INTERIM REPORT ON
PHOSPHORUS REMOVAL FEASIBILITY REPORT FOR THE BARRINGTON WASTEWATER TREATMENT FACILITY

December 2015

Prepared Under Contract to the Village of Barrington

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EXECUTIVE SUMMARY

The Village of Barrington is required under National Pollutant Discharge Elimination System (NPDES) Permit No. IL0021598 (effective July 1, 2015), to prepare a phosphorus removal feasibility report specific to the Barrington Wastewater Treatment Facility (WWTF) on the method, time frame, and costs for reducing effluent phosphorus to monthly average discharges of 1.0 mg/L and 0.5 mg/L on a seasonal basis and on a year round basis. The feasibility report is due to the Illinois Environmental Protection Agency (IEPA) by July 1, 2016, and this interim report is due to the IEPA on January 1, 2016.

Phosphorus removal can be accomplished either biologically or chemically, broadly speaking. To accomplish enhanced biological phosphorus removal (EBPR), anaerobic conditions must be established within a portion of the activated sludge treatment process to cultivate phosphorus accumulating organisms (PAOs). Nitrate concentration must be sufficiently low within this zone for proper anaerobic conditions to exist and enrich the PAOs. Accordingly, most effective EBPR can only be accomplished when combined with denitrification – the biological removal of nitrates. Biological denitrification occurs under anoxic conditions – characterized by the presence of nitrate and absence of oxygen – when facultative anaerobes use the nitrate to replace the metabolic function of oxygen converting the nitrate to elemental gaseous nitrogen. Both BPR and denitrification require a source of carbon for the metabolic processes of the microbes. This carbon source is characterized by the amount of soluble chemical oxygen demand (sCOD) and volatile fatty acids (VFAs) in the process.

Chemical phosphorus removal is accomplished by the addition of a chemical precipitant to the wastewater treatment process followed by coagulation of the phosphorus (by surface complexation with metal oxide precipitants) and physical removal by settling in clarifiers and/or filtration. The most commonly used coagulants at wastewater treatment plants are ferric chloride, aluminum sulfate (alum), and polyaluminum chloride (PAC). Ferric chloride is more corrosive than alum and PAC. All can be very effective in phosphorus removal.

The Barrington WWTF was not designed for biological nutrient removal when it was initially constructed and expanded. The Barrington WWTF was designed to reduce biochemical oxygen demand (BOD_5) of the wastewater and to oxidize influent ammonia to nitrate. An alum addition system was constructed at Barrington WWTF when the current aeration basins were constructed, but there is no evidence that the alum system was ever operated. The piping of that alum system was tested as a part of this project and determined to be inadequate for current or future needs.

A full-scale pilot test of the anaerobic-oxic (AO) process for BPR has been in place at the Barrington WWTP since 2012, but successful removal of phosphorus has not been achieved. Measurements of oxidation-reduction potential (ORP), nitrate, sCOD, and VFA in the anaerobic zone, primary effluent, and return activated sludge (RAS) indicate the following:

- Anaerobic conditions have not been successfullty established in the desired anaerobic zone based on ORP measurements.
- High nitrate concentrations in the return activated sludge (RAS) prevent anaerobic conditions from occurring in the desired anaerobic zone.
- The sCOD and VFA in the primary effluent are low, which limits the potential for BPR and denitrification.

A bench scale test was performed to assess the viability of denitrifying the return activated sludge (RAS) prior to entering the anaerobic zone. The required detention times would require a reactor at least the size of one of the three existing aeration channels. Denitrification of the RAS by this process was deemed uneconomic.

Bench scale tests were also performed to assess fermentation of the RAS and primary sludge for increasing sCOD and VFA available to the EBPR and denitrification processes – a procedure known as carbon augmentation. Construction of a primary sludge fermenter for carbon augmentation was considered viable. RAS fermentation was not evaluated further, as the required fermenter would be significantly larger than that for primary sludge fermentation.

Due to the concerns with low influent sCOD and high nitrate in the RAS, the Modified University of Cape Town (mUCT) configuration for EBPR was considered the most likely to be feasible. In the mUCT configuration, the activated sludge basin would be operated with an anaerobic zone, followed by an anoxic zone, followed by an oxic (aerobic) zone. An internal mixed liquor recycle (IMLR) stream would convey nitrate rich mixed liquor from the end of the oxic zone to the second section of the anoxic zone. The RAS would be returned to the first section of the anoxic zone. A second IMLR stream would convey denitrified mixed liquor from the end of that first section of the anoxic zone to the head of the anaerobic zone.

Based on the low food-to-nutrient ratios for the primary effluent (BOD_5-to-Phosphorus ratio of 18 to 19, compared to a recommended minimum of 25), a fermenter or external carbon source would still be required to reduce the remaining nitrates in the RAS to sustain effective BPR. A primary sludge fermenter would present its own significant operational challenges, most notably odor concerns. The Barrington WWTF is located adjacent to or in close proximity to community baseball fields, Barrington High School, a golf course, and residences.

Chemical phosphorus removal is the most technically feasible option for reducing effluent phosphorus concentrations to 1.0 mg/L or 0.5 mg/L at the Barrington WWTF. Initial modeling to estimate alum dose requirements and sludge production due to chemical phosphorus removal was performed. Additional site-specific pilot testing including a jar test is recommended before finalizing the design of an alum system. Also, the solids handling system at the Barrington WWTF must be evaluated to ensure it can handle the predicted increase in solids production.

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LIST OF ACRONYMS AND ABBREVIATIONS

A/O	Anaerobic-Oxic Process
A2O	Anaerobic-Anoxic-Oxic Process
ACH	Aluminum chlorohydrate
BOD	Biological Oxygen Demand (5-day, unless otherwise specified)
BPR	Biological Phosphorus Removal
COD	Chemical Oxygen Demand
rbCOD	Readily Biodegradable COD
sCOD	Soluble COD
DPAO	Denitrifying phosphorus accumulating organism
EBPR	Enhanced Biological Phosphorus Removal
FRSG	Fox River Study Group
GAO	Glycogen accumulating organism
H&H	Huff & Huff, Inc. a subsidiary of GZA
HAO	Hydrous aluminum oxide
HFO	Hydrous ferric oxide
HRT	Hydraulic Retention Time (nominal, not including recycle streams)
IEPA	Illinois Environmental Protection Agency
IMLR	Internal Mixed Liquor Recycle
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids
mUCT	Modified University of Cape Town Process
NH_3-N	Ammonia (as nitrogen)
NO_3-N	Nitrate (as nitrogen)
NPDES	National Pollutant Discharge Elimination System
ORP	Oxidation-Reduction Potential
P	Phosphorus
PAC	Polyaluminum chloride
PAO	Polyphosphate Accumulating Organism
RAS	Return Activated Sludge
SDNR	Specific Denitrification Rate
SRT	Solids Retention Time
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
UCT	University of Cape Town Process
VFA	Volatile Fatty Acids
VSS	Volatile Suspended Solids
WAS	Waste Activated Sludge

1. INTRODUCTION

The Village of Barrington operates the Barrington Wastewater Treatment Facility (Barrington WWTF) located in Barrington, Illinois, under National Pollutant Discharge Elimination System (NPDES) Permit No. IL0021598 (effective July 1, 2015). The Village of Barrington is required under the NPDES permit to prepare a *Phosphorus Removal Feasibility Report* (Feasibility Report) specific to the Barrington WWTF on the method, time frame, and costs for reducing effluent phosphorus to monthly average discharges of 1.0 mg/L and 0.5 mg/L on a seasonal basis and on a year round basis. The Feasibility Report is due to be submitted to the Illinois Environmental Protection Agency (IEPA) by July 1, 2016 and is to be shared with the Fox River Study Group (FRSG).

Huff & Huff, Inc. (H&H) under contract with the Village of Barrington prepared this *Interim Report on Phosphorus Removal Feasibility Report for the Barrington Wastewater Treatment Plant* (Interim Report), due to the IEPA by January 1, 2016. The following key items are provided in this Interim Report:

- Description of the current design and operation of the Barrington WWTF
- Discussion of the progress in the analysis of raw wastewater characteristics for development of design loadings
- An initial evaluation of feasibility of enhanced biological phosphorus removal (EBPR) based on food-to-nutrient ratios
- Discussion of expected challenges for implementing EBPR at the Barrington WWTF
- Discussion of additional analyses to be incorporated into the Feasibility Report

The IEPA's preference[1], rather than chemical precipitation of phosphorus, is for biological nutrient removal (BNR) to be implemented where practical as a retrofit in an existing facility because of BNR's performance, overall sustainability, and lower indirect environmental impacts. BNR has the additional environmental advantage of typically including a degree of nitrogen removal in addition to EBPR. The focus of this Interim Report is on the feasibility of retrofitting the Barrington WWTF for EBPR.

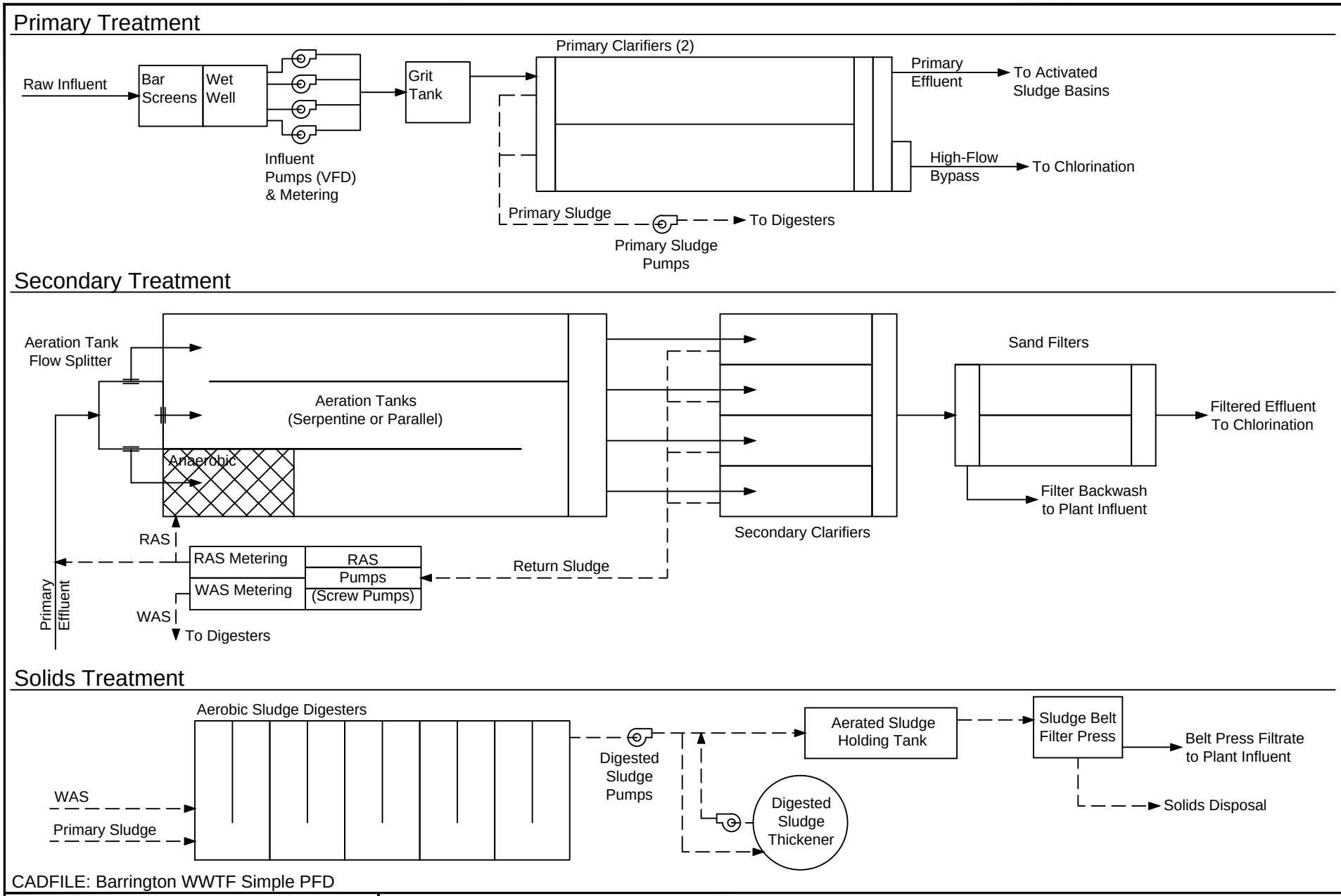
2. CURRENT CONFIGURATION OF THE BARRINGTON WWTF

The Barrington WWTF is a conventional wastewater treatment plant which uses an aerobic (aerated) activated sludge treatment process for nitrification (oxidation of ammonia-nitrogen to nitrate-nitrogen) and treatment of biochemical oxygen demand (BOD). A curtain and mixer were installed in the aeration basin in July 2012 for a full-scale pilot test of the anaerobic-oxic (AO) configuration for EBPR.

The following unit processes are employed at the Barrington WWTF, as shown in the process flow diagram provided in Figure 2-1 and the site layout provided in Figure 2-2:

- Grit Removal
- Primary Clarification
- Anaerobic Zone of Activated Sludge Basin
- Aerated Activated Sludge Basin
- Secondary Clarification
- Sand Filtration
- Chlorination and Dechlorination
- Aerobic Sludge Digestion
- Sludge Thickening by Belt Filter Press

The activated sludge basin volume is 1.26 million gallons. In the current AO pilot test configuration, 0.14 million gallons is anaerobic and 1.12 million gallons is aerated. The Design Average Flow (DAF) is 3.68 million gallons per day (mgd) and the Design Maximum Flow (DMF) for complete treatment is 10.2 mgd, as specified in the NPDES permit. The DAF is about 50% greater than the actual observed average flow rate. At the observed average influent flow rate of 2.43 mgd, the hydraulic retention times are 1.4 hours anaerobic and 11.1 hours aerobic (12.5 hours total).



CADFILE: Barrington WWTF Simple PFD

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Figure 2-1
Process Flow Diagram of Major Processes at Barrington WWTF

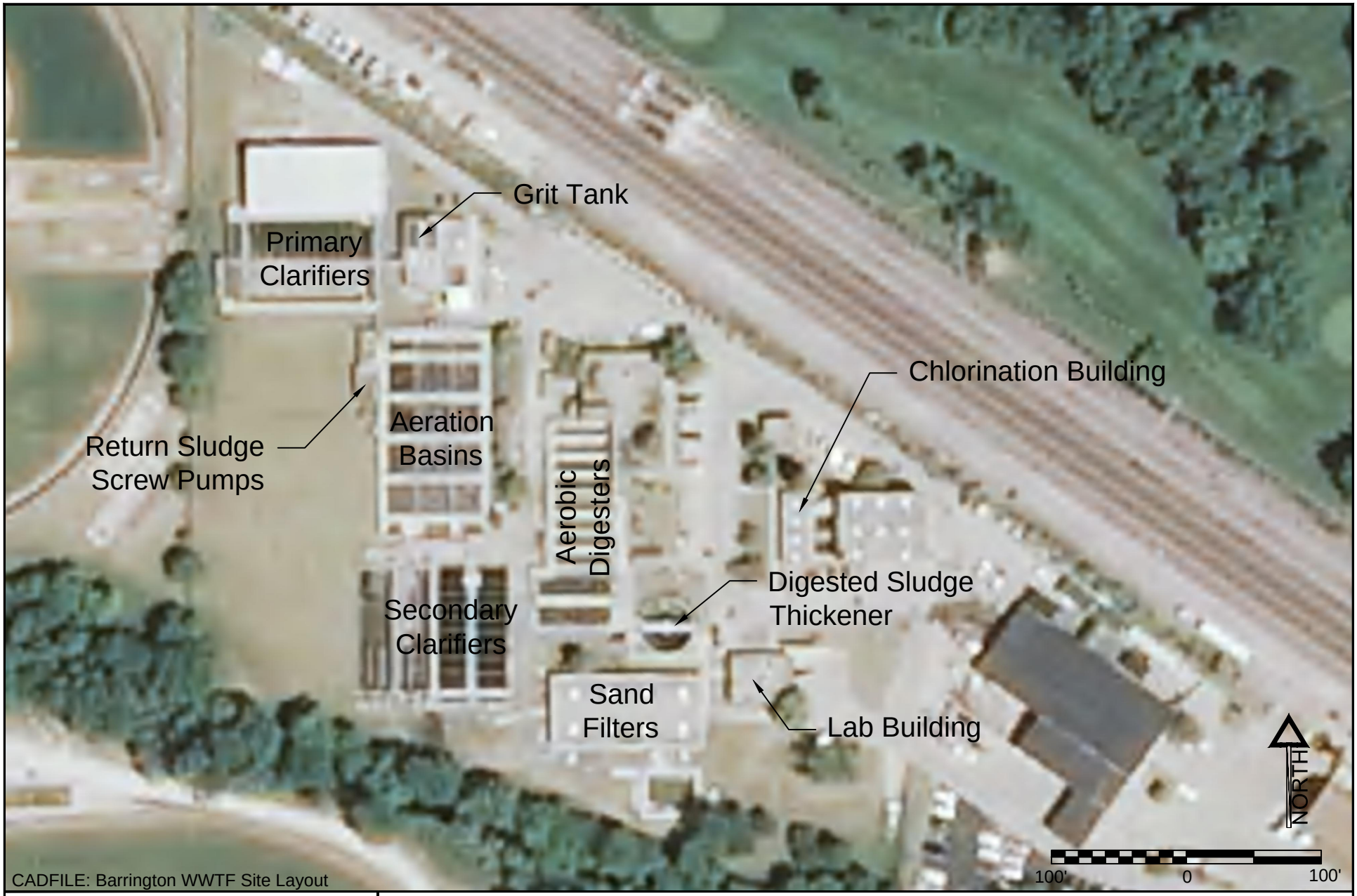

Figure 2-2
Site Layout of Barrington WWTF

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3. BARRINGTON WWTF DESIGN VALUES

H&H analyzed the following data sets to prepare design values for wastewater characteristics at the Barrington WWTF:

- Monthly Plant operation logs from January 2009 through October 2015
- Influent total phosphorus data collected several days per month in the summer of 2011, summer of 2013, and January through August 2014
- Primary effluent (from the primary clarifiers) data collected during a preliminary biological phosphorus removal study conducted in the summer of 2014.

Design values for plant influent and primary effluent are provided in Table 3-1 and Table 3-2, respectively, for conditions of Observed Average Flow, Design Average Flow (DAF), and Design Maximum Flow (DMF). The Observed Average Flow was 2.43 million gallons per day (mgd), based on the 95th percentile upper confidence limit (UCL) of the mean daily flow rate. The DAF of 3.68 mgd and DMF of 10.2 mgd for complete treatment are specified in the NPDES permit. The DAF is about 50% greater than the observed average flow.

A significant amount of data for the following wastewater parameters was available from the monthly plant operation logs:

- Raw wastewater influent flow rate
- Raw wastewater 5-day biological oxygen demand (BOD)
- Raw wastewater total suspended solids (TSS) concentration
- Raw wastewater ammonia-nitrogen (NH_3-N) concentration
- Primary effluent (from primary clarifiers) BOD
- Primary effluent TSS concentration
- Mixed liquor suspended solids (MLSS) concentration
- Waste activated sludge (WAS) flow rate
- TSS concentration of the WAS

A significant number (158) of influent total phosphorus (P) sample results were available, also. For these parameters with substantial monitoring data, the wastewater constituent loadings at Observed Average Flow were based on the 95th percentile UCL of the mean loading as calculated from Plant monitoring data, and the design loading at DMF was set to the 99.5-percentile loading observed in the Plant monitoring data. The wastewater constituent design concentrations were then calculated based on the flow rate and loading at the Observed Average Flow and the DMF. The

concentrations at the DAF were assumed to equal the concentrations at the Observed Average Flow.

No chemical oxygen demand (COD) sampling results were available in the data sets analyzed. H&H assumed that the ratio of BOD-to-COD was 0.6 and estimated the COD based on the observed BOD.

A limited amount (13 samples) of soluble COD (sCOD) and total P data was available for the primary effluent from the study performed in the summer of 2014. The design total P concentration for the primary effluent at observed average flow and DAF was set to the maximum of the measured concentrations from that study, and the design total P concentration at the DMF was set to the average from that study.

The ratio of sCOD-to-COD with a value of 0.26 was calculated from the average primary effluent sCOD observed in the summer 2014 study and the estimated primary effluent COD. The raw influent and primary effluent COD concentrations were estimated from the average BOD concentrations reported in the analyzed monthly operating reports for the Plant. The design values of sCOD in the plant influent and primary effluent were then estimated by applying the sCOD-to-COD ratio to convert COD values to sCOD.

To evaluate the effect of high influent flow rates on wastewater constituent concentrations, plots of BOD, TSS, and total P versus influent flow rate are provided in Figure 3-1, Figure 3-2, and Figure 3-3. Generally, lower influent concentrations were observed as flow rate increased. However, due to the scatter of data evident on these plots, H&H instead developed the design values at DMF based on the extremes (99.5-percentile) of observed loadings. Histograms of influent BOD and influent total P loading are provided in Figure 3-4 and Figure 3-5, respectively. Two apparent outlier raw influent BOD loadings in the range of 13,000 pounds per day (lb/day) were observed in the 985-sample data set. The 99.5-percentile of the BOD loadings (7,934 lb/day) corresponds well to the maximum of the observed loadings after discarding the outlier data. The 99.5-percentile total P loading (276 lb/day) corresponds well to the maximum observed raw influent total P loading (311 lb/day).

The flow rates and select characteristics of the sludge streams and sidestreams throughout the Barrington WWTF based on the historic operational data and engineering estimates are provided in Table 3-3. Of particular note is the phosphorus concentration in the sludge filter press filtrate, which is returned to the head of the plant. A total of 31 samples collected in the summer of 2011 and one sample from 2014 were available to characterize the filtrate phosphorus concentration. The samples from 2011 ranged from 35 mg/L to 398 mg/L total P, while the sample from 2014 resulted in 8 mg/L total P.

Table 3-4 summarizes the historic nutrient loads to the activated sludge process at Barrington WWTF including the loads from the sidestreams. The sludge press filtrate is estimated to account for 25% of the total phosphorus loading to the activated sludge process.

Barrington Wastewater Treatment Facility

Table 3-1
Summary of Raw Influent Wastewater Characteristic Design Values

Parameters at Design Operating Conditions		Observed Average Flow	Design Average Flow (DAF)	Design Maximum Flow (DMF)
Influent Flow Rate[1]	(mgd)	2.43	3.68	10.2
Plant Influent Characteristics				
BOD_5				
Design Loading[2,3,4]	(lb/day)	2,732	4,141	7,934
Design Concentration[5,6]	(mg/L)	135	135	93
COD				
Design Loading[7]	(lb/day)	4,553	6,901	13,223
Design Concentration[7]	(mg/L)	225	225	155
sCOD				
Design Loading[8]	(lb/day)	1,185	1,797	3,443
Design Concentration[8]	(mg/L)	59	59	40
TSS				
Design Loading[2,3,4]	(lb/day)	2,551	3,866	11,784
Design Concentration[5,6]	(mg/L)	126	126	139
Total P				
Design Loading[2,3,4]	(lb/day)	94	142	276
Design Concentration[5,6]	(mg/L)	4.6	4.6	3.2
NH_3-N				
Design Loading[2,3,4]	(lb/day)	258	391	612
Design Concentration[5,6]	(mg/L)	12.7	12.7	7.2
TKN				
Design Loading[9]	(lb/day)	430	652	1,021
Design Concentration[9]	(mg/L)	21.2	21.2	12.0
NO_3-N				
Design Loading[10]	(lb/day)	0	0	0
Design Concentration[10]	(mg/L)	0	0	0

Notes:

1) Based on NPDES permit limits
2) Loadings at Observed Average Flow are based on 95% UCL of the mean sampled/monitored loadings.
3) Loadings at DAF are based on DAF and design concentration at DAF.
4) Loadings at DMF are based on 99.5th percentile of sampled/monitored loadings.
5) Design concentrations at Observed Average Flow and DMF are based on measured loadings and design flow rates
6) Design concentration at DAF was assumed equal to concentration at Observed Actual Flow.
7) Estimated as COD = BOD / 0.6

   Design BOD_5-to-COD Ratio = 0.6
8) Ratio of sCOD-to-COD estimated based on average measured sCOD in primary effluent in summer 2014 study divided by average primary effluent COD, as estimated based on measured primary effluent BOD_5.

