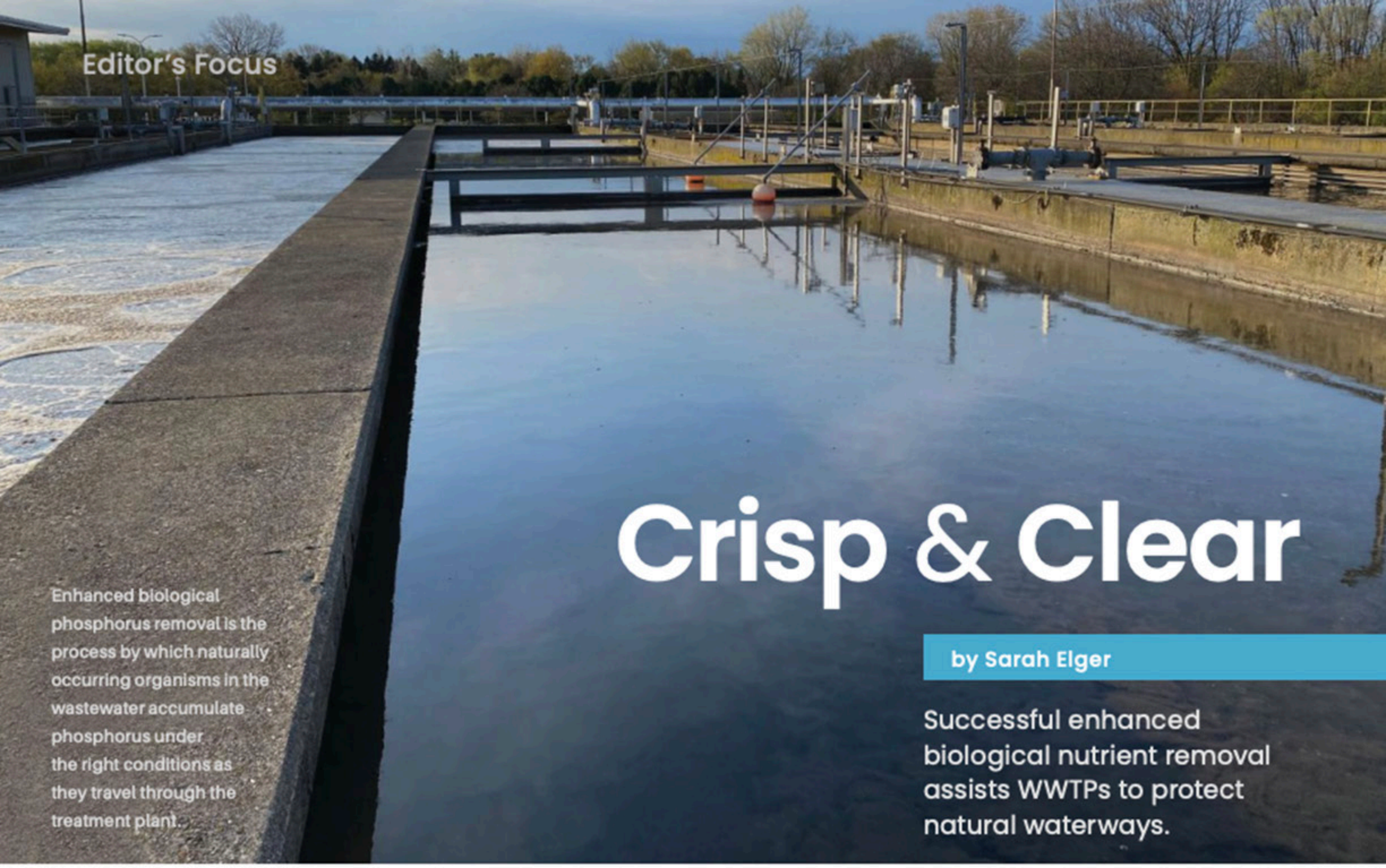

Crisp & Clear

by Sarah Elger

Successful enhanced biological nutrient removal assists WWTPs to protect natural waterways.

