

University of Nevada, Reno

**DEVELOPMENT AND CALIBRATION OF A BIOWIN PROCESS MODEL TO
EVALUATE TREATMENT ALTERNATIVES FOR OPTIMIZED EFFICIENCY**

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ABSTRACT

DEVELOPMENT AND CALIBRATION OF A BIOWIN PROCESS MODEL TO EVALUATE TREATMENT ALTERNATIVES FOR OPTIMIZED EFFICIENCY

A biological process model was developed using BioWin to evaluate treatment performances at the Truckee Meadows Water Reclamation Facility (TMWRF) in Reno, Nevada. Historical flow and loading data for the facility were analyzed and used to develop a preliminary BioWin model for the existing plant layout. To aid in model development, several different two-week sampling campaigns were implemented to capture the plant influent loading and target chemical constituent concentrations in internal recycle streams. The sampling campaigns helped determine the influent wastewater fractions needed to properly calibrate the BioWin model. Upon further investigation, process data revealed that the activate sludge Systems 1 and 2 within the facility operate differently; as such, the two systems were modeled and calibrated individually. By sampling both the plant influent and recycle streams separately, and modeling each process flow as their own input, the model can be readily modified if influent loads or internal processes change in the future. The BioWin model for the existing process scheme was developed so that alternative processes can be investigated. Research efforts then focused on expanding the model to evaluate anticipated performance of alternative treatment configurations. The alternatives investigated include activated sludge reconfiguration for biological nutrient removal (BNR) treatment and chemical treatment for enhanced phosphorus removal. BNR activated sludge configurations investigated include the anaerobic/anoxic/aerobic (A²O), 5-stage Bardenpho, Standard and Modified University of Capetown (UCT), Virginia Initiative

Plant (VIP), and Modified Ludzack-Ettinger (MLE) processes. In combination with the MLE activated sludge configuration, chemical treatment for enhanced phosphorus removal was also investigated. After analyzing carbon and nutrient removal between the alternative treatment configurations, the aeration demand was investigated to compare requirements of the current process to proposed alternatives. Finally, the energy and chemical costs of the current TMWRF process were compared to the alternative designs.

TABLE OF CONTENTS

ABSTRACT.....	i
LIST OF TABLES.....	vii
LIST OF FIGURES.....	x
LIST OF ACRONYMS.....	xiv
Chapter 1 : Introduction.....	1
Chapter 2 : Literature Review.....	3
2.1 Contaminants of Concern in Wastewater.....	3
2.2 Impact of Contaminants on Surface Waters.....	4
2.2.1 Eutrophication.....	4
2.2.2 Hypoxia.....	5
2.2.3 Taste and Odor.....	6
2.3 Wastewater Reuse.....	7
2.3.1 Irrigation.....	8
2.3.2 Groundwater Recharge.....	9
2.3.3 Potable Reuse.....	10
2.4 Regulations.....	11
2.4.1 Regulation History.....	11
2.4.2 NPDES Permits.....	14

2.5 Wastewater Nutrient Treatment	16
2.5.1 Physical Treatment.....	16
2.5.2 Biological Treatment	16
2.5.3 Nitrification and Denitrification	20
2.5.4 Phosphorus Removal	24
2.5.5 Combined CNP Treatment.....	27
2.6 BioWin.....	30
2.6.1 Introduction and Application	30
2.6.2 Case Studies	31
2.6.3 BioWin Model Inputs and Important Parameters	33
Chapter 3 : Problem Statement/Aim of Research	36
3.1 Purpose of Project.....	36
3.2 Project Tasks.....	36
3.3 TMWRF Process Layout	37
Chapter 4 : Model Development and Calibration of the Truckee Meadows Water Reclamation Facility	39
4.1 Preliminary Analyses and Sampling Campaigns.....	39
4.1.1 Historical Data	39
4.1.2 Initial Sampling Campaigns.....	49
4.1.3 Additional Sampling Campaign.....	50

4.2 TMWRF Sampling Campaign Data.....	54
4.3 BioWin Model Calibration	61
4.3.1 TMWRF Data Corrections.....	63
4.3.2 Process Units and Plant Configuration	70
4.3.3 Influent Wastewater Characteristics	76
4.3.4 Solids and Nutrients Calibration.....	79
4.3.5 Aeration Calibration.....	82
4.4 Model Predictions and Accuracy	94
4.4.1 Main (Summer) Sampling Campaign	94
4.4.2 Other Sampling Campaigns	102
4.5 Model Sensitivity Analysis	112
Chapter 5 Design and Evaluation of Combined CNP Treatment Alternatives.....	118
5.1 Modifications to Current TMWRF Operation	118
5.1.1 Modified Ludzack-Ettinger Activated Sludge Process.....	118
5.1.2 Chemical Treatment for Phosphorus Removal	125
5.2 Future TMWRF Activated Sludge Treatment Alternatives.....	127
5.3 Current and Alternative Process Comparisons	142
5.3.1 Treatment	142
5.3.2 Aeration Demand.....	148

5.3.3 Energy and Chemical Costs	150
5.4 Other Impacts to TMWRF Operation	156
Chapter 6 : Conclusion and Recommendations	159
REFERENCES	165
APPENDIX A – 2017 TMWRF Plant Influent Data.....	170
APPENDIX B – Fall, Winter, & Summer Sampling Sampaigh Data	183
APPENDIX C – Influent Stream Concentrations and Assumptions	200
APPENDIX D – TMWRF Process Schematic	204
APPENDIX E – BioWin Models.....	206
APPENDIX F – DO Sampling Campaign Data	226
APPENDIX G – MLE Recycle Ratio Analysis.....	231
APPENDIX H – Safety Data Sheets.....	236

LIST OF TABLES

Table 2.1: Clean Water Act and Major Amendments (codified generally as 33 §§1251-1387)	13
Table 2.2: Discharge limitations, monitoring, and reporting requirements for TMWRF.	15
Table 2.3: Major biological treatment processes used for wastewater treatment	19
Table 2.4: Important BioWin parameters and purposes	35
Table 4.1: Average concentrations and standard deviation for seasonal 2017 data	40
Table 4.2: Average load and standard deviations for seasonal 2017 data	41
Table 4.3: Seasons with maximum loads and significant difference between fall and winter	49
Table 4.4: Additional data requested in fall and winter for model development	50
Table 4.5: Summer campaign composite sample analyses information	53
Table 4.6: Summer campaign grab sample analyses information	54
Table 4.7: Average plant influent values for the three sampling campaigns	56
Table 4.8: Average primary influent values for the sampling campaigns	57
Table 4.9: Average primary effluent values for the sampling campaigns	58
Table 4.10: Average secondary effluent values for the sampling campaigns.....	59
Table 4.11: Average aeration system values for the sampling campaigns	60
Table 4.12: Average recycle stream values for the summer campaign	61
Table 4.13: Original and updated FFCOD:COD ratios	64
Table 4.14: Plant influent and recycle stream flows for Systems 1 and 2	66
Table 4.15: BioWin influent specifier parameters measured during summer campaign..	69
Table 4.16: Physical parameters for the primary clarifiers.....	74

Table 4.17: Physical parameters for the activated sludge tanks	75
Table 4.18: Physical parameters for the secondary clarifiers	75
Table 4.19: COD influent data for plant influent and recycle streams	77
Table 4.20: Particulate substrate and inert COD:VSS ratios	77
Table 4.21: COD influent fractions based on BioWin influent specifier	78
Table 4.22: Adjusted BioWin parameters for solids calibration.....	80
Table 4.23: Adjusted BioWin kinetic parameters for N and P removal	81
Table 4.24: Updated BioWin aeration parameters.....	83
Table 4.25: Number of diffusers for the aeration zones in the activated sludge	84
Table 4.26: Average DO values for each pass in both systems	84
Table 4.27: System 1 updated summer DO values using calculated	90
Table 4.28: System 2 updated summer DO values using calculated ratios	90
Table 4.29: System 1 measured vs. model data comparison	95
Table 4.30: System 2 measured vs. model data comparison	96
Table 4.31: Fall sampling campaign updated flows	104
Table 4.32: Winter sampling campaign updated flows	104
Table 4.33: Fall System 1 measured vs. model data comparison	108
Table 4.34: Fall System 2 measured vs. model data comparison	109
Table 4.35: Winter System 1 measured vs. model data comparison	110
Table 4.36: Winter System 2 measured vs. model data comparison	111
Table 4.37: Adjusted influent values for model sensitivity analysis	112
Table 5.1: Design and operation criteria for the primary fermenters	120

Table 5.2: Typical and selected design criteria used for modeled activated sludge processes	129
Table 5.3: Methanol dose required for nitrogen removal	133
Table 5.4: Components used for energy calculation.....	150
Table 5.5: Energy component specifications on current and alternative processes.....	153

LIST OF FIGURES

Figure 3.1: Process schematic section used for model development (TMWRF, 2018) ...	37
Figure 4.1: BOD seasonal load variance for 2017	42
Figure 4.2: COD seasonal load variance for 2017	42
Figure 4.3: Ammonia seasonal load variance for 2017	43
Figure 4.4: NO _x seasonal load variance for 2017	43
Figure 4.5: TKN seasonal load variance for 2017	44
Figure 4.6: SKN seasonal load variance for 2017	44
Figure 4.7: OP seasonal load variance for 2017	45
Figure 4.8: TP seasonal load variance for 2017	45
Figure 4.9: Alkalinity seasonal load variance for 2017	46
Figure 4.10: TSS seasonal load variance for 2017	46
Figure 4.11: TDS seasonal load variance for 2017	47
Figure 4.12: T-test analysis and corresponding P-values for significant differences	48
Figure 4.13: Process schematic for TMWRF's current 2° biological treatment of both systems	71
Figure 4.14: BioWin model for TMWRF's current 2° biological treatment of both systems	72
Figure 4.15: Original DO assumptions for the activated sludge tanks	86
Figure 4.16: System 1 DO ratios for the three DO sampling campaigns	88
Figure 4.17: System 2 DO ratios for the three DO sampling campaigns	89
Figure 4.18: System 1 aeration profile using updated DO ratios	91
Figure 4.19: System 2 aeration profile using updated DO ratios	91

Figure 4.20: System 1 total aeration demand using updated DO ratios.....	93
Figure 4.21: System 2 total aeration demand for using updated DO ratios	93
Figure 4.22: System 1 solids model vs. measured data profile.....	98
Figure 4.23: System 2 solids model vs. measured data profile.....	99
Figure 4.24: System 1 NO _x and P model vs. measured data profile.....	99
Figure 4.25: System 2 NO _x and P model vs. measured data profile.....	100
Figure 4.26: System 1 ammonia and TKN model vs. measured data profile	100
Figure 4.27: System 2 ammonia and TKN model vs. measured data profile	101
Figure 4.28: System 1 COD and FCOD model vs. measured data profile	101
Figure 4.29: System 2 COD and FCOD model vs. measured data profile	102
Figure 4.30: System 1 secondary effluent N concentrations with flow variation.....	114
Figure 4.31: System 1 secondary effluent P concentrations with flow variation	114
Figure 4.32: System 1 secondary effluent solids concentrations with flow variation	115
Figure 4.33: System 1 secondary effluent COD concentrations with flow variation	115
Figure 4.34: System 2 secondary effluent N concentrations with flow variation.....	116
Figure 4.35: System 2 secondary effluent P concentrations with flow variation	116
Figure 4.36: System 2 secondary effluent solids concentrations with flow variation	117
Figure 4.37: System 2 secondary effluent COD concentrations with flow variation	117
Figure 5.1: System 1 SE N conc. with/without primary clarifiers and with PF	120
Figure 5.2: System 2 SE N conc. with/without primary clarifiers and with PF	121
Figure 5.3: System 1 N conc. with PF and PD	122
Figure 5.4: System 2 N conc. with PF and PD	123
Figure 5.5: MLE process schematic with PF and PD	124

Figure 5.6: System 1 SE P conc. for MLE and chemical treatment	126
Figure 5.7: System 2 SE P conc. for MLE and chemical treatment	127
Figure 5.8: Volume increases to alternative activated sludge processes	130
Figure 5.9: System 1 SE N conc. with PF.....	131
Figure 5.10: System 2 SE N conc. with PF.....	131
Figure 5.11: System 1 SE N conc. with PF, PD, and methanol for alternative A.S. processes	133
Figure 5.12: System 2 SE N conc. with PF, PD, and methanol for alternative A.S. processes	134
Figure 5.13: System 1 SE P conc. for alternative A.S. processes.....	135
Figure 5.14: System 2 SE P conc. for alternative A.S. processes.....	136
Figure 5.15: A ² O with process schematic with PF and PD (per system)	137
Figure 5.16: 5-stage Bardenpho process schematic with PF (per system)	138
Figure 5.17: Standard UCT process schematic with PF and PD (per system)	139
Figure 5.18: Modified UCT process schematic with PF and PD (per system).....	140
Figure 5.19: VIP process schematic with PF and PD (per system)	141
Figure 5.20: System 1 N concentrations of alternatives treatment processes.....	143
Figure 5.21: System 2 N concentrations of alternative treatment processes	143
Figure 5.22: System 1 P concentrations of alternative treatment processes.....	144
Figure 5.23: System 2 P concentrations of alternative treatment processes	144
Figure 5.24: System 1 solid concentrations of alternative treatment processes	146
Figure 5.25: System 2 solid concentrations of alternative treatment processes	146
Figure 5.26: System 1 COD concentrations of alternative treatment processes.....	147

Figure 5.27: System 2 COD concentrations of alternative treatment processes.....	147
Figure 5.28: System 1 aeration demand of alternative treatment processes	149
Figure 5.29: System 2 aeration demand of alternative treatment processes	149
Figure 5.30: Total energy cost of alternative treatment processes.....	152
Figure 5.31: Total chemical cost of alternative treatment processes	154
Figure 5.32: Total energy and chemical costs of alternative treatment processes	155
Figure 5.33: Total energy and chemical costs per year for alternative processes.....	156
Figure 5.34: System 1 sludge production of alternative treatment processes.....	158
Figure 5.35: System 2 sludge production of alternative treatment processes.....	158

LIST OF ACRONYMS

1° – Primary clarifier/treatment	DO – Dissolved oxygen
2° – Secondary clarifier/treatment	DON – Dissolved organic nitrogen
A/O – Anaerobic/aerobic activated sludge configuration	EBPR – Enhanced biological phosphorus removal
A ² O – Anaerobic/anoxic/aerobic activated sludge configuration	EFF – Effluent
AER – Aerobic	EfOM – Effluent organic matter
ANA – Anaerobic	EPA – Environmental Protection Agency
ANOX – Anoxic	FBOD – Filtered BOD
AOB – Ammonia oxidizing bacteria	FCBOD – Filtered carbonaceous BOD
A.S. – Activated sludge	FCOD – Filtered COD
BAT – Best available technology economically achievable	FFCOD – Flocculated and filtered COD
BNR – Biological nutrients removal	FTKN – Filtered TKN
BOD – Biological oxygen demand	FTP – Filtered total phosphorus
BPT – Best practicable control technology	FWPCA – Federal Water Pollution Control Act
CBOD – Carbonaceous biological oxygen demand	gpd – Gallons per day
CNP – Carbon and nutrients (nitrogen and phosphorus)	HAA – Haloacetic acids
COD – Chemical oxygen demand	HAB – Harmful algae blooms
Conc. – Concentration	HRT – Hydraulic retention time
CWA – Clean Water Act	INF – Influent
DBP – Disinfection by-products	IR – Internal recycle
	lb/d – Pounds per day
	M&R – Monitor and report
	mg/L – Milligrams per liter

mgd – Million gallons per day	RAS – Return activated sludge
MLE – Modified Ludzack-Ettinger activated sludge configuration	SE – Secondary effluent
MLSS – Mixed liquor suspended solids	SKN – Soluble Kjeldahl nitrogen
MLVSS – Mixed liquor volatile suspended solids	SMP – Soluble microbial products
MPN – Most probable number	SRT – Solids retention time
n/m – Not measured	SS – Suspended solids
N – Nitrogen	TDS – Total dissolved solids
NH ₃ – Ammonia	THM – Trihalomethanes
NO ₂ – Nitrite	TKN – Total Kjeldahl nitrogen
NO ₃ – Nitrate	TMWRF – Truckee Meadows Water Reclamation Facility
NO _x – Nitrate + nitrite	TN – Total nitrogen
NOB – Nitrite oxidizing bacteria	TP – Total phosphorus
NPDES – National Pollutant Discharge Elimination System	TSS – Total suspended solids
OP – Orthophosphate	UCT – University of Cape Town activated sludge configuration
P – Phosphorus	UNR – University of Nevada, Reno
PAO – Phosphorus accumulating organisms	VFA – Volatile fatty acids
PHA – Polyhydroxyalkanoates	VIP – Virginia Initiative Plant activated sludge configuration
Poly P – Intracellular polyphosphate	VSS – Volatile suspended solids
PD – Post denitrification	w/ – With
PF – Primary fermentation	w/o – Without
ppd – Pounds per day	WAS – Waste activated sludge
PS – Primary sludge	

CHAPTER 1 : INTRODUCTION

Surface water quality is of vital importance in the environment, and with growing population, technology, and urbanization, has become one of the biggest environmental concerns. Surface waters can be impaired by pollution from nonpoint and point sources. Nonpoint sources can include excess fertilizers, herbicides, and insecticides from agricultural or residential lands, oil, grease, and toxic chemicals from urban runoffs, or even from atmospheric deposition (EPA, Basic Information about Nonpoint Source (NPS) Pollution, 2018). Generally, nonpoint sources are hard to regulate and address, unlike its point sources. Point source pollution is easier to identify and address as it comes from a single location. Factories and powerplants are common sources of point source pollution, but one of the biggest sources are municipal wastewater treatment plants (Society, 2019). Nonpoint and point source pollution can be detrimental to surface waters as it releases harmful constituents into waterways such as nutrients, toxic chemicals, and harmful microorganisms. When it comes to municipal wastewater treatment plant effluents, nutrients are one of the biggest concerns. High concentrations of nutrients in wastewater effluents can lead to eutrophication, hypoxia conditions, and taste and odor issues that can cause problems for the aquatic system, wildlife, and recreational use.

In order to minimize or eliminate these problems, under the Clean Water Act (CWA), the Environmental Protection Agency (EPA) issues National Pollutant Discharge Elimination System (NPDES) permits to municipal treatment plants. These permits require the discharger to follow technology-based effluent limits and are also required to be in compliance with reporting deadlines and monitoring activities (CRS, 2016). Under the

Truckee Meadow Water Reclamation Facilities' (TMWRF) NPDES permit, with respect to nutrients, TMWRF has a daily maximum limit for nitrate of 2.0 mg/L $\text{NO}_3\text{-N}$, a 30-day average load for total nitrogen (TN) of 500 lb/d as nitrogen (N), a 30-day average limit of total phosphorus (TP) of 0.4 mg/L as P, and a 30-day average phosphorus load of 134 lb/d as phosphorus (P). This project was designed to develop a TMWRF process model in order to optimize treatment performance by evaluating alternative treatment methods. The treatment alternatives investigate the secondary effluents to ensure that water quality regulations are still achieved.

This thesis has been organized as follows: Chapter 2 provides a literature review and background information on constituents of concern in water, and associated issues when poorly treated, and various treatment methods. Included in the literature review is also an introduction to the modeling software, BioWin, and case studies that have utilized the BioWin model. Chapter 3 introduces the research project. Chapter 4 covers the methods for model development and calibration of TMWRF's current activated sludge process along with model accuracy. Chapter 5 covers the methods for the BNR treatment alternatives and a comparison to carbon, nitrogen, and phosphorus (CNP) treatment efficiency, aeration requirements, and energy and chemical costs, and Chapter 6 provides a conclusion and recommendations for future projects.

CHAPTER 2 : LITERATURE REVIEW

2.1 Contaminants of Concern in Wastewater

Wastewater treatment effluents can have detrimental effects on surface waters and the environment if not properly treated. The effluent may consist of a complex mixture of different contaminants, such as organic matter, nutrients, solids, microorganisms and bacteria, metals, salt, and pharmaceutical drugs (Pereda et al., 2020). All these pollutants can be harmful to surface waters and the aquatic system if left untreated; however, among the contaminants, organic matter and nutrients are of biggest concern for wastewater treatment plants.

Organic matter in wastewater varies by location, but in general, organic matter is natural and biological material that can come from the decomposition of living organisms, food, feces, plants, and soil, essentially, organic matter is anything that is found within natural, engineered, terrestrial, and aquatic environments, or is carbon-based. Organic matter removal is an essential component of wastewater treatment, as it is the most predominant contaminant that enters the treatment plant and is used in the treatment process. Measuring specific organic matter constituents can prove difficult, but rather, organic matter is generally measured by determining the amount of oxygen needed to consume it, in terms of biochemical oxygen demand (BOD) or chemical oxygen demand (COD) (Hamilton, 2016). Organic matter is a contaminant of concern in wastewater because if left untreated can lower oxygen in receiving waters. When analyzing effluent organic matter (EfOM) the primary composition of EfOM is the original organic matter that was not removed, soluble microbial products (SMPs), which are formed during biological treatment, and harmful

chemicals (Shon et al., 2007). In order to alleviate problems associated with organic matter in surface waters, wastewater treatment plants need to ensure they are adequately following discharge limits.

Nutrient loading into surface waters is an ongoing concern to the environment. Although, a significant portion on nutrient loading into surface waters is due to nonpoint sources, such as urban and agricultural runoff, wastewater treatment plant effluents as a point source can discharge high loads of nutrients into surface waters if inadequately treated (Carey and Migliaccio, 2009). The primary source of nutrients are nitrogen and phosphorus, and although essential to maintaining a balance in the aquatic system, can have negative effects if left at elevated levels. Nutrients support fish and shellfish production in the aquatic system and often times nutrients in the form of fertilizer are added to aquatic systems to increase production of fish when nutrients are levels are too low and species of fish are endangered (Mischke, 2012). However, while there are some positive roles of nutrients in surface waters, more often than not, the negatives effects greatly out way the positives. Increased discharge of nutrients into surface waters through nonpoint and point sources can lead to impaired water quality issues such as eutrophication, hypoxia, and taste, color, and odor issues (Wurtsbaugh et al., 2019).

2.2 Impact of Contaminants on Surface Waters

2.2.1 Eutrophication

Eutrophication at its root means “well nourished” and generally refers to an increase in nutrients in surface waters. This phenomenon dates back, and there are accounts of indigenous tribe avoiding shellfish at different times in the year due to discolored water

and poisonous fish (Anderson et al., 2002). It wasn't until the late 1800s when scientists first classified the phenomenon when noticing the abundance of new species of cyanobacteria in Lake Zurich, Switzerland; the scientist also observed that there was a loss of oxygen in the waters and that because of this, fish species population, such as the trout and whitefish, began to decline (Wurtsbaugh et al., 2019). Eutrophication can lead to the creation of harmful algae blooms (HABs) which produce toxins in which the cell's physical structure or accumulated biomass affect organisms and alter the food web dynamics within the system (Anderson et al., 2002). Due to the toxicity created by these HABs, the environment is put at risk as the aquatic ecosystem is altered. These alterations to surface waters can lead to a decline in a sustainable habitat for wildlife and can lead to mass mortality rates for wild and fish life. The HABs can also affect human life as the toxins produced can affect human health if consuming shellfish, or if using the surface waters for recreational use as the toxins can be transferred through inhalation or water contact.

Studies have been conducted and a relationship between nutrient loading and the harmful cyanobacteria blooms show that an increase in nutrient loading results in an increase in HABs (Gilbert and Burkholder, 2011). Therefore, it is essential that wastewater treatment plants follow discharge limits for nitrogen and phosphorus as to not increase the human involvement with the eutrophication phenomenon.

2.2.2 Hypoxia

Hypoxia generally occurs in ocean waters, but there are cases where hypoxia occurs in fresh surface waters. Hypoxia is a scenario when the dissolved oxygen in the water is at a critically low level, or close to anoxic conditions, and dead zones form that can cause fish,

shellfish, corals, and aquatic plants to die. The presence of hypoxia has existed throughout time, but human activities, primarily in the form of nutrient pollution, which includes agricultural runoff, fossil-fuel burning, and wastewater treatment effluents, have increased the occurrence of hypoxia in surface waters (NOAA, 2019). Nutrient pollution causes eutrophication which leads to large scale hypoxia in aquatic systems all around the world (Wu et al., 2003). Hypoxia occurs when there is a decrease in oxygen from its saturation level. This happens when thermal and haline stratification of water due to freshwater discharge and summer warming, nutrient utilization by phytoplankton, and sequent settling of phytoplankton to bottom waters occur (Rabouilla et al., 2008). This condition is closely related to the amount of nutrients and organic matter that are discharged into systems. When high levels of nutrients are discharged into surface waters, the nutrients can accelerate cyanobacteria and algae blooms, which in turn consumes the dissolved oxygen for growth; and organic matter will settle and be decomposed by benthic fauna and bacteria which utilize the oxygen in the system (Rabouilla et al., 2008). To ensure that hypoxia conditions do not occur, it is of vital importance that wastewater treatment plants meet nutrient and organic matter discharge limits or ensure that adequate aeration is performed at the effluent point. Advance tools, such as biological treatment and simulation models, can help treatment plant managers and operators optimize processes to reduce pollutant loads to surface waterbodies.

2.2.3 Taste and Odor

Although not generally regulated, taste and odor are crucial to the public's perception of surface waters, especially when in an urbanized area. Taste and odor issues of surface water

makes society anxious about using the water for drinking purposes, reuse, or recreational purposes, even though it is not directly tied to human health, unlike other pathogens or chemical pollutants. When it comes to wastewater effluents and taste and odor issues, it is normally caused by eutrophication problems where cyanobacteria are produced. Certain species of cyanobacteria can produce geosmin and 2-methylisoborneol, which are commonly the main source of taste and odor issues in drinking water (Wu and Duirk, 2013). Other sources of taste and odor issues are sulfur and nitrogen-containing compounds. Sulfur-containing compounds often give a “rotten egg” smell and are usually released in systems under anaerobic conditions (Urase and Sasaki, 2013). One growing concern in the water and wastewater treatment field are the formation of disinfection by-products (DBPs). DBPs are often formed during the disinfection phase of the treatment process. Two major classes of DBPs are trihalomethanes (THMs) and haloacetic acids (HAAs), which are formed during the chlorine disinfection process (Padhi et al., 2019). Aside from taste and odor issues, these DBPs can result in health issues such as damage to the livers, kidneys, and central nervous system, and are suspected to increase the risk of cancer. Another DBP is 2,4,6-trichloroanisole and can be formed from the chlorophenols and are among the compounds that have an earthy and musty odors (Urase and Sasaki, 2013).

2.3 Wastewater Reuse

As society grows, water demand increases and there becomes a scarcity for water around the world. Water is essential for all life, and although 70% of earth is covered by water, only a fraction of it (2.5%) is freshwater. Of that 2.5%, most is trapped in ice and snow

surrounding the Antarctic and Arctic regions. It is estimated that from the twentieth century to the twenty-first century, the total annual water withdrawal increased by six-folds, increasing from 600 km³/year to 3,800 km³/year (Becerra-Castro et al., 2015). Due to the increase consumption, the use of water has far exceeded the recharge levels and there is need for water reuse practices, which makes wastewater effluents a valuable resource, as opposed to a waste product. Treated wastewater is often times used as a resource for irrigation, urban and recreational, aquaculture, industrial uses, and groundwater recharge (Akhoundi and Sara, 2018).

2.3.1 Irrigation

One of the most common wastewater reuse applications is using treated wastewater as a resource for irrigation purposes. There are many advantages to using reclaimed wastewater for irrigation purposes including: nutrient recovery possibilities, socioeconomic implications, reduction of fertilizer application, and effluent disposal. When using treated wastewater as a resource for irrigation, quality criteria of the wastewater need to be implemented focusing on conventional pollutants: BOD, COD, pH, total suspended solids (TSS), heavy metals, and microorganisms, such as viruses, bacteria, and protozoa (Fatta-Kassinos et al., 2011). If not properly monitored, these contaminants can be detrimental for humans and the environment. Some contaminants can be problematic when using wastewater for irrigation purposes as they persist throughout the treatment process. These contaminants include certain inorganic compounds, heavy metals, persistent organic pollutants, pharmaceutically active compounds, and disinfection by-products (Fatta-Kassinos et al., 2011). If not removed from wastewater effluents, these pollutants may limit

the suitability of wastewater as a resource for irrigation as it can be harmful to beneficial microbes and inhibit function, such as element cycling, pollutant degradation, and plant growth. These pollutants often affect the soil microbial communities that are regulated by various abiotic and biotic factors; they disrupt physicochemical soil properties, such as pH and organic content, and establish microbial community disturbances (Becerra-Castro et al., 2015). These pollutants can also be harmful to humans as they can be absorbed by the crops and ingested. Other contaminants of concern that can be more commonly found in wastewater are common ions such as sodium, potassium, calcium, chloride, and bromide. When using wastewater effluents as a resource for irrigation, treatment plants need to ensure contaminants are removed from irrigated waters as to not adversely affect the soil and crops.

2.3.2 Groundwater Recharge

Although treated wastewater is most commonly used for irrigation purposes, water scarcity demands that society looks to other alternatives for reuse. One of the fastest growing uses for treated wastewater is to artificially recharge subsurface groundwater aquifers. The process to use treated wastewater to recharge the groundwater involves transporting the reclaimed water where it can be passively or manually inputted into the subsurface. The most common ways to inject the water into the ground is using pumps and injection wells, or by passive infiltration via percolation basins. There are two main benefits in using reclaimed water for groundwater recharge. The first benefit is the health of the aquifer; recharging groundwater mitigates overdraft conditions and prevents salt-water intrusions in coastal regions (Fournier et al., 2016). The second benefit is that recharging groundwater

provides a net saving of water. In other words, the water that would otherwise be lost to the environment is being saved, increasing water availability (Fournier et al., 2016).

2.3.3 Potable Reuse

One of the most controversial topics in wastewater reuse is using treated wastewater as a potable water source; however, the implementation of using treated wastewater for this purpose is not limited by the quality of water produced, but rather, social objections. Many people see the logic behind using treated wastewater as a potable water source but are reluctant to use it. Wastewater provides the “yuck factor” and often creates a barrier for water reuse. Studies have been conducted on using treated wastewater as a potable source and incorporates models on emotion, attitudes, subjective norms, risk perceptions, perceived control, knowledge, trust, environmental obligations, and intended behaviors on why society might or might not be acceptable to this reuse application (Nancarrow et al., 2009).

There are two types of applications for using treated wastewater as a potable source: direct and indirect. Indirect potable reuse is widely more accepted in society and is a water recycling application that discharges highly treated wastewater into groundwater or surface waters with the intent of recharging drinking water supplies (Rodriguez et al., 2009). By discharging the treated wastewater into the environment, the environment acts as a buffer that can further purify the water. The second application is direct potable reuse, and of the two, is the more controversial topic. Instead of discharging into an existing aquifer or surface water, treated wastewater is directly incorporated into the municipal water supply system. By incorporating treated wastewater directly into a water supply system, the

environment cannot act as a buffer for water purification; however, when treated properly, direct potable reuse offers the opportunity to reduce distance that purified water needs to travel, reducing costs, and increasing available purified water in urbanized areas (Leverenz et al., 2011). Whether wastewater is used for indirect or direct potable reuse, the level of treatment is exceedingly advanced and usually employs a combination of microfiltration, reverse osmosis, and advance oxidation processes, ensuring exceptional water quality (McCurry et al., 2017).

2.4 Regulations

2.4.1 Regulation History

It is a common misconception that water quality regulations started with the Clean Water Act (CWA) of 1977, but the history of water regulation dates back even farther. The origin of water quality controls dates to the Federal Water Pollution Control Act (FWPCA) of 1948 and was aimed to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. To achieve this objective, it is declared that with the provisions of the FWPCA (33 U.S.C. 1251, 1948)

- Discharge of pollutants into the navigable waters be eliminated by 1985;
- An interim goal of water quality which provides protection and propagation of fish, shellfish, and wildlife and provides for recreation in an on the water be achieved by 1983;
- Discharge of toxic pollutants in toxic amounts be prohibited;
- Federal financial assistance be provided to construct publicly owned treatment works for wastewater treatment;

- Areawide treatment management planning processes be developed and implemented to assure adequate control of sources of pollutants in each state;
- Major research and demonstration effort be made to develop technology necessary to eliminate the discharge of pollutants into navigable waters, waters of contiguous zone and oceans; and
- Programs for the control of nonpoint sources of pollution be developed and implemented into an expeditious manner to enable the goals of the Act to be met through the control of both point and nonpoint sources of pollution.

It was these national goals under the FWPCA that helped mold the foundation of today's Clean Water Act and process in which water pollution is addressed. Since the creation and of FWPCA of 1948 and its major amendment known as the CWA of 1977, the Act has had many other notable amendments that fine-tuned water quality regulations and are included in Table 2.1 (CRS, 2016) . The CWA known today has two parts and are under Title II and VI; the first part deals with financial assistance for municipal sewage treatment plant construction, and the second are the regulatory requirements that apply to industrial and municipal dischargers, which include wastewater treatment plants. Under the Act, technology-based limitations were implemented in order to clean up waste discharges. The first technology-based limitations that was implemented was best practicable technologies (BPT) that required municipal wastewater treatment plants to meet secondary treatment goals. Originally, BPT practices were designed to control conventional pollutants like suspended solids, BOD, fecal coliform and bacteria, and pH, but did not focus on more toxic material. By 1989, the Act implemented greater control regulations and included best available

technology (BAT) treatment practices which focused more on the toxic substances (CRS, 2016). From the creation of the FWPCA to what we know as the CWA today, and the many amendments in between, regulations and limitations have been implemented to ensure discharges into waters do not significantly impact the water quality.

Table 2.1: Clean Water Act and Major Amendments (codified generally as 33 §§1251-1387)

Year	Act	Public Law
1948	Federal Water Pollution Control Act	P.L. 80-845 (Act of June 30, 1948)
1956	Water Pollution Control Act of 1956	P.L. 84-660 (Act of July 9, 1956)
1961	Federal Water Pollution Control Act Amendments	P.L. 87-88
1965	Water Quality Act of 1965	P.L. 89-234
1966	Clean Water Restoration Act	P.L. 89-753
1970	Water Quality Improvement Act of 1970	P.L. 91-224, Part I
1972	Federal Water Pollution Control Act Amendments	P.L. 92-500
1977	Clear Water Act of 1977	P.L. 95-217
1981	Municipal Wastewater Treatment Construction Grants Amendments	P.L. 97-117
1987	Water Quality Act of 1987	P.L. 100-4
2014	Water Resource Reform and Development Act of 2014 (Title V)	P.L. 113-121

(CRS, 2016)

2.4.2 NPDES Permits

In order to comply with regulations and limitations, the CWA directs the EPA to issue NPDES permits, under Title 40 of the CFR Part 122, to industrial and municipal dischargers to ensure regulations are met. Under the provisions of this section the EPA determines what a state must do obtain approval to operate its program by establishing NPDES permits for discharge of pollutants from point sources into waters of the United States (40 CFR Part 122). The EPA uses technology-based effluent limitations, such as BPT or BAT, to establish the minimum level of treatment of pollutants from point source discharges (EPA, National Pollutant Discharge Elimination System (NPDES), 2016). An example NPDES permit for the Truckee Meadows Water Reclamation Facility is provided in Table 2.2 (Nevada Division of Environmental Protection, 2012).

Table 2.2: Discharge limitations, monitoring, and reporting requirements for TMWRF

Parameters	Units	Discharge Limitations			Monitoring Requirements		
		30-day Average	Daily Max	30-day Avg Load (ppd)	Sampling Locations	Monitoring Frequency	Monitoring Type
Influent Flow Rate	MGD	44.0	M&R	-	INF (i)	Continuous	Flow meter
Effluent Flow Rate	MGD	M&R	M&R	-	EFF (ii)	Continuous	Flow meter
BOD ₅ (uninhibited)	mg/L	M&R	M&R	M&R	INF (i)	3 Times/Week	Composite
		20	30	7,339-avg 11,009-max	EFF (ii)		
TSS	mg/L	M&R	M&R	M&R	INF (i)	3 Times/Week	Composite
		20	30	7,339-avg 11,009-max	EFF (ii)		
TDS	mg/L	-	500	120,168	EFF (ii)	Weekly	Composite
TN as N	mg/L	-	-	500	EFF (ii)	Weekly	Composite
TKN as N	mg/L	M&R	M&R	-	EFF (ii)	Weekly	Composite
Nitrate as N	mg/L	-	2.0	-	EFF (ii)	Daily	Composite
DON as N	mg/L	M&R	M&R	-	EFF (ii)	Weekly	Composite
Total Ammonia as N	mg/L	-	I.A.1.c.2	-	EFF (ii)	Daily	Composite
TP as P	mg/L	0.40	-	134	EFF (ii)	Daily	Composite
Alkalinity as CaCO ₃	mg/L	M&R	M&R	-	EFF (ii), iv	Weekly	Composite
Hardness as CaCO ₃	mg/L	M&R	M&R	-	iv	Quarterly	Discrete
TRC	mg/L	-	0.10	-	EFF (ii)	Daily	Discrete
Temperature ΔT	°C	M&R			iii, v	Weekly	Discrete
		< 2.0					
Fecal Coliform	MPN/100ml	200	400	-	EFF (ii)	Daily	Discrete
Escherichia Coli	MPN/100ml	126	410	-	EFF (ii)	Daily	Discrete
DO	mg/L	-	≥ 5.0	-	EFF (ii)	Daily	Discrete
pH-SV	S.U.	-	6.5-9.0	-	EFF (ii)	Daily	Discrete
		M&R			iii	Weekly	

(Nevada Division of Environmental Protection, 2012)

2.5 Wastewater Nutrient Treatment

2.5.1 Physical Treatment

Physical treatment of wastewater is often the first step to remove contaminants but often requires additional processes through means of biological or chemical treatment. Some examples of physical treatment include screening, mixing and flocculation, gravity separation, and grit removal. These physical processes are capable of removing particles of various size. Nutrients can be removed by these physical means when the nutrients are incorporated into biomass. During primary clarification, approximately 10% of total Kjeldahl nitrogen (TKN) (Department of Environmental Conservation) and 1.0 mg/L TP (Polson, 2017) is removed through TSS that leaves the system. It is difficult to remove large amounts of nutrients through physical processes without the addition of other processes such as biological or chemical treatment.

2.5.2 Biological Treatment

Biological treatment of wastewater has the following goals (Metcalf and Eddy, 2014):

- Transform dissolved and particulate biodegradable constituents into acceptable end products through oxidation;
- Capture and incorporate suspended and non-settleable colloidal solids into biological flocs or biofilm;
- Transform or remove nutrients, such as nitrogen and phosphorus; and
- Remove specific trace organic constituents and compounds.

Biological treatment is facilitated by microorganisms that oxidize dissolved and particulate organic matter by utilizing oxygen, nitrogen, and phosphorus to convert the organic matter into simple products such as biomass, water, and gas emissions; these simple end products are then able to be readily removed. The microorganisms in biological treatment are classified by carbon and energy source, temperature, and oxygen utilization. Microorganisms that use organic material as a carbon source are *heterotrophic* while *autotrophic* microbes use inorganic carbon for cell synthesis. Microorganisms that use light as an energy source are *phototrophs* whereas *chemotrophs* use energy from chemical reactions (Davis, 2010). Each species of microorganism thrives at a certain range of temperature and are known as *psychrophiles* (>20°C), *mesophiles* (25-40°C), *thermophiles* (45-60°C), and *hyperthermophiles* (60-100°C) (Davis, 2010). For wastewater treatment, probably the most important classification of microorganisms is oxygen utilization. Microorganisms that utilize oxygen as an electron acceptor in their oxidation-reduction reactions are *aerobic*, *anaerobic* if there is an absent of electron acceptors, and *anoxic* if the microorganisms utilize electron acceptors other than oxygen, such as nitrate. This classification is the most important because it dictates what kind of treatment performance is to be expected, whether its phosphorus uptake and release, nitrification, or BOD oxidation. Some important microorganisms in wastewater treatment include bacteria, fungi, algae, protozoa, rotifers, and crustaceans. When it comes to types of biological treatment processes, there are two types: suspended growth processes and attached growth processes. The suspended growth process uses the microorganisms in liquid suspension, often requiring aeration and/or mixing to maintain the suspension. Many of these activated sludge processes are used for the biodegradation of organic substances, operated under

aerobic and anoxic conditions, and occasionally anaerobic conditions when there is a high organic concentration (Metcalf and Eddy, 2014). Rather than being suspended in a liquid phase, in attached growth processes, the microorganisms are attached to a surface where they form a biofilm. The packing material used to grow the microorganisms range from a variety of material such as rock, gravel, slag, sand, wood, and synthetic material with a high surface area to volume ratio. These attached growth processes are operated under aerobic and anaerobic conditions and can be either submerged in liquid or partially submerged creating an air space between the biofilm (Metcalf and Eddy, 2014). The most common type of attached growth process is the trickling filter which is typically used for BOD removal but is used for nitrification at TMWRF. Table 2.3 provides examples of difference type of suspended and attached growth process with their intended uses.

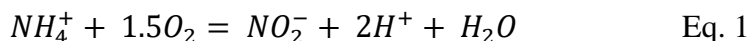
Table 2.3: Major biological treatment processes used for wastewater treatment

Type	Common Name	Use
Aerobic Processes:		
Suspended	Activated sludge process	CBOD removal, nitrification
	Aeration lagoons	CBOD removal, nitrification
	Aerobic digestion	Stabilization, CBOD removal
	Membrane bioreactor	CBOD removal, nitrification
	Nitritation process	Nitritation
Attached	Biological aerated filters	CBOD removal, nitrification
	Moving bed bioreactor	CBOD removal, nitrification
	Packed-bed reactors	CBOD removal, nitrification
	Rotating biological contractors	CBOD removal, nitrification
	Trickling filters	CBOD removal, nitrification
Hybrid	Trickling filter/activated sludge	CBOD removal, nitrification
	Integrated fix film activated sludge	CBOD removal, nitrification
Anoxic Processes:		
Suspended	Suspended-growth denitrification	Denitrification
Attached	Attached growth denitrification filter	Denitrification
Anaerobic Processes:		
Suspended	Anaerobic contact processes	CBOD removal
	Anaerobic digestion	Stabilization, solid destruction, pathogen kill
	Anammox process	Denitritation, ammonia removal
Attached	Anaerobic packed and fluidized bed	CBOD removal, waste stabilization, denitrification
Sludge Blanket	Upflow anaerobic sludge blanket	CBOD removal, especially high strength wastes
Hybrid	Upflow sludge blanket/attached growth	CBOD removal

(Metcalf and Eddy, 2014)

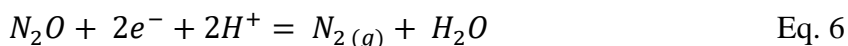
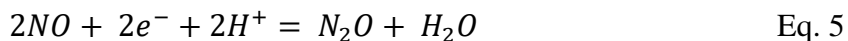
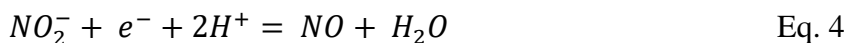
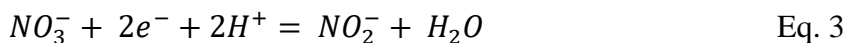
2.5.3 Nitrification and Denitrification

Biological nitrogen removal has been widely applied in wastewater treatment in the last few decades and is comprised of two steps: nitrification and denitrification. The most abundant form of nitrogen in wastewater influents is ammonia. It is important to oxidize ammonia into other forms of nitrogen because ammonia is more toxic than nitrate ions due to lower oxygen or ammonia toxicity at higher pH. Even when nitrogen is not fully removed from wastewater, by oxidizing ammonia, the toxicity of the water can be reduced by six-folds (Burnashova et al., 2018). The first step to nitrogen removal utilizes ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB), while the second step reduces the nitrate to nitrite and nitrogen gas by denitrifying bacteria (Zeng et al., 2017). Nitrification itself is a two-step process in where ammonia is oxidized to nitrite in the first step generally by *Nitrosomonas*. These nitrifiers are aerobic and use oxygen to oxidize the ammonia. The second step in nitrification is the oxidation of nitrite to nitrate by *Nitrospira* and *Nitrobacter* bacteria (Rittman and McCarty, 2001). Equations 1 and 2 show the general oxidation reactions of nitrification.



The second step to nitrogen removal in wastewater treatment is denitrification. Denitrification is a biological process in where nitrate and nitrite are converted to nitrogen gas, generally by heterotrophic bacteria (Park et al., 2009). Denitrifying bacteria are facultative aerobes which means they can use nitrate and nitrite as electron acceptors when oxygen is limited. If oxygen is present, however, they may utilize oxygen instead of the

nitrogen species. These denitrifiers rely heavily on environmental conditions such as temperature, pH, dissolved oxygen, and presence of nitrate and carbon (Foglar and Briski, 2003). Often when sufficient carbon is not available, an additional carbon source is added; the most common additional substrates are methanol, acetate, and ethanol. Like nitrification, denitrification is a step-wise process where nitrate is reduced to nitrite, nitric oxide, nitrous oxide, and nitrogen gas (Rittman and McCarty, 2001). Equations 3-6 show the general reactions for denitrification.



There are two main wastewater treatment processes that induce nitrification and denitrification. The most common processes are suspended growth processes, otherwise known as the activated sludge process, in where nitrification and denitrification occur in the secondary biological treatment train. The second type of process is the attached growth process, in which nitrification towers and denitrification filters are used for nitrogen removal.

2.5.3.1 Activated Sludge N Removal

For nitrogen removal, the activated sludge process is a suspended growth process where the heterotrophic and nitrifying bacteria coexist. These activated sludge processes are a combination of anoxic and aerobic reactors that remove nitrogen and BOD. The aerobic

zones oxidize the ammonia to nitrate, while the anoxic zones convert the nitrate to nitrogen gas. Organic carbon (BOD) removal occurs in both zones. For these activated sludge processes to be efficient, there are crucial aspects for the reactors. There needs to be mixing in the reactors, a quiescent settler, sludge recycle, mixed liquor recycle, and an adequate solids retention time (SRT). The most common biological activated sludge processes for nitrogen removal are the Modified Ludzack-Ettinger (MLE), 4-stage Bardenpho process, and oxidation ditch processes. In the MLE process, an anoxic zone precedes the aerobic and receives mixed liquor from the aerobic reactor (Song et al., 2015). This mixed liquor provides nitrate to the anoxic zone to facilitate denitrification. The second most common activated sludge process for nitrogen removal is the 4-stage Bardenpho process which was developed in 1973 and was designed to overcome the incomplete denitrification of the anoxic/aerobic process (Li et al., 2020). In this process, pre-anoxic/aerobic and post-anoxic/aerobic reactors are incorporated to remove any residual nitrogen. Additional carbon may also be incorporated in the post-anoxic reactor if sufficient carbon is not available. Oxidation ditches are typically oriented in a “racetrack” configuration where water passes through aerated and unaerated zones to accomplish combined BOD and nitrogen removal.

2.5.3.2 Nitrification Towers and Denitrification Filters

Aside from suspended growth processes, like the activated sludge process, nitrification can occur in attached growth processes. A common process includes the use of nitrification towers, otherwise known as nitrification trickling filters. These trickling filters are non-submerged fixed film biological reactors that usually use rock or plastic as media to

grow the biofilm. Design of the trickling filters depends on what type of treatment is desired and whatever the treatment objective may be, trickling filters share three characteristics (Rittman and McCarty, 2001):

- Wastewater is applied in a “trickling” condition in which water moves downward along the porous biofilm media and air moves upward or downward to supply oxygen;
- Water exiting the bottom of the filter is routed to settlers or filters to reduce suspended solid and BOD concentrations; and
- Effluent wastewater is recycled to establish hydraulic loading control throughout the filters

Nitrification works in the trickling filters when the microorganisms create a biofilm on the filter media and as water and air is applied to the filter, the AOBs and NOBs oxidize the ammonia to nitrate. The advantages of the nitrification towers over activated sludge processes are that they require less energy, are simpler to operate with no issues of mixed liquor control and sludge wasting, no bulking problems in secondary clarifiers, better sludge thickening, less maintenance, and better recovery from shock toxic loads (Metcalf and Eddy, 2014). However, despite their advantages, they do come with distinct disadvantages. Trickling filters are more susceptible to sudden detachment of the biofilm, which can happen during periods of air stagnation (Rittman and McCarty, 2001). This detachment of the biofilm can cause deterioration of effluent water quality as the suspended solids in the effluent increase and can affect the substrate removal and ammonia oxidation. Nitrification towers are able to oxidize ammonia to nitrate; however, they cannot perform

denitrification like an activated sludge process and require an additional process to convert the nitrate to nitrogen gas.

In scenarios where nitrification towers are used for the oxidation of ammonia to nitrate, attached growth denitrification processes are often used as a post-anoxic treatment step. Almost any biofilm system works for denitrification, when oxygen is limited within the system, and often include rotating biological contactors, submerged fixed beds of rock, sand, limestone, or plastic media, fluidized beds of sand, or activated carbon, circulating beds, and membrane bioreactors (Rittman and McCarty, 2001). Under the correct operating conditions, such as providing sufficient carbon, nitrate loading rates, hydraulic loading rates, and influent feed conditions, attached growth processes for denitrification are effective at converting nitrate to nitrogen gas. One disadvantage of these attached growth processes is that they may require backwashing to control solids and the biofilm.

2.5.4 Phosphorus Removal

2.5.4.1 Enhanced Biological Phosphorus Removal

Enhanced biological phosphorus removal (EBPR) is a biological process in which heterotrophic bacteria are able to sequester high levels of *intracellular polyphosphate* (poly P) (Rittman and McCarty, 2001). Biomass generated in normal biological processes contain 2-3% phosphorus; however, the EBPR process is capable of increasing this fraction of P in biomass to as much as 12% (Nielsen et al., 2011). This is achieved because the EBPR process takes advantage of a complex microbial ecosystem with the key organisms to this process being polyphosphate-accumulating organisms (PAOs). The most common configuration to the EBPR process is the *Phoredox*, otherwise known as the

anaerobic/aerobic (A/O) process. This process contains an anaerobic reactor, followed by an aerobic, operated at low SRTs. The low SRT allows for PAO growth while inhibiting growth of other microorganisms, such as AOBs and NOBs, which could have negative impacts on phosphorus removal. For the EBPR process to be efficient, there are four essential components (Rittman and McCarty, 2001):

- The influent wastewater and recycle sludge must first enter an anaerobic reactor with electron acceptors (oxygen and nitrate) being limited;
- The mixed liquor leaves the anaerobic zone and enters the aerobic where ample electron acceptors are available through aeration, which allows the heterotrophic bacteria to grow;
- The mixed liquor leaving the bioreactors must be settled and recycled back to the anaerobic tank, ensuring alternating anaerobic and aerobic conditions; and
- The sludge is to be wasted once enriched with poly P.

In the anaerobic zone of the EBPR configuration, the PAOs take up volatile fatty acids (VFAs) that are present in the influent wastewater, or produced through fermentation, and form polyhydroxyalkanoates (PHAs) (Nielsen et al., 2011). The PAOs require energy to perform polymerization which comes from the hydrolysis of poly P. During hydrolysis, phosphorus is released into the environment, which is why there is an increase in phosphorus concentration in the anaerobic reactors. When the wastewater and heterotrophic bacteria enter the aerobic reactor, the process is reversed as there is an ample supply of electron acceptors. The PAOs utilize the PHAs and oxygen to consume the phosphorus and grow, thus removing phosphorus from the water and incorporating it in

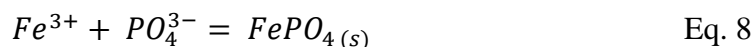
cellular material. Under the right operational conditions, the EBPR process is capable of achieving very low phosphorus concentrations.

2.5.4.2 Chemical Treatment

Although biological treatment for phosphorus removal is more economical, the extent to which phosphorus is removed is greatly influenced by wastewater characteristics and other environmental factors, and often, biological phosphorus removal is supported by chemical precipitation (Mbamba et al., 2019a). Compared to biological processes for phosphorus removal, chemical precipitation is often more stable and reliable for high phosphorus wastewaters (Sun et al., 2017). The most common metal-salts used in phosphorus chemical treatment are aluminum and iron. These cations will form precipitates with the orthophosphate anion and will be incorporated into sludge where it can be removed from the system. Equations 7 and 8 show the generalized chemical reaction with aluminum, iron, and phosphorus. When dealing with chemical treatment of phosphorus, there are many factors that must be considered in the chemistry of the metal salt addition, which are (Rittman and McCarty, 2001):

- Phosphate forms competing complexes, such as CaHPO_4 , MgHPO_4 , and FeHPO_4^+ , thus decreasing the total phosphate that is present;
- Aluminum and iron form other complexes, specifically with organic ligands, or precipitate as $\text{Al}(\text{OH})_3(s)$, decreasing the available Al^{3+} and Fe^{3+} ;
- Not all total phosphorus is present as orthophosphate, and is incorporated into organic compounds;

- Optimal pH for chemical precipitation may not be compatible with microbiological activity; and
- Precipitation reactions may be kinetically controlled and not reach maximum efficiency.



Due to these factors and complications, the chemical dosage of these metal-salts are often 1.5-2.5 times greater than the theoretical stoichiometric value. Chemical treatment for phosphorus removal is a viable option when biological treatment is not sufficient to reduce phosphorus levels to pre-established limits, and is usually added into the primary clarifiers, activated sludge, or secondary clarifiers (Mbamba et al., 2019a). One of the biggest disadvantages of chemical treatment is the increased sludge produced, which may require additional sludge handling process.

2.5.5 Combined CNP Treatment

Nutrient removal is essential to wastewater treatment and is achievable by nitrification and denitrification for nitrogen, and EBPR or chemical treatment for phosphorus. The previous sections have provided insight on processes in which nitrogen and phosphorus can be removed independently from wastewater, but there are benefits associated with removing each contaminant simultaneously. Combined CNP treatment is the most common way to remove nitrogen and phosphorus together and is often removed by biological activated sludge processes. These BNR processes rely on an arrangement of different environmental

redox conditions with separate anaerobic, anoxic, and aerobic reactors where nitrification and denitrification occur, and phosphorus is accumulated by heterotrophic organisms (Ashrafi et al., 2019). The anaerobic reactors are often placed upstream of the anoxic where organic substrate is sequestered by PAOs and phosphorus is released, wastewater then flows to the anoxic zone where denitrification occurs after being provided a nitrate recycle stream from the final aerobic zone where nitrification and phosphorus uptake take place. In some situations, the organic substrate used for phosphorus accumulation leaves little substrate for denitrification, resulting in partial nitrogen removal and the need for post-denitrification processes (Fang et al., 2016). There are many different configurations to these BNR activated sludge processes for combined nitrogen and phosphorus removal due to the reactor placement and internal recycle streams, which offer numerous opportunities for diverse flow paths, and performance greatly depends on the wastewater characteristics (Chuler and Xiao, 2008). The most common BNR configurations for combined CNP treatment and their process description are (Metcalf and Eddy, 2014):

➤ Anaerobic/Anoxic/Aerobic (A²O) Process

- The A²O process has an anoxic zone located between the anaerobic and aerobic reactors and is used for phosphorus removal with nitrification;
- Nitrate is recycled from the aerobic zone to the anoxic zone for denitrification, which minimizes the amount of nitrate in the anaerobic zone; and
- Return activated sludge (RAS) from the secondary clarifier is recycled to the anaerobic reactor.

➤ 5-Stage Bardenpho Process

- A modified version of the 4-stage Bardenpho process that provide an anaerobic, pre-anoxic, pre-aerobic, post-anoxic, and post-aerobic reactors;
- Mixed liquor from the first aerobic reactor is recycled to the pre-anoxic reactor;
- The post-anoxic reactor is used for additional denitrification using nitrate produced in the first aerobic reactor, this post-anoxic reactor has the option for an additional carbon source;
- The final aerobic reactor is used to strip any residual nitrogen gas and increase the DO concentration to prevent phosphorus release in the secondary clarifiers; and
- RAS from secondary clarifiers is recycled to the anaerobic reactor.

➤ University of Capetown (UCT) Process

- The UCT process has an anaerobic, anoxic, and aerobic configuration and was developed to minimize nitrate entering the anaerobic reactors; and
- Has three recycle streams instead of two: internal nitrate recycle from the aerobic reactor to the anoxic, mixed liquor from anoxic reactor to anaerobic, and RAS from secondary clarifiers to anoxic reactor.

➤ Modified UCT Process

- The modified UCT process was designed to separate the nitrate recycle stream and the RAS and consist of an anaerobic, anoxic, anoxic, and aerobic configuration; and

- Mixed liquor is introduced to the anaerobic zone from the first anoxic zone, RAS is introduced from the secondary clarifiers to the first anoxic zone, and the nitrate recycle stream is introduced to the second anoxic zone.

➤ Virginia Initiative Plant (VIP) Process

- The VIP process is similar to the A²O and UCT processes, consisting of an anaerobic, anoxic, and aerobic configuration, except for increased staging and recycle stream methods;
- Each zone is divided into at least two completely mixed cells in series;
- RAS entered the first anoxic stage, mixed liquor enters the first anaerobic stage from the final anoxic stage, and nitrate recycle enters the first anoxic stage from the final aerobic stage; and
- The VIP process typically enhances phosphorus removal compared to other processes with nitrification still being performed in the aeration reactors.

2.6 BioWin

2.6.1 Introduction and Application

BioWin is a wastewater model simulator software that can tie together biological, chemical, and physical processes to provide insight on wastewater treatment plant operations. This software is used worldwide by consulting engineers, infrastructure owners, regional municipalities, water authorities, equipment manufacturers, academic institutions, and wastewater treatment plants. BioWin can be used for many applications such as selection of optimal treatment processes, reduce capital investments, energy consumption and operating costs, decisions on plant operation, teach students and plant

operators of wastewater fundamentals, and to build models for emerging technologies (EnviroSim, 2020). Wastewater treatment systems can be configured using BioWin by using the many process modules, which include activated sludge bioreactors, anaerobic and aerobic digesters, settling tanks, holding tanks, equalization tanks, and dewatering units, all with the option for different input elements (EnviroSim, BioWin Help Manual, 2020). Although BioWin is a powerful tool for wastewater analysis, it does come with limitations as the model needs to be evaluated against extensive data sets to provide the most accurate simulation and it is the responsibility of the user to assess and confirm that the results generated by the program are appropriate.

2.6.2 Case Studies

There are many research studies that use the BioWin modeling software to develop process models to predict treatment performance, optimize treatment efficiency, or to compare model predicted data to pilot-scale studies and full-scale treatment plants. The following provides insight on some research papers that have used the BioWin modeling software to investigate model predictions compared to experiment or actual wastewater treatment plant data.

- In 2006, a research group in Arizona used the BioWin modeling software to evaluate process alternatives when creating a master plan for the expansion of the City of Avondale Wastewater Treatment Plant. The group used the model to evaluate expansion alternatives that involved additions to the plant including influent equalization basins and primary clarifiers, expansion to the aeration basins and secondary clarifiers, and converting the existing activated sludge process to membrane

- bioreactors. Their study showed that BioWin can be an effective tool in comparing different secondary treatment options with careful model calibration. The model was able to determine that the added equalization basins and primary clarifiers would be the most cost effective option when expanding the plant while still maintaining effluent water quality (Lei et al., 2006).
- A research group at the Research Center of Biotechnology of the Russian Academy of Sciences used the BioWin software to model an anammox process. They used the mathematical model to analyze the removal of ammonium nitrogen from wastewater. The group used experimental studies to calculate kinetic and stoichiometric coefficients that are incorporated into the model. After analyzing the predicted model values with experimental data, they concluded that the results obtained from model calculations were similar to those obtained from the experiments, indicating that the model possessed a high predictive ability for the biotechnology of the anammox process (Dorofeev et al., 2017).
 - The BioWin software can be used to evaluate full-scale treatment performances in order to optimize actual operation which was used by a research group in China to simulate a dynamic analysis on advanced nitrate nitrogen removal in a deep bed denitrification filter (DBDNF). They used measured data from the DBDNF pilot system to develop a BioWin model where they concluded that after model calibration, the model values were consistent with measured data, enforcing the effectiveness of the model simulations (Ji et al., 2019).
 - One advantage BioWin has as a model simulator is the ability to predict effluent values when changes are made to the treatment process. Effluent regulations can change based

- on new strict water quality limitations, and BioWin can be used to predict if treatment plants are capable of meeting new regulations. A group of researchers at the University of Trieste, Italy, characterized three wastewater treatment plants in the BioWin model in order to support upgrades to the plant to meet new effluent requirements. They used influent characteristics and activated sludge performances and studies the application of respirometry. They calibrated the model and ran the simulations to account for 11 months of historical data and results showed that the model was in agreement of actual effluent data and that the BioWin model was able to predict nitrification and denitrification performances (Vitanza et al., 2016).
- Another research group from the Hohai University, China, utilized BioWin to analyze three scenarios to improve the performance of a wastewater treatment plant. They wanted to investigate the possibility of wasting sludge from either the aeration tank or secondary clarifier, the construction of a new oxidation ditch, and the construction of an equalization tank. They were able to calibrate the BioWin model based on wastewater characteristics to successfully evaluate each scenario. Results showed that construction of a new oxidation ditch or equalization tank was not necessary, and that the sludge should be wasted from the aeration tank during wet seasons to reduce solid loading of the clarifiers (Oleyiblo et al., 2014).

2.6.3 BioWin Model Inputs and Important Parameters

When developing a BioWin model, there are key parameters and input values that need to be considered. Important values include influent constituents, physical layout of the treatment system (e.g., reactor size, configuration, and aeration conditions), and kinetic and

stoichiometric parameters. The influent constituents provide information needed for BioWin to determine influent fractions and wastewater characteristic, while the kinetic and stoichiometric parameters are used to calibrate and evaluate treatment performance. In addition to fractions and wastewater characteristics, important parameters in the influent, such as carbon, nitrogen, phosphorus, and solids, are also used to analyze model calibration and accuracy. Table 2.4 contains the key parameters when developing a BioWin model along with their associated purpose.

Table 2.4: Important BioWin parameters and purposes

Parameter	Abbreviation	Purpose	
		Influent Fractions/WW Characteristics	Model Calibration and Accuracy
Biochemical oxygen demand 1	BOD	x	
Filtered BOD 1	FBOD	x	
Carbonaceous BOD 2	CBOD	x	
Filtered CBOD 2	FCBOD	x	
Chemical oxygen demand	COD	x	x
Filtered COD	FCOD	x	x
Flocculated and Filtered COD	FFCOD	x	
Ammonia	NH3	x	x
Nitrate (NO3) + Nitrite (NO2)	NOx	x	x
Total Kjeldahl nitrogen	TKN	x	x
Soluble Kjeldahl nitrogen	SKN	x	
Orthophosphate	OP	x	x
Total phosphorus	TP	x	x
Alkalinity	-	x	x
Acetate	-	x	
pH	-	x	
Total suspended solids	TSS	x	x
Volatile suspended solids	VSS	x	x
Ammonia oxidizing bacteria growth rate	AOB	Used to optimize ammonia profile	
Nitrite oxidizing bacteria growth rate	NOB	Used to optimize NOx profile	
Phosphorus accumulating organisms	PAO	Used to optimize phosphorus profile	
Particulate substrate COD:VSS ratio	-	Used to optimize solids profile	
Particulate inert COD:VSS ratio	-	Used to optimize solids profile	
Ordinary heterotrophic aerobic yield	OHO yield (aerobic)	Used to optimize solids profile	

¹ BOD is not as important as COD as BioWin uses COD inputs

² The inhibitor used for CBOD and FCBOD interferes with the model and BOD and FBOD is used

CHAPTER 3 : PROBLEM STATEMENT/AIM OF RESEARCH

3.1 Purpose of Project

The purpose of this project is to evaluate process and treatment performance at the Truckee Meadows Water Reclamation Facility through comprehensive data collection. Based on the data collection process the University of Nevada, Reno (UNR), in collaboration with TMWRF technical and laboratory personnel, developed and calibrated a BioWin process model of the current secondary treatment process. Following the development and calibration of the BioWin model, multiple treatment alternatives were evaluated, using the calibrated model, including modifications to current plant configurations, and modifications to account for future expansion. In addition to treatment performance, aeration demand and energy and chemical costs between the current and modified treatment alternatives were evaluated.

3.2 Project Tasks

In order to build, verify, and apply the process model, there were four main research tasks;

- Review existing plant data regarding flows and concentration of key water quality parameters and flows necessary to develop a process model
- Based on data analysis, develop sampling campaigns to capture additional data needed for model development
- Using data from sampling campaigns, develop and calibrate a BioWin process model for current biological treatment and verify model performance

- Using the calibrated model, investigate alternative process configurations to analyze and compare CNP treatment performance, aeration demand, and energy and chemical costs to current TMWRF process.

3.3 TMWRF Process Layout

The Truckee Meadows Water Reclamation Facility main treatment train consist of primary treatment (screening, grit tanks, and primary clarifiers), secondary treatment (biological activated sludge and secondary clarifiers), tertiary treatment (nitrification towers, denitrification filters, and media filters), and disinfection (chlorine contact tank). The full plant layout is contained in Appendix D. The model primarily focuses on the biological secondary treatment, consisting of primary clarification, biological activated sludge, and secondary clarification. Figure 3.1 shows the process schematic section that the model is centered around.

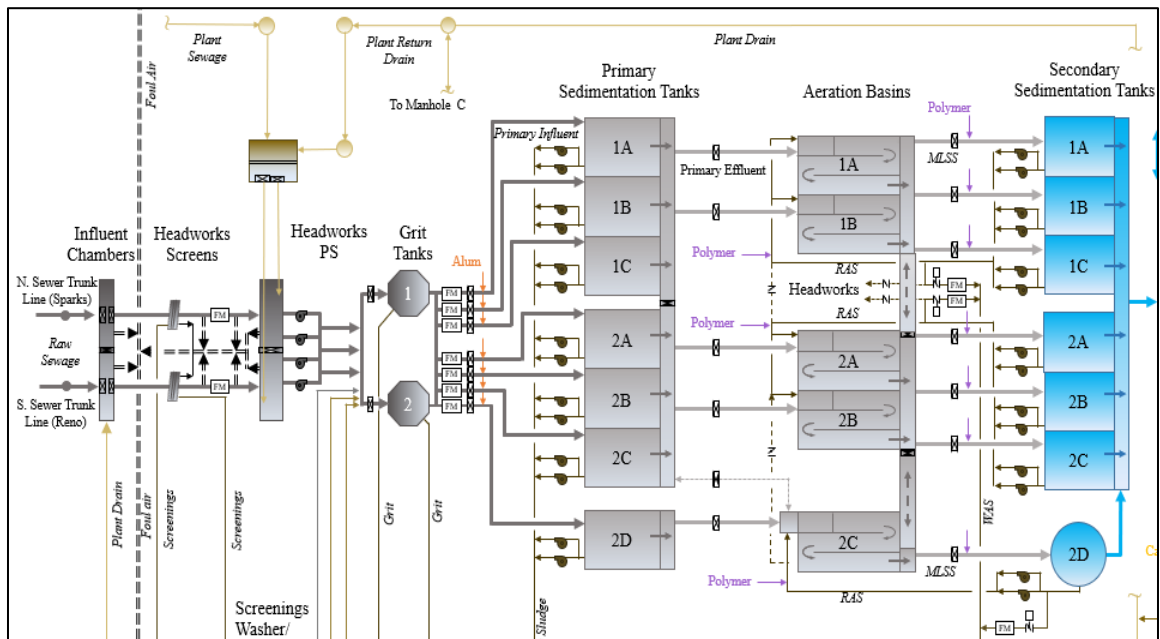


Figure 3.1: Process schematic section used for model development (TMWRF, 2018)

As revealed in the figure, the treatment process consists of two main trains, Systems (Sys) 1 and 2, denoted by 1A-C and 2A-C for primary and secondary clarification and 1A-B and 2A-B for biological activated sludge. It should be noted that primary clarifier 2D, activated sludge tank 2C, and secondary clarifier 2D represent System 3 and was not modeled since this system is used for centrate treatment. When developing the BioWin model, parallel primary and secondary clarifiers (i.e., A, B, and C), and activated sludge trains A and B for each system were modeled as single units, assuming similar performance in the processes. More information is contained in Section 4.3.2. Along with the north and south plant influent lines, Figure 3.1 shows some recycle streams that enter the influent through the plant drain. The recycle streams are detailed in Sections 4.3.1.2 and 4.3.1.3.

CHAPTER 4 : MODEL DEVELOPMENT AND CALIBRATION OF THE TRUCKEE MEADOWS WATER RECLAMATION FACILITY

4.1 Preliminary Analyses and Sampling Campaigns

4.1.1 Historical Data

The first step to model development and calibration was to analyze historical TMWRF data to determine optimal times for sampling throughout the year. When developing the model, it was desired to use maximum loads to account for the “worst case” scenario regarding plant performance. In order to investigate when maximum loads occurred, plant influent data from 2017 were analyzed. The data were categorized based on the meteorological seasons with December-February representing winter, March-May for spring, June-August for summer, and September-November for fall. When determining maximum loads, an average value over the course of the season was investigated along with its standard deviation. Table 4.1 summarizes the plant influent average concentrations with the associated standard deviation, and Table 4.2 provides data for the plant influent loads. A complete overview of the plant influent data from 2017 is contained in Appendix A. In addition to analyzing the maximum average loads for each season, the variances between each season were investigated. Figures 4.1-4.11 depict the load variations between each season for BOD, COD, Ammonia, NO_x, TKN, SKN, OP, TP, Alkalinity, TSS, and TDS. The figures are whisker plots that show the variation of the constituents during the corresponding seasons. The figures show the average value, represented by the solid circle, quartiles 1 and 3, representing the median of the lower and upper half of the data set, and error bars, showing the variation.

