

Phosphorus Removal Guidance for Wastewater Utilities in Michigan's Western Lake Erie Basin



MICHIGAN DEPARTMENT OF
ENVIRONMENT, GREAT LAKES, AND ENERGY



MOONSHOT
MISSIONS



Great Lakes
Protection Fund

October 2024

This publication is intended for guidance only and may be impacted by changes in legislation, rules, policies, and procedures adopted after the date of publication. Although this publication makes every effort to teach users how to meet applicable compliance obligations, use of this publication does not constitute the rendering of legal advice.

EGLE does not discriminate on the basis of race, sex, religion, age, national origin, color, marital status, disability, political beliefs, height, weight, genetic information, or sexual orientation in the administration of any of its programs or activities, and prohibits intimidation and retaliation, as required by applicable laws and regulations.

To request this material in an alternate format, contact EGLE-Accessibility@Michigan.gov or 800-662-9278.

Prepared by Moonshot Missions



Moonshot Missions is a 501(c)(3) nonprofit founded on the principle that everyone, particularly those in disadvantaged communities, has the right to safe, accessible, and affordable drinking water and clean waterways. All contributions are tax-deductible, and Moonshot Missions' taxpayer identification number is 87-2485211.

Moonshot achieves this mission by sending experienced water professionals into the field to build trusted, peer-to-peer relationships with local leaders, and together assess conditions and identify, select, and develop technically and financially sound projects to transform utilities and the communities they serve. Moonshot transforms this hard-won experience into practical guides and guidance manuals to help all utilities and communities with common water challenges.

Funded by the Great Lakes Protection Fund



Acknowledgements

This report was prepared by Moonshot Missions for the Michigan Department of Environment, Great Lakes, and Energy (MI EGLE), with generous funding from the Great Lakes Protection Fund (GLPF). We are deeply grateful for their support and commitment to advancing environmental protection and community resilience.

Below is a list of contributors who played a crucial role in the creation of this document:

ORGANIZATION	REPRESENTATIVES
MICHIGAN ENVIRONMENT, GREAT LAKES, AND ENERGY	Phil Argiroff, Chris Veldkamp, Tom Asmus
MOONSHOT MISSIONS	Rania Bashar, Nick Meurer, Laura Wilson, Ashley Holmes
OHIO EPA WASTEWATER COMPLIANCE ASSISTANCE UNIT	Andrew Gall, Jon VanDommelen

We would also like to recognize the invaluable contributions of our partners, stakeholders, and colleagues who provided insights and feedback throughout this project. Their expertise has greatly enriched the report.

The work reflects the collective dedication and vision of everyone involved, and we are grateful for their support in making this project possible.



Table of Contents

Acknowledgements.....	viii
How to Use This Document	vii
Document Structure Overview:.....	viii
CHAPTER 1: Background and Goals	1
1.1 Background	1
1.1.1 Western Lake Erie Basin (WLEB) Phosphorus Challenges	1
1.2 Aim of the guidance document:	2
CHAPTER 2: Phosphorus Removal Method from Municipal Wastewater	3
2.1 Removal Methods.....	3
2.1.1 Enhanced Biological Phosphorus Removal (EBPR).....	3
2.1.2 EBPR Process Configurations.....	5
2.2 EBPR Modifications.....	9
2.2.1 Oxidation Ditches	9
2.2.2 Sequencing Batch Reactors (SBR).....	11
2.2.3 Chemical Treatment for Phosphorus Removal.....	12
2.2.4 Chemical Treatment with EBPR.....	18
CHAPTER 3: Optimization Strategies.....	18
3.1 General Practices	18
3.1.1 Using Instrumentation for Optimization	18
3.1.2 Data Collection and Analysis	23
3.2 Diagnosing the EBPR Process.....	26
3.2.1 Nutrient Profile.....	26
3.2.2 Diagnosing the Anaerobic Zone	26
3.2.3 Diagnosing the Anoxic Zone	29
3.2.4 Diagnosing the Aerobic Zone	30
3.3 Biological Treatment Optimization	31
3.3.1 Side Stream Management.....	31
3.3.2 Creating Zones within Conventional Activated Sludge Systems	33
3.3.3 Return Activated Sludge and Waste Activated Sludge Optimization	34
3.3.4 Aerobic Digester Return Liquor Optimization	35
3.3.5 Controlling Centrate from Dewatering Processes.....	36
3.3.6 Septage and High Strength Waste.....	36



3.3.7 Secondary Phosphorus Release	37
3.3.8 Optimizing with Mixing	37
3.3.9 Optimization Strategies for Oxidation Ditches	38
3.3.10 SBR Optimization Strategies	40
3.4 Chemical Treatment.....	41
3.4.1 Jar Testing	41
3.4.2 pH Adjustment	42
3.4.3 Chemical Molar Ratios	43
3.4.4 Two-Point Chemical Addition	43
CHAPTER 4: Source Control and Pretreatment.....	44
4.1 Sewer Use Ordinance	44
4.2 Industrial Pretreatment Program	45
4.3 Adaptive Management Programs	45
CHAPTER 5: Case Studies	45
5.1 Cedarburg, WI.....	46
5.2 Abilene, KA.....	49
5.4 Bradford, OH	53
5.5 Onedia, TN	56
5.6 Parsons, KA	58
5.7 Conroe, TX.....	60
CHAPTER 6: Training and Resources	62
CHAPTER 7: Funding and Technical Assistance Opportunities	64
References.....	67
Appendix A: Chemical Phosphorus Jar Testing Protocol	68
Appendix B: Lab Testing Resources.....	71
Appendix C: Instrumentation Resources	72
Appendix D: Hydraulic Retention Time Calculation.....	74



List of Figures

Figure 1: Polyphosphate Accumulating Organisms (PAOs) Life Cycle	4
Figure 2: Typical EBPR Reactor Configuration	5
Figure 3: EBPR Reactor Configuration with Anaerobic, Anoxic, and Aerobic Zones	6
Figure 4: Type 1 Oxidation Ditch with no Anoxic or Anaerobic Zone	9
Figure 5: Type 2 Oxidation Ditch with only Anoxic and Aerobic Zones	10
Figure 6: Type 3 Oxidation Ditch with Anaerobic and Aerobic Zones	10
Figure 7: Type 4 Oxidation Ditch with Aerobic, Anoxic, and Anerobic Zones	11
Figure 8: Sequencing Batch Reactor (SBR) Operational Phases	12
Figure 9: Chemical Dosing Locations	15
Figure 10: Sampling Locations for EBPR Process	26
Figure 11: Two-Point Chemical Addition	44
Figure 12: Cedarburg WWTP	46
Figure 13: Cedarburg WWTP Process Diagram	46
Figure 14: Abilene WWTP	49
Figure 15: Abilene WWTP Process Diagram	49
Figure 16: Great Bend WWTP	51
Figure 17: Great Bend WWTP Process Diagram	51
Figure 18: Bradford WWTP	53
Figure 19: Bradford WWTP Process Diagram	53
Figure 20: Oneida STP	56
Figure 21: Oneida STP Process Flow Diagram	56
Figure 22: Parsons WWTP	58
Figure 23: Parsons WWTP Process Diagram	58
Figure 24: Conroe Southwest Regional WWTP	60
Figure 25: Conroe Southwest Regional WWTP Process Diagram	60
Figure 26: Dosing Table	70
Figure 27: Dosage Curve	70

List of Tables

Table 1: List of Affected Facilities	2
Table 2: Advantages and Disadvantages of EBPR	8
Table 3: Commonly Used Chemicals for Phosphorus Removal	14
Table 4: Advantages and Disadvantages of Chemical Removal	17
Table 5: ORP Optimal Ranges and Corrective Actions	20
Table 6: Optimal DO Ranges and Corrective Actions	21
Table 7: General Instrumentation Maintenance Protocol	23
Table 8: Sampling Collection Points	25
Table 9: Anaerobic Zone Sampling Protocol	28
Table 10: Anoxic Zone Sampling Protocol	29
Table 11: Aerobic Zone Sampling Protocol	30
Table 12: Solids Optimization Protocol	32
Table 13: Secondary Phosphorus Release Corrective Actions	37
Table 14: Chemical pH Ranges	42



How to Use This Document

This guidance document is designed to assist wastewater treatment plant (WWTP) personnel and stakeholders in understanding and optimizing phosphorus removal processes using low-cost operational strategies. The focus is on both Enhanced Biological Phosphorus Removal (EBPR) and Chemical Phosphorus Removal, with practical strategies for monitoring, diagnosing, and improving system performance.

The information included in this document was obtained from available literature, EPA reports, practical experience and direct communication with practitioners actively working in the field. Tables, figures and diagrams were presented where appropriate for illustrative purposes.

While the document provides a broad range of solutions, not all will be applicable to every treatment plant. The user can refer to several other documents mentioned in the 'References' section for detailed information. The following steps outline the best way to utilize this document:

1. **Identify Your Treatment Process:**

- Determine the wastewater treatment process you employ: Conventional Activated Sludge, Oxidation Ditch, or Sequencing Batch Reactor (SBR).

2. **Identify Your Phosphorus Removal Method:**

- Assess whether your plant primarily uses EBPR, chemical phosphorus removal, or a combination of both.
- For a fundamental understanding of EBPR, refer to [Section 2.1.1 Enhanced Biological Phosphorus Removal \(EBPR\)](#), [2.1.2 EBPR Process Configurations](#), and [2.2 EBPR Modifications](#).
- For chemical phosphorus removal, refer to [Section 2.2.3 Chemical Treatment for Phosphorus Removal](#).
- If your plant uses both methods, ensure you review the relevant sections for each process.

3. **Perform Diagnostics (for EBPR Systems):**

- If your plant employs EBPR, conduct a diagnostic profile to evaluate whether your system is achieving optimal phosphorus removal. The diagnostic process is a step-by-step procedure that identifies the information required to make engineering judgements necessary at each step of the evaluation process. Detailed instructions for this process are available in [Section 3.2 Diagnosing the EBPR Process](#).

4. **Review Chemical Feeding Guidelines (for Chemical Systems):**



- If your plant uses chemical phosphorus removal, familiarize yourself with the chemical feeding guidelines provided in [Section 3.4 Chemical Treatment](#).
5. **Optimize Operations:**
- Based on the diagnostic results or your current operational challenges, explore the operational strategies, corrective actions and case studies detailed in the document to optimize your plant's performance.

Document Structure Overview:

- **Chapters 1 & 2:** Provide a comprehensive overview of phosphorus removal processes, including both EBPR and chemical methods.
- **Chapters 3 & 4:** Focus on process and source control strategies for optimizing phosphorus removal in various WWTP setups.
- **Chapter 5:** Includes case studies from real wastewater treatment plants that illustrate the practical application of the strategies discussed.
- **Chapters 6 & 7:** Offer additional resources, including training materials and potential funding opportunities to support your phosphorus removal efforts.



CHAPTER 1: Background and Goals

1.1 Background

Phosphorus removal in wastewater is crucial for protecting the Great Lakes ecosystem due to its significant impact on water quality and ecological balance. Phosphorus is a key nutrient for all life. However, it can promote harmful algal blooms (HABs) and other water quality issues when present in excessive amounts in the waterways. HABs pose serious threats to ecosystems, human health, and economies. They deplete oxygen in water, leading to dead zones where aquatic life cannot survive, and produce toxins harmful to animals and humans, causing illnesses or even death. HABs also impact recreational water activities and industries reliant on clean water, such as tourism and fishing, due to beach closures and contaminated water supplies.

1.1.1 Western Lake Erie Basin (WLEB) Phosphorus Challenges

Efforts to control Total Phosphorus (TP) in the Western Lake Erie Basin (WLEB) began in 2013 with the City of Detroit's Great Lakes Water Authority (GLWA) receiving more stringent TP limits on their discharge permit, responding to the reoccurrence of HABs in the WLEB and hypoxia concerns in the Central Lake Erie Basin (CLEB). In 2016, Michigan, Ontario, and Ohio signed a Collaborative Agreement to better control TP concentrations at key Publicly Owned Treatment Works (POTW) in the WLEB and CLEB. Following this, Michigan completed its Domestic Action Plan (DAP) in 2018 as part of its commitment under the Collaborative Agreement. This action aligns with the requirements of the Great Lakes Water Quality Agreement (GLWQA), specifically under Annex 4, which mandates Michigan to reduce TP concentrations further to combat HABs and hypoxia in the WLEB. To date, these point source control efforts have led to the annual removal of 400-450 metric tons of TP from the WLEB. This achievement represents more than 50 percent of the total reduction needed to meet Michigan's overall goal of a 40 percent reduction, contributing towards the collective targets set by the GLWQA, Annex 4. The strategy also emphasizes non-point source solutions, including addressing agricultural runoff, as part of the broader effort to meet these reduction goals. This approach alleviates some pressure on POTWs by focusing on cost-effective operational controls instead of requiring significant capital expenditures.

Due to a newly implemented phosphorus discharge standard of 0.5 mg/L in the growing seasons, the Michigan communities discharging into the WLEB will be required to optimize their phosphorus removal process. These communities' populations range from 2,000 to 620,000, covering a broad spectrum of demographics. The facilities themselves vary significantly in terms of secondary treatment processes, including conventional activated sludge, oxidation ditches, sequencing batch reactors, membrane bioreactors, rotating biological contactors, and tertiary treatment, with capacities ranging from 1 million Gallons per Day (MGD) to 930 MGD. [Table 1](#) provides a more detailed breakdown of the 25 facilities affected by these new limits.



Table 1: List of Affected Facilities

TREATMENT PLANT	CITY	TREATMENT PROCESS	FLOW (MGD)
ADRIAN WWTP	Adrian, MI	Activated Sludge	7
ANN ARBOR WWTP	Ann Arbor, MI	Activated Sludge	29.5
BEDFORD TWP WWTP	Erie, MI	Activated Sludge	6
BERLIN TWP WWTP	Newport, MI	Activated Sludge	1.8
BRIGHTON WWTP	Brighton, MI	Tertiary	2.25
CHELSEA WWTP	Chelsea, MI	Oxidation Ditch	1.3
COMMERCE TWP WWTP	Commerce Township, MI	Oxidation Ditch	8.5
DOWNRIVER WTP	Wyandotte, MI	Activated Sludge	125
DUNDEE WWTP	Dundee, MI	Membrane Bioreactor	1.5
GLWA WRRF	Detroit, MI	Activated Sludge	930
GROSSE ILE TWP WWTP	Grosse Ile Township, MI	Rotating Biological Contactor	2.25
MILAN WWTP	Milan, MI	Oxidation Ditch	2.5
MILFORD WWTP	Milford, MI	Oxidation Ditch	1.04
MONROE METRO WWTP	Monroe, MI	Activated Sludge	24
NORTHFIELD TWP WWTP	Whitmore Lake, MI	Trickling Filter	1.3
OAKLAN CO WALLED LK NOVI WWTP	Novi, MI	Activated Sludge	3.5
ROCKWOOD WWTP	Rockwood, MI	Trickling Filter	1
ROLLIN-WOODSTOCK WWTP	Addison, MI	Activated Sludge	1.2
SOUTH HURON VALLEY UA WWTP	Brownstown, MI	Activated Sludge	24
SALINE WWTP	Saline, MI	Sequencing Batch Reactor	1.81
SOUTH LYON WWTP	South Lyon, MI	Sequencing Batch Reactor	2.5
TECUMSEH WWTP	Tecumseh, MI	Activated Sludge	1.61
TRENTON WWTP	Trenton, MI	Activated Sludge	6.5
WIXOM WWTP	Wixom, MI	Tertiary	2.8
YCUA REGIONAL WWTP	Ypsilanti, MI	Activated Sludge	51.2

1.2 Aim of the guidance document:

The aim of this document is to:

1. Provide a comprehensive overview of various phosphorus removal methods used for secondary treatment in municipal wastewater treatment plants, and
2. Outline cost-effective operational and process control strategies to improve phosphorus removal at wastewater treatment plants.

Process control strategies are augmented by case studies from wastewater treatment plants, showcasing successful implementations of these strategies. This document intends to equip WLEB WWTP operations staff with comprehensive knowledge of all aspects of phosphorus removal and optimization techniques that achieve phosphorus reduction with existing infrastructure.



CHAPTER 2: Phosphorus Removal Method from Municipal Wastewater

2.1 Removal Methods

Municipal wastewater typically contains between 4-8 mg/L of total phosphorus. To meet the new limits of 0.5 mg/L, most treatment facilities will employ secondary treatment processes.

Phosphorus removal through secondary treatment can be broadly classified into two main categories: biological and chemical. Enhanced Biological Phosphorus Removal (EBPR) uses specific microorganisms to extract phosphorus, which is then removed as biosolids. Chemical removal involves adding chemicals that bind with phosphorus, forming a precipitate that settles in the sludge. EBPR can achieve removal efficiencies of 80-90%, though it may require additional chemical treatment to meet very low effluent limits. Chemical removal can achieve effluent concentrations below 1.0 mg/L, depending on dosage and conditions ([Minnesota Pollution Control Agency, n.d.](#)).

2.1.1 Enhanced Biological Phosphorus Removal (EBPR)

The Enhanced Biological Phosphorus Removal (EBPR) process with activated sludge systems is a sophisticated method employed in wastewater treatment to efficiently remove phosphorus. EBPR requires specific bacteria, known as polyphosphate accumulating organisms (PAOs), which can absorb and store phosphorus in excess of their immediate needs under particular conditions. The operation of EBPR a strategic arrangement of – anaerobic and aerobic zones that are crucial to its success. [Figure 1](#) illustrates the PAO life cycle and its purpose in each zone of biological treatment.



Polyphosphate Accumulating Organisms

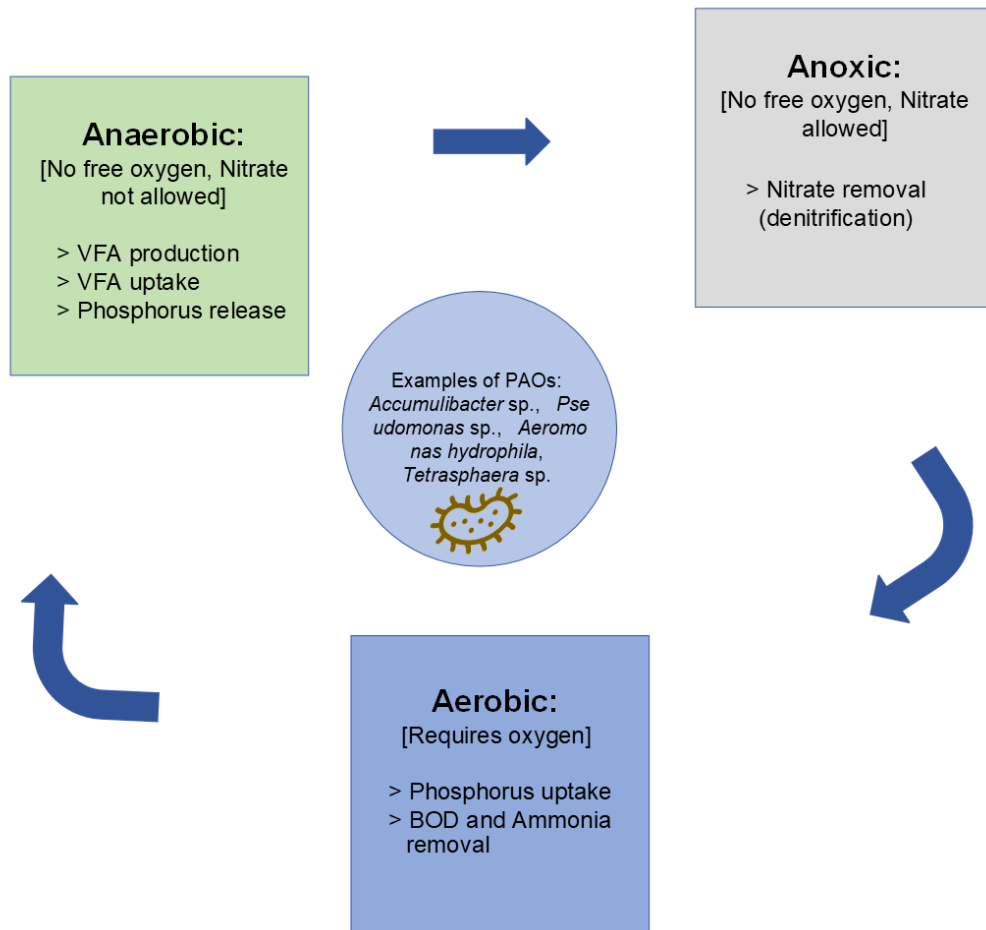


Figure 1: Polyphosphate Accumulating Organisms (PAOs) Life Cycle

A critical component of the successful EBPR process is Volatile Fatty Acids (VFAs), which serve as an essential carbon source for PAOs. VFAs energize PAOs, enabling them to uptake phosphorus efficiently. Ensuring a consistent and robust source of VFAs is vital for maintaining steady EBPR operations. Raw influent rich in organic matter often provides an abundance of VFAs. Additionally, septic haulers and high-strength organic loads can significantly contribute to the VFA supply, as can septic conditions in the collection system that naturally generate VFAs from organic matter breakdown. For successful EBPR, a ratio of Biochemical Oxygen Demand (BOD) to phosphorus of at least 20:1 or Chemical Oxygen Demand (COD) to phosphorus of at least 45:1 is recommended, highlighting the importance of sufficient organic carbon availability for the process.