Enhanced biological phosphorus removal is the process by which naturally occurring organisms in the wastewater accumulate phosphorus under the right conditions as they travel through the treatment plant.

Short, gentle pulses during the deep cycle generate volatile fatty acids and redistribute microroganisms without disrupting the fermentation layer.

Regulatory changes throughout the United States drive municipal wastewater treatment plants (WWTPs) to continually improve their approaches to phosphorus removal. Treating wastewater to meet specific effluent limits can substantially reduce nitrogen and phosphorus discharge, which protects natural bodies of water and prevents disastrous ecological impacts on marine habitats.

Some treatment plants use chemicals to remove phosphorus, which can be a costly and unsustainable approach. As such, facilities in the U.S. are seeking ways to successfully implement nutrient removal strategies that meet regulatory needs without stressing the budget.

Enhanced Biological Phosphorus Removal 101

Enhanced biological phosphorus removal (EBPR) is the process by which naturally occurring organisms in the wastewater accumulate phosphorus under the right conditions as they travel through the treatment plant (see Figure 1, page 15). The microbes that accumulate phosphorus are named phosphorus accumulating organisms (PAOs).

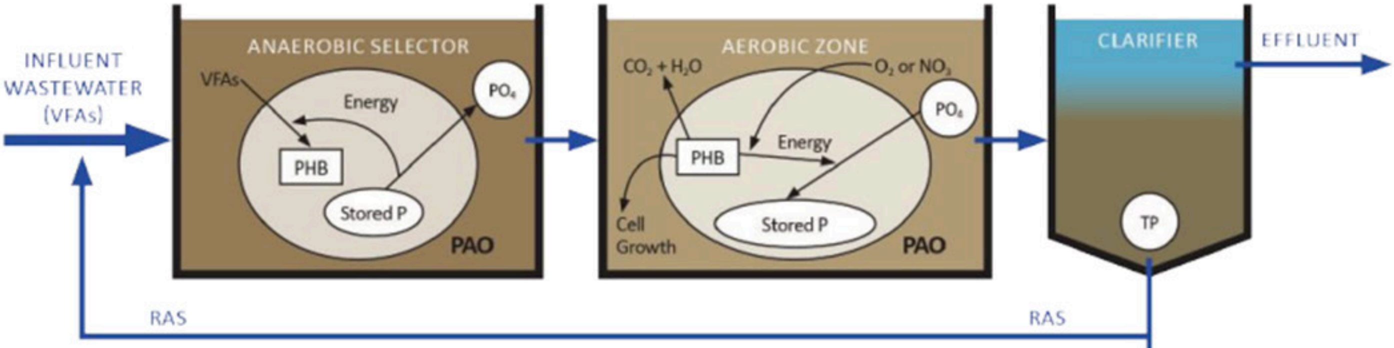

Figure 1. The enhanced biological phosphorus removal process flow chart. Return activated sludge from the clarification process flows through anaerobic and aerobic zones for phosphorus removal.

In activated sludge processes with consecutive anaerobic and aerobic environments, PAOs thrive. In the anaerobic phase, PAOs consume carbon in the form of volatile fatty acids (VFAs), and release stored phosphorus as an energy source.

The EBPR process is sensitive to influent characteristics. The adequacy of surplus VFAs in the anaerobic selector is particularly crucial to achieving consistent EBPR. The ratio of biochemical oxygen demand to total phosphorus (BOD:TP) in the bioreactor influent is commonly used as indicator of a plant's ability to achieve EBPR.

If the influent BOD:TP is lower than 25:1, it is known as carbon-limited, and sufficient VFAs may not be available, resulting in ineffective EBPR. A few common causes of carbon limited conditions are weak or diluted influent, excessive BOD removal in primary clarifiers, and significant recycled phosphorus from sludge processing operations.

To avoid costly carbon addition, facilities with insufficient influent VFAs can encourage additional VFA production through fermentation generated by in-line methods within the main process or by using sidestream methods. PAOs constitute a small subset of the bacterial population in the mixed liquor.