Average Primary BOD5 (mg/L)	102
Estimated Average Primary COD (mg/L)	170
Average Primary sCOD (mg/L)	44
Estimated sCOD-to-COD Ratio	0.26

9) Assumed NH_3-N comprises 60% of TKN (TKN = NH_3-N / 0.6).
10) Assumed no NO_3-N is present in influent

Barrington Wastewater Treatment Facility

Table 3-2
Summary of Primary Effluent Characteristic Design Values

Parameters at Design Operating Conditions		Observed Average Flow	Design Average Flow (DAF)	Design Maximum Flow (DMF)
Primary Effluent Flow Rate[1]	(mgd)	2.43	3.68	10.2
Primary Effluent Characteristics				
BOD_5				
Design Loading[2,3,4]	(lb/day)	1,916	2,904	5,564
Design Concentration[5,6]	(mg/L)	95	95	65
COD				
Design Loading[7]	(lb/day)	3,193	4,840	9,273
Design Concentration[7]	(mg/L)	158	158	109
sCOD				
Design Loading[8]	(lb/day)	831	1,260	2,414
Design Concentration[8]	(mg/L)	41	41	28
TSS				
Design Loading[2,3,4]	(lb/day)	1,210	1,833	5,965
Design Concentration[5,6]	(mg/L)	60	60	70
VSS				
Design Loading[2,3,4]	(lb/day)	1,028	1,558	5,070
Design Concentration[5,6]	(mg/L)	51	51	60
nbVSS				
Design Loading[2,3,4]	(lb/day)	308	468	1,521
Design Concentration[5,6]	(mg/L)	15	15	18
Total P				
Design Loading[9]	(lb/day)	107	157	301
Design Concentration	(mg/L)	5.3	5.1	3.5
NH_3-N				
Design Loading	(lb/day)	258	391	612
Design Concentration[10]	(mg/L)	12.7	12.7	7.2
TKN				
Design Loading	(lb/day)	430	652	1,021
Design Concentration[10]	(mg/L)	21.2	21.2	12.0
NO_3-N				
Design Loading	(lb/day)	0	0	0
Design Concentration[10]	(mg/L)	0	0	0

Notes:

1) Assumed equal to plant influent flow rate
2) Loadings at Observed Average Flow are based on 95% UCL of the mean sampled/monitored loadings.
3) Loadings at DAF are based on DAF and design concentration at DAF.
4) Loadings at DMF are based on 99.5th percentile of sampled/monitored loadings.
5) Design concentrations at Observed Average Flow and DMF are based on measured loadings and design flow rates
6) Design concentration at DAF was assumed equal to concentration at Observed Actual Flow.
7) Estimated as COD = BOD / 0.6

   Design BOD_5-to-COD Ratio = 0.625
8) Ratio of sCOD-to-COD estimated based on average measured sCOD in primary effluent in summer 2014 study divided

Average Primary BOD5 (mg/L)	102
Estimated Average Primary COD (mg/L)	170
Average Primary sCOD (mg/L)	44
Estimated sCOD-to-COD Ratio	0.26

9) Engineering estimate based on assumption that 2% of TSS in raw influent is particulate P, all digester filtrate P is soluble, all sand filter backwash P is particulate, and particulate P is removed at same efficiency as TSS in the primary clarifiers: (Primary Effluent P) = (Influent Soluble P) - (Influent Particulate P) x (TSS Removal Efficiency); Maximum measured primary effluent P was 4.6 mg/L in summer 2014 (13 samples)
10) Assumed equal to plant influent concentration

Barrington Wastewater Treatment Facility

Table 3-3
Summary of Historic Sludge Stream Characteristics

Wastewater Plant Operational Parameter / Characteristic		Design Value: At Observed Average Flow	Design Value: At DAF	Design Value: At DMF	Basis
Raw Influent					
pH	(s.u.)	7.8	7.8	7.8	Average
Mixed Liquor - Aeration Basin, Current Operations					
TSS Concentration	(mg/L)	4,097	4,097	4,097	Average measured
TSS Inventory	(dry-lb)	43,127	43,127	43,127	
Solids Retention Time	(days)	68	68	68	SRT = TSS Wasted / TSS Inventory
MLVSS	(mg/L)	3,482	3,482	3,482	Assumed VSS:TSS = 0.85, typical
Return Activated Sludge (RAS) - Current Operations					
RAS-to-Influent Flow Ratio		0.52	0.36	0.15	Regression analysis
Flow Rate	(mgd)	1.27	1.34	1.53	
NO_3-N					
Concentration	(mg/L)	12.4	12.4	12.4	95th percentile UCL of mean
Loading	(lb/day)	131	139	158	
TSS Concentration	(mg/L)	8,225	8,225	8,225	Average
VSS Concentration	(mg/L)	6,991	6,991	6,991	Assumed VSS:TSS = 0.85, typical
Primary Sludge					
Flow Rate[(1)]	(gallons/day)	27,256	41,314	118,271	
Solids Concentration	(mg/L)	5,900	5,900	5,900	Bench scale tests, summer 2014
Production Rate	(dry-lb/day)	1,341	2,033	5,820	
Waste Activated Sludge (WAS) - Current Operations					
Flow Rate	(gallons/day)	9,616	9,616	9,616	Long-term average (including "zeros" in flow for days with no wasting)
TSS Concentration	(mg/L)	7,852	7,852	7,852	
Solids (TSS) Wasted	(dry-lb/day)	630	630	630	
Dewatered Sludge - Current Operations					
Solids Concentration	(mg/L)	200,000	200,000	200,000	Assumed
Flow Rate[(2)]	(gallons/day)	1,182	1,596	3,867	
Production Rate	(dry-lb/day)	1,971	2,663	6,449	

Barrington Wastewater Treatment Facility

Table 3-3
Summary of Historic Sludge Stream Characteristics

Wastewater Plant Operational Parameter / Characteristic		Design Value: At Observed Average Flow	Design Value: At DAF	Design Value: At DMF	Basis
Sludge Press Filtrate - Current Operations					
Flow Rate[(2)]	(gallons/day)	35,690	49,333	124,020	At Observed Average Flow; Calculated[(2)]
Solids Concentration	(mg/L)	0	0	0	Assumed negligible for this calculation
Total P					
Concentration	(mg/L)	123	123	123	Average
Loading	(lb/day)	36.5	50.5	127.0	
Secondary Clarifier Overflow - Returned in Sand Filter Backwash					
Flow Rate	(mgd)	2.43	3.68	10.2	
TSS					
Concentration	(mg/L)	20	20	20	Assumed
Loading	(lb/day)	405	614	1,701	
Particulate P in Solids					
Concentration	(mg/L)	0.34	0.34	0.34	Assumed VSS:TSS = 0.85
Loading	(lb/day)	7	10	29	and biosolids are 2% P

Notes:

1) Based on mass balance of solids and liquid streams for raw influent, primary effluent, and primary sludge.
   $Q_{raw} * TSS_{raw} = Q_{prim\text{-}eff} * TSS_{prim\text{-}eff} + Q_{prim\text{-}sludge} * TSS_{prim\text{-}sludge}$
   If $Q_{raw} = Q_{prim\text{-}eff}$, then $Q_{prim\text{-}sludge} = Q_{raw} * (TSS_{raw} - TSS_{prim\text{-}eff}) / TSS_{prim\text{-}sludge}$

2) Based on mass balance of solids and liquid streams for WAS, primary sludge, thickened sludge, and sludge press filtrate.
   $Q_{prim\text{-}sludge} * TSS_{prim\text{-}sludge} + Q_{WAS} * TSS_{WAS} = Q_{dewatered} * TSS_{dewatered} + Q_{filtrate} * TSS_{filtrate}$
   If $TSS_{filtrate} = 0$, then $Q_{dewatered} = (Q_{WAS} * TSS_{WAS} + Q_{prim\text{-}sludge} * TSS_{prim\text{-}sludge}) / TSS_{dewatered}$
   $Q_{WAS} + Q_{prim\text{-}sludge} = Q_{dewatered} + Q_{filtrate}$, therefore: $Q_{filtrate} = Q_{WAS} + Q_{prim\text{-}sludge} - Q_{dewatered}$

Barrington Wastewater Treatment Facility

Table 3-4
Summary of Historic Nutrient Loads Including Sidestreams

Parameters at Design Operating Conditions		Observed Average Flow	Design Average Flow (DAF)	Design Maximum Flow (DMF)
Influent Flow Rate	(mgd)	2.43	3.68	10.2
Total P Load Summary				
Plant Influent	(lb/day)	94	142	276
Sludge Press Filtrate[1,2]	(lb/day)	37	51	127
Sand Filter Backwash[3]	(lb/day)	7	10	29
TOTAL	(lb/day)	137	203	432
Total P Load Contribution Summary [4]				
Plant Influent		68%	70%	64%
Sludge Press Filtrate		27%	25%	29%
Sand Filter Backwash		5%	5%	7%
TKN Load Summary				
Plant Influent	(lb/day)	430	652	1,021
Sludge Press Filtrate	(lb/day)	----------	Not Sampled	----------
Sand Filter Backwash	(lb/day)	----------	Not Sampled	----------
TOTAL	(lb/day)	430	652	1,021

Notes:

1) Sludge press filtrate Total P concentration is based on the average of 31 samples in summer 2011 and one sample in summer of 2014. The results from 2011 displayed a significant amount of variability and ranged from 35 mg/L to 398 mg/L. The sample from 2014 resulted in 8 mg/L. Additional sampling is recommended to more accurately assess the Total P loading from the sludge press filtrate.

2) The sludge press filtrate flow rate was estimated based on a mass balance of the solids and liquid streams in the primary sludge, WAS, thickened sludge, and filtrate. The basis of the calculation was the estimated primary sludge flow rate, measured primary sludge TSS concentration, measured hisoric WAS flow rate, measured WAS TSS concentration, and assumed thickened sludge and filtrate TSS concentrations.

3) Based on assumed TSS concentration of 20 mg/L overflowing the secondary clarifier weir, 0.85 ratio of VSS-to-TSS, and 2% total P in the VSS. Assumes all solids overflowing the clarifier weir are returned to the head of the plant in the filter backwash.

4) Fraction of total load to the activated sludge process from each stream.

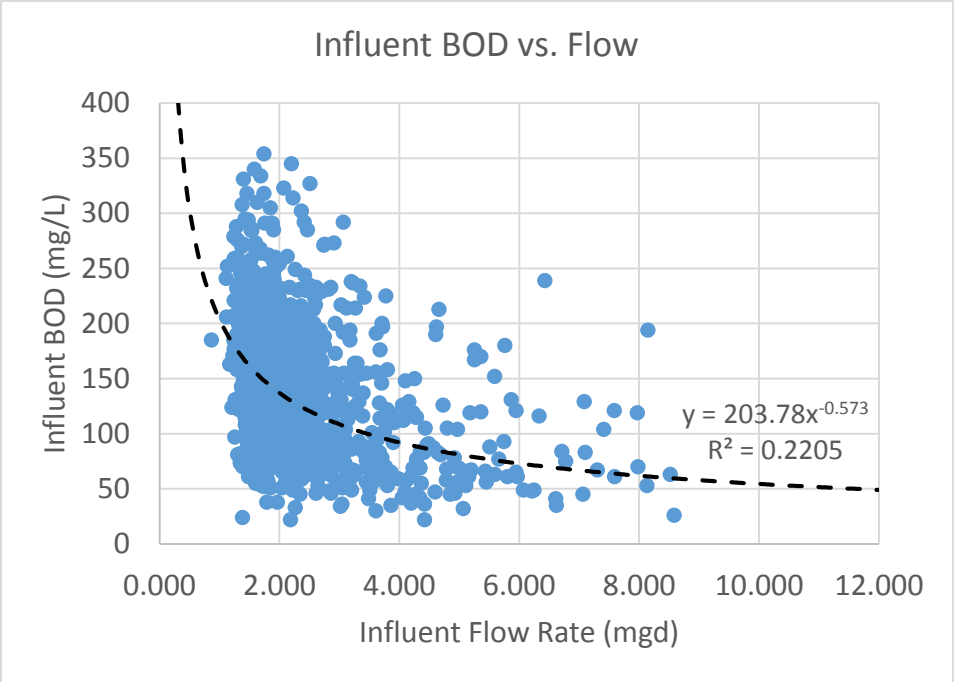


Figure 3-1. Influent BOD versus Flow Rate

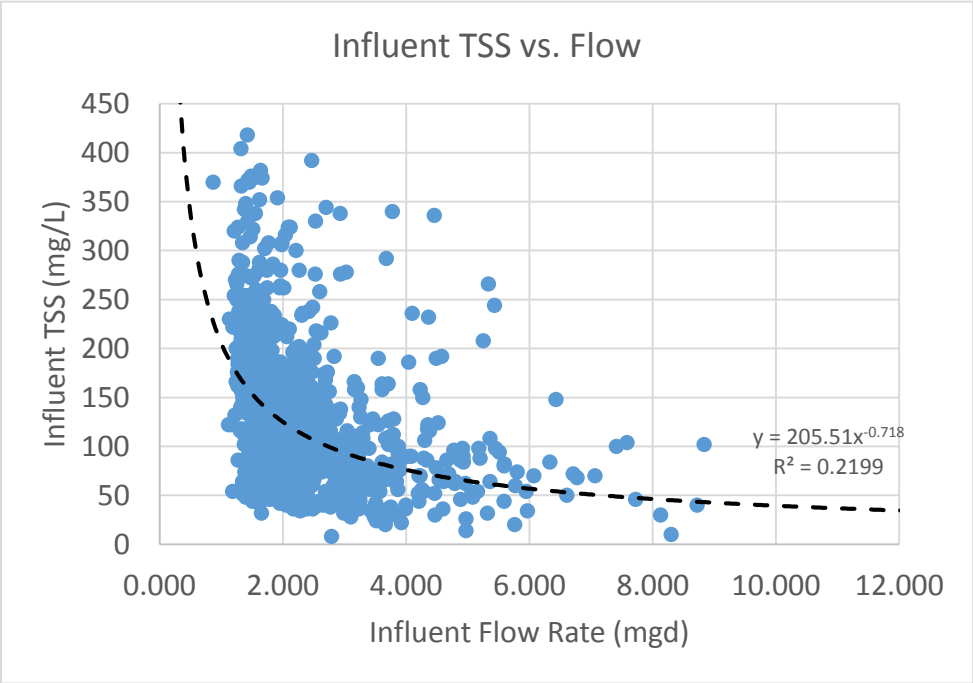


Figure 3-2. Influent TSS versus Flow Rate

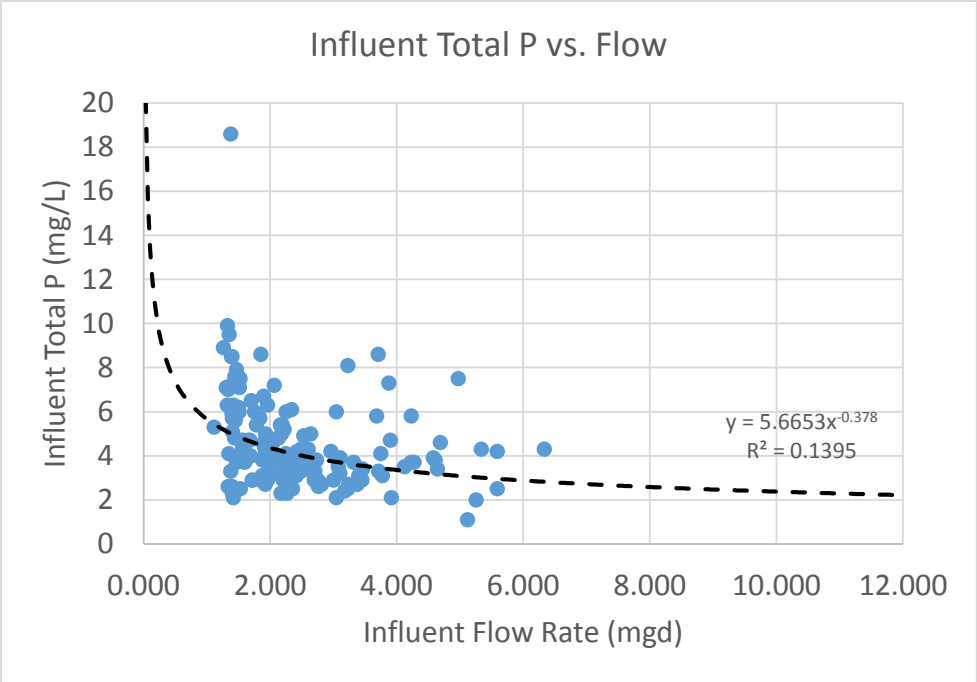


Figure 3-3. Influent Total P versus Flow Rate

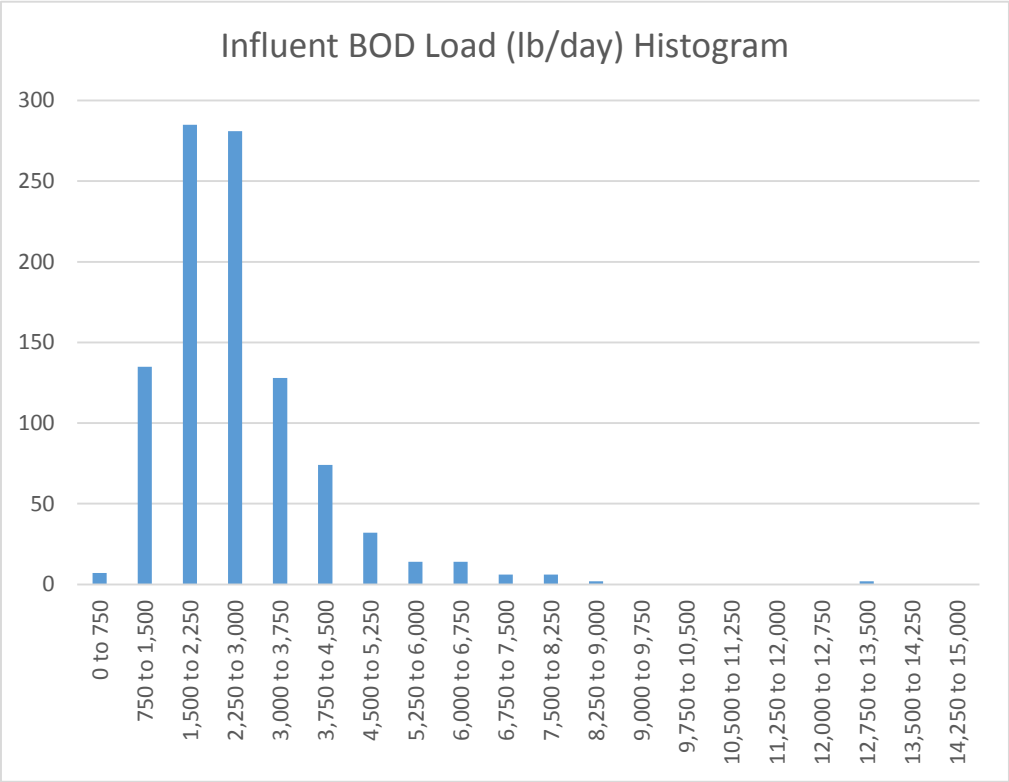


Figure 3-4. Influent BOD Loading Histogram

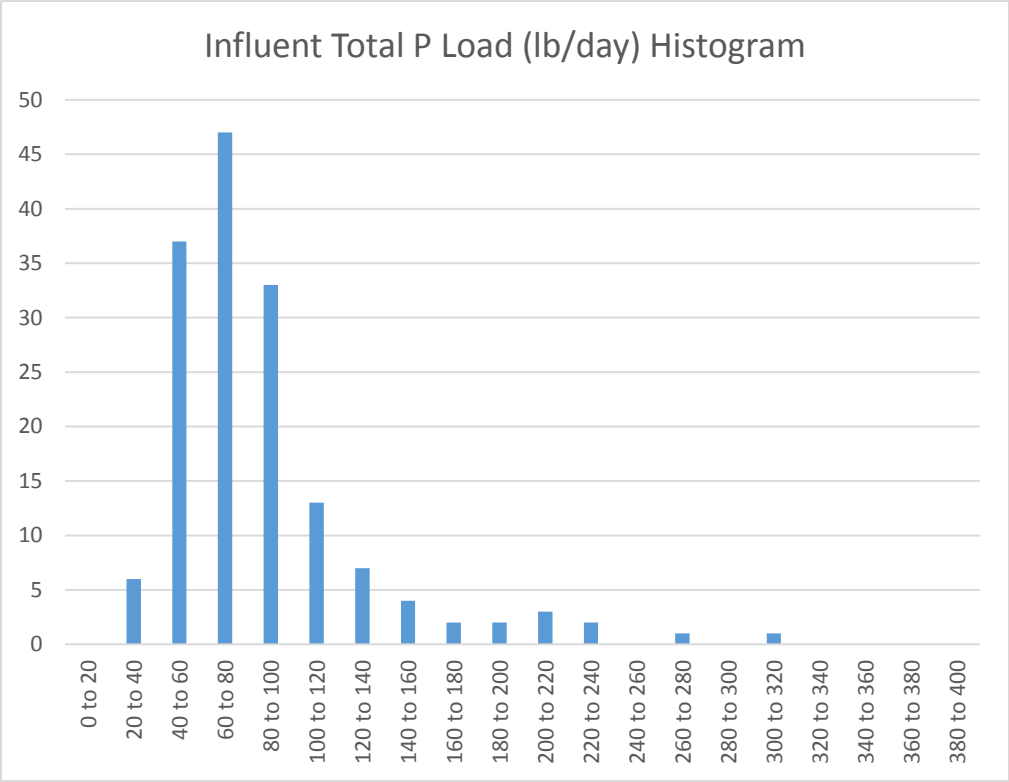


Figure 3-5. Influent Total Phosphorus Loading Histogram

4. PRELIMINARY EBPR FEASIBILITY ANALYSIS

4.1. EBPR Background

EBPR[2,3] occurs in a two-step process utilizing phosphorus accumulating organisms (PAOs) requiring an anaerobic and an aerobic zone. The anaerobic zone for biological phosphorus removal must have low concentrations of both oxygen and nitrate.

The first step of EBPR occurs in the anaerobic zone. High energy polyphosphate is used by PAOs, which releases phosphorus as orthophosphate as the PAOs consume acetate and other short-chain volatile fatty acids (VFAs). In the aerobic zone, the PAOs assimilate orthophosphate and store the phosphorus in their cellular mass as polyphosphate. The stored phosphorus is removed from the wastewater when sludge is wasted from the system.