Table 4.1: Average concentrations and standard deviation for seasonal 2017 data

Parameter (mg/L)	Winter	Spring	Summer	Fall
BOD	250.1 ± 47.5	245.3 ± 45.3	236.6 ± 24.7	243.8 ± 20.8
COD	431.1 ± 140.1	415.4 ± 137.2	405.1 ± 91.9	428.5 ± 113.0
Ammonia	26.6 ± 3.8	26.1 ± 3.8	27.1 ± 1.2	29.0 ± 1.9
NO _x	0.1 ± 0.2	0.1 ± 0.2	0.1 ± 0.1	0.1 ± 0.1
TKN	41.4 ± 5.3	40.5 ± 5.2	41.6 ± 2.0	45.2 ± 3.6
SKN	31.5 ± 3.0	31.0 ± 3.1	31.0 ± 0.7	33.5 ± 1.1
OP	3.3 ± 0.6	3.2 ± 0.6	3.1 ± 0.1	3.3 ± 0.3
TP	5.4 ± 0.8	5.1 ± 0.7	4.8 ± 0.3	5.3 ± 0.6
Alkalinity	212.2 ± 21.9	210.0 ± 18.9	211.3 ± 7.4	231.0 ± 14.5
TSS	206.3 ± 44.6	199.2 ± 38.2	202.8 ± 34.9	210.0 ± 31.5
TDS	422.8 ± 43.1	443.3 ± 43.4	432.5 ± 19.1	440.9 ± 35.3

n = 13 – 92 for each season

Table 4.2: Average load and standard deviations for seasonal 2017 data

Parameter (mg/L)	Winter	Spring	Summer	Fall
BOD	63,289 ± 7,717	62,740 ± 7,755	55,248 ± 5,990	56,228 ± 5,253
COD	101,017 ± 32,824	97,343 ± 32,158	94,916 ± 21,524	100,401 ± 26,489
Ammonia	6,230 ± 883	6,123 ± 879	6,341 ± 262	6,800 ± 452
NO _x	34 ± 49	30 ± 44	17 ± 18	27 ± 30
TKN	9,700 ± 1,237	9,495 ± 1,217	9,747 ± 467	10,584 ± 842
SKN	7,377 ± 720	7,269 ± 724	7,270 ± 168	7,855 ± 268
OP	764 ± 138	748 ± 141	725 ± 69	775 ± 72
TP	1,275 ± 176	1,193 ± 156	1,124 ± 152	1,240 ± 138
Alkalinity	49,721 ± 5,143	49,214 ± 4,436	49,504 ± 1,742	54,131 ± 3,408
TSS	48,353 ± 10,445	46,689 ± 8,951	47,528 ± 8,188	49,212 ± 7,388
TDS	103,754 ± 10,110	103,880 ± 10,169	101,339 ± 4,472	103,321 ± 8,283

n = 13 – 92 for each season

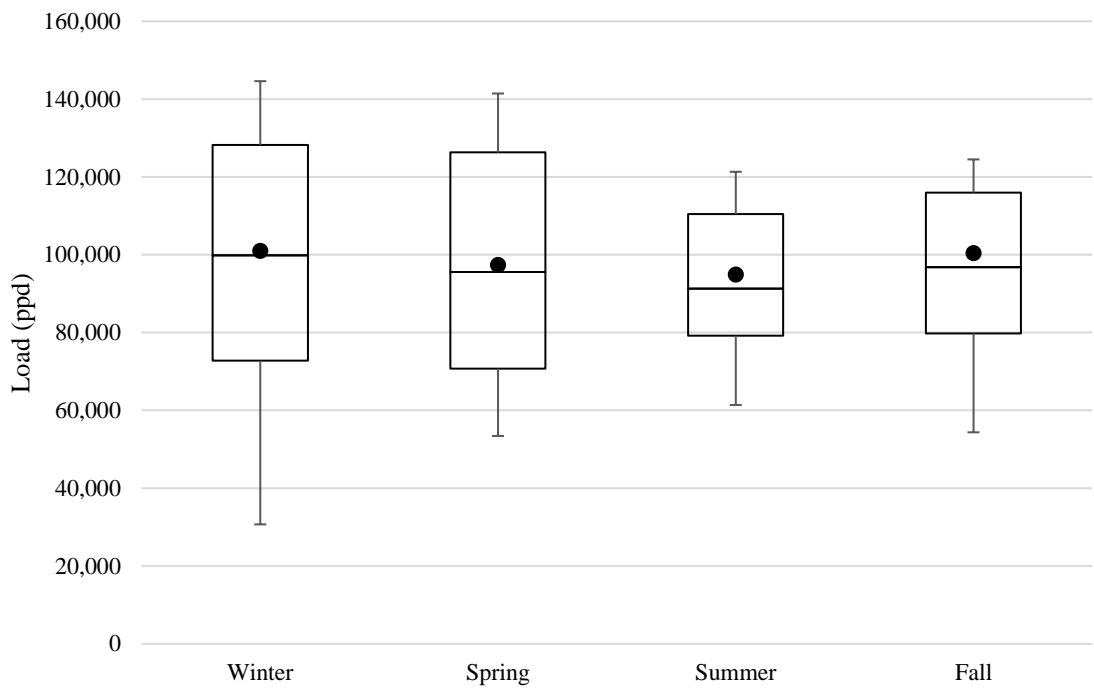


Figure 4.1: BOD seasonal load variance for 2017

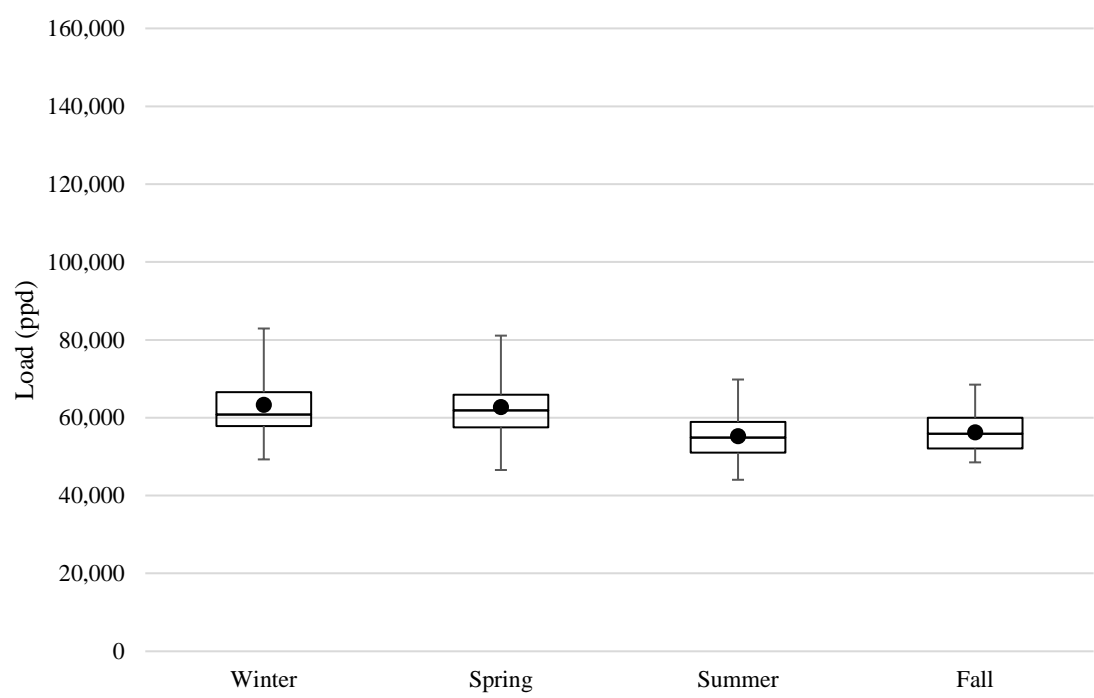


Figure 4.2: COD seasonal load variance for 2017

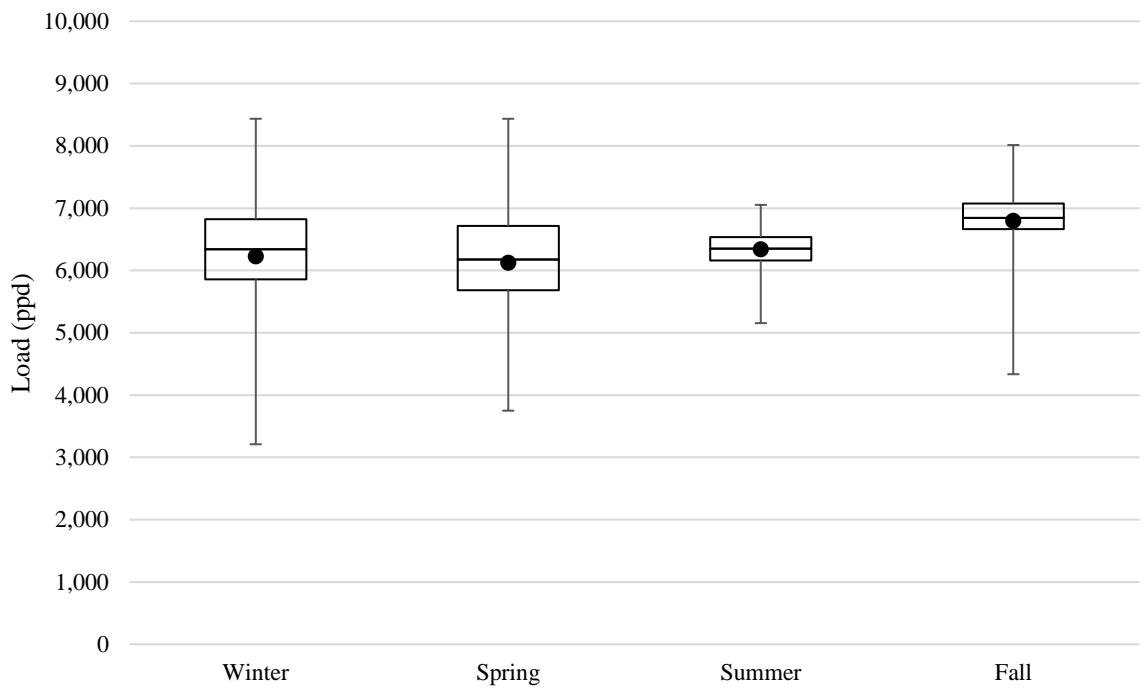


Figure 4.3: Ammonia seasonal load variance for 2017

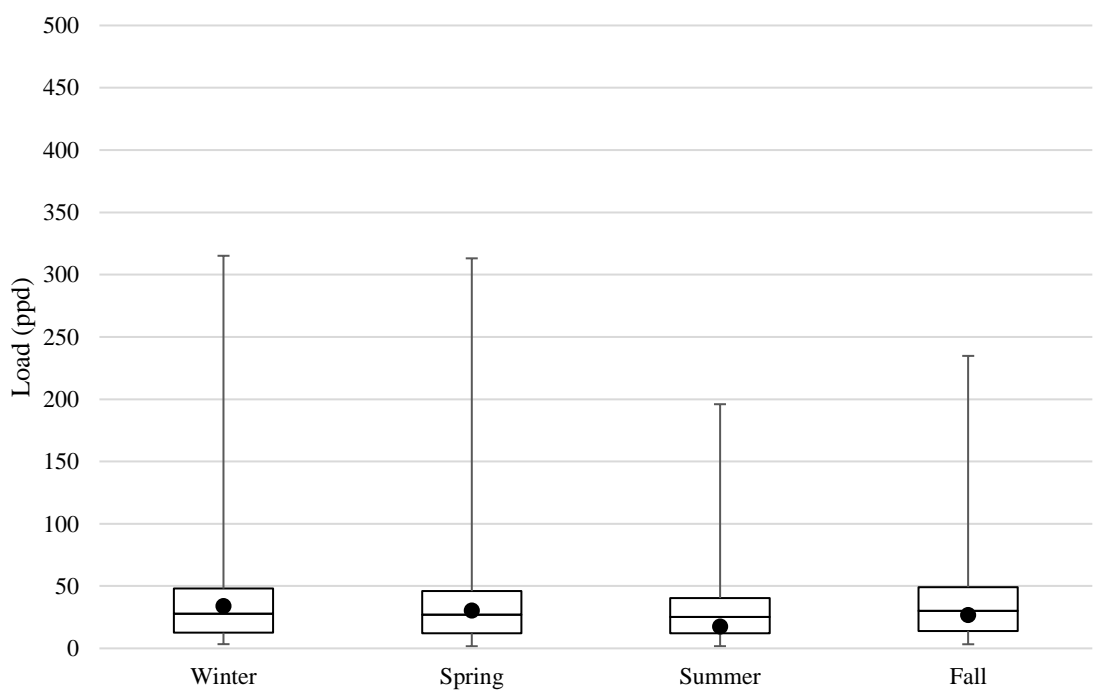


Figure 4.4: NO_x seasonal load variance for 2017

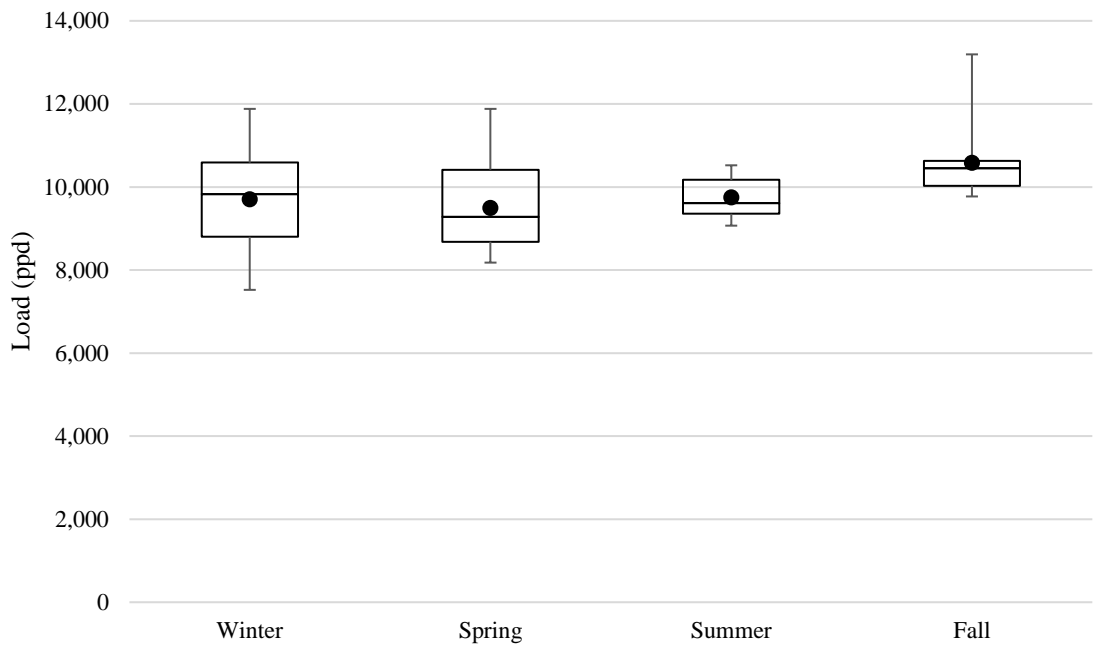


Figure 4.5: TKN seasonal load variance for 2017

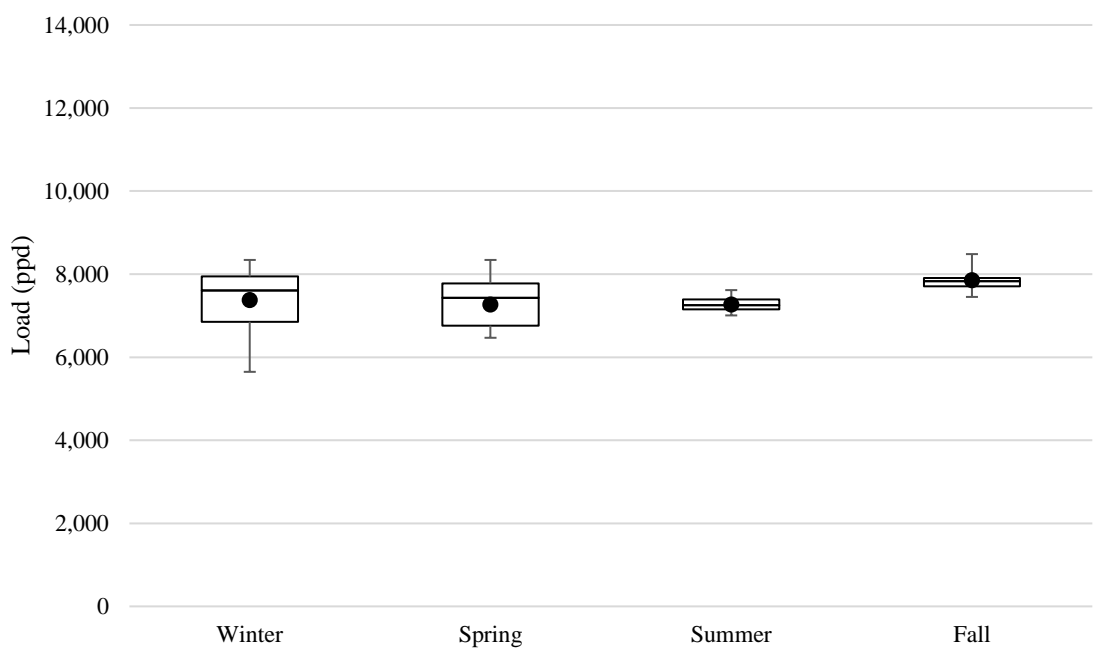


Figure 4.6: SKN seasonal load variance for 2017

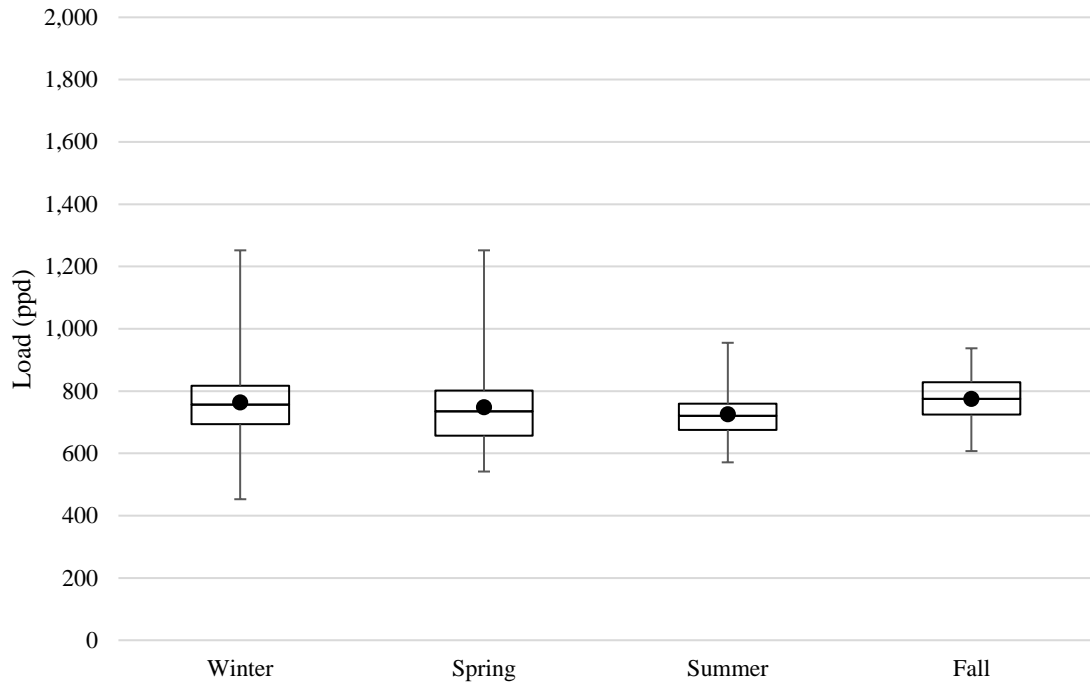


Figure 4.7: OP seasonal load variance for 2017

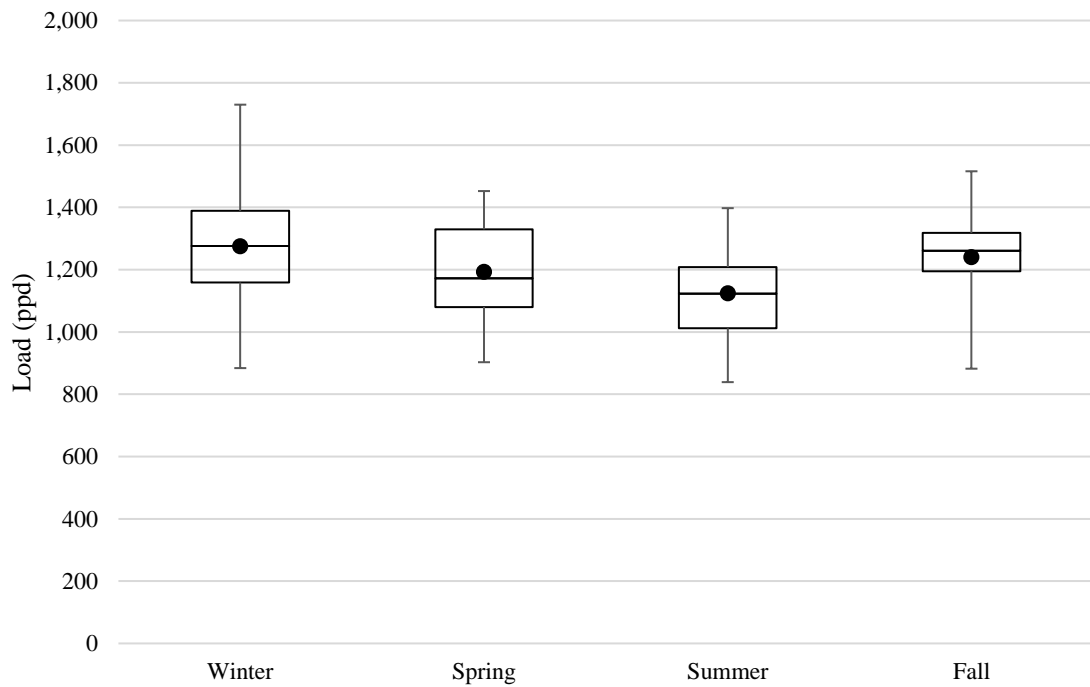


Figure 4.8: TP seasonal load variance for 2017

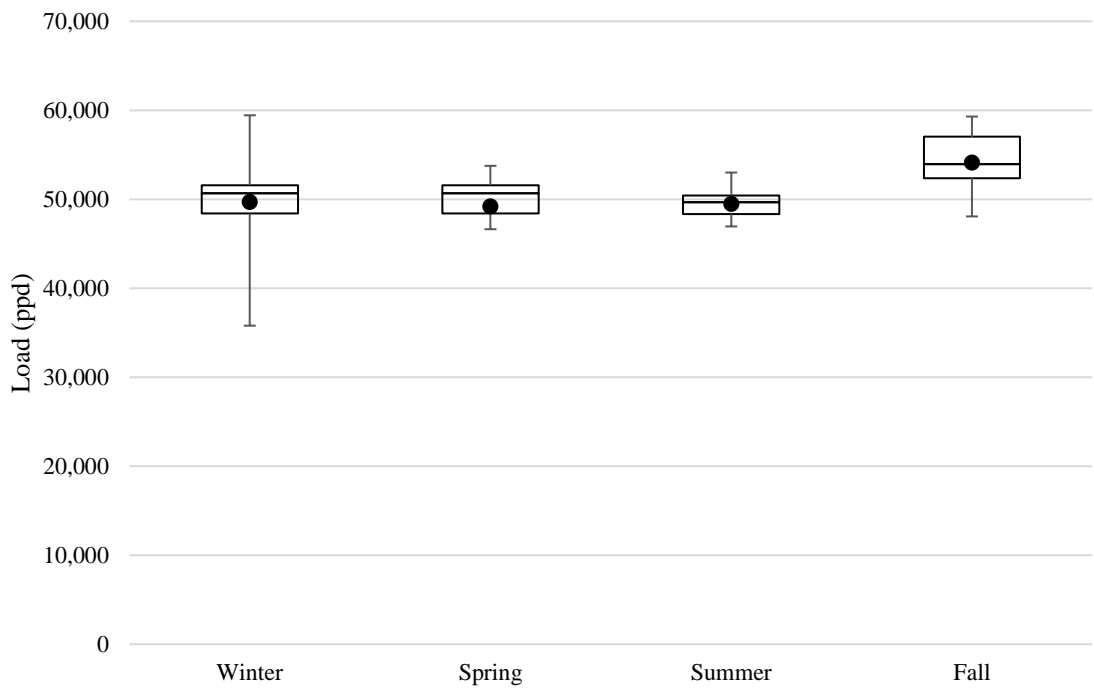


Figure 4.9: Alkalinity seasonal load variance for 2017

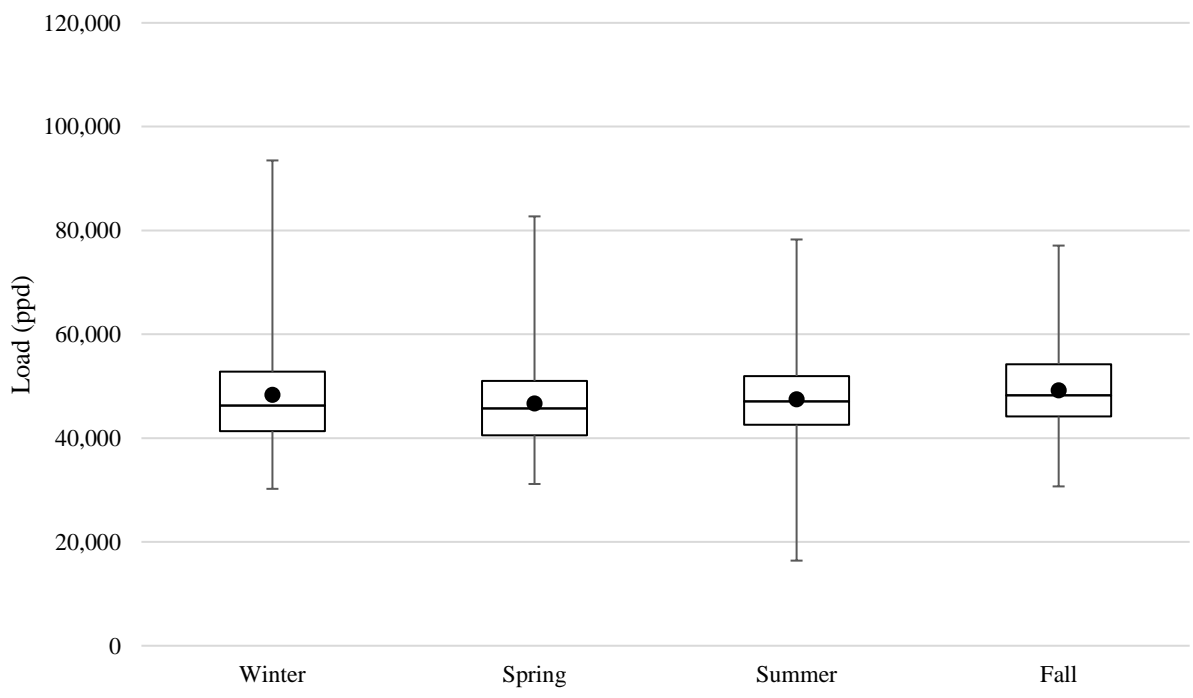


Figure 4.10: TSS seasonal load variance for 2017

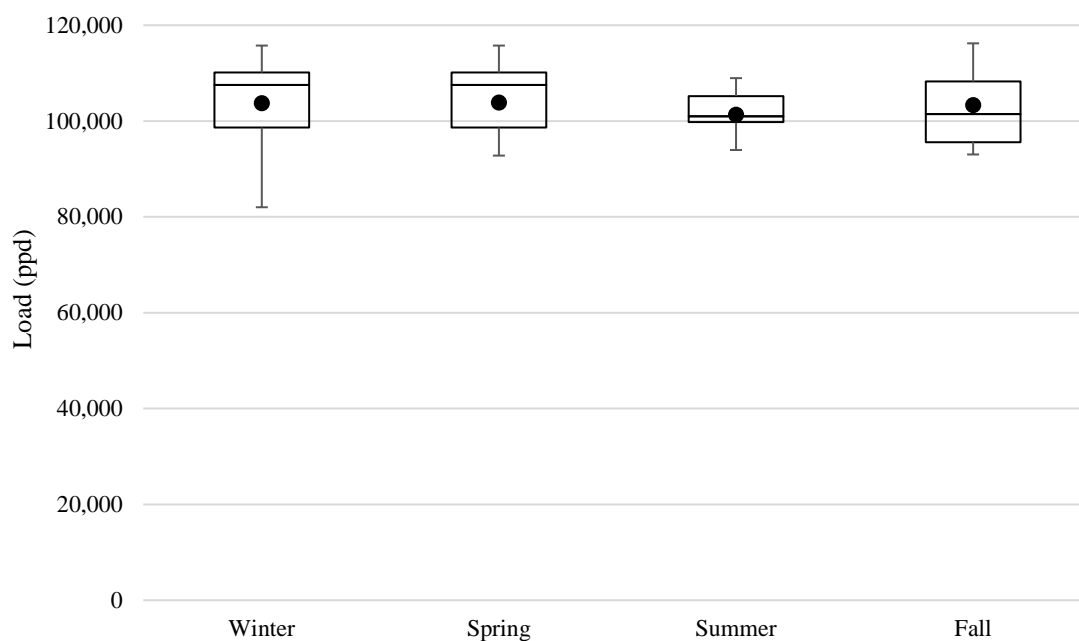


Figure 4.11: TDS seasonal load variance for 2017

As revealed by the trends depicted in the figures, there is some variance within the constituents between seasons. Analyzing the data and average loads within each parameter, it was observed that most of the maximum loads occur in either fall or winter, with the exception of total dissolved solids (TDS), which had a maximum load in the spring. From this analysis, it was determined that sampling should be performed in these two seasons; however, in order to accurately confirm that fall and winter have true maximum loads, statistical t-test analyses, using a two-sample of equal variances with an alpha value of 0.05, were performed between the two seasons and the P-values were calculated. Results from this analysis are depicted in Figure 4.12. Performing these t-tests determined whether fall and winter are significantly different from each other with respect to maximum loads. As seen from the figure, BOD, ammonia, TKN, SKN, and alkalinity have significant

differences between fall and winter as the P-values are less than the alpha value of 0.05. It should be noted that although TDS has a maximum load during the spring, analysis shows that the P-value for spring compared to winter is 0.41, and 0.44 for the spring to fall comparison, indicating no significant difference between the seasons. The season with the maximum load for each parameter, along with whether there are significant differences between fall and winter is contained in Table 4.3.

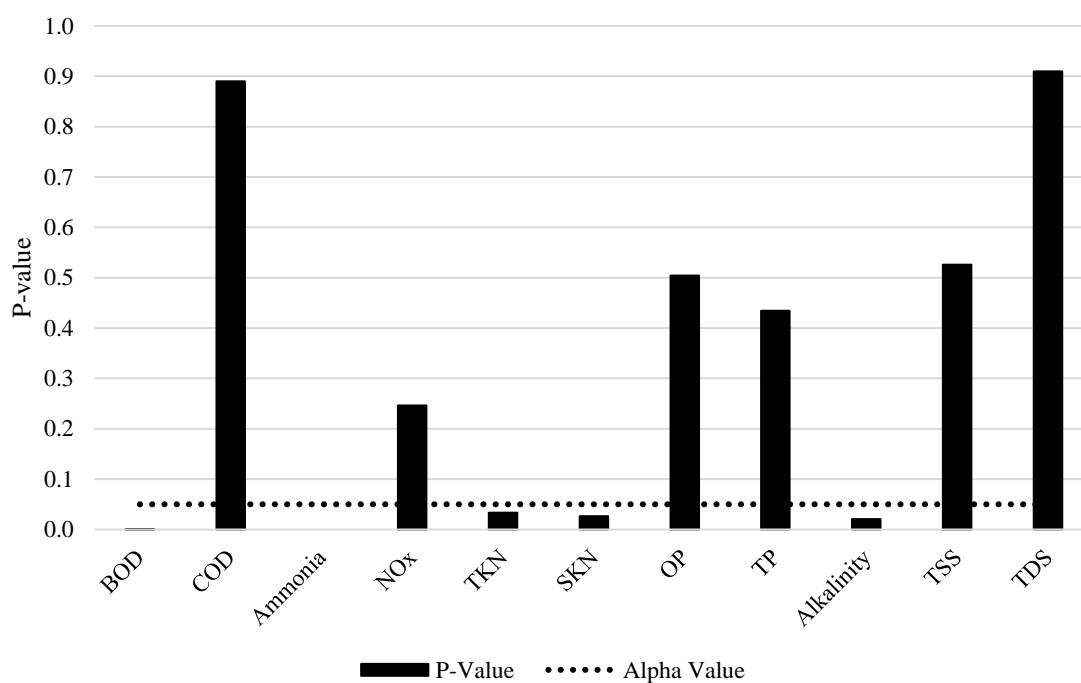


Figure 4.12: T-test analysis and corresponding P-values for significant differences

Table 4.3: Seasons with maximum loads and significant difference between fall and winter

Parameter	Winter	Spring	Summer	Fall	Significant Difference
BOD	✘				Yes
COD	✘				No
Ammonia				✘	Yes
NO _x	✘				No
TKN				✘	Yes
SKN				✘	Yes
OP				✘	No
TP	✘				No
Alkalinity				✘	Yes
TSS				✘	No
TDS ¹		✘			No

¹ The TDS maximum loads in spring are not significantly different from fall and winter

4.1.2 Initial Sampling Campaigns

After analysis of historical data to determine maximum load seasons, the initial sampling campaigns were developed. Based on the previous analysis, data revealed that sampling should occur in both fall and winter to capture all maximum loads. Two-week sampling campaigns were developed for both fall and winter and were in effect from October 28 – November 8, 2018 for the fall, and January 27 – February 7, 2019 for the winter. After investigation of the BioWin model inputs, a list of parameters needed for model calibration was developed. Most of the parameters needed for model calibration are routinely analyzed by TMWRF personnel in the facility laboratory; however, there are some analyses not performed that were needed for model calibration. Table 4.4 provides information on the additional analyses needed for model calibration including sample type, sample frequency,

and which lab was to perform the analysis. It should be noted that the additional plant influent samples for CBOD and VSS were added to the winter sampling campaign and were not performed during the fall.

Table 4.4: Additional data requested in fall and winter for model development

Parameter	Sample Type	Frequency	Performed by:	
			TMWRF	UNR
Plant INF				
CBOD ¹	Composite	3-times/wk	x	
VSS ¹	Composite	3-times/wk	x	
Primary EFF Sys 1 & 2				
Acetate	Composite	5-times/wk		x
CBOD	Composite	3-times/wk	x	
FCBOD	Composite	3-times/wk	x	
FCOD	Composite	3-times/wk	x	
FFCOD	Composite	3-times/wk		x
pH	Grab	3-times/wk	x	
TKN	Composite	3-times/wk	x	
VSS	Composite	3-times/wk	x	

¹ Additional analysis added to winter campaign

4.1.3 Additional Sampling Campaign

After the initial sampling campaigns and model calibration, it was realized that more data was needed to fully and accurately calibrate the BioWin model, specifically dealing with

recycle streams. Initially, plant influent and primary effluent were the focal points of sample analysis, but after further investigation, process schematics showed that recycle streams combined with plant influent at the headworks and just before primary clarification and initial sampling and model calibration did not account for the recycle streams. After consulting with engineers at Brown & Caldwell (the firm performing the TMWRF Facility Plan review), it was decided to change the CBOD and FCBOD analyses to BOD and FBOD as the inhibitor used in the CBOD and FCBOD analyses can negatively affect wastewater characterization (Harrison, 2019). Another change that was made from the fall and winter campaign to the new campaign was the analysis of acetate. During the fall sampling campaign, ion chromatography was used to determine acetate concentrations. Unfortunately, the ion chromatography instrument at UNR did not perform well and resulted in incomplete acetate data. For the winter campaign, UNR outsourced the acetate samples to WetLabs where the acetate analysis would be conducted. For the additional sampling campaign, acetic acid analysis was used instead of acetate as TMWRF has the means to perform this analysis and can be used in the future without the need to outsource samples to an outside lab. With these changes, a new sampling campaign was developed to provide an extensive analysis on plant influent, primary influent, primary effluent, secondary effluent (SE), RAS, aeration, and recycle streams. The new sampling campaign was another two-week campaign and was in effect during the summer from June 23 – July 6, 2019. Table 4.5 provides information on the summer sampling campaign for the composite samples and Table 4.6 for the grab samples. As detailed in the table, this sampling campaign was much more extensive than the previous fall and winter campaigns, comprising of most of the constituents at every location in the primary and secondary

treatment trains. As stated before, the fall and winter sampling campaigns did not account for the recycle streams, and significantly impacted wastewater characterization. The summer sampling campaign incorporated the recycle streams, which included the gravity thickeners (GT), waste from the denitrification filters (denite waste), thickened wasted activated sludge (TWAS), and phosphorus rich supernatant (PRS) recycle streams. By incorporating the recycle streams, model calibration would be able to categorize the true plant influent for biological treatment.

Table 4.5: Summer campaign composite sample analyses information

Day	Date	Plant INF			Primary INF (Sys 1 & 2)		Primary EFF (Sys 1 & 2)			Secondary EFF (Sys 1 & 2)			RAS (Sys 1 & 2)	Aeration (Sys 1 & 2)	
		COD, FCOD, OP, TP, FTP, Alkalinity, NH ₃ , TKN, FTKN	BOD, FBOD	TSS, VSS, FFCOD (UNR)	BOD, FBOD, COD, FCOD, OP, TP, FTP, Alkalinity, NH ₃ , TKN, FTKN	TSS, VSS, FFCOD (UNR)	BOD, FBOD, COD, FCOD, OP, TP, FTP, Alkalinity, NH ₃ , TKN, FTKN	FBOD	TSS, VSS, FFCOD (UNR)	OP, TP, NH ₃ , NO ₂ , NO ₃	BOD, FBOD, COD, FCOD, FFCOD (UNR) TSS, TKN, FTKN, FTP, Alkalinity	OP, TP, NH ₃ , NO ₂ , NO ₃	TSS	TSS, VSS (UNR)	OP, NH ₃ , NO ₃ (10 grab samples each)
S	23-Jun	x		x	x	x	x	x	x	x	x	x	x	x	
M	24-Jun	x		x						x			x		10
T	25-Jun	x	x	x	x	x	x	x	x	x	x	x	x	x	10
W	26-Jun	x	x	x						x			x		10
T	27-Jun	x	x	x	x	x	x	x	x	x	x	x	x	x	
F	28-Jun	x		x									x		
S	29-Jun	x		x									x		
S	3-Jun	x		x	x	x	x	x	x	x	x	x	x	x	
M	1-Jul	x		x						x			x		10
T	2-Jul	x	x	x	x	x	x	x	x	x	x	x	x	x	10
W	3-Jul	x	x	x						x			x		10
T	4-Jul	x	x	x	x	x	x	x	x	x	x	x	x	x	
F	5-Jul	x		x									x		
S	6-July	x		x									x		

Table 4.6: Summer campaign grab sample analyses information

Day	Date	Primary EFF (Sys 1 & 2) + Gravity Thickener		Denite Waste Biomass	TWAS Underflow	PRS
		COD, FCOD, TSS, VFA	FFCOD (UNR)	COD, TSS, Alkalinity, NO ₂ , NO ₂	TSS, TP	COD, TSS, TP, Alkalinity, NH ₃ , OP
S	23-Jun	✘	✘	✘	✘	✘
M	24-Jun					
T	25-Jun	✘	✘	✘	✘	✘
W	26-Jun					
T	27-Jun	✘	✘	✘	✘	✘
F	28-Jun					
S	29-Jun					
S	3-Jul	✘	✘	✘	✘	✘
M	1-Jul					
T	2-Jul	✘	✘	✘	✘	✘
W	3-Jul					
T	4-Jul	✘	✘	✘	✘	✘
F	5-Jul					
S	6-July					

4.2 TMWRF Sampling Campaign Data

After the three sampling campaigns were conducted, the UNR coordinated with TMWRF personnel to compile the data into multiple spreadsheets for further analysis. The summer campaign data was primarily used for model calibration as it was the most extensive data collection campaign and included the changes made from the previous fall and winter

campaigns, including the incorporation of the recycle streams. In collaboration with the plant engineer at TMWRF, Mr. Casey Mentzer, the data set for the summer campaign was analyzed for potential outliers that would skew wastewater characterization. Potential outliers were compared with historical data to investigate the percentiles of when values occurred, or if lab errors occurred in analysis, to justify removal from the data set. Once the outliers were removed from the data set, an average value for the constituents over the course of the campaign were calculated and used to develop a steady-state BioWin model. The average values of the more important parameters (BOD, COD, nitrogen and phosphorus species, alkalinity, and solids) for the three sampling campaigns are summarized in Table 4.7 for the plant influent, Table 4.8 for the primary influents, Table 4.9 for the primary effluents, Table 4.10 for the secondary effluents, and Table 4.11 for the aeration systems. Table 4.12 also provides the information for the recycle streams during the summer campaign. The full data set for the fall, winter, and summer sampling campaigns is in Appendix B.

Table 4.7: Average plant influent values for the three sampling campaigns

Parameter (mg/L)	Fall	Winter	Summer
Flow (mgd)	25.8	28.2	27.2
BOD	263.7	267.0	263.8
FBOD	n/m	n/m	103.7
COD	535.9	544.8	544.8
FCOD	n/m	n/m	213.6
FFCOD ¹	160.8	163.4	147.7
Ammonia	31.4	29.4	28.3
NO ₂	0.1	0.1	0.1
NO ₃	0.0	0.0	0.8
TKN	47.4	44.3	44.0
OP	3.6	3.2	3.0
TP	5.6	5.1	4.9
Alkalinity	225.3	210.2	208.2
TSS	214.3	234.5	212.6
VSS	n/m	218.0	193.3

¹ Using updated FFCOD:COD ratio – explained in Section 4.3.1.1

n/m = not measured

Table 4.8: Average primary influent values for the sampling campaigns

Parameter (mg/L)	Fall	Winter	Summer
Primary INF Sys 1			
Flow (mgd)	16.0	17.1	16.2
BOD	258.0	257.0	250.0
COD	546.8	494.7	505.5
FCOD	n/m	n/m	184.2
Ammonia	n/m	n/m	36.3
TKN	n/m	n/m	52.6
OP	n/m	n/m	4.0
TP	n/m	n/m	7.0
Alkalinity	n/m	n/m	239.3
TSS	200.5	191.2	230.6
VSS	n/m	n/m	211.2
Primary INF Sys 2			
Flow (mgd)	17.9	15.8	18.8
BOD	218.0	247.0	228.2
COD	489.5	502.5	513.3
FCOD	n/m	n/m	181.3
Ammonia	n/m	n/m	35.5
TKN	n/m	n/m	50.8
OP	n/m	n/m	4.0
TP	n/m	n/m	6.7
Alkalinity	n/m	n/m	229.3
TSS	186.8	198.2	210.4
VSS	n/m	n/m	185.7

n/m = not measured

Table 4.9: Average primary effluent values for the sampling campaigns

Parameter (mg/L)	Fall	Winter	Summer
Primary EFF Sys 1			
BOD	175.0	188.0	175.8
COD	339.5	313.3	357.3
FCOD	193.0	177.0	198.0
Ammonia	29.7	37.2	65.5
NO ₂	0.6	0.3	0.2
NO ₃	1.0	0.3	0.2
TKN	41.0	46.2	48.0
OP	4.3	3.9	4.1
TP	5.6	5.2	5.8
Alkalinity	226.9	230.3	235.9
TSS	86.7	81.0	93.7
VSS	79.0	76.5	84.4
Primary Sludge (mgd)	0.2	0.2	0.2
Primary EFF Sys 2			
BOD	163.5	165.0	152.3
COD	311.0	333.0	326.2
FCOD	181.3	186.8	187.1
Ammonia	28.5	33.7	34.8
NO ₂	0.3	0.2	0.1
NO ₃	0.9	0.1	0.2
TKN	36.3	44.7	45.5
OP	4.2	3.5	4.0
TP	5.5	5.0	5.5
Alkalinity	221.4	222.4	228.2
TSS	77.8	80.5	82.0
VSS	68.0	78.2	71.3
Primary Sludge (mgd)	0.2	0.2	0.2

Table 4.10: Average secondary effluent values for the sampling campaigns

Parameter (mg/L)	Fall	Winter	Summer
Secondary EFF Sys 1			
BOD	41.3	15.6	54.5
COD	52.1	55.0	68.3
FCOD	42.5	41.2	42.8
Ammonia	14.6	32.6	25.4
NO ₂	3.4	0.3	1.8
NO ₃	3.0	0.5	1.8
TKN	n/m	n/m	28.5
OP	0.3	0.3	0.2
TP	0.7	0.6	0.8
Alkalinity	n/m	n/m	190.6
TSS	9.5	9.9	17.2
VSS	10.7	9.3	n/m
Secondary EFF Sys 1			
BOD	55.2	36.8	41.8
COD	55.6	57.5	57.7
FCOD	41.8	37.2	42.7
Ammonia	14.1	27.3	23.8
NO ₂	3.1	0.4	2.4
NO ₃	2.6	0.7	2.3
TKN	n/m	n/m	26.4
OP	0.5	0.1	0.3
TP	0.9	0.7	0.7
Alkalinity	n/m	n/m	177.7
TSS	9.9	16.1	12.1
VSS	11.5	14.5	n/m

n/m = not measured

Table 4.11: Average aeration system values for the sampling campaigns

Parameter (mg/L)	Fall	Winter	Summer
Aeration Sys 1			
MLSS	1,177	1,507	1,207
MLVSS	1,091	1,296	984
EFF OP	0.2	0.1	0.1
RAS (mgd)	8.9	8.7	8.4
WAS (mgd)	0.7	0.5	0.7
WAS SS	3,219	4,505	3,243
Aeration Sys 2			
MLSS	1,084	1,578	1,140
MLVSS	991	1,328	977
EFF OP	0.4	0.1	0.1
RAS (mgd)	9.8	8.2	9.4
WAS (mgd)	0.7	0.5	0.7
WAS SS	2,743	4,384	3,338

Table 4.12: Average recycle stream values for the summer campaign

Parameter (mg/L)	Gravity Thickener	Denite Waste	TWAS	PRS
Flow (mgd)	0.1	0.2	1.3	0.3
COD	1265	1080	n/m	1815
FCOD	680.0	n/m	n/m	n/m
FFCOD ¹	575.9	n/m	n/m	847.3
Ammonia	n/m	n/m	n/m	98.7
OP	n/m	n/m	n/m	137.3
TP	n/m	n/m	7.9	1392
TSS	287.3	734.3	26.5	2890
Alkalinity	n/m	127.8	n/m	n/m
Acetic Acid	168.8	n/m	n/m	n/m

¹ Using updated FFCOD:COD ratio – explained in section 4.3.1.1

n/m = not measured

4.3 BioWin Model Calibration

Once the data were collected and organized, the next task was to develop and calibrate the BioWin model. As stated before, the summer campaign data was used for model development since it is more accurate for wastewater characteristics due to the incorporation of recycle streams. Once calibrated to the summer campaign, the models were simulated using fall and winter data to determine the accuracy of the model, as outlined in Section 4.4.2. The steps used for model calibration follow the Water Environment Research Foundation’s methods for wastewater characterization in activated

sludge modeling (Melcer et al., 2003) and the BioWin calibration steps provided by EnviroSim; however, before model development could begin, there were additional corrections to the data that needed to be investigated, specifically involving uncertainties to the data, see Section 4.3.1. Once the corrections were applied to the data, the model could be developed and calibrated. The typical procedure for model calibration involves the following steps:

- Set up plant configuration in the simulator, assuming typical influent wastewater characteristics and default kinetic and stoichiometric parameters (Melcer et al., 2003).
- Specify data on physical parameters: unit dimensions, input influent and recycle flows, and temperature (Melcer et al., 2003).
- Use the BioWin influent specifier to calculate wastewater characteristics and fractions (EnviroSim, 2020).
- Calculate primary effluent percent solids removal based on system data and input into BioWin. Check primary effluent solids concentration to verify results and adjust if necessary (EnviroSim, 2020).
- Fit the secondary effluent solids concentration. Adjust percent solids removal or sludge settling parameters for secondary clarifiers until predicted TSS matches measured data (Melcer et al., 2003).
- Check model predictions for MLSS, MLVSS, and WAS SS. If values do not match up, it may be necessary to adjust stoichiometric parameters such as ordinary heterotrophic yield coefficient to obtain match (Melcer et al., 2003).
- Check the ammonia profile in the activated sludge tanks and fine-tune the maximum specific growth rate for AOBs (Melcer et al., 2003). Perform an iterative analysis on

different growth rates and observe the effect on effluent ammonia and nitrification performance to achieve optimized parameter (EnviroSim, 2020).

- Check the orthophosphate profile in activated sludge. If there is no P release/uptake, check DO, VFA, and nitrate concentrations. Use model parameters to fine-tune effluent P quality (Melcer et al., 2003).
- Input DO values in activated sludge tanks and check aeration demand based on plant data.

4.3.1 TMWRF Data Corrections

4.3.1.1 COD Fractions

The first data correction that was made involved the FFCOD:COD ratios. Upon initial data collection and analysis, the FFCOD:COD ratio appeared to be on the lower side of typical values. The engineers at Brown & Caldwell suggested that the FFCOD:COD could be inaccurate and would negatively alter the wastewater characteristics and affect treatment performance. From previous work, Brown & Caldwell has observed a FFCOD:COD ratio of 0.20 – 0.34 for plant influent (Harrison, 2019). The summer campaign data analysis determined that the FFCOD:COD ratio for plant influent was 0.22 and 0.20 for primary influent. These ratios are on the lower end of the range and could be susceptible to error. It was hypothesized that the error could have originated from the holding time on the COD samples. TMWRF personnel carried out the analysis for COD and FCOD, while UNR performed the FFCOD analysis. The COD samples were 24-hour composite samples, and while TMWRF could perform the analysis after the 24-hour collection period, UNR researchers were able to obtain the samples from the plant the following day, adding

approximately an extra 12 hours before analysis was performed. To determine if the COD ratios were accurate, TMWRF performed analyses on COD, FCOD, and FFCOD from grab samples and measured the concentration of the three parameters immediately after sampling, alleviating any holding time inaccuracies. These COD analyses were performed for the plant influent, primary influent, primary effluent, and gravity thickener. Analysis showed that the FCOD:COD ratio was consistent with that of the sampling campaign while the FFCOD:COD ratio increased, being more on par with the average of typical ratios provided by Brown & Caldwell. Table 4.13 provides information on the original FFCOD:COD ratios from the sampling campaign and the updated ratios. It should be noted that during the fall and winter, a FFCOD:COD ratio of 0.30 was used, making the updated ratios more consistent with this value than the original ratios obtained for summer sampling. The primary effluent and gravity thickener ratios were markedly higher than influent ratios due to soluble COD being more predominant at these treatment locations. These updated ratios were used to determine the FFCOD concentrations that were used during the sampling campaign using the sampling campaign's COD values.

Table 4.13: Original and updated FFCOD:COD ratios

Location	Original FFCOD:COD	Updated FFCOD:COD
Plant INF	0.22	0.27
Primary INF	0.20 – 0.21 ¹	0.26 – 0.28 ¹
Primary EFF	0.29 – 0.30 ¹	0.43 – 0.46 ¹
Gravity Thickener	0.43	0.46

¹The range is due to Systems 1 and 2 having different ratios

.3.1.2 Recycle Stream Flows

One of the first challenges encountered when analyzing the summer dataset was that the hydraulics were not balanced. Plant influent flow was measured at 27.20 mgd and measured recycle stream flows totaled 1.99 mgd, but primary influent flows measured at 34.94 mgd, leaving 5.75 mgd unaccounted. The plant engineer at TMWRF indicated that the unaccounted flow entering the primaries could be from septage or other flows entering the primary plant drain that get recycled back to the front of the plant. Due to the unaccounted flows, an additional flow stream termed “unknown” was incorporated into the model. In order to balance the hydraulics, assumptions were made on each influent stream. The plant influent, denite waste, TWAS, and PRS were assumed to combine at the headworks and get split 50/50 to Systems 1 and 2, noting that System 3 was offline during the summer campaign. TMWRF’s plant engineer shared that the gravity thickener recycle stream does not enter the headworks, but still gets split 50/50 to Systems 1 and 2, and so this assumption was made on the gravity thickener stream. Finally, the unknown stream was used to balance the hydraulics in the primaries for both systems. Table 4.14 provides information on the flow split for each system utilizing these assumptions and Figures 4.13 and 4.14 in Section 4.3.3 show visual representations of the flow splits. It should be noted that all the recycle streams are split 50/50 to each system except for the unknown stream, which has a significantly larger flow to System 2. This assumption to the unknown stream could be accurate as System 2 generally handles a higher flow than System 1.

Table 4.14: Plant influent and recycle stream flows for Systems 1 and 2

Stream (mgd)	Total Flow	To Sys 1	To Sys 2
Plant INF	27.20	13.60	13.60
Gravity Thickener	0.12	0.06	0.06
Denite Waste	0.23	0.12	0.12
TWAS	1.30	0.65	0.65
PRS	0.34	0.17	0.17
Unknown	5.75	1.56	4.20
Primary INF	34.94	16.15	18.79

4.3.1.3 Recycle Stream Constituents

One of the biggest issues with the data was the fact that all parameters needed for the BioWin influent specifier were not measured during the sampling campaign for the recycle streams. Table 4.15 provides information on which parameters were measured, represented by an ✖, and which were not, represented by a blank space. As seen from the table, there are many parameters that were still needed to determine the wastewater characteristics of the recycle streams. To fully characterize the recycle streams, some key assumptions had to be made. The following provides the assumptions that were made for each recycle stream where data were not measured:

➤ Gravity thickener:

- ▶ Average primary effluent values from both systems were used to determine the ammonia, TKN, OP, TP, and alkalinity
- ▶ NO_x and pH were assumed based on input from TMWRF's plant engineer
- ▶ Updated COD ratios were used to determine the FFCOD

- ▶ Average BOD:COD and FBOD:BOD ratios from the primary effluents were used to determine BOD and FBOD
- ▶ A typical VSS:TSS ratio of 0.90 was used to determine VSS (Metcalf and Eddy, 2014)
- Denite waste:
 - ▶ TKN and TP were determined by the stoichiometric ratio of nitrogen and phosphorus in biomass since this is the primary solid composition in this stream
 - ▶ NO_x, OP, acetate, and pH were assumed based on input from TMWRF's plant engineer
 - ▶ Updated COD ratios were used to determine the FCOD and FFCOD
 - ▶ Average BOD:COD and FBOD:BOD ratios were used to determine BOD and FBOD
 - ▶ A typical VSS:TSS ratio of 0.90 was used to determine VSS
- TWAS:
 - ▶ Average secondary effluent values from both systems were used to determine the COD, ammonia, NO_x, TKN, OP, TP, and alkalinity
 - ▶ Acetate and pH were assumed based on input from TMWRF's plant engineer
 - ▶ FCOD and FFCOD were determine using average COD ratios from secondary effluent
 - ▶ Average secondary BOD:COD and FFBOD:COD ratios were used to determine BOD and FBOD
 - ▶ A typical VSS:TSS ratio of 0.90 was used to determine VSS

- PRS:
 - ▶ TKN was assumed to be present as ammonia
 - ▶ NO_x , acetate, and pH were assumed based on input from TMWRF's plant engineer
 - ▶ Updated COD ratios were used to determine FCOD and FFCOD
 - ▶ Average BOD:COD and FBOD:BOD ratios were used to determine BOD and FBOD
 - ▶ A typical VSS:TSS ratio of 0.90 was used to determine VSS
- Unknown
 - ▶ A spreadsheet was developed to calculate the weighted flow balance concentrations of the unknown stream
 - ▶ Weighted flow balance concentrations were compared to measured primary influent data and the percent difference was minimized
 - ▶ FCOD and FFCOD were determined by the updated COD ratios using the calculated COD value
 - ▶ It should be noted that the plant influent acetate concentration was unknown, but the flow weighted balance assumption was used to calculate the acetate in the plant influent

By applying these assumptions to the recycle streams, the UNR research team was able to determine the wastewater characteristics and apply them to the BioWin model. The assumptions to the influent and recycle streams and their corresponding values is summarized in Appendix C.

Table 4.15: BioWin influent specifier parameters measured during summer campaign

Parameter	Gravity Thickener	Denite Waste	TWAS	PRS
Flow	x	x	x	x
BOD				
FFBOD				
COD	x	x		x
FCOD	x			
FFCOD				
Ammonia				x
NO _x				
TKN				
OP				x
TP			x	x
Alkalinity		x		x
VSS				
TSS	x	x	x	
Acetate	x			
pH				

4.3.2 Process Units and Plant Configuration

After all the data corrections were made, the next step of the model development process was to build the model in BioWin. The model focuses on biological treatment and consist of the influent and recycle streams, primary clarifiers, the activated sludge process, and secondary clarifiers. TMWRF's process schematic of the full plant was used as resource for model configuration and is contained in Appendix D. Following data analysis, it became clear that Systems 1 and 2 operate differently with different concentrations and flows (e.g. see Table 4.8 for primary influent data). For this reason, two separate models were constructed to represent Systems 1 and 2 individually. They were distinguished by the splitting of the influent and recycle flows as needed to match actual system flows. Figure 4.13 provides the overall schematic with both systems before each system was separated and Figure 4.14 is the BioWin representation. The BioWin schematics for each individual system are contained in Appendix E.

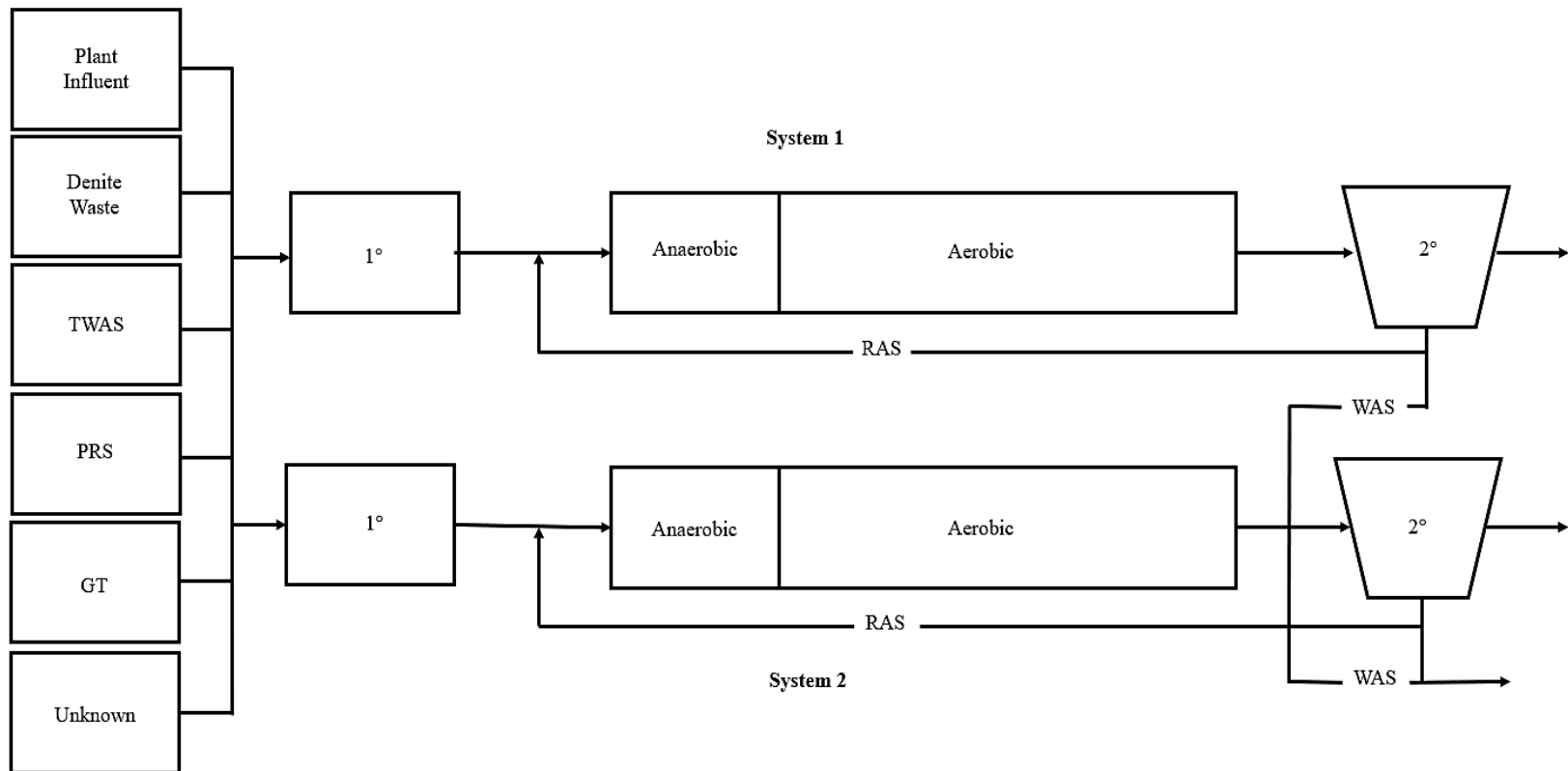


Figure 4.13: Process schematic for TMWRF's current 2° biological treatment of both systems

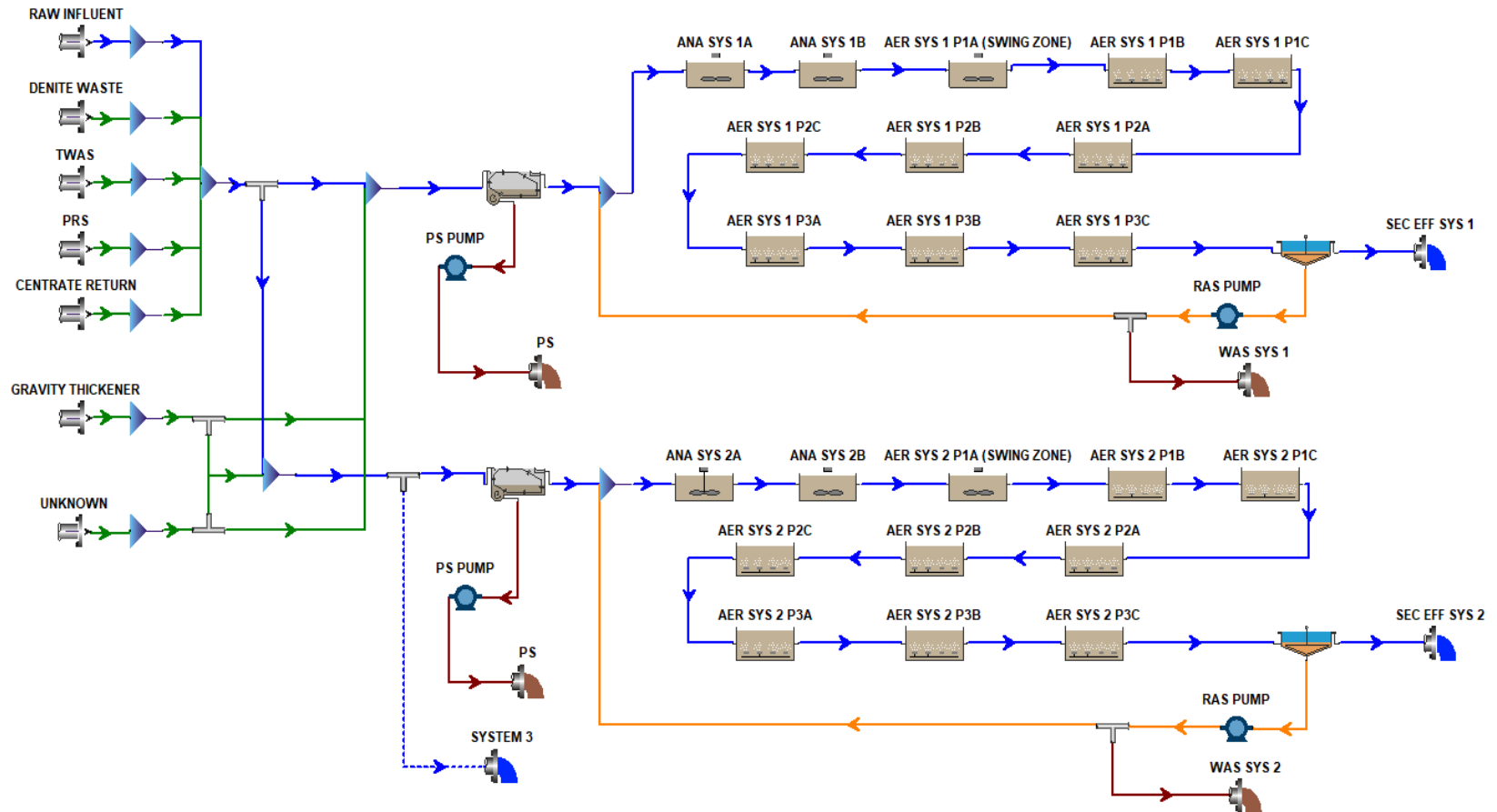


Figure 4.14: BioWin model for TMWRF's current 2° biological treatment of both systems

As seen from the figures, the influent and recycle streams were modeled as separate inputs since each stream had different wastewater characteristics. The advantage of modeling each stream as a separate input is that in the future the streams can be modified individually as opposed to one combined input. The streams are split to each system based on the assumptions made in Section 4.3.1.2. After the flow split, the first treatment process is the primary clarifiers. TMWRF uses three primary clarifiers for each system, but for the purpose of the model, the three clarifiers were combined into one and performance of each clarifier is assumed to be the same. After the primary clarifiers, the flow enters the activated sludge process. Like the primary clarifiers, the activated sludge tanks were combined, incorporating trains A and B of each system into one train. TMWRF's activated sludge process models that of an EBPR A/O process and consists of an anaerobic and aerobic zone. The anaerobic zone is approximately 14% of the activated sludge volume, with 86% being the aerobic zone. The activated sludge process simulates a PFR performance and has three passes, with the anaerobic and aerobic zones being split into smaller cells. In the model, the anaerobic zone consists of two cells, while the aerobic zone has three cells per pass, with a total of nine aerobic cells. It is important to note that the first cell in the aerobic zone acts as a swing zone and is operated under anaerobic conditions to mimic actual process operation. After the activated sludge process the flow enters the secondary clarifiers, which again are simplified in the BioWin model, combining the three clarifiers per system into one. Included in the model configuration is the sludge from the primary clarifiers and the RAS and WAS from the secondary clarifiers.

After the process units were constructed in the BioWin model, the next step was to input the physical parameters of each unit. The flows were inputted into each influent stream and

the wastewater was characterized, see Section 4.3.3. Primary clarifiers, activated sludge tanks, and secondary clarifiers' physical dimensions were sized based on the values in Tables 4.16, 4.17, and 4.18. It should be noted that the activated sludge tanks were split according to the percent of volume each cell has compared to the total activated sludge volume. Finally, the primary sludge, RAS, and WAS flows were incorporated based on the values in Tables 4.9 and 4.11.

Table 4.16: Physical parameters for the primary clarifiers

Parameter	TMWRF Data	BioWin Values
No. per System	3	1
Length (ft)	82	-
Width (ft)	82	-
SWD (ft)	11	11
Effective Surface Area, each (ft ²)	5,280	15,840

Table 4.17: Physical parameters for the activated sludge tanks

Parameter	TMWRF Data	BioWin Values
No. per System	2	1
Length (ft)	540	-
Width (ft)	27	27
SWD (ft)	15.5	15.5
Anaerobic Volume, each (MG)	0.24	0.48
ANA 1A Volume (MG)	-	0.24
ANA 1B Volume (MG)	-	0.24
Aerobic Volume, each (MG)	1.45	2.90
AER 1A Volume (MG)	-	0.44
AER 1B Volume (MG)	-	0.18
AER 1C Volume (MG)	-	0.37
AER 2A Volume (MG)	-	0.25
AER 2B Volume (MG)	-	0.33
AER 2C Volume (MG)	-	0.32
AER 3A Volume (MG)	-	0.33
AER 3B Volume (MG)	-	0.34
AER 3C Volume (MG)	-	0.34

Table 4.18: Physical parameters for the secondary clarifiers

Parameter	TMWRF Data	BioWin Values
No. per System	3	1
Length (ft)	92	-
Width (ft)	92	-
SWD (ft)	11.5	11.5
Effective Surface Area, each (ft ²)	6,640	19,920

4.3.3 Influent Wastewater Characteristics

As previously discussed, BioWin has an influent specifier that determines the wastewater characteristics of each influent and recycle stream. The influent specifier has input measurements for flow, BOD, FBOD, COD, FCOD, FFCOD, ammonia, NO_x , TKN, OP, TP, alkalinity, VSS, TSS, acetate, and pH. Using the measured data and assumptions made on the recycle stream, the values were entered into individual specifiers for each influent and recycle stream as summarized in Table 4.19. After inputting the values into the specifier, the next step was to estimate the F_{up} (unbiodegradable particulate [gCOD/g of total COD]), F_{zbh} (ordinary heterotrophic COD fraction [gCOD/g of total COD]), and F_{xsp} (non-colloidal slowly biodegradable [gCOD/g of slowly degradable COD]), until the specifier calculated values matched measured values. Once a match was achieved, the specifier determined the particulate substrate and inert COD:VSS ratios and COD influent wastewater fractions, as summarized in Tables 4.20 and 4.21. It should be noted Table 4.21 provides information only on the fractions that were changed from default values, all other fractions remained at the BioWin default values. The particulate substrate and inert COD:VSS ratios were calculated for each influent and recycle streams, however, these parameters are a global parameter in BioWin. To alleviate this problem, a flow weighted calculation was used to determine the average ratios from all streams of 1.50.

Table 4.19: COD influent data for plant influent and recycle streams

Parameter (mg/L)	Plant INF	Gravity Thickener	Denite Waste	TWAS	PRS	Unknown
Flow (mgd)	27.20	0.12	0.23	1.30	0.34	5.75
COD	544.8	1,265.7	1,079.5	64.5	1,814.5	300.0
NO _x	0.8	0.0	0.0	4.1	0.0	0.0
TKN	44.0	46.7	92.0	27.5	847.3	43.0
TP	4.9	5.7	20.5	7.9	137.3	8.5
Alkalinity (mmol/L)	4.2	4.6	2.6	3.7	57.8	4.0
ISS	19.3	28.7	73.4	2.7	139.2	20.0
pH (-)	7.3	6.1	8.8	6.7	7.6	7.4

Table 4.20: Particulate substrate and inert COD:VSS ratios

Parameter	Plant INF	Gravity Thickener	Denite Waste	TWAS	PRS	Unknown
Particulate substrate COD:VSS ratio	1.71	2.26	0.69	0.91	0.61	0.71
Particulate inert COD:VSS ratio	1.71	2.26	0.69	0.91	0.61	0.71

4.3.4 Solids and Nutrients Calibration

Once the wastewater fractions were updated for each influent and recycle stream, the model calibration process could begin. The model calibration process is described in Section 4.3, but essentially, the calibration process consists of primary effluent solids calibration, solids inventory consisting of the secondary effluent and activated sludge solids calibration, and nutrients calibration. Before these three calibration steps could be performed, primary influent concentrations needed to be optimized. This was done by establishing a hydraulic balance and optimizing the concentrations in the influent and recycle streams; see Sections 4.3.1.2 and 4.3.1.3. Once primary influent values were optimized, the second step in calibration was to compare measured versus model primary effluent values. The main step in calibrating primary effluent values was to adjust the primary clarifier percent removal of solids. Upon investigation, adjusting the primary clarifier percent solids removal from a default value of 65% in BioWin version 5.3, and 55% in version 6.0, to 61% proved optimal. It should be noted that after the primary solids calibration, a new version of BioWin was introduced (version 6.0) and this used for the remainder of the project. After the primary effluent values were optimized, the solids inventory from the aeration tanks and secondary clarifiers were evaluated as the next calibration step. When calibrating the solids inventory, two parameters played a key role in optimizing model values with measured TMWRF values, which were the secondary clarifier percent solids removal and the OHO aerobic yield in the stoichiometric parameters section of the model. Both parameters were adjusted to calibrate the solids inventory and a default value of 99.8% percent removal was adjusted to 99.1% for the secondary clarifiers, and an OHO aerobic yield of 0.66 was adjusted to 0.75. Table 4.22 provides information on the adjusted parameters for solids calibration.

