

TECHNICAL MEMORANDUM

Date: June 20, 2022
To: Duane Leach and Karen Allen, City of Snohomish
From: Tom Giese, P.E. and Soundarya Krishnamurthy, E.I.T., BHC Consultants, LLC
CC: Andrew Sics, P.E., City of Snohomish
Subject: Snohomish WWTP Nutrient Optimization Analysis



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BHC Consultants, LLC

1. Introduction

The Washington State Department of Ecology (Ecology) issued a nutrient general permit effective January 1, 2022. The purpose of this permit is to improve water quality in Puget Sound to improve the health and population of aquatic wildlife by reducing nitrogen loading. As one of the identified moderate dischargers to Puget Sound in the permit, the City of Snohomish (City) must meet specific requirements pertaining to monitoring of nutrients in the influent and effluent, evaluating alternatives to meet future nutrient limits, and optimizing performance of the wastewater treatment plant (WWTP) to reduce discharge of total inorganic nitrogen (TIN). The City has been assigned an action level of 83,600 pounds per year (lbs./yr.) of TIN. The permit requires the City to identify and evaluate a list of alternatives to optimize performance of the existing WWTP with the goal of minimizing discharge of TIN during this first permit cycle and ensure the total annual discharge remains below the assigned action level. The City must prioritize and update a working list of alternatives for meeting the action level with the existing treatment processes. Of the alternatives identified, those found to exceed a reasonable implementation cost or timeframe may be assigned a lower priority and excluded from the initial efforts but should still be retained on the working list for future consideration.

Once an alternative is selected for implementation, the City must report on the implementation during the first annual report due March 31, 2023. This report must describe the alternative and how it was implemented including:

- Estimated TIN reduction.
- Implementation costs.
- Start date and duration of implementation.
- Refinements to the alternative made during implementation.
- Description of anticipated and unanticipated challenges.
- Impacts to the overall treatment performance, as a result of implementing the alternative.
- Actual TIN reduction.

The City hired BHC Consultants, LLC (BHC) to assist the City with identifying, evaluating, and predicting performance of potential alternatives for optimization of TIN removal and providing information on anticipated costs and suggestions for implementation of the selected alternative(s).

1.1 Overview of the Snohomish WWTP

Wastewater enters the influent lift station through a 30-inch gravity sewer pipe and is lifted over 20 feet by the screw pumps. Additional wastewater flow is introduced just upstream of the screen through an 18-inch sewer force main from the Combined Sewer Overflow (CSO) Pump Station. Under normal flow conditions, wastewater is mechanically screened and then fed by gravity to Lagoon No. 1, which has a normal volume of 10 million gallons and is aerated and completely mixed by 18 floating surface aerators. From Lagoon No. 1, the wastewater travels through each of Lagoons No. 2, 3, and 4, which have a normal volume of 3.5 million gallons each and each contains eighteen submerged fixed film (SFF) modules and three floating surface aerators. Air provided to the SFF modules is typically sufficient for mixing and aeration. As the wastewater travels through each of these lagoons, the wastewater is detained for biological oxidation of organic matter and ammonia, and subsequent settling of biomass. The SFF modules provide aeration and attachment media to support growth of nitrifying microorganisms. They also support growth and attachment of heterotrophic microorganisms for increased removal of carbonaceous biochemical oxygen demand (CBOD).

The wastewater exits Lagoon No. 4 through the outlet structure into the effluent control structure. The filters are used to reduce effluent TSS, and subsequently effluent CBOD₅, particularly during the critical warmer dry weather months (July through October). The filters can treat effluent flow up to 0.8 MGD, which is conveyed by the filter pump station. The effluent from the filters flows to the mixing manhole and is mixed with the remaining flow from Lagoon No. 4. Any flow not treated through the filters is conveyed directly to the mixing manhole. At the mixing manhole, peracetic acid (PAA) is added for disinfection. From the mixing

manhole, the effluent flow proceeds to the contact tank where sufficient contact time is provided to reduce the fecal coliform count. After leaving the contact tank, the disinfected effluent is conveyed through an outfall pipe to discharge into the Snohomish River. A process flow diagram is presented in Figure 1.

1.2 Current WWTP Performance

The current National Pollutant Discharge Elimination System (NPDES) permit requires the WWTP to produce effluent with a combined CBOD load and nitrogenous biochemical oxygen demand (NBOD) load of no more than 134 pounds per day (lbs./d) on a monthly average during July through October. The NPDES permit defines the NBOD load as 2.1 times the effluent ammonia-nitrogen (ammonia-N) load. The ammonia-N and CBOD loads are calculated as the effluent flow in million gallons per day (MGD) times the concentration in milligrams per liter (mg/L) times a factor of 8.34 pounds per million gallons per mg/L. The WWTP performance as it pertains to effluent CBOD, ammonia-N, and NBOD + CBOD for November 2020 through June 2021 and July 2021 through October 2021 is summarized in Table 1 below.

Table 1
WWTP Effluent

Effluent Parameter	November 2020 – June 2021	July 2021 – October 2021
Flow, MGD	1.56	0.77
CBOD, mg/L	7.1	2.0
CBOD, lbs./d	92.5	13.0
Ammonia-N, mg/L	6.95	0.11
Ammonia-N, lbs./d	90.4	0.74
NBOD + CBOD, lbs./d	282.4	14.6
TKN, mg/L	9.7	1.7
Nitrate-N + Nitrite-N, mg/L	11.0	19.0
Total Nitrogen, mg/L	20.7	20.7

As is evident from the data in Table 1, the WWTP easily achieves the permit requirements for July through October. The NBOD load is significantly higher during November through June, because the City cycles aeration to the SFF media modules during most of that time to save energy. During July through October, the SFF modules are continuously aerated to maximize availability of dissolved oxygen (DO) for nitrification. However, the total nitrogen remains approximately the same during both periods, suggesting no significant difference in denitrification. This is because during November through June there is limited nitrification occurring due to colder temperatures and lower DO concentrations, both of which do not support nitrification, and during July through October all lagoons are fully aerated so that there is little or no anoxic volume to support denitrification.

