REPORT

Phosphorus Optimization Plan & Phosphorus Treatment Feasibility Study

Prepared for

City of West Chicago

October 1, 2017

ch2m

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Executive Summary

Water discharges from water reclamation facilities in the state of Illinois are regulated by the Illinois Environmental Protection Agency (IEPA). The IEPA has been working with wastewater agencies in the state for several years on the development and implementation of phosphorus removal limits to be included in the state's discharge permits. The state does not currently regulate phosphorus discharges, but IEPA is looking to develop a reasonable technology based limit for incorporation in all state discharge permits.

The City of West Chicago (the City) owns the West Chicago Regional Wastewater Treatment Plant (WWTP). In the most recent discharge permit, the City was required to complete a Phosphorus Removal and Optimization Feasibility Study. This study looked to develop the capital and operating cost impacts for the West Chicago WWTP for the following three potential technology based limits:

- Potential Limit 1: 1.0 mg/L
- Potential Limit 2: 0.5 mg/L
- Potential Limit 3: 0.1 mg/L

Currently, the West Chicago WWTP removes approximately 1.1 mg/L of phosphorus in the existing treatment processes (Figure ES-1). Additional treatment components are required to further reduce this phosphorus concentration to any of the three potential discharge limits.

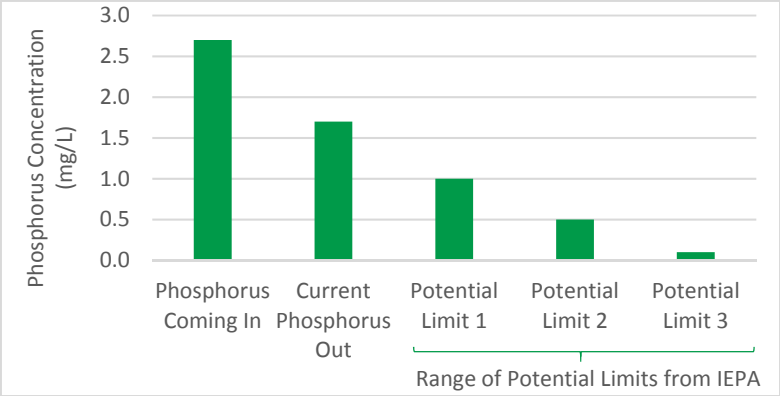

Figure ES-1. Current Phosphorous Concentrations

At the West Chicago WWTP, 2.7 mg/L of phosphorus is currently coming into the facility, and 1.6 mg/L remains after treatment; IEPA is requiring West Chicago to develop cost estimates for implementing three potential limits.

Site-specific capital and operating costs were developed to upgrade the West Chicago WWTP to achieve each of the potential IEPA limits. These costs are summarized in Table ES-1. These costs are associated with constructing biological phosphorus removal (BPR) treatment components and the addition of chemicals to bind phosphorus. West Chicago has done an admirable job in investing in infrastructure that will prepare the WWTP to remove more phosphorus, such as the recent improvements to filter facilities. This wise investment reduces the capital requirements to achieve all three potential limits. In addition, due to the potential energy savings associated with a BPR process, the annual operating cost increase is projected to be less than 10 percent for Potential Limit 1.

Table ES-1. Estimated Capital and Operating Costs for Achieving the Three Potential IEPA Limits

	Capital Cost Requirement[a]	Annual Operating Cost[b]
Current Operation	-	$0.26 M
Potential Limit 1	$1.8 M	$0.27 M
Potential Limit 2	$1.8 M	$0.27 M
Potential Limit 3	$1.8 M	$0.33 M

[a]*All improvements will also necessitate capital improvements to the aeration system that are currently in the Capital Improvements Plan.*
[b]*Annual cost related to aeration, chemical addition, and biosolids production*

It is recommended that West Chicago plan on implementing BPR for compliance with future IEPA compliance. By selecting a biological-based solution, and participating in the DuPage River Salt Creek Water Group, the timeline for implementation of phosphorus removal is extended for the City of West Chicago until October 1, 2026.

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Acronyms and Abbreviations

AO	Anoxic-Oxic Process
A^2O	Anaerobic, Anoxic, Oxic Process
BNR	biological nutrient removal
BOD	biochemical oxygen demand
BPR	biological phosphorus removal
COD	chemical oxygen demand
CIP	Capital Improvements Plan
City	City of West Chicago
DO	dissolved oxygen
gpm	gallon(s) per minute
IEPA	Illinois Environmental Protection Agency
lbs/day	pound(s) per day
ISS	inorganic suspended solids
mg/L	milligram(s) per liter
mgd	million gallon(s) per day
MLSS	mixed liquor suspended solids
NH3	ammonia
NPDES	National Pollution Discharge Elimination System
OHO	ordinary heterotrophic organisms
RAS	return activated sludge
scfm	standard cubic feet per minute
SND	simultaneous nitrification and denitrification
TKN	total Kjeldahl nitrogen
TSS	total suspended solids
TP	total phosphorus
TWAS	thickened waste activated sludge
SRT	solids retention time
SWD	side water depth
VFA	volatile fatty acids
VSS	volatile suspended solids
WWTP	wastewater treatment plant
WAS	waste activated sludge

SECTION 1

Background

Under the terms of the October 1, 2015 Illinois Environmental Protection Agency (IEPA) National Pollution Discharge Elimination System (NPDES) permit for the West Chicago Regional Wastewater Treatment Plant (WWTP), Special Condition 18 requires that a written Phosphorus Discharge Optimization Plan be prepared and submitted to the IEPA prior to October 1, 2017. In developing the plan, the City of West Chicago (City) is required to evaluate a range of measures for reducing phosphorus discharges from the WWTP, including possible source reduction measures, operational improvements, and minor low-cost facility modifications that will optimize reduction in phosphorus discharges from the WWTP. Permit Special Condition 18 also requires that a feasibility study be done to evaluate the costs and requirements to achieve phosphorus effluent limits of 1.0 milligram per liter (mg/L), 0.5 mg/L and 0.1 mg/L. This report presents the results of the optimization plan and the feasibility study. The City has flexibility with how the recommended improvements are incorporated, as the City is a participating member of the DuPage River Salt Creek Workgroup. Participating in this workgroup provides the following implementation schedules for the City:

- If chemical phosphorus removal is implemented, improvements must be complete by October 1, 2025 to achieve a 1.0-mg/L effluent phosphorus limitation.
- If biological phosphorus removal (BPR) is implemented, improvements must be completed by October 1, 2026 to achieve a 1.0-mg/L effluent phosphorus limitation.

This extended timeline gives the City the opportunity to implement a phased approach to completion of recommended improvements. Therefore, as part of this evaluation, potential phasing steps will be developed for the recommended alternative.

SECTION 2

Existing Facility

2.1 NPDES permit

The current NPDES permit (No. IL0023469) under which the WWTP operates has an average design flow of 7.64 million gallons per day (mgd) and a maximum design flow of 20.3 mgd. It also has a monthly average Total Phosphorus limit of 64 pounds per day (lbs/day) to be measured 3 times per week via 24-hour composite. This amounts to 1.0 mg/L phosphorous during average design flow. However, this effluent limit is dependent on the City completing the tasks associated with Special Condition 18 in the permit. As long as the City is in compliance with the specified items listed in Special Condition 18, a phosphorus limit will not be in effect until 2025 or 2026, depending on the selected phosphorus removal technology. If the City chose not to complete the items listed in Special Condition 18, it would be required to meet the 1 mg/L effluent discharge immediately. The main requirements of Special Condition 18 are completion of this Phosphorus Removal Optimization Plan and participation in the DuPage River Salt Creek Workgroup.

This NPDES discharge permit became effective on October 1, 2015, was modified and reissued on December 13, 2016, and expires September 30, 2020. Effluent requirements from the NPDES permit are listed in Table 2-1.

Table 2-1. NPDES Limits for Nutrients at Design Average Flow of 7.64 mgd

Parameter	Average (lbs/day), (mg/L)	Daily Maximum (lbs/day), (mg/L)	Sample Frequency, Type
Orthophosphate, as P	Monitor	--	1/month, composite
Total Phosphorus, as P	64, 1.0	--	3/week, composite Implementation timeline depending on complying with Special Condition 18
Ammonia, March, as N	147, 2.3	510, 8.0	3/week, composite
Ammonia, April-October, as N	96, 1.5	191, 3.0	3/week, composite
Ammonia, November -February, as N	255, 4.0	510, 8.0	3/week, composite
Nitrate/Nitrite, as N	Report	--	1/month, composite
Total N, as N	Report	--	1/month, composite

2.2 Plant Description

The West Chicago WWTP is a conventional activated sludge plant. Bar screens and aerated grit tanks provide preliminary treatment. Liquids treatment consists of primary clarifiers, aeration basins, secondary clarifiers, and filtration followed by chlorine disinfection and dechlorination prior to discharge to the East Branch of the DuPage River. The tertiary sand filters were recently converted to disc filters. Solids treatment consists of gravity belt thickening of waste activated sludge (WAS) (which replaced the original dissolved air flotation process), mesophilic anaerobic digestion of combined primary sludge and thickened WAS, and belt filter presses for dewatering. An aerial of the plant is shown on Figure 2-1. A process flow diagram is presented on Figure 2-2. Table 2-2 presents major process unit quantities and sizing.

