Effects of Microbial Inoculator Generators (MIGs) on Nitrogenous Compounds and Phosphorus Adsorption Devices on Phosphoric Compounds in a Septic System Pilot Study

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Abstract

This report is intended to answer the following question: What is the fate of nitrogenous and phosphoric compounds in microbial inoculator generators and phosphorus adsorption devices in an onsite treatment application? In anticipation of a long-term investigation, a short-term (four months) pilot study was undertaken to validate the study's research design and to collect preliminary results to answer the research question. A pilot study was conducted at Brookfield Wastewater Treatment Facility [WWTF] in Brookfield, Wisconsin. The pilot study featured a small wastewater treatment system consisting of one septic tank, two microbial inoculator generators [MIGs], one tank with a pump for recycle flow, and one phosphorus adsorption device. The study was conducted at the Brookfield facility because of the easy access to sufficient amounts of wastewater. During the pilot study, it was discovered that an unusual syphon developed in the system, associated with the configuration of the system. A syphon occurs when a pipe becomes pressurized, forcing liquids to flow when a pump is not in operation. In this study, the syphon operation had a dramatic effect on the fate of nitrogenous compounds in the final effluent. Sampling began June 17, 2022, then the syphon was discovered August 25, 2022, and the final sample was collected October 20, 2022. This syphon is unlikely to occur in a normal installation of the equipment, so the nitrification and denitrification results for this pilot study are separated by results that include the data following date of the appearance of the syphon and those that do not. However, the fate of phosphoric compounds was unaffected by the syphon, so all available phosphorus data were used for results. The results of this pilot study suggest that the use of MIG and phosphorus-removal technology for private onsite wastewater treatment systems [POWTSs] shows promise in the removal of nitrogen and phosphorus nutrients. Leveraging the lessons learned from this pilot study, a long-term and comprehensive study is recommended.

Keywords: microbial inoculator generator [MIG], phosphorus, nitrogen, phosphorus adsorption, inoculation, titanium dioxide, nutrient removal, onsite wastewater treatment, denitrification, nitrification, National Pollutant Discharge Elimination System [NPDES] permit

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Nomenclature

Symbols

n	Number of Samples
S_d	Standard Deviation of Differences
$\bar{x}_d$	Sample Mean Difference
z	Z Test Statistic, Value of Standard Deviations from Mean Difference
α	Alpha, Level of Significance

Abbreviations

Ammonia	NH_3/NH_4^+
BOD_5	Five-Day Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
MIG	Microbial Inoculator Generator
Nitrate	NO_3^-
Nitrite	NO_2^-
POWTS	Private Onsite Wastewater Treatment System
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TSS	Total Suspended Solids
WWTF	Wastewater Treatment Facility

Effects of Microbial Inoculator Generators (MIGs) on Nitrogenous Compounds and Phosphorus Adsorption Devices on Phosphoric Compounds in a Septic System Pilot Study

This report describes and explains a pilot study that investigated the fate of wastewater nutrient pollution (nitrogen and phosphorus) in a septic system installation featuring the use of microbial inoculator generators [MIGs] and a phosphorus adsorption device. The centralized wastewater treatment industry commonly has stringent regulatory limits requiring the removal of nitrogenous compounds from wastewater; similarly, limits can also exist (depending on local or state regulatory enforcement) for phosphoric compounds, but most of the focus is on technology for large-scale wastewater treatment facilities [WWTFs]. However, WWTFs are not the only solution for treating wastewater. Decentralized systems are used by approximately 20 percent of homes for wastewater treatment (U.S. Environmental Protection Agency, 2023). Nutrient removal technology for these private onsite wastewater treatment system [POWTS] installations, which are often unregulated in nutrient discharges, would also reduce nutrient pollution in proximate water bodies. Nutrient pollution is detrimental to both water quality and human health (Wisconsin Department of Health Services, 2021; National Research Council, 2000). It is hypothesized that the use of MIG and phosphorus adsorption technology in a septic system installation will result in the reduction of nitrogenous and phosphoric compounds in wastewater.

The research, findings, and conclusions from this paper address the fate of nitrogenous and phosphoric compounds in a pilot study deployed at Brookfield WWTF. The pilot study featured the installation of a small POWTS at the Brookfield (Wisconsin) WWTF. The Brookfield WWTF was selected in part because it provided easy access to sufficient amounts of nutrient-polluted wastewater for testing. The pilot study system consisted of a trash tank, two microbial inoculator generators [MIGs] with a recycle flow feeding back to the trash tank, and a phosphorus adsorption device. The goals of the study were to validate the research design and to collect preliminary data results with respect to the use of MIG and phosphorus adsorption technology in a septic system to learn whether the system would feature a reduction in nitrogenous and phosphoric compounds in the wastewater treated by the system. Samples were taken across several locations through the pilot configuration on an approximately weekly basis. During the pilot study, a syphon occurred in the influent piping. Syphon flow occurs when a temporary vacuum is formed as a result of a difference in pressure associated with the unequal weights of fluids in two parts of a pipe (Encyclopedia Britannica Kids, n.d.). One way to avoid syphoning in a piping system is to use a vacuum breaker (Advantage Engineering, n.d.). A syphon occurred in the system because the vacuum breaker failed to stop the syphon from forming. Following the occurrence of the syphon, the results varied greatly from the results before the syphon and the data saw an increase in the ammonia and nitrate concentration in the final effluent when compared to the data from before the syphon. The data following the syphon was not considered representative of the fate of nitrogenous compounds within the system. Therefore, in this report, results are provided for nitrogenous compounds as two separate results. One result includes only data before the syphon occurred and the other result includes the full data set. The MIG appears to be an effective tool for nitrogen removal for POWTSs and the phosphorus adsorption device appears to reduce the total phosphate of wastewaters. More research is needed to produce more definitive conclusions, but the pilot study resulted in many suggestions for future installations.

Background

The research question for this report is: What is the fate of nitrogenous and phosphoric compounds in an onsite wastewater treatment system featuring MIGs and titanium dioxide-based phosphorus adsorption devices? The following topics need to be examined when considering the research question. What is nutrient pollution? What are the common technologies for nutrient treatment in both centralized and onsite systems? How do MIGs work? How does titanium dioxide adsorb phosphorus? How can titanium dioxide be reused? This report explains these topics to break down the complex research question posed.

Nutrient Pollution

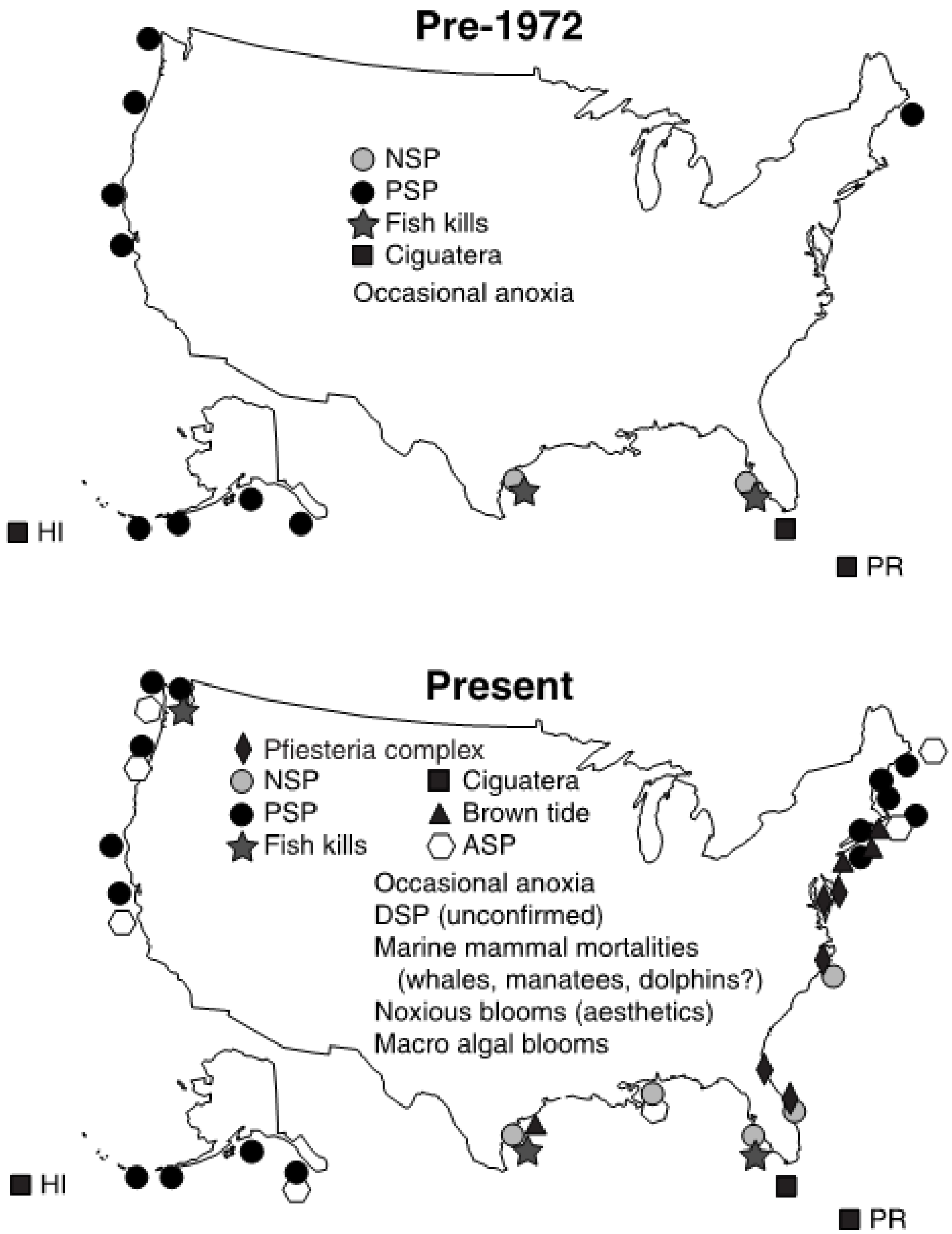
Nutrient pollution is defined as “excess amounts of nitrogen and phosphorus in aquatic systems” (United States Environmental Protection Agency [US EPA], 2015, pg. ES-1). Nutrient pollution affects human health and the environment. Excess nitrates in drinking water cause conditions including infant methemoglobinemia, also known as “blue baby syndrome”, in which a baby’s skin turns blue. This condition occurs due to the presence of excess nitrates, which reduce the oxygen content of the infant’s blood (Wisconsin Department of Health Services, 2021). Environmental impacts of excess nutrients include rapid algal growth, which reduces the oxygen content of the water and is known as eutrophication (Minnesota Pollution Control Agency, 2009). The areas in water bodies with low levels of oxygen are often described as dead zones, where large numbers of fish die (United States Environmental Protection Agency, 2021). Nutrient discharge limits into inland bodies of water are often established to limit these drastic decreases in oxygen within a water body (United States Geological Survey, 2019).

Nutrient pollution is documented in shoreline regions across the United States. Fish kills, macro algal blooms, and brown tide are all conditions or events resulting from nutrient pollution

(National Research Council, 2000). The effects of nutrient pollution are increasingly apparent when discharges occur directly to standing water bodies (National Research Council, 2000). Figure 1 depicts the increase in harmful algal blooms [HABs] in the United States. Gilbert and Burford (2017) observe that the most effective way to reduce HABs is through the reduction of nutrient pollution. One source of nutrient discharges is wastewater (U.S. Environmental Protection Agency, 2023).

Figure 1

Harmful Algal Bloom Occurrences Across the United States



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Note. Adapted from "Figure 1-2" by the National Research Council, 2000, *Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution*, p. 29 (https://doi.org/10.17226/9812).

Regulation of wastewater discharges is varied. One regulatory method is through discharge permits. The Clean Water Act authorized the National Pollutant Discharge Elimination

System (NPEDS) permit program. The purpose of the program is to control water pollution by regulating sources that discharge pollutants into waters in the United States. These sources are referred to as "point sources." “The United States Environmental Protection Agency (EPA) defines point source pollution as ‘any single identifiable source of pollution from which pollutants are discharged, such as a pipe, ditch, ship or factory smokestack’” (National Ocean Service, n.d., para. 1). One common point source is a WWTF. NPDES permits can regulate the pollutants responsible for nutrient pollution: nitrogen and phosphorus. These parameters are considered nonconventional pollutants in NPDES permits (United States Environmental Protection Agency, 2010). These permits typically provide requirements for the maximum discharge of a constituent over a given time with the goal of improving water quality. Other permit parameters include BOD_5 and TSS, of which the reference standard is 30 mg/L of each (Mahamah, 2015).

Wastewater is treated in one of two types of systems: centralized or decentralized treatment. Centralized wastewater treatment is used for large-scale systems to serve a region, where decentralized wastewater treatment is typically relatively small-scale systems serving smaller areas close to the wastewater source (Fluence News Team, 2021). While all centralized systems are required to obtain a discharge permit, only some POWTSs are required to obtain a discharge permit. The threshold at which a discharge permit is required depends on the legislature of the state of installation. In Wisconsin, for example, the Department of Natural Resources (DNR) only regulates systems of underground dispersal of domestic wastewater if the system design flow rate is greater than or equal to 12,000 gallons per day or the actual flow rate is greater than or equal to 8,000 gallons per day (Wisconsin Department of Natural Resources, n.d.). As a result, most residential septic systems are not regulated by permits in Wisconsin.

Instead, the regional health departments are responsible for regulation of small-scale POWTS (Eau Claire City-County Health Department, n.d.).

Attaining Nutrient Discharge Limits Through Nutrient Removal Technology

The inclusion of nitrogen and nitrogenous compounds in NPDES permits began approximately 50 years ago (National Research Foundation, 2000). Phosphorus compounds have been added to some of the NPDES permits in several states, including California and Wisconsin (United States Environmental Protection Agency, 2022a). Permit limits that have nutrient discharge limits require additional technology to achieve the nutrient removal rates required by the governing body.

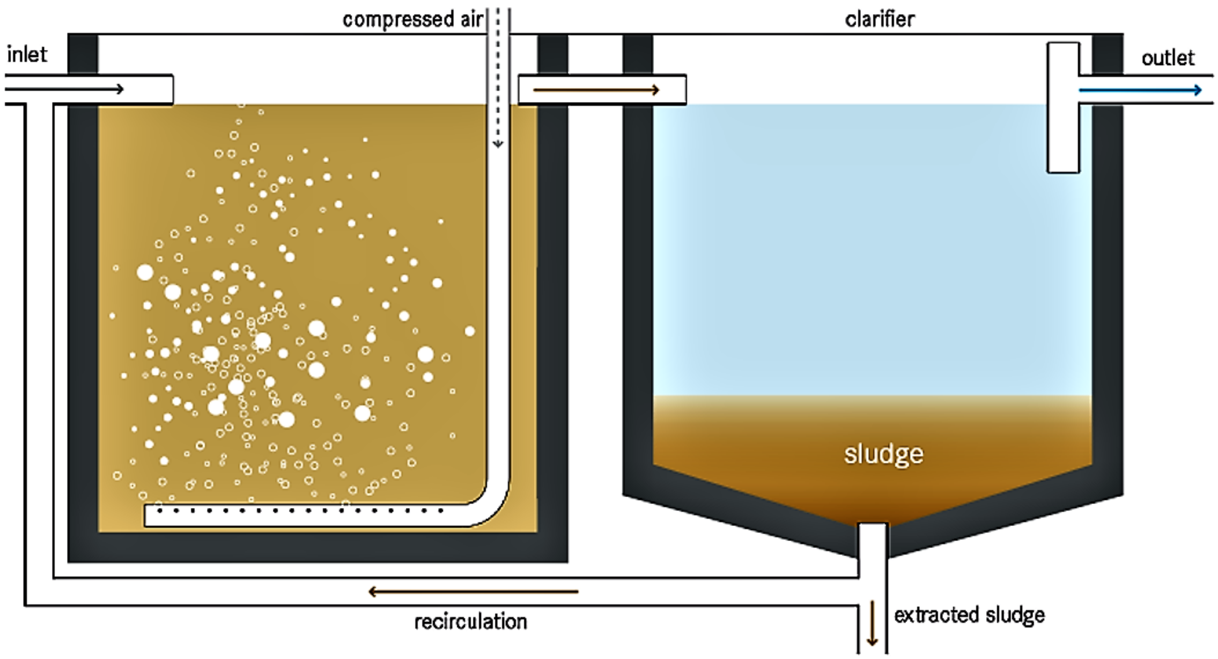
Nitrogen and phosphorus removal technology are commonly used in centralized systems but are rare in POWTS installations. NPDES permits for some states include nutrient regulation provisions in septic system regulations as a way to reduce the impact of nitrogen and phosphorus (United States Environmental Protection Agency, 2022b).