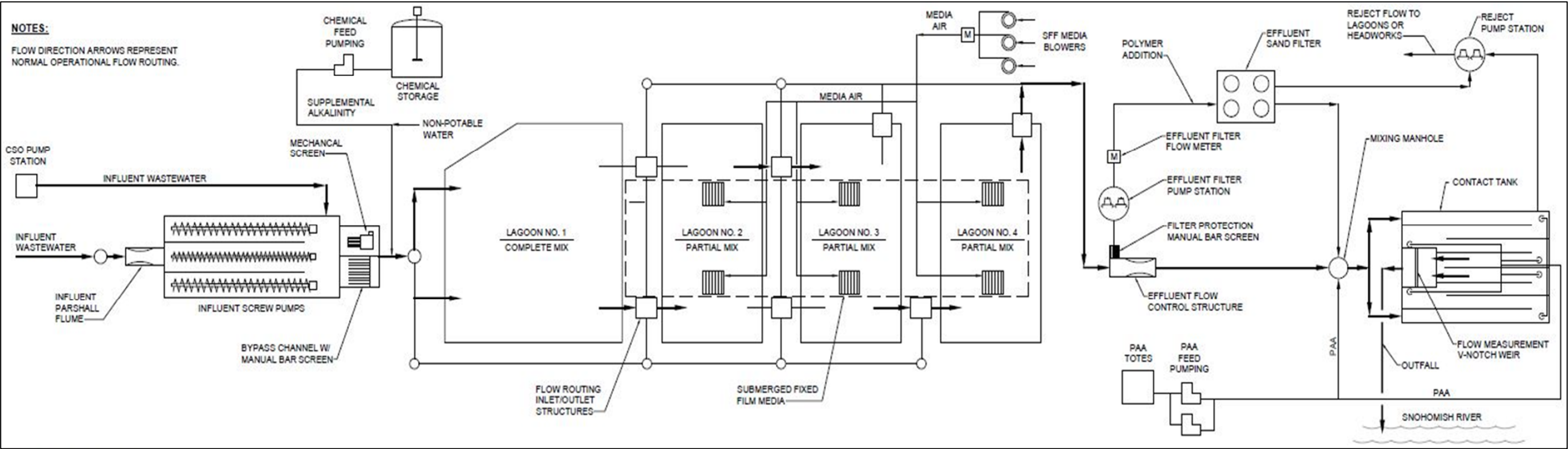


Figure 1 – WWTP Schematic

2. Identification of Nutrient Removal Alternatives

Seven different alternatives were initially identified for consideration. These alternatives are listed below followed by an illustration and description of each.

- Alternative 1 – Step Feed.
- Alternative 2 – Cycled Aeration to SFF Modules.
- Alternative 3 – Cycled Aeration to SFF Modules with Step Feed.
- Alternative 4 – Cycled Aeration to SFF Modules with Supplemental Carbon.
- Alternative 5 – Cycled Aeration in Lagoon 1.
- Alternative 6 – Year-Round Nitrification.
- Alternative 7 – Denitrifying in Existing Sand Filters.

2.1 Alternative 1 – Step Feed

Step feed would divert a portion of the influent wastewater from Lagoon 1 to Lagoon 2 or 3, as illustrated in Figure 2. This could increase the available carbon for denitrification in Lagoon 2 and/or 3. Two existing gates at the headworks outlet structure could be used to split flow between the east and west inlets to Lagoon 1. The west inlet to Lagoon 1 can be re-routed to Lagoon 2 or 3 using existing inlet/outlet structures.

Because the gates at the headworks outlet structure are not automated and there is no flow measurement in either of the Lagoon 1 inlet pipes, there is currently no way to maintain a consistent flow split for a step feed. As a result, the gates would need to be manually positioned and repositioned with changing conditions resulting in significant variations in the step feed flow. A substantial investment would be required to provide automated positioning of the gates and monitoring of the step feed flow.

2.2 Alternative 2 – Cycled Aeration to SFF Modules

Cycled aeration to the SFF modules during July through October, as opposed to continuous aeration, would potentially generate periodic anoxic conditions that could boost denitrification. As illustrated in Figure 3, cycled aeration would be focused on Lagoons 2 and/or 3. Lagoon 4 would remain fully aerobic to ensure complete nitrification prior to discharge.

Cycled aeration would utilize the alternating aerobic/anoxic mode already programmed for the SFF modules. Current programming allows selection of which Partial-Mix lagoons are alternating and which are full aerobic, as well as adjustment of the cycle time and aeration rate.