Figure 2-1. Aerial of West Chicago Wastewater Treatment Plant
Source: Google Earth, 2017

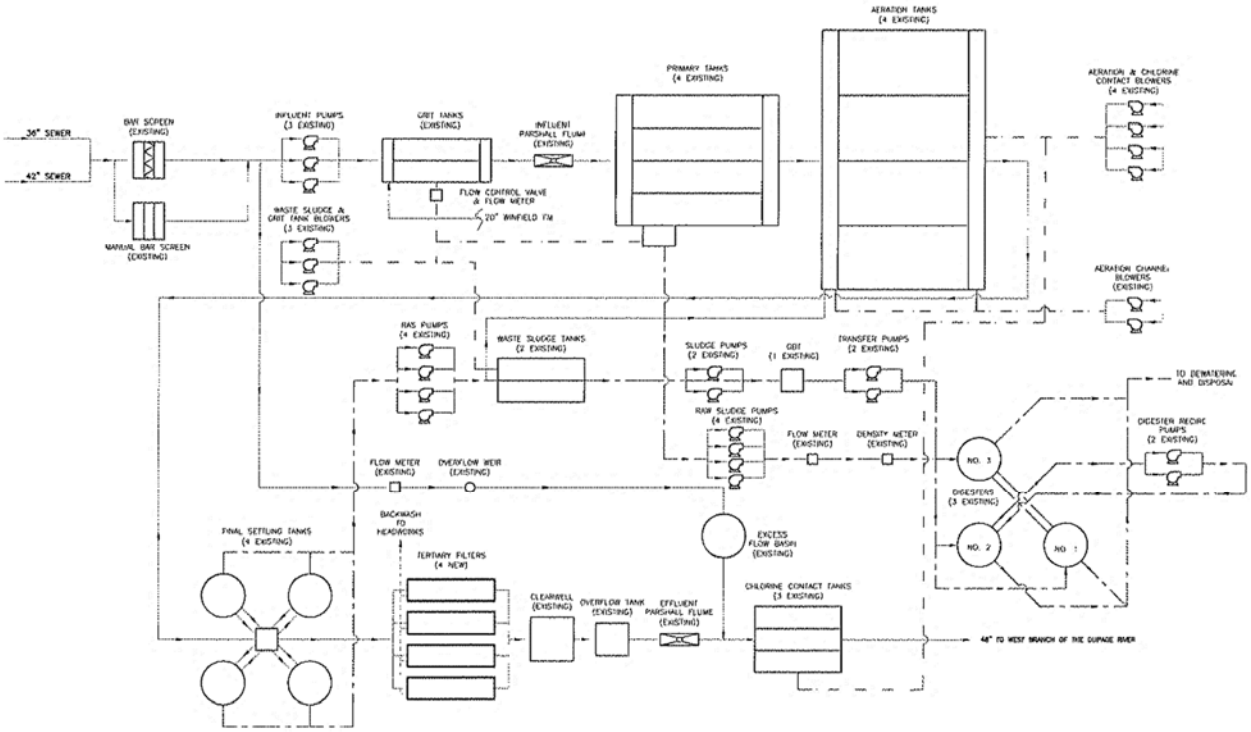

Figure 2-2. Wastewater Treatment Plant Process Flow Diagram

Table 2-2. Major Unit Process Details

Process	Quantity, dimensions	Comments
Aerated Grit Chambers	Four grit chambers; each 40 feet x 8 feet x 8 feet SWD; each volume of 19,150 gallons	Typically, only one online
Rectangular Primary Clarifiers	Four primary clarifiers; each 116 feet x 31 feetx 7.7 feet SWD; each surface area of 3,600 ft^2	Typically, only three online
Aeration Basins	Four basins; each 174'x 50'x18' SWD; each volume of 1.174 million gallons	Typically, all four online; historical dissolved oxygen (DO) setpoint ~ 6.0 mg/L
Blowers	Four Roots blowers; each 2,000 scfm	Typically, only wo online
Circular Secondary Clarifiers	Four secondary clarifiers; each 85 feet in diameter, 12 feet SWD	Typically, only three online; historically ~ 50% return activated sludge (RAS) rate
Waste Sludge Tanks		Coarse bubble aeration
Gravity Belt Thickeners	Two, 2m GBTs; each 500 gallons per minute (gpm) hydraulic capacity, 1,320 pounds per hour solids loading capacity	Typically, 95% capture, 4% TWAS solids concentration; typically, 8 hours per day
Belt Filter Press Dewatering	Two, 2m BFPs; each 80 gpm hydraulic capacity; 2,000 pounds per hour solids loading capacity	Typically, 95% capture, 15% solids concentration, typically, both units online, 5 hours per day
Mesophilic Anaerobic Digestion	Three digesters; two primary, one secondary, 55 feet in diameter, 34 feet depth max. each active volume 0.506 million gallons	Typically, one primary offline

2.3 Historical Data

Three years of plant influent data (January 1, 2014 through December 31, 2016) were analyzed to determine how frequently flow and load exceeds average values, and by how much. The plant collects 24-hour composite samples 3 times per week to monitor biochemical oxygen demand (BOD), total suspended solids (TSS), ammonia expressed in units of elemental nitrogen (NH3-N), and total phosphorus expressed in units of elemental phosphorus (TP-P). To remove questionably high or low values that could be the result of sampling or analytical uncertainty, the influent loads were calculated and data screened to exclude greater than or less than 1.5 times the inner quartile range (75th percentile minus the 25th percentile values). The average of this daily load data, as well as un-screened flow data, was deemed representative of average daily conditions, while the maximum value was considered for the maximum day condition. The maximum of the 30-day rolling average was determined to be the maximum month condition. These flows and loads are presented in Table 2-3.

Table 2-3. Current Flows and Loads Based on 3-Years of Historical Data

		Average Annual	Maximum Month	Maximum Day
Flow	mgd	5.9	8.9	19.9
COD	lbs/day	15,510	20,170	28,180
BOD	lbs/day	8,730	13,110	17,620
TSS	lbs/day	6,170	7,840	10,470
Ammonia - N	lbs-N/day	740	880	1,070
Total - P	lbs-P/day	135	175	210

COD = chemical oxygen demand

2.4 Wastewater Constituent Relationships

The ratios between various constituents in the raw influent establish a reference for various process considerations. These ratios are presented in Table 2-4. The NH_4:TKN ratio indicates the form of nitrogen coming into the plant. The COD:BOD ratio indicates the amount of the organic matter that is biodegradable. The TSS:BOD ratio indicates the solids content and quality of wastewater. The VSS:TSS ratio identifies the amount of ISS in TSS as the difference between VSS and TSS. The TP:BOD ratio is an indicator of how much carbon is available for BPR. The more readily biodegradable carbon in the form of VFAs or fermentable soluble BOD that can be quickly converted to VFAs, the greater potential there is for efficient BPR. The TKN:BOD ratio is an indicator of the plant's ability to denitrify, as it demonstrates how much carbon is available for nitrate reduction. If the TKN:BOD value is too high, supplemental carbon is usually required to sufficiently denitrify.

Table 2-4. Raw Influent Ratios

Period	NH4:TKN	COD:BOD	TSS:BOD	TP:BOD	TKN:BOD
Average of 12 Days Where Everything was Measured	NA	1.7	0.82	0.017	NA
3-year Average	NA	NA	0.74	NA	NA
Typical Domestic Wastewater (M&E, 2003)	0.67	2.0-2.2	0.6-1.2	0.035	0.12-0.24

NA = Historical data of associated parameters was not available in sufficient frequency to determine relationships; for these values typical industry values were utilized

2.5 Plant Performance

The average loads and constituent relationships presented above should be considered with caution. The plant experiences wide swings in influent quality that have a seasonal influence. Figure 2-3 shows the of seasonal variation of influent BOD on mixed liquor suspended solids (MLSS) concentration and WAS solids production.

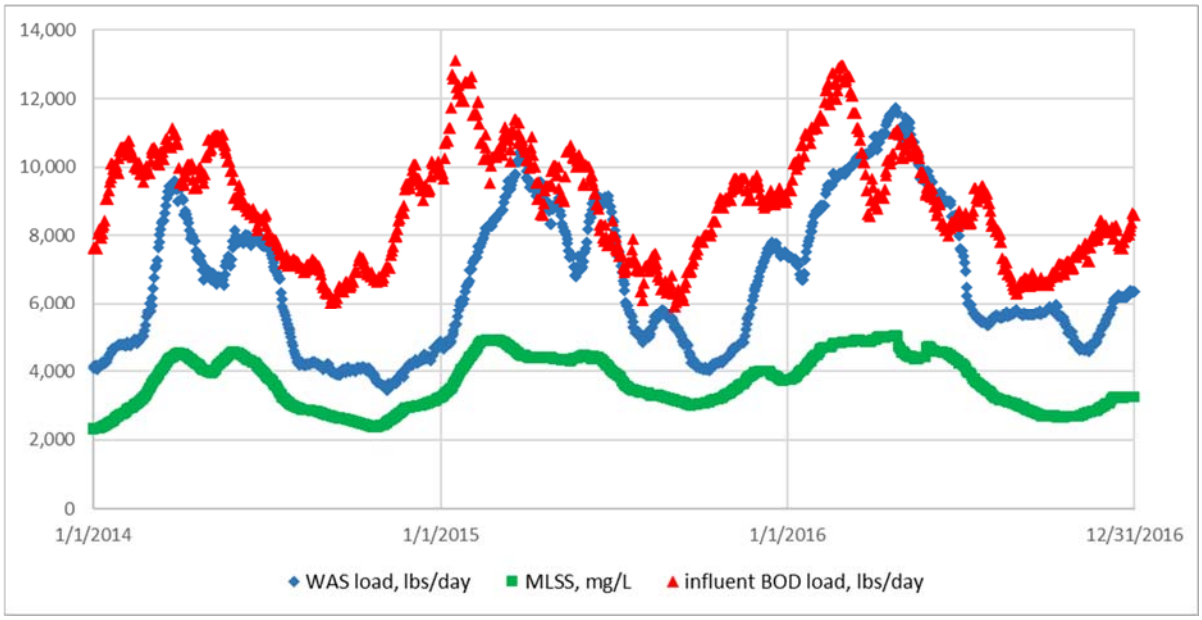

Figure 2-3. WWTP 30-day Rolling Averages of Influent BOD Load, WAS Load, and MLSS Concentration

