Missouri Municipal Nutrient Optimization Pilot Project

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MISSOURI DEPARTMENT OF NATURAL RESOURCES
GRANT TECH
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T8 Environmental

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This report serves as fullfillment of the Final Report requirement for Missouri Municipal Wastewater Nutrient Optimization Pilot Project

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ACRONYM LIST

Acronym	Meaning
AWT	Advanced Wastewater Treatment
BOD	Biochemical Oxygen Demand
BNR	Biological Nutrient Removal
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EPA	US Environmental Protection Agency
GHG	Greenhouse Gas
HAB	Harmful Algae Bloom
IR	Internal Recycle
I&I	Inflow and Infiltration
JV	Joint-Venture (Grant Tech Solutions and T8 Environmental LLC)
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt Hour
lb/d or lb/day	Pounds per Day
lb/yr or lb/year	Pounds per Year
MARB	Mississippi Atchafalaya River Basin
MG	Million Gallons
MGD	Million Gallons per Day
mg/L	Milligrams per Liter (equivalent to parts per million)
MLE	Modified Ludzack Ettinger
MoDNR	Missouri Department of Natural Resources
mV	Millivolt
N_2	Nitrogen Gas
NH_3	Ammonia-nitrogen
NH_4	Ammonium-nitrogen
NO_2	Nitrite-nitrogen
NO_3	Nitrate-nitrogen
NPDES	National Pollution Discharge Elimination System
O_2	Oxygen
Org-N	Organic Nitrogen
ORP	Oxidation Reduction Potential
PAO	Phosphorus Accumulating Organisms
PDSA	Deming's "Plan, Do, Study, Act" cycle
PO_4^{-3}/ PO_4	Phosphate
POTW	Publicly Owned Treatment Works
Q	Flow Rate
SBR	Sequencing Batch Reactor
SCADA	System Control and Data Acquisition
SRP	Soluble Reactive Phosphorus
TIN	Total Inorganic Nitrogen
TKN	Total Kjeldahl Nitrogen
t-N/TN/ total-N	Total Nitrogen

Acronym	Meaning
t-P/TP/ total-P	Total Phosphorus
TPE_{rem}	Total Pollutant Equivalent Removed
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
VFA	Volatile Fatty Acids
VFD	Variable Frequency Drive
WQT	Water Quality Trading
WWTF	Wastewater Treatment Facility, same as WWTP
WWTP	Wastewater Treatment Plant, same as WWTF

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EXECUTIVE SUMMARY

Background

The Missouri Department of Natural Resources (MoDNR) awarded an 18-month contract to Grant Tech Solutions and T8 Environmental LLC for the Missouri Municipal Nutrient Optimization Pilot Project. The aim of the project was to work with a small group of Missouri wastewater treatment facilities (WWTFs) to optimize their operations for reduction of the nutrients Nitrogen and Phosphorus. After visiting each of the eight facilities selected by MoDNR, the contractors developed facility-specific plans for the initial optimization efforts. The contractors conducted three additional onsite visits to each facility, provided a minimum of monthly remote web meetings with each facility, and unlimited email and telephone support as needed. The initial plans were tweaked and modified over time to try to maximize optimization. Ultimately, staff at each WWTF determined how far they were willing to push optimization – some more willing than others. At various points during the optimization effort every facility showed varying degrees of additional nutrient reduction. **By project's end, every facility had shown reductions in Nitrogen and/or Phosphorus.**

Ideally, optimization would take place over a minimum two-year period to help mitigate the effects of climate and other anomalous issues arising at wastewater treatment plants. For example, the winter and spring of 2025 were colder and wetter than average, and both factors affect treatment plant operations. Regardless, following implementation of their optimization plans, the Pilot facilities were able to collect 4-12 months of data. Additionally, the optimization process is sequential – nitrogen is typically reduced first, then phosphorus, so the time spent on phosphorus optimization is generally less than nitrogen optimization. Because of the short data collection period, optimization data for periods shorter than one year were extrapolated to compute yearly loading data.

The contractors also tracked energy usage. Optimization generally involves the creation of zones in liquid processes with less oxygen. Oxygen is supplied by aeration equipment that requires high energy input. Therefore, reducing oxygen input means less intense aeration and less energy demand. **Five of eight facilities showed improved efficiency after optimization by reducing more nutrient per unit of energy utilized.**

Overall Key Results

The best metric to assess improved performance associated with optimization is the reduction in concentrations of total nitrogen (TN) and total phosphorus (TP). Unlike measurement of pounds per day discharged, or pounds per day removed, concentration is independent of the effects of influent flow concentration. As seen in Table 1, five of eight plants had reduced TN concentration post-optimization. Two of the other three plants had negligible increase and remained below the TN goal of 10 mg/L. All eight facilities showed a reduction in TP concentration.

OVERALL, PILOT FACILITIES REDUCED TN CONCENTRATION 41% AND TP CONCENTRATION 30%

Table 1 – Pre and-Post Optimization Concentration

	Effluent Avg - mg/L					
	Pre-Optimization		Post-Optimization		% Improvement	
Facility	**TN**	**TP**	**TN**	**TP**	**TN**	**TP**
Boonville	23.6	4.3	7.8	1.7	67	61
Duckett Cr	22.4	3.9	3.0	1.7	86	56
Herculaneum	33.5	4.0	22.4	3.5	33	14
Independence	13.6	2.1	16.1	1.7	-18	21
Jeff City	8.2	2.8	8.3	2.1	-1.9	27
Oak Grove	8.5	5.7	8.7	4.8	-2.1	15
St Charles	19.0	3.0	16.3	2.3	14	23
St Peters	26.2	3.1	9.4	2.5	64	20
Average	19.4	3.6	11.5	2.5	41	30

Most of the eight facilities reduced the mass of nutrients to varying degrees prior to the Optimization Pilot Project. Based on the two previous years' data, the facilities removed 763 tons per year of nutrients. After the Optimization Project, the same eight facilities removed 1089 tons per year of nutrients - 326 additional tons per year, or 652,000 additional pounds per year were reduced post optimization. Total nitrogen (TN) was reduced by 46% and total phosphorus (TP) was reduced by 20%. A summary of the pre- and post-optimization reductions for each facility are included in Table 2. Since flows increased significantly for most of the Pilot facilities during the optimization period, the values in Table 2 represent flow-normalized values. This will be discussed in more detail in the Results section.

OPTIMIZATION REDUCED AN *ADDITIONAL* 326 TONS/YR (652,000 LBS/YR) OF NUTRIENTS END-OF-PIPE

Note that Herculaneum reported slightly more TP mass discharged (1.6 lb/day) than mass in their influent pre-optimization which resulted in an extremely large percentage improvement. The actual reduction in mass discharged is relatively small.

Energy reduction was observed in most facilities. Five of eight facilities improved their *energy efficiency* which evaluates the pounds of pollutant removed per kilowatt-hour of energy input. Overall, a 37% increase in energy efficiency was observed. A more in-depth discussion on energy usage is provided later in the report, but this improvement is substantial.

OPTIMIZATION IMPROVED ENERGY EFFICIENCY BY 37%

Pre- and post-energy usage, costs, and efficiency for each facility are presented in Table 3. The kilowatt hours per month and costs per month are based on actual billing data. The data is somewhat misleading since most facilities saw an increase in flow during the optimization period which drives more energy use and cost regardless of optimization. The Results section of the report evaluates kilowatt hours and cost per million gallons treated to provide a more accurate comparison of energy savings based on an equivalent volume of wastewater treated.

Table 2 – Overall Nutrient Reduction

	Pounds Reduced – lb/day							
	Pre-Optimization		Post-Optimization		Additional Reduced		Additional % Reduced	
Facility	TN	TP	TN	TP	TN	TP	TN	TP
Boonville	119	14.4	184	27.5	65	13.1	55	91
Duckett Cr	775	73.1	1077	112.8	302	39.7	39	54
Herculaneum	5	-1.6	42	1.7	36	3.2	669	207
Independence	162	17.2	266	20.4	144	3.3	89	19
Jeff City	1248	196.8	1460	226.9	211	30.1	17	15
Oak Grove	184	30.4	248	20.1	63	-10.2	34	-34
St Charles	609	68.7	581	61.6	-28	-7.0	-5	-10
St Peters	586	98.0	1480	122.6	894	24.5	153	25
Total – lb/day	3,689	497.0	5,376	593.7	1,687	96.7	46	20
Total - tons/yr	673	90.7	981	108.4	308	17.6	46	20

Table 3 – Energy Use, Cost, and Efficiency

	Pre-Optimization		Post-Optimization		% Improvement		Energy Efficiency – kWh/lb Removed		
Facility	kWh/mo	Cost/mo	kWh/mo	Cost/mo	kWh	Cost	Pre-Opt	Post-Opt	% Improvement
Boonville	88,955	$6,876	58,760	$4,806	34	30	0.52	0.23	56
Duckett Cr	359,637	$27,542	323,677	$24,912	10	10	0.35	0.23	35
Herculaneum	50,288	$3,979	35,179	$3,066	30	23	1.98	0.86	56
Independence	254,271	$36,920	267,715	$44,242	-5	-20	0.46	0.47	-3
Jeff City	276,242	$22,434	252,327	$19,603	9	13	0.14	0.12	14
Oak Grove	73,689	$6,055	66,594	$5,965	10	1	0.22	0.25	-16
St Charles	374,941	$26,736	343,889	$25,274	8	5	0.38	0.41	-14
St Peters	428,579	$31,649	317,742	$25,760	26	19	0.35	0.20	44
Average	238,325	$20,274	208,235	$19,204	15	10	0.55	0.35	37

The overall nutrient reduction for the eight Pilot Facilities and the improved energy efficiency for removing those nutrients was substantial. Generally, the goal of a pilot project of any type is to utilize a small representative group as a predictor of potential impact to a larger population group.