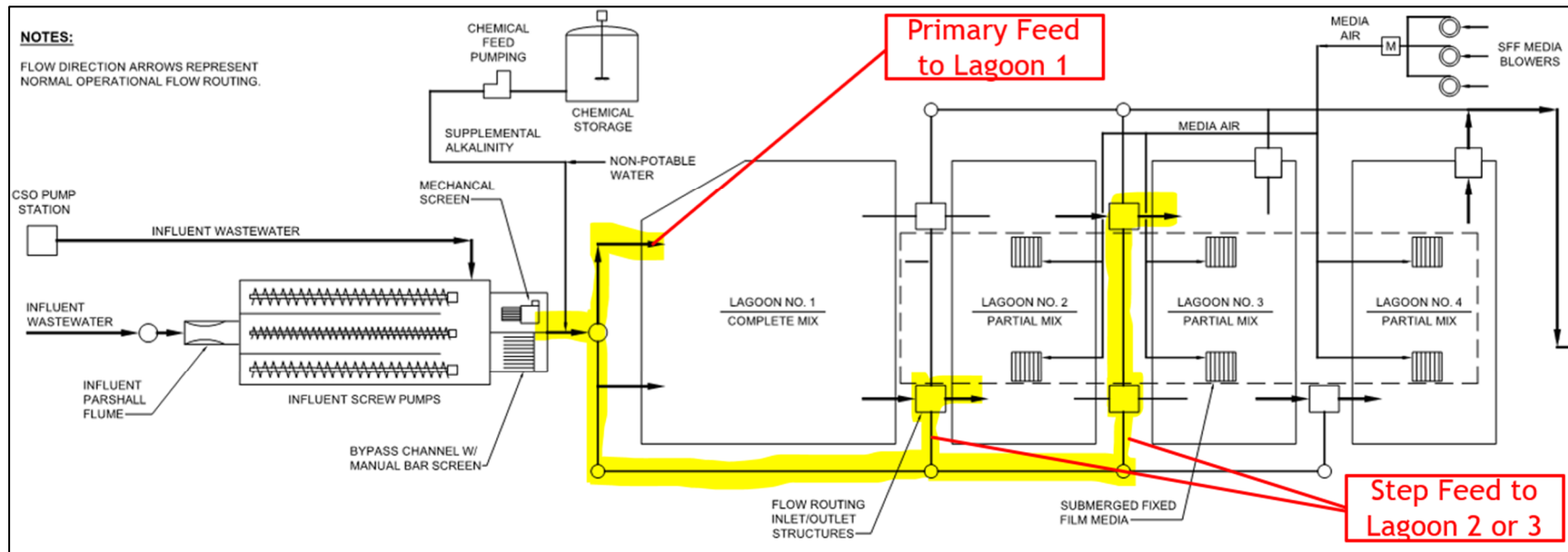


Figure 2 – Alternative 1 Illustration

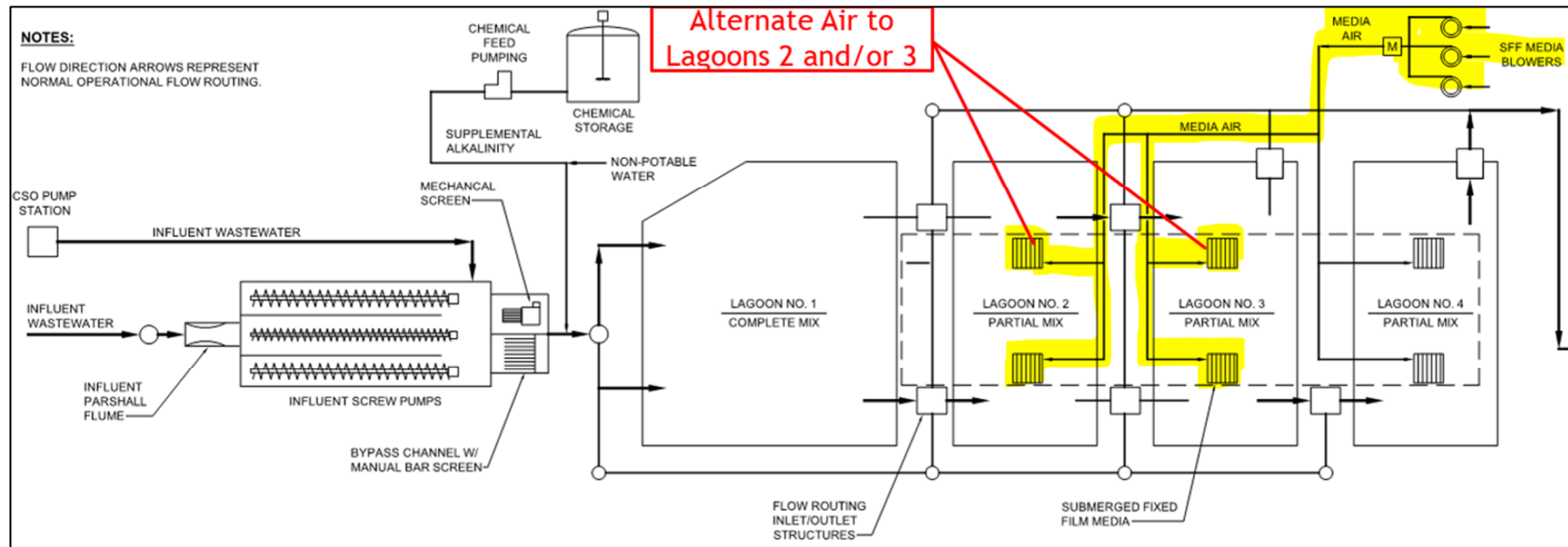


Figure 3 – Alternative 2 Illustration

2.3 Alternative 3 – Cycled Aeration to SFF Modules with Step Feed

Cycled aeration to the SFF modules with step feed is a combination of Alternatives 1 and 2, as illustrated in Figure 4. Cycled aeration would provide periodic anoxic conditions and step feed would increase available carbon, which together could potentially increase denitrification more than either alternative alone.

2.4 Alternative 4 – Cycled Aeration to SFF Modules w/ Supplemental Carbon

As shown in Figure 5, Alternative 4 is the same as Alternative 3 except that a synthetic carbon source (e.g., Micro-C) would be used to drive denitrification instead of carbon from step feed of the influent wastewater.

A synthetic carbon source would allow for dosing more carbon and achieving a more consistent carbon feed rate compared to step feed. This would likely better maximize denitrification with cycled aeration compared to step feed. Purchase of synthetic carbon and a metering pump would be required. Because the synthetic carbon source has a very high concentration, a single tote would likely last multiple weeks, such that a bulk storage container would not be necessary, and the delivery totes themselves could be used for storage and the synthetic carbon metered directly from the totes. Two totes could be kept on site at a time so that there is a spare when one runs out allowing time for delivery of a new tote.

2.5 Alternative 5 – Cycled Aeration in Lagoon 1

As illustrated in Figure 6, the aerators could be cycled in Lagoon 1, which would reduce the DO concentration in effluent from Lagoon 1. A lower DO concentration entering Lagoon 2 may improve the ability to effectively generate anoxic conditions for denitrification in Lagoon 2 and/or 3. Additionally, aerator cycling may even generate some localized anoxic conditions in Lagoon 1 that might boost denitrification. Unlike cycling aeration to the SFF modules, each aerator must be run at a frequent enough interval to avoid significant settling of suspended solids and biomass, which would reduce the effective treatment volume.

2.6 Alternative 6 – Year-Round Nitrification

As illustrated in Figure 7, one or two of the partial-mix lagoons could be operated in full aerobic mode during November through June to increase nitrification. The remaining one or two partial-mix lagoons would remain operating in the alternating aerobic/anoxic mode to promote some denitrification. This could be combined with supplemental carbon addition or step feed to try and further boost denitrification.