PAOs assimilate a greater amount of orthophosphate in the aerobic zone when it is preceded by release of orthophosphate in an anaerobic zone. The anaerobic zone enriches the population of PAOs in the sludge by providing conditions in which the PAOs thrive in comparison to other microbes. The anaerobic step requires sufficient concentration of VFAs for release of orthophosphate to occur. Both biological steps of BPR require sufficient soluble COD (sCOD).

BPR must be accompanied by denitrification in plants designed for nitrification in order to minimize nitrates entering the anaerobic zone. In WWTFs designed for EBPR and BOD reduction, an anaerobic-oxic (A/O) configuration may be sufficient for EBPR. The A/O configuration for EBPR is depicted schematically in Figure 4-1. A full-scale pilot test of EBPR has been in operation at Barrington WWTP since July 2012. An anaerobic zone at the beginning of the activated sludge basin was sectioned off by installation of a baffle separating the anaerobic zone from the aerated zone in an AO configuration and installation of a mixer.

For WWTFs which require nitrification of ammonia, denitrification usually must also be implemented for EBPR to be successful. The anaerobic-anoxic-oxic (A2O) configuration is one of several capable of EBPR and nitrogen removal. A nitrate rich internal mixed liquor recycle (IMLR) stream is delivered from the oxic zone to the anoxic zone to achieve denitrification while the RAS is returned from the secondary clarifiers to the anaerobic zone in the A2O configuration. The A2O process is depicted schematically in Figure 4-1.

Even low nitrate concentrations in the RAS entering the anaerobic zone of an A2O configuration may still limit the performance of BPR if the sCOD and VFA concentrations are low in the effluent from the primary clarifiers. In this case, the sCOD and VFA concentrations may be increased by operation of a primary sludge fermenter or by addition of an external carbon substrate. Alternatively, the University of Cape Town (UCT) activated sludge configuration may be implemented to avoid loading the anaerobic zone with nitrates from the RAS. In the UCT

configuration, the RAS is recycled to the anoxic zone instead of the anaerobic zone, the nitrate-rich IMLR is established from the aerobic zone to the anoxic zone, and a second IMLR stream, called the anoxic recycle, is established from the end of the anoxic zone to the head of the anaerobic basin. The anoxic recycle provides increased solids residence time (SRT) in the anaerobic zone. The UCT process is depicted schematically in Figure 4-1.

The Modified UCT (mUCT) process provides additional protection of the anaerobic zone from loading with nitrates. The mUCT is similar to the UCT configuration except that separate, consecutive anoxic zones are established for the RAS and the nitrified IMLR. The RAS is returned to the first anoxic zone, and the anoxic IMLR is conveyed from the end of this first anoxic zone back to the inlet of the anaerobic zone. The nitrified IMLR is conveyed to the second anoxic zone. Because the total nitrate loading ahead of the anoxic IMLR is lower in the mUCT process than in the standard UCT process, the anoxic IMLR is more reliably denitrified before reaching the anaerobic zone. The mUCT process is depicted schematically in Figure 4-1.

4.2. Current Nutrient Removal Configuration and Performance

The Barrington WWTP is currently configured for nitrification but not denitrification. An anaerobic zone at the beginning of the activated sludge basin was baffled off from the aerobic zone for a full-scale pilot test of an AO configuration for EBPR in July 2012. Based on high nitrate concentration measured in the RAS and high oxidation-reduction potential (ORP) measurements, anaerobic conditions are not being consistently achieved in the anaerobic zone.

4.2.1. A/O Pilot Test Results

Influent and effluent total phosphorus was measured in the summer of 2011 prior to installation of the anaerobic zone baffle and in the summers of 2013 and 2014 after installation of the baffle and mixer. Phosphorus removal performance at the Barrington WWTP was essentially unchanged after installation of the anaerobic zone.

Table 4-1
Summary of AO Process Pilot Test Results

Parameter	Prior to Anaerobic Zone Baffle Summer 2011	After Anaerobic Zone Baffle Summers of 2013 and 2014
Average Influent Total Phosphorus, Composite (mg/L)	6.3	3.7
Average Plant Effluent Total Phosphorus, Composite (mg/L)	5.0	3.1
Average Phosphorus Removal (% Removal)	12%	14%

The poor performance of EBPR with the AO configuration after installation of the baffle and mixer is attributed to elevated nitrate concentration in the RAS and low influent sCOD. Average nitrate in the RAS was 12.2 mg/L NO_3-N over the course of sampling in the summers 2013 and 2014. For three samples collected in June 2014, the average nitrate was 15.6 mg/L NO_3-N in the (mixed) baffled anaerobic zone.

The sCOD in the primary clarifier effluent (influent to the anaerobic zone) ranged from 23 mg/L to 94 mg/L with an average of 44 mg/L for 13 samples collected in May 2014 through July 2014. The average sCOD concentration at the inlet of the baffled anaerobic zone was 69 mg/L over that same period.

Microbes capable of using nitrate as an electron acceptor will outcompete PAOs for available sCOD when nitrate is present in the anaerobic (or anoxic) zone. The sCOD used for nitrate consumption has been estimated to be 6.6 lb sCOD/lb NO_3-N. Based on a concentration of 15.6 mg/L NO_3-N in the baffled anaerobic zone, a concentration of 103 mg/L sCOD would be consumed for denitrification, significantly more than the available sCOD. Even at the nitrate concentration in RAS measured in summer 2013 (8.9 mg/L NO_3-N), the sCOD consumption for nitrification would be 59 mg/L sCOD.

The conditions in the baffled off section of the activated sludge basin are clearly anoxic rather than anaerobic. Additionally, low sCOD concentrations likely limit the performance of biological nutrient removal for both phosphorus and nitrogen. Efforts to establish EBPR should focus on providing sufficient sCOD and VFAs to the anaerobic zone and incorporating denitrification into the activated sludge process.

Typically, all three Barrington WWTF aeration basins are operated in serpentine. With the typical raw influent flow rates being lower than the DMF and DAF, the plant operates at high SRT (68 days, on average). Operating at such a high SRT can contribute to secondary release of phosphorus due to cell lysis[4].

4.2.2. Current Aeration Practices

DO concentration has been correlated with the abundance of PAOs and glycogen accumulating organisms (GAOs) in activated sludge[5,6]. GAOs compete with PAOs for VFAs in the anaerobic zone and are detrimental to the performance of EBPR systems. In a study[7] on the effect of DO concentration on PAO-GAO competition, poor phosphorus removal performance and a high number of GAOs were observed at DO concentrations of 4.5-5.0 mg/L, while DO concentrations of approximately 2.5-3.0 mg/L seemed to correlate with a greater abundance of PAOs[5]. In another study[6], reducing the DO concentration in the nitrate-rich IMLR from 0.1 mg/L to 0.01 mg/L by degassing provided favorable conditions for denitrifying phosphate accumulating organisms (DPAOs) to be sustained in the A2O treatment system. At the DO concentration of 0.1 mg/L, denitrifying glycogen accumulating organisms (DGAOs) proliferated resulting in relatively poor EBPR performance.

The aeration basin at the Barrington WWTF is equipped with fine bubble diffusers which effectively aerate the activated sludge basin. The air blower is equipped with a variable frequency drive (VFD) motor; however, the blower cannot achieve great enough differential pressure to overcome the static hydraulic pressure head in the aeration basin at lower motor speeds. Thus, to achieve consistent nitrification and meet effluent ammonia limits, the average dissolved oxygen (DO) concentration is 8.7 mg/L within the aeration basins. This elevated DO concentration would likely be detrimental to effective EBPR.

4.3. Food-to-Nutrient Ratios

The food-to-nutrient ratios for a wastewater stream can indicate if the wastewater will be amenable to BNR processes, both for denitrification and for EBPR. Food is measured as either BOD, COD, or sCOD, and the nutrients are TKN or total P. Units for both food and nutrient are on a mass basis (i.e. mg/L-to-mg/L or lb/day-to-lb/day). A range of suggested minimum values for the food-to-nutrient ratio have been provided in the literature[2–4,8], and the effective ratio will vary from one plant to another depending upon the amount of fermentation which occurs in the collection system producing VFA and whether both EBPR and denitrification are needed. Typically, the following ratios are recommended for EBPR to operate successfully without addition of supplementary carbon (food):

Table 4-2
Summary of Minimum Required Food-to-Nutrient Ratios for BNR

Food Basis	Minimum Food-to-Nitrogen Ratio for Denitrification	Minimum Food-to-Phosphorus Ratio for EBPR
BOD	5	25
COD	9	45
sCOD	2	15

The food-to-nutrient ratios for the design loadings at the Barrington WWTF are summarized in Table 4-3. The evaluation includes the nutrient loads from the sidestreams – the sludge belt filter press filtrate and the sand filter backwash in the case of the Barrington WWTF. The ratios are provided for both the raw influent wastewater with sidestreams and the primary effluent, to provide an indication of how the BOD removal in the primary clarifiers affects the ratios. For nitrogen, only the primary clarifier effluent was considered. Additional characterization of the sidestreams is recommended to determine the food content, nitrogen content (TKN and NO_3-N), phosphorus content, and the flow rate of sludge press filtrate. The current estimates are based on the data sets described in Section 3 of this Interim Report.

Both primary effluent and raw influent with the sidestreams fall short of the required food-to-phosphorus ratios for effective EBPR to be achieved (18 to 19 BOD:P for primary effluent and 17 to 19 BOD:P for raw influent with sidestreams, versus 25 BOD:P needed). A significant portion (25%) of the estimated total P loading to the activated sludge process is from the sludge filter press filtrate. The most recent sample of the filtrate, collected in 2014, resulted in a total P concentration of 8 mg/L, which is much lower than the other 31 samples of the filtrate collected in 2011 ranging from 35 to 398 mg/L. This evaluation includes the samples from 2011. Also, the engineering estimate of the particulate phosphorus returned in the sand filter backwash accounts for about 5% of the total phosphorus loading to the activated sludge process. Additional phosphorus sampling of the sludge press filtrate is recommended.

This initial screening analysis of food-to-nutrient ratios indicates that EBPR is unlikely to be feasible without supplementary carbon addition.

Barrington Wastewater Treatment Facility

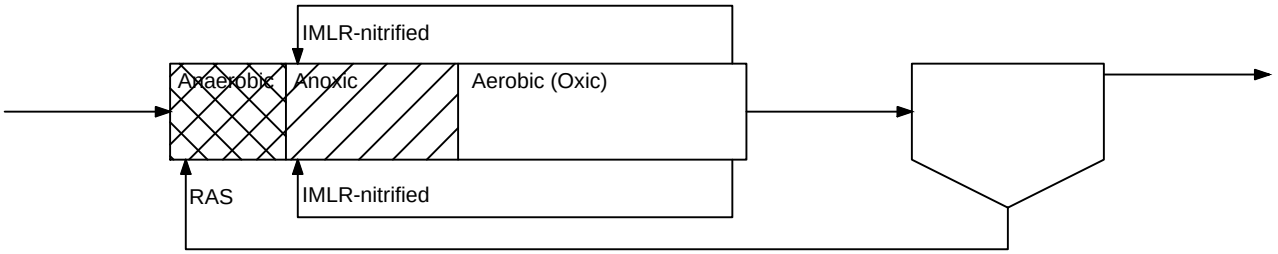
Table 4-3
Historic Food-to-Nutrient Loading Ratios in the Activated Sludge Process

Parameters at Design Operating Conditions		Observed Average Flow	Design Average Flow (DAF)	Design Maximum Flow (DMF)	Recommended Minimum Value for BNR[1]
Influent Flow Rate	(mgd)	2.43	3.68	10.2	
Combined Plant Influent, Sludge Press Filtrate, and Sand Filter Backwash [2]					
BOD_5-to-Total P Ratio		18	19	17	25
COD-to-Total P Ratio		30	32	29	45
sCOD-to-Total P Ratio		8	8	8	15
Primary Effluent					
BOD_5-to-Total P Ratio		18	19	18	25
COD-to-Total P Ratio		30	31	31	45
sCOD-to-Total P Ratio		8	8	8	15
BOD_5-to-TKN Ratio		4	4	5	5
COD-to-TKN Ratio		7	7	9	9
sCOD-to-TKN Ratio		2	2	2	2

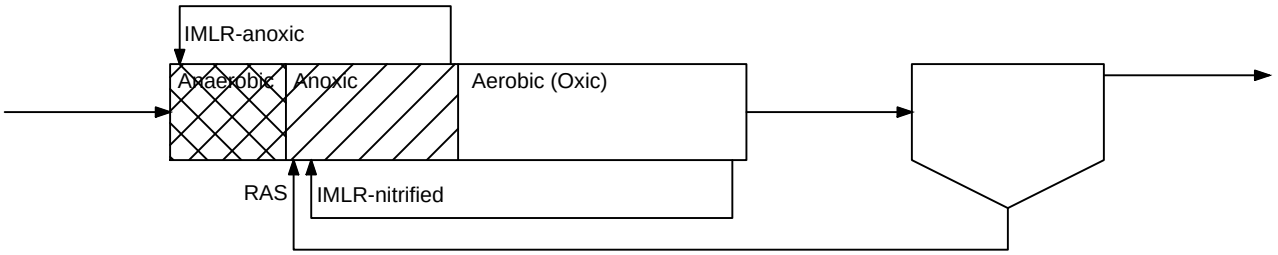
Notes:
1) BNR = Biological Nutrient Removal
2) Includes the long-term average phosphorus and TKN loading from the sludge press filtrate.

A/O Process

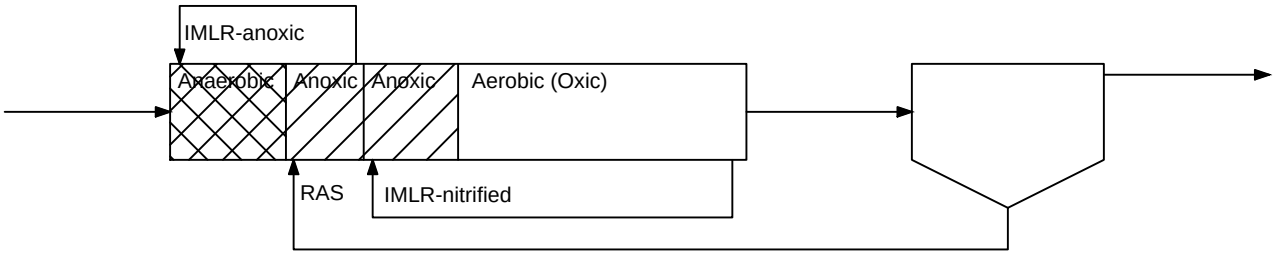
A2O Process



University of Cape Town (UCT) Process



Modified University of Cape Town (mUCT) Process



CADFILE: Select EBPR PFDs

Huff & Huff, incorporated
a Subsidiary of GZA Geoenvironmental

Figure 4-1
Select EBPR Process Flow Diagrams

4.4. Bench-Scale Test Results for EBPR

Bench-scale tests were conducted in the summer of 2014 to evaluate options for improving EBPR performance at Barrington WWTF. The results of these tests are documented herein.

4.4.1. RAS Denitrification

A major factor which limited the removal of phosphorus in the pilot test of the AO process was the nitrate loading to the anaerobic zone from the RAS. The potential for RAS denitrification was evaluated in two bench scale tests. The purpose of the first test was to assess the viability of a RAS fermenter. By measuring ORP, the potential for RAS denitrification was also evaluated. A sample of RAS was collected in a 5-gallon bucket on June 23, 2014, stirred continuously, and sampled twice daily for five days. The nitrate concentration in RAS – 15 mg/L – was in the typical range. Within four hours of collecting a sample of RAS and beginning a fermentation test (see Section 2.2.1), the ORP of the RAS had dropped from +165 mV to -128 mV. Nitrate concentration determined by third party laboratory analysis remained between 0.8 mg/L and 2.2 mg/L throughout the RAS fermentation test. From this test, a detention time of less than four hours would be sufficient.

On July 17, 2014, a second RAS denitrification test was performed similarly to the first, but ORP was measured every 10 minutes to better determine the required detention time. The purpose of the second RAS denitrification test was to determine if a retention time of three hours or less would be sufficient for denitrification to occur. Over the 3-hour course of the test, the ORP dropped from +195.0 mV to only +164.8 mV. The high ORP after three hours suggests that denitrification of the RAS could not be consistently achieved in a reactor with a three-hour retention time. Also, the elevated nitrate concentrations in the RAS sustained throughout July 2014[a] indicate that the four-hour detention time for denitrification determined in the first RAS test would not be sufficient without an additional carbon source.

Building a reactor specifically for denitrification of the RAS is not recommended because it would require over 600,000 gallons in capacity at the DAF, and at least during parts of the year would require a supplemental carbon source. A better option to explore for preventing nitrate loading to the anaerobic zone is the UCT process which directs the high-nitrate RAS to the anoxic zone. The only recycle stream to the anaerobic zone in the UCT process is the denitrified mixed liquor from the end of the anoxic zone.

[a] Between July 7, 2014 and August 4, 2014, the nitrate concentration in seven samples of RAS collected approximately weekly and analyzed at Barrington WWTF ranged from 28.3 mg/L to 47.0 mg/L with an average of 35.0 mg/L.

4.4.2. RAS Fermentation Bench Scale Test

Another factor contributing to the lack of phosphorus removal with the AO configuration pilot test was the low food-to-nutrient ratio of the influent to the activated sludge process. A bench-scale test was performed to assess the viability of fermenting RAS for a source of supplemental carbon.

A sample of RAS was collected in a 5-gallon bucket on June 23, 2014, stirred continuously, and sampled twice daily for five days. Analyses of samples by Suburban Laboratories, Inc. (Suburban Labs) located in Geneva, Illinois included sCOD, VFA, nitrate for each sample and volatile suspended solids (VSS) in the initial sample. DO, ORP, pH, and temperature were measured when each sample was collected. The results of these analyses and measurements are provided in Table 4-4.

The concentration of nitrate in RAS measured in the Barrington WWTP lab on the day the sample of RAS was collected for this experiment was 15 mg/L. The nitrate concentration in RAS measured at Barrington WWTP typically ranges from 3.5 mg/L to 47 mg/L with a median concentration of 12 mg/L. A higher initial nitrate concentration would delay the onset of fermentation and consume additional VFAs as denitrification occurs.

Figure 4-2 depicts the concentration of VFA and sCOD in the bench-scale RAS fermenter over the course of the test. The maximum VFA concentration resulted 47 hours after beginning the fermentation test. The concentration of sCOD increased throughout the entire 95 hours of fermenter operation.

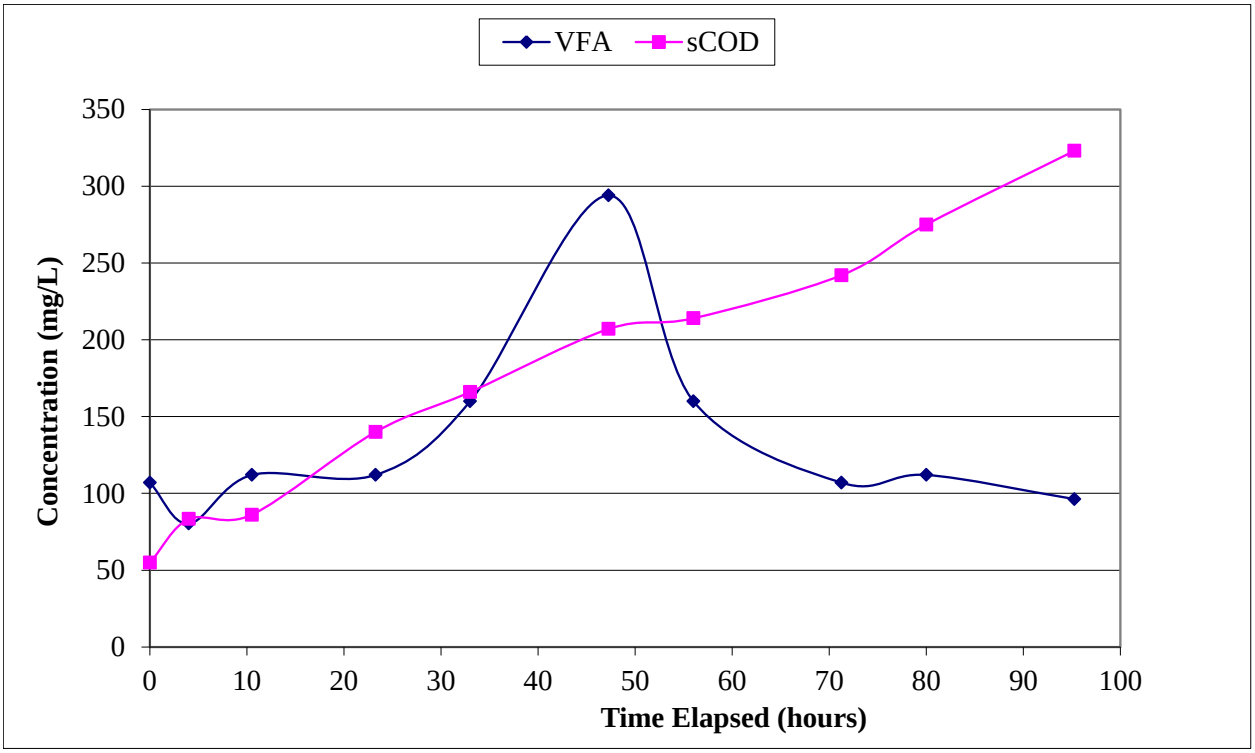
The VFA yield, defined as the mass of VFA increase per mass of VSS loaded to the fermenter, was 0.03 g-VFA/g-VSS in the RAS fermenter, based on the increase from 107 mg/L to 294 mg/L over 47 hours and initial VSS of 5,710 mg/L. The SRT of 47 hours would be appropriate for sizing the RAS fermenter.

Table 4-4
RAS Fermentation Bench Scale Test Results

Time Elapsed (hours)	DO (mg/L)	ORP (mV)	Temp (ºC)	pH	sCOD (mg/L)	Nitrate (mg/L)	VFA (mg/L)	VSS (mg/L)
0.00	3.20	+165.2	17.0	--	55	15[a]	107	5,710
4.00	0.42	-128.0	19.2	7.06	83	0.77	80	5,960
10.50	0.98	-140.0	20.4	7.68	86	1.07	112	--
23.25	0.77	-208.0	21.6	8.04	140	0.78	112	--
33.00	0.91	-209.0	21.1	8.25	166	2.16	160	--
47.25	0.80	-225.0	21.5	8.25	207	0.91	294	--
56.00	0.92	-223.0	21.6	8.23	214	0.86	160	--
71.25	0.88	-205.0	21.4	8.20	242	1.12	107	--
80.00	0.87	-229.0	21.4	8.27	275	0.62	112	--
95.25	0.74	-221.0	21.6	8.32	323	1.76	96	--

a. 15 mg/L nitrate based on routine measurements by Barrington WWTP performed day of sample collection. The sample collected as part of the RAS fermentation test at time zero resulted in 1.27 mg/L nitrate, but this sample likely underwent denitrification in the sample bottle between the time of collection and analysis.

Figure 4-2
RAS Fermentation Test – VFA and sCOD Over Time



4.4.3. Primary Sludge Fermentation Bench Scale Test

A sample of primary sludge was collected in a 5-gallon bucket on July 7, 2014, stirred continuously, and sampled twice daily for five days. Analyses of samples by Suburban Labs included sCOD and VFA for each sample, nitrate in the first three samples, and VSS in the initial sample. DO, ORP, pH, and temperature were measured when each sample was collected. The results of these analyses and measurements are provided in Table 4-5.

