

TECHNICAL MEMORANDUM

Date: July 18, 2022
To: Jason Crain and Jeff Cobb, City of Marysville
From: Tom Giese, P.E. and Soundarya Krishnamurthy, E.I.T.
CC: Adam Benton, City of Marysville
Subject: Marysville WWTP Nutrient Optimization Analysis



Tom Giese, PE
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 Marysville (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 592,000 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.

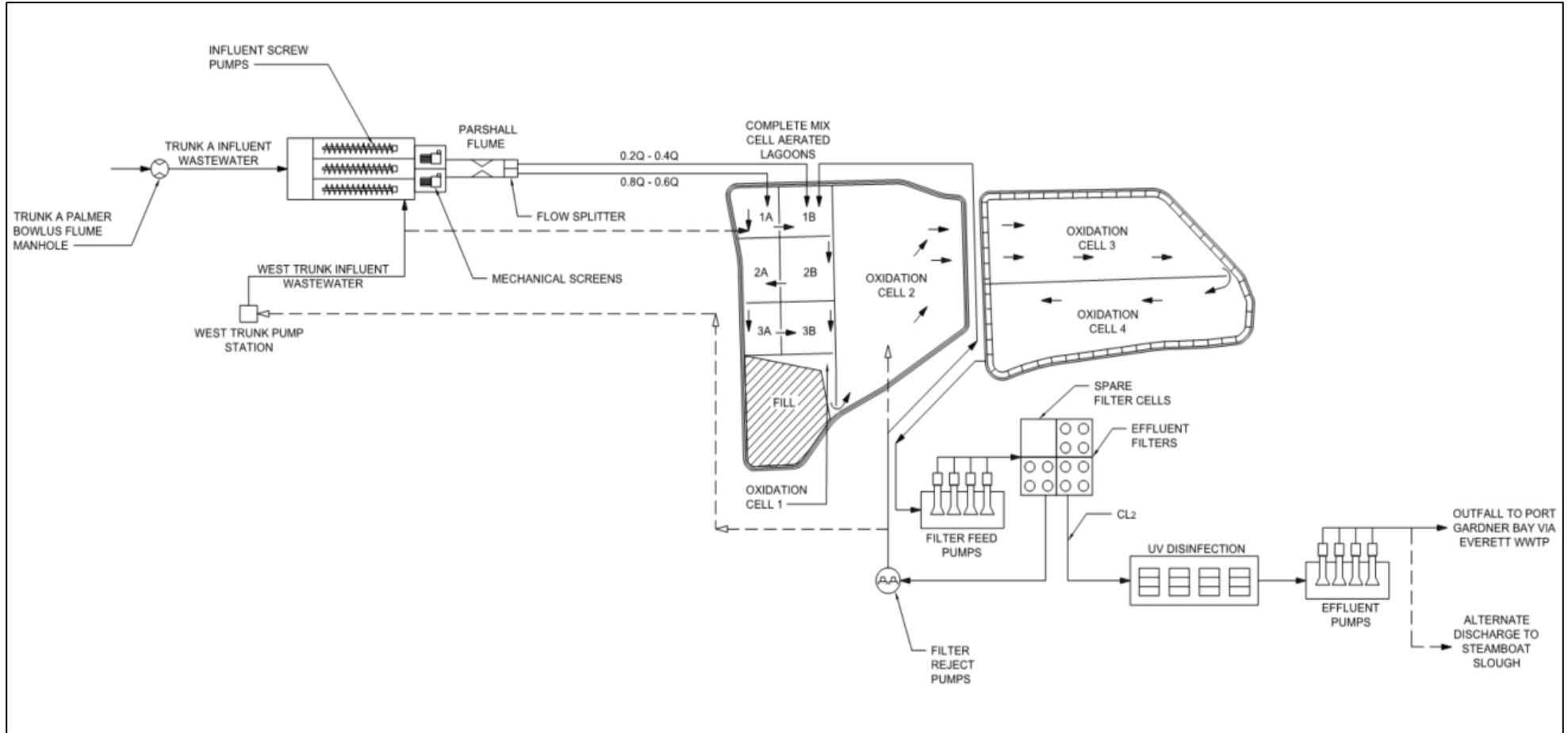
The City hired BHC Consultants, LLC (BHC) to assist the City with identifying, evaluating, and predicting performance of potential alternatives for optimization of TIN removal and providing information on anticipated costs and suggestions for implementation of the selected alternative(s).

1.1 Overview of the Marysville WWTP

The Marysville WWTP uses a lagoon system for removal of biochemical oxygen demand (BOD) and total suspended solids (TSS). Influent is pumped up to the headworks where screenings are removed. From the headworks, screened wastewater flows by gravity to aerated lagoon cells. There are six completely mixed aerated cells located in the north lagoon (Lagoon 1). After the aerated lagoon cells, are four facultative lagoon cells (oxidation cells), which largely serve to settle out solids, but also help to further reduce remaining BOD. Oxidation Cells 1 and 2 are in Lagoon 1, and Oxidation Cells 3 and 4 are located to the south in Lagoon 2. Although much of Oxidation Cell 1 in Lagoon 1 has recently been filled, the reduction in volume has not impacted the efficiency of treatment. An effluent structure is located in the final oxidation cell (Oxidation Cell 4), which collects treated effluent for conveyance by gravity to a pump station. The pump station lifts effluent into the sand filters, which are used for tertiary treatment. The sand filters are designed to remove most of the remaining solids that do not settle well, which largely consists of algae and/or daphnia that feed off the algae, as well as debris from aquatic and shoreline vegetation that collects in the lagoons. Filtered effluent then undergoes ultraviolet (UV) disinfection prior to effluent pumping to the Port Gardner Bay outfall (shared with the City of Everett) or Steamboat Slough.

A process flow diagram is presented in Figure 1.

Figure 1 – WWTP Schematic



1.2 Current WWTP Performance

The current National Pollutant Discharge Elimination System (NPDES) permit requires the WWTP to produce effluent with a monthly average CBOD load of no more than 2,650 pounds per day (lbs/d) when discharging to Port Gardner Bay and 1,376 lbs./d when discharging to Steamboat Slough. Discharge to Steamboat Slough is limited to 6.6 MGD during November through June and is limited to only flushing for maintenance of the outfall during July through October. The NPDES permit does not currently include any limits on nitrogen except that the concentration of ammonia-nitrogen (ammonia-N) in the effluent cannot exceed 48.3 mg/L when discharging to Steamboat Slough for outfall maintenance during July through October. The average effluent quality as it pertains to CBOD, TSS, and nitrogen for January 2019 through April 2022 is summarized in Table 1 below.