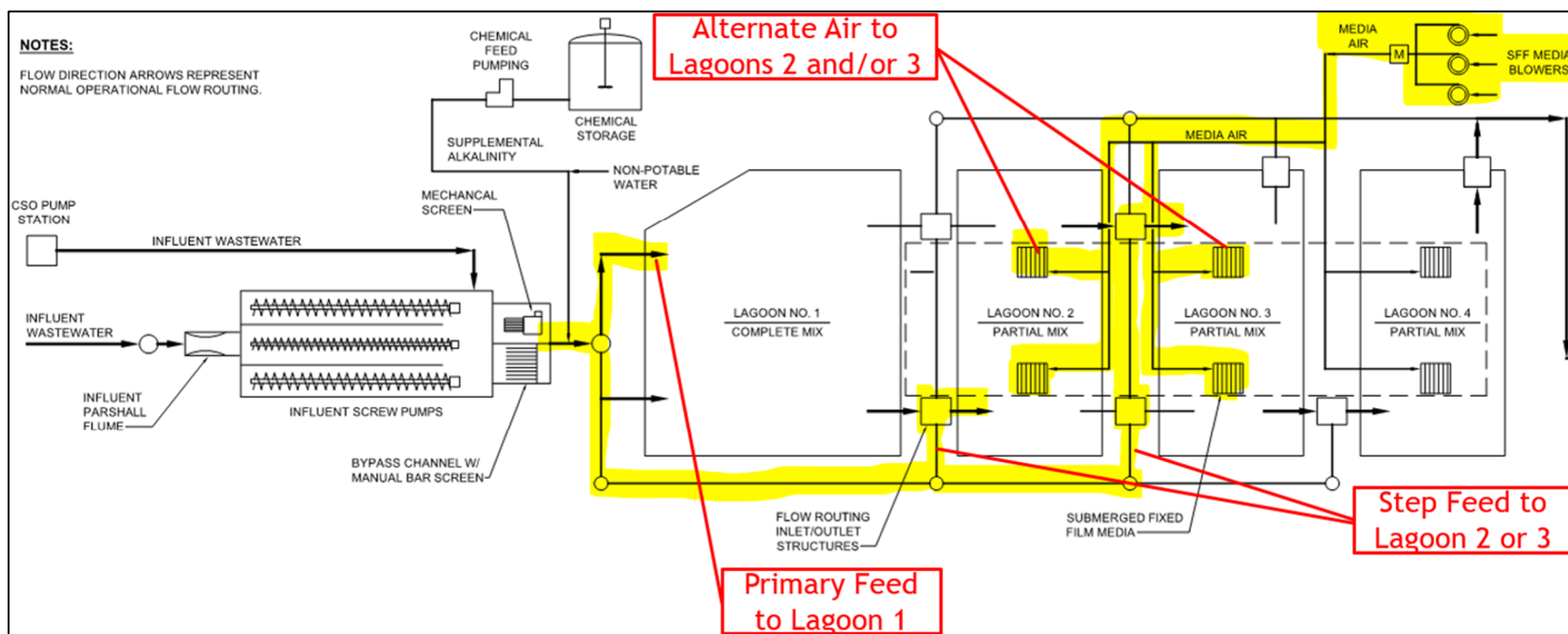


Figure 4 – Alternative 3 Illustration

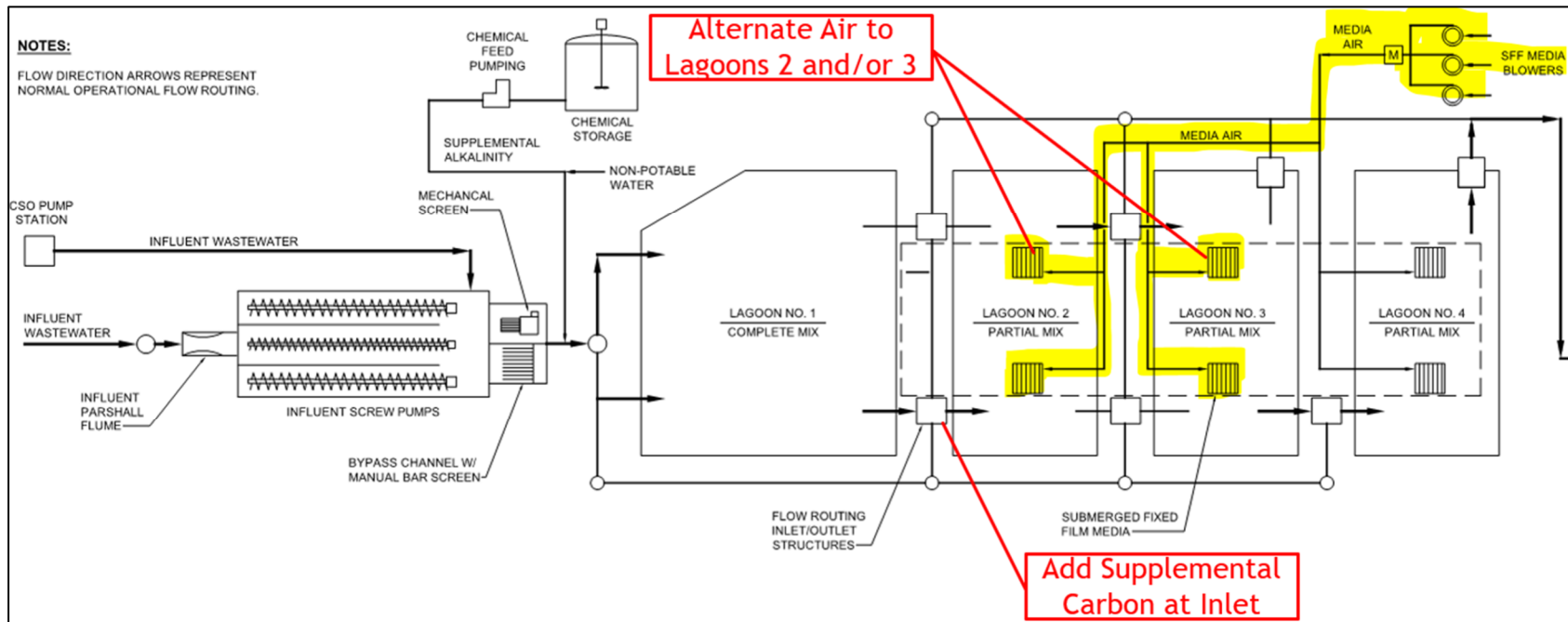


Figure 5 – Alternative 4 Illustration

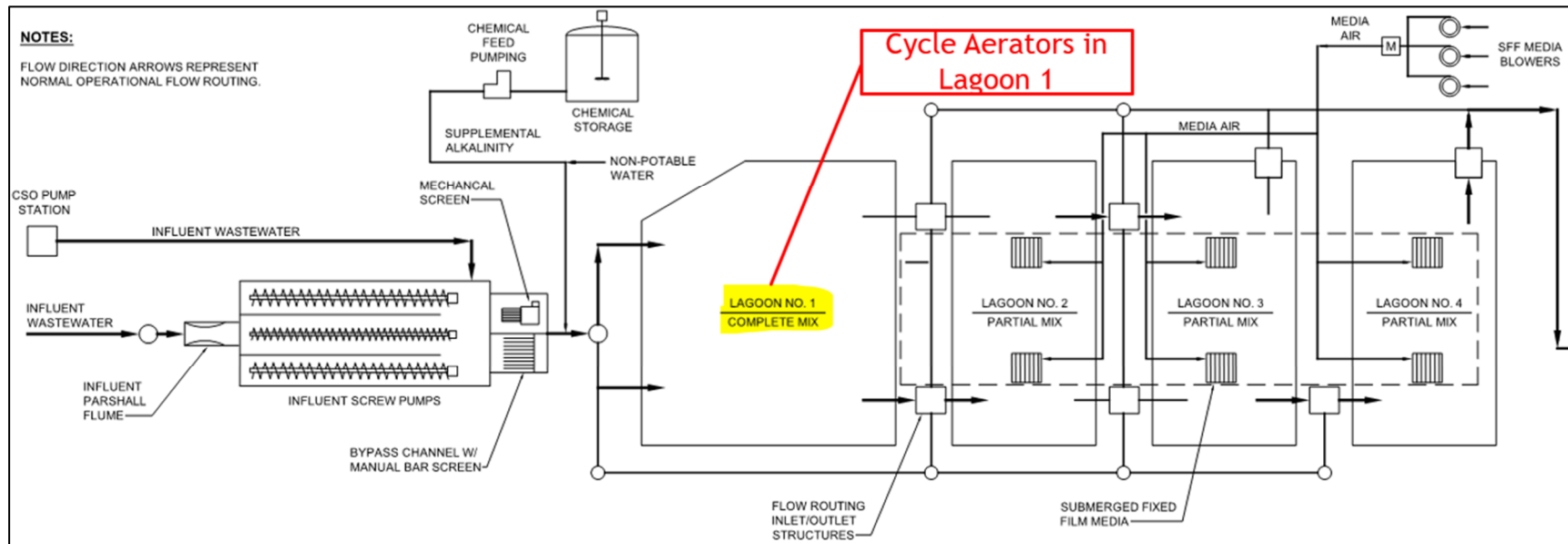


Figure 6 – Alternative 5 Illustration

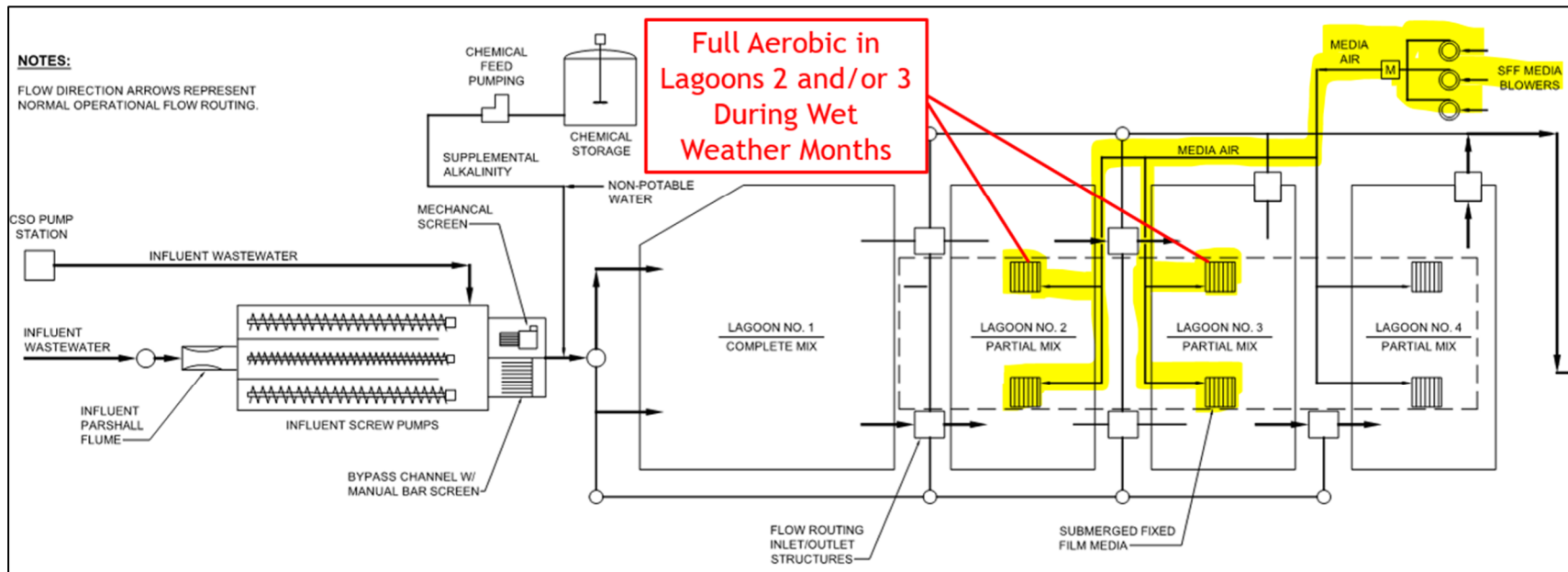


Figure 7 – Alternative 6 Illustration

2.7 Alternative 7 – Denitrifying in Existing Sand Filters

As illustrated in Figure 8, synthetic carbon could be dosed into the lagoon effluent pumped to the existing Dynasand filters to utilize them as denitrifying filters. Typical hydraulic loading for Dynasand filters as denitrifying filters is 0.13 to 0.44 feet per minute. This equates to 0.28 to 0.94 MGD for the existing filter cells. Typical nitrogen loading for Dynasand filters as denitrifying filters is 0.02 to 0.12 lbs./d per cubic feet of media. This equates to 25 to 166 lbs./d for existing filter cells. At the current minimum flow of about 0.6 MGD, the concentration range would be 5 to 33 mg/L of nitrate plus nitrite. The current maximum concentration of nitrate plus nitrite is 30 mg/L, such that it appears feasible to use the existing filters as denitrifying filters.

3. Evaluation of Nutrient Removal Alternatives

The evaluation of alternatives consisted of a two-step process. First, the identified alternatives were prioritized based on which could be implemented with minimal impacts on cost and WWTP performance, while presumably still capable of a noticeable reduction in effluent TIN. Next, process modeling was conducted to assess the benefits of the higher priority alternatives and develop recommendations for initial implementation.