2.1.2 EBPR Process Configurations

2.1.2.1 Anaerobic Zones

Anaerobic zones are characterized by the absence of dissolved oxygen (DO), creating septic conditions. These conditions are conducive for PAOs to uptake VFAs and, in the process, release orthophosphate into the mixed liquor. To sustain this cycle, Return Activated Sludge (RAS) is typically redirected to the entrance of the anaerobic zone. This reintroduces PAOs into an oxygen-free environment, enabling them to continuously release phosphorus and uptake VFAs in a recurring process. Anaerobic zones are equipped with some form of mixing to keep particulates and microbes in suspension, facilitating their interaction. Additionally, the anaerobic zone serves as a fermenter, facilitating the breakdown of organic matter under septic conditions, with VFAs being produced as a byproduct. An optimal hydraulic retention time (HRT) for efficient VFA uptake in the anaerobic zone generally ranges from 2 to 3 hours. [Figure 2](#) illustrates a standard EBPR treatment process that is only able to remove phosphorus and not nitrogen.

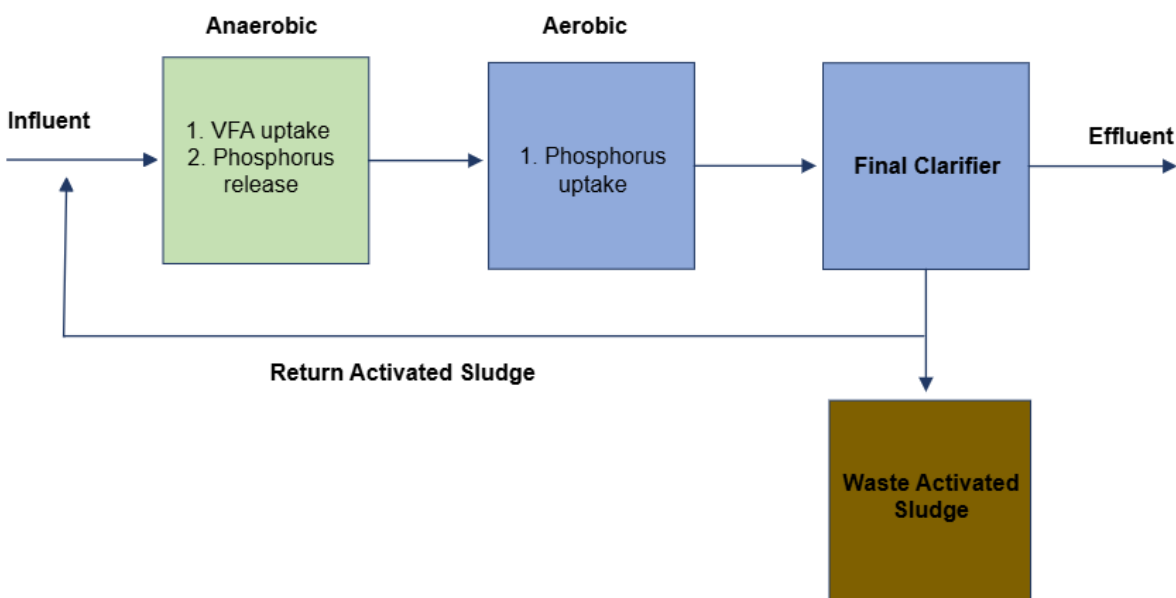


Figure 2: Typical EBPR Reactor Configuration

2.1.2.2 Anoxic Zones (if present)

Anoxic zones are environments in which oxygen is available only in combined forms, such as nitrates (NO_3^-), nitrites (NO_2^-), or sulfates (SO_4^{2-}) within an aqueous medium. This condition is essential for denitrification, the process whereby denitrifying bacteria use organic matter to reduce nitrate or nitrite to nitrogen gas. **An anoxic zone is not essential to the EBPR process.** However, if nitrate is present in the anaerobic zone, it can interfere with the EBPR process.

Anoxic zones typically acquire nitrate and nitrite either through an internal recycle stream of mixed liquor from the aerobic zone or via backflow from the aerobic zone. Like anaerobic zones, anoxic zones are equipped with mixing mechanisms to ensure effective interaction between organic material and microbes. These zones are typically situated after anaerobic zones in treatment systems to ensure that PAOs have already utilized VFAs for phosphorus release. While nitrifying bacteria operate under aerobic conditions to convert ammonia to nitrate (nitrification), denitrifying bacteria work in anoxic conditions to remove nitrates/nitrites, thus preventing competition with PAOs for VFAs. [Figure 3](#) illustrates a complete nutrient removal process which can remove both phosphorus and nitrogen.

Anaerobic/Anoxic/Aerobic Process

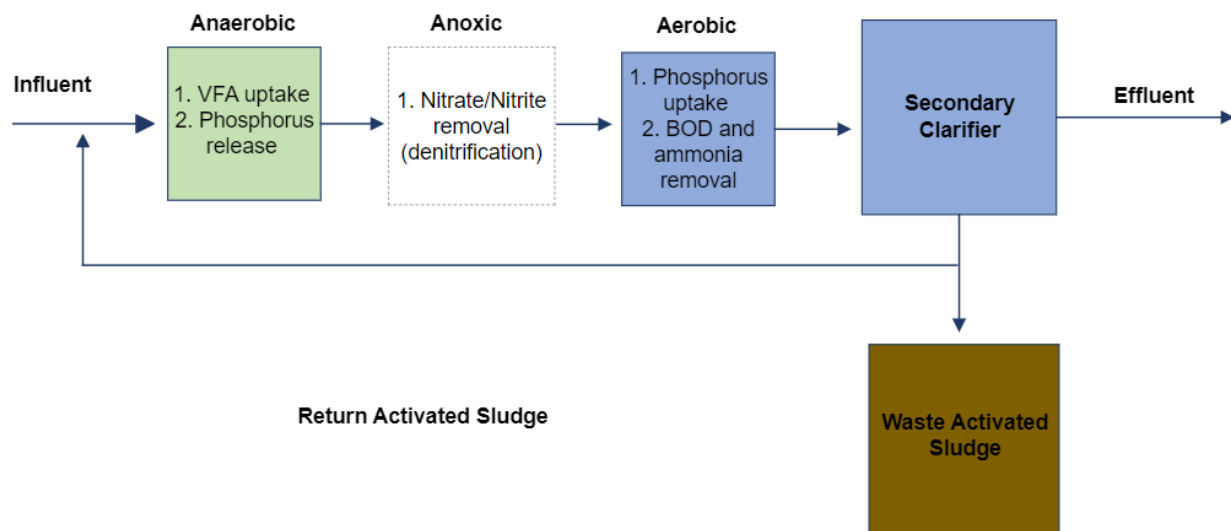


Figure 3: EBPR Reactor Configuration with Anaerobic, Anoxic, and Aerobic Zones

2.1.2.3 Aerobic Zones

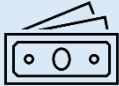
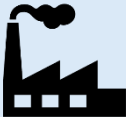
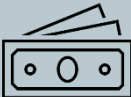
The aerobic zone constitutes a critical phase where an oxygen-rich environment is provided. PAOs use the oxygen to utilize the energy reserved from VFAs consumed during the anaerobic phase, leading to the active uptake of phosphorus. This uptake significantly exceeds the phosphorus released in the anaerobic stage, ensuring a net removal of phosphorus from the wastewater. Beyond phosphorus removal, the aerobic zone is pivotal for the reduction of BOD and the process of nitrification, further purifying the water by breaking down organic matter and converting ammonia into nitrate.

2.1.2.4 Advantages and Disadvantages

EBPR presents several advantages, such as energy efficiency, reduced chemical usage, decreased sludge production, and enhanced environmental sustainability. Although the initial investment in infrastructure may be significant, EBPR stands as an effective long-term solution for phosphorus removal. Over time, it compensates for the upfront costs through savings on energy and chemicals. However, some challenges include the operational complexity and the risk of process failure due to plant disturbances or seasonal variations. Nonetheless, with ongoing advancements in instrumentation and technology, maintaining and operating EBPR systems is becoming more manageable. Additionally, high flow events during spring and summer, often resulting from inflow and infiltration (I&I), pose a risk of washing out the selector zones and disrupting the biological process. [Table 2](#) outlines the advantages and disadvantages of EBPR.



Table 2: Advantages and Disadvantages of EBPR

Advantages	Disadvantages
Reduction of biosolids 	Significant initial investment 
Reduced chemical use 	Operational complexity 
Decreased sludge production 	Risk of process failure due to plant disturbances 
Enhanced environmental sustainability 	Inflow and Infiltration (I&I) can dilute influent loadings, creating a food imbalance and disrupting the anaerobic process due to shortened Hydraulic Retention Time (HRT) caused by increased hydraulic loading 
Effective long-term solution for phosphorus removal 	
Savings on energy and chemicals 	
Advancements in instrumentation and technology have made operating EBPR systems more manageable 	

2.2 EBPR Modifications

In addition to the three-step BNR process configurations, EBPR can also be performed in modified process configurations such as oxidation ditches or sequencing batch reactors (SBR). Oxidation ditches are widely used in smaller-scale systems. Each type of treatment system offers different advantages and limitations, but the biological concepts and strategies are still applicable to all these systems in one way or another.

2.2.1 Oxidation Ditches

Oxidation ditch systems generally utilize surface aerators and mechanical mixers as opposed to diffusers. The surface aerators add air and mix the wastewater, propelling the flow to circulate around the ditch and creating a current. This can be beneficial for EBPR by keeping some of the solids in suspension even when the aeration is off. If the aeration is off long enough, solids will eventually settle out. However, this flexibility allows operators to use less air and optimize the EBPR process in ways that conventional activated sludge systems cannot. Additionally, oxidation ditches are designed to handle varying flow rates and loads, and their longer hydraulic retention times enhance the degradation of organic matter and the removal of nutrients. Despite these advantages, oxidation ditches generally have a larger footprint compared to conventional activated sludge systems due to their extended aeration and longer retention times. For information regarding the optimization of oxidation ditch operations see [3.3.9 Optimization Strategies for Oxidation Ditches](#).

2.2.1.1 Types of Oxidation Ditches

According to the U.S. Environmental Protection Agency's *Oxidation Ditches* webinar (2022), there are four main types of oxidation ditches:

1. No Anoxic or Anaerobic Zone: These are designed strictly for BOD and ammonia removal.

1. No Anoxic or Anaerobic zones

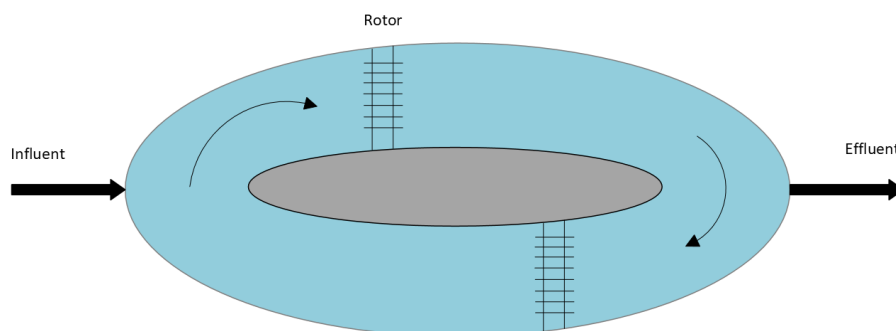


Figure 4: Type 1 Oxidation Ditch with no Anoxic or Anaerobic Zone

2. Only Anoxic and Aerobic Zones: Built for BOD and ammonia removal, and subsequent denitrification.

2. Only Anoxic and Aerobic Zones

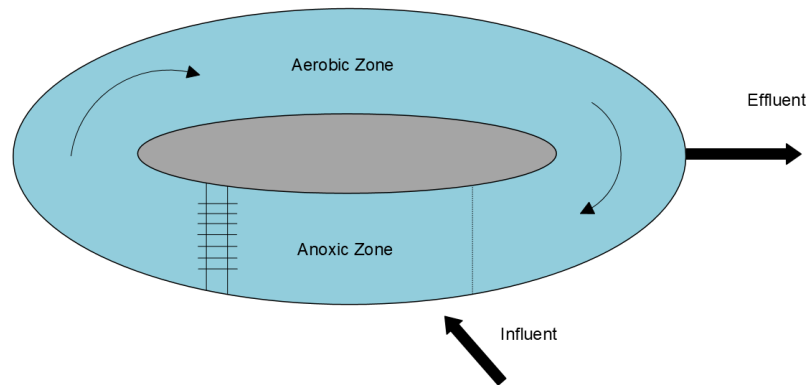


Figure 5: Type 2 Oxidation Ditch with only Anoxic and Aerobic Zones

3. Anaerobic and Aerobic Zones: Designed for phosphorus removal and not total nitrogen removal.

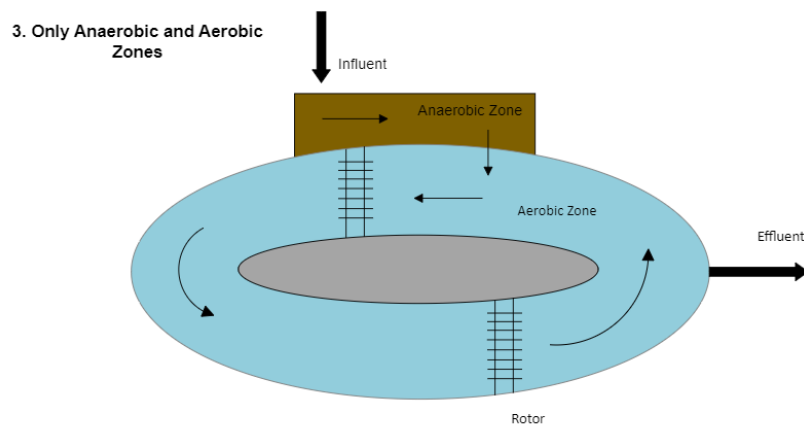


Figure 6: Type 3 Oxidation Ditch with Anaerobic and Aerobic Zones

4. Aerobic, Anoxic and Anaerobic Zones: These consist of both anaerobic and anoxic zones and can achieve BOD, ammonia, and phosphorus removal.

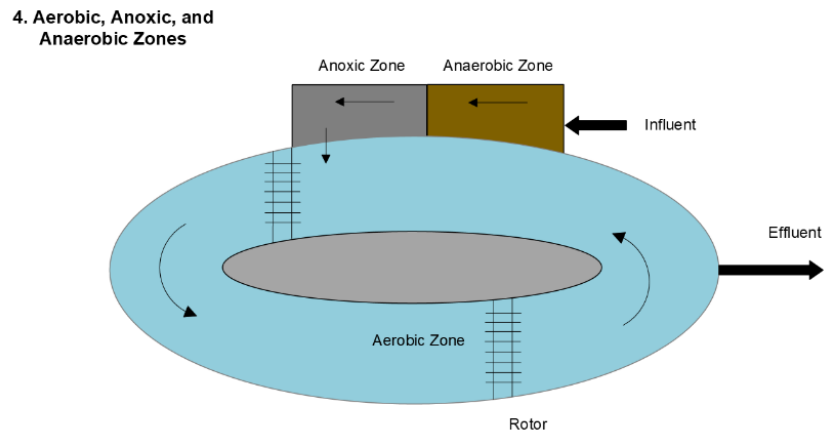


Figure 7: Type 4 Oxidation Ditch with Aerobic, Anoxic, and Anaerobic Zones

2.2.2 Sequencing Batch Reactors (SBR)

Sequencing Batch Reactors (SBRs) are an activated sludge process that operates in batch mode, treating wastewater in cycles as opposed to a continuous-flow mode. This batch operation allows for flexible operation and control, which is particularly beneficial for EBPR. SBR systems typically consist of one or more reactors, and in some cases, flow equalization tanks are used to manage inflow variations, enabling continuous treatment even when one tank is in a non-fill phase. For information regarding the operational optimization of SBRs see [3.3.10 SBR Optimization Strategies](#).

SBR's Four Operational Phases:

1. Fill Phase: Raw influent enters the reactor where initial mixing occurs. This phase may include static fill (no mixing), mixed fill (mixing without aeration), or aerated fill (mixing with aeration) depending on process requirements.
2. React Phase: Air is added to the reactor to provide oxygen for biological treatment. This phase promotes the degradation of organic matter and nitrification.
3. Settle Phase: Aeration and mixing are stopped, allowing solids to settle by gravity. This phase results in a clear supernatant layer above the settled sludge.
4. Decant Phase: The clarified supernatant (treated final effluent) is carefully removed from the reactor without disturbing the settled sludge.

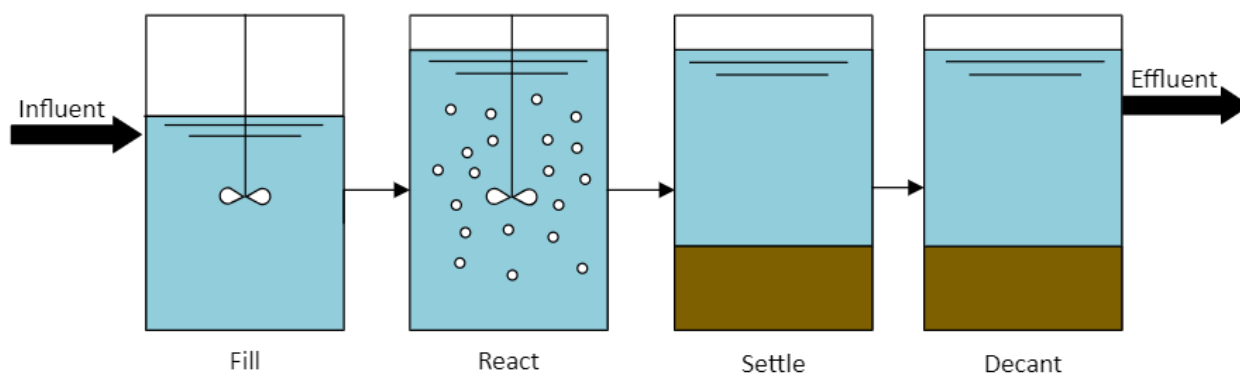


Figure 8: Sequencing Batch Reactor (SBR) Operational Phases

2.2.3 Chemical Treatment for Phosphorus Removal

Chemical treatment for phosphorus removal is one of the most commonly employed methods for reducing phosphorus levels in wastewater. It involves the addition of specific chemicals to the wastewater, which react with phosphorus to form insoluble precipitates. These precipitates then settle out in the sludge and in turn wasted out of the process. Choice of chemicals is usually dependent upon the characteristics of the wastewater, making certain chemicals suitable for certain characteristics. Factors such as cost, treatment goals, and operational considerations play critical roles in determining the most appropriate chemical for phosphorus removal. Each plant must tailor its chemical dosing strategy to its specific operational goals, wastewater makeup, and regulatory requirements to optimize phosphorus removal efficiency and overall treatment effectiveness.

2.2.3.1 Commonly Used Chemicals

Iron Salts

In chemical phosphorus removal, iron salts are among the most widely used, with ferrous chloride being particularly common. Ferrous chloride is one of the more cost-effective chemicals available due to its less refined state, which, however, may affect its effectiveness compared to more refined chemicals like ferric chloride and ferric sulfate. Ferric sulfate and ferric chloride have a distinct advantage over ferrous chloride because they possess a known and consistent iron content. This consistency results in more reliable treatment outcomes, and these compounds are easier to optimize for enhanced chemical control. In contrast, ferrous chloride's effectiveness can vary, as its iron content may differ across batches, and it may contain higher amounts of metal solids. These characteristics can lead to increased sludge production and present risks of clogging pumps and pipes, making phosphorus removal outcomes more

unpredictable. Additionally, all iron salts are highly corrosive, posing potential health and safety risks to operational staff and causing wear and tear on operational equipment.