The rest of the bacteria do not consume VFAs; if given time during fermentation, they break down complex soluble organic compounds to form VFAs. As the fermentation blanket forms, VFA is produced and consumed by PAOs. Therefore, the fermentation process simultaneously conditions PAOs and provides an environment for VFA production.

When the PAOs run out of stored phosphorus, they cannot accept more VFA — i.e., they are full. To maximize the process, the surplus VFA must be transported out of the fermentation blanket to the hungry PAOs in the upper layers of the reactor.

PAOs store food under anaerobic conditions and then process the stored food under aerobic conditions. After passing through the anaerobic selector, the activated sludge enters an aerobic zone where PAOs use the VFA they have consumed as an energy source for phosphorus uptake. Phosphorus uptake in the aerobic environment is significantly greater than phosphorus release in the anaerobic zone, resulting in lower effluent levels.

Technology for EBPR

One way of achieving EBPR is with the BioMix-DC enhanced anaerobic mixing system, launched by EnviroMix in 2021 (see Figure 2, page 16). This technology optimizes EBPR, transforming a traditional anaerobic selector into an intensified fermentation tank by alternating a long deep cycle with a short mixing cycle.

During the non-mixed deep cycle, a fermentation blanket forms and VFAs are produced. PAOs in the blanket consume the VFAs, while releasing stored phosphorus. The deep cycle not only generates VFAs, but it also delivers intermittent pulses to redistribute microorganisms and VFAs without disrupting the fermentation layer. Redistribution is accomplished through short, gentle pulses of compressed air. These pulses transport the VFAs upward without resuspending the blanket or disrupting the fermentation process. Overall, this gentle pulsing helps keep PAOs and VFA happily in balance, resulting in an abundant PAO population.

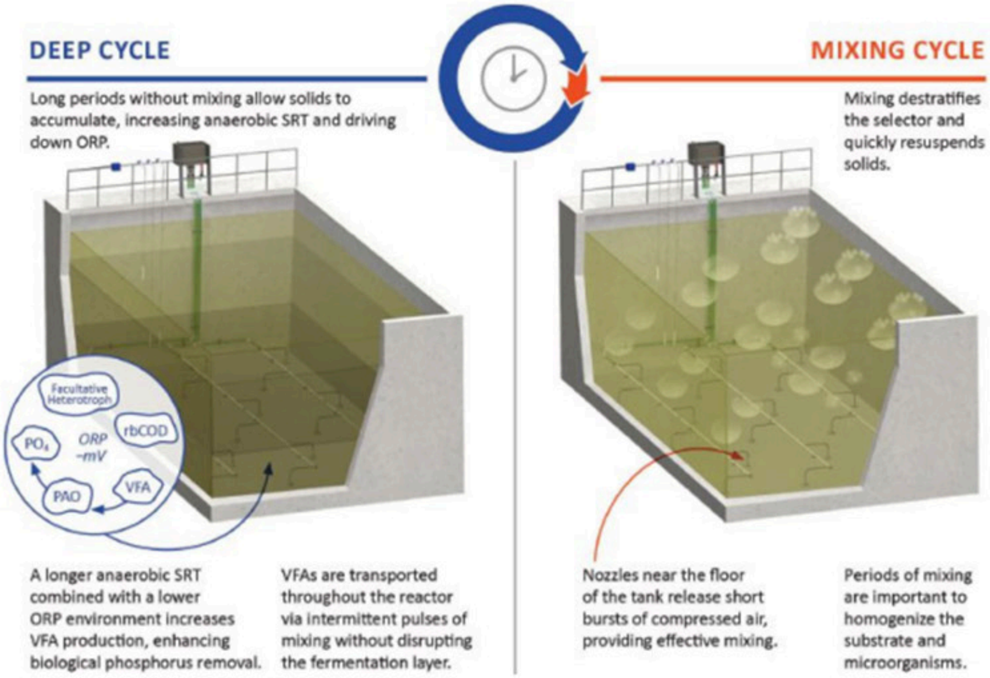

Figure 2. How the deep cycle and mixing cycle for DC-BioMix works.