SECTION 3

Phosphorus Reduction and Optimization

As part of the planning process for phosphorus removal, IEPA requires an evaluation of phosphorus loads for potential reduction and optimization. The goal of this requirement is to identify if a WWTP has an influent phosphorus concentration that is significantly higher than typical for domestic wastewater. If higher than domestic concentrations are not present, there is likely minimal opportunity to achieve decreases in phosphorus loading through source reduction strategies.

3.1 Influent Phosphorus Sources

In anticipation of future phosphorus regulations, the City began measuring influent phosphorus in 2014. This monitoring was implemented to ensure that the City had sufficient data to better understand potential variation in influent phosphorus concentration, and whether a significant industrial input of phosphorus may be present. During this time, the facility's influent phosphorus load averaged 2.74 mg/L. This is a typical concentration for a WWTP treatment domestic wastewater. The sources of the influent phosphorus load are commercial, residential and industrial sources. These concentrations and loads are typical for a wastewater facility the size of West Chicago's.

The City is currently conducting a survey of industrial dischargers to determine which industries potentially contribute to phosphorus loadings and the specific practices (e.g., manufacturing byproducts, cleaning operations) that could be altered to reduce phosphorus loadings. For example, it may be possible for dischargers to substitute non-phosphorus based cleaners to reduce the phosphorus loading to the plant. In the second stage of this survey, the survey will be revised, businesses that are not identified as significant phosphorus dischargers will be removed from the list, and samples will be collected from the identified high-phosphorus dischargers.

3.2 Reduction Potential of Influent Phosphorus Sources

Reduction of high phosphorus loads from commercial or industrial sources can be a cost-effective method to reduce phosphorus effluent concentrations for some communities. For West Chicago, the influent phosphorus concentrations are near typical for a domestic wastewater facility. This suggests that there is not likely to be single large contributors of phosphorus to the WWTP, which reduces the likelihood of significant reductions in phosphorus being realized through source reduction. However, there are still advantages to proactively discussing phosphorus sources and exploring the use of phosphorus free cleaning alternatives with industrial users that discharge to the WWTP to help reduce influent phosphorus loads.

3.3 Industry-Specific Phosphorus Minimization and Water Conservation Plans

WWTP staff will continue to work with individual industries to determine whether they can reduce their phosphorus loadings. However, there does not appear to be the potential for significant reductions in industrial contributions.

3.4 Local Phosphorus Limit Implementation

If it is found that industrial and commercial sources could reduce their phosphorus loadings, the City will consider implementing local limits on phosphorus or a voluntary reduction program.

SECTION 4

Phosphorus Treatment Facility

4.1 Wastewater Characterization

For evaluating the feasibility of enhanced BPR, it is important to characterize the COD, nitrogen, and phosphorus fractions of the raw influent wastewater. COD is the base unit of measurement of all carbonaceous components in wastewater, accounting for biodegradable, non-biodegradable, soluble, and particulate components. The characterization of what enters the plant not only determines what can be degraded and therefore what passes through the plant, it also determines what is returned to the front of the plant from sidestream processes. While parameter concentrations of domestic wastewater may vary from day to day and month to month, the fractionation of those parameters are assumed to remain constant over time because the sources and types of contribution within a collection system are constant and are thus constants in the model.

For more detailed studies requiring a higher level of process model calibration, short duration, rigorous sampling campaigns are conducted at a plant to get high-resolution data on influent, primary effluent, sidestream, and final effluent data to increase understanding of both influent constituents as well as wastewater fractions, sometimes refined down to hourly measurements. For the WWTP, only historically measured parameters from daily composite samples were available. These values were used in a fractionation estimation tool to be used for this exercise. Estimated and typical values are presented in Table 4-1. This level of detail is commensurate with the accuracy required for the current feasibility study.

Table 4-1. Influent Fractions

Name	Typical %	WWTP %
VSS Fraction of TSS	85	80
Filtered COD Fraction (incl. colloids, VFA)	40.5	50.0
Filtered Flocculated COD Fraction (incl. VFA)	20.2	25.0
VFA Fraction of Filtered COD	11.8	12.8
Unbiodegradable Filtered COD Fraction	11.8	12.8
Influent Particulate Inert COD Fraction	14.0	14.0
Influent Heterotrophic Fraction of COD	5.0	5.0
Influent Endogenous Products Fraction of OHOs	20	20
Unbiodegradable Fraction of Influent Colloids	20	20
Ammonia Fraction of TKN	69.8	70.0
Phosphate Fraction of TP	58.1	50.0
N Fraction of Filtered Biodegradable COD	4	4.0
P Fraction of Filtered Biodegradable COD	1	1.0

4.2 Process Model Development

The use of a process model is critical to understanding the chemical and biological reaction rates that would be required to meet effluent phosphorus limitations. The ability of any model to accurately represent reality depends on the quality of the inputs. Measuring conditions at a WWTP is arguably the most challenging part of the exercise. Wastewater treatment facilities are highly dynamic—they have many moving parts, variable influent, and both continuous and intermittently operated processes. There is also uncertainty inherent to sampling and analysis. Early stage efforts often raise questions about where better data are needed when discrepancies appear between plant data and model results. Explanations for such discrepancies can often be deduced, which not only improves the understanding of the plant but increases the reliability and value of the model.

The level of calibration depends on the objectives. High-level modeling exercises are excellent tools for planners, engineers, and operators. They provide a complete picture of relative process performance. They can indicate when and where sampling, analysis, and even data entry may be biased or erroneous. They can demonstrate behavior related to dynamic conditions or changes in operation. Most valuably, they provide the ability to evaluate relative differences between proposed treatment alternatives and future flow and load scenarios.

Using the process sizes from Table 2-2, the average annual influent from Table 2-3, estimated influent fractions from Table 4-1, and other parameters based on historical performance (Table 4-2), a configuration was built in SUMO (Figure 4-1), a commercially available wastewater process simulation software, and a steady state simulation was completed.

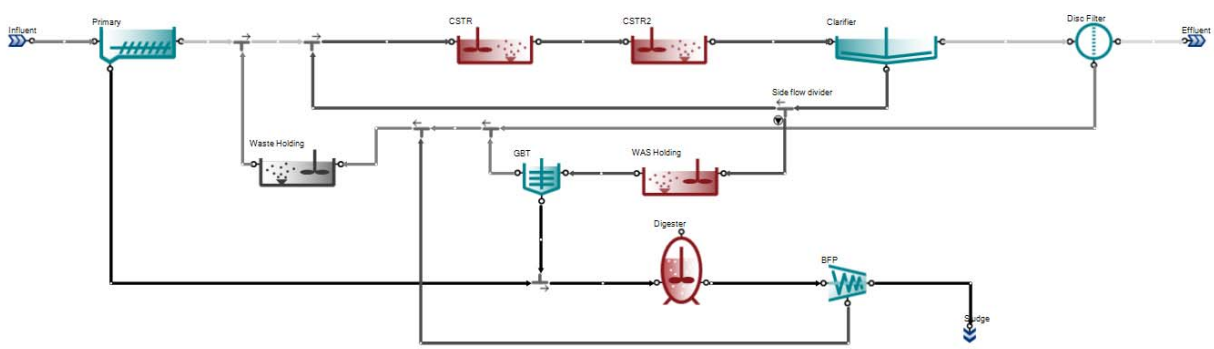

Figure 4-1. Sumo Schematic of the Existing Process Units

Table 4-2. Operating Inputs Based on Historical 3-Year Averages

Parameter	Plant Data (3-year average)
Primary Clarifier % Removal	52%
Primary Sludge Concentration, %	3.5%
Temperature, C	15
Aeration Basin SRT, Days	16
Aeration Basin DO, mg/L	5.0
RAS Rate, % of Influent	76%
MLSS, mg/L	3600
Cake, % solids	15.6%
Cake, Dry tons/day	2.67

4.3 Alternatives Analysis

Four alternative process configurations and operational changes were evaluated using the SUMO simulation software based on the high-level calibration effort presented above that would allow the plant to reduce effluent phosphorus to consistently meet potential future permit limits of 1 mg/L, 0.5 mg/L and 0.1 mg/L at average and maximum month conditions. The alternatives evaluated are described below:

Alternative 1: Chemical Phosphorus Removal – A chemical precipitation method in which a chemical (e.g., ferric chloride, aluminum sulfate or polyaluminum chloride) is dosed to wastewater, causing destabilization of suspended (including colloidal) particles through charge neutralization and results in the binding of phosphorus compounds. Solids particles collide causing cohesion and floc particle growth, which increase in density and settle out of suspension. The solids, which contain phosphorus, are removed from the treatment process through the wasting of secondary sludge. The efficiency of full chemical removal can be improved by using an online phosphate analyzer and by monitoring flow when dosing metal salts.