Aluminum Salts

Aluminum salts share similar applications with iron salts in wastewater treatment but are generally considered a more expensive option. The most common aluminum salts used for phosphorus removal are aluminum sulfate (alum), poly aluminum chloride (PAC), and sodium aluminate. While aluminum-based products may not be as widely used as their iron-based counterparts, the choice between aluminum and iron salts ultimately depends on their effectiveness and suitability for a specific treatment process, pH, and composition of wastewater.

Rare Earth

Rare earth chemicals such as lanthanide salts and cerium represent an emerging technology with significant promise in the field of wastewater treatment. Although generally more expensive than traditional metal salts, they have demonstrated superior phosphorus removal at lower dosages. In certain cases, this efficiency can render them cost-competitive with traditional metal salts. The use of rare earth chemicals is the most cost-effective in smaller facilities, typically those with flows around 1 MGD or less, as opposed to larger ones. These chemicals can achieve much lower phosphorus concentrations than traditional metal salts, enhance dewatering processes in filter presses and centrifuges, reduce sludge volume, and improve clarifier solids coagulation. Furthermore, rare earth chemicals are considered non-toxic and safer to handle compared to traditional metal salts, offering additional advantages in terms of operational safety and environmental impact. **It should be noted that at the time this document was written lanthanide salts were undergoing a trial for regulatory approval in the state of Michigan. The product is currently widely used in surrounding states in the Great Lakes region.**

[Table 3](#) outlines commonly used chemicals for phosphorus removal and provides the advantages and disadvantages of each, as well as estimated cost.



Table 3: Commonly Used Chemicals for Phosphorus Removal

CHEMICAL	COST	ADVANTAGES	DISADVANTAGES
FERROUS CHLORIDE	\$	•Efficient at removing TP. •Less pH impact than alum. •Cost effective. •Effective in reducing odor of hydrogen sulfide.	•High sludge production. •Corrosive and can create fouling on other equipment. •Requires safe handling due to corrosiveness. •May require pH adjustment. •Can impact UV disinfection
FERRIC CHLORIDE	\$\$	•Highly effective for phosphorus removal. •Works well in a variety of conditions. •Effective in reducing odor of hydrogen sulfide.	•Corrosive and can create fouling on other equipment. •Requires safe handling due to corrosiveness. •May require pH adjustment. •More expensive than ferrous. •Can impact UV disinfection
ALUMINUM SULFATE (ALUM)	\$\$	•Widely used and known for effectiveness. •Improves water clarity (turbidity reduction). •Less corrosive than iron salts.	•High sludge production. •Can lower pH and may require pH adjustment. •Toxicity is a concern at high doses.
POLY ALUMINUM CHLORIDE (PAC)	\$\$\$	•More efficient at lower doses than alum. •Less impact on pH. •Produces less sludge. •Less corrosive than iron salts.	•More expensive than alum and ferrous products. •Potential health risks associated with residual aluminum.
SODIUM ALUMINATE	\$\$\$\$	•Useful in high pH. •Does not decrease pH. •Less corrosive than iron salts. •Can help with filament control.	•High cost. •Limited availability to other coagulants. •Not as widely used.
RARE EARTH CHEMICALS	\$\$\$\$\$	•Extremely efficient at low doses. •Low sludge production. •Minimal impact on pH. •Nontoxic and safe to handle. •Low risk of freezing in very low temperatures, up to -40 F.	•High cost. •Newer technology and not as proven as traditional salts. •May not be as readily available as traditional salts.



2.2.3.2 Chemical Dosing Locations

Chemical dosing locations can vary from plant to plant, depending on the specific treatment process, chemical feed piping configuration, and the composition of the wastewater. Common dosing areas include pre-primary clarification, which helps solids settle out in the primary sludge, thereby enhancing removal efficiency early in the process. Pre-aeration dosing is often advantageous for ferrous chloride, as the iron becomes oxidized in the presence of oxygen, leading to the formation of better flocs with the Mixed Liquor Suspended Solids (MLSS). This aids in phosphorus removal and improves settling in the secondary clarifier. Post-aeration dosing is also effective, particularly when solids begin to settle out in the secondary clarifier, providing a final polishing step to achieve low phosphorus levels in the final effluent. When determining optimal dosing locations, it is important to consider adequate mixing, sufficient detention time, and appropriate dosing. [Figure 9](#) illustrates common chemical dosage locations throughout the treatment process.

In some instances, iron salts are fed at the head of the plant to mitigate odors associated with hydrogen sulfide (H₂S), leveraging the precipitative and oxidative properties of iron to control sulfide levels. Ultimately, the choice of chemical dosing location depends on several factors, including the type of chemical used, the characteristics of the wastewater, and the available feed points within the plant.

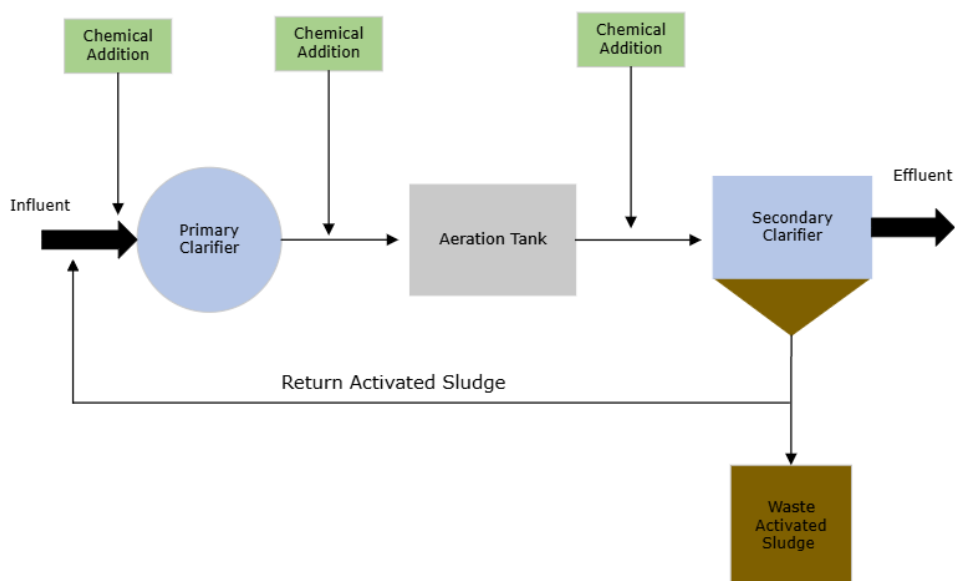


Figure 9: Chemical Dosing Locations

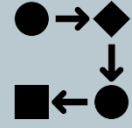
2.2.3.3 Advantages and Disadvantages

Chemical treatment for phosphorus removal remains a prevalent practice in wastewater treatment, offering consistent results with minimal operational oversight, which many facilities find appealing. The primary disadvantages of chemical treatment include concerns over the safe handling of chemicals, fluctuating costs, the production of biosolids, and the potential corrosiveness to infrastructure and plant equipment. Additionally, there are concerns related to freight logistics; with a limited number of freight drivers, costs may rise further, or shipments may be delayed, potentially leading to inadequate treatment. Supply chain issues, exacerbated by global disruptions, add another layer of complexity, affecting the availability and timely delivery of essential chemicals. This can pose significant challenges for water treatment operations, necessitating robust contingency planning and flexibility in treatment approaches to ensure uninterrupted service.

[Table 4](#) outlines the advantages and disadvantages of chemical treatment.



Table 4: Advantages and Disadvantages of Chemical Removal

Advantages	Disadvantages
Consistent results with minimum operational oversight 	Concerns over safe handling of chemicals 
	Fluctuating costs 
	Production of biosolids 
	Potential corrosion to infrastructure and plant equipment 
	Freight logistics may cause costs to rise or shipments to be delayed 
	Supply chain issues may affect availability or timely treatment of essential chemicals 
	Iron salts can interfere with the efficacy of UV light disinfection 

2.2.4 Chemical Treatment with EBPR

In some scenarios, the most effective strategy for phosphorus treatment involves a combination of both chemical treatment and Enhanced Biological Phosphorus Removal (EBPR). This approach is particularly relevant for facilities subject to very stringent total phosphorus (TP) limits, which might be challenging to meet using either method alone. Typically, EBPR serves as the primary treatment mechanism, with chemical dosing implemented as needed to ensure compliance with regulatory limits. When plants continually administer a polishing or maintenance dose, it can reduce the chemical's response time because a residual amount is already present in the system.

CHAPTER 3: Optimization Strategies

3.1 General Practices

3.1.1 Using Instrumentation for Optimization

Instrumentation is one of the most cost-effective ways to monitor and optimize wastewater phosphorus removal, particularly the EBPR process. Monitoring Oxygen Reduction Potential (ORP) and Dissolved Oxygen (DO) are critical for ensuring optimal biological treatment. Ideally, integrating inline sensors for ORP and DO into the aeration process and connecting them with the SCADA system represents the most efficient approach. However, handheld ORP and DO meters can also be valuable tools for assessing the effectiveness of the EBPR process. Inline sensors that provide real-time data to the SCADA system can be synchronized with the aeration process to maximize treatment efficiency while reducing energy consumption. Considering aeration is often the most energy-intensive part of wastewater treatment, investing in instrumentation can lead to significant energy savings, often offsetting the initial investment costs while also promising additional future savings. For more information and web links to specific instrumentation products applicable to these processes, see [Appendix C: Instrumentation Resources](#).

3.1.1.1 ORP Monitoring Strategies for Optimization

ORP can indicate the presence of anoxic or anaerobic conditions necessary for the initial phase of EBPR. During this phase, PAOs release phosphorus into the water and uptake VFAs as a carbon source. Essentially, ORP measures the extent of oxygen consumption relative to the activity of PAOs. ORP measurements are expressed in millivolts (mV). This measurement is particularly valuable for monitoring selector zones to ensure that conditions are optimal for PAOs to perform effective treatment. Additionally, ORP can assess PAO activity in the aerobic process and can be used in conjunction with DO levels to determine optimal DO setpoints. For plants aiming to optimize EBPR or establish biological phosphorus removal, ORP serves as an



excellent tool for identifying optimal treatment conditions. Once the initial selector zones are established, regular monitoring is essential to detect and address any operational upsets. Continuous monitoring of ORP within these specified ranges can optimize the entire EBPR process, ensuring efficient phosphorus removal while maintaining energy efficiency and operational stability. More information regarding ORP can be found at [Wastewater Blog ORP](#) and [YSI ORP](#).

Anaerobic Zone (-100 to -250 mV)

The Negative ORP range indicates reducing conditions necessary for PAOs to release phosphorus and uptake VFAs. If ORP is too high, it suggests oxidative conditions which are unfavorable for phosphorus release. Conversely, an excessively low ORP could indicate an overly strong reducing environment, which might suppress optimal microbial activity. Optimal treatment in the anaerobic zone typically occurs around an ORP of -250 mV.

Anoxic Zone (if present) (+50 to -50 mV)

This zone aims to reduce nitrates without introducing free oxygen. ORP readings near zero are ideal. Too high readings might indicate incomplete denitrification or oxygen presence, disrupting the process.

Aerobic Zone (+25 to +250 mV)

Positive ORP values indicate oxidative conditions where oxygen is present for PAOs to uptake phosphorus effectively. Too high ORP values in this zone can lead to over-aeration, which is energy-inefficient and can cause process disturbances such as excessive foaming or poor settling in clarifiers. In some instances, over-aeration can also have adverse effects on the anoxic and anaerobic zones if the excess DO makes its way backwards into those zones. Optimal treatment in the aerobic zone typically occurs around an ORP of +250 mV.

[Table 5](#) outlines the optimal ranges for ORP in the different process zones, identifies potential problems and causes when these zones are out of range, and suggests corrective actions to address these issues.



Table 5: ORP Optimal Ranges and Corrective Actions

PROCESS ZONE	EXPECTED ORP RANGE	POTENTIAL PROBLEM	POTENTIAL CAUSES	CORRECTIVE ACTIONS
ANAEROBIC ZONE	-100 to -250 mV	ORP too high (>-100 mV)	Presence of oxygen or nitrates, inadequate VFA availability.	Be sure no oxygen is entering the zone, ensure complete denitrification in prior stages, increase VFA supply.
		ORP too low (<-250 mV)	Excessive VFAs, reduced microorganism activity.	Reduce organic loading, adjust RAS rates, check microorganism health.
ANOXIC ZONE (IF PRESENT)	+50 to -50 mV	ORP too high (>+50 mV)	Incomplete denitrification, oxygen intrusion.	Confirm anoxic conditions, optimize denitrification process, be sure no excess oxygen is entering zone which may be caused by too much air in the aerobic zone
		ORP it too low (<-50 mV)	Over reduction.	Adjust process controls by increasing mixing, RAS rates, and internal recycling rates from the aerobic zone. Additionally increasing air in the aerobic zone and adjusting WAS rates can also create more favorable anoxic conditions.
AEROBIC ZONE	+25 to +250 mV	ORP too high (>+250 mV)	Over aeration, insufficient biochemical activity.	Decrease aeration rates, monitor microorganism health and activity.
		ORP too low (<+25 mV)	Inadequate aeration, high organic load.	Increase aeration, check for proper mechanical operation equipment.



3.1.1.2 DO Monitoring Strategies for Optimization

Measuring DO is one of the most crucial parameters in wastewater treatment. DO measurements are expressed in milligrams per liter (mg/L). In EBPR process, maintaining a balanced oxygen level is essential to ensure that PAOs have a favorable environment to remove phosphorus. Although DO measurement predominantly pertains to the aerobic zone, it can also be monitored in the anaerobic and anoxic zones to verify that conditions remain unfavorable for oxygen-dependent processes. Aside from optimizing process control, precise DO management can also lead to substantial energy savings.

[Table 6](#) outlines optimal DO ranges for each biological zone as well as control actions.

Table 6: Optimal DO Ranges and Corrective Actions

PROCESS ZONE	OPTIMAL DO RANGE	PURPOSE AND IMPACT	CONTROL ACTIONS
ANAEROBIC ZONE	0 mg/L	Ensures no oxygen is present to promote phosphorus release from PAOs and uptake of VFAs.	Ensure no oxygen is entering this zone. Reduce air in the aerobic zone if it is too high.
ANOXIC ZONE (IF PRESENT)	0.2 to 0.5 mg/L	Allows for denitrification without disturbing the phosphorus release process, maintaining a balance that supports subsequent phosphorus uptake in the aerobic zone.	Optimize RAS and mixing rates to maintain minimal but uniform oxygen concentration. Reduce air in the aerobic zone if it is too high.
AEROBIC ZONE	2 to 3 mg/L	Provides sufficient oxygen for PAOs to effectively uptake phosphorus, supporting aerobic metabolism without excessive aeration to promote energy efficiency.	Regularly calibrate and maintain DO sensors. Adjust aeration rates based on real time monitoring to maintain desired range.

Using ORP to Optimize DO Levels

ORP is generally a more reliable indicator in the anaerobic and anoxic zones; however, in the aerobic zone, DO is traditionally used as the primary process control parameter. Nevertheless, ORP can still play a significant role alongside DO for optimization purposes. By measuring ORP in the aerobic zone and correlating it with DO levels, operators can more precisely determine the optimal DO conditions necessary for efficient phosphorus uptake by PAOs.

For instance, although the typical optimal DO range in the aerobic zone is 2-3 mg/L, the ideal ORP range for effective phosphorus uptake is usually around +250 mV. If it is observed that the plant is achieving good phosphorus treatment (+250 mV) at a DO of 1.7 mg/L, and the plant



normally runs at a setpoint of DO 2.5 mg/L, then that facility might be over-aerating and not achieving the best EBPR treatment. Therefore, running at a lower DO setpoint might be better for the process.

It should be noted that continuously monitoring both ORP and DO in this instance is an important process practice, as they can indicate changes in the process. If the facility has the ability to have both inline ORP and DO sensors, being able to control air feed off of ORP can be very beneficial for EBPR.

3.1.1.3 Inline/Online Orthophosphate Analyzer

Inline/online orthophosphate analyzers are very effective in optimizing chemical treatment, especially in EBPR plants that only use chemicals as a polishing agent. They provide real-time monitoring, relayed to the plant's SCADA system, which can automatically activate a pump to dose chemicals at a specified rate, thereby adjusting the phosphorus levels to within the desired range. Leveraging such automated feedback mechanisms represents one of the most reliable and cost-effective strategies for ensuring consistent and efficient phosphorus removal.

3.1.1.4 Instrumentation Maintenance

Proper maintenance of DO and ORP probes is crucial for ensuring consistent and effective treatment, as well as for prolonging the lifespan of the instrumentation. Implementing a standard preventative maintenance protocol, which includes a detailed checklist and a regular schedule, is an effective strategy to ensure that an EBPR facility operates optimally at all times. Since ORP probes have an electrode, it is essential to keep this electrode in wet storage when not in use or submerged in the process to prevent it from drying out.

[Table 7](#) illustrates a general preventative maintenance protocol for DO and ORP instrumentation. It should be noted that these are general guidelines, and all maintenance tasks should be performed **according to the manufacturer's specifications**. The frequency and specifics of maintenance tasks may vary depending on the make and model of the sensors.



Table 7: General Instrumentation Maintenance Protocol

MAINTENANCE TASK	PROCEDURE	FREQUENCY	PURPOSE	DETAILS
CALIBRATION	Calibrate probes. Use solution for ORP.	ORP: Monthly DO: Bi-weekly (Per manufacturer's guidelines)	Ensures accuracy of readings by adjusting the probe to standard conditions.	Use calibration solutions specific to each probe type, if applicable. (Per manufacturer's guidelines)
CLEANING	Clean the probe sensors and membranes.	Weekly (Per manufacturer's guidelines)	Prevents fouling and ensures accurate sensor readings.	Gently brush the probe sensors with a soft spung under lukewarm water.
INSPECTION	Inspect the probe and cable connections.	Daily to Weekly	Check for any signs of wear or damage that could affect performance.	Look for cracks, leaks, or loose connections that could compromise probe function. Ensure waterproof seals are intact.
MEMBRANE REPLACEMENT (DO ONLY)	Replace the membrane cap.	Every 6 months (Per manufacturer's guidelines)	Maintains membrane integrity for accurate DO measurements.	Follow the manufacturer's guidelines to replace the membrane. Ensure the O-ring and membrane are properly seated.
ELECTROLYTE REFILL (ORP ONLY)	Refill the electrolyte solution.	Every 6 months or as per usage. (Per manufacturer's guidelines)	Ensures consistent and stable ORP measurements.	Use the recommended electrolyte solution and refill as directed in the probe manual.

3.1.2 Data Collection and Analysis

Regular data collection and analysis are critical to ensuring that EBPR processes operate at optimal levels. While some tests may be required for both raw influent and final effluent to comply with NPDES permit regulations, they are also crucial throughout the process for informed process control decisions. Conducting laboratory tests for process control is important for optimizing operations, troubleshooting, diagnosing issues, and enhancing biological activity.



Common tests that should be conducted for process optimization include Total Phosphorus, Orthophosphate, BOD, Nitrates, COD, and VFAs. Adequate data collection is essential because it reveals trends in the treatment process, which can be used to determine optimal treatment times, identify seasonal variations, and detect plant upsets. Furthermore, this data helps operators establish baselines, enabling them to make informed operational changes to optimize the process based on these baselines. It should be noted that not all these tests are mandatory, and there is some overlap between them. For more information and web links to specific lab tests and products applicable to these processes, see [Appendix B: Lab Testing Resources](#).

Total Phosphorus

Total phosphorus represents the sum of all forms of phosphates in wastewater and is often the regulatory focus for phosphorus removal. TP testing is typically limited in terms of immediate analysis due to the acid digestion process required for the samples. Consequently, it is not always the most efficient option for making quick operational decisions. Orthophosphate works just as well as a process control test due to its efficiency.

Orthophosphate

Orthophosphate is the soluble or reactive form of phosphorus. This test can be conducted without acid digestion, providing operators with quick results, typically within minutes. Operators can convert orthophosphate to phosphorus using a conversion factor. The general conversion factor from orthophosphate (as PO_4) to elemental phosphorus (P) is to divide the orthophosphate value by 3. This method is particularly useful in the anaerobic zone, where the effluent phosphorus concentration leaving the anaerobic zone should be 3 times higher than that of the influent. **It is important to note that when running an orthophosphate test on MLSS the sample should be filtered through a micron filter to remove any particulate matter that might interfere with the test.** This increase indicates that PAOs are releasing their phosphorus for VFA uptake. More information on phosphorus and orthophosphate, including conversions can be found at [EPA Phosphorus Testing](#).

