



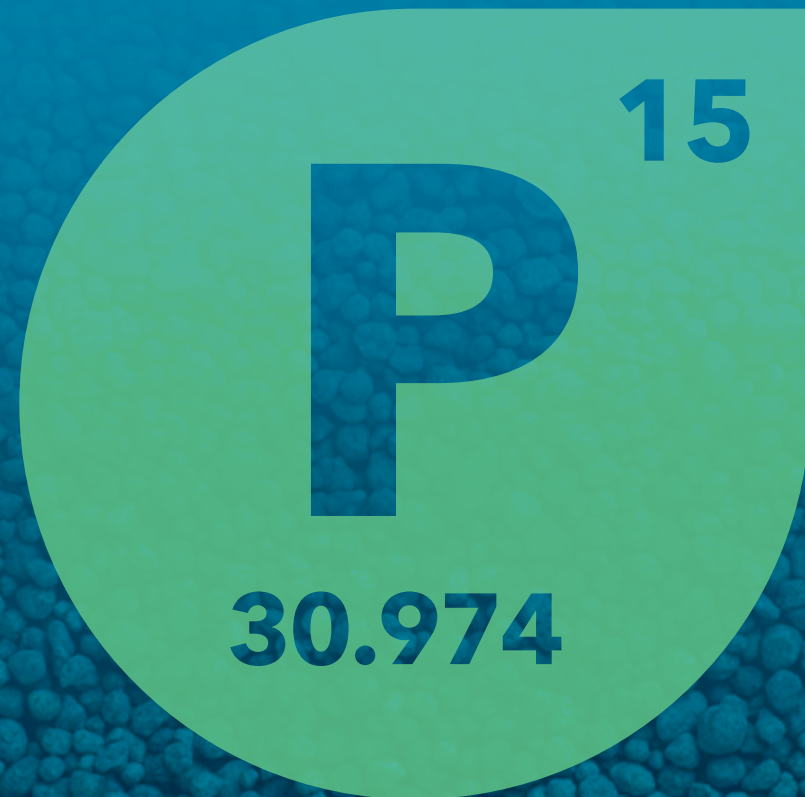
# PHOSPHORUS IN WASTEWATER

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A COMPLETE GUIDE TO PHOSPHORUS LIMITS,  
ONLINE ANALYSIS, & REMOVAL STRATEGIES.



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YSI Municipal Water  
e-book • XA00171

# PREFACE

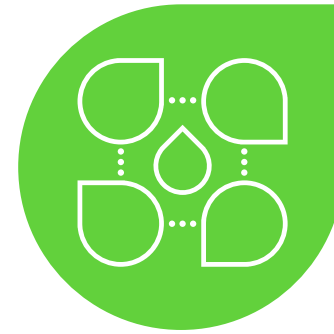
**Thank you for downloading YSI's  
Phosphorus in Wastewater e-book!**

Please continue reading to learn about the science of phosphorus, phosphorus limits in municipal wastewater and removal strategies to help meet wastewater treatment goals and effluent limits.

YSI has a long history of helping municipal wastewater treatment facilities meet their treatment goals – from developing the first portable dissolved oxygen meter and manufacturing the golden standard for BOD probes, to today's IQ SensorNet system of sensors for water quality monitoring and control.

We hope you find this information useful. Please contact us if you have any feedback or if we can assist you with your water monitoring and treatment needs.

*We truly value your input!*



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# PHOSPHORUS **BASICS**



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# Intro to Phosphorus

One of the pressing issues currently facing wastewater treatment is **excess phosphorus**.

Phosphorus removal is a high priority for many **Water Resource Recovery Facilities** (WRRFs), and new facilities are often designed specifically for this purpose. As our freshwater resources are continually strained and affected by excess nutrients, effluent limits for Total Phosphorus (T.P.) are spreading and becoming lower.

Traditional secondary treatment facilities were not designed to meet these reduced limits because the phosphorus problem has only recently become a prominent issue. However, nutrient removal technologies are advancing quickly and helping facilities achieve their phosphorus removal goals.

With YSI's [IQ SensorNet](#) and [Alyza IQ PO4](#) orthophosphate analyzer, operators have instrumentation designed specifically to aid in phosphorus removal from wastewater.

This e-book will explain the mechanism of phosphorus removal, the treatment options that help meet new or increasingly stringent total phosphorus effluent limits, and how monitoring orthophosphate can help monitor or control your phosphorus removal process.



*Total phosphorus effluent limits are becoming more stringent throughout the US to protect our nation's natural water bodies.*

# Discovery

Phosphorus was accidentally discovered in 1669 by a German physician named **Hennig Brandt** (Hansen, 2019).

Brandt's goal was to discover the philosopher's stone, a mythical substance that could turn base metals into gold or silver. He was convinced that this substance could be extracted from human urine, so he spent many of his days collecting numerous samples and studying them within his laboratory.

The tale of his discovery began with boiling down thousands of gallons of urine, combining this with sand and charcoal, and then burning this mixture as hot as possible within his furnace. This process produced a glowing white vapor, which Brandt, the first ever to view the substance, had named **phosphorus**.

Hennig Brandt as depicted by  
François-Marius Granet



**The Alchemist**  
François-Marius Granet  
(1775-1849)  
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# Research Spotlight

**Dr. Nancy G. Love** is the Borchardt and Glysson Collegiate Professor of Civil and Environmental Engineering at the University Michigan.

In collaboration with her students, Dr. Love works at the interface of water, infrastructure and public health in both domestic and global settings.

The group advances public and environmental health using chemical, biological and computational approaches applied to water systems, and co-design methods in partnership with communities.



Dr. Love's Twitter:  
**@love\_h2o**

A student examines a special urine-diverting toilet and urinal that is part of a research project to turn urine into fertilizer.

## ADVANCING PHOSPHORUS RECOVERY

Today's approach for phosphorus management is inefficient.

We mix urine with feces at the collection point, use water to convey the waste to the WRRF, then at some WRRFs we invest energy to partly reconcentrate the phosphorus into biosolids or other phosphorus-rich solid products.

But what if urine never mixed with feces? Urine separation at the toilet and processing separately from the other sewage allows us to convert urine into useful fertilizers, such as phosphorus-rich struvite.

**Struvite** is a mineral form of P useful in farming that is free of the pharmaceuticals originally in the urine. Life cycle assessments have shown urine separation and processing to fertilizer to be more sustainable than phosphorus management through conventional WRRFs or through P mining.

At the University of Michigan, a demonstration building-scale system designed by the Rich Earth Institute uses a urine-separating toilet and a waterless urinal to collect urine, process it using multiple treatment steps that prevent odor formation, concentrate, pasteurize, and remove pharmaceuticals, and produce a liquid fertilizer product.



Learn more about:  
**Resource Efficiency**

# Phosphorus Uses

Years after Brandt’s discovery, phosphorus was in chemistry textbooks and began making its way into manufactured products.

Due to the **highly reactive nature** of pure phosphorus, it was used to produce matches and bombs. Phosphorus was also discovered to be a vital nutrient to living organisms, so it became an additive into fertilizers.

The naturally occurring phosphorus forms, called **phosphates**, also became popular for use in manufacturing in numerous industries, including food, cosmetics, cleaning agents, and many more.

Within the **water treatment industry**, phosphates are used as a water softener, to de-scale water boilers and coolers, and as an additive in drinking water distribution to prevent pipe leaching.



Technical Note Download

How Online Orthophosphate Analyzers Can Help Control Pipe Corrosion in Drinking Water

View Tech Note

# Phosphorus & Life

## LIVING ORGANISMS

Phosphorus is essential to **all life on Earth** and one of the six primary elements necessary for living organisms, along with carbon, hydrogen, oxygen, nitrogen, and sulfur.

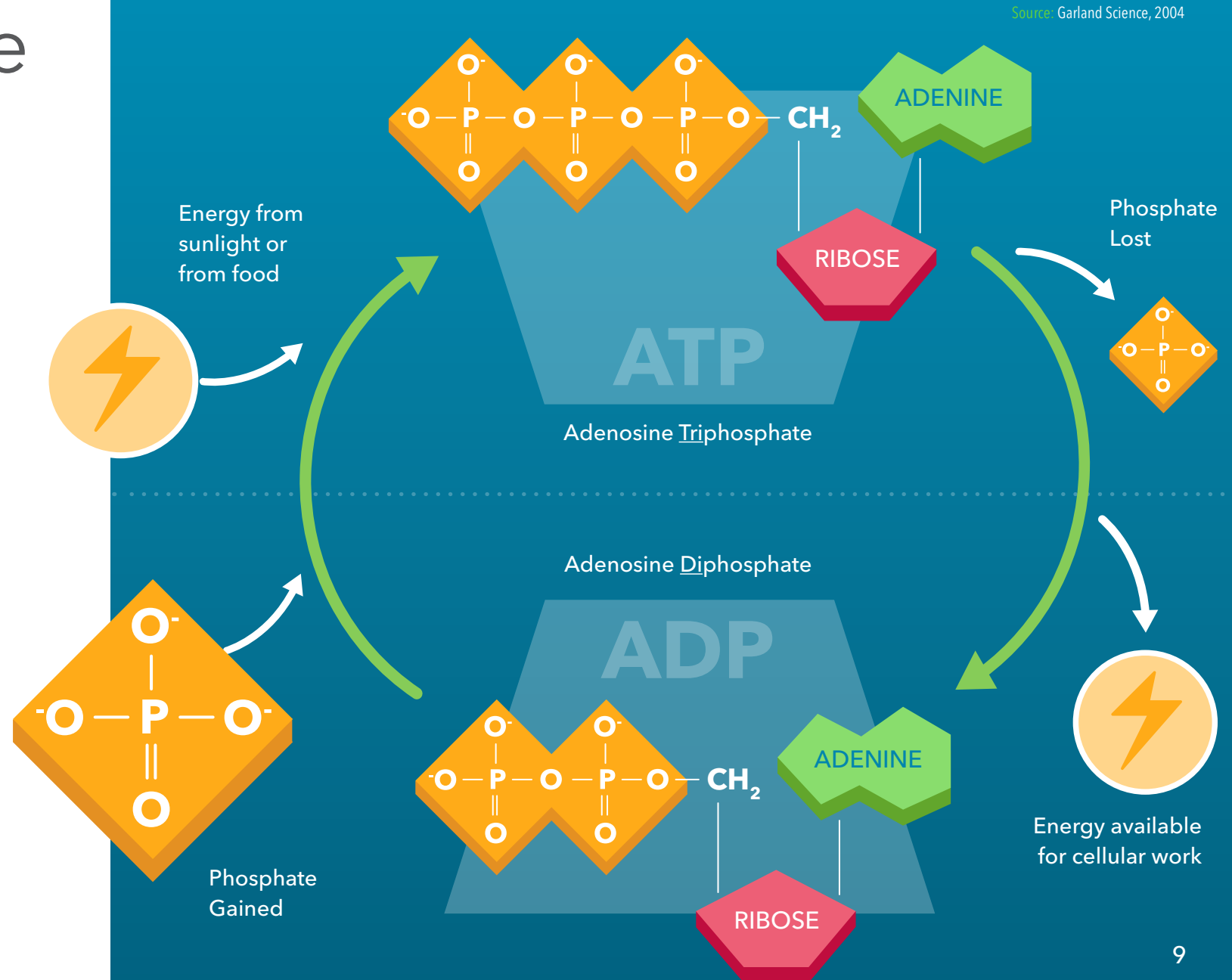
Due to the instability of elemental phosphorus, nearly all phosphorus occurs as a form of phosphate.

One key example is ATP (Adenosine 5' – triphosphate), which is essential to energy transfer within the cells of plants and animals.

In the process of converting stored ATP from light or food into ADP (Adenosine diphosphate), energy is released and used by the cells of the plant or animal.

Similarly, phosphate is also a building block for the nucleic acids within DNA and RNA, meaning the transfer of genetic material **depends on phosphorus**.

## PHOSPHORUS BASICS



# Phosphorus & Life

## DIET

More specifically, for humans, the intake of **phosphorus in our diet is crucial**. Besides being essential for energy and genetic transfer, it plays significant roles in bones and teeth, enzyme activation, and cellular energy storage (National Institutes of Health).