Assuming the Pilot Facilities are representative of the larger population of municipal WWTFs, data from the eight pilot facilities can be extrapolated to the entire population. **Extrapolating the design flow of 55.5 MGD to the design flow of entire universe of major municipal WWTFs in Missouri (1,236 MGD[1]) could result in over 10 million additional pounds per year of nitrogen and phosphorus being removed from Missouri waters and reducing the impact of those nutrients on downstream waters**.

Overall nutrient reduction at the eight Missouri municipal wastewater treatment facilities not designed to remove nitrogen or phosphorus was mostly unthinkable just over a decade ago. Missouri, like

[1] Missouri's Domestic and Industrial Wastewater Treatment Plants Total Phosphorus Discharges. 2022. Geosyntech Consultants. https://www.geosyntec.com/images/pdf/MO%20Proposed%20NPDES%20White%20Paper_2022.pdf

others, demonstrates that optimization of mechanical wastewater treatment plants is not only possible but produces significant reduction at minimal cost, and in many cases with operational savings.

Optimization, as opposed to a significant capital outlay, can result in major cost savings to municipalities. A Midwest environmental engineering firm estimates construction costs of $13.5 million (2025 dollars) per million gallons of wastewater treated (Johnson, 2022). The entire cost of the Pilot Project was approximately $250,000. This includes the cost of the Pilot Project contract services plus additional costs incurred by the Pilot facilities, minus any energy savings. At least three facilities are likely able to meet the MoDNR nutrient goals via optimization with <u>no</u> costly construction upgrade. Other facilities can combine optimization with chemical addition, greatly minimizing their construction costs.

AT LEAST THREE OF EIGHT PILOT CAN LIKELY MEET THE MoDNR NUTRIENT GOALS WITHOUT SPENDING MILLIONS OF DOLLARS FOR CONSTRUCTION

Missouri's pilot project experience demonstrates that there is little to lose and much to gain in implementing widespread municipal wastewater treatment plant nutrient optimization.

Besides the obvious benefit of reduced nutrient discharge improving receiving water quality, other benefits of optimization include:

- Cost – optimization costs, if any, typically run communities in the ***thousands of dollars***, whereas significant infrastructure improvements typically run in the ***millions of dollars***. This is particularly important for small communities that may not be able to afford new infrastructure.
- Energy Savings – optimization generally involves scaling back aeration of wastewater. Aeration is the most energy intensive aspect of wastewater treatment. Any reduction in energy is an immediately realized cost saving to a community.
- Incidental Environmental Impact – optimization will generally result in lowered energy utilization which results in fewer greenhouse gas emissions. Other positive environmental impacts can include:
  - Immediate Improvements in Water Quality
  - Lowered Chemical Use
- Incidental Economic Benefits – optimization can result in lowered operating costs for a community. Other incidental economic benefits typically accrue from optimization/better quality wastewater. Those benefits include:
  - Capital Cost Avoidance
  - Decreased Drinking Water Treatment Cost
  - Increased Recreation Value
  - Increased Property Value

The Missouri optimization effort has demonstrated wastewater nutrient treatment optimization can work in reducing nutrient discharge for most municipal wastewater treatment facilities with only a small investment in operator education, testing equipment, supplies, and technical assistance.

The benefits of successful optimization are many and important – improved effluent quality, improved receiving water quality, lower operation and maintenance costs, and other tangential environmental benefits. For these reasons, it makes both economic and environmental sense for all mechanical municipal wastewater treatment facilities to evaluate, develop, and implement an optimization plan.

PROJECT DESCRIPTION

Missouri Request for Proposals

In 2023, the Missouri Department of Natural Resources, Division of Environmental Quality, Water Protection Program solicited proposals from vendors for implementing a pilot project to develop recommendations for wastewater treatment facilities (WWTFs) to reduce nutrients without construction upgrades. The concept was for the selected vendor to be charged with making recommendations to affect the optimization of nutrient reduction at eight WWTFs pre-selected by MoDNR. The selected vendor would accomplish this by identifying customized operational changes at each WWTF and providing technical support for the facilities. Following one year's implementation, the selected vendor would communicate nutrient reductions along with lessons learned from the pilot project to the Missouri Department of Natural Resources (MoDNR) – both verbally and in writing. MoDNR would then communicate the findings to the broader municipal wastewater treatment community.

The pilot project falls under the larger umbrella of Missouri's Nutrient Loss Reduction Strategy. The Strategy serves as a mechanism to coordinate nutrient reduction from both point sources (WWTFs) and nonpoint sources (primarily surface runoff of nutrients). The Strategy also serves to support the goals of Gulf of America Hypoxia Task Force (HTF):

- Reduce the five-year running average of the size of the Gulf Hypoxic Zone.
- Restore and protect the waters of the 31 states in the Mississippi/Atchafalaya River Basin (MARB) through implementation of nutrient and sedimentation reduction actions.
- Improve communities and economic conditions across the MARB.

The Task Force consists of representatives of the ten mainstem Mississippi River states, each of which has established nutrient reduction goals and plans for achieving those goals. Unlike most nonpoint source activities that require decades of implementation to see results, reduction from WWTFs can accrue almost immediately if successful.

A contract for the Pilot Project was awarded to a Joint Venture of Grant Tech Solutions and T8 Environmental LLC (JV) based on their selection as the winning vendor. The JV put forth a proposal with the following general process design that was ultimately implemented as shown in Figure 1:

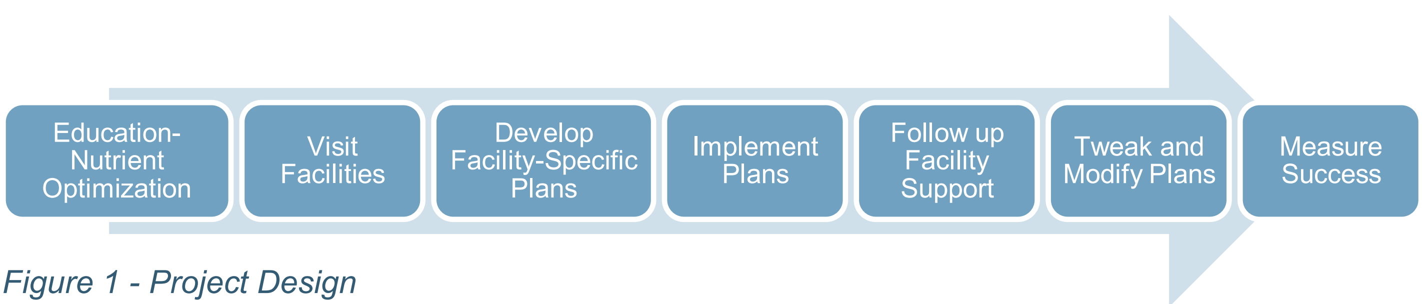

Figure 1 - Project Design

The process anticipated frequent meetings between the JV and WWTF staff to fine-tune operations throughout the project. The process also built in required monthly meetings with MoDNR staff to keep them informed on progress.

The process shown in Figure 1 basically follows the Deming Plan, Do, Study, Act (PDSA) process as shown in Figure 2. (Moen, 2010). The goal of PDSA is to drive continuous improvement. How the key PDSA components were utilized in the Optimization Project follow:

1. **Plan** – The JV provided basic nutrient reduction education and practical application prior to visiting the plant sites. After visiting and assessing each WWTF, a customized optimization plan was developed and presented to the staff at each WWTF.
2. **Do** – The WWTF staff implemented the initial plan and collected operational results to assess the impact on the WWTF effluent.
3. **Study** – Together with WWTF staff, the JV reviewed process data to assess the effect of the changes undertaken to optimize the WWTF. Where changes proved successful, no tweaks to operations were made. In most cases, however, additional operational changes were discussed to further optimize each WWTF.
4. **Act** – Additional identified changes were implemented as WWTF staff were comfortable.

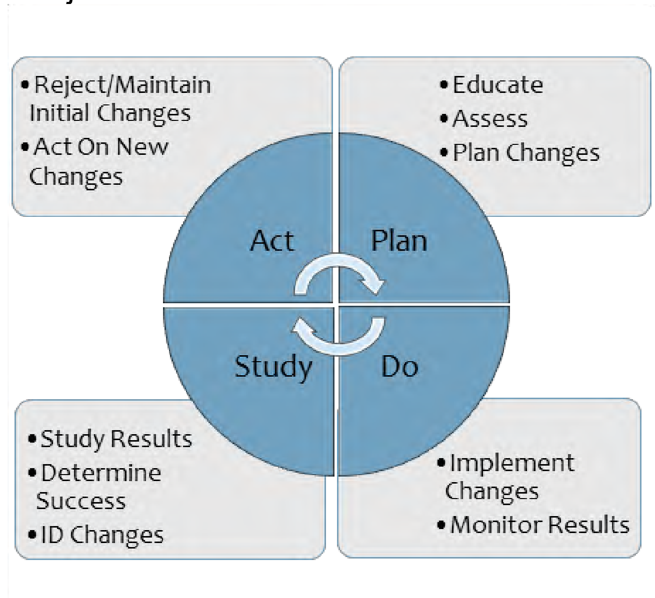

Figure 2 - Deming Plan, Do, Study, Act Process

The process continued throughout the entirety of the project, making operational adjustments as agreed upon by the JV and WWTF staff. The tweaks were based on process control data collected by WWTF staff and shared with the contractors during monthly (or more frequent) video meetings. The JV also visited each Pilot WWTF three additional times during the project for a total of four onsite visits per WWTF-- the initial visit and three follow up visits--to also help the WWTFs home in on their best operating state.

Finding the best operating state usually takes time. When optimizing a biological process, it often takes weeks or months to observe a change in effluent quality. Thus, as discussed later, it is somewhat subjective to identify a specific date when a WWTF is operating in a fully optimized mode. It should also be noted that there may be more than one optimization scheme for each facility. For example, a summer operating mode and a winter operating mode.

The JV was required to provide a timeline for the project for MoDNR-approval. The JV proposed an 18-month project timeline which was approved by MoDNR. The approved timeline provided approximately a year’s data on which to measure success. The timeline follows in Figure 3.