Nitrogen Removal Technology

One common method of biological nitrogen removal is a process called activated sludge. This process is energy intensive and requires blowers to disperse air in a portion of the basins. See Figure 2 for a diagram of activated sludge systems. An activated sludge system typically requires regular maintenance and intervention to achieve consistently low concentrations of nitrogenous compounds. The efficiency of nitrogen removal in activated sludge processes is improved through the use of ferric chloride (Bowden et al., 2015).

Figure 2

Activated Sludge Process Diagram



Note. Adapted from "Activated Sludge Systems" by Elizabeth Tilley et al., 2016, *Compendium of Sanitation Systems and Technologies*, p. T.12.

Trickling filters are also used for nitrogen removal in some WWTFs. Trickling filters are less energy intensive than activated sludge systems because no blowers are required for oxygenation, but the nitrogen removal rates are typically lower than the typical removal rates associated with activated sludge plants (Constantinou et al., 2013).

Another method of biological nitrogen removal is a variation of the activated sludge process referred to as integrated fixed film activated sludge [IFAS]. IFAS systems consist of an activated sludge system with the addition of a suspended material for biomass growth (Metcalf & Eddy, Inc. et al., 2013). IFAS systems typically have improved nitrogen reduction compared to typical activated sludge systems.

There are a variety of other biological nitrogen treatment methods available, including sequencing batch reactors, anaerobic fixed film reactors, and oxidation ditches (Metcalf & Eddy, Inc. et al., 2013).

Phosphorus Removal Technology

The two types of phosphorus removal techniques used in municipal WWTFs are biological phosphorus removal and chemical phosphorus removal.

Biological phosphorus removal first creates environments in the process flow that encourage microorganisms to release the phosphorus contained in the cell. Next, a different environment supports uptake of phosphorus from the wastewater by microorganisms. This uptake, referred to as “luxury uptake,” is greater than the initial release and results in a reduction of phosphorus concentrations in wastewater when the microorganisms are settled out of the wastewater. Biological phosphorus removal typically requires space beyond any existing process buildings and requires regular monitoring. The operation of biological phosphorus removal is more complex than chemical phosphorus removal because the future removal rates are dictated by the current operation of the system. If the ideal microorganisms are not preserved, future removal will be impacted. Typically, biological phosphorus removal includes chemical phosphorus measures for when the biological phosphorus removal is not achieving the necessary standards. Biological phosphorus removal can typically reduce the total phosphorus concentration to 1 mg/L, but chemical phosphorus removal is required to meet final effluent requirements below 1 mg/L (Metcalf & Eddy, Inc., et al., 2013).

Chemical phosphorus removal through chemical precipitation uses chemicals such as ferric chloride and aluminum sulfate [alum] to flocculate and settle out phosphoric compounds (Minnesota Pollution Control Agency, 2006). Flocculation is the “process by which small particles in a suspension increase in size resulting from particle collisions" (Metcalf & Eddy, Inc. et al., 2013, p. 307). This method can often be implemented as an addition to any existing processes and is often required for phosphorus limits below 1 mg/L. Chemical precipitation is often paired with a tertiary filtration system to remove the flocculated phosphoric compounds. Chemical precipitation is energy and chemical intensive for most systems because the dosing of chemical often requires mixers or blowers to combine with the existing process (Metcalf & Eddy, Inc. et al., 2013).

Effluent phosphorus limits below 1 mg/L typically require either chemical-only treatment or a combination of biological and chemical phosphorus treatments. The combined biological and chemical phosphorus treatment is typically used to reduce the required chemical for chemical treatment by removing much of the phosphorus through biological phosphorus treatment (Metcalf & Eddy, Inc. et al., 2013). The reduction in chemical reduces the treatment cost.

These phosphorus removal techniques are used in various biological phosphorus removal technologies. Each technology features different methods of removing the phosphorus using biological and/or chemical phosphorus removal and thus each technology has its associated advantages and disadvantages. Several include experience, space requirements, odor, sludge production, and chemical usage. Sludge is the settled microorganisms that are removed from a process and wasted or reused within the system. Sludge production increases with chemical phosphorus removal because more floc is settled out into sludge through the addition of the chemical (Metcalf & Eddy, Inc., et al., 2013).

Summary of Nutrient Removal Technology

Nutrient removal technology and techniques employ processes for municipal WWTFs that typically require a substantial footprint and significant energy usage. These processes can also require chemicals such as ferric chloride or “alum” to meet NPDES discharge limits.

Chemistry of Microbial Inoculator Generators [MIGs]

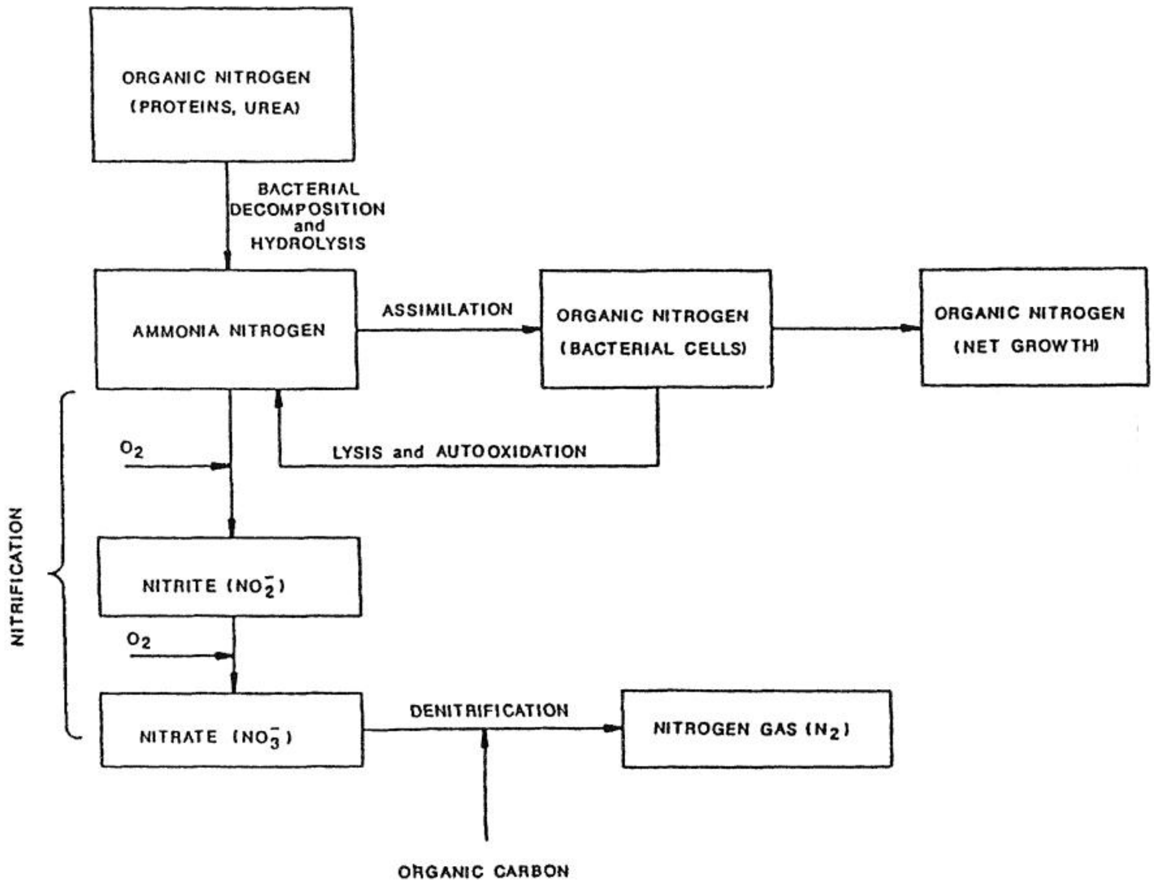
The United States Patent #7,658,851 is a MIG system (Knight Treatment Systems, 2023). This patented technology was installed as both MIG 1 and MIG 2 in this pilot study system. Though this technology was supplied by Knight Treatment Systems, the interpretation of data was not influenced by this potential conflict of interest.

A MIG is a technology that uses inoculation to cultivate specific bacteria to reduce BOD, TSS, and total nitrogen (Knight Treatment Systems, 2023). The MIG is similar to the IFAS systems because it is also an attached growth activated sludge process used for nitrification (Nelson & Rawson, 2010). However, unlike a typical IFAS system, the MIG system also uses inoculation (Nelson & Rawson, 2010). Inoculation is the addition of something such as bacteria to grow in an existing system (Cambridge English Dictionary, 2023). The system is inoculated through the introduction of bacteria to the tanks as a way to grow necessary bacteria to encourage performance of the system.

Like a typical IFAS system, the MIG utilizes biological nitrogen removal to oxidize ammonia into nitrate and nitrite (Nelson & Rawson, 2004; Vande Boom, 2018). However, first BOD_5 must be oxidized before nitrogen can be oxidized (Delzer & McKenzie, 2003). Biological nitrogen removal converts ammonium into nitrate using bacteria through nitrification and then the nitrate is reduced to nitrogen gas through denitrification. Nitrogen gas is harmless while nitrate can be impactful on human health, so denitrification is an essential part of the nitrogen removal process. The final result of the nitrification and denitrification is a reduction in total nitrogen (Hoseinzadeh, 2019). Figure 3 depicts the nitrification and denitrification processes.

Figure 3

Nitrogen Transformation in Biological Nitrogen Treatment Processes



Note. Adapted from "Figure 2-1. Nitrogen transformation in biological treatment processes" edited by Richard Sedlak, 1991, *Phosphorus and Nitrogen Removal from Municipal Wastewater: Principles and Practice*, p. 4 (https://doi.org/10.1201/9780203743546).

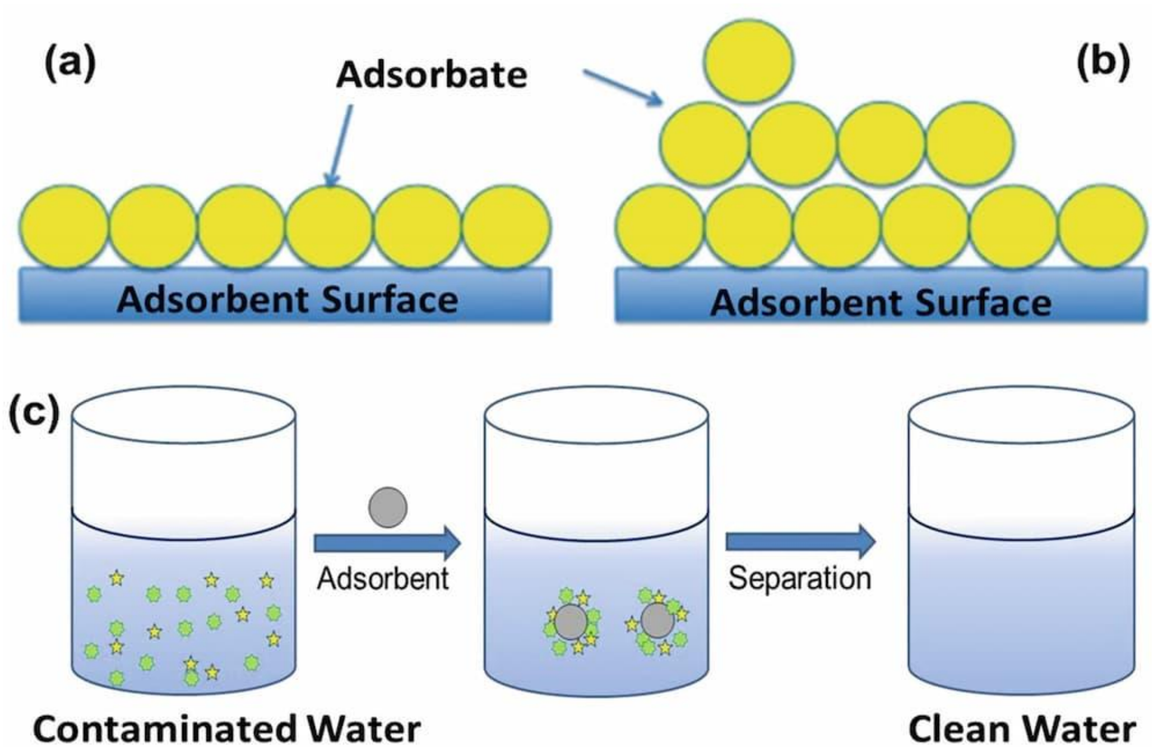
Nitrification relies on nitrifying bacteria that require oxygen to complete the nitrification process (Ward, 2008). On the contrary, denitrifying bacteria require anoxic or anaerobic conditions with dissolved oxygen concentrations of less than 0.2 mg/L (Seitzinger et al., 2006). For biological nitrogen treatment systems including MIGs, it is important for the system to have both aerobic and anoxic/anaerobic components for the system to reduce the total nitrogen through nitrification and then denitrification. Nitrifying bacteria grow very slowly compared to other organisms, so it is important to have enough nitrifying bacteria present in the system to continue to nitrify (Office of Ground Water and Drinking Water, 2002). Alkalinity is consumed during nitrification (Hoseinzadeh, 2019) while alkalinity is produced during denitrification (Norbisrath, 2020). Denitrification takes place using heterotrophic denitrifying bacteria that require organic carbon for both the denitrification process and for cell growth (Rajita & Bhatia, 2019). Heterotrophic bacteria are defined as "microorganisms that use organic carbon as food" rather than sunlight (H2O Distributers, n.d., para. 1). For this reason, carbon content is another important consideration in wastewater treatment because a wastewater without enough organic carbon will experience limited denitrification.

Chemistry of the Phosphorus Adsorption with Titanium Dioxide

An adsorbent is "a substance that attracts other substances to its surface to form a film" (Oxford Reference, n.d.). Figure 4 depicts the adsorption of an adsorbate and the water treatment capabilities. Titanium dioxide is an adsorbent used for a variety of applications (Lanin et al., 2007; Graver Technologies, 2015). According to Graver Technologies, the manufacturer of MetSorb® HMRG, the media has the capacity to adsorb 10 mg of phosphate per gram of media used (M. Noga, personal communication, October 30, 2022).

Figure 4

Adsorption Diagram



Note. Adapted from "Adsorption Solutions" by WEC Projects, n.d., Adsorption: *Adsorption Solutions*, para. 2 (wecprojects.com/solutions/processes/adsorption/).

Adsorption of phosphates on titanium dioxide is dependent on the characteristics of the contaminated fluid. According to Kang et al. (2011), phosphate adsorption "decreases with increasing pH, whereas the phosphate uptake by [titanium dioxide] increases with increasing ionic strength of the solution" (p. 455). Other limiters of the adsorption of other substances on titanium dioxide include higher wastewater temperatures and the addition of external ions (Bsoul et al., 2019).