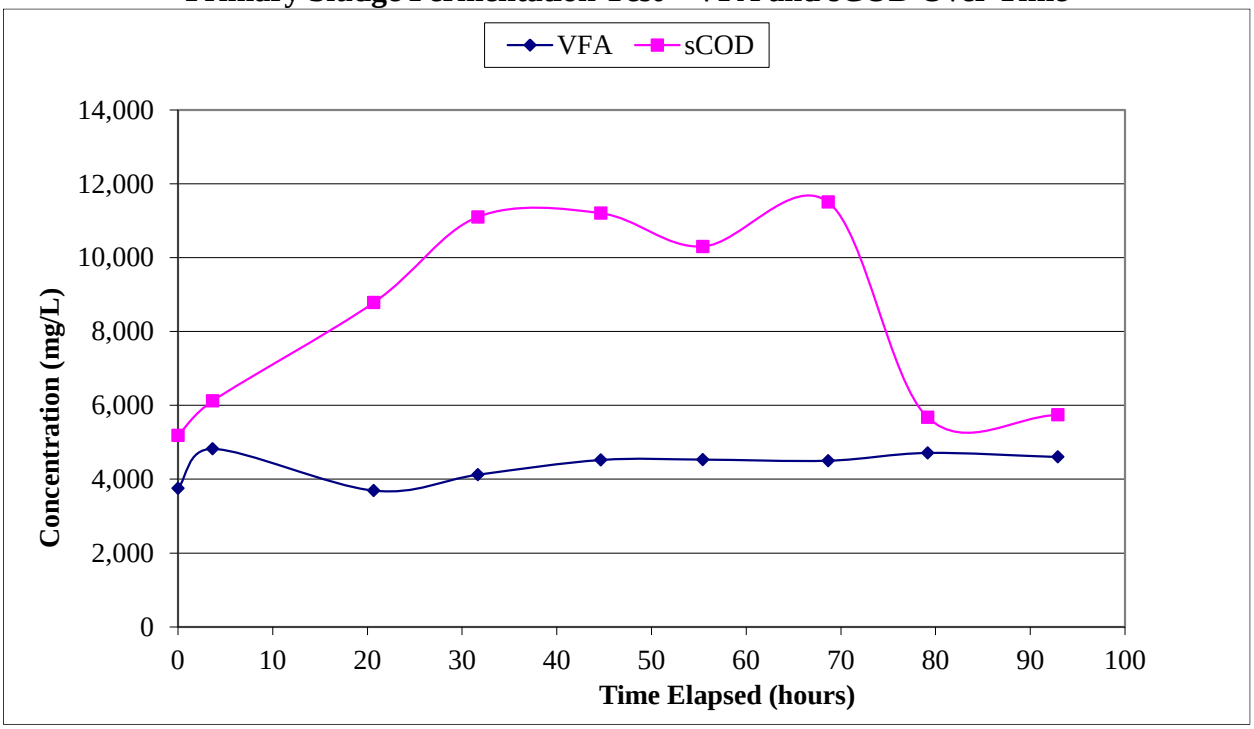
Table 4-5
Primary Sludge Fermentation Bench Scale Test Results

Time Elapsed (hours)	DO (mg/L)	ORP (mV)	Temp (ºC)	pH	sCOD (mg/L)	Nitrate (mg/L)	VFA (mg/L)	VSS (mg/L)
0.00	0.40	-52.0	20.1	4.33	5,180	2.18	3,750	16,000
3.67	0.27	-226.0	21.5	5.56	6,120	1.85	4,820	--
20.67	2.49	-21.0	26.8	5.09	8,780	1.47	3,690	--
31.67	1.46	+54.4	23.0	5.27	11,100	--	4,120	--
44.67	0.32	-118.0	23.3	5.85	11,200	--	4,520	--
55.42	0.49	-32.4	22.1	5.28	10,300	--	4,530	--
68.67	0.40	-156.0	22.1	5.68	11,500	--	4,500	--
79.17	0.37	-37.0	30.2	5.39	5,670	--	4,710	--
92.92	1.72	-105.0	20.4	5.98	5,740	--	4,600	--

Figure 4-3 depicts the VFA and sCOD concentration in the bench-scale primary sludge fermenter of the duration of the test. The ORP and concentration of DO and VFA all fluctuated during the test and did not display the anticipated trends – rapidly decreasing ORP and DO concentration followed by consistently low ORP and DO concentration and steadily increasing VFA concentration. The increase in DO and decrease in VFA concentration at 20.67 hours of operation were particularly unexpected,

Based on initial VFA of 3,750 mg/L, VSS of 16,000 mg/L, and VFA of 4,820 mg/L at 3.67 hours, the VFA yield from the primary sludge fermentation was 0.07 g-VFA/g-VSS. This was double the yield observed from fermenting RAS but on the low end of the range of observed VFA yields – 0.05 to 0.30 g-VFA/g-VSS – in other tests of primary sludge fermentation[9]. An increase in VFA concentration of 1,000 mg/L during primary sludge fermentation is an appropriate, conservative design value on the basis of this experiment.

Figure 4-3
Primary Sludge Fermentation Test – VFA and sCOD Over Time



4.5. Most Promising Option for Implementing EBPR

The two primary hurdles to overcome for implementing EBPR at the Barrington WWTF are low food-to-phosphorus ratios in the influent to the activated sludge process and high nitrates in the RAS. High DO concentrations within the aeration basin will hinder EBPR. An EBPR process would need to overcome these obstacles for successful implementation at the Barrington WWTF.

To minimize secondary phosphorus release due to cell lysis in the aeration basins, the SRT in the aeration basins would need to be reduced. Solids would need to be wasted at a greater flow rate, which would result in a thinner mixed liquor for a constant aeration volume. To maintain the desired MLSS concentration, the aeration volume may need to be adjusted by using the third aeration basin only during periods of high raw influent flow rates and loadings.

4.5.1. Modified University of Cape Town Process

Due to the combination of low food-to-nutrient ratios and high nitrate concentration in the RAS, the mUCT process is the most promising for achieving EBPR at the Barrington WWTF. While the mUCT process mitigates the negative impacts of low food-to-nutrient ratio for EBPR, the BOD-

to-phosphorus ratio should still be at least 25 to expect successful results[2,4]. The estimated BOD-to-phosphorus ratio for primary effluent at the Barrington WWTF is 18 to 19.

4.5.2. Activated Sludge Basin Sizing

A mathematical model of the Barrington WWTF was developed for sizing of the activated sludge basins in the mUCT configuration and to estimate the amount of phosphorus reduction which could be achieved biologically under optimized operating conditions at the Barrington WWTF. Kinetic growth parameters were based on typical values[2]. Both winter and summer kinetics were evaluated at three influent flow rates and loadings – the historically observed average flow rate, the DAF, and the DMF – the design values for which were provided previously. The full results of the model are provided in Appendix A.

The volume of the aeration basins was not changed from existing. Rather than operating all three aeration basins continuously with a high SRT (60 to 80 days) to prevent the mixed liquor from being very thin, the third aeration basin was brought in operation at only the DMF allowing a sufficient MLSS (2,100 to 4,700 mg/L) to be maintained at SRTs appropriate for BNR (14 to 18 days).

The following provides an overview of the modeling procedure, which was encoded into a spreadsheet:

1. Set the SRT for the entire activated sludge system and the active volume of each basin (anaerobic, anoxic, and oxic basins).
2. Calculate the heterotrophic biomass production, biomass debris production, and biomass production of nitrifiers in the aeration basin, based on typical growth kinetic parameter values adjusted for winter or summer temperatures as appropriate.
3. Calculate the required SRT in the oxic zone based on the kinetics of nitrification. Applied a factor of safety equal to 1.8, based on the ratio of 95th percentile loading to daily average loading of NH_3-N.
    a. Check that the selected SRT in Step 1 for the oxic zone is greater than the required SRT for nitrification.
4. Calculate the mixed liquor solids inventories (MLVSS, MLSS, and active biomass) based on selected SRT and calculated biomass production. Assumes biomass production is dominated by the aerobic zone and biomass production in the anaerobic and anoxic zones is relatively negligible.
5. Calculate the mixed liquor solids concentrations (MLVSS, MLSS, and active biomass), equal to the solids inventory divided by the total volume of the basins.

6. Calculate the appropriate RAS-to-Influent flow ratio based on the relationship between HRT, SRT, MLSS, and TSS in the RAS. Assumed that TSS in the RAS will be similar to current operation (8,225 mg/L).
7. Calculate the amount of NH_3-N oxidized to NO_3-N in the oxic zone, the oxygen demand in the oxic zone, and the alkalinity consumed in the oxic zone.
8. Calculate the nitrified IMLR-to-Q ratio and the NO_3-N loading to the anoxic zone based on mass balance of nitrogen. Used target effluent concentration of 5 mg/L NO_3-N.
9. Calculate the specific denitrification rate (SDNR) in the anoxic zone based on F/M ratio and ratio of sCOD-to-COD. Adjust for effects of temperature and IMLR-to-Q ratio.
10. Calculate the denitrification capacity based on SDNR, anoxic volume, and biomass concentration and compare to the NO_3-N loading. Adjust anoxic basin volume if needed, then repeat from Step 1.
11. Check that the SRT of the anaerobic zone is within recommended ranges for EBPR (1.5 to 4 days SRT with fermentation in the anaerobic zone desired[4]).
12. Calculate the potential for phosphorus removal by EBPR using a factor of 10 lb-sCOD per lb-P removed by EBPR. Calculate the phosphorus removal by non-PAO heterotrophic biomass assuming 1.5% P in the biomass. The sum of these is the total potential for biological phosphorus removal.
13. Calculate the effluent phosphorus load, equal to the difference between the total phosphorus load to the anaerobic zone and the total potential for biological phosphorus removal. Calculate the effluent phosphorus concentration, equal to the effluent phosphorus load divided by the effluent flow rate.

The supplementary carbon addition required for the mUCT system to achieve effluent phosphorus concentrations of 1.0 mg/L and 0.5 mg/L was estimated, as summarized in Table 4-6. The demand for supplementary sCOD was driven primarily by the need for denitrification in addition to EBPR. Denitrification is necessary to maintain anaerobic conditions in the anaerobic zone, as the Barrington WWTF must perform nitrification to comply with effluent NH_3-N limits.

4.5.3. Primary Sludge Fermentation

The food-to-nutrient ratios at the Barrington WWTF are too low to sustain EBPR without supplemental carbon addition, either chemically or through primary sludge fermentation. Fermenting primary sludge is the more desirable option. The estimated maximum sCOD loads available from primary sludge fermentation are provided in Table 4-6, based on the near-maximum sCOD concentration of 11,000 mg/L observed in the bench-scale primary sludge fermentation test.

A primary sludge fermenter could provide the supplemental carbon needed to sustain EBPR at the Barrington WWTF. However, significant operational concerns would be associated with a primary sludge fermenter. The Barrington WWTF is located adjacent to community baseball fields, a golf course, Barrington High School, and residences. Primary sludge fermentation has great potential to produce nuisance odors. A covered reactor and odor control system would be required to mitigate odors. Recycling of primary sludge in a fermenter can lead to the buildup of a fibrous gooey substance that is difficult to handle, clogs pumps, and accumulates in the digesters[4,9].

Barrington Wastewater Treatment Facility

Table 4-6
Summary of Influent sCOD and Supplemental Carbon Demand

Parameters at Design Operating Conditions		Observed Average Flow	Design Average Flow (DAF)	Design Maximum Flow (DMF)
Influent sCOD	(lb/day)	1,185	1,797	3,443
Primary Effluent sCOD	(lb/day)	831	1,260	2,414
Supplemental sCOD Demand for Denitrification and EBPR				
At 1.0-mg/L Effluent P	(lb/day)	843	1,290	1,955
At 0.5-mg/L effluent P	(lb/day)	944	1,443	2,381
Primary Sludge Flow Rate	(gal/day)	27,256	41,314	118,271
sCOD from Fermentation	(mg/L)	11,000	11,000	11,000
sCOD Available	(lb/day)	2,500	3,790	10,850

5. CHEMICAL PHOSPHORUS REMOVAL OPTIONS

Chemical phosphorus removal is achieved by precipitation of phosphorus, typically with aluminum sulfate (alum) or ferric chloride. Other precipitants such as polyaluminum chloride (PAC) and aluminum chlorohydrate (ACH) should also be considered. Chemical phosphorus removal can be employed as the primary means of phosphorus removal, as an enhancement or polishing step with biological phosphorus removal, or as a backup for biological phosphorus removal.

Chemical phosphorus removal acts on the soluble phosphorus, referred to as orthophosphate, which consists of PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$, and H_3PO_4. At the pH ranges typical of municipal wastewater treatment, chemical removal of orthophosphate by iron and aluminum is achieved primarily through surface complexation of the orthophosphate with hydrous ferric oxides (HFO) or hydrous aluminum oxides (HAO) precipitates[4,10].

The precipitant addition can occur at a number of points throughout the WWTP with varying advantages and disadvantages. Solid HFO/HAO-phosphate complex is removed through the municipal WWTF's normal solids handling systems. Possible chemical dosing points include before primary clarification ("preprecipitation"), before secondary treatment prior to either the aeration basins or secondary clarifiers ("simultaneous precipitation"), or after secondary treatment ("postprecipitation")[4]. The optimal points of dosing will depend on such factors as alkalinity and orthophosphate concentration at the point of dosing, whether sufficient phosphorus is available for the biological treatment process, and the contact time and mixing intensity afforded by the dosing location.

Chemical phosphorus removal alone can achieve low levels of effluent phosphorus, but several disadvantages must be considered. Operational expenses are increased due to the required purchase of the precipitant and increased sludge production. Solids handling systems must be adequately sized to handle the increased sludge production when retrofitting existing plants. Also, alum and ferric chloride consume alkalinity and may cause a drop in pH detrimental to biological treatment processes for wastewater with insufficient alkalinity. Alkalinity is also required for nitrification. A significant advantage of PAC is that it consumes less alkalinity than alum. PAC is also reported to be more effective at low temperature than alum, but PAC costs are typically 2-3 times greater than alum.

Alum, PAC, and ferric chloride can all be effective precipitants. Safety and material handling should be a practical consideration when choosing which precipitant to use. Ferric chloride is typically a more effective and efficient precipitant than alum, but ferric chloride poses a greater safety risk than alum. Ferric is highly corrosive to metal equipment and may cause serious impacts to health upon contact or ingestion. The hazards of alum and PAC are similar. Material safety data sheets (MSDS) for each are provided in Appendix C.

5.1. Existing Chemical Phosphorus Removal Equipment

The Barrington WWTP was designed and constructed for chemical precipitation using alum and polymer addition for coagulation in the late 1970s. This equipment has not been used for decades. The alum system consisted of a 7,500-gallon PVC lined tank located at the Control Building, a feed pump, a 1-inch PVC line to the end of each aeration basin, and a 1-inch PVC line to the grit tank. The polymer system consisted of a dry polymer mixing system and blending tank, a feed pump, a 1½-inch PVC line to the end of each aeration basin, and a 1½-inch PVC line to the grit tank. The feed pump system also contained a third backup/swing pump for both alum and polymer.

The polymer mixing system has now been removed with the room converted to office space. The feed piping from the chemical pumps to the grit chamber and aeration basins was pressure tested on July 17, 2014. The 1½-inch line to the grit tank is in working condition with no leaks observed. The 1-inch line to the grit tank is routed along the ceiling through a room with 480-volt motor control center equipment and was not tested.

Neither line to the aeration tanks held pressure, so they cannot be relied on for a new alum delivery system. The pressure in these lines reached only 20 psig from a 65-psig static pressure water supply with no flow observed at the outlet to the aeration basins, indicating a leak in the piping.

The valves at the end of the lines to the aeration tanks could not be actuated. H&H was hesitant to apply too much torque to the valves at the risk of sheering off the PVC pipe below the water level in the aeration basins. H&H believes they are currently closed – no flow was observed from the valves.

5.2. Recommended New Chemical Phosphorus Removal Equipment

Chemical phosphorus removal is recommended for the Barrington WWTF due to the inadequate food-to-nutrient ratios for EBPR and additional operational complexity which would be required for successful EBPR. Alum or polyaluminum chloride (PAC) are currently considered the leading coagulant options on the basis of effectiveness and safety during handling and storage. Equipment sizing and cost estimates herein are based on alum, but a jar test of alum and PAC is recommended before installation of any chemical coagulant system.

We recommend plumbing for the following alum addition points, which would allow for any of the three dosing schemes, as depicted in Figure 5-1:

- Grit tank
- At the digested sludge belt filter press filtrate recycle
- At the outlet of the primary clarifiers, downstream of the high-flow weir

- At the outlet of the aeration basins ahead of the secondary clarifiers
- At the Parshall flume ahead of the sand filters, as a polishing step

Adding alum at the grit tank would allow for mixing and flocculation to occur ahead of the primary clarifiers. Consumption of alkalinity by the alum coagulant is not expected to be problematic for the downstream biological treatment processes because the raw wastewater has high alkalinity. Removal of phosphorus through preprecipitation typically provides the most efficient use of chemical precipitant. Potential disadvantages of this dosing location are that increasing alkalinity was demonstrated to decrease the effectiveness of orthophosphate removal with ferric chloride[11], and removal of too great an amount of phosphorus in the primary clarifiers could hinder the subsequent biological treatment process.

Dosing the sludge press filtrate would provide an efficient use of alum on a high-phosphorus sidestream. To fully realize the efficiency of this dosing point, a flocculation tank would likely need to be provided.

Alum dosing at the outlet of the primary clarifiers would allow for flash mixing in the pipe between the primary clarifiers and the aeration basin and would allow for extended contact time ahead of the secondary clarifiers. Extended contact time resulted in lower residual orthophosphate concentrations in experiments[12,11]. Alum dosing at the end of the aeration channel would provide a mixing zone within the turbulent aeration basin. If mixing and flocculation with this dosing point prove insufficient during full scale pilot testing, construction of separate rapid mixing and flocculation tanks between the aeration basins and the secondary clarifiers should be considered.

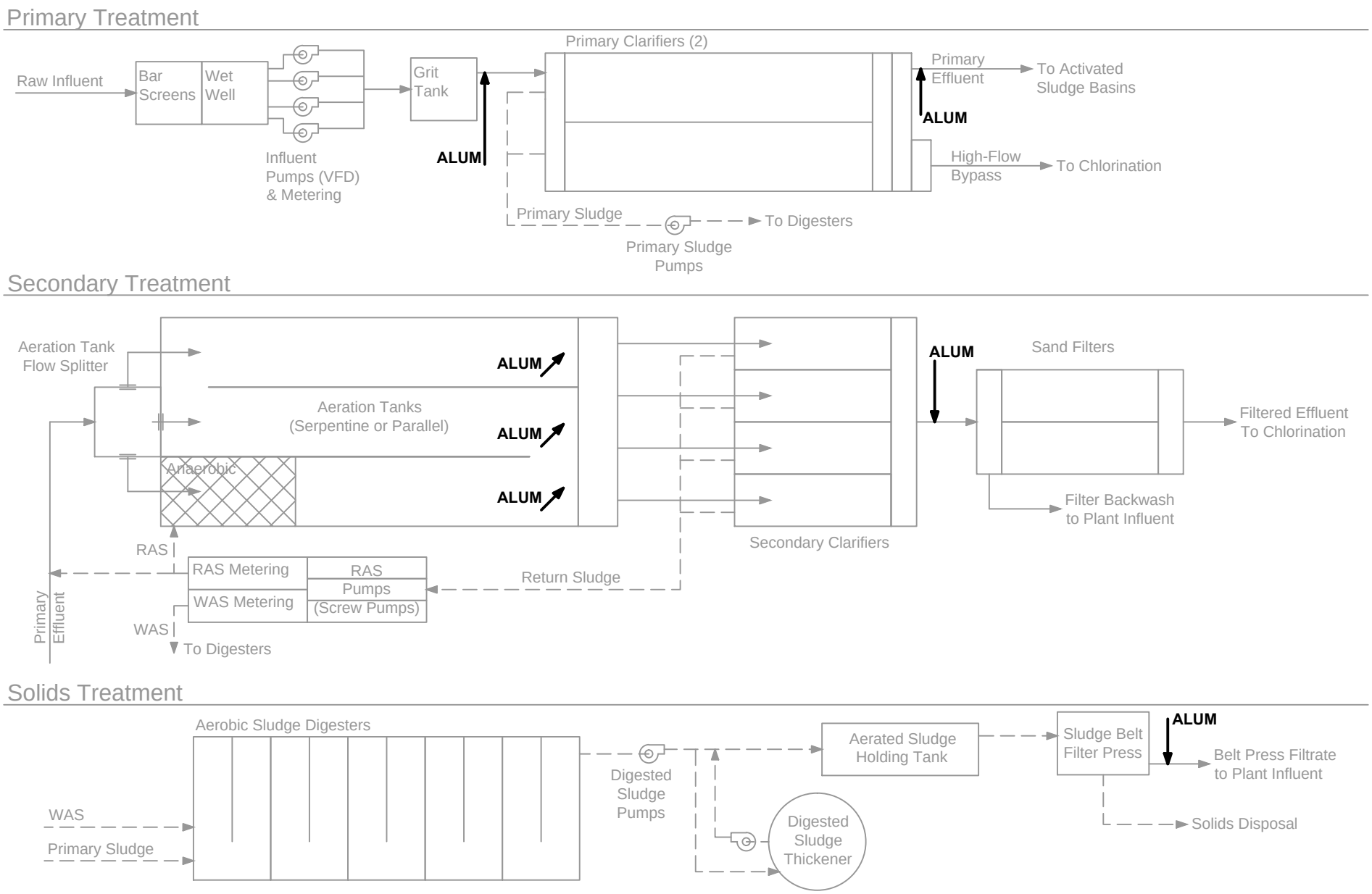
Dosing alum just ahead of the sand filters can provide a polishing step which helps achieve lower levels of phosphorus in the final effluent. A new flocculation tank may need to be provided ahead of the sand filters for this doing location to be effective, however.

Although the alum tank is conveniently located for filling from a tanker truck, we do not recommend using the existing alum tank for future operations. A new tank within a new chemical storage and feed building is recommended. Preliminary estimates of the alum dosing, alum storage, and changes in sludge production following the methods provided by the Water Environment Federation[4] are provided in Appendix B. Alum dosing for both preprecipitation and simultaneous precipitation was assumed. The results of this model are summarized in Table 5-1.

Two 12,000-gallon aboveground tanks are recommended. For an effluent phosphorus concentration of 0.5-mg/L, each tank would hold a 5-day supply of alum at maximum phosphorus loading (15 days at observed average flow/loading), for a total supply of 10 days at maximum flow/loading (30 days at observed average flow/loading). A minimum storage supply of 10 days is recommended in the 10-State Standards[13].