Biochemical Oxygen Demand (BOD) and Carbonaceous Biochemical Oxygen Demand (CBOD)

BOD/CBOD is a 5-day test used to determine the organic strength of wastewater. This metric is critical in the EBPR process because a higher organic matter typically means a greater concentration of VFAs are present. Essentially, BOD/CBOD testing assesses whether there is a sufficient food source for PAOs. The ideal ratio of BOD to TP should be 20:1 or greater to ensure effective phosphorus removal. The main difference between BOD and CBOD is that CBOD uses a nitrification inhibitor to prevent false oxygen uptake by nitrifiers present. CBOD is only generally used by plants that are not required to remove nitrogen as part of their NPDES permit.



Chemical Oxygen Demand (COD)

COD testing is very similar to BOD testing; however, it measures all oxidizable matter as opposed to strictly aerobic biodegradable matter. Additionally, the test can be completed in just 3 hours, as opposed to 5 days, providing operators with more timely data to assist with operational decisions. The COD to phosphorus ratio should be at least 45:1.

Nitrates

Nitrate is an oxidized form of nitrogen, generated by the nitrification process. Measuring nitrate levels is crucial in the anaerobic and in side streams to ensure that no denitrifying bacteria are present. These bacteria could interfere with the EBPR process by utilizing available carbon sources that are necessary for PAOs. Alternatively, nitrates should be present in the anoxic zone to indicate that denitrification is occurring.

Volatile Fatty Acid (VFA)

As VFAs are the food source for PAOs in the anaerobic zone, it is critical to ensure that sufficient VFAs are present. According to the Manual of Practice No. 29, pg. 272, between 5 to 10 mg/L of VFAs are needed to remove 1 mg/L of phosphorus. It should be noted that measuring BOD or COD can be just as effective when evaluating VFA concentrations.

[Table 8](#) outlines the tests described above and their desired sampling locations. For a more detailed breakdown of what the optimal ranges should be for each zone of biological treatment see [3.2 Diagnosing the EBPR Process](#).

Table 8: Sampling Collection Points

TESTING PARAMETER	SAMPLING LOCATIONS
TOTAL PHOSPHORUS	Raw influent, primary effluent, side streams, and final effluent
ORTHOPHOSPHATE	Raw influent, primary effluent, anaerobic zone, and final effluent
BOD	Raw influent and primary effluent
COD	Raw influent and primary effluent
NITRATE	RAS, anaerobic zone, aerobic zone, and side streams
VFA	Beginning of anaerobic zone



3.2 Diagnosing the EBPR Process

The key to having a successful EBPR process relies on understanding each part of the process, the operating parameters for each step, and the data and monitoring required to ensure optimal operating conditions. The use of instrumentation and lab testing are the most important ways to diagnose and troubleshoot the EBPR process.

[Figure 10](#) illustrates the optimal sampling locations and parameters throughout the entire treatment process to diagnose the EBPR process. It should be noted that not all of the parameters and locations are applicable or required for every wastewater plant, as each plant is different.

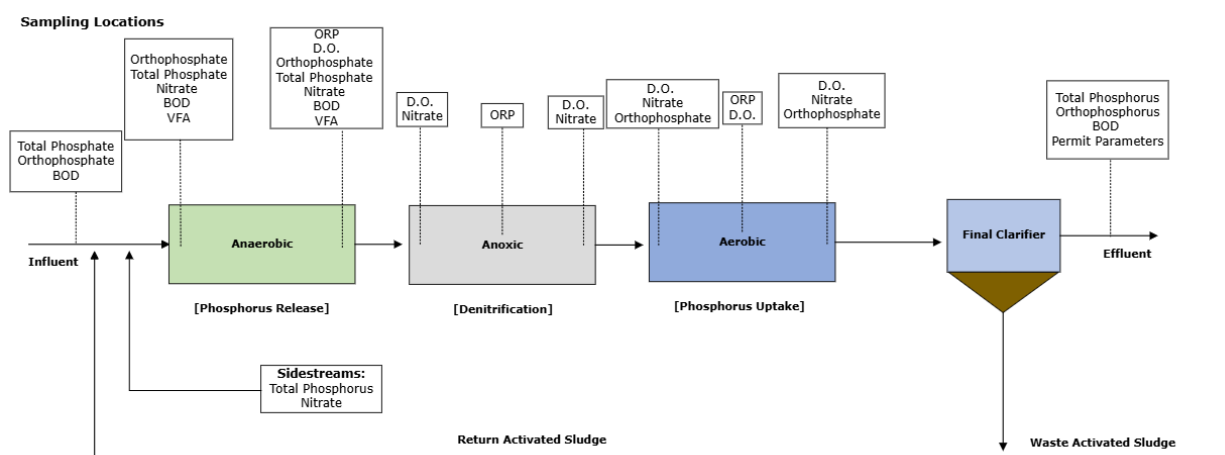


Figure 10: Sampling Locations for EBPR Process

3.2.1 Nutrient Profile

The first step towards diagnosing a process is to get a baseline of how things are currently running. This can be done by performing a nutrient profile, testing for nitrate, phosphorus, and BOD as outlined for each zone. Once that data is gathered and analyzed, operators can make process adjustments accordingly and utilize instrumentation to fine-tune the process of each zone, as outlined in the tables that follow. All of the required testing and sample points are broken down in the following sections. Please refer to [Figure 10](#), [Table 9](#), [Table 10](#), and [Table 11](#) when performing a nutrient profile.

3.2.2 Diagnosing the Anaerobic Zone

The most important aspects of the anaerobic zone in the EBPR process are ensuring the absence of oxygen and nitrifying bacteria, the availability of a sufficient amount of VFAs, and

that PAOs are actively releasing phosphorus and up taking VFAs. An ORP range of -100 to -250 mV indicates that phosphorus release is occurring and that there is no dissolved oxygen present. Additionally, testing for phosphorus and nitrates provides precise insight into the conditions within this zone. Additional information regarding ORP problems and corrective actions can be found in [Table 5](#).

Phosphorus should be tested at the beginning of the anaerobic zone and again at the end. The concentration of phosphorus should be three times higher at the end of the zone, indicating that phosphorus release has occurred by the PAOs. Orthophosphate testing is generally preferred because it takes only a few minutes, whereas total phosphorus testing can take hours.

Nitrate tests should also be performed at the beginning and the end of the zone and should be undetectable, indicating that there are no nitrifiers present that would outcompete the PAOs for VFA uptake.

VFA and BOD tests can be conducted to ensure that there is enough carbon for the PAOs. BOD should be measured at the front and the end of the anaerobic zone. A reduction in BOD from the front to the end of the zone indicates that VFAs are being consumed by the PAOs. VFA tests are not necessary if BOD tests are being run, as BOD is a broader measurement of biodegradable organic matter, encompassing various forms of carbon. A sufficient BOD ratio is 20:1 to total phosphorus, and VFA should be in the range of 5 to 10 mg/L for 1 mg/L of total phosphorus.

[Table 9](#) illustrates sampling protocol for the anaerobic zone and includes testing parameters, sampling locations, desired concentrations, and potential issues if results are out of range.



Table 9: Anaerobic Zone Sampling Protocol

TESTING PARAMETER	PURPOSE	SAMPLING LOCATIONS	DESIRED RANGE	POTENTIAL PROBLEMS
ORP	To ensure that P release is happening.	End of anaerobic zone.	-100 to -250 mV	If the range is too high nitrifiers may be present. If the range is too low conditions may be too septic.
D.O.	To ensure that denitrification isn't occurring.	End of anaerobic zone.	0 mg/L	If oxygen is present, check for air entering the anaerobic zone. This can sometimes happen from over aerating the aerobic zone.
ORTHOPHOSPHATE OR TOTAL PHOSPHORUS	To ensure P release is happening.	Front and end of anaerobic zone.	3 times higher concentration at the end of the anaerobic zone.	If phosphorus is not higher at the end of the zone, P release is not occurring. If phosphorus is 4 or more times higher conditions may be too septic.
NITRATE	To ensure nitrifiers aren't present.	Front and end of anaerobic zone and RAS.	0 mg/L	If nitrates are present, check for D.O. entering the anaerobic zone. If D.O. is present, it is likely that back mixing of oxygen is taking place. Lower D.O. in the beginning of the aerobic zone or extend the anaerobic zone, if possible. If nitrates are present in RAS, adjust return rates.
BOD	To ensure there is a food source for PAOs.	Front and end of anaerobic zone.	20:1 ratio at the front of the basin and a reduction at the end of the basin.	If ratio is low entering the zone, increase carbon source. If there is not a reduction from the front to the end of the zone, ensure there is adequate mixing and no D.O. entering the zone.
VFA	To ensure there is a food source for PAOs.	Front and end of anaerobic zone.	5 to 10 mg/L for 1 mg/L of total phosphorus.	If ratio is low entering the zone, increase carbon source. If there is not a reduction from the front to the end of the zone, ensure there is adequate mixing and no D.O. entering the zone.



3.2.3 Diagnosing the Anoxic Zone

If the plant is equipped with an anoxic zone, the most important aspect to monitor is that denitrification is occurring. It is crucial to ensure that nitrification occurs only in the aerobic zone, not in the anoxic zone, because nitrification in the anoxic zone would indicate the presence of oxygen, which would disrupt the process. Nitrates should be present in the anoxic zone as they are the substrate for denitrifying bacteria, but they should be reduced by the end of this zone. There should also be little to no oxygen present, as it would interfere with the denitrification process.

An ORP range of +50 to -50 mV indicates suitable conditions for denitrification. Additionally, running nitrate tests at the beginning and end of the anoxic zone is essential. At the beginning of the anoxic zone, nitrate tests should show the presence of nitrates, indicating that nitrification in the preceding aerobic zone was effective. By the end of the anoxic zone, nitrate levels should be low or undetectable, indicating that denitrification is successfully occurring.

It is also important to ensure that nitrates do not end up in the anaerobic zone, as this would lead to competition between denitrifying bacteria and PAOs for VFAs, preventing PAOs from effectively taking up VFAs.

[Table 10](#) illustrates a sampling protocol for the anoxic zone and includes testing parameters, sampling locations, desired concentrations, and potential issues if results are out of range.

Table 10: Anoxic Zone Sampling Protocol

TESTING PARAMETER	PURPOSE	SAMPLING LOCATIONS	DESIRED RANGE	POTENTIAL PROBLEMS
ORP	To ensure denitrification is occurring.	Front, middle, and end of the anoxic zone.	+50 to -50 mV	If ORP is high, check for D.O. If ORP is low, there may not be nitrifiers present.
D.O.	To ensure denitrification is occurring.	Front and end of the anoxic zone.	0 to 0.5 mg/L	If D.O. is present, make sure oxygen is not entering the anoxic zone. Make sure there is no excess oxygen in the aerobic zone that is making its way back into the anoxic zone.
NITRATE	To ensure nitrifiers are present to denitrify.	Front and end of anoxic zone.	There should be higher concentrations at the front of the anoxic zone and a reduction close to 0 at the end.	If there is no reduction, make sure DO is not entering the zone. DO would likely be back mixing from the aerobic zone.



3.2.4 Diagnosing the Aerobic Zone

The main purpose of the aerobic process in EBPR is to ensure that PAOs are up taking phosphorus and that nitrification is occurring. Maintaining consistent DO levels of 2-4 mg/L is crucial for ensuring phosphorus uptake and nitrification. It is important to avoid excessive D.O. levels, especially at the beginning of the zone, because excessive D.O. can migrate back into the anoxic zones and interfere with the denitrification process. ORP levels of +25 to +250 mV indicate that there is sufficient oxygen in the zone and that phosphorus uptake by PAOs is occurring. Additional information regarding ORP and D.O. problems and corrective actions can be found in [Table 5](#) and [Table 6](#).

Orthophosphate should be measured at the beginning of the aerobic zone, where high levels are expected, and again at the end, where there should be a significant reduction, indicating that PAOs have removed phosphorus from the wastewater.

Nitrate levels should also be monitored to ensure that the nitrification process is working correctly and not interfering with EBPR. Nitrates should be measured at the beginning of the aerobic zone, where they should be low, and again at the end of the zone, where they should be significantly higher, indicating that the nitrification process is functioning correctly.

[Table 11](#) illustrates a sampling protocol for the aerobic zone and includes testing parameters, sampling locations, desired concentrations, and potential issues if results are out of range.

Table 11: Aerobic Zone Sampling Protocol

TESTING PARAMETER	PURPOSE	SAMPLING LOCATIONS	DESIRED RANGE	POTENTIAL PROBLEMS
ORP	To ensure PAOs are up taking P.	Middle and end of the aerobic zone. Middle being optimal.	+50 to +250 mV	If ORP is outside of desired range, check and adjust D.O.
D.O.	To ensure PAOs are up taking P.	Front, middle and end of aerobic zone. Middle being optimal.	2 to 4 mg/L	If D.O. is out of range, adjust air feed accordingly.
NITRATE	To ensure that nitrification is occurring.	Front and end of anoxic zone.	Concentrations should be lower at the front of the zone and higher at the end.	If there is not an increase in nitrates at the end of the basin, check air feed and microbiology.
ORTHOPHOSPHATE	To ensure PAOs are up taking P.	Front and end of anoxic zone.	Concentrations should be higher at the front and significantly reduced at the end of the zone.	If concentrations don't reduce significantly at the end of the aerobic zone, check, and adjust D.O.



3.3 Biological Treatment Optimization

EBPR involves numerous variables that can influence its effectiveness, making consistent operation challenging. However, various cost-effective practices are available to optimize and streamline the process. These strategies often involve modest investments in instrumentation and laboratory testing or enhancements to treatment that leverage existing infrastructure and processes in innovative ways.

3.3.1 Side Stream Management

Side streams in wastewater treatment typically refer to flows of water or wastewater that diverge from the main flow entering the treatment plant. These are usually flows that have already been processed in some capacity within the treatment facility and are temporarily extracted from the conventional treatment process before being reintroduced at a later stage. The most well-known side streams are Return Activated Sludge (RAS) and Waste Activated Sludge (WAS), which are critical to daily operational procedures and are regularly monitored and adjusted.

Optimizing RAS and WAS can significantly enhance the EBPR process. Other side streams, such as return liquor (decant) from aerobic and anaerobic digesters, centrate from dewatering processes, and high-strength waste loads from haulers like septic loads, are less frequently monitored. These streams are often high in total phosphorus (TP) and can adversely affect the EBPR process. Therefore, strategic management of these side streams is crucial.

While it is typically essential to minimize the disruptive effects of side streams on the EBPR process, in certain cases, the VFAs present in them can be utilized as a strategic resource to promote phosphorus removal. Effective side stream management involves not only routine monitoring and adjustment but also incorporating strategies to utilize beneficial components within these streams to optimize the EBPR process.

[Table 12](#) outlines common solid parameters, how to control them, the optimal ranges, and potential problems with corrective actions when they are out of range. Please note that these are general guidelines and will vary significantly depending on the facility. Additionally, if a facility is attempting to implement or optimize EBPR for the first time, solids parameters will likely change from previous methods of operation.



Table 12: Solids Optimization Protocol

PARAMETER	CONTROL	OPTIMAL RANGE	POTENTIAL PROBLEMS	CORRECTIVE ACTIONS
MCRT ALSO KNOWN AS SRT (DAYS)	Wasting	5-15 days (Conventional Activated Sludge) 15-30 days (Oxidation Ditches)	Insufficient PAO growth: Not enough sludge age to support PAO proliferation, leading to inadequate phosphorus release in the anaerobic zone.	Extend MCRT: Adjust wasting rates to increase sludge age, ensuring adequate time for PAO development and function.
SVI (ML/L)	Wasting	80 to 150 mL/L 100 being optimal	High SVI: Indicates poor settleability which can lead to washouts of PAOs in the anaerobic zone.	Improve Settleability: Optimize aeration patterns and check for the presence of filamentous bacteria; adjust MLSS concentration if necessary.
WAS RATE (%)	Pump speed	Dependent on MCRT, MLSS, and or F/M.	Excessive Wasting: Leads to loss of PAOs, reducing the phosphorus release capacity. Low WAS Rate: Causes accumulation of old sludge, decreasing the efficiency of phosphorus release in the anaerobic zone.	Increase HRT: Adjust inflow rates or tank volumes to ensure sufficient hydraulic retention time for process stability. Increase WAS Rate: Manage old sludge removal effectively to rejuvenate the biomass.
HRT (HOURS)	Return Rate	1-3 hrs. (anaerobic zone)	Short HRT: Not enough contact time for adequate phosphorus release and VFA uptake by PAOs in the anaerobic zone. High HRT: Secondary phosphorus release can occur due to VFA depletion and PAOs release	Increase HRT: Adjust RAS rates by decreasing return to allow for proper phosphorus release and VFA uptake by PAOs in anaerobic zone. Decrease HRT: Increase RAS rates by increasing return, increase influent flow if possible, or shorten



F/M	Wasting	0.2 to 0.5 (Conventional Activated Sludge) 0.03 to 0.10 (Oxidation Ditches)	additional phosphorus. High F/M Ratio: Overloading with organics can lead to excessive VFAs that PAOs cannot effectively utilize, causing imbalance in the anaerobic zone.	selector zone, if possible. Adjust F/M Ratio: Decrease wasting rates to restore balance of PAOs and VFAs.
MLSS (MG/L)	Wasting or MCRT	1,000-4,000 mg/L	Low MLSS: Insufficient biomass to absorb VFAs effectively, leading to reduced phosphorus uptake in aerobic conditions.	Increase MLSS: Adjust RAS and WAS rates to maintain higher biomass concentrations.
RAS RATE (%)	Pump Speed	Dependent on final clarifier blankets and anaerobic zone HRT.	Low RAS Rate: Inadequate recirculation of PAOs back to the anaerobic zone, impairing phosphorus release.	Increase RAS Rate: Increase RAS rate to boost PAO return to the anaerobic zone, improving VFA uptake and phosphorus release.

3.3.2 Creating Zones within Conventional Activated Sludge Systems

A cost-effective approach to converting a conventional activated sludge system into an EBPR process involves creating anaerobic and aerobic zones within the aeration basin. This approach is similar to creating zones in oxidation ditches. If the aeration basins are equipped with shutoff valves for multiple air zones, operators can shut off the air supply to the front zones of the basin, creating an anaerobic selector zone where phosphorus-accumulating organisms (PAOs) can release phosphorus through fermentation. This is possible only if there is physical separation within the basin to control air delivery in individual parts of the basin.

The remaining zones of the aeration basin will continue to supply air, allowing PAOs to uptake phosphorus in aerobic conditions. To prevent solids from settling out in the anaerobic zone due to the absence of air, it is advisable to "air bump" the front zone for about 15 minutes per day by briefly opening the air valve. While effective in the short term, this method is less efficient compared to installing submersible mixers, which would offer better mixing and reduce the operational burden of manual air bumping. Although installing mixers incurs upfront costs, it could ultimately save money on energy by reducing the need for aeration in that part of the basin. For a case study on related to converting a conventional activated sludge plant to EBPR, see [5.7 Conroe, TX](#).



Key factors to consider when implementing this approach include Hydraulic Retention Time (HRT), back mixing of oxygen, baffling, and nutrient monitoring.

Hydraulic Retention Time (HRT):

HRT is a quick calculation to determine if the system has the capacity to accommodate EBPR. The calculation for HRT, and an example for determining these rates applicable to anaerobic and aerobic conditions, can be found in [Appendix D: Hydraulic Retention Time Calculation](#).

Nutrient Monitoring:

Nutrient monitoring is essential to optimize the process when applying the zoning strategy. It helps ensure that each zone is performing as expected. See section [3.2.1 Nutrient Profile](#) for a comprehensive breakdown on monitoring for each zone.

Back Mixing of Oxygen:

Back mixing of oxygen can occur when there is no physical separation between anaerobic, anoxic, and aerobic zones, allowing oxygen to leak into anaerobic areas and disrupt the process. To minimize back mixing:

1. Avoid overfeeding dissolved oxygen (DO) at the beginning of the aerobic zone.
2. Create an extended oxygen-free buffer zone (extend the anaerobic and or anoxic zone if possible.)
3. Install physical barriers or baffles. Cost-effective solutions might include hanging metal sheeting from the sides of the basin to create a barrier, improving mixing and preventing oxygen backflow.