Table 1
WWTP Effluent

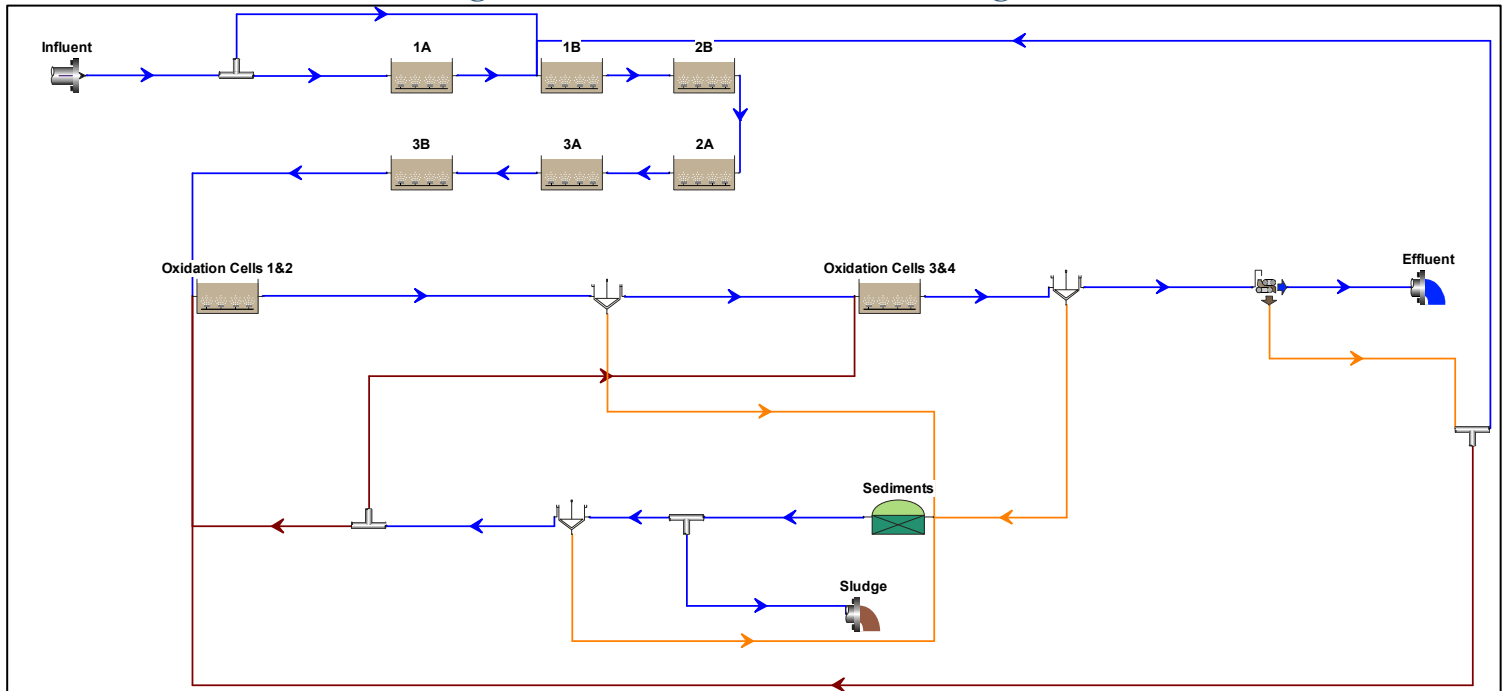
Effluent Parameter	January 2019 – April 2022 Average
Flow, MGD	5.24
CBOD, mg/L	12
CBOD, lbs/d	500
TSS, mg/L	26
TSS, lbs/d	1,073
Ammonia-N, mg/L	34.7
Nitrate + Nitrite, mg/L	0.9
Total Kjeldahl Nitrogen (TKN), mg/L	40.8
TIN, mg/L	35.6
Total Nitrogen (TN), mg/L	41.7

As is evident from the data in Table 1, the WWTP generally does not achieve substantial nitrification, given the high average concentration of ammonia. This could be due to insufficient hydraulic residence time to grow a significant population of nitrifying organisms, insufficient dissolved oxygen to support the growth of nitrifying organisms, and/or insufficient alkalinity to buffer against a drop in pH during nitrification causing inhibition of nitrification. Additionally, nitrification rates are significantly slower during cold weather. Whatever nitrate is produced from nitrification that is occurring appears to be largely removed in the facultative oxidation cells via denitrification, as evidenced by the low nitrate and nitrite concentrations in the effluent.

2. Process Modeling

A process model of the existing WWTP was developed using the BioWin program developed by EnviroSim. Each aerated lagoon cell is modeled as a single bioreactor element, since they are typically completely mixed with minimal settling of solids. Oxidation Cells 1 and 2 were modeled as a bioreactor element followed by a point clarifier element to account for settling of solids in these two cells. Similarly, Oxidation Cells 3 and 4 were modeled as a bioreactor element followed by a point clarifier element. The settled solids are directed to an anaerobic digester element to account for the storage and digestion of solids that also occurs in the oxidation cells. All of the lagoon effluent passes through a solids separation element that represents the sand filters. Reject from the solids separation element is returned to Aerated Lagoon Cell 1B to represent the filter reject flow. The BioWin process model diagram is shown in Figure 2 below.

Figure 2 – BioWin Process Model Diagram



While the City was collecting supplemental data to better define influent parameters, available influent data and typical ratios for municipal wastewater were utilized as part of an initial modeling effort. This initial modeling effort was conducted to make a general assessment of the alternatives identified in Section 3 below to help determine which would be viable and warrant further and more detailed analysis. The available influent data utilized in this initial modeling effort was gathered from discharge monitoring reports for 2019 through 2021 and is summarized in Table 2 below.

Table 2
2019 – 2021 Average Influent Characteristics

Influent Parameter	2019 – 2021 Average
Flow, MGD	5.36
CBOD, mg/L	259
TSS, mg/L	290
TKN, mg/L	45
Total Phosphorus, mg/L	6.5

3. Identification and Screening of Nutrient Removal Alternatives

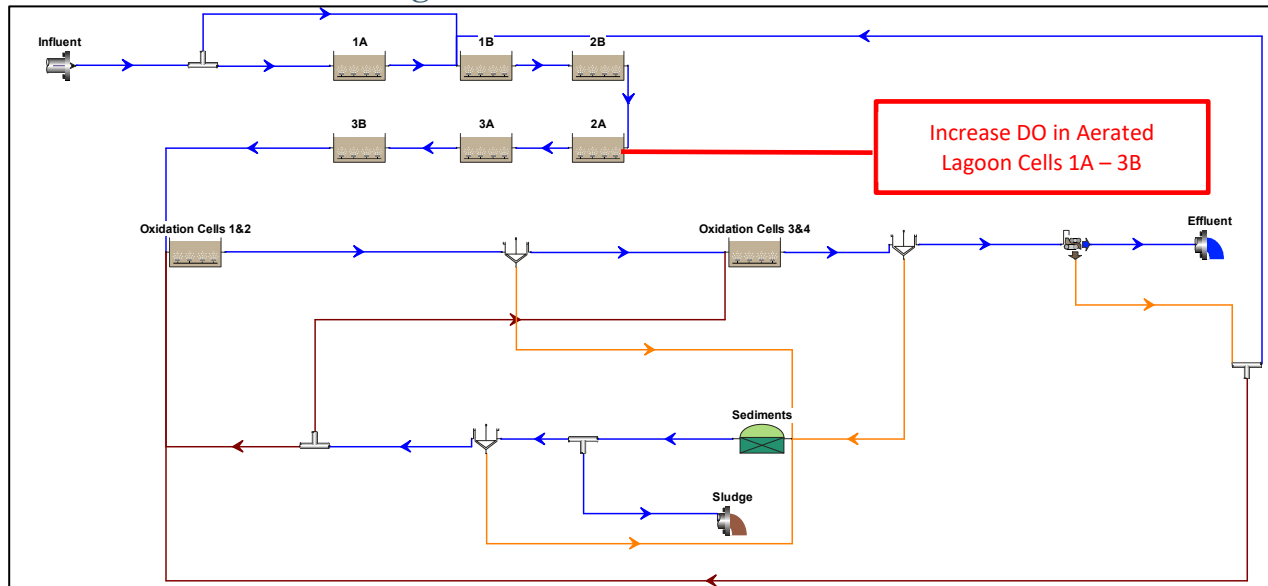
Nine different alternatives were initially identified for consideration. These alternatives are listed below followed by a description, illustration, and initial assessment of each.