End of Life of Titanium Dioxide

There are currently no known options for reuse or recycling of titanium dioxide (Jones & Shaw, 2016). In addition, some sources state that titanium dioxide is suspected of causing cancer

(Sigma-Aldrich Corporation, 2015; New Jersey Department of Health, 2016). Ultimately, more research is needed regarding the disposal and end of life of titanium dioxide and spent titanium dioxide media.

Methods

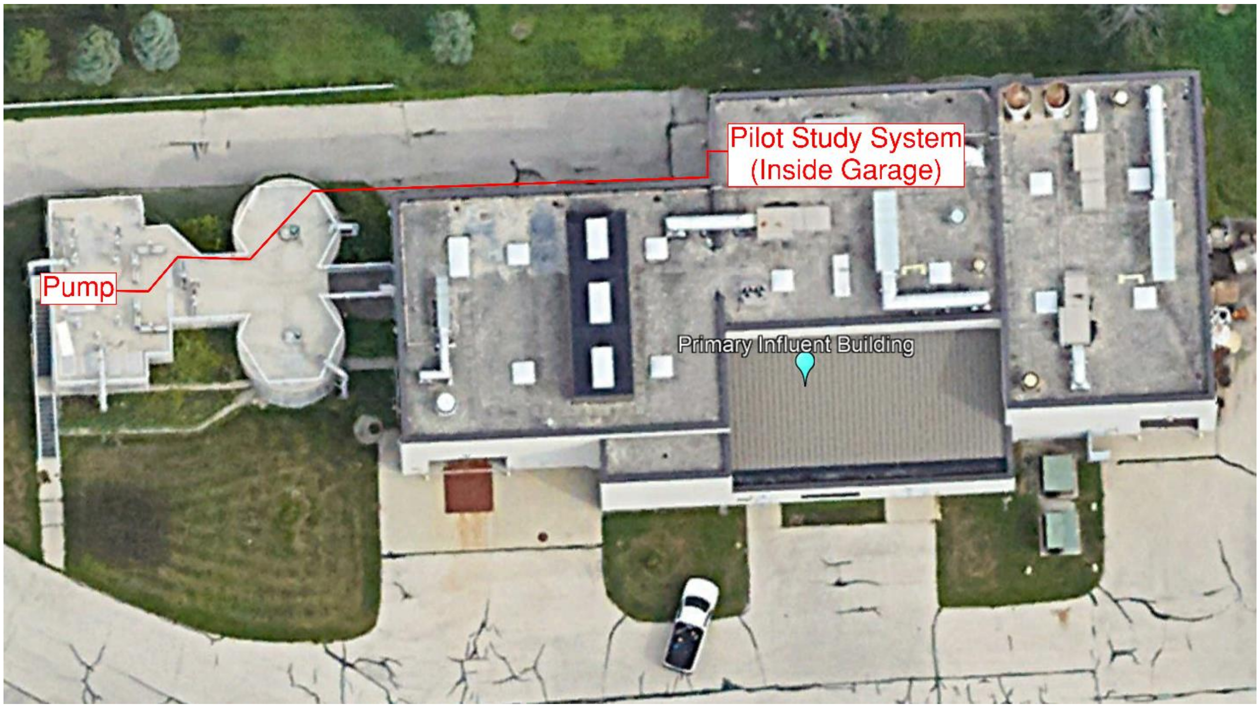
In this pilot study, both the MIG and the phosphorus adsorption device were investigated to determine the fate of the nitrogenous and phosphoric compounds following treatment by the system. The MIGs, tanks, pumps, and associated piping were installed on April 1, 2022, and the phosphorus adsorption device was installed on September 20, 2022. Data were collected from June 17, 2022, through October 20, 2022. The pilot remained in place until October 26, 2022.

Description of the Pilot System Installation

The pilot was installed in the garage of the Brookfield WWTF's preliminary treatment building. This location provided easy access to screened wastewater in a space that maintained temperatures above freezing. True installations are below the ground surface at a depth below the frost line, so this location was selected to mimic the conditions of a typical POWTS. Screened wastewater was combined with backwash water from the filters used with ferric chloride in the splitter structure. Ferric chloride is used by Brookfield WWTF as a coagulant to flocculate and settle out the phosphorus at the plant. The combined screened wastewater was pumped from the splitter structure down approximately 30 feet to the ground surface, through the wall of the garage, and into the pilot installation. Because of the large elevation difference between the pumped screened influent and the influent discharge location into the tanks, it was hypothesized that a syphon would be likely to occur in the system. As a preventative measure, a vacuum breaker was installed in the influent piping prior to the influent discharge location into the tanks. Following treatment, the final effluent from the pilot installation flowed into a floor drain in the garage where it flowed to combine with the raw wastewater influent at the beginning of the Brookfield WWTF's process. Figure 5 shows the pilot installation with relation to Brookfield WWTF, and Figure 6 features the diagram of the pilot system at the beginning of the project.

Figure 5

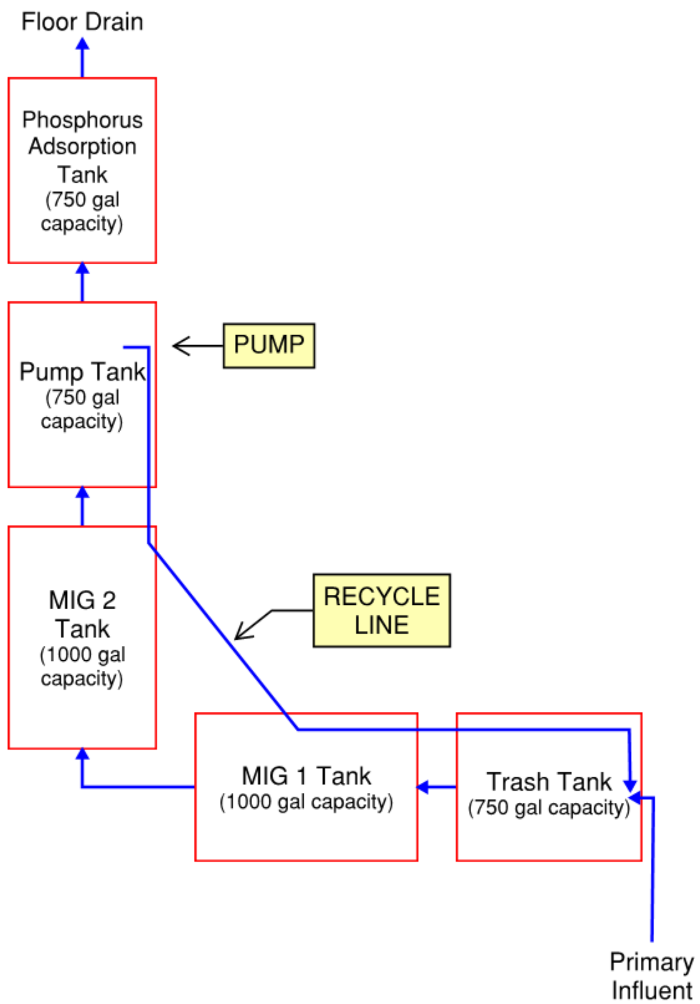
Pilot Study Installation at Brookfield WWTF



Note. Imagery adapted from Google Earth Pro.

Figure 6

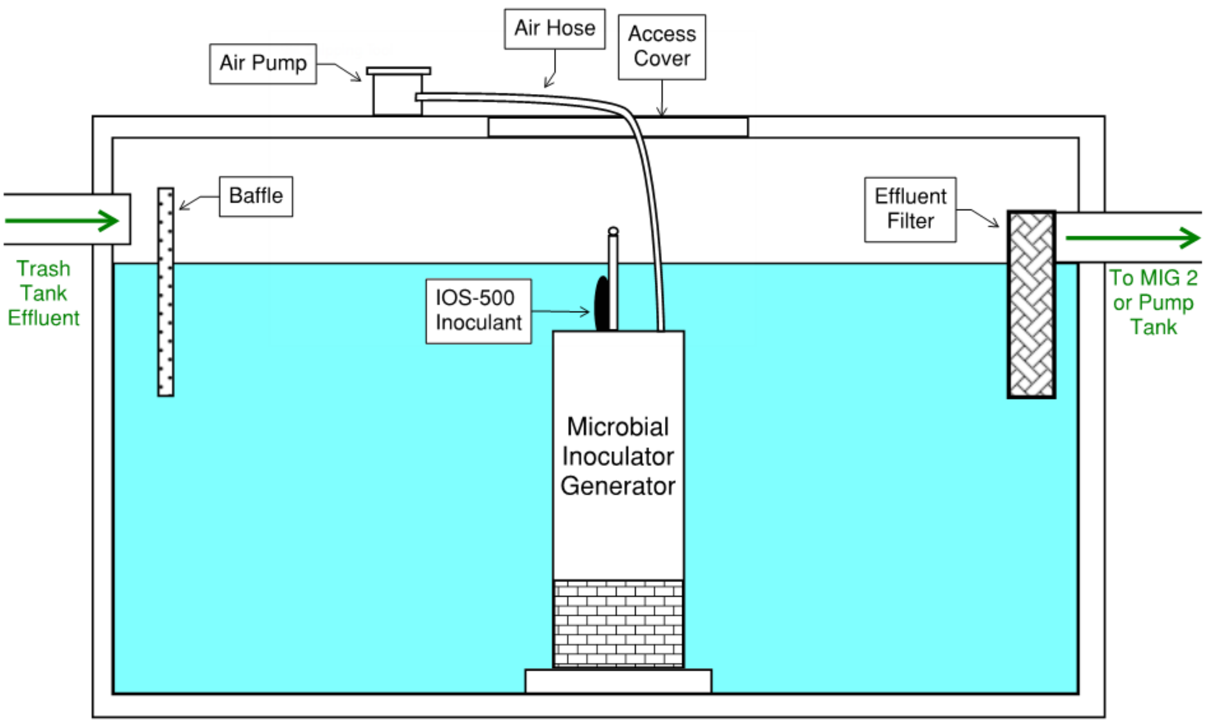
Pilot Study Installation Diagram at the Start of the Project



The pilot study system included the following concrete tanks: a 750-gallon tank (Trash Tank), two 1,000-gallon tanks (MIG 1 Tank and MIG 2 Tank), a 750-gallon tank (Pump Tank), and a 750-gallon tank (Phosphorus Adsorption Tank). A schematic of the pilot study system is shown as Figure 9. The primary influent pump pulled screened influent from the splitter structure and pumped into the garage where it combined with recycle flow in the Trash Tank influent. The wastewater gravity flowed through the remainder of the system and through the outfall to the floor drain. A WK-40 unit was installed in both the MIG 1 Tank and MIG 2 Tank. The WK-40 features one media tower with a diffuser at the bottom that supplies 1.58 cfm at 2 psi from a small blower (Knight Treatment Systems, Inc., n.d.). The effluent side of the MIG 1 Tank and MIG 2 Tank featured an effluent filter for removal of any large particulate matter. Figure 7 shows the installation diagram for the MIG Tanks and Figure 8 is a photograph of one of the MIG Tanks in the pilot system with the MIG in service.

Figure 7

MIG Installation Diagram for MIG 1 Tank and MIG 2 Tank



Note. Adapted with permission from “White Knight MIG™ Treatment System” by Knight Treatment Systems, Inc., n.d., *Enhanced Microbial Augmentation for New Septic Systems*, p. 1.

Figure 8

MIG Pilot Study Installation Photograph for MIG 1 Tank and MIG 2 Tank

The inoculant used for these MIG systems is known as IOS-500, a proprietary blend of biological material specifically intended for nitrogen removal (B. Rawson, personal communication, March 28, 2022). Figure 8 depicts the IOS-500 inoculant attached to the handle of the MIG.

Figure 9

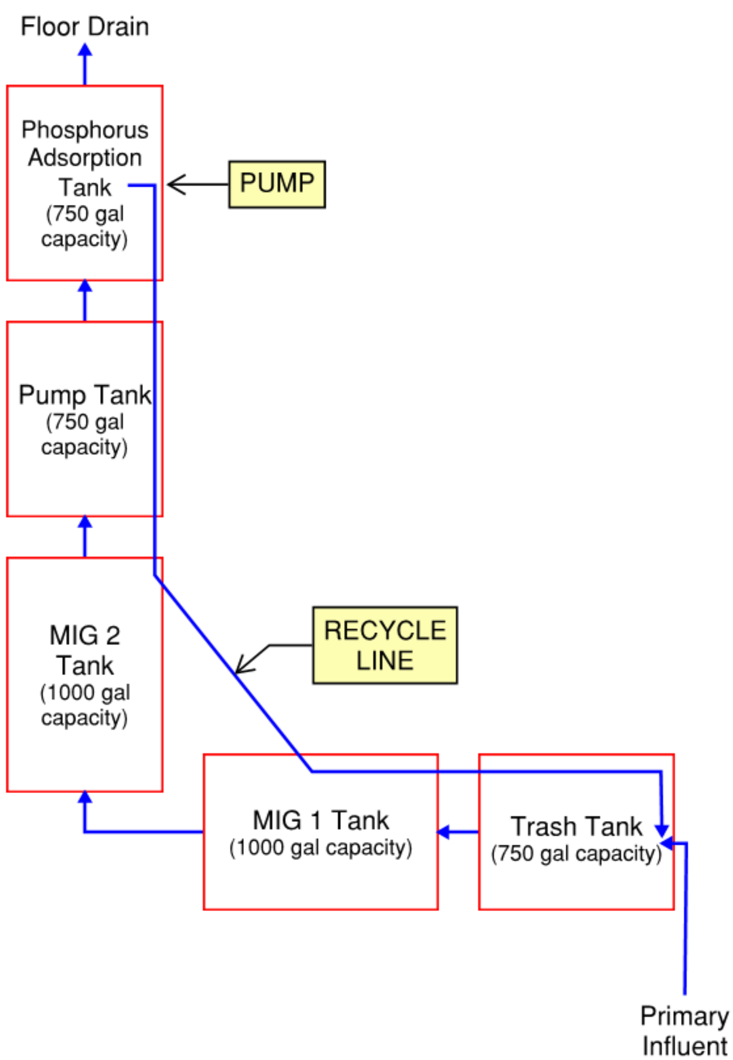
IOS-500 Inoculant Attached to MIG in Pilot Study Installation Photograph for MIG 1 Tank and MIG 2 Tank

The influent pump operated at a rate of 6 gallons per minute on a cycle of one minute on and ten minutes off throughout the day. This rate remained constant throughout the pilot and resulted in a total daily flow of 864 gallons. Dosing by the influent pump from the splitter structure represents a constant flow pattern with intermittent loading.

At the start of the pilot, the pump for recycle flow was located in the Pump Tank as shown in Figure 6. However, the recycle pump was moved to the Phosphorus Adsorption Tank on July 28, 2022, as shown in Figure 10. The pump was moved with the intention of improving the denitrification by improving the recycle feed for denitrification. When the pump was located in the pump tank, the heterotrophic bacteria in the recycle flow had only multiplied in the pump tank before pumping. The pump was moved into the phosphorus adsorption tank to ensure that the heterotrophic bacteria could grow in both the pump tank and phosphorus adsorption tank. This adjustment in the pilot should have theoretically increased the pilot system's ability to grow the bacteria by doubling the volume with optimal conditions to complete the denitrification process. The recycle pump operated at 5 gallons per minute and operated on a cycle of 5 minutes on and 30 minutes off throughout the day. The recycle flow also remained constant through the entire pilot and resulted in a total daily recycle flow of 1,029 gallons.