Any extra phosphorus is processed in the **kidneys** and discharged from the body, contributing to the phosphorus in wastewater.

## PHOSPHORUS PLAYS A ROLE IN



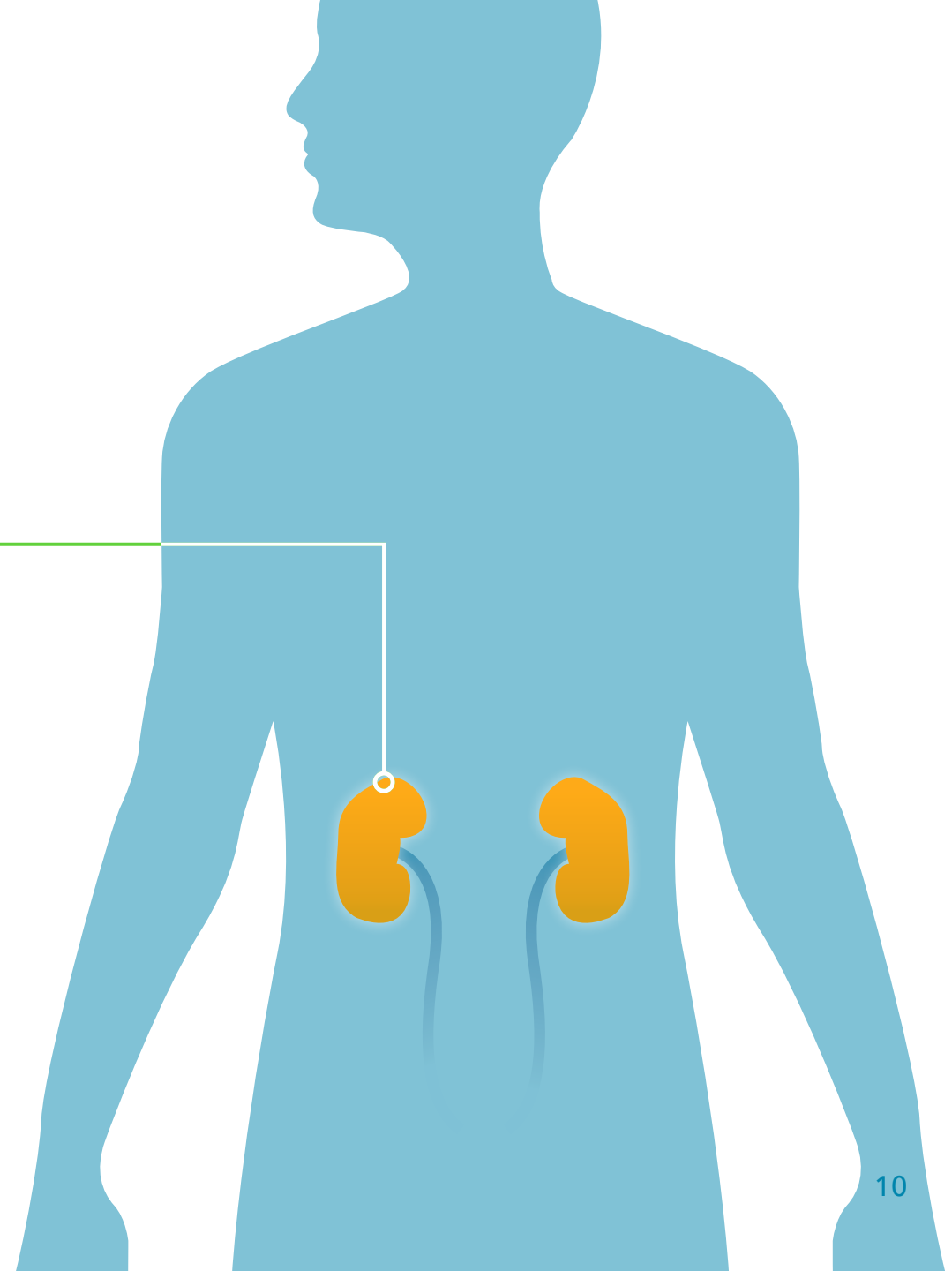
HUMAN  
ENERGY



BONES &  
TEETH



CELLULAR  
ENERGY



# Phosphorus & Life

## ECOSYSTEM

Phosphorus plays a significant role in our ecosystem and is greatly influenced by human activity. It is a limiting nutrient in freshwater systems, meaning that photosynthetic organisms like algae can grow and continually reproduce when phosphorus is abundant.

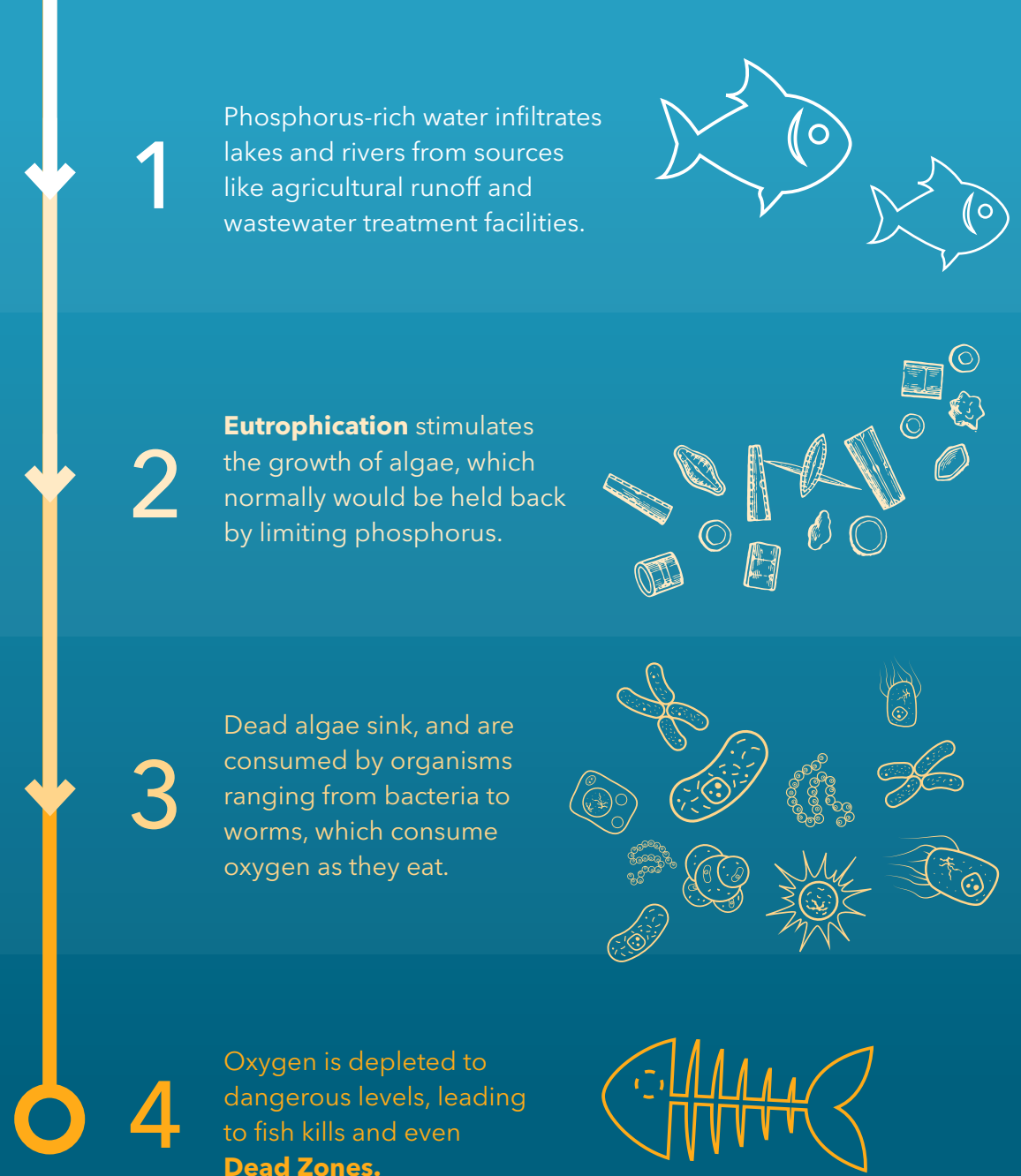
When freshwater bodies have an excess of phosphorus, eutrophication can occur. The water becomes overly enriched with minerals and nutrients, stimulating **excessive algal growth** (or an algal bloom).

While not all algal growth is bad, **eutrophication** can foster the growth of blue-green algae which can be toxic to humans and animals. These algal blooms are referred to as harmful algal blooms, or HABs, which humans and animals should avoid coming into contact with.

Toxic or not, excessive algal growth can have cascading impacts within the ecosystem as well. The excessive algal biomass consumes oxygen at night, with oxygen rapidly recovering and even exceeding 100% saturation through photosynthetic oxygen generation during the day. These swings affect fish and other aquatic life, but not near as much as when the algae die and are decomposed by organisms that consume oxygen in the process.

This is the source of severe hypoxia that leads to **dead zones**—regions where aquatic life dies off for a lack of dissolved oxygen.

## PHOSPHORUS BASICS



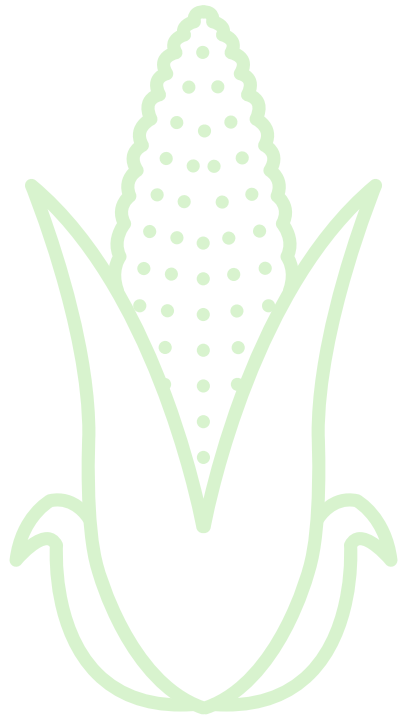
# Phosphorus & Life

## ECOSYSTEM, Continued

Multiple sources of nutrient pollution contribute to the issue of eutrophication. As a significant component of fertilizers, phosphorus and nitrogen are common in lawn and agricultural runoff.

**Excessive use of fertilizer** leaches from its intended application and makes its way into our natural water bodies. Sources like agricultural runoff are considered nonpoint sources and comprise a large portion of the excess nutrients.

**Water Resource Recovery Facilities,** on the other hand, are considered point sources for nutrients since there is a defined location of the discharge into the water body. Reducing the phosphorus at the point sources, such as the effluent of WRRFs, is part of the larger effort to reduce nutrients and preserve our lakes, rivers, streams, and estuaries.





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# PHOSPHORUS **IN WASTEWATER**



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# The Clean Water Act

In the United States, effluent phosphorus limits are regulated by the United States Environmental Protection Agency through NPDES (National Pollution Discharge Elimination System) permitting of wastewater treatment plants.

In the late 1960s and early 1970s, water quality in United States waterways became a public concern when Time Magazine published a story of a **river on fire**.

The **Cuyahoga River** near Cleveland, Ohio, had again caught fire on June 22nd, 1969. This 1969 fire was small and quickly controlled compared to past fires, so the famous picture was actually from a previous fire 17 years earlier (Latson, 2015).

This Time publication alerted the public about the issues with **unregulated dumping** in nearly every water body near major U.S. cities, encouraging scientists and legislators to figure out why the fires occurred and how to avoid them.

As a result, the **1972 Clean Water Act** was introduced by the federal government, leading to increased funding for wastewater treatment plants to reduce point-source pollution. Over the next 20 years, the U.S. spent around \$350 billion constructing and operating wastewater treatment plants.



**Original Caption:** Firemen stand on a bridge over the Cuyahoga River to spray water on the tug Arizona, as a fire, started in an oil slick on the river, sweeps the docks at the Great Lakes Towing Company site in Cleveland. November 1<sup>st</sup>, 1952.