Table 4.22: Adjusted BioWin parameters for solids calibration

Parameter	Default	Adjusted Value
Primary Clarifier Percent Removal (%)	65 (55 ¹)	61
Secondary Clarifier Percent Removal (%)	99.8	99.1
OHO Aerobic Yield (-)	0.66	0.75

¹ BioWin version 6.0

After the solids in the model were calibrated, the next step was to analyze the nitrification and phosphorus removal performance. For nitrification performance, the AOB growth rate was reviewed and updated as needed using the iterative process described in Section 4.3. Initially, the same global AOB growth rate for both systems was used, but upon further inspection of the plant data collected during the summer sampling campaign and historical plant operational data, this did not seem appropriate. Systems 1 and 2 had average SRTs of 1.73 and 1.62 days, respectively, during the two-week sampling campaign. When reviewing the nitrification performance between the two systems, collected data revealed that System 2 exhibited more nitrification than system 1 ($\text{NO}_x \sim 4.7$ mg/L for System 2 compared to ~ 3.6 mg/L for System 1) despite having a lower SRT and a higher flow rate. A lower SRT is generally associated with lower nitrification performance but since System 2 had more nitrification at a lower SRT it was hypothesized that System 2 had a higher AOB maximum growth rate and the model was calibrated as such. To optimize calibration, System 1 AOB maximum growth rate was adjusted to 1.15/day and System 2 AOB maximum growth rate was adjusted to 1.25/day. These values are higher than typical AOB growth rates and it is hypothesized that the reason for the high values is that TMWRF's activated sludge process achieves nitrification at relatively low SRTs when judged by typical industry standards. Another potential reason for the high nitrification performance is that TMWRF's tertiary processes may contain nitrifiers in the recycle streams,

thereby increasing the nitrification performance (i.e., by having AOB and NOBs in the influent from recycle streams). When analyzing the nitrate and nitrite concentrations in the secondary effluent, measured data revealed that NO_x levels were split approximately equal between nitrate and nitrite, but default kinetic values in BioWin predicted that most of the NO_x consisted of nitrite. Therefore, the NOB growth rate was adjusted to 1.51/day and 1.62/day for Systems 1 and 2, respectively, to match the measured concentrations of nitrate and nitrite.

Once the nitrification performance was optimized, the phosphorus removal performance was the next step in the calibration process. According to Brown & Caldwell process engineers, the phosphorus kinetic and stoichiometric parameters are not typically adjusted, but since TMWRF operates very differently from most plants (e.g., high nitrification at low SRT), it was not possible to achieve the measured phosphorus removal with default parameters. The maximum specific growth rates for PAO were adjusted in the iterative process in order to optimize the BioWin predictions for OP and TP values to measured plant data. The PAO growth rate default value was adjusted from 0.95/day to 1.35/day for System 1, and 1.50/day for System 2. Similar to the nitrification performance, the values are different for each system due to different treatment performances. Table 4.23 shows the adjustments made to the nitrogen and phosphorus kinetic parameters in order to achieve measured nitrification and phosphorus removal.

Table 4.23: Adjusted BioWin kinetic parameters for N and P removal

Parameter (1/d)	Default	Sys 1 Value	Sys 2 Value
AOB maximum growth rate	0.90	1.15	1.25
NOB maximum growth rate	0.70	1.51	1.62
PAO maximum growth rate	0.95	1.35	1.50

4.3.5 Aeration Calibration

The final calibration step, once solids and nutrients were optimized, was to investigate the aeration demand in the activated sludge. Before the aeration demand could be optimized in the model, the aeration parameters within the model first needed to be adjusted to account for TMWRF specifications. BioWin's aeration parameters consist of parameters for aeration, diffuser, Henry's law constants, mass transfer, surface aerators, blower, anaerobic digester, and emission factor specifications. In collaboration with TMWRF's plant engineer, the parameters for aeration, diffuser, and blower specifications were updated in BioWin to account for the plant's actual specifications. Table 4.24 provides information for the updated aeration, diffuser, and blower parameters. It should be noted that the parameters listed are only the ones that were updated, all other parameters were left at default values in BioWin. TMWRF does not use surface aerators or anaerobic digesters in this part of the treatment process so these parameters were not adjusted. Information on Henry's law constants, mass transfer, and emission factors were not assessed on-site, so the parameters were kept at BioWin default values. After the aeration parameters were updated to match TMWRF specifications, the next step was to input the number of diffusers into each aeration zone. This information was provided by the plant engineer and is summarized in Table 4.25. The number of diffusers provided for each zone are for individual activated sludge trains. To accommodate the combination of both trains in each system, the number of diffusers were doubled to account for the doubled volume. Finally, once aeration parameters and the number of diffusers in each aeration zone were updated, the final step was to input DO values for each zone. As stated previously, the BioWin model incorporates trains A and B of the activated sludge process into one train.

For this reason, an average DO value for each pass was determined from the two trains, using data from the summer campaign, and inputted into the model. Table 4.26 summarizes the DO values in each aeration pass for the two systems.

Table 4.24: Updated BioWin aeration parameters

Parameter	Default	Adjusted Value
Aeration		
Surface Pressure (kPa)	101.325	85.771
Diffuser		
Area of One Diffuser (ft ²)	0.441	0.442
Diffuser Mounting Height (ft)	0.820	0.900
Min. Air Flow Rate per Diffuser [20°C, 1 atm] (ft ³ /min)	0.294	0.750
Max. Air Flow Rater per Diffuser [20°C, 1 atm] (ft ³ /min)	5.886	4.000
'A' in Diffuser Pressure Drop = $A + B*[Qa/Diff]$ + $C*[Qa/Diff]^2$ (psi)	0.444	0.508
Blower		
Intake Filter Pressure Drop (psi)	0.508	0.200
Pressure Drop Through Distribution Sys [Piping/Valves] (psi)	0.435	0.630
'A' in Blower Efficiency = $A + B*Qa + C*Qa^2$	0.750	0.700

Table 4.25: Number of diffusers for the aeration zones in the activated sludge

Pass	Zone	No. Diffusers per Train	No. Diffusers in BioWin
1	1A	0 ¹	0 ¹
1	1B	319	638
1	1C	698	1,396
2	2A	597	1,194
2	2B	597	1,194
2	2C	597	1,194
3	3A	478	956
3	3B	478	956
3	3C	478	956

¹ Although zone 1A has diffusers, the zone is operated under anaerobic conditions and so the number of diffusers are set to 0

Table 4.26: Average DO values for each pass in both systems

Pass	Sys 1	Sys 2
1	1.85	1.77
2	1.99	1.98
3	2.50	2.48

Following initial aeration demand calibration, analysis revealed that the BioWin predicted air flow rates in each pass did not accurately match measured data. It was hypothesized that the reason for this was that the DO values during the summer campaign were measured at the end of pass one, middle of pass two, and end of pass three and were not representative of the whole pass. Originally, the DO values in each pass were assumed to be constant throughout each pass, based on measured values, seen in Figure 4.15. In the figure, the solid colors indicate where DO was measured, with the hatched colors being the

assumption that the DO values of each pass corresponded to the measured value. The model showed that this assumption was not accurate. To alleviate this problem, three DO sampling campaigns were implemented to determine the DO ratios in each pass compared to the DO probe readings at the end of pass one, middle of pass two, and end of pass three.

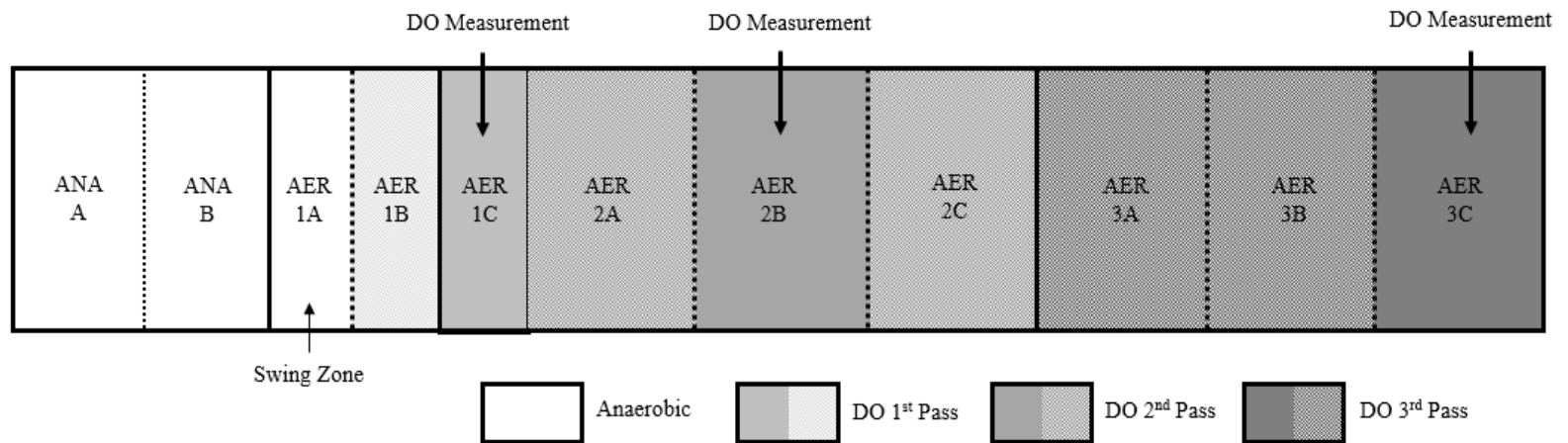


Figure 4.15: Original DO assumptions for the activated sludge tanks

The first DO sampling campaign assumed that variation in DO only occurs between the anaerobic zone and the aeration zones in pass one. This assumption was made because DO variation likely occurs when the activated sludge goes from zero DO to a set-point of 2.0 mg/L. Once the DO reaches the set-point value, little variation will occur in passes two and three. Grab samples for DO were measured for the activated sludge system trains 1A, 1B, 2A, and 2B on October 23, 2019. The DO measurements were determined for post-anaerobic, midway of pass one, and end of pass one, corresponding with zones 1A, 1B, and 1C in the model. The average system DO ratio for each zone was then calculated. The second DO sampling campaign assumed that all activated sludge trains have similar DO values, but variation occurs in all passes. DO sampling for this campaign occurred on October 30, 2019, and the DO values were measured in activated sludge train 2B at the middle of first pass, end of first pass, and the beginning, middle, and end of passes two and three, corresponding to zones 1B, 1C, 2A, 2B, 2C, 3A, 3B, and 3C. The DO ratios were then determined and applied to both Systems 1 and 2 in the model. The final DO sampling campaign was much more extensive and assumed that all activated sludge trains were different and had variation in all passes. This campaign consisted of four days of grab sample DO measurements with data collected November 6-8 and November 12, 2019, with two grab sample measurements on November 8. The DO measurements were determined for all four activated sludge trains at the beginning, middle, and end of each pass, corresponding to the zones A, B, and C of all passes. The DO ratios were determined by taking an average value of trains A and B for System 1, and trains A and B for System 2, over the course of the four days. Figure 4.16 shows the DO ratio variation of the three DO sampling campaigns for System 1, and Figure 4.17 for System 2. As revealed in the two

figures, the ratios follow the same pattern for both systems, with the largest variation between the three campaigns being in zones 1B and 3A for System 1 and zones 1B, 2A, and 3A for System 2. It should be noted that the first DO sampling campaign only focused on pass one, and no data points were collected for the other two passes. The DO in zone 1A is left at zero due to this zone being operated anaerobically. The data for the three DO sampling campaigns, including measured DO values and calculated ratios, are summarized in Appendix F.

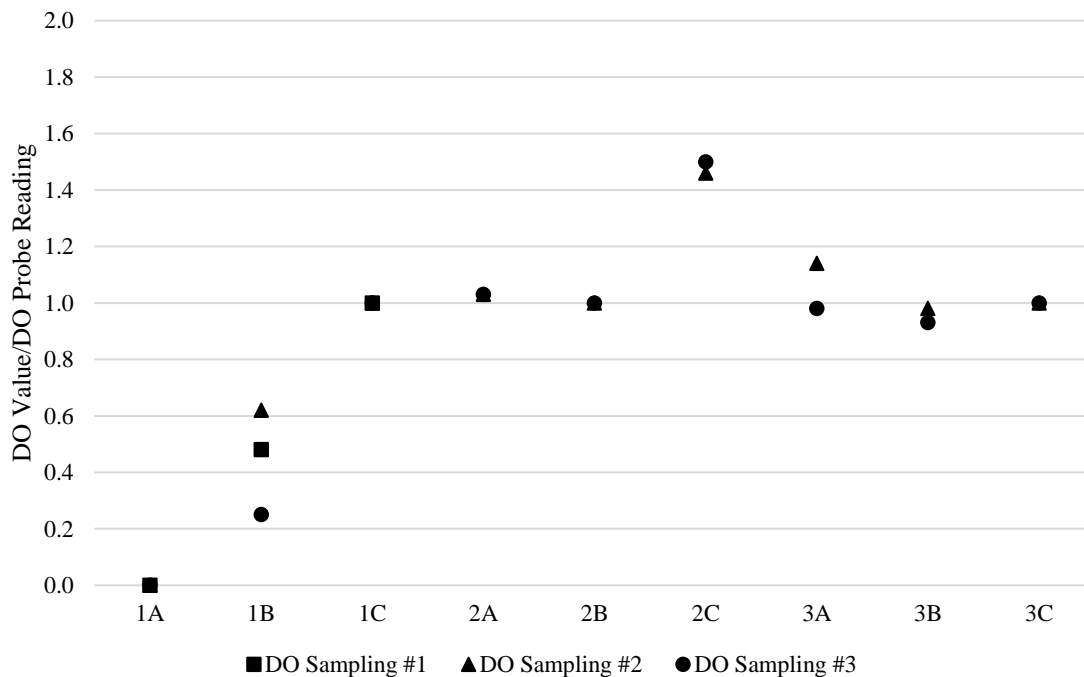


Figure 4.16: System 1 DO ratios for the three DO sampling campaigns

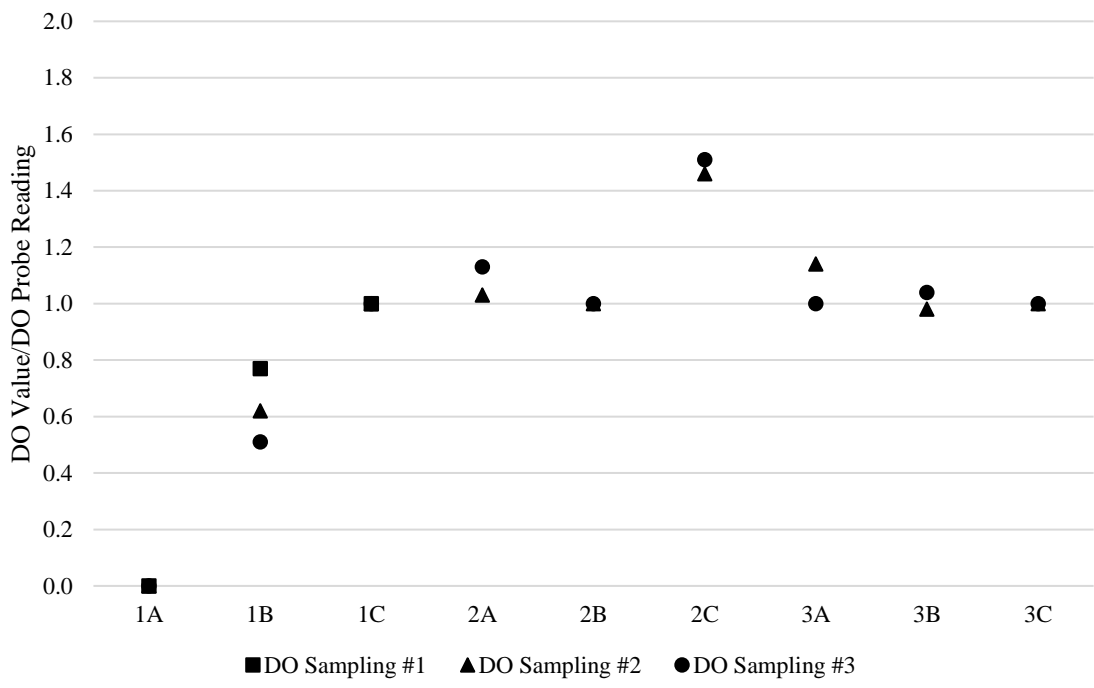


Figure 4.17: System 2 DO ratios for the three DO sampling campaigns

After these DO ratios were determined from the three DO sampling campaigns, each of sampling campaign ratios were applied to the original summer campaign DO values to evaluate the aeration demand. Table 4.27 provides the corrected DO values for the summer campaign data utilizing the updated DO ratios from each DO sampling campaign for System 1 and Table 4.28 summarizes values for System 2. Figure 4.18 provides the model predicted aeration profile using the corrected DO values for System 1 and Figure 4.19 contains data for System 2.

Table 4.27: System 1 updated summer DO values using calculated

Zone	DO Sampling #1	Do Sampling #2	DO Sampling #3
1A	0.00	0.00	0.00
1B	0.89	1.15	0.46
1C	1.85	1.85	1.85
2A	1.99	2.05	2.05
2B	1.99	1.99	1.99
2C	1.99	2.91	2.99
3A	2.50	2.85	2.45
3B	2.50	2.45	2.33
3C	2.50	2.50	2.50

Table 4.28: System 2 updated summer DO values using calculated ratios

Zone	DO Sampling #1	Do Sampling #2	DO Sampling #3
1A	0.00	0.00	0.00
1B	1.36	1.10	0.90
1C	1.77	1.77	1.77
2A	1.98	2.04	2.24
2B	1.98	1.98	1.98
2C	1.98	2.89	2.99
3A	2.48	2.83	2.48
3B	2.48	2.43	2.58
3C	2.48	2.48	2.48

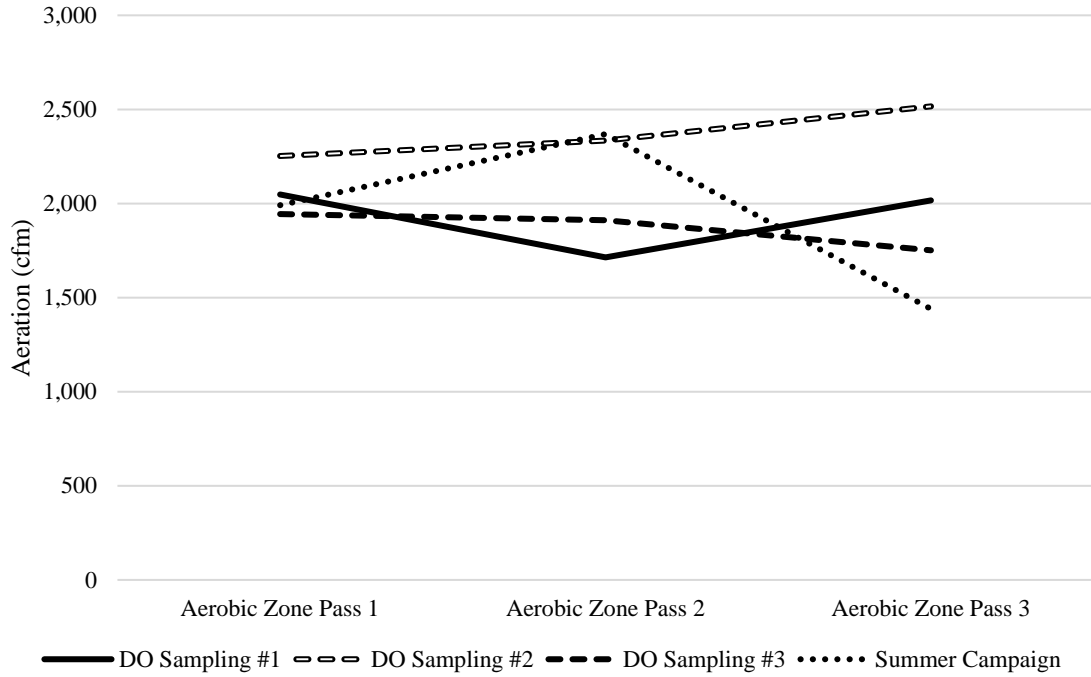


Figure 4.18: System 1 aeration profile using updated DO ratios

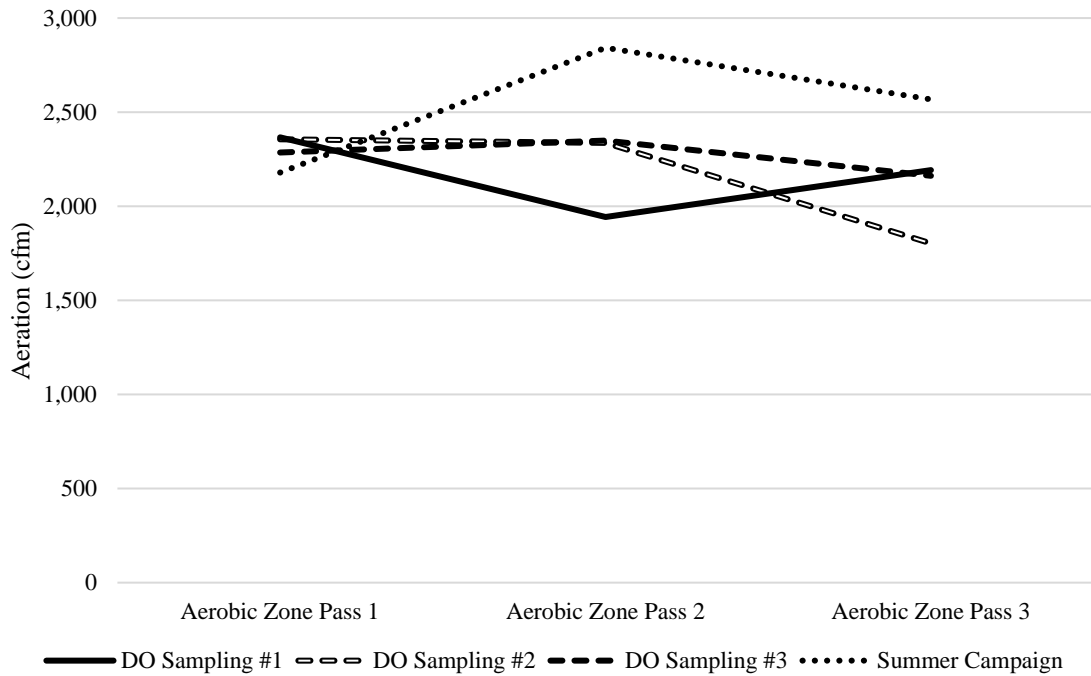


Figure 4.19: System 2 aeration profile using updated DO ratios

As revealed from the figures, even with updated DO ratios, it proved difficult to obtain aeration optimization on a pass-by-pass basis. The updated DO ratios greatly increased the optimization for passes one and three; however, it remains unclear why pass two exhibited marked differences. Based on the data, it appears that DO sampling campaign #3 has the best fit to measured data. To confirm this, the total aeration over the entire activated sludge systems was investigated. Figures 4.20 and 4.21 show the total aeration demand for System 1 and System 2, respectively. The figures confirm the previous analysis that when looking at both systems, DO sampling campaign #3 proved optimal and was used for the model calibration. All BioWin input values that were used for model calibration are contained in Appendix E, following the BioWin schematics for the A/O process. The BioWin input values include process unit dimensions, aeration operation within the activated sludge tanks, influent characteristics of all influent streams, kinetic and stoichiometric parameters, flows, and other operational parameters.

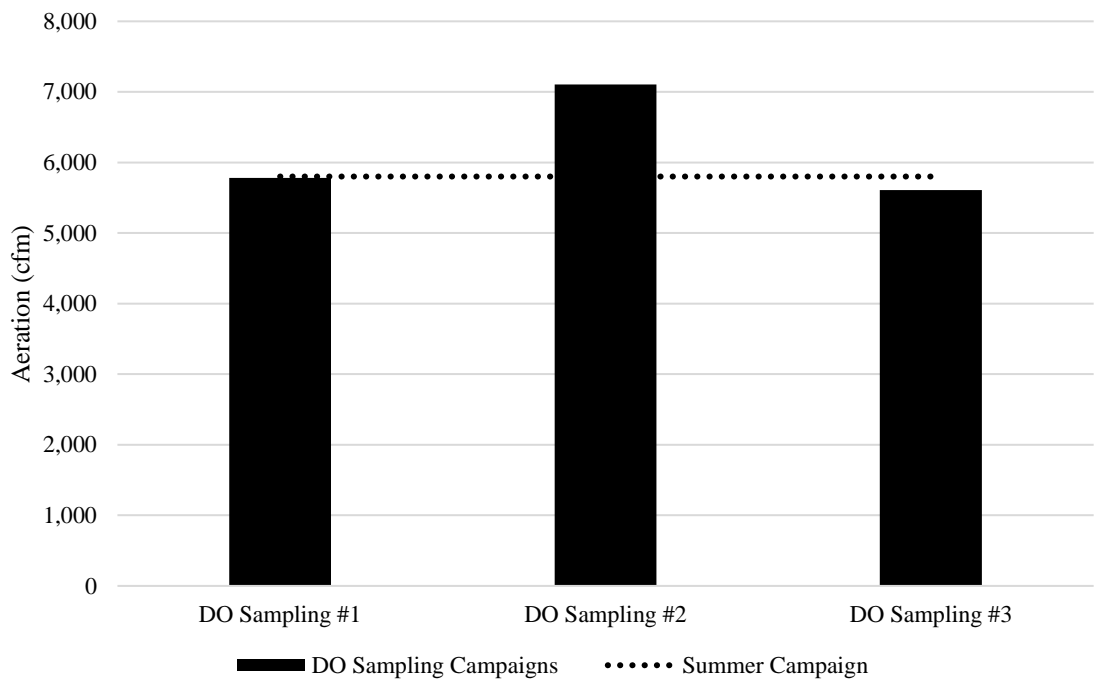


Figure 4.20: System 1 total aeration demand using updated DO ratios

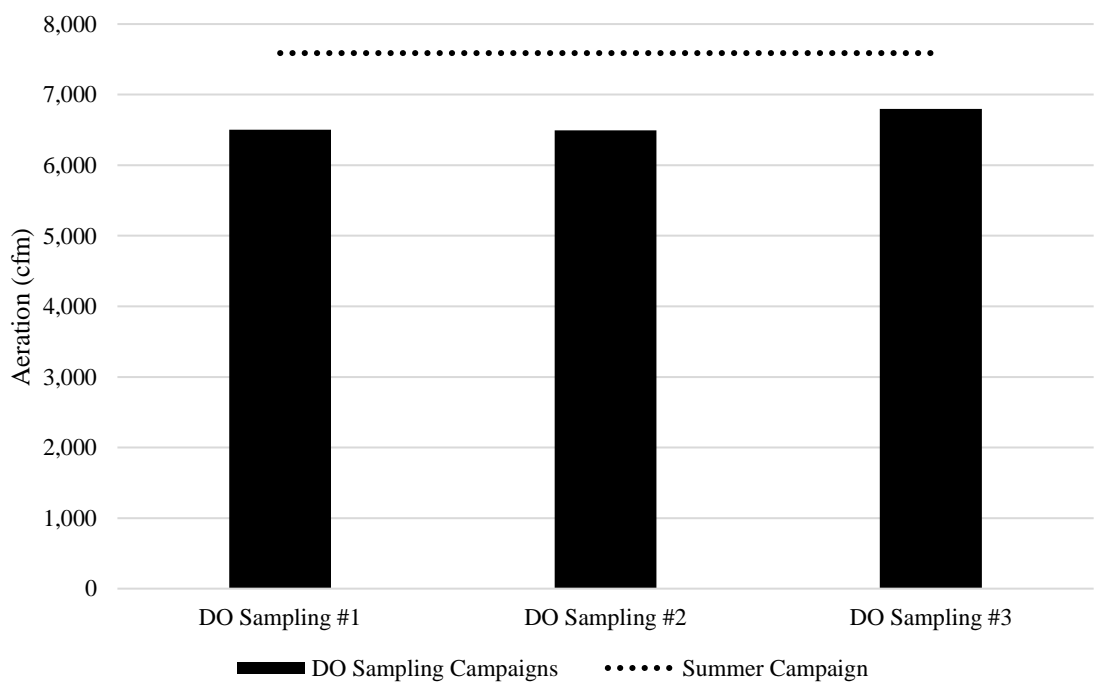


Figure 4.21: System 2 total aeration demand for using updated DO ratios

4.4 Model Predictions and Accuracy

Once the BioWin models were fully calibrated, the next task was to compare model predicted values with measured data. For model accuracy, typical differences are within 10% for most constituents, except for NO_x, phosphorus species, and secondary effluent solid concentrations, which have a typical difference of 1 mg/L for NO_x, 0.5 mg/L for phosphorus, and 5 mg/L for solids (Rieger et al., 2012). Model calibration was performed based on the summer sampling campaign as it provided the most in-depth analysis of TMWRF data. Once model accuracy was confirmed using this data set, the model was applied to the initial fall and winter campaigns.

4.4.1 Main (Summer) Sampling Campaign

When determining model accuracy, the main locations that were investigated were the primary influent, primary effluent, solids inventory, and secondary effluent. The parameters that were analyzed were the main constituents of concern, which included COD, FCOD, nitrogen species, phosphorus species, alkalinity, and solids. Tables 4.29 and 4.30 provide the comparison of model predicted values to measured values for Systems 1 and 2, respectively.

Table 4.29: System 1 measured vs. model data comparison

Location	Parameter (mg/L)	Measured Value	Model Value	Difference	Typical
Primary INF	COD	505.5	521.8	3.2%	<10%
	FCOD	184.2	202.4	9.9%	<10%
	Ammonia	36.3	36.2	0.3%	<10%
	TKN	52.6	52.1	0.9%	<10%
	OP	4.0	4.0	0.0	0.5 mg/L
	TP	7.0	6.9	0.1	0.5 mg/L
	Alkalinity	239.3	234.5	2.0%	<10%
	TSS	230.6	233.7	1.3%	<10%
	VSS	211.2	213.4	1.0%	<10%
Primary EFF	COD	357.3	328.2	8.1%	<10%
	FCOD	198.0	202.4	2.2%	<10%
	Ammonia	35.3	36.2	2.5%	<10%
	NO _x	0.4	0.8	0.4	1 mg/L
	TKN	48.0	46.1	4.0%	<10%
	OP	4.1	4.0	0.2	0.5 mg/L
	TP	5.8	5.1	0.7	0.5 mg/L
	Alkalinity	235.9	234.5	0.6%	<10%
	TSS	93.7	92.0	4.8%	<10%
Solids Inventory	VSS	84.4	84.0	0.5%	<10%
	MLSS	1,260	1,163	3.6%	<10%
	MLVSS	984	1,000	1.6%	<10%
	MLVSS:MLSS	0.8	0.9	5.4%	<10%
	WAS SS	3,052	3,240	6.1%	<10%
Secondary EFF	SRT (d)	1.7	1.8	1.2%	<10%
	COD	68.3	60.3	11.7% *	<10%
	FCOD	42.8	40.3	5.9%	<10%
	Ammonia	25.4	26.1	3.1%	<10%
	NO _x	3.6	3.6	0.1	1 mg/L
	OP	0.2	0.1	0.1	0.5 mg/L
	TP	0.8	0.6	0.2	0.5 mg/L
TSS	17.2	16.2	0.9	5 mg/L	

* Outside typical accuracy range

Table 4.30: System 2 measured vs. model data comparison

Location	Parameter (mg/L)	Measured Value	Model Value	Difference	Typical
Primary INF	COD	513.3	490.9	4.4%	<10%
	FCOD	181.3	198.2	9.3%	<10%
	Ammonia	35.5	34.5	2.4%	<10%
	TKN	50.8	50.8	0.2%	<10%
	OP	4.0	4.0	0.0	0.5 mg/L
	TP	6.7	7.1	0.4	0.5 mg/L
	Alkalinity	229.3	229.5	0.1%	<10%
	TSS	210.4	215.8	2.6%	<10%
	VSS	185.7	195.5	5.3%	<10%
Primary EFF	COD	326.2	313.3	4.0%	<10%
	FCOD	187.1	198.2	5.9%	<10%
	Ammonia	34.8	34.7	0.5%	<10%
	NO _x	0.3	0.7	0.4	1 mg/L
	TKN	45.5	44.8	1.5%	<10%
	OP	4.0	4.0	0.0	0.5 mg/L
	TP	5.5	5.2	0.3	0.5 mg/L
	Alkalinity	228.2	229.5	0.6%	<10%
	TSS	82.0	84.9	3.5%	<10%
Solids Inventory	VSS	71.3	76.9	7.9%	<10%
	MLSS	1,140	1,181	3.6%	<10%
	MLVSS	977	1,004	2.8%	<10%
	MLVSS:MLSS	0.9	0.9	0.8%	<10%
	WAS SS	2,925	3,394	16.0% *	<10%
Secondary EFF	SRT (d)	1.6	1.6	2.5%	<10%
	COD	57.7	56.2	2.6%	<10%
	FCOD	42.7	36.3	15.1% *	<10%
	Ammonia	23.8	24.2	1.4%	<10%
	NO _x	4.7	4.4	0.3	1 mg/L
	OP	0.3	0.1	0.2	0.5 mg/L
	TP	0.7	0.7	0.1	0.5 mg/L
TSS	12.1	16.2	4.1	5 mg/L	

* Outside typical accuracy range

As outlined in the tables, the model predicted values are within typical differences of measured data except for a few parameters. The first parameter that was not within the typical difference is the TP value of System 1 in the primary effluent. This error is most likely due to the assumptions in the recycle streams regarding flow splits. It is possible that the phosphorus in the recycle streams did not split according to the assumptions made. When analyzing the difference of both Systems 1 and 2, the observed average difference is 0.5 mg/L which is within the typical difference. The second model predicted value that does not fall within the typical range is the WAS SS for System 2. This error is likely caused by the wastewater fractions for solids and the OHO aerobic yield value used. BioWin can have a difficult time providing accurate results, especially when multiple influent streams are used as each stream has different wastewater characteristics. Another reason for the error could be that Systems 1 and 2 have different OHO aerobic yield values, similar to the kinetic parameters for nutrients, but in the calibration process, the same value was used for both systems. It is important to note that when calibrating solids, the entire solids inventory must be optimized as a whole, not just one parameter. When analyzing System 1 WAS SS, the difference between the model predicted value and measured value did fall within the typical range. The last parameters that were out of typical ranges are the secondary effluent COD for System 1, and the FCOD for System 2. Again, these parameters can be difficult to calibrate accurately as the influent wastewater fractions of each stream affect the model as a whole. It is also important to note that the average measured COD value is higher than previous analyses. When investigating the difference of the parameters, System 1 had an overall difference of approximately 4% and overall difference of approximately 6% for System 2, both within the established typical difference

of 10%. Visual representations of the model's accuracy for Systems 1 and 2 is provided in Figures 4.22 and 4.23 for solids, Figures 4.24 and 4.25 for NO_x and phosphorus species, Figures 4.26 and 4.27 for ammonia and TKN, and Figures 4.28 and 4.29 for COD and FCOD.

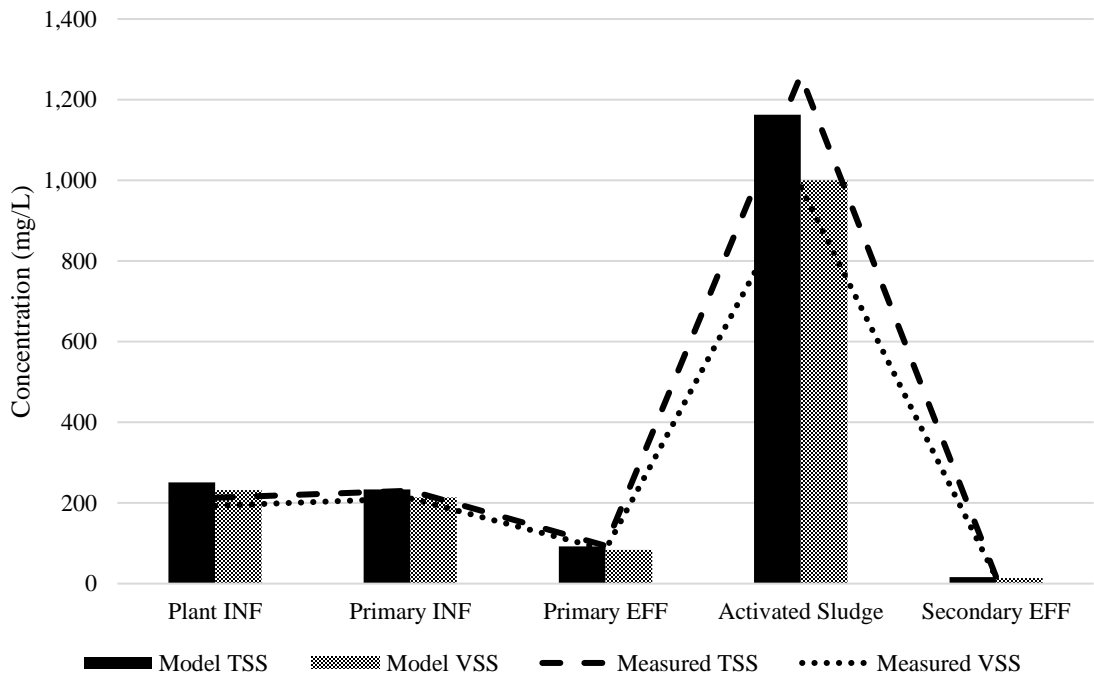


Figure 4.22: System 1 solids model vs. measured data profile

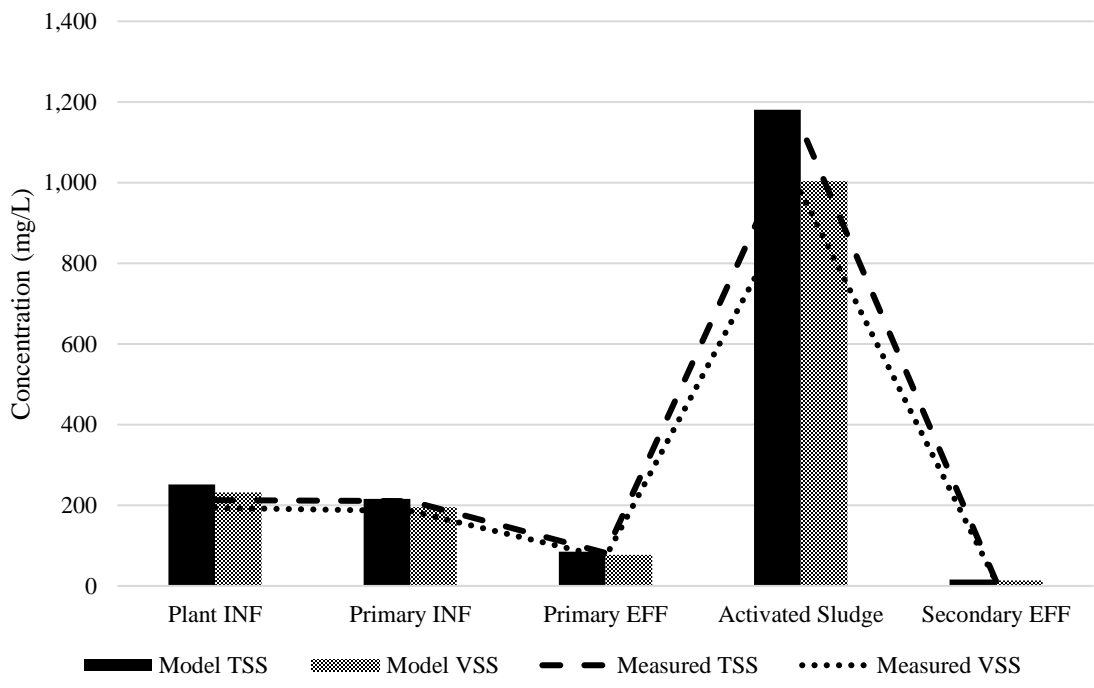


Figure 4.23: System 2 solids model vs. measured data profile

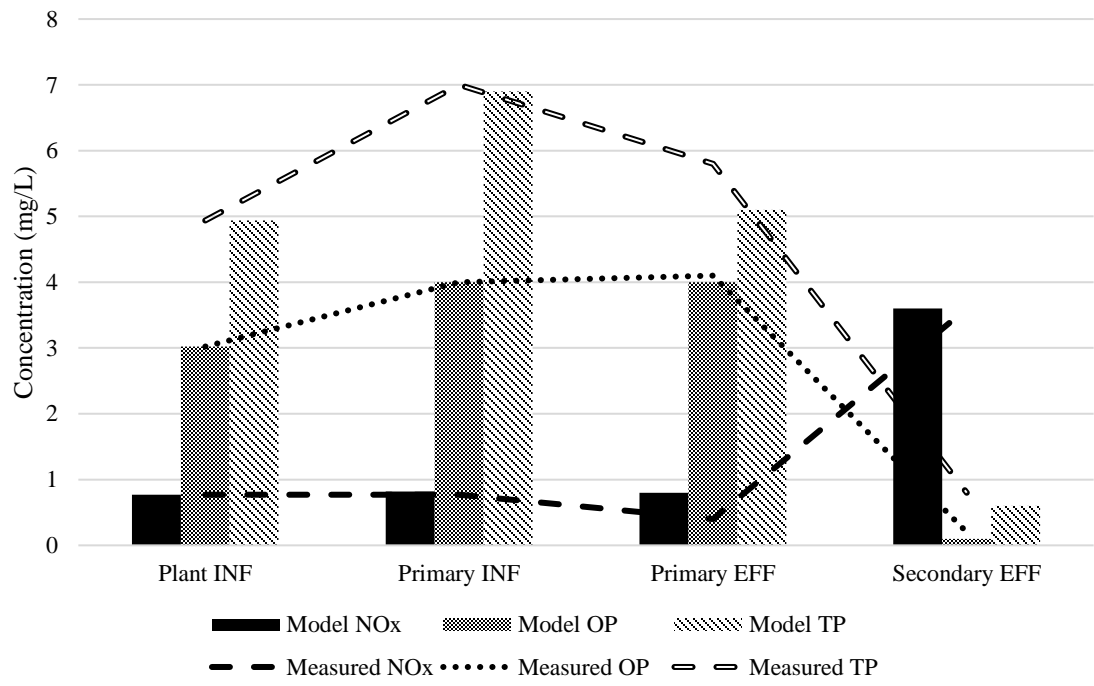


Figure 4.24: System 1 NO_x and P model vs. measured data profile

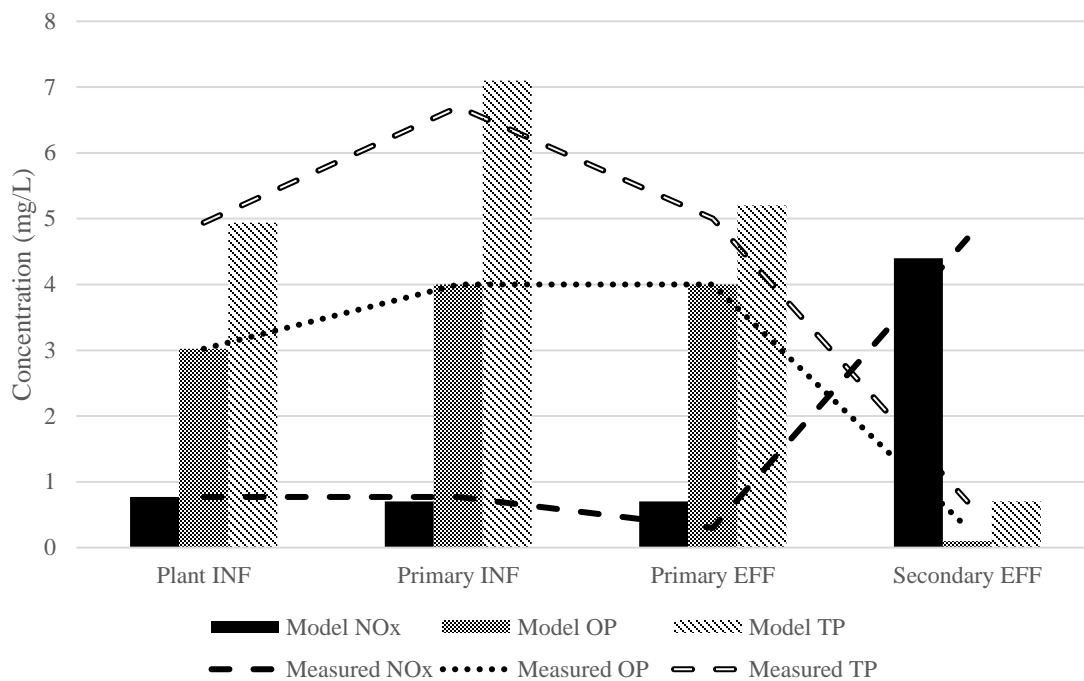


Figure 4.25: System 2 NO_x and P model vs. measured data profile

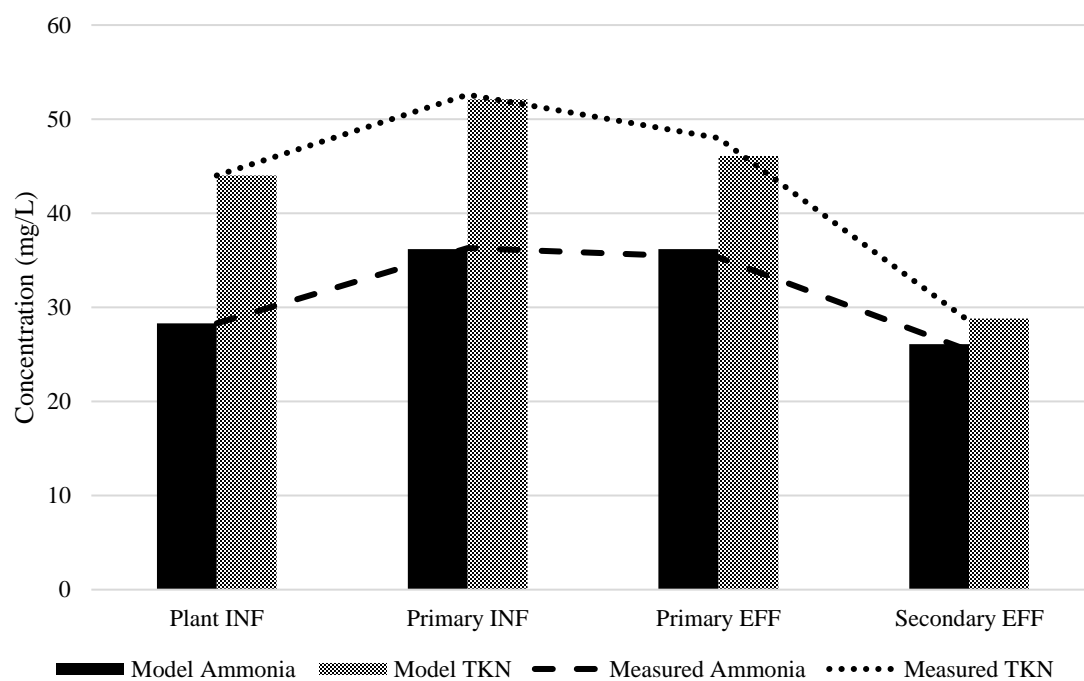


Figure 4.26: System 1 ammonia and TKN model vs. measured data profile

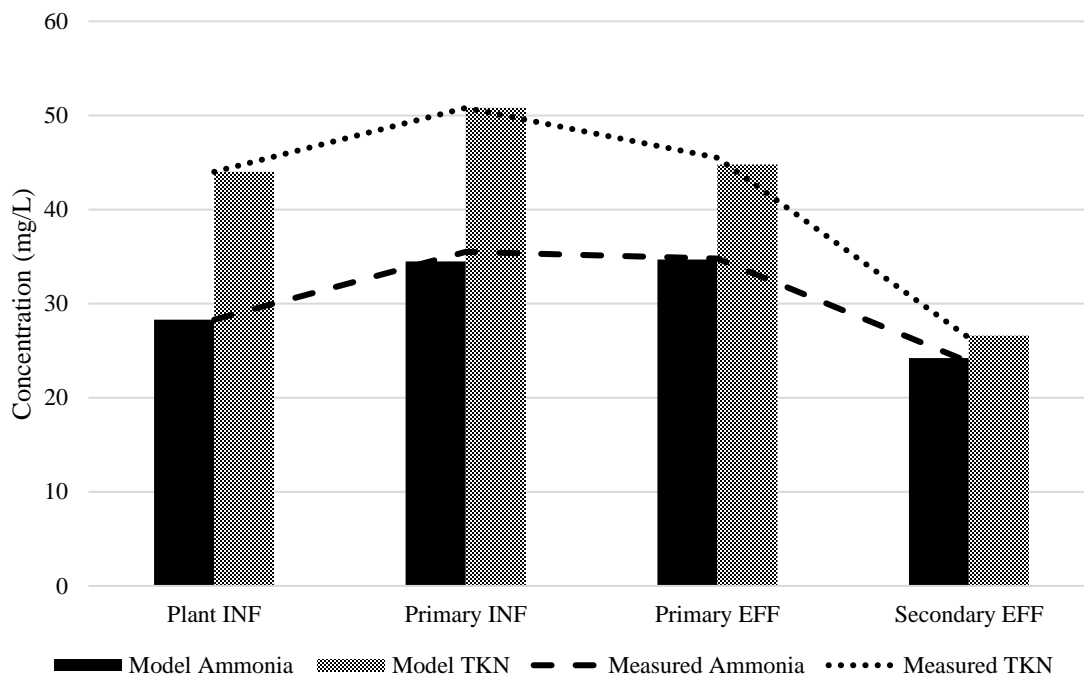


Figure 4.27: System 2 ammonia and TKN model vs. measured data profile

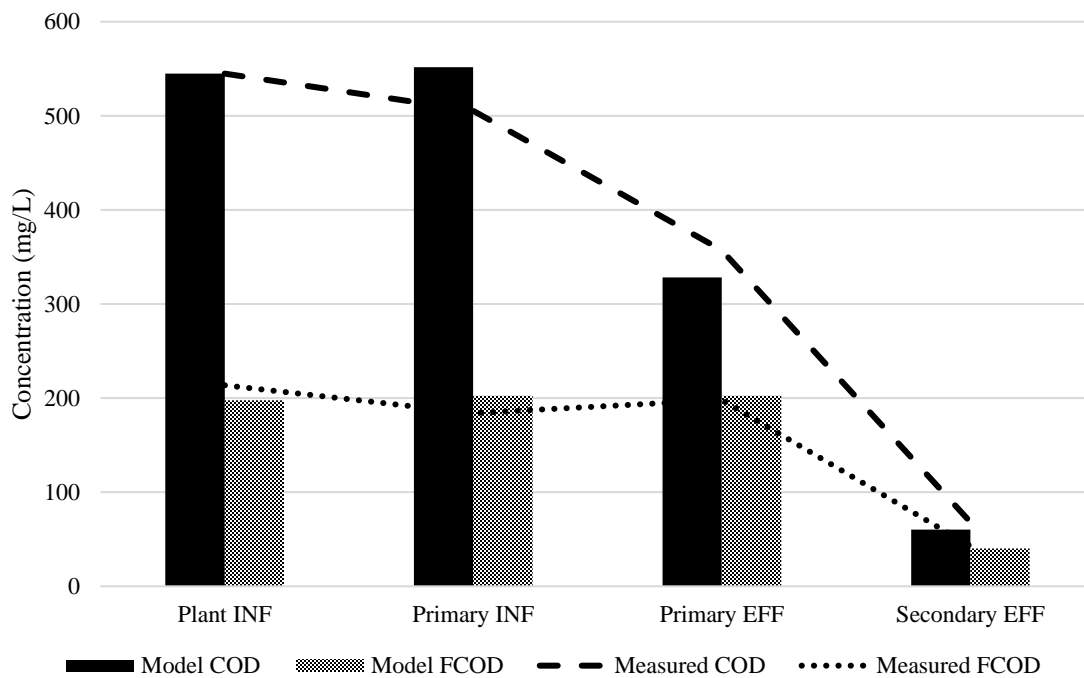


Figure 4.28: System 1 COD and FCOD model vs. measured data profile

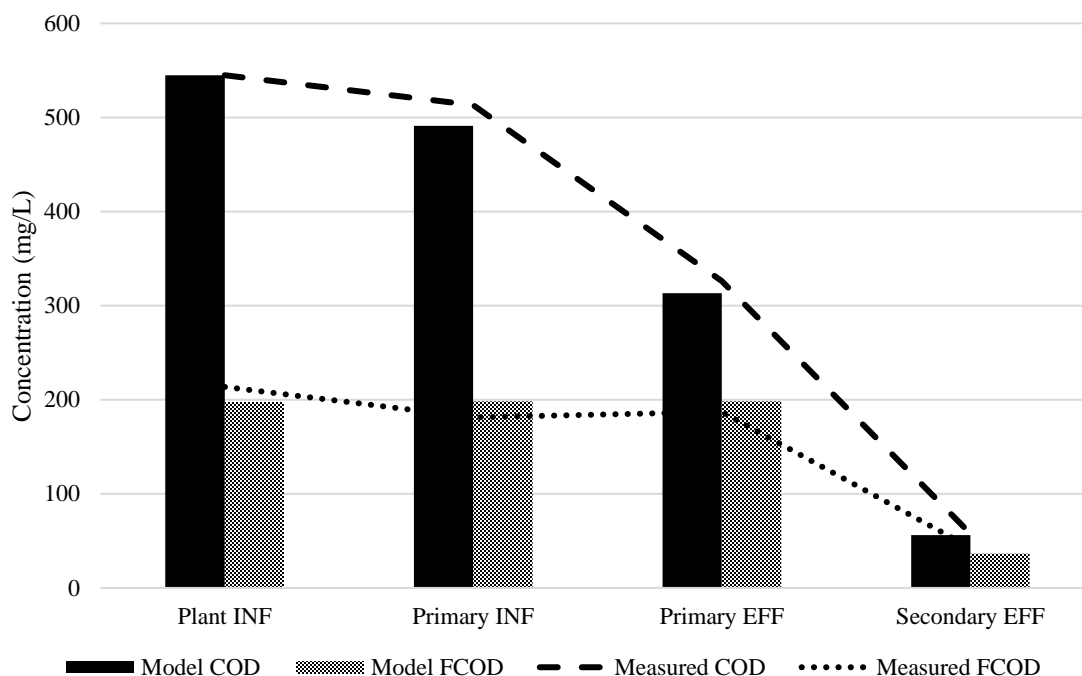


Figure 4.29: System 2 COD and FCOD model vs. measured data profile

4.4.2 Other Sampling Campaigns

Before the model could be applied to the previous fall and winter campaigns, there were corrections and assumptions that needed to be made to the data sets. The fall and winter campaigns were not as extensive as the summer campaign, and as a result, there were a lot of missing data. Another important aspect related to the fall and winter campaigns was that during these sampling periods, the PRS recycle stream was not operational. Also, during the fall and winter campaigns, System 3 was online and acted as the centrate treatment train. To correct these problems, assumptions had to be made regarding flows and constituents.

4.4.2.1 Fall and Winter Flows

As stated previously, during the fall and winter periods, the PRS recycle stream was not operational, there was a centrate recycle sidestream, and System 3 was online. The previous flow assumptions made for the summer sampling campaign no longer applied and needed to be adjusted. In the model, the PRS recycle stream was made inactive, and because there was little data on the centrate stream, it was incorporated into the unknown stream. Since System 3 was online, the previous 50/50% split to Systems 1 and 2 was adjusted to a 48/48/4% split for the three systems. This value was provided by TMWRF's plant engineer as a reasonable estimate based on system operation at that time. It was also assumed that the other recycle streams (gravity thickener, denite waste, and TWAS) remained consistent with summer data as data were not collected during the fall and winter for these process flows. Again, the unknown stream was used to balance the hydraulics in all systems. Using these assumptions, the model was updated to account for flow changes. Tables 4.31 and 4.32 contain the adjusted flows for fall and winter, respectively. As captured in the tabular data, during the winter campaign, System 1 appears to have a higher flow rate. This is generally a typical occurrence based on historical data, but it was assumed that more of the unknown and centrate recycle streams enter System 1 rather than System 2 to balance the hydraulics.

Table 4.31: Fall sampling campaign updated flows

Stream (mgd)	Total Flow	To Sys 1	To Sys 2	To Sys 3
Plant INF	25.80	12.38	12.38	1.03
Gravity Thickener	0.12	0.06	0.06	0.00
Denite Waste	0.23	0.11	0.11	0.01
TWAS	1.30	0.62	0.62	0.05
Unknown ¹	8.85	2.80	4.75	1.29
Primary INF	36.30	15.98	17.93	2.39

¹ The unknown stream incorporates the unknown flows and the centrate treatment recycle stream

Table 4.32: Winter sampling campaign updated flows

Stream (mgd)	Total Flow	To Sys 1	To Sys 2	To Sys 3
Plant INF	28.20	13.54	13.54	1.13
Gravity Thickener	0.12	0.06	0.06	0.00
Denite Waste	0.23	0.11	0.11	0.01
TWAS	1.30	0.62	0.62	0.05
Unknown ¹	9.80	2.74	1.47	5.59
Primary INF	39.65	17.07	15.80	6.78

¹ The unknown stream incorporates the unknown flows and the centrate treatment recycle stream

4.4.2.2 Fall and Winter Constituents

Similar to the summer campaign, a spreadsheet was developed to determine the unknown parameters during the fall and winter based on a mass balance approach. Plant influent values were updated with corresponding fall and winter data, while the gravity thickener, denite waste, and TWAS recycle stream constituents were kept constant with measured summer data. Unfortunately, during the fall and winter sampling periods, the only measured data for primary influent were BOD, COD, and TSS. This made it difficult to match measured primary influent values with model predictions as there were very few data available. The following discussion provides the assumptions that were made to determine primary influent values where values were unknown:

- BOD, FBOD, FCOD, FFCOD, and VSS were calculated using typical ratios observed during the summer campaign
- Ammonia, NO_x, OP, and alkalinity were assumed to be the same as primary effluent values
- TKN was calculated based on primary effluent values, assuming 10% removal of TKN in the primary clarifiers (Department of Environmental Conservation)
- TP was calculated based on primary effluent values, assuming 1 mg/L removal of TP in the primary clarifiers (Polson, 2017)

With the updated plant influent data, and assumptions made to the recycle streams and primary influent, the constituents in the unknown stream, which include the centrate treatment recycle stream, were calculated using the flow weighted mass balance approach. The values used for each stream, and the assumptions, for both fall and winter is

summarized in Appendix C. Analyzing the unknown stream shows that changes need to be made to the concentrations in order to balance the primary influent data, which seems appropriate due to the combination of the centrate treatment recycle stream in the unknown stream.

4.4.2.3 Fall and Winter Model Accuracy

After the flows and concentrations of the influent streams were updated, the next step was to input the updated values into the BioWin model. The updated values include influent flows, RAS/WAS flows, plant influent concentrations, the unknown stream concentrations, and water temperature. Values that were not adjusted included wastewater characteristics, kinetic and stoichiometric parameters, solid percent removals, and DO values in the activated sludge process. The reason for maintaining these values without adjustments was to determine the overall accuracy of the model calibration; if calibrated correctly, using these parameters across all sampling campaigns should reasonably reflect measured data. Tables 4.33 and 4.34 provide the comparison between model predicted values and measured data in the sampling campaign for fall systems 1 and 2. For the winter sampling campaign, the comparison between model and measured data is summarized in Tables 4.35 and 4.36. Approximately 80% of the parameters calculated by BioWin were within typical values compared to measured data. When analyzing the fall comparison, System 1 and 2 have an overall difference of 5.2% and 14.0%, respectively. The reason for fall having a high percent difference in System 2 is largely due to the high nitrification performance and effluent nitrogen concentrations. During the fall period, the plant experienced very good nitrification performance, despite having low SRTs (1.8 days for both systems) and similar

temperatures to summer. It is believed that the higher nitrification performance could be due to an increase in nitrifiers in the recycle streams due to nitrification tower treatment during this time. For the winter comparison, BioWin calculated an overall percent difference for System 1 and 2 of 6.9% and 7.3%. Other than the anomaly in the fall System 2 comparison, the overall percent differences reside within the typical value of 10%. It is important to note that TMWRF does occasionally experience higher nitrification rates in the activated sludge (~10 mg/L nitrate). The smaller errors in measured compared to model data is likely due to the assumption of combining the centrate sidestream with the unknown stream. This assumption is most likely not accurate as the centrate and unknown streams have different loadings and are split differently to each system. Despite inaccuracies in the assumptions, the model predicted measured values relatively well and confirms the accuracy of the model, especially if the centrate and unknown streams were distinguishing classified.

Table 4.33: Fall System 1 measured vs. model data comparison

Location	Parameter (mg/L)	Measured Value	Model Value	Difference	Typical
Primary INF	COD	546.8	517.5	5.4%	<10%
	TSS	200.5	230.3	14.9% *	<10%
Primary EFF	COD	339.5	330.6	2.6%	<10%
	FCOD	213.3 ¹	209.2	1.9%	<10%
	Ammonia	29.7	28.4	4.4%	<10%
	NO _x	1.6	1.2	0.4	1 mg/L
	TKN	41.0	38.8	5.5%	<10%
	OP	4.3	3.5	0.7 *	0.5 mg/L
	TP	5.6	4.8	0.8 *	0.5 mg/L
	Alkalinity	226.9	227.5	0.3%	<10%
	TSS	86.7	90.7	4.6%	<10%
	VSS	79.0	81.1	2.7%	<10%
Solids Inventory	MLSS	1,177	1,225	4.1%	<10%
	MLVSS	1,091	1,044	4.3%	<10%
	MLVSS:MLSS	0.9	0.9	0.5%	<10%
	WAS SS	3,219	3,276	1.8%	<10%
	SRT (d)	1.8	1.9	5.6%	<10%
Secondary EFF	COD	52.1	59.3	13.9% *	<10%
	FCOD	42.5	37.9	10.8% *	<10%
	Ammonia	14.6	13.9	5.2%	<10%
	NO _x	6.9	6.4	0.6	1 mg/L
	OP	0.3	0.1	0.2	0.5 mg/L
	TP	0.7	0.6	0.1	0.5 mg/L
	TSS	9.5	17.5	8.0 *	5 mg/L

¹ Updated FCOD:COD ratio of 0.39

* Outside typical accuracy range

Table 4.34: Fall System 2 measured vs. model data comparison

Location	Parameter (mg/L)	Measured Value	Model Value	Difference	Typical
Primary INF	COD	512.0	514.9	0.6%	<10%
	TSS	186.8	223.2	19.5% *	<10%
Primary EFF	COD	311.0	336.4	8.2%	<10%
	FCOD	199.7 ¹	220.7	10.5% *	<10%
	Ammonia	28.5	27.2	4.4%	<10%
	NO _x	1.3	1.8	0.6	1 mg/L
	TKN	36.3	37.4	3.2%	<10%
	OP	4.2	3.8	0.5	0.5 mg/L
	TP	5.5	5.2	0.3	0.5 mg/L
	Alkalinity	211.4	230.5	4.1%	<10%
	TSS	77.8	87.8	12.8% *	<10%
	VSS	68.0	77.3	13.7% *	<10%
Solids Inventory	MLSS	1,084	1,335	23.1% *	<10%
	MLVSS	991	1,124	13.4% *	<10%
	MLVSS:MLSS	0.9	0.8	1.7%	<10%
	WAS SS	2,742	3,631	32.4% *	<10%
	SRT (d)	1.8	1.8	3.3%	<10%
Secondary EFF	COD	55.6	57.5	3.5%	<10%
	FCOD	41.8	34.6	17.3% *	<10%
	Ammonia	14.1	4.7	66.9% *	<10%
	NO _x	6.6	11.3	4.7 *	1 mg/L
	OP	0.5	0.1	0.4	0.5 mg/L
	TP	0.9	0.7	0.3	0.5 mg/L
	TSS	9.9	18.9	9.0 *	5 mg/L

¹ Updated FCOD:COD ratio of 0.39

* Outside typical accuracy range

Table 4.35: Winter System 1 measured vs. model data comparison

Location	Parameter (mg/L)	Measured Value	Model Value	Difference	Typical
Primary INF	COD	494.7	493.7	0.2%	<10%
	TSS	191.2	221.6	15.9% *	<10%
Primary EFF	COD	313.3	310.8	0.8%	<10%
	FCOD	192.9 ¹	192.0	8.5%	<10%
	Ammonia	37.2	30.1	18.9% *	<10%
	NO _x	0.6	0.6	0.0	1 mg/L
	TKN	46.2	41.5	10.2%	<10%
	OP	3.9	3.3	0.6 *	0.5 mg/L
	TP	5.2	4.5	0.8 *	0.5 mg/L
	Alkalinity	230.3	321.5	0.5%	<10%
	TSS	81.0	87.2	7.7%	<10%
	VSS	76.5	79.3	3.7%	<10%
Solids Inventory	MLSS	1,504	1,419	5.7%	<10%
	MLVSS	1,296	1,217	6.1%	<10%
	MLVSS:MLSS	0.9	0.9	0.2%	<10%
	WAS SS	4,211	4,053	3.7%	<10%
	SRT (d)	2.2	2.3	4.6%	<10%
Secondary EFF	COD	55.0	63.2	14.9% *	<10%
	FCOD	41.2	39.1	4.9%	<10%
	Ammonia	32.6	28.9	11.5% *	<10%
	NO _x	0.7	0.1	0.7	1 mg/L
	OP	0.3	0.0	0.3	0.5 mg/L
	TP	0.6	0.6	0.0	0.5 mg/L
	TSS	9.9	19.5	9.5%	5 mg/L

¹ Updated FCOD:COD ratio of 0.39

* Outside typical accuracy range

Table 4.36: Winter System 2 measured vs. model data comparison

Location	Parameter (mg/L)	Measured Value	Model Value	Difference	Typical
Primary INF	COD	502.5	458.6	8.7%	<10%
	TSS	198.2	197.9	0.2%	<10%
Primary EFF	COD	333.0	294.9	11.5% *	<10%
	FCOD	196.0 ¹	188.4	3.9%	<10%
	Ammonia	33.7	32.1	5.0%	<10%
	NO _x	0.4	1.0	0.6	1 mg/L
	TKN	44.7	45.0	0.8%	<10%
	OP	3.5	3.8	0.3	0.5 mg/L
	TP	5.0	5.2	0.3	0.5 mg/L
	Alkalinity	222.4	253.0	13.8% *	<10%
	TSS	80.5	77.9	3.2%	<10%
	VSS	78.2	71.1	9.0%	<10%
Solids Inventory	MLSS	1,578	1,355	14.1% *	<10%
	MLVSS	1,328	1,138	14.3% *	<10%
	MLVSS:MLSS	0.9	0.8	2.0%	<10%
	WAS SS	4,175	3,837	8.1%	<10%
	SRT (d)	2.4	2.3	3.8%	<10%
Secondary EFF	COD	57.5	57.3	0.3%	<10%
	FCOD	38.2	34.5	9.6%	<10%
	Ammonia	37.3	31.9	16.6% *	<10%
	NO _x	1.1	0.5	0.6	1 mg/L
	OP	0.1	0.0	0.1	0.5 mg/L
	TP	0.7	0.7	0.1	0.5 mg/L
	TSS	14.5	18.8	4.3%	5 mg/L

¹ Updated FCOD:COD ratio of 0.39

* Outside typical accuracy range

4.5 Model Sensitivity Analysis

In conjunction with model accuracy and validation, a sensitivity analysis was performed in order to observe treatment performance when raw influent flow and concentrations were altered. To evaluate performance, the raw influent flow, COD, TKN, and TP concentrations were changed to plus and minus 5%, 10%, and 20% of current values. Table 4.37 provides information on the influent values used in the sensitivity analysis.

Table 4.37: Adjusted influent values for model sensitivity analysis

Percent Adjustment	Flow	COD	TKN	TP
-20%	21.8	435.7	35.2	4.0
-10%	24.5	490.2	39.6	4.4
-5%	25.8	517.4	41.8	4.7
0% (current value)	27.2	544.7	44.0	4.9
+5%	28.6	571.9	46.2	5.2
+10%	29.9	599.1	48.4	5.4
+20%	32.6	653.6	52.8	5.9

After adjusting the influent values, the secondary effluent concentrations, within each system, for COD, FCOD, ammonia, TKN, NO_x, OP, TP, TSS, and VSS were analyzed to observe treatment performance. Analysis showed that changing the influent concentrations had little effect on secondary effluent values, but altering the flow greatly changed treatment performance. Figures 4.30-4.33 give insight on how treatment performance was affected for System 1, and Figures 4.34-4.37 for System 2, respectively, when changing

influent flow. As depicted in the figures, nitrification performance greatly decreases with increasing flow, and is largely due to the lower HRT within the activated sludge, giving inadequate time for biological activity to occur. For phosphorus removal, the analysis shows that removal performance has a parabolic curve, where phosphorus removal is greatly decreased at low and high flow rates. Performance is reduced at lower flow rates due to the increasing nitrification performance and increased NO_x to the anaerobic zones. At current operation, the NO_x in the RAS is approximately 4 mg/L, with a mixed concentration of approximately 2 mg/L in the anaerobic zone. At the lowest flow rate, the NO_x concentration in the RAS is 18 mg/L with a mixed concentration over 7 mg/L. The anaerobic zones are designed to be free of electron acceptors and increasing the NO_x in the anaerobic zone inherently decreases phosphorus removal. Phosphorus removal performance is then decreased at higher flow rates due to the lower HRT. At the highest flow rate, the HRT is decreased by 14%, and at the design PAO maximum growth rate, gives inadequate time for full phosphorus release and uptake. The figures also reveal that changes to influent flow has little effect on solid and COD removal.