For the WWTP, chemical addition would consist of dosing ferric chloride or alum to the channel that sends secondary clarifier effluent to the disk filters. This channel has a hydraulic residence time of only a few minutes, but with the addition of mixers this channel will provide sufficient coagulation and flocculation time to generate metal hydroxide flocs for the adsorption and removal of orthophosphate. An enclosed heated chemical building would be required for housing the pumping and delivery system, and a heat-traced storage tank would be required. This tank would be sized for 30-days of chemical storage at average flow conditions. Figure 4-2 provides a process flow diagram for chemical addition, assuming ferric chloride is used. No changes would be made to the aeration basins. Figure 4-3 shows the location of the building, storage tank, and mixers in the secondary effluent channel.

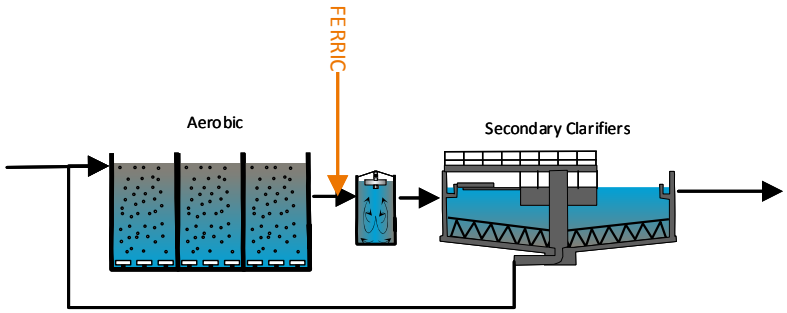

Figure 4-2. Process Flow Diagram of Chemical Addition

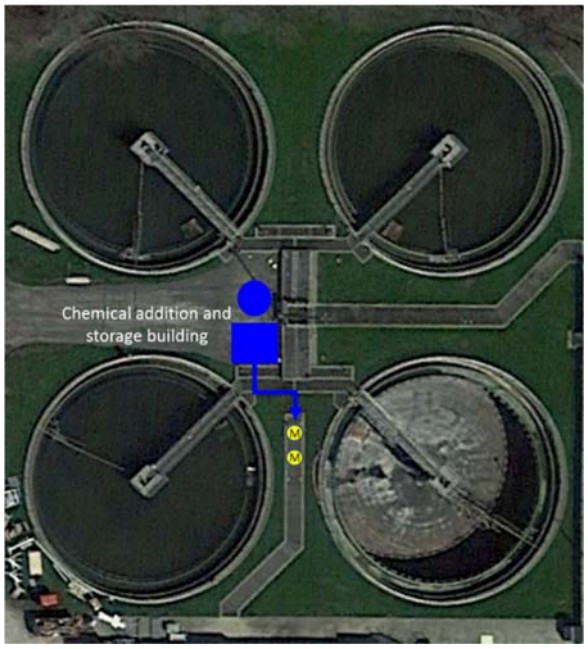

Figure 4-3. Proposed Modifications to Implement Chemical Addition

Alternative 2: Anoxic-Oxic (AO) Process (BPR 1) – A BPR process; this basic process uses an Anaerobic selector zone prior to a traditional activated sludge aerobic (Oxic) zone. A portion of the activated sludge is returned to the head of the aeration basin and mixed with influent wastewater before entering the anaerobic zone. Within the anaerobic zone, biomass uptakes readily biodegradable COD (rbCOD) and releases orthophosphate from stored polyphosphate granules into the surrounding wastewater. Upon entering the aerobic zone, biomass utilizes the stored rbCOD and rapidly uptakes phosphorus in excess of metabolic needs, storing it again as polyphosphate. Phosphorus is removed from the liquid treatment process through the wasting of secondary sludge. Figure 4-4 provides a process flow diagram for the AO process. Figure 4-5 shows proposed modifications required to implement AO in two parallel trains within the four existing aeration basins. Note that this process configuration provides increased operational flexibility and stability by having parallel, multiple pass configurations. Additional alternatives were evaluated that utilized a single baffle wall and a reduced number of mixers, but that configuration limited the flexibility to take basins offline for maintenance activities. A key component of the AO process evaluation was the inclusion of low DO conditions in the aeration basins to select for simultaneous nitrification and denitrification (SND). This simplified the construction of the facility.

Figure 4-4. AO Process Configuration

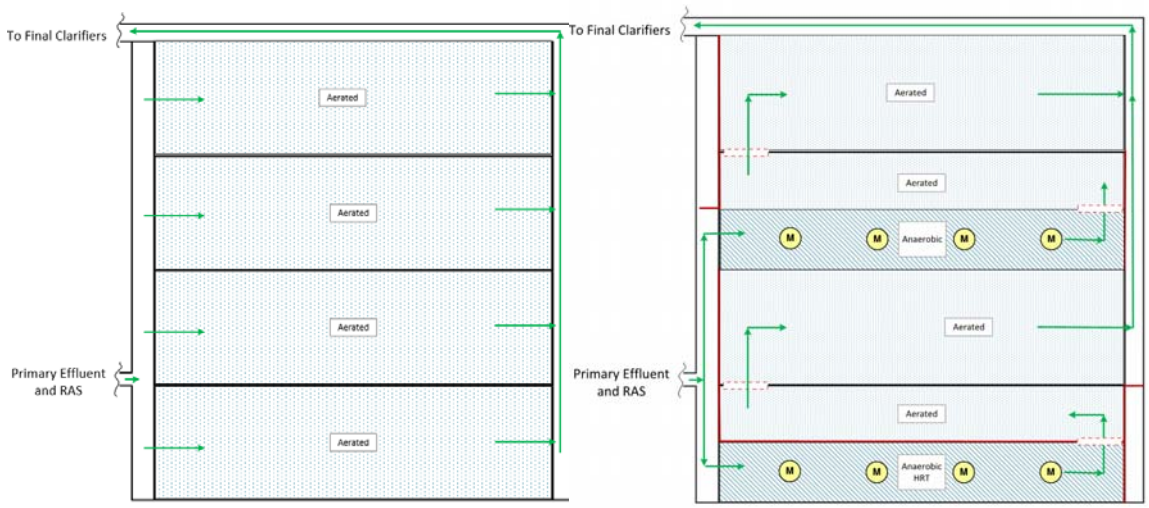

Figure 4-5. Existing Aeration Basin (left) and Proposed Modifications to the Existing Aeration Basins to Implement an AO Process (right)

Alternative 3: Anaerobic, Anoxic, Oxic Process (A2O) Process (BPR 2) – A BPR process; this process uses both an Anaerobic (no nitrate, no oxygen) selector zone and an Anoxic (no oxygen, but with nitrate) selector zone prior to a traditional activated sludge aerobic (Oxic) zone. A portion of the activated sludge is returned to the head of the aeration basin and mixed with influent wastewater before entering the anaerobic zone. Within the anaerobic zone, biomass uptakes readily biodegradable COD (rbCOD) and releases phosphorus stored as polyphosphate into the surrounding wastewater. Denitrification occurs in the anoxic zone with nitrate being converted to nitrogen gas. Upon entering the aerobic zone, biomass utilizes the stored rbCOD and rapidly uptakes phosphorus more than metabolic needs. Because the WWTP is required to nitrify to comply with the NPDES permit for effluent ammonia, nitrate is produced. Nitrate can interfere with the efficiency of BPR by utilizing carbon for denitrification rather than BPR. To account for increased nitrate, the A^2O process also includes an internal mixed liquor recycle, whereby nitrified mixed liquor is recycled to the anoxic zone, where denitrification can occur. The addition of the mixed liquor recycle subsequently reduces nitrate concentrations in the return activated sludge which will be recycled to the anaerobic zone.

Wastewater solids containing phosphorus are removed from the treatment process through the wasting of secondary sludge. Both biological phosphorus removal and biological nitrogen removal are achieved through the A^2O process. Figure 4-6 provides a process flow diagram, while Figure 4-7 shows proposed modifications required to implement A^2O in two parallel trains within the four existing aeration basins.