The blaze destroyed three tugs, three buildings, and the ship repair yards.

**Source:** Smithsonian Magazine



City councilmen inspect pollution in the Cuyahoga River in 1964.

**Source:** Smithsonian Magazine

# The Clean Water Act

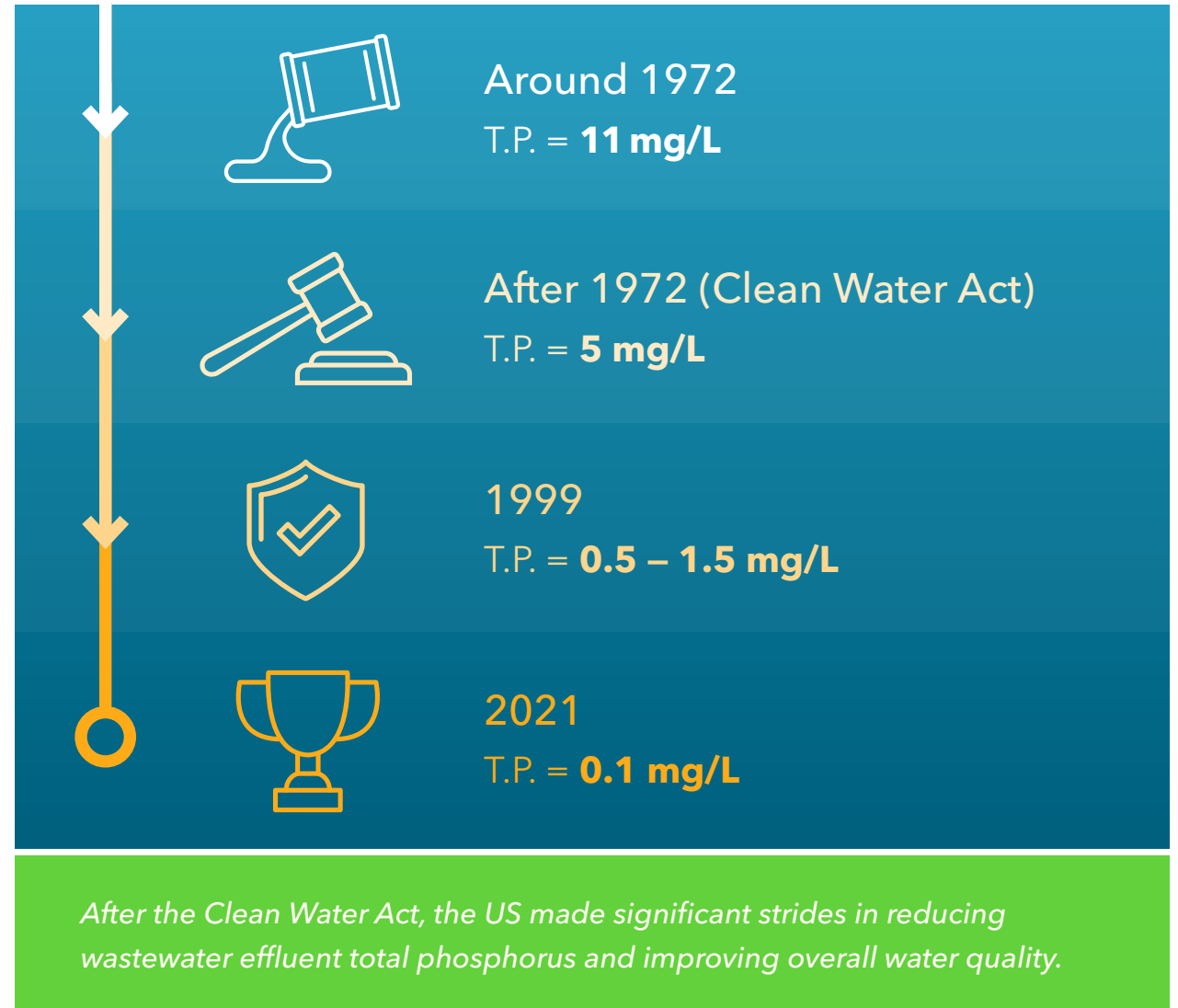
## Continued

Around the time of the **Clean Water Act**, total phosphorus effluent concentrations had peaked around 11 mg/L.

Thanks to restrictions of phosphates in detergents and improved wastewater treatment from the Clean Water Act, total phosphorus effluent concentrations were reduced to 5 mg/L.

Even with these improvements, further restrictions of effluent total phosphorus concentrations were needed to significantly improve our water quality (Litke, 1999). By 1999, facilities requiring phosphorus removal would have limits of 0.5 mg/L to 1.5 mg/L in critical regions such as the Great Lakes watershed.

Today, total phosphorus effluent limits are issued in new regions throughout the U.S., and some areas are beginning to achieve **ultra-low limits** below 0.1 mg/L T.P.



# Forms in Wastewater

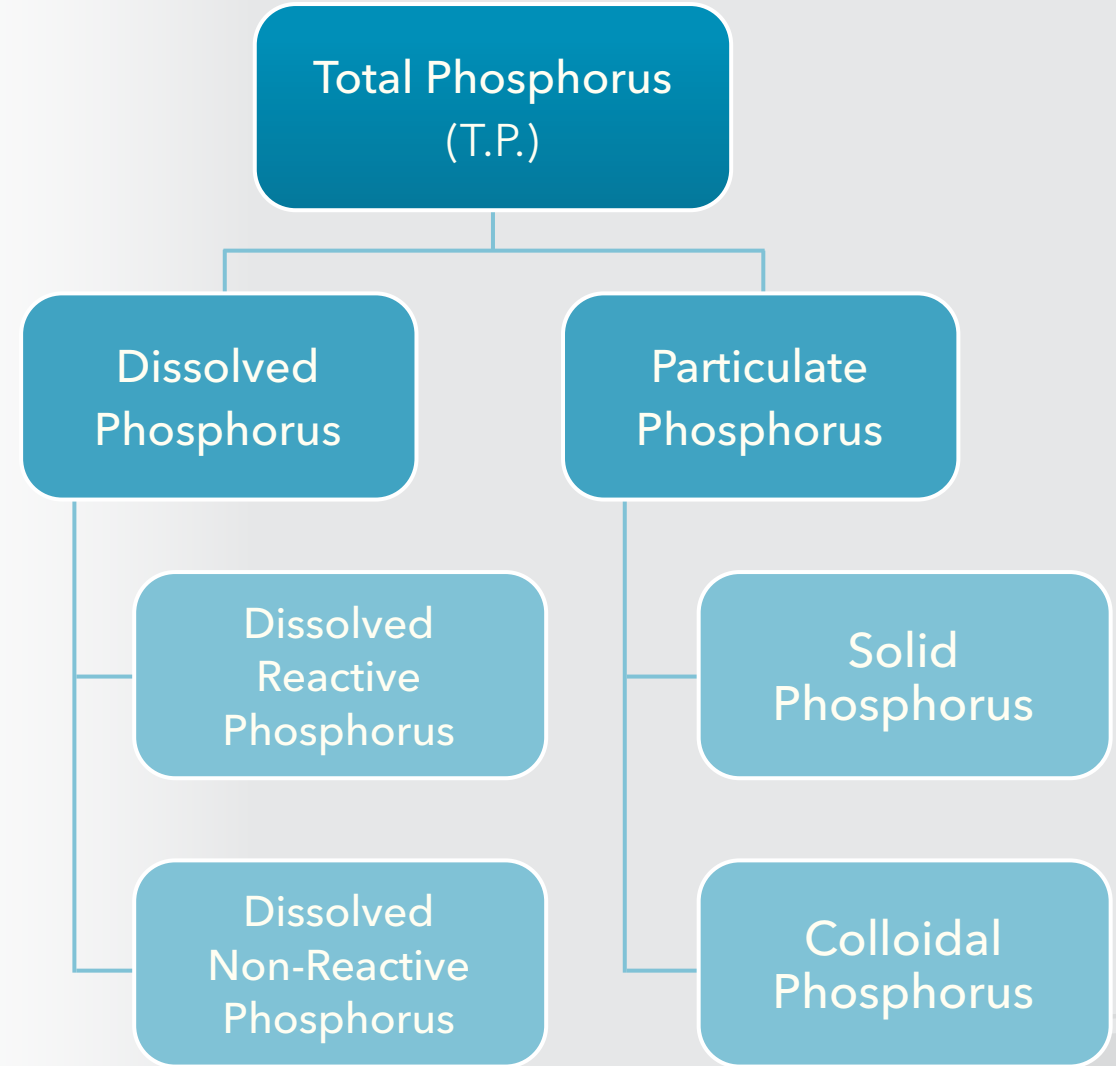
It is essential to understand the **different forms of phosphorus** present in wastewater to understand its measurement and removal.

In reality, all phosphorus in wastewater is bound into a **phosphate compound**, but the forms discussed in this section group these compounds at a higher level.

**Total phosphorus** (T.P.), referenced earlier with NPDES permitting, is the parameter that WRRFs are responsible for when removing phosphorus. By definition, total phosphorus is the sum of all the different forms of phosphorus present (Baird & Bridgewater, 2017). Total phosphorus can then be broken down into dissolved phosphorus (including orthophosphate) and particulate phosphorus, which can break down even further, see figure (*right*).

Each of these types of phosphorus has significance during the wastewater process. However, for simplicity, the most important are **dissolved reactive phosphorus** and **solid phosphorus**.

The overall goal with phosphorus removal is to convert as much dissolved reactive phosphorus into solid phosphorus, which facilities can then remove through gravity separation or filtration, a concept discussed in further detail in the [Phosphorus Removal section](#).





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# PHOSPHORUS **MEASUREMENT**



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# Testing Methods

Considering that there are many different phosphorus forms in wastewater, it makes sense that **several analytical techniques** are available to quantify most of them. The most common measured parameters are **total phosphorus** and **orthophosphate**.

**Total phosphorus** is often measured because this is the parameter regulated (required) on the effluent permits of WRRFs. For this reason, facilities will sample and test for total phosphorus at the effluent. However, operators can measure it throughout the process or even upstream of the plant to determine phosphorus loading and removal efficiency.

Since total phosphorus requires the **digestion of the sample** to turn all phosphorus into orthophosphate for measurement, analysis is primarily conducted within a laboratory (Baird & Bridgewater, 2017).

When measuring orthophosphate, the digestion step is skipped entirely, and the sample is filtered instead. Consequently, orthophosphate is a more efficient method, meaning it can be conducted more rapidly in a laboratory setting and implemented in an online analyzer.

**Orthophosphate** measurement is the primary method for online analysis throughout all stages of a wastewater facility. Assuming maximum solids are removed during clarification and filtration, orthophosphate represents nearly all of the phosphorus at the facility's effluent. Since phosphorus removal strategies aim to convert orthophosphate into solid phosphorus, orthophosphate analyzers have become the primary tool for controlling or monitoring these strategies.



Wastewater  
Solutions



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**YSI has over 70 years of experience** developing and manufacturing instrumentation used in various fields, with wastewater being one of the most common applications.

YSI provides laboratory, portable and online sensors for wastewater. The data from these instruments are used to monitor treatment process, automatically control actions based on sensor readings, and ensure treatment goals are met.