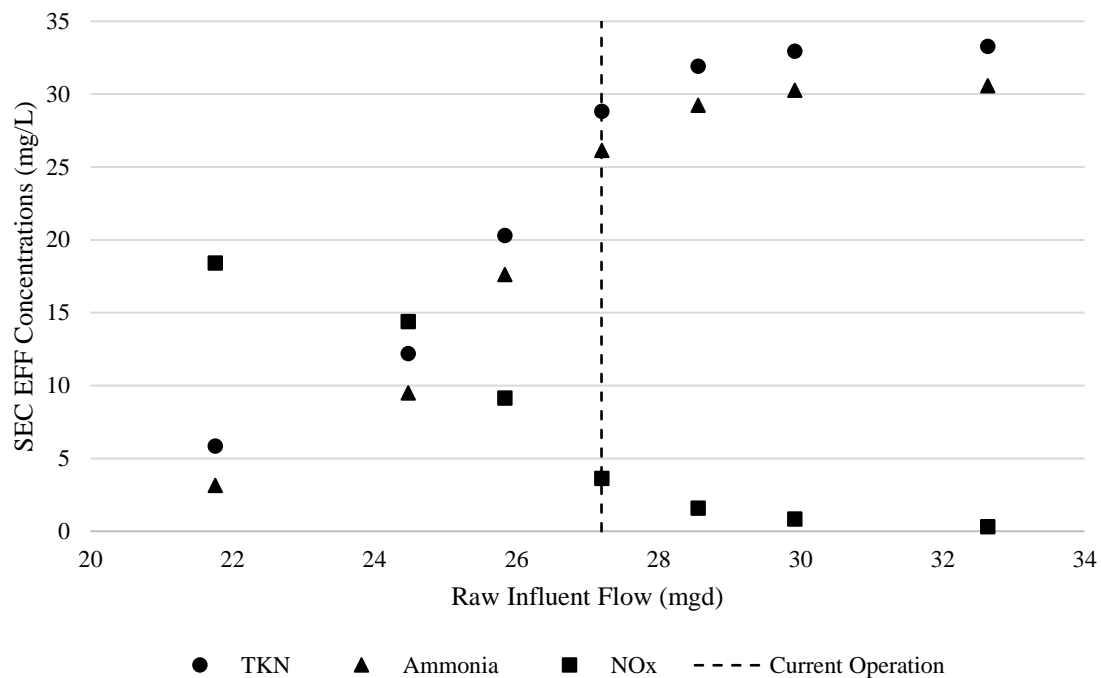


Figure 4.30: System 1 secondary effluent N concentrations with flow variation

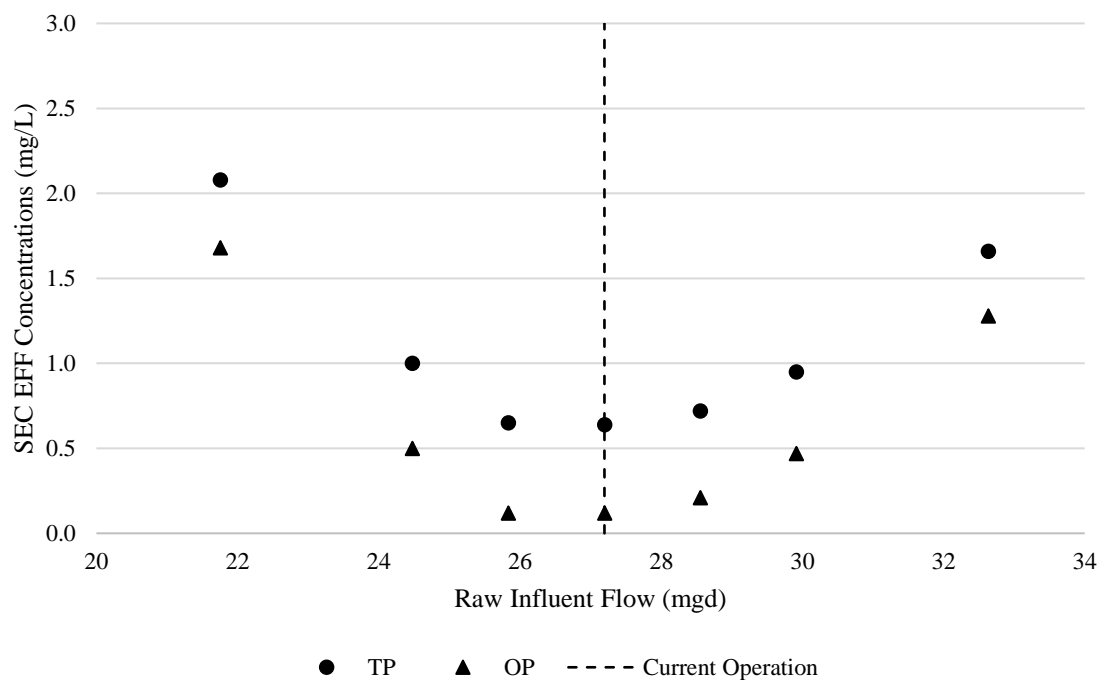


Figure 4.31: System 1 secondary effluent P concentrations with flow variation

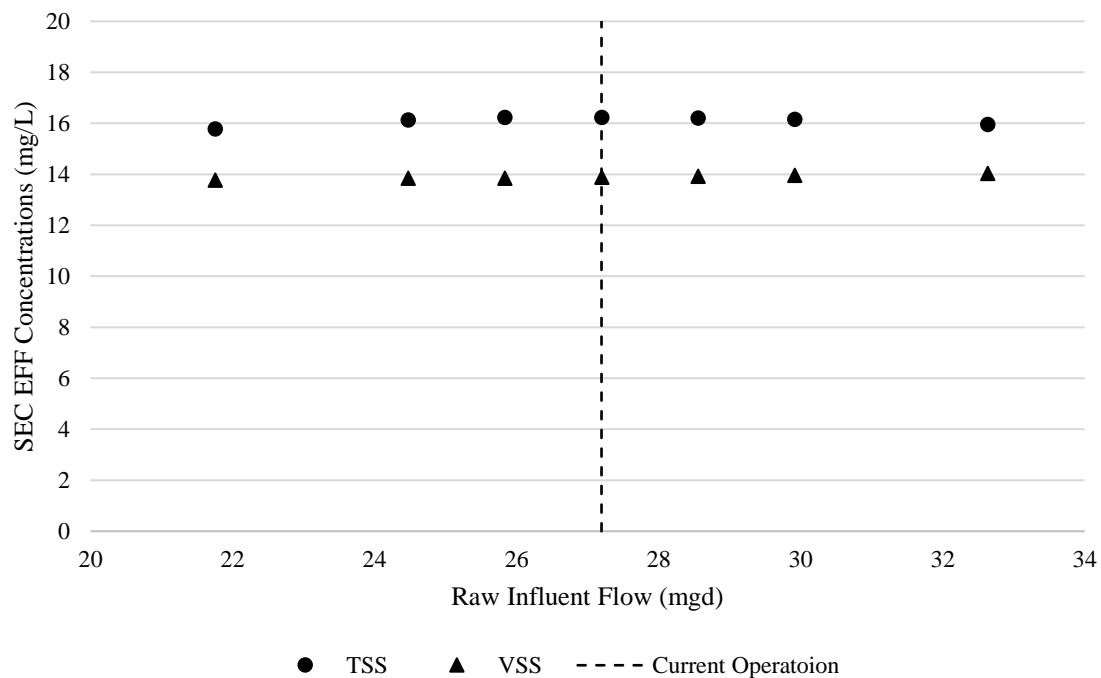


Figure 4.32: System 1 secondary effluent solids concentrations with flow variation

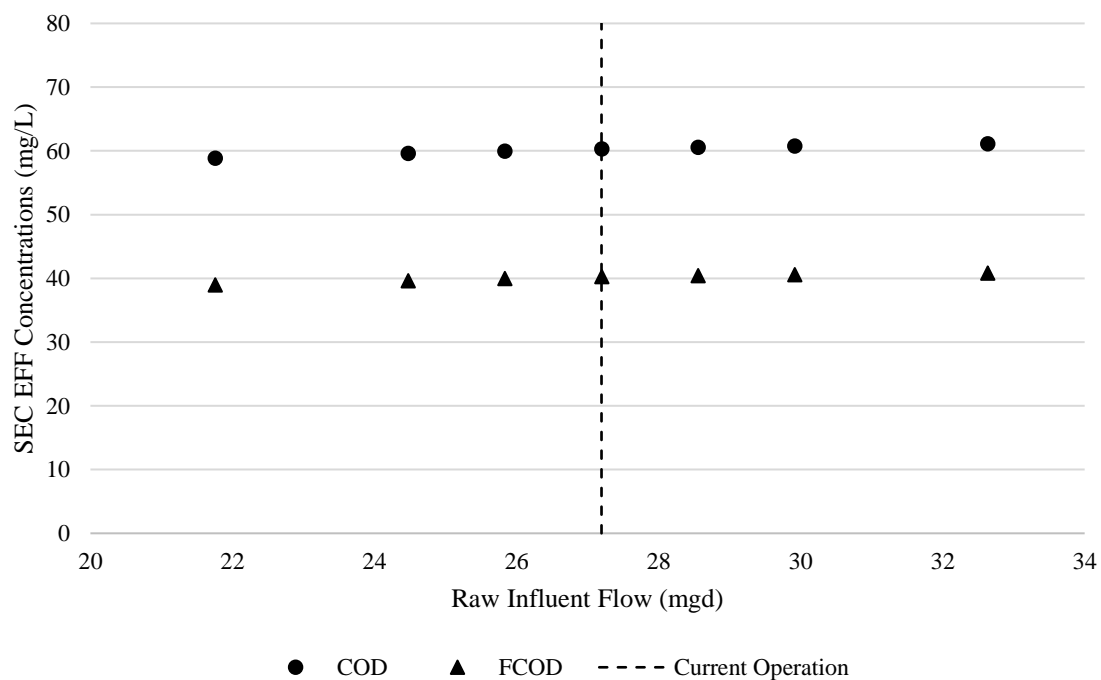


Figure 4.33: System 1 secondary effluent COD concentrations with flow variation

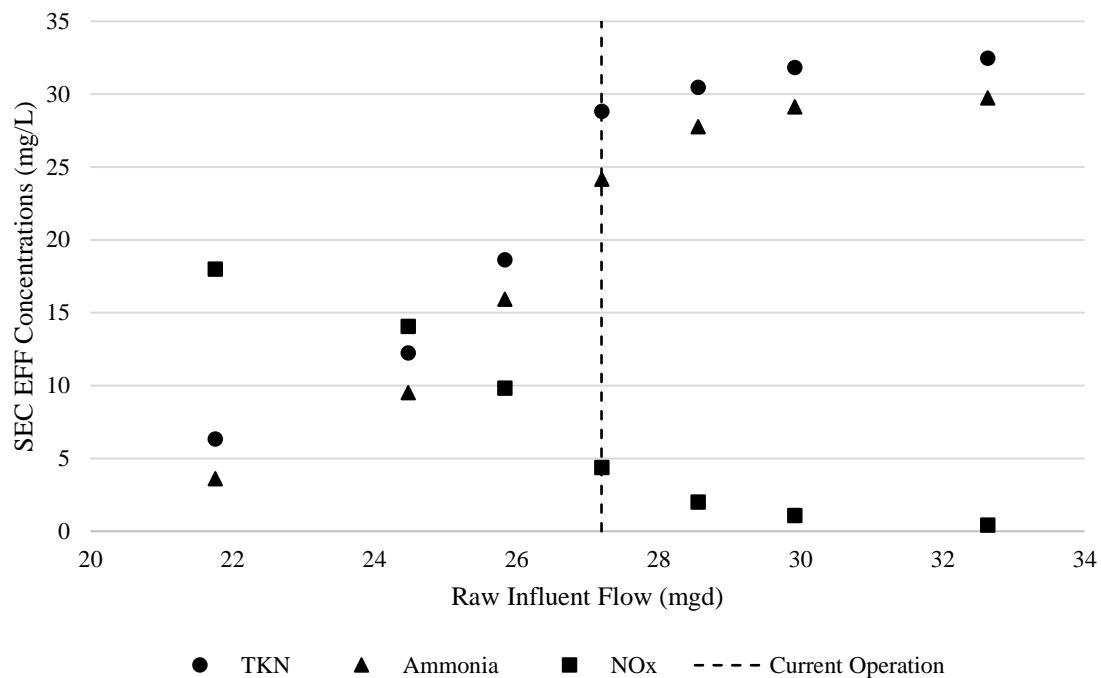


Figure 4.34: System 2 secondary effluent N concentrations with flow variation

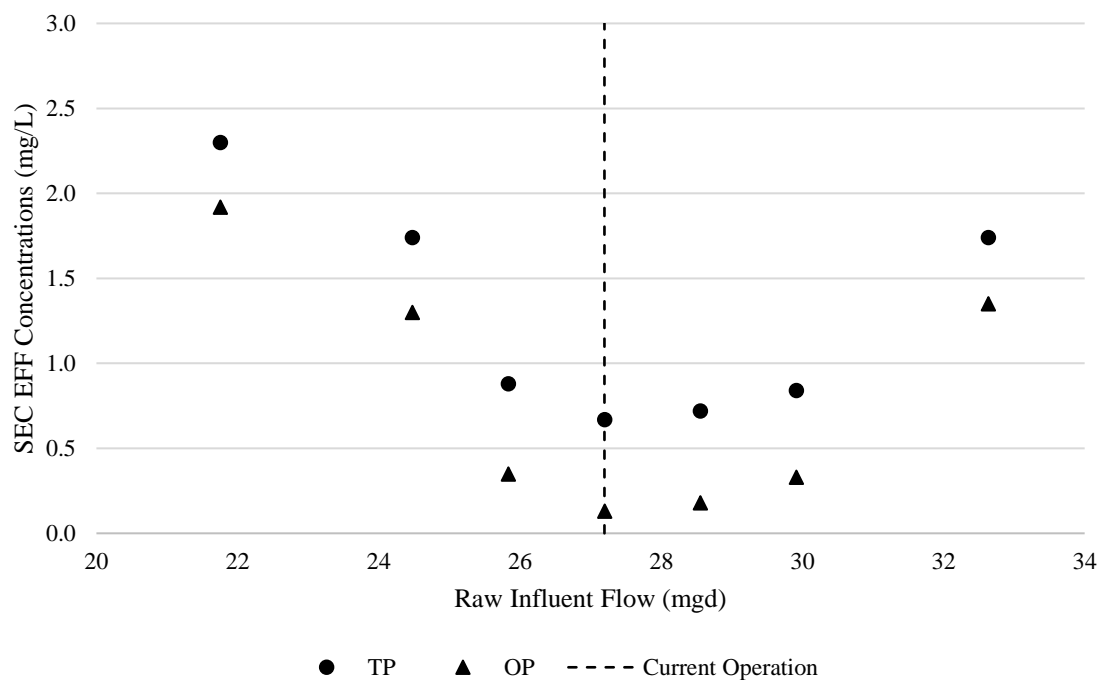


Figure 4.35: System 2 secondary effluent P concentrations with flow variation

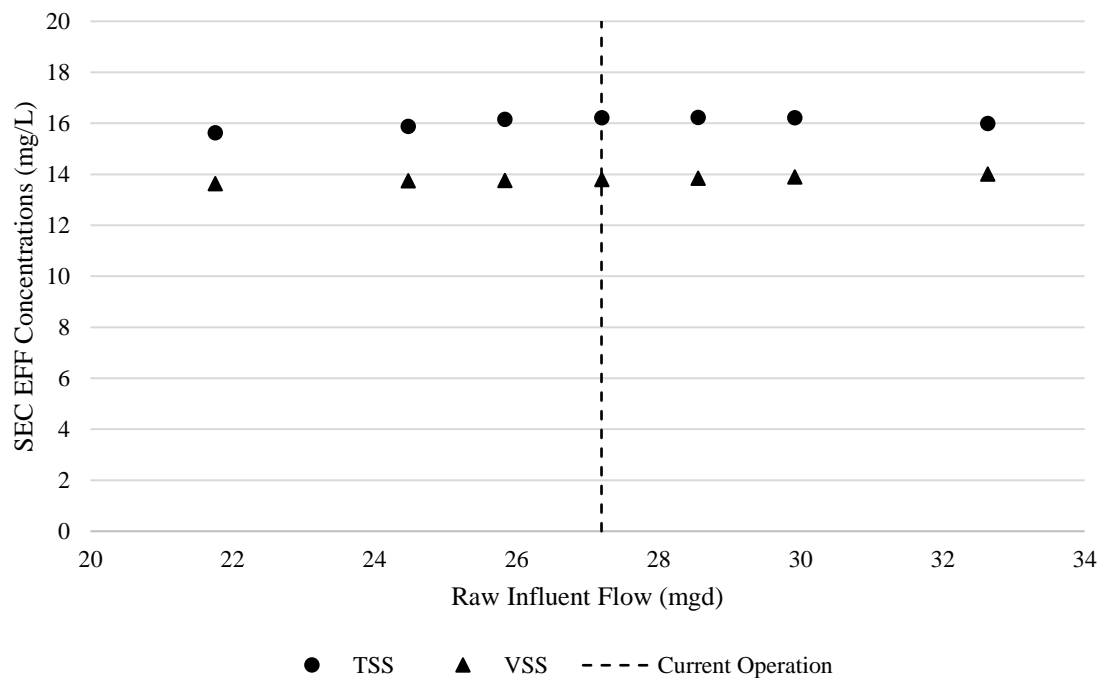


Figure 4.36: System 2 secondary effluent solids concentrations with flow variation

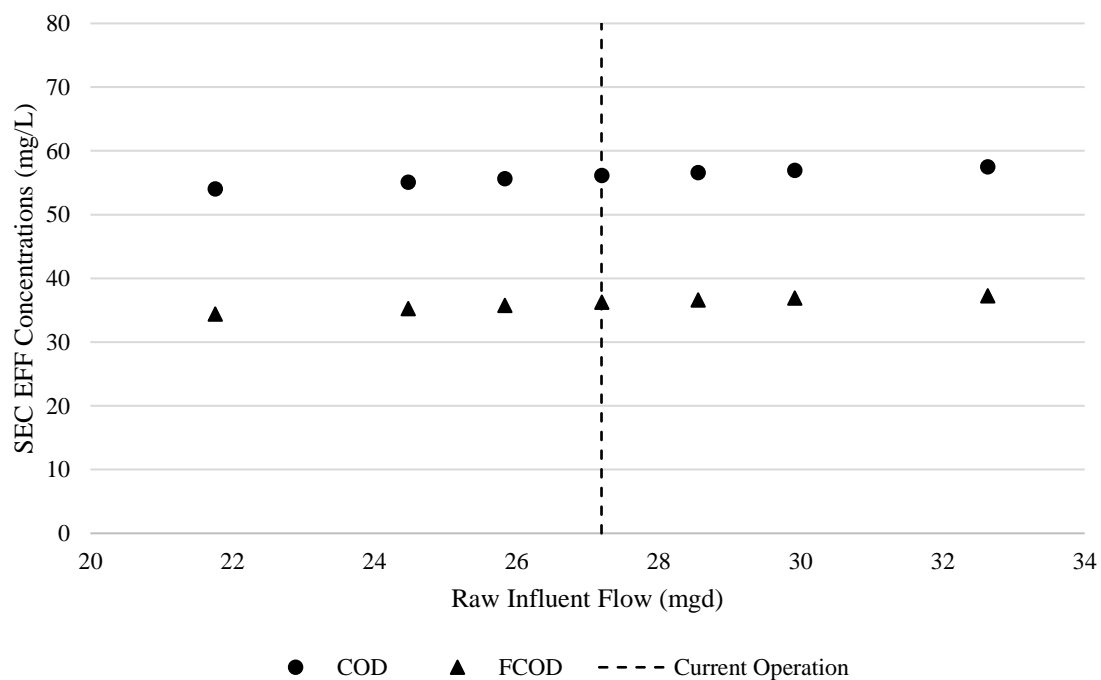


Figure 4.37: System 2 secondary effluent COD concentrations with flow variation

CHAPTER 5 DESIGN AND EVALUATION OF COMBINED CNP TREATMENT ALTERNATIVES

5.1 Modifications to Current TMWRF Operation

Once the TMWRF BioWin model had been developed, calibrated, and checked for accuracy the model was used to evaluate multiple potential treatment alternatives for future operation. The first alternative evaluated was a reconfiguration of TMWRF's current activated sludge treatment process and the implementation of phosphorus removal by chemical treatment. The purpose of this exercise was to investigate if treatment performance could be improved and if cost could be reduced by eliminating the need for additional nutrient processes beyond activated sludge.

5.1.1 Modified Ludzack-Ettinger Activated Sludge Process

TMWRF currently uses an EBPR A/O activated sludge process for phosphorus removal in conjunction with soluble organic carbon conversion. Modification to this treatment process includes the reconfiguration of the A/O process to a Modified Ludzack-Ettinger (MLE) process for nitrification and denitrification. This reconfiguration would be done by taking the anaerobic zones and turning them into anoxic zones with the implementation of an internal nitrate recycle stream and increasing the SRT. An SRT of 10 days was selected within typical values of 7-14 days for nitrification. With the implementation of an internal recycle (IR) stream, multiple recycle ratios were analyzed within the model, for the IR and RAS. IR and RAS flows are typically 100-400% and 25-100% of the influent system flows, respectively (Metcalf and Eddy, 2014). Model results indicated that nitrate was not being completely converted to nitrogen gas and removed from the system. It was hypothesized

that this observation indicated that the systems were carbon limited, despite having a COD:N ratio above 7. To investigate if the systems were carbon limited, the nitrification and denitrification performance were analyzed by taking the primary clarifiers offline in the model. This exercise showed a decrease in NO_x concentrations of approximately 35% for both systems. Knowing that performance increased when primary clarifiers were offline, the recycle ratios were applied to the models when primary clarifiers were online and offline to find optimal conditions. Detailed data from this recycle ratio analysis is contained in Appendix G. Analysis revealed that 300% IR and 75% RAS ratios proved optimal. Although taking the primary clarifiers offline helped with nitrogen removal, removing the primary clarifiers in large treatment plants is not a common practice. To improve nitrogen removal performance by keeping the primary clarifiers, primary fermentation (PF) was enhanced and incorporated into the model. Primary fermentation is the process of sending primary sludge to a biologically activated reactor with a prolonged reaction time, which results in solids hydrolysis and release of organic carbon and VFA byproducts. The carbon and VFAs are then recycled to the activated sludge process for increased treatment performance. Primary clarifiers were used as the primary fermenters in the model and existing infrastructure (former phostrip tanks) at TMWRF would be suitable as the primary fermenters. Table 5.1 summarizes the design and operation criteria for the primary fermenters. By using primary fermentation to increase the carbon and VFA loadings to the activated sludge process, and keeping the primary clarifiers online, the treatment performance mirrors the performance observed when the primary clarifiers were offline. Figure 5.1 compares the secondary effluent soluble nitrogen concentrations for the current A/O, MLE with primary clarifiers, MLE without primary clarifiers, and MLE with

primary fermentation processes for System 1 and Figure 5.2 presents similar data for System 2.

Table 5.1: Design and operation criteria for the primary fermenters

Parameter	Value	Typical
No. per Sys	1	1
Depth (ft)	11	-
Effective Surface Area (ft ²)	5,280	1/3 total primary clarifier area ¹
Underflow (mgd)	0.08	1/2 primary sludge flow ¹
Recycle to Activated Sludge (mgd)	0.14	-
Wasted Primary Sludge (mgd)	0.02	-

¹ (EnviroSim, 2020)

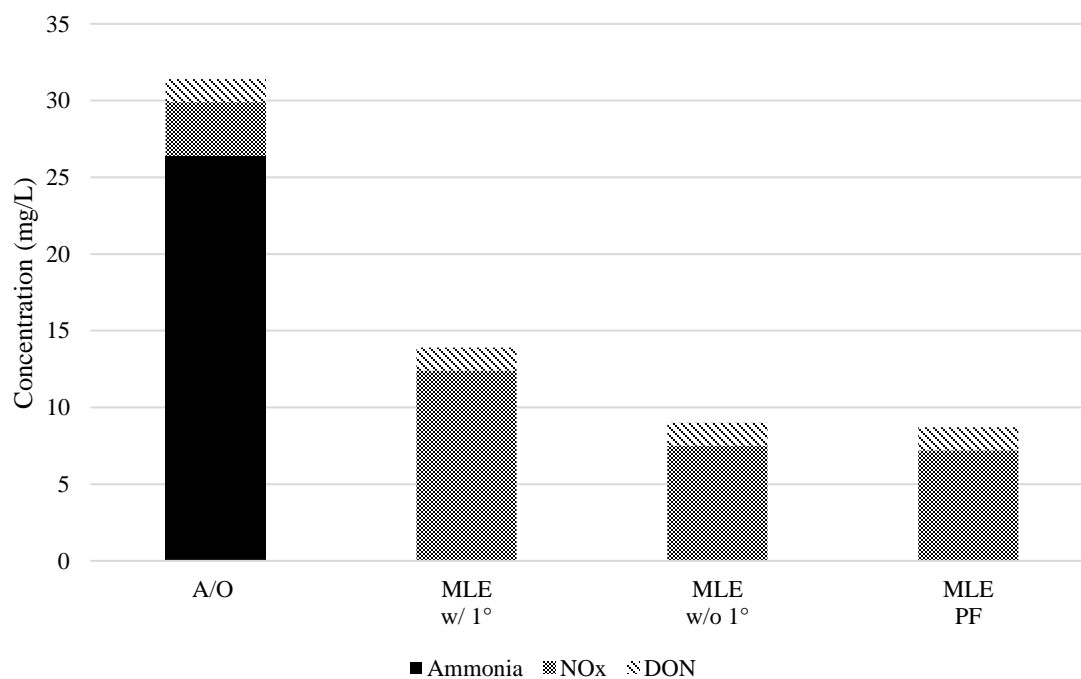


Figure 5.1: System 1 SE N conc. with/without primary clarifiers and with PF

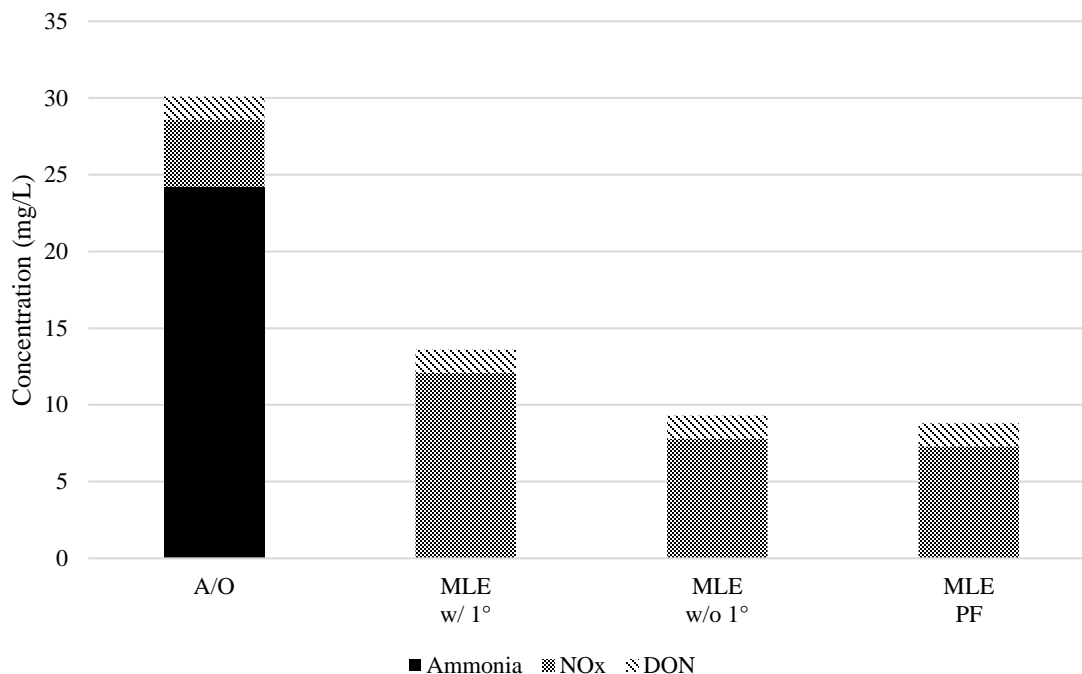


Figure 5.2: System 2 SE N conc. with/without primary clarifiers and with PF

As revealed in the figures, nitrogen removal greatly increases by modifying the current A/O process to an MLE process, with further increase in performance observed with primary fermentation. Although nitrogen removal is increased by the modification to an MLE process, further NO_x removal would be required before chemical treatment for phosphorus removal can occur. Often, when full nitrogen removal is not achieved, there is need for a post-denitrification (PD) reactor. Research shows that the post-anoxic reactor often has an HRT similar to that of the aerobic zones. System 1 aerobic zone had an HRT of 4.3 hours, and System 2 had an HRT of 3.7 days. To design the post-anoxic reactor, an HRT of 4 hours was selected, which corresponded to a post-anoxic volume of three million gallons and was used for both systems. It should be noted that if TMWRF were to convert to an MLE process, construction of post-anoxic reactors would need to be done since there

is not adequate existing tank volume. Figure 5.5 shows the process schematic. Once the post-anoxic reactors were implemented within the model, the secondary effluent nitrogen concentrations were compared for the A/O, MLE with primary fermentation, and MLE with primary fermentation and post-denitrification processes. Figures 5.3 and 5.4 contain data for Systems 1 and 2, respectively. As seen from the figures, the effluent nitrogen concentrations are within an acceptable range (<2 mg/L), and treatment of phosphorus could begin. It should be noted that in order to negate ammonification in the post-denitrification reactor, a DO setpoint of 0.05 mg/L was used. The MLE BioWin models for the individual systems are in Appendix E. With the MLE-PF-PD process, TN values were 1.5 mg/L and 1.7 mg/L for Systems 1 and 2, respectively. These values correspond to N loads of 375 lb/d and 425 lb/d, respectively, at current plant flows.

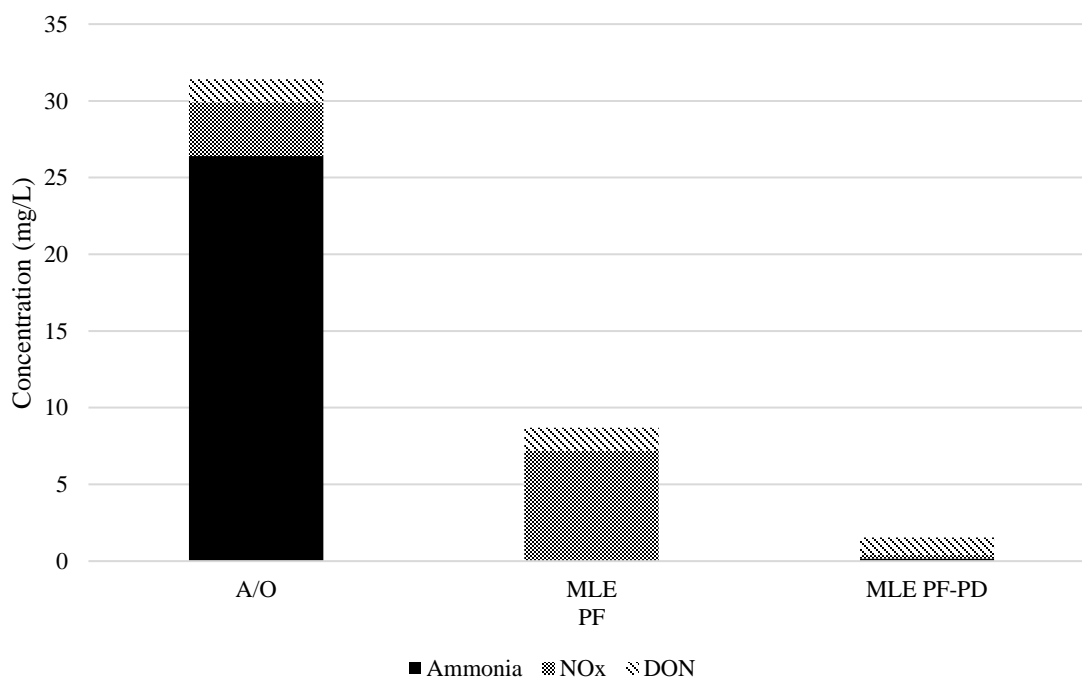


Figure 5.3: System 1 N conc. with PF and PD

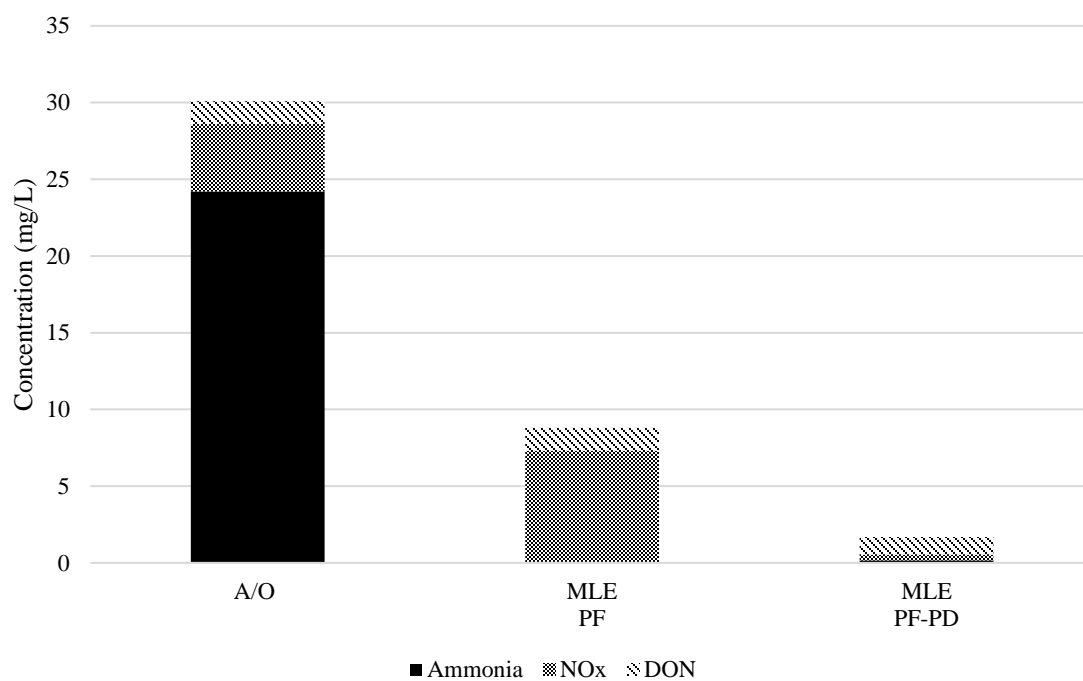


Figure 5.4: System 2 N conc. with PF and PD

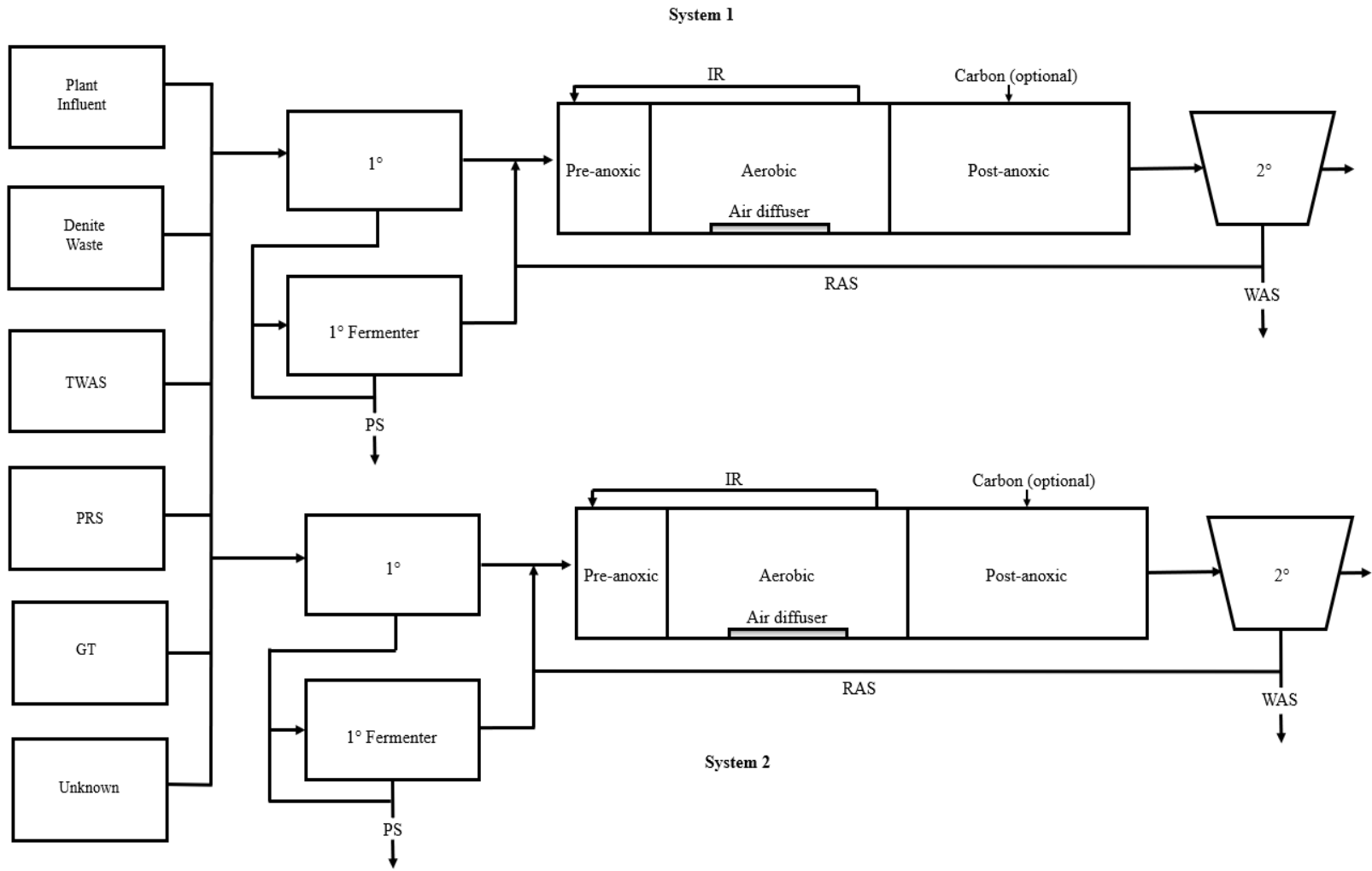


Figure 5.5: MLE process schematic with PF and PD

5.1.2 Chemical Treatment for Phosphorus Removal

After evaluating the treatment of nitrogen by modifying TMWRF's A/O process to an MLE process for nitrogen removal, the next task was to implement chemical treatment for phosphorus removal. TMWRF currently uses an EBPR process for phosphorus removal; however, by converting the A/O process to an MLE process, biological phosphorus treatment would not be achieved as the MLE process is incapable of enhanced phosphorus removal. In order to treat phosphorus in conjunction with the MLE process, chemical treatment would be needed. The chemicals used for phosphorus treatment are generally aluminum sulfate (alum) and ferric chloride. Alum was selected for this study as it is more commonly used in the wastewater treatment industry and is currently used at TMWRF. Research shows that the chemical is often added to the primary clarifiers, activated sludge tanks, or secondary clarifiers (Mbamba et al., 2019b). It was decided to use alum and add the chemical prior to the secondary clarifiers. The decision to treat phosphorus downstream of the activated sludge was made because if too much phosphorus is removed in the primary clarifiers or activated sludge tanks, then there could be inadequate quantities of phosphorus for biosolid accumulation in the activated sludge. The strength of alum used is approximately 48% as $\text{Al}_2\text{SO}_4 \cdot 14\text{H}_2\text{O}$ and the material safety data sheet is in Appendix H. Based on model observations, an alum dose of 1,000 gpd for System 1 and 1,500 gpd for System 2 would be needed to achieve acceptable phosphorus levels. Figure 5.6 compares the secondary effluent phosphorus concentrations for System 1 of the current treatment process with that of the MLE process with and without chemical treatment and Figure 5.7 presents data for System 2. As seen from the figures, the phosphorus levels without chemical treatment do not meet TMWRF's NPDES permit for TP of 134 lb/d

(~700 lb/d without chemical treatment), and therefore prove the need for chemical treatment. The BioWin models with chemical treatment are included with the MLE configurations in Appendix E. In general, operation with chemical treatment was on-par with current performance with secondary effluent concentrations for Systems 1 and 2 being 0.65 mg/L and 0.67 mg/L for current operation, and 0.78 mg/L and 0.85 mg/L for Systems 1 and 2 with the MLE chemical treatment process.

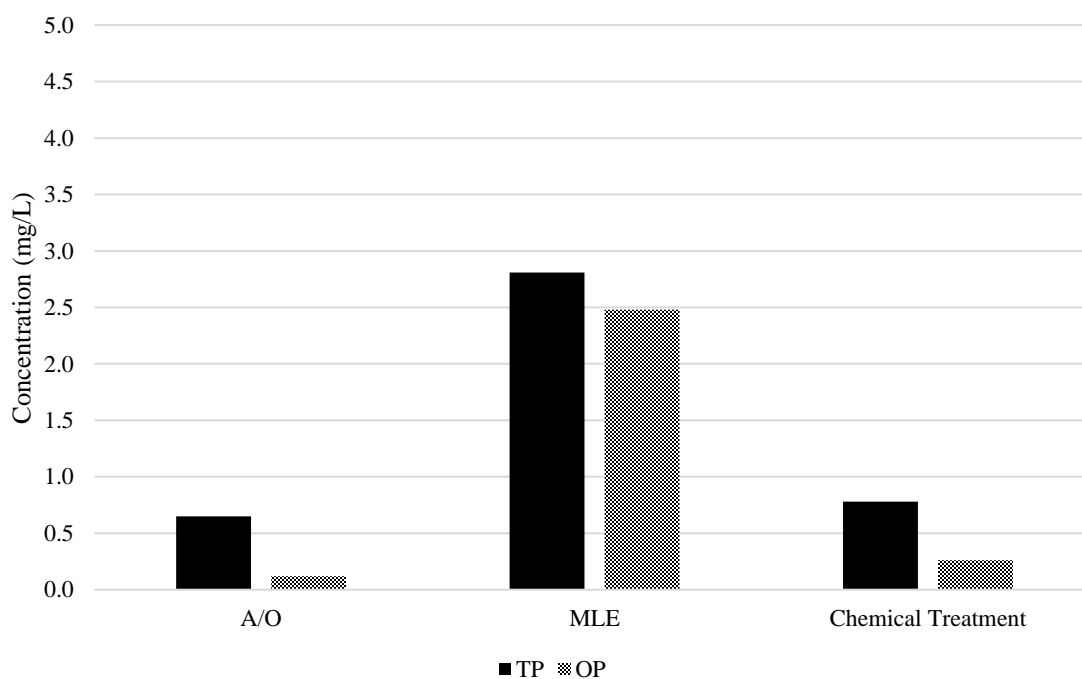


Figure 5.6: System 1 SE P conc. for MLE and chemical treatment

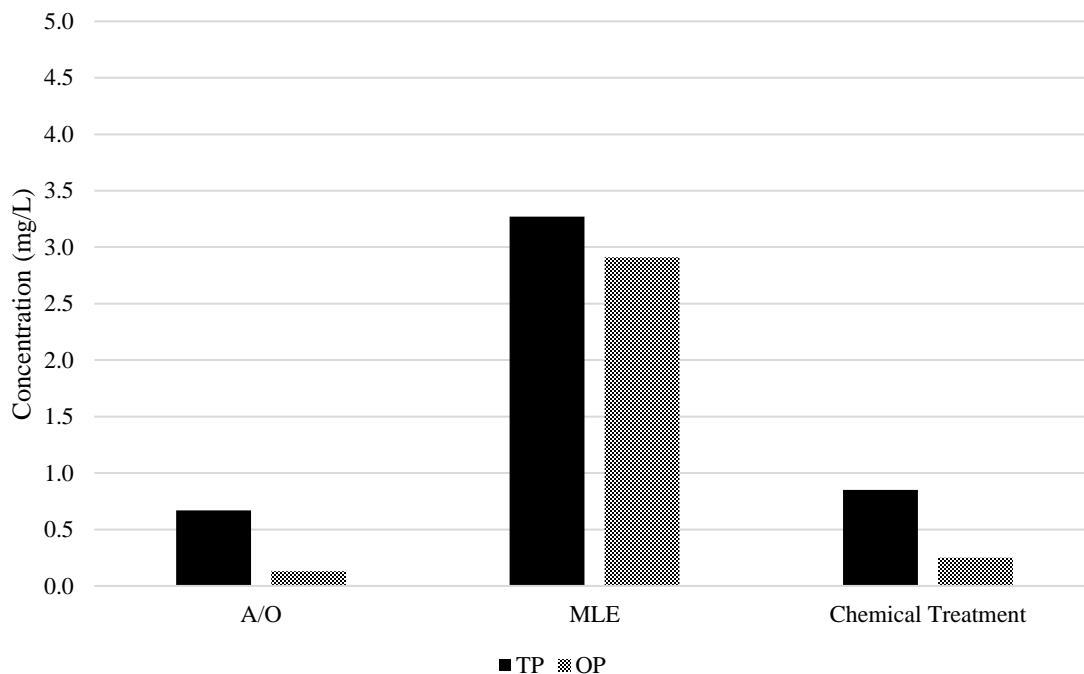


Figure 5.7: System 2 SE P conc. for MLE and chemical treatment

5.2 Future TMWRF Activated Sludge Treatment Alternatives

In addition to the alternatives analysis of converting the current A/O process to an MLE process with chemical treatment, future scenarios were analyzed if new activated sludge tanks were constructed. This analysis investigated carbon, nitrogen, and phosphorus (CNP) treatment done solely in the activated sludge process. Benefits of using the activated sludge process for combined CNP treatment is that tertiary nitrification and denitrification is not required, and there is no need for alum for phosphorus chemical treatment. Both nitrogen and phosphorus treatment in activated sludge processes generally require larger tank volumes and would require additional construction at TMWRF. The activated sludge processes investigated in this analysis were the A²O, 5-stage Bardenpho, Standard UCT, Modified UCT, and VIP processes. Since these processes would require construction of

new activated sludge tanks, typical design criteria were used in determining size, HRT, SRT, and recirculation/recycle ratios. When determining the volume required for each system, based on typical HRT values, a flow rate of 20 mgd was used. This flow rate accounts for any flow variation between the two systems as well as any minor flow increases. Table 5.2 provides the typical design criteria ranges, with the selected values for model design being bolded, for each activated sludge process and Figure 5.8 shows the increase to activated sludge volume, per system, compared to the existing treatment layout.

Table 5.2: Typical and selected design criteria used for modeled activated sludge processes

Design parameter/ process	SRT, d	MLSS, mg/L	Anaerobic zone HRT, h	Anoxic zone HRT, h	Aerobic zone HRT, h	RAS, % of influent	Internal recycle, % of influent
A/O	2-5	3,000-4,000	0.5-1.5	-	1-3	25-100	-
A ² O	5-25 (10)	3,000-4,000	0.5-1.5 (1.0)	1-3 (2.0)	4-8 (6.0)	25-100 (62.5)	100-400 (250)
5-stage Bardenpho	10-20 (10)	3,000-4,000	0.5-1.5 (1.0)	1-3 (2.0)	4-12 (8.0)	50-100 (75)	200-400 (300)
				(1 st stage)	(1 st stage)		
				2-4 (3.0)	0.5-1 (0.75)		
				(2 nd stage)	(2 nd stage)		
UCT	10-25 (10)	3,000-4,000	1-2 (1.5)	2-4 (3.0)	4-12 (8.0)	80-100 (90)	200-400 (300) (anoxic)
							100-300 (200) (aerobic)
VIP	5-10 (10)	2,000-4,000	1-2 (1.5)	1-2 (1.5)	4-6 (5.0)	80-100 (90)	100-200 (150) (anoxic)
							100-300 (200) (aerobic)

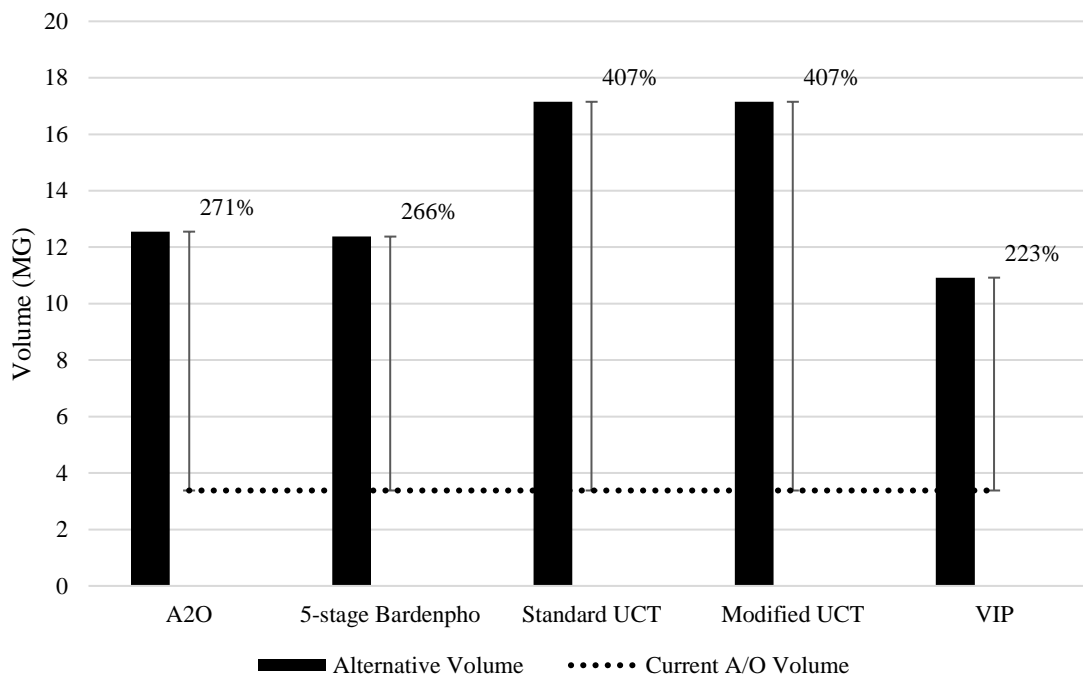


Figure 5.8: Volume increases to alternative activated sludge processes

An SRT of 10 days was used for all activated sludge processes to remain consistent between the models and since this value is within the typical range for all processes. The SRT value was also used to mirror the SRT of the MLE process in the previous evaluation. It was hypothesized that since the MLE process appeared to be carbon limited, the future alternative process would be as well. For this reason, primary fermentation was used with the primary fermenters having design criteria of that of the MLE primary fermenters. After the design criteria for each activated sludge process was inputted into individual models, the nitrogen removal of each model was analyzed. Figures 5.9 and 5.10 compare the secondary effluent soluble nitrogen concentrations of current and alternative designs for Systems 1 and 2, respectively.

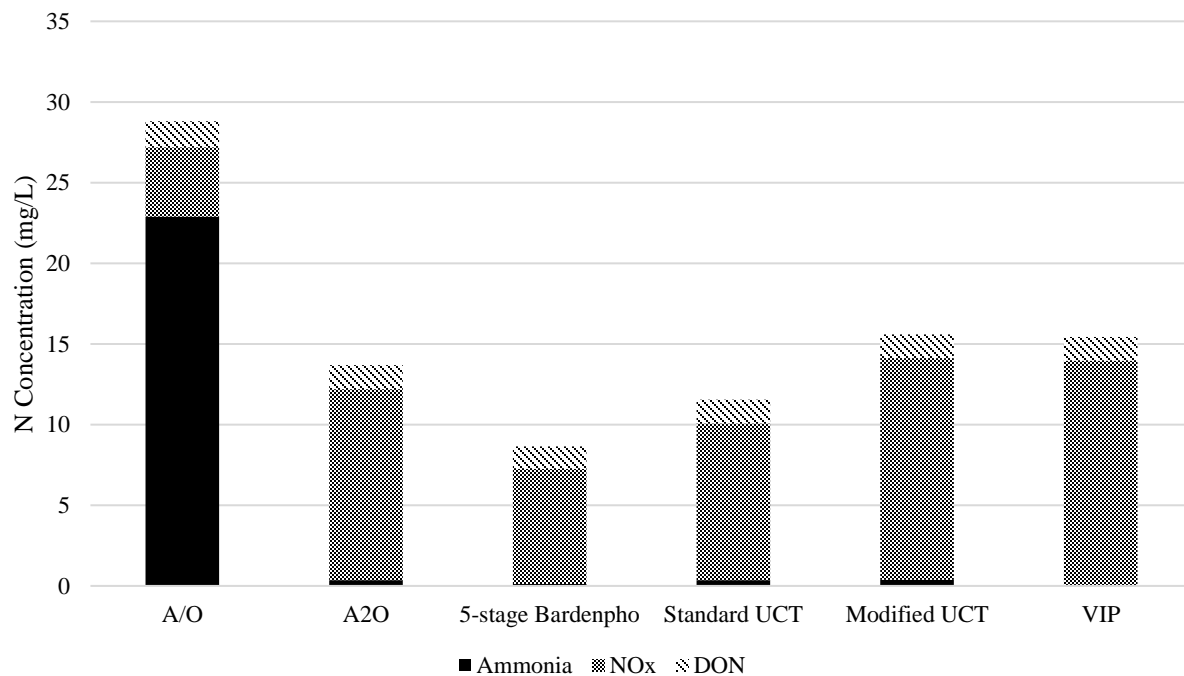


Figure 5.9: System 1 SE N conc. with PF

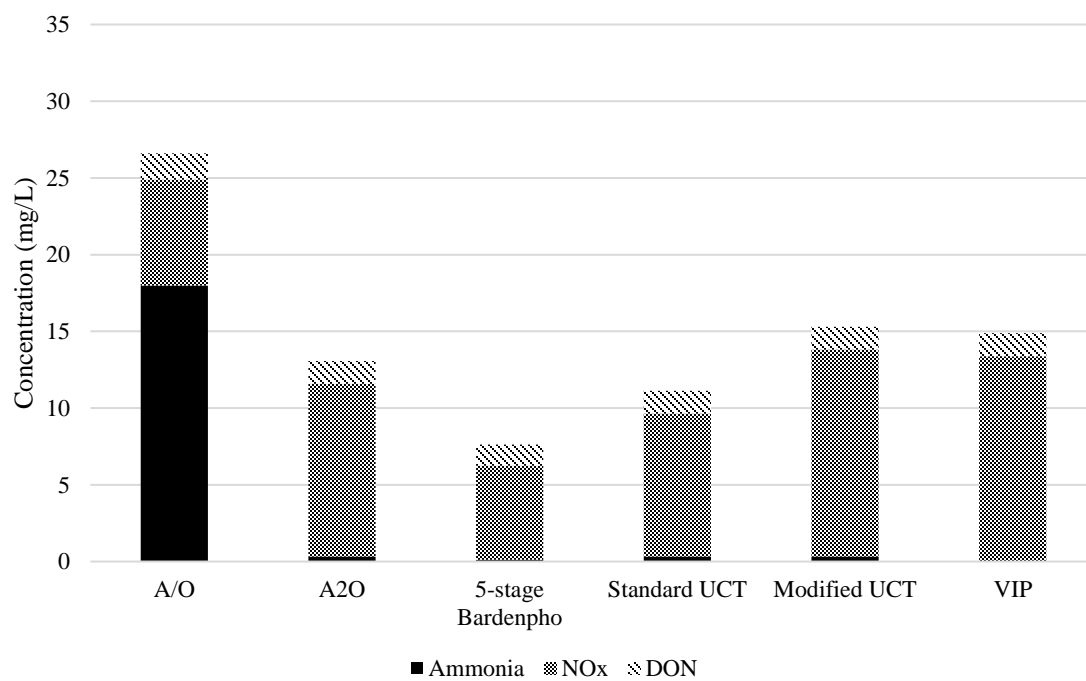


Figure 5.10: System 2 SE N conc. with PF

As revealed in the figures, complete nitrogen removal was not observed, and similar to the MLE process, all processes evaluated had need for post denitrification. The method for designing the post-denitrification reactor is similar to that of the MLE design, in which the HRT of the post-anoxic tank mimics that of the aerobic tanks. Following analysis, it was observed that complete nitrogen removal is not achieved with the determined tank size. It is not practical to design a larger post-anoxic tank than the one implemented, so methanol addition was used as an additional carbon source in the post-denitrification reactor. Methanol acts as the electron donor and is able to convert the remaining NO_x to nitrogen gas. The methanol used has a strength of 99.8% and its material safety data sheet is included in Appendix H. It should be noted that the 5-stage Bardenpho process has a built-in location for methanol addition, in the post-anoxic tank and would not have a separate post-denitrification reactor. Methanol addition in the anoxic tanks for the other activated sludge processes did not increase nitrogen removal and therefore, those configurations would need a post-denitrification tank. It should be noted that ammonification was observed in the post-denitrification reactor. To minimize ammonification, a DO setpoint of 0.05 mg/L was used in the reactor, which still promotes denitrification. The DO within the post-denitrification reactor played a significant role in the methanol use. Table 5.3 provides the dose of methanol needed for residual nitrogen removal in each activated sludge process at a DO setpoint of 0.05 mg/L, which would increase at increasing DO concentrations. With the addition of post-denitrification tank and methanol, the nitrogen concentrations would be reduced to an acceptable level, seen in Figures 5.11 and 5.12 for System 1 and 2, respectively.

Table 5.3: Methanol dose required for nitrogen removal

Process	System 1 (gpd)	System 2 (gpd)
A ² O	750	850
5-stage Bardenpho	750	750
Standard UCT	750	800
Modified UCT	800	1,100
VIP	750	950

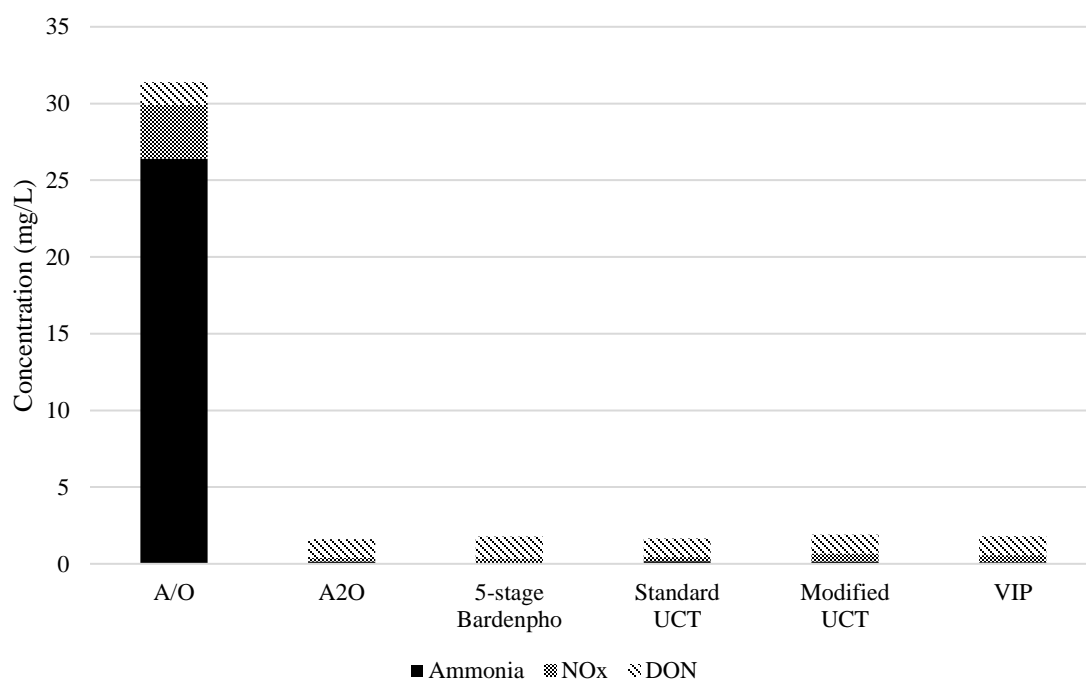


Figure 5.11: System 1 SE N conc. with PF, PD, and methanol for alternative A.S. processes

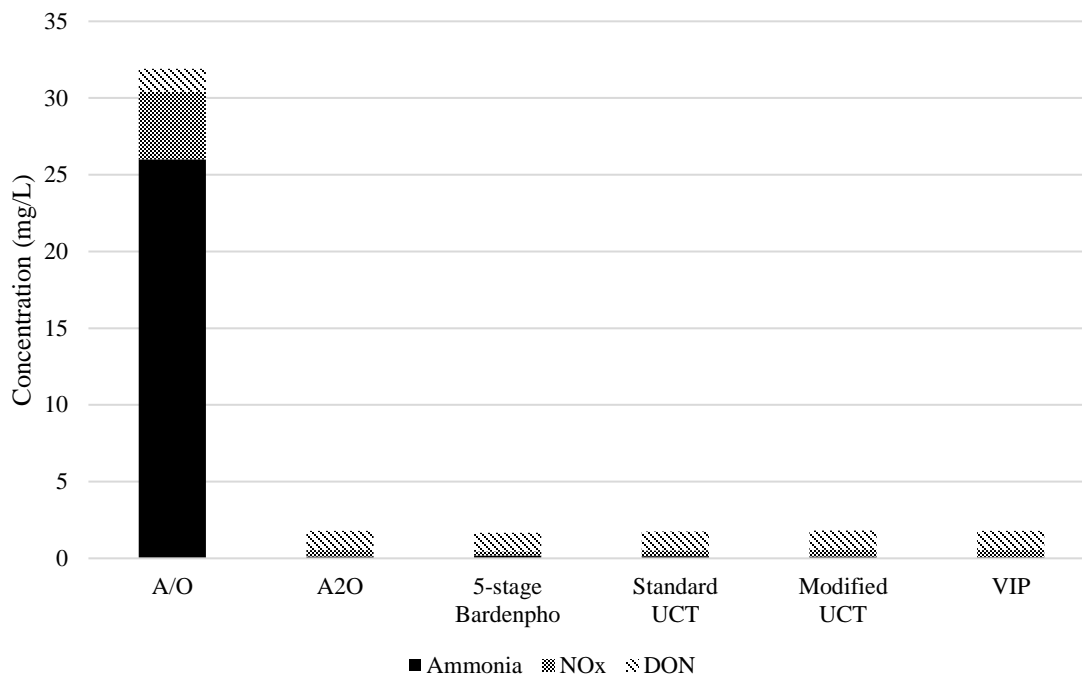


Figure 5.12: System 2 SE N conc. with PF, PD, and methanol for alternative A.S. processes

After nitrogen removal was achieved in the treatment alternatives, the phosphorus concentrations were investigated. These combined CNP processes were able to remove phosphorus due to the implementation of anaerobic zones at the front of each process. Phosphorus removal is achieved because phosphorus release is carried out in the anaerobic zones before interference with the nitrate in the anoxic zones and then removed in the aerobic zone by phosphorus uptake. Figures 5.13 and 5.14 compares the phosphorus levels in each activated sludge process for Systems 1 and 2, respectively. As seen from the figures, phosphorus is greatly reduced, even more so than the current A/O process. It should be noted that the primary fermenter increased phosphorus removal as more VFAs were introduced to the activated sludge. Figures 5.15 – 5.19 show the process schematics on a

per system basis for the A²O, 5-stage Bardenpho, standard UCT, modified UCT, and VIP processes, respectively. As seen from the figures, each process consists of different anaerobic, anoxic, and aerobic zone configuration with various RAS and IR recirculation schemes. The BioWin models for each activated sludge process and system are in Appendix E.

