewater types, such as those presented in Ling et al. (2022). To determine historical wastewater strength, pretreatment data from 2021 and 2022 were reviewed to estimate an order-of-magnitude nitrogen load from high-strength surcharge customers in King County's sewer service area. This analysis indicated that the industrial dischargers with high-strength surcharge represent potentially about 6 to 8 percent of the TN influent loading to the WWTPs.

4.1.2 Septage

South Plant receives residential septage and chemical toilet waste (non-wastewater treatment flow) at a septage receiving facility located on the treatment plant site. Septage receiving introduces a nitrogen source into the activated sludge process that has a greater strength than normal influent wastewater. Among other inputs, the septage receiving operation at South Plant includes contributions from the following sources:

- Solids from the Carnation and Vashon WWTPs
- Solids from other regional treatment plants
- Septage from households and businesses served by septic systems
- Portable toilet wastes from regional construction sites, events, and other locations
- Recreational vehicle wastewater

Table 4-2 shows the approximate volume and solids loading from septage receiving at South Plant. The annual volume of septage received (in million gallons) was tabulated and converted to a daily solids mass loading using an assumed concentration of 2 percent solids (20,000 mg/L) and averaging the loading over 365 days. Assuming 8 percent nitrogen content (by mass) of the solids from septage receiving, about 920 to 1,050 lb/day of nitrogen enter the South Plant treatment process via septage, representing approximately 1.3 to 1.5 percent of the TN influent loading to the WWTP. The nitrogen content of septage could be further validated by conducting sampling at South Plant.

Table 4-2. Septage receiving data

Year	Million gallons	Solids concentration, mg/L (assumed 2% solids)	Dry tons of solids per year	Equivalent daily solids loading (lb/day)	lb/day nitrogen (assumes 8% N content)	Influent load %
2019	25.2	20,000	2,102	11,500	920	1.3%
2020	28.6	20,000	2,385	13,100	1,048	1.5%
2021	26.9	20,000	2,243	12,300	984	1.4%

4.2 Residential and Commercial Sources

The main source of nitrogen within the sewer service area is generally domestic. Residential and commercial flows make up the majority of flows to WTD's WWTPs, and so these sources represent the greatest loading of TN to the WWTPs. Possible strategies to reduce TIN from new multi-family/dense residential and commercial buildings include urine recovery, composting toilets, and greywater reuse.

4.3 Investigation of Nitrogen Reduction Measures

The list of potential nitrogen reduction measures developed were as follows:

- **Reduce nitrogen loading from residential and commercial sources:** This measure would consist of residential and commercial load reduction through load diversion approaches consisting of blackwater (i.e., wastewater from toilets) urine recovery and/or composting toilets and greywater reuse (i.e., wastewater from other non-toilet water uses such as sinks, showers, and laundry facilities).
 - Urine separation from blackwater and composting toilets, and subsequent use as a fertilizer is complex and requires broad retooling of residential fixtures and broad societal acceptance. It has not been implemented on a large scale in the United States, but is technically possible (Larsen et al., 2021; Wald, 2022). Policy barriers exist and regulatory changes would be required in the Washington State Administrative Code and the King County Code to allow building-scale on-site decentralized treatment for multi-family residential and commercial buildings. Regulatory changes also may be required to allow reuse, depending on the treatment method and desired end use.
 - In Washington state, greywater recycling is currently approved only for two applications (subsurface irrigation, per WAC 246-274, and project-by-project authorized use for non-potable uses inside buildings per the Uniform Plumbing Code, as adopted by Washington State per WAC 51-56). Limitations associated with these allowed uses include the seasonal nature of the subsurface irrigation use and the regulatory complexity of the indoor uses, which arises from such uses being regulated differently across local health and plumbing code authorities.

Another limitation to implementation of the measures described above is that WTD is a wholesale wastewater utility with contracted component agencies. This means WTD does not have direct jurisdiction over residential and commercial wastewater sources; instead, WTD's contracted component agencies have jurisdiction. WTD also does not have jurisdiction over land use, building, or plumbing permitting, which are overseen by local jurisdictions and Public Health—Seattle & King County. WTD cannot implement these measures without widespread policy change including changes to local building codes, contractual agreements, and other complex implementation requirements, including decentralized operations and maintenance.