Table 5-1
Summary of Estimated Alum Dosing Requirement and Sludge Production for Chemical Phosphorus Removal

	For 1.0-mg/L Effluent Phosphorus	**For 0.5-mg/L Effluent Phosphorus**
Total Alum Dose (lb/d as Al; gal/d 50% alum)		
At Observed Average Flow	321 lb-Al/d; 638 gal/d	382 lb-Al/d; 757 gal/d
At DAF	462 lb-Al/d; 916 gal/d	553 lb-Al/d; 1,097 gal/d
At DMF	877 lb-Al/d; 1,740 gal/d	1,149 lb-Al/d; 2,280 gal/d
Increase in Sludge Production		
At Observed Average Flow	1,668 dry-lb/d	1,868 dry-lb/d
At DAF	2,430 dry-lb/d	2,734 dry-lb/d
At DMF	5,671 dry-lb/d	6,566 dry-lb/d



CADFILE: Barrington WWTF Simple PFD

Huff & Huff, incorporated
a Subsidiary of GZA Geoenvironmental

Figure 5-1
Schematic of Recommended Alum Feed Points
Barrington WWTF

6. CONCLUSION

A thorough evaluation of the potential to modify the Barrington WWTF for EBPR has been performed. The evaluation included operation of a full-scale pilot test of the A/O configuration for EBPR, bench scale tests for fermentation of primary sludge and denitrification of WAS, an evaluation of food-to-nutrient ratios in the wastewater, and modeling of the Barrington WWTF plant to size the anoxic and anaerobic basins for the mUCT configuration. Due to the following factors, further modifications to attempt EBPR are not recommended for the Barrington WWTF:

- Low food-to-nutrient ratios: The primary effluent sCOD is insufficient to sustain EBPR for the phosphorus and nitrogen loads at Barrington WWTF.
- Odor concerns for primary fermentation: A primary sludge fermenter (or other supplementary carbon source) would be required to overcome the problem of low sCOD in the primary effluent entering the EBPR reactors. The Barrington WWTF is located adjacent to community baseball fields, Barrington High School, a golf course, and residences. Potential failure of odor the odor control device for a primary sludge fermenter would likely lead to complaints from neighbors.
- Successful implementation of EBPR would require a significantly more complicated biological treatment system than is currently used at the Barrington WWTF. In addition to management of two new internal mixed liquor recycle streams for the mUCT process, rigorous management of the SRT for the mixed liquor would be needed. The mUCT system would need to be operated with much shorter SRT (14 to 18 days) than is typical for current operations (68 days on average). Operation of the primary fermenter would present additional challenges including the odor concerns noted previously and buildup of fibrous substances which are difficult to handle and can affect digester, pump, and piping performance.

Chemical phosphorus removal is recommended for the Barrington WWTF. Chemical phosphorus removal would alleviate or negate several of the major concerns with EBPR. A fully aerobic biological system could be maintained minimizing odor concerns. Low food-to-nutrient ratios are not problematic for chemical phosphorus removal, and the biological treatment system could be operated in essentially the same manner as it is currently.

6.1. Recommended Future Work for Phosphorus Removal

Recommended upcoming work to evaluate feasibility of chemical phosphorus removal for the Barrington WWTF includes the following:

- Jar testing of several precipitants including alum, PAC, and ACH, with and without polymer.
- Characterization of the phosphorus speciation throughout the Barrington WWTF to assist in the final design of the chemical phosphorus removal system.
- Additional sampling of the sludge press filtrate is needed to determine the phosphorus concentration in that sidestream with more certainty. Weekly sampling for the next several months is recommended.
- Additional data regarding the phosphorus concentration in biosolids specific to the Barrington WWTF may be available. If so, this data will be implemented into the modeling of phosphorus mass balance at the Barrington WWTF.
- Chemical phosphorus removal is expected to result in significant increases to the solids production from the Barrington WWTF. An evaluation of the solids handling capabilities must also be completed.
- A functional layout of chemical phosphorus removal equipment for the Barrington WWTF must be developed.
- Capital and operating costs for chemical phosphorus removal must be completed.

7. REFERENCES

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Appendix A

mUCT Basin Sizing Calculation

Appendix A
Barrington WWTF Interim Phosphorus Removal Report

Table A-1. mUCT Model Equations

Variable	Description	Equation
Q	Influent Flow Rate (mgd)	--
T	Activated Sludge Temperature (^{o}C)	--
$V_{total,active}$	Total Activated Sludge Reactor Volume (gallons)	$V_{oxic,active} + V_{ANO,active} + V_{ANA,active}$
HRT_{total}	Hydraulic Retention Time of Activated Sludge Reactors (hours)	$V_{total,active} / Q$
SRT	Design SRT, selected to maintain MLVSS (days)	--
SRT_{oxic}	Aeration Basin Solids Retention Time (days)	
SRT_{ANO}	Anoxic Basin Solids Retention Time (days)	
SRT_{ANA}	Anaerobic Zone SRT (days)	
$P_{X,VSS}$	Total Estimated VSS Production, equals WAS VSS (lb/day)	$P_{X,VSS,hetero} + P_{X,VSS,debris} + P_{X,nbVSS} + P_{X,VSS,n}$
$P_{X,TSS}$	Total Estimated Solids Production, equals WAS Solids (lb/day)	$(P_{X,VSS,hetero} + P_{X,VSS,debris} + P_{X,VSS,n})/0.85 + P_{X,nbVSS} + P_{X,iTSS}$
$P_{X,bio,VSS}$	Total Estimated Active Biomass Production (lb/day)	$P_{X,VSS,hetero} + P_{X,VSS,n}$
$M_{X,VSS}$	Inventory of MLVSS (pounds)	$SRT \times P_{X,VSS}$
$M_{X,TSS}$	Inventory of MLSS (pounds)	$SRT \times P_{X,TSS}$
$M_{X,bio,VSS}$	Inventory of Active Biomass (pounds)	$SRT \times P_{X,bio,VSS}$
X_{VSS}	Mixed Liquor Volatile Suspended Solids (mg/L)	$M_{X,VSS} / V_{total}$
X_{TSS}	Mixed Liquor Suspended Solids (mg/L)	$M_{X,TSS} / V_{total}$
X_{e}	Mixed Liquor Active Biomass Concentration (mg/L)	$M_{X,bio,VSS} / V_{total}$
$Y_{obs,TSS}$	Observed Yield based on TSS (lb-TSS/lb-bCOD)	$P_{X,TSS} / (Q \times (bCOD_{inf} - bCOD_{eff,calc}))$

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Table A-1. mUCT Model Equations

Variable	Description	Equation
Aeration Basin - Existing Plant		
$V_{oxic,max}$	Volume - Total of Aeration Basins (gal)	
$V_{oxic,single}$	Volume - Each Aeration Tank (gal)	*Length x Width x Depth*
	Length - Each Aeration Tank (ft)	
	Width - Each Aeration Tank (ft)	
	Depth - Each Aeration Tank (ft)	
$N_{oxic,tanks}$	Number of Aeration Tanks in Service	
$V_{oxic,active}$	Volume - Total of Aeration Basins (gal)	$N_{oxic,tanks} \ x \ V_{oxic,single}$
HRT_{oxic}	Aeration Basin Hydraulic Retention Time (hours)	$V_{oxic,active} \ / \ Q$
SRT_{oxic}	Aeration Basin Solids Retention Time (days)	$SRT \ x \ (V_{oxic,active} \ / \ V_{total})$
SRT_{nitrif}	Minimum SRT for Nitrification, calculated (days)	See "Nitrifier Kinetic Parameters & Design"
F/M	Food-to-Microorganism Ratio (lb-cBOD/lb-VSS-d)	$(Q \ x \ bCOD_{inf}) / (V_{oxic,active} \ x \ X_{VSS})$
Heterotrophic Kinetic Parameters & Design		
	See Metcalf & Eddy (4th Ed.), Table 8-10 for parameter values	
μ_m	Maximum Specific Growth Rate, Heterotrophs (lb-VSS/lb-VSS-d)	$\mu_m \ x \ \theta\text{-}\mu_m \ \wedge (T - 20^o C)$
K_s	Half-Velocity Constant, Heterotrophs (mg-bCOD/L)	$K_s \ x \ \theta\text{-}K_s \ \wedge (T - 20^o C)$
k_d	Endogenous Decay Rate, Heterotrophs (lb-VSS/lb-VSS-d)	$k_d \ x \ \theta\text{-}k_d \ \wedge (T - 20^o C)$
Y	Yield, Heterotrophs (lb-VSS/lb-bCOD)	
$\theta\text{–}\mu_m$	Temperature Constant at 20°C, Max Specific Growth Rate	
$\theta\text{–}K_s$	Temperature Constant at 20°C, Half-Velocity Constant	
$\theta\text{–}k_d$	Temperature Constant at 20°C, Endogenous Decay Rate	
f_d	Fraction of Biomass Remaining as Cell Debris	

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Table A-1. mUCT Model Equations

Variable	Description	Equation
$cBOD_{eff,limit}$	Effluent cBOD Limit (mg/L)	
$cBOD_{inf}$	Influent cBOD to Aeration Basin (mg/L)	
$bCOD_{eff,limit}$	Effluent bCOD Limit, based on 1.6 lb-COD/lb-BOD (mg/L)	
$bCOD_{inf}$	Influent bCOD, based on 1.6 lb-COD/lb-BOD (mg/L)	
$bCOD_{eff,calc}$	Calculated Effluent bCOD, function of SRT & kinetics; Based on SRT required for nitrification (mg/L)	$[K_s \ x (1 + k_d \ x \ SRT_{oxic,design})] / [SRT_{oxic,design} \ x (\mu_m - k_d) - 1]$
$P_{X,VSS,hetero}$	Heterotrophic Biomass Production (lb-VSS/d)	$[Q \ Y (bCOD_{inf} - bCOD_{eff,calc})] / [1 + k_d \ SRT]$
$P_{X,VSS,debris}$	Cell Debris Biomass Production (lb-VSS/d)	$[f_d \ k_d \ Q \ Y (bCOD_{inf} - bCOD_{eff,calc}) SRT] / [1 + k_d \ SRT]$
$nbVSS_{inf}$	Non-biodegradable VSS in Primary Effluent (mg/L)	
$iTSS_{inf}$	Estimated inert TSS in Primary Effluent (mg/L)	$TSS - VSS$
$P_{X,nbVSS}$	Non-Biodegradable VSS Loading (lb-VSS/d)	$Q \ x \ nbVSS_{inf}$
$P_{X,iTSS}$	Inert TSS Loading (lb-TSS/d)	$Q \ x \ iTSS_{inf}$
Nitrifier Kinetic Parameters & Design		
μ_{mn}	Maximum Specific Growth Rate, Nitrifiers (lb-VSS/lb-VSS-d)	
K_n	Half-Velocity Constant, Nitrifiers (mg-NH_4-N/L)	
k_{dn}	Endogenous Decay Rate, Nitrifiers (lb-VSS/lb-VSS-d)	
Y_n	Yield, Nitrifiers (lb-VSS/lb-NH_3-N)	
θ–μ_{mn}	Temperature Constant at 20°C, Max Specific Growth Rate	
θ–K_n	Temperature Constant at 20°C, Half-Velocity Constant	
θ–k_{dn}	Temperature Constant at 20°C, Endogenous Decay Rate	
$NH_3\text{-}N_{eff}$	Effluent Nitrogen Concentration Limit (mg/L)	
TKN_{inf}	Influent TKN Concentration (mg/L)	
$NO_3\text{-}N_{eff,assumed}$	Assumed Effluent Nitrate Concentration, 80% of TKN (mg/L)	
K_o	Half-Saturation Constant for DO (mg/L)	
DO	Design Aeration Basin Dissolved Oxygen (mg/L)	

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Barrington WWTF Interim Phosphorus Removal Report

Table A-1. mUCT Model Equations

Variable	Description	Equation
μ_n	Specific Growth Rate, Nitrifiers (lb-VSS/lb-VSS-d)	$[(\mu_{mn} \times NH_3\text{-}N_{eff}) / (K_n + NH_3\text{-}N_{eff})] \times [DO / (K_o + DO)] - k_{dn}$
$SRT_{oxic,theoretical}$	Theoretical SRT for Nitrification (days)	$1 / \mu_n$
$FS_{nitrification}$	Factor of Safety for Nitrification, NH_3-N_{peak}-to-NH_3-$N_{average}$	
$SRT_{oxic,design}$	Design SRT for Nitrification	$FS_{nitrification} \times SRT_{oxic,theoretical}$
$P_{X,VSS,n}$	Nitrifier Biomass Production (lb-VSS/d)	$[Q Y_n (NO_3\text{-}N_{eff,assumed})] / [1 + k_{dn} SRT]$
Oxygen & Alkalinity Consumption by Nitrification		
R_o	Oxygen Demand, without denitrification (lb/hour)	
$NO_3\text{-}N_{oxic}$	Estimated NH_3-N to NO_3-N Conversion (mg/L)	$(TKN_{inf}) - (NH_3\text{-}N_{eff}) - (0.12 P_{X,VSS} / Q)$
$NO_3\text{-}N_{oxic,mass}$	Estimated NO_3-N loading from oxic zone (lb/day)	$Q \times (NO_3\text{-}N_{oxic})$
$(CaCO_3:NH_3\text{-}N)_{factor}$	Stoichiometric Alkalinity Requried for Nitrification (lb-$CaCO_3$/lb-NH_3-N)	
Alk_{USED}	Amount of Alkalinity Consumed (mg/L)	$(NO_3\text{-}N_{oxic,mass}) (CaCO_3:NH_3\text{-}N)_{factor}$
Return Activated Sludge		
$RAS:Q$	RAS-to-Influent Flow Rate Ratio	$[1 - (HRT / SRT)] / [(TSS_{RAS} / X_{TSS}) - 1]$
RAS	RAS Flow Rate (mgd)	$Q \times (RAS:Q)$
TSS_{RAS}	TSS Concentration (mg/L)	assumed equal to average current value
VSS_{RAS}	VSS Concentration (mg/L)	assumed equal to average current value
X_{RAS}	Active Biomass Concentration (mg/L)	$VSS_{RAS} \times [X_e / X_{VSS}]$
Waste Activated Sludge		
Q_w	WAS Flow Rate (gal/day)	$P_{X,TSS} / TSS_{WAS}$
TSS_{WAS}	TSS Concentration, same as RAS (mg/L)	assumed equal to RAS
VSS_{WAS}	VSS Concentration, same as RAS (mg/L)	assumed equal to RAS

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Table A-1. mUCT Model Equations

Variable	Description	Equation
Anoxic Zone Basin - New Plant Expansion		
$V_{ANO,each}$	Anoxic Zone Volume (gal) Length - Each Aeration Tank (ft) Width - Each Aeration Tank (ft) Depth - Each Aeration Tank (ft) Cross Sectional Area (ft^2)	
V_{ANO1}	Modified UCT Anoxic Zone 1 (RAS) Volume (gal) Length - Each Aeration Tank (ft) Width - Each Aeration Tank (ft) Depth - Each Aeration Tank (ft) Cross Sectional Area (ft^2)	
V_{ANO2}	Modified UCT Anoxic Zone 2 (IMLR) Volume (gal) Length - Each Aeration Tank (ft) Width - Each Aeration Tank (ft) Depth - Each Aeration Tank (ft) Cross Sectional Area (ft^2)	
V_{ANO1}/V_{ANO}	Fraction of Total Anoxic Zone Volume for First Anoxic Zone in Modified UCT Configuration (RAS Anoxic Zone)	
V_{ANO2}/V_{ANO}	Fraction of Total Anoxic Zone Volume for Second Anoxic Zone in Modified UCT Configuration (Nitrate-IMLR Anoxic Zone)	
N_{ANO}		
$V_{ANO,active}$		
HRT_{ANO}	Anoxic Basin Hydraulic Retention Time (hours)	V_{ANO} / Q
SRT_{ANO}	Anoxic Basin Solids Retention Time (days)	$V_{ANO} / V_{total,active} \ x \ SRT$
Q_{ANO}	Total Flow Rate in Anoxic Zone including Recycle (mgd)	$Q + RAS + IMLR_{nitrate}$
v_{ANO}	Velocity in Anoxic Zone Channel (ft/s)	$Q_{ANO} / Area\text{-}Cross\text{-}Section$

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Table A-1. mUCT Model Equations

Variable	Description	Equation
$NO_3\text{-}N_{eff}$	Target Effluent NO_3-N (mg/L)	
$NO_3\text{-}N_{oxic}$	Amount of NO3-N from Oxic Zone, per Influent Flow (mg/L)	See nitrification design section
$IMLR_{nitrate}:Q$	Nitrate-Rich IMLR-to-Influent Flow Rate Ratio	$(NO_3\text{-}N_{oxic}) / (NO_3\text{-}N_{eff}) - 1 - (RAS:Q)$
$IMLR_{nitrate}$	Nitrate-Rich IMLR Flow Rate (mgd)	$Q \times (IMLR_{nitrate}:Q)$
$NO_3\text{-}N_{ANO,LOAD}$	Loading of NO_3-N to the Anoxic Zone (lb/day)	$(Q_{RAS} + Q_{ANO}) \times NO_3\text{-}N_{eff}$
F/M_b	Anoxic Zone Food-to-Microorganism Ratio (lb-cBOD/lb-VSS-d)	$[Q\ cBOD_{inf}] / [V_{ANO,active}\ X_e]$
$sCOD:COD$	Estimated Ratio of sCOD-to-COD in Influent	
$SDNR_b$	Specific Denitrification Rate, f(F/M_b); (lb-NO_3-N/lb-VSS-d)	Metcalf & Eddy, Figure 8-23
$\theta\text{–}K_n$	Temperature Constant at 20°C, Half-Velocity Constant	
$SDNR_T$	Temperature-Corrected SDNR (lb-NO_3-N/lb-VSS-d)	$SDNR_b \times \theta\text{-}K_n \wedge (T - 20^oC)$
$SDNR_{adj}$	IMLR Ratio-Adjusted SDNR (lb-NO_3-N/lb-VSS-d)	See Metcalf & Eddy (4th Ed.) Eq. 8-45 and 8-46
NO_r	Nitrate Removal Capacity (lb-NO_3-N/d)	$V_{ANO,active} \times SDNR_{adj} \times X_e$
	Nitrate Removal Capacity less Loading (lb-NO_3-N/d)	$(NO_r) - (NO_3\text{-}N_{ANO,LOAD})$
Oxygen and Alkalinity Credit		
$R_{o,ANO}$	Anoxic Oxygen Credit (lb/hour)	$(NO_3\text{-}N_{ANO,load}) \times (Oxygen\ Credit\ Factor)$
	Anoxic Oxygen Credit Factor (lb-O_2/lb-NO_3-N)	
Alk_{ANO}	Anoxic Alkalinity Credit (mg/L)	$[(NO_3\text{-}N_{oxic}) - (NO_3\text{-}N_{eff})] \times (Alkalinity\ Credit\ Factor)$
	Anoxic Alkalinity Credit Factor (lb-$CaCO_3$/lb-NO_3-N)	

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Table A-1. mUCT Model Equations

Variable	Description	Equation
Anaerobic Zone Basin - New Plant Expansion		
$V_{ANA,each}$	Anaerobic Zone Volume, per Basin (gal) Length - Each Aeration Tank (ft) Width - Each Aeration Tank (ft) Depth - Each Aeration Tank (ft)	
$N_{ANA,active}$	Number of Active Anaerobic Basins	
$V_{ANA,active}$	Total Active Anaerobic Zone Volume (gal)	
HRT_{ANA}	Anaerobic Zone HRT (hours)	V_{ANA} / Q
SRT_{ANA}	Anaerobic Zone SRT (days)	$V_{ANA} / V_{total,active} \ x \ SRT$
$IMLR_{ANA}:Q$	Anoxic-to-Anaerobic IMLR-to-Influent Flow Rate Ratio	
$IMLR_{ANA}$	Anoxic-to-Anaerobic IMLR Flow Rate (mgd)	
$sCOD_{prim,load}$	Soluble COD Loading from Primary Effluent (lb/day)	
$sCOD_{load}$	Soluble COD Loading to Anaerobic Basin (lb/day)	
$sCOD/P_{factor}$	Unit amount of sCOD per P removed (lb-sCOD/lb-P)	
P-sCOD-limit	sCOD-limited Phosphorus Removal Potential (lb-P/day)	$(sCOD_{load}) / (sCOD/P_{factor})$
P/VSS-hetero	Phosphorus content of non-EBPR Heterotrophic Biomass (lb-P/lb-VSS)	
P-hetero	Phosphorus used for non-EBPR Heterotrophic Biomass (lb-P/day)	$(P_{X,VSS,hetero}) \ x \ (P/VSS\text{-}hetero)$
$P_{removal\text{-}potential}$	Total EBPR Phosphorus Removal Potential (lb-P/day)	$(P\text{-}sCOD\text{-}limit) + (P\text{-}hetero)$
$P_{inf,load}$	Phosphorus Loading from Primary Effluent (lb/day)	
P_{inf}	Total Phosphorus Primary Effluent Conc. (mg/L)	
$P_{eff,load}$	Total Phosphorus Effluent Load (lb/day)	$P_{inf,load} - P_{removal\text{-}potential}$
P_{eff}	Total Phosphorus Effluent Concentration (mg/L)	$P_{eff,load} / Q$

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Table A-1. mUCT Model Equations

Variable	Description	Equation
Supplementary Carbon Demand		
$sCOD{:}NO_3\text{-}N_{factor}$	Unit sCOD Demand for Nitrate Removal (lb-sCOD/lb-NO_3-N)	
sCOD Demand for BNR Processes		
$sCOD_{demand,NO3\text{-}N,load}$	sCOD Demand for Nitrate Removal (lb-sCOD/day)	$(sCOD{:}NO_3\text{-}N_{factor}) \times (NO_3\text{-}N_{ANA,load})$
$sCOD_{demand,P,1\text{-}mg/L}$	sCOD Demand for EBPR to 1-mg/L P (lb/day)	$(P_{inf} - 1.0\ mg/L)(Q)(sCOD/P_{factor})$
$sCOD_{demand,P,0.5\text{-}mg/L}$	sCOD Demand for EBPR to 0.5-mg/L P (lb/day)	$(P_{inf} - 0.5\ mg/L)(Q)(sCOD/P_{factor})$
$sCOD_{demand,1\text{-}mgP/L,total}$	Total sCOD Demand for BNR to 1-mg/L P (lb/day)	$sCOD_{demand,NO3\text{-}N,load} + sCOD_{demand,P,1\text{-}mg/L}$
$sCOD_{demand,0.5\text{-}mgP/L,total}$	Total sCOD Demand for BNR to 0.5-mg/L P (lb/day)	$sCOD_{demand,NO3\text{-}N,load} + sCOD_{demand,P,0.5\text{-}mg/L}$
sCOD Loading and Supplemental sCOD Demand		
$sCOD_{prim,load}$	Soluble COD Loading from Primary Effluent (lb/day)	
$sCOD_{supp\text{-}load,1\text{-}mgP/L,total}$	Supplemental sCOD for BNR to 1-mg/L P (lb/day)	$sCOD_{demand,1\text{-}mgP/L,total} - sCOD_{prim,load}$
$sCOD_{supp\text{-}load,0.5\text{-}mgP/L,total}$	Supplemental sCOD for BNR to 0.5-mg/L P (lb/day)	$sCOD_{demand,0.5\text{-}mgP/L,total} - sCOD_{prim,load}$
$sCOD_{supp\text{-}conc,1\text{-}mgP/L,total}$	Supplemental sCOD for BNR to 1-mg/L P (mg/L)	$sCOD_{supp\text{-}load,1\text{-}mgP/L,total} / Q$
$sCOD_{supp\text{-}conc,0.5\text{-}mgP/L,total}$	Supplemental sCOD for BNR to 0.5-mg/L P (mg/L)	$sCOD_{supp\text{-}load,0.5\text{-}mgP/L,total} / Q$

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Table A-2. mUCT Model Results - Scenario 1
Scenario 1: With Primary Clarifiers and No Supplementary Carbon