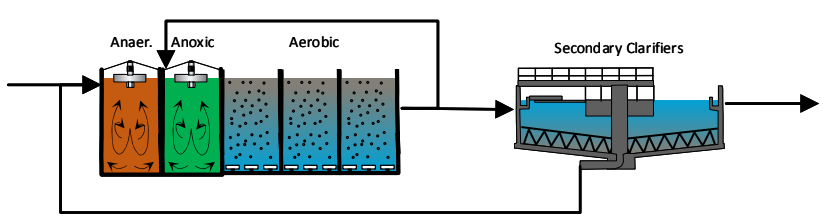

Figure 4-6. A^2O Process Configuration

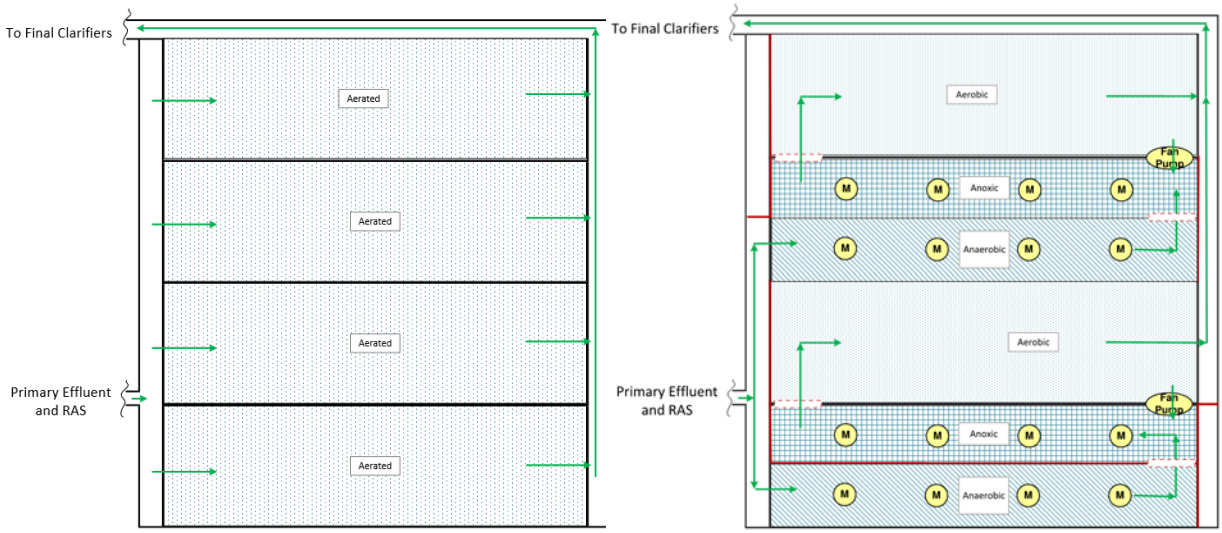

Figure 4-7. Existing Aeration Basin (left) and Proposed Modifications to the Existing Aeration Basins to Implement an A^2O Process (right)

Alternative 4: Five-Stage Process (Biological Nutrient Removal [BPR] 3) – Yet another biological phosphorus removal process; this process begins with an anaerobic selector zone and is followed by alternating anoxic and aerobic zones. A portion of the activated sludge is returned to the head of the aeration basin and mixed with influent wastewater before entering the anaerobic zone. The metabolic processes in regards to phosphorus is similar to those which take place in the AO and A^2O process, and like the AO process, denitrification occurs in the anoxic zones. There is an internal mixed liquor recycle, whereby nitrified mixed liquor is recycled to the anoxic zone. Denitrification occurs in the anoxic zone with nitrate being converted to nitrogen gas. The five-stage process is more complicated, but if well-run can achieve lower effluent TP. Figure 4-8 provides a process flow diagram for the five-stage process. Figure 4-9 shows proposed modifications required to implement a five-stage process in two parallel trains within the existing four aeration basins.

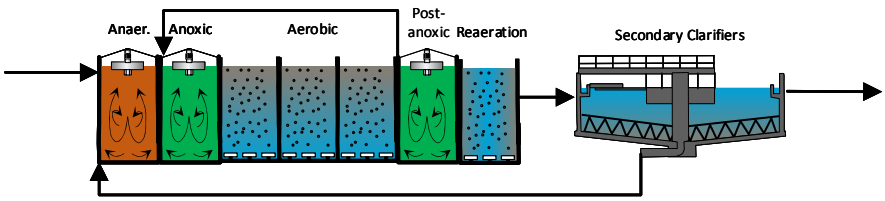

Figure 4-8. Five-Stage Process Configuration

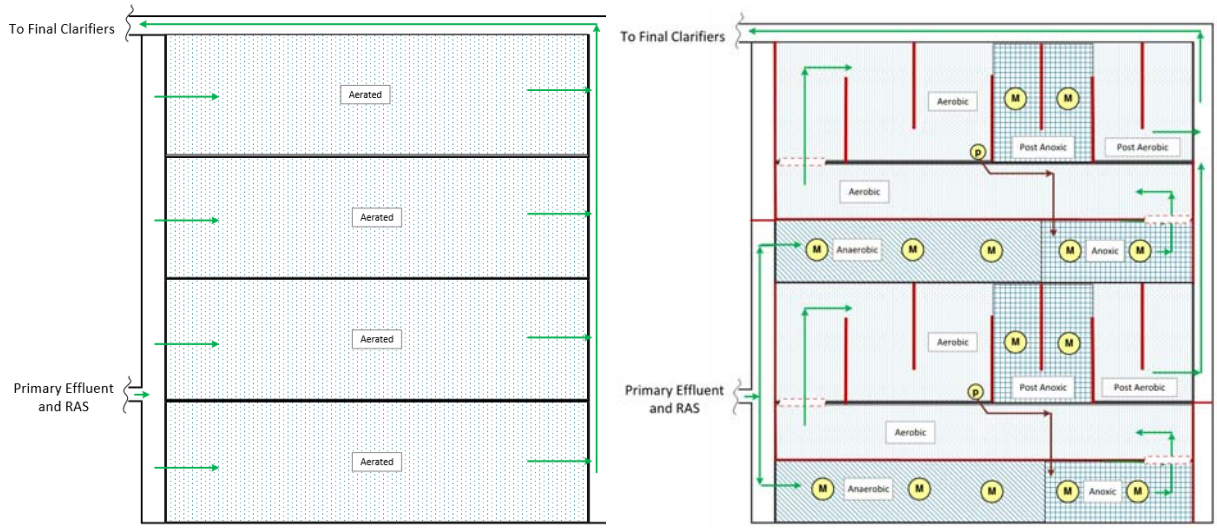

Figure 4-9. Existing Aeration Basin (left) and Proposed Modifications to the Existing Aeration Basins to Implement a Five-Stage Process (right)

Considerations for biological phosphorus removal– BPR processes remove orthophosphate from solution, sequester it in biological solids as polyphosphate, and remove those solids via wasting. This phosphorus is released in anaerobic digesters as orthophosphate which subsequently needs to be removed from digested sludge with chemical addition either within the digesters or before dewatering. This is done for two reasons; (1) avoid returning that phosphorus load to the head of the plant and (2) prevent the formation of struvite (equimolar magnesium:ammonium:phosphate), a mineral deposit that can cause problems at BPR plants with digesters. For this exercise, it was assumed that ferric chloride would be added to thickened WAS and primary sludge being sent to the digesters. This has benefits of not only preventing struvite formation and reducing the orthophosphate load back to the head of the plant, but providing hydrogen sulfide odor control. Figure 4-10 shows inline ferric addition to the digester feed sludge for the AO, A^2O, and five-stage BPR alternatives.

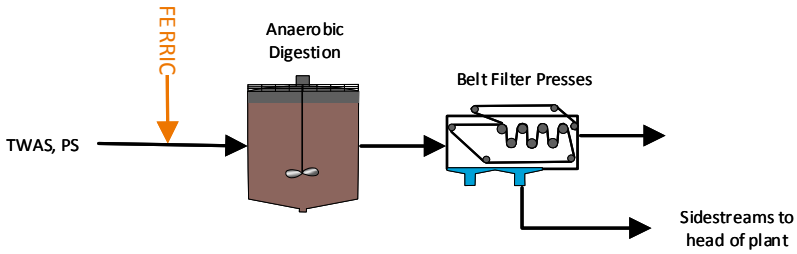

Figure 4-10. Process Configuration to Minimize Orthophosphate Return and Struvite Formation

Aeration System Improvements – Implementation of a BPR process would require reconfiguration of the existing aeration system at the WWTP, including diffusers, air distribution piping, and blowers. As the City currently has aeration system improvements in their near-term Capital Improvements Plan (CIP), the cost of the aeration system improvements was included in the opinion of probable construction cost for each alternative. The revised estimate for the aeration system improvements was based on full replacement of the existing system with improvements to airflow control and delivery. The presented costs are for the full aeration system and represent an update to the CIP estimate; the aeration improvement price presented is not in addition to the current CIP value. Nevertheless, for all life-cycle cost evaluations for phosphorus based improvements, the new aeration system capital

improvement cost was included, and the reduced annual operating cost associated with more efficient equipment and increased aeration control was added.

Low Level Phosphorus – Typically, to achieve a 0.1 mg/L effluent limit, a facility would require the addition of tertiary treatment facilities. There are several different tertiary technologies that can achieve a 0.1 mg/L effluent phosphorus limit, one of which is cloth media filters. With anticipated phosphorus discharge regulations in future NPDES permits, the City had the foresight to increase the performance of the existing tertiary treatment process by retrofitting the existing media filters with cloth media filters. The existing sand filters were aging and in need of repair. By investing in the new cloth media filter technology, the City was able to maximize the value of their investment by not only rehabilitating a critical piece of aging infrastructure and reducing current operating costs, but also preparing the facility for future phosphorus limitations.