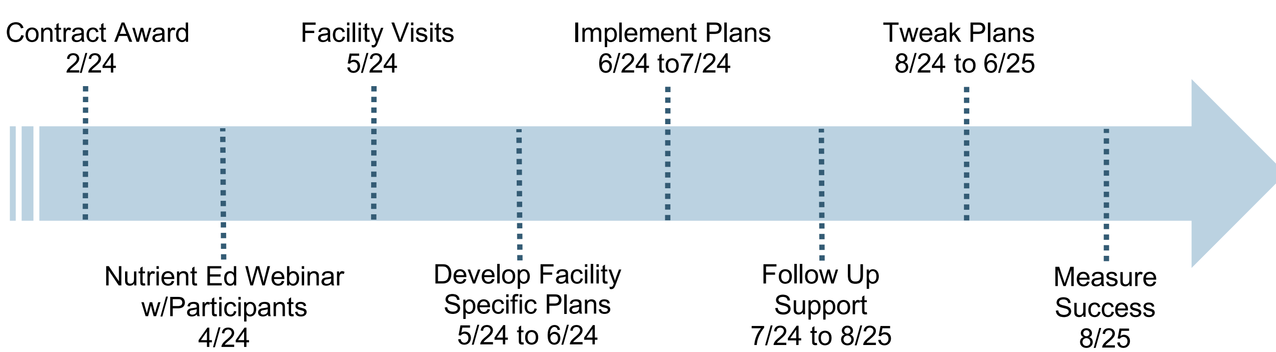

Figure 3 - Project Timeline

Nutrient Pollution/Optimization Benefits

Why be concerned about nutrients in wastewater? Nutrient pollution is perhaps the single most vexing national water quality problem. Municipal wastewater dischargers cause and/or contribute to degraded water quality – Missouri dischargers are no exception.

So how can nutrients – nitrogen and phosphorus – be a problem? They are needed by humans, plants, and animals to sustain life. The answer is that nutrients in moderation are vital to human and animal life plus plant growth; however, an overabundance of nitrogen and phosphorus in water creates numerous problems. Excess nutrients cause unwanted algal growth. Excessive algal growth can: 1) cause taste and odor problems for drinking water suppliers; 2) in some instances, result in harmful algal blooms (HABs) that produce compounds toxic to both humans and animals; 3) limit desired aquatic life; and 4) negatively impact water-based recreation (USEPA, 2016). Additionally, nitrate, which is a form of nitrogen, is limited in public water supplies under the Safe Drinking Water Act. Nitrate can cause methemoglobinemia (blue baby syndrome) in infants and is thought to be a possible cause of stomach cancers (Schullehner, et al., 2018). If these excess pollutants exist in the source water for a drinking water supplier, additional costly treatment must be implemented to meet Safe Drinking Water Act requirements and make drinking water palatable for consumers (Dunlap, et al, 2015).

The primary sources of nutrient pollution include agricultural runoff, atmospheric deposition, and wastewater treatment plant discharges. While some industrial wastewater treaters have the potential to discharge nutrients, not all do. All municipal wastewater treatment plants however do discharge nutrients. Therefore, reducing nutrients discharged from municipal wastewater treatment plants results in an improvement in water quality. In addition to water quality improvement, nutrient reduction via optimization offers other benefits:

- Cost – optimization costs, if any, typically run communities in the thousands of dollars, whereas significant infrastructure improvements typically run in the millions of dollars. This is particularly important for small communities that may not be able to afford new infrastructure.
- Energy Savings – optimization generally involves scaling back aeration of wastewater. Aeration is the most energy intensive part of wastewater treatment. Any reduction in energy is an immediately realized cost saving to a community.
- Incidental Environmental Impact – optimization will generally result in lowered energy utilization which results in fewer GHG emissions. Other positive environmental impacts can include:
    - Lowered Chemical Use - any nutrient reduction that can be achieved biologically has minimal cost, whereas chemicals are costly, add additional pollutants to the wastewater stream, and their manufacture and transport generate GHGs. Reduced chemical use also results in substantial ongoing cost savings for a community.
    - More Consistent Effluent – optimized wastewater treatment plants tend to be more stable and produce better solids-settling characteristics which reduce solids and organic discharges to receiving waters while making biosolids handling more effective.
- Incidental Economic Benefits – optimization can result in lowered operating costs for a community. Other incidental economic benefits typically accrue from optimization/better quality wastewater treatment (Dodds, et al, 2009). Those benefits include:
    - Capital Cost Avoidance – optimized treatment can extend the life of an existing secondary wastewater treatment plant, thus avoiding immediate capital costs that a community can use for other priority projects.

- Decreased Drinking Water Treatment Cost – optimized treatment can reduce all forms of nitrogen (nitrate, nitrite, ammonia, and organic nitrogen) and phosphorus which can reduce drinking water costs from downstream water suppliers. As noted previously, excess nitrates can cause blue baby syndrome while excess nitrogen and phosphorus can cause taste, odor, and toxins. Drinking water suppliers spend millions of dollars annually to control taste, odor, and toxins caused by excess nutrients.
- Increased Recreation Value – optimized treatment reduces nutrient pollution that can improve fishing and boating activities due to a reduction in harmful algal blooms and objectionable algal growth, e.g., long, stringy algae that interferes with wading, boating, and fishing.
- Increased Property Value – studies have shown that water quality has a direct impact on property and real estate value – the higher the water quality, the higher the property value.

Mitigation of nutrients has multiple positive benefits. Mitigating nutrients at reasonable cost is a win-win for the citizens of Missouri and the environment.

NUTRIENT OPTIMIZATION

The shrewd use of existing treatment equipment and basins has been shown to reduce the wastewater discharge of nutrients by as much as ninety percent, or more. All the optimized facilities in the Project utilize mechanical biological wastewater treatment – microorganisms that process wastewater. Most of Missouri's existing mechanical wastewater treatment plants are designed for "secondary", or "advanced secondary" treatment – a technology from the 1980s and 1990s. *Secondary Treatment* is aimed at reducing organic matter and solids in raw, domestic wastewater. If organic matter and solids are not properly treated, the discharge from the treatment facility will depress the dissolved oxygen in the water receiving the effluent. If dissolved oxygen is reduced enough in a waterbody, fish and other aquatic life can be negatively affected and perhaps result in their death. *Advanced Secondary Treatment* adds ammonia reduction to conventional secondary treatment. While either secondary or advanced secondary treatment may incidentally remove nutrients, the process is not designed to reduce nutrients.

WWTFs designed to biologically and/or chemically reduce nitrogen and phosphorus utilize processes that are collectively referred to as biological nutrient reduction (BNR) or advanced wastewater treatment (AWT). BNR treatment facilities are designed to alter the treatment environment to favor microorganisms that reduce nitrogen and phosphorus, while still providing secondary treatment. Some of these wastewater treatment plants also add chemicals (alum, ferric/ferrous sulfate, or chloride) for phosphorus reduction. Chemical treatment is generally a large, ongoing treatment expense.

While BNR is designed to create different types of environments to favor certain microorganisms, there are several ways the treatment environment can be altered in an existing WWTF only designed for secondary treatment. These include reducing aeration; creating low oxygen zones; increasing the amount of time the microorganisms remain in the treatment system; or implementing actions that *select* the types of microorganisms that reduce nutrients. While the mechanisms for nutrient reduction are the same for all biological treatment facilities, each plant is a little different in its design and wastewater characteristics. So, what works at one wastewater treatment plant may not be as successful at another. However, there are several different optimization options that can be explored based on the specific treatment plant. If optimization can significantly reduce nutrients, it can always be achieved at a much lower cost than having to construct new or significantly upgraded WWTFs – generally less than $50,000 as opposed to tens of millions of dollars for design and construction.

To understand the optimization activities undertaken at each of the Pilot Project facilities, a basic understanding of nutrient reduction in wastewater treatment is helpful. A discussion of nitrogen and phosphorus reduction in very basic terms follows.

Nitrogen Reduction

Nitrogen in municipal wastewater primarily comes from protein broken down and excreted by humans. Nitrogen can be associated with plant and animal proteins from industrial and commercial facilities – particularly the food processing sector. Nitrogen in the influent to WWTFs is primarily in the form of ammonia (NH_3) and organic nitrogen (Org-N). The majority of WWTF NPDES permits contain limits for various forms of nitrogen – e.g. NH_3 in most municipal permits while some may have limits for nitrate+nitrite (NO_3+NO_2) and/or total nitrogen (TN). Total nitrogen is the sum of NH_3+NO_3+NO_2+Org-N.

For decades, municipal WWTFs have had permit limits for NH_3. Ammonia, in relatively low concentration, is toxic to aquatic life - the reason most WWTFs have had ammonia limits. Treatment for NH_3 involves "nitrification" - adding sufficient oxygen to wastewater to treat carbon material (measured as biochemical oxygen demand, or BOD) to low levels then converting the NH_3 to NO_3. By converting from NH_3 to NO_3, the form of nitrogen is changed from a toxic form to a non-toxic form. More recently, concern has also focused on NO_3 because it is a form of nitrogen that, while non-toxic, is readily used by algae in surface waters and can produce excessive plant/algal growth. Excess algal growth can result in blooms of harmful, toxic algae and lead to oxygen depletion. Severe oxygen depletion leads to hypoxia which can eliminate desirable aquatic life.

To reduce nitrate, WWTFs go through a process called "denitrification". Denitrification occurs in a low oxygen (anoxic) environment with sufficient BOD and forces denitrifying organisms to utilize the oxygen associated with nitrate – $N\underline{O}_3$ - to further remove BOD. As the oxygen is consumed, the remaining form of nitrogen is nitrogen gas which rises harmlessly to the atmosphere. Thus, nitrogen can be <u>removed</u> from wastewater. There is always some TN remaining since municipal WWTF processes do not remove or reduce Org-N. The limit of reasonable technology for TN reduction is around 3-5 mg/L. The nitrification/denitrification process is shown graphically in Figure 4 where ammonia is converted to nitrite then nitrate with the addition of oxygen, followed by nitrate being reduced to nitrogen gas in an environment with no additional oxygen added.