Figure 10

Pilot Study Installation Diagram at the End of the Project



The Phosphorus Adsorption Tank utilized a patented technology called the Knight Nutrient Removal Device [KNuRD]. The phosphorus adsorption unit has a shell with small holes to allow controlled infiltration of the wastewater and the internal component consists of an effluent filter with a hardware cloth material covering the surface inside the tubes (Nelson, Knight, & Noga, 2001). The media used inside the phosphorus adsorption device is MetSorb® HMRG. Figure 11 shows the installation diagram of the KNuRD in the Phosphorus Adsorption Tank. Figure 12 shows the internal component of the KNuRD partially filled with the titanium dioxide media and Figure 13 is the KNuRD in the pilot installation before the media was integrated.

Figure 11

Phosphorus Adsorption Device Installation in Phosphorus Adsorption Tank

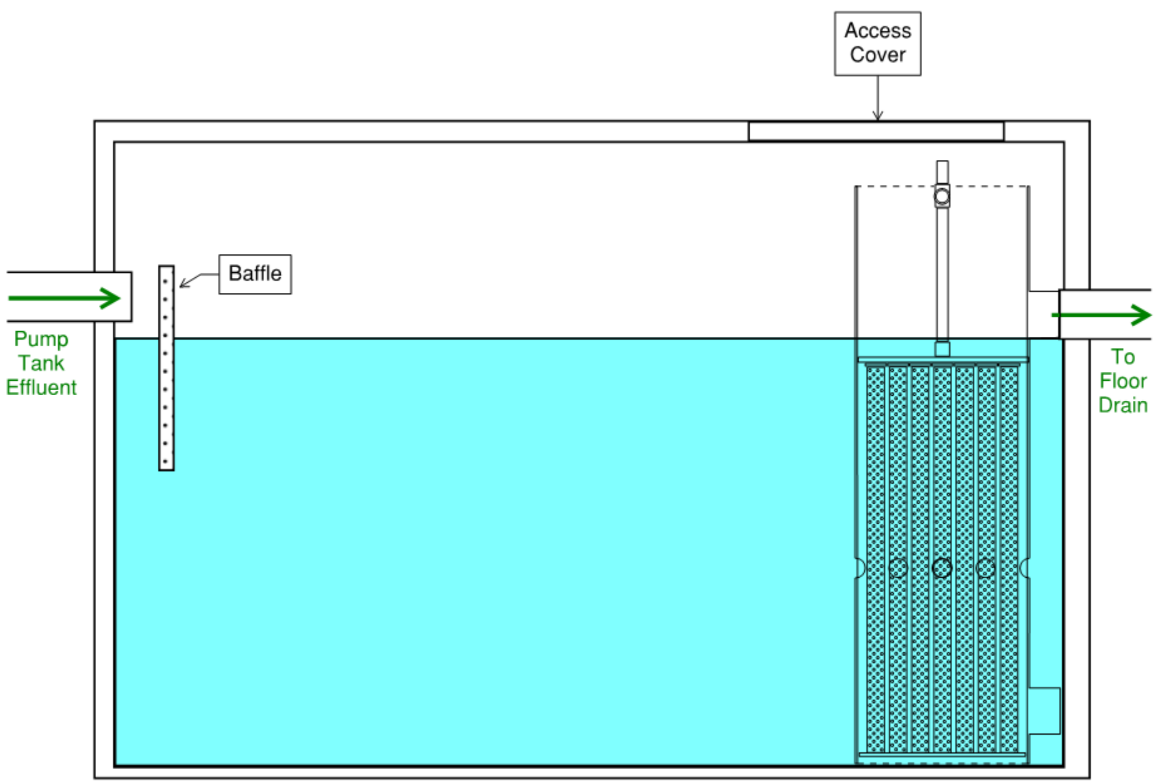


Figure 12

KNuRD Internal Unit Partially Filled with Titanium Dioxide

Figure 13

KNuRD in Pilot Prior to Media Integration

The phosphorus adsorption device was installed later than the remainder of the system due to complications associated with the incorporation of the media. This limited the number of samples collected and therefore reduced the quality of the data associated with the phosphorus adsorption device. This late installation can be attributed to issues associated with the integration of the media into the phosphorus adsorption device. The original design of the phosphorus adsorption device did not include hardware cloth inside the tubes of the effluent filter. However, the media was smaller in diameter than the holes of the effluent filter, so hardware cloth was used to increase the retainage of the media in the tubes. Unfortunately, the hardware cloth in several of the tubes did not extend to the top of the effluent filter due to error in installation of the cloth, so the media was not added to the top of the effluent filter in several tubes. Additionally, the phosphorus adsorption unit with media in the tubes was left in the maintenance garage near the tanks prior to installation. A pump was operated overnight near the unit, which caused vibrations to sift out the finer media before the unit was installed. After the finer media was removed, additional media was added to restore the column of media to the original height, but the media did not completely fill the tubes. Since the tubes were not entirely full, the contact time of the wastewater with the titanium dioxide media was reduced. This might have reduced the phosphate treatment of the system.

Sampling and Data Collection

Samples were collected at various locations throughout the pilot installation approximately once per week from June 17, 2022, through October 20, 2022. The parameters evaluated include total suspended solids [TSS], total solids [TS], ammonia, nitrate, nitrite, total Kjeldahl nitrogen [TKN], 5-day biochemical oxygen demand [BOD_5], chemical oxygen demand [COD], total phosphorus [TP], and *E. coli*. Parameters varied across sample locations and sample collection dates. Sampling on June 17th, June 24th, and July 5th represented baseline sampling, in which sampling took place for the effluent side of the trash tank, effluent side of MIG 1, effluent side of MIG 2, the influent side of the phosphorus adsorption unit, and the final effluent. These samples were used to determine if the system was operating as expected and determine whether there were significant differences between the weekly samples. The remaining samples are considered ongoing samples in which important parameters that were expected to change were identified and sampled accordingly. The total phosphorus parameter had ongoing samples starting on September 15th, just before the phosphorus adsorption unit was installed on September 20th.

All samples taken for this pilot study were taken as grab samples. According to the Science and Ecosystem Support Division (2017), “[a] grab sample should be representative of the wastewater conditions at the time of sample collection” (p. 13). To collect a representative sample, the grab samples were collected in the same location every time using a 3 foot long, 1L sample dipper. The dipper was rinsed before the collection of all samples. The final effluent samples were collected from falling wastewater flow from the final effluent pipe. Care was taken to ensure the biomass growing in the final effluent pipe was not dislodged. The influent to the trash tank was collected by disconnecting the influent pipe and turning on the influent pump. Falling wastewater flow was collected from the influent pipe. The sample collection from all other wastewater sites was collected close to the outlet of the tank. The sample solids concentration was ensured to be representative of the treated wastewater by collecting from the wastewater above the sludge blanket, within approximately the top 12 inches of the water.

Samples for nitrate, nitrite, TKN, COD, BOD, ammonia, and phosphorus were brought to Eurofins SF Analytical Laboratories [Eurofins] for analysis. Eurofins is a State of Wisconsin Department of Natural Resources Certified Laboratory (Eurofins, 2022) and therefore performs compliant analyses in accordance with §299.11 (7), Stats. of Wisconsin (Wisconsin Department of Natural Resources, 2023a). Data collected from Eurofins were summarized into reports following data analysis and then compiled in Microsoft Excel. Samples tested for *E. coli* and TSS were brought to the laboratory at Milwaukee School of Engineering [MSOE] for analysis. Note that the laboratory at MSOE is not a certified laboratory. U.S. EPA method 160.2 was used at the MSOE laboratory for TSS analysis (National Environmental Methods Index, 1971). The *E. coli* analyses were completed using an IDEXX Quanti-Tray Sealer 2000 and Colilert. Colilert is EPA-approved for total coliform and *E. coli* analysis of wastewater (IDEXX, n.d.). Data from analyses completed at the MSOE laboratory were written on paper tables and then compiled with Eurofins data in Microsoft Excel. TN was calculated featuring the results from Eurofins using Equation (1), which is derived from the definition of total nitrogen (Metcalf & Eddy, Inc. et al., 2013):

$$TN = Nitrate + Nitrite + TKN. \quad (1)$$

The primary influent data were collected by Brookfield WWTF as daily composite samples of the facility's primary influent. Composite samples are collected throughout a period of time and are used to represent the average wastewater quality (Science and Ecosystem Support Division, 2017). Brookfield WWTF analyzed ammonia, BOD_5, total phosphorus, and TSS for the primary influent composite samples. It was assumed that the Brookfield WWTF influent would have the same characteristics as the influent pulled by this pilot study. Brookfield WWTF also provided primary influent flow data. All Brookfield WWTF data from June through October of 2022 are included in Appendix A.

Statistical Analysis Method

The samples were analyzed by a paired hypothesis test to determine the 95% confidence interval of reduction of individual constituents. To accurately compare the pairs of data, it was necessary to select the starting and final sample dates according to the hydraulic retention time.

Hydraulic retention time is the average time it takes for matter to travel from one point to another. Daily influent sample analyses were provided by Brookfield WWTF. The daily samples allowed the delay to be in terms of days rather than relying on samples collected weekly for this pilot study. However, samples that have starting locations at the effluent side of MIG 2 and the influent side of the phosphorus adsorption tank had less frequent data available, so no delay was used. Table 1 shows the selected time delays between the dates of the starting and final sample dates for paired hypothesis testing.

Table 1

Paired Analysis Delays by Analysis Sample Location

Starting Sample Location	Final Sample Location	Sample Delay
Primary Influent	Final Effluent	5 Days
Primary Influent	Effluent Side of MIG 2	3 Days
Effluent Side of MIG 2	Final Effluent	No Delay
Influent Side of Phosphorus Adsorption Unit	Final Effluent	No Delay

Paired hypothesis test results are calculated using Equation (2) (LibreTexts Statistics, 2022):

$$\left(\bar{x}_d - z_{\frac{\alpha}{2}}\frac{s_d}{\sqrt{n}}, \bar{x}_d + z_{\frac{\alpha}{2}}\frac{s_d}{\sqrt{n}}\right). \quad (2)$$

Using Equation (2), one-sided paired hypothesis tests are described by a single value where two-sided tests are described by an interval. Note that the number of samples greatly impact the results of the hypothesis testing.

The 95% confidence interval infers a significance level of 5% for a Type 1 error, or a false-positive error. The null hypothesis for each scenario was that the difference is equal to zero. Several of the tests were completed as two-sided hypothesis tests, but the rest were completed as one-sided tests. The one-sided tests were used when only a reduction in constituent concentration could be expected for the system. For one-sided hypothesis tests, the alternative hypothesis is that the difference is greater than zero. Two-sided tests were used when the constituent concentration could be expected to either increase or decrease. For two-sided hypothesis tests, the alternative hypothesis is that the difference is not zero. Nitrogenous compounds were analyzed as two-sided tests because biological nitrogen removal could increase or decrease constituent concentration. Table 2 displays the type of hypothesis test according to the parameter analyzed.

Table 2

Hypothesis Test Type by Parameter

Parameter	Test Type
Ammonia	Two-Sided Paired Hypothesis
Nitrate	Two-Sided Paired Hypothesis
TKN	Two-Sided Paired Hypothesis
TN	Two-Sided Paired Hypothesis
TP	One-Sided Paired Hypothesis
BOD	One-Sided Paired Hypothesis
TSS	One-Sided Paired Hypothesis

The paired hypothesis test statistical analyses were calculated using Minitab Statistical Software.

Results and Discussion

The results derived from the data for this analysis required that several assumptions be made before conclusions were generated. These assumptions include:

- Brookfield WWTF's screened influent water quality data were representative of the pilot system influent values
- Brookfield WWTF's screened influent water quality data were completed using the same testing protocol as the data analyzed at MSOE and Eurofins

The screened influent was pumped from the splitter structure, in which the screened influent was retained before gravity flowing to the next part of the process. The splitter structure received constant flow that appeared to mix the contents completely. The water level was maintained at relatively consistent levels within the structure. The consistent mixing of the screened influent and the constant timed dosing of the influent Trash Tank makes it feasible to assume that the Brookfield WWTF screened wastewater samples were representative of the system influent values. In addition, on August 17, 2022, the influent to the trash tank was collected and analyzed. The results were not very different from the Brookfield WWTF values for that day. As such, the assumption that the Brookfield WWTF data were representative of the pilot system influent values is valid, and therefore, Brookfield WWTF data were used to describe the change in water quality across the system. The second assumption relates to the testing protocol across all analyzing entities. The lab used for Brookfield WWTF's analysis and Eurofins are both certified laboratories. The testing procedure used at MSOE was consistent with that of certified laboratories as well. Therefore, it is reasonable to conclude that the analyses are comparable.

When considering the results of the study, there are several limitations of the data with respect to the application to POWTS installations. The following are the limitations of the pilot study data:

- The wastewater pumped from the screened influent of Brookfield WWTF has more dilute wastewater than a typical POWTS. This is a potential limitation in the application of the results to a typical installation.
- The HRT from the phosphorus adsorption device to the final effluent and the MIG 2 effluent to the final effluent were not accounted for in the paired hypothesis test results because daily data were not available within the pilot study system.
- Samples were collected as grab samples rather than composite samples. The results from grab samples are less representative of the sample over time than composite samples.

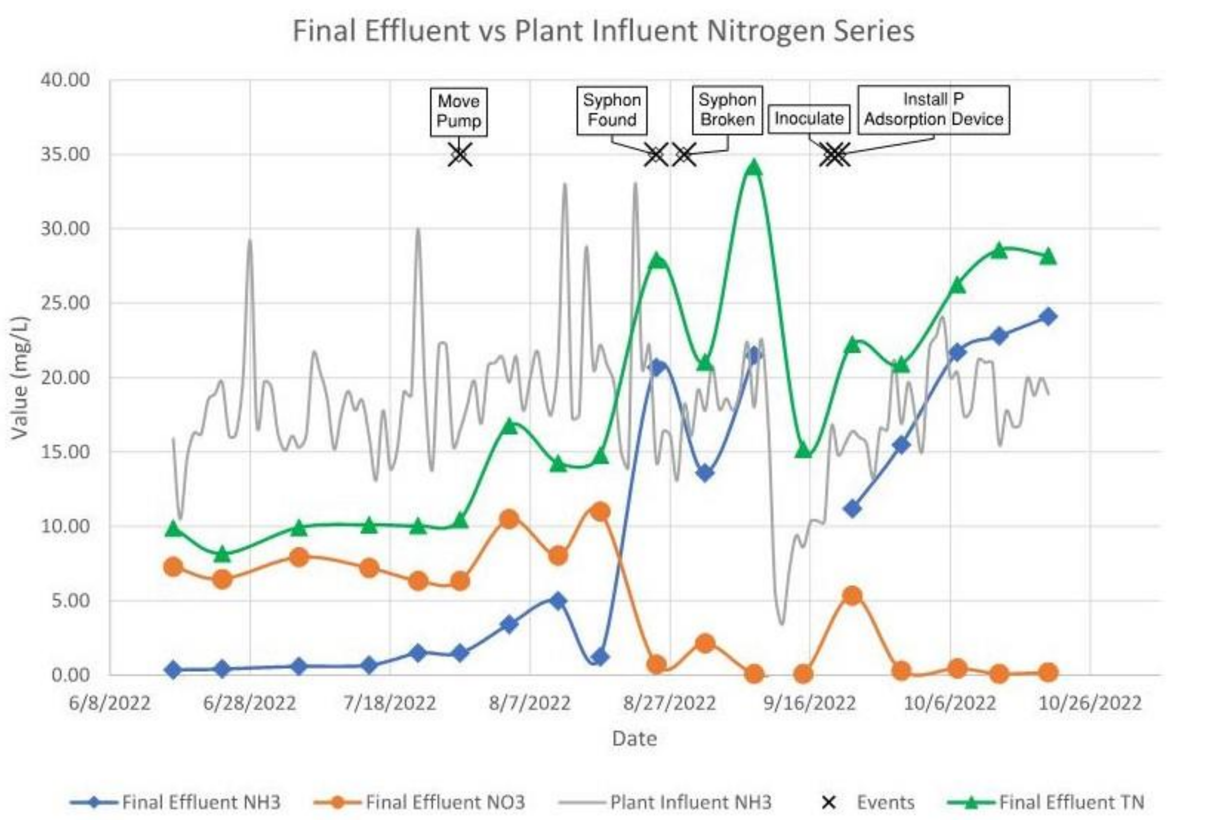
- The samples were not collected at the same time each week and were not always collected on the same day each week.
- There were small variations in data collection. The exact location of sample collection varied slightly in depth and proximity to the effluent baffle.