4.4 Results

Performance – The SUMO process model (discussed in Section 3) was used to simulate the performance of the four alternate process configurations (chemical phosphorus removal [ChemP], BPR 1, BPR 2, and BPR 3 and estimated operating costs to achieve each of the three effluent limits [1.0, 0.5, and 0.1 mg/L]). For the BPR simulations, chemical was added to the sidestream to inhibit detrimental struvite formation until the effluent exceeded the target limit. If the effluent exceeded the target limit, chemical was also added to the liquid stream for effluent polishing.

Simulations indicate that, at average conditions, the three BPR configurations can achieve an effluent phosphorus concentration of approximately 0.2 mg/L without addition of chemical to the aeration basins and 25 gallons per day of chemical addition to the digesters to control struvite (Figure 4-11). Full chemical phosphorus removal would require 70 gallons per day of chemical addition to achieve a 1 mg/L effluent limitation (target 0.8 mg/L). For all four conditions, simulations indicate that at least a 50 percent reduction in aeration requirement can be achieved.

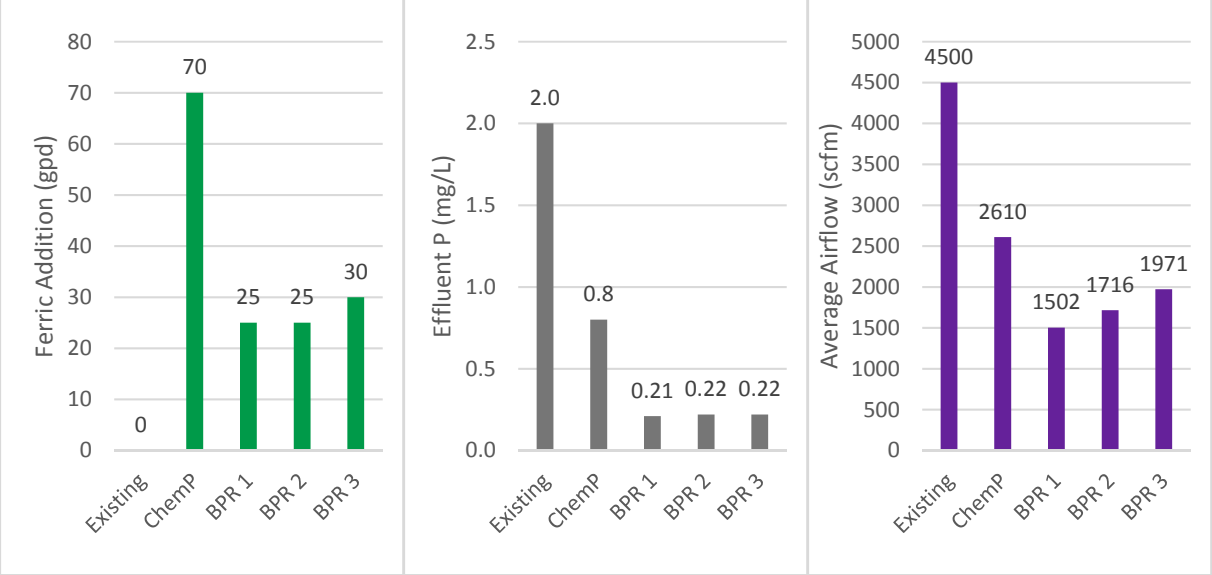

Figure 4-11. Summary of Simulation Results Targeting 1.0 mg/L Effluent Phosphorus Concentration at Average Conditions

As effluent phosphorus limits decreased from 1.0 to 0.5 to 0.1 mg/L, there would not be an increased capital requirement. This is due to the existing tertiary cloth media filters that were recently installed. The main difference would be the increased amount of chemical addition required to bind phosphorus. Table 4-3 summarizes the daily average chemical dosing requirement to achieve the effluent phosphorus limitations. Note that aeration basin chemical addition would not be required for the BPR

alternatives until the effluent limit was reduced to 0.1 mg/L; all chemical addition for 1.0 and 0.5 mg/L limits would be added to the digesters for the BPR alternatives.

Table 4-3. Ferric Chloride Dosing Requirements in Gallons per Day for Decreasing Effluent Limitations for the Four Simulated Process Configurations

	1.0 mg/L Effluent	0.5 mg/L Effluent	0.1 mg/L Effluent
Chemical Phosphorus Removal	70	124	288
BPR 1	25	25	39
BPR 2	25	25	41
BPR 3	25	25	41

To assess the stability of BPR over a period of time, a 2-year dynamic simulations was developed based on historic data for the WWTP. By simulating the varying wastewater characteristics, an understanding of the dynamics of BPR relative to the changing industrial loads at the WWTP can be assessed. As shown on Figure 4-12, simulations predict a decrease in secondary effluent performance during the summer season when loadings are lower. However, the tertiary filters help to stabilize performance across the entire period.

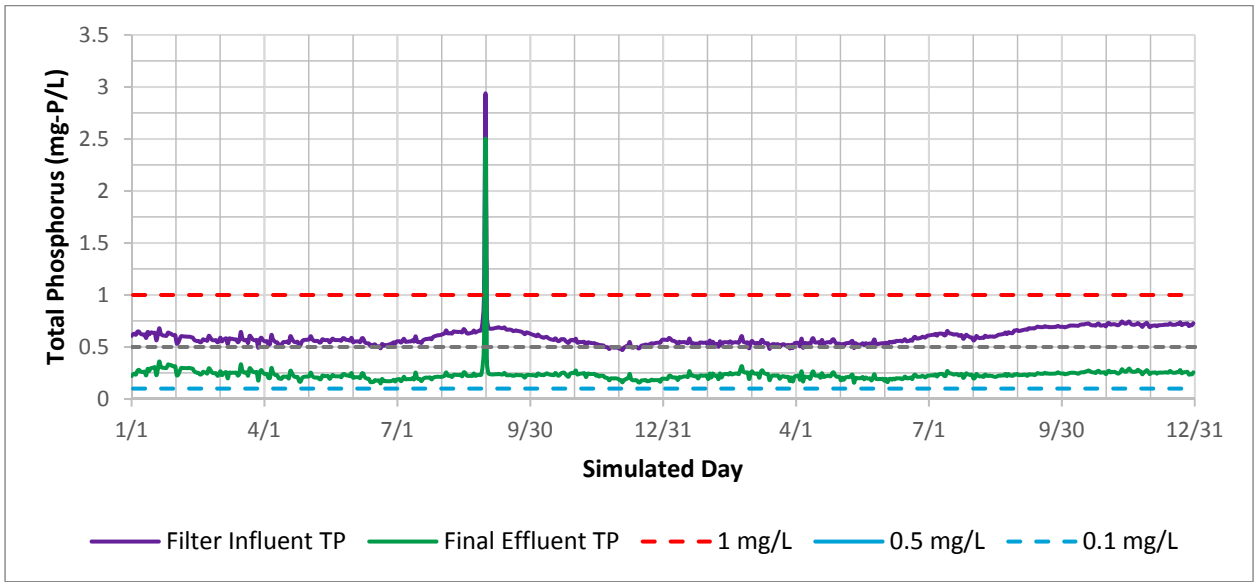

Figure 4-12. Two-Year Dynamic Simulation of Effluent Phosphorus with the BPR 1 Configuration

BPR would be able to consistently meet either a 1.0 or a 0.5 mg/L effluent phosphorus limit because of the wastewater characteristics and the existing tertiary filters.

Predicted airflow reduction is driven by two major components. The first is achievable blower turndown. Existing blowers are constant speed and each contribute an airflow of 2,250 standard cubic feet per minute (scfm). This limits the functional blower output to approximately 1,900 scfm with one blower in operation and 4,500 scfm with two blowers in operation. Given the airflow requirements for process performance, this results in a very tight range of operation around a tight airflow value of 4,500 scfm.

Simulations were developed using 3 years of influent data to better understand the range of airflow requirements and potential impacts of process improvements. The range of airflow data can be visualized in a probability distribution plot. The existing distribution results in a small distribution surface area (Figure 4-13, top).

If new blowers were implemented with new diffusers and improved controls, a wider range of airflows would be observed with the most common airflow rage in the 2,000 to 2,500 scfm range (Figure 4-13, middle).

Time implementation of a BPR configuration would have a similar airflow distribution as a non-BPR configuration with improved blowers and control. However, the most common airflow range would now shift down to 1,500 to 2,000 scfm (Figure 4-13, bottom).

For annual cost estimates, the distribution shown in Figure 4-13 (middle) will be used for the aeration cost for chemical phosphorus removal. BPR annual costs will use the distribution in Figure 4-13 (bottom) for the annual aeration costs. Although the aeration improvements are not required for chemical phosphorus removal, if the existing airflow ranges were used with the chemical phosphorus removal alternative but the new airflow distributions were used with the BPR alternatives, it would skew the life-cycle costs when comparing the different phosphorus removal alternatives.