3.3.3 Return Activated Sludge and Waste Activated Sludge Optimization

RAS and WAS rates in EBPR are two of the most crucial components for successful TP removal. Proper management of RAS and WAS rates ensures that the PAO population is maintained at optimal levels to effectively remove phosphorus from wastewater. Key parameters to ensure that PAOs remain in an optimal range include Sludge Age or Mean Cell Residence Time (MCRT) also known as Solids Retention Time (SRT), Sludge Volume Index (SVI), Mixed Liquor Suspended Solids (MLSS) concentration, Food to Microorganism Ratio (F/M), and Hydraulic Retention Time (HRT). MLSS, MCRT, and F/M are closely related parameters; most plants tend to focus on one rather than the others. However, understanding all three provides operators with comprehensive evidence they can use to optimize the process. It is important to note that every plant has different treatment methods, operates differently, and has a unique wastewater makeup; therefore, generalized guidelines might not always apply to every plant. However, they provide a good starting point. From there, it is up to the operators to determine the most optimal ranges for their specific facility. [Table 12](#) outlines general guidelines for optimal ranges, potential problems, and corrective actions based on how these ranges affect the EBPR process.



3.3.4 Aerobic Digester Return Liquor Optimization

The aerobic digestion process involves breaking down the organic matter in WAS under aerobic conditions. Through this process, the volume of sludge disposal is reduced through concentration. Due to the high organic concentrations in the WAS, this presents a unique opportunity for VFA production under anaerobic conditions. In other words, the digester can serve as a fermentation tank and produce VFAs and PAOs by cycling air on and off. For this process to be successful, the aerobic digester must have a way to send return liquor or supernatant back to the head of the plant. Most aerobic digesters have a draw-down tube or telescopic valve that allows the supernatant to return to the head of the plant while the solids settle at the bottom of the digester when the air is off. Phosphorus release will occur during air-off cycles, and this can be a challenge if not managed correctly, as it will make its way back to the head of the plant as supernatant. However, with proper monitoring and operation, the digester can serve as a fermentation tank, allowing plants to produce VFAs and PAOs if they do not currently have the ability to do so.

Using aerobic digestion as a fermenter is a cost-effective method for creating VFAs and PAOs. While this process allows for PAO and VFA production, it can also save significant energy. By cycling air on and off for periods of time, anaerobic conditions form, favoring VFA production from the settled sludge when the air is off. Since WAS naturally contains PAOs, they will release phosphorus during the air-off cycles and uptake VFAs. During the air-on cycles, PAOs will consume the released phosphorus as they multiply. It typically takes 7 to 10 days for PAOs to consistently reproduce, but as the population begins to strengthen, they can be sent back to the head of the plant to effectively uptake phosphorus in the aeration process. During air-on cycles, the telescopic or overflow valve should be lowered into the water to capture the active PAOs and return them to the head of the plant. Some control parameters are as follows:

- 2-3 hours should be targeted for air-on and off cycles.
- During air-off cycles, ORP readings should stabilize around -250 mV, indicating optimal conditions for VFA formation and uptake.
- According to the U.S. Environmental Protection Agency's *Oxidation Ditches* [webinar](#) (2022), a general rule of thumb is to return about 10% of your daily WAS to ensure a consistent process.

These are general guidelines, and it will be up to operators to develop their own set of operational parameters based on their plant. For additional information on sidestream fermentation see the *Sidestream Fermentation* section in [3.3.9 Optimization Strategies for Oxidation Ditches](#). For additional information on ORP, see [3.1.1.1 ORP Monitoring Strategies for Optimization](#). For a successful case study on this process, see Case Study [5.6 Parsons, KA](#).



3.3.5 Controlling Centrate from Dewatering Processes

Centrate from dewatering is one of the most common contributors to side stream phosphorus. Dewatering equipment such as Gravity Belt Thickeners (GBT), Centrifuges, Dissolved Air Flotation (DAF), and Belt Filter Presses are among the more commonly used technologies. As they dewater and thicken the solids, the excess water that is removed—generally high in phosphorus, as well as BOD, TSS, and Ammonia—usually gets returned to the head of the facility. These high-strength loads can substantially impact the EBPR process, particularly by driving TP levels up and making it harder for PAOs to perform effectively.

The best course of action in controlling centrate is to monitor and regularly test the centrate for P to understand the concentrations being returned to the head of the plant. With this knowledge, operators can make informed decisions about wasting, phosphorus chemical removal, and other operational adjustments that may be impacted by the concentration of centrate.

Another strategy is to time the operation of dewatering equipment to balance the load of the centrate, if possible. For instance, if a plant has a night operator and experiences low TP loadings at night, running the dewatering equipment in the evening could balance out the loadings. This approach avoids higher loadings during the day and leads to more consistent treatment.

Regular monitoring of side stream concentrations and comparing data over long-term trends are crucial and play an important role in EBPR.

3.3.6 Septage and High Strength Waste

Septic and holding tank waste can be very high in organic matter, especially phosphorus. Due to these high organic loads, they can disrupt the treatment process. Septage haulers typically arrive sporadically, and their unpredictability can complicate plant operations, particularly affecting the EBPR process. However, septic loads aren't entirely detrimental and can be beneficial to EBPR. Because septage is usually very high in organic matter, it also tends to be rich in VFAs, which are advantageous for EBPR, especially if a plant struggles to produce sufficient VFAs from its normal loadings. Due to the unpredictable nature of septic loads, they should be closely monitored. A good practice is to take a sample from each load and record the date and time; this information can be crucial in pinpointing the source of any disturbances.

In terms of using septage for optimization, if a plant has an old or extra basin not currently in use, a beneficial strategy could be to convert it into a holding tank for septic discharge. This septage can then be gradually added to the head of the plant as needed to ensure a consistent supply of VFAs and organic matter, thereby enhancing TP removal. This process should be controlled by monitoring the anaerobic zone with ORP measurements and pumping septage into the zone as needed to maintain a stable ORP range of approximately -200 to -250 mV. For additional information regarding ORP, see section [3.1.1.1 ORP Monitoring Strategies for Optimization](#). For a case study on optimizing EBPR with septic waste, see [5.1 Cedarburg, WI](#).



3.3.7 Secondary Phosphorus Release

Secondary phosphorus release refers to the unintended release of phosphorus back into the water during treatment, following its biological uptake, which can lead to reduced TP removal efficacy. Some common causes of secondary phosphorus release include: excessively long anaerobic zone retention time, prolonged retention time of settled sludge in the final clarifier, extended retention time in the aerobic stage, and long-term storage of WAS, causing phosphorus to be released back into solution and returning to the biological process via side streams. Table 13 outlines some potential causes of secondary phosphorus release and corrective actions.

Table 13: Secondary Phosphorus Release Corrective Actions

PROBLEM	CAUSE	CORRECTIVE ACTION
RAPID PHOSPHORUS UPTAKE IN AERATION BASIN BUT FINAL EFFLUENT TP IS HIGHER	Secondary release occurring in aeration basin	Monitor TP profile of aeration basin; reduce SRT by wasting more sludge
	Secondary release occurring in sludge blanket in final clarifier due to excessive anaerobic conditions	Check phosphorus in RAS and sludge blanket in final clarifier; reduce sludge blanket depth by increasing return rate
	If phosphorus increases at end of anoxic zone, secondary release occurring with excessive HRT	Monitor phosphorus profile through anoxic zone; reduce anoxic zone HRT if possible
GOOD PHOSPHORUS RELEASE IN ANAEROBIC ZONE BUT POOR PHOSPHORUS REMOVAL BOD/TP RATIO HAS CHANGED	If anaerobic HRT is too long, secondary release could occur after VFAs are used up	Monitor TP profile through selector basins; increase RAS to reduce anaerobic HRT
	High phosphorus in side stream recycles	Monitor BOD, TP, and orthophosphate in raw influent to anaerobic zone, control volume of side stream phosphorus removal

3.3.8 Optimizing with Mixing

Proper mixing is a critical component of the EBPR process. It optimizes contact between microorganisms and substrates, prevents settling and stratification, and maintains uniform distribution within the reactor. Mixing plays a unique role in each selector zone, which means that specific guidelines govern how mixing should be conducted in each zone.

Anaerobic Zone

Mixing in the anaerobic zone is essential for encouraging the release of phosphorus from PAOs and the uptake of VFAs in this zone. Mixing is purely mechanical and is generally maintained at a low intensity to ensure that no oxygen is introduced into the process, which is crucial for the anaerobic metabolism of PAOs.



In many EBPR plants, mixing does not need to be continuous; intermittent mixing can be sufficient. This approach helps in managing energy costs while still facilitating effective contact between PAOs and VFAs. If a plant struggles with VFA production, reducing the intensity of mixing—or employing intermittent mixing—can help promote better septic conditions, which are conducive to the fermentation processes necessary for enhancing VFA production. In some instances, running mixers for as little as 15 minutes a day can be enough to promote the most optimal conditions for VFA production. For more information on successful mixing optimization, see Case Study [5.1 Cedarburg, WI](#).

Anoxic Zone (if present)

The primary purpose of mixing in the anoxic zone is to facilitate denitrification. Contrary to the needs of nitrifying bacteria, which oxidize ammonia to nitrate and require dissolved oxygen, denitrifying bacteria operate under oxygen-free conditions. Therefore, mixing in the anoxic zone is designed to keep the contents evenly distributed and to prevent the reintroduction of dissolved oxygen, which would inhibit the denitrification process. The intensity of mixing should be moderate and similar to the anaerobic zone.

Aerobic Zone

Mixing in the aerobic zone is critical for facilitating the uptake of phosphorus by polyphosphate-accumulating organisms. In this zone, these organisms require not only contact with phosphorus but also a sufficient supply of dissolved oxygen, which they use for energy production and growth. Therefore, mixing here serves two main purposes: to maintain uniform distribution of oxygen and to enhance contact between these organisms and the phosphorus in the wastewater.

Unlike the purely mechanical mixing in the anaerobic and anoxic zones, mixing in the aerobic zone involves both mechanical mixing and the strategic introduction of air or pure oxygen. This is typically achieved through aeration systems that vigorously disperse oxygen throughout the tank. The intensity of mixing and aeration in this stage is usually managed based on a dissolved oxygen setpoint, which ensures that adequate oxygen levels are maintained to meet the metabolic needs of the polyphosphate-accumulating organisms and to keep the process mix uniform across the basin.

3.3.9 Optimization Strategies for Oxidation Ditches

Depending on the type of oxidation ditch a plant has, optimization strategies might be somewhat limited, but there are three potential options that operators can explore to optimize their process, even if the ditch's capabilities seem limited. According to the U.S. Environmental Protection Agency's Oxidation Ditches [webinar](#) (2022), the three options are creating zones, cycling air on and off, and side stream fermentation. As with all optimization options, they will differ from plant to plant, and it will be up to operators to develop a proper operational strategy



using process control methods to find the right settings for their operation. Developing optimal operation can often take weeks and months of trial and error to determine what works best for your facility. When attempting to employ any of these strategies, it is important to properly monitor and diagnose the process along the way to ensure that things are working properly.

Please see sections [3.1.2 Data Collection and Analysis](#), [3.2 Diagnosing the EBPR Process](#), and [3.3.3 Return Activated Sludge and Waste Activated Sludge Optimization](#) on how to diagnose and monitor the EBPR process.

Creating Zones

Creating zones in an oxidation ditch involves modifying certain areas or spaces within the ditch to serve specific functions that they may not have been initially designed for. While most oxidation ditches are equipped with an aerobic zone and often an anoxic or anaerobic zone, ditches are often missing one of the three zones or may not have been designed for complete nutrient removal, focusing instead on either nitrogen or phosphorus removal. Operators may need to create additional zones to achieve EBPR.

To create these zones, operators can modify the operations of mixers and aerators. For example, if a plant is equipped for only nitrogen removal and has an anoxic and aerobic zone, then turning off the aerators for extended periods in one ring of the aerobic zone can create an anoxic zone that will aid the denitrification process. By closing down any recycling gates in the initial anoxic zone, it then becomes anaerobic, allowing PAOs to release phosphorus and uptake VFAs. For case studies of plants that have successfully employed this strategy, see Case Studies [5.3 Great Bend, KA](#) and [5.4 Bradford, OH](#).

Cycling Air On and Off

This strategy still incorporates some of the methods used in creating zones but cycling air on and off can be a very effective way to improve the EBPR process and save on energy costs. Many facilities tend to over-mix and sometimes add too much air to their process, which can interfere with EBPR. Similar to the zone creation strategy, cycling air on and off in the aerobic portion of the ditch can create anoxic or anaerobic conditions, thereby forming a temporary fermentation zone.

One of the key benefits of cycling air on and off is its ability to produce VFAs, particularly if a plant is underloaded and struggling with VFA production. By turning off the air for extended periods and allowing organic material to break down under septic conditions, the material can convert to VFAs. Utilizing ORP and DO instrumentation can be extremely helpful with this strategy, as it allows for real-time monitoring of conditions and better control of the process to prevent overly septic conditions. For case studies of plants that have successfully employed this strategy, see Case Study [5.5 Onedia, TN](#).



Sidestream Fermentation

Considering that some plants struggle with VFA production, sidestream fermentation can be an effective way to address this shortfall. Sidestream fermentation involves taking WAS and allowing it to ferment in an anaerobic environment to produce VFAs. The VFA-rich supernatant is then sent back to the head of the plant, making these VFAs available for PAOs to uptake.

Since an anaerobic environment is necessary for fermentation, the sludge settles out, and in most cases, the decant or supernatant, which contains the VFAs, is sent back to the head of the plant. This practice can generally occur in any tank or process that has the capability to return liquid to the head of the plant, such as gravity thickeners, sludge holding tanks, or digesters. For example, in an aerobic digester, this method may involve creating septic conditions by cycling air on and off to ensure proper fermentation. For case studies of plants that have successfully employed this strategy, see Case Study [5.6 Parsons, KA](#).

3.3.10 SBR Optimization Strategies

According to the U.S. Environmental Protection Agency's *Sequencing Batch Reactor* [webinar](#) (2022), the two most common methods of optimizing EBPR in SBRs are side stream fermentation and maximizing air on and off phases. Both of these strategies have been covered in previous sections of this document, but more process-specific information can be found below.

Sidestream Fermentation

Side stream fermentation is a viable alternative for wastewater treatment plants that have low raw influent BOD and face challenges in VFA production. If a plant has a sludge holding tank, aerobic digester, or any other type of tank where WAS can be transferred and allowed to remain under anaerobic conditions, the organics can break down and produce VFAs, making side stream fermentation a practical option.

The plant must have the capability to pump a portion of these solids back into the SBR. A general guideline is to pump approximately 10% of the plant's WAS to a holding tank, such as an aerobic digester, and hold it for about 2-10 days. During this time, air is cycled on and off to facilitate the breakdown of organics and VFA production. After the fermentation phase, a portion of the sludge should be cycled back to the SBR.

It is crucial to monitor the tank conditions during fermentation to prevent excessive septic conditions. This can be achieved by measuring ORP and sampling orthophosphate levels. Optimal ORP values should be in the range of -200 mV to -300 mV. Orthophosphate levels should ideally be three times higher at the end of the air-off cycle. If conditions exceed these limits, indicating excessive septic conditions, the air should be turned back on sooner. For more



information regarding ORP and orthophosphate sampling see section [3.1.1.1 ORP Monitoring Strategies for Optimization](#) and for a related case study, please see [5.6 Parsons, KA](#).

Maximizing Air On and Off Cycles

Similarly to side stream fermentation, maximizing air on and off cycles follows many of the same principles for VFA production and phosphorus release. Optimizing these cycles relies heavily on monitoring. Using ORP and conducting orthophosphate tests will provide the necessary process control data to fine-tune the air cycles, ensuring maximum VFA production and proper phosphorus release during the air off cycles, as well as proper phosphorus uptake during the air on cycles. ORP ranges during the air off cycles should be between -200 mV to -300 mV, with orthophosphate levels approximately three times higher at the end of the cycle. During the air on cycles, ORP should be around +250 mV. Additionally, it is important to monitor nitrogen levels to ensure that nitrification and denitrification processes do not interfere with the EBPR process. For more information regarding ORP and orthophosphate sampling, see [3.1.2 Data Collection and Analysis](#) and [3.1.1.1 ORP Monitoring Strategies for Optimization](#). For a successful case study, see Case Study [5.2 Abilene, KA](#).

3.4 Chemical Treatment

Chemical treatment for phosphorus removal is far less complicated than EBPR; however, there are multiple strategies that can be used to ensure it achieves its maximum removal potential. In some instances, chemical optimization can save significant amounts of money by utilizing jar testing to determine the optimal chemicals and dosages, evaluating molar ratios, assessing pH levels, and changing chemical addition points. Operators can then use this information to effectively assess their chemical usage and the types of chemicals they employ to enhance their phosphorus removal performance. Additionally, inline phosphorus sensors can be a very useful tool in achieving adequate chemical dosing. More information on inline phosphorus sensors can be found in section [3.1.1.3 Inline/Online Orthophosphate Analyzer](#).

3.4.1 Jar Testing

Jar testing offers a straightforward and cost-effective method for evaluating a plant's chemical treatment performance. As a laboratory procedure, it simulates and optimizes the coagulation/flocculation processes integral to water and wastewater treatment plants. This bench-scale test enables operators to identify the most effective types and dosages of coagulants or flocculants required to meet specific water quality goals. Furthermore, jar testing facilitates the evaluation of alternative chemicals, potentially revealing more suitable options that enhance a plant's operation. It aids in optimizing chemical dosages to reduce expenses and in assessing the impact of different dosing locations on treatment efficacy. A standard jar testing protocol for wastewater phosphorus removal can be found at [Appendix A: Chemical Phosphorus Jar Testing Protocol](#).



Utilizing the jar testing results to create a dosage table is one of the most cost-effective approaches to optimizing chemical usage. In this instance, it creates a balance of not overdosing or underdosing the chemical.

The most effective approach to creating a dosage table involves performing jar tests on the chemical using samples from the intended dosing point in the wastewater treatment process. For instance, if the intended chemical feed point is post-aeration MLSS, then the jar tests should be conducted using a sample from this location.

Once the jar tests are complete, calculate the results as a percentage of removal. After determining the removal percentage, analyze the data to identify the most cost-effective and optimal dosage. Daily samples should be taken just upstream of the chemical dosage point, and the results should be correlated to the dosage chart to determine the appropriate chemical dosage. Alternatively, a dosing table can be created based on the molar ratio, although jar testing will provide the most optimal data.

3.4.2 pH Adjustment

pH plays a critical role throughout the wastewater treatment process, especially in the chemical removal of phosphorus. This is largely because metal salts, which are commonly used in this process, can significantly alter the chemical makeup of the wastewater. When these salts are added, they often decrease the pH, making it challenging to maintain pH balance. For instance, the most effective pH range for alum is typically between 5.0 and 7.0, while for iron salts, it is between 6.5 and 7.5. However, these salts can still be effective outside these ranges to some extent.

Table 14: Chemical pH Ranges

CHEMICAL	OPTIMAL PH RANGE
ALUMINUM SALTS	5.0 – 7.0
IRON SALTS	6.5 – 7.5

When it is difficult to maintain optimal pH ranges, additional chemicals may need to be added to adjust the pH. Often, the pH will tend to be lower after the addition of metal salts, requiring the addition of a base to raise the pH back to an optimal range.

Rare earth chemicals, a newer technology in wastewater treatment, show promise in affecting the wastewater chemistry minimally when used in the process. These chemicals do not significantly lower alkalinity or alter water pH, thus often eliminating the need for additional pH-adjusting chemicals.

As with any significant chemical adjustments in wastewater treatment, conducting jar tests should be the first step. These tests assess the chemical reactions between the phosphorus



removal chemicals and the specific wastewater being treated, helping to determine the most effective treatment strategy before implementing broader changes. Additional information on chemical pH ranges can be found at [Phosphorus Treatment and Removal Technologies](#).

3.4.3 Chemical Molar Ratios

The molar ratio in chemical phosphorus removal refers to the ratio of the moles of the chemical coagulant added to the wastewater to the moles of phosphorus present. This ratio is crucial for determining the effectiveness of phosphorus removal and ensuring economical usage of chemicals. While utilizing the molar ratio provides a quick and straightforward way to assess your chemical feed rates, it does not account for other variables in the wastewater that could impact the efficiency of chemical precipitation, such as pH, temperature, and total suspended solids (TSS). Nonetheless, it offers a general estimate of where dosages should be in relation to the phosphorus concentrations present. A spreadsheet that includes an automatic molar ratio calculation can be found [here](#).

A practical approach for assessing molar ratios is to take a sample just upstream of the chemical feed point to test the phosphorus concentration, then correlate this concentration with the appropriate molar ratio for the chemical being used. Although jar testing remains the most informative method for fine-tuning chemical dosages, molar ratios can serve as a preliminary guide and be used in conjunction with jar testing results to determine optimal dosage rates.