These limitations may impact the reproducibility of the study and the application of results to other studies. Typical installations would experience diurnal flow patterns or other variations in the influent flows and loadings. Despite these limitations, it is expected that the results describe the expected treatment outcomes of similar systems.

Unfortunately, despite the preventative addition of a vacuum breaker to the influent wastewater line, a syphon did form in the pilot system. The syphon was found in the pilot system on August 25, 2022 and was broken on August 29, 2022. Though the syphon was noticed on August 25, nobody had observed the system since August 19. This means that the true length that the syphon remained unbroken could be as long as 10 days rather than 4 days. The syphon made the plant influent flow ten times greater. Unfortunately, the impact of this syphon on nitrification was not realized at this time, so the operation of the system was continued as it had been before the syphon. Figure 14 depicts the nitrogen series (TN, nitrate, ammonia) data throughout the duration of the pilot study project. The ammonia, nitrate, and total nitrogen values changed significantly between the sample taken August 17, 2022, and August 25, 2022. While the final effluent ammonia concentration was consistently at or below approximately 5 mg/L prior to August 17, 2022, the subsequent data never fell below 10 mg/L of ammonia. Additionally, the nitrate concentration was between approximately 6 mg/L and 11 mg/L prior to August 17, 2022 but generally stayed below 3 mg/L during the remainder of the pilot study. These results are indicative of a loss of nitrification. While ammonia would normally convert to nitrate through nitrification, the loss of nitrification would instead only allow the denitrification of the existing nitrate in the system.

Figure 14

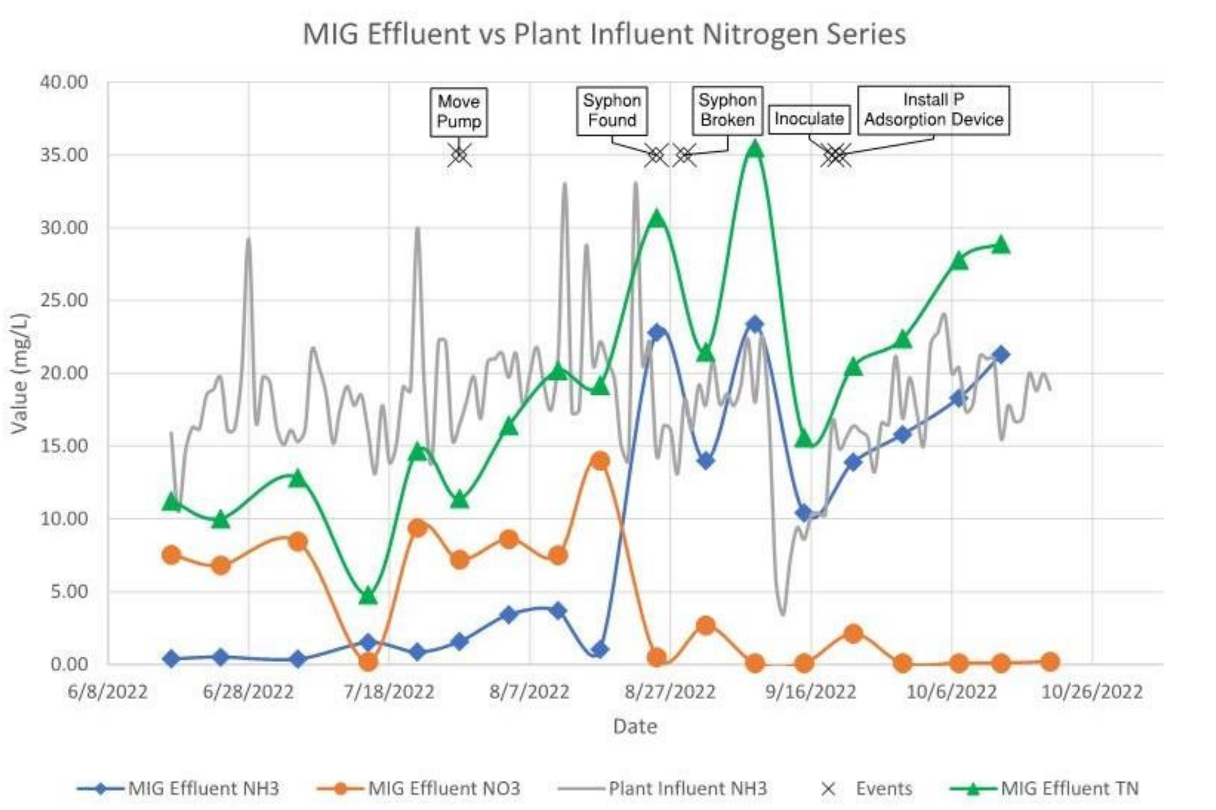
Final Effluent versus Plant Influent Nitrogen Series Graph



It was hypothesized that the extreme flow event associated with the syphon resulted in the loss of the nitrifying bacteria in the system. When the nitrifying bacteria were no longer present in the system, nitrification could no longer take place despite the presence of ideal growing conditions. Since nitrifying bacteria grow slowly, the lack of nitrifying bacteria in the system impacted the long-term nitrification of the system. The results from the plant influent to final effluent of nitrogen series, seen in Figure 14, are consistent with the plant influent and MIG 2 effluent results, shown in Figure 15. Similarly, it appears that nitrification was inhibited following the syphon.

Figure 15

Plant Influent versus MIG 2 Effluent Nitrogen Series Graph



On September 19, 2022, the system was inoculated again. The following sample resulted in higher nitrate values and lower ammonia values, which indicates that some nitrification took place. However, it appears that not enough inoculant was added to compensate for the nitrifying bacteria lost during the syphon.

The stark difference in the results from the time prior to the occurrence of the syphon compared to all data collected indicated that the results should be separated. Thus, paired hypothesis testing for the nitrogen series constituents was analyzed as data prior to the syphon and all data. Data prior to the syphon includes data from June 17, 2022, through August 17, 2022. Normal installations of the equipment would have a much smaller difference in elevation between the wastewater source and the tank location, which greatly reduces the likelihood of the occurrence of a syphon. Therefore, it is likely that the pre-syphon results are applicable to typical POWTS installations of this kind.

The purpose of the pilot testing of the phosphorus adsorption device was to determine whether the system would remove the phosphate and determine how to improve the system for future use. Figure 16 depicts the phosphorus results and includes the primary influent, phosphorus adsorption unit influent, and the final effluent. The final effluent values show consistent reduction of phosphorus from the primary influent to the final effluent and from the phosphorus adsorption unit influent to the final effluent. However, the final effluent total phosphorus level appears to plateau at approximately 1.2 mg/L. It is hypothesized that the final effluent total phosphorus levels maintain a relatively consistent concentration because the remaining portions of the total phosphorus are not adsorbable phosphate and therefore cannot be removed. It is further hypothesized that the phosphorus reduction occurring between the primary influent and the MIG 2 effluent are partially attributed to the possible presence of ferric chloride in the primary and partially attributed to the settling of insoluble particulate phosphorus in the influent.

Figure 16

Final Effluent, Phosphorus Adsorption Device Influent, and Plant Influent Total Phosphorus Graph

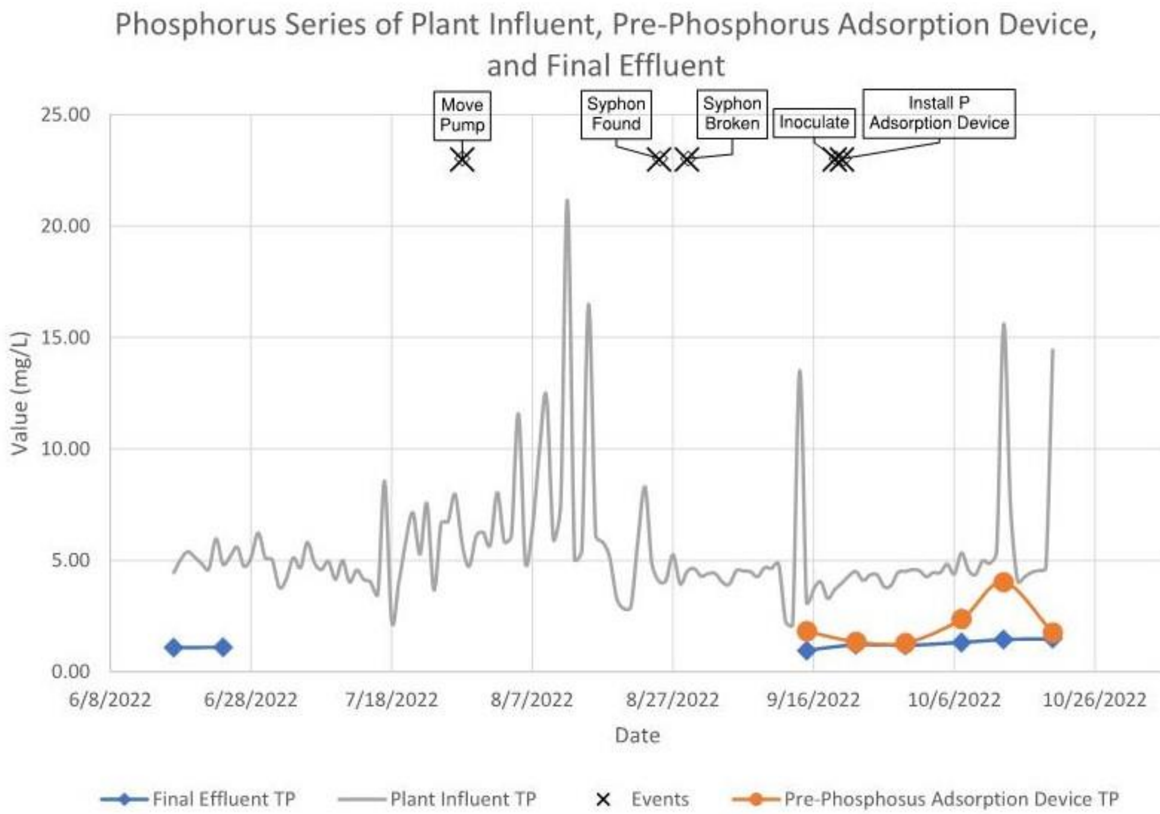


Figure 17 depicts the BOD_5 levels of the primary influent, MIG effluent, and final effluent. The final effluent BOD_5 is always below 50 mg/L and consistently at or below 30 mg/L.

Figure 17

Plant Influent, MIG Effluent, and Final Effluent BOD_5 Graph

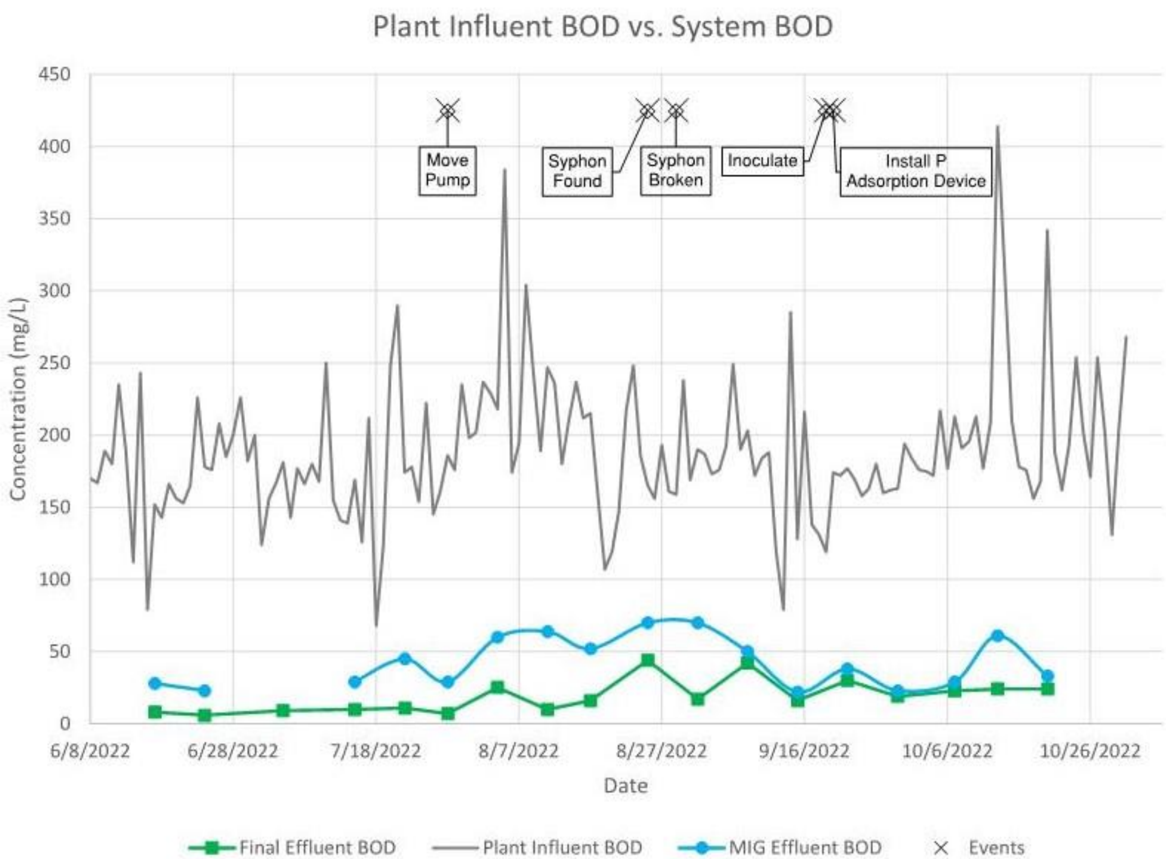
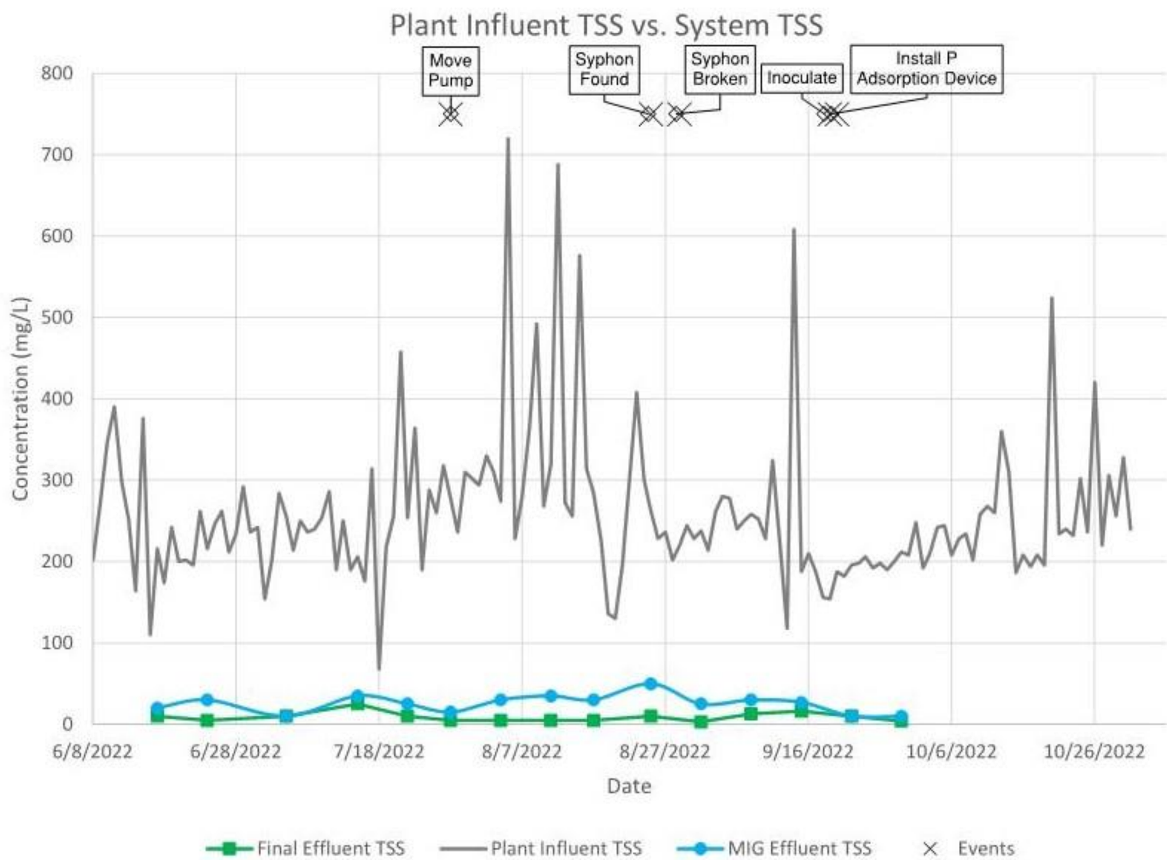


Figure 18 depicts the TSS results for the primary influent, MIG effluent, and final effluent of the pilot system. The TSS results indicate that the final effluent TSS concentration is always at or below 25 mg/L and consistently at or below 15 mg/L. When examining the MIG effluent results, it appears that the majority of the TSS treatment occurs before the MIG effluent as the concentration in the MIG effluent is quite low. This represents a huge reduction in TSS compared to the preliminary influent.