[YSI.com/Wastewater](https://www.ysi.com/Wastewater)

# Laboratory Testing

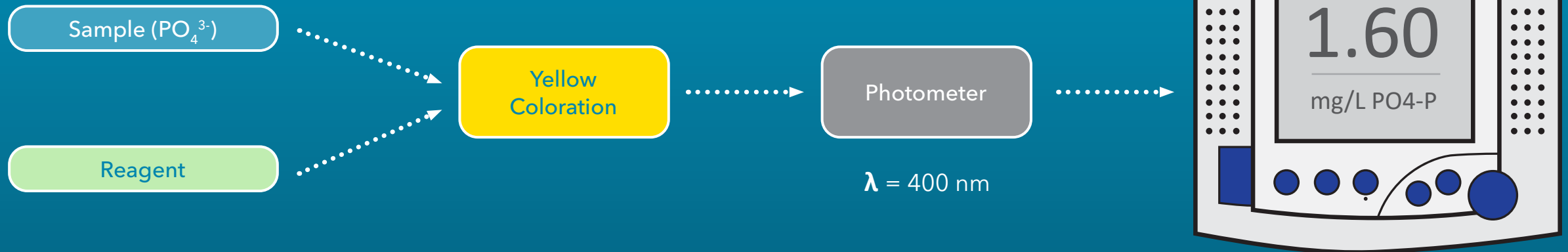
The **quantification** of the different types of phosphorus is conducted in two general steps. The first is to convert or isolate the phosphorus form of interest into dissolved orthophosphate, followed by the colorimetric determination of orthophosphate. For total phosphorus, this means **digestion for an entire sample** is required to convert all forms to orthophosphate, followed by a colorimetric test for orthophosphate (Baird & Bridgewater, 2017).

Several digestion methods exist, and the recommended method depends on the requirements of the application and the technician's preference.

The persulfate oxidation method is the simplest, most efficient, and suitable for most wastewater applications. It requires adding an oxidizing reagent, heating to 120°C for 55 minutes, and a pH adjustment before the colorimetric orthophosphate measurement.

The orthophosphate measurement **via colorimetry** is required for all phosphorus tests, but the steps prior determine the form of phosphorus quantified. Besides total phosphorus, dissolved reactive phosphorus is the other form primarily monitored in wastewater. For this measurement, filtration through 0.45μ is used to isolate the dissolved phosphorus in the sample from the particulate phosphorus. This is usually conducted by operators or lab technicians using syringe filters or a vacuum filter (Buchner funnel).

## Yellow Method: Colorimetric Measurement of Orthophosphate



# Laboratory Testing

## Continued

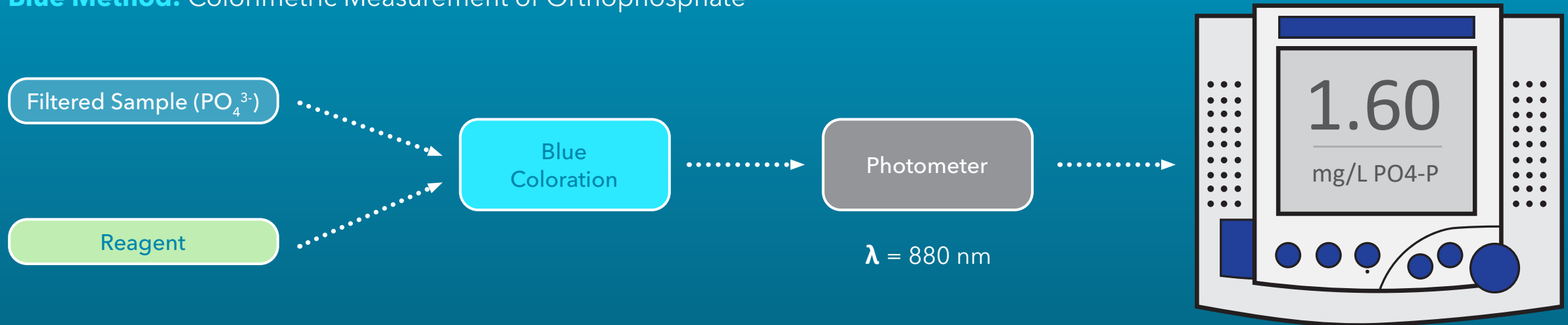
There are also multiple methods for orthophosphate colorimetry. The **yellow method**, or vanadomolybdate, is the method used by the YSI Alyza IQ PO4. This method consists of mixing the sample with a single reagent which produces a yellow coloration depending on the amount of orthophosphate in the sample.

A photometer then measures the sample's absorbance at 400 nm. The analyzer then calculates a milligrams per liter concentration for orthophosphate.

The yellow method is most suitable for routine analysis and has a detection limit of 0.02 mg/L.

The benefit of the yellow method is that it is quite stable and repeatable compared to other colorimetric methods. The **blue method** (ascorbic acid) and stannous chloride method can measure lower but require more careful control of the sample and are more susceptible to interferences.

## Blue Method: Colorimetric Measurement of Orthophosphate



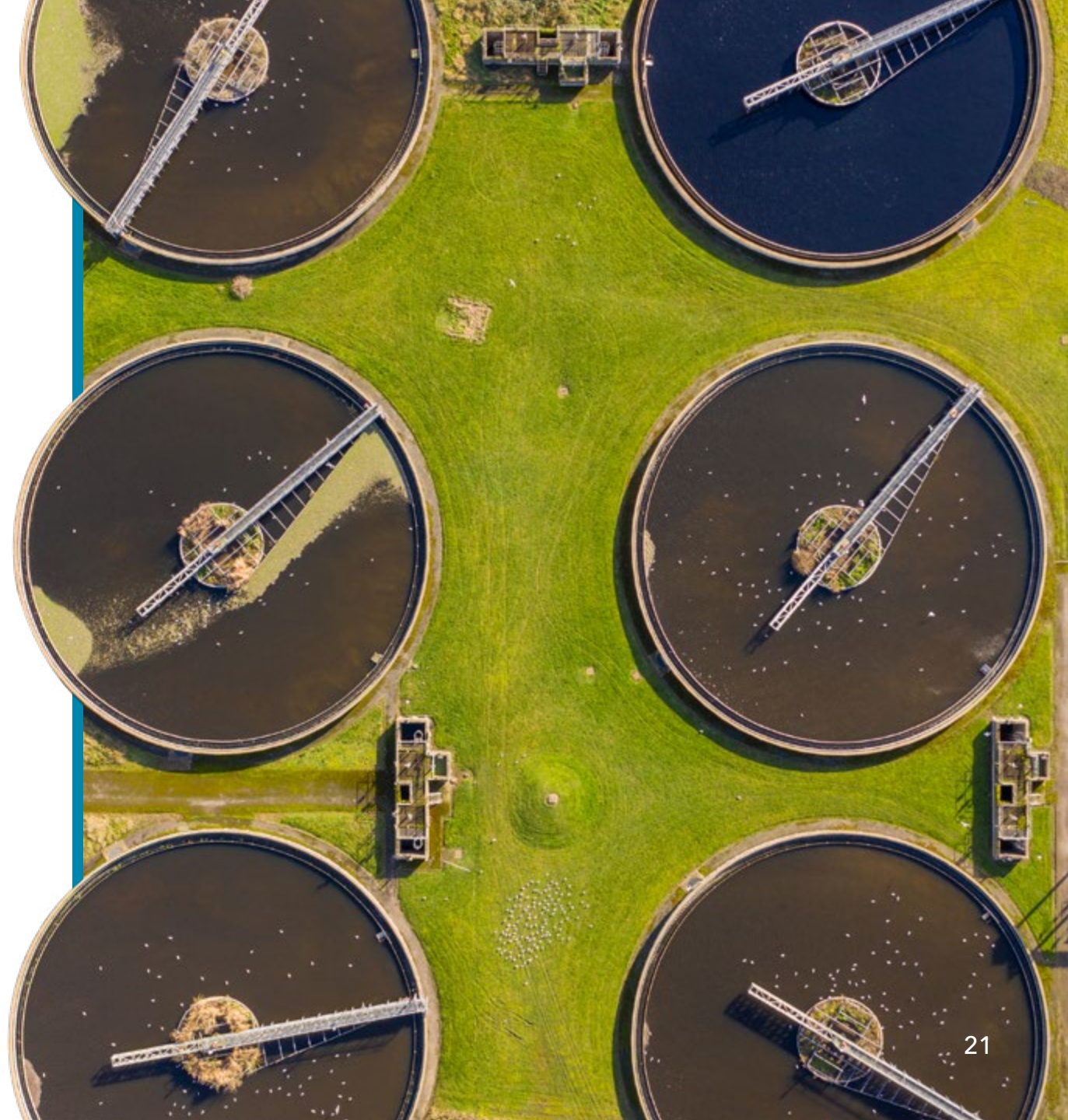
# Online Analyzers

Since in-situ sensor technologies for phosphorus or orthophosphate have not been developed yet, **online wet-chemistry analyzers** are the primary method for continuous orthophosphate monitoring.

The **goal** of installing an online analyzer is to have a fully automated laboratory procedure running continuously with minimal maintenance.

Manual sample preparation, reagents/sample mixing, and measurement are examples of the challenges overcome when automating these lab tests.

At the dawn of online analyzer technology, these instruments were large, difficult to maintain, and used high amounts of reagents. Advancements in today's analyzers have reduced reagent volume, maintenance requirements, improved diagnostics, and overall usability.



# Online Analyzers

## Continued

Online analyzers have been adapted for use in WRRFs by using **advanced filtration systems** that remove the high solids typical in wastewater.

**In-situ filters** can be placed directly into the process, removing solids by pulling water through the filter with a pump. The benefit of the in-situ filter is the simplicity of operation. All that is required is to install the filter in the process and then maintain it with occasional cleanings and filter replacement.

Another popular method is to use a **flow-through filtration** system. These systems have sample lines run directly to the wall-mounted unit and filter the sample before being pumped to the analyzer. These filters often require less frequent maintenance than the in-situ filter due to self-cleaning options, but it also involves a submersible pump and additional plumbing to bring the sample to the unit.

Many applications require outdoor installations, so proper heating and cooling mechanisms are necessary. These cabinets often require significant space, so different mounting options are provided to meet rail, wall, or stand applications.



Online analyzers are traditionally maintenance-heavy. Alyza IQ PO4 is designed to make maintenance as easy as possible.



# Alyza IQ PO4

YSI's solution for online orthophosphate measurements is the **Alyza IQ wet chemistry analyzer** platform. **Alyza IQ PO4** is part of the YSI IQ SensorNet, so it can be networked with other IQ sensors in the facility or used as a standalone analyzer.

The Alyza IQ PO4 is simple to operate with automatic cleaning and automatic calibration to ensure the analyzer provides accurate measurements with minimal intervention. It advances online analyzer technology in several ways. First, it utilizes IV-style bags to hold the chemical solutions, resulting in easy and safe replacement. The drip-free connections ensure the solutions are not spilled during exchanges.

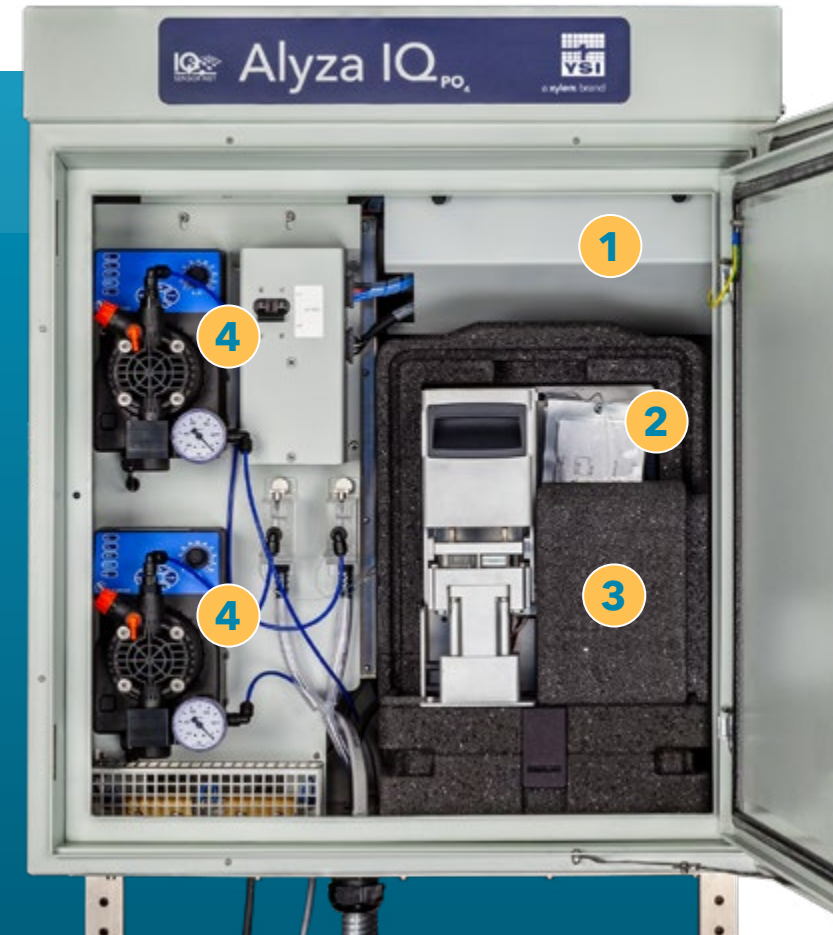
Alyza IQ PO4 also uses a minimal amount of reagent per measurement. At 10-minute sample intervals, solutions will only need to be exchanged every six months. The Alyza IQ PO4 uses five microliters of reagent per measurement, which amounts to less than 1 ml per day at 10-minute intervals. Essential to these advancements is the utilization of Alyza's Multi-Port Mixing Valve (MPV). The MPV reduces the reagent volume of an online analyzer by allowing the analyzer to switch between drawing samples, reagents, and solutions quickly with only a single valve.