Reduce septage receiving from hauled septage and chemical toilets: This measure would reduce or eliminate septage receiving at South Plant. The South Plant septage receiving facility is the only facility operating within King County. Furthermore, septage systems themselves are regulated by Public Health—Seattle & King County, not WTD, so agencies beyond WTD have legal jurisdiction. Termination of the septage receiving operations could lead to illegal dumping or illicit discharges to the collection system. Failure to regularly pump out septic tanks could result in improperly performing septic systems and degraded regional water quality. Septage receiving is an essential business activity necessary to protect regional water quality.

- **Reduce nitrogen loading or pretreatment from industrial sources to reduce the TN loading from high-strength industrial sources:** This measure would include evaluating the development of nitrogen local limits, or some other source reduction strategy, for industrial dischargers to protect effluent quality for NPDES discharge permit compliance. Characterization of influent nitrogen load is needed to identify contribution percentages from residential vs. commercial vs. industrial sources on a mass loading basis per treatment plant. This strategy should not be considered if it is determined that industrial mass loadings are a small or insignificant percentage of the influent loadings at the WWTPs compared to residential and other non-industrial sources. Also, development of numeric nitrogen local discharge limits cannot be established until water quality criteria are promulgated. Until that time, an additional assessment of this strategy's cost and benefit would be required.

To better quantify nitrogen loading from industrial sources and determine possible pretreatment opportunities, additional analysis is required. Future steps the County is considering include:

- **Sample septage** at South Plant to verify assumed nitrogen content.
- **Evaluate which industrial sources may benefit from further characterization** of nitrogen discharge to prioritize specific dischargers with higher relative load for potential next steps. If implemented, this effort would provide additional and more accurate data to understand relative contributions.
- **Conduct further sampling of identified industrial dischargers** for nitrogen during regular compliance sampling, as staff resources allow.
- **Potentially collaborate with targeted dischargers on best management practices** based on sampling and additional research.

- **Conduct sewershed-wide sampling once nitrogen water quality limits are promulgated.** Such sampling would inform the County of the nitrogen impact from industries and provide information to inform next steps or future measures.
- **Implementation of local discharge limits** for nitrogen, or other types of industrial source reduction strategies, may be a long-term consideration for the County if it is shown that industrial sources are significant contributors to the overall TN load and reductions are feasible. This will be assessed in long-term planning efforts by WTD. Local discharge limits can be developed only after nitrogen water quality limits are finalized. The time and effort required to implement a local discharge limit needs to be well understood by all stakeholders prior to any effort to develop local limits for TN.

Table 4-3 provides a summary of influent nitrogen reduction measures.

Table 4-3. Influent nitrogen reduction measures

Strategy	Treatment plant	Implementation time	Achieves TIN loading reduction?	Next steps
Prioritized potential measures				
1. Sampling septage to verify nitrogen content	South Plant	Immediate	No	Re-evaluate as part of adaptive management
2. Identify industrial dischargers for additional sampling	South Plant, Brightwater, West Point	1–2 years	No	Re-evaluate as part of adaptive management
3. Conduct sampling of identified industrial dischargers	South Plant, Brightwater, West Point	1–2 years	No	Re-evaluate as part of adaptive management
4. Collaborate on best management practices with targeted dischargers	South Plant, Brightwater, West Point	3–5 years	Possibly, requires additional characterization	Re-evaluate as part of adaptive management and potentially long-term planning
Eliminated measures				
Reduce N loading from industrial sources (sewershed sampling, local discharge limits)	South Plant, Brightwater, West Point	5–10 years	N/A (Potentially low TIN reduction, additional analysis required, currently infeasible)	Eliminated, re-evaluate in long term planning and/or when water quality based effluent limits are promulgated
Reduce septage receiving	South Plant	N/A	N/A (Infeasible, not required)	Not required to be considered, eliminated
Reduce N loading from residential and commercial sources	All	N/A	N/A (Infeasible)	Eliminated

5.0 References

- Larsen, T. A., Riechmann, M. E., and Udert, K. M. 2021. State of the art of urine treatment technologies: A critical review. *Water Research X*, 13, 100114.
- Ling, A. et al., Water Environment Federation (Ed). 2022. Industrial Wastewater and Pretreatment. In WEF (Ed.), *Wastewater Treatment Fundamentals III: Advanced Treatment* (pp. 1–23). Water Environment Federation.
- Metcalf & Eddy. 2014. *Wastewater Engineering: Treatment and Resource Recovery*. McGraw Hill.
- Wald, C. 2022. The Urine Revolution: How Recycling Pee Could Help to Save the World. *Nature*, 602(7896). 202-206.

Appendix A Declaration of Nitrogen Removal Optimization Selection

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