- Alternative 1 – Increase Dissolved Oxygen (DO)
- Alternative 2 – Cycled Aeration
- Alternative 3 – Influent Flow Split
- Alternative 4 – Parallel Flow Configuration
- Alternative 5 – Alkalinity Addition
- Alternative 6 – Supplemental Carbon Addition
- Alternative 7 – Denitrifying in Existing Effluent Filters
- Alternative 8 – Lagoon Dredging
- Alternative 9 – Additional Aeration in Oxidation Cells

3.1 *Alternative 1 – Increased Dissolved Oxygen (DO)*

Increasing the level of aeration and DO in the aerated lagoon cells would increase the available oxygen for nitrification. Lower levels of aeration and DO can result in heterotrophic bacteria that oxidize CBOD out competing slower growing nitrifying bacteria for the available oxygen. Figure 2 illustrates that adjustments to DO levels would be focused on the aerated lagoon cells.

Figure 3 – Alternative 1 Illustration



As shown in Table 3, initial process modeling suggests a higher DO concentration in the aerated cells can reduce effluent TN. This is likely due to higher DO concentrations supporting greater nitrification, which then allows increased denitrification in the oxidation cells. The initial process modeling assumed all aerated cells have the same DO concentration. It appears that the benefits of higher DO diminish above a DO concentration of about 4 mg/L.

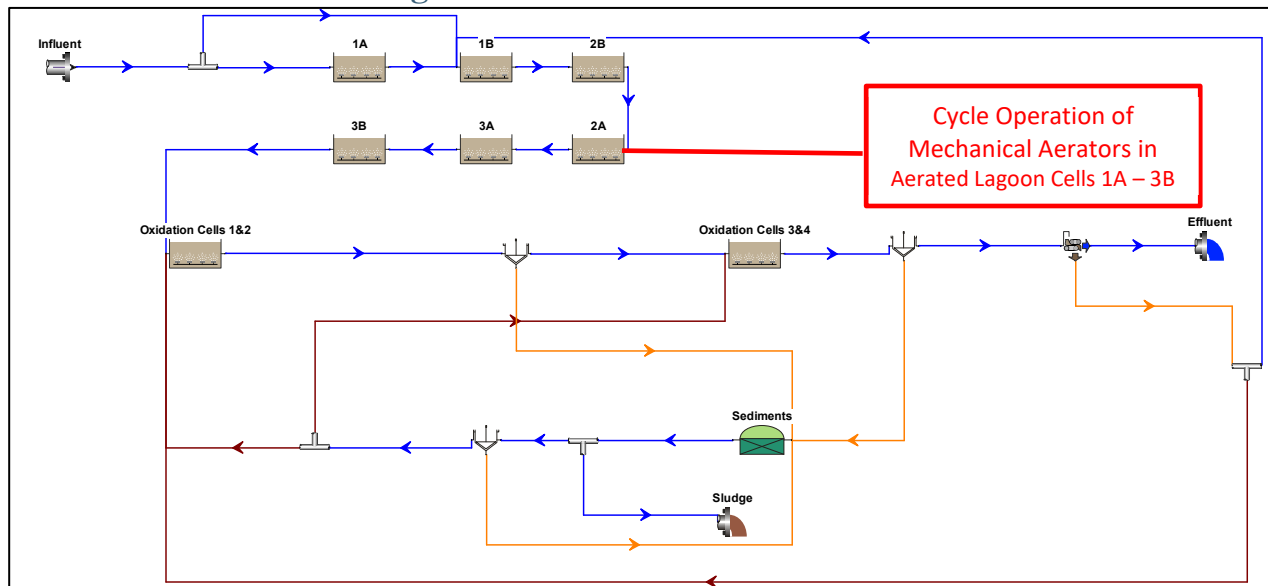
Table 3
Comparison of DO Set Points

Cell DO mg/L	Influent Flow MGD	Effluent TN mg/L	Effluent BOD mg/L	Effluent TSS mg/L
2.0	5.36	24.5	13.2	21.7
3.0	5.36	21.7	11.4	21.6
4.0	5.36	20.5	10.7	21.4
4.5	5.36	20.1	10.5	21.4
5.0	5.36	19.9	10.3	21.3
6.0	5.36	19.6	10.1	21.3

3.2 Alternative 2 - Cycled Aeration

Cycling aeration in the aerated lagoon cells, as opposed to continuous aeration, could potentially generate periodic anoxic conditions that could boost denitrification. Cycled aeration would periodically reduce operation of the mechanical aerators in an attempt to reduce DO and form localized anoxic zones to support denitrification. As illustrated in Figure 4, cycled aeration would be implemented in one or more of the aerated lagoon cells.

Figure 4 – Alternative 2 Illustration



Initial process modeling investigating cycled aeration using an aeration pattern of DO set to 4 mg/L for 1.5 hours followed by 0 mg/L of DO for 1.5 hours, with this pattern repeated. In reality, DO would deplete over a period of time when aeration was off or reduced and then increase over time when full aeration returned. However, the simplistic representation used in the initial modeling still provides a valuable assessment of how cycled aeration would likely function. A summary of the process modeling results for cycled aeration in different aerated lagoon cells is provided in Table 4 below. Lagoon cells marked “FULL” are continuously aerated with no cycling. Lagoon cells marked “CYCLE” have cycled aeration as described above. The initial modeling results suggest that cycled aeration in the aerated lagoon cells may reduce nitrogen removal. This is likely because cycled aeration will reduce DO available for nitrification and that anoxic volume in the oxidation cells is likely sufficient to achieve denitrification of the nitrate generated, such that generating additional anoxic volume in the aerated lagoon cells is counterproductive. Additionally, implementing cycled aeration would likely require some programming modifications to allow setting and adjusting cycle times.