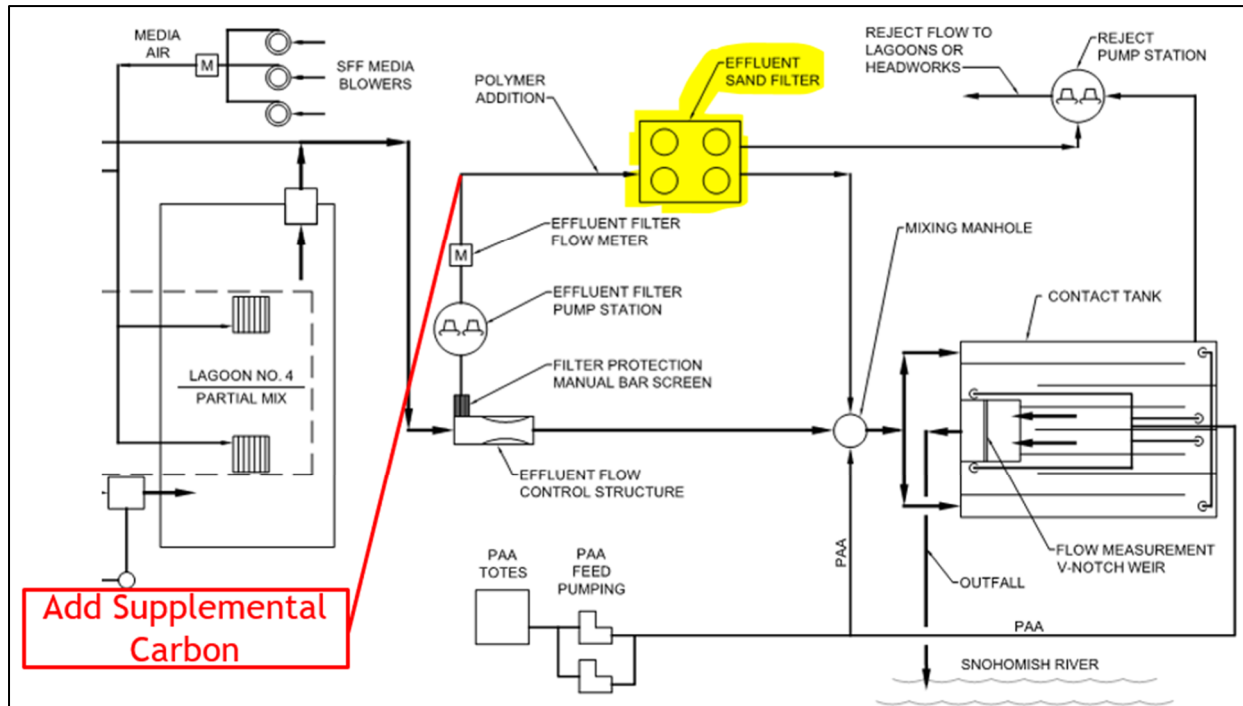


Figure 8 – Alternative 7 Illustration

3.1 Prioritization of Alternatives

Alternatives 1 and 3 would not have adequate control of the step feed without significant investment in automated gates, flow monitoring, and additional programming that would likely be on the order of \$100,000 or more. Alternative 1 or 3 could be considered later if it is determined that denitrification is carbon limited and the amount of synthetic carbon required to achieve a sufficient level of denitrification to remain below the action level is cost prohibitive.

The City had previously experimented with year-round nitrification in 2020. It was noted that during high flows, the continuous aeration and shorter hydraulic retention time reduced solids settling in Lagoons 2, 3, and 4 enough that the effluent TSS limit could be violated. Therefore, Alternative 6 is assigned a lower priority. However, Alternative 6 could be revisited in the future by modifying control programming for aeration of the SFF modules so that aeration will automatically revert back to cycled aeration from continuous aeration at an adjustable high flow set point to reduce or avoid issues pertaining to elevated TSS in the lagoon effluent.

Alternative 7 was assigned the lowest priority. The existing filters can only treat up to 0.8 MGD and there is concern that adding synthetic carbon could increase biological growth in the filters enough that they experience issues with plugging and reduced hydraulic throughput.

Alternatives 2, 4, and 5 were assigned highest priority. Therefore, these alternatives were examined further using process modeling to assess their potential benefit and develop recommendations for implementation of one or a combination of these alternatives.

3.2 Process Modeling

A process model of the existing WWTP was developed using the BioWin program developed by EnviroSim. Lagoon 1 is modeled as a single bioreactor element, since it is typically completely mixed with minimal settling of solids. Lagoons 2, 3, and 4 with the SFF modules are modeled as moving bed bioreactor (MBBR) elements, where the moving media is representative of the SFF modules. Additionally, each MBBR is followed by a point clarifier element to account for settling of solids in these three lagoons. The settled solids are directed to an anaerobic digester element to account for the storage and digestion of solids that also occurs in these three lagoons. At least a portion of the lagoon effluent (up to 0.8 MGD) passes through a solids separation element to represent the sand filters. Reject from the solid's separation element is returned to Lagoon 1 to represent the filter reject flow. The BioWin process model diagram is shown in Figure 9 below.