			Winter Design Conditions			Summer Design Conditions		
Variable	**Description**	**Fixed Values**	**At Observed Average Flow**	**At DAF**	**At DMF**	**At Observed Average Flow**	**At DAF**	**At DMF**
Q	Influent Flow Rate (mgd)	--	2.43	3.68	10.2	2.43	3.68	10.2
T	Activated Sludge Temperature (^{o}C)		10	10	10	20	20	20
$V_{total,active}$	Total Activated Sludge Reactor Volume (gallons)		1,146,500	1,451,500	1,872,250	725,750	1,146,500	1,872,250
HRT_{total}	Hydraulic Retention Time of Activated Sludge Reactors (hours)		11.3	9.5	4.4	7.2	7.5	4.4
SRT	Design SRT, selected to maintain MLVSS (days)		18.0	18.0	14.0	14.0	17.0	14.0
SRT_{oxic}	Aeration Basin Solids Retention Time (days)		13.2	10.4	9.4	8.1	12.5	9.4
SRT_{ANO}	Anoxic Basin Solids Retention Time (days)		3.2	5.1	3.1	4.0	3.0	3.1
SRT_{ANA}	Anaerobic Zone SRT (days)		1.6	2.5	1.5	1.9	1.5	1.5
$P_{X,VSS}$	Total Estimated VSS Production, equals WAS VSS (lb/day)		839	1,272	3,965	897	1,287	3,958
$P_{X,TSS}$	Total Estimated Solids Production, equals WAS Solids (lb/day)		1,114	1,689	5,291	1,182	1,707	5,283
$P_{X,bio,VSS}$	Total Estimated Active Biomass Production (lb/day)		406	615	1,964	474	634	1,956
$M_{X,VSS}$	Inventory of MLVSS (pounds)		15,106	22,898	55,515	12,557	21,883	55,412
$M_{X,TSS}$	Inventory of MLSS (pounds)		20,058	30,404	74,080	16,551	29,017	73,959
$M_{X,bio,VSS}$	Inventory of Active Biomass (pounds)		7,309	11,078	27,490	6,636	10,776	27,381
X_{VSS}	Mixed Liquor Volatile Suspended Solids (mg/L)		1,580	1,892	3,555	2,075	2,289	3,549
X_{TSS}	Mixed Liquor Suspended Solids (mg/L)		2,098	2,512	4,744	2,734	3,035	4,737
X_{e}	Mixed Liquor Active Biomass Concentration (mg/L)		764	915	1,761	1,096	1,127	1,754
$Y_{obs,TSS}$	Observed Yield based on TSS (lb-TSS/lb-bCOD)		0.37	0.37	0.41	0.39	0.37	0.41

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Barrington WWTF Interim Phosphorus Removal Report

Table A-2. mUCT Model Results - Scenario 1
Scenario 1: With Primary Clarifiers and No Supplementary Carbon

			Winter Design Conditions			Summer Design Conditions		
Variable	**Description**	**Fixed Values**	**At Observed Average Flow**	**At DAF**	**At DMF**	**At Observed Average Flow**	**At DAF**	**At DMF**
Aeration Basin - Existing Plant								
$V_{oxic,max}$	Volume - Total of Aeration Basins (gal)	1,262,250						
$V_{oxic,single}$	Volume - Each Aeration Tank (gal)	420,750						
	Length - Each Aeration Tank (ft)	150						
	Width - Each Aeration Tank (ft)	25						
	Depth - Each Aeration Tank (ft)	15						
$N_{oxic,tanks}$	Number of Aeration Tanks in Service		2	2	3	1	2	3
$V_{oxic,active}$	Volume - Total of Aeration Basins (gal)		841,500	841,500	1,262,250	420,750	841,500	1,262,250
HRT_{oxic}	Aeration Basin Hydraulic Retention Time (hours)	--	8.3	5.5	3.0	4.2	5.5	3.0
SRT_{oxic}	Aeration Basin Solids Retention Time (days)		13.2	10.4	9.4	8.1	12.5	9.4
SRT_{nitrif}	Minimum SRT for Nitrification, calculated (days)		8.8	8.8	8.8	6.2	6.2	6.2
F/M	Food-to-Microorganism Ratio (lb-cBOD/lb-VSS-d)		0.17	0.22	0.22	0.26	0.18	0.22
Heterotrophic Kinetic Parameters & Design								
	See Metcalf & Eddy (4th Ed.), Table 8-10 for parameter values							
μ_m	Maximum Specific Growth Rate, Heterotrophs (lb-VSS/lb-VSS-d)	6.0	3.1	***MSGR_hetero_perday_WINTER***		6.0	***MSGR_hetero_perday_SUMMER***	
K_s	Half-Velocity Constant, Heterotrophs (mg-bCOD/L)	20.0	13.5	***Ks_hetero_mg_per_L_WINTER***		20.0	***Ks_hetero_mg_per_L_SUMMER***	
k_d	Endogenous Decay Rate, Heterotrophs (lb-VSS/lb-VSS-d)	0.12	0.12	***kd_hetero_perday_WINTER***		0.12	***kd_hetero_perday_SUMMER***	
Y	Yield, Heterotrophs (lb-VSS/lb-bCOD)	0.40						
$\theta-\mu_m$	Temperature Constant at 20°C, Max Specific Growth Rate	1.07						
$\theta-K_s$	Temperature Constant at 20°C, Half-Velocity Constant	1.04						
$\theta-k_d$	Temperature Constant at 20°C, Endogenous Decay Rate	1.00						
f_d	Fraction of Biomass Remaining as Cell Debris	0.15						

Table A-2. mUCT Model Results - Scenario 1
Scenario 1: With Primary Clarifiers and No Supplementary Carbon

			Winter Design Conditions			Summer Design Conditions		
Variable	**Description**	**Fixed Values**	**At Observed Average Flow**	**At DAF**	**At DMF**	**At Observed Average Flow**	**At DAF**	**At DMF**
$cBOD_{eff,limit}$	Effluent cBOD Limit (mg/L)	10						
$cBOD_{inf}$	Influent cBOD to Aeration Basin (mg/L)	95						
$bCOD_{eff,limit}$	Effluent bCOD Limit, based on 1.6 lb-COD/lb-BOD (mg/L)	16						
$bCOD_{inf}$	Influent bCOD, based on 1.6 lb-COD/lb-BOD (mg/L)	151						
$bCOD_{eff,calc}$	Calculated Effluent bCOD, function of SRT & kinetics; Based on SRT required for nitrification (mg/L)		1.1	***S_bCOD_eff_mg_per_L_WINTER***		1.0	***S_bCOD_eff_mg_per_L_SUMMER***	
$P_{X,VSS,hetero}$	Heterotrophic Biomass Production (lb-VSS/d)		385	584	1,908	454	607	1,910
$P_{X,VSS,debris}$	Cell Debris Biomass Production (lb-VSS/d)		125	189	481	115	186	481
$nbVSS_{inf}$	Non-biodegradable VSS in Primary Effluent (mg/L)		15.2	15.2	17.9	15.2	15.2	17.9
$iTSS_{inf}$	Estimated inert TSS in Primary Effluent (mg/L)		9.0	9.0	10.5	9.0	9.0	10.5
$P_{X,nbVSS}$	Non-Biodegradable VSS Loading (lb-VSS/d)		308	468	1,521	308	468	1,521
$P_{X,iTSS}$	Inert TSS Loading (lb-TSS/d)		181	275	895	181	275	895
Nitrifier Kinetic Parameters & Design								
μ_{mn}	Maximum Specific Growth Rate, Nitrifiers (lb-VSS/lb-VSS-d)	0.75	0.38	***MSGR_nitrif_perday_WINTER***		0.75	***MSGR_nitrif_perday_SUMMER***	
K_n	Half-Velocity Constant, Nitrifiers (mg-NH_4-N/L)	0.74	0.44	***Kn_nitrif_mg_per_L_WINTER***		0.74	***Kn_nitrif_mg_per_L_SUMMER***	
k_{dn}	Endogenous Decay Rate, Nitrifiers (lb-VSS/lb-VSS-d)	0.08	0.05	***kdn_nitrif_perday_WINTER***		0.08	***kdn_nitrif_perday_SUMMER***	
Y_n	Yield, Nitrifiers (lb-VSS/lb-NH_3-N)	0.12						
θ–μ_{mn}	Temperature Constant at 20°C, Max Specific Growth Rate	1.070						
θ–K_n	Temperature Constant at 20°C, Half-Velocity Constant	1.053						
θ–k_{dn}	Temperature Constant at 20°C, Endogenous Decay Rate	1.040						
NH_3-N_{eff}	Effluent Nitrogen Concentration Limit (mg/L)		2.5	***NH3N_Eff_Limit_WINTER***		1.2	***NH3N_Eff_Limit_SUMMER***	
TKN_{inf}	Influent TKN Concentration (mg/L)		21.2	21.2	12.0	21.2	21.2	12.0
NO_3-$N_{eff,assumed}$	Assumed Effluent Nitrate Concentration, 80% of TKN (mg/L)		17.0	17.0	9.6	17.0	17.0	9.6
K_o	Half-Saturation Constant for DO (mg/L)	0.5						
DO	Design Aeration Basin Dissolved Oxygen (mg/L)	2.0						
μ_n	Specific Growth Rate, Nitrifiers (lb-VSS/lb-VSS-d)		0.21	***SGR_nitrif_perday_WINTER***		0.29	***SGR_nitrif_perday_SUMMER***	

Table A-2. mUCT Model Results - Scenario 1
Scenario 1: With Primary Clarifiers and No Supplementary Carbon

			Winter Design Conditions			Summer Design Conditions		
Variable	**Description**	**Fixed Values**	**At Observed Average Flow**	**At DAF**	**At DMF**	**At Observed Average Flow**	**At DAF**	**At DMF**
$SRT_{oxic,theoretical}$	Theoretical SRT for Nitrification (days)		4.87			3.43		
$FS_{nitrification}$	Factor of Safety for Nitrification, NH_3-N_{peak}-to-NH_3-$N_{average}$	1.8						
$SRT_{oxic,design}$	Design SRT for Nitrification		8.8	***SRT_nitrif_days_WINTER***		6.2	***SRT_nitrif_days_SUMMER***	
$P_{X,VSS,n}$	Nitrifier Biomass Production (lb-VSS/d)		20.9	31.7	55.8	19.5	26.5	46.2
Oxygen & Alkalinity Consumption by Nitrification								
R_o	Oxygen Demand, without denitrification (lb/hour)		65	98	245	61	97	246
$NO_3\text{-}N_{oxic}$	Estimated NH_3-N to NO_3-N Conversion (mg/L)		13.8	13.8	3.9	14.7	15.0	5.2
$NO_3\text{-}N_{oxic,mass}$	Estimated NO_3-N loading from oxic zone (lb/day)		279	422	332	298	460	444
$(CaCO_3:NH_3\text{-}N)_{factor}$	Stoichiometric Alkalinity Requried for Nitrification (lb-$CaCO_3$/lb-NH_3-N)	7.07						
Alk_{USED}	Amount of Alkalinity Consumed (mg/L)		97	97	28	104	106	37
Return Activated Sludge								
$RAS:Q$	RAS-to-Influent Flow Rate Ratio		0.30	0.40	1.30	0.50	0.60	1.30
RAS	RAS Flow Rate (mgd)		0.73	1.47	13.26	1.21	2.21	13.26
TSS_{RAS}	TSS Concentration (mg/L)		8,225	8,225	8,225	8,225	8,225	8,225
VSS_{RAS}	VSS Concentration (mg/L)		6,991	6,991	6,991	6,991	6,991	6,991
X_{RAS}	Active Biomass Concentration (mg/L)		3,383	3,383	3,462	3,695	3,443	3,455
Waste Activated Sludge								
Q_w	WAS Flow Rate (gal/day)		16,244	24,623	77,136	17,234	24,882	77,010
TSS_{WAS}	TSS Concentration, same as RAS (mg/L)		8,225	8,225	8,225	8,225	8,225	8,225
VSS_{WAS}	VSS Concentration, same as RAS (mg/L)		6,991	6,991	6,991	6,991	6,991	6,991

Table A-2. mUCT Model Results - Scenario 1
Scenario 1: With Primary Clarifiers and No Supplementary Carbon

			Winter Design Conditions			Summer Design Conditions		
Variable	**Description**	**Fixed Values**	**At Observed Average Flow**	**At DAF**	**At DMF**	**At Observed Average Flow**	**At DAF**	**At DMF**
Anoxic Zone Basin - New Plant Expansion								
$V_{ANO,each}$	Anoxic Zone Volume (gal)	205,000						
	Length - Each Aeration Tank (ft)	91						
	Width - Each Aeration Tank (ft)	20						
	Depth - Each Aeration Tank (ft)	15						
	Cross Sectional Area (ft^2)	300						
V_{ANO1}	Modified UCT Anoxic Zone 1 (RAS) Volume (gal)	45,556						
	Length - Each Aeration Tank (ft)	20						
	Width - Each Aeration Tank (ft)	20						
	Depth - Each Aeration Tank (ft)	15						
	Cross Sectional Area (ft^2)	300						
V_{ANO2}	Modified UCT Anoxic Zone 2 (IMLR) Volume (gal)	159,444						
	Length - Each Aeration Tank (ft)	71						
	Width - Each Aeration Tank (ft)	20						
	Depth - Each Aeration Tank (ft)	15						
	Cross Sectional Area (ft^2)	300						
V_{ANO1}/V_{ANO}	Fraction of Total Anoxic Zone Volume for First Anoxic Zone in Modified UCT Configuration (RAS Anoxic Zone)	0.22						
V_{ANO2}/V_{ANO}	Fraction of Total Anoxic Zone Volume for Second Anoxic Zone in Modified UCT Configuration (Nitrate-IMLR Anoxic Zone)	0.78						
N_{ANO}			1	2	2	1	1	2
$V_{ANO,active}$			205,000	410,000	410,000	205,000	205,000	410,000
HRT_{ANO}	Anoxic Basin Hydraulic Retention Time (hours)		2.0	2.7	1.0	2.0	1.3	1.0
SRT_{ANO}	Anoxic Basin Solids Retention Time (days)		3.2	5.1	3.1	4.0	3.0	3.1
Q_{ANO}	Total Flow Rate in Anoxic Zone including Recycle (mgd)		6.8	10.3	23.5	7.3	11.4	23.5
v_{ANO}	Velocity in Anoxic Zone Channel (ft/s)		0.04	0.05	0.12	0.04	0.06	0.12

Table A-2. mUCT Model Results - Scenario 1
Scenario 1: With Primary Clarifiers and No Supplementary Carbon

			Winter Design Conditions			Summer Design Conditions		
Variable	**Description**	**Fixed Values**	**At Observed Average Flow**	**At DAF**	**At DMF**	**At Observed Average Flow**	**At DAF**	**At DMF**
$NO_3\text{-}N_{eff}$	Target Effluent NO_3-N (mg/L)		5.0	5.0	5.0	5.0	5.0	5.0
$NO_3\text{-}N_{oxic}$	Amount of NO3-N from Oxic Zone, per Influent Flow (mg/L)		13.8	13.8	3.9	14.7	15.0	5.2
$IMLR_{nitrate}:Q$	Nitrate-Rich IMLR-to-Influent Flow Rate Ratio		1.5	1.4	0.0	1.5	1.5	0.0
$IMLR_{nitrate}$	Nitrate-Rich IMLR Flow Rate (mgd)		3.6	5.2	0.0	3.6	5.5	0.0
$NO_3\text{-}N_{ANO,LOAD}$	Loading of NO_3-N to the Anoxic Zone (lb/day)		182	276	553	202	322	553
F/M_b	Anoxic Zone Food-to-Microorganism Ratio (lb-cBOD/lb-VSS-d)		1.47	0.93	1.34	1.02	1.51	1.34
sCOD:COD	Estimated Ratio of sCOD-to-COD in Influent	0.26						
$SDNR_b$	Specific Denitrification Rate, f(F/M_b); (lb-NO_3-N/lb-VSS-d)		0.20	0.20	0.24	0.21	0.27	0.26
$\theta\text{–}K_n$	Temperature Constant at 20°C, Half-Velocity Constant	1.026						
$SDNR_T$	Temperature-Corrected SDNR (lb-NO_3-N/lb-VSS-d)		0.15	0.15	0.19	0.21	0.27	0.26
$SDNR_{adj}$	IMLR Ratio-Adjusted SDNR (lb-NO_3-N/lb-VSS-d)		0.14	0.15	0.19	0.20	0.26	0.26
NO_r	Nitrate Removal Capacity (lb-NO_3-N/d)		184	464	1,118	379	492	1,560
	Nitrate Removal Capacity less Loading (lb-NO_3-N/d)		2	188	565	176	170	1007
Oxygen and Alkalinity Credit								
$R_{o,ANO}$	Anoxic Oxygen Credit (lb/hour)		22	33	66	24	38	66
	Anoxic Oxygen Credit Factor (lb-O_2/lb-NO_3-N)	2.86						
Alk_{ANO}	Anoxic Alkalinity Credit (mg/L)		31	31	0	35	36	1
	Anoxic Alkalinity Credit Factor (lb-$CaCO_3$/lb-NO_3-N)	3.57						

Appendix A
Barrington WWTF Interim Phosphorus Removal Report

Table A-2. mUCT Model Results - Scenario 1
Scenario 1: With Primary Clarifiers and No Supplementary Carbon

			Winter Design Conditions			Summer Design Conditions		
Variable	**Description**	**Fixed Values**	**At Observed Average Flow**	**At DAF**	**At DMF**	**At Observed Average Flow**	**At DAF**	**At DMF**
Anaerobic Zone Basin - New Plant Expansion								
$V_{ANA,each}$	Anaerobic Zone Volume, per Basin (gal)	100,000						
	Length - Each Aeration Tank (ft)	45						
	Width - Each Aeration Tank (ft)	20						
	Depth - Each Aeration Tank (ft)	15						
$N_{ANA,active}$	Number of Active Anaerobic Basins		1	2	2	1	1	2
$V_{ANA,active}$	Total Active Anaerobic Zone Volume (gal)		100,000	200,000	200,000	100,000	100,000	200,000
HRT_{ANA}	Anaerobic Zone HRT (hours)		1.0	1.3	0.5	1.0	0.7	0.5
SRT_{ANA}	Anaerobic Zone SRT (days)		1.6	2.5	1.5	1.9	1.5	1.5
$IMLR_{ANA}:Q$	Anoxic-to-Anaerobic IMLR-to-Influent Flow Rate Ratio		2.0	2.0	1.0	2.0	2.0	1.0
$IMLR_{ANA}$	Anoxic-to-Anaerobic IMLR Flow Rate (mgd)		4.86	7.36	10.20	4.86	7.36	10.20
$sCOD_{prim,load}$	Soluble COD Loading from Primary Effluent (lb/day)		831	1,260	2,414	831	1,260	2,414
$sCOD_{load}$	Soluble COD Loading to Anaerobic Basin (lb/day)		831	1,260	2,414	831	1,260	2,414
$sCOD/P_{factor}$	Unit amount of sCOD per P removed (lb-sCOD/lb-P)	10						
P-sCOD-limit	sCOD-limited Phosphorus Removal Potential (lb-P/day)		83	126	241	83	126	241
P/VSS-hetero	Phosphorus content of non-EBPR Heterotrophic Biomass (lb-P/lb-VSS)	0.015						
P-hetero	Phosphorus used for non-EBPR Heterotrophic Biomass (lb-P/day)		6	9	29	7	9	29
$P_{removal\text{-}potential}$	Total EBPR Phosphorus Removal Potential (lb-P/day)		89	135	270	90	135	270
$P_{inf,load}$	Phosphorus Loading from Primary Effluent (lb/day)		107	157	301	107	157	301
P_{inf}	Total Phosphorus Primary Effluent Conc. (mg/L)		5.3	5.1	3.5	5.3	5.1	3.5
$P_{eff,load}$	Total Phosphorus Effluent Load (lb/day)		18	22	31	17	22	31
P_{eff}	Total Phosphorus Effluent Concentration (mg/L)		0.9	0.7	0.4	0.8	0.7	0.4
Supplementary Carbon Demand								
$sCOD:NO_3\text{-}N_{factor}$	Unit sCOD Demand for Nitrate Removal (lb-sCOD/lb-NO_3-N)	4						

Table A-2. mUCT Model Results - Scenario 1
Scenario 1: With Primary Clarifiers and No Supplementary Carbon

			Winter Design Conditions			Summer Design Conditions		
Variable	**Description**	**Fixed Values**	**At Observed Average Flow**	**At DAF**	**At DMF**	**At Observed Average Flow**	**At DAF**	**At DMF**
sCOD Demand for BNR Processes								
$sCOD_{demand,NO3\text{-}N,load}$	sCOD Demand for Nitrate Removal (lb-sCOD/day)		729	1,105	2,212	810	1,289	2,212
$sCOD_{demand,P,1\text{-}mg/L}$	sCOD Demand for EBPR to 1-mg/L P (lb/day)		864	1,261	2,158	864	1,261	2,158
$sCOD_{demand,P,0.5\text{-}mg/L}$	sCOD Demand for EBPR to 0.5-mg/L P (lb/day)		965	1,414	2,583	965	1,414	2,583
$sCOD_{demand,1\text{-}mgP/L,total}$	Total sCOD Demand for BNR to 1-mg/L P (lb/day)		1,593	2,366	4,370	1,674	2,550	4,370
$sCOD_{demand,0.5\text{-}mgP/L,total}$	Total sCOD Demand for BNR to 0.5-mg/L P (lb/day)		1,694	2,519	4,795	1,775	2,704	4,795
sCOD Loading and Supplemental sCOD Demand								
$sCOD_{prim,load}$	Soluble COD Loading from Primary Effluent (lb/day)		831	1,260	2,414	831	1,260	2,414
$sCOD_{supp\text{-}load,1\text{-}mgP/L,total}$	Supplemental sCOD for BNR to 1-mg/L P (lb/day)		762	1,106	1,955	843	1,290	1,955
$sCOD_{supp\text{-}load,0.5\text{-}mgP/L,total}$	Supplemental sCOD for BNR to 0.5-mg/L P (lb/day)		863	1,259	2,381	944	1,443	2,381
$sCOD_{supp\text{-}conc,1\text{-}mgP/L,total}$	Supplemental sCOD for BNR to 1-mg/L P (mg/L)		38	36	23	42	42	23
$sCOD_{supp\text{-}conc,0.5\text{-}mgP/L,total}$	Supplemental sCOD for BNR to 0.5-mg/L P (mg/L)		43	41	28	47	47	28

Appendix B

Alum Dose and Sludge Production Calculation

Appendix B
Barrington WWTF Interim Phosphorus Removal Report

Table B-1. Chemical Phosphorus Removal Model
Scenario 1: With Alum Added ahead of Primary and Secondary Clarification