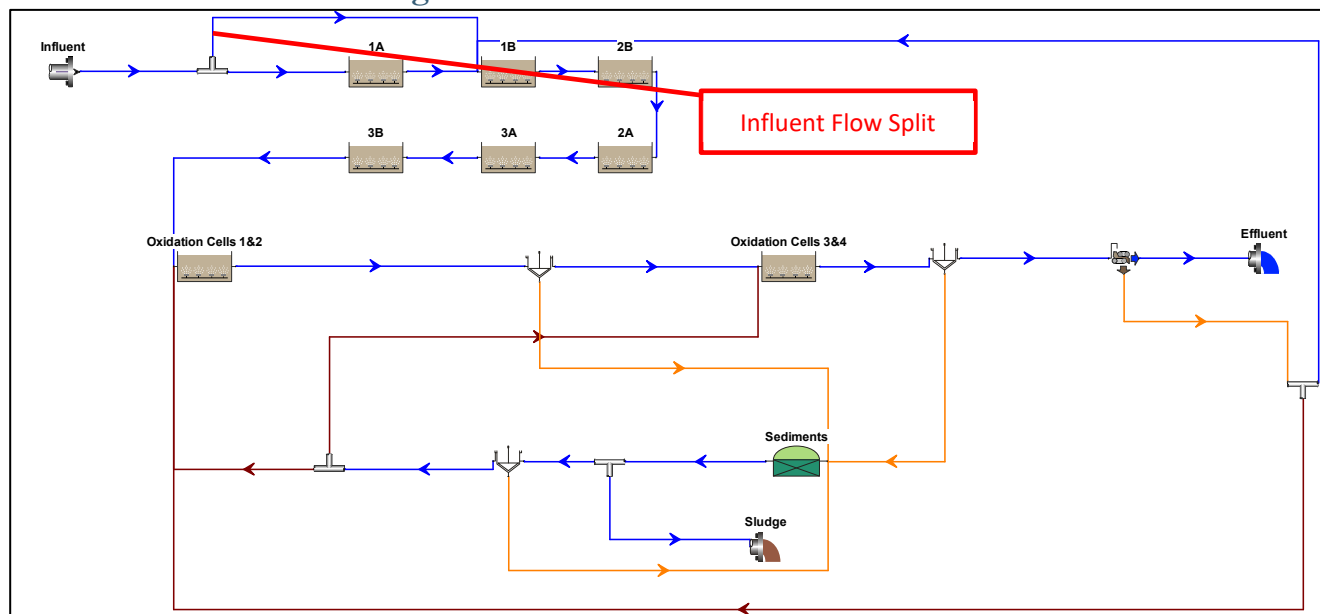
Table 4
Comparison of Cycled Aeration

Trial	Aerated Lagoon Cell						Flow MGD	Total N mg/L	N-NH3 mg/L	TSS mg/L	BOD mg/L
	1A	1B	2B	2A	3A	3B					
1	FULL	FULL	FULL	FULL	FULL	FULL	5.36	20.1	18.4	21.4	10.5
2	CYCLE	FULL	FULL	FULL	FULL	FULL	5.36	20.3	18.6	21.4	10.6
3	CYCLE	CYCLE	CYCLE	FULL	FULL	FULL	5.36	22.0	20.3	21.6	11.3
4	CYCLE	CYCLE	CYCLE	CYCLE	CYCLE	CYCLE	5.36	22.9	21.2	21.7	11.7

3.3 Alternative 3 – Influent Flow Split

Influent flow split would divert a greater portion of the influent wastewater from Lagoon 1A to Lagoon 1B, as illustrated in Figure 5. This could reduce loading in Aerated Lagoon Cell 1A to promote higher DO and a less competitive environment for nitrifying organisms. Currently the flow split is approximately 80% to Aerated Lagoon Cell 1A and 20% to Aerated Lagoon Cell 1B.

Figure 5 – Alternative 3 Illustration



A comparison of different influent flow splits from initial process modeling, based on DO of 4.5 mg/L in all aerated lagoon cells, is summarized in Table 5 below. This modeling suggests that a more even flow split is beneficial to nitrogen removal. Looking at model predictions of ammonia concentrations and nitrifier biomass in the aerated lagoon cells, it appears that a more even flow split allows for greater availability of DO in Cell 1A, such that more nitrifiers are grown overall in the aerated lagoon cells providing higher levels of nitrification. Based on shifting more flow to Cell 1B, process modeling results in Table 6 show that operating at higher DO in the cells does not have as significant an impact on nitrogen removal with the redistribution of flow compared to Alternative 1 without a redistribution of flow.

Table 5
Comparison of Influent Flow Splits

Influent Flow Split (1A/1B)	Influent Flow MGD	DO mg/L	Effluent TN mg/L	Effluent NH3-N mg/L	Effluent BOD mg/L	Effluent TSS mg/L
90/10	5.36	4.5	20.6	18.9	10.9	21.5
80/20	5.36	4.5	20.1	18.4	10.5	21.4
70/30	5.36	4.5	19.5	17.8	10.1	21.3
60/40	5.36	4.5	18.4	16.7	9.8	21.2
50/50	5.36	4.5	16.3	14.6	9.4	21.2
40/60	5.36	4.5	13.6	11.9	8.8	21.2
35/65	5.36	4.5	13.4	11.7	8.9	21.2
30/70	5.36	4.5	13.5	11.8	9.1	21.3

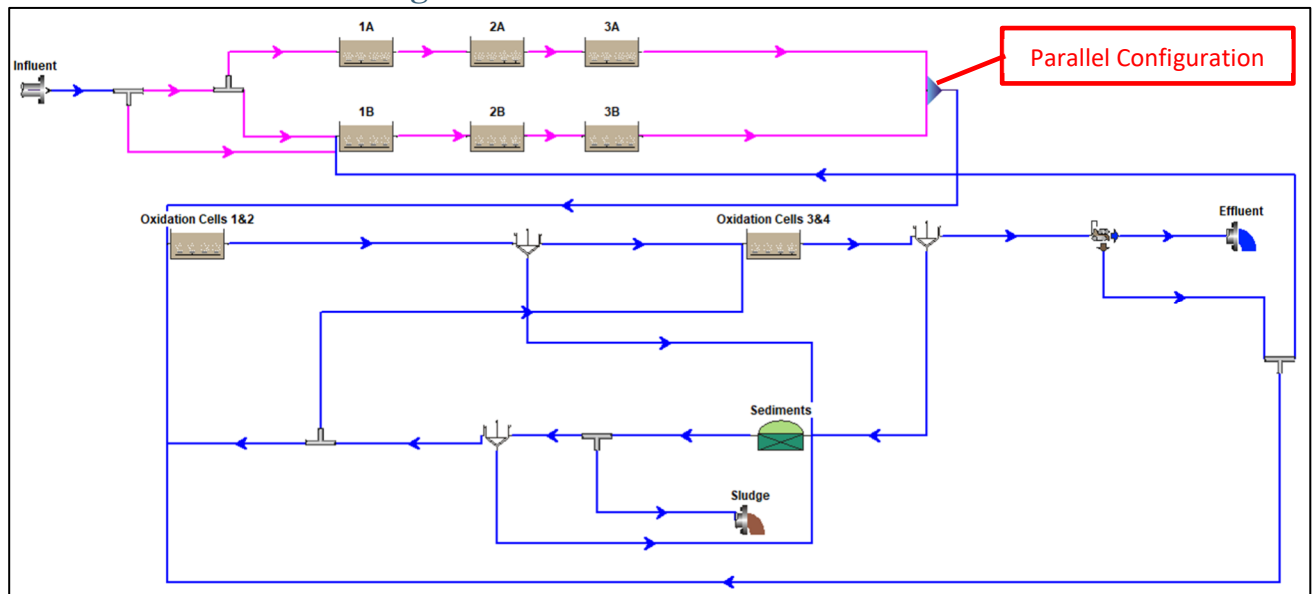
Table 6
Comparison of DO at 35/65 Influent Flow Split

Influent Flow Split (1A/1B)	Influent Flow MGD	DO mg/L	Effluent TN mg/L	Effluent NH3-N mg/L	Effluent BOD mg/L	Effluent TSS mg/L
35/65	5.36	2.0	13.1	11.4	10.2	21.4
35/65	5.36	3.0	13.2	11.5	9.5	21.3
35/65	5.36	4.5	13.4	11.7	8.9	21.2
35/65	5.36	5.0	13.4	11.7	8.6	21.2

3.4 Alternative 4 – Parallel Flow Configuration

As shown in Figure 6, Alternative 4 includes operating the aerated lagoon cells in a parallel configuration. Half of the influent would flow through Aerated Lagoon Cells 1A, 2A and 3A and the other half of the influent would flow through Aerated Lagoon Cells 1B, 2B and 3B. There are existing “windows” in the baffles separating these cells that can be rearranged to switch from series to parallel flow. Since this is an available option, it was decided to see if this might have a beneficial impact on nitrogen removal.

Figure 6 – Alternative 4 Illustration



As shown in Table 7 below, there is a predicted 20% reduction in TN when changing the configuration from series (80/20 flow split) to parallel flow. It appears that the reason for this benefit is the same as modifying the influent flow split under Alternative 3, but the modified influent flow split with series operation appears to have a greater benefit. This is likely due to the fact that a series configuration allows for more nitrification overall due to the improved efficiency that is typically associated with more cells in series.