During the mixing cycle, the fermentation blanket is uniformly suspended to discourage methanogenic activity and recharge the blanket with organic matter for more VFA production. Utilizing BioMix compressed gas mixing, large bubbles are released through engineered nozzles near the floor of the tank, creating an upwelling motion and circulatory currents to completely mix the reactor.

In 2022, BioMix-DC was selected as a Water Environment Federation (WEF) Innovative Technology Award winner. Each year, WEF recognizes technologies and companies who have introduced new and innovative products or services related to the water and wastewater industry.

Compared to continuous mechanical mixing in anaerobic selectors, BioMix-DC provides energy savings of 90% or greater. It is adaptable and compatible with in-line mixed liquor fermentation, sidestream return activated sludge fermentation, and sidestream mixed liquor fermentation.

The Proof is in the Data

Once the factors that lead to successful EBPR are understood, measuring that success can be relatively straightforward. Using samples collected from multiple BioMix-DC installations across the U.S., the data demonstrates how plants are achieving environments with low oxidation reduction potential (ORP), fermentation blanket formation, VFA production, and high levels of phosphorus release in anaerobic selectors.

Deep anaerobic conditions are critical to promote the growth of PAOs. To demonstrate this, ORP was measured in anaerobic selectors mixed with compressed gas mixing at two plants for 30 days (see Figure 3, page 18). Both maintained low ORP levels— on average below negative 400 — showing that BioMix-DC delivers deep anaerobic conditions.

When mixing is suspended, the biomass settles and accumulates at the bottom of the tank. A sludge blanket forms, creating a fermentation layer. Accumulating solids create a higher concentration of sludge, which, in

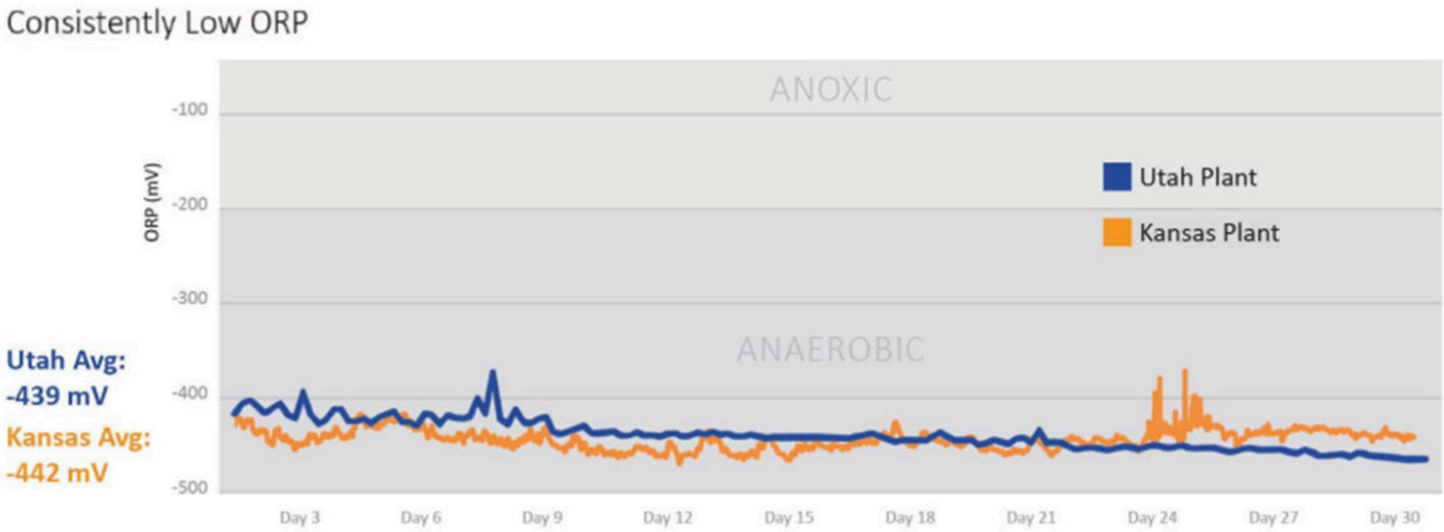

Figure 3. Oxidation reduction potential in Utah and Kansas with enhanced biological phosphorus removal equipment in place.