Variable	Description	Equation	Fixed Values	At Observed Average Flow	At DAF	At DMF
Q	Influent Flow Rate (mgd)	--	--	2.43	3.68	10.2
Primary Clarifier Influent Characteristics						
$P_{inf,load}$	Phosphorus Loading from Raw Influent (lb/day)			107	157	301
$P_{filtrate,load}$	Phosphorus Loading from Sludge Press Filtrate (lb/day)			37	51	127
$P_{backwash,load}$	Phosphorus Loading from Sand Filter Backwash (lb/day)			7	10	29
$P_{total,load}$	Total Phosphorus Loading (lb/day)			150	218	457
$P_{total,prim}$	Primary Influent Total Phosphorous Conc. (mg/L)	$P_{total,load} / Q$		7.4	7.1	5.4
$P_{part,prim}$	Primary Influent Particulate Phosphorous Conc. (mg/L)	$TSS_{prim} \times X_{P,TSS,prim}$		2.5	2.5	2.8
$P_{ortho,prim}$	Primary Influent Orthophosphate Conc. (mg-P/L)	$P_{total,prim} - P_{part,prim}$		4.9	4.6	2.6
TSS_{prim}	Primary Influent TSS Conc. (mg/L)			126	126	139
$X_{P,TSS,prim}$	Percent Phosphorous in Primary TSS		2.00%			
Primary Alum Dose Determination						
P_{ortho,res_1}	Primary Effluent Residual Orthophosphate Conc. (mg-P/L)		0.1			
(Al/P)	Aluminum-to-Phosphorus Molar Ratio		3			
$Al_{dose,prim}$	Primary Aluminum Dose (mg-Al/L)	$(Al/P)\ (P_{ortho,prim} - P_{ortho,res_1})\ (27\ g\text{-}Al/mol) / (31\ g\text{-}P/mol)$		12.5	11.7	6.5
Secondary Alum Dose Determination						
$P_{ortho,sec}$	Secondary Orthophosphate Influent Conc. (mg-P/L)	$P_{total,prim} - (P_{ortho,prim} - P_{ortho,res_1})$		2.6	2.6	2.9
TSS_{eff}	Effluent TSS Conc. (mg/L)		12			
$X_{P,TSS,eff}$	Percent Phosphorous in Effluent TSS		2.50%			
$P_{part,eff}$	Effluent Particulate Phosphorous Conc. (mg/L)		0.30			

Appendix B
Barrington WWTF Interim Phosphorus Removal Report

Table B-1. Chemical Phosphorus Removal Model
Scenario 1: With Alum Added ahead of Primary and Secondary Clarification

Variable	Description	Equation	Fixed Values	At Observed Average Flow	At DAF	At DMF
Dose for 1.0-mg/L Effluent Total Phosphorus						
$P_{total,limit}$	Effluent Total Phosphorus Limit (mg/L)		1.0			
$P_{ortho,eff}$	Target Effluent Orthophosphate (mg-P/L)	$P_{total,limit} - P_{part,eff}$	0.70			
(Al/P)	Aluminum-to-Phosphorus Molar Ratio		2			
$Al_{dose,sec}$	Secondary Aluminum Dose (mg-Al/L)	$(Al/P)\ (P_{ortho,sec} - P_{ortho,eff})\ (27\ g\text{-}Al/mol) / (31\ g\text{-}P/mol)$		3.3	3.3	3.8
$Al_{dose,total}$	Total Aluminum Dose	$Al_{dose,prim} + Al_{dose,sec}$		15.9	15.0	10.3
Dose for 0.5-mg/L Effluent Total Phosphorus						
$P_{total,limit}$	Effluent Total Phosphorus Limit (mg/L)		0.5			
$P_{ortho,eff}$	Target Effluent Orthophosphate (mg-P/L)	$P_{total,limit} - P_{part,eff}$	0.20			
(Al/P)	Aluminum-to-Phosphorus Molar Ratio		3			
$Al_{dose,sec}$	Secondary Aluminum Dose (mg-Al/L)	$(Al/P)\ (P_{ortho,sec} - P_{ortho,eff})\ (27\ g\text{-}Al/mol) / (31\ g\text{-}P/mol)$		6.3	6.3	7.0
$Al_{dose,total}$	Total Aluminum Dose (mg-Al/L)	$Al_{dose,prim} + Al_{dose,sec}$		18.8	18.0	13.5
Alum Requirements and Storage						
$(Al/alum)_{mass}$	Mass Percent Aluminum in Alum ($Al_2(SO_4)_3\ 14\ H_2O$)		9.08%			
ρ_{alum}	Bulk liquid alum density (lb/gal)		11.1			
$(Al/alum)_{bulk}$	Mass Percent Alum in Bulk Solution		50%			
Dose and Storage for 1.0-mg/L Effluent Total Phosphorus						
$Al_{dose,total,mass}$	Total Aluminum Dose, mass basis (lb-Al/day)	$Q \times Al_{dose,total}$		321	462	877
$Alum_{dose,total,mass}$	Total Alum Dose, mass basis (lb-Al/day)			3,538	5,083	9,660
$Alum_{dose,total,bulk}$	Total Alum Dose, bulk liquid (gal-alum/day)	$Alum_{dose,total,mass} / [\ (Al/alum)_{bulk} \times \rho_{alum}\ ]$		638	916	1,740
$V_{alum,10\text{-}d}$	10-day Supply of Alum (gallons)	$10\ days \times Alum_{dose,total,bulk}$		--	--	17,405
	Days of Alum Supply			27	19	10
Dose and Storage for 0.5-mg/L Effluent Total Phosphorus						
$Al_{dose,total,mass}$	Total Aluminum Dose, mass basis (lb-Al/day)	$Q \times Al_{dose,total}$		382	553	1,149
$Alum_{dose,total,mass}$	Total Alum Dose, mass basis (lb-Al/day)			4,203	6,089	12,655
$Alum_{dose,total,bulk}$	Total Alum Dose, bulk liquid (gal-alum/day)	$Alum_{dose,total,mass} / [\ (Al/alum)_{bulk} \times \rho_{alum}\ ]$		757	1,097	2,280
$V_{alum,10\text{-}d}$	10-day Supply of Alum (gallons)	$10\ days \times Alum_{dose,total,bulk}$		--	--	22,801

Appendix B
Barrington WWTF Interim Phosphorus Removal Report

Table B-1. Chemical Phosphorus Removal Model
Scenario 1: With Alum Added ahead of Primary and Secondary Clarification

Variable	Description	Equation	Fixed Values	At Observed Average Flow	At DAF	At DMF
Sludge Generation Effects						
Increased Primary Solids Removal Efficiency						
$R_{TSS,new}$	Assumed Primary TSS Removal with Alum (%)		75%			
$R_{TSS,old}$	Current Primary TSS Removal without Alum (%)		53%			
$M_{TSS,prim,new}$	Increase in Primary Solids Removal (dry lb/day)	$(R_{TSS,new} - R_{TSS,old})\ TSS_{prim}\ Q$		572	867	2,642
$(Al/P)_{stoich}$	Stoichiometric Al per P removed (mol-Al/mol-P)		0.8			
MW_{precip}	Assumed MW of alum-phosphate precipitate (g/mol)		142			
MW_{excess}	MW of excess alum precipitate ($Al(OH)_3$) (g/mol)		78			
Chemical Primary Sludge Production						
$Al_{dose,prim,molar}$	Primary Aluminum Dose (mmol-Al/L)	$Al_{dose,prim}$ / (27 g-Al/mol)		0.464	0.433	0.242
$\Delta P_{ortho,prim}$	Primary Orthophosphate Removal (mg-P/L)	$P_{ortho,prim} - P_{ortho,res_1}$		4.8	4.5	2.5
$\Delta P_{ortho,prim,molar}$	Primary Orthophosphate Removal (mol-P/L)	$\Delta P_{ortho,prim}$ / (31 g-P/mol)		0.155	0.144	0.081
$Al_{dose,prim,stoich}$	Stoichiometric Primary Alum Dose (mmol-Al/L)	$(Al/P)_{stoich}\ x\ \Delta P_{ortho,prim,molar}$		0.124	0.115	0.064
$Al_{dose,prim,excess}$	Excess Primary Alum Dose (mmol-Al/L)	$Al_{dose,prim,molar} - Al_{dose,prim,stoich}$		0.340	0.318	0.177
X_{Al-P}	Alum-phosphate Sludge Production (mg/L)	$\Delta P_{ortho,prim,molar}\ x\ MW_{precip}$		22	20	11
$X_{Al(OH)3}$	Excess Alum Precipitate ($Al(OH)_3$) Production (mg/L)	$Al_{dose,prim,excess}\ x\ MW_{excess}$		27	25	14
$X_{Al,total}$	Total Chemical Sludge Production (mg/L)	$X_{Al-P} + X_{Al(OH)3}$		48	45	25
$P_{X,Al,total}$	Total Chemical Sludge Production (dry lb/day)	$Q\ X_{Al,total}$		982	1,389	2,150
$\Delta P_{X,TSS,prim}$	Total increase in primary sludge production (dry lb/day)	$M_{TSS,prim,new} + P_{X,Al,total}$		1,554	2,256	4,792
	Current primary sludge production (dry lb/day)			1,341	2,033	5,820
	Increase over current (%)			116%	111%	82%

Appendix B
Barrington WWTF Interim Phosphorus Removal Report

Table B-1. Chemical Phosphorus Removal Model
Scenario 1: With Alum Added ahead of Primary and Secondary Clarification

Variable	Description	Equation	Fixed Values	At Observed Average Flow	At DAF	At DMF
Change in Biomass Production from Aeration Basin						
$R_{BOD,new}$	Assumed Primary BOD5 Removal with Alum (%)		50%			
$R_{BOD,old}$	Current Primary BOD5 Removal without Alum (%)		30%			
Y_{obs}	Observed Yield in Aeration Basin (lb-VSS/lb-BOD)		0.28			
S_{inf}	Raw Influent BOD5 (mg/L)			135	135	93
S_{new}	Primary Effluent BOD5 with Alum (mg/L)	$S_{inf}\ (1 - R_{BOD,new})$		67	67	47
S_{old}	Primary Effluent BOD5 without Alum (mg/L)	$S_{inf}\ (1 - R_{BOD,old})$		95	95	65
S_{eff}	Secondary Effluent BOD5 (mg/L)		10			
$P_{X,new}$	Solids production with Alum (lb-VSS/day)	$Y_{obs}\ (S_{new} - S_{eff})\ Q$		325	493	871
$P_{X,old}$	Solids production without Alum (lb-VSS/day)	$Y_{obs}\ (S_{old} - S_{eff})\ Q$		479	726	1,317
$\Delta P_{X,VSS}$	Change in Solids production (lb-VSS/day)	$P_{X,new} - P_{X,old}$		-154	-233	-446
$\Delta P_{X,TSS,WAS}$	Change in BioSolids production (lb-TSS/day)	$\Delta P_{X,VSS} / 0.85$		-181	-274	-525
Chemical Secondary Sludge Production at 1.0-mg/L Eff. P						
$Al_{dose,sec,molar}$	Secondary Aluminum Dose (mmol-Al/L)	$Al_{dose,sec} / (27\ g\text{-}Al/mol)$		0.124	0.124	0.140
$\Delta P_{ortho,sec}$	Secondary Orthophosphate Removal (mg-P/L)	$P_{ortho,sec} - P_{ortho,eff}$		1.9	1.9	2.2
$\Delta P_{ortho,sec,molar}$	Secondary Orthophosphate Removal (mol-P/L)	$\Delta P_{ortho,prim} / (31\ g\text{-}P/mol)$		0.062	0.062	0.070
$Al_{dose,sec,stoich}$	Stoichiometric Secondary Alum Dose (mmol-Al/L)	$(Al/P)_{stoich}\ x\ \Delta P_{ortho,sec,molar}$		0.050	0.050	0.056
$Al_{dose,sec,excess}$	Excess Secondary Alum Dose (mmol-Al/L)	$Al_{dose,sec,molar} - Al_{dose,sec,stoich}$		0.074	0.074	0.084
$X_{Al\text{-}P}$	Alum-phosphate Sludge Production (mg/L)	$\Delta P_{ortho,sec,molar}\ x\ MW_{precip}$		9	9	10
$X_{Al(OH)3}$	Excess Alum Precipitate ($Al(OH)_3$) Production (mg/L)	$Al_{dose,sec,excess}\ x\ MW_{excess}$		6	6	7
$X_{Al,total}$	Total Chemical Sludge Production (mg/L)	$X_{Al\text{-}P} + X_{Al(OH)3}$		15	15	16
$\Delta P_{X,Al,sec}$	Total Secondary Chemical Sludge Production (dry lb/day)	$Q\ X_{Al,total}$		295	448	1,403

Appendix B
Barrington WWTF Interim Phosphorus Removal Report

Table B-1. Chemical Phosphorus Removal Model
Scenario 1: With Alum Added ahead of Primary and Secondary Clarification

Variable	Description	Equation	Fixed Values	At Observed Average Flow	At DAF	At DMF
Chemical Secondary Sludge Production at 0.5-mg/L Eff. P						
$Al_{dose,sec,molar}$	Secondary Aluminum Dose (mmol-Al/L)	$Al_{dose,sec}$ / (27 g-Al/mol)		0.234	0.234	0.258
$\Delta P_{ortho,sec}$	Secondary Orthophosphate Removal (mg-P/L)	$P_{ortho,sec} - P_{ortho,eff}$		2.4	2.4	2.7
$\Delta P_{ortho,sec,molar}$	Secondary Orthophosphate Removal (mol-P/L)	$\Delta P_{ortho,prim}$ / (31 g-P/mol)		0.078	0.078	0.086
$Al_{dose,sec,stoich}$	Stoichiometric Secondary Alum Dose (mmol-Al/L)	$(Al/P)_{stoich} \times \Delta P_{ortho,sec,molar}$		0.062	0.062	0.069
$Al_{dose,sec,excess}$	Excess Secondary Alum Dose (mmol-Al/L)	$Al_{dose,sec,molar} - Al_{dose,sec,stoich}$		0.172	0.172	0.190
X_{Al-P}	Alum-phosphate Sludge Production (mg/L)	$\Delta P_{ortho,sec,molar} \times MW_{precip}$		11	11	12
$X_{Al(OH)3}$	Excess Alum Precipitate ($Al(OH)_3$) Production (mg/L)	$Al_{dose,sec,excess} \times MW_{excess}$		13	13	15
$X_{Al,total}$	Total Chemical Sludge Production (mg/L)	$X_{Al-P} + X_{Al(OH)3}$		24	24	27
$\Delta P_{X,Al,sec}$	Total Secondary Chemical Sludge Production (dry lb/day)	$Q \; X_{Al,total}$		496	751	2,298
Summary of Sludge Generation Effects at 1.0-mg/L Effluent P						
$\Delta P_{X,TSS,prim}$	Total increase in primary sludge production (dry lb/day)			1,554	2,256	4,792
$\Delta P_{X,TSS,WAS}$	Change in BioSolids production (lb-TSS/day)			-181	-274	-525
$\Delta P_{X,Al,sec}$	Total Secondary Chemical Sludge Production (dry lb/day)			295	448	1,403
$\Delta P_{X,total}$	Net Change in Sludge Production (dry lb/day)	$\Delta P_{X,TSS,prim} + \Delta P_{X,TSS,WAS} + \Delta P_{X,Al,sec}$		1,668	2,430	5,671
	Current Solids Production Rate (dry lb/day)			1,971	2,663	6,449
	Increase Over Current (%)			85%	91%	88%
Summary of Sludge Generation Effects at 0.5-mg/L Effluent P						
$\Delta P_{X,TSS,prim}$	Total increase in primary sludge production (dry lb/day)			1,554	2,256	4,792
$\Delta P_{X,TSS,WAS}$	Change in BioSolids production (lb-TSS/day)			-181	-274	-525
$\Delta P_{X,Al,sec}$	Total Secondary Chemical Sludge Production (dry lb/day)			496	751	2,298
$\Delta P_{X,total}$	Net Change in Sludge Production (dry lb/day)	$\Delta P_{X,TSS,prim} + \Delta P_{X,TSS,WAS} + \Delta P_{X,Al,sec}$		1,868	2,734	6,566
	Current Solids Production Rate (dry lb/day)			1,971	2,663	6,449
	Increase Over Current (%)			95%	103%	102%

Appendix C

MSDSs for Chemical Phosphorus Removal Precipitants

Material Safety Data Sheet

SECTION 1 – CHEMICAL PRODUCT AND COMPANY INFORMATION

Product Name: Ferric Chloride Solution **Chemical Family:** Inorganic Iron Salt

Manufacturer's Name: Evoqua Water Technologies - Municipal Services Business Unit
Address: 2650 Tallevast Road, Sarasota, FL 34243
Product/Technical Information Phone Number: 1.941.355.2971
Medical/Handling Emergency Phone Number: CHEMTREC 1.800.424.9300
24 hours a day
Transportation Emergency Phone Number: CHEMTREC 1.800.424.9300
24 hours a day

Issue Date: November 2005
Revision Number / Date: Rev 4 January 2014

SECTION 2 – COMPOSITION INFORMATION

Chemical Name	Percent by Weight	CAS#
Ferric Chloride	39-47	7705-08-0
Hydrochloric Acid	<0.5	7647-01-0
Water	Balance	7732-18-5

SECTION 3 – HAZARDS IDENTIFICATION

Appearance & Odor: Reddish-brown liquid with slightly acidic odor.

Emergency Overview: Corrosive! Contact with the liquid, mists, or vapors will burn and may cause severe injury, including death.

Fire & Explosion Hazards: During a fire, irritating/toxic hydrogen chloride and phosgene gas may be generated. Ferric chloride reacts with most metals to give flammable, potentially explosive hydrogen gas. Hydrogen gas can accumulate to explosive concentrations inside confined spaces.

Primary Route(s) of Exposure: Skin and eye contact, ingestion and inhalation.

Inhalation – Acute Effects: Irritation to mucous membranes, difficulty breathing.

Skin Contact – Acute Effects: Irritation and possibly burns.

Eye Contact – Acute Effects: Irritation and possibly burns.

Ingestion – Acute Effects: Irritation of the mouth and stomach. Symptoms of severe poisoning include stomach pain, vomiting, diarrhea, dehydration, shock, pallor, weak pulse, drowsiness, dilated pupils, and coma.

SECTION 4 – FIRST AID MEASURES

Inhalation First Aid: If symptoms are experienced, move victim to fresh air. Give artificial respiration ONLY if breathing has stopped. Do not use mouth-to-mouth method if victim ingested or inhaled the substance; induce artificial respiration with the aid of a pocket mask equipped with a one-way valve or other proper respiratory medical device. Obtain medical attention IMMEDIATELY.

Skin Contact First Aid: IMMEDIATELY flush skin with running water for at least 15 minutes while removing contaminated clothing. Get IMMEDIATE medical attention.

Eye Contact First Aid: Immediately flush eyes with running water for at least 20 minutes, occasionally lifting upper and lower lids, until no evidence of chemical remains. Obtain medical attention IMMEDIATELY.

Ingestion First Aid: If swallowed, DO NOT INDUCE VOMITING. Give large quantities of water. Never give anything by mouth to an unconscious person. Loosen tight clothing such as a collar, tie, belt, or waistband. Seek IMMEDIATE medical attention.

Note to Physician: For inhalation, consider oxygen. Avoid gastric lavage or emesis. Repeated dosage may cause hemosiderosis with possible damage to the liver and pancreas.

SECTION 5 – FIRE FIGHTING MEASURES

Flash Point/Method: Not applicable.

Auto Ignition Temperature: Not applicable.

Upper/Lower Explosion Limits: Not applicable.

Extinguishing Media: Water spray, fog, or regular foam appropriate for surrounding material. Cool any exposed containers with water.

Fire Fighting Procedures: As with any fire, fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode. Move exposed containers from fire area if it can be done without risk. Use water to keep fire-exposed containers cool.

Fire & Explosion Hazards: During a fire, irritating/toxic hydrogen chloride and phosgene gas may be generated. Ferric chloride reacts with most metals to give flammable, potentially explosive hydrogen gas. Hydrogen gas can accumulate to explosive concentrations inside confined spaces.

Hazardous Products of Decomposition and/or Combustion: Hydrogen chloride, hydrogen, phosgene.

NFPA Ratings: HEALTH - 3 FLAMMABILITY- 0 REACTIVITY - 1

SECTION 6 – ACCIDENTAL RELEASE MEASURES

Restrict access to area until completion of clean up. Ensure trained personnel conduct clean up. Wear adequate personal protective equipment. **DO NOT TOUCH SPILLED MATERIAL.** Stop leak if possible without personal risk.

Small Spills: Absorb spill with sand or non-combustible dry material and collect in appropriate container for disposal. Flush area with water.

Large Spills: Prevent entry into sewers and confined areas. Dike if possible. Keep unnecessary people away, isolate hazard area, and deny entry. Absorb spill with sand or non-combustible dry material and collect in appropriate container for disposal. Flush area with water.

DO NOT DUMP ON THE GROUND OR INTO ANY BODY OF WATER. All disposal methods must be in compliance with all Federal, State, Local and Provincial laws, and regulations. Regulations may vary in different locations. Waste characterizations and compliance with applicable laws are the responsibility solely of the waste generator.

SECTION 7 – HANDLING AND STORAGE

Handling: Store in corrosion-proof area. Containers of this material may be hazardous when empty, since they retain product residues (vapors, liquid); observe all warnings and precautions listed for the product. Use FRP or PVC pipes.

Storage: Store in tightly closed container, preferably the supplier container. Do not store in metal containers. Fiberglass, plastic, or rubber lined tanks may be used for storage. Protect from damage. Keep dry. Read the label before use. Keep separated from incompatible substances.

SECTION 8 – PERSONAL PROTECTION/ EXPOSURE CONTROL

Respiratory Protection: Under conditions of frequent use or heavy exposure, respiratory protection may be needed.

Skin Protection: Wear impervious protective clothing, including boots, gloves, lab coat, apron, or coveralls as appropriate to prevent skin contact.

Eye Protection: Wear splash resistant chemical goggles and a full face shield if splashing is possible. Maintain eye wash fountain and quick-drench facilities in work area.

Ventilation Protection: A ventilation system of local and/or general exhaust is recommended.

Other Protection: Safety showers, with quick opening valves which stay open, and eye wash fountains, or other means of washing the eyes with a gentle flow of cool to tepid water, should be readily available in all areas where this material is handled or stored. Water should be supplied through insulated and heat-traced lines to prevent freeze-ups in cold weather.

Exposure Limits: Exposure limits have not been established for this product. However, for some ingredients:

Soluble iron salts:	Hydrochloric acid:
OSHA PEL – 1 mg/m3 (as Fe)	OSHA PEL – 5 ppm (Ceiling)
ACGIH: TLV - 1 mg/m^3 (as Fe)	ACGIH TLV – 2 ppm (Ceiling)

SECTION 9 – PHYSICAL AND CHEMICAL PROPERTIES

Appearance & Odor: Reddish-brown liquid with slightly acidic odor.

Vapor Pressure: 40 (mm Hg at 20ºC)

Vapor Density (Air=1): Not applicable

Boiling Point: 106ºC (223ºF)

Melting Point: Not applicable

Specific Gravity: 1.47

Solubility in Water: 100%

Volatile Percentage: Not applicable

pH: less than 1

Flash Point/method: Not applicable

Auto Ignition Temperature: Not applicable

SECTION 10 – STABILITY AND REACTIVITY

Stability: Stable at normal temperatures and pressure

Incompatibilities: Metals, bases (alkaline materials), halocarbons, acids, and combustible materials. Forms shock sensitive explosive mixtures with some metals (e.g. potassium; sodium).

Polymerization: Will not occur.

Decomposition: Thermal decomposition: hydrochloric acid. Contact with metals may evolve flammable hydrogen gas. Container may explode when heated.

Conditions to Avoid: Heat, flames, sparks, and other sources of ignition. Dangerous gases may accumulate in confined spaces. May ignite or explode on contact with combustible materials.

SECTION 11 – TOXICOLOGICAL INFORMATION

Chronic Effects: Repeated dosage may cause hemosiderosis with possible damage to the liver and pancreas.

Toxicological Data: Ferric Chloride Solid (anhydrous) Oral LD_{50} (rat) = 450 mg/kg.

Carcinogenicity/Mutagenicity: Ferric chloride is not classified as carcinogenic by ACGIH (American Conference of Governmental Industrial Hygienists) or IARC (International Agency for Research on Cancer), not regulated as carcinogens by OSHA (Occupational Safety and Health Administration), and not listed as carcinogens by NTP (National Toxicology Program).