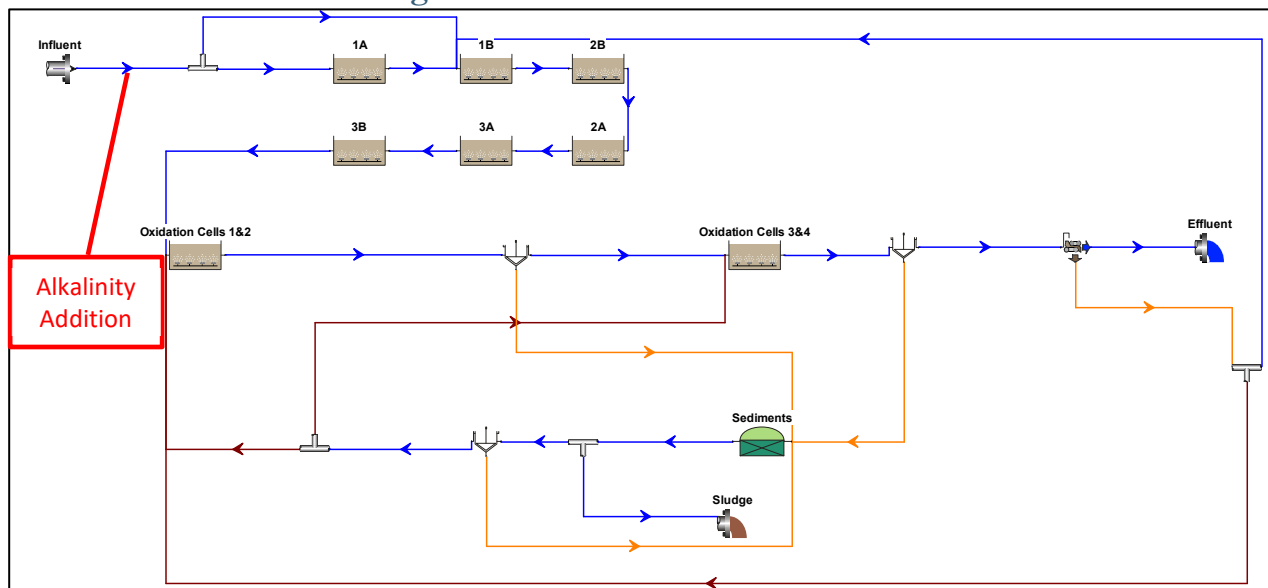
Table 7
Comparison of Series and Parallel Flow

Configuration	Influent Flow MGD	DO mg/L	Effluent TN mg/L	Effluent BOD mg/L	Effluent TSS mg/L
Series (80/20)	5.36	4.5	20.1	10.5	21.4
Parallel (50/50)	5.36	4.5	16.2	10.3	21.5

3.5 Alternative 5 – Alkalinity Addition

As illustrated in Figure 8, alkalinity can be added to the influent to support stable nitrification, if subsequent modeling demonstrates this would help support additional nitrification. Nitrification consumes alkalinity, which can lead to a reduction in pH. Nitrification typically starts to become inhibited at pH less than 6.5. Adding alkalinity increases buffering against a reduction in pH. If alkalinity were to be added it is recommended it be added in the form of magnesium hydroxide. Compared to other sources of supplemental alkalinity (e.g., sodium hydroxide), it is not prone to freezing, is safer to handle, and will not adversely raise pH in the same way other chemicals would if overdosed.

Figure 8 – Alternative 5 Illustration



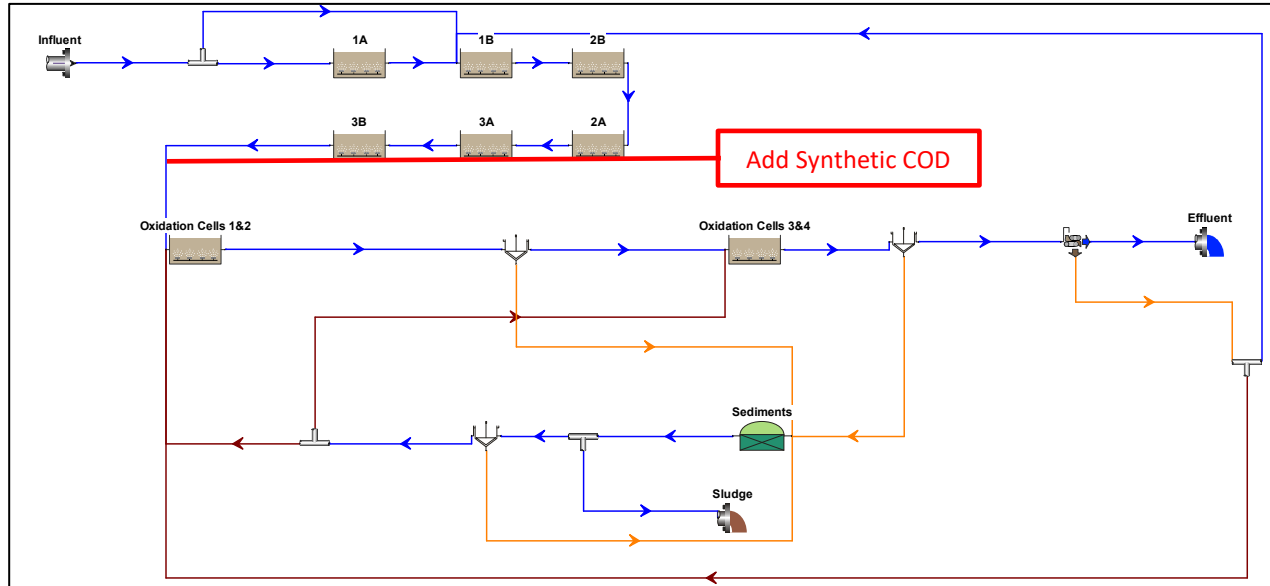
There was limited information available on influent alkalinity when conducting the initial process modeling. Subsequent process modeling will utilize alkalinity data collected by the City between 2019 and 2021. The amount of alkalinity in the influent in combination with the degree of nitrification will determine whether supplemental alkalinity will be beneficial.

3.6 Alternative 6 – Supplemental Carbon

In some instances, there is insufficient carbon remaining in the wastewater following nitrification to support denitrification. In such instances, addition of a synthetic carbon source can be used to enhance denitrification. This would require purchase of synthetic carbon (e.g., Micro-C) and a metering pump to pace dosing of the synthetic carbon with flow. 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. As illustrated in Figure 7, the synthetic carbon could be dosed where the flow enters to first oxidation cell following nitrification in the aerated lagoon cells.

Figure 9 – Alternative 6 Illustration



For the initial process modeling, a dose of 150 gallons per day of synthetic supplemental carbon was assumed. As shown in Table 8 below, dosing supplemental carbon does not appear to improve nitrogen removal and instead raises effluent BOD. This is likely due to the fact that the limited nitrification does not require substantial carbon for denitrification and the long retention time in the oxidation cells allows time for carbon that is typically less available in conventional treatment system to breakdown and become available for use in denitrification.