Figure 18

Plant Influent, MIG Effluent, and Final Effluent TSS Graph



The results were analyzed using a paired hypothesis test to determine the 95% confidence interval of reduction in concentration of each constituent between two selected locations. The reduction confidence intervals are provided in Table 3, 4, 5, and 6. The full data set is provided in Appendix A.

Table 3

Reduction Results, Primary Influent to Final Effluent

Parameter	95% Confidence Interval of Reduction [mg/L]
Ammonia, Pre-Syphon Data	15.06 - 18.73
Ammonia, All Data	3.47 - 13.33
Total Phosphorus, After Installation	>2.64
Total Phosphorus, All Data	>3.14
BOD, All Data	>157
TSS, All Data	>241

Table 4

Reduction Results, Primary Influent to the Effluent Side of MIG 2

Parameter	95% Confidence Interval of Reduction [mg/L]
Ammonia, Pre-Syphon Data	15.46 - 18.61
Ammonia, All Data	4.00 - 13.55
BOD, All Data	>131
TSS, All Data	>217

Table 5 shows that the 95% confidence interval of reduction of nitrate includes both negative and positive levels. When more nitrification takes place, more ammonia is converted to nitrate and the ammonia concentration decreases while the nitrate concentration increases. However, when there is an improvement in denitrification, the nitrate is converted to nitrogen gas and the nitrate concentration decreases. Thus, it is within the expectations that the confidence interval of reduction could include both positive and negative values.

Table 5

Reduction Results, Effluent Side of MIG 2 to Final Effluent

Parameter	95% Confidence Interval of Reduction [mg/L]
Nitrate, Pre-Syphon Data	-2.47 - 2.14
Nitrate, All Data	-1.37 - 0.81
TKN, Pre-Syphon Data	0.6 - 3.4
TKN, All Data	0.9 - 2.4
TN, Pre-Syphon Data	-0.8 - 4.4
TN, All Data	0.0 - 2.7

Table 6 shows that the 95% confidence interval of reduction of total phosphorus following installation is -0.18 mg/L compared to 0.06 mg/L prior to installation. Figure 19 and Figure 20 show the boxplot of the differences in total phosphorus concentration between the influent side of the phosphorus adsorption unit and the final effluent. Figure 19 represents only the data collected following the installation of the unit and Figure 20 represents all data. A total of 6 samples were collected on the influent side of the phosphorus adsorption unit, including one sample collected before the installation of the unit.

Table 6

Reduction Results, Influent Side of the Phosphorus Adsorption Unit to Final Effluent

Parameter	95% Confidence Interval of Reduction [mg/L]
Total Phosphorus, All Data	>0.06
Total Phosphorus, After Installation	>-0.18

Figure 19

Boxplot of Differences in Total Phosphorus Concentration from the Influent Side of the Phosphorus Adsorption Unit to the Final Effluent Using Data Following the Phosphorus Adsorption Unit Installation

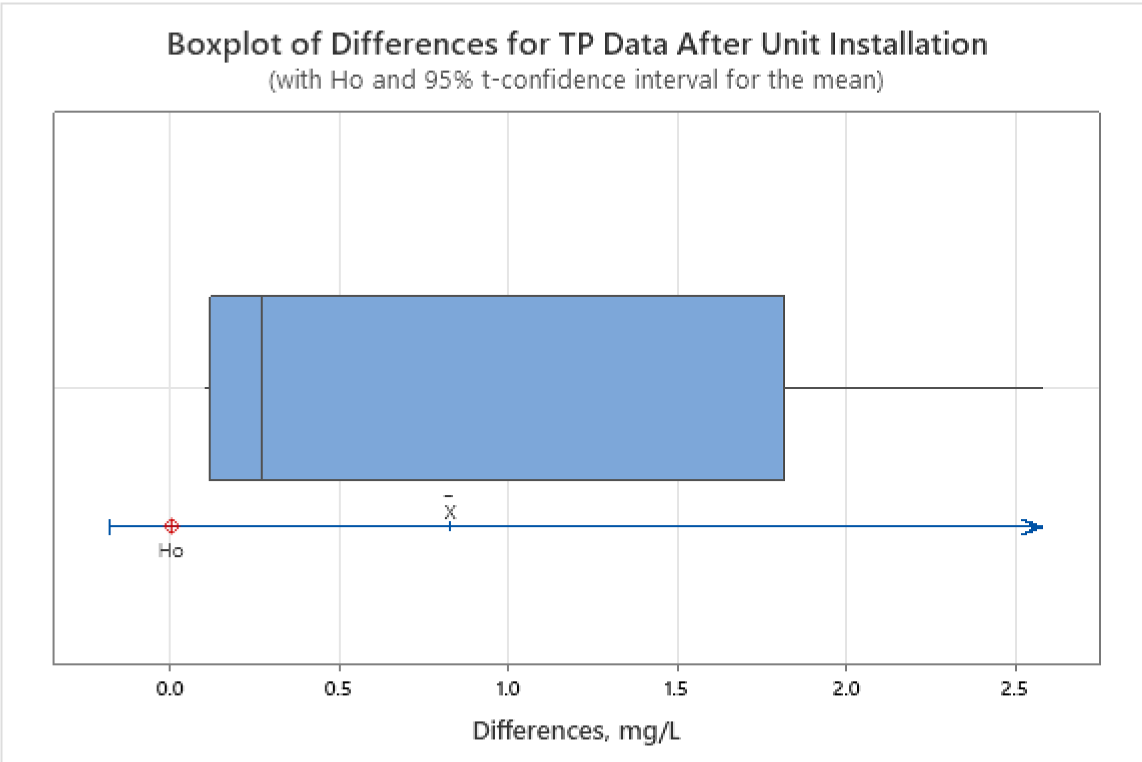
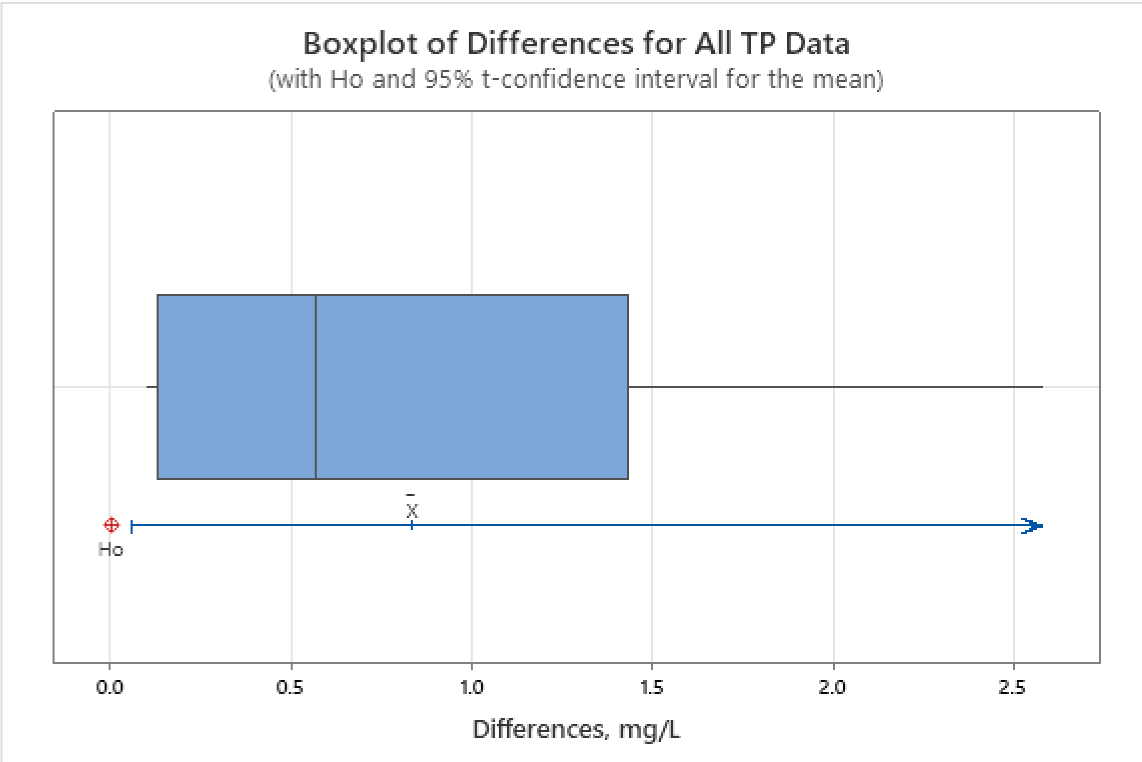


Figure 20

Boxplot of Differences in Total Phosphorus Concentration from the Influent Side of the Phosphorus Adsorption Unit to the Final Effluent Using All Data



As shown in Figure 19 and Figure 20, all data had a difference in concentration that was greater than zero. However, the 95% confidence interval is calculated using Equation (2), which includes the standard deviation in samples, the number of samples, and the sample mean difference (LibreTexts Statistics, 2022). While the mean of the differences is approximately the same between all data and only the data following installation, the number of samples is smaller when using only the data following installation. This difference in sample numbers appears to be the reason the confidence interval is negative for the data following the installation of the phosphorus adsorption device.

Table 7 shows the average final effluent concentration of each constituent. The average final effluent concentration of total nitrogen is 11.6 mg/L in the time before the syphon occurred. As mentioned before in Equation (1), total nitrogen consists of nitrate, nitrite, and TKN. The average final effluent concentration of nitrate before the syphon is 7.91 mg/L, as shown in Table 7. Denitrification will continue to take place in oxygen-limited conditions following discharge of the effluent into soil. In a typical system, the final effluent would be discharged into a leach field or mound system, both of which would allow denitrification to continue to take place before the effluent reaches groundwater. The nitrate concentration is within the Wisconsin public health groundwater quality standards of 10 mg/L (Wisconsin Department of Natural Resources, 2023b). The typical direct groundwater discharge limit for total nitrogen is 10 mg/L in Wisconsin (Wisconsin Department of Natural Resources, 2018). Though the average effluent total nitrogen concentration is above the typical permit limit for direct discharges, this is not a direct discharge. It is expected that additional treatment would take place in the soil layer before meeting the groundwater.

Table 7

Average Final Effluent Concentration by Parameter

Parameter	Average Brookfield WWTF Influent Concentration [mg/L]	Average Final Effluent Concentration [mg/L]
Ammonia, Pre-Syphon Data	17.76	1.64
Ammonia, All Data	17.50	9.76
Nitrate, Pre-Syphon Data	-	7.91
Nitrate, All Data	-	4.49
TKN, Pre-Syphon Data	-	3.6
TKN, All Data	-	13.7
TN, Pre-Syphon Data	-	11.6
TN, All Data	-	18.3
Total Phosphorus, After Installation	5.08	1.27
Total Phosphorus, All Data	5.29	1.23
BOD, All Data	186	19
TSS, All Data	254	9

The overarching goal of POWTSs is to provide wastewater treatment with minimal operation and supervision activities. This pilot study was generally successful in maintaining final effluent water quality while avoiding significant operation and supervision activities. The only major operation maintenance activity during the pilot study was the intervention required at the time of the syphon. However, the unlikely nature of the syphon in a typical installation suggests that the equipment utilized in the pilot study would meet the goals of POWTSs in a typical installation.

Conclusion

Excessive nutrient discharges to the environment lead to nutrient pollution, which is extremely impactful on both human health and the environment. For example, excess nitrates lead to “blue baby syndrome” in which a baby’s skin turns blue (Wisconsin Department of Health Services, 2021). Nutrient pollution also leads to low oxygen levels that create dead zones where large quantities of fish die (United States Environmental Protection Agency, 2021). Other documented impacts of nutrient pollution in the United States include macro algal blooms and brown tide (National Research Council, 2000).

One potential source of the nutrients is wastewater. Wastewaters from septic systems are a source of nitrogen and phosphorus (US Environmental Protection Agency, 2023). Nutrient treatment of wastewater is possible with a variety of treatment techniques, but these techniques are typically used by centralized WWTFs (Metcalf & Eddy, Inc. et al., 2013).

MIGs and phosphorus adsorption devices are options for maintaining the goals of POWTSs while also treating for nutrients. MIG technology relies on biological nitrogen removal (Nelson, Knight, & Noga, 2001). Biological nitrogen removal requires both nitrification and denitrification to remove nitrogen from the wastewaters (Sedlak, 1991). The phosphorus adsorption device uses chemical phosphorus removal by adsorption (Nelson, & Rawson, 2010). Two MIG units and one phosphorus adsorption unit were operated during this pilot study to determine the nutrient removal capabilities of the MIG and phosphorus reduction system.

During the study, a syphon impacted the nitrification capabilities of the system. However, the results before the occurrence of the syphon are promising and show a 95% confidence interval of reduction in ammonia of 15.06 to 18.73 mg/L. The phosphorus adsorption device appears to reduce the concentration of total phosphorus in the system, but no additional conclusions can be provided when considering the small number of samples.

Recommendations

Further research is needed to determine the nutrient removal capabilities of the MIG and the phosphorus adsorption unit. However, the pilot study revealed several potential improvements for future installations using these technologies. One operating recommendation for the treatment of nitrogenous compounds is the employment of on and off cycles for the air supplied to the MIG device as a way to improve the denitrification of the system by encouraging the growth of heterotrophic bacteria in the MIG unit. Additionally, it is likely that additional inoculation for normal- or low-strength wastewaters would improve the nitrification of the MIG units. More frequent inoculation would also increase the likelihood that the system maintains nitrification when stressed by factors such as low temperature or high flow events. For the phosphorus adsorption unit, it is recommended that other media be explored due to the lack of reuse capabilities and limitations of total phosphorus removal by titanium dioxide media. If use of the titanium dioxide media is continued, it is recommended that a larger diameter adsorption medium be utilized or a hardware cloth with much smaller gaps be utilized in the phosphorus adsorption device.