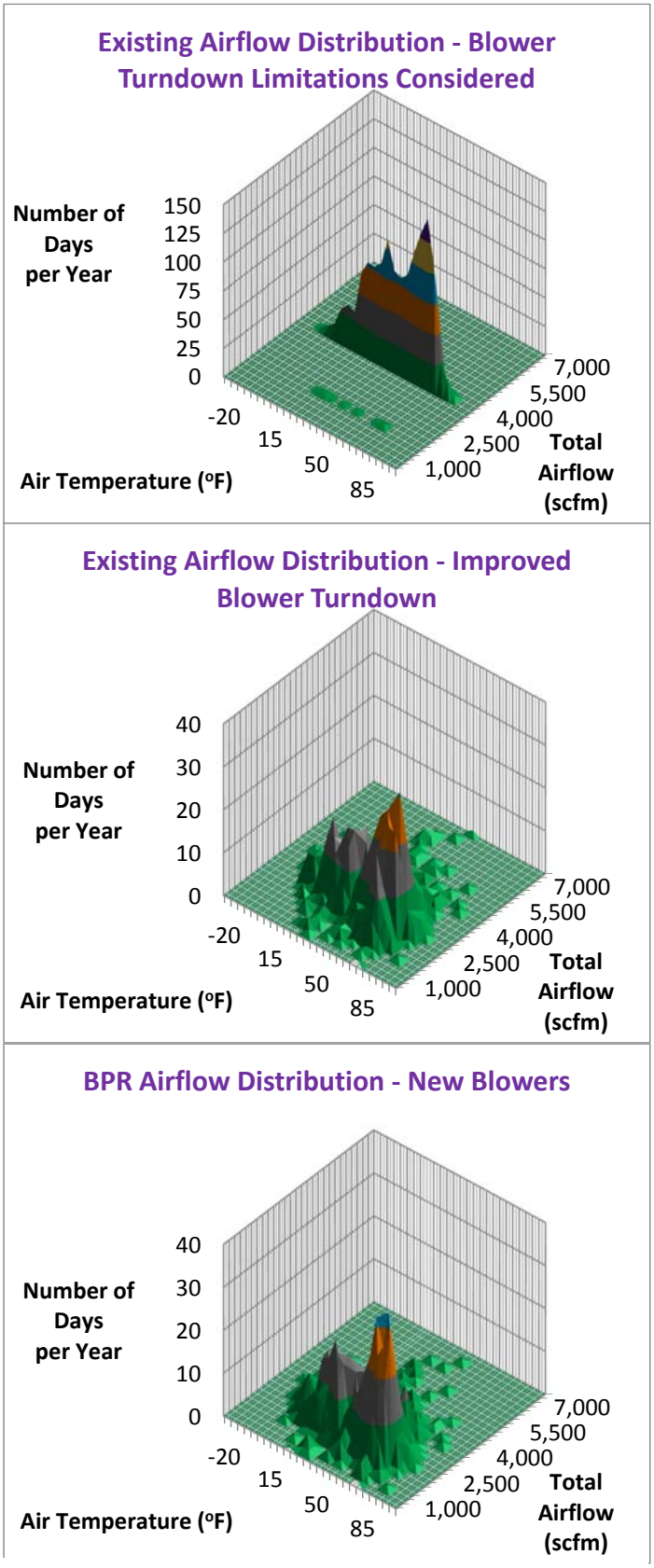

Figure 4-13. Probability distributions for airflow requirements. *Existing blowers (top), existing process configuration with new blowers (middle), and BPR configurations with new blower (bottom)*

Annual Operating Cost – Future annual operating costs were projected based on current operating costs (unit costs for life-cycle evaluation included in Appendix B). Annual operating costs impacted by phosphorus removal include blower energy use; mixing and pumping energy; solids disposal; and ferric (Fe) requirements. The estimated annual costs, as compared to current operating costs, are shown on Figure 4-14. For the 1.0 and 0.5 mg/L effluent limits, annual operating costs are estimated to increase by less than $25,000 for the BPR configurations.

Figure 4-14. Annual Cost Estimates for the Four Phosphorus Configurations at the Three Effluent Limits as Compared to Current Operating Costs

Capital improvements costs – Capital improvements were estimated for each alternative. Cost estimate details are included in Appendix B. Capital costs are summarized in Table 4-4. As discussed, there were three main components to each alternative: aeration system improvements, chemical feed facilities, and BPR improvements. As graphically shown on Figure 4-15, most the costs associated with the BPR improvements are associated with the aeration system. This capital cost will be required in the next 5 years regardless of phosphorus removal requirements due to the aging infrastructure issues of the existing aeration system.

Table 4-4. Capital Cost Estimates for Each Alternative

	No Phosphorus Removal	Chemical Phosphorus Removal	BPR 1	BPR 2	BPR 3
Aeration System Improvements	$1,892,000	$1,892,000	$1,892,000	$1,892,000	$1,892,000
Chemical Feed Facilities	$0	$945,000	$945,000	$945,000	$945,000
BPR Improvements	$0	$0	$877,000	$1,253,000	$3,020,000
Total Cost	$1,892,000	$2,837,000	$3,714,000	$4,089,000	$5,856,000

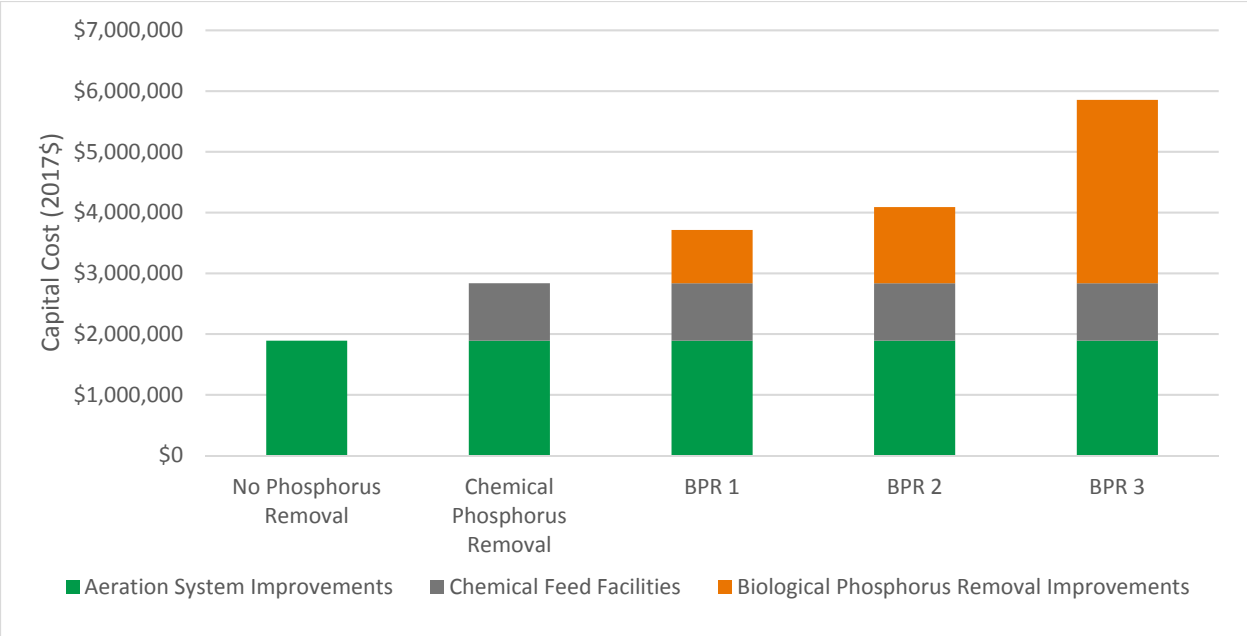

Figure 4-15. Distribution of Capital Cost between the Three Project Components

Life Cycle Cost Analysis – Based on the capital cost estimates and annual operational cost projects developed on Figure 4-14, the 20-year life-cycle costs for the four alternatives were developed for the three effluent phosphorus limitations (1.0, 0.5, and 0.1 mg/L). The 20-year costs are summarized in Figure 4-16. Full chemical removal and the AO process have a similar 20-year life cycle cost for the 1.0 and 0.5 mg/L effluent limits. For an effluent limit of 0.1 mg/L, the AO process has a significantly lower life-cycle cost.