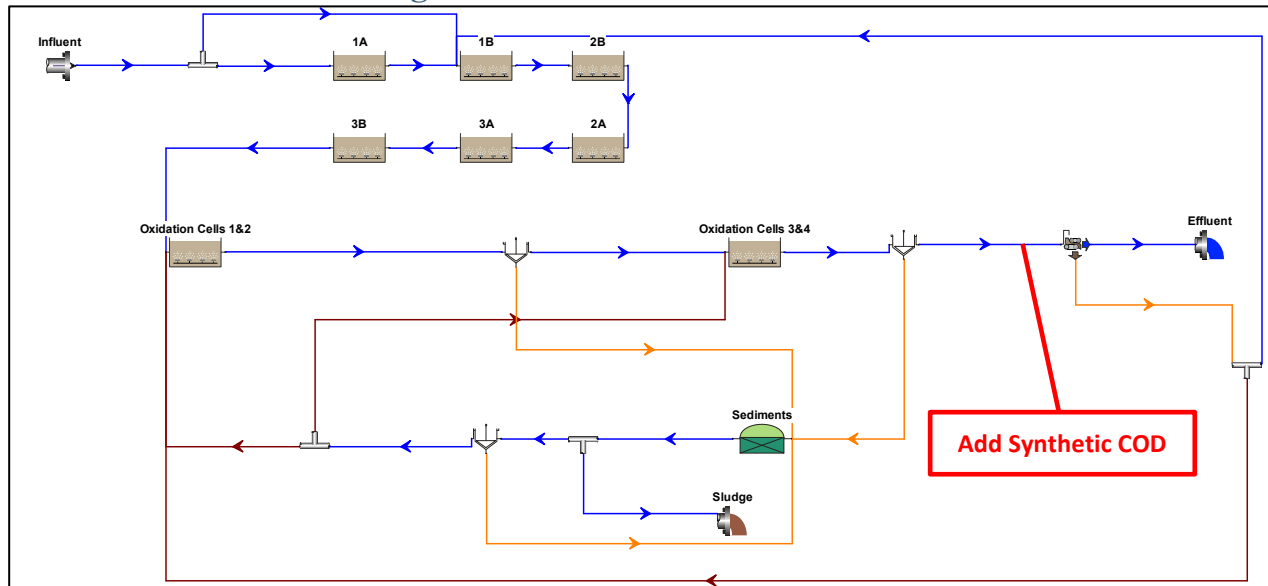
Table 8
Comparison with and without Synthetic Carbon

Dosing Synthetic Carbon?	Influent Flow MGD	DO mg/L	Effluent TN mg/L	Effluent BOD mg/L	Effluent TSS mg/L
No	5.36	4.5	20.1	10.5	21.4
Yes	5.36	4.5	20.7	21.8	22.9

3.7 Alternative 7 – Denitrifying in Existing Effluent Filters

Synthetic carbon could also 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, which equates to 3.4 to 11.4 MGD based on the current size and number of filters.

Figure 8 – Alternative 7 Illustration



Use of the existing effluent filters as denitrifying filters should only be considered as a last resort. Although the existing filters might theoretically have sufficient hydraulic capacity to operate denitrifying filters, it could be difficult to control the dose of synthetic carbon to promote just the right amount of growth on the sand media. Too much synthetic carbon yielding excess growth would plug the filters and too little would not yield significant removal of nitrogen.

3.8 Alternative 8 – Dredging Lagoon Cells

The City is planning to incorporate dredge grit and other heavy solids from Aerated Lagoon Cells 1A and 1B in the near future. This involves mechanically removing the solids that have accumulated at the bottom of these cells and dewatering and disposing of these solids. Removing the accumulated solids would in turn maximize the volume for treatment and reduce the potential release of ammonia from digestion of the accumulated solids.

3.9 Alternative 9 – Additional Aeration in Oxidation Cells

It is possible that increasing oxygen transfer in the oxidation cells might help increase nitrification, and thus allow for greater denitrification. This would require addition of mechanical aerators to the oxidation cells, which would be a significant investment. Currently, there are only a few aspirating aerators in the oxidation cells primarily to prevent accumulation of solids in corners and help establish the direction of flow. Initial process modeling suggests that there is no significant decrease in effluent total nitrogen when the oxygen transfer rate is doubled in the oxidation cell.

Table 9
Increasing Oxygen Transfer in Oxidation Cell 1

Cell DO mg/L	OTR lb/hr	Influent Flow MGD	Effluent TN mg/L	Effluent BOD mg/L	Effluent TSS mg/L
4.5	6.13	5.36	20.1	10.5	21.4
4.5	11.99	5.36	19.87	10.25	21.27

3.10 Alternatives Selected for Further Evaluation

The following is a summary of the discussion and initial process modeling for the identified alternatives:

- Alternative 1 – Increasing DO did not seem to provide a significant benefit with the modified influent flow split and the City indicated DO is typically high already (~ 4 mg/L), at least during the warmer summer months when nitrification would be more prominent, as a result of maintaining proper mixing. Therefore, Alternative 1 will not be evaluated further, except as it may relate to other alternatives.
- Alternative 2 – As discussed above, cycled aeration did not indicated any significant benefit and will not be considered further.
- Alternative 3 – Initial process modeling indicated modifying the influent flow split between Cells 1A and 1B could significantly improve nitrification, and thus nitrogen removal. This will be further validated.
- Alternative 4 – Initial process modeling indicated operating the aerated lagoon cells in parallel was not as effective as series operation with a modified influent flow split. Therefore, this alternative will not be considered further.
- Alternative 5 – As indicated in the discussion above, further process modeling with additional data will be conducted to determine if alkalinity addition would improve nitrification significantly.
- Alternative 6 – Initial process modeling indicated supplemental carbon was not beneficial to improving nitrogen removal. This will be validated with further process modeling using additional data. If confirmed, this alternative will not be considered further.
- Alternative 7 – As discussed above, utilizing the existing effluent filters as denitrifying filters will not be considered further at this time due to potential for issues with plugging and limiting hydraulic capacity. This alternative will only be considered in the future if other viable alternatives have been implemented and further nitrogen reduction is necessary.
- Alternative 8 – As discussed above, the City already has plans to conduct dredging in Cells 1A and 1B, which will help maximize treatment capacity in the aerated lagoon cells, thereby helping to support optimal nitrification.

- Alternative 9 – As discussed above, addition of mechanical aerators to the oxidation cells would be a significant investment that would be better invested in the planned future conversion to an activated sludge process.

In summary, the City already plans to implement Alternative 8, and Alternatives 3 and 5 will be evaluated further, which may also involve some recommendations for DO pertaining to Alternative 1. Alternatives 7 and 9 are given low priority and will only be considered in the future if required. Alternatives 2 and 4 are not considered beneficial and so will not be retained for future consideration. If the initial conclusions for Alternative 6 are confirmed with further process modeling, this alternative will also not be retained for future consideration.

4. Evaluation of Selected Nutrient Removal Alternatives

The evaluation of selected alternatives involves further process modeling using additional data collected and provided by the City that will help provide more accurate predictions compared to the initial process modeling. This will be used to validate initial findings and develop specific recommendations for implementation.

4.1 Supplemental Data

The influent characteristics can significantly impact the effectiveness of denitrification within the WWTP processes. For example, low influent alkalinity may provide inadequate buffering to avoid a significant drop in pH that would inhibit nitrification. 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 10 below.

Table 10
Supplemental Data Collected

Date	Alkalinity	Influent						Effluent COD
		pH	COD	fCOD	fCBOD	CBOD	VSS	
3/2/2022	144	7.1	440	190	71	180	257	42
3/9/2022	156	7.4	560	200	80	202	227	35
3/16/2022	162	7.3	550	230	92	188	217	52
3/23/2022	137	7.4	500	200	83	179	203	52
3/30/2022	155	7.2	610	240	103	257	287	47
4/5/2022	156	7.1	680	200	91	227	-	52
4/12/2022	-	7.1	540	220	81	215	173	46
4/19/2022	-	7.6	600	220	125	245	247	50
4/26/2022	-	7.1	610	200	89	281	-	63

The City also provided available historical data for influent alkalinity that had already been collected but was not included with the monthly discharge monitoring reports. This alkalinity data is summarized in Table 11.