Reproductive Effects: TDLo Rat 1 day (intratesticular) 12976 µg/kg; TDLo Rat 1 day (intravaginal) 29/mg/kg pre pregnancy continuous.

Target Organs: No data.

SECTION 12 – ECOLOGICAL INFORMATION

Ecotoxicological Information: TLm Daphnia 15 ppm/96 hr fresh water / Conditions of bioassay not specified.

Persistence and Degradation: No data available

SECTION 13 – DISPOSAL CONSIDERATIONS

Material that cannot be used or chemically reprocessed and empty containers should be disposed of in accordance with all applicable regulations. Product containers should be thoroughly emptied before disposal. Generators of waste material are required to evaluate all waste for compliance with RCRA and any local disposal procedures and regulations.
NOTE: State and local regulations may be more stringent than federal regulations.

SECTION 14 – TRANSPORTATION INFORMATION

DOT Shipping Description: Ferric Chloride Solution
Hazard Class/Division: 8 - corrosive liquid
UN Number: UN2582
Packing Group: II

SECTION 15 – REGULATORY INFORMATION

OSHA: Hazardous as a Corrosive Liquid - 29 CFR 1920.1200
CERCLA: Hazardous substance - reportable quantity (RQ) = 1000 lb. (454 kg)
SARA Regulations: 313 and 40 CFR 372: N
SARA Hazard Categories, SARA Sections 311/312 (40 CFR 370.21):

Acute:	Y	
Chronic:	N	OSHA Process Safety (29 CFR 1910.119): N
Fire:	N	
Reactive:	N	
Sudden Release:	N	

Clean Water Act Requirements: Designated as a hazardous substance under section 311(b)(2)(A) of the Federal Water Pollution Control Act and further regulated by the Clean Water Act Amendments of 1977 and 1978. These regulations apply to discharges of this substance.

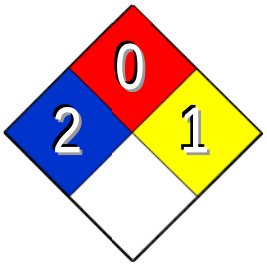
TSCA Inventory Status: Y
California Proposition 65: N
Right-To-Know Lists: Massachusetts, New Jersey, Pennsylvania, California. This product does not contain, nor is it manufactured with ozone-depleting substances.

SECTION 16 – OTHER INFORMATION

Disclaimer: The information contained herein is based on data considered accurate. However, no warranty is expressed or implied regarding the accuracy of these data or the results to be obtained from the use thereof. It is the buyer's responsibility to ensure that its activities comply with federal, state, provincial, and local laws.

Revision Indicator: Legal Entity name change 01/16/14

MATERIAL SAFETY DATA SHEET

NFPA	HMIS	PPE	Symbol(s)
			Regulated

Current Issue Date: February 18, 2014	Revision Number: 1

1. PRODUCT AND COMPANY IDENTIFICATION

Product Name:	**Liquid Alum**
Other/Generic Names:	Aluminum Sulfate, Alum, Alun 48, Aluminum Sulphate 48%
Recommended Use:	Water treatment. Various industrial uses.
Manufacturer:	Chemtrade Solutions LLC 90 East Halsey Road Parsippany, NJ 07054 Chemtrade Chemicals Canada Ltd. 90 East Halsey Road Parsippany, NJ 07054
For More Information:	Customer Service US ONLY: 800-631-8050 (Monday – Friday 9:00AM – 4:30PM) Customer Service CANADA ONLY: 866-543-3896 (Monday – Friday 9:00AM – 4:30PM)
Emergency Telephone Number:	US ONLY - CALL CHEMTREC: 800-424-9300 (24 Hours/Day, 7 Days/Week) OUTSIDE THE US – CALL CHEMTREC: 1-703-527-3887 (24 Hours/Day, 7 Days/Week) CANADA ONLY - CALL CANUTEC: 613-996-6666 (24 Hours/Day, 7 Days/Week)

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW: A clear, light green or amber liquid with a negligible odor. Can irritate the skin and eyes. May be harmful if swallowed. Not flammable, but may release toxic vapors if decomposed in a fire.

OSHA Status:	This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200)
<u>Potential Health Affects</u>	
Skin:	May cause skin irritation.
Eyes:	May strongly irritate or burn the eyes.
Inhalation:	Product mists may cause irritation to the respiratory tract.
Ingestion:	May irritate the gastrointestinal tract. Concentrated solutions may cause burns to the digestive tract.
Delayed Effects:	None known.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Component	CAS No	Weight %
Aluminum sulfate	10043-01-3	~48.5 (dry basis)
Water	7732-18-5	Balance

4. FIRST AID MEASURES

Eye Contact	Immediately flush eyes with water for at least 15 minutes. Get medical attention if irritation persists.
Skin Contact	Flush with plenty of water, removing contaminated clothing. If irritation develops, get medical attention.
Inhalation	Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get prompt medical attention.
Ingestion	Do not induce vomiting. Immediately give large quantities of water. Get medical attention immediately.
Notes to Physician	Treat symptomatically

5. FIRE-FIGHTING MEASURES

Flammable Properties

FLASH POINT:	Not Flammable
FLASH POINT METHOD:	Not Applicable
AUTOIGNITION TEMPERATURE:	Not Applicable
UPPER FLAME LIMIT (VOLUME % IN AIR):	Not Applicable
LOWER FLAME LIMIT (VOLUME % IN AIR):	Not Applicable
FLAME PROPAGATION RATE (SOLIDS):	Not Applicable
OSHA FLAMMABILITY CLASS:	Not Applicable
SUITABLE EXTINGUISHING MEDIA:	Water spray, foam, carbon dioxide or dry chemical
UNSUITABLE EXTINGUISHING MEDIA:	No information available

Explosion Limits

Hazardous Combustion Products	No information available
Impact sensitivity	No information available
Sensitivity to static discharge	No information available
Specific Hazards Arising from the Chemical	Keep product and empty container away from heat and sources of ignition.
Protective Equipment and Precautions for Firefighters	Wear self-contained breathing apparatus (SCBA) and full protective equipment. Use water spray to keep containers cool.

6. ACCIDENTAL RELEASE MEASURES

IN CASE OF SPILL OR OTHER RELEASE	Dilute small spills or leaks cautiously with plenty of water. Neutralize any further residue with alkali such as soda ash, lime or limestone. Adequate ventilation is required if soda ash or limestone is used, because of the consequent release of carbon dioxide gas. Large spills should be diked up with soda ash and neutralized as above. Collect liquid and/or residue and dispose of in accordance with applicable regulations.

7. HANDLING AND STORAGE

Handling	Keep container tightly closed when not in use. Avoid contact with skin, eyes, and clothing. Avoid breathing vapors or mists. Remove contaminated clothing and wash thoroughly after handling.
Storage	Keep storage container tightly closed. Store in a cool, dry, well-ventilated area or cabinet. Isolate from incompatible substances. Store and ship in plastic or rubber-lined containers.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Component	ACGIH TLV	OSHA PEL	Ontario TWAEV	Mexico OEL (TWA)	NIOSH IDLH
Aluminum sulfate	2 mg/m^3	2 mg/m^3		TWA: 2 mg/m^3	

Engineering Measures	Use local exhaust to keep airborne concentrations below the permissible exposure limits.

Personal Protective Equipment

Eye/Face Protection	Wear hard hard (or other head covering) and chemical safety goggles. Do not wear contact lenses.
Skin Protection	Wear appropriate personal protective clothing to prevent skin contact. If prolonged or repeated contact is anticipated, all clothing should be impervious to liquid.
Respiratory Protection	A respiratory protection program that meets OSHA 1910.134 and ANSI Z88.2 or applicable federal/provincial requirements must be followed whenever workplace conditions warrant respirator use. NIOSH's "Respirator Decision Logic" may be useful in determining the suitability of various types of respirators.
General Hygiene Considerations	To identify additional Personal Protective Equipment (PPE) requirements, it is recommended that a hazard assessment in accordance with the OSHA PPE Standard (29CFR 1910.132) be conducted before using this product. Eyewash and safety showers are recommended.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance	Clear, light green or amber liquid
Color	Clear, light green or amber
Chemical Formula	~48.5% $Al_2(SO_4)_3$ $14H_2O$ in water
Odor	None
Odor Threshold	No information available
Physical State	Liquid
pH	2.0-2.4
Flash Point	Not flammable
Autoignition Temperature	Not applicable
Boiling Point/Range	101 ^{o}C / 214 ^{o}F
Melting Point/Range	-16°C /4°F
Flammability Limits in Air	No information available
Explosive Properties	No information available
Oxidizing Properties	No information available
Evaporation Rate	Not determined
Vapor Pressure	Not applicable
Vapor Density	Not applicable
Specific Gravity	1.335
Partition Coefficient (n-octano/water)	No information available
Viscosity	No information available
Molecular Weight	594 for $Al_2(SO_4)_3$ $14H_2O$
Water Solubility	100%
VOC Content (%)	0

10. STABILITY AND REACTIVITY

Chemical Stability	Normally stable. If evaporated to dryness, residue should not be exposed to elevated temperatures (above 760°C), as this will yield toxic and corrosive gases.
Incompatible Products	Alkalis and water reactive materials such as oleum: causes exothermic reactions.
Hazardous Decomposition Products	At elevated temperatures, sulfur oxides may be formed. These are toxic and corrosive and are oxidizers. Sulfur trioxide is also a fire hazard. The loss of these gases leaves a caustic residue.
Possibility of Hazardous Reactions	Will not occur.

11. TOXICOLOGICAL INFORMATION

Acute Toxicity

Component Information

Component	LD50 Oral	LD50 Dermal	LC50 Inhalation
Aluminum sulfate	1930 mg/kg (rat) 6207 mg/kg (mouse		

Irritation No information available
Corrosivity No information available
Sensitization No information available

Chronic Toxicity
Carcinogenicity There are no known carcinogenic chemicals in this product.
Mutagenic Effects No information available
Reproductive Effects No information available
Developmental Effects No information available
Teratogenicty No information available
Target Organ Effects No information available
Other Adverse Effects No information available
Endocrine Disruptor Information No information available

12. ECOLOGICAL INFORMATION

Ecotoxicity
Contains no substances known to be hazardous to the environment or not degradable in waste water treatment plants.

Component	Freshwater Algae	Freshwater Fish	Microtex	Water Flea
Aluminum sulfate		LC50 = 100 mg/L Carassius auratus 96 h LC50 = 37 mg/L Gambusia affinis 96 h		EC50 = 136 mg/L 15 min

Persistence and Degradability No information available
Bioaccumulation No information available
Mobility in Environmental Media No information available
Other adverse affects **Aluminum sulfate component:**
14 ppm/36 hr/fundulus/fatal/fresh water; 240 ppm/48 hr/mosquito fish/TLm/water type not specified; TLm Mosquito fish, 235 ppm, 96 hours; LC50 Largemouth bass, 250 ppm, 96 hours

13. DISPOSAL CONSIDERATIONS

Waste Disposal Methods Dispose of waste in accordance with all federal, state, and local regulations.
Contaminated Packaging Empty containers should be taken for local recycling, recovery or waste disposal.

14. TRANSPORT INFORMATION

DOT Regulated
Proper Shipping Name Corrosive liquid, acidic, inorganic, n.o.s. (contains aluminum sulfate)
Hazard Class 8
UN-No UN3264
Packing Group PGIII

TDG Regulated
Hazard Class 8
UN-No UN3264
Packing Group PGIII

15. REGULATORY INFORMATION

International Inventories

TSCA	Yes
DSL	Yes
ELINCS	No
EINECS	Yes
ENCS	Yes
CHIINA	Yes
KECL	Yes
PICCS	Yes
AICS	Yes

U.S. Federal Regulations

SARA 313

Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA). This product contains the following chemicals which are subject to the reporting requirements of the Act and Title 40 of the Code of Federal Regulations, Part 372: None

SARA 311/312 Hazardous Categorization

Chronic Health Hazard	No
Acute Health Hazard	Yes
Fire Hazard	No
Sudden Release of Pressure Hazard	No
Reactive Hazard	No

Clean Water Act

Component	CWA – Reportable Quantities	CWA – Toxic Pollutants	CWA – Priority Pollutants	CWA – Hazardous Substances
Aluminum sulfate	5000 lb			X

CERCLA

Component	CERCLA RQ (lb)	SARA TPQ (lb)
Aluminum sulfate	5000 lb	

U.S. State Regulations

California Proposition 65

This product does not contain any Proposition 65 chemicals.

State Right-to-Know

Component	Massachusetts	New Jersey	Pennsylvania	Illinois	Rhode Island
Aluminum sulfate	X	X	X		

Other International Regulations

Mexico	No information available
Canada	This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all the information required by the CPR.

WHMIS Hazard Class	
E Corrosive material	
D2B Toxic materials	

16. OTHER INFORMATION

Current Issue Date:	February 18, 2014
Previous Issue Date:	November 30, 2012
Revision Summary:	New Chemtrade Template

Disclaimer:

All information, statements, data, advice and/or recommendations, including, without limitation, those relating to storage, loading/unloading, piping and transportation (collectively referred to herein as "information") are believed to be accurate and reliable. However, no representation or warranty, express or implied, is made as to its completeness, accuracy, fitness for a particular purpose or any other matter, including, without limitation, that the practice or application of any such information is free of patent infringement or other intellectual property misappropriation. Chemtrade Logistics Inc. and its affiliates (collectively, "Chemtrade") are not engaged in the business of providing technical, operational, engineering or safety information for a fee, and, therefore, any such information provided herein has been furnished as an accommodation and without charge. All information provided herein is intended for use by persons having requisite knowledge, skill and experience in the chemical industry. Chemtrade shall not be responsible or liable for the use, application or implementation of the information provided herein, and all such information is to be used at the risk, and in the sole judgment and discretion, of such persons, their employees, advisors and agents.

End of MSDS

MATERIAL SAFETY DATA SHEET

ClearPAC

Section 01 - Chemical And Product And Company Information

Product Identifier ……... ClearPAC

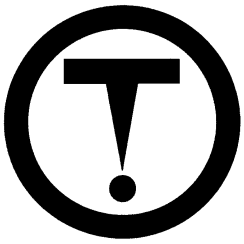
Product Use …….....Drinking water treatment

Supplier Name…….…. ClearTech Industries Inc.
2302 Hanselman Avenue
Saskatoon, SK. Canada
S7L 5Z3

Prepared By.....…….….. ClearTech Industries Inc. Technical Department
Phone: (306)664-2522

Preparation Date.....…….…. December 14, 2009

24-Hour Emergency Phone…….. 306-664-2522



Section 02 - Composition / Information on Ingredients

Hazardous Ingredients....……..... Polyhydroxyl aluminum chloride 25-40%

CAS Number.....……..... Polyhydroxyl aluminum chloride 1327-41-9

Synonym (s).....……...Poly aluminum chloride

CLEARTECH

Section 03 - Hazard Identification

Inhalation..... Product does not readily for a vapour, so inhalation is only likely to occur if a mist is formed. Irritation of respiratory tract may result from mist exposure.

Skin Contact / Absorption..... Direct contact can cause irritation & possible corrosive burning.

Eye Contact..... Severely irritating to the eyes.

Ingestion..... Ingestion can cause corrosive burns to mouth, throat, esophagus. Small amounts of product which enter the lungs during ingestion or vomiting can cause serious lung injury and death.

Exposure Limits..... ACGIH/TLV-TWA: 2mg/m^3 (as Al)

Section 04 - First Aid Measures

Inhalation..... Remove victim to fresh air. Give artificial respiration only if breathing has stopped. If breathing is difficult, give oxygen. Seek immediate medical attention.

Skin Contact / Absorption..... Remove contaminated clothing. Wash affected area with soap and water. Seek medical attention if irritation occurs or persists

Eye Contact..... Flush immediately with water for at least 20 minutes. Forcibly hold eyelids apart to ensure complete irrigation of eye tissue. Seek immediate medical attention

Ingestion..... Do not induce vomiting. If vomiting occurs, lean victim forward to prevent breathing in vomitus. Give large amounts of water. Do not give anything by mouth to an unconscious or convulsing person. Seek immediate medical attention.

Additional Information..... Not available

Section 05 - Fire Fighting

Conditions of Flammability..... Non-flammable

Means of Extinction..... Does not burn or support combustion. Use extinguishing agents suitable for surrounding fire.

Flash Point.....Not applicable

Auto-ignition Temperature.....Not applicable

Upper Flammable Limit .....Not applicable

Lower Flammable Limit.....Not applicable

Hazardous Combustible Products... Hydrochloric acid fumes

Special Fire Fighting Procedures..... Wear NIOSH-approved self-contained breathing apparatus and protective clothing.

Explosion Hazards.....None

Section 06 - Accidental Release Measures

Leak / Spill.....Wear appropriate personal protective equipment. Ventilate area. Stop or reduce leak if safe to do so. Prevent material from entering sewers.

Deactivating Materials.....Neutralize with alkaline material. Dilute solutions of soda ash, lime, or limestone. Note that carbon dioxide may form as a result, ensure area has proper ventilation.

Section 07 - Handling and Storage

Handling Procedures.....Use proper equipment for lifting and transporting all containers. Use sensible industrial hygiene and housekeeping practices. Wash thoroughly after handling. Avoid all situations that could lead to harmful exposure.

Storage Requirements.....Ideal storage temperatures should be 10-35°C in a well ventilated area. Store away from incompatibles. Keep storage area separate from populated work areas. Do not store in containers made of aluminum, magnesium, zinc, copper.

Section 08 - Personal Protection and Exposure Controls

Protective Equipment

Eyes.....Chemical goggles, full-face shield, or a full-face respirator is to be worn at all times when product is handled. Contact lenses should not be worn; they may contribute to severe eye injury.

Respiratory……... Respiratory protection is not normally required. If use creates vapours, mists, or aerosols, then a NIOSH-approved respirator with a dust/mist cartridge is recommended.

Gloves……..... Impervious gloves of chemically resistant material (rubber or PVC) should be worn at all times. Wash contaminated clothing and dry thoroughly before reuse.

Clothing……..……..... Body suits, aprons, and/or coveralls of chemical resistant material should be worn at all times. Wash contaminated clothing and dry thoroughly before reuse.

Footwear……..... Impervious boots of chemically resistant material should be worn at all times.

Engineering Controls

Ventilation Requirements……..... Mechanical ventilation (dilution or local exhaust), process or personnel enclosure and control of process conditions should be provided. Supply sufficient replacement air to make up for air removed by exhaust systems.

Other……..... Emergency shower and eyewash should be in close proximity.

Section 09 - Physical and Chemical Properties

Physical State.....……...……... Liquid

Odor and Appearance…..……... Clear, odourless, colourless liquid

Odor Threshold...……..... Not available

Specific Gravity (Water=1)…….. 1.22-1.26

Vapor Pressure (mm Hg, 20C)…….. Not available

Vapor Density (Air=1)..……..... Not available

Evaporation Rate.....……..…….. Not available

Boiling Point.....…….…..... 105°C

Freeze/Melting Point....……..... -20°C

pH.....…….…. 2.2-2.8

Water/Oil Distribution Coefficient.... Not available

Bulk Density..... Not available

% Volatiles by Volume..... Not available

Solubility in Water..... Hydrolyses

Molecular Formula..... Complex mixture

Molecular Weight..... Not applicable. Mixture.

Section 10 - Stability and Reactivity

Stability..... Normally stable.

Incompatibility..... Avoid contact with strong alkalis, strong acids, oxidizers, zinc, aluminum, and hydro-reactive materials.

Hazardous Products of Decomposition.. May liberate sulphur, aluminum oxides, hydrogen chloride, and chlorine when boiled to dryness or heated above 200°C.

Polymerization..... Will not occur

Section 11 - Toxicological Information

Irritancy..... Mild irritant

Sensitization..... Not a sensitizer

Chronic/Acute Effects..... Repeated & prolonged exposure of the skin to low concentrations of liquid can cause dermititis. Does not accumulate in the body.

Synergistic Materials..... None reported

Animal Toxicity Data..... LD_{50}(rat,oral): > 5000mg/kg

Carcinogenicity..... Not considered to be carcinogenic by NTP, IARC, and OSHA.

Reproductive Toxicity..... Not available

Teratogenicity..... Not available

Mutagenicity..... Not available

CLEARTECH

Section 12 - Ecological Information

Fish Toxicity..... Not available

Biodegradability..... Not available

Environmental Effects..... Stop or reduce leak if safe to do so. Prevent from entering sewers or waterways by dyking with inert materials. Contact with lead pipes may lead to increased lead content.

Section 13 - Disposal Consideration

Waste Disposal..... Dispose in accordance with all federal, provincial, and/or local regulations including the Canadian Environmental Protection Act.

Section 14 - Transportation Information

TDG Classification

Class..... 8

Group..... II

PIN Number..... UN 3264

Other..... Secure containers (full and/or empty) with suitable hold down devises during shipment.

Section 15 - Regulatory Information

WHMIS Classification.....D2, E

NOTE: THE PRODUCT LISTED ON THIS MSDS HAS BEEN CLASSIFIED IN ACCORDANCE WITH THE HAZARD CRITERIA OF THE CANADIAN CONTROLLED PRODUCTS REGULATIONS. THIS MSDS CONTAINS ALL INFORMATION REQUIRED BY THOSE REGULATIONS

NSF Certification.....Product is certified under NSF/ANSI Standard 60 for coagulation and flocculation at a maximum dosage of 250mg/L.

Section 16 - Other Information

Note: The responsibility to provide a safe workplace remains with the user. The user should consider the health hazards and safety information contained herein as a guide and should take those precautions required in an individual operation to instruct employees and develop work practice procedures for a safe work environment. The information contained herein is, to the best of our knowledge and belief, accurate. However, since the conditions of handling and use are beyond our control, we make no guarantee of results, and assume no liability for damages

incurred by the use of this material. It is the responsibility of the user to comply with all applicable laws and regulations.

Attention: Receiver of the chemical goods / MSDS coordinator

As part of our commitment to the Canadian Association of Chemical Distributors (CACD) Responsible Distribution® initiative, ClearTech Industries Inc. and its associated companies require, as a condition of sale, that you forward the attached Material Safety Data Sheet(s) to all affected employees, customers, and end-users. ClearTech will send any available supplementary handling, health, and safety information to you at your request.

If you have any questions or concerns please call our customer service or technical service department.

ClearTech Industries Inc. - Locations

Corporate Head Office: 2302 Hanselman Avenue, Saskatoon, SK, S7L 5Z3
Phone: 306-664-2522
Fax: 306-665-6216

www.ClearTech.ca

Location	Address	Postal Code	Phone Number	Fax Number
Richmond, B.C.	12431 Horseshoe Way	V7A 4X6	604-272-4000	604-272-4596
Calgary, AB.	5516E - 40th St. S.E.	T2C 2A1	403-279-1096	403-236-0989
Edmonton, AB.	11750 - 180th Street	T5S 1N7	780-452-6000	780-452-4600
Saskatoon, SK.	2302 Hanselman Avenue	S7L 5Z3	306-933-0177	306-933-3282
Regina, SK.	555 Henderson Drive	S42 5X2	306-721-7737	306-721-8611
Winnipeg, MB.	340 Saulteaux Crescent	R3J 3T2	204-987-9777	204-987-9770
Mississauga, ON.	7480 Bath Road	L4T 1L2	905-612-0566	905-612-0575

24 Hour Emergency Number - All Locations - 306-664-2522