References

Advantage Engineering. (n.d.). *Typical vacuum breaker / anti-siphon system*. Advantage Engineering. https://advantageengineering.com/fyi/048/advantageFYI048.php#:~:text=The%20purpose%20of%20the%20vacuum,the%20supply%20and%20return%20lines.

Bowden, G., Tsuchihashi, R., & Stensel, H. D. (2015). *Technologies for sidestream nitrogen removal*. IWA Publishing. https://doi.org/10.2166/9781780407890

Bsoul, A. A., Hailat, M., Abdelhay, A., Tawalbeh, M., Jum'h, I., & Bani-Melhem, K. (2019, June 25). Treatment of olive mill effluent by adsorption on titanium oxide nanoparticles. *Science of the Total Environment, 688*(1), 1327-1334. https://doi.org/10.1016/j.scitotenv.2019.06.381

Cambridge Dictionary. (2023). Inoculation. In *Cambridge Dictionary*. https://dictionary.cambridge.org/us/dictionary/english/inoculation

Constantinou, A., Dai, Y., & Griffiths, P. (2013). Enhanced nitrogen removal in trickling filter plants. *Water Science & Technology, 67*(10), 2273-2280. https://doi.org/10.2166/wst.2013.119

Delzer, G. C. & McKenzie, S. W. (2003). *Chapter A7. Section 7.0. Five-day biochemical oxygen demand*. United States Geological Survey. https://pubs.usgs.gov/twri/twri9a7/twri9a7_nfmchap7_2_bod.pdf

Eau Claire City-County Health Department. (n.d.). *Septic systems.* The City of Eau Claire. https://www.eauclairewi.gov/government/our-divisions/health-department/inspections-and-testing/septic-systems

Encyclopedia Britannica Kids. (n.d.). Siphon. In *Encyclopedia Britannica*. https://kids.britannica.com/students/article/siphon/277075#:~:text=Siphon%20flow%20starts%20when%20part,two%20ends%20of%20the%20tube.

Eurofins. (2022). *Certifications*. Eurofins US. https://www.eurofinsus.com/environment-testing/resources/certifications/

Fluence News Team. (2021, March 10). *Decentralized versus centralized treatment*. Fluence. https://www.fluencecorp.com/decentralized-vs-centralized-treatment/#:~:text=Centralized%20treatment%2C%20which%20is%20characterized,serving%20a%20more%20localized%20area.

Gilbert, P. M. & Burford, M. A. (2017). Globally changing nutrient loads and harmful algal blooms. *Oceanography*, *30*(1), 58-69. https://doi.org/10.5670/oceanog.2017.110

Google. (2022). *Google Earth Pro* (Version 7.3.6.9345). Google. https://www.google.com/earth/versions/

Graver Technologies. (2015, July). *MetSorb® HMRG: Effective, low-cost adsorbent for removal of heavy metals*. Graver Technologies. https://assets-global.website-files.com/605bb73f62e039589786b760/61548ee47c2538d1436fec79_MetSorb(R)%20HMRG%20datasheet.pdf

H2O Distributors. (n.d.). *Heterotrophic bacteria in drinking water*. H2O Distributers. https://www.h2odistributors.com/pages/contaminants/contaminant-heterotroph.asp

Hoseinzadeh, E. (2019). *Nitrogen removal processes for wastewater treatment.* Bentham Science Publishers. https://doi.org/10.2174/97898114165831190101

IDEXX. (n.d.). *Colilert*. IDEXX. https://www.idexx.com/en/water/water-products-services/colilert/

Jones, K. & Shaw, P. (2016, October). *Disposal of titanium dioxide industry waste to landfill – radiation exposures: Models v site-specific measurements* [PowerPoint Slides]. International Atomic Energy Agency. https://nucleus.iaea.org/sites/orpnet/resources/Shared%20Documents/Jones-DIsposal-of-Titanium-Dioxide-Industry.pdf

Kang, S. A., Li, W., Lee, H. E., Phillips, B. L., & Lee, Y. J. (2011, August 16). Phosphate uptake by TiO_2: Batch studies and NMR spectroscopic evidence for multisite adsorption. *Journal of Colloid and Interface Science, 364*(1), 455-461. https://doi.org/10.1016/j.jcis.2011.07.088

Knight Treatment Systems, Inc. (n.d.). *Enhanced microbial augmentation for new septic systems*. Knight Treatment Systems, Inc. Retrieved from https://www.knighttreatment.com/s/WhiteKnightMIGProductBriefNewConstruction.pdf

Knight Treatment Systems. (2023). *White Knight Microbial Inoculator Generators™: Enhanced biological augmentation technology conquers septic system failures*. Knight Treatment Systems. https://www.knighttreatment.com/products

Lanin, S.N., Vlasenko, E.V., Kovaleva, N.V., & Zung, F.T. (2008). The adsorption properties of titanium dioxide. *Russian Journal of Physical Chemistry, 82*(12), 2388-2391. http://dx.doi.org/10.1134/S0036024408120315

LibreTexts Statistics. (2022, January 8). *10.5: Matched or paired samples.* LibreTexts Statistics. https://stats.libretexts.org/Courses/Lake_Tahoe_Community_College/Book%3A_Introductory_Statistics_(OpenStax)_With_Multimedia_and_Interactivity/10%3A_Hypothesis_Testing_and_Confidence_Intervals_with_Two_Samples/10.05%3A_Matched_or_Paired_Samples

Mahamah, D. S. (2015, May 16). State-of-the-art in managing sludge settling problems for some treatment plants in the United States. *American Journal of Biological and Environmental Statistics, 1*(2), 58-65.

Metcalf & Eddy Inc., Tchobanoglous, G., Burton, F. L., Tsuchihashi, R., & Stensel, H. D. (2013). *Wastewater engineering: Treatment and resource recovery* (5th ed.). McGraw-Hill Professional.

Minnesota Pollution Control Agency. (2006). *Phosphorus treatment and removal technologies.* https://www.pca.state.mn.us/sites/default/files/wq-wwtp9-02.pdf

Minnesota Pollution Control Agency. (2009, February). *Low dissolved oxygen in water*. Minnesota Pollution Control Agency. https://www.pca.state.mn.us/sites/default/files/wq-iw3-24.pdf

National Environmental Methods Index. (1971). *Operating procedure: Wastewater sampling.* U.S. Environmental Protection Agency. https://www.epa.gov/sites/default/files/2017-07/documents/wastewater_sampling306_af.r4.pdf

National Ocean Service. (n.d.). *Point source*. National Oceanic and Atmospheric Administration. https://oceanservice.noaa.gov/education/tutorial_pollution/03pointsource.html

National Research Council. (2000). *Clean coastal waters: Understanding and reducing the effects of nutrient pollution.* National Academy Press. https://doi.org/10.17226/9812

Nelson, D. J. & Rawson, R. (2010). *Method of growing bacteria for use in wastewater treatment* (U.S. Patent No. 7,658,851). U.S. Patent and Trademark Office. https://image-ppubs.uspto.gov/dirsearch-public/print/downloadPdf/7658851

Nelson, D. J., Knight, J. E., & Noga, M. C. (2001). *Apparatus and method for wastewater nutrient recovery* (U.S. Patent No. 6,331,249). U.S. Patent and Trademark Office. https://image-ppubs.uspto.gov/dirsearch-public/print/downloadPdf/6331249

New Jersey Department of Health. (2016, May). *Right to know: Hazardous substance fact sheet.* New Jersey Department of Health. https://nj.gov/health/eoh/rtkweb/documents/fs/1861.pdf

Norbisrath, M. (2020, May). *In-situ investigation of alkalinity – denitrification coupling in the sediment – water column interface.* The SAO/NASA Astrophysics Data System. https://doi.org/10.5194/egusphere-egu2020-1555

Office of Ground Water and Drinking Water. (2002, August 15). *Nitrification*. U.S. Environmental Protection Agency. https://www.epa.gov/sites/default/files/2015-09/documents/nitrification_1.pdf

Oxford Reference. (n.d.). Adsorbent. In *Oxford Reference*. https://www.oxfordreference.com/display/10.1093/oi/authority.20110803095352517;jsessionid=3BDAB87577269AF3A68D4605E77C0077

Rajita, A. & Bhatia, R. (2019, October 6). Role of heterotrophic aerobic denitrifying bacteria in nitrate removal from wastewater. *Journal of Applied Microbiology, 128*(5), 1261-1278. https://doi.org/10.1111/jam.14476

Science and Ecosystem Support Division. (2017). *EPA-NERL: 160.2: Non-filterable residue by drying oven.* U.S. Environmental Protection Agency. https://www.nemi.gov/methods/method_summary/5213/

Sedlak, R. (Ed.). (1991). *Phosphorus and nitrogen removal from municipal wastewater: Principles and practice.* CRC Press. https://doi.org/10.1201/9780203743546

Seitzinger, S., Harrison, J. A., Bohlke, J. K., Bouwman, A. F., Lowrance, R., Peterson, B., Tobias, C., & Van Drecht, G. (2006, December 1). Denitrification across landscapes and waterscapes: A synthesis. *Ecological Applications, 16*(6), 2064-2090. https://doi.org/10.1890/1051-0761(2006)016[2064:DALAWA]2.0.CO;2

Sigma-Aldrich Corporation. (2015, February 27). *Safety data sheet*. Sigma-Aldrich Corporation. https://www.sigmaaldrich.com/AR/en/sds/aldrich/718467

Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., & Zurbrügg, C. (2016). *Compendium of sanitation systems and technologies*. The International Water Association.

United States Environmental Protection Agency. (2010). *NPDES permit writers' manual*. U.S. Environmental Protection Agency. https://www.epa.gov/sites/default/files/2015-09/documents/pwm_2010.pdf

United States Environmental Protection Agency. (2015). *A compilation of cost data associated with the impacts and control of nutrient pollution.* U.S. Environmental Protection Agency. https://www.epa.gov/sites/default/files/2015-04/documents/nutrient-economics-report-2015.pdf

United States Environmental Protection Agency. (2021, August 13). *Nutrient pollution: The issue*. https://www.epa.gov/nutrientpollution/issue

United States Environmental Protection Agency. (2022a, July). *Compendium of state and regional NPDES nutrient permitting approaches.* https://www.epa.gov/system/files/documents/2022-04/compendium-of-npdes-nutrient-permitting-approaches.pdf

United States Environmental Protection Agency. (2022b, August 23). *Frequent questions on septic systems*. United States Environmental Protection Agency. https://www.epa.gov/septic/frequent-questions-septic-systems

United States Environmental Protection Agency. (2023, April 7). *Sources and solutions: Wastewater.* United States Environmental Protection Agency. https://www.epa.gov/nutrientpollution/sources-and-solutions-wastewater

United States Geological Survey. (2019, March 3). *Nutrients and eutrophication.* https://www.usgs.gov/mission-areas/water-resources/science/nutrients-and-eutrophication#overview

Vande Boom, J. M. (2018). *Impacts of microbial inoculator generators (MIGs) on nitrogenous compounds in septic systems* [Master's Capstone Project Report. Milwaukee School of Engineering] Milwaukee School of Engineering Institutional Repository. http://milwaukee.sdp.sirsi.net/client/en_US/search/asset/2221.

Ward, B. B. (2008, September 30). *Chapter 5 – Nitrification in marine systems.* Academic Press. https://doi.org/10.1016/B978-0-12-372522-6.X0001-1

WEC Projects. (n.d.). *Adsorption: Adsorption Solutions.* WEC. https://www.wecprojects.com/solutions/processes/adsorption/

Wisconsin Department of Health Services. (2021, April 15). *Infant methemoglobinemia (blue baby syndrome)*. https://www.dhs.wisconsin.gov/water/blue-baby-syndrome.htm#:~:text=Infant%20methemoglobinemia%20is%20also%20called,early%20in%20life%20(acquired).

Wisconsin Department of Natural Resources. (2018, October). *Nutrient removal – total nitrogen study guide: Subclass N.* Wisconsin Department of Natural Resources.

https://dnr.wi.gov/topic/opcert/documents/StudyGuideNutrientRemovalTotalNitrogen.pdf

Wisconsin Department of Natural Resources. (2023a, February). *Laboratories*. Wisconsin Department of Natural Resources. https://dnr.wisconsin.gov/topic/labCert/certified-lab-lists

Wisconsin Department of Natural Resources. (2023b, March). *Current groundwater standards*. Wisconsin Department of Natural Resources. https://dnr.wisconsin.gov/topic/Groundwater/CurrentStandards.html

Wisconsin Department of Natural Resources. (n.d.). *Private onsite wastewater treatment systems [POWTS]*. https://dnr.wisconsin.gov/topic/Wastewater/NonDomestic.html

Appendix A: Complete Data Set

Table A1. Primary Influent Data from Brookfield WWTF – June 2022

Date	Influent Flow [MGD]	Ammonia as N [mg/L]	BOD [mg/L]	Phosphorus [mg/L]	TSS [mg/L]
6/1/2022	8.26	25.8	201	5.34	334
6/2/2022	8.06	22.2	217	5.21	258
6/3/2022	7.84	18	175	4.64	204
6/4/2022	7.86	14.5	163	4.09	188
6/5/2022	8.11	16.2	210	4.98	248
6/6/2022	9.46	18	116	3.58	132
6/7/2022	8.67	23.8	160	5.09	232
6/8/2022	9.88	17.8	170	4.52	202
6/9/2022	9.26	16.8	170	3.45	270
6/10/2022	8.67	17.5	189	6.46	346
6/11/2022	8.36	15.8	180	4.84	390
6/12/2022	8.18	17.7	235	7.22	298
6/13/2022	9.53	19.7	189	5.18	252
6/14/2022	7.26	12.1	112	3.45	164
6/15/2022	10.1	16.6	243	8.71	376
6/16/2022	11.02	9.3	79	2.71	110
6/17/2022	9.57	15.9	152	4.45	216
6/18/2022	8.78	10.5	143	5.05	174
6/19/2022	8.52	14.6	166	5.39	242
6/20/2022	8.44	16.3	156	5.14	200
6/21/2022	8.09	16.2	153	4.84	202
6/22/2022	7.82	18.5	165	4.61	196
6/23/2022	7.71	18.9	226	5.98	262
6/24/2022	7.52	19.7	178	4.84	216
6/25/2022	7.38	16.1	176	5.16	246
6/26/2022	7.34	16.2	208	5.6	262
6/27/2022	7.63	20	185	4.73	212
6/28/2022	7.59	29.2	200	5.14	234
6/29/2022	7.4	16.8	226	6.24	292
6/30/2022	7.08	19.7	182	5.12	236