Mixing occurs within the MPV before being pushed to the optical block for measurement. MPV replacement is simple, performed only by pulling a lever, making maintenance easy. The Alyza IQ PO4 also offers new onboard diagnostics for intuitive operation.

## PHOSPHORUS MEASUREMENT

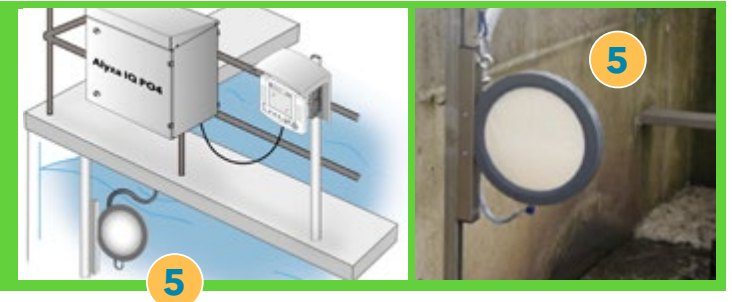
### Main Parts

- 1 Electronics
- 2 Reagents & Solutions
- 3 Photometric Unit
- 4 Sample Pumps



- 5 In-Situ Filter

The in-situ filter is immersed directly in the water and brings clean sample to the analyzer.



# Meet Alyza. The Simple Choice.



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YSI's wet chemistry analyzer for  
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Measure ammonium  
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# 4

# PHOSPHORUS **REMOVAL**



# Overview

There are **several strategies** available for phosphorus removal in wastewater. Chemical removal, biological removal, and tertiary filtration are all options depending on treatment goals and the facility's needs.

With all the possibilities, phosphorus removal may seem complicated, but they all accomplish the same goal. The concept of phosphorus removal is to convert as much dissolved phosphorus as possible into particulate phosphorus, then settling or filtering the particulate phosphorus to remove it from the process.

**Chemical removal** involves the dosing of a metal salt to precipitate phosphorus into a solid form. **Biological removal** requires the cultivation of phosphorus accumulating organisms (PAOs) by providing the correct environmental conditions within the process. These PAOs uptake large amounts of phosphorus within their cells, which are later settled or filtered.

Finally, **tertiary filtration** is used in combination with chemical or biological removal, which uses filtration systems post-secondary treatment to reduce total phosphorus to ultra-low levels. Each has its pros and cons, so the strategy implemented should be based on the needs of each particular facility.

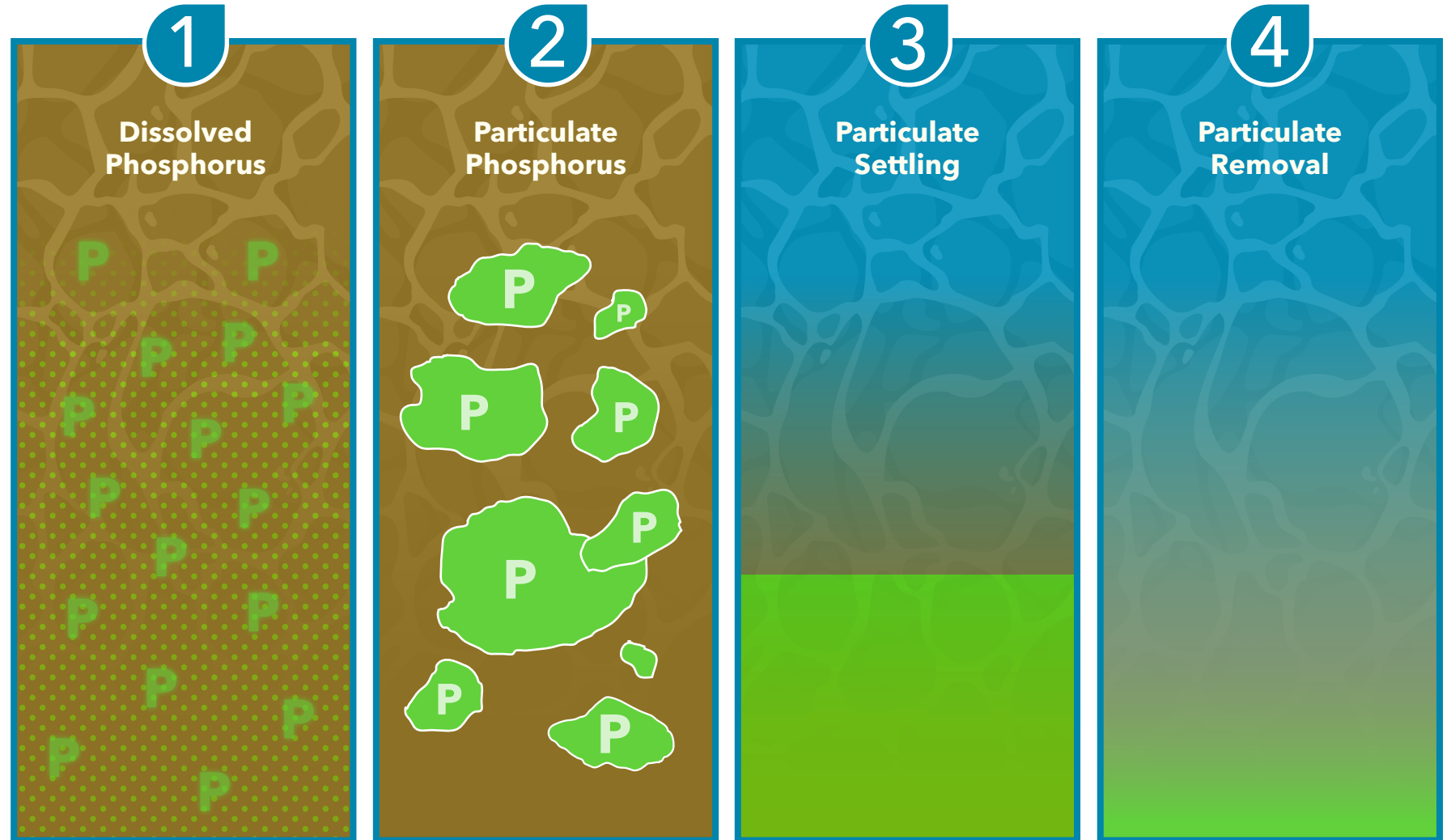
Aside from the importance of converting dissolved phosphorus to particulate phosphorus, these strategies rely heavily on the effectiveness of the solids separation processes. The clarification and filtration within a facility must have their effluent TSS concentrations very low. Any suspended solids escaping through the final effluent will increase the total phosphorus but would be undetected by an orthophosphate analyzer.



# Stages of Phosphorus Removal

**Phosphorus removal** (both chemical and biological) can be broken down into four general steps:

- 1** Influent wastewater is high in dissolved phosphorus.
- 2** Dissolved phosphorus is converted into particulate phosphorus either chemically or biologically.
- 3** These particulate solids are settled in a clarifier or filtered.
- 4** Particulate solids are removed from process, reducing the total phosphorus concentration in the water.



# Chemical Removal

When metal salts are added to the process water, they encourage the creation of **hydrous metal oxide** flocs called **HMOs**.

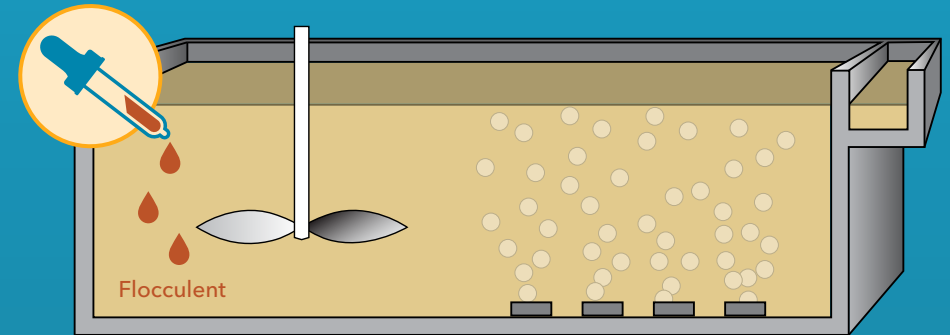
The metal ions' positive charge attracts the phosphate ion's negative charge and precipitates into a solid. With enough turbulence and mixing, precipitates can form together to create the suspended HMO floc within the water.

The HMO floc's surface is complex, containing many additional reactive sites for dissolved phosphorus to bond with the salts within the floc. The complex surface also manages to capture any particulate phosphorus suspended in the water, making chemical removal very effective.

These HMOs can be produced with several different metal salt flocculants, mostly aluminum or iron-based. Aluminum sulfate and ferric chloride are the most common, which earns them the nicknames alum and ferric.

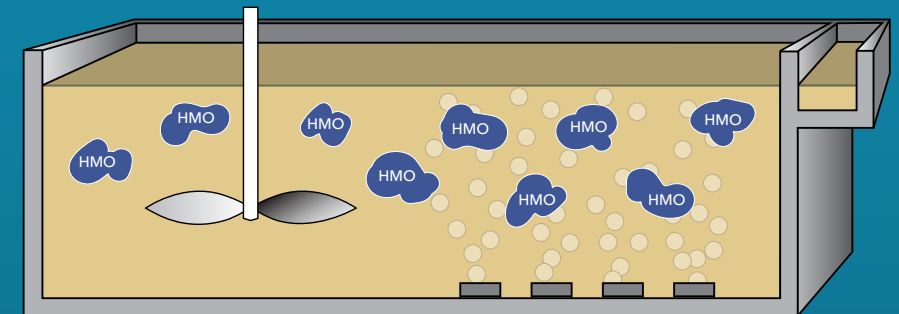
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Process water is dosed with a **metal salt flocculent**.  
(Alum, ferric, etc.)



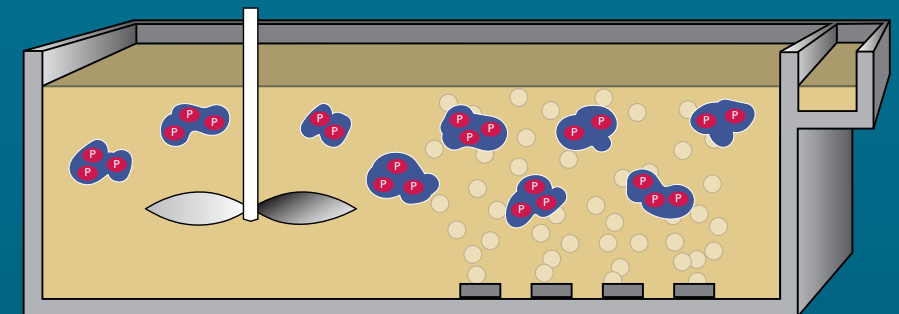
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The metal salt reacts with the water to produce **HMO floc**.



3

HMO floc binds to dissolved phosphorus and captures particulate phosphorus.