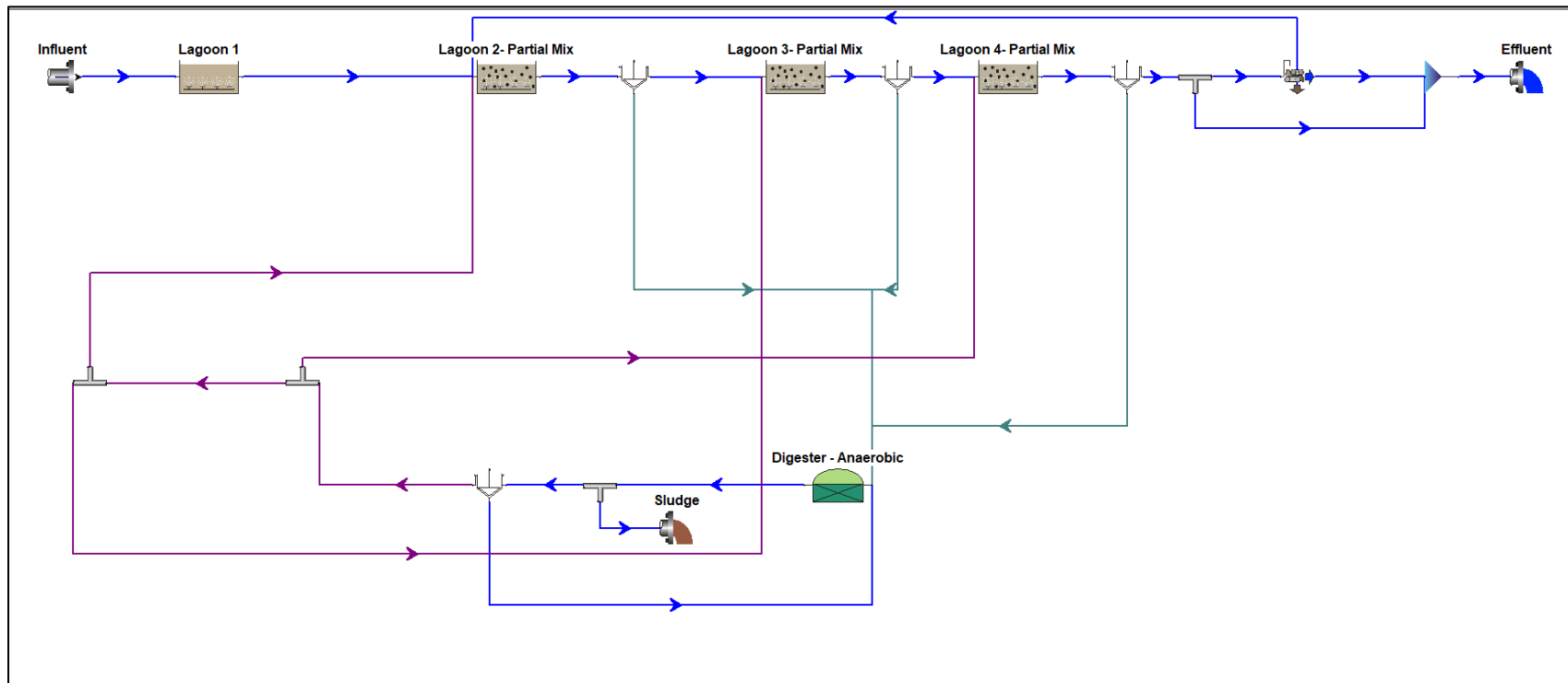


Figure 9 – BioWin Process Model Diagram

The influent characteristics can significantly impact the effectiveness of denitrification within the WWTP processes. For example, a low carbon-to-nitrogen ratio and/or a lower amount of readily available soluble chemical oxygen demand (COD) may limit the availability of carbon for denitrification and result in slower and/or less denitrification. In order to improve predictions of the BioWin process model, the City collected supplemental data that was provided to BHC in addition to data from the monthly discharge monitoring reports. This supplemental data is summarized in Table 2 below.

Table 2
Supplemental Testing Data

Date	Influent Value (mg/L)						Effluent COD, mg/L
	Alkalinity	pH	COD	fCOD	fCBOD	VSS	
3/1/2022	82.2	7.38	219	51	29	74	36
3/8/2022	119.0	7.39	300	92	46	54	39
3/15/2022	110.0	7.47	298	88	47	66	44
3/22/2022	85.6	7.33	130	20	25	70	35
3/29/2022	127.2	7.32	396	116	86	134	37
4/5/2022	133.4	7.21	189	67	37	154	27
4/12/2022	107.0	7.32	342	80	53	76	16
4/19/2022	153.2	7.39	550	110	82	190	40

Comparing the supplemental data with measured CBOD and total suspended solids (TSS) for the same dates, BHC developed ratios for these parameters compared to average CBOD and TSS for June through October. These ratios were then applied to the June through October average CBOD and TSS influent concentrations to develop a typical influent characterization for the Snohomish WWTP. This influent characterization is summarized in Table 3 below. The filtered CBOD value was adjusted to better match the calculated value based on other influent parameters.

Table 3
Average June - October Influent Wastewater Characterization

Parameter	Value, mg/L	Parameter	Value, mg/L
Total COD	556	Total Kjeldahl Nitrogen (TKN)	39.2
Filtered COD (fCOD)	143	Nitrate	0.6
Total CBOD	280	Ammonia	29.7
Filtered CBOD (fCBOD)	55	Alkalinity	188
TSS	282	pH	7.4
VSS	166	Effluent COD	63

Influent values for June through October were used because this is when temperatures are such that full nitrification is achieved and therefore potential denitrification is maximized. An average temperature of 20 degrees Celsius was used for June through October based on historical data. The average flow during June through October is 0.88 MGD based on historical data.

First, model runs were conducted for Alternative 2 by cycling aeration to the SFF media modules in Lagoons 2 and/or 3. Initially, a comparison was made using a 6-hour cycle time with aeration on for 2 hours and off for 4 hours. This cycle was used to compare a baseline model (no cycling of aeration) with cycling aeration in Lagoon 2 and cycling aeration in both Lagoons 2 and 3. A summary of the results are shown in Table 4 below. Based on this analysis, it appears that cycling aeration in both Lagoons 2 and 3 produces the best results without impacting nitrification or removal of CBOD. A scenario was run with half of the volume for Lagoon 2, simulating buildup of settled solids over time. This did not appear to have an adverse impact on CBOD removal or the level of nitrification but did result in significantly less nitrogen removal.

Table 4
Comparison of Alternative 2 Lagoon Aeration Cycling

Parameter	Baseline	Lagoon 2 Cycling	Lagoon 2 Cycling	Lagoon 2 & 3 Cycling
Effluent Ammonia, mg/L	0.2	0.2	0.2	0.2
Effluent Nitrate, mg/L	23.9	20.5	23.0	17.2
Effluent Total Nitrogen (TN), mg/L	25.7	22.3	24.8	18.9
Effluent CBOD, mg/L	1.0	1.1	1.1	1.1
Aeration Each Lagoon, scfm	540	540	540	540
Aeration Time, hrs	N/A	2	2	2
Cycle Time, hrs	N/A	6	6	6
Available Lagoon 2 Volume, %	100	100	50	100

Next, the model was run with different aeration and cycle times for Lagoons 2 and 3 to see if a shorter cycle time and/or shorter time with aeration off would impact the predicted results. A summary of this analysis is provided in Table 5 below. Based on this analysis, it appears a longer cycle time with aeration off for a longer duration provides better denitrification. This could be due to allowing more time to deplete DO and generate more localized anoxic volume and/or more time for carbon to breakdown into more readily available forms to be consumed by the bacteria during denitrification. Reduced volume in Lagoon 2 did not appear to have an adverse impact on CBOD removal or the level of nitrification, but did yield less nitrogen removal, though to a less degree compared to cycling aeration in only Lagoon 2.

Table 5
Comparison of Alternative 2 Cycle Times

Parameter	Trial 3 Lagoon 2 & 3 Cycling	Trial 2 Lagoon 2 & 3 Cycling	Trial 1 Lagoon 2 & 3 Cycling	Trial 1 Lagoon 2 & 3 Cycling
Effluent Ammonia, mg/L	0.2	0.2	0.2	0.3
Effluent Nitrate, mg/L	19.3	19.3	17.2	19.9
Effluent Total Nitrogen (TN), mg/L	21.0	21.0	18.9	21.7
Effluent CBOD, mg/L	1.0	1.1	1.1	1.2
Aeration Each Lagoon, scfm	540	540	540	540
Aeration Time, hrs	1	2	2	2
Cycle Time, hrs	1	2	6	6
Available Lagoon 2 Volume, %	100	100	100	50

Next, the model was run using a 6-hour cycle time in Lagoons 2 and 3 with lower aeration horsepower in Lagoon 1 to simulate cycled aeration. Most aerators in Lagoon 1 must be running to keep the lagoon completely mixed and biomass suspended, but the aerators in operation could be cycled to reduce DO in Lagoon 1, which might support more denitrification in Lagoons 2 and 3 without compromising nitrification. Model runs comparing effluent with all aerators in Lagoon 1 running and two-thirds of the aerators running at any one time are shown in Table 6 below for comparison. Based on this analysis, it appears that cycling aerators and reducing DO in Lagoon 1 might help improve denitrification slightly in Lagoons 2 and 3, though as indicated before reduced volume in Lagoon 2 increases effluent nitrate and total nitrogen some.