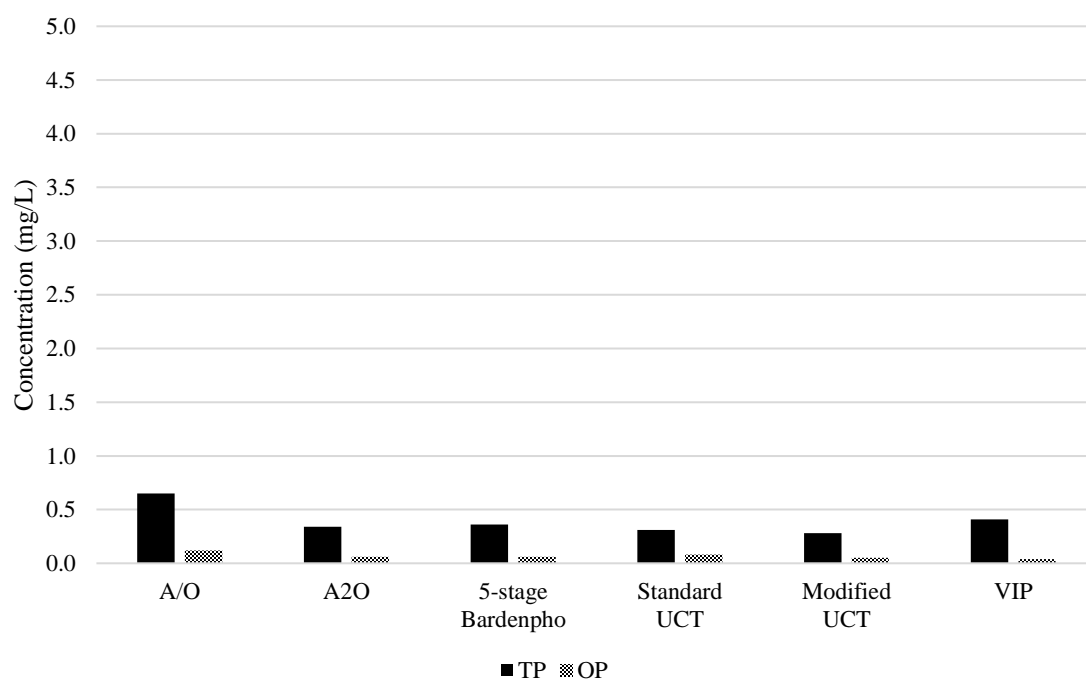


Figure 5.13: System 1 SE P conc. for alternative A.S. processes

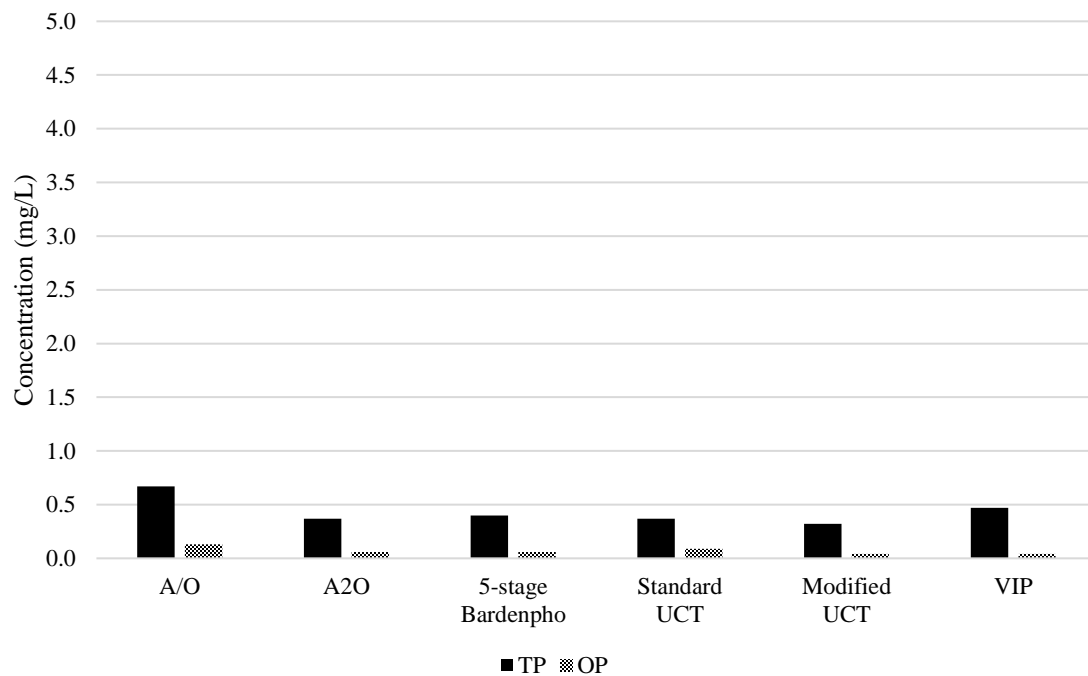


Figure 5.14: System 2 SE P conc. for alternative A.S. processes

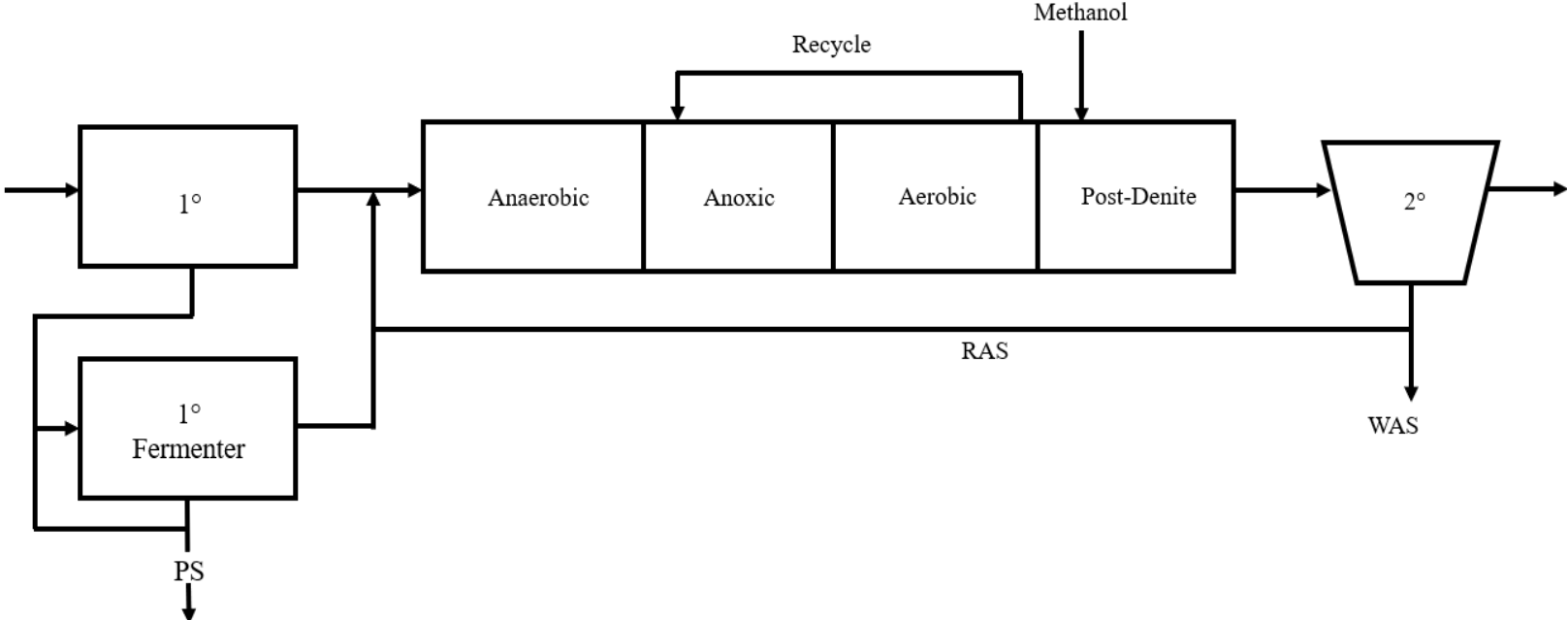


Figure 5.15: A²O with process schematic with PF and PD (per system)

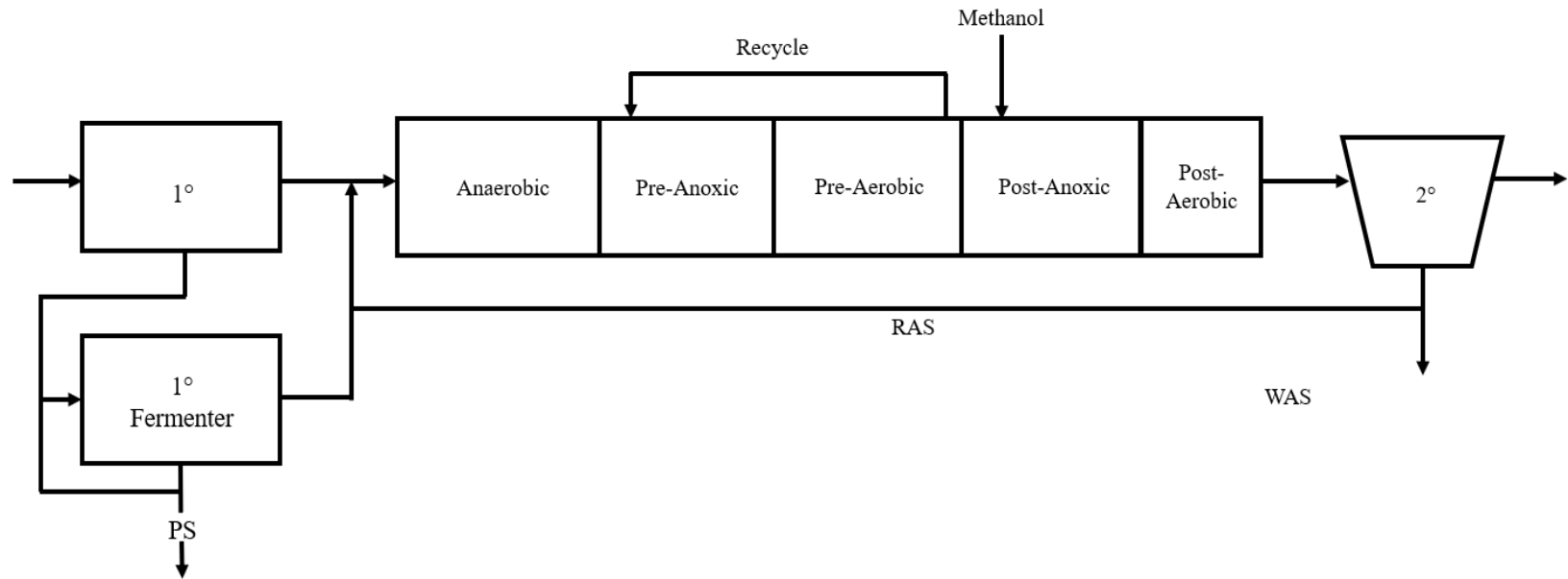


Figure 5.16: 5-stage Bardenpho process schematic with PF (per system)

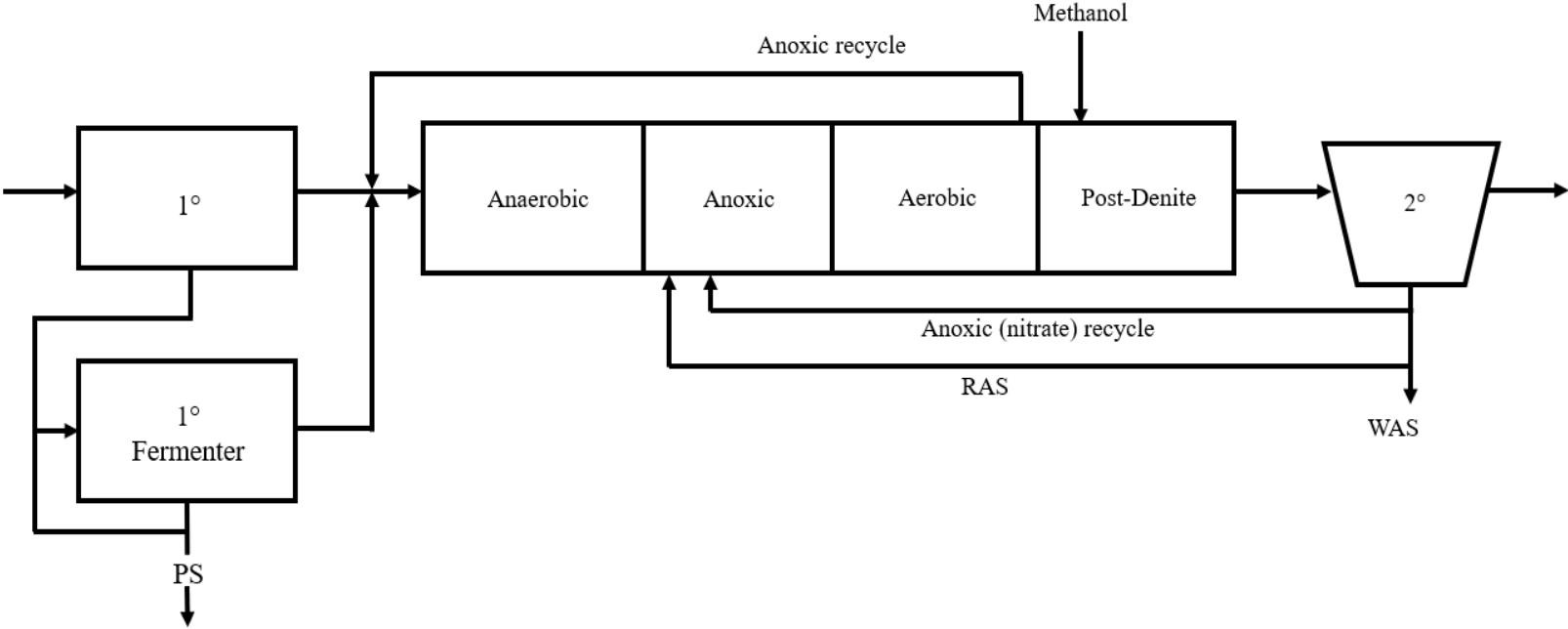


Figure 5.17: Standard UCT process schematic with PF and PD (per system)

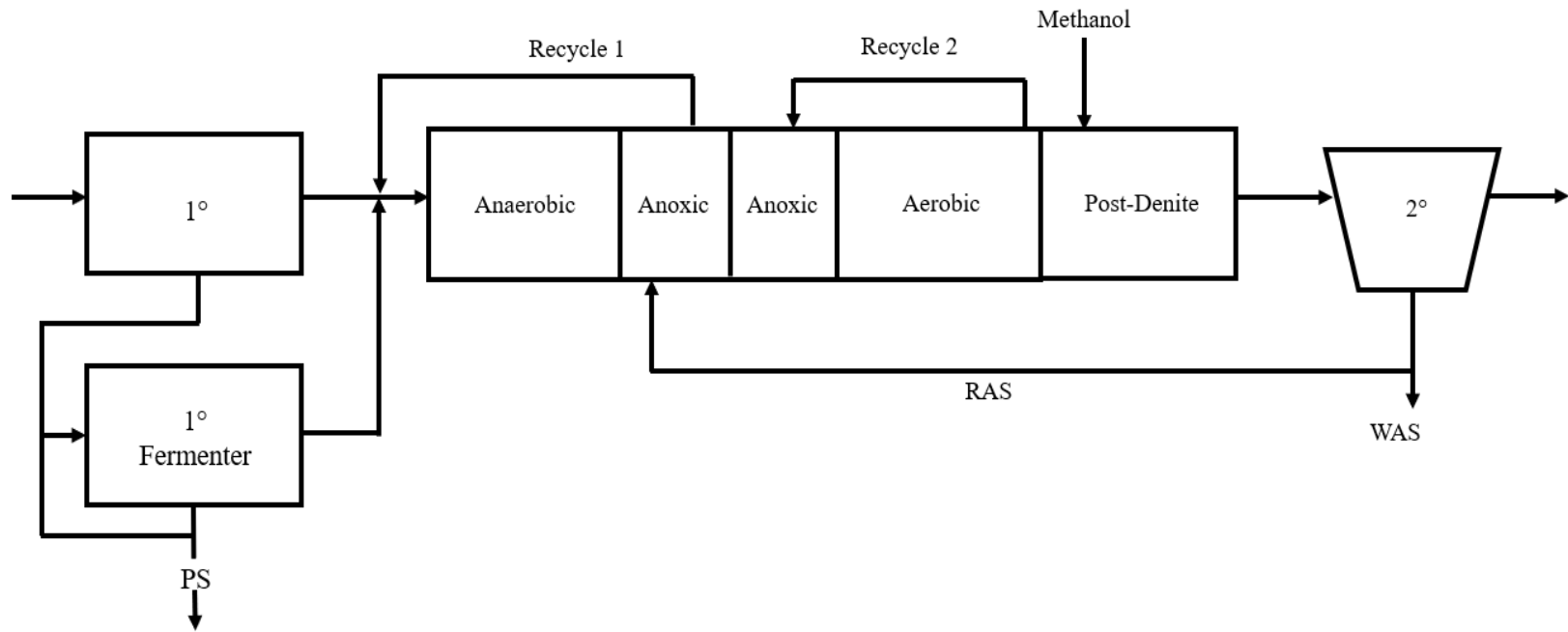


Figure 5.18: Modified UCT process schematic with PF and PD (per system)

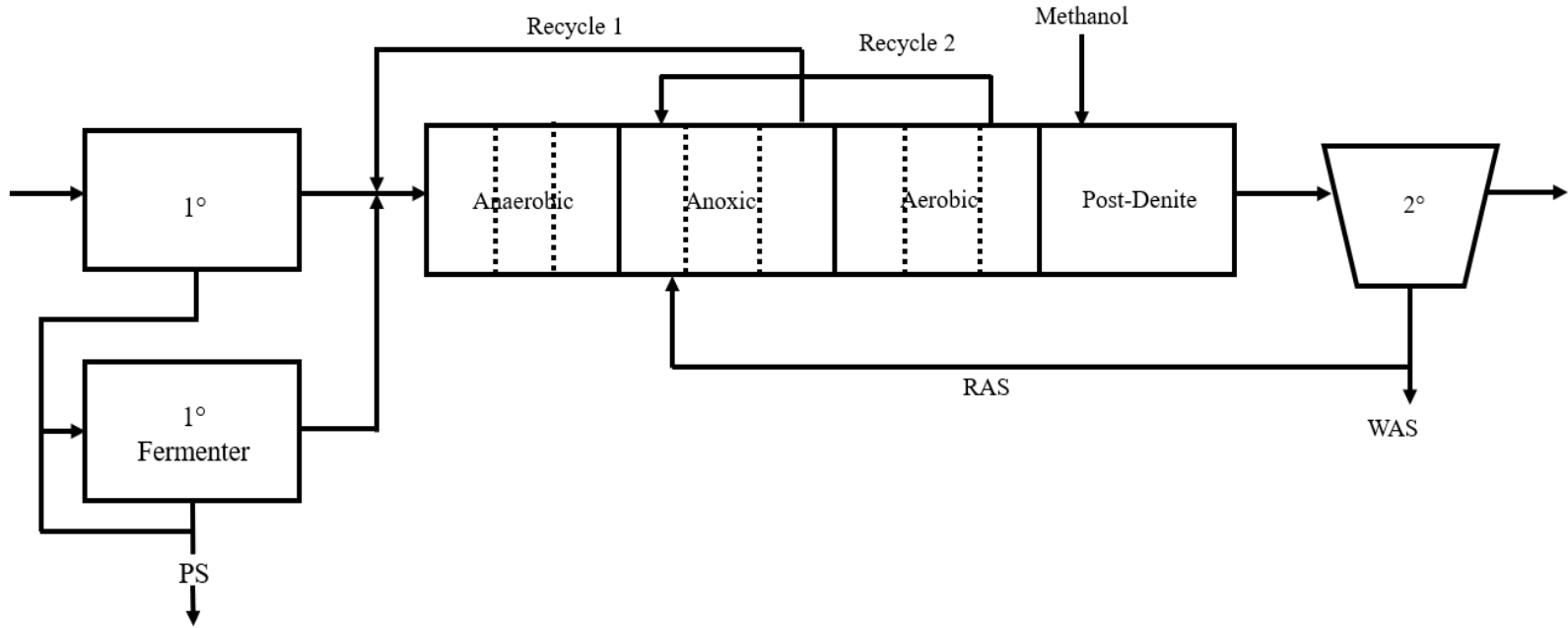


Figure 5.19: VIP process schematic with PF and PD (per system)

5.3 Current and Alternative Process Comparisons

After evaluation of treatment performance of the MLE process with chemical treatment and the future combined CNP alternatives, an overall comparison of treatment performance, aeration demand, and energy and chemical costs was investigated.

5.3.1 Treatment

When analyzing treatment performance between all alternatives, nitrogen and phosphorus species were compared for nutrients, TSS and VSS for solids, and COD and FCOD for carbon. Secondary effluent values were used in the comparison as it was the final location of biological treatment within the model. Figures 5.20 and 5.21 reveal the nitrogen comparison between the alternatives for Systems 1 and 2, respectively. As revealed in the figures, under the right operating conditions, nitrogen can be greatly reduced with most of the effluent nitrogen being DON. For phosphorus, the MLE process uses chemical treatment to remove phosphorus while the combined CNP alternatives rely on biological treatment within the activated sludge processes. Figures 5.22 and 5.23 show the secondary effluent TP and OP concentrations for Systems 1 and 2, respectively. The figures for phosphorus reveal that phosphorus removal was similar to TMWRF's current A/O process. The MLE process with chemical treatment has a slightly higher TP and OP concentration than current performance but it still within typical values (<1 mg/L). For the combined CNP treatment processes, there was an increase in phosphorus removal and is largely due to the increased VFAs to the activated sludge processes produced by the primary fermenters.

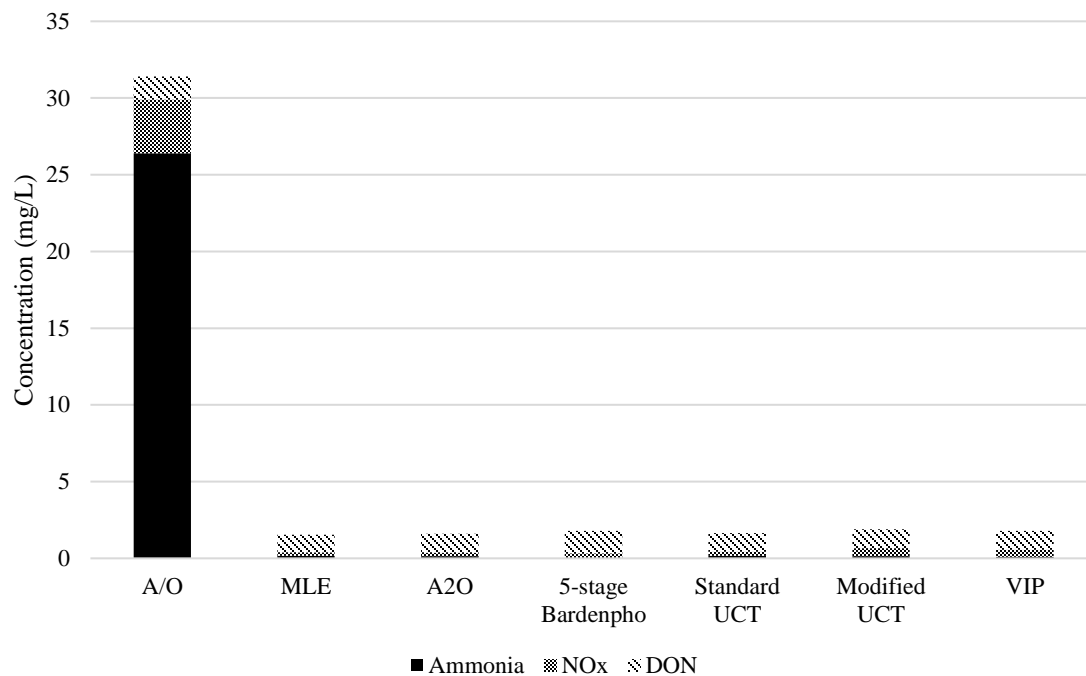


Figure 5.20: System 1 N concentrations of alternatives treatment processes

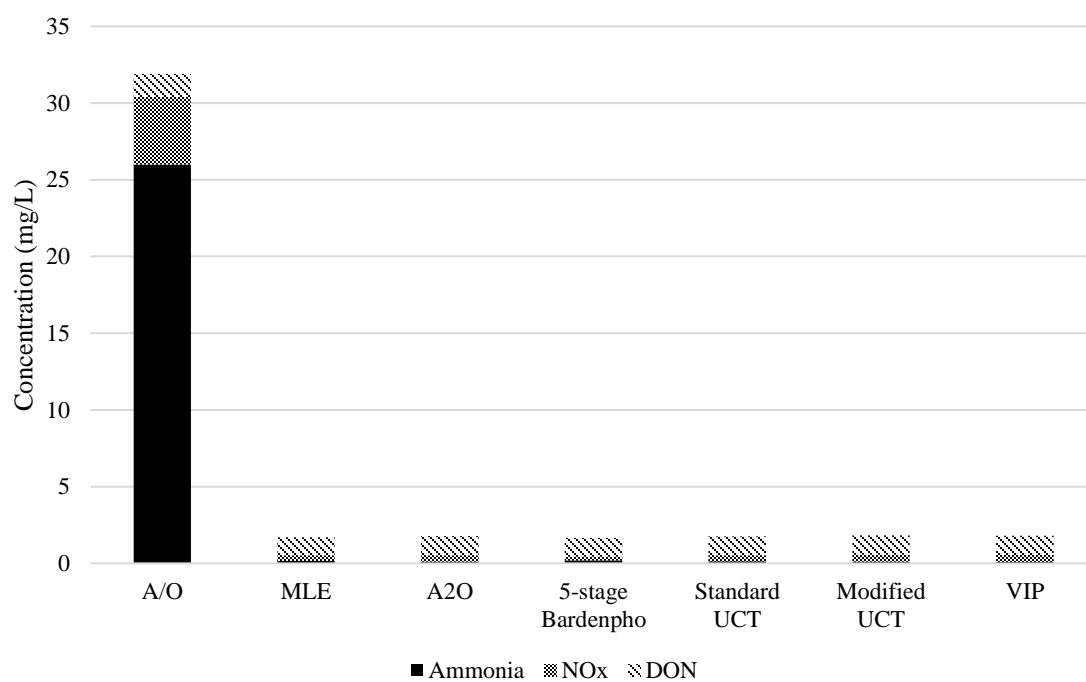


Figure 5.21: System 2 N concentrations of alternative treatment processes

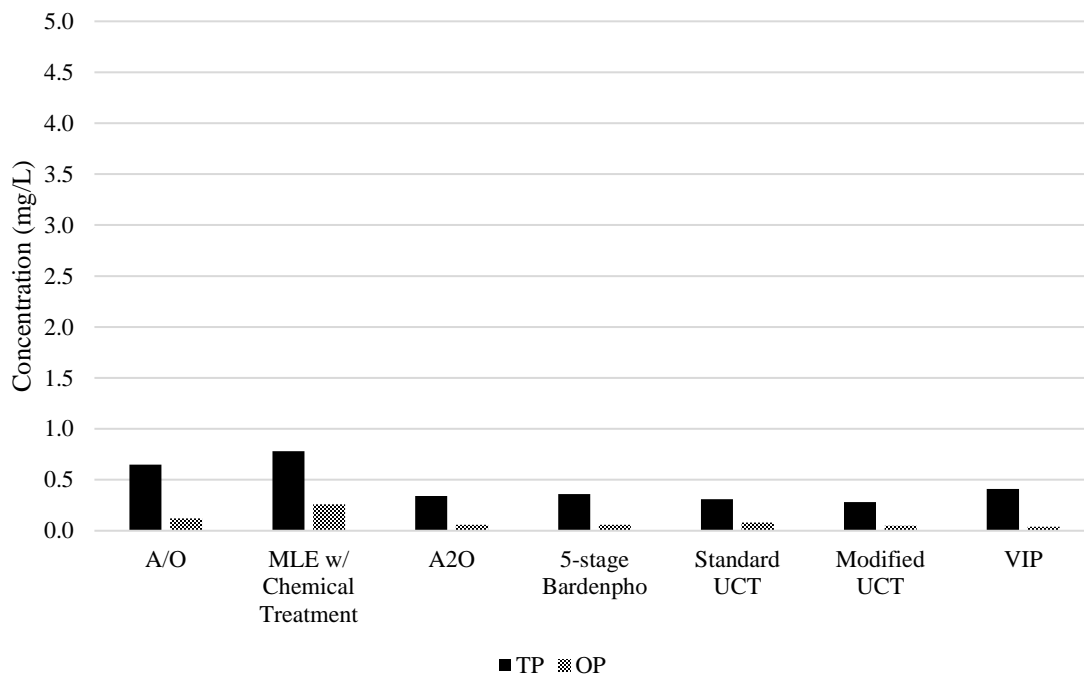


Figure 5.22: System 1 P concentrations of alternative treatment processes

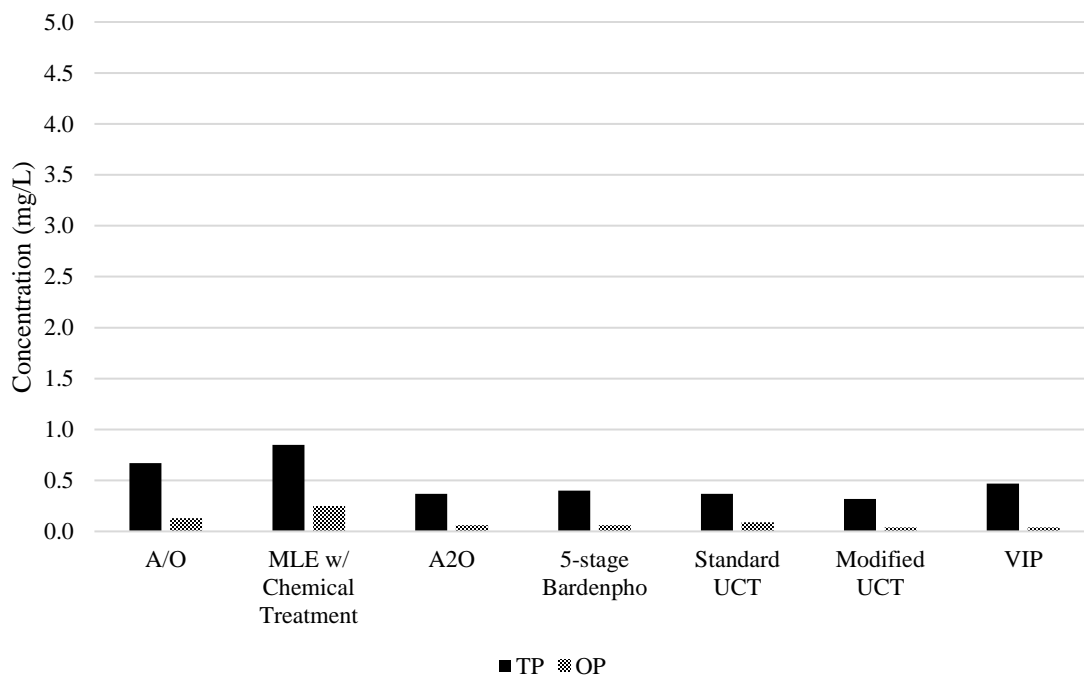


Figure 5.23: System 2 P concentrations of alternative treatment processes

The next parameter to compare is the TSS and VSS for solid concentrations in secondary effluent. The effluent solid concentrations are calculated based on the percent solids removal in the secondary clarifiers. When calibrating the model, a percent removal of 99.1% was used to mimic current operation. This value would not accurately predict solid concentrations of the alternative designs. The MLSS drastically increases within the activated sludge basins (i.e., 1,000 -1,500 mg/L in current performance to 3,000 mg/L in alternative designs). Higher solid flux to the secondary clarifiers would likely increase the solid removal performance. For this reason, the secondary solid's percent removal in the modeled secondary clarifiers was reverted back to the BioWin default value of 99.8%. Figures 5.24 and 5.25 contain the secondary effluent TSS and VSS concentrations for current and alternative treatment for Systems 1 and 2, respectively. As shown in the figures, there is an increase in performance for the combined CNP alternatives, which would be expected with a higher MLSS concentration. Lastly, COD and FCOD was compared to analyze carbon removal performance. Figures 5.26 and 5.27 show the secondary effluent concentrations for System 1 and 2, respectively. As revealed in the figures, the COD and FCOD concentrations remain consistent with that of current treatment performance.

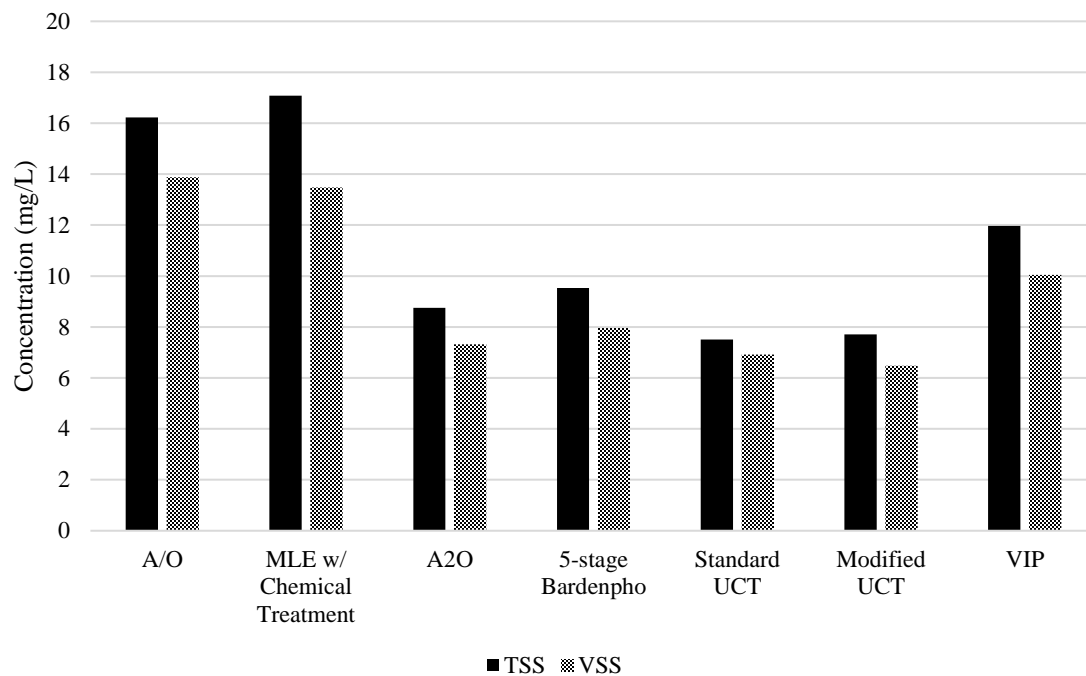


Figure 5.24: System 1 solid concentrations of alternative treatment processes

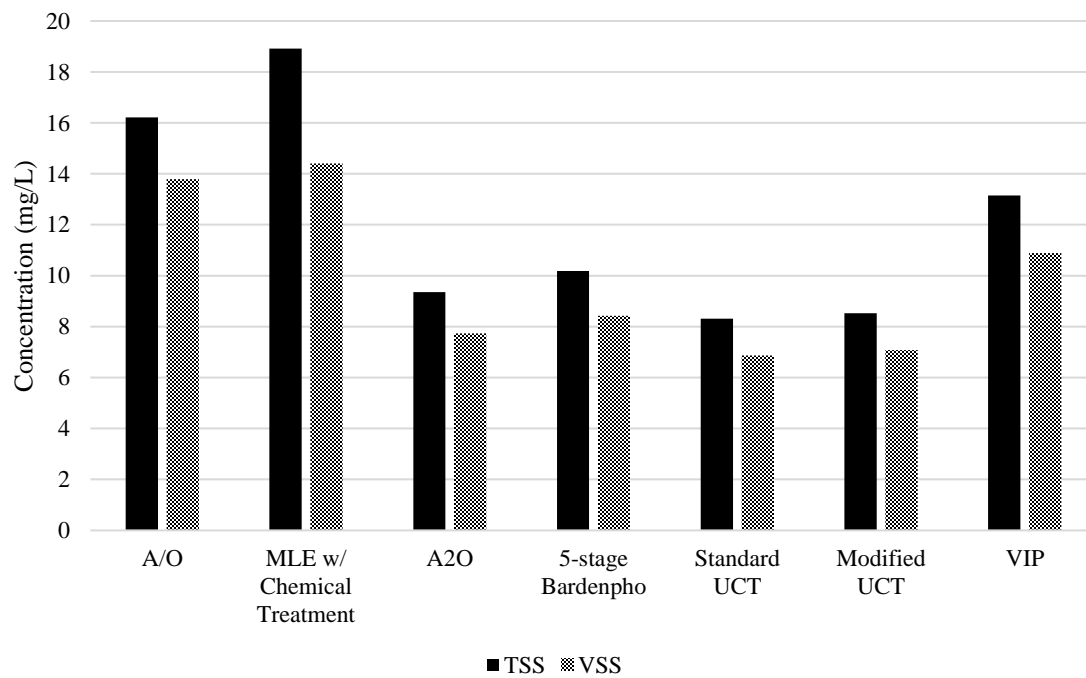


Figure 5.25: System 2 solid concentrations of alternative treatment processes

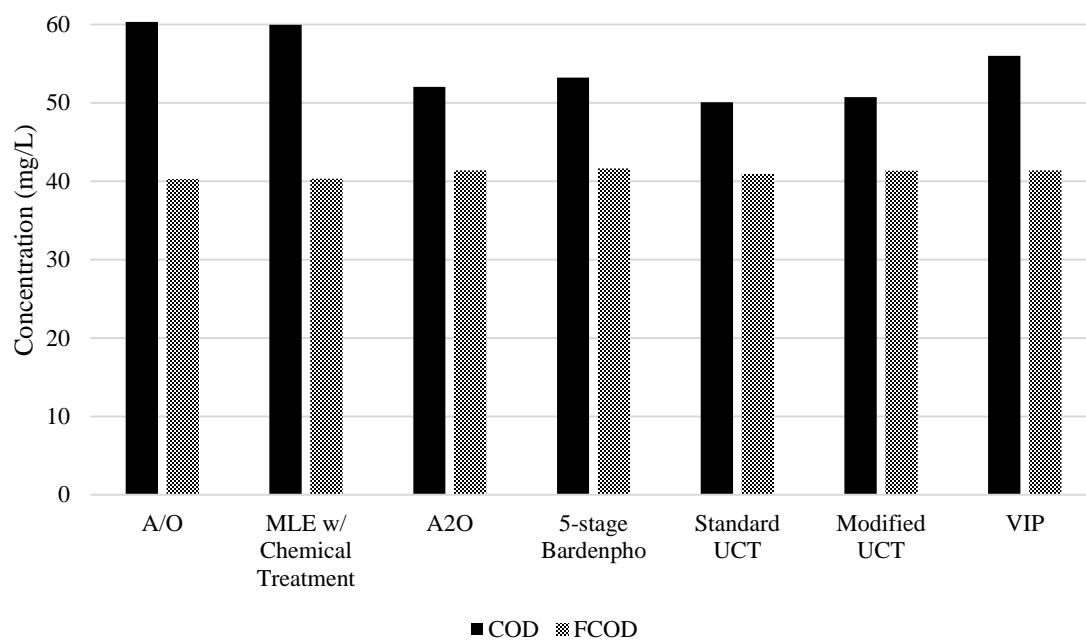


Figure 5.26: System 1 COD concentrations of alternative treatment processes

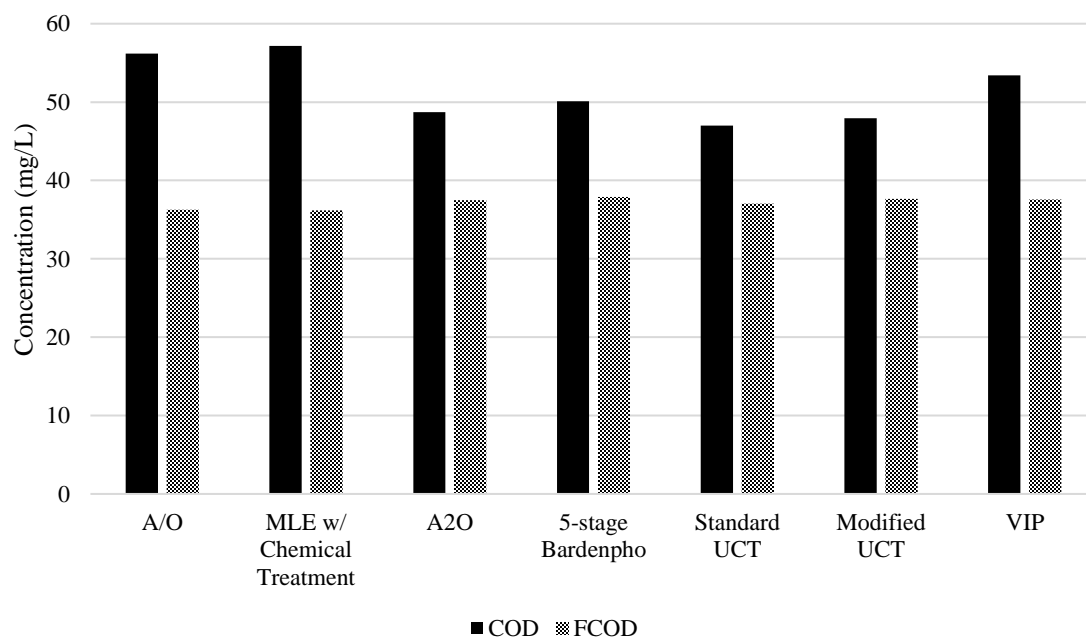


Figure 5.27: System 2 COD concentrations of alternative treatment processes

5.3.2 Aeration Demand

Following treatment performance, the next analysis was comparing the required aeration demand in the activated sludge processes for current and alternative treatment processes. It is expected that the aeration demand will significantly increase as nitrogen removal requires high aeration and there is a higher SRT in the treatment alternatives (1.8 days for existing operation compared to 10 days for CNP simulations). It should be noted that the aeration needed for the current nitrification towers is not included in the comparison. The nitrification towers use fans to provide air needed for nitrification and therefore does not have a feedback loop to maintain DO. Rather, the nitrification fans will be used in the comparison for energy, see Section 5.3.3. Figures 5.28 and 5.29 contain the aeration comparison of current and alternative treatment processes for the two treatment systems. As shown in the figures, aeration needed for alternative processes is approximately three-times as much as the current process.

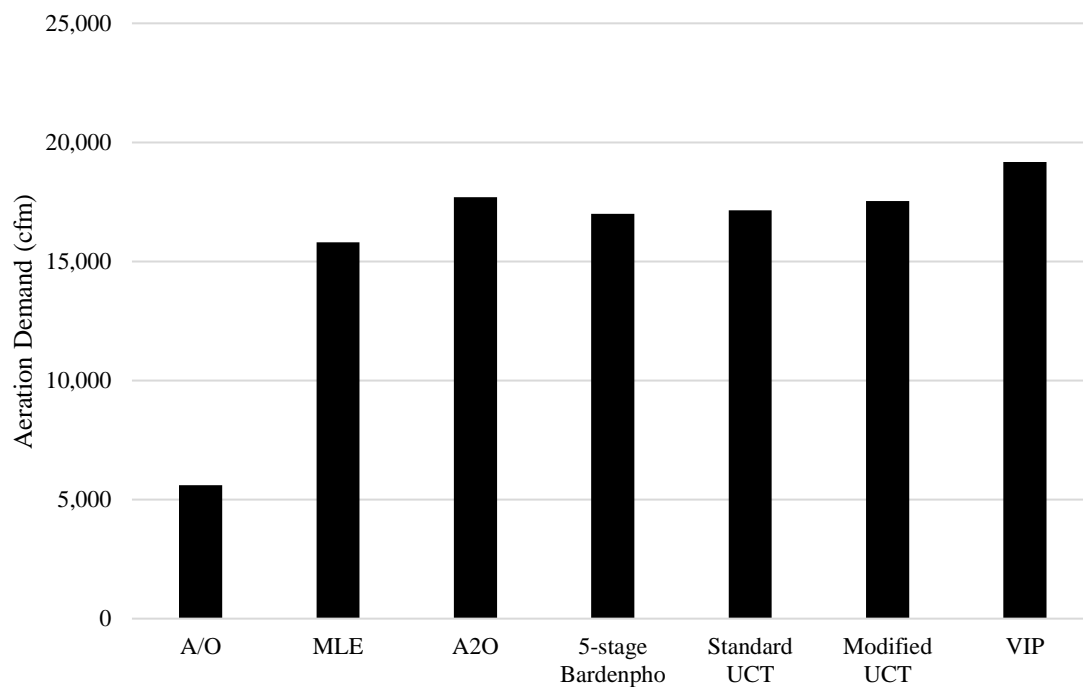


Figure 5.28: System 1 aeration demand of alternative treatment processes

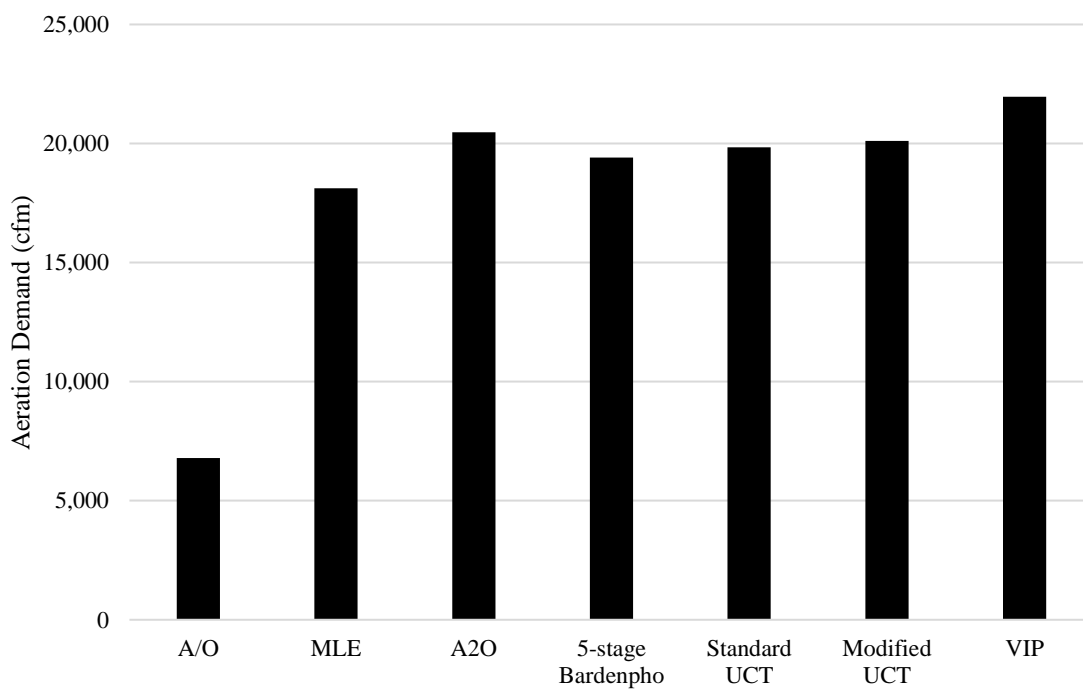


Figure 5.29: System 2 aeration demand of alternative treatment processes

5.3.3 Energy and Chemical Costs

The last analysis performed was the comparison of energy and chemical costs related to current and alternative treatment processes. For the energy and chemical costs, only the components related to nitrogen and phosphorus removal were used to determine costs. Table 5.4 provides information on components used in energy calculation for current and alternative processes.

Table 5.4: Components used for energy calculation

Component	Current Treatment	Alternative Treatment
Primary Sludge Pumps	✘	✘
Primary Fermenter Pumps		✘
RAS Pumps	✘	✘
Internal Recycle Pumps		✘
Nitrification Pumps	✘	
Nitrification Fans	✘	
Denitrification Pumps	✘	
Methanol Pumps	✘	✘ (combined CNP processes)
Alum Pumps		✘ (MLE process)
Aeration	✘	✘

Before energy costs could be calculated, the power required for IR pumps for each process needed to be determined. After discussion with TMWRF's plant engineer and manager, the only suitable location for the IR pumps would be at deck level. This would require approximately 180 feet of pipe and a 36-inch diameter pipe. Suction lift and frictional losses were analyzed in order to determine the total discharge head (TDH). The elevation difference was 17 feet and the frictional loss was determined from Equations 9 and 10, where f is the frictional loss coefficient, ϵ is the equivalent roughness (ft), d is the pipe diameter (ft), Re is the Reynolds number, h_f is the head loss due to friction (ft), L is the length (ft), V is the flow velocity (ft/s), and g is gravity (ft/s^2). It should be noted that the BioWin default pipe specification of concrete smooth (steel forms) was used for the equivalent roughness. From analysis, it was determined that the TDH was approximately 20 feet. Once the TDH was determined, Equation 11 was used to determine the pump size, knowing the IR flows in each process, where Q is the flow (gpm), H is the TDH (ft), and η is the efficiency, which was assumed to be 85%. Table 5.5 provides the information on pump sizes for current and alternative treatment processes that were used in determining energy costs. Once the pumps were sized, the values were inputted into BioWin and an energy cost of \$0.065/kWh is used, provided by the plant engineer. BioWin then determines the energy cost related to pumping and aeration and is contained in Figure 5.30. This energy comparison is for the total energy of System 1 and 2 in dollars per treated wastewater (MG).

$$\frac{1}{\sqrt{f}} = -2 \log \left(\frac{\varepsilon}{3.7d} + \frac{5.72}{Re^{0.9}} \right) \quad \text{Eq. 9}$$

$$h_f = \frac{fL}{d} \frac{V^2}{g} \quad \text{Eq. 10}$$

$$P = \frac{QH}{3960\eta} \quad \text{Eq. 11}$$

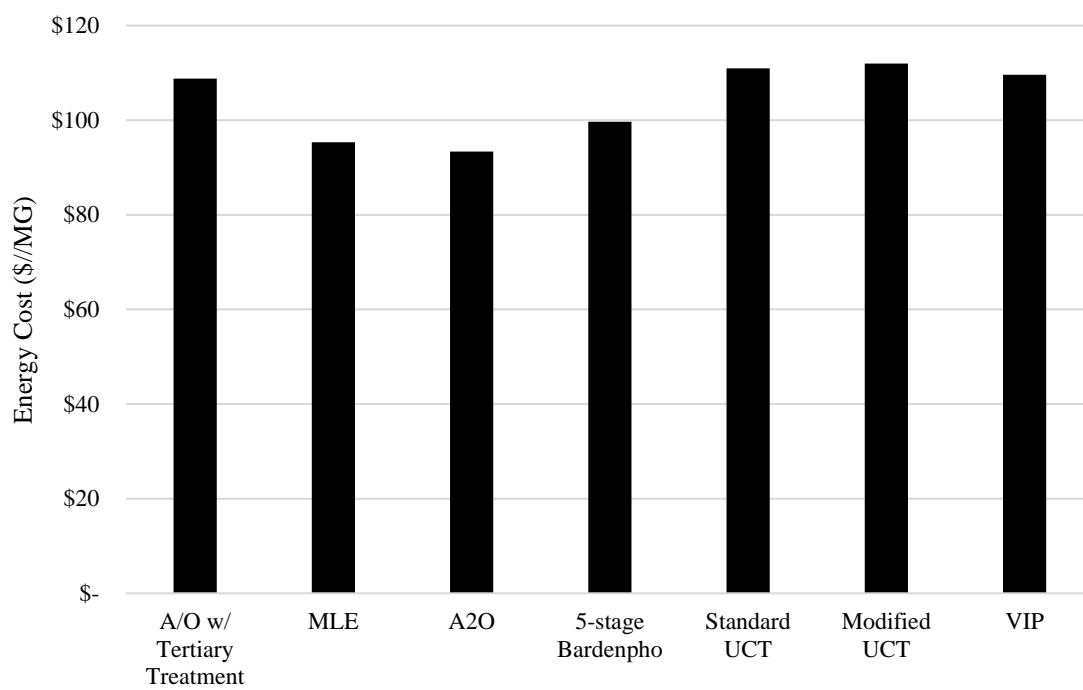


Figure 5.30: Total energy cost of alternative treatment processes

Table 5.5: Energy component specifications on current and alternative processes

Component	No.	No. per System	Power, each (hp)	System 1 Power (hp)	System 2 Power (hp)	Total Power (hp)
Primary Sludge Pumps	6	3	15	45	45	90
RAS Pumps	6	3	100	300	300	600
Nitrification Influent Pumps	3	-	250	-	-	750
Nitrification Fans	6	-	10	-	-	60
Denitrification Pumps	3	-	400	-	-	1,200
MLE IR Pumps	4	2	120	240	240	480
A2O IR Pump	4	2	100	200	200	400
5-stage Bardenpho IR Pump	4	2	120	240	240	480
Standard UCT IR Pump 1	4	2	120	240	240	480
Standard UCT IR Pump 2	4	2	80	160	160	320
Modified UCT IR Pump 1	4	2	120	240	240	480
Modified UCT IR Pump 2	4	2	80	160	160	320
VIP IR Pump 1	4	2	60	120	120	240
VIP IR Pump 2	4	2	80	160	160	320
PF Pumps	4	2	45	90	90	180
Methanol Pump	4	2	1	2	2	4
Alum Pump	4	2	1	2	2	4

For chemical costs, methanol and alum are the only chemicals used in nitrogen and phosphorus treatment. Methanol is used in the current tertiary treatment process, using an average of 3,065 gpd, and the combined CNP treatment alternatives, with methanol use outlined in Section 5.2. Alum is only used in the chemical treatment of phosphorus in the MLE treatment alternative which uses 1,000 gpd and 1,500 gpd for Systems 1 and 2, respectively. Chemical costs (February, 2020) were provided by TMWRF's plant engineer, which are \$1.46/gal for methanol and \$1.17/gal for alum. It should be noted that the costs are fairly volatile and can fluctuate. Figure 5.31 shows the chemical costs associated with the current and alternative treatment processes in dollars per treated wastewater (MG). As revealed in the figure, the chemical costs for all the alternatives are significantly less than current chemical use.

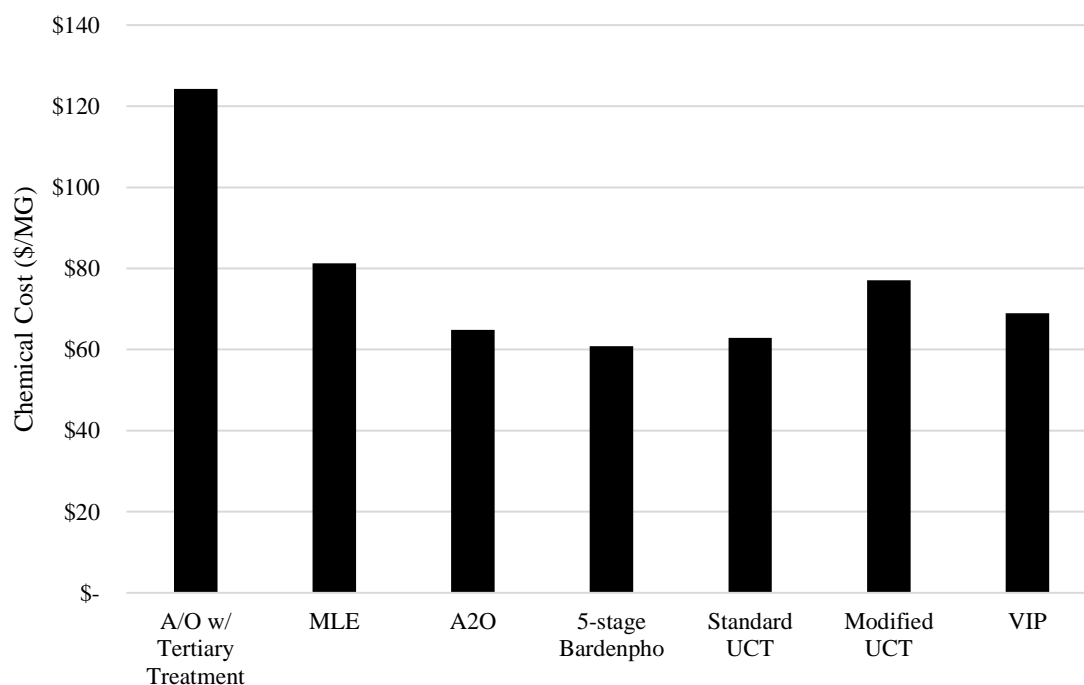


Figure 5.31: Total chemical cost of alternative treatment processes

Analyzing the data shows that the energy costs are not drastically different from the current treatment process, although tertiary treatment is no longer required, and is largely due to the implementation of the IR pumps. Chemical costs, however, are drastically reduced in the alternatives. Figures 5.32 and 5.33 show the combined energy and chemical costs of the alternatives in dollars per million gallons of treated wastewater and dollars per year, respectively. Since optimal treatment performance can be achieved under the right operating conditions, associated costs can be the defining factor in an alternative selection. The figures reveal that if the A²O or 5-stage Bardenpho alternatives is selected as the new treatment process, over \$700,000 can be saved per year.

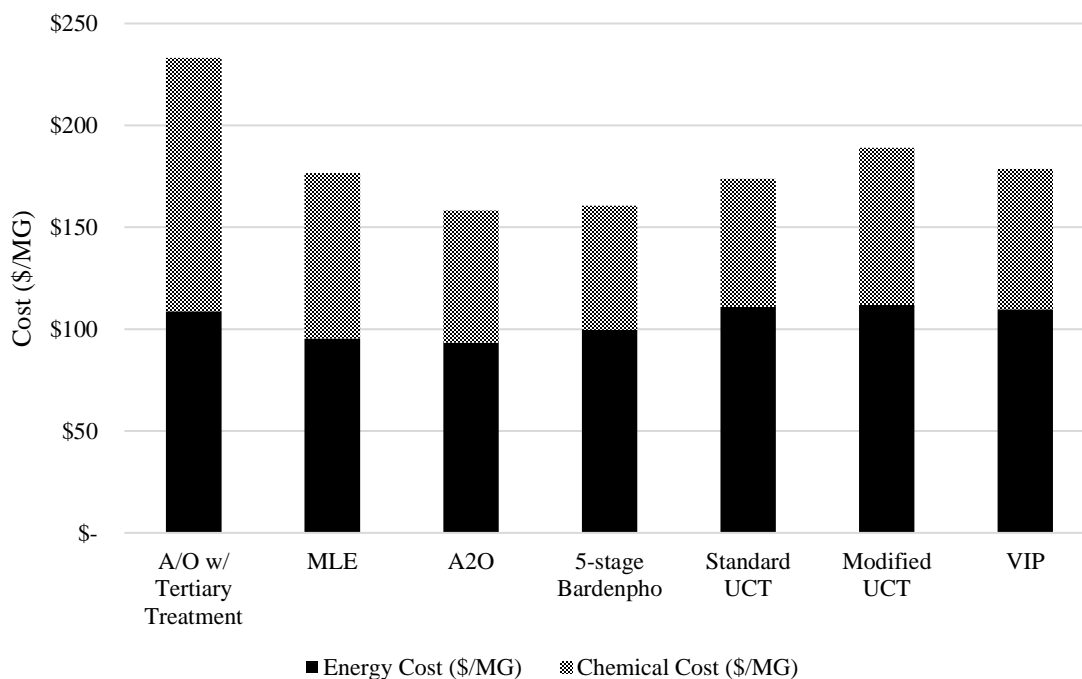


Figure 5.32: Total energy and chemical costs of alternative treatment processes

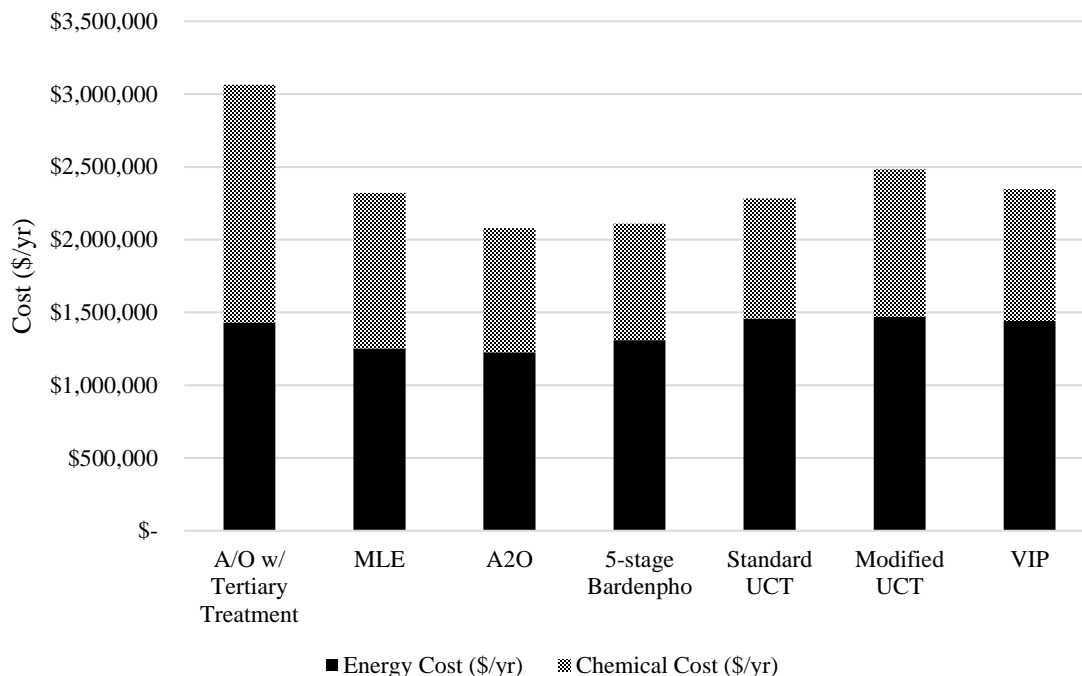


Figure 5.33: Total energy and chemical costs per year for alternative processes

5.4 Other Impacts to TMWRF Operation

If TMWRF's current treatment process were to be changed to one of the alternative treatment processes, there are other impacts to TMWRF's operation that needs to be considered. The first potential impact relates to changes with the dewatering operations due to dewaterability characteristics of the waste activated sludge. In the MLE process, phosphorus removal would be carried out by chemical treatment. The sludge would have a lower phosphorus content and the dewatering operation would likely see an increase in performance (higher biosolid TS, lower polymer consumption, lower hauling costs). The second change is also related to the MLE treatment process; since alum is used as the chemical for phosphorus treatment, sulfuric acid may not be needed in downstream processes. Sulfuric acid is used during enhanced disinfection for pH adjustment. The alum

addition for phosphorus removal would lower the pH in the effluent, decreasing or eliminating the need of sulfuric acid. TMWRF currently uses an average of 400 gpd of sulfuric acid at a cost of \$1.46/gal. Removing or decreasing the need of sulfuric acid would also lower chemical costs. One change to current operation, brought up by the plant engineer, is the potential decommissioning of TMWRF's Ostara process. The plant engineer indicated that since soluble P declines in the treatment alternatives, the Ostara process could be decommissioned which has hefty sunken costs. An increase in aeration requirements were observed in the treatment alternatives due to the nitrogen treatment and the higher SRT. TMWRF would need to install additional blowers to accommodate this increase, and currently, TMWRF has plans to construct an additional blower building. The last change to operation that needs to be considered is changes to sludge production. Sludge production comes from the primary sludge and waste activated sludge. Since enhanced primary fermentation is implemented in the treatment alternatives, the primary sludge volume decreases. On the other hand, waste activated sludge would increase due to higher MLSS concentrations and wasting rates. Figures 5.34 and 5.35 contain the BioWin predicted changes to sludge production for Systems 1 and 2, respectively.

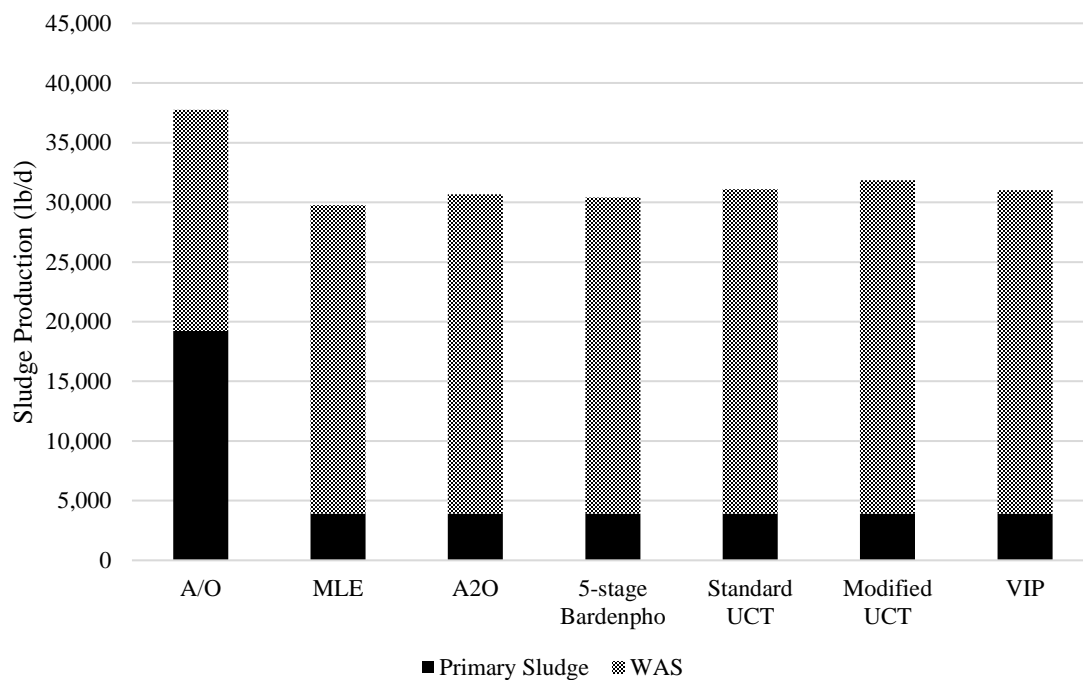


Figure 5.34: System 1 sludge production of alternative treatment processes

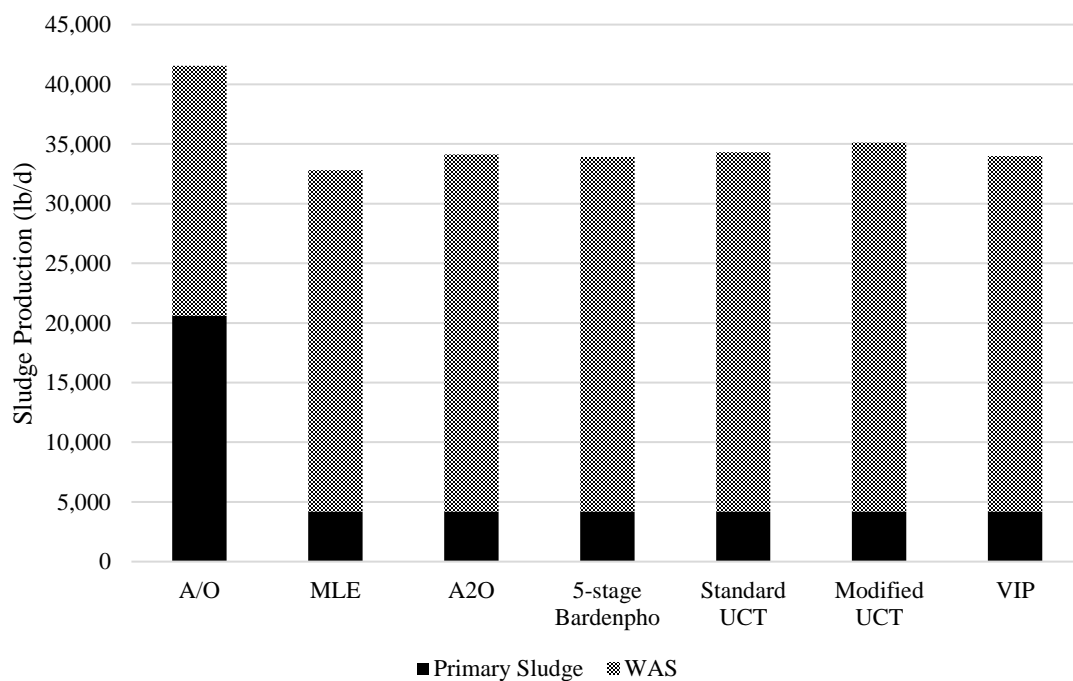


Figure 5.35: System 2 sludge production of alternative treatment processes

CHAPTER 6 : CONCLUSION AND RECOMMENDATIONS

Wastewater treatment is essential to maintaining environmental water quality due to negative impacts wastewater could have if left untreated. If left untreated, wastewater can be discharged into surface waters comprising of complex mixture of different contaminants, such as organic matter, nutrients, solids, microorganisms and bacteria, metals, salt, and pharmaceutical drugs. These contaminants can cause water toxicity, eutrophication, hypoxia, taste and odor issues, and be detrimental to the environment and aquatic systems. When properly treated, wastewater can be a viable resource used for irrigation, groundwater recharge, and potable reuse, alleviating water scarcity issues.

This project focuses primarily on biological treatment of nitrogen and phosphorus. Elevated nutrient levels in wastewater effluents lead to harmful water conditions such as eutrophication and hypoxia. There are many ways nutrients can be removed from wastewater and consist of physical, chemical, or biological treatment. Physical treatment incorporates the nitrogen and phosphorus in biosolids and is removed by screening or sedimentation. Chemical treatment generally refers to phosphorus treatment. Aluminum sulfate and ferric chloride are common chemicals used in chemical precipitation. The chemicals create phosphorus rich precipitant solids and can be removed from systems through physical means. Biological treatment is the most common form of nutrient treatment and generally consists of suspended or attached growth systems where microorganisms facilitate nutrient removal.

BioWin, a modeling software for wastewater treatment, has many applications that can evaluate various scenarios including selection of optimal treatment processes, reduce

capital investments, energy consumption and operating costs, decisions on plant operation, and to build models for emerging technologies. The modeling software can also be used to teach students and plant operators of wastewater fundamentals. BioWin was used in this project to develop a process model of the Truckee Meadows Water Reclamation Facility and evaluate combined CNP treatment alternatives.

When developing the BioWin model, the first step was to analyze historical data to observe wastewater loading trends. Analyzing the data revealed that TMWRF had maximum loads in the fall and winter seasons and initial sampling campaigns were developed during the fall (October 28 – November 8, 2018) and winter (January 27 – February 7, 2019). The purpose of the sampling campaigns was to capture influent concentrations and flows needed for model calibration. Following initial sampling, analysis revealed that there was not adequate data to accurately calibrate the model. The initial campaigns did not capture recycle streams, such as the gravity thickener, denite waste, TWAS, and PRS recycle streams, and the wastewater characteristics were not correct. To incorporate the recycle streams, an extensive summer sampling campaign (June 23 – July 6, 2019) was developed in collaboration with Brown & Caldwell and TMWRF to capture all influent loads. Following sampling and data corrections, the model was configured based on TMWRF's secondary biological treatment (primary clarifiers, activated sludge, and secondary clarifiers) and the data were used to determine wastewater characteristics and fractions of all influent streams and inputs for the model. Once physical parameters and influent loads were incorporated into the model, the next step was to calibrate the model, which consisted of solids, nutrients, and aeration calibration. After model calibration, the BioWin predicted values were compared to measured data from the summer sampling campaign to determine

model accuracy, and analysis showed that most parameters were within the typical difference of 10%. Although the fall and winter campaigns lacked adequate data, the model was used to evaluate performance during these seasons. With proper assumptions the models were able to predict approximately 80% of the parameters for fall and winter measured data.

Following model calibration and validation, the calibrated model was used to evaluate different treatment alternatives. The first alternative evaluated was the modification of TMWRF's current A/O process to an MLE process with chemical treatment. The MLE processes performs nitrification and denitrification in the activated sludge by incorporating an internal nitrate recycle stream. An SRT of 10 days was selected and recycle ratio analyses were performed to determine ideal operating conditions for the MLE process and analysis showed that a 300% IR and 75% RAS was optimal. Analysis showed that the process was carbon limited, but by enhancing primary fermentation and increasing carbon and VFAs to the activate sludge could increase nitrogen removal by 35%. A post-denitrification reactor was included in the MLE model to reduce the remaining nitrogen to acceptable levels (<2 mg/L) in order to commence with phosphorus removal by chemical means. Aluminum sulfate was selected as the chemical for phosphorus treatment due to the fact that it is common use in the industry and its existing use at TMWRF. Alum addition was incorporated into the models prior to the secondary clarifiers and the models revealed that alum doses of 1,000 and 1,500 gpd was needed to reduce phosphorus to typical levels of less than 1 mg/L.

The other treatment alternatives evaluated using the calibration models was combined CNP treatment. Activated sludge processes evaluated were the A²O, 5-stage Bardenpho, Standard and Modified UCT, and the VIP processes. These processes incorporate nitrogen and phosphorus removal in the activated sludge by having anaerobic, anoxic, and aerobic zones. Since these processes treat nitrogen and phosphorus simultaneously, the activated sludge volumes are significantly larger than that of the A/O and MLE processes and new activated sludge tanks would need to be constructed. The combined CNP activated sludge processes were design for 20 mgd per system and used typical HRT values. An SRT of 10 days was selected for the processes as it resided within the typical values for each process and to mirror the MLE process. Enhanced primary fermentation was utilized in the processes to increase nitrogen removal. Similar to the MLE process, there was need for post-denitrification. In order to minimize the volume of the post-denitrification tank, methanol was used as a carbon source, rather than relying on endogenous decay. The 5-stage Bardenpho process does not require a post-denitrification tank as the process already incorporates methanol addition; however, the models showed that the other processes did require the post-denitrification tank. Model predicted values revealed that nitrogen and phosphorus were reduced to acceptable levels (<2 mg/L for nitrogen and <1 mg/L for phosphorus). The enhanced primary fermentation also showed that the increased VFAs to the activated sludge further increased phosphorus removal, resulting in concentrations lower than current operation.

Following treatment, aeration demand and energy and chemical costs were investigated. Aeration requirements for the CNP activated sludge process significantly increased, tripling in values compared to the existing system. The higher value was a result of nitrogen

removal within the activated sludge tanks and the longer SRT (10 days compared to current 1.8 days). This increase would likely cause need for additional blowers at TMWRF. When analyzing energy cost, the cost associated with nitrogen and phosphorus removal were investigated. Costs associated with energy and chemicals are calculated at \$0.065/kWh for energy, and \$1.46/gal and \$1.17/gal for methanol and alum, respectively. For current plant operation, the calculated energy costs are associated with the primary sludge pumps, RAS pumps, nitrification tower pumps, nitrification tower fans, denitrification filter pumps, methanol pumps, and the energy required for aeration. The treatment alternatives evaluated eliminate the nitrification tower and denitrification filter pumps and fans, but adds the internal recycle and primary fermentation pumps, and methanol and alum pumps for the activated sludge processes. Methanol was the only chemical used in cost calculations for current operation and the combined CNP alternatives, while alum was used in the MLE with chemical treatment alternative. Calculations show that energy costs are not too different from current operation and is primarily due to the elimination of tertiary treatment. The addition of internal recycle flows and increased aeration in the CNP systems off-set many of those costs. Chemical costs, however, significantly decrease in the alternatives, with the A²O and 5-stage Bardenpho processes having the lowest associated costs. When combining energy and chemical costs associated with nitrogen and phosphorus removal, the models show that the A²O and 5-stage Bardenpho processes can decrease annual costs by over \$700,000 per year. When selecting an alternative for future expansion or modifications, operational costs and capital investment can be the defining factors. Although treatment can be optimized in all alternatives, the A²O and 5-stage Bardenpho processes would be optimal due to its associated operational costs and lower

footprint compared to the UCT processes. The MLE process is also a viable alternative if chemical treatment for phosphorus is preferred.

Recommendations for further studies would be to select an optimal treatment alternative and incorporate a pilot-study to evaluate actual performance. TMWRF's System 3 is currently being used as a sidestream centrate treatment, but the treatment train could be modified to accommodate a pilot-study. Another study, as discussed with the plant engineer and manager, would be to use BioWin to model the System 3 centrate treatment and evaluate treatment efficiency. The final recommendation would be to perform another fall and winter sampling campaign and incorporate the recycle streams. Model predicted values for the fall and winter revealed that approximately 20% of parameters did not fall within typical differences of measured values. This is largely due to the assumptions made in the fall and winter as there were inadequate data collected in those campaigns. Overall, BioWin is a viable tool when evaluating treatment alternatives and can be used to influence treatment plant decisions.