Figure 4 – Nitrification/Denitrification Process

Assuming a WWTF is currently converting NH_3 to NO_3 (nitrification), the goal of TN optimization is to find a place(s) in the WWTF treatment process where an anoxic or low-oxygen zone can be developed to spur denitrification. This can be accomplished in several ways that are dependent on the physical characteristics of a WWTF.

Phosphorus Reduction

Phosphorus in municipal wastewater primarily comes from human waste, detergents, and industrial processes. Excess phosphorus in wastewater also leads to algal blooms which can be toxic and/or oxygen depleting. In the wastewater field, phosphorus is usually addressed as total phosphorus (TP). Total phosphorus is the sum of both soluble and particulate phosphorus. Soluble phosphorus is often referred to as soluble reactive phosphorus (SRP) or phosphate (PO_4^{-3}). Phosphate bound to microbial solids is referred to as particulate phosphorus.

Unlike nitrogen, phosphorus is not removed from wastewater by dispersing phosphorus molecules into the atmosphere. Phosphorus is ultimately accumulated by microorganisms. Therefore, care must be taken to manage the microorganisms properly, or the phosphorus can be released which results in higher effluent concentrations.

To reduce PO_4 in wastewater, WWTFs must have a location in the liquid process where an anaerobic/septic environment can be established. In a septic environment, volatile fatty acids (VFAs) are generated. In the anaerobic zone, phosphorus accumulating organisms (PAOs) feed on the VFAs and subsequently release soluble phosphorus. These are referred to as "energized" PAOs.

Once the energized PAOs and the soluble phosphorus are returned to the aerated/oxic zone of the WWTF, the PAOs take up all the soluble phosphorus they released plus soluble phosphorus in the wastewater influent into their cell structure. Some of these organisms (or solids) are removed from the process. As long as the solids are properly managed and not allowed to re-release phosphorus, there is an overall net reduction in TP between the WWTF influent and effluent.

The goal of TP optimization is to find a place(s) in the WWTF treatment process where an anaerobic/septic or no-oxygen zone can be developed to spur VFAs and PAO development then ultimately the uptake of phosphorus in an aerobic environment. There are generally two ways to establish these zones – inline and sidestream. Inline treatment involves establishing an anaerobic zone in an existing aeration tank. This is typically done by reducing mechanically provided oxygen or turning aeration off all together. Sidestream phosphorus treatment is done outside of the aeration tank. Sidestream treatment generally involves using a tank to hold waste microorganisms (solids) and allowing them to go septic to produce VFAs and PAOs. This is sometimes referred to as fermentation. The fermented solids are then recycled back into the main treatment process where the PAOs will remove P in the aerobic/oxic portion of the facility. If a WWTF has an unused tank, digester, or a sludge holding tank, a facility may be able to establish a sidestream fermenter with existing tankage.

The fermentation process is not as simple as it may sound. There needs to be sufficient operational control to ensure the proper amount of fermentation takes place - things like sufficient holding time, adequate mixing, and a mechanism to move fermented solids back to the main treatment plant. Too little fermentation will result in not enough energized PAOs being generated. Too much fermentation will result in too much soluble phosphorus being returned to the treatment process which overwhelms the treatment microorganisms and results in excessive phosphorus in the facility effluent.

While most WWTFs are familiar with using dissolved oxygen (DO) control, many are unfamiliar with using oxidation reduction potential (ORP) to control their process. ORP is particularly valuable in identifying anoxic and anaerobic zones for denitrification and phosphorus reduction, respectively. A DO probe can measure oxygen from 0-20 mg/L, but it does not give a clue as to whether measuring 0 mg/L is an anoxic environment or an anaerobic environment. An ORP probe operates on a scale of -1200 mV to +1200 mV. For WWTF operations, the effective range is around -300 mV to +400 mV and provides the operator with an indication of how anaerobic, or how anoxic a particular environment may be. This information is invaluable for promoting denitrification and phosphorus removal. In Figure 5, the blue-colored arrows provide the typical ORP ranges for wastewater treatment zones, while the boxes within the double-headed arrows indicate the target ranges the contractors recommend.

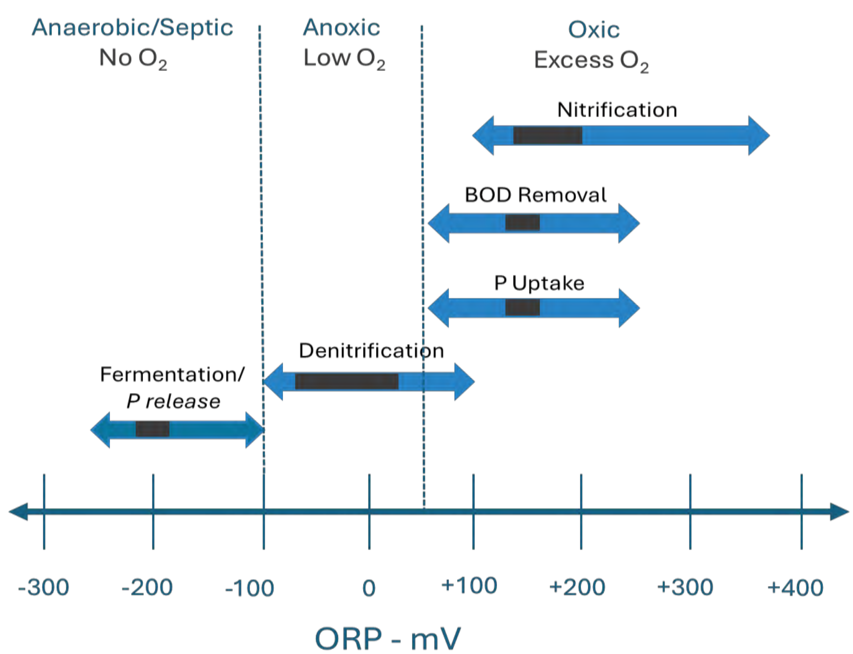

Figure 5 - ORP Ranges for Wastewater Treatment

DATA ANALYSIS

Nutrients

Effluent data were available for a period of record from 2010 through mid-2025 for most of the facilities. It was agreed that data from January 2023 forward would be used for reporting on this project. Those data were analyzed to determine the outcome of optimization efforts at each plant. In most cases, data were available on a monthly average basis from EPA's ICIS-NPDES reporting system[2] or the Missouri Clean Water Information System[3]. In a few instances obvious data anomalies existed. Data anomalies were handled as follows:

1. Full Record Not Available. Where the full record of data from January 2023 until mid-2025 was not available, the available data were used, and the output was truncated to reflect only those data – e.g., data from the City of Oak Grove was not available due to "No Discharge" being reported one month.
2. Influent/Effluent Data interchanged. There were a handful of times when it appeared influent and effluent data were swapped – data that were obviously a result of entry errors or sample contamination error. In those few cases, the facility was contacted, and the data set was modified. For example, one month Herculaneum reported an influent nitrate of 22 mg/l and effluent of 0.2 mg/L; neither of which are reasonable.
3. Seasonal Data. In a small number of instances, data were only required to be reported seasonally. In those cases, data were extrapolated from the beginning and ending of the seasonal data for the months where no data were available. Herculaneum ammonia effluent data is an example.
4. Influent BOD and TSS Data Not Required in the Permit (Oak Grove). Percent removal and effluent BOD was required. Influent was calculated as follows: BOD_{eff} ÷ (1-% Removal).
5. Ammonia (NH3) > Total Kjeldahl Nitrogen (TKN). Some facilities reported NH_3 values being greater than TKN. Since NH_3 is a subset of TKN, NH_3 should always be smaller than TKN. After contacting facilities, some indicated they had a contract laboratory perform TKN but performed NH_3 testing on their own. Sometimes samples were taken at different times leading to discrepancies. The higher of TKN or NH_3 was used when computing the TN values.
6. Total Nitrogen (TN). None of the permits required TN to be reported. TN was calculated as (NO_3+NO_2) + the higher of TKN or NH_3.
7. At times, TP was reported PO_4-Phosphorus instead of P-Phosphorus as required by the permit – Oak Grove for example. If the WWTF staff confirmed PO_4 was reported instead of TP, the reported value was divided by 3.066 – the conversion from PO_4 concentration to TP concentration.

Once the anomalies were rectified in data sets for each of the treatment facilities, an analysis of nutrient concentration (mg/L) reduction was completed for each facility. The analysis consisted of taking the annual average concentration of the data for the pre-optimization period of record (generally starting January 2023) and comparing that to the average of the optimization period for each facility.

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2 https://echo.epa.gov/tools/data-downloads/icis-npdes-dmr-and-limit-data-set

3 https://apps5.mo.gov/mocwis_public/dmrSearch.action

The monthly data were further converted into a rolling annual average. A rolling annual average is an average of the previous 12 months of monthly averages. A rolling average is commonly utilized for data collected as a time series to smooth out short-term fluctuations. This makes the rolling annual average the preferred statistic for evaluating WWTF performance over time because it filters short-term variations and focuses on long-term trends. All the optimized WWTFs rely on biological treatment which is subject to variability based on climate (poorer treatment in cooler weather); potential chemical upset; power loss; etc. Thus, a rolling annual average will best demonstrate data trends. The use of rolling annual average is also preferred for nutrient discharges because nutrients generally do not present immediate impacts on water quality like a toxic pollutant; the impacts are cumulative, and longer term.

It should be noted that for this project, only 12 months or less of optimization data are available, so the rolling annual average may include some pre-optimization data. In almost all cases, this will skew the values higher than the actual trend. Ideally, two years of data would be desired to go through two full winters and two full summers to even out seasonal impacts.

An additional concern is the robustness of the data. All the Pilot facilities were only required by permit to collect only one compliance sample per month. Therefore, the entire data set for each facility consists of 12 or fewer discrete samples for TN and TP for the project timeline – essentially a snapshot of the effluent on 12 or fewer days. Regardless, the available data show some very positive trends.