Table 6
Comparison of Alternative 5 with Cycling Lagoon 1 Aerators

Parameter	Lagoon 1 All Aerators On	Lagoon 1 Cycling Aerators	Lagoon 1 Cycling Aerators
Effluent Ammonia, mg/L	0.2	0.2	0.3
Effluent Nitrate, mg/L	17.2	16.4	19.4
Effluent Total Nitrogen (TN), mg/L	18.9	18.2	21.3
Effluent CBOD, mg/L	1.1	1.1	1.2
# Aerators On in Lagoon 1	18	12	12
Lagoon 2 & 3 Aeration Time, hrs	2	2	2
Lagoon 2 & 3 Cycle Time, hrs	6	6	6
Available Lagoon 2 Volume, %	100	100	50

Lastly, model runs were conducted with addition of supplemental carbon to Lagoon 2 in an attempt to help drive denitrification. The model assumed MicroC 2000 was dosed for supplemental carbon. Model runs incorporated cycling aerators in Lagoon 1 and a 6-hour cycle time in Lagoons 2 and 3, except Trial 4 was run with no cycling of aeration in Lagoons 2 and 3. A summary of the results are provided in Table 7.

Table 7
Comparison of Alternative 4 with Supplemental Carbon

Parameter	Trial 1 Lagoon 1, 2 & 3 Cycling	Trial 2 Lagoon 1, 2 & 3 Cycling	Trial 3 Lagoon 1, 2 & 3 Cycling	Trial 4 Lagoon 1 Cycling
Effluent Ammonia, mg/L	0.2	0.2	0.2	0.2
Effluent Nitrate, mg/L	3.2	5.7	9.7	18.5
Effluent Total Nitrogen (TN), mg/L	5.1	7.6	11.5	20.3
Effluent CBOD, mg/L	1.5	1.6	1.3	1.1
MicroC Dose, gpd	50	50	25	25
# Aerators On in Lagoon 1	12	12	12	12
Aeration Time, hrs	2	2	2	N/A
Cycle Time, hrs	6	6	6	N/A
Available Lagoon 2 Volume, %	100	50	100	100
Lagoon 1 DO, mg/L	4.7	4.7	4.7	4.7
Lagoon 2 DO, mg/L	0.0	0.0	0.0	0.1
Lagoon 3 DO, mg/L	0.0	0.0	0.0	3.0
Lagoon 4 DO, mg/L	5.0	4.7	4.8	6.0

As can be seen from the results presented in Table 7, dosing supplemental carbon essentially eliminates the DO residual in Lagoons 2 and 3 with cycled aeration. However, it appears dosing supplemental carbon with cycled aeration could substantially reduce total nitrogen in the effluent without adversely impacting nitrification. With full aeration in Lagoons 2 and 3, DO is still near zero in Lagoon 2 and there is very little benefit to dosing supplemental carbon. Also, as noted before, there is some decrease in nitrogen removal with reduced volume in Lagoon 2, but this does not appear to impact nitrification or CBOD removal.

3.3 Evaluation of Priority Alternatives

It appears that cycling aeration in Lagoon 2 could reduce effluent TN by an average of up to 13% during June through October, and by a total of about 26% if aeration is also cycled in Lagoon 3. As solids accumulate in Lagoon 2 over time, it is predicted that TN removal in Lagoon 2 with cycled aeration would be reduced to only about 4%, but with cycled aeration also in Lagoon 3 total TN removal of about 16%

could be achieved. Additionally, cycling aerators in Lagoon 1 could help reduce effluent TN by about another 3%. However, since cycling aerators in Lagoon 1 is not an uncommon practice at the WWTP, this reduction should not be included in the predictions. Because cycling aeration requires only adjustments to operational settings and does not require additional power, labor, or maintenance, there is no cost associated with Alternatives 2 and 5. In fact, reduced energy use and operating time of aerators would decrease power and maintenance costs.

Based on the modeling results, each gallon of MicroC, when used in conjunction with cycled aeration, removes about 2 pounds of TN. A dose of 25 gpd is estimated to reduce effluent TN by up to an additional 26% and a dose of 50 gpd is estimated to reduce effluent TN by up to an additional 51%. At a cost of about \$4 per gallon, the cost to remove nitrogen using MicroC is about \$2 per pound of TN, not including the cost of a metering pump, piping/tubing, etc.

4. Recommendations for Implementation

It is recommended that the City cycle aerators in Lagoon 1, as has often been practiced historically. Additionally, it is recommended the City operate for about 2 months with cycled aeration in only Lagoon 2 using a 6-hour cycle with 2 hours of aeration and 4 hours unaerated. This will result in very low DO residuals in Lagoon 2, but with warmer temperatures most nitrification occurs in Lagoon 1. Furthermore, keeping Lagoons 3 and 4 fully aerated should allow complete nitrification of any ammonia exiting Lagoon 1. It is recommended that during this time the City periodically measure ammonia in Lagoons 2, 3, and 4 to assess how much nitrification is occurring in each. If after the first two months the data indicates that there is little ammonia entering Lagoons 3 and 4, as suggested by the process model, aeration can also be cycled in Lagoon 3 to promote additional denitrification.

Continue to monitor ammonia in Lagoons 2, 3, and 4. As fall approaches and temperatures cool, nitrification rates will slow. The process model predicts that even at temperatures of 15 degrees Celsius effluent ammonia should still be around 0.5 mg/L with cycled aeration in Lagoons 2 and 3. However, if ammonia exiting Lagoon 1 increases significantly and/or ammonia entering Lagoon 4 increases substantially, switch back to full aeration in Lagoon 3.

It is recommended that dosing of supplemental carbon not be implemented at this time. Because it appears cycled aeration alone could provide a measurable benefit and there is significant cost associated with use of supplemental carbon (e.g., a dose of 50 gpd would cost about \$30,000 for June through October), it is recommended that use of supplemental carbon be given lower priority. Should the need arise in the future to further reduce effluent nitrogen, supplemental carbon could be considered for implementation. For example, should the effectiveness of cycled aeration be significantly reduced due to accumulation of solids over time in Lagoon 2, and perhaps Lagoon 3 to a lesser extent, addition of supplemental carbon would increase effectiveness of the available volume.