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APPENDIX A – 2017 TMWRF PLANT INFLUENT DATA

January

	Daily Composite												Weekly Composite	
	Flow - North Trunk	Flow - South Trunk	BOD	COD	TSS	TDS	Ammonia	Nitrite	Nitrate	OP	TP	Alkalinity	TKN	SKN
<i>Units</i>	<i>MGD</i>	<i>MGD</i>	<i>mg/L - O₂</i>	<i>mg/L - O₂</i>	<i>mg/L</i>	<i>mg/L</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L - P</i>	<i>mg/L - P</i>	<i>mg/L - CaCO₃</i>	<i>mg/L -N</i>	<i>mg/L -N</i>
1/1/2017	11.9	14.7		579.0	243.0		31.0	0.1		3.5	6.1			
1/2/2017	12.0	13.8		430.0	252.0		30.1	0.1		3.5	5.2			
1/3/2017	11.8	14.2		457.0	182.0		29.5	0.1		3.1	4.9	206.5		
1/4/2017	14.6	17.3	242.0	368.0	223.0	350.0	23.7	0.1		3.0	5.2			
1/5/2017	13.2	16.0	297.0	490.0	238.0		25.8	0.1		3.4	5.8			
1/6/2017	12.8	15.7		357.0	196.0		28.5	0.1		3.5	5.0			
1/7/2017	12.5	13.9		304.0	222.0		30.2	0.1		3.7	5.7		42.9	32.6
1/8/2017	14.9	22.4		258.0	252.0		20.8	0.0		3.6	4.9			
1/9/2017	19.4	24.7		133.0	242.0		17.2	1.0	0.2	2.8	3.8			
1/10/2017	20.5	21.7		249.0	187.0	466.0	22.7	0.0		3.4		194.5		
1/11/2017	22.1	22.3		255.0	129.0		16.8	0.8		3.0				
1/12/2017	17.8	20.8	153.0	384.0	163.0		25.8	0.1		5.1				
1/13/2017	19.0	20.7		221.0	198.0		28.9	0.1	0.1	4.3				
1/14/2017	16.7	19.4		213.0	196.0		30.0	0.0		5.3			32.3	32.5
1/15/2017	17.8	19.0		339.0	272.0		32.8	0.1	0.1	4.9				
1/16/2017	16.8	19.7		327.0	184.0		36.0	0.1		4.7				
1/17/2017	16.9	18.6	227.0	299.0	240.0	459.0	30.0	0.0		4.9		211.3		
1/18/2017	15.0	17.4	261.0	442.0	195.0		26.7	0.1		3.8				
1/19/2017	14.6	16.9	220.0	355.0	157.0		25.1	0.1		3.0				
1/20/2017	14.5	16.5		441.0	215.0		24.2	0.1		3.1				
1/21/2017	14.3	15.5		480.0	195.0		25.1	0.0		3.2			43.8	32.4
1/22/2017	15.0	16.9		286.0	167.0		24.9	0.1		2.9				
1/23/2017	14.8	16.7		373.0	211.0		25.1	0.0		2.7				
1/24/2017	14.4	16.3	231.0	422.0	193.0	470.0	25.0	0.1		3.0		214.8		
1/25/2017	14.2	16.1	250.0	349.0	190.0		26.1	0.1		3.3				
1/26/2017	14.0	16.0	236.0	582.0	184.0		27.3	0.1		3.3				
1/27/2017	14.1	15.7		449.0	195.0		26.5	0.1	0.2	3.4				
1/28/2017	13.9	15.1		487.0	202.0		27.2	0.1		3.3			37.8	28.7
1/29/2017	14.3	16.2		340.0	214.0		26.5	0.0		3.3				
1/30/2017	14.2	16.9		383.0	170.0		25.0	0.1		2.7				
1/31/2017	13.2	14.4	232.0	516.0	197.0	486.0	26.5	0.1		3.1		216.3	39.3	30.1

February

	Daily Composite												Weekly Composite	
	Flow - North Trunk	Flow - South Trunk	BOD	COD	TSS	TDS	Ammonia	Nitrite	Nitrate	OP	TP	Alkalinity	TKN	SKN
<i>Units</i>	<i>MGD</i>	<i>MGD</i>	<i>mg/L - O₂</i>	<i>mg/L - O₂</i>	<i>mg/L</i>	<i>mg/L</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L - P</i>	<i>mg/L - P</i>	<i>mg/L - CaCO₃</i>	<i>mg/L -N</i>	<i>mg/L -N</i>
2/1/2017	13.5	15.4	238.0	422.0	170.0		26.9	0.1		3.4	5.0			
2/2/2017	13.2	15.1	283.0	338.0	208.0		27.0	0.1		2.5	5.9			
2/3/2017	13.4	15.1		312.0	226.0		26.4	0.1	0.1	3.1	5.5			
2/4/2017	13.3	14.6		337.0	164.0		27.1	0.1		3.3	5.0		41.0	31.7
2/5/2017	13.9	16.2		310.0	227.0		25.8	0.1		2.8	5.2			
2/6/2017	13.4	15.6		422.0	197.0		27.7	0.1		3.0	4.6			
2/7/2017	13.5	15.9		447.0	170.0	457.0	27.4	0.0		2.7	4.6	201.5		
2/8/2017	13.5	16.7	322.0	251.0	293.0		25.3	0.1		3.2	5.6			
2/9/2017	13.3	15.7	325.0	298.0	292.0		26.4	0.1		3.3	6.1			
2/10/2017	17.2	24.7	170.0	164.0	194.0		15.8	0.2		2.4				
2/11/2017	16.8	19.8		670.0	178.0		22.5	0.0		2.8			39.6	27.3
2/12/2017	15.0	17.6		273.0	188.0		25.2	0.0		2.8				
2/13/2017	14.4	17.2		308.0	173.0		24.7	0.1		2.8				
2/14/2017	13.8	16.0	226.0	399.0	176.0	477.0	25.8	0.0		3.0		216.2		
2/15/2017	14.0	16.7	235.0	379.0	155.0		24.6	0.0		3.3				
2/16/2017	13.5	15.3	240.0	419.0	233.0		24.8	0.1		2.8				
2/17/2017	14.0	16.5		266.0	210.0		26.3	0.1	0.2	2.8				
2/18/2017	13.8	16.1		260.0	152.0		26.0	0.0		3.3			36.2	29.4
2/19/2017	14.1	16.6		457.0	175.0		24.8	0.1		2.8				
2/20/2017	16.7	18.9		420.0	213.0		22.0	0.1		2.4				
2/21/2017	20.8	21.9	152.0	131.0	150.0	366.0	13.7	0.3	0.5	1.9		152.8		
2/22/2017	21.6	22.2	179.0	498.0	135.0		16.7	0.3	0.6	2.2				
2/23/2017	19.7	21.1	178.0	249.0	137.0		19.7	0.3		2.1				
2/24/2017	17.0	19.5		301.0	169.0		22.3	0.1	0.2	2.7				
2/25/2017	16.3	18.1		385.0	129.0		22.8	0.0		2.8			32.1	24.1
2/26/2017	16.2	18.8		267.0	156.0		24.1	0.0		3.0				
2/27/2017	16.8	18.8		286.0	187.0		22.6	0.0		2.5				
2/28/2017	15.2	16.4	230.0	300.0	174.0	494.0	23.8	0.1		2.5		218.4	36.8	28.8

March

	Daily Composite												Weekly Composite	
	Flow - North Trunk	Flow - South Trunk	BOD	COD	TSS	TDS	Ammonia	Nitrite	Nitrate	OP	TP	Alkalinity	TKN	SKN
<i>Units</i>	<i>MGD</i>	<i>MGD</i>	<i>mg/L - O₂</i>	<i>mg/L - O₂</i>	<i>mg/L</i>	<i>mg/L</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L - P</i>	<i>mg/L - P</i>	<i>mg/L - CaCO₃</i>	<i>mg/L -N</i>	<i>mg/L -N</i>
3/1/2017	15.3	17.6	239.0	380.0	178.0		23.6	0.0		2.6	4.5			
3/2/2017	14.9	16.5	206.0	417.0	165.0		24.4	0.1		2.8	4.6			
3/3/2017	14.8	16.9		258.0	177.0		24.9	0.1		3.1	5.3			
3/4/2017	14.5	15.5		280.0	172.0		24.1	0.0		2.8	4.6		37.3	28.9
3/5/2017	16.0	18.5		299.0	187.0		23.5	0.1		2.4	4.1			
3/6/2017	15.1	17.1		385.0	167.0		23.5	0.0		2.6	3.9			
3/7/2017	14.3	15.8	186.0	446.0	150.0	467.0	24.9	0.0		2.8	4.4	225.6		
3/8/2017	14.4	16.5	252.0	325.0	232.0		23.6	0.1		2.8	5.8			
3/9/2017	14.0	15.6	314.0	592.0	303.0		23.7	0.1		2.7	6.2			
3/10/2017	13.9	15.6		310.0	292.0		24.2	0.1		2.9				
3/11/2017	13.9	15.2		332.0	210.0		25.1	0.1	0.3	3.4			40.2	29.5
3/12/2017	14.4	16.3		363.0	178.0		25.0	0.1		3.1				
3/13/2017	14.2	16.2		316.0	204.0		26.2	0.1		3.0				
3/14/2017	13.6	14.7	283.0	464.0	249.0	450.0	26.3	0.1		2.6		224.7		
3/15/2017	13.7	15.0	214.0	380.0	170.0		26.2	0.1		2.6				
3/16/2017	13.5	15.1	266.0	447.0	211.0		25.4	0.1		3.4				
3/17/2017	14.5	15.2		745.0	349.0		27.0	0.1		3.6				
3/18/2017	14.7	12.7		477.0	196.0		25.8	0.0		3.1			41.9	30.4
3/19/2017	15.0	14.3		538.0	197.0		28.3	0.0		2.9				
3/20/2017	14.9	13.8		419.0	182.0		25.0	0.1		2.4				
3/21/2017	15.7	14.3	229.0	462.0	195.0	446.0	23.9	0.1		2.7		206.7		
3/22/2017	16.1	13.7	231.0	372.0	135.0		24.1	0.1		2.8				
3/23/2017	15.4	14.3	216.0	440.0	211.0		23.6	0.1		2.9				
3/24/2017	15.3	14.1		486.0	228.0		24.4	0.1	0.2	3.0				
3/25/2017	15.7	14.0		424.0	160.0		25.0	0.0		2.8			37.5	28.1
3/26/2017	16.1	13.4		318.0	182.0		27.8	0.0		3.0				
3/27/2017	16.1	14.2		470.0	210.0		24.9	0.0		2.8				
3/28/2017	15.6	14.3	250.0	489.0	193.0	457.0	25.6	0.0		2.3		215.5		
3/29/2017	15.6	13.9	252.0	488.0	228.0	437.0	24.1	0.1		2.7				
3/30/2017	16.2	13.7	274.0	471.0	179.0	444.0	25.3	0.1		2.8				
3/31/2017	15.9	13.2		445.0	192.0	429.0	25.9	0.1	0.1	3.2			38.3	29.7

April

	Daily Composite												Weekly Composite	
	Flow - North Trunk	Flow - South Trunk	BOD	COD	TSS	TDS	Ammonia	Nitrite	Nitrate	OP	TP	Alkalinity	TKN	SKN
<i>Units</i>	<i>MGD</i>	<i>MGD</i>	<i>mg/L - O₂</i>	<i>mg/L - O₂</i>	<i>mg/L</i>	<i>mg/L</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L - P</i>	<i>mg/L - P</i>	<i>mg/L - CaCO₃</i>	<i>mg/L -N</i>	<i>mg/L -N</i>
4/1/2017	16.1	14.2		486.0	191.0	438.0	25.7	0.0		3.3	4.9		40.8	31.0
4/2/2017	16.3	13.3		316.0	164.0	434.0	26.5	0.0		2.6	4.6			
4/3/2017	15.9	15.0		417.0	208.0	433.0	24.9	0.0		2.7	5.6			
4/4/2017	15.5	13.2	270.0	447.0	177.0	448.0	26.9	0.0		2.5	5.1	213.7		
4/5/2017	15.3	13.8	218.0	497.0	164.0		26.6	0.1		3.0	5.2			
4/6/2017	15.5	12.5	233.0	333.0	182.0		26.5	0.1		2.4	5.1			
4/7/2017	16.7	16.0		295.0	240.0		24.6	0.2		3.0	5.8			
4/8/2017	17.5	13.9		484.0	211.0		24.3	0.0		3.2	5.0		41.0	33.9
4/9/2017	17.3	15.3		305.0	237.0		25.2	0.1		2.8	4.9			
4/10/2017	16.6	15.4		831.0	198.0		25.0	0.1		3.3				
4/11/2017	16.1	13.6	245.0	522.0	169.0	450.0	26.5	0.1		2.9		242.6		
4/12/2017	16.0	14.0	232.0	399.0	171.0		25.4	0.1		2.5				
4/13/2017	16.1	13.1	250.0	509.0	179.0		26.4	0.1		2.9				
4/14/2017	16.2	14.8		345.0	235.0		25.2	0.2		3.2				
4/15/2017	16.5	13.5		283.0	194.0		25.3	0.0		3.2			40.3	30.0
4/16/2017	16.6	14.0		330.0	182.0		25.2	0.0		3.0				
4/17/2017	15.8	14.0		322.0	170.0		26.7	0.1		2.6				
4/18/2017	16.1	13.8	275.0	362.0	217.0	406.0	24.2	0.1		2.8		217.6		
4/19/2017	16.2	13.3	261.0	290.0	173.0		24.9	0.1		2.7				
4/20/2017	16.0	13.8	246.0	396.0	191.0		26.5	0.1		2.5				
4/21/2017	15.4	13.7		388.0	216.0		25.5	0.1	0.1	3.5				
4/22/2017	15.7	13.7		411.0	146.0		25.8	0.0		3.1			39.0	31.0
4/23/2017	16.3	13.9		327.0	173.0		24.0	0.1		2.9				
4/24/2017	15.9	14.7		439.0	232.0		25.7	0.1		2.4				
4/25/2017	15.6	13.4	282.0	456.0	197.0	434.0	26.1	0.1		3.0		211.3		
4/26/2017	15.5	15.0	274.0	483.0	286.0		23.3	0.1		2.8				
4/27/2017	15.7	14.0	255.0	460.0	195.0		25.5	0.1		2.4				
4/28/2017	16.0	14.1		445.0	183.0		26.5	0.1		3.1				
4/29/2017	16.2	13.3		435.0	153.0		26.0	0.0		3.2			39.4	29.7
4/30/2017	16.4	14.7		408.0	184.0		26.3	0.0		3.0			39.7	30.8

May

	Daily Composite												Weekly Composite	
	Flow - North Trunk	Flow - South Trunk	BOD	COD	TSS	TDS	Ammonia	Nitrite	Nitrate	OP	TP	Alkalinity	TKN	SKN
<i>Units</i>	<i>MGD</i>	<i>MGD</i>	<i>mg/L - O2</i>	<i>mg/L - O2</i>	<i>mg/L</i>	<i>mg/L</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L - P</i>	<i>mg/L - P</i>	<i>mg/L - CaCO3</i>	<i>mg/L -N</i>	<i>mg/L -N</i>
5/1/2017	15.8	14.7		461.0	195.0		24.8	0.1		2.7	4.4			
5/2/2017	15.8	13.4	306.0	386.0	182.0	412.0	24.1	0.1		2.9	4.8	206.7		
5/3/2017	15.8	13.1	248.0	309.0	187.0		25.6	0.1		3.3	5.0			
5/4/2017	15.9	12.8	227.0	337.0	174.0		25.8	0.1		2.9	5.1			
5/5/2017	15.7	13.9		494.0	192.0		25.8	0.1		3.5	5.4			
5/6/2017	17.5	11.9		382.0	219.0		25.6	0.1		3.0	5.0		37.6	29.0
5/7/2017	17.5	15.5		283.0	228.0		25.5	0.0		2.8	4.7			
5/8/2017	16.6	15.1		501.0	191.0		25.8	0.1		2.8	4.1			
5/9/2017	16.2	13.6	234.0	556.0	209.0	423.0	25.1	0.1		2.7	4.7	200.7		
5/10/2017	16.3	13.0	260.0	395.0	193.0		26.2	0.1		3.2				
5/11/2017	16.2	13.8	235.0	249.0	223.0		26.3	0.1		3.0				
5/12/2017	16.2	12.7		461.0	215.0		16.0	0.2		3.1				
5/13/2017	17.1	14.1		380.0	208.0		25.4	0.1		2.7			38.7	28.7
5/14/2017	16.9	14.3		300.0	214.0		26.6	0.1		3.2				
5/15/2017	16.6	14.6		513.0	188.0		24.8	0.1		2.8				
5/16/2017	16.2	14.0	233.0	482.0	162.0	410.0	27.3	0.1		3.1		208.4		
5/17/2017	16.2	13.9	231.0	383.0	133.0		26.2	0.1		3.1				
5/18/2017	16.1	14.2	277.0	411.0	199.0		25.9	0.1		3.1				
5/19/2017	16.0	13.8		312.0	188.0		26.6	0.2		3.2				
5/20/2017	16.1	13.0		326.0	155.0		26.4	0.1		2.8			38.5	30.7
5/21/2017	16.2	14.2		414.0	290.0		27.5	0.1		3.1				
5/22/2017	15.7	14.3		453.0	188.0		25.0	0.1		2.5				
5/23/2017	15.6	13.5	318.0	329.0	172.0	396.0	24.1	0.0		3.1		199.0		
5/24/2017	15.7	13.3	329.0	308.0	179.0		26.2	0.1		3.1				
5/25/2017	15.6	13.9	252.0	402.0	157.0		26.2	0.1		3.0				
5/26/2017	15.6	13.5		475.0	162.0		26.7	0.1		3.1				
5/27/2017	15.8	12.5		413.0	186.0		27.5	0.1		3.0			38.0	28.4
5/28/2017	16.1	15.3		336.0	201.0		26.7	0.1		2.8				
5/29/2017	16.3	12.6		228.0	215.0		24.1	0.1		2.8				
5/30/2017	15.7	14.5	234.0	423.0	170.0	416.0	24.8	0.1		2.5		204.3		
5/31/2017	15.4	13.5	235.0	326.0	186.0		26.6	0.2	0.3	3.1			34.9	27.6

June

	Daily Composite												Weekly Composite	
	Flow - North Trunk	Flow - South Trunk	BOD	COD	TSS	TDS	Ammonia	Nitrite	Nitrate	OP	TP	Alkalinity	TKN	SKN
<i>Units</i>	<i>MGD</i>	<i>MGD</i>	<i>mg/L - O₂</i>	<i>mg/L - O₂</i>	<i>mg/L</i>	<i>mg/L</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L - P</i>	<i>mg/L - P</i>	<i>mg/L - CaCO₃</i>	<i>mg/L -N</i>	<i>mg/L -N</i>
6/1/2017	15.5	13.8	207.0	437.0	167.0		25.6	0.1		3.2	4.8			
6/2/2017	15.5	13.4		565.0	257.0		26.2	0.1	0.6	3.3	4.7			
6/3/2017	15.6	13.6		461.0	193.0		27.2	0.0		3.4	5.2		38.7	29.9
6/4/2017	16.0	12.8		390.0	258.0		29.2	0.1		3.1	5.8			
6/5/2017	15.6	15.0		675.0	228.0		26.5	0.1		3.1	4.6			
6/6/2017	15.3	13.9	267.0	580.0	242.0		26.3	0.1		3.3	4.8	209.3		
6/7/2017	15.5	13.2	292.0	521.0	231.0	410.0	26.0	0.1		2.8	5.7			
6/8/2017	15.2	12.5	242.0	456.0	194.0		26.3	0.1		2.7	5.0			
6/9/2017	15.6	14.1		449.0	185.0		26.3	0.1	0.2	3.2	5.0			
6/10/2017	15.8	12.6		427.0	218.0		28.2	0.1		2.8			40.0	30.0
6/11/2017	16.2	14.1		436.0	174.0		27.5	0.0		2.8				
6/12/2017	16.6	14.1		521.0	249.0		28.1	0.1		3.2				
6/13/2017	16.0	14.3	243.0	311.0	215.0	426.0	26.5	0.1		3.0		203.4		
6/14/2017	15.8	13.7	244.0	556.0	206.0		26.5	0.1		3.0				
6/15/2017	15.5	13.2	222.0	266.0	178.0		26.9	0.0		3.1				
6/16/2017	15.5	14.4		471.0	166.0		25.7	0.1	0.1	3.1				
6/17/2017	15.6	12.7		290.0	234.0		26.4			2.7			39.5	30.7
6/18/2017	15.6	12.4		280.0	216.0		26.4	0.1		2.4				
6/19/2017	15.6	13.5		366.0	216.0		25.5	0.1		2.6				
6/20/2017	15.4	13.3	240.0	519.0	212.0	405.0	25.3	0.1		3.0		206.3		
6/21/2017	15.5	12.3	241.0	646.0	210.0		24.7	0.1		3.2				
6/22/2017	15.4	13.7	204.0	417.0	156.0		25.1	0.1		2.8				
6/23/2017	15.4	13.5		315.0	213.0		26.9	0.1		3.2				
6/24/2017	15.3	12.5		474.0	185.0		27.1	0.1		2.8			41.8	30.6
6/25/2017	15.5	13.8		342.0	168.0		24.4	0.1		2.9				
6/26/2017	15.5	13.1		483.0	192.0		27.8	0.1		2.9				
6/27/2017	15.3	12.9	218.0	346.0	161.0	449.0	26.4	0.1		3.2		200.9		
6/28/2017	15.2	12.9	248.0	346.0	198.0		26.1	0.1		3.2				
6/29/2017	15.0	12.9	256.0	268.0	201.0		27.0	0.1		3.6				
6/30/2017	15.0	13.9		334.0	244.0		26.8	0.1		2.6			42.9	32.5

July

	Daily Composite												Weekly Composite	
	Flow - North Trunk	Flow - South Trunk	BOD	COD	TSS	TDS	Ammonia	Nitrite	Nitrate	OP	TP	Alkalinity	TKN	SKN
<i>Units</i>	<i>MGD</i>	<i>MGD</i>	<i>mg/L - O₂</i>	<i>mg/L - O₂</i>	<i>mg/L</i>	<i>mg/L</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L - P</i>	<i>mg/L - P</i>	<i>mg/L - CaCO₃</i>	<i>mg/L -N</i>	<i>mg/L -N</i>
7/1/2017	15.1	12.4		456.0	201.0		27.5	0.1		2.6	3.7		40.7	31.9
7/2/2017	15.1	13.3		402.0	191.0		25.7	0.1		3.0	4.0			
7/3/2017	15.4	13.0		436.0	190.0		25.6	0.1		3.3	4.9			
7/4/2017	15.2	11.3	281.0	369.0	287.0	431.0	25.7	0.1		3.0	4.5	200.4		
7/5/2017	15.0	12.7	212.0	448.0	133.0		25.3	0.1		3.7	4.9			
7/6/2017	15.0	12.5	256.0	562.0	221.0		25.5	0.1		3.2	5.5			
7/7/2017	14.9	12.6		520.0	224.0		27.6	0.1		4.1	5.9			
7/8/2017	15.1	12.4		383.0	253.0		27.8	0.1		3.0	3.8		43.7	30.3
7/9/2017	15.1	13.3		394.0	194.0		28.1	0.1		3.1	4.7			
7/10/2017	15.0	13.2		500.0	194.0		27.7	0.1		2.9				
7/11/2017	15.1	12.2	242.0	502.0	209.0		28.7	0.0		2.9		217.0		
7/12/2017	15.0	12.9	222.0	490.0	181.0	401.0	28.3	0.1		3.2				
7/13/2017	15.0	13.2	252.0	340.0	245.0		26.1	0.1		3.1				
7/14/2017	15.0	12.4		372.0	188.0		26.0	0.2		2.8				
7/15/2017	14.8	12.0		412.0	229.0		27.6	0.1		2.7			40.1	30.9
7/16/2017	15.1	13.1		271.0	166.0		26.5	0.1		3.0				
7/17/2017	15.2	11.8		435.0	204.0		27.9	0.1		2.9				
7/18/2017	15.2	13.9	213.0	347.0	166.0	465.0	26.6	0.1		3.0		211.9		
7/19/2017	15.1	12.5	270.0	367.0	208.0		25.8	0.1		3.0				
7/20/2017	15.0	12.6	240.0	294.0	208.0		29.2	0.1		2.8				
7/21/2017	14.9	12.6		338.0	155.0		27.4	0.1		2.6				
7/22/2017	15.1	12.1		411.0	206.0		27.9	0.1		2.8			41.3	30.7
7/23/2017	15.1	12.7		323.0	180.0		26.9	0.1		2.8				
7/24/2017	15.0	12.8		353.0	234.0		27.4	0.1		3.1				
7/25/2017	14.9	13.0	288.0	357.0	281.0		29.9	0.1		3.3		226.2		
7/26/2017	14.9	13.5	230.0	338.0	163.0	454.0	26.0	0.1		3.2				
7/27/2017	14.8	12.4	194.0	514.0	200.0		28.5	0.0		3.1				
7/28/2017	14.8	12.7		415.0	219.0		26.0	0.1	0.2	3.2				
7/29/2017	15.2	11.9		399.0	237.0		28.2	0.1		2.9			44.9	31.6
7/30/2017	14.9	13.9		278.0	192.0		28.0	0.0		2.8				
7/31/2017	14.8	12.9		389.0	217.0		26.7	0.1		2.9			39.7	31.5

August

	Daily Composite												Weekly Composite	
	Flow - North Trunk	Flow - South Trunk	BOD	COD	TSS	TDS	Ammonia	Nitrite	Nitrate	OP	TP	Alkalinity	TKN	SKN
<i>Units</i>	<i>MGD</i>	<i>MGD</i>	<i>mg/L - O₂</i>	<i>mg/L - O₂</i>	<i>mg/L</i>	<i>mg/L</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L - P</i>	<i>mg/L - P</i>	<i>mg/L - CaCO₃</i>	<i>mg/L -N</i>	<i>mg/L -N</i>
8/1/2017	14.4	13.1	213.0	520.0	169.0	433.0	26.4	0.1		3.1	4.9	207.3		
8/2/2017	14.7	13.1	220.0	446.0	199.0		26.9	0.1		3.7	5.1			
8/3/2017	15.0	12.7	218.0	444.0	191.0		28.7	0.1		3.1	5.4			
8/4/2017	14.6	13.3		333.0	172.0		28.1	0.1		3.6	6.0			
8/5/2017	14.8	11.5		481.0	178.0		30.1	0.1		2.9	4.1		43.3	31.2
8/6/2017	15.6	13.0		489.0	217.0		27.7	0.0		3.0	3.6			
8/7/2017	15.3	14.8		338.0	213.0		27.1	0.1		2.9	4.4			
8/8/2017	15.1	12.3	223.0	274.0	70.0	438.0	27.5	0.1		3.1	4.2	213.2		
8/9/2017	15.0	12.5	240.0	383.0	231.0		27.3	0.1		3.2	4.3			
8/10/2017	15.2	12.8	241.0	380.0	205.0		27.8	0.1		3.5				
8/11/2017	15.1	13.9		331.0	227.0		27.1	0.1		3.5				
8/12/2017	15.3	12.0		329.0	228.0		27.5	0.0		2.8			39.7	30.3
8/13/2017	15.5	12.4		348.0	184.0		28.4	0.1		3.1				
8/14/2017	15.0	13.7		404.0	238.0		27.1	0.1		3.0				
8/15/2017	14.6	13.0	239.0	472.0	204.0	428.0	28.0	0.1		3.2		221.4		
8/16/2017	14.6	12.6	216.0	348.0	175.0		28.6	0.1		3.5				
8/17/2017	14.7	12.7	212.0	376.0	174.0		27.7	0.0		3.1				
8/18/2017	14.7	13.4		511.0	227.0		22.0	0.1		3.7				
8/19/2017	15.0	11.3		370.0	164.0		26.0	0.0		2.8			40.3	31.4
8/20/2017	15.3	12.4		273.0	157.0		27.7	0.1		3.3				
8/21/2017	15.0	14.1		303.0	217.0		27.4	0.1		3.0				
8/22/2017	14.8	12.1	228.0	293.0	189.0	456.0	26.8	0.1		3.6		215.2		
8/23/2017	15.0	12.8	228.0	262.0	182.0		28.0	0.1		3.5				
8/24/2017	14.9	12.3	204.0	344.0	189.0		28.2	0.1		3.7				
8/25/2017	15.0	13.4		323.0	194.0		28.6	0.1		3.1				
8/26/2017	15.3	12.4		614.0	238.0		26.6	0.1		3.0			44.5	31.9
8/27/2017	15.5	12.1		323.0	190.0		27.9	0.1		3.4				
8/28/2017	15.2	14.0		462.0	159.0		26.7	0.1		2.9				
8/29/2017	15.0	12.7	237.0	291.0	219.0	426.0	29.1	0.1		3.3		214.0		
8/30/2017	15.1	12.6	224.0	360.0	183.0		27.7	0.1		3.5				
8/31/2017	15.0	13.0	298.0	477.0	334.0		27.8	0.1		3.5			44.4	31.0

September

	Daily Composite												Weekly Composite	
	Flow - North Trunk	Flow - South Trunk	BOD	COD	TSS	TDS	Ammonia	Nitrite	Nitrate	OP	TP	Alkalinity	TKN	SKN
<i>Units</i>	<i>MGD</i>	<i>MGD</i>	<i>mg/L - O₂</i>	<i>mg/L - O₂</i>	<i>mg/L</i>	<i>mg/L</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L - P</i>	<i>mg/L - P</i>	<i>mg/L - CaCO₃</i>	<i>mg/L -N</i>	<i>mg/L -N</i>
9/1/2017	14.8	12.2		329.0	233.0		28.5	0.1		3.2	5.6			
9/2/2017	14.9	12.3		334.0	217.0		28.7	0.1		2.9	3.8		42.1	31.8
9/3/2017	14.8	13.1		305.0	188.0		29.6	0.1		3.4	5.2			
9/4/2017	15.6	12.2		387.0	205.0		29.2	0.1		2.7	4.4			
9/5/2017	15.1	14.7	274.0	515.0	241.0	454.0	29.0	0.1		3.1	5.2	223.5		
9/6/2017	14.8	12.8	231.0	521.0	203.0		27.0	0.1		3.0	5.4			
9/7/2017	15.0	12.7	231.0	277.0	209.0		27.5	0.1		3.1	5.6			
9/8/2017	14.9	13.4		308.0	190.0		25.8	0.1		2.9	5.1			
9/9/2017	15.2	13.0		324.0	198.0		29.4	0.0		3.0	4.0		42.7	33.0
9/10/2017	15.4	12.7		327.0	208.0		28.3	0.1		3.1				
9/11/2017	14.8	13.9		438.0	208.0		27.4	0.1		2.9				
9/12/2017	14.6	13.6	222.0	375.0	181.0	398.0	29.1	0.1		3.3		205.3		
9/13/2017	14.9	13.0	243.0	317.0	243.0		29.3	0.1		3.8				
9/14/2017	14.9	12.8	261.0	339.0	272.0		18.5	0.3	0.2	2.6				
9/15/2017	14.7	14.4		356.0	176.0		27.6	0.1	0.2	3.3				
9/16/2017	15.1	12.2		312.0	202.0		25.9	0.1		2.7			42.2	33.5
9/17/2017	15.4	13.3		299.0	205.0		28.2	0.1		3.4				
9/18/2017	15.1	12.8		419.0	226.0		29.1	0.1		3.0				
9/19/2017	14.6	14.3	261.0	514.0	206.0	397.0	27.8	0.1		3.6		205.2		
9/20/2017	14.6	12.7	224.0	302.0	151.0		29.7	0.1		4.0				
9/21/2017	14.9	13.4	241.0	479.0	189.0		28.4	0.1		3.5				
9/22/2017	14.7	13.1		232.0	159.0		27.1	0.1	0.1	3.6				
9/23/2017	15.0	13.3		281.0	231.0		28.5	0.1		2.8			42.9	33.4
9/24/2017	15.1	13.6		402.0	181.0		30.3	0.1		3.3				
9/25/2017	14.5	13.7		376.0	131.0		26.2	0.1		2.8				
9/26/2017	14.5	13.8	223.0	441.0	174.0	412.0	29.0	0.1		3.3		233.1		
9/27/2017	14.3	12.2	247.0	384.0	194.0		28.6	0.1		3.7				
9/28/2017	14.3	13.9	237.0	441.0	191.0		27.2	0.1		3.0				
9/29/2017	14.5	12.5		775.0	245.0		28.6	0.1	0.1	3.3				
9/30/2017	14.9	12.6		414.0	182.0		31.3	0.1		3.5			45.1	33.3

October

	Daily Composite												Weekly Composite	
	Flow - North Trunk	Flow - South Trunk	BOD	COD	TSS	TDS	Ammonia	Nitrite	Nitrate	OP	TP	Alkalinity	TKN	SKN
<i>Units</i>	<i>MGD</i>	<i>MGD</i>	<i>mg/L - O2</i>	<i>mg/L - O2</i>	<i>mg/L</i>	<i>mg/L</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L - P</i>	<i>mg/L - P</i>	<i>mg/L - CaCO3</i>	<i>mg/L -N</i>	<i>mg/L -N</i>
10/1/2017	15.1	13.9		371.0	187.0		29.4	0.1		3.2	5.1			
10/2/2017	14.8	13.8		395.0	232.0		28.0	0.1		3.4	5.7			
10/3/2017	14.5	13.2	238.0	327.0	192.0	408.0	29.2	0.1		3.2	5.4	232.4		
10/4/2017	14.4	12.2	226.0	360.0	170.0		33.7	0.1		3.7	5.7			
10/5/2017	14.3	14.1	238.0	495.0	234.0		28.5	0.1		3.2	5.9			
10/6/2017	14.0	13.1		432.0	188.0		26.3	0.1	0.4	3.1	5.2			
10/7/2017	14.5	12.2		410.0	174.0		29.7	0.1		3.4	5.1		44.6	33.3
10/8/2017	15.1	12.9		561.0	220.0		32.2	0.1		3.5	5.4			
10/9/2017	14.8	14.1		521.0	232.0		29.7	0.1	0.3	2.7	4.8			
10/10/2017	14.5	13.8	240.0	295.0	171.0	403.0	28.7	0.1		3.5		226.8		
10/11/2017	14.3	12.0	237.0	518.0	208.0		30.2	0.1		3.6				
10/12/2017	14.5	13.3	215.0	500.0	187.0		29.4	0.1		3.4				
10/13/2017	14.3	14.4		393.0	192.0		28.5	0.2	0.3	3.3				
10/14/2017	14.7	12.6		351.0	239.0		30.4	0.1		3.6			44.4	33.7
10/15/2017	15.3	13.1		506.0	200.0	430.0	30.4	0.1		3.5				
10/16/2017	14.4	14.1		436.0	228.0		30.2	0.1		3.2				
10/17/2017	14.1	13.5	214.0	349.0	139.0		28.6	0.1		3.5		223.5		
10/18/2017	14.1	12.9	273.0	366.0	221.0		30.1	0.1		3.9				
10/19/2017	14.2	12.9	260.0	494.0	197.0		28.7	0.1		3.8				
10/20/2017	14.8	14.5		624.0	262.0		29.5	0.2		3.7				
10/21/2017	14.9	13.3		504.0	246.0		29.8	0.1		3.4			56.3	33.7
10/22/2017	15.0	13.7		392.0	184.0	433.0	30.5	0.1		3.3				
10/23/2017	14.3	15.0		332.0	228.0		29.8	0.1		3.2				
10/24/2017	13.8	13.6	219.0	345.0	180.0		29.5	0.1		3.5		229.2		
10/25/2017	14.0	12.7	246.0	317.0	226.0		29.2	0.1		3.2				
10/26/2017	13.8	13.8	298.0	461.0	329.0		27.5	0.1		3.5				
10/27/2017	13.8	13.0		413.0	210.0		27.5	0.1	0.2	3.4				
10/28/2017	14.2	13.1		450.0	183.0		29.4	0.1		3.3			44.3	31.8
10/29/2017	14.7	13.3		321.0	181.0	457.0	29.7	0.1		3.3				
10/30/2017	14.2	14.4		491.0	215.0		27.4	0.4	0.4	2.9				
10/31/2017	13.7	12.4	232.0	460.0	215.0		30.4	0.1		3.1		230.3	41.7	32.8

November

	Daily Composite												Weekly Composite	
	Flow - North Trunk	Flow - South Trunk	BOD	COD	TSS	TDS	Ammonia	Nitrite	Nitrate	OP	TP	Alkalinity	TKN	SKN
<i>Units</i>	<i>MGD</i>	<i>MGD</i>	<i>mg/L - O₂</i>	<i>mg/L - O₂</i>	<i>mg/L</i>	<i>mg/L</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L - P</i>	<i>mg/L - P</i>	<i>mg/L - CaCO₃</i>	<i>mg/L -N</i>	<i>mg/L -N</i>
11/1/2017	14.0	13.7	232.0	372.0	188.0		29.4	0.1		3.6	5.5			
11/2/2017	14.1	13.6	210.0	351.0	195.0		28.9	0.1		3.9	5.2			
11/3/2017	13.8	13.5		470.0	240.0		30.2	0.2	0.1	3.7	6.5			
11/4/2017	14.5	12.3		448.0	202.0		30.9	0.1		3.6	5.2		44.8	33.8
11/5/2017	15.0	13.5		440.0	189.0	493.0	31.1	0.1		3.3	5.5			
11/6/2017	14.4	14.9		610.0	232.0		28.7	0.1		2.9	4.8			
11/7/2017	14.3	12.7	237.0	429.0	225.0		29.2	0.1		3.7	5.7	253.1		
11/8/2017	14.1	13.7	268.0	474.0	229.0		29.5	0.3	0.2	3.2	6.4			
11/9/2017	13.7	13.0	224.0	457.0	186.0		28.9	0.1	0.1	3.4	5.7			
11/10/2017	14.1	13.1		315.0	196.0		25.6	0.1		3.0				
11/11/2017	14.7	13.2		314.0	208.0		30.6	0.1		3.5			45.4	35.5
11/12/2017	14.9	13.2		394.0	263.0		30.7	0.1		3.6				
11/13/2017	14.1	14.7		509.0	255.0		29.7	0.1		2.8				
11/14/2017	13.7	12.4	237.0	338.0	198.0	462.0	29.7	0.1		3.7		243.4		
11/15/2017	13.8	13.7	264.0	342.0	214.0		31.1	0.1		3.6				
11/16/2017	15.1	16.7	224.0	362.0	253.0		24.5	0.1		2.9				
11/17/2017	16.3	15.6		308.0	227.0		26.1	0.0		3.4				
11/18/2017	15.2	13.2		396.0	199.0		30.5	0.1		3.3			45.3	32.6
11/19/2017	15.5	14.3		495.0	218.0	489.0	30.3	0.1		3.0				
11/20/2017	14.3	14.7		416.0	234.0		29.0	0.1		3.4				
11/21/2017	14.0	14.1	290.0	567.0	269.0		30.4	0.1		3.5		251.4		
11/22/2017	14.2	13.1	263.0	587.0	252.0		28.0	0.1		2.9				
11/23/2017	14.4	13.1	266.0	658.0	233.0		29.5	0.1		3.3				
11/24/2017	13.3	13.1		723.0	253.0		30.7	0.1		3.1				
11/25/2017	14.0	12.4		633.0	267.0		34.2	0.1		3.7			50.3	36.2
11/26/2017	14.6	13.0		501.0	161.0		30.7	0.1		3.3				
11/27/2017	14.4	14.7		890.0	223.0		29.0	0.1		2.8				
11/28/2017	14.2	13.3	262.0	523.0	195.0	496.0	30.3	0.1		3.3		246.0		
11/29/2017	14.2	13.1	246.0	500.0	197.0		30.6	0.1	0.4	3.7				
11/30/2017	14.2	13.4	256.0	455.0	201.0		29.7	0.1		3.6			45.4	34.4

December

	Daily Composite												Weekly Composite	
	Flow - North Trunk	Flow - South Trunk	BOD	COD	TSS	TDS	Ammonia	Nitrite	Nitrate	OP	TP	Alkalinity	TKN	SKN
<i>Units</i>	<i>MGD</i>	<i>MGD</i>	<i>mg/L - O₂</i>	<i>mg/L - O₂</i>	<i>mg/L</i>	<i>mg/L</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L -N</i>	<i>mg/L - P</i>	<i>mg/L - P</i>	<i>mg/L - CaCO₃</i>	<i>mg/L -N</i>	<i>mg/L -N</i>
12/1/2017	14.0	14.1		506.0	245.0		28.8	0.1	0.4	3.8	6.0			
12/2/2017	14.4	13.0		638.0	330.0		30.7	0.1		3.7	7.0		47.6	34.6
12/3/2017	15.1	13.7		386.0	231.0		29.2	0.0		3.1	5.6			
12/4/2017	14.7	14.5		558.0	210.0		28.4	0.1		3.1	4.8			
12/5/2017	14.4	13.4	249.0	530.0	211.0	460.0	27.4	0.1		3.0	5.4	253.7		
12/6/2017	14.3	13.3	265.0	451.0	213.0		28.6	0.1		3.7	4.6			
12/7/2017	14.2	13.4	359.0	677.0	399.0		25.5	0.1		3.1	7.4			
12/8/2017	14.1	14.0		583.0	288.0		28.8	0.1		3.4	6.0			
12/9/2017	14.7	13.2		464.0	243.0		30.1	0.1	0.8	3.6	6.1		44.2	32.7
12/10/2017	15.2	13.8		443.0	188.0		29.3	0.1		3.0				
12/11/2017	14.5	15.6		608.0	227.0		28.1	0.1	0.3	3.3				
12/12/2017	14.3	13.1	250.0	629.0	173.0	421.0	29.9	0.1		3.5		220.2		
12/13/2017	14.4	13.4	261.0	545.0	173.0		28.7	0.1	0.1	3.3				
12/14/2017	14.1	14.4	271.0	590.0	211.0		27.8	0.1		3.1				
12/15/2017	14.3	12.7		545.0	194.0		28.4	0.2	0.3	3.6				
12/16/2017	14.8	13.3		470.0	185.0		29.7	0.2	0.2	3.5			45.1	34.2
12/17/2017	15.2	13.8		563.0	187.0		30.6	0.1		3.3				
12/18/2017	14.3	14.8		734.0	229.0		28.0	0.1		3.1				
12/19/2017	13.1	13.5	255.0	575.0	172.0	404.0	30.0	0.1		3.4		222.8		
12/20/2017	13.9	13.2	288.0	542.0	204.0		28.9	0.1		3.1				
12/21/2017	14.1	13.7	283.0	664.0	223.0		28.3	0.1		3.5				
12/22/2017	14.2	13.7		620.0	199.0		28.5	0.1		3.5				
12/23/2017	13.9	12.7		698.0	353.0		30.1	0.1		3.9			47.5	33.8
12/24/2017	14.6	13.7		553.0	218.0		29.2	0.1		3.2				
12/25/2017	13.6	13.0		635.0	237.0		31.6	0.1		3.3				
12/26/2017	14.5	11.5	293.0	564.0	209.0	446.0	31.8	0.1		3.9		229.4		
12/27/2017	14.6	14.3	317.0	644.0	207.0		28.4	0.1		3.4				
12/28/2017	14.6	13.3	287.0	530.0	197.0		28.3	0.1		3.3				
12/29/2017	14.4	13.7		566.0	217.0		30.5	0.1		3.7				
12/30/2017	14.2	12.8		602.0	214.0		30.5	0.1		3.9			45.4	35.2
12/31/2017	14.7	13.0		548.0	249.0		29.5	0.3	0.1	3.2			50.7	35.6

APPENDIX B – FALL, WINTER, & SUMMER SAMPLING SAMPAIGN DATA

Plant Influent Data

	Plant INF [Alkalinity]	Plant INF [Ammonia]	Plant INF [BOD]	Plant Inf [FBOD]	Plant INF [COD]	Plant INF [FCOD]	Plant INF [FFCOD]	Plant INF [CBOD]	Plant INF [VSS]	Plant INF [NO3]	Plant INF [NO2]	Plant INF [OP]	Plant INF [TP]	Plant INF [FTP]	Plant INF [TDS]	Plant INF [TSS]	Plant INF [TDN]	Plant INF Composite Weekly [TKN]	Plant INF Composite Weekly [SKN]	
Units	mg/L CaCO3	mg/L - N	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L	mg/L - N	mg/L - N	mg/L - P	mg/L - P	mg/L - P	mg/L	mg/L	mg/L - N	mg/L - N	mg/L - N	
6/23/2019	202.90	28.30			518.00	204.00	116.00		141.00	nd	0.05	2.50	4.36	3.58		153.00		42.00	32.20	
6/24/2019	198.72	27.30			515.00	209.00	127.00		174.00	nd	0.08	2.52	4.41	3.02		191.00		42.50	31.90	
6/25/2019	215.90	27.80	294.00	105.00	482.00	213.00	120.00		236.00	nd	0.07	3.19	4.99	3.08		259.00		45.20	32.30	
6/26/2019	204.26	28.40	252.00	103.00	591.00	211.00	121.00		183.00	nd	0.07	2.88	5.10	2.93		202.00		42.90	32.70	
6/27/2019	207.74	28.80	295.00	108.00	579.00	205.00	134.00		180.00	1.01		3.37	5.00	3.26		202.00		42.60	33.00	
6/28/2019	212.79	28.30				222.00	116.00		228.00	nd		3.44	5.75	3.35		236.00		44.80	33.30	
6/29/2019	206.24	29.50			534.00	193.00	108.00		172.00	nd	0.08	3.35	5.16	3.36		182.00		42.40	33.20	
6/30/2019	208.93	28.30			552.00	220.00	121.00		223.00	nd	0.08	2.79	4.52	3.39		239.00		45.90	33.70	
7/1/2019	206.01	29.90			528.00	223.00	134.00		168.00	nd	0.06	2.91	4.59	3.28		178.00		45.40	33.50	
7/2/2019	208.43	27.20	263.00	107.00	588.00	225.00	121.00		204.00	nd	0.08	2.63	4.92	2.86		236.00		46.10	32.30	
7/3/2019	205.32	27.00	248.00	107.00	504.00	221.00	106.00		197.00	nd	0.08	3.08	5.22	3.13		223.00		43.40	31.10	
7/4/2019	212.69	27.40	231.00	92.20	526.00	206.00	108.00		190.67	nd	0.07	3.07	4.70	2.97		218.67		42.60	31.80	
7/5/2019	210.93	28.40			569.00	235.00	130.00		216.00	0.93	0.16	3.40	5.81	3.28		228.00		45.80	34.40	
7/6/2019	213.49	29.50			597.00	204.00				0.38	0.18	3.15	4.62	3.06		228.00		44.40	34.80	
1/27/2019		29.90			550.00				220.00	nd	0.06	3.20	4.74			192.00	29.93			
1/28/2019		28.20			469.00					nd	0.06	2.67	4.33			156.00	28.23			
1/29/2019	210.52	29.90	251.00		490.00				226.00	167.00	nd	0.07	3.22	4.79		422.00	141.00	29.93		
1/30/2019		30.50	275.00						252.00		nd	0.06	3.68	5.02			230.00	30.54		
1/31/2019		30.50	305.00		573.00				250.00	285.00	nd	0.07	3.43	6.48			284.00	30.54	45.40	37.50
2/1/2019		30.20			826.00						nd	0.14	3.87	6.68			511.00			
2/2/2019		27.40			572.00						nd	0.08	3.01	4.03			232.00		43.20	33.70
2/3/2019		29.10			553.00				125.00		nd	0.06	3.22	3.86			120.00	29.14		
2/4/2019		28.90			512.00						nd	0.07	2.56	4.63			228.00	28.95		
2/5/2019	209.88	30.70	287.00		434.00				236.00	314.00	nd	0.06	3.86	6.84		446.00	298.00	30.74		
2/6/2019		27.00	237.00						215.00		nd	0.07	2.90	4.74			207.00	27.04		
2/7/2019		30.00	247.00		469.00				219.00	197.00	nd	0.08	3.25	5.02			215.00	30.05		
10/28/2018		29.60			505.00						nd	0.06	3.42	5.74		418.00	175.00	29.64		
10/29/2018		29.20			566.00						nd	0.07	3.04	5.80			208.00	29.25		
10/30/2018	226.06	28.80	237.00		499.00						nd	0.07	3.53	5.19			222.00	28.85		
10/31/2018		32.30	263.00		558.00						nd	0.10	3.51	5.16			245.00	32.39	48.60	33.10
11/1/2018		33.10	262.00		502.00						nd	0.07	3.83	6.25			246.00	33.15		
11/2/2018		31.60			521.00						nd	0.11	4.11	6.92			241.00			
11/3/2018		32.50			588.00						nd	0.08	3.45	4.60			226.00		46.20	34.80
11/4/2018		32.20			459.00						nd	0.07	3.10	4.28		414.00	208.00	32.24		
11/5/2018		30.90			564.00						nd	0.07	3.37	5.24			235.00	30.95		
11/6/2018	224.50	30.40	259.00		575.00						nd	0.07	3.91	6.90			189.00	30.42		
11/7/2018		31.90	234.00		475.00						nd	0.06	3.20	4.70			232.00	31.92		
11/8/2018		34.50	327.00		619.00						nd	0.08	4.11	6.43			144.00	34.53		

Primary Effluent System 1 Data

	Primary EFF Sys 1 [Alkalinity]	Primary EFF Sys 1 [Ammonia]	Primary EFF Sys 1 [BOD]	Primary EFF Sys 1 [FBOD]	Primary EFF Sys 1 [COD]	Primary EFF Sys 1 [FCBOD]	Primary EFF Sys 1 [FFCOD]	Primary EFF Sys 1 [CBOD]	Primary EFF Sys 1 [FCOD]	Primary EFF Sys 1 [VSS]	Primary EFF Sys 1 [TKN]	Primary EFF Sys 1 [SKN]	Primary EFF Sys 1 [NO3]	Primary EFF Sys 1 [NO2]	Primary EFF Sys 1 [OP]	Primary EFF Sys 1 [TP]	Primary EFF Sys 1 [FTP]	Primary EFF Sys 1 [TSS]
Units	mg/L CaCO3	mg/L - N	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L	mg/L - N	mg/L - N	mg/L - N	mg/L - N	mg/L - P	mg/L - P	mg/L - P	mg/L
6/23/2019	236.83	36.40	175.00	78.80	335.00		90.00		179.00	84.00	48.90	39.20	nd	0.05	4.73	7.10	4.90	94.00
6/24/2019	228.59	35.20	195.00		383.00				199.00		49.00	39.60			4.38	6.29	4.48	
6/25/2019	241.81	37.00	183.00	95.40	365.00		104.00		206.00	92.00	48.00	40.50	nd	0.06	4.93	5.94	4.61	102.00
6/26/2019	232.85	32.70	190.00		403.00				221.00		49.10	38.70			4.24	5.34	4.05	
6/27/2019	240.15	37.00	184.00	94.80	344.00		114.00		185.00	83.00	48.60	38.30	0.23	0.23	4.44	5.62	4.10	103.00
6/28/2019																		
6/29/2019																		
6/30/2019	239.70	36.40	169.00	98.60	364.00		121.00		212.00	85.00	49.30	45.20	nd	0.07	3.30	5.91	4.33	88.00
7/1/2019	231.70	34.80	175.00		369.00				206.00		48.50	40.50			3.39	5.84	3.81	
7/2/2019	230.77	33.60	159.00	87.60	326.00		106.00		194.00	78.00	44.00	38.80	nd	0.32	3.65	5.18	3.68	89.00
7/3/2019	234.06	35.30	170.00		348.00				197.00		47.60	40.10			4.15	5.61	4.09	
7/4/2019	242.21	35.00	158.00	85.60	336.00		97.00		181.00		46.60	39.40	nd	0.26	4.18	5.27	3.90	86.00
7/5/2019																		
7/6/2019																		
1/27/2019		43.80			320.00		49.30			83.00	50.30		nd	0.09	3.86	5.13		82.00
1/28/2019																		
1/29/2019	223.54	31.70	163.00		306.00	82.00	58.00	148.00	187.00	72.00	42.50		0.10	0.49	3.56	5.17		76.00
1/30/2019						79.60	54.20	140.00	195.00									
1/31/2019		37.10			298.00	54.80		129.00	162.00	79.00	48.00		<0.06	0.40	3.82	5.20		88.00
2/1/2019																		
2/2/2019																		
2/3/2019		36.60			361.00		76.20			85.00	43.90		nd	0.11	3.93	4.84		85.00
2/4/2019																		
2/5/2019	236.98	34.90	148.00		308.00	66.20	42.70	135.00	171.00	74.00	43.60		0.44	0.52	3.84	5.49		76.00
2/6/2019						73.40	41.70	141.00	178.00									
2/7/2019		38.80			287.00	61.80		135.00	169.00	66.00	48.90		0.40	0.32	4.40	5.50		79.00
10/28/2018		28.50			340.00		72.80			72.00	40.40		nd	0.10	4.13	5.07		89.00
10/29/2018							66.70											
10/30/2018	227.78	29.70	164.00		331.00	88.80	68.40	153.00	202.00	84.00	38.00		1.41	0.67	3.87	5.48		98.00
10/31/2018						65.80		142.00	188.00									
11/1/2018		29.50			328.00	67.60		138.00	179.00	90.00	39.70		1.22	1.09	3.80	5.32		87.00
11/2/2018																		
11/3/2018																		
11/4/2018		31.50			353.00		68.10			76.00	41.30		0.20	0.38	4.21	5.22		78.00
11/5/2018							61.40											
11/6/2018	226.08	29.90	186.00		368.00	92.00	38.10	153.00	219.00	80.00	40.00		nd	0.66	5.29	6.87		87.00
11/7/2018						83.80		153.00	203.00									
11/8/2018		29.20			317.00	62.20		123.00	167.00	72.00	46.60		1.06	0.92	4.38	5.49		81.00

Primary Effluent System 2 Data

	Primary EFF Sys 2 [Alkalinity]	Primary EFF Sys 2 [Ammonia]	Primary EFF Sys 2 [BOD]	Primary EFF Sys 2 [FBOD]	Primary EFF Sys 2 [COD]	Primary EFF Sys 2 [FCBOD]	Primary EFF Sys 2 [FFCOD]	Primary EFF Sys 2 [CBOD]	Primary EFF Sys 2 [FCOD]	Primary EFF Sys 2 [VSS]	Primary EFF Sys 2 [TKN]	Primary EFF Sys 2 [SKN]	Primary EFF Sys 2 [NO3]	Primary EFF Sys 2 [NO2]	Primary EFF Sys 2 [OP]	Primary EFF Sys 2 [TP]	Primary EFF Sys 2 [FTP]	Primary EFF Sys 2 [TSS]
Units	mg/L CaCO3	mg/L - N	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L	mg/L - N	mg/L - N	mg/L - N	mg/L - N	mg/L - P	mg/L - P	mg/L - P	mg/L
6/23/2019	232.92	232.92	143.00	77.40	301.00			85.00	164.00	79.00	47.30	38.20	nd	0.05	4.15	7.14	4.73	90.00
6/24/2019	228.12	228.12	171.00		340.00				192.00		44.40	41.30			4.05	6.51	4.73	
6/25/2019	234.31	234.31	165.00	90.60	333.00		102.00		191.00	93.00	45.80	39.30	nd	0.06	4.64	5.63	4.46	102.00
6/26/2019	220.15	220.15	159.00		380.00				202.00		46.70	39.90			4.28	5.01	4.04	
6/27/2019	231.75	231.75	146.00	78.20	290.00			98.00	190.00	63.00	45.50	39.00	0.19	0.15	4.42	5.26	4.01	84.00
6/28/2019																		
6/29/2019																		
6/30/2019	225.80	225.80	139.00	81.80	327.00		111.00		193.00	60.00	47.50	38.80	nd	0.11	3.66	5.38	4.15	72.00
7/1/2019	217.69	217.69	143.00		335.00				184.00		44.50	37.50			3.47	5.13	3.65	
7/2/2019	218.81	218.81	152.00	80.80	309.00		101.00		188.00	71.00	42.60	36.50	0.13	0.27	3.51	5.19	3.63	74.00
7/3/2019	235.79	235.79	160.00		334.00				192.00		46.00	38.10			4.00	5.22	4.01	
7/4/2019	237.00	237.00	145.00	77.20	313.00		91.00		175.00	62.00	44.60	36.80	nd	0.25	3.61	5.01	3.81	70.00
7/5/2019																		
7/6/2019																		
1/27/2019		37.30			340.00		74.30			73.00	47.10		nd	0.07	3.85	4.83		77.00
1/28/2019																		
1/29/2019	215.77	31.90	180.00		343.00	Lab Error	58.50	Lab Error	196.00	85.00	40.10		nd	0.30	3.37	4.73		88.00
1/30/2019						85.20	49.50	150.00	208.00									
1/31/2019		33.70			320.00	61.80		145.00	180.00	80.00	44.60		nd	0.20	3.58	4.88		95.00
2/1/2019																		
2/2/2019																		
2/3/2019		33.50			369.00					60.00	43.10		nd	0.06	3.26	4.84		71.00
2/4/2019																		
2/5/2019	228.97	32.90	150.00		313.00	67.80	60.20	141.00	172.00	88.00	48.90		0.11	0.43	3.41	5.06		68.00
2/6/2019						83.40	62.20	146.00	185.00									
2/7/2019		33.00			313.00	67.80		129.00	180.00	83.00	44.40		0.14	0.31	3.68	5.33		84.00
10/28/2018		27.20			308.00		70.00			49.00	34.40		nd	0.06	3.66	4.85		75.00
10/29/2018							37.60											
10/30/2018	220.71	25.70	160.00		303.00	73.20	41.20	138.00	186.00	81.00	35.60		1.10	0.44	4.01	5.60		87.00
10/31/2018						65.20		121.00	180.00									
11/1/2018		29.30			284.00	60.40		121.00	164.00	67.00	37.00		1.05	0.63	3.86	5.08		77.00
11/2/2018																		
11/3/2018																		
11/4/2018		29.70			322.00		73.60			73.00	36.10		<0.06	0.25	4.26	5.24		76.00
11/5/2018							81.10											
11/6/2018	222.11	29.30	167.00		352.00	86.20	53.20	153.00	207.00	76.00	38.00		<0.06	0.34	5.02	6.56		80.00
11/7/2018						77.20		131.00	188.00									
11/8/2018		29.70			297.00	57.80		124.00	163.00	62.00	36.60		0.65	0.35	4.51	5.40		72.00

Aeration System Data

	Aeration 1A MLSS [TSS]	Anaerobic 1A OP [OP]	EFF 1A OP [OP]	Aeration 1A Alkalinity [Alkalinity]	Aeration 1B MLSS [TSS]	Anaerobic 1B OP [OP]	EFF 1B OP [OP]	Aeration 1B Alkalinity [Alkalinity]	Aeration 2A MLSS [TSS]	Anaerobic 2A OP [OP]	EFF 2A OP [OP]	Aeration 2A Alkalinity [Alkalinity]	Aeration 2B MLSS [TSS]	Anaerobic 2B OP [OP]	EFF 2B OP [OP]	Aeration 2B Alkalinity [Alkalinity]
Units	mg/L	mg/L - P	mg/L - P	mg/L CaCO3	mg/L	mg/L - P	mg/L - P	mg/L CaCO3	mg/L	mg/L - P	mg/L - P	mg/L CaCO3	mg/L	mg/L - P	mg/L - P	mg/L CaCO3
6/23/2019	1,080.00		0.13		1,200.00		0.07		1,080.00		0.12		1,160.00		0.14	
6/24/2019	1,320.00		0.35		1,450.00		0.33		1,300.00		0.32		1,310.00		0.33	
6/25/2019	1,140.00		0.06	197.15	1,240.00		0.07	193.76	1,170.00		0.07	174.38	1,220.00		0.07	178.62
6/26/2019	1,240.00		0.10		1,240.00		0.11		1,180.00		0.08		1,210.00		0.10	
6/27/2019	1,240.00		0.06		1,250.00		0.05		1,110.00		0.06		1,240.00		0.10	
6/28/2019	1,210.00		0.05		1,210.00		0.06		1,250.00		0.05		1,230.00		0.07	
6/29/2019	1,110.00		0.06		1,150.00		0.06		1,150.00		0.08		1,150.00		0.08	
6/30/2019	1,020.00		0.05		1,250.00		0.05		1,130.00		0.06		1,110.00		0.09	
7/1/2019	1,120.00		0.11		1,170.00		0.10		1,090.00		0.08		1,180.00		0.11	
7/2/2019	1,130.00		0.05	192.23	1,150.00		0.05	182.5	1,120.00		< 0.04	160.92	1,180.00		< 0.04	170.32
7/3/2019	1,100.00		0.04		1,220.00		0.05		1,190.00		0.04		1,160.00		0.05	
7/4/2019	1,070.00		0.05		1,150.00		0.05		1,060.00		0.07		1,060.00		0.09	
7/5/2019	1,300.00		0.06		1,350.00		0.06		1,130.00		0.57		1,210.00		0.09	
7/6/2019	1,170.00				1,230.00		< 0.04		1,080.00		0.06	< 0.04	1,150.00		0.07	
1/27/2019	1,406.00	15.98	0.07		1,972.00	16.93	0.04		1,442.00	14.64	<0.04		1,464.00	12.73	0.06	
1/28/2019	1,808.00	16.75	0.08		2,082.00	16.83	0.13		1,860.00	15.86	0.10		1,716.00	13.36	0.11	
1/29/2019	1,480.00	15.47	0.04	219.02	1,516.00	15.28	0.05	218.04	1,504.00	13.51	0.05	206.65	1,500.00	11.31	0.06	205.00
1/30/2019	1,518.00	17.54	0.22		1,544.00	16.15	0.20		1,576.00	15.10	0.18		1,570.00	11.21	0.16	
1/31/2019	1,428.00	14.26	0.07		1,508.00	13.28	0.05		1,606.00	12.86	0.04		1,606.00	12.94	0.04	
2/1/2019	1,392.00	13.58	0.11		1,518.00	13.90	0.13		1,520.00	13.22	0.14		1,522.00	12.53	0.14	
2/2/2019	1,374.00	17.50	0.06		1,514.00	18.21	0.05		1,640.00	17.65	0.05		1,510.00	16.49	0.05	
2/3/2019	1,362.00	11.46	0.05		1,498.00	11.06	0.05		1,538.00	11.58	0.04		1,560.00	10.25	0.05	
2/4/2019	1,550.00	13.31	<0.04		1,552.00	13.45	<0.04		1,488.00	12.47	<0.04		1,592.00	12.71	0.33	
2/5/2019	1,624.00	13.66	0.06	216.07	1,456.00	12.55	0.05	216.65	1,552.00	12.65	<0.04	205.59	1,570.00	12.10	<0.04	205.29
2/6/2019	1,156.00	12.98	0.08		1,348.00	13.35	0.05		1,608.00	12.05	0.05		1,626.00	11.78	0.05	
2/7/2019	1,198.00	12.97	<0.04		1,370.00	12.25	<0.04		1,612.00	14.45	<0.04		1,680.00	12.70	<0.04	
10/28/2018	1,118.00	16.72	0.05		1,302.00	15.03	<0.04		1,090.00	13.82	0.05		982.00	12.63	0.07	
10/29/2018	1,024.00	14.98	<0.04		1,138.00	14.43	0.07		1,004.00	11.61	0.05		990.00	10.80	0.05	
10/30/2018	1,182.00	14.50	0.05	159.63	1,210.00	14.10	0.05	158.89	1,116.00	11.72	0.06	156.90	1,028.00	10.36	0.06	151.49
10/31/2018	1,188.00	13.73	<0.04		1,230.00	11.78	<0.04		1,094.00	11.30	0.06		1,040.00	10.13	0.07	
11/1/2018	1,120.00	12.76	0.04		1,212.00	12.05	<0.04		1,092.00	12.11	0.17		1,056.00	10.33	0.18	
11/2/2018	1,114.00	15.60	0.06		1,174.00	14.65	0.06		1,134.00	14.78	0.67		1,022.00	12.27	0.74	
11/3/2018	884.00	15.01	0.42		960.00	13.59	0.45		1,170.00	13.12	0.60		780.00	11.59	0.82	
11/4/2018	1,118.00	15.93	0.11		1,218.00	14.08	0.07		1,104.00	13.90	0.37		974.00	12.40	0.52	
11/5/2018	1,168.00	15.82	0.07		1,272.00	15.13	0.06		1,108.00	13.26	0.51		998.00	13.41	0.49	
11/6/2018	1,188.00	18.74	0.07	167.72	1,354.00	17.58	0.05	153.88	1,208.00	13.28	1.00	171.74	1,098.00	11.51	0.84	167.56
11/7/2018	1,112.00	14.30	0.06		1,252.00	14.31	0.04		1,148.00	11.58	0.17		1,136.00	10.41	0.20	
11/8/2018	1,228.00	14.50	1.44		1,480.00	14.38	1.40		1,206.00	13.27	1.40		1,438.00	12.31	1.35	

Aeration System and RAS Data

	ML Comp Sys 1 [TSS]	ML Comp Sys 1 [VSS]	ML Comp Sys 2 [TSS]	ML Comp Sys 2 [VSS]	RAS 1A TSS [TSS]	RAS 1B TSS [TSS]	RAS 1C TSS [TSS]	RAS 2A TSS [TSS]	RAS 2B TSS [TSS]	RAS 2C TSS [TSS]	RAS Sys 1 [VSS]	RAS Sys 2 [VSS]
Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
6/23/2019	1,040.00	880.00	1,120.00	970.00	3,240.00	3,200.00	3,300.00	3,040.00	2,760.00	3,040.00		
6/24/2019					2,540.00	3,400.00	3,300.00	3,020.00	2,620.00	2,960.00		
6/25/2019	1,200.00	940.00	1,270.00	1,150.00	3,220.00	3,680.00	4,320.00	3,120.00	2,960.00	3,300.00		
6/26/2019					3,340.00	3,380.00	3,620.00	3,360.00	2,980.00	3,040.00		
6/27/2019	1,080.00	880.00	1,150.00	930.00	2,980.00	3,120.00	3,160.00	3,120.00	3,060.00	3,220.00		
6/28/2019					2,800.00	2,900.00	3,380.00	3,480.00	2,720.00	2,500.00		
6/29/2019					2,840.00	2,900.00	3,460.00	3,040.00	2,920.00	2,820.00		
6/30/2019	1,320.00	1,050.00	1,090.00	920.00	2,820.00	2,640.00	2,480.00	2,900.00	2,580.00	2,760.00		
7/1/2019					2,640.00	2,520.00	3,080.00	2,780.00	2,640.00	2,560.00		
7/2/2019	1,360.00	1,120.00	1,020.00	880.00	3,060.00	3,060.00	2,960.00	3,340.00	3,140.00	2,580.00		
7/3/2019					2,980.00	3,000.00	3,020.00	3,320.00	3,020.00	2,760.00		
7/4/2019	1,240.00	1,033.33	1,190.00	1,010.00	2,580.00	2,920.00	2,960.00	2,860.00	2,400.00	2,640.00		
7/5/2019					2,920.00	2,600.00	2,620.00	2,580.00	2,640.00	2,500.00		
7/6/2019					2,740.00	3,000.00	2,540.00	3,140.00	2,940.00	2,640.00		
1/27/2019		1,462.00		1,256.00	4,244.00		4,468.00	4,108.00	4,364.00	3,396.00	3,716.00	3,356.00
1/28/2019					4,508.00		4,828.00	4,572.00	4,384.00	3,488.00		
1/29/2019		1,296.00		1,298.00	3,572.00		3,792.00	4,244.00	4,168.00	3,172.00	3,304.00	3,372.00
1/30/2019					3,864.00		4,380.00	4,376.00	4,344.00	3,504.00		
1/31/2019		1,276.00		1,338.00	3,672.00		4,384.00	4,416.00	4,388.00	3,368.00	3,368.00	3,376.00
2/1/2019					3,932.00		4,480.00	4,392.00	4,492.00	3,452.00		
2/2/2019					3,748.00		3,648.00	4,584.00	4,292.00	3,252.00		
2/3/2019		1,288.00		1,328.00	3,844.00		4,088.00	4,116.00	4,420.00	3,908.00	3,448.00	3,620.00
2/4/2019					4,120.00		4,604.00	4,892.00	4,736.00	3,768.00		
2/5/2019		1,342.00		1,364.00	3,996.00		4,736.00	4,760.00	4,520.00	3,708.00	4,000.00	3,876.00
2/6/2019					4,532.00		4,360.00	4,496.00	4,648.00	3,988.00		
2/7/2019		1,114.00		1,384.00	4,764.00		4,500.00	4,680.00	4,944.00	3,960.00	3,996.00	3,992.00
10/28/2018		1,106.00		956.00	2,888.00	3,456.00	2,992.00	2,500.00	2,460.00	2,332.00	2,896.00	2,248.00
10/29/2018					2,988.00	3,500.00	3,180.00	2,492.00	2,392.00	2,216.00		
10/30/2018		1,070.00		954.00	2,896.00	3,600.00	3,092.00	2,592.00	2,620.00	2,572.00	2,960.00	2,316.00
10/31/2018					2,712.00	3,888.00	3,272.00	2,680.00	2,704.00	2,672.00		
11/1/2018		1,058.00		976.00	3,600.00	3,528.00	3,032.00	2,696.00	2,664.00	2,368.00	2,940.00	2,252.00
11/2/2018					2,352.00	3,616.00	2,816.00	2,576.00	2,592.00	2,468.00		
11/3/2018					2,648.00	3,448.00	2,736.00	3,124.00	2,956.00	2,268.00		
11/4/2018		1,028.00		900.00	2,548.00	3,568.00	3,088.00	2,676.00	2,612.00	2,200.00	2,776.00	2,256.00
11/5/2018					2,540.00	3,396.00	3,140.00	2,532.00	2,656.00	2,432.00		
11/6/2018		1,140.00		1,006.00	2,576.00	3,848.00	3,092.00	2,676.00	2,856.00	2,664.00	2,760.00	2,476.00
11/7/2018					2,516.00	3,544.00	3,260.00	2,808.00	2,752.00	2,676.00		
11/8/2018		1,146.00		1,154.00	2,552.00	3,644.00	3,248.00	2,820.00	2,948.00	2,836.00	2,812.00	2,516.00