Table A2. Primary Influent Data from Brookfield WWTF – July 2022

Date	Influent Flow [MGD]	Ammonia as N [mg/L]	BOD [mg/L]	Phosphorus [mg/L]	TSS [mg/L]
7/1/2022	6.96	19.4	200	5.02	242
7/2/2022	6.67	16.2	124	3.79	154
7/3/2022	6.56	15.1	156	4.15	200
7/4/2022	7.32	16.1	167	5.12	284
7/5/2022	8.99	15.3	181	4.66	256
7/6/2022	9.46	16.1	143	5.82	214
7/7/2022	8.48	21.6	177	4.89	250
7/8/2022	8.03	20.4	166	4.59	236
7/9/2022	7.63	18.6	180	4.96	240
7/10/2022	7.63	15.2	168	4.15	254
7/11/2022	8.18	17.5	250	5	286
7/12/2022	8.22	19.1	155	4.02	190
7/13/2022	7.9	17.8	141	4.57	250
7/14/2022	7.65	18.5	139	4.15	190
7/15/2022	9.02	16	169	4.04	206
7/16/2022	8.33	13.1	126	3.49	176
7/17/2022	7.94	17.8	212	8.57	314
7/18/2022	7.84	13.9	68	2.28	68
7/19/2022	7.47	15.1	123	4.02	218
7/20/2022	7.34	19.1	248	5.85	256
7/21/2022	7.26	18.8	290	7.15	458
7/22/2022	7.19	30	174	5.28	254
7/23/2022	7.71	19.1	178	7.56	364
7/24/2022	8.53	13.8	154	3.67	190
7/25/2022	8	22.2	222	6.65	288
7/26/2022	7.65	22.2	145	6.74	260
7/27/2022	7.67	15.4	161	7.97	318
7/28/2022	7.28	16.5	186	5.71	278
7/29/2022	7.18	18.1	176	4.73	236
7/30/2022	6.94	19.8	235	6.1	310
7/31/2022	6.9	16.9	198	6.26	302

Table A3. Primary Influent Data from Brookfield WWTF – August 2022

Date	Influent Flow [MGD]	Ammonia as N [mg/L]	BOD [mg/L]	Phosphorus [mg/L]	TSS [mg/L]
8/1/2022	7.02	20.8	202	5.69	294
8/2/2022	7.02	21	237	8.04	330
8/3/2022	7.13	21.4	229	5.82	310
8/4/2022	7.09	19.7	218	6.08	274
8/5/2022	7.35	21.4	384	11.59	720
8/6/2022	6.65	17.8	174	4.96	228
8/7/2022	7.09	20	194	6.4	280
8/8/2022	7.67	21.8	304	9.99	366
8/9/2022	7.64	19.2	245	12.39	492
8/10/2022	7.45	17.5	189	5.92	268
8/11/2022	6.98	21.2	247	7.45	320
8/12/2022	6.82	33	236	21.17	688
8/13/2022	6.49	17.3	180	5.05	272
8/14/2022	6.61	17.5	211	5.41	256
8/15/2022	6.82	28.8	237	16.5	576
8/16/2022	6.8	20.6	212	6.12	314
8/17/2022	6.61	22.2	215	5.82	284
8/18/2022	6.56	20.8	161	5.14	226
8/19/2022	6.57	19.6	107	3.26	136
8/20/2022	6.99	15	119	2.83	130
8/21/2022	6.92	14	147	2.9	196
8/22/2022	6.92	33	217	5.9	302
8/23/2022	6.82	20.6	248	8.3	408
8/24/2022	7.03	22.2	186	4.84	300
8/25/2022	10.05	14.4	165	4.06	262
8/26/2022	7.34	16.4	156	4.09	228
8/27/2022	6.69	16.1	193	5.25	236
8/28/2022	7.69	13.1	161	3.95	202
8/29/2022	7.75	18.2	159	4.5	220
8/30/2022	7.03	16.1	238	4.64	244
8/31/2022	6.82	19.2	169	4.29	228

Table A4. Primary Influent Data from Brookfield WWTF – September 2022

Date	Influent Flow [MGD]	Ammonia as N [mg/L]	BOD [mg/L]	Phosphorus [mg/L]	TSS [mg/L]
9/1/2022	6.52	17.8	190	4.41	238
9/2/2022	6.27	20.8	187	4.41	214
9/3/2022	5.93	17.9	173	4.02	262
9/4/2022	5.83	18.6	176	3.93	280
9/5/2022	6.19	17.8	192	4.54	278
9/6/2022	6.21	19.2	249	4.52	240
9/7/2022	6.17	22.4	190	4.5	250
9/8/2022	5.98	18	203	4.27	258
9/9/2022	5.87	22.6	172	4.68	252
9/10/2022	5.71	16.9	184	4.64	228
9/11/2022	24.58	5.6	188	4.85	324
9/12/2022	30.17	3.4	120	2.23	220
9/13/2022	17.27	7.1	79	2.1	118
9/14/2022	13.83	9.4	285	13.53	608
9/15/2022	11.84	8.6	128	3.13	188
9/16/2022	10.39	10.3	216	3.72	210
9/17/2022	9.42	10.4	138	4.04	188
9/18/2022	9.05	10.3	131	3.29	156
9/19/2022	8.66	16.7	119	3.7	154
9/20/2022	8.52	14.8	174	3.99	188
9/21/2022	8.17	15.6	172	4.31	182
9/22/2022	8.07	16.4	177	4.5	196
9/23/2022	7.9	16	169	4.11	198
9/24/2022	7.96	15.6	158	4.34	206
9/25/2022	8.71	13.2	163	4.36	192
9/26/2022	8.67	16.6	180	3.83	198
9/27/2022	8.11	16.5	160	3.88	190
9/28/2022	7.81	21.2	162	4.47	200
9/29/2022	7.67	16.9	163	4.5	212
9/30/2022	7.43	19.7	194	4.59	208

Table A5. Primary Influent Data from Brookfield WWTF – October 2022

Date	Influent Flow [MGD]	Ammonia as N [mg/L]	BOD [mg/L]	Phosphorus [mg/L]	TSS [mg/L]
10/1/2022	7.23	17.4	184	4.54	248
10/2/2022	7.23	15.1	176	4.27	192
10/3/2022	7.26	22	175	4.45	210
10/4/2022	7.22	22.8	172	4.45	242
10/5/2022	7.11	24	217	4.84	244
10/6/2022	6.9	20	177	4.38	208
10/7/2022	6.86	20.4	213	5.34	228
10/8/2022	6.76	17.4	191	4.57	234
10/9/2022	6.68	17.9	196	4.36	202
10/10/2022	6.68	21.2	213	4.98	258
10/11/2022	6.66	21	177	4.86	268
10/12/2022	7.34	21	209	5.37	260
10/13/2022	7.05	15.5	414	15.61	360
10/14/2022	6.52	17.8	312	7.4	310
10/15/2022	6.31	16.7	210	4.06	186
10/16/2022	6.29	16.9	178	4.27	208
10/17/2022	6.39	20	176	4.47	194
10/18/2022	6.29	18.8	156	4.54	208
10/19/2022	6.42	20	168	4.68	196
10/20/2022	6.44	18.9	342	14.45	524
10/21/2022	6.17	18.9	188	5.18	234
10/22/2022	5.85	16.9	162	4.31	240
10/23/2022	5.85	16.6	193	4.75	232
10/24/2022	6.05	19.5	254	5.92	302
10/25/2022	6.73	21.6	202	5.53	236
10/26/2022	6.99	18.3	171	4.31	420
10/27/2022	6.63	18	254	4.68	220
10/28/2022	6.4	20.4	202	4.27	306
10/29/2022	6.19	17.6	131	3.22	256
10/30/2022	6.29	15.5	204	4.12	328
10/31/2022	6.17	18.1	268	4.09	240

Table A6. Data from Samples Collected Within the Pilot Study.

Site	Sample	Sample Date	TSS (mg/L)	TS (%)	NH3 (mg/L)	NO3 (mg/L)	NO2 (mg/L)	TKN (mg/L)	TN (mg/L)	organic N (mg/L)	BOD (mg/L)	COD (mg/L)	TP (mg/L)	E. coli MPN/100 mL
2	001	6/17/2022	40	0.16	3.23	3.28	0.20	5.3	8.8	2.07	33	54	1.26	-
4	002	6/17/2022	40	0.16	1.32	5.70	0.60	5.5	11.8	4.18	43	77	1.93	-
6	003	6/17/2022	20	0.16	0.39	7.54	0.10	3.6	11.2	3.21	28	54	1.75	-
9	004	6/17/2022	30	0.14	0.30	7.65	0.10	2.3	10.1	2	32	45	1.23	-
11	005	6/17/2022	10	0.15	0.37	7.30	0.20	2.4	9.9	2.03	8	45	1.09	-
2	006	6/24/2022	15	0.12	1.79	4.84	0.40	3.6	8.8	1.81	35	54	1.44	-
4	007	6/24/2022	20	0.13	1.63	4.40	0.80	4.4	9.6	2.77	30	59	1.63	-
6	008	6/24/2022	30	0.11	0.51	6.82	0.30	2.9	10.0	2.39	23	73	1.76	-
9	009	6/24/2022	15	0.11	0.52	6.72	0.20	-	6.9	-0.52	18	54	1.40	-
11	010	6/24/2022	5	0.12	0.43	6.47	0.10	1.6	8.2	1.17	6	41	1.10	-
2	011	7/5/2022	10	0.15	1.61	6.20	0.70	4.7	11.6	3.09	28	82	-	-
4	012	7/5/2022	5	0.15	1.08	6.50	0.90	4.4	11.8	3.32	-	82	-	-
6	013	7/5/2022	10	0.15	0.38	8.44	0.30	4.1	12.8	3.72	-	95	-	-
9	014	7/5/2022	15	0.15	0.30	8.60	0.30	3.1	12.0	2.8	-	86	-	-
11	015	7/5/2022	10	0.15	0.60	7.94	0.40	1.6	9.9	1	9	59	-	-
2	016	7/15/2022	40	0.13	7.94	8.90	0.20	14.0	23.1	6.06	53	-	-	-
6	017	7/15/2022	35	0.14	1.50	0.20	0.20	4.4	4.8	2.9	29	-	-	-
11	018	7/15/2022	25	0.14	0.68	7.22	0.50	2.4	10.1	1.72	10	-	-	-
2	019	7/22/2022	30	0.13	9.74	0.20	-	15.2	15.4	5.46	59	-	-	-
6	020	7/22/2022	25	0.13	0.86	9.38	-	5.3	14.7	4.44	45	-	-	-
11	021	7/22/2022	10	0.14	1.50	6.35	-	3.7	10.1	2.2	11	-	-	-
6	022	7/28/2022	15	0.15	1.58	7.20	-	4.2	11.4	2.62	29	-	-	-
11	023	7/28/2022	5	0.14	1.50	6.36	-	4.1	10.5	2.6	7	-	-	-
6	024	8/4/2022	30	0.16	3.42	8.63	-	7.8	16.4	4.38	60	-	-	62,000
11	025	8/4/2022	5	0.15	3.42	10.50	-	6.3	16.8	2.88	25	-	-	14,000
6	026	8/11/2022	35	0.16	3.69	7.51	-	12.7	20.2	9.01	64	-	-	55,000
11	027	8/11/2022	5	0.15	4.99	8.06	-	6.2	14.3	1.21	10	-	-	5,500
0	028	8/17/2022	190	0.24	14.40	0.02	0.00	24.9	24.9	10.50	70	-	-	3,700,000
6	029	8/17/2022	30	0.17	1.04	14.00	0.00	5.2	19.2	4.16	52	-	-	34,000
11	030	8/17/2022	5	0.16	1.25	10.90	0.10	3.8	14.8	2.55	16	-	-	9,100
6	031	8/25/2022	50	0.16	22.80	0.51	-	30.2	30.7	7.40	70	-	-	240,000
11	032	8/25/2022	10	0.15	20.70	0.74	-	27.2	27.9	6.50	44	-	-	240,000
6	033	9/1/2022	25	0.14	14.00	2.69	-	18.8	21.5	4.80	70	-	-	49,000
11	034	9/1/2022	3	0.13	13.60	2.16	-	18.9	21.1	5.30	17	-	-	8,200
6	035	9/8/2022	30	0.14	23.40	0.10	-	35.4	35.5	12.00	50	-	-	240,000
11	036	9/8/2022	13	0.14	21.50	0.10	-	34.1	34.2	12.60	42	-	-	240,000
6	037	9/15/2022	27	0.11	10.40	0.10	-	15.5	15.6	5.10	22	-	-	82,000
10	038	9/15/2022	20	0.11	-	-	-	-	-	-	-	-	1.82	7,800
11	039	9/15/2022	16	0.11	-	0.10	-	15.1	15.2	15.10	16	-	0.96	-
6	040	9/22/2022	10	0.12	13.90	2.12	-	18.4	20.5	4.50	38	-	-	200,000
10	041	9/22/2022	10	0.12	-	-	-	-	-	-	-	-	1.35	-
11	042	9/22/2022	10	0.12	11.20	5.36	-	16.9	22.3	5.70	30	-	1.21	73,000
6	043	9/29/2022	10	0.14	15.80	0.10	-	22.3	22.4	6.50	23	-	-	61,000
10	044	9/29/2022	7	0.14	-	-	-	-	-	-	-	-	1.29	11,000
11	045	9/29/2022	4	0.14	15.50	0.32	-	20.6	20.9	5.10	19	-	1.19	8,800
6	046	10/7/2022	-	-	18.30	0.10	-	27.7	27.8	9.40	29	-	-	-
10	047	10/7/2022	-	-	-	-	-	-	-	-	-	-	2.37	-
11	048	10/7/2022	-	-	21.70	0.47	-	25.8	26.3	4.10	23	-	1.32	-
6	049	10/13/2022	-	-	21.30	0.10	-	28.8	28.9	7.50	61	-	-	-
10	050	10/13/2022	-	-	-	-	-	-	-	-	-	-	4.03	-
11	051	10/13/2022	-	-	22.80	0.10	-	28.5	28.6	5.70	24	-	1.45	-
6	052	10/20/2022	-	-	-	0.20	-	-	-	-	33	-	-	-
10	053	10/20/2022	-	-	-	-	-	-	-	-	-	-	1.76	-
11	054	10/20/2022	-	-	24.10	0.20	-	28.0	28.2	3.90	24	-	1.49	-

Note. The hyphen ("-") means data were not analyzed. Site 0 is the influent to the pilot system, site 2 is the effluent side of the trash tank, site 4 is the effluent side of the MIG 1 Tank, site 6 is the effluent side of the MIG 2 Tank, site 9 is the effluent side of the pump tank, site 10 is the influent side of the phosphorus adsorption tank, and site 11 is the final effluent.

Appendix B: Letter of Authorization from Knight Treatment Systems

Knight Treatment Systems
"Guardians of Water Quality®"
281 Co. Rt. 51A, Oswego, NY 13126
1-800-560-2454 / 315-343-8521 / Fax 315-343-2941
www.knighttreatment.com

May 24, 2023

Ms. Alexis Countryman, Honors Civil Engineering Student
C/O Milwaukee School of Engineering
1025 North Broadway
Milwaukee WI. 53202

Re: Letter of Authorization

To whom it may concern,

Ms. Alexis Countryman, Master's Candidate at the Milwaukee School of Engineering, is duly authorized to make use of, reproduce and/or copy all relevant images and documents that are the property of Knight Treatment Systems, Inc. with regard to the White Knight Microbial Inoculator Generator™ (MIG) for inclusion within her Master's Thesis Project.

Respectfully,

Mark C. Noga, President

Cc: D Nelson, MSOE
File

Civil Engineering

Capstone Report Approval Form

Master of Science in Civil Engineering -- MSCVE

Milwaukee School of Engineering

This capstone report, entitled "Effects of Microbial Inoculator Generators (MIGs) on Nitrogenous Compounds and Phosphorus Adsorption Devices on Phosphoric Compounds in a Septic System Pilot Study," submitted by the student Alexis K. Countryman, has been approved by the following committee:

Faculty Advisor: ______________________________ Date: ________________

Professor Douglas Nelson, M.A.T., Associate Professor

Faculty Member: ______________________________ Date:________________

Professor Jeff MacDonald, M.S., Adjunct Associate Professor

Faculty Member: ______________________________ Date: ________________

Dr. William Gonwa, Ph.D., Professor

Faculty Member: ______________________________ Date: ________________

Dr. Anne Alexander, Ph.D., Associate Professor