# Dosing

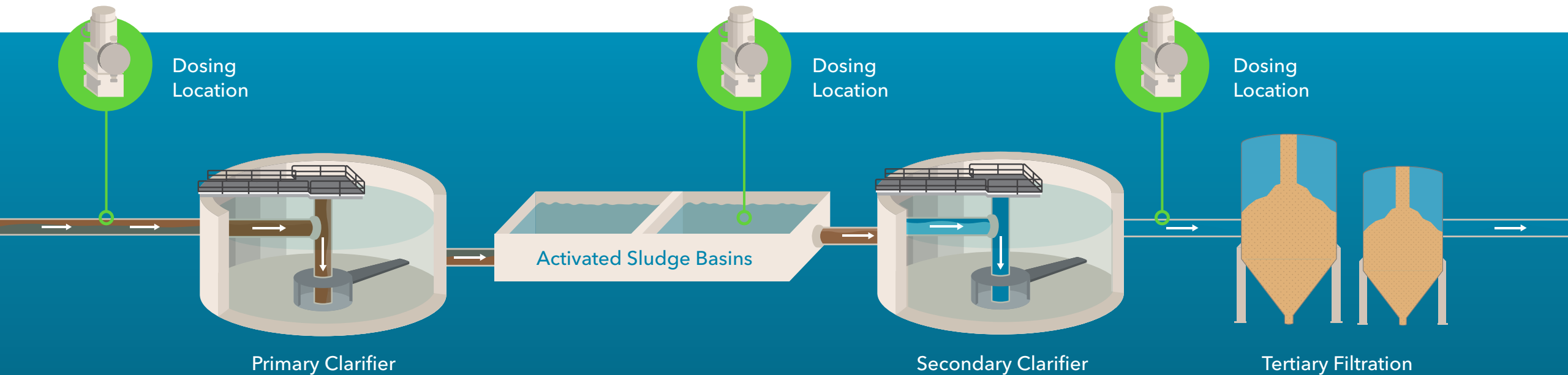
**Dosing** can occur in several parts of the wastewater treatment process. Dosing before primary sedimentation can yield quality results and reduce total phosphorus concentrations to less than 1 mg/L T.P.

For **activated sludge plants**, dosing within aeration basins can effectively achieve good phosphorus removal with reduced chemical usage.

The recirculation of sludge and additional absorption from the activated sludge floc aids the phosphorus removal.

Perhaps the best place to add chemicals for facilities attempting to achieve very low total phosphorus limits (below 0.1 mg/L) would be post-secondary treatment.

In **secondary effluent water**, most solids have been removed. The phosphorus present in this location should be in the dissolved form, allowing for a strong reaction between the metal ion and the orthophosphate.



# Dosing Amount

The required dose is highly dependent on the **dissolved phosphorus** present in the water.

Theoretically, dosing 1 mole of alum or ferric is equivalent to removing 1 mole of phosphorus. Simplified, this means to remove 1 mg/L phosphorus, 9.6 mg/L of alum, or 5.2 mg/L of ferric would need to be dosed.

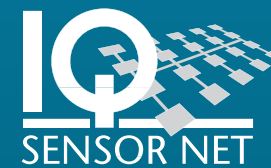
Facilities typically dose much more than required, and efficacy is dependent on a few factors, such as pH (ideally 5.6–7.5), mixing strategy, and other wastewater characteristics.

The best way to always dose the correct amount in order to achieve the goals of a WRRF is to utilize an **online orthophosphate analyzer**.

Orthophosphate analyzers, like the [Alyza IQ PO4](#), can provide the necessary information to calculate and control chemical dosing automatically.

Since orthophosphate is the target for chemical dosing, this measurement can directly control the dosing. Also, orthophosphate analyzers are more affordable and easier to use than total phosphorus analyzers, making them ideal for controlling and monitoring chemical dosing.

PHOSPHORUS **REMOVAL**



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# Dosing Strategies

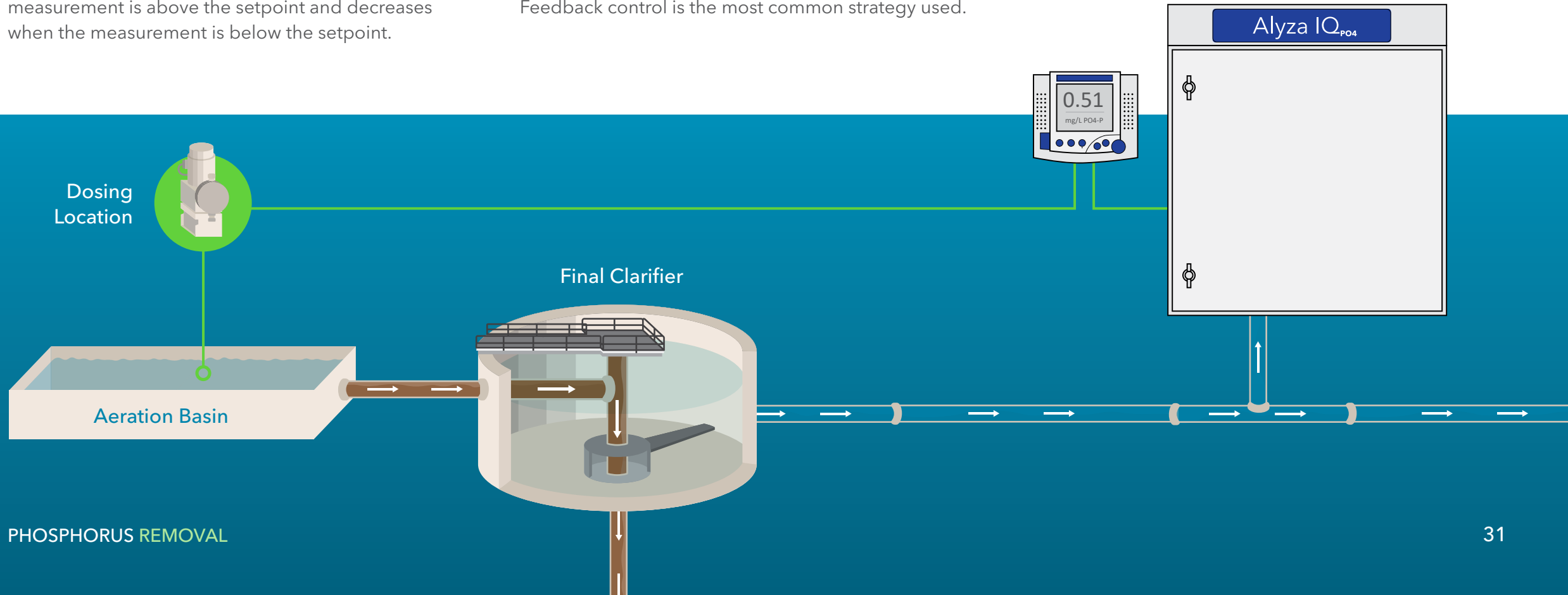
There are two strategies for using an orthophosphate measurement for dosing control, **feedback** and **feed-forward control**.

**Feedback control** is often controlled with a setpoint. Dosing increases when the orthophosphate measurement is above the setpoint and decreases when the measurement is below the setpoint.

The goal is to maintain a dosing rate that keeps the orthophosphate measurement nearest to the setpoint. The orthophosphate analyzer sampling location is downstream of the dosing point but not too far to reduce lag time.

Feedback control is the most common strategy used.

**Feed-forward control** is load proportional, meaning the upstream orthophosphate measurement is used to calculate a dosing rate based on the incoming load. The higher the orthophosphate load, the higher the chemical dose required (St. Pierre & Smith, 2014).



# Case Study: Oconomowoc, WI

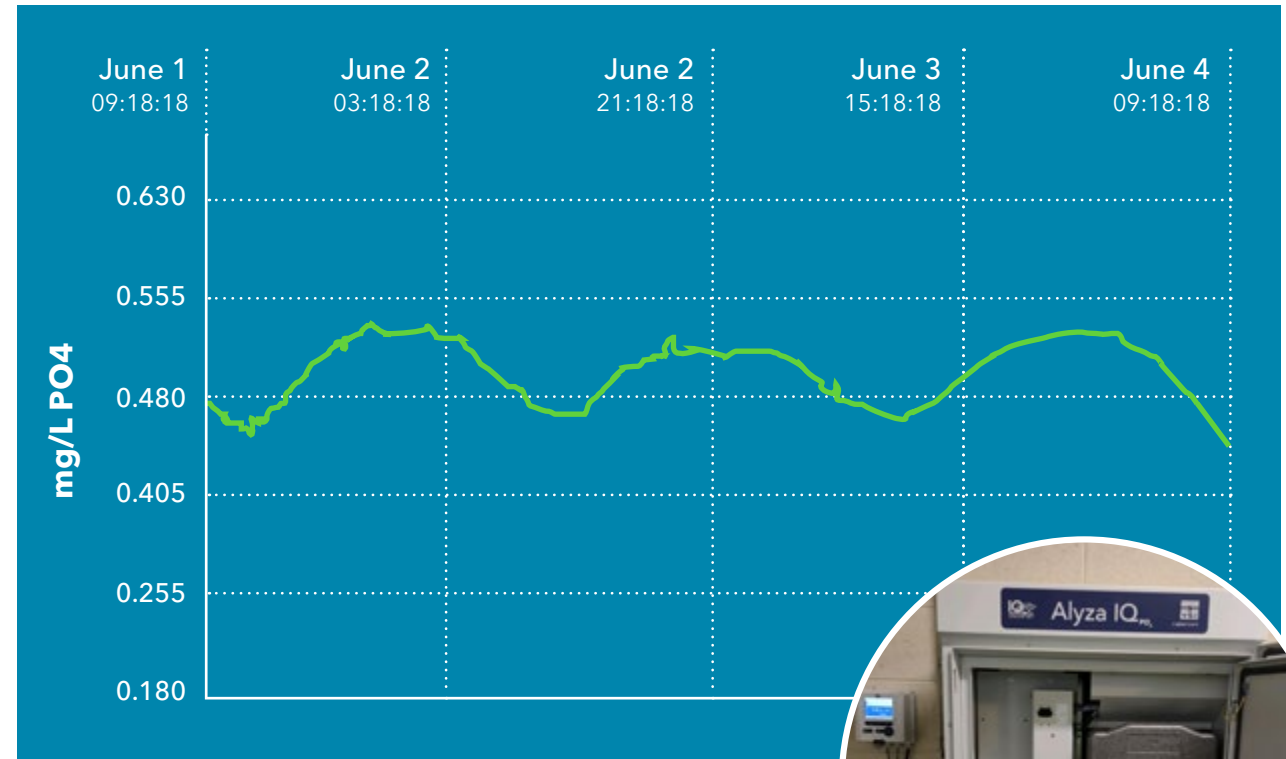
Effluent total phosphorus limits in **Wisconsin** are lower than ever before, with many facilities required to meet limits well below 1.0 mg/L T.P.

The City of Oconomowoc WWTF is no exception. Their facility is part of the Wisconsin Department of Natural Resources Adaptive Management Plan, in which the facility can reduce their effluent total phosphorus down to below 0.6 mg/L T.P. through optimization, slight operational changes, or limited facility upgrade. With the installation of an **Alyza IQ PO4**, Oconomowoc could optimize their chemical phosphorus removal process, meet their new effluent T.P. limit, and avoid a major facility upgrade.

Prior to owning an Alyza, Oconomowoc was dosing ferric based on two daily grab samples, which is less efficient as phosphorus loading fluctuates throughout the day. Today, the Alyza provides a feedback signal from its location downstream of tertiary filtration and automatically adjusts ferric dosing at the end of their aeration basins. The control strategy continuously doses a minimum of 3 gal/hr, but increases proportionally to the orthophosphate concentration when it rises above their 0.5 mg/L PO4 set point.

Operations Manager of Oconomowoc WWTF, Kevin Freber, says “We’ve had a great experience with the Alyza. The operators like it, we’ve received training from YSI and the local rep Mulcahy Shaw Water, and we can now maintain the unit ourselves.” Similar to Oconomowoc, the Alyza IQ PO4 can help facilities across the US achieve better phosphorus removal.