Table 11
Influent Alkalinity Data

Year	Average Influent Alkalinity mg/L CaCO ₃	Minimum Influent Alkalinity mg/L CaCO ₃	Maximum Influent Alkalinity mg/L CaCO ₃
2019	188	167	216
2020	185	139	276
2021	172	134	207
2019 - 2021	180	134	276

4.2 *Process Modeling for Selected Alternatives*

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 Marysville WWTP. This influent characterization is summarized in Table 12 below. The influent alkalinity was determined as the average of the 2019 to 2021 data provided by the City.

Table 12
Average Influent Wastewater Characterization

Parameter	Value, mg/L	Parameter	Value, mg/L
Total COD	768	Total Kjeldahl Nitrogen (TKN)	52
Filtered COD (fCOD)	291	Nitrate	0.2
Total CBOD	289	Ammonia	32.3
Filtered CBOD (fCBOD)	124	Alkalinity	180
TSS	325	pH	7.3
VSS	285	Effluent COD	65

Influent values for June through October were used because this is when temperatures are such that substantial nitrification could be achieved in the aerated lagoon cells 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 4.6 MGD based on 2019 to 2021 historical data.

First, model runs were conducted for Alternative 5 to determine the impacts of adding supplemental alkalinity. Nitrification consumes alkalinity, which can lead to a reduction in pH. Adding alkalinity increases buffering against a reduction in pH and subsequent inhibition of biological activity. The addition of supplemental alkalinity was accomplished by increasing the alkalinity of the influent in the process model. The average influent alkalinity for June through October is about 200 mg/L as calcium carbonate (as CaCO₃), which equates to 4 millimoles per liter (mmol/L). A summary of the process model predictions at different influent alkalinity concentrations is shown in Table 13 below. The model runs shown in Table 13 assume DO concentrations of 4.0 mg/L in the aerated lagoon cells, 80% of influent flow to Aerated Lagoon Cell 1A and 20% to Aerated Lagoon Cell 1B.

Table 13
Influent Alkalinity Addition as CaCO₃

Influent Flow MGD	Influent Alkalinity mg/L	Supplemental Alkalinity mg/L	Effluent TN mg/L	Effluent BOD mg/L	Effluent TSS mg/L
4.6	200	0	42.4	36.2	22.7
4.6	250	50	36.5	21.2	22.5
4.6	300	100	23.1	11.4	22.0
4.6	350	150	15.3	9.8	21.7
4.6	400	200	7.6	3.7	21.7
4.6	450	250	8.1	1.8	21.3

Based on this analysis, it appears that insufficient influent alkalinity leads to significant inhibition of nitrification without addition of supplemental alkalinity. Additionally, the model indicates inhibition of activity by heterotrophic bacteria resulting in reduced BOD removal. The impacts would likely be not as significant if actual temperatures or influent nitrogen are lower or actual influent alkalinity is higher, but regardless there appears to be a substantial benefit from addition of supplemental alkalinity. The model predicts a supplemental alkalinity dose of even just 100 mg/L as CaCO₃ could reduce effluent total nitrogen by nearly half.

Next, the model was run with different Dissolved Oxygen levels in the aeration basins at a constant dose of supplemental alkalinity. A supplemental alkalinity dose of 200 mg/L as CaCO₃ was used for these modeling runs, and an 80/20 flow split was retained for Aerated Lagoon Cells 1A and 1B. As shown in Table 14, process modeling suggests that a higher DO concentration in the aerated lagoon cells may improve BOD

removal some but does not appear to have a significant impact on nitrogen removal. Therefore, there does not appear to be any reason to change current aeration parameters, which normally yields DO concentrations around 4.0 mg/L. Therefore, DO concentrations of 4.0 mg/L in the aerated lagoon cells was retained for subsequent model runs.

Table 14
DO set points in Aerated Lagoon Cells

Influent Flow MGD	DO Set Point mg/L	Effluent TN mg/L	Effluent BOD mg/L	Effluent TSS mg/L
4.6	3.0	7.7	6.1	21.5
4.6	4.0	7.6	3.7	21.7
4.6	4.5	7.6	3.0	21.7
4.6	5.0	7.6	2.6	21.7
4.6	6.0	7.6	2.3	21.7

Next, the model was run with changes to the influent flow split between Aerated Lagoon Cells 1A and 1B from the current target of 80/20. A supplemental alkalinity dose of 200 mg/L as CaCO₃ was used for these model runs. A summary of the results is shown in Table 15 below. Based on the analysis, there may be a small benefit to having a more even flow split indicated by slight reductions in effluent total nitrogen and BOD. Additionally, further examination of the model runs shows increased ammonia oxidizing biomass in the aerated lagoon cells with a more even flow split, as noticed with initial modeling. However, it appears that changes to influent characteristics (most notably a significantly higher COD concentration) based on supplemental testing data has mitigated the more significant benefits observed during the initial modeling.

Table 15
Influent Flow Split

Influent Flow Split (1A/1B)	Influent Flow MGD	Effluent TN mg/L	Effluent BOD mg/L	Effluent TSS mg/L
80/20	4.6	7.58	3.68	21.65
70/30	4.6	7.35	2.98	21.66
60/40	4.6	7.36	2.96	21.66
50/50	4.6	7.48	3.04	21.69
40/60	4.6	7.66	2.95	21.77
35/65	4.6	7.56	2.44	21.68
30/70	4.6	8	3	21.89

Lastly, model runs were conducted with addition of supplemental carbon to Oxidation Cell 1 to help drive denitrification. The model assumed MicroC 2000 was dosed for supplemental carbon. A summary of the results is provided in Table 16.

Table 16
Supplemental Carbon Addition

Carbon gpd	Influent Flow MGD	Effluent TN mg/L	Effluent BOD mg/L	Effluent TSS mg/L
0	4.6	7.58	3.71	21.65
50	4.6	7.94	8.53	21.98
100	4.6	8.2	12.31	23
250	4.6	8.14	18.78	24.91

Dosing supplemental carbon does not appear to improve nitrogen removal and instead slightly raises effluent BOD. As deduced from the initial modeling, this is likely because the long retention time in the oxidation cells allows time for carbon that is typically less available in conventional treatment systems to breakdown and become available for use in denitrification.

4.3 Nitrification Inhibition

It appears that addition of supplemental alkalinity should significantly improve nitrification by keeping pH near neutral, which would allow for denitrification in the oxidation cells. Furthermore, supplemental alkalinity would also prevent reduced BOD removal from inhibition of activity by heterotrophic bacteria due to low pH, which process modeling results also suggest may occur without supplemental alkalinity. However, the City reports that there is no drop in pH through the aerated lagoon cells. The City checked calibration of the pH meter and confirmed that pH in the lagoons remains near neutral. Furthermore, periodic sampling and testing of ammonia in the aerated lagoon cells indicates that significant nitrification activity is not occurring, even with high DO concentrations (around 4 mg/L) and high summer temperatures. These observations suggest that nitrification in the aerated lagoons is inhibited. Typically, there should be noticeable nitrification and an accompanying reduction in ammonia under the current conditions, as suggested by the model and performance of other lagoon facilities in the region. Examination of the lagoon microbiology by Ryan Hennessy (a microbiology services consultant) indicated that nitrifying bacteria was viewed only occasionally in samples, further supporting the conclusion that nitrification is somehow inhibited.