Stratified TSS Levels

	Ohio Plant	North Carolina Plant	Colorado Plant
Surface Layer	500-2,000 mg/L	1,000-3,000 mg/L	1,200-2,500 mg/L
Bulk Liquid	3,000-5,000 mg/L	3,000-5,000 mg/L	2,500-6,000 mg/L
Fermentation Layer	>10,000 mg/L	>10,000 mg/L	>10,000 mg/L

Figure 4. Total suspended solids data for Ohio, North Carolina and Colorado.

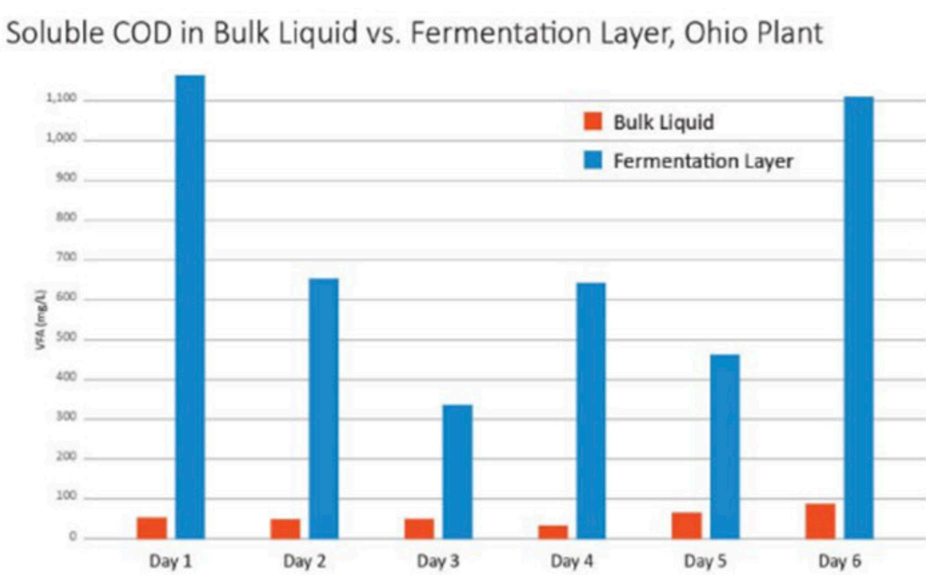

Figure 5. Comparison of soluable carbon in bulk liquid and the fermentation layer in Ohio.

turn, increases the anaerobic mass fraction and solids retention time. Over time, the fermentation layer produces VFAs through the processes of hydrolysis and fermentation.

Total suspended solids (TSS) data from three different plants (see Figure 4) show distinct, stratified layers. The data from these plants demonstrate a well-established fermentation blanket.

Once a fermentation blanket is formed, concentrations of soluble carbon in the bulk liquid can be compared with the fermentation layer (see Figure 5). The surplus carbon in the fermentation layer indicates that not only are VFAs being generated, but that the VFAs exceed the amount the PAOs in the blanket can consume. With VFAs available, the PAOs now have an abundance of VFAs to consume, leading to the release of stored phosphorus and PAO growth.

When PAOs consume VFAs, they release phosphorus. To verify this, concentrations of ortho-phosphate (PO_4) were measured in the influent and in the fermentation blanket (see Figure 6, page 19). The measurements in the blanket were 10 to 100 times higher than the concentrations found in the influent, confirming high levels of VFA consumption and substantial phosphorus release. Subsequent luxury phosphorus uptake follows in the aerobic reactors, resulting in low levels of effluent total phosphorus.

For plants aiming to achieve successful EBPR, the measurement that matters most is effluent total phosphorus (see Figure 7, page 19).