**Post-Filtration Orthophosphate** (3-Day Trend)



*The Alyza at Oconomowoc WWTF (right) measures orthophosphate continuously, controlling ferric dosing and ensuring effluent Phosphorus is below 0.6 mg/L T.P.*



# Bio-Removal

Biological nutrient removal (BNR) is the cultivation of select microorganisms and bacteria to remove nutrients from wastewater. Enhanced biological phosphorus removal (EBPR) is the BNR process designed to remove phosphorus using PAOs, or **phosphorus accumulating organisms**.

The entire process depends on enhancing the PAOs to take up more phosphorus than they typically would. This secondary treatment process requires putting PAOs through two phases, an anaerobic phase followed by an aerobic phase

In the anaerobic phase, the organisms are stressed by the lack of dissolved oxygen and nitrate. As a result, the PAOs utilize their polyphosphates as energy to continue to take up BOD from the water (specifically volatile fatty acids or VFAs) and converted it to poly-B-hydroxybutyrate (PHB) for storage (Smith, 2019).

The phosphorus in the water will increase from all the PAOs releasing their polyphosphate stores.

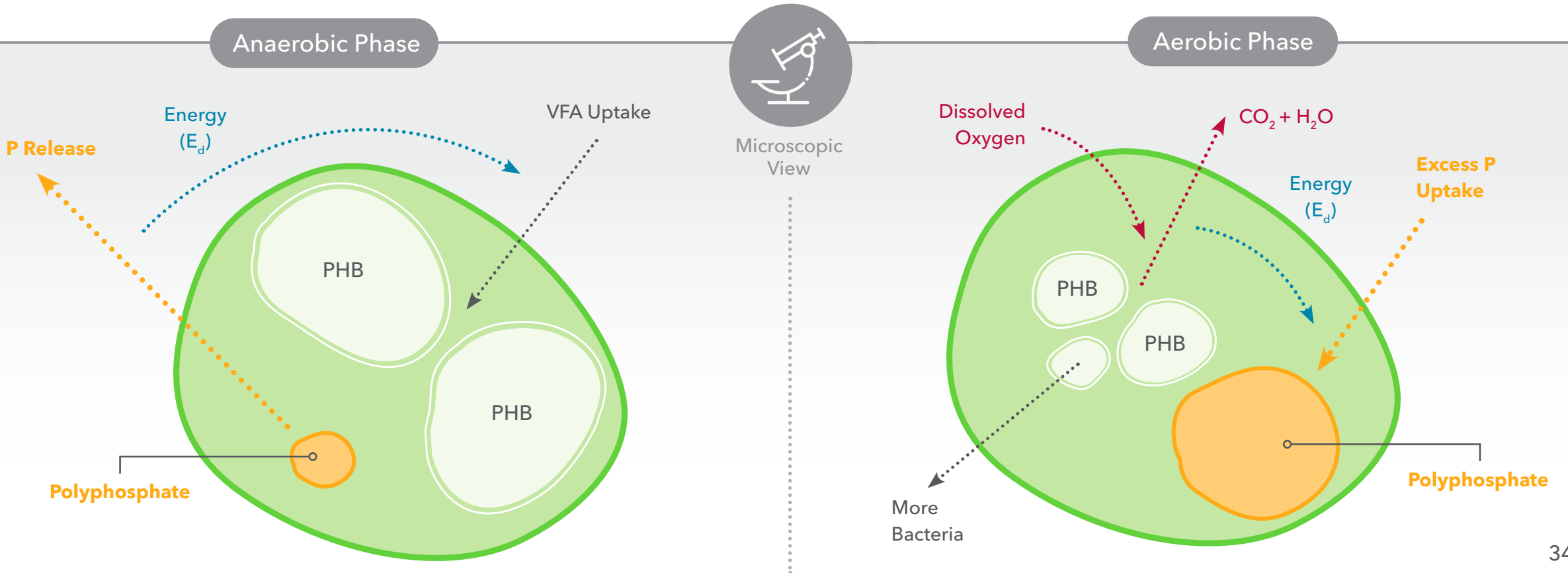


# PAOs

When the **PAOs** (phosphorus accumulating organisms) reach the aerobic phase, they will have a huge competitive advantage over the other microorganisms in the water with their stored PHB.

Their accumulated PHB store is metabolized with the newly reintroduced dissolved oxygen, creating large amounts of energy. This energy is used for reproducing more PAOs and **"luxury uptake"** of phosphorus from the water into their cells.

The increased PAO population and the excess phosphorus uptake within each PAO reduce the phosphorus content within the water. These PAOs are later removed from the process by settling or filtration, taking their phosphorus stores with them.



# Anerobic Zone

For the **EBPR process**, correct conditions within the anaerobic zone are essential:

- Any dissolved oxygen or nitrate will disrupt the phosphorus release of the PAOs.

Both provide competition for the available BOD in the water, meaning other organisms would more quickly consume the BOD within the water before the PAOs. Achieving true anaerobic conditions is very important.

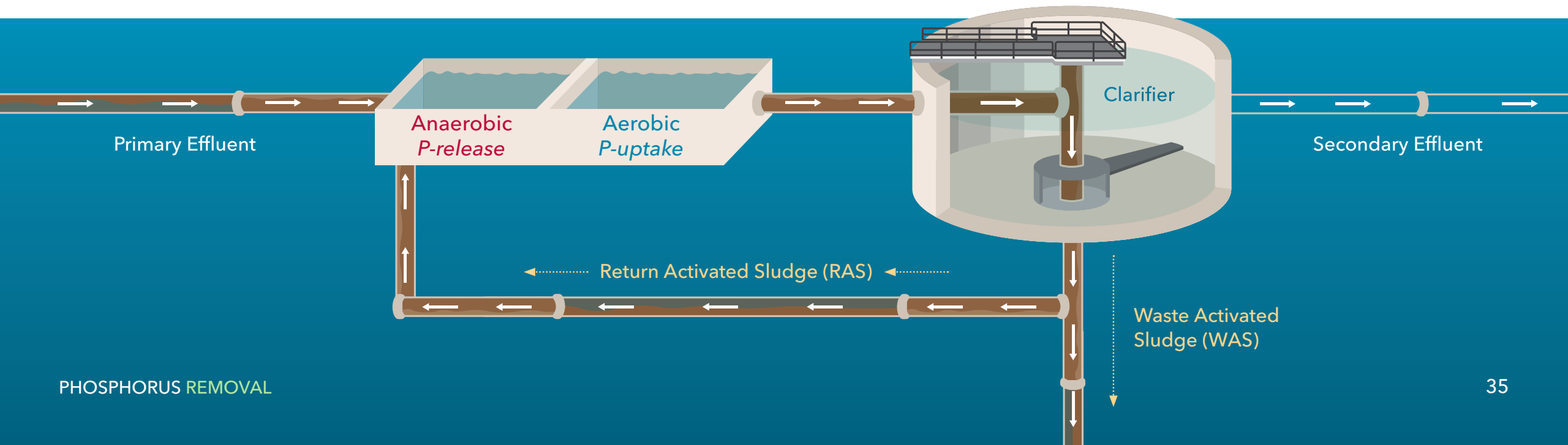
- There needs to be sufficient BOD loading for the uptake of the phosphorus within the system.

The BOD to phosphorus ratio (BOD:P) is used to characterize this relationship. For good biological phosphorus removal, a ratio of greater than 40:1 is ideal.

- This BOD needs to be readily biodegradable, like volatile fatty acids (VFAs).

All BOD will eventually break down to a biodegradable form in anaerobic conditions, but retention times may not be long enough for this to occur (Ross, 2013).

Testing for VFAs directly or a soluble BOD/COD test may give a better idea of the true ratio of BOD used for anaerobic uptake.



# Process Monitoring

Monitoring the EBPR process with instrumentation can help maintain consistent performance and quickly alert an operator of any issues. Orthophosphate is again a crucial parameter. The Alyza IQ PO4 can monitor EBPR performance and final effluent concentrations. Without online orthophosphate monitoring, routine grab samples can get the job done. However, continuous data can help alert you of issues with the EBPR process and ensure sufficient treatment at all times, even with variable loadings. Besides orthophosphate, several other sensors are available within **YSI's IQ SensorNet** that can monitor EBPR.

**Oxidation-reduction potential (ORP)** is a common parameter for monitoring and controlling anaerobic processes. It can indicate the type of biological activity occurring within a tank, so maintaining the ORP value within a particular range (-150 to -250 mV) can ensure anaerobic conditions are present. Dissolved oxygen (D.O.) sensors are commonly used to monitor and control aeration in many activated sludge facilities. This is also the case with EBPR in which D.O. sensors can maintain aeration output at the optimum level for the aerobic zone.

Carbon parameters, like COD and BOD, can now be monitored online with advanced U.V. sensing technology. These sensors can quantify the amount of biodegradable carbon available within an anaerobic zone, indicating if additional carbon needs to be provided for a proper BOD:P ratio. Finally, if volatile fatty acids are a concern, they can be measured directly using laboratory procedures. YSI auto-titrators can make monitoring VFAs quick and accurate to ensure the growth of PAOs.

## YOU **ALWAYS** HAVE A CHOICE



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### You have a choice in process monitoring.

YSI has been developing and manufacturing water quality monitoring instrumentation in the U.S. for 70 years.



IQ 2020  
Controller

### It's time to partner with YSI.

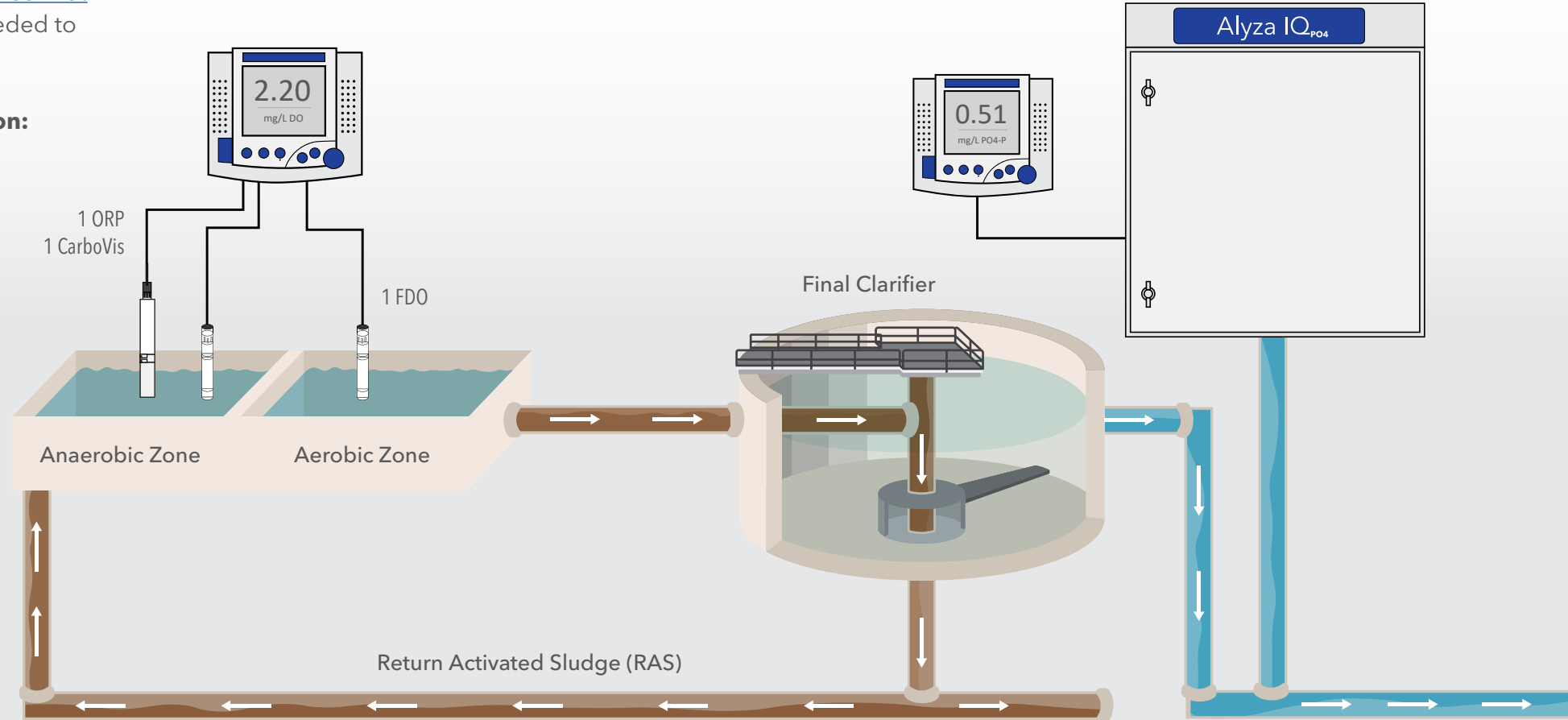


# Process Monitoring

Online process monitoring with [IQ SensorNet](#) provides the 24/7 continuous data needed to keep tabs on your system.