The TN and TP data for each facility were then plotted as a time series with individual monthly averages plotted as bars and overlayed by the rolling annual average represented as a solid line – Figure 6. The MoDNR concentration goals were superimposed on the graphs. Utilizing a combination plot in this fashion demonstrates the month-to-month variability (bars) and the long-term data trend (solid line). Note the time series on the X-axis begins with January 2023, which reflects the fact that while the beginning of the data set was 2023, since it takes 12 months of data to generate a rolling annual average – so rolling annual average data includes data from 2022.

Individual facility write ups include the graphical analyses for total-nitrogen and total-phosphorus for each facility.

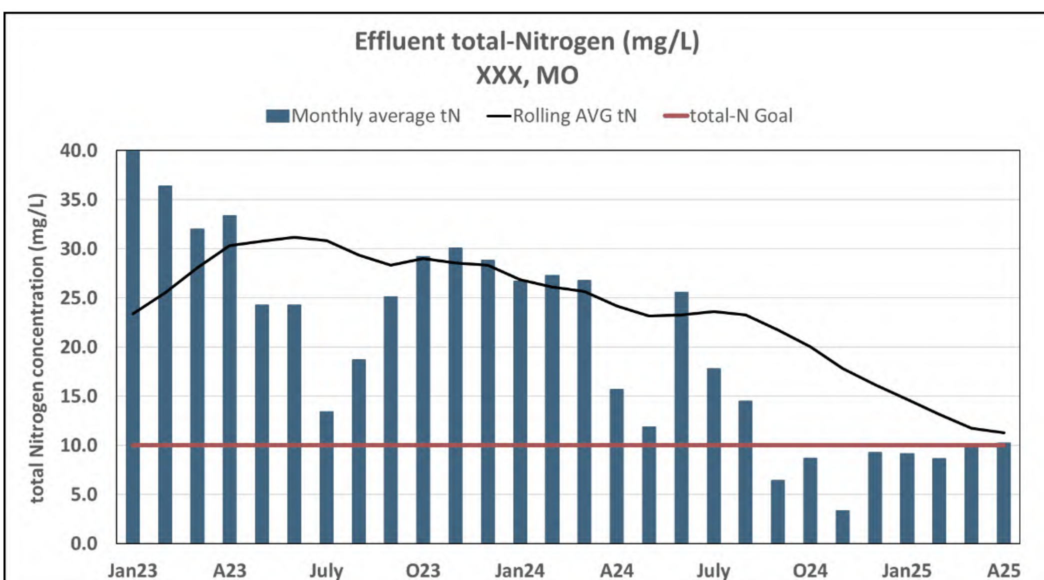

Figure 6 – Example Nutrient Data Plot

Flow data were analyzed in the same manner as nutrient concentration – averaging monthly average flows from 2023 forward to estimate the pre- and post-optimized flow. It should be noted that flows during the optimization period were generally higher than previous years' flows which skews the data higher than under normal flow conditions. Those flows were then used to estimate the mass reduction in units of pounds per day (lb/day) of TN and TP using the following formula:

$$\text{lb/day Nutrient} = \text{Nutrient Concentration (mg/L)} \times \text{Flow (MGD)} \times 8.34$$

The problem with comparing pre- and post-optimization mass discharge with the flows being generally higher post optimization is that the lb/day metric can be skewed artificially higher when comparing pre- and post-optimization discharge. For example, if concentration remained the same pre- and post-optimization, the mass discharged (pounds or tons) would increase. Increased flow to the Pilot WWTFs ranged from 6% to 21% higher, averaging 13% higher than previous years. To address the issue with higher flow, mass discharged in lb/day will be adjusted for flow by utilizing the same rate of flow measured pre-optimization to calculate post optimization mass. This will be referred to as "adjusted flow rate".

Again, with less than one year of data in most cases, data must be extrapolated to compute an annual average mass. The daily average is multiplied by 365 days to estimate a yearly average.

To best assess the impacts of optimization, the report looks at ***additional*** pounds of nutrients reduced. Total pounds reduced is simply a computation of mass of nutrient in the influent minus mass of nutrient in the effluent:

$$\text{Total Mass Reduced} = (\text{Y mg/L} \times \text{Flow (MGD)} \times 8.34)_{\text{influent}} - (\text{Y mg/L} \times \text{Flow (MGD)} \times 8.34)_{\text{effluent}}$$

Additional pounds of nutrients reduced is the difference between the mass of nutrients reduced pre-optimization to mass of nutrients reduced post-optimization computed as follows:

$$\text{Total Mass Reduced}_{\text{post}} - \text{Total Mass Reduced}_{\text{pre}}$$

Additional pounds reduced provides an estimate of the improved nutrient reduction post optimization. As discussed previously, the additional mass removed will use the adjusted flow rate in order to fairly compare pre- and post-optimization discharge.

An additional caution is that the permits for each of the Pilot facilities require only a single compliance sample per month for N and P. However, each of the permits requires sampling for flow either daily, or one day per week. Thus, flow data and N/P data do not coincide. Therefore, a monthly average flow computed based on data averaged from 5 to 31 days per month is used to compute the monthly mass of a single daily sample of influent and effluent TN and TP concentration. Over the long term, a sufficiently large data set will normalize high and low flows, however a restricted data set as is the case for this project will be affected.

Once the data are rectified as discussed above, they are evaluated in terms of concentration (mg/L) and mass (pound or tons). Why look at both concentration reduction and mass reduction? Concentration reduction provides insight into treatment improvement – whether the optimization techniques have improved the effectiveness of the treatment process. As noted above, mass is a function of the concentration multiplied by the flow. So, if the concentration goes down and the flow remains the same, the percentage of mass reduced is the same as the percentage of concentration reduced. Over time, as populations increase, flow typically increases. Thus, if the concentration remains the same the mass will increase on the same percentage basis as the flow.

When dealing with nutrients, both measures are important. Concentration is generally more important in flowing waters (streams and rivers) where a steady state of nutrient concentration below a certain level will mitigate against algae overproduction. For catchments like lakes, ponds, estuaries, and even larger bodies like the Gulf of America, mass becomes a concern. Catchments allow nutrients to build up over time. As the mass builds up, it will eventually raise the concentration in the catchment that can fuel algae blooms.

This study has shown that both reduction measures – concentration and mass - can be achieved. As noted previously, significant reductions in overall concentration and mass were both achieved.

Energy

Tracking energy use and cost is not as straightforward as nutrient reduction. As stated previously, nutrient data is extracted from NPDES permit-mandated discharge monitoring reports (DMRs) which span calendar months. Energy bills are typically not tied to specific calendar months. They span non-specific periods between electrical meter readings. As an example, for two consecutive bills one might cover October 19 to November 21, and the second November 22 to December 19. To compare energy use to nutrient reduction, we need to use a common timeframe – a calendar month. Since the DMR data is already reported for calendar months, the electrical data must be rectified to calendar months. To resolve the energy data, a calendar month energy bill must be estimated. In this example, the method used was to compute the daily usage for the first bill and multiply by 21 – the number of November days covered by the first bill. The same daily computation was made for the second bill and multiplied by 9 – the number of November days covered by the second bill. The 2 values were then added together to estimate the energy use for the calendar month of November. A similar computation was made for cost. While each is an estimate, it produces a more accurate assessment of calendar month electrical usage and cost.

Once the energy use and cost data are rectified to calendar months, they can easily be compared with DMR data to develop assessments of energy use and cost associated with optimization. Most WWTFs use more energy in the summer months. Therefore, it is imperative when comparing electrical usage at an individual plant to use common months. For example – data from any July should only be compared with other July data.

While the use and cost metrics can show increases or decreases within a particular WWTF, comparison between facilities requires a standardized metric since there is an order of magnitude difference in the size of the pilot facilities. The pros and cons of several metrics reviewed are shown in Table 4.

The kWh/TPE_{rem} metric may be unfamiliar to some, however it has been identified in Europe as an excellent metric in accounting for nutrient reduction efficiency (Enerwater, 2018). The metric creates an equivalent pollutant reduction by summing the weighted pollutant mass removed for COD, TN, and TP according to the following formula:

Total Pollution Equivalent (TPE)=COD (kgCOD)+20 TN (kgTN)+100 TP (kgTP)*

**Without COD data, BOD*2 can be used.*

It is estimated this metric reflects the largest single portion of overall energy used at most treatment plants – aeration at 53%. It is larger than the energy used for pumping, disinfection, and solids management combined. An EU benchmark of 0.488 kWh/kg TPE_{rem} (0.221 kWh/lb TPE_{rem}) has been established.

Table 4 – Energy Measures

Metric	Pros	Cons
kWh/MG	• Data calculable for all plants • Published national and international benchmarks • Most used metric	• Pumping costs may disproportionately impact • Not tied to nutrient reduction
kWh/lb BOD removed	• Data calculable for all plants • Allows comparison between plants • Published national and international benchmarks • Commonly used	• Not tied to nutrient reduction • Tied primarily to secondary treatment
$/MG	• Data calculable for all plants • Allows comparison between plants	• No national metric • Not directly tied to nutrient reduction • Costs not always comparable ○ Differing rates ○ Rate changes during study period ○ Differing factors – e.g. peaking charges ○ Economy of scale ○ Type of aeration used
kWh/TPE$_{rem}$	• Data calculable for all plants • Takes nutrient reduction into account • Measures energy efficiency – lb of pollutant removed for each kW input • International benchmark	• Must estimate COD from BOD

This report assessed the following metrics to ascertain whether energy reduction/cost could be observed for the duration of the project:

- $/MG – Provides good information within a particular plant for assessing pre and-post optimization energy cost. However, the drawbacks noted above make this a less desirable metric for inter-plant comparison. As has been noted several times, the flow at six of the eight Pilot facilities increased more than 5% during the optimization period. This metric normalizes the costs pre- and post-optimization and will be used to estimate cost savings within a particular plant.
- kWh/MG - Provides good information within a particular plant for assessing pre- and post-optimization energy use. However, the drawbacks noted above make this a less desirable metric for inter-plant comparison. As has been noted several times, the flow at six of the eight Pilot facilities increased more than 5% during the optimization period. This metric normalizes the kWh usage pre and-post optimization and will be used to estimate energy savings within a particular plant.
- kWh/lb TPE$_{rem}$ –This metric is the most informative in terms of linking nutrient treatment optimization to energy use. The metric is the only one that weights nutrient reduction when calculating the energy efficiency of treatment.