Aeration DO Data

	1A Aeration 1st Pass DO	1A Aeration 2nd Pass DO	1A Aeration 3rd Pass DO	1B Aeration 1st Pass DO	1B Aeration 2nd Pass DO	1B Aeration 3rd Pass DO	2A Aeration 1st Pass DO	2A Aeration 2nd Pass DO	2A Aeration 3rd Pass DO	2B Aeration 1st Pass DO	2B Aeration 2nd Pass DO	2B Aeration 3rd Pass DO
Units	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - O2
6/23/2019	1.98	2.01	2.55	1.89	2.04	2.56	1.94	2.02	2.54	1.90	2.01	2.50
6/24/2019	1.52	1.82	2.34	1.44	1.84	2.36	1.50	1.82	2.32	1.58	1.83	2.18
6/25/2019	1.98	2.00	2.53	1.72	2.01	2.51	1.89	2.01	2.52	1.84	2.01	2.53
6/26/2019	1.76	2.01	2.51	1.72	2.00	2.51	1.84	2.00	2.50	1.93	2.00	2.51
6/27/2019	1.81	2.00	2.52	1.75	2.00	2.50	1.44	1.99	2.49	1.81	1.99	2.49
6/28/2019	1.94	1.95	2.44	1.90	1.96	2.46	1.92	1.93	2.43	1.73	1.92	2.41
6/29/2019	2.00	2.00	2.50	1.95	2.00	2.51	1.97	2.00	2.50	1.80	1.98	2.48
6/30/2019	1.74	2.05	2.56	1.80	2.06	2.56	1.73	2.04	2.55	1.69	1.97	2.54
7/1/2019	1.48	2.02	2.51	1.83	2.02	2.51	1.22	2.00	2.51	1.59	1.95	2.52
7/2/2019	1.72	2.00	2.50	1.93	2.00	2.50	1.30	2.01	2.50	1.64	2.00	2.51
7/3/2019	2.00	2.00	2.50	1.99	2.01	2.50	1.94	2.00	2.50	1.76	2.00	2.50
7/4/2019	1.93	2.01	2.51	1.96	2.00	2.51	1.94	2.01	2.50	1.89	2.01	2.50
7/5/2019	2.01	2.01	2.49	1.96	1.99	2.49	2.01	1.99	2.49	1.95	2.00	2.49
7/6/2019	2.01	2.01	2.52	2.02	2.00	2.52	2.00	2.01	2.50	1.94	2.02	2.50
1/27/2019	2.09	2.09	2.48	2.09	2.09	2.48	2.13	2.10	2.13	2.06	2.09	2.07
1/28/2019	2.01	2.01	2.15	2.01	2.01	2.15	2.01	2.01	2.00	2.00	2.01	2.02
1/29/2019	2.00	2.01	2.16	2.00	2.01	2.16	1.99	2.00	1.99	1.99	2.00	1.99
1/30/2019	2.00	2.00	2.37	2.00	2.00	2.37	2.02	2.01	2.00	2.00	2.01	1.99
1/31/2019	2.01	2.00	2.57	2.01	2.00	2.57	2.01	2.01	2.01	2.01	2.02	1.99
2/1/2019	2.02	1.99	2.82	2.02	1.99	2.82	2.01	1.99	1.99	1.99	2.00	1.96
2/2/2019	2.06	2.00	2.69	2.06	2.00	2.69	2.04	1.99	2.00	1.99	2.00	1.98
2/3/2019	2.19	2.11	2.75	2.19	2.11	2.75	2.10	2.11	2.34	2.07	2.10	2.31
2/4/2019	2.00	2.00	2.75	2.00	2.00	2.75	2.01	2.00	2.50	1.99	2.01	2.51
2/5/2019	2.03	2.01	3.09	2.03	2.01	3.09	2.00	2.01	2.50	2.00	2.01	2.50
2/6/2019	2.29	2.15	4.04	2.29	2.15	4.04	2.02	2.00	2.49	2.00	2.00	2.48
2/7/2019	2.03	2.00	3.49	2.03	2.00	3.49	2.01	2.00	2.50	2.01	2.01	2.50
10/28/2018	2.07	2.07	1.56	1.88	2.05	1.56	2.06	2.05	1.55	2.03	2.05	1.54
10/29/2018	2.02	2.02	1.51	1.86	2.00	1.49	2.01	1.99	1.48	1.96	2.00	1.50
10/30/2018	2.01	2.01	1.51	1.92	2.00	1.52	2.00	2.00	1.51	1.99	2.02	1.52
10/31/2018	2.02	2.00	1.47	1.99	1.99	1.48	1.99	1.97	1.46	1.83	1.97	1.45
11/1/2018	2.00	1.99	1.48	1.97	1.98	1.48	1.90	1.99	1.48	1.82	1.99	1.48
11/2/2018	1.97	1.98	1.47	1.80	1.97	1.46	1.33	1.97	1.47	1.23	1.97	1.46
11/3/2018	1.99	2.00	1.50	1.89	2.00	1.50	1.88	2.00	1.49	1.96	2.00	1.50
11/4/2018	2.07	2.03	1.55	1.78	2.03	1.55	2.04	2.02	1.55	2.01	2.02	1.52
11/5/2018	2.02	2.03	1.53	1.89	2.00	1.54	1.99	2.00	1.49	1.86	2.00	1.50
11/6/2018	2.01	2.00	1.50	2.01	1.99	1.50	1.99	2.01	1.50	1.87	2.01	1.52
11/7/2018	1.99	2.03	1.50	1.99	1.99	1.52	2.00	2.01	1.51	1.91	2.01	1.51
11/8/2018	2.00	2.00	1.50	2.01	1.99	1.50	1.99	2.00	1.50	1.99	2.00	1.50

Secondary Effluent System 1 Data

	Secondary EFF Sys 1 [Ammonia]	Secondary EFF Sys 1 [Alkalinity]	Secondary EFF Sys 1 [BOD]	Secondary EFF Sys 1 [FBOD]	Secondary EFF Sys 1 [COD]	Secondary EFF Sys 1 [NO3]	Secondary EFF Sys 1 [NO2]	Secondary EFF Sys 1 [TKN]	Secondary EFF Sys 1 [TKN]	Secondary EFF Sys 1 [OP]	Secondary EFF Sys 1 [TP]	Secondary EFF Sys 1 [FTP]	Secondary EFF Sys 1 [TSS]	Secondary EFF Sys 1 [VSS]	Secondary EFF Sys 1 [FCOD]	Secondary EFF Sys 1 [FFCOD]
Units	mg/L - N	mg/L CaCO3	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - N	mg/L - N	mg/L - N	mg/L - N	mg/L - P	mg/L - P	mg/L - P	mg/L	mg/L	mg/L - O2	mg/L - O2
6/23/2019	23.60	178.15	40.90	6.10	58.00	2.41	2.38	26.30	24.80	0.37	0.60	0.52	18.00		45.00	31.00
6/24/2019	24.00				62.00	1.79	1.96			0.43	0.72		16.00			
6/25/2019	23.80	184.96	34.00	nd	64.00	1.92	2.00	26.70	24.40	0.41	0.85	0.54	13.00		37.00	32.00
6/26/2019	25.00		52.40		74.00	2.01	2.03			0.31	0.90		19.00			
6/27/2019	25.10	194.15	55.70	6.50	57.00	1.62	1.82	29.80	28.60	0.19	0.88	0.36	18.00		39.00	36.00
6/28/2019	25.30					1.63	1.71			0.18	0.96		16.00			
6/29/2019	27.30					1.53	1.64			0.17	0.91		20.00			
6/30/2019	26.10	189.53	60.50	4.50	73.00	1.38	1.67	30.00	27.90	0.16	0.68	0.32	18.00		45.00	41.00
7/1/2019	25.50				71.00	2.63	1.55			0.15	0.53		16.00			
7/2/2019	25.00	195.37	68.80	4.10	70.00	1.27	1.55	29.50	24.90	0.16	0.73	0.29	14.00		46.00	32.00
7/3/2019	25.20		60.40		75.00	1.59	1.60			0.17	0.90		23.00			
7/4/2019	26.50	201.67	63.60	5.40	79.00	1.99	1.61	28.90	27.80	0.15		0.29	17.00		45.00	36.00
7/5/2019	25.50					1.71	1.71			0.16	0.88		15.00			
7/6/2019	27.20					1.58	1.70			0.17	0.81					
1/27/2019	36.20				59.00	0.60	0.40			0.17	0.56		13.00	9.00		
1/28/2019	33.10				54.00	0.57	0.36			0.15	0.37		4.00			
1/29/2019	29.50				55.00	0.51	0.26			0.22	0.64		14.00	9.00	39.00	
1/30/2019	27.90		<20.0		56.00	0.49	0.26			0.18	0.49		11.00		38.00	
1/31/2019	30.10				52.00	0.50	0.30			0.16	0.47		9.00	8.00	46.00	
2/1/2019	38.00				62.00	0.68	0.29			0.16	0.48		19.00			
2/2/2019	35.90				53.00	0.46	0.23			0.23	0.42		5.00			
2/3/2019	33.50				49.00	0.48	0.21			0.24	0.61		10.00	10.00		
2/4/2019	29.40				56.00	0.38	0.18			0.25	0.43		11.00			
2/5/2019	29.90				59.00	0.35	0.13			0.55	1.06		11.00	9.00	43.00	
2/6/2019	32.30		15.60		52.00	0.32	0.14			0.95	1.16		6.00		40.00	
2/7/2019	35.50				53.00	0.40	0.19			0.27	0.68		6.00	11.00	41.00	
10/28/2018	14.20				53.00	2.84	2.76			0.18	0.72		13.00	11.00		
10/29/2018	13.40				49.00	2.56	2.69			0.21	0.51		12.00			
10/30/2018	14.00				48.00	2.92	2.88			0.20	0.73		14.00	17.00	40.00	
10/31/2018	13.90		45.80		47.00	2.92	3.39			0.20	0.56		9.00		40.00	
11/1/2018	15.60				48.00	3.41	3.42			0.21	0.57		10.00	9.00	37.00	
11/2/2018	14.70				52.00	3.43	3.59			0.28	0.78		10.00			
11/3/2018	13.90				49.00	3.13	3.53			0.31	0.61		8.00			
11/4/2018	15.80				55.00	2.79	3.35			0.31	0.72		8.00	10.00		
11/5/2018	14.40				56.00	2.57	3.43			0.30	0.68					
11/6/2018	13.70				52.00	3.58	4.10			0.26	0.69		7.00	8.00	46.00	
11/7/2018	15.00		36.80		58.00	2.80	3.75			0.29	0.60		5.00		45.00	
11/8/2018	16.90				58.00	3.00	3.94			0.24	0.74		8.00	9.00	47.00	

Secondary Effluent System 2 Data

	Secondary EFF Sys 2 [Ammonia]	Secondary EFF Sys 2 [Alkalinity]	Secondary EFF Sys 2 [BOD]	Secondary EFF Sys 2 [FBOD]	Secondary EFF Sys 2 [COD]	Secondary EFF Sys 2 [NO3]	Secondary EFF Sys 2 [NO2]	Secondary EFF Sys 2 [TKN]	Secondary EFF Sys 2 [TKN]	Secondary EFF Sys 2 [OP]	Secondary EFF Sys 2 [TP]	Secondary EFF Sys 2 [FTP]	Secondary EFF Sys 2 [TSS]	Secondary EFF Sys 2 [VSS]	Secondary EFF Sys 2 [FCOD]	Secondary EFF Sys 2 [FFCOD]
Units	mg/L - N	mg/L CaCO3	mg/L - O2	mg/L - O2	mg/L - O2	mg/L - N	mg/L - N	mg/L - N	mg/L - N	mg/L - P	mg/L - P	mg/L - P	mg/L	mg/L	mg/L - O2	mg/L - O2
6/23/2019	20.60	177.85	52.80	9.90	49.00	3.35	3.08	24.20	22.80	0.39	0.75	0.52	13.00		57.00	<30
6/24/2019	21.40				62.00	2.59	2.44			0.42	0.77		12.00			
6/25/2019	22.20	169.18	38.70	nd	65.00	2.49	2.54	25.80	22.70	0.35	0.55	0.47	13.00		34.00	31.00
6/26/2019	22.60		30.40		54.00	2.67	2.63			0.36	0.73		11.00			
6/27/2019	23.30	173.37	43.40	6.02		2.50	2.47	28.00	24.30	0.35	0.70	0.46	10.00		41.00	32.00
6/28/2019	24.30					2.44	2.42			0.38	0.77		8.00			
6/29/2019	25.40					2.20	2.34			0.38	0.78		12.00			
6/30/2019	27.60	176.02	38.80	<3.00	54.00	2.65	2.56	27.40	27.20	0.38	0.72	0.52	11.00		43.00	39.00
7/1/2019	23.80				51.00	2.63	1.55			0.34	0.58		9.00			
7/2/2019	23.40	176.67	43.70	5.90	54.00	1.87	2.16	25.60	23.50	0.36	1.11	0.49	14.00		41.00	<30
7/3/2019	23.70		44.90		63.00	1.63	2.20			0.28	0.80		15.00			
7/4/2019	24.50	193.01		6.70	67.00	1.69	2.21	27.20	26.10	0.16	0.73	0.28	14.00		40.00	31.00
7/5/2019	25.10					1.86	2.21			0.18	0.71		11.00			
7/6/2019	25.70					1.55	2.31			0.21	0.70		17.00			
1/27/2019	29.80				63.00	0.90	0.47			0.13	0.85		16.00	14.00		
1/28/2019	27.60				52.00	0.79	0.45			0.11	0.34		12.00			
1/29/2019	26.80				58.00	0.66	0.34			0.12	0.81		21.00	16.00	37.00	
1/30/2019	25.70		36.80		61.00	0.69	0.32			0.11	0.82		19.00		38.00	
1/31/2019	27.50				56.00	0.77	0.39			0.10	0.77		19.00	16.00	44.00	
2/1/2019	30.50				63.00	0.75	0.37			0.08	0.72		20.00			
2/2/2019	27.40				63.00	0.71	0.32			0.10	0.34		15.00			
2/3/2019	26.90				62.00	0.70	0.37			0.08	0.78		20.00	15.00		
2/4/2019	24.70				55.00	0.61	0.37			0.07	0.23		11.00			
2/5/2019	25.80				60.00	0.67	0.37			0.08	0.87		29.00	16.00	37.00	
2/6/2019	26.90		<24		47.00	0.86	0.44			0.29	0.57		6.00		38.00	
2/7/2019	28.30				50.00	0.67	0.45			0.20	0.65		5.00	10.00	35.00	
10/28/2018	11.40				64.00	2.60	3.12			0.15	0.94		20.00	18.00		
10/29/2018	11.40				56.00	2.31	2.84			0.14	0.46		14.00			
10/30/2018	12.90				53.00	2.08	2.71			0.15	0.79		16.00	12.00	42.00	
10/31/2018	13.50		61.80		51.00	1.84	2.49			0.14	0.73		10.00		40.00	
11/1/2018	16.50				53.00	2.67	3.09			0.34	0.88		14.00	11.00	39.00	
11/2/2018	14.90				51.00	3.04	3.13			0.74	1.18		12.00			
11/3/2018	13.90				51.00	3.14	3.68			0.85	1.16		2.00			
11/4/2018	15.40				58.00	2.94	3.40			0.66	1.03		10.00	10.00		
11/5/2018	14.60				59.00	2.54	3.17			0.58	1.03		9.00			
11/6/2018	14.90				59.00	2.35	3.00			1.06	1.42		8.00	9.00	43.00	
11/7/2018	14.80		48.60		59.00	2.32	3.26			0.47	0.83		2.00		43.00	
11/8/2018	15.40				53.00	2.77	3.82			0.35	0.80		2.00	9.00	44.00	

Additional Data

	North Channel Flow (MGD)	South Channel Flow (MGD)	Total INF Flow	Primary Flow	North pH	South pH	Primary EFF Sys 1 Temp	Primary EFF Sys 2 Temp	RAS Flow 1A (MGD)	RAS Flow 1B (MGD)	RAS Flow 1C (MGD)	RAS Flow 2A (MGD)	RAS Flow 2B (MGD)	RAS Flow 2C (MGD)	RAS Flow 2D (MGD)
Units	(MGD)	(MGD)	(MGD)	(MGD)	SU	SU	C	C	MGD	MGD	MGD	MGD	MGD	MGD	MGD
6/23/2019	15.81	7.26	23.07	34.22	7.26	7.61	21.71	21.37	2.80	2.80	2.80	3.09	3.09	3.09	
6/24/2019	15.45	7.24	22.69	36.58	7.24	7.56	21.91	21.52	2.92	2.92	2.92	3.31	3.31	3.31	
6/25/2019	15.18	7.20	22.39	36.58	7.20	7.51	21.96	21.60	2.89	2.89	2.89	3.28	3.28	3.28	
6/26/2019	15.07	7.03	22.11	34.94	7.03	7.45	21.96	21.55	2.79	2.79	2.79	3.16	3.16	3.16	
6/27/2019	14.94	7.07	22.01	35.30	7.07	7.46	21.92	21.54	2.81	2.81	2.81	3.18	3.18	3.18	
6/28/2019	14.91	7.16	22.07	34.85	7.16	7.50	21.92	21.55	2.77	2.77	2.76	3.12	3.13	3.13	
6/29/2019	15.30	7.22	22.51	35.56	7.22	7.64	22.00	21.64	2.87	2.87	2.88	3.17	3.17	3.17	
6/30/2019	15.30	7.14	22.44	34.53	7.14	7.61	22.06	21.69	2.84	2.84	2.84	3.08	3.08	3.07	
7/1/2019	15.03	7.21	22.24	34.97	7.21	7.56	22.14	21.75	2.82	2.82	2.82	3.12	3.12	3.12	
7/2/2019	14.86	7.15	22.01	35.51	7.15	7.47	22.24	21.85	2.83	2.82	2.82	3.16	3.16	3.16	
7/3/2019	14.68	7.25	21.93	33.95	7.25	7.51	22.29	21.95	2.72	2.72	2.73	3.04	3.04	3.04	
7/4/2019	14.33	7.27	21.61	34.19	7.27	7.51	22.40	22.04	2.78	2.78	2.78	3.05	3.05	3.05	
7/5/2019	14.58	7.23	21.81	33.99	7.23	7.39	22.56	22.18	2.77	2.77	2.78	3.04	3.04	3.04	
7/6/2019	14.94	7.24	22.18	34.01	7.24	7.45	22.71	22.38	2.78	2.78	2.78	3.05	3.05	3.05	
1/27/2019	15.03	11.94	26.97	37.00	7.22	7.27	8.33	10.71	2.74	2.74	2.78	2.51	2.51	2.51	5.10
1/28/2019	15.45	12.42	27.87	37.80	7.10	7.14	8.26	10.61	2.78	2.78	2.78	2.56	2.56	2.56	5.07
1/29/2019	16.23	12.48	28.70	41.58	7.13	7.13	8.26	10.67	3.09	3.09	3.09	2.83	2.83	2.83	5.11
1/30/2019	14.81	13.10	27.91	38.01	7.17	7.15	8.30	10.69	2.83	2.83	2.86	2.60	2.59	2.60	5.11
1/31/2019	14.49	11.19	25.68	37.58	7.15	7.18	8.36	10.69	2.77	2.77	2.84	2.55	2.55	2.55	5.08
2/1/2019	14.27	12.46	26.73	38.91	7.14	7.26	8.33	10.56	2.84	2.84	2.86	2.62	2.62	2.62	5.02
2/2/2019	16.49	13.65	30.13	42.45	7.17	7.25	8.03	10.28	3.16	3.16	3.21	2.89	2.88	2.88	5.04
2/3/2019	15.62	12.77	28.39	39.28	7.25	7.24	7.97	10.34	2.91	2.91	2.99	2.70	2.70	2.70	5.09
2/4/2019	17.46	13.26	30.72	42.07	7.17	7.19	7.52	9.85	3.06	3.06	3.06	2.91	2.91	2.91	5.24
2/5/2019	15.56	13.27	28.83	41.23	7.17	7.20	7.68	10.07	2.42	2.42	3.05	2.84	2.84	2.84	5.25
2/6/2019	15.34	13.22	28.55	40.33	7.11	7.23	7.48	9.95	2.90		2.87	2.87	2.87	2.87	5.13
2/7/2019	15.34	12.47	27.81	39.53	7.17	7.21	7.50	9.98	2.89	2.80	2.88	2.76	2.76	2.76	5.20
10/28/2018	14.36	12.78	27.14	37.09	7.46	7.40	13.41	15.72	3.06	3.11	3.11	3.31	3.31	3.31	5.05
10/29/2018	13.90	13.61	27.52	38.12	7.43	7.32	13.36	15.66	3.09	3.11	3.11	3.48	3.48	3.48	5.01
10/30/2018	13.82	12.25	26.07	38.09	7.45	7.31	13.04	15.33	2.95	3.01	3.00	3.59	3.59	3.59	4.97
10/31/2018	13.52	13.93	27.45	37.00	7.43	7.32	12.96	15.24	2.86	2.93	2.93	3.48	3.48	3.48	4.97
11/1/2018	13.56	10.11	23.67	35.85	7.42	7.31	12.96	15.29	2.90	2.90	2.90	3.33	3.33	3.33	4.96
11/2/2018	13.54	12.76	26.30	36.83	7.49	7.34	13.15	15.48	3.01	3.01	3.01	3.26	3.26	3.26	4.98
11/3/2018	14.18	9.51	23.70	33.36	7.47	7.34	13.13	15.46	2.89	2.98	2.98	2.81	2.81	2.81	5.05
11/4/2018	14.54	12.01	26.55	36.73	7.50	7.33	13.11	15.46	3.14	3.20	3.20	3.12	3.11	3.12	5.07
11/5/2018	12.90	12.80	25.70	37.48	7.51	7.30	13.03	15.37	3.02	3.03	3.04	3.38	3.38	3.38	5.04
11/6/2018	13.94	10.88	24.82	35.16	7.51	7.31	12.76	15.12	2.68	2.77	2.76	3.37	3.37	3.37	4.92
11/7/2018	13.97	11.68	25.65	34.29	7.60	7.38	12.60	14.99	2.86	2.92	2.90	3.07	3.07	3.07	4.91
11/8/2018	14.08	10.52	24.60	35.63	7.53	7.33	12.34	14.72	2.80	2.80	2.80	2.93	2.93	2.93	4.89

Additional Data

	Primary Sludge Flow (to Gravity Thickener)	Gravity Thickener Estimated Overflow (gpm)	TPS Flow (gpm)	Sys 1 WAS Flow (MGD)	Sys 1 Waste SS (mg/L)	Sys 2 WAS Flow (MGD)	Sys 2 Waste SS (mg/L)	Primary Flow 1A MGD	Primary Flow 1B MGD	Primary Flow 1C MGD	Primary Flow 2A MGD	Primary Flow 2B MGD	Primary Flow 2C MGD	Primary Sludge (each)	Primary Sludge (each)
Units	gpm	gpm	gpm	MGD	mg/L	MGD	mg/L	MGD	MGD	MGD	MGD	MGD	MGD	gpm	MGD
6/23/2019	234.88			0.68	3,097.00	0.73	3,416.74	7.21	0.00	8.47	6.39	6.47	5.67		
6/24/2019	247.19			0.68	3,313.48	0.74	3,469.80	7.81	0.00	9.05	6.77	6.88	6.07		
6/25/2019	259.57			0.69	3,326.24	0.74	3,493.52	7.79	0.00	9.06	6.77	6.88	6.08		
6/26/2019	255.69			0.69	3,421.38	0.74	3,398.52	7.35	0.00	8.65	6.47	6.60	5.87		
6/27/2019	243.64			0.69	3,447.63	0.74	3,524.62	7.48	0.00	8.74	6.41	6.71	5.96		
6/28/2019	243.41			0.69	3,185.89	0.74	3,620.15	7.37	0.00	8.73	6.19	6.66	5.91		
6/29/2019	215.54			0.69	3,213.74	0.74	3,519.56	7.64	0.00	8.86	6.35	6.72	5.99		
6/30/2019	194.01			0.68	2,998.68	0.74	3,441.22	7.42	0.00	8.66	6.16	6.47	5.82		
7/1/2019	193.78			0.69	3,168.59	0.74	3,433.73	7.45	0.00	8.79	6.25	6.57	5.91		
7/2/2019	193.78			0.69	3,340.99	0.74	3,372.92	7.61	0.00	8.92	6.36	6.64	5.98		
7/3/2019	193.26			0.69	3,274.13	0.74	3,146.48	7.20	0.00	8.51	6.13	6.35	5.75		
7/4/2019	194.63			0.69	3,155.72	0.74	3,141.16	7.30	0.00	8.61	6.14	6.38	5.76		
7/5/2019	193.74			0.68	3,160.95	0.74	2,989.68	7.24	0.00	8.49	6.15	6.37	5.74		
7/6/2019	193.83			0.68	3,293.77	0.74	2,764.35	7.22	0.00	8.49	6.19	6.38	5.73		
1/27/2019	239.50	99.59	139.91	0.50	4,504.83	0.50	4,359.82	6.17	5.93	6.07	4.88	5.38	5.72	39.92	0.00
1/28/2019	238.91	103.27	135.63	0.53	4,491.04	0.50	4,316.07	6.03	4.76	6.37	5.12	5.49	5.91	39.82	0.00
1/29/2019	237.39	117.37	120.01	0.55	4,475.02	0.50	4,311.61	5.58	5.78	5.91	4.83	5.11	5.39	39.56	0.00
1/30/2019	204.41	84.46	119.94	0.55	4,492.77	0.50	4,394.21	5.84	5.80	5.87	5.04	5.20	5.50	34.07	0.00
1/31/2019	202.53	82.49	120.04	0.55	4,484.26	0.50	4,519.73	5.85	5.98	5.72	2.57	6.00	6.33	33.75	0.00
2/1/2019	248.68	128.63	120.05	0.55	4,470.71	0.50	4,324.56	5.77	6.06	4.20	0.21	7.34	7.70	41.45	0.00
2/2/2019	276.95	135.43	141.52	0.54	4,449.32	0.49	4,302.03	4.98	5.99	6.01	0.21	7.20	7.32	46.16	0.00
2/3/2019	282.24	143.58	138.66	0.51	4,487.75	0.45	4,392.81	5.07	6.05	6.06	0.23	7.75	7.93	47.04	0.00
2/4/2019	282.17	162.09	120.08	0.50	4,490.65	0.45	4,401.58	5.17	6.11	6.10	0.23	7.77	7.94	47.03	0.00
2/5/2019	287.19	167.13	120.07	0.50	4,605.33	0.45	4,432.53	4.85	5.61	5.60	4.04	4.45	6.99	47.87	0.00
2/6/2019	287.56	168.45	119.11	0.50	4,570.66	0.45	4,392.08	5.59	5.94	5.92	8.55	0.04	7.81	47.93	0.00
2/7/2019	281.93	165.69	116.23	0.50	4,534.94	0.45	4,466.05	5.86	6.15	6.08	9.00	0.04	8.37	46.99	0.00
10/28/2018	292.28	193.43	98.86	0.67	3,236.81	0.74	2,935.78	5.35	5.67	5.64	6.09	6.01	5.90	48.71	0.00
10/29/2018	313.89	213.96	99.93	0.67	3,261.87	0.74	2,942.30	3.71	6.49	6.58	6.26	6.42	6.27	52.31	0.00
10/30/2018	255.98	154.90	101.08	0.67	3,234.54	0.73	2,880.07	0.02	7.85	8.22	6.12	6.83	6.63	42.66	0.00
10/31/2018	229.92	110.87	119.06	0.66	3,230.30	0.73	2,841.10	0.01	7.67	7.97	5.93	6.61	6.41	38.32	0.00
11/1/2018	254.04	144.10	109.95	0.67	3,193.15	0.73	2,642.42	0.01	7.35	7.58	5.69	6.37	6.11	42.34	0.00
11/2/2018	268.35	158.26	110.08	0.67	3,198.98	0.69	2,650.69	2.21	6.73	7.01	5.69	6.14	5.93	44.72	0.00
11/3/2018	311.48	201.46	110.03	0.67	3,207.70	0.69	2,658.58	4.97	5.28	5.41	5.16	5.01	4.98	51.91	0.00
11/4/2018	304.81	194.70	110.11	0.67	3,202.23	0.69	2,623.24	5.48	5.73	5.89	5.71	5.60	5.59	50.80	0.00
11/5/2018	297.61	187.53	110.08	0.67	3,214.75	0.69	2,635.33	6.41	3.00	6.97	6.14	6.13	6.15	49.60	0.00
11/6/2018	266.42	156.35	110.08	0.67	3,206.72	0.68	2,677.12	6.88	0.02	7.41	6.02	6.16	6.19	44.40	0.00
11/7/2018	265.90	156.57	109.33	0.67	3,221.27	0.64	2,717.79	8.01	0.02	7.88	5.69	5.85	5.75	44.32	0.00
11/8/2018	277.62	157.71	119.91	0.67	3,223.59	0.64	2,710.79	8.19	0.03	8.05	5.73	5.95	5.90	46.27	0.00

Recycle Stream Data (Summer Campaign)

Denite Waste Biomass							
	Daily Average			Grab			
	Denite rx 2 Waste Biomass Flow	Denite rx 3 Waste Biomass Flow	Denite rx 4 Waste Biomass Flow	COD	TSS	Alkalinity	NO2+NO3
Units	gpm	gpm	gpm	mg/L - O2	mg/L	mg/L-CaCO3	mg/L-N
6/23/2019	55.45	56.39	46.69	675.00	472.00	119.01	<0.06
6/24/2019	55.84	56.77	46.46				
6/25/2019	56.06	56.70	46.49	964.00	640.00	122.42	<0.06
6/26/2019	55.85	56.29	46.38				
6/27/2019	55.55	56.14	46.58	1,881.00	1,250.00	138.40	<0.06
6/28/2019	55.49	56.17	46.76				
6/29/2019	55.57	56.31	47.04				
6/30/2019	55.44	56.16	47.12	1,147.00	772.00	122.05	<0.06
7/1/2019	55.64	55.95	47.28				
7/2/2019	56.06	55.75	47.50	564.00	432.00	124.43	<0.06
7/3/2019	55.91	55.39	47.50				
7/4/2019	55.86	55.23	47.43	1,246.00	840.00	140.21	<0.06
7/5/2019	55.66	54.86	47.59				
7/6/2019	55.76	54.68	47.54				
PRS (Centrate Return)							
	Daily	Grab					
	Centrate Flow to Headworks	COD	TSS	Alkalinity	Ammonia	TP	OP
Units	gpm	mg/L - O2	mg/L	mg/L-CaCO3	mg/L-N	mg/L - P	mg/L - P
6/23/2019	246.66	2,299.00	1,840.00	3,031.16	940.00	235.57	195.84
6/24/2019	244.07						
6/25/2019	250.17	2,385.00	1,790.00	2,767.90	891.00	136.92	69.70
6/26/2019	249.67						
6/27/2019	238.03	2,325.00	1,920.00	3,006.28	811.00	202.36	118.37
6/28/2019	250.12						
6/29/2019	250.35						
6/30/2019	250.63	1,880.00	1,290.00	2,774.82	884.00	58.89	29.41
7/1/2019	217.55						
7/2/2019	225.48	810.00	470.00	2,755.95	587.00	85.36	71.42
7/3/2019	225.05						
7/4/2019	226.64	1,188.00	1,040.00	3,001.47	971.00	104.98	107.26
7/5/2019	225.37						
7/6/2019	225.16						

Recycle Stream Data

	TWAS Underflow					
	DAF Influent Flow	TWAS Flow Out	TWAS Undflow Flow	TWAS Polymer Addition	Grab	
					TSS	TP
Units	MGD	gpm	MGD	gph	mg/L	mg/L - P
6/23/2019	1.41	87.37	1.28	3.09	19.00	6.59
6/24/2019	1.42	85.49	1.30	3.14		
6/25/2019	1.43	88.03	1.30	3.14	32.00	9.45
6/26/2019	1.43	86.48	1.30	3.15		
6/27/2019	1.43	85.05	1.30	3.14	32.00	6.73
6/28/2019	1.43	85.59	1.31	3.15		
6/29/2019	1.43	86.01	1.30	3.14		
6/30/2019	1.42	85.57	1.30	3.13	36.00	9.31
7/1/2019	1.43	85.31	1.31	3.15		
7/2/2019	1.42	86.84	1.30	3.14	24.00	6.86
7/3/2019	1.43	88.10	1.30	3.14		
7/4/2019	1.43	85.54	1.30	3.14	16.00	8.18
7/5/2019	1.42	83.36	1.30	3.13		
7/6/2019	1.42	83.72	1.30	3.13		

APPENDIX C – INFLUENT STREAM CONCENTRATIONS AND ASSUMPTIONS

Summer

Parameter (mg/L)	Raw Influent	Gravity Thickener	Denite Waste	TWAS	PRS	Unknown
Flow (mgd)	27.2	0.1	0.2	1.3	0.3	5.8
COD	544.8	1,265.7	1,079.5	64.5	1,814.5	300.0
TKN	44.0	46.7	92.0	27.5	847.3	43.0
TP	4.9	5.7	20.5	7.9	137.3	8.5
NO _x	0.9	0.0	0.0	4.1	0.0	0.0
pH	7.3	6.1	8.8	6.7	7.6	7.4
Alkalinity	208.2	232.1	127.8	184.2	2,889.6	200.0
FCOD	213.6	680.0	622.9	42.8	1,047.0	173.1
FFCOD	147.1	575.9	491.2	34.0	825.6	136.5
Acetate	20.0	168.8	0.0	0.0	0.0	0.0
Ammonia	28.3	35.1	0.0	24.6	847.3	25.0
OP	3.0	4.1	0.2	0.3	98.7	3.8
BOD	263.8	606.8	517.6	49.1	871.0	100.0
FBOD	103.7	316.9	270.3	6.6	454.6	5.0
VSS	193.3	258.6	660.9	23.9	1,252.5	180.0
TSS	212.5	287.3	734.3	26.5	1,391.7	200.0

Parameter (mg/L)	Primary INF Sys 1	Primary INF Sys 2
Flow (mgd)	16.2	18.8
COD	505.5	513.3
TKN	52.6	50.8
TP	7.0	6.7
NO _x	0.4	0.3
pH	-	-
Alkalinity	239.3	229.3
FCOD	184.2	181.3
FFCOD	136.5	138.6
Acetate	17.0	14.0
Ammonia	36.3	35.5
OP	4.0	4.0
BOD	250.0	228.2
FBOD	85.6	82.5
VSS	211.2	185.7
TSS	230.2	210.4

Provided Data
Average Secondary Effluent Values
Primary Effluent Values
Fractions
N/P in Biomass
Assumed Values
As Ammonia
Average Primary Effluent Values
Flow Weighted Balance

Fall

Parameter (mg/L)	Raw Influent	Gravity Thickener	Denite Waste	TWAS	Unknown
Flow (mgd)	25.8	0.1	0.2	1.3	8.9
COD	535.9	1,265.7	1,079.5	64.5	500.0
TKN	47.7	46.7	92.0	27.5	35.0
TP	5.6	5.7	20.5	7.9	11.0
Nox	0.1	0.0	0.0	4.1	5.5
pH	7.4	6.1	8.8	6.7	7.4
Alkalinity	225.3	232.1	127.8	184.2	250.0
FCOD	209.0	680.0	622.9	42.8	288.5
FFCOD	160.8	575.9	491.2	34.0	227.5
Acetate	22.0	168.8	0.0	0.0	0.0
Ammonia	31.4	35.1	0.0	24.6	25.0
OP	3.6	4.1	0.2	0.3	8.0
BOD	263.8	606.8	517.6	49.1	250.0
FBOD	103.7	316.9	270.3	6.6	100.0
VSS	192.9	258.6	660.9	23.9	80.0
TSS	214.3	287.3	734.3	26.5	120.0

Parameter (mg/L)	Primary INF Sys 1	Primary INF Sys 2
Flow (mgd)	16.0	17.9
COD	546.8	489.5
TKN	45.6	40.3
TP	6.6	6.5
NO _x	1.6	1.2
pH	-	-
Alkalinity	226.9	221.4
FCOD	213.3	190.9
FFCOD	164.0	146.9
Acetate	21.0	15.5
Ammonia	29.7	28.5
OP	4.3	4.2
BOD	267.9	239.9
FBOD	104.5	93.5
VSS	172.1	168.1
TSS	191.2	186.8

Provided Data
Assume Constant from Summer Data
Primary Effluent
Fractions
Flow Weighted Balance
PRS (offline)

Winter

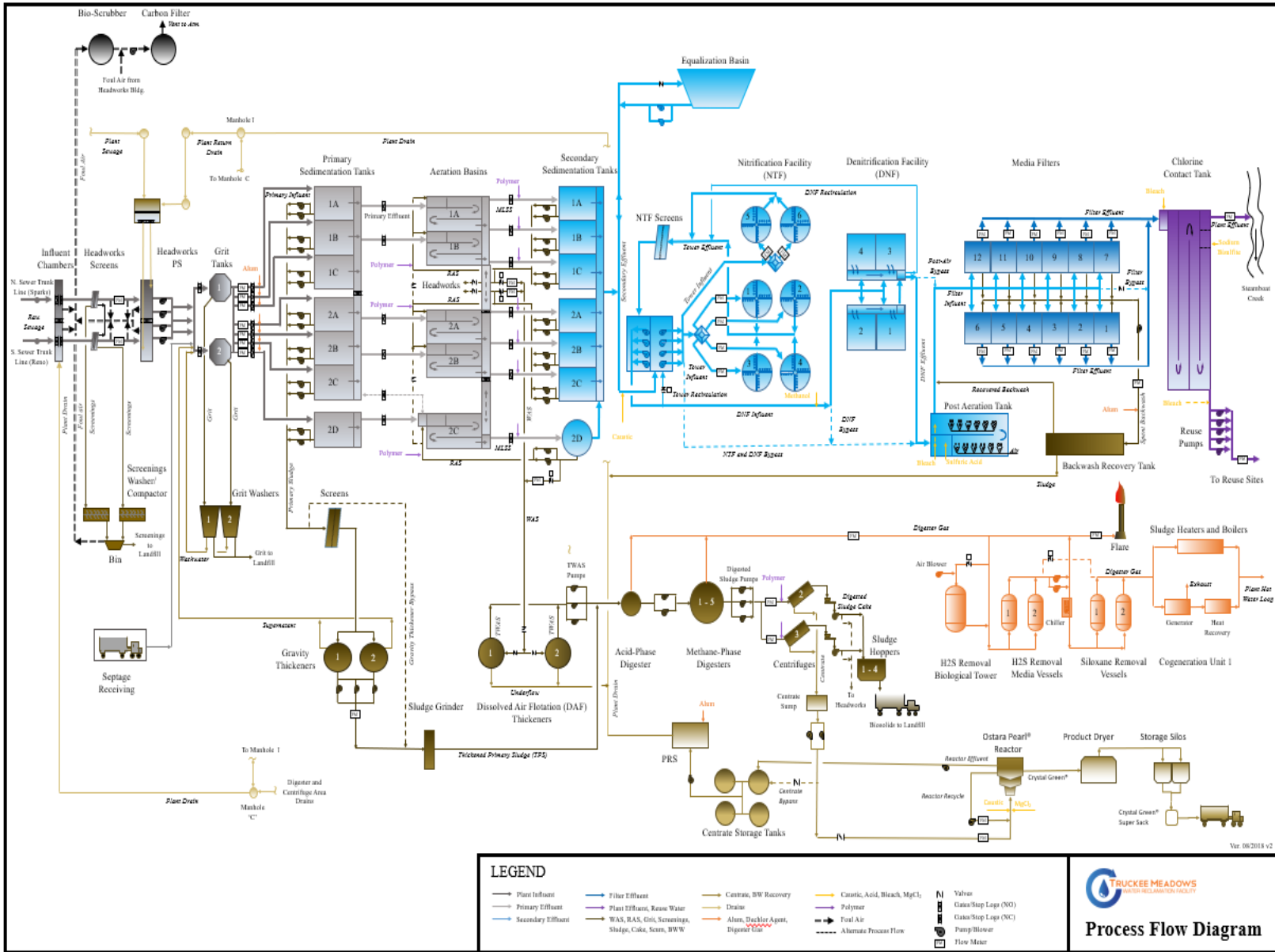
Parameter (mg/L)	Raw Influent	Gravity Thickener	Denite Waste	TWAS	Unknown
Flow (mgd)	28.2	0.1	0.2	1.3	9.8
COD	544.8	1,265.7	1,079.5	64.5	300.0
TKN	44.3	46.7	92.0	27.5	70.0
TP	5.1	5.7	20.5	7.9	11.0
Nox	0.1	0.0	0.0	4.1	2.5
pH	7.2	6.1	8.8	6.7	7.4
Alkalinity	210.2	232.1	127.8	184.2	350.0
FCOD	212.5	680.0	622.9	42.8	173.1
FFCOD	163.4	575.9	491.2	34.0	136.5
Acetate	13.0	168.8	0.0	0.0	0.0
Ammonia	29.4	35.1	0.0	24.6	60.0
OP	3.2	4.1	0.2	0.3	8.0
BOD	267.0	606.8	517.6	49.1	200.0
FBOD	104.9	316.9	270.3	6.6	100.0
VSS	211.1	258.6	660.9	23.9	5.0
TSS	234.5	287.3	734.3	26.5	10.0

Parameter (mg/L)	Primary INF Sys 1	Primary INF Sys 2
Flow (mgd)	17.1	15.8
COD	494.7	502.5
TKN	51.3	49.7
TP	6.2	6.0
Nox	0.6	0.4
pH	-	-
Alkalinity	230.3	222.4
FCOD	192.9	196.0
FFCOD	148.4	150.8
Acetate	nd	11.0
Ammonia	37.2	33.7
OP	3.9	3.5
BOD	257.0	247.0
FBOD	100.2	96.3
VSS	172.1	178.4
TSS	191.2	198.2

nd = not detected

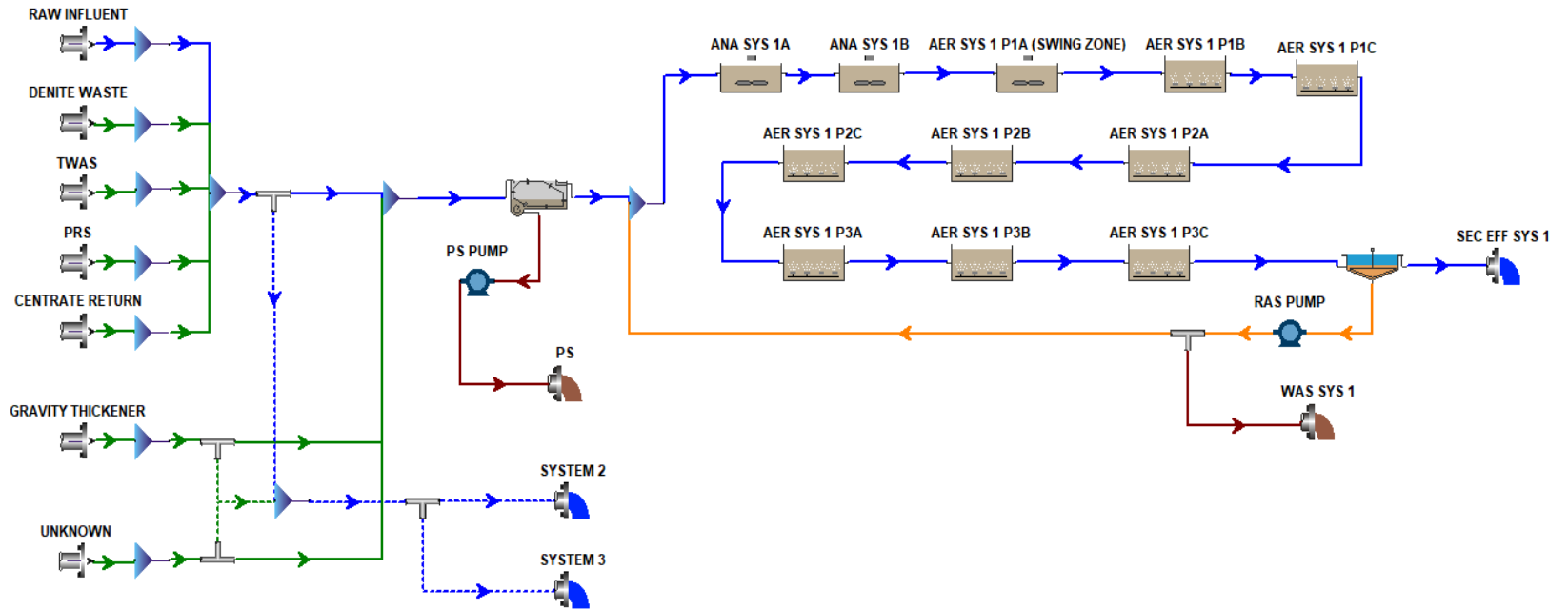
Provided Data
Assume Constant from Summer Data
Primary Effluent
Fractions
Flow Weighted Balance
PRS (offline)

APPENDIX D – TMWRF PROCESS SCHEMATIC

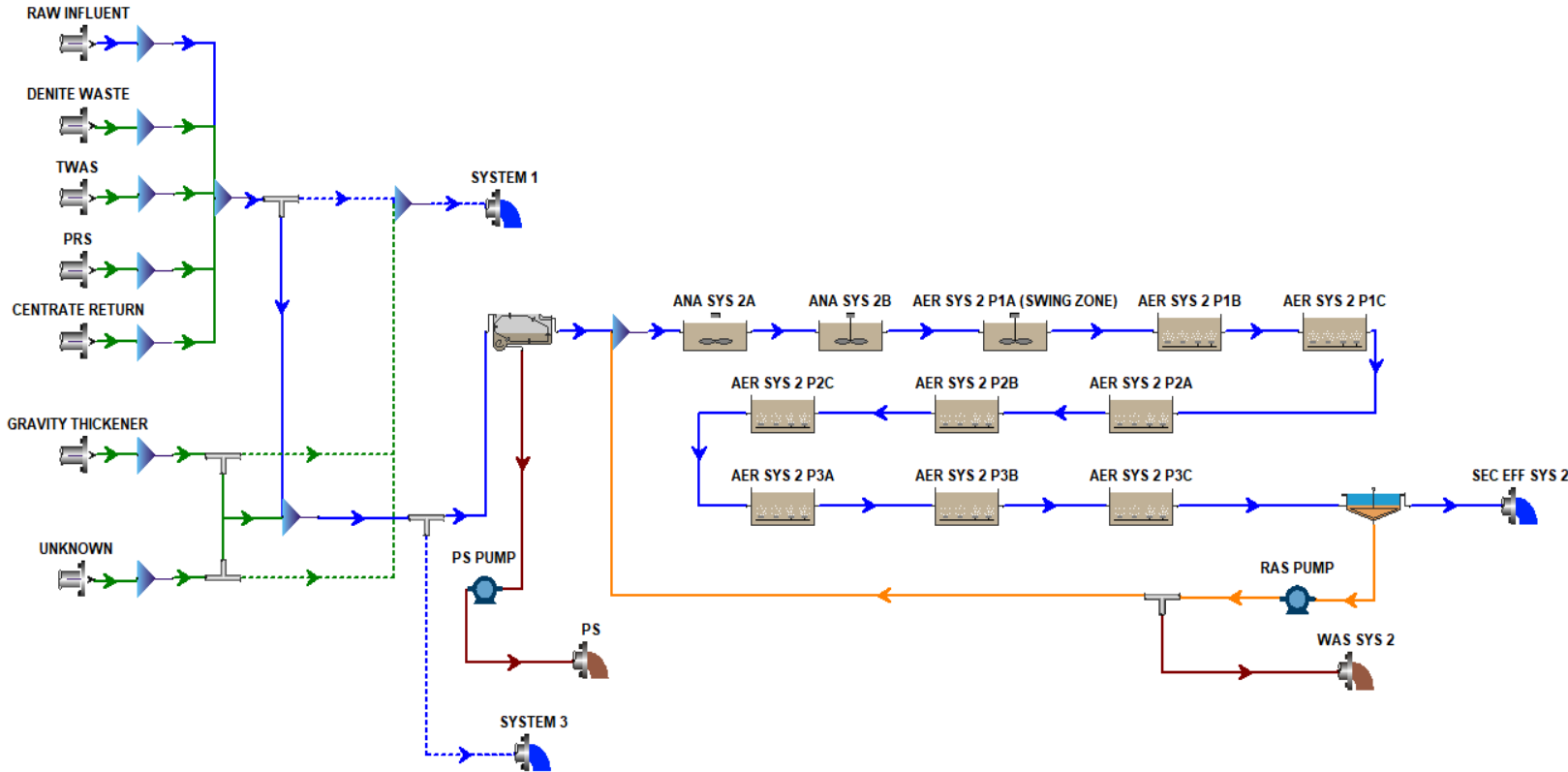


APPENDIX E – BIOWIN MODELS

A/O Process – System 1



A/O Process – System 2



Process Unit	Length (ft)	Width (ft)	SWD (ft)	Effective Surface Area (ft²)	Volume (MG)
Primary Clarifier	82.0	82.0	11.0	15,840	-
Secondary Clarifier	92.0	92.0	11.5	19,920	-
Activated Sludge Reactors					
ANA A	-	27.0	15.5	-	0.24
ANA B	-	27.0	15.5	-	0.24
AER 1A	-	27.0	15.5	-	0.44
AER 1B	-	27.0	15.5	-	0.18
AER 1C	-	27.0	15.5	-	0.37
AER 2A	-	27.0	15.5	-	0.25
AER 2B	-	27.0	15.5	-	0.33
AER 2C	-	27.0	15.5	-	0.32
AER 3A	-	27.0	15.5	-	0.33
AER 3B	-	27.0	15.5	-	0.34
AER 3C	-	27.0	15.5	-	0.34

Process Unit	No. Diffusers	System 1 DO (mg/L)	System 2 DO (mg/L)
ANA 1A	0	0.00	0.00
ANA 1B	0	0.00	0.00
AER 1A	0	0.00	0.00
AER 1B	638	0.46	0.90
AER 1C	1,396	1.85	1.77
AER 2A	1,194	2.05	2.24
AER 2B	1,194	1.99	1.98
AER 2C	1,194	2.99	2.99
AER 3A	956	2.45	2.48
AER 3B	956	2.33	2.58
AER 3C	956	2.50	2.48

Parameter (mg/L)	Plant INF	Gravity Thickener	Denite Waste	TWAS	PRS	Unknown
Flow (mgd)	27.20	0.12	0.23	1.30	0.34	5.75
COD	544.80	1,265.70	1,079.50	64.50	1.814.5	300.00
NO _x	0.80	0.00	0.00	4.10	0.00	0.00
TKN	44.00	46.70	92.00	27.50	847.30	43.00
TP	4.90	5.70	20.50	7.90	137.30	8.50
Alkalinity (mmol/L)	4.20	4.60	2.60	3.70	57.80	4.00
ISS	19.30	28.70	73.40	2.70	139.20	20.00
pH (-)	7.30	6.10	8.80	6.70	7.60	7.40

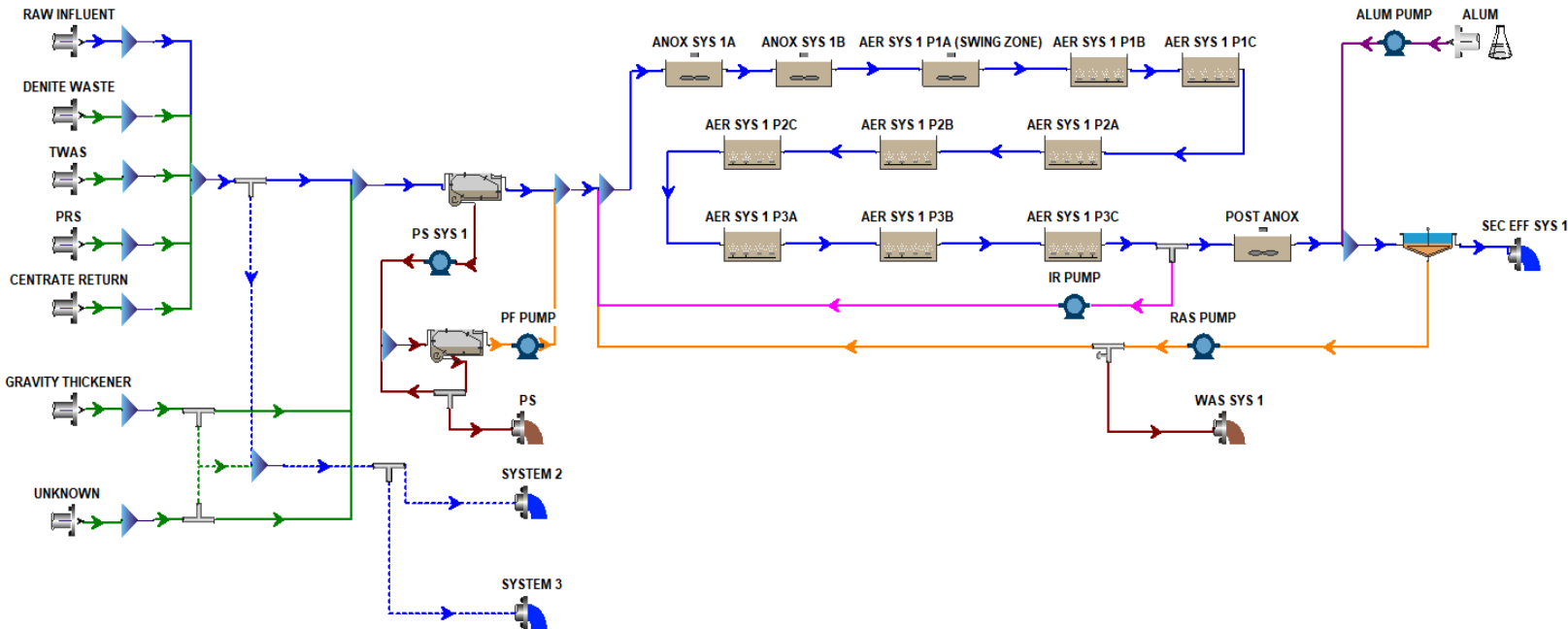
Parameter	System 1 Value	System 2 Value
Aeration		
Surface Pressure (kPa)	85.771	85.771
Diffuser		
Area of One Diffuser (ft ²)	0.442	0.442
Diffuser Mounting Height (ft)	0.900	0.900
Min. Air Flow Rate per Diffuser [20°C, 1 atm] (ft ³ /min)	0.750	0.750
Max. Air Flow Rater per Diffuser [20°C, 1 atm] (ft ³ /min)	4.000	4.000
'A' in Diffuser Pressure Drop = $A + B*[Qa/Diff] + C*[Qa/Diff]^2$ (psi)	0.508	0.508
Blower		
Intake Filter Pressure Drop (psi)	0.200	0.200
Pressure Drop Through Distribution Sys [Piping/Valves] (psi)	0.630	0.630
'A' in Blower Efficiency = $A + B*Qa + C*Qa^2$	0.700	0.700
Stoichiometric		
Particulate substrate COD:VSS ratio	1.500	1.500
Particulate inert COD:VSS ratio	1.500	1.500
OHO Yield (aerobic)	0.750	0.750
Kinetic		
AOB maximum growth rate (1/d)	1.150	1.250
NOB maximum growth rate (1/d)	1.510	1.620
PAO maximum growth rate (1/d)	1.350	1.500
Other		
Primary Clarifier Percent Removal (%)	61.0	61.0
Secondary Clarifier Percent Removal (%)	99.1	99.1

Splitter	Fraction [S/(S+M)]
Headworks	0.5
Gravity Thickener	0.5
Unknown	0.73
System 3	0

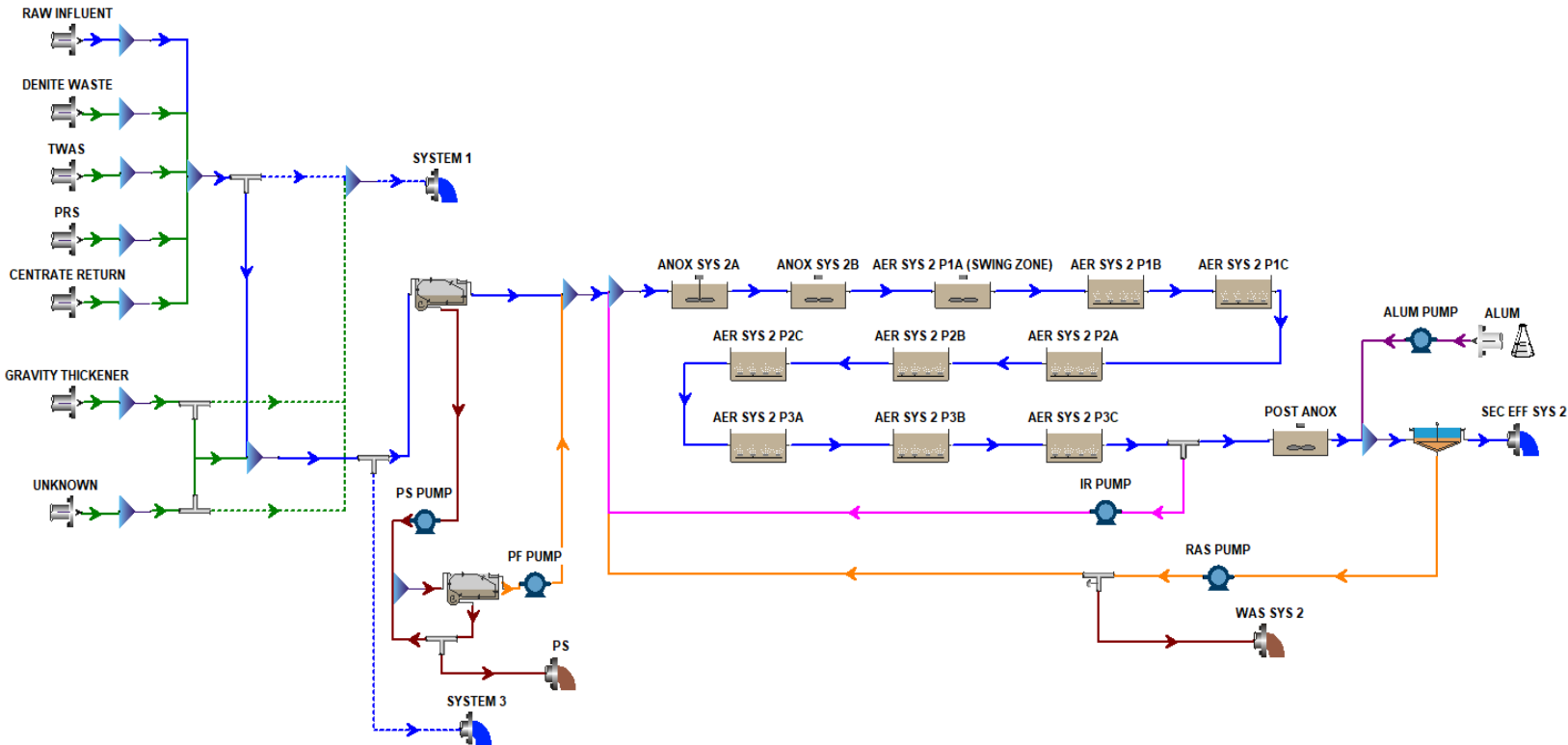
Parameter	System 1 Flow (mgd)	System 2 Flow (mgd)
Primary Sludge	0.16	0.16
RAS	8.44	9.40
WAS	0.69	0.74

Other Parameters	Value
Temperature (°C)	21.5
Energy Consumption (\$/kWh)	0.065
Methanol (\$/gal)	1.46
Aluminum (\$/gal)	1.17
Primary Sludge Pump (hp)	45
RAS Pump (hp)	300

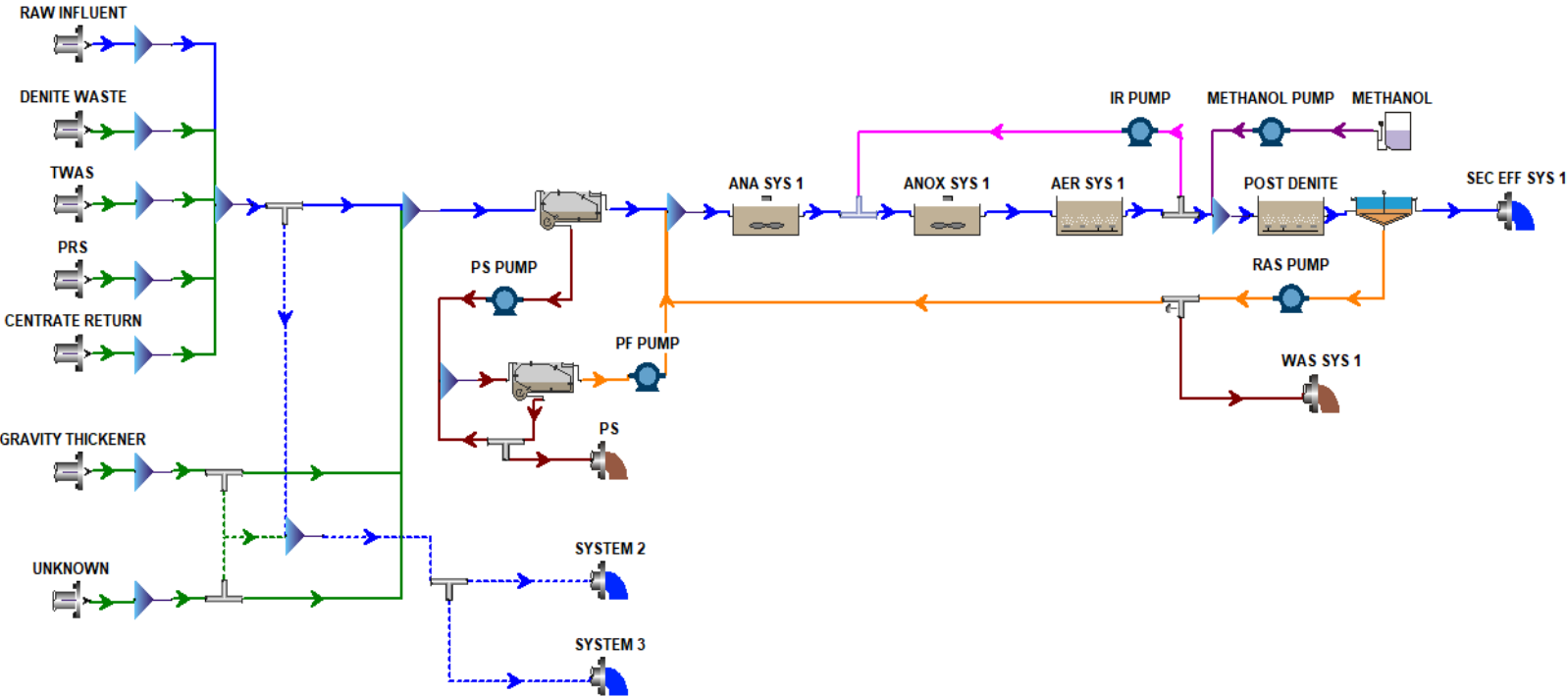
MLE Primary Fermentation/Post-Denitrification/Chemical Treatment Process – System 1

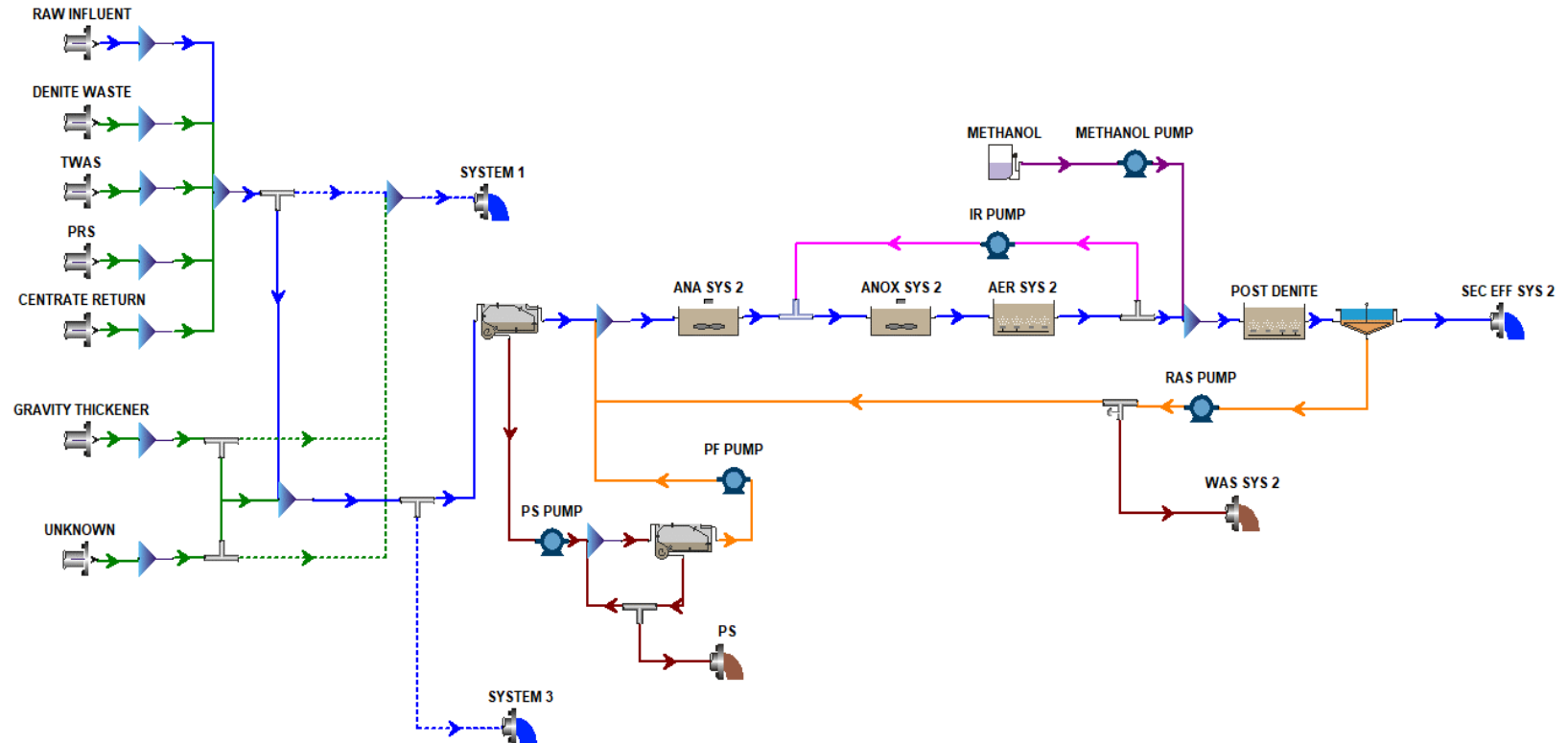


MLE Primary Fermentation/Post-Denitrification/Chemical Treatment Process – System 2