Research by BHC found that an abundance of algae can be toxic to nitrifying bacteria (Choi, C., et al., Nitrifying Bacterial Growth Inhibition in The Presence of Algae and Cyanobacteria. *Biotechnology and Bioengineering*. December 2010). Ryan Hennessy confirmed in a videoconference that an abundance of algae (particularly blue-green algae) could inhibit nitrification. Given that reject flow from the filters, which has high concentrations of algae discharges to Cell 1B of the aerated lagoon cells, it is quite likely that the

algae is indeed inhibiting nitrification. This would explain why there is apparently no nitrification activity under the currently favorable conditions.

The City also has the capability of sending the reject flow to Oxidation Cell 2. Changing the discharge of the reject flow from Cell 1B to Oxidation Cell 2 should substantially reduce the concentration of algae in the aerated lagoon cells, which could result in a significant increase in nitrification if the high concentration of algae in the aerated lagoon cells is indeed inhibiting nitrification. A comparison of results for the two discharge locations, assuming no inhibition of nitrification, is shown in Table 17. This comparison assumes the current 80/20 flow split between Cells 1A and 1B and current typical DO residual of 4 mg/L. Additionally, the reject flow rate was corrected to the average flow of 700 gpm for June through October. Previous model results had assumed a lower reject flow rate, which had some impact on performance due to the change in residence time in the aerated lagoon cells.

Table 17
Comparison of Reject Flow Discharge Locations

Reject Flow Discharge Location	Influent Flow MGD	Influent Alkalinity mg/L	Supplemental Alkalinity mg/L	Effluent TN mg/L	Effluent BOD mg/L	Effluent TSS mg/L
Cell 1B	4.6	200	0	39.4	15.7	23.7
Cell 1B	4.6	250	50	35.4	9.2	23.1
Cell 1B	4.6	300	100	20.5	6.1	22.5
Cell 1B	4.6	350	150	11.6	4.1	21.9
Cell 1B	4.6	400	200	6.0	2.2	21.2
Ox. Cell 2	4.6	200	0	39.7	19.1	23.1
Ox. Cell 2	4.6	250	50	35.3	8.9	22.6
Ox. Cell 2	4.6	300	100	21.6	4.8	21.7
Ox. Cell 2	4.6	350	150	13.7	3.7	21.3
Ox. Cell 2	4.6	400	200	8.0	2.1	20.8

As shown in Table 17, the potential nitrogen removal with reject flow discharged to Cell 1B is higher, because ammonia in that return stream could be nitrified with the influent in the aerated lagoon cells, but the potential removal rate is still almost as great with reject flow discharged to Oxidation Cell 2.

4.4 Evaluation of Selected Alternatives

As discussed above, it appears that high concentrations of algae in the reject flow that is receive into Cell 1B is inhibiting nitrification activity. If this inhibition were removed or significantly decreased by directing discharge of reject flow to Oxidation Cell 2, process modeling suggests that addition of supplemental

alkalinity may be necessary to prevent a significant drop in pH and could also substantially increase nitrification in the aerated lagoon cells, and subsequent denitrification in the oxidation cells.

Additional modeling confirmed the conclusions of the initial modeling regarding increased DO concentrations and dosing supplemental carbon. Increased DO concentrations did not appear to have a significant benefit on nitrification and supplemental carbon did not increase denitrification, as nearly all nitrate was already being denitrified without supplemental carbon. Changing to a more even flow split appeared to increase the mass of ammonia oxidizing bacteria, as also indicated with the initial modeling, but the impact of a more even flow split on effluent nitrogen was less noticeable, likely due to the significantly higher COD concentrations than initially assumed.

Typical chemicals used for supplemental alkalinity are sodium hydroxide (NaOH) or magnesium hydroxide ($Mg(OH)_2$). Magnesium hydroxide is becoming more common because it is easier to handle because it is less hazardous, requires less volume for the same buffering capacity, is not subject to freezing at moderately low temperatures, and does not increase pH as much if overdosed. However, because it is a slurry a mixer is required to keep solids in suspension. To gauge the impact of $Mg(OH)_2$ specifically at different doses, the model was run simulating addition of magnesium hydroxide at different rates, assuming reject flow is discharged to Oxidation Cell 2. A summary of these model runs is shown in Table 18.

Table 18
Magnesium Hydroxide Addition

Mg(OH)₂ gpd	Influent Flow MGD	Effluent TN mg/L	N Removal Cost, \$/lb	Effluent BOD mg/L	Effluent TSS mg/L
0	4.6	39.4	\$0	15.7	23.7
200	4.6	32.2	\$2.06	6.3	22.3
300	4.6	21.2	\$1.22	4.8	21.7
400	4.6	16.0	\$1.27	4.3	21.5
500	4.6	10.8	\$1.30	2.8	21.4

Process modeling indicates that a 300 gpd dose of $Mg(OH)_2$ is needed to prevent excessively low pH without nitrification inhibition. As indicated in Table 18, a $Mg(OH)_2$ dose of 300 gpd is predicted to reduce effluent TN by about 46% and a dose of 500 gpd by about 72%. Based on a cost of \$2.85 per gallon for $Mg(OH)_2$, the cost per pound of nitrogen removed is around \$1.30 at doses of 300 gpd and above. Typically, at these volumes of chemical, the supplier will provide the storage tank and appurtenances, such that the City need only provide a metering pump, piping/tubing, etc. At a dose of 300 gpd (roughly equivalent to increasing the influent alkalinity by 150 mg/L as $CaCO_3$) for 5 months (June through October), the cost of $Mg(OH)_2$ would be about \$130,000 per year. However, as discussed previously, if temperatures

or influent nitrogen are lower or influent alkalinity is higher than simulated in the model, similar effluent results could be seen at a lower dose.

5. Recommendations for Implementation

It is recommended that the City change the discharge of the reject flow from Cell 1B to Oxidation Cell 2. After this change is made, over time the concentration of algae in the aerated lagoon cells should decrease and then the growth of nitrifiers should increase. It will likely take several weeks for significant nitrification to be observed. The City should continue to periodically monitor pH and ammonia across the aerated lagoon cells to track the progress of nitrification and determine if the pH is dropping and addition of supplemental alkalinity is needed.

If pH levels in the aerated lagoon cells are near 6.0 or effluent pH is below 6.5, it is recommended that the City dose supplemental alkalinity to maintain adequate pH during June through October when nitrification is expected to occur, which will also help to further increase nitrogen removal. Dosing of supplemental alkalinity should start at 300 gpd and be adjusted as needed based on monitoring pH.

It is recommended that a more even flow split between Aerated Lagoon Cells 1A and 1B be considered. Although additional modeling did not indicate as significant a benefit as suggested by initial modeling, it did indicate there may be a slight improvement in effluent quality and that it would help increase the mass of ammonia oxidizing bacteria.

It is recommended that the City proceed with dredging in Aerated Lagoon Cells 1A and 1B. This will maximize treatment capacity in these cells, which may help boost nitrification.

Neither use of supplemental carbon nor increased DO concentrations in the aerated lagoon cells showed a benefit. Therefore, neither of these are recommended for future consideration, along with cycled aeration and use of the parallel flow configuration as discussed prior.

The addition of aerators to the oxidation cells and the use of the existing effluent filters as denitrifying filters are not recommended for consideration at this time. The addition of aerators would be expensive and involve substantial work to provide power to additional aerators. Operating the existing effluent filters as denitrifying filters would require a difficult balance of microbial growth in the effluent filters that is sufficient to achieve significant nitrogen reduction but not excessive such that it would risk plugging the filters. Should there be a need for additional nitrogen removal in the future, these options could be revisited at that time.