3.4.4 Two-Point Chemical Addition

In some cases, plants have the ability to feed chemicals in multiple locations. If this is possible, two-point addition can be an effective way to maximize phosphorus removal. Since these chemicals act as precipitants and separate phosphorus from the wastewater through sedimentation, effective dosing locations should be before the primary and secondary clarification processes. Dosing right before the primary clarification process allows for initial phosphorus removal, as phosphorus will precipitate with the primary sludge, thereby reducing the amount of phosphorus entering the secondary treatment process. Then, dosing again as the MLSS leaves the aerobic process and enters the final clarification, ensures any remaining phosphorus precipitates out in the final clarifiers. Splitting up the chemical dosing between these two stages of treatment can offer a higher percentage of removal as well as potential cost savings. [Figure 11](#) illustrates a standard two-point chemical treatment process.



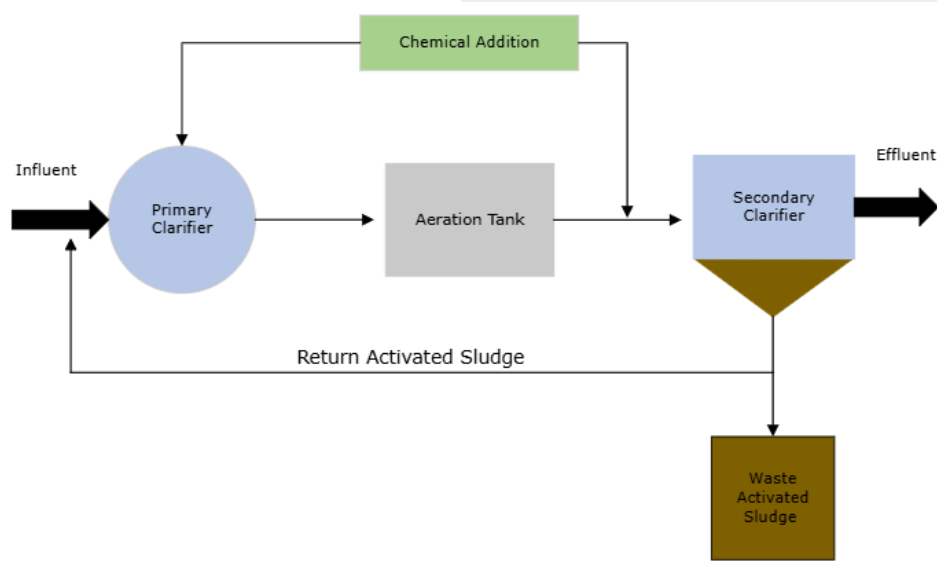


Figure 11: Two-Point Chemical Addition

CHAPTER 4: Source Control and Pretreatment

Source control and pretreatment are crucial not only for identifying the sources of phosphorus within the collection system but also for reducing it through point source control. By minimizing phosphorus at the source, the load entering the wastewater treatment plant is reduced, making it easier and more cost-effective for the plant to achieve lower regulatory limits.

4.1 Sewer Use Ordinance

Identifying major sources of phosphorus is the first step in reducing the burden of high phosphorus loads entering the collection system. Due to stricter regulations, most household product manufacturers have significantly reduced the amount of phosphorus in their products in recent years, leading to lower phosphorus contributions from domestic sources. Common major industrial sources include dairies, food processing facilities, metal finishers, hospitals, schools, and car washes. Source control can be effectively implemented by regularly monitoring these industrial sources known for high phosphorus usage.

Source control and monitoring can be successfully implemented through a Sewer Use Ordinance (SUO). An SUO is a regulatory document used by municipalities to govern the use of public and private sewer systems. It typically includes regulations on discharges, pretreatment requirements, fees and charges, enforcement, and penalties. By employing these mechanisms, utilities can hold industries accountable for their discharges into the sewer system, ensuring compliance with the limits outlined in the ordinance. This approach significantly reduces the load on wastewater treatment facilities. An example of an SUO can be found at [GLWA SUO](#).

Another significant but less-discussed source of phosphorus is the use of phosphates in drinking water systems. Phosphates are often employed to sequester iron and serve as a coating agent, preventing lead from leaching into the drinking water from lead service lines. Despite progress in removing lead service pipes from water distribution systems, it is likely that utilities will continue to use phosphorus-based chemicals to prevent lead leaching until all lead components are completely eliminated. For WWTPs, options to control this source of phosphorus remain limited. However, a practical approach may involve collaborating with the local water utility to explore safe, joint efforts to reduce the use of phosphorus-based inhibitors.

4.2 Industrial Pretreatment Program

An Industrial Pretreatment Program (IPP), typically a component of a SUO, mandates that industrial facilities treat their wastewater to remove harmful pollutants before discharging it into the municipal sewer system. IPPs involve issuing permits to industrial users, monitoring their discharges, enforcing compliance with pretreatment standards, and performing inspections and sampling. An important aspect of an IPP is conducting unannounced visits to industrial facilities, which help ensure compliance beyond what is observed during scheduled inspections. An example of an IPP can be found at [GLWA IPP](#).

4.3 Adaptive Management Programs

In addition to Sewer Use Ordinances and Industrial Pretreatment, several adaptive management opportunities are available to help reduce phosphorus in source water. For combined sewer systems, this can include implementing green stormwater infrastructure like rain gardens, bioswales, and permeable pavements to help reduce the volume of water and the concentration of pollutants that get sent to the wastewater treatment plant. Some states have implemented an Adaptive Management Program which allows wastewater treatment facilities to partner with landowners, municipalities, agricultural producers, and others to implement programs to reduce nonpoint source pollutants within the watershed in order to meet water quality requirements. While Michigan does not currently have a regulated Adaptive Management Program at this time, MIEGLE has released an adaptive management plan, “Michigan’s Adaptive Management Plan to Reduce Phosphorus Loading into Lake Erie” that outlines current progress and future plans for implementing Adaptive Management Programs.

CHAPTER 5: Case Studies

Much of this document has outlined different strategies and ways to optimize the phosphorus removal process. This section presents distinct case studies where many of the outlined strategies have been used in real-world scenarios and have proven to be successful.



5.1 Cedarburg, WI



Figure 12: Cedarburg WWTP

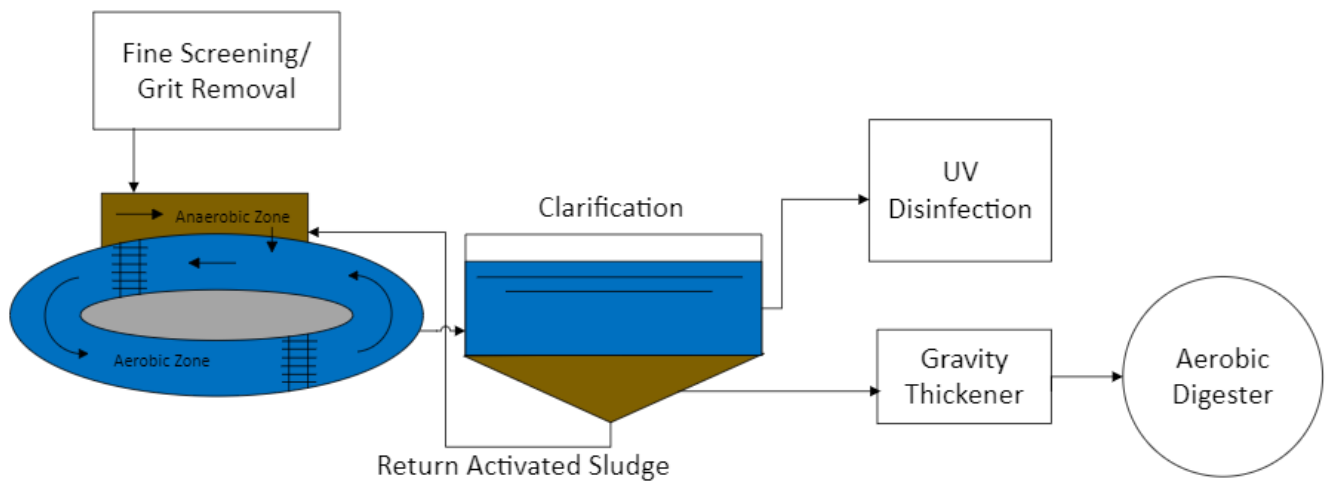


Figure 13: Cedarburg WWTP Process Diagram

SECONDARY TREATMENT	SIZE MGD	POPULATION SERVED	OPTIMIZATION	PHOSPHORUS RESULTS
OXIDATION DITCH (TYPE 3) WITH FERROUS CHLORIDE	2.3 MGD (Avg Flow) 8.0 MGD (Peak Design Flow)	12,000	Surface aerator VFD upgrade, mixing optimization, instrumentation upgrades and septic hauling optimization.	1.0 mg/L (Limit) 0.7 mg/L (Before) 0.3-0.4 mg/L (After)

Background: The City of Cedarburg WWTP is a type 3 oxidation ditch. The process configuration is slightly different from most type 3 ditches in that the anaerobic zone is situated in the middle of the ditch, with the flow then moving to the outer ring and working its way inward towards an outfall to the final clarifiers. The plant has an average flow rate of 2.3 MGD, with a peak flow design of 8 MGD, and serves a population of 12,000 people. There is limited industry, which can sometimes result in inconsistent VFA production. The plant also employs ferrous chloride as a polishing agent.

In 2015, the Wisconsin Department of Natural Resources conducted a TMDL with a goal to significantly reduce phosphorus levels in the Milwaukee River basin, into which Cedarburg discharges. The potential reduction in WWTP discharge standard was from 1.0 mg/L down to 0.3 mg/L, and in some cases, even as low as 0.1 mg/L. Cedarburg plant was able to achieve 0.7 mg/L of phosphorus concentration in their treated final effluent. To proactively respond to the potential regulatory changes, Cedarburg WWTP opted to create an internal optimization strategy aimed at achieving stricter limits and preventing the need for a substantial capital upgrade.

Optimization Efforts: There were two main parts to Cedarburg's optimization efforts:

- Upgrading instrumentation and adding VFDs to the surface aerators, and
- Optimizing their septic hauler receiving to increase VFA production.

Cedarburg's oxidation ditch comprised of six surface aerators, which initially had constant speed drives. The constant speed drives not only used excessive energy but also resulted in over-mixing. The plant obtained grant money through a partnership with "Focus on Energy," a Wisconsin-based program collaborating with energy providers, residents, and businesses to identify energy efficiency-related cost-saving opportunities. Through this program, the facility replaced all six constant speed aerator drives with new ABB VFDs, replaced old Royce cathode DO probes with new YSI optical probes, added a YSI ORP probe in the outer ring, and covered all SCADA programming costs. The grant did not fund the entire project, but it reduced the overhead costs substantially.

With the addition of VFDs and new instrumentation, operators were able to better control the DO in the oxidation ditch, significantly decrease mixing in the outer ring and create an extended anaerobic zone. Operators also removed some of the mixing paddles from the aerators on the outer ring to introduce even less oxygen when running as well as changed the run times from 15



minutes every hour to 15 minutes every 4 hours. ORP and DO were both constantly monitored and trended on SCADA in the outer ring to ensure optimal anaerobic conditions. Operators also fine-tuned the amount of DO in the aerobic zones of the ditch, creating optimal conditions for PAOs to uptake phosphorus.

Aside from the equipment upgrades and modifications, the city also had an offsite septic receiving station about a mile from the treatment plant. The city decided to close the dump site and force septic haulers to discharge directly at the WWTP. The concentrated loading, undiluted by other flows en route from the dump site, had an immediate impact on the WWTP. The reduced travel distance meant that loadings would reach the oxidation ditch in 20-30 minutes instead of several hours.

As septic loads are high in VFAs, this provided the WWTP with an abundance of food for the PAOs, further optimizing the EBPR process. The addition of ORP and DO probes empowered operators with a real-time approach to refining the process, along with the addition of VFDs on the aerators. This enabled closer monitoring and optimization of DO levels, better mixing control, and a reduction in the use of ferrous chloride, although not its complete elimination.

Results: Through the success of equipment and instrumentation upgrades, process optimization, and operational control, the Cedarburg WWTP managed to reduce phosphorus levels from an average of approximately 0.7-0.8 mg/L to a consistent range of 0.3-0.4 mg/L, with occasional readings as low as 0.2 mg/L. Notably, due to the lack of septic loads, particularly during weekends, it remained necessary to continue a "maintenance" dose of ferrous chloride to act as a buffer during instances when the EBPR process wasn't operating optimally.

Despite initial financial investments, the returns from energy and chemical savings were substantial. With the assistance of grants, the projected payback period was approximately two years. Although the plant eventually faced new limits of 0.8 mg/L, Cedarburg managed to achieve considerable cost reductions and even surpassed its targets for total phosphorus through optimization efforts.



5.2 Abilene, KA



Figure 14: Abilene WWTP

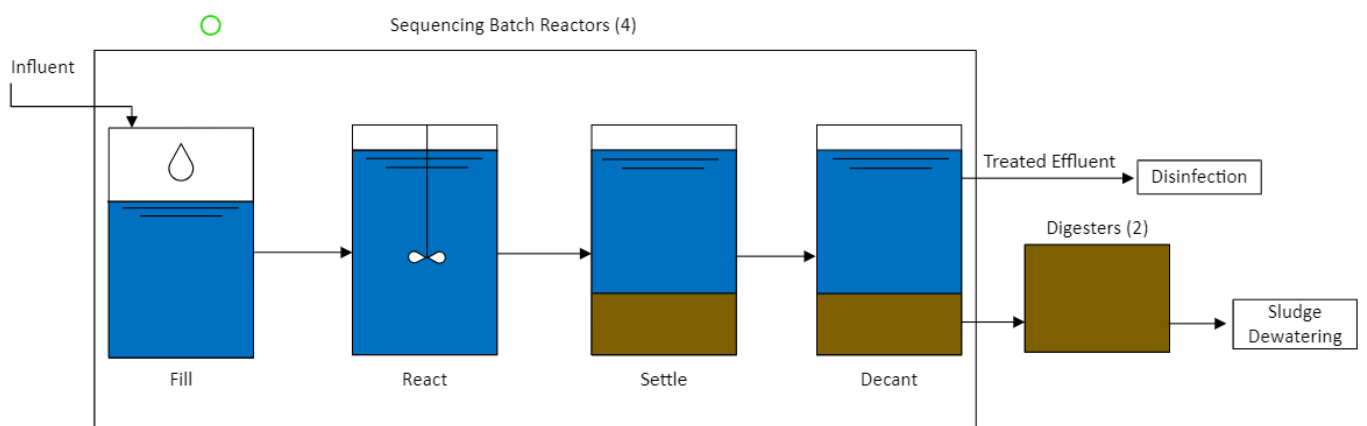


Figure 15: Abilene WWTP Process Diagram

SECONDARY TREATMENT	SIZE MGD	POPULATION SERVED	OPTIMIZATION	PHOSPHORUS RESULTS
ACTIVATED SLUDGE (SEQUENCING BATCH REACTOR)	0.5 MGD (Average Flow) 1.5 MGD (Design Flow)	6,400	Air cycling	1 mg/L (Limit) 2 mg/L (Before) <1 mg/L (After)

Background: The City of Abilene Wastewater Treatment Plant is a sequencing batch reactor plant with 4 sequencing batch reactors and two digesters. The plant is designed for 1.5 MGD but treats an average of 0.4 to 0.6 MGD. Sequencing batch reactors are designed for nitrogen removal, but the plant operators have been able to adjust the air cycle times in the sequencing batch reactors to efficiently and effectively remove phosphorus.

Optimization Efforts: There was one method that Abilene implemented to optimize their EBPR process:

- Cycling air off long enough to create septic environments for VFA production, but not long enough that secondary phosphorus release would occur.

In typical sequencing batch reactor operation, one or more reactors are aerated while other reactors are idle. The aerated sequencing batch reactor converts ammonia to nitrate under aerobic conditions, and with the BOD in the raw influent and under anoxic conditions, the nitrate is converted to nitrogen gas and removed from the system. The sludge in the idle reactor is allowed to settle and clean water is decanted from the top.

The Abilene Wastewater Treatment Plant operators adjusted the timing of the air on and off cycles in the reactors to optimize the process to treat not only nitrogen, but phosphorus as well. They adjusted the air off cycle time to be long enough for the reactor to become a septic environment for volatile fatty acid (VFA) production in the settled sludge blanket that phosphorus accumulating organisms (PAOs) will consume. However, they noticed that as the settled cycle got longer, the PAOs eventually died off and re-released phosphorus. Therefore, they adjusted the timing so it was long enough for VFA production but short enough that phosphorus would not be re-released. Part of the timing optimization is also to create an environment to remove the nitrate so there is no competition for the PAOs to consume the VFAs. This is done by keeping the cycles short enough so that all of the flow can be nitrified and denitrified.

Results: The average total phosphorus in the raw influent is 9 mg/L and the average in the final effluent is 1 mg/L. There is no chemical addition for phosphorus removal and the cycling of air benefits the plant with less energy consumption. While this process was not designed specifically for phosphorus removal, it has been successful in creating the proper environment for nutrient removal, allowing the plant to meet permit requirements without additional cost or equipment.



5.3 Great Bend, KA



Figure 16: Great Bend WWTP

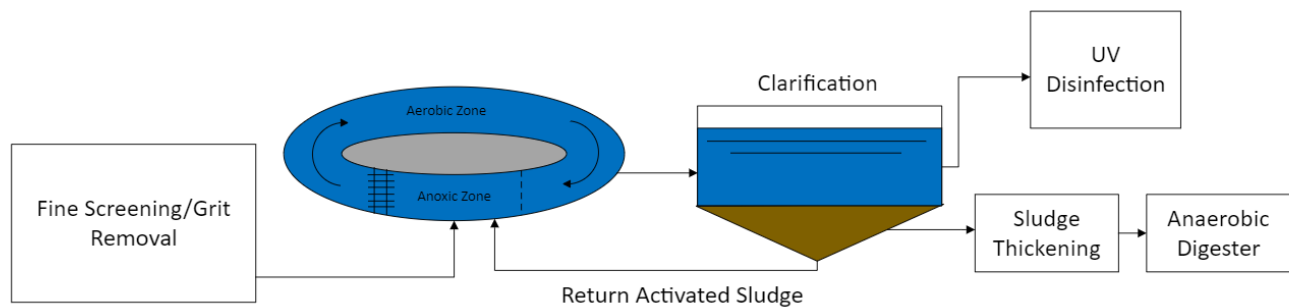


Figure 17: Great Bend WWTP Process Diagram

SECONDARY TREATMENT	SIZE MGD	POPULATION SERVED	OPTIMIZATION	PHOSPHORUS RESULTS
OXIDATION DITCH (TYPE 2)	1.28 MGD (Avg Flow) 3.6 MGD (Design Flow)	15,000	Converted anoxic zone to fermenter, surface aerator VFD upgrade and addition of DO probe.	1.0 mg/L (Limit) 2.0 mg/L (Before) 0.5 mg/L (After)

Background: The Great Bend WWTP is a type 2 oxidation ditch that serves 15,000 people and has an average flow of 1.28 MGD with a design flow of 3.6 MGD. In April 2020, the city received a letter from KDHE informing them of new nutrient limits: 10 mg/L total nitrogen and 1 mg/L total phosphorus. The facility does not employ any chemical treatment for phosphorus removal. To meet these new limits, the facility had two potential options: optimize their current process with low investment costs or spend \$6 million on a plant upgrade.

Optimization Efforts: There were two main parts to Great Bends optimization plan:

- Converting the anoxic zone into a fermenter, and
- Upgrading aerator drives to VFDs and adding DO probes.

A two-step plan was developed to operate the main body of the ditch to continue removing ammonia while also removing nitrates. This involved using the pre-anoxic zone, originally designed for nitrate removal, for phosphorus reduction. The second step involved adjusting the pre-anoxic zone to become anaerobic and function as a fermenter.

One of the main changes that made this possible was the installation of a VFD on the surface aerator. This gave operators much better control over DO levels. The ability to control the DO feed with the aerator at different speeds, rather than an all-or-nothing approach, and to constantly monitor the DO levels, gave operators significantly more control over their aerobic process. This helped control nitrogen levels and create an anoxic environment in the ditch, allowing the pre-anoxic zone to become anaerobic and aid EBPR. Operators made several DO setpoint adjustments over the course of weeks, generally making DO adjustments of 0.1 mg/L at a time.

The second step involved closing the gate that lets recycle flow from the ditch into the pre-anoxic zone. By closing the gate, nitrifying bacteria were kept out of the pre-anoxic zone, making it anaerobic. The pre-anoxic zone also had a mixer, which was adjusted to run for only 15 minutes per day rather than constantly, allowing solids to settle out and become completely septic. In these septic conditions, solids settled out and produced VFAs. As the flow then passed into the main body of the ditch, the PAOs released phosphorus and took up VFAs in the now anaerobic zone, then took up phosphorus in the aerobic zone.