Prior to the implementation of BioMix-DC, the effluent phosphorus at the North Carolina

STEPS TO SUCCESSFUL EBPR
Simply stated, to ensure EBPR success, WWTPs need to:

- Establish an anaerobic selector with oxidation-reduction potential consistently below -200 mV.
- Allow mixed liquor to settle, creating a fermentation blanket with longer anaerobic solids retention time.
- Promote conditions for fermentation and hydrolysis for volatile fatty acids generation.
- Encourage phosphorus release in the anaerobic reactor.

Phosphorus Release Data

Plant	Influent PO_4	Fermentation Blanket PO_4
Ohio	3-9 mg/L	15-100 mg/L
Wisconsin	2-11 mg/L	23-47 mg/L

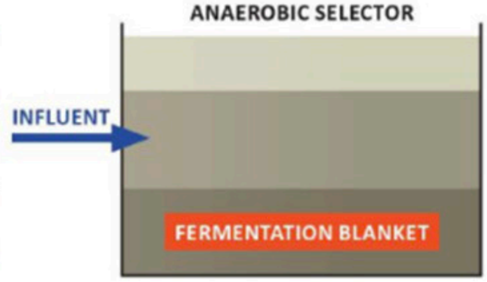

Figure 6. PO_4 in Ohio and Wisconsin.

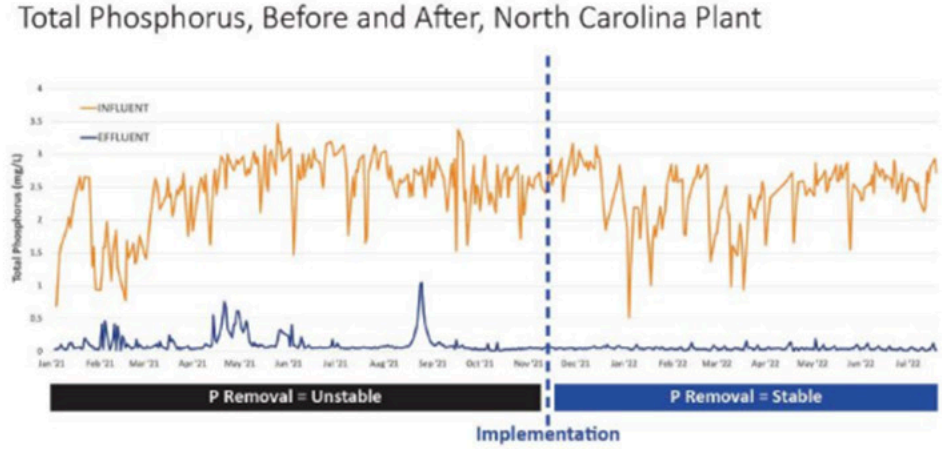

Figure 7. Total phosphorus before and after the North Carolina Plant's BioMix solution installation.

plant was inconsistent. After implementation, the performance stabilized, resulting in consistent effluent quality with fewer spikes in phosphorus.

Removing phosphorus from municipal wastewater to comply with permitted effluent limits helps protect surface water bodies from devastating ecological outcomes while recovering a valuable nutrient for reuse as fertilizer.

In addition to the nutrient removal benefits, BioMix-DC also delivers a net energy savings of 90% through the combination of eliminating mixing for long periods of time and the use of a high efficiency compressed gas mixing system.

Substantial savings are also realized by plants that need to supplement EBPR with carbon addition and/or chemical dosing for precipitation, specifically for plants that have low influent BOD:TP ratios or low influent VFAs. A reduction in chemicals used for precipitation directly results in reduced sludge volumes, and subsequently reduced sludge disposal costs.

An enhanced anaerobic mixing system supports successful EBPR, minimizes energy and chemical consumption, and enables WWTPs to do their part in delivering a clean future for critical water resources.

Sarah Elger, P.E. is the director of strategy and marketing at EnviroMix Inc. She has been in the water and wastewater industry for more than 15 years and specializes in biological wastewater treatment and process controls. Elger received her B.S. in engineering mechanics from University of Wisconsin; received her M.S. in environmental engineering from Milwaukee School of Engineering; and is a registered professional engineer in the State of Wisconsin.