The energy efficiency measure is plotted as a time series with individual monthly averages plotted as bars. It is overlayed by the energy cost in terms of $/MG represented as a solid line – Figure 7. The benchmark value is included as a solid horizontal line.

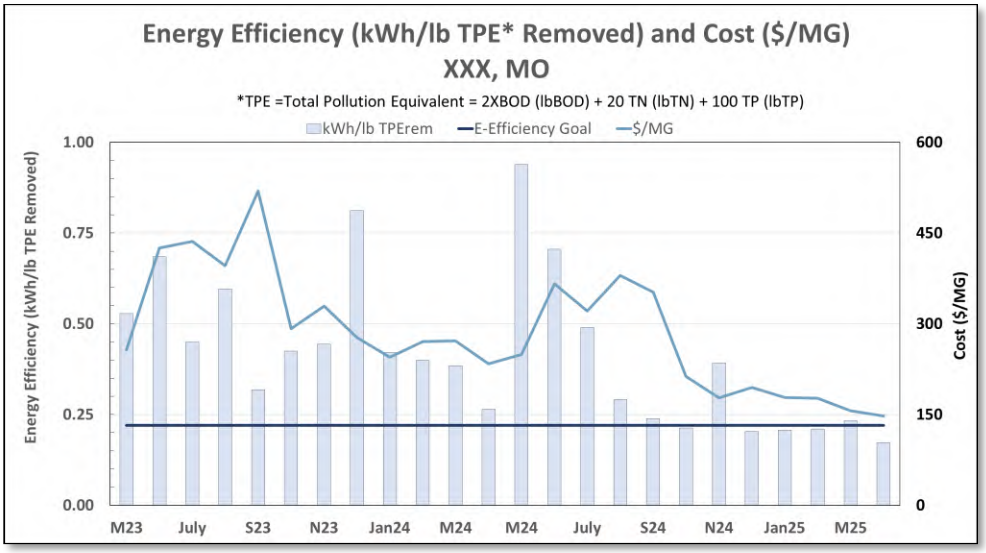

Figure 7 - Example Energy Data Plot

RESULTS

Due to the constraints of the pilot project timeline, less than one year of data must be evaluated when comparing post-optimization facility performance with pre-optimization performance for most facilities. Ideally, two years of optimization data would be available to mitigate seasonal and other anomalous conditions that affect all WWTFs. However, with some extrapolation and review of data trends, conclusions can be drawn from the available data.

Nutrients

Overall, five of eight facilities are trending downward in terms of the concentration of TN discharged. Jefferson City and Oak Grove showed little change but still met the goal of 10 mg/L. Independence suffered a mid-project upset which caused TN to rise. A different optimization approach at Independence started late in the project is showing good TN reduction. All eight facilities are trending downward in terms of TP concentration (Table 5). This metric indicates majority of treatment plants can reduce nutrients with modified operations.

Table 5 – Mass Discharged Trend

		Post-Optimization	
Facility	**Treatment Type**	**TN**	**TP**
Boonville	Oxidation Ditch (Orbal)	↓	↓
Duckett Cr	Oxidation Ditch (Orbal)	↓	↓
Herculaneum	Oxidation Ditch (Orbal)	↓	↓
Independence	Conventional A/S	↑	↓
Jeff City	Sequencing Batch Reactor (SBR)	←→	↓
Oak Grove	Extended Aeration	←→	↓
St Charles	Conventional A/S	↓	↓
St Peters	Oxidation Ditch (Orbal)	↓	↓

Key	
Mass Trending Down	↓
Mass Trending Up	↑
Mass Trending Neutral	←→

More specifically, Missouri has set TN and TP goals for WWTFs. The TN goal is 10 mg/L as a rolling annual average. The TP goal is more complicated – there are four different ways to achieve the goal as described below[4]:

1. Concentration-Based Compliance. The compliance value is 1.0 mg/L computed as a rolling annual average. However, the rolling annual average is only evaluated with each December's computed value. The permittee must collect compliance samples weekly and compute a monthly average. The rolling annual average is computed from the monthly average values.

2. Mass-based Compliance. Mass-based compliance is computed once per year in December. The mass discharged is computed by multiplying the actual average monthly flow (MGD) by the monthly average TP concentration (mg/L) then multiplying by 8.34. Monthly averages are

[4] Total Phosphorus Permit Implementation Guidance 1.0. https://dnr.mo.gov/document-search/total-phosphorus-permit-implementation-guidance-june-2024

computed from weekly average samples. From the monthly averages, a rolling annual average is computed.

Mass Discharged = Monthly Avg MGD X Monthly Average TP Concentration (mg/L) X 8.34

The Target Mass is computed by multiplying the **Design Flow** (MGD) by the 1.0 mg/L TP and then multiplying by 8.34.

Target Mass = Design MGD X 1.0 mg/L TP X 8.34

If the Mass Discharged < Target Mass, compliance is achieved. This concept is similar to TMDL calculations that compute mass allowances based on WWTF's design flow and fixed effluent concentration.

3. <u>Influent to Effluent Reduction Compliance</u>. The permittee must collect two years of weekly influent TP data – 104 samples. The mass for each sample is computed by multiplying the TP concentration by measured flow (MGD) then multiplying by 8.34. From the mass data, the permittee will compute two separate 12-month averages (lb/day) from the collected data. The two 12-month samples will be averaged to determine the *Annual Average Influent* TP load to the facility.

   The *Permitted TP Load* will be calculated by computing a 75% reduction of the influent mass. After the computation of the Permitted Load, the permittee will be required to sample the effluent load weekly and compute a monthly average Effluent TP Load. A rolling monthly average load will be computed and compared to the Permitted TP Load each December. If the rolling annual average Effluent TP load < Permitted TP load, compliance is achieved.

4. <u>Effluent Reduction Compliance</u>. Permittees must collect up to five years of representative effluent data and calculate an annual TP load (lb/yr). Annual loads will be computed for each of the years of data - January through December. The December Annual TP load values are averaged to compute the average annual *Effluent TP Load* (lb/yr).

   The *Permitted TP Load* (lb/yr) will be calculated by computing a 75% reduction of the Influent Load computed above. After the computation of the Permitted Load, the permittee will be required to sample the effluent load weekly and compute a monthly average Effluent TP Load. A rolling monthly average load will be computed and compared to the Permitted TP Load each December. If the rolling annual average Effluent TP load < Permitted TP load, compliance is achieved

Since the current permit requirements for influent TP sampling in all Pilot Facility permits are once per month, the current sampling requirement does not meet the weekly sampling requirement of the *Missouri Total Phosphorus Permit Implementation Guidance 1.0*. Additionally, the Guidance envisions one, two, or five years of data to assess compliance. Therefore, the Pilot data available to assess compliance with the reduction goals is not as robust as envisioned by the Guidance. Weekly samples will give a much more accurate picture of compliance with the reduction targets. However, this report will make an estimate of compliance with the first three methods – concentration-based compliance; mass-based compliance; and a 75% reduction. The 75% reduction estimate will evaluate the percent reduction from influent to effluent TP monthly.

The analysis of compliance with the TN and TP goals is shown in Table 6. Five of eight facilities met the TN goal for a significant number of months – not enough for all to meet a rolling annual average –

but have demonstrated compliance. Of note is Duckett Creek SD #2. Attaining an effluent concentration of 3.0 mg/L over the length of the project is remarkable. The limit of biological treatment technology is generally thought to be around 3 mg/L TN (Water Environment Federation, 2015). At 3.0 mg/L, the Duckett Creek staff have not only optimized, but maximized TN reduction.

At least two facilities, Boonville and Duckett Creek, have achieved the TP concentration and mass reduction goals for several consecutive months. Jefferson City and St. Peters are close. For Boonville and Duckett Cr, having less than one year's data and a single month of outlier data confounds meeting the 1 mg/L goal; however, there is sufficient monthly data where ≤ 1mg/L was met to estimate compliance. Interestingly, neither Boonville nor Duckett Cr met the 75% reduction goal. An analysis of the data indicates the higher-than-normal flows at the facilities generated higher mass values which precluded compliance with the 75% reduction goal. This indicates the Missouri Implementation Guidance is wise to assess two years of data to set an influent load baseline to mitigate anomalous flow conditions over a short period of time.

Table 6 – Compliance with Goals

	TN Goal	TP Goals		
Facility	**mg/l**	**mg/L**	**Mass Reduction**	**75% Reduction**
Boonville	7.8	1.7*	Y	71%
Duckett Cr	3.0	1.7*	Y	63%
Herculaneum	22.4	3.5	N	10%
Independence	16.1	1.7	N	18%
Jeff City	8.3	2.1	N	65%
Oak Grove	8.7	4.8	N	36%
St Charles	16.3	2.3	N	41%
St Peters	9.4	2.5	N	52%

*1.0 mg/L met for several months. Less than 12 months of optimization data available for a rolling annual average

Concentration Performance

As noted previously, effluent concentration data can provide insight into the treatment performance of a facility. Concentration is independent of facility flow, so it is an indicator of improved treatment performance. Effluent mass may be less indicative of performance since it is dependent on flow. Thus, if a WWTF reduces TN concentration by 20% over a period of time, but flow increases by 25% for the same period, more mass would be discharged. Does that mean that there was no improvement in treatment? No - it only means added flow increased the mass discharged, even though concentration had been reduced. Concentration data is presented in Table 7.
There were several facilities with notable concentration reductions of over 50%, and all WWTFs showed improved performance for TN, TP, or TN and TP. Further explanation for specific facilities with slight increases in concentration include:

- Jefferson City was already meeting the TN goal prior to the Pilot Project. So, a 2% increase in TN concentration is insignificant - 8.2 mg/L vs 8.3 mg/L.
- Independence has little control over the ability to turn down aeration. They have very high horsepower blowers that are not VFD-controlled. Therefore, they must operate in an air on/air off scheme by manually valving off air drops to try to establish anoxic and anaerobic

zones. The blowers must also be re-started manually if power is lost, which happened at least three times during the project. Progress was made initially, but power loss and too much aeration off time upset the plant and caused a small increase in TN. Later in the project, an extra basin was brought online which shows progress in reducing TN. In addition, the plant is in the midst of a project to install smaller blowers that are VFD-controlled.