Results: The results that Great Bend achieved through these optimization efforts were significant. They were able to lower their phosphorus levels from 2.0 mg/L to 0.5 mg/L and their nitrogen levels from 10 mg/L to 6 mg/L, avoiding a \$6 million capital upgrade. Overall, the plant invested roughly \$50,000 in VFD upgrades, DO sensor investments, and SCADA programming costs. However, these costs are offset and pay for themselves over time due to the significant amount of energy being saved.



5.4 Bradford, OH

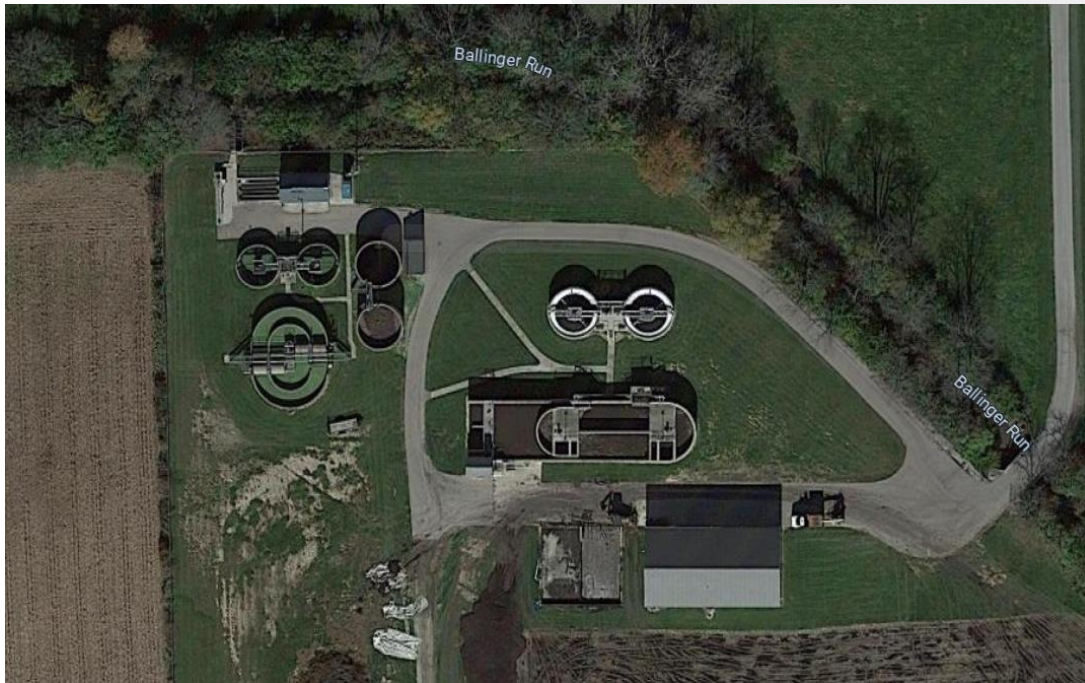


Figure 18: Bradford WWTP

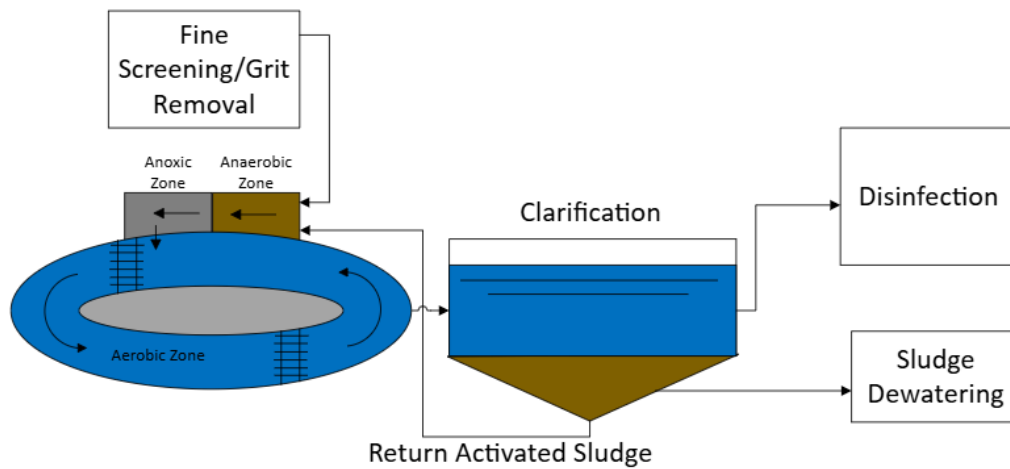


Figure 19: Bradford WWTP Process Diagram

SECONDARY TREATMENT	SIZE MGD	POPULATION SERVED	OPTIMIZATION	PHOSPHORUS RESULTS
OXIDATION DITCH (TYPE 4)	.048 MGD (Design Flow) 0.55 MGD (Avg Flow)	2,000	Nutrient profiling, DO and mixing optimization, fermentation	1.0 mg/L (Limit) 0.9 mg/L (Average)

Background: The Village of Bradford, Ohio WWTP adheres to conventional biological wastewater treatment methods, utilizing an oxidation ditch for the biological process. With an average flow rate of approximately 0.55 million gallons per day (MGD) and a design capacity of 0.48 MGD, it experiences high levels of inflow and infiltration (I&I). The current treatment plant is relatively new (construction completed in 2013) and was brought online as part of a larger project to discontinue the combined sewer infrastructure in the village. Even with the separation of the sewer and storm drain infrastructure, Bradford has experienced fluctuations in the raw influent and has struggled to meet permit requirements, including the 1 mg/L total phosphorus final effluent limit, because of the large amounts of I&I still making its way into the collection system. Through an innovative process optimization approach, the plant was able to meet the total phosphorus final effluent limit consistently and save money on energy consumption and chemical usage.

Optimization Approach: There were three main optimization methods that Bradford implemented:

- Performing a nutrient profile to diagnose the EBPR process,
- Lowering aerator speeds to optimize the nitrification/denitrification process in the oxidation ditch, and
- Installing timers on mixers in the anaerobic and anoxic zones and minimizing internal recycling rates to create a large fermentation zone.

The initial step taken in the optimization process for Bradford was to develop a nutrient profile through the system's two anaerobic tanks, anoxic tank, and the oxidation ditch. This nutrient profile showed that the system had large levels of nitrate, causing the anaerobic tank to be unable to reach anaerobic conditions. This discovery allowed the focus of the optimization to be reducing the nitrate concentrations in the system.

The system was currently set up to recycle nitrate, but this internal recycling was not necessary to meet permitting requirements because there is no limit for total nitrogen. Therefore, the recycle gate was partially closed (and later fully closed following positive results) and reduced the nitrate in the tanks to around 6 mg/L.

The downstream aerator of the oxidation ditch had previously been turned off and the upstream aerator was turned down from 55 Hz to 38 Hz using the previously installed VFDs. This encouraged nitrification-denitrification on the downstream end of the oxidation ditch and reduced the nitrate going to the anoxic tank. This also caused the DO to drop slightly (by less



than 0.3 mg/L). The ammonia increased slightly but remained well below the permit limits, allowing for the full closure of the nitrate feed gate.

These steps to reduce the nitrate were successful but the soluble carbon in the wastewater was too low to allow denitrification of the return activated sludge (RAS) and phosphate release. This was addressed through process control modifications to create a fermentation zone in the anaerobic and anoxic tanks. Timers installed on the in-line mixers in these tanks were used to shut down the mixers for 3.5 hours and then turn them back on for 0.5 hours. The nitrates in the settled sludge that formed while the mixers were off were denitrified and carbon was released, allowing the phosphorus accumulating organisms (PAOs) to release orthophosphate.

Results: The optimization process dropped the total phosphorus below the monthly permitted average of 1 mg/L. The levels were low enough that the plant shut off the alum feed for chemical phosphorus removal and was still able to meet the permit requirements. The nitrate levels have also been low following the adjustments.

Following the optimization, the plant only exceeded the total phosphorus limits one month out of the 7 observed during the study period. In this month, the plant was subjected to approximately double the design flow for the month.

The plant operators have implemented nutrient profiling across the system once or twice a week and have continued to see positive results from the optimization strategies. The optimization process for the plant costs very little to implement, with the only facility upgrades being to add timers to the mixers. The plant is saving approximately \$1,000/month on alum and has reduced energy consumption through the efficient cycling of the mixers. With the proper tools now in hand, the plant is able to continue monitoring the process for nutrient levels and make adjustments as needed to meet the target final effluent requirements.



5.5 Oneida, TN



Figure 20: Oneida STP

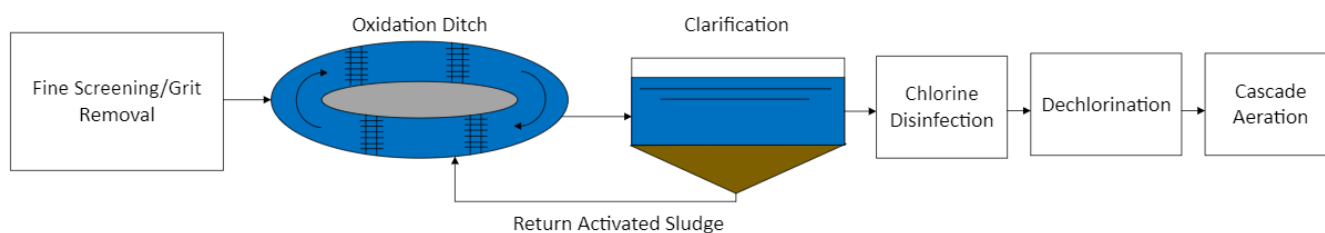


Figure 21: Oneida STP Process Flow Diagram

SECONDARY TREATMENT	SIZE MGD	POPULATION SERVED	OPTIMIZATION	PHOSPHORUS RESULTS
OXIDATION DITCH	0.998 MGD (Avg Design Flow)	3700	Air Cycling, Reduced Mixing, Process monitoring	0.9 mg/L (Before) 0.3 mg/L (After)

Background: The Town of Oneida STP treats municipal wastewater via oxidation ditch followed by chlorination, de-chlorination and cascade aeration. The plant's average design flow is 0.998 MGD and serves a population of roughly 3700 people. The plant reduced energy usage and improved nutrient removal performance through operational optimization efforts.

Optimization Efforts: The optimization process involved modification of the operation of Oneida's oxidation ditches. Instead of the four rotors running 24/7, the following changes were made:

- The aeration rotor nearest the influent was turned off, and
- The other three rotors were cycled on for the three hours and off for the three hours.

This change resulted in a big improvement in final effluent phosphorus concentration and total nitrogen removal. However, the plant was still experiencing seasonal phosphorus spikes.

To remedy that, the plant implemented an effective biological phosphorus monitoring strategy. With the help of a spectrophotometer provided by the Tennessee Department of Environmental Quality (TDEC), the staff monitored the effects of different operational changes. They achieved the best phosphorus removal by discontinuing the use of mixers that historically operated when the aeration rotors were off. This reduction in mixing allowed an anaerobic layer of settled mixed liquor to form during rotor-off periods, which created optimal conditions for biological phosphorus removal. During the summer months, however, the settled sludge became overly septic, necessitating the operation of one of the two mixers to prevent phosphorus spikes in the final effluent.

Results: The Oneida STP achieved compliance with regulatory limits for phosphorus discharge into local water bodies. Optimization efforts also resulted in improved overall plant efficiency and reduced operational costs associated with energy usage.



5.6 Parsons, KA



Figure 22: Parsons WWTP

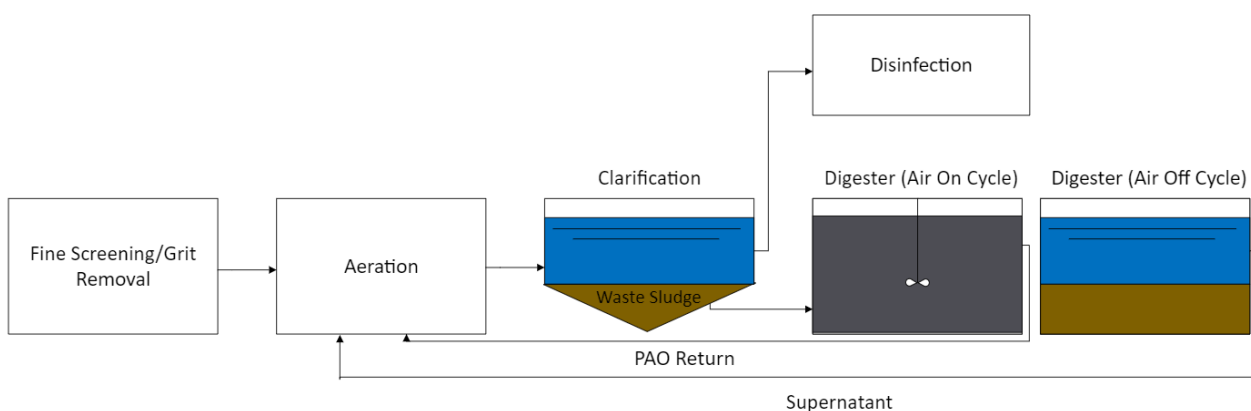


Figure 23: Parsons WWTP Process Diagram

SECONDARY TREATMENT	SIZE MGD	POPULATION SERVED	OPTIMIZATION	PHOSPHORUS RESULTS
PACKAGE PLANT	1.6 MGD (Average Flow) 2.5 MGD (Design Flow)	9,700	Side Stream Fermentation	1 mg/L (Limit) >0.5 mg/L (Before) 0.2 mg/L (After)

Background: The wastewater treatment plant for the City of Parsons, Kansas is a conventional activated sludge package plant that is designed to treat 2.5 MGD. The plant implemented

several upgrades to their treatment system that were designed to target nitrogen removal. The innovative process was also found to reduce total phosphorus in the final effluent, allowing the plant to meet the permitting requirements and serve as an example for an innovative approach to nutrient removal.

Optimization Efforts: The City of Parsons WWTP has made several changes to their facility. The trickling filters and old clarifiers have been placed out of service and new plant equipment includes three aerobic digesters and an aeration basin around the two clarifiers as part of a conventional active sludge package plant using a continuously sequencing reactor process.

The three digesters are programmed to cycle air off and on at the same rate and time, typically half and half. The process of cycling air through the digesters allows them to act as fermentation tanks when the air is off for a long enough period of time, creating septic conditions and allowing volatile fatty acid (VFA) production. This energizes the phosphorus accumulating organisms (PAOs). When the digesters then enter the aerated cycle and the sludge is wasted, telescoping valves are lowered to allow the energized PAOs to flow back to the headworks to enter the aeration process and uptake phosphorus. Without wasting the sludge during the aerated cycle and without a long enough air off cycle, only relatively clean water would be wasted, and the energized bacteria would not be utilized to support phosphorus removal.

The aeration basins are also equipped to cycle air on and off, independently of the digester's cycle, with an aeration header with diffusers that move around the tank to aerate and mix the tank. The aerobic cycle is designed for ammonia removal and is programmed and optimized to achieve a targeted DO concentration. If the DO concentration is above the target, the header will automatically complete some cycles without aeration.

Results: The average total phosphorus in the raw influent is 6.8 mg/L and the monthly average in the final effluent is 0.2 mg/L over the last 3 years. There is no chemical addition for phosphorus removal and the cycling of air benefits the plant with less energy consumption. While this process was not designed specifically for phosphorus removal, it has been successful in creating the proper environment for nutrient removal, allowing the plant to meet permit requirements without additional cost or equipment.



5.7 Conroe, TX



Figure 24: Conroe Southwest Regional WWTP

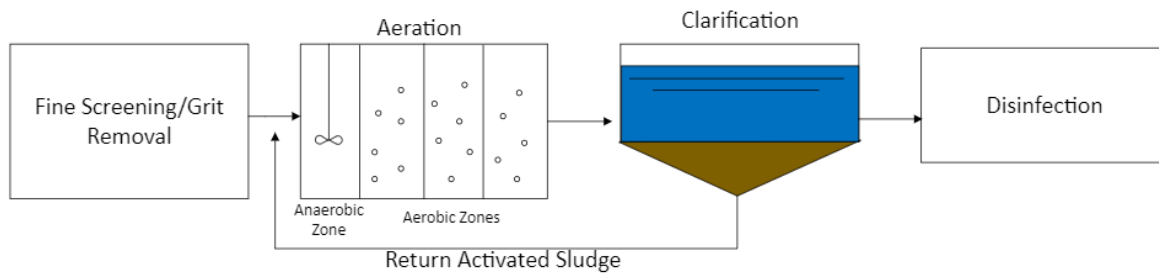


Figure 25: Conroe Southwest Regional WWTP Process Diagram

SECONDARY TREATMENT	SIZE MGD	POPULATION SERVED	OPTIMIZATION	PHOSPHORUS RESULTS
ACTIVATED SLUDGE	11 MGD (Average Flow)	90,000	Addition of an anaerobic zone, RAS pump VFD and flow meter addition, and DO optimization	0.8 mg/L (After)

Background: The Conroe Southwest Regional Wastewater Treatment Plant in Conroe, Texas treats an average of 11 MGD and has undergone several improvements since its construction in 1974. Some of these improvements include the addition of fine-bubble aeration and single-stage, high-speed blowers. The plant does not currently have a permitted phosphorus limit but as Texas has begun implementing nutrient limits for nitrogen and limits for TSS, the City anticipates future phosphorus limits. The plant was also experiencing frequent repair downtime and needed upgrades, so the expected future nutrient limits were an important factor to consider for the upgrade design.

Optimization Efforts: Several modifications were made to the plant process including: rerouting the RAS flow from step feed to a single location, installing sluice gates for isolation of each aeration basin, installing weirs in the basins for level control, reducing the size of the RAS piping to allow higher velocity in the line, flow control in the RAS pumps through flow metering and variable frequency drive motor control, and aeration basin diffuser modifications.

The plant was previously configured to utilize its six aeration basins and six clarifiers in pairs. Flow from each aeration basin would go to a dedicated clarifier, and the RAS from each clarifier would flow back to the same aeration basin. This RAS was unmetered and uncontrolled, and the system was only designed for step feed rather than plug feed, making it challenging to properly mix the influent and RAS flow. The upgraded system rerouted the RAS flow to a single location to mix with the raw influent, reduced the pipe size to incorporate the RAS at a more appropriate velocity, and added flow metering and variable frequency drive motor control to the RAS pumps to allow for flow control.

The RAS distribution system into the aeration basins was also upgraded to include sluice gates on the wall sleeves, allowing for isolation of each basin. Overflow weirs were installed in each basin to reduce variability in basin depth to just a few inches. Additionally, the first quarter of the aeration basins was modified by removing the diffusers and creating an anaerobic selector zone by adding a baffle wall and a top-entry mixer in the first section of each basin. This zone helps the nutrient removal process by inhibiting the growth of filamentous bacteria while supporting the growth of phosphorus-accumulating organisms (PAOs). The basin's single-stage, high-speed blowers were also equipped with a new controller to regulate dissolved oxygen in the aerobic stage of each basin. Each basin has three individual manual valves that can be adjusted to further optimize DO levels.

Results: While the plant does not currently have permitted phosphorus limits, the upgrades have allowed them to average around 0.8 mg/L of total phosphorus in the effluent. The upgrades have also improved other nutrients and TSS removal and have saved the plant money on power consumption and chlorine disinfection. Power consumption has dropped by 25%. As lower phosphorus limits are applied, the plant plans to continue streamlining their solids wasting process and aeration to further optimize phosphorus removal.



CHAPTER 6: Training and Resources

Below are several training opportunities, webinars, and additional information on wastewater phosphorus removal, many of which served as resources for this document. Operators and plant managers can use this information to expand their knowledge on these subjects and take advantage of training opportunities that offer continuing education credits (CECs) to help with license renewal.