## Six benefits of online instrumentation:

- 1 Access to continuous data
- 2 Monitor process efficiency
- 3 Reduced energy and chemical costs
- 4 Effluent compliance monitoring
- 5 More precise treatment
- 6 Reduce manual sampling



# Tertiary Filtration

Phosphorus removal has been the nutrient of concern for several decades in parts of the U.S. that discharge into freshwater ecosystems. WRRFs in these regions have introduced several techniques and technologies to reduce their total phosphorus discharge as much as possible.

Using **tertiary filtration**, facilities can reduce total phosphorus to ultra-low levels of less than 0.1 mg/L. Tertiary filtration is usually used in combination with chemical or biological removal because it still relies on the concept of converting as much orthophosphate into particulate phosphorus.

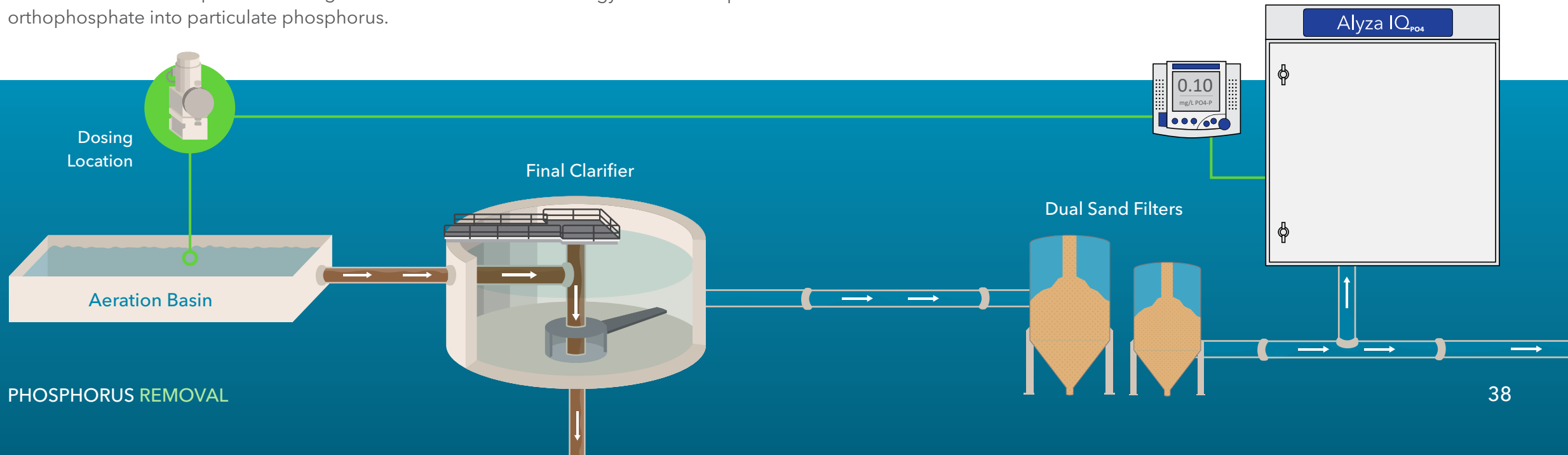
These processes usually work to reduce total phosphorus by greatly reducing effluent TSS.

Some common types of tertiary filtration include sand, mixed media, cloth media, membrane, disc filtration, and more. These processes are employed after the secondary effluent and may be used in combination with disinfection before the final effluent.

Tertiary filtration comes in many different forms from many manufacturers, so thorough research of the technology chosen is imperative.

Depending on the design, some can be retrofit into an already operating facility, or a new facility can be designed around the use of tertiary filtration.

Orthophosphate analyzers are frequently used at tertiary treatment facilities to monitor the effectiveness of ultra-low phosphorus removal. With the 0.02 mg/L P minimum detection limit of the Alyza IQ PO<sub>4</sub>, continuous measurements well below current effluent total phosphorus limits will detect trends at all levels and alert operators to any process issues.



# Conclusion

Each phosphorus removal strategy has its pros and cons. The decision on which strategy to use should depend on the **needs of the facility**.

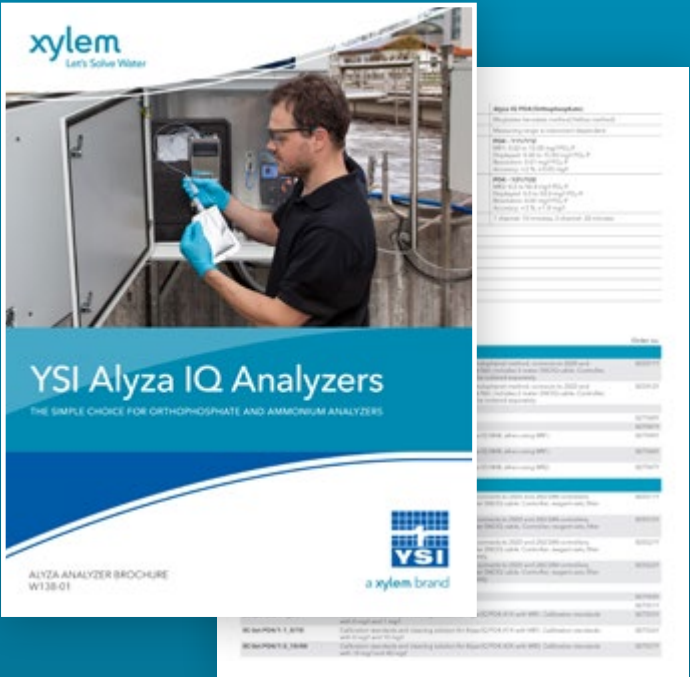
For example, **chemical removal** is easy to implement and has a low possibility of failure, but the increased operating costs associated with purchasing chemicals and increased solids produced need to be considered.

For **EBPR**, low operating cost is a benefit of this type of removal process; however, there are large infrastructure requirements with the need for an anaerobic zone, and the influent water characteristics need to be evaluated for proper COD to phosphorus ratio and VFAs.

Finally, we have **tertiary filtration**, which has the benefit of being able to reach these ultra-low phosphorus levels. Still, tertiary filtration must be used in combination with another removal process, and the equipment can be expensive to implement.

The expansion of phosphorus effluent limits into new regions and lower limits have greatly increased the need for better technologies. Control strategies for chemical dosing are improving and becoming easier to use. Research into enhanced biological phosphorus removal is making it more reliable and effective.

Also, instrumentation for the monitoring parameters, particularly orthophosphate analyzers, are becoming more advanced, requiring less maintenance, and reaching very low minimum detection limits. The information within this e-book provides the basic knowledge for how phosphorus removal occurs and why it is important.



**Alyza IQ PO4 Brochure Download**

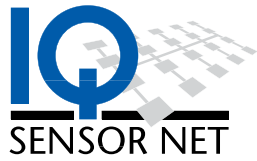
The Simple Choice for Orthophosphate and Ammonium Analyzers

**View Brochure**

# 5

## REFERENCES & RESOURCES

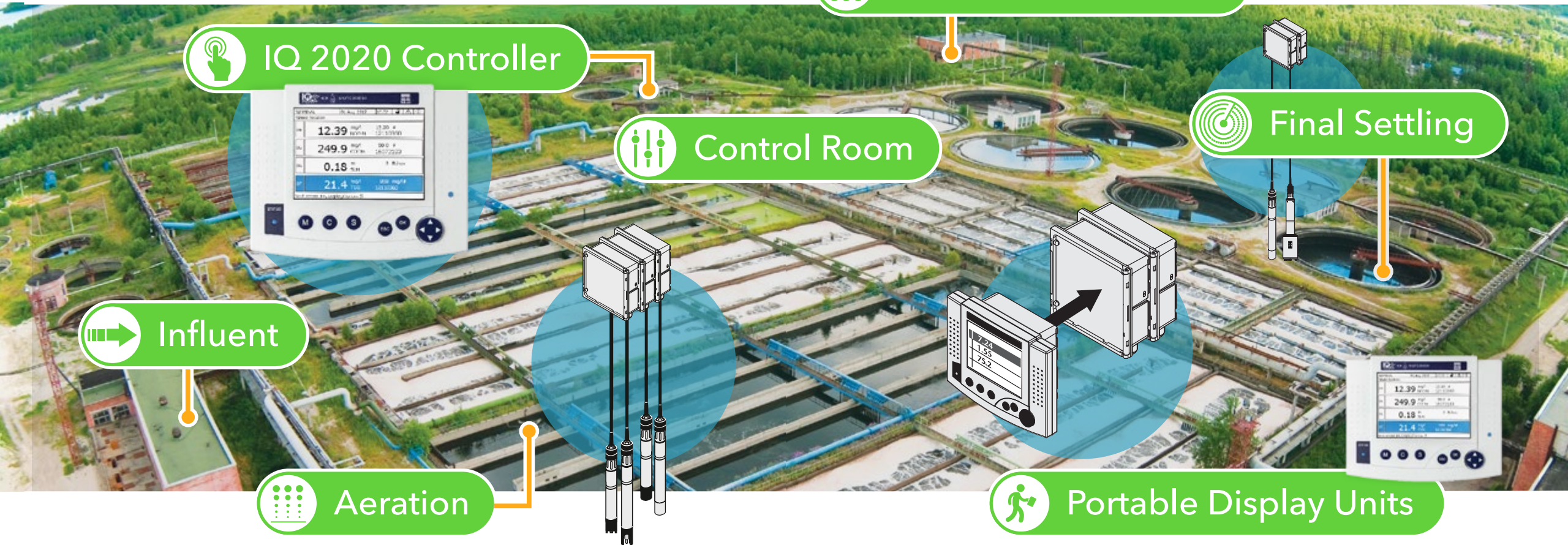




**IQ SensorNet** is a monitoring and control system of analytical instrumentation that assures compliance, improves treatment reliability, and minimizes energy and chemical usage. Display and report on up to 20 water quality sensors within a single network.



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**Parameters available:**

- Orthophosphate
- Dissolved Oxygen
- Ammonium
- Nitrate & Nitrite
- COD, BOD, TOC, DOC
- UVT-254, SAC
- Sludge Level
- pH & ORP
- TSS & Turbidity
- Temperature
- Conductivity



[YSI.com/IQSN](https://www.ysi.com/IQSN)



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# Resources



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[Info@YSI.com](mailto:Info@YSI.com)

## Ask a Question

Don't be shy, ask us anything! It doesn't have to just be about phosphorus removal. We like answering all kinds of customer questions!



[YSI.com/IQSN](https://www.ysi.com/IQSN)

## IQ SensorNet

IQ SensorNet continuously monitors water quality throughout the wastewater treatment process, from the influent through the effluent, increasing efficiency and lowering costs.



[YSI.com/Alyza](https://www.ysi.com/Alyza)

## Alyza IQ PO4

Have aqueous samples? Think they might be full of orthophosphate? Find out with scientific accuracy using Alyza IQ PO4 for online monitoring.

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- 2) a leading global water technology company.

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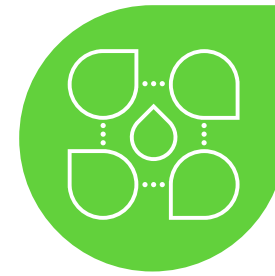
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