- Oak Grove, like Jefferson City had a slight increase in TN, however the plant still met the TN goal. Oak Grove hired a new lead operator in October who made needed operational changes – particularly lowering the MLSS concentration. The plant experienced some upset initially and suffered some mechanical breakdowns.

Table 7 – Concentration-Based Performance– Pre vs Post Optimization

	Effluent Avg - mg/L					
	Pre-Optimization		Post-Optimization		% Improvement	
Facility	TN	TP	TN	TP	TN	TP
Boonville	23.6	4.3	7.8	1.7	67%	61%
Duckett Cr	22.4	3.9	3.0	1.7	86%	56%
Herculaneum	33.5	4.0	22.4	3.5	33%	14%
Independence	13.6	2.1	16.1	1.7	-18%	21%
Jeff City	8.2	2.8	8.3	2.1	-2%	27%
Oak Grove	8.5	5.7	8.7	4.8	-2%	15%
St Charles	19.0	3.0	16.3	2.3	14%	23%
St Peters	26.2	3.1	9.4	2.5	64%	20%

Another interesting technique to look at concentration performance is using box and whisker plots. Box and whisker plots provide a large amount of information in a single graph – more than the monthly average value. The plot also indicates the maximum value observed, the minimum value observed, the median value, the 25th percentile (25% of values lower than), and the 75th percentile (75% of values lower than) – See Figure 8. The box and whisker plots for TN and TP are presented in Figures 9 and 10, respectively.

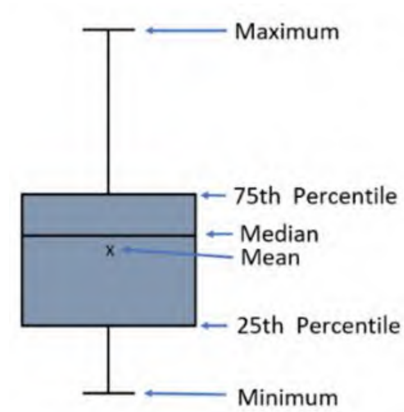

Figure 8 - Box/Whisker Plot

Like Table 7, Figure 9 also shows all but three facilities reduced TN concentration, however it provides a visual demonstration that the increases are insignificant. It also visually shows that five facilities met the TN goal.

Additional information that can be gleaned from Figure 9 includes:

- For Boonville, Duckett Cr, and St Peters **the worst monthly TN concentration post-optimization (upper whisker) was better than the best monthly TN concentration pre-optimization (lower whisker)**.
- For Boonville, Duckett Cr, St Peters, and Jefferson City the minimal effluent concentration variability post-optimization (narrow box and short whiskers) is indicative of consistent operation which implies the long-term viability of operating in an optimized mode.

- For Herculaneum, effluent variability was high and the effluent concentration higher than the other facilities. As will be discussed in the case study, Herculaneum had long periods where various equipment breakdowns affected treatment. The positive to be taken from Herculaneum is that some reductions took place post-optimization despite the numerous equipment failures.

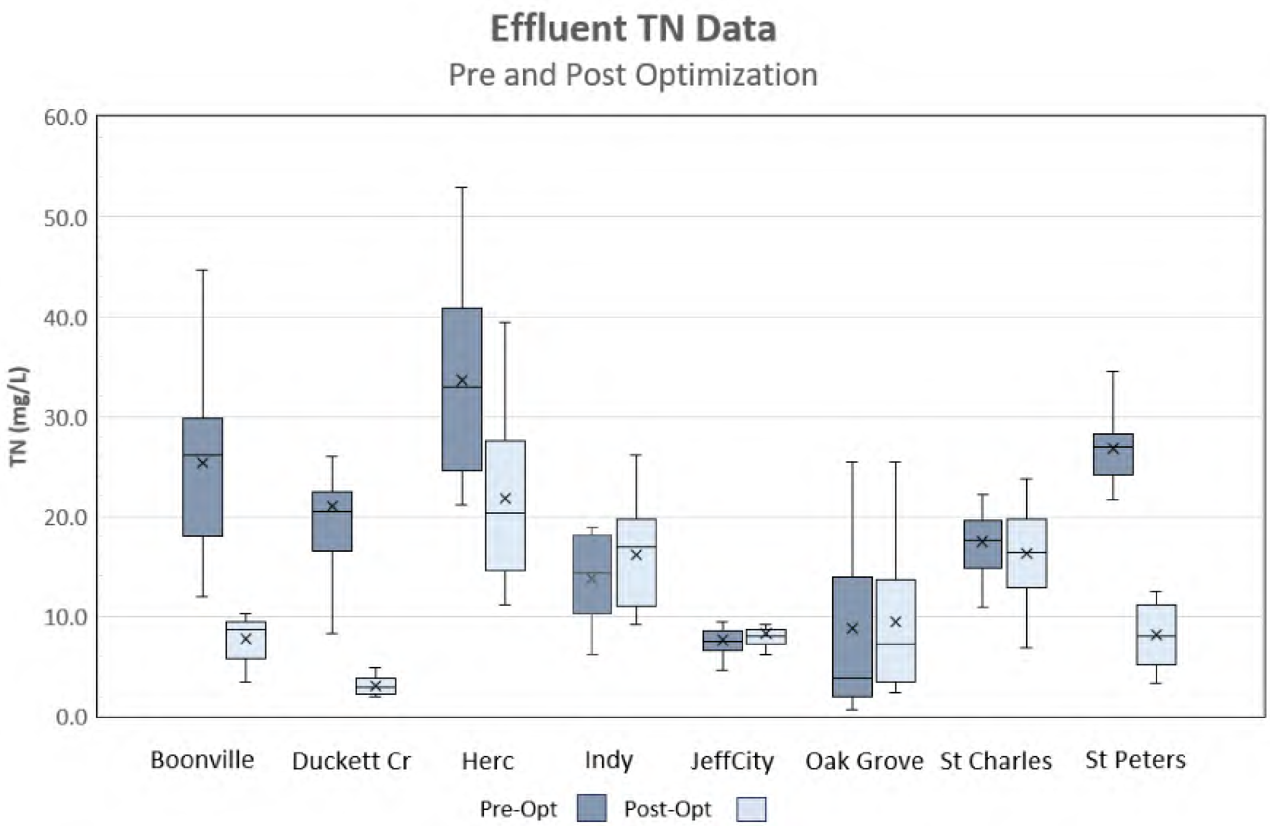

Figure 9 - Total Nitrogen Performance for All Facilities

As noted previously, less time was spent on TP reduction since TN reduction typically needs to take place before TP reduction can be successful. The microorganisms responsible for TP reduction also require a longer time to increase in quantities sufficient to reduce TP.

With additional time spent on TP, lower effluent concentrations would be expected. This is particularly true for Independence where the current aeration system is grossly oversized. It is difficult to establish an anaerobic zone where aeration cannot be reliably reduced for sufficient periods of time without upsetting the process. The new aeration system being installed should provide more opportunities to reduce TP. Regardless, Figure 10 indicates that all facilities reduced TP to some degree including six of the eight reducing TP to $\leq$1 mg/L at some point during optimization (the lower whisker). Figure 10 also shows:

- Both the Boonville and the Duckett Cr median values are near 1.0 mg/L. Both facilities had numerous consecutive months with TP less than 1.0 mg/L.
- Oak Grove by far discharged the highest amount of TP while also experiencing wide variability in the amount of TP discharged. At least a portion of the high effluent values can be explained by the extremely high influent TP at Oak Grove - approximately 60% higher than the average of the other seven facilities. Staff at Oak Grove are exploring the possibility of a source of high nutrient wastewater being directed to the facility.