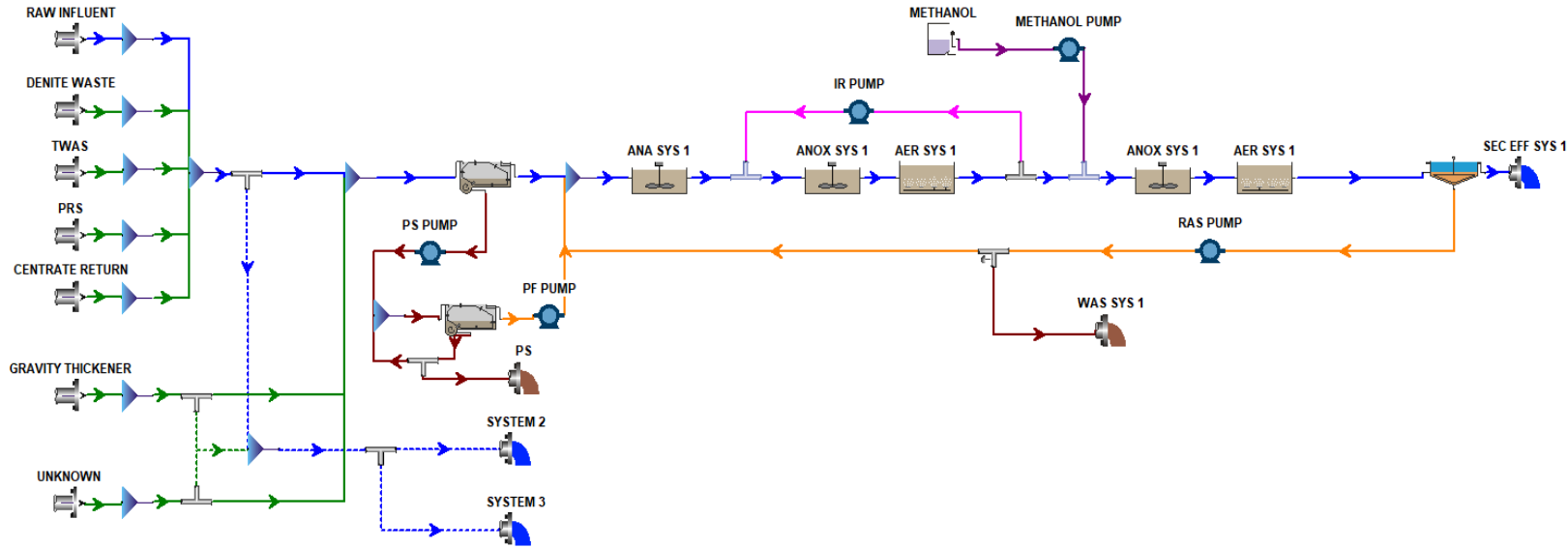


A²O Primary Fermentation/Post-Denitrification – System 1

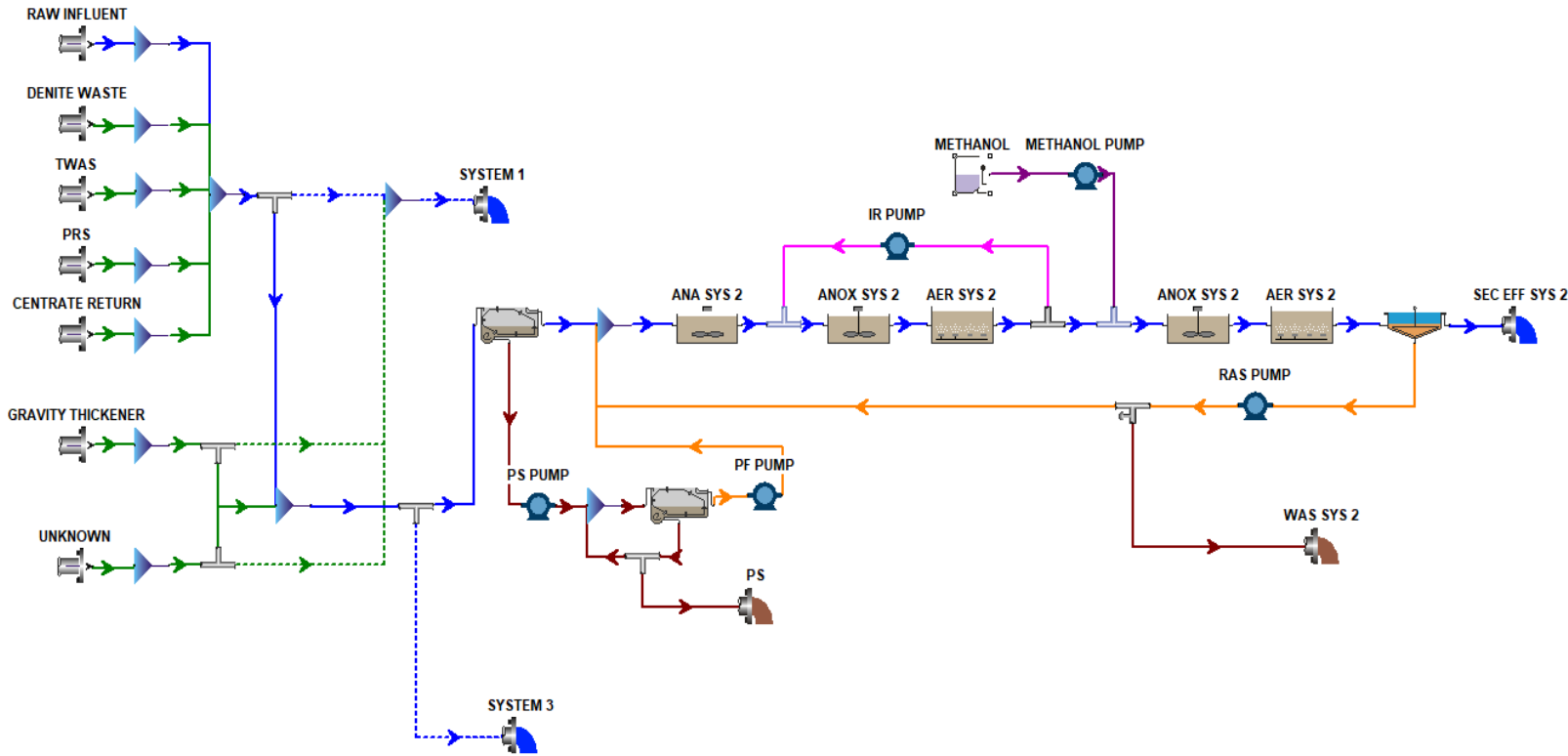


A²O Primary Fermentation/Post-Denitrification – System 2

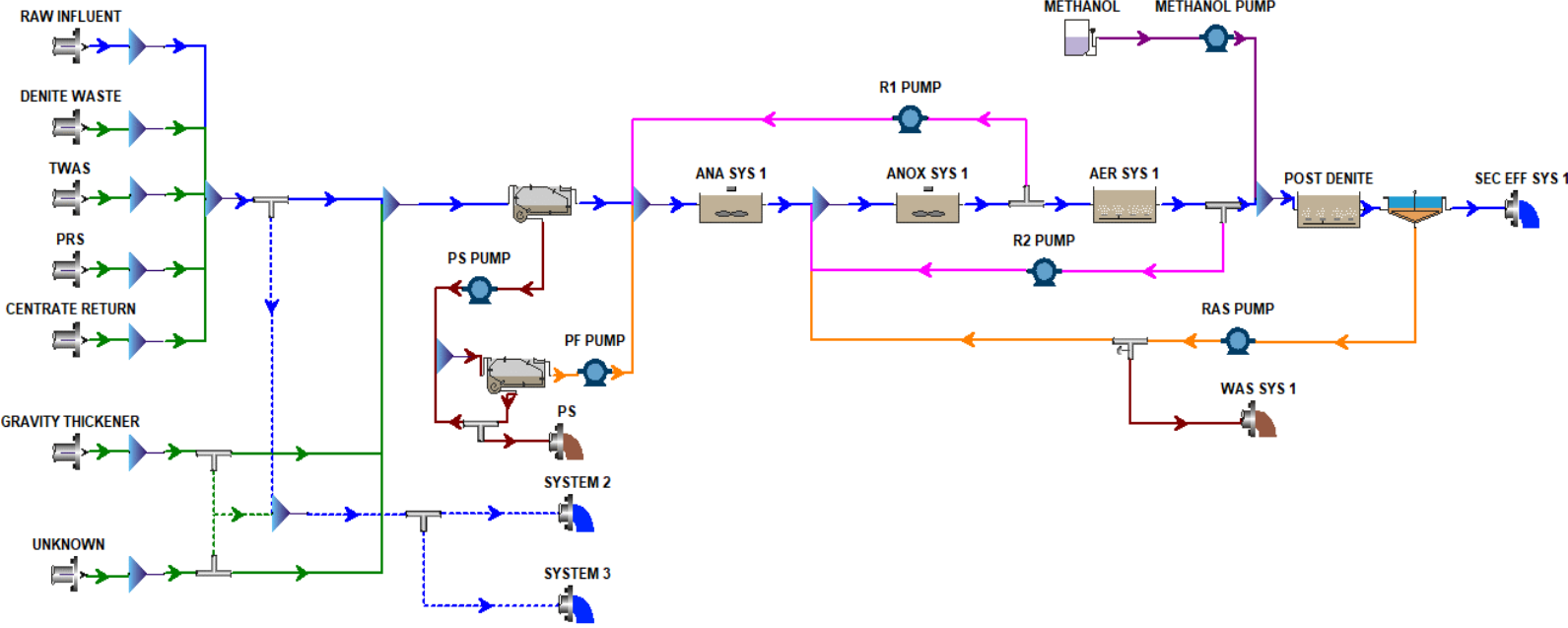
5-stage Bardenpho Primary Fermentation – System 1



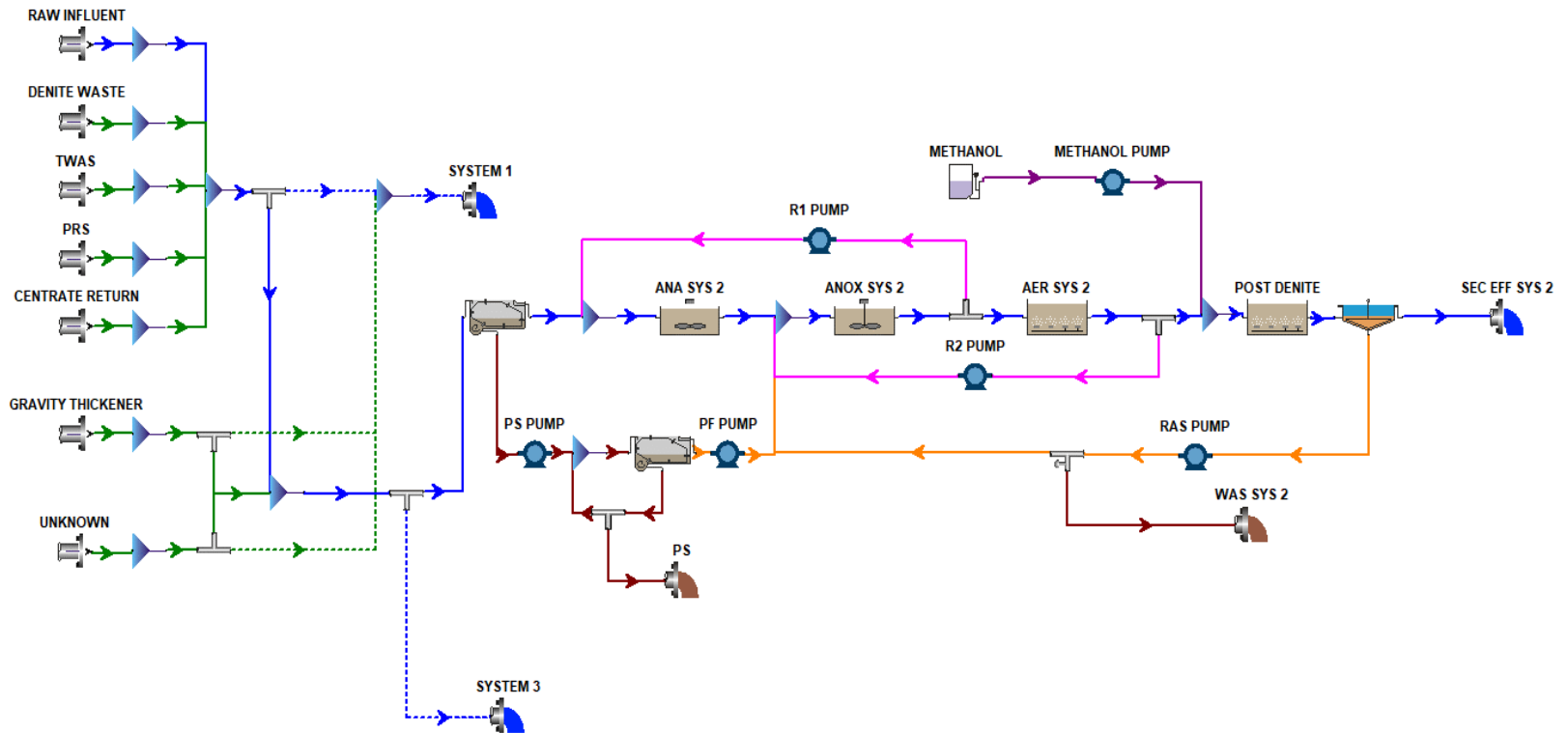
5-stage Bardenpho Primary Fermentation – System 2



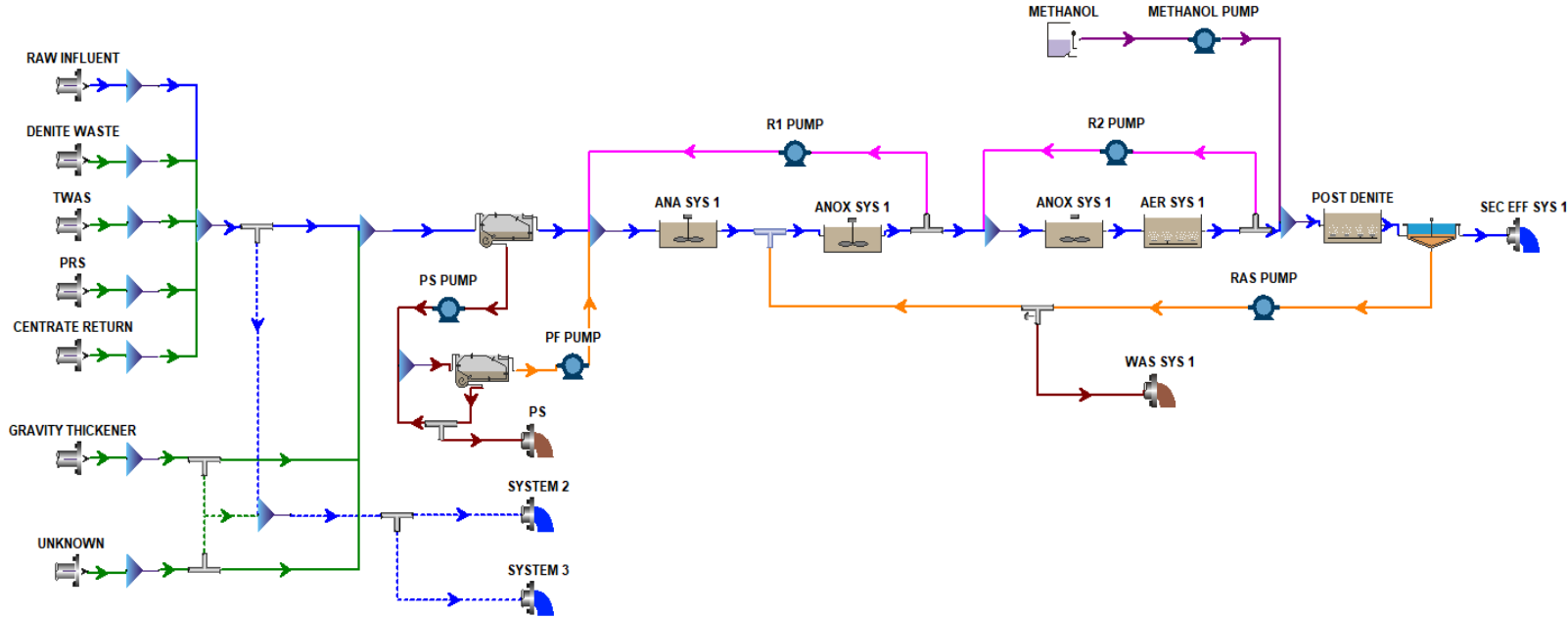
Standard UCT Primary Fermentation/Post-Denitrification – System 1



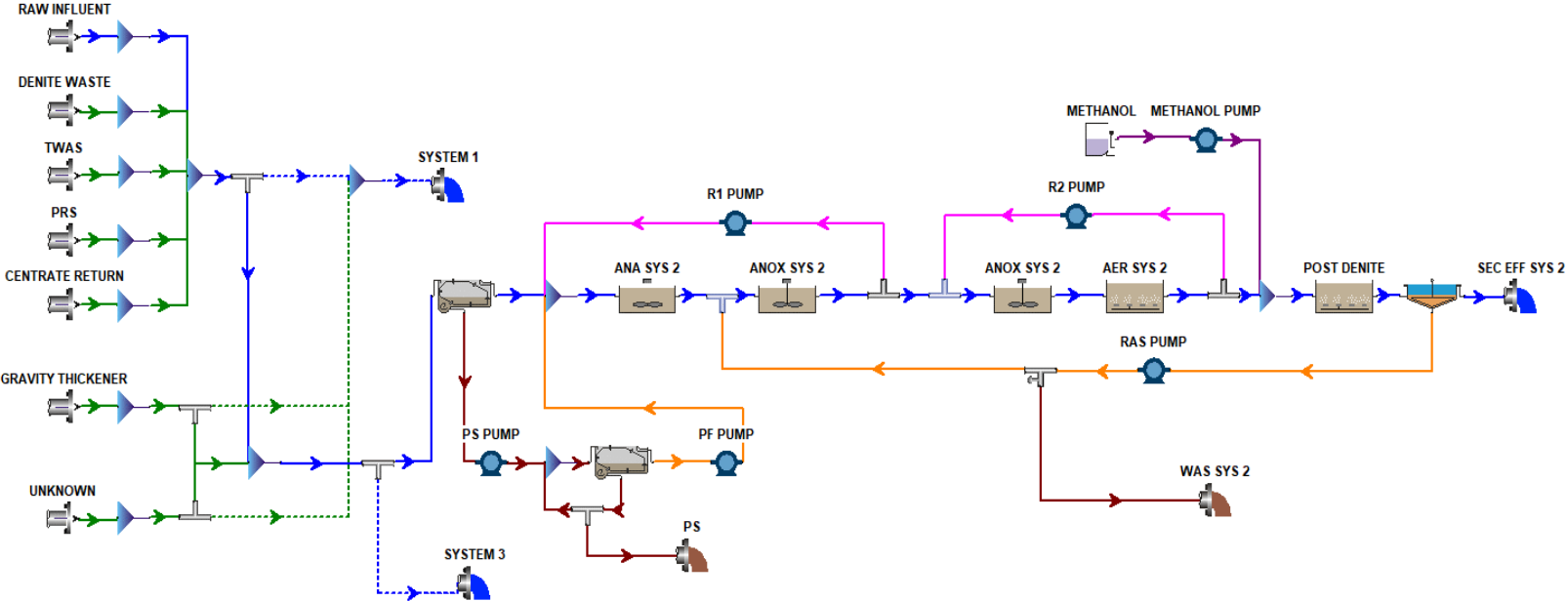
Standard UCT Primary Fermentation/Post-Denitrification – System 2



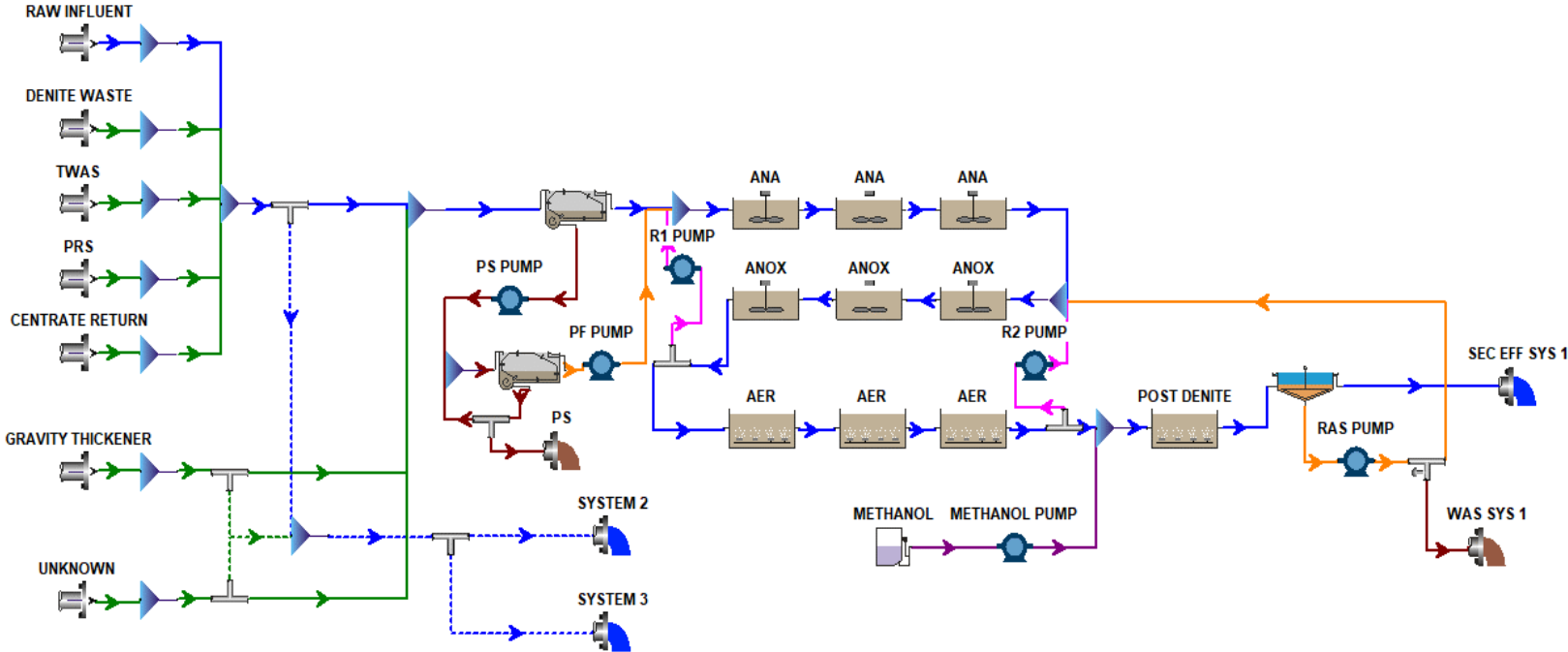
Modified UCT Primary Fermentation/Post-Denitrification – System 1



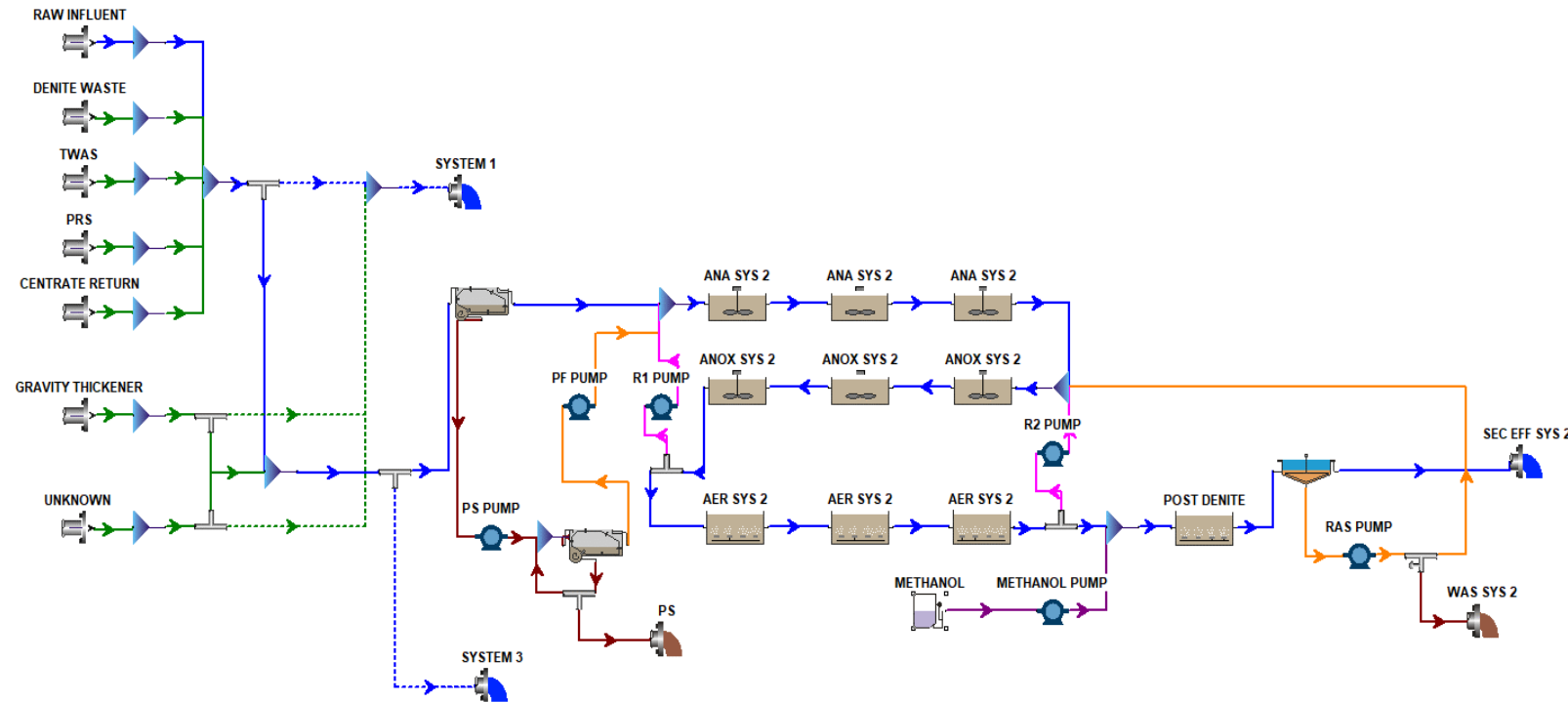
Modified UCT Primary Fermentation/Post-Denitrification – System 2



VIP Primary Fermentation/Post-Denitrification – System 1



VIP Primary Fermentation/Post-Denitrification – System 2



APPENDIX F – DO SAMPLING CAMPAIGN DATA

DO Sampling Campaign #1 Data

DO (mg/L)				
Location	Sys 1A	Sys 1B	Sys 2A	Sys 2B
Post-ANA	0.07	0.32	0.79	0.63
Midway to 1 st Probe	0.83	0.80	1.69	1.79
1 st Pass Probe	1.72	1.69	2.15	2.39

DO Sampling Campaign #2

DO (mg/L)	
Location	Sys 2B
1st Pass Middle	1.30
1 st Pass End	2.10
2 nd Pass Beginning	2.20
2 nd Pass Middle	2.13
2 nd Pass End	3.10
3 rd Pass Beginning	2.22
3 rd Pass Middle	1.91
3 rd Pass End	1.95

DO Sampling Campaign #3

11/6/2019 – 11:00 AM DO Values (mg/L)				
Location	Sys 1A	Sys 1B	Sys 2A	Sys 2B
1st Pass Middle	0.20	0.20	1.10	0.90
1 st Pass End	1.50	1.70	3.20	1.80
2 nd Pass Beginning	1.80	2.30	3.20	1.90
2 nd Pass Middle	2.20	2.20	3.00	3.30
2 nd Pass End	3.20	3.00	3.20	4.00
3 rd Pass Beginning	2.50	2.20	2.60	3.90
3 rd Pass Middle	2.00	2.30	2.50	4.00
3 rd Pass End	2.30	2.20	2.30	3.60

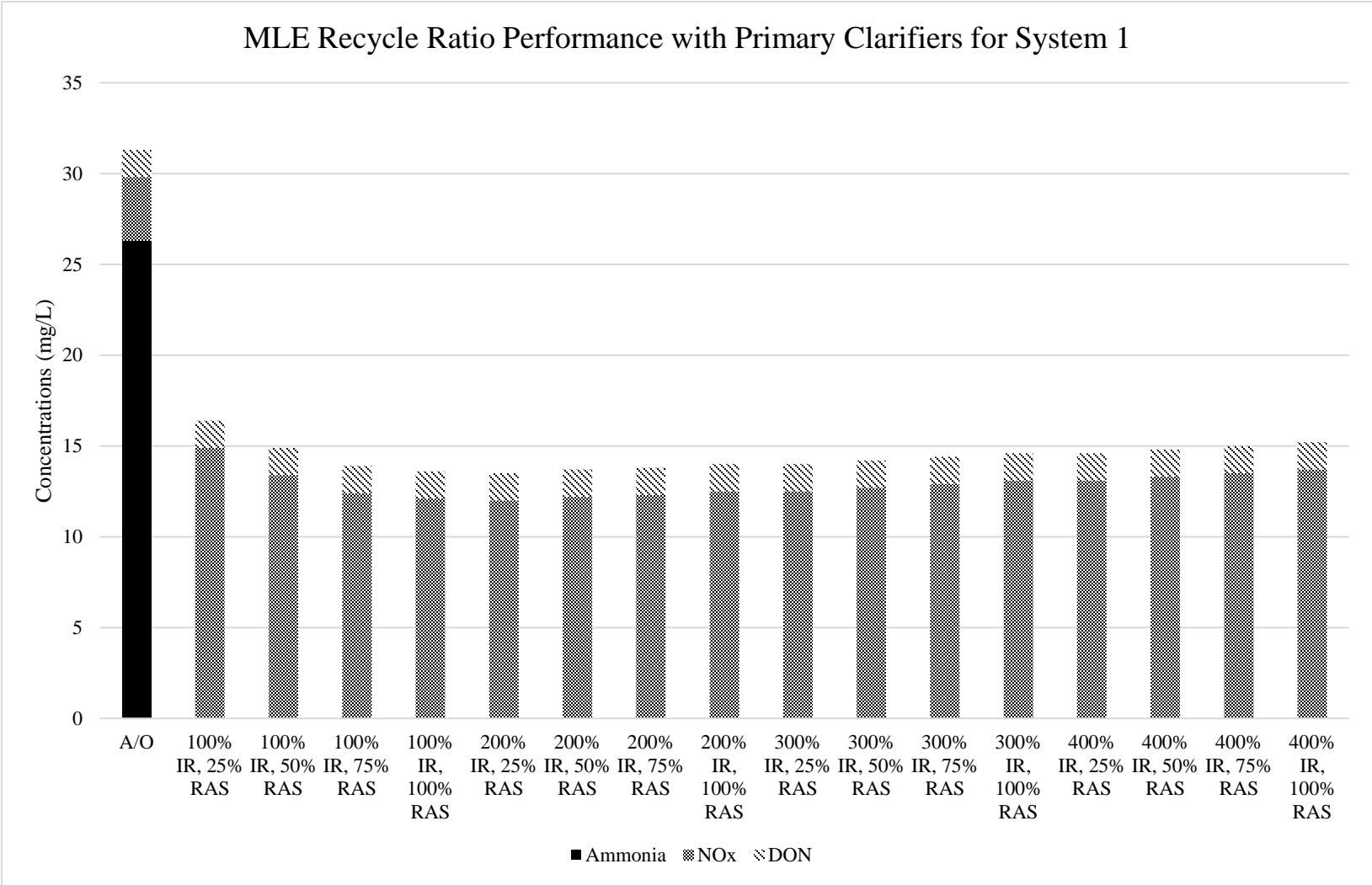
11/7/2019 – 11:00 AM DO Values (mg/L)				
Location	Sys 1A	Sys 1B	Sys 2A	Sys 2B
1st Pass Middle	0.30	0.10	1.90	0.70
1 st Pass End	2.00	1.80	4.30	1.10
2 nd Pass Beginning	1.90	1.90	4.00	2.80
2 nd Pass Middle	2.20	2.20	3.50	3.00
2 nd Pass End	3.10	3.40	3.70	4.00
3 rd Pass Beginning	2.30	2.60	2.90	3.80
3 rd Pass Middle	2.30	2.50	2.50	3.70
3 rd Pass End	2.50	2.50	2.60	4.00

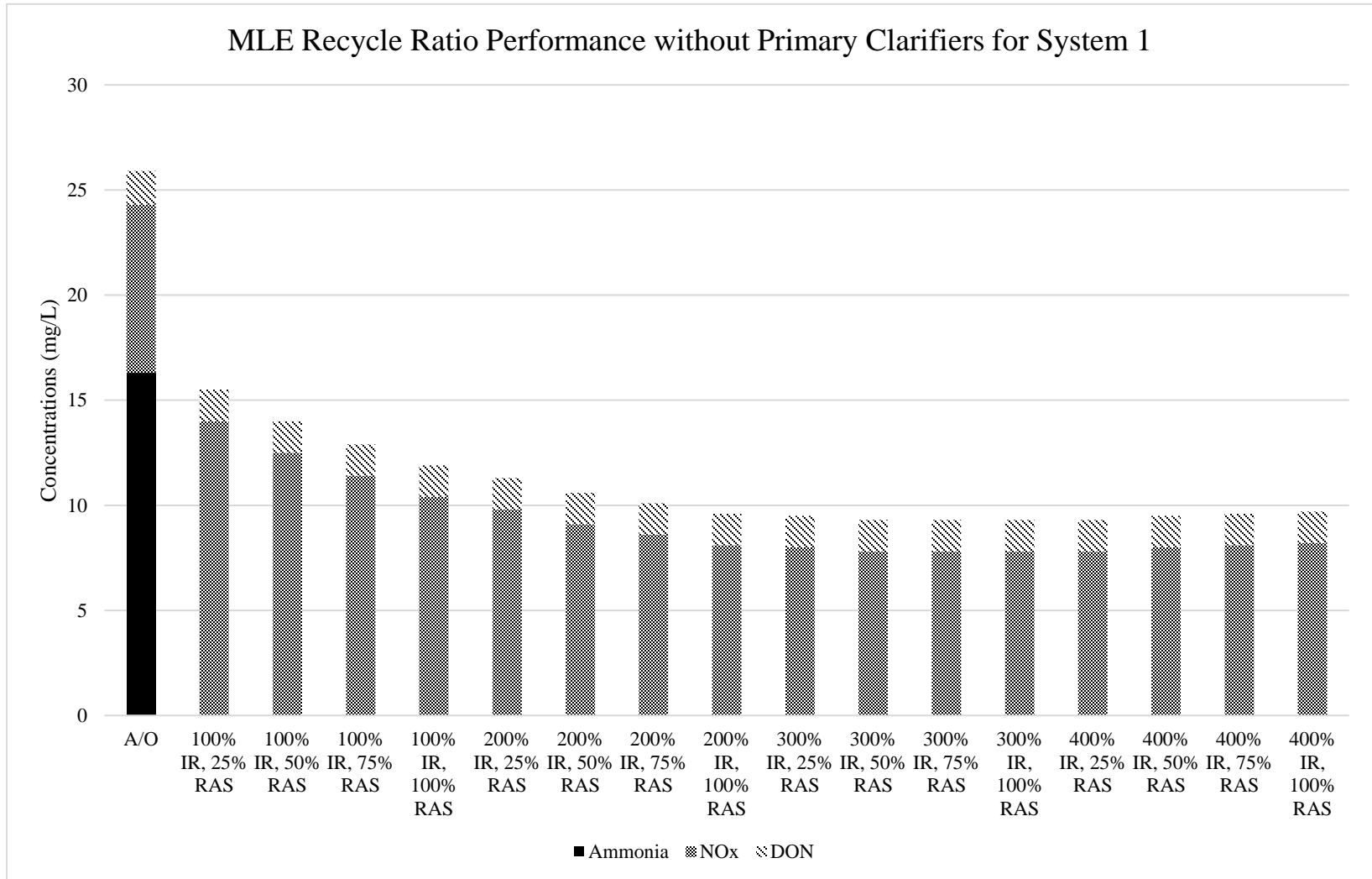
11/8/2019 – 11:00 AM DO Values (mg/L)				
Location	Sys 1A	Sys 1B	Sys 2A	Sys 2B
1st Pass Middle	0.40	0.20	0.50	0.70
1 st Pass End	2.20	2.40	1.00	1.00
2 nd Pass Beginning	1.80	2.00	1.70	1.20
2 nd Pass Middle	1.60	1.60	1.30	1.10
2 nd Pass End	2.90	2.70	2.00	2.10
3 rd Pass Beginning	2.00	2.20	2.00	2.00
3 rd Pass Middle	2.00	2.10	2.20	2.40
3 rd Pass End	2.10	2.20	2.00	2.00

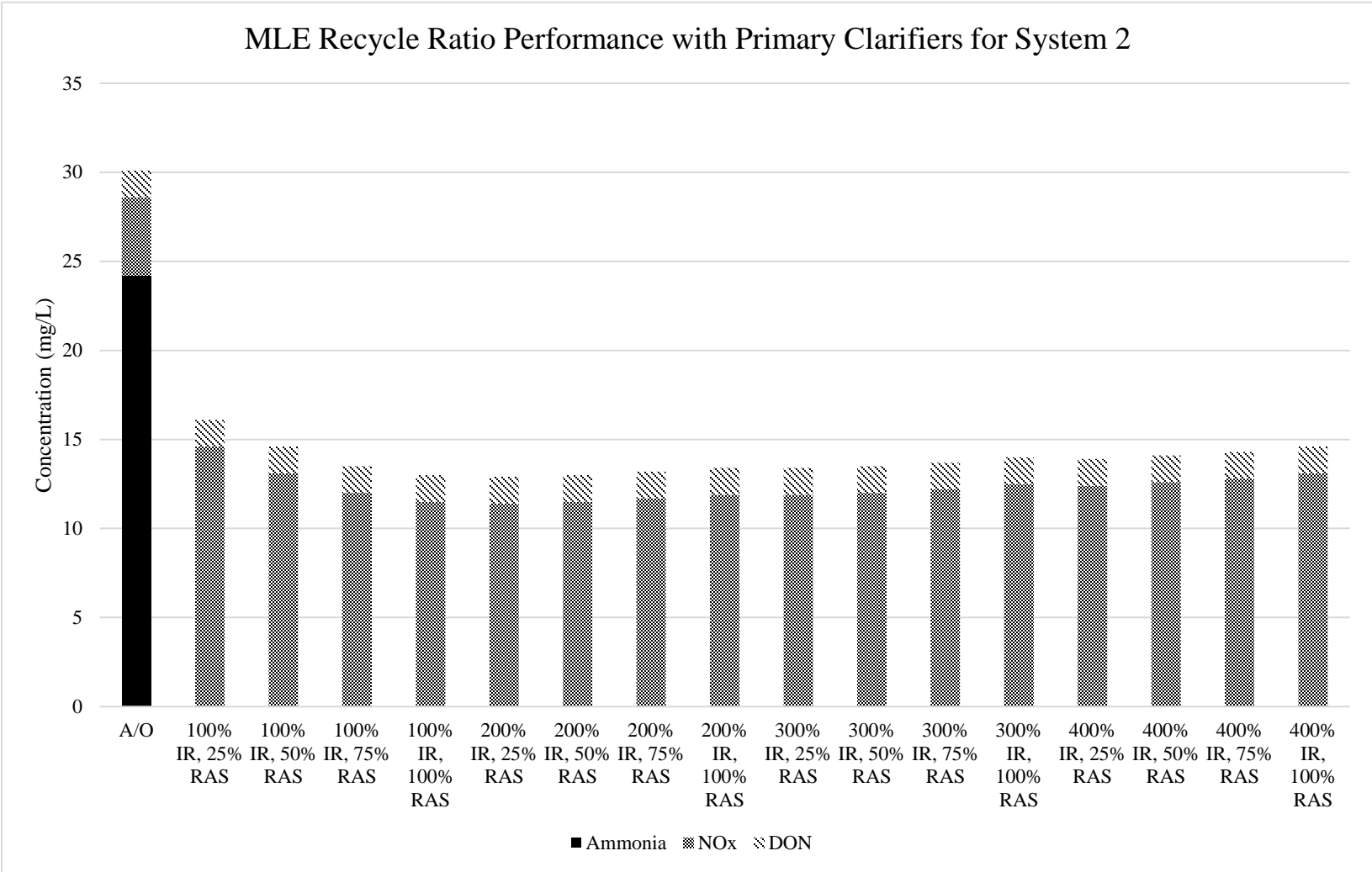
11/8/2019 – 5:10 PM DO Values (mg/L)				
Location	Sys 1A	Sys 1B	Sys 2A	Sys 2B
1st Pass Middle	1.77	1.01	1.20	1.10
1 st Pass End	2.39	1.30	1.44	1.73
2 nd Pass Beginning	2.40	2.25	2.13	1.36
2 nd Pass Middle	2.17	2.38	1.59	1.42
2 nd Pass End	3.00	3.09	2.89	2.15
3 rd Pass Beginning	1.99	1.90	1.87	1.18
3 rd Pass Middle	1.83	1.96	2.01	1.47
3 rd Pass End	1.94	2.01	2.06	1.01

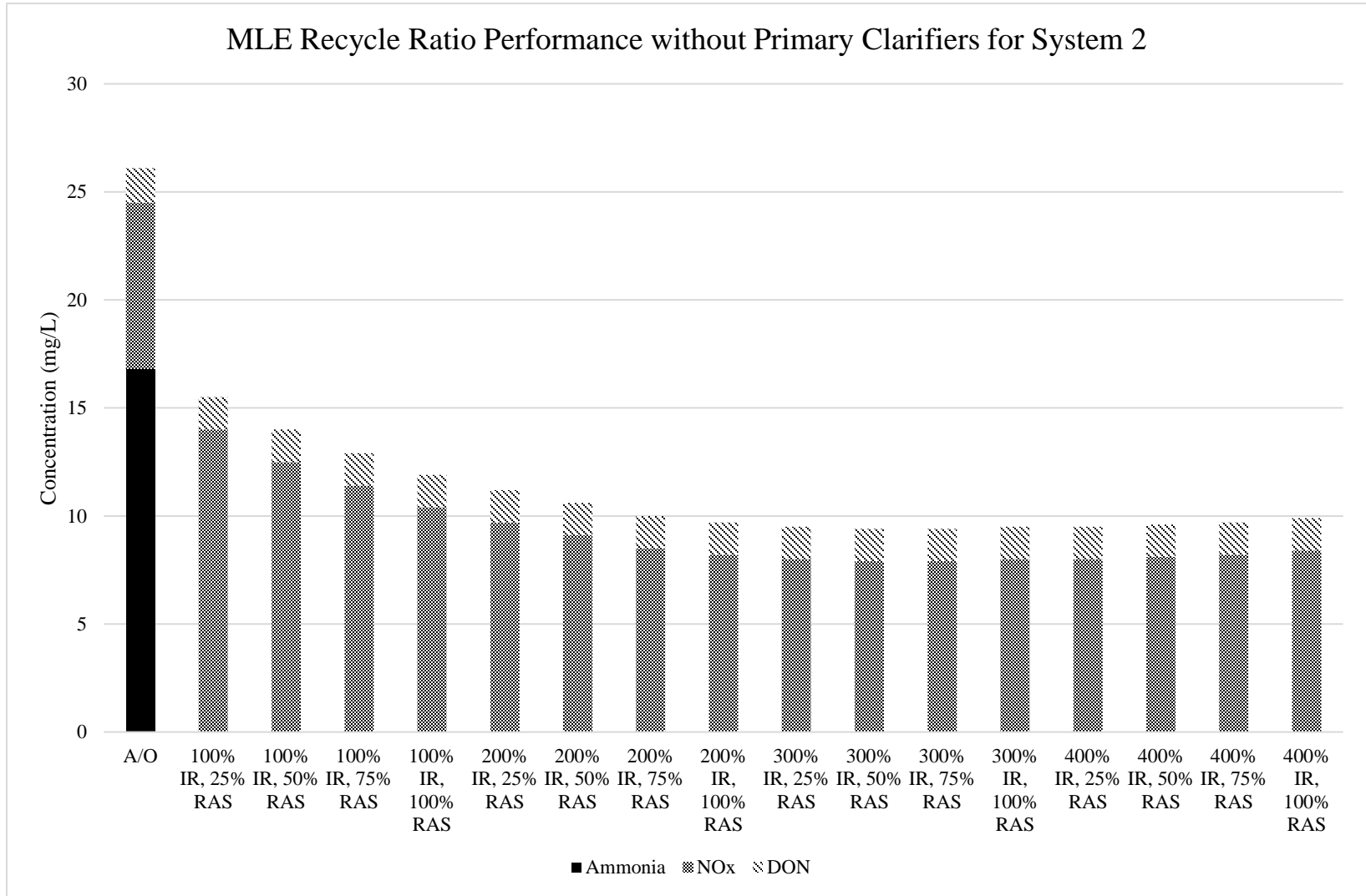
11/12/2019 – 11:00 AM DO Values (mg/L)				
Location	Sys 1A	Sys 1B	Sys 2A	Sys 2B
1st Pass Middle	0.44	0.28	0.65	0.79
1 st Pass End	2.91	2.09	2.14	2.25
2 nd Pass Beginning	2.80	1.85	1.80	1.49
2 nd Pass Middle	2.08	2.02	1.30	1.01
2 nd Pass End	3.02	3.14	1.97	2.30
3 rd Pass Beginning	1.78	2.04	2.03	1.56
3 rd Pass Middle	1.71	1.79	2.25	1.33
3 rd Pass End	1.92	2.26	2.54	1.51

APPENDIX G – MLE RECYCLE RATIO ANALYSIS









APPENDIX H – SAFETY DATA SHEETS

SAFETY DATA SHEET

1. Identification

Product identifier	Aluminum Sulfate - Liquid/Liquid Alum/Alum	
Other means of identification		
Synonyms	Aluminium Sulfate Liquid (8.2-8.3% as Al ₂ O ₃) * Aluminum Sulfate Liquid (27.5-28.9% as Al ₂ SO ₄) * Aluminum Sulfate Liquid (47.8-48.4% as Al ₂ SO ₄ ·14H ₂ O)	
Recommended use	Not available.	
Recommended restrictions	None known.	
Manufacturer/Importer/Supplier/Distributor information		
Manufacturer		
Company name	Thatcher Company of Nevada, Inc.	
Address	2302 Larkin Circle Sparks, NV 89431	
Telephone	General Assistance	801 972 4587
E-mail	inquiries@tchem.com	
Emergency phone number	Chemtec (CCN 22106)	800 424 9300

2. Hazard(s) identification

Physical hazards	Not classified.	
Health hazards	Acute toxicity, oral	Category 4
	Skin corrosion/irritation	Category 2
	Serious eye damage/eye irritation	Category 1
	Specific target organ toxicity, single exposure	Category 3 respiratory tract irritation
Environmental hazards	Hazardous to the aquatic environment, acute hazard	Category 2
OSHA defined hazards	Not classified.	
Label elements		



Signal word	Danger	
Hazard statement	Harmful if swallowed. Causes skin irritation. Causes serious eye damage. May cause respiratory irritation. Toxic to aquatic life.	
Precautionary statement		
Prevention	Avoid breathing mist or vapor. Wash thoroughly after handling. Do not eat, drink or smoke when using this product. Use only outdoors or in a well-ventilated area. Avoid release to the environment. Wear protective gloves. Wear eye/face protection.	
Response	If swallowed: Call a poison center/doctor if you feel unwell. If on skin: Wash with plenty of water. If inhaled: Remove person to fresh air and keep comfortable for breathing. If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a poison center/doctor. Rinse mouth. If skin irritation occurs: Get medical advice/attention. Take off contaminated clothing and wash before reuse.	
Storage	Store in a well-ventilated place. Keep container tightly closed. Store locked up.	
Disposal	Dispose of contents/container in accordance with local/regional/national/international regulations.	
Hazard(s) not otherwise classified (HNOC)	None known.	
Supplemental information	72.5% of the mixture consists of component(s) of unknown acute oral toxicity. 72.5% of the mixture consists of component(s) of unknown acute hazards to the aquatic environment.	

3. Composition/information on ingredients

Mixtures

Chemical name	Common name and synonyms	CAS number	%
Aluminum Sulfate		10043-01-3	20 - < 30
Other components below reportable levels			70 - < 80

*Designates that a specific chemical identity and/or percentage of composition has been withheld as a trade secret.

4. First-aid measures

Inhalation	Remove victim to fresh air and keep at rest in a position comfortable for breathing. Call a POISON CENTER or doctor/physician if you feel unwell.
Skin contact	Remove contaminated clothing. Wash with plenty of soap and water. If skin irritation occurs: Get medical advice/attention. Wash contaminated clothing before reuse.
Eye contact	Immediately flush eyes with plenty of water for at least 15 minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Get medical attention immediately.
Ingestion	Rinse mouth. If vomiting occurs, keep head low so that stomach content doesn't get into the lungs. Get medical advice/attention if you feel unwell.
Most important symptoms/effects, acute and delayed	Severe eye irritation. Symptoms may include stinging, tearing, redness, swelling, and blurred vision. Permanent eye damage including blindness could result. May cause respiratory irritation. Skin irritation. May cause redness and pain.
Indication of immediate medical attention and special treatment needed	Provide general supportive measures and treat symptomatically. Keep victim warm. Keep victim under observation. Symptoms may be delayed.
General information	If you feel unwell, seek medical advice (show the label where possible). Ensure that medical personnel are aware of the material(s) involved, and take precautions to protect themselves. Show this safety data sheet to the doctor in attendance.

5. Fire-fighting measures

Suitable extinguishing media	Water fog. Foam. Dry chemical powder. Carbon dioxide (CO ₂).
Unsuitable extinguishing media	Do not use water jet as an extinguisher, as this will spread the fire.
Specific hazards arising from the chemical	Not applicable.
Special protective equipment and precautions for firefighters	Wear suitable protective equipment.
Fire fighting equipment/instructions	Move containers from fire area if you can do so without risk.
Specific methods	Use standard firefighting procedures and consider the hazards of other involved materials.
General fire hazards	No unusual fire or explosion hazards noted.

6. Accidental release measures

Personal precautions, protective equipment and emergency procedures	Keep unnecessary personnel away. Keep people away from and upwind of spill/leak. Wear appropriate protective equipment and clothing during clean-up. Avoid breathing mist or vapor. Do not touch damaged containers or spilled material unless wearing appropriate protective clothing. Ensure adequate ventilation. Local authorities should be advised if significant spillages cannot be contained. For personal protection, see section 8 of the SDS.
Methods and materials for containment and cleaning up	<p>Large Spills: Stop the flow of material, if this is without risk. Dike the spilled material, where this is possible. Cover with plastic sheet to prevent spreading. Absorb in vermiculite, dry sand or earth and place into containers. Prevent product from entering drains. Following product recovery, flush area with water.</p> <p>Small Spills: Wipe up with absorbent material (e.g. cloth, fleece). Clean surface thoroughly to remove residual contamination.</p> <p>Never return spills to original containers for re-use. For waste disposal, see section 13 of the SDS.</p>
Environmental precautions	Avoid release to the environment. Prevent further leakage or spillage if safe to do so. Avoid discharge into drains, water courses or onto the ground. Inform appropriate managerial or supervisory personnel of all environmental releases.

7. Handling and storage

Precautions for safe handling	Provide adequate ventilation. Do not get this material in contact with eyes. Avoid breathing mist or vapor. Avoid contact with eyes, skin, and clothing. Avoid prolonged exposure. Do not taste or swallow. When using, do not eat, drink or smoke. Wear appropriate personal protective equipment. Wash hands thoroughly after handling. Avoid release to the environment. Observe good industrial hygiene practices.
Conditions for safe storage, including any incompatibilities	Store locked up. Store in original tightly closed container. Store away from incompatible materials (see Section 10 of the SDS).

8. Exposure controls/personal protection

Occupational exposure limits

US. ACGIH Threshold Limit Values

Material	Type	Value	Form
Aluminium sulfate	TWA	1 mg/m ³	Respirable fraction.

Components	Type	Value	Form
Aluminum Sulfate (CAS 10043-01-3)	TWA	1 mg/m ³	Respirable fraction.

US. NIOSH: Pocket Guide to Chemical Hazards

Material	Type	Value
Aluminium sulfate	TWA	2 mg/m ³

Components	Type	Value
Aluminum Sulfate (CAS 10043-01-3)	TWA	2 mg/m ³

Biological limit values	No biological exposure limits noted for the ingredient(s).
Appropriate engineering controls	Good general ventilation (typically 10 air changes per hour) should be used. Ventilation rates should be matched to conditions. If applicable, use process enclosures, local exhaust ventilation, or other engineering controls to maintain airborne levels below recommended exposure limits. If exposure limits have not been established, maintain airborne levels to an acceptable level. Eye wash facilities and emergency shower must be available when handling this product.
Individual protection measures, such as personal protective equipment	
Eye/face protection	Wear safety glasses with side shields (or goggles) and a face shield.
Skin protection	
Hand protection	Wear appropriate chemical resistant gloves. Suitable gloves can be recommended by the glove supplier.
Other	Wear appropriate chemical resistant clothing. Use of an impervious apron is recommended.
Respiratory protection	In case of insufficient ventilation, wear suitable respiratory equipment. Chemical respirator with organic vapor cartridge.
Thermal hazards	Wear appropriate thermal protective clothing, when necessary.
General hygiene considerations	Keep away from food and drink. Always observe good personal hygiene measures, such as washing after handling the material and before eating, drinking, and/or smoking. Routinely wash work clothing and protective equipment to remove contaminants.

9. Physical and chemical properties

Appearance	Liquid.
Physical state	Liquid.
Form	Liquid.
Color	Colorless to light yellow.
Odor	None.
Odor threshold	Not available.
pH	2.2
Melting point/freezing point	Not available.
Initial boiling point and boiling range	Not available.
Flash point	Not available.

Evaporation rate	Not available.
Flammability (solid, gas)	Not applicable.
Upper/lower flammability or explosive limits	
Flammability limit - lower (%)	Not available.
Flammability limit - upper (%)	Not available.
Explosive limit - lower (%)	Not available.
Explosive limit - upper (%)	Not available.
Vapor pressure	Not available.
Vapor density	Not available.
Relative density	Not available.
Solubility(ies)	
Solubility (water)	Infinite
Partition coefficient (n-octanol/water)	Not available.
Auto-ignition temperature	Not available.
Decomposition temperature	Not available.
Viscosity	Not available.
Other information	
Density	11.09 lb/gal estimated
Explosive properties	Not explosive.
Flammability	non-flammable
Oxidizing properties	Not oxidizing.

10. Stability and reactivity

Reactivity	The product is stable and non-reactive under normal conditions of use, storage and transport.
Chemical stability	Material is stable under normal conditions.
Possibility of hazardous reactions	Hazardous polymerization does not occur.
Conditions to avoid	Contact with incompatible materials.
Incompatible materials	None known.
Hazardous decomposition products	No hazardous decomposition products are known.

11. Toxicological information

Information on likely routes of exposure

Inhalation	May cause irritation to the respiratory system. Prolonged inhalation may be harmful.
Skin contact	Causes skin irritation.
Eye contact	Causes serious eye damage.
Ingestion	Harmful if swallowed.
Symptoms related to the physical, chemical and toxicological characteristics	Severe eye irritation. Symptoms may include stinging, tearing, redness, swelling, and blurred vision. Permanent eye damage including blindness could result. May cause respiratory irritation. Skin irritation. May cause redness and pain.

Information on toxicological effects

Acute toxicity	In high concentrations, vapors are anesthetic and may cause headache, fatigue, dizziness and central nervous system effects. Harmful if swallowed. May cause respiratory irritation.
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Product	Species	Test Results
Aluminium sulfate		
<u>Acute</u>		
Oral		
LD50	Guinea pig	490 mg/kg
	Mouse	> 730 mg/kg

Product	Species	Test Results
	Rat	1930 mg/kg
Components	Species	Test Results
Aluminum Sulfate (CAS 10043-01-3)		
Acute		
Oral		
LD50	Guinea pig	490 mg/kg
	Mouse	> 730 mg/kg
	Rat	1930 mg/kg

* Estimates for product may be based on additional component data not shown.

Skin corrosion/irritation	Causes skin irritation.
Serious eye damage/eye irritation	Causes serious eye damage.
Respiratory or skin sensitization	
Respiratory sensitization	Not a respiratory sensitizer.
Skin sensitization	This product is not expected to cause skin sensitization.
Germ cell mutagenicity	No data available to indicate product or any components present at greater than 0.1% are mutagenic or genotoxic.
Carcinogenicity	This product is not considered to be a carcinogen by IARC, ACGIH, NTP, or OSHA.
US. OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)	
	Not listed.
Reproductive toxicity	This product is not expected to cause reproductive or developmental effects.
Specific target organ toxicity - single exposure	May cause respiratory irritation.
Specific target organ toxicity - repeated exposure	Not classified.
Aspiration hazard	Not an aspiration hazard.
Chronic effects	Prolonged inhalation may be harmful.

12. Ecological information

Ecotoxicity	Toxic to aquatic life.		
Components	Species	Test Results	
Aluminum Sulfate (CAS 10043-01-3)			
Aquatic			
Crustacea	EC50	Amphipod (<i>Crangonyx pseudogracilis</i>)	11.8 - 14 mg/l, 48 hours
Fish	LC50	Fathead minnow (<i>Pimephales promelas</i>)	3.4 - 5.8 mg/l, 96 hours

* Estimates for product may be based on additional component data not shown.

Persistence and degradability	No data is available on the degradability of this product.
Bioaccumulative potential	No data available.
Mobility in soil	No data available.
Other adverse effects	No other adverse environmental effects (e.g. ozone depletion, photochemical ozone creation potential, endocrine disruption, global warming potential) are expected from this component.

13. Disposal considerations

Disposal instructions	Collect and reclaim or dispose in sealed containers at licensed waste disposal site. Do not allow this material to drain into sewers/water supplies. Do not contaminate ponds, waterways or ditches with chemical or used container. Dispose of contents/container in accordance with local/regional/national/international regulations.
Local disposal regulations	Dispose in accordance with all applicable regulations.
Hazardous waste code	The waste code should be assigned in discussion between the user, the producer and the waste disposal company.

Waste from residues / unused products	Dispose of in accordance with local regulations. Empty containers or liners may retain some product residues. This material and its container must be disposed of in a safe manner (see: Disposal instructions).
Contaminated packaging	Since emptied containers may retain product residue, follow label warnings even after container is emptied. Empty containers should be taken to an approved waste handling site for recycling or disposal.

14. Transport information

DOT

UN number	UN3264
UN proper shipping name	Corrosive liquid, acidic, inorganic, n.o.s. (ALUMINIUM SULFATE SOLUTION)
Transport hazard class(es)	
Class	8
Subsidiary risk	-
Label(s)	8
Packing group	III
Special precautions for user	Read safety instructions, SDS and emergency procedures before handling.
Special provisions	IB3, T7, TP1, TP28
Packaging exceptions	154
Packaging non bulk	203
Packaging bulk	241

DOT BULK

BULK

UN number	UN3264
UN proper shipping name	Corrosive liquid, acidic, inorganic, n.o.s. (ALUMINIUM SULFATE SOLUTION)
Transport hazard class(es)	
Class	8
Label(s)	8
Packing group	III
Special precautions for user	Read safety instructions, SDS and emergency procedures before handling.
Special provisions	IB3, T7, TP1, TP28
Packaging exceptions	154
Packaging non bulk	203
Packaging bulk	241

IATA

UN number	UN3264
UN proper shipping name	Corrosive liquid, acidic, inorganic, n.o.s.
Transport hazard class(es)	
Class	8
Subsidiary risk	-
Packing group	III
Environmental hazards	No.
ERG Code	8L
Special precautions for user	Read safety instructions, SDS and emergency procedures before handling.
Other information	
Passenger and cargo aircraft	Allowed.
Cargo aircraft only	Allowed.

IMDG

UN number	UN3264
UN proper shipping name	CORROSIVE LIQUID, ACIDIC, INORGANIC, N.O.S.
Transport hazard class(es)	
Class	8
Subsidiary risk	-
Packing group	III
Environmental hazards	
Marine pollutant	No.
EmS	F-A, S-B
Special precautions for user	Read safety instructions, SDS and emergency procedures before handling.

Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code Not established.

DOT; DOT Bulk packaging type



IATA; IMDG



15. Regulatory information

US federal regulations All components are on the U.S. EPA TSCA Inventory List.
This product is a "Hazardous Chemical" as defined by the OSHA Hazard Communication Standard, 29 CFR 1910.1200.

TSCA Section 12(b) Export Notification (40 CFR 707, Subpt. D)

Not regulated.

CERCLA Hazardous Substance List (40 CFR 302.4)

Aluminum Sulfate (CAS 10043-01-3) Listed.

SARA 304 Emergency release notification

Not regulated.

US. OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)

Not listed.

Superfund Amendments and Reauthorization Act of 1986 (SARA)

Hazard categories Immediate Hazard - Yes
Delayed Hazard - No
Fire Hazard - No
Pressure Hazard - No
Reactivity Hazard - No

SARA 302 Extremely hazardous substance

Not listed.

SARA 311/312 Hazardous chemical No

SARA 313 (TRI reporting)

Not regulated.

Other federal regulations

Clean Air Act (CAA) Section 112 Hazardous Air Pollutants (HAPs) List

Not regulated.

Clean Air Act (CAA) Section 112(r) Accidental Release Prevention (40 CFR 68.130)

Not regulated.

Clean Water Act (CWA) Section 112(r) (40 CFR 68.130) Hazardous substance

Safe Drinking Water Act (SDWA) Not regulated.

US state regulations

US - New Jersey RTK - Substances: Listed substance

Aluminum Sulfate (CAS 10043-01-3)

US. California Controlled Substances. CA Department of Justice (California Health and Safety Code Section 11100)

Not listed.

US. Massachusetts RTK - Substance List

Aluminum Sulfate (CAS 10043-01-3)

US. New Jersey Worker and Community Right-to-Know Act

Not regulated.

US. Pennsylvania RTK - Hazardous Substances

Aluminum Sulfate (CAS 10043-01-3)

US. Pennsylvania Worker and Community Right-to-Know Law

Aluminum Sulfate (CAS 10043-01-3)

US. Rhode Island RTK

Aluminum Sulfate (CAS 10043-01-3)

US. California Proposition 65

California Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65): This material is not known to contain any chemicals currently listed as carcinogens or reproductive toxins.

International Inventories

Country(s) or region	Inventory name	On inventory (yes/no)*
Australia	Australian Inventory of Chemical Substances (AICS)	Yes
Canada	Domestic Substances List (DSL)	Yes
Canada	Non-Domestic Substances List (NDSL)	No
China	Inventory of Existing Chemical Substances in China (IECSC)	Yes
Europe	European Inventory of Existing Commercial Chemical Substances (EINECS)	Yes
Europe	European List of Notified Chemical Substances (ELINCS)	No
Japan	Inventory of Existing and New Chemical Substances (ENCS)	Yes
Korea	Existing Chemicals List (ECL)	Yes
New Zealand	New Zealand Inventory	Yes
Philippines	Philippine Inventory of Chemicals and Chemical Substances (PICCS)	Yes
United States & Puerto Rico	Toxic Substances Control Act (TSCA) Inventory	Yes

*A "Yes" indicates that all components of this product comply with the inventory requirements administered by the governing country(s).

A "No" indicates that one or more components of the product are not listed or exempt from listing on the inventory administered by the governing country(s).

16. Other information, including date of preparation or last revision

Issue date	12-01-2017
Version #	01
NFPA ratings	Health: 3 Flammability: 0 Instability: 0

NFPA ratings



Disclaimer

The information provided in this Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication. The information given is designed only as a guidance for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered a warranty or quality specification. The information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any process, unless specified in the text.

Revision Information

Product and Company Identification: Alternate Trade Names

Product #: 430840 Name: METHANOL (6.60 PPG) Desc:
 From: BRENNTAG PACIFIC INC. To: Tuesday, April 06, 2010

Murex N.A., Ltd./Mitsubishi International Corp.

Methanol
 MSDS Code: 1611
 Date Prepared: 03/03/00

MATERIAL SAFETY DATA SHEET

1. Chemical Product and Company Information

Product Name: Methanol
 Synonyms: Methyl Alcohol; Wood Alcohol; Methyl Hydroxide
 CAS Number: 67-56-1
 Supplier: Murex N.A., Ltd. / Mitsubishi International Corp.
 Address: 15441 Knoll Trail, Suite 260, Dallas, TX 75248
 General Assistance: 972.702.0021
 24 Hour Emergency: CHEMTREC Assist: 800.424.9300

2. Composition/Information on Ingredients

Ingredient	CAS Number	% Weight
Methyl Alcohol	67-56-1	99.8
Water (See Section 8 for Exposure Limits)	7732-18-5	Tracc

3. Hazard Identification

Emergency Overview

Warning! Flammable liquid and vapor. Severely irritating to the skin, eyes, and respiratory tract. Overexposure may cause nervous system damage.

Potential Health Effects

Eye Contact: Contact causes severe irritation with reversible corneal damage.
Skin Contact: Contact causes severe irritation. Absorption from skin contact may cause symptoms similar to those listed under "Ingestion."
Inhalation: Breathing causes severe mucous membrane and respiratory irritation. Visual system damage may progress from visual blurring to complete blindness. Overexposure may cause nervous system damage.
Ingestion: Swallowing may cause mucous membrane and gastrointestinal irritation with nausea and abdominal pain. Ingestion of large amounts causes central nervous system depression and symptoms ranging from drunkenness to unconsciousness, narcosis, coma, respiratory failure, and death. Nausea, vomiting, gastrointestinal bleeding, and abdominal pain may occur. Visual system damage may progress from visual blurring to complete blindness. Overexposure may cause nervous system damage.
Special Toxic Effects: Testing in laboratory animals suggests that this chemical or a component of this product may cause adverse effects on the developing fetus.

TEL 972.702.0021
 972.960.2135

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4. First Aid Measures

- Eye:** Flush immediately with large amounts of water for at least fifteen minutes. Eyelids should be held away from the eyeball to ensure thorough rinsing. Get immediate medical attention.
- Skin:** Immediately flush skin with plenty of water for at least fifteen minutes while removing contaminated clothing and shoes. Get immediate medical attention. Launder clothing before reuse. Discard contaminated leather goods.
- Inhalation:** If symptoms develop, remove affected person from source of exposure. If breathing is difficult, administer oxygen, if available. Get medical attention if irritation persists.
- Ingestion:** Immediately call local physician, a local emergency room, or a poison control center. If victim is conscious, give one to three glasses of water and induce vomiting. Do not make an unconscious person vomit. Do not give anything by mouth if victim is semi-conscious or unconscious. Get immediate medical attention.

5. Firefighting Measures

Flashpoint:	13°C (55°F)	Lower Flammability Limit: >6
Auto-ignition Temperature:	385°C (417°F)	Upper Flammability Limit: <36

Basic Firefighting Procedures

Use dry chemical, alcohol foam, all-purpose AFFF or CO₂ to extinguish fire. Water may be ineffective but should be used to cool fire-exposed containers, structures, and to protect personnel. If leak or spill has not ignited, ventilate area and use water spray to disperse gas or vapor and to protect personnel attempting to stop a leak. Use water to dilute spills and flush them away from the sources of ignition. Do not flush down public sewers or other drainage systems. Move container from fire area if you can do it without risk. Exposed firefighters must wear MSHA/NIOSH approved positive pressure self-contained breathing apparatus with full face mask and full protective clothing. In advanced or massive fires, firefighting should be done from a safe distance or from a protective location.

Unusual Fire and Explosion Hazards

Dangerous when exposed to heat or flame. Vapors form flammable or explosive mixtures with air at room temperature. Vapor or gas may spread to distant ignition sources and flash back. Vapors or gas may accumulate in low areas. Runoff to sewer may cause fire or explosion hazard. Containers may explode in heat of fire. Vapors may concentrate in confined areas.

6. Accidental Release Measures

Handling and Storage

Avoid contact with eyes, skin, and clothing. Avoid breathing vapors and aerosols. Use with adequate ventilation. Use good personal hygiene practices. Wash hands before eating, drinking, smoking, or using toilet facilities. Remove contaminated clothing and clean before reuse. Wash thoroughly after work using soap and water. Assure that proper personal protection measures are taken when opening or entering confined storage vessels. Keep away from heat, sparks, and flame. Use only with adequate ventilation. Keep operating temperatures below ignition temperatures at all times. Use non-sparking tools. Store in tightly closed containers in cool, dry, isolated, well-ventilated area away from heat, sources of ignition, and incompatibles. Ground lines and equipment used during transfer to reduce the possibility of static spark-initiated fire or explosion. Store at ambient or lower temperature.

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Keep containers tightly closed and upright when not in use. Protect against physical damage. Store in original container. Store out of direct sunlight.

7. Exposure Controls/Personal Protection

Exposure Limits

Ingredient	OSHA		ACGIH		AIHA	Supplier
	TWA	STEL	TWA	STEL	WEEL	
Methyl Alcohol	200 ppm, skin	none	200 ppm, skin	250 ppm, skin	none	none
Water	none	none	none	none	none	none

Personal Protection Equipment (PPE)

- Eye Protection:** Avoid eye contact with this material. Wear safety glasses or chemical goggles. Provide an eyewash station in the work area.
- Skin Protection:** Avoid skin contact. When working with this substance, wear appropriate chemical protective gloves. Depending upon conditions of use, additional protection may be necessary such as face shield, apron, arm-covers, etc. Provide safety showers any location where skin contact can occur. Suggested protective materials are butyl rubber and teflon.
- Respiratory Protection:** If exposure limits are exceeded, or if irritation is experienced, NIOSH approved respiratory protection should be worn. Normally, a NIOSH approved respirator for organic vapors is generally acceptable. For high concentrations and for oxygen-deficient atmospheres, use a NIOSH approved air-supplied respirator. Ventilation and other forms of engineering controls are often the preferred means for controlling chemical exposures. Respiratory protection may be needed for non-routine or emergency situations. Respiratory protection must be provided in accordance with OSHA regulations (29 CFR 1910.134).

8. Physical and Chemical Properties

Boiling Point:	65°C (149°F)	Specific Gravity:	.7893@15.55°C
Melting Point:	-97.8°C (-144°F)	% Volatile:	100.00
Vapor Pressure:	100 mm Hg @ 21.2°C (38.2°F)	Evaporation Rate:	>1
Vapor Density (Air=1):	1.1	Viscosity:	0.738cSt@ 20°C
% Solubility in H₂O:	Complete	Octanol/H₂O Partition Coef:	0.77
Pour Point:	No Data	pH:	No data
Molecular Formula:	CH ₃ OH	Molecular Weight:	32.04
Odor/Appearance:	Clear, colorless, volatile liquid with ether-like odor		

9. Stability and Reactivity

Stability/Incompatibility

Stable under conditions of norm use. Incompatible with acetyl bromide, calcium carbide, chlorine, chromic anhydride, cyanuric chloride, dichloromethane, diethyl zinc, lead perchlorate, magnesium, metals, strong oxidizers, perchloric acid, phosphorous trioxide, potassium, sodium hydro chlorite, sulfuric acid, and zinc.

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Hazardous Reactions/Decomposition Products

Combustion may produce CO and CO₂.

10. Disposal Considerations

This substance, when discarded or disposed of, is hazardous waste according to Federal regulations (40 CFR 261). It is listed as Hazardous Waste Number U154, so listed due to its ignitability. The transportation, storage, treatment, and disposal of this waste material must be conducted in compliance with 40 CFR 262, 263, 264, 268, 270. Disposal can occur only in properly permitted facilities. Check state and local regulations for any additional requirements, as these may be more restrictive than federal laws and regulations. Chemical additions, processing or otherwise altering this material may make the waste management information presented in this MSDS incomplete, inaccurate, or otherwise, inappropriate.

11. Transportation Information

U.S. Department of Transportation (DOT)

Proper Shipping Name:	Methanol
Hazard Class:	3
UN/NA Code:	UN 1230
Packing Group:	PG II
Bill of Lading Descrip.:	Methanol, 3, UN 1230, PG II, RQ
Labels Required:	Flammable Liquid, Poison
Placards Required:	Flammable, Poison

12. Regulatory Information

U.S. Federal Regulations

Comprehensive Environmental Response Compensation and Liability Act of 1980 (CERCLA):

The reportable quantity for this material is 5,000 pounds. Any spill or other release, or substantial threat of release, of this material to the air, water, or land (unless entirely contained in the work place) equal to or in excess of the reportable quantity must be reported immediately to the National Response Center (800/424-8802) as required by U.S. Federal law. Also contact appropriate state and local regulatory agencies. Contact the Coast Guard if spilled into navigable waterways under their jurisdiction. Failure to report may result in substantial civil and criminal penalties.

Toxic Substance Control Act (TSCA):

All components of this product are listed on the TSCA inventory.

Clean Water Act (CWA):

Neither the product nor its components are listed under Federal regulations. Contact your local/state authorities to determine if substances are regulated under their jurisdiction.

Clean Air Act (CAA):

Component(s) are listed under various sections of the CAA. Contact your local/state authorities to determine if substances are regulated under their jurisdiction.

Superfund Amendments and Reauthorization Act (SARA) Title III Information:

(Listed below are the hazard categories for SARA Section 311/312 (40 CFR 370))

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Immediate Hazard: X Delayed Hazard: X Fire Hazard: X
 Pressure Hazard: -- Reactivity Hazard: --

(This product contains the following toxic chemical(s) subject to reporting requirements of SARA Section 313 (40 CFR 372))

Ingredient	CAS Number	Max. %
Methyl Alcohol	67-56-1	99.8

State Regulations

California:

(This product contains the following chemical(s) known to the State of California to cause cancer, birth defects, or reproductive harm)

Ingredient	CAS Number

*No ingredients listed in this section

Massachusetts:

(This product contains the following chemical(s) which are listed as an extraordinarily hazardous substance as defined in Massachusetts Right-to-Know Law, Department of Health, Chapter 105, Section 670.005.

Ingredient	CAS Number

*No ingredients listed in this section

Pennsylvania:

(This product contains the following chemical(s) which are listed as a special hazardous substance as defined in Pennsylvania Right-to-Know Law, Section 3800.

Ingredient	CAS Number

*No ingredients listed in this section

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International Regulations

Canadian Environmental Protection Act

(This product contains the following chemical(s) which are listed under the Domestic Substance List)

Ingredient	CAS Number
Methyl Alcohol	67-56-1
Water	7732-18-5

(This product contains the following chemical(s) which are listed on the Non-Domestic Substance List)

Ingredient	CAS Number

*No ingredients listed in this section

Canadian Workplace Hazardous Materials Information Systems (WHMIS)

(The following WHMIS categories apply to this product)

Compressed Gas:	-	Flammable/Combustible:	X	Oxidizer:	-
Acutely Toxic:	X	Other Toxic Effects:	X	Biohazardous:	-
Corrosive:	-	Dangerously Reactive:	-		

13. Other Information

National Fire Protection Association (NFPA) Ratings

Health: 1 Flammability: 3 Reactivity: 0 Special Hazard: -

Disclaimer

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