TRAINING	
NAME	Description
VEOLIA OPERATOR TRAINING	This is a free online operator training program that covers all aspects of wastewater treatment.
MICHIGAN WATER ENVIRONMENTAL ASSOCIATION	Counts for CECs Wastewater training classes for all wastewater professionals, including but not limited to: operators, lab techs, engineers, maintenance techs, etc. Counts for CECs
WEBINARS	
EPA OPTIMIZING NUTRIENT REMOVAL IN ACTIVATED SLUDGE WWTPS	This webinar offers cost effective operational approaches to optimize nutrient removal in activated sludge processes. Many of the solutions are outlined in this document.
EPA OPTIMIZING NUTRIENT REMOVAL IN SEQUENCING BATCH REACTORS	This webinar offers cost effective operational approaches to optimize nutrient removal in SBR processes. Many of the solutions are outlined in this document.
EPA OPTIMIZING NUTRIENT REMOVAL IN OXIDATION DITCHES	This webinar offers cost effective operational approaches to optimize nutrient removal in oxidation ditch processes. Many of the solutions are outlined in this document.
YSI ESSENTIALS OF PHOSPHORUS REMOVAL	This webinar offers a wide variety of phosphorus strategies, monitoring methods, and case studies.
ADVANCED CONTROL TECHNIQUES ENHANCE BIOLOGICAL PHOSPHORUS REMOVAL AND SAVE SIGNIFICANT OPERATING COSTS	Counts for CECs This webinar offers EBPR control techniques to save money on operating costs.
RESOURCES	
WDNR PHOSPHORUS REMOVAL STUDY GUIDE	Operations study guide for phosphorus removal.
TIP SHEET: CHEMICAL ADDITION TO CONTROL TOTAL PHOSPHOROUS	Additional information on chemical optimization.
GLWA INDUSTRIAL PRETREATMENT MANUAL	Extensive overview of GLWA's industrial pretreatment program.
PHOSPHORUS TREATMENT AND REMOVAL TECHNOLOGIES	Minnesota Pollution Control Agency phosphorus document.
YSI HOW TO USE ORP	A guide on how to use ORP as an indicator for different wastewater applications.



[UNDERSTANDING ORP](#)

[EPA PHOSPHORUS TESTING GUIDANCE](#)

[GLWA SEWER USE ORDINANCE](#)

[MICHIGAN'S ADAPTIVE MANAGEMENT PLAN TO
REDUCE PHOSPHORUS LOADING INTO LAKE ERIE](#)

A thorough guide on the basics of ORP in wastewater.
Provides an overview on how to lab test phosphorus concentrations.

Overview of GLWAs sewer use ordinance.

MI EGLE's guidance document for adaptive management programs.



CHAPTER 7: Funding and Technical Assistance Opportunities

While this document aims to help utilities meet lower phosphorus limits through enhancements to existing infrastructure, in some instances, capital upgrades are unavoidable. Below are some potential funding opportunities that utilities might qualify for to upgrade their infrastructure for improved phosphorus removal. The programs listed offer either grants or low-interest loans offered by state and federal agencies. For instance, utilizing the Energy Efficiency and Conservation Block Grant Program could enable a utility to optimize an outdated aeration process by installing VFDs on blowers, replacing old blowers with new energy-efficient models, swapping out inefficient air diffusers, and adding D.O. instrumentation to reduce energy use. This would also give operators greater control over the aeration process, leading to improved phosphorus removal performance. In most cases, upgrading old, inefficient equipment with newer, energy-efficient alternatives will not only enhance the treatment process but also pay for itself through energy savings, ultimately saving the utility money in the long run.

Additionally, communities can utilize the no-cost technical assistance of EPA Environmental Finance Centers (EFCs). EFCs are organizations that manage and mobilize funds to support environmental projects, provide technical and policy assistance, and help build capacity for sustainable environmental finance initiatives. EFCs offer onsite technical assistance and evaluation of treatment processes, working with communities to find cost-effective solutions to their challenges. This may involve implementing process changes or helping communities identify and apply for funding to address their needs. In terms of phosphorus removal, this support can be very beneficial in helping plants better assess their treatment processes and identify cost-effective strategies to meet lower phosphorus limits.

GRANT AND LOAN OPPORTUNITIES			
FUND	Type	Funding Entity	Description
CLEAN WATER STATE REVOLVING FUND	Loan	MI EGLE	Low interest federal loan for wastewater infrastructure projects.
RENEWABLES READY COMMUNITIES AWARD	Grant	MI EGLE	State grant program for renewable energy adoption.
ENERGY EFFICIENCY AND CONSERVATION BLOCK GRANT PROGRAM	Grant	Department of Energy	Grant program designed to assist states, local governments, and Tribes in implementing strategies to reduce energy use, to reduce fossil fuel emissions, and to improve energy efficiency.
EPA COMMUNITY CHANGE GRANT	Grant and Partnership	MI EGLE and EPA	This grant program is dedicated to making wastewater treatment facilities more energy efficient. It supports initiatives that aim to reduce energy consumption, lower greenhouse gas emissions, and enhance the



			sustainability of treatment processes. By fostering partnerships with the community, the program also seeks to involve local stakeholders in efforts to improve environmental outcomes and promote a more sustainable future.
<u>COMMUNITY ENERGY MANAGEMENT PROGRAM</u>	Grant	MI EGLE	Grant program for communities to improve energy management and accelerate the implementation of energy efficiency and renewable energy. This particular program is more focused on underserved/environmental justice communities.
<u>WATERSMART SMALL-SCALE WATER EFFICIENCY PROJECTS</u>	Grant	Department of the Interior, Bureau of Reclamation, Water Resources and Planning Office	Grant program that supports wastewater treatment plants in implementing small-scale water efficiency projects. The program provides financial assistance to facilities aiming to enhance their water and energy efficiency, reduce water consumption, and lower operational costs.
<u>MICHIGAN ENVIRONMENTAL JUSTICE IMPACT GRANT</u>	Grant	MI EGLE	Grant program that support projects that reduce environmental health burdens in communities disproportionately affected by pollution. This grant can be used for infrastructure upgrades, pollution prevention measures, and initiatives that improve water quality and environmental outcomes, particularly in environmental justice/underserved communities.

TECHNICAL ASSISTANCE PROVIDERS		
ORGANIZATION	Type	Description
<u>MOONSHOT MISSIONS</u>	National Environmental Finance Center	Non-profit collective of water and wastewater professionals which matches utilities with resources, tools, and techniques for success. Moonshot provides no cost assistance in helping utilities with technical, financial, and managerial needs.



[RURAL COMMUNITIES ASSISTANCE
PARTNERSHIP \(RCAP\)](#)

National Environmental Finance
Center

A national network of non-profit partners working to provide **no cost** water and wastewater technical assistance, training, resources, and support to rural communities across the country.

[THE ENVIRONMENTAL JUSTICE
THRIVING COMMUNITIES
TECHNICAL ASSISTANCE CENTERS
PROGRAM](#)

EPA

The EJ TCTACs Program provides technical assistance to underserved communities to address wastewater management challenges. It helps improve infrastructure, compliance with environmental regulations, and promotes sustainable practices. This support is crucial for reducing pollution, enhancing public health, and ensuring equitable access to clean water and effective wastewater treatment systems.



References

Minnesota Pollution Control Agency. (n.d.). Phosphorus management plan for municipalities: Guidance manual (wq-wwtp9-02). Minnesota PCA. Retrieved from:

<https://www.pca.state.mn.us/sites/default/files/wq-ww>

U.S. Environmental Protection Agency. (2022, March 31). Optimizing nutrient removal in activated sludge wastewater treatment plants [Webinar]. EPA.

<https://www.epa.gov/compliance/optimizing-nutrient-removal-activated-sludge-wastewater-treatment-plants>

U.S. Environmental Protection Agency. (2022, January 27). Optimizing nutrient removal in oxidation ditches [Webinar]. EPA.

<https://www.epa.gov/compliance/optimizing-nutrient-removal-oxidation-ditches>

U.S. Environmental Protection Agency. (2022, February 17). Optimizing nutrient removal in sequencing batch reactors [Webinar]. EPA.

<https://www.epa.gov/compliance/optimizing-nutrient-removal-sequencing-batch-reactors>

U.S. Environmental Protection Agency. (2019). Nutrient control design manual (EPA/600/R-10/100). U.S. Environmental Protection Agency. Retrieved from:

https://www.epa.gov/sites/default/files/2019-08/documents/nutrient_control_design_manual.pdf

The Wastewater Blog. (2016, December 18). ORP. The Wastewater Blog. Retrieved from:

<https://www.thewastewaterblog.com/single-post/2016/12/18/orp>

Water Environment Federation (WEF). (2008). Operation of municipal wastewater treatment plants: Manual of practice No. 11 (6th ed.) Water Environment Federation. New York, New York: McGraw-Hill.

Wisconsin Department of Natural Resources. (n.d.). Phosphorus: Understanding the nutrient and its impact. Wisconsin DNR. Retrieved from:

<https://widnr.widen.net/s/jvtdn6l bj2/studyguidephosphorus>

Wisconsin Department of Natural Resources. (n.d.). *Study guide: Suspended growth*. Wisconsin Department of Natural Resources. Retrieved from:

<https://widnr.widen.net/s/cxvksl jx7/studyguidesuspendedgrowth>

YSI Inc. (n.d.). ORP management in wastewater as an indicator of process efficiency. YSI Inc.

Retrieved from: <https://www.ysi.com/file%20library/documents/application%20>



Appendix A: Chemical Phosphorus Jar Testing Protocol

1. Supplies Needed

- a. Beaker (preferably 1-liter but 2-liter will also work)
- b. Magnetic stirrer
- c. Magnetic stir bar
- d. Micropipette
- e. 0.45-micron filter (if testing samples with significant particulate)
- f. pH meter
- g. Spectrophotometer or colorimeter for phosphorus test (Hach TNT or Powder Pillow method are easiest)

2. Sample Collection and Preparation

- a. Collect sample from desired dosing locations.
 - i. Note that samples should be taken during normal flows and not wet weather.
- b. Split sample into either 1-liter or 2-liter beakers
 - i. If using 2-liter beakers, make sure to multiply dosage x2.

3. Dosage Calculation (Neat)

- a. A volume of 1 mL of water has a weight of 1 gram. When chemicals are added, it can be assumed that the solution weight is the same as the weight of the water.
- b. When using a 1-liter beaker and micropipette, the target dosage rate is $X / \text{specific gravity}$, in microliters. For example, if the chemical has a specific gravity of 1.37 and you want to dose 10 mg/L, you would add $(10 / 1.37)$ 7.30 microliters to a 1-liter beaker of sample.
 - i. If using a 2-liter beaker, multiply the above calculation x2.
- c. Start with 10 mg/L and work up in increments of 10. i.e., 10,20,30, etc.

4. Testing Procedure

- a. Run initial phosphorus and pH test on each sample before introducing the chemical. If sample contains heavy particulate, it is a good practice to filter the sample through a 0.45-micron filter before performing the phosphorus test. (Take sample from the same place in each beaker with a steady hand to not disrupt floc.) Typically, orthophosphate testing is done for convenience purposes. Total phosphorus test measures all forms of phosphorus in a sample by digesting the sample to convert other forms to orthophosphate. However, the digestion process is time consuming. For convenience, phosphorus can be measured as orthophosphate using HACH test kits and converted to PO_4 as P using a conversion factor. The conversion factor for orthophosphate to PO_4 -P is $X / 3.06$.



For example, if the ortho value is 3.42 (3.42 / 3.06) the estimated PO₄-P concentration will be 1.14 mg/L. Although this method is not the most accurate way of quantifying TP in wastewater, it can still be employed to save time since the most dominant species of phosphorus in wastewater is orthophosphate.

- b. Dose chemical “neat.”
- c. Mixing and settling times are as follows:
 - i. Rapid mixing: 300-400 rpm for 30 seconds to 1 minute.
 - ii. Slow mixing: 35-40 rpm for 5 to 10 minutes.
 - iii. Sedimentation: 15 to 30 minutes
- d. Run phosphorus and pH test to determine chemical performance.
 - i. The conversion factor for orthophosphate to total phosphate can again be used for convenience purposes.
 - ii. The final sample should be taken from the same place as the initial sample in the beaker.

5. Plotting and Results Interpretation

- a. Record results on a jar testing evaluation form.
 - i. Include volumes, pH, phosphorus concentrations, etc.
- b. Note any observations made during the test.
 - i. This can include floc appearance and any changes observed after adding the chemical.
- c. Plot results on a graph to create a dosage curve.
 - i. Microsoft Excel works well for recording bench testing results.
 - ii. Results should be calculated into percentage removal to assess performance: $\text{initial concentration (mg/L)} - \text{final concentration (mg/L)} / \text{initial concentration} \times 100$
 - iii. Results can then be automatically transformed into a graph. Figures 1 and 2 demonstrate examples of a dosing table and curve. (Please note that the results below are just generic and not real-world results.)



	A	B	C	D	E
1	Dose mg/L	Ferrous Chloride (% Rem)	Alum (% Rem)	Ferric Chloride (% Rem)	Rare Earth (% Rem)
2	0				
3	10	25	40	30	40
4	20	28	45	35	50
5	30	35	56	37	60
6	40	42	54	40	70
7	50	50	60	46	80
8	60	60	64	50	90
9	70	65	68	52	100
10	80	70	72	60	100
11	90	71	75	65	100
12	100	72	80	75	100
13	110	73	85	88	100
14					

Figure 26: Dosing Table

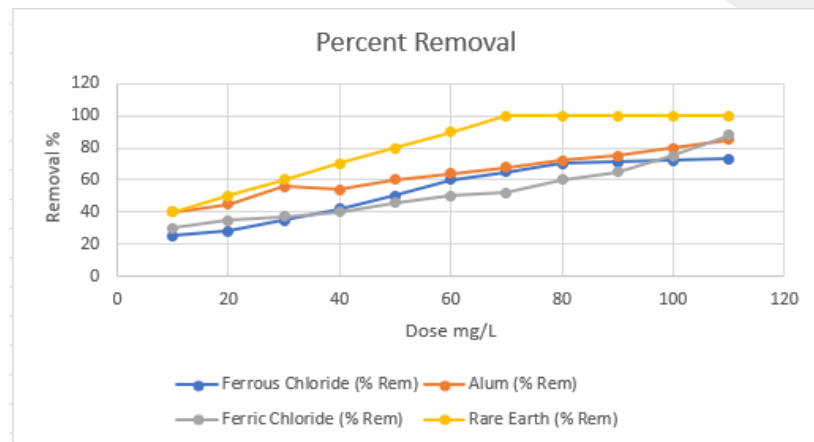


Figure 27: Dosage Curve

Appendix B: Lab Testing Resources

While this document does not aim to endorse any specific brands or products, the Hach TNT methods are one of the most efficient ways to monitor process control and have been widely adopted in the wastewater treatment industry. There are two Hach methods available: the Powder Pillow method and the TNT Plus method. The Powder Pillow method is a more cost-effective option and involves adding pre-measured powder reagent packets to a tube or beaker, as opposed to using pre-filled vials. It is also more limited in terms of the range of tests it can perform and may not be as precise as the TNT Plus method, which often utilizes a spectrophotometer. However, for many process control applications, the accuracy provided by a colorimeter in the Powder Pillow method is sufficient. It should be noted that any TNT Plus test will require the purchase of a spectrophotometer, while the Powder Pillow method will require the purchase of either a colorimeter or a spectrophotometer, as both instruments can be used to read the results of this method. Before making any purchases, it is important to check the specifications and method links for each test to ensure compatibility with the instrumentation and testing methods or consult with a Company (Hach) representative.

INSTRUMENTATION	
WEBSITE LINK	Description
HACH DR3900 SPECTROPHOTOMETER	Compatible with TNT Plus, Powder Pillow methods, and more. Very useful for in-depth laboratory testing.
HACH DR1900 PORTABLE SPECTROPHOTOMETER	A scaled down and portable version of the DR3900.
HACH DRB200 DIGITAL REACTOR BLOCK	Digester required for performing total phosphorus analysis opposed to ortho phosphorus.
HACH DR900 PORTABLE COLORIMETER	Portable colorimeter which is the more cost-effective approach if only running the powder pillow method.
HACH TNT PLUS TEST KITS	
TNT VFA TEST	Test compatible with the DR3900 or DR1900. Specs and Method
TNT PHOSPHORUS TEST	Test compatible with the DR3900 or DR1900. The DRB200 will also be required for the digestion process for total phosphorus concentrations. Specs and Method
TNT AMMONIA TEST	Test compatible with the DR3900 or DR1900. Specs and Method
TNT COD TEST	Test compatible with the DR3900 and DR1900. Specs and Method
TNT NITRATE TEST	Test compatible with DR3900 and DR1900. Specs and Method
POWDER PILLOWS	
PHOSPHORUS POWDER PILLOW TEST	Test compatible with DR900, DR1900, and DR3900. Specs and Method
NITRATE POWDER PILLOW TEST	Test compatible with DR900, DR1900, and DR3900. Specs and Method



Appendix C: Instrumentation Resources

While this document does not aim to endorse any specific brands or products, it provides an overview of various instrumentation sensors, both inline and portable, that are widely used across the industry. The choice of brand is entirely at the discretion of each facility, depending on considerations such as price, specific needs, and effectiveness. A good practice when choosing a brand is to reach out to a neighboring/collaborating facility or ask a distributor for reference facilities to understand how the product performs before making an investment. When making a purchase of this nature, it's essential to consult with a company or sales representative to ensure you're selecting the right instrument for your plant's specific needs.

DISSOLVED OXYGEN (D.O.) SENSORS		
SENSOR WEB LINK	Type	Description
<u>HACH LDO DO SENSOR</u>	Inline/Online	This probe will also require the purchase and installation of a Hach SC controller. It is best to speak with a company rep before purchasing this piece of equipment.
<u>HACH HQ1130 PORTABLE DO METER</u>	Portable	Handheld meter for DO sampling.
<u>YSI PRO20I DO METER</u>	Portable	Handheld meter for DO and temperature.
<u>YSI ODO200 OPTICAL DO METER</u>	Portable	Handheld instrument that is an optical-based dissolved oxygen meter ideal for DO sampling.
<u>YSI SENSORNET FDO DO PROBE</u>	Inline/Online	This probe will also require the purchase and installation of a YSI IQ 2020 controller. It is best to speak with a company rep before purchasing this piece of equipment.
<u>YSI PROQUATRO MULTIPARAMETER METER</u>	Portable	Handheld meter that measures both DO and ORP as well as a variety of other parameters. Will require separate purchases of probes for different parameters.
<u>HQ4200 PORTABLE MULTI-METER</u>	Portable	Handheld 2 channel meter that supports both DO and ORP as well as a variety of other parameters. Will require separate purchases of probes for different parameters.
OXYGEN REDUCTION POTENTIAL (ORP) SENSORS		
<u>HACH HQ110 PH/ORP/MV METER</u>	Portable	Handheld meter that measures pH and ORP.
<u>HACH ONLINE PROCESS ORP SENSOR</u>	Inline	This probe will also require the purchase and installation of a Hach SC controller. It is best to speak with a company rep before



<u>YSI PROQUATRO MULTIPARAMETER METER</u>	Portable	purchasing this piece of equipment. Handheld meter that measures both DO and ORP as well as a variety of other parameters. Will require separate purchases of probes for different parameters.
<u>YSI SENSORNET 700 ORP PROBE</u>	Inline/Online	This probe will also require the purchase and installation of a YSI IQ 2020 controller. It is best to speak with a company rep before purchasing this piece of equipment.
<u>HQ4200 PORTABLE MULTI-METER</u>	Portable	Handheld 2 channel meter that supports both DO and ORP as well as a variety of other parameters. Will require separate purchases of probes for different parameters.
PHOSPHORUS		
<u>HACH PHOSPHAX ANALYZER</u>	Inline/Online	One of the more widely used inline phosphorus analyzers in the industry.
<u>YSI P700 IQ ORTHOPHOSPHATE ANALYZER</u>	Inline/Online	A popular option but not as widely used as Hach.
<u>ABB AZTEC AW636 PHOSPHATE ANALYZER</u>	Inline/Online	A newer option that is less used.



Appendix D: Hydraulic Retention Time Calculation

This specific example is for calculating aerobic and anaerobic retention times; however, this same formula applies to any tankage in the wastewater process.

Calculate the plant flow per hour:

Plant Flow (MGD) / 24 (hrs/day) = Million Gallons/Hour (MGH)

Determine the HRT:

Tank Volume (MG) / Flow (MGH)

If there are multiple aeration tanks, include them in the calculation. Also, account for how much of the tank volume will be anaerobic to determine the anaerobic and aerobic HRTs.

For example, in a plant with a flow of 8 MGD, two aeration basins of 1.4 MG each, and 40% of the tanks converted to anaerobic conditions:

$1.4 \text{ (tank vol)} \times 2 \text{ (basins)} \times 0.4 \text{ (anaerobic \%)} = 1.12 \text{ (anaerobic vol)}$

$8 \text{ (MGD)} / 24 \text{ hrs/day} = 0.33 \text{ (MGH)}$

$1.12 / 0.33 = 3.39 \text{ hrs under anaerobic conditions}$

To determine aerobic HRT, replace the anaerobic percentage with the aerobic percentage (60% in this case). Typical HRTs are 2-3 hours for anaerobic/anoxic zones and 6-8 hours for aerobic zones. These values may vary based on plant loadings, so ongoing monitoring and adjustment are crucial.