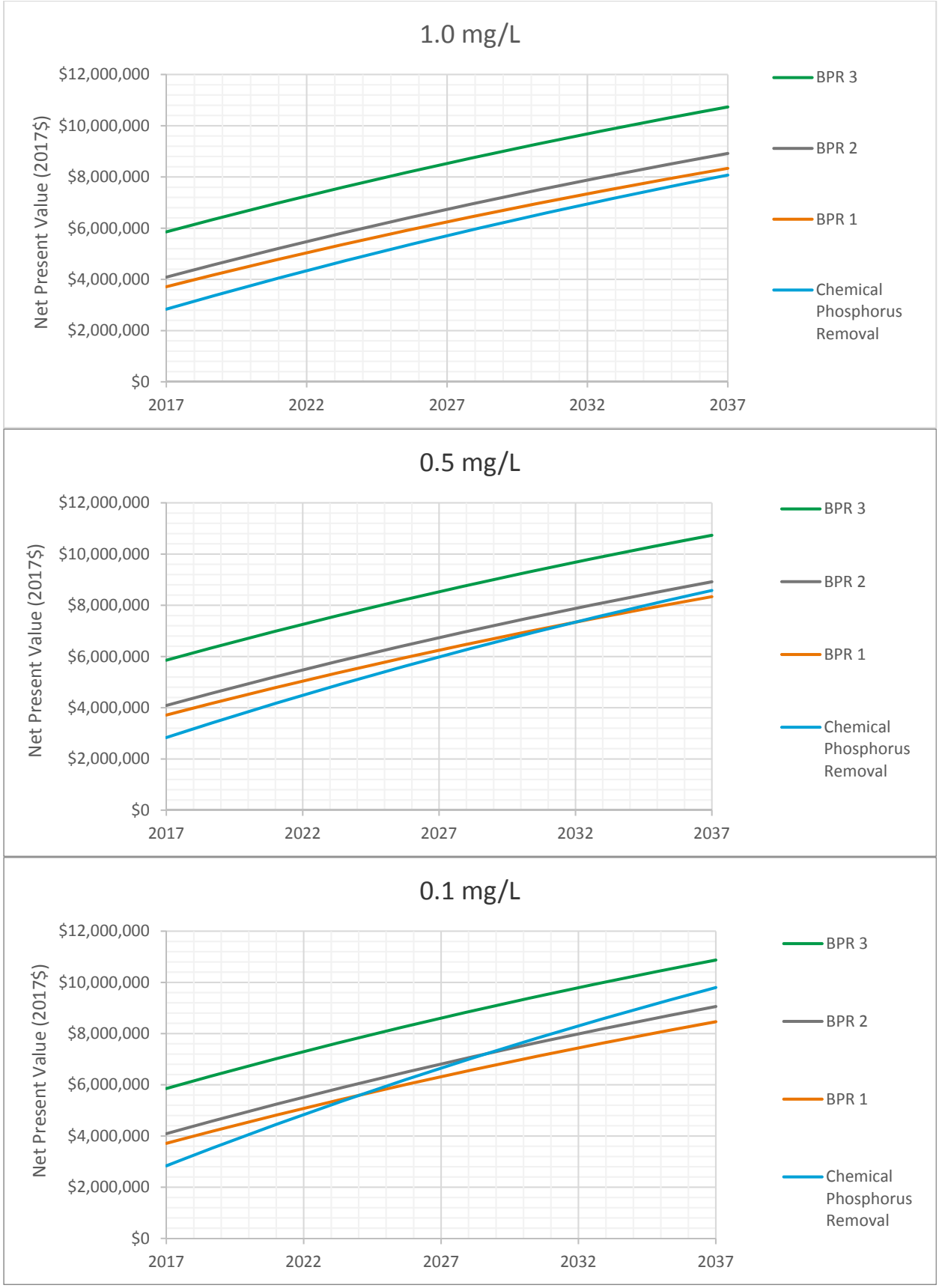

Figure 4-16. 20-year Life-Cycle Projections for the Four Phosphorus Treatment Alternatives at the Three Effluent Limitations

SECTION 5

Conclusions and Next Steps

There was not a clear-cut economic advantage for either chemical or BPR at effluent phosphorus limitations of 1.0 or 0.5 mg/L. However, at an effluent limitation of 0.1 mg/L, the benefits of BPR resulted in a 20-year life-cycle savings of approximately $1.3M, and a payback on capital as compared to chemical phosphorus removal of approximately 7 years. An additional benefit of BPR is that it reduces the cost uncertainty moving forward by reducing the purchase of chemicals and energy. While energy costs have been relatively stable over the past decade, there can be large fluctuations in chemical costs that can impact the stability of operating budgets.

It is recommended that the City implement a staged approach to compliance with effluent phosphorus requirements. Participation in the DuPage River Salt Creek Workgroup provides extended adoption periods for both chemical phosphorus removal (compliance by 2025) or BPR (compliance by 2026). It is recommended the BPR be implemented with the following key steps:

- Aeration system improvements: As part of the aeration systems improvements included in the City's current CIP, it is recommended that the baffle wall and mixers required for the AO process be included in the aeration basin improvements work.
- BPR testing: After completion of aeration system improvements and components for the AO process are installed, the City can test the field performance of the improvements.
- Chemical feed system construction: Approximately 3 years before the final effluent phosphorus limitation is promulgated, construction of the chemical feed system is recommended.

SECTION 6

References

Google Earth. 2017.

Tchobanoglous, George, et al. Wastewater Engineering: Treatment and Reuse. McGraw-Hill, 2003.

Appendix A
Simulation Results

Table A-1. Alternatives Analysis – Annual Average Results

	Baseline	Chemical P	AO	A^2O	5 Stage
Chemical dosage (gpd)	0	250	25	25	30
Effluent TP (mg P/L)	2.1	0.16	0.21	0.22	0.22
Effluent ortho-P (mg P/L)	1.9	0.014	0.01	0.015	0.012
MLSS (mg TSS/L)	2,529	1,842	15	9	9
Sludge production (tons/day)	2.00	2.51	19	18	14
Effluent ammonia (mg N/L)	0.1	0.32	2,580	2,558	1,953
Effluent nitrate (mg N/L)	17	15	2.55	2.54	2.57
Effluent TN (mg N/L)	18	17	0.67	0.77	0.41
Clarifier Solids Flux, lbs/d/sf	13.0	9.5	4.0	3.4	2.5
Clarifier Hydraulic Loading, gpd/sf	617	617	13.3	13.1	10.0
Clarifier Effluent TSS, mg/L	10	10	616	616	587
Disc Filter loading, mg/L	10	32	10	10	10
Disc Filter loading, lbs/day	513	1,666	513	513	513
GBT Loading, lbs/day	3,702	6,011	5,377	5,553	5319
BPF loading, lbs/day	4,200	5,274	5,370	5,341	5,406
Oxygen Mass Flow (lbs/day)	117968	66542	40,405	46,139	52,998
Air Flow at field conditions (scfm)	4820	2719	1,650	1,886	2,166
air flow (scfm)	4406	2474	1502	1716	1971
Standard oxygen transfer rate (lbs/day)	36,676	20,688		14,044	18,169

Table A-2. Alternatives Analysis – Maximum Month Results

	Baseline	Low DO, SRT	Chemical P	AO	A^2O	5 Stage
Chemical dosage (gpd)	0	0	350		250	150
Effluent TP (mg P/L)	1.8	1.6	0.16		0.21	0.21
Effluent ortho-P (mg P/L)	1.6	1.5	0.024		0.0096	0.015
MLSS (mg TSS/L)	3,596	1,916	2,504		4,293	2,402
Sludge production (tons/day)	2.81	2.93	3.48		3.00	2.80
Effluent ammonia (mg N/L)	0.19	0.35	0.35		0.79	0.43
Effluent nitrate (mg N/L)	13	12	12		2.4	1.9
Effluent TN (mg N/L)	14	13	13		3.8	3
Clarifier Solids Flux, lbs/d/sf	28.4	15.2	19.8		34.0	19.0
Clarifier Hydraulic Loading, gpd/sf	946	946	946		946	946
Clarifier Effluent TSS, mg/L	10	10	10		10	10

Table A-2. Alternatives Analysis – Maximum Month Results

	Baseline	Low DO, SRT	Chemical P	AO	A^2O	5 Stage
Disc Filter loading, mg/L	10	10	31		10	10
Disc Filter loading, lbs/day	780	780	2,395		780	780
Disc filter effluent TSS, mg/L	2.0	2.0	2.0	2.0	2.0	2.0
GBT Loading, lbs/day	5,259	6,247	8,164		9,320	6,518
BPF loading, lbs/day	5,913	6,175	7,322		6,322	6,591
Oxygen Mass Flow (lbs/day)	139,774	86,323	86,512		70,820	68,805
Air Flow at field conditions (scfm)	5,711	3,527	3,535		2,893	2,811
air flow (scfm)	5,198	3,210	3,218		2,634	2,559
Standard oxygen transfer rate (lbs/day)	43,455	26,838	26,897		22,017	21,391

Appendix B
Cost Analysis

Table B-1. Annual Cost Parameters and Cost Ranges Utilized in Life-Cycle Cost Estimation

Cost Inputs	Current Value
Electricity Cost ($/kWh)	0.03163
Ferric Chloride Cost ($/lbFe)	0.66
Biosolids Disposal Cost, $/dry ton	261.82

kWh = kilowatt-hour(s)

Table B-2. Net Present Value Assumptions

Net Present Value (NPV) Calculation:	
i =	0.05
n =	20
Annual Inflation % =	0.03

Technical Memorandum

Phosphorus Discharge Optimization Plan (PDOP) Progress Report

West Chicago/Winfield Wastewater Authority

Date: April 26, 2023

To: IEPA

From: Terry Boyer, PE, Donohue & Associates, Inc.

Mehul T. Patel, PE, City of West Chicago – Director of Public Works

Brent Lautenbach, Jacobs - Project Manager - West Chicago/Winfield Wastewater

Re: West Chicago/Winfield Wastewater Authority
NPDES Permit No. IL0023469 – PDOP Status Annual Progress Report

Reporting Period: Through March 2023

The NPDES permit requires the Authority to provide a progress report by March 31 every year.

The PDOP concluded the following:

The Authority will continue to monitor influent phosphorus from the users on the system and will consider setting local limits if the influent concentrations to the wastewater treatment plant indicate that there are significant phosphorus contributions from commercial or industrial sources.

Status Report:

The Authority has been monitoring the influent concentrations and they continue to be in the range that is typical for domestic wastewater.

In addition, the Authority has started design efforts on an A2O system to achieve biological nutrient removal (BNR) at the wastewater treatment plant. This BNR system is expected to be under construction in 2024.