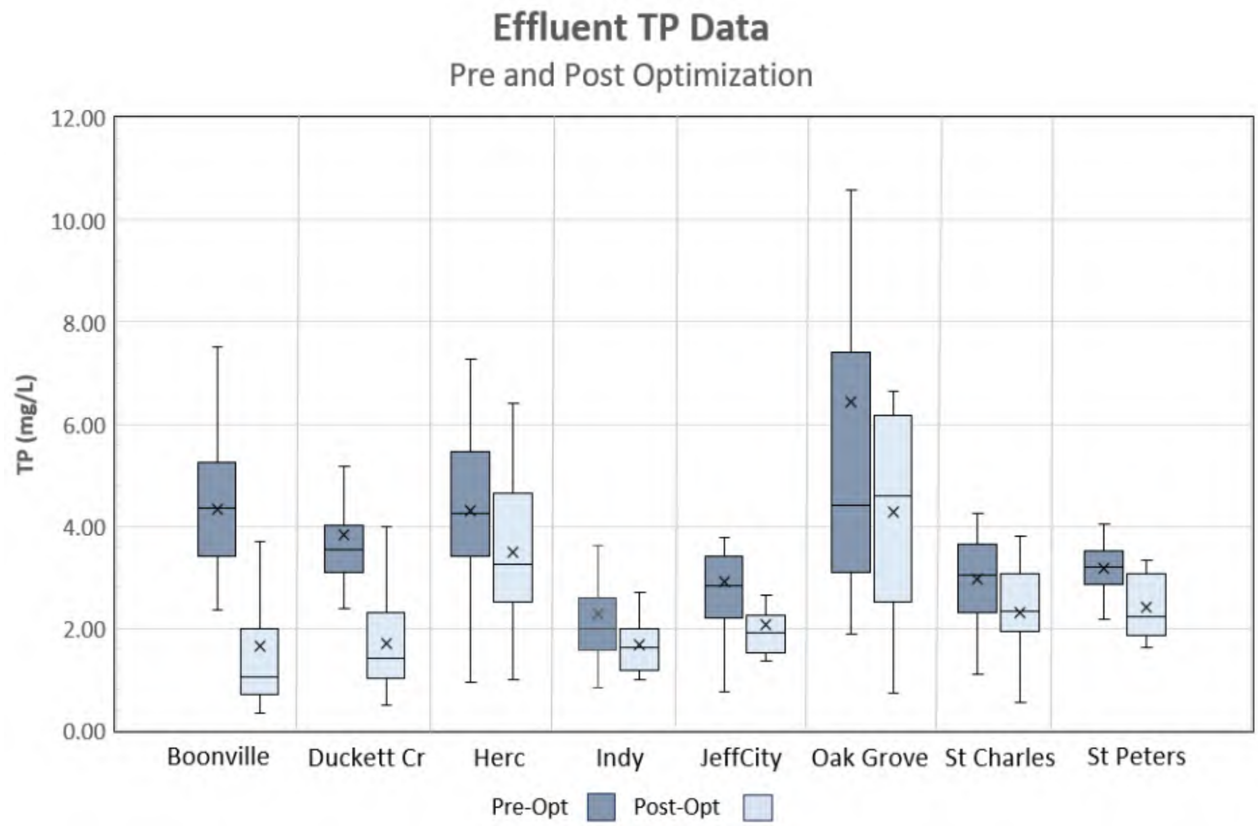

Figure 10 - Total Phosphorus Concentration for All Facilities

The fact that all facilities can biologically reduce TP gives the owners of the facilities another option when TP limits are included in their NPDES permits – in lieu of major new construction, an inexpensive chemical feed system could be added to "trim" the phosphorus effluent concentration when needed. However, chemicals are expensive and are ongoing costs. So, for every mg/L reduction in phosphorus biologically, chemical use will be cut proportionately. This can add up to hundreds of thousands to millions of dollars annually depending on the size of the facility. Owners would ultimately have to evaluate the ongoing cost of chemical addition against construction, but significant biological reduction prior to chemical addition will make that option more competitive.

Mass Performance

Mass-based performance was improved for most Pilot facilities for TN and/or TP. As discussed earlier, it is possible to have improved treatment based on effluent pollutant concentration (mg/L) while discharging a larger mass (lb) of pollutant because of flow increases. The flow during the Project period was significantly greater than in either of the previous two years for most facilities. Therefore, in some cases the mass of pollutants discharged increased even with improved concentration performance. Herculaneum is a perfect example – the TP concentration decreased while the TP mass discharged increased. The flow at Herculaneum during the study period increased 21%. Therefore, the values reported in Table 8 are based on adjusting the post-optimization flow to pre-optimization levels which reduces the post optimization mass but gives a more accurate comparison.

Another way to look at mass-based performance is the *additional* lb/day removed as a result of optimization – Table 9. Whereas Table 8 only looks at the actual end-of-pipe mass, the data in Table 9 assesses the mass of nutrient removed between the influent and effluent.

Influent concentrations and flows were somewhat different for most plants pre- and post-optimization. Thus, calculating the mass removed (influent - effluent) can provide a more accurate picture of the effect of optimization.

Table 8 – Mass-Based Performance – Pre vs Post Optimization

	Adjusted Effluent Avg - lb/day					
	Pre-Optimization		Post-Optimization		% Improvement	
Facility	**TN**	**TP**	**TN**	**TP**	**TN**	**TP**
Boonville	155	29	57	11	64%	62%
Duckett Cr	880	150	126	70	86%	53%
Herculaneum	129	15	113	18	12%	-17%
Independence	731	111	823	86	-13%	23%
Jeff City	464	155	494	132	-6%	15%
Oak Grove	55	37	61	37	-10%	0.4%
St Charles	806	126	709	97	12%	23%
St Peters	1222	143	498	126	59%	12%
Total	4442	767	2881	577	35%	25%

Table 9 – Additional Mass Removed Pre- vs Post-Optimization

	Pounds Reduced – lb/day							
	Pre-Optimization		Post-Optimization		Additional Reduced		Additional % Reduced	
Facility	**TN**	**TP**	**TN**	**TP**	**TN**	**TP**	**TN**	**TP**
Boonville	119	14.4	184	27.5	65	13.1	55%	91%
Duckett Cr	775	73.1	1077	112.8	302	39.7	39%	54%
Herculaneum	5	-1.6	42	1.7	36	3.2	669%	207%
Independence	162	17.2	305	20.4	144	3.3	89%	19%
Jeff City	1248	196.8	1460	226.9	211	30.1	17%	15%
Oak Grove	184	30.4	248	20.1	63	-10.2	34%	-34%
St Charles	609	68.7	581	61.6	-28	-7.0	8%	-10%
St Peters	586	98.0	1480	122.6	894	24.5	153%	25%
Total	3689	497.0	5376	594	1687	96.7	46%	20%

Total Overall Performance

While discussion thus far has intentionally dealt with comparison of TN and TP reduction resulting from optimization, Table 10 provides the *total* percent concentration and mass of nutrients reduced by the WWTFs. Total reduction assesses the total amount of nutrient removed between the WWTF influent and WWTF effluent post-optimization. All the Pilot facilities were removing some amount of nutrients prior to optimization. Therefore, the total reduction is approximately the sum of pre-optimization and *additional* post-optimization reduction.

Five of eight of the Pilot facilities are removing over three-quarters of their influent mass TN. Four of eight are removing over half of their influent mass of TP. MoDNR's *Total Phosphorus Permit Implementation Guidance 1.0* estimates that once TP requirements are incorporated into NPDES permits, there is expected to be a statewide 60% TP reduction from point sources. Three of the eight Pilot facilities exceeded 60% reduction in TP post-optimization.

Table 10 – Total Mass and Concentration-Based Performance Post-Optimization

	Total Reduction			
	Concentration (mg/L)		Mass (lb/day)	
Facility	TN % Reduction	TP % Reduction	TN % Reduction	TP % Reduction
Boonville	77%	70%	77%	71%
Duckett Cr	90%	65%	90%	64%
Herculaneum	28%	12%	28%	11%
Independence	25%	18%	26%	18%
Jeff City	76%	66%	76%	64%
Oak Grove	81%	36%	79%	37%
St Charles	48%	39%	48%	41%
St Peters	77%	43%	77%	52%

Energy

Energy use for the participating facilities was highly variable. The cost per MG treated ranged from $100 to over $300 – Figure 11. As a rule, there is an economy of scale associated with the cost of treatment. Smaller facilities such as those at Boonville, Herculaneum, and Oak Grove generally have a higher cost of treatment per million gallons treated compared to larger facilities.

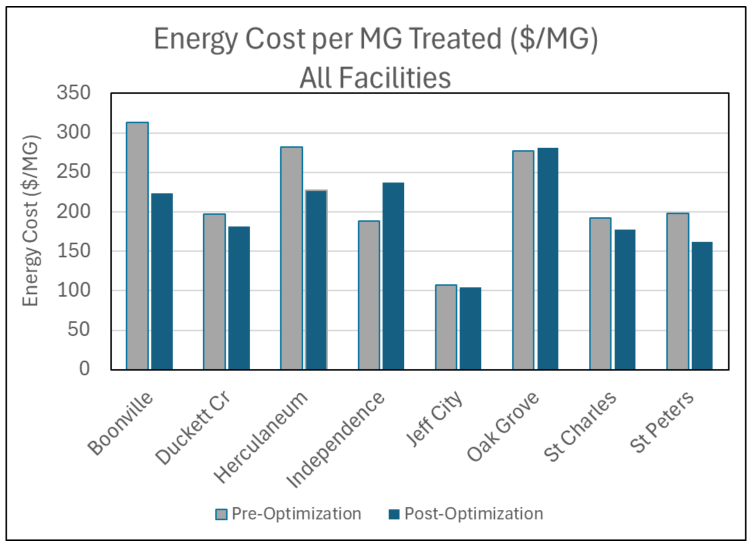

Figure 11 - Energy Cost - $/MG

Other factors that affect energy costs for the Pilot facilities are:

1. Oversized aerators. Several facilities' aeration systems were significantly oversized. Two facilities routinely had to blow excess air off to prevent damage to blowers. Independence is actively seeking to rectify that problem with a project expected to be completed in August 2025.

2. Variable frequency drives. Most facilities <u>did not</u> have variable frequency drives (VFDs) which would have allowed them to "turn down" their aerators to more closely match their needs.

3. Aerator type. Blowers coupled with fine bubble diffusers are usually more energy efficient than brush or disc type aerators.

4. Motor and blower efficiency. Older motors that drive aeration equipment are less efficient than newer motors. Newer blower technology also aims for higher efficiency.

5. Dissolved Oxygen (DO) control schemes. Three facilities with variable frequency drives (VFDs) controlled the treatment process by maintaining a DO setpoint – as DO falls below a set point, more aeration (requiring more energy) is provided. Duckett Creek is an example where DO control was used. Even when they turned off four of their 12 aerators, the other aerators remained on for longer periods to achieve the DO setpoint. Thus, even though the Duckett Creek facility turned off 33% of their aerators, the number of kilowatt-hours used only decreased by 9%.

The best measure for assessing energy impacts associated with nutrient optimization is energy efficiency. Energy efficiency for this document is calculated by assessing the weighted pounds of BOD, TN, and TP that are reduced per kilowatt-hour of energy input to the treatment process.

As noted previously, a benchmark efficiency metric developed in the EU is 0.22 kilowatt-hour per pound of total pollutant equivalent removed (kWh/TPErem). Five of eight facilities were able to see more efficient energy use – Table 11. Jefferson City and St Peters exceeded the benchmark value, with several others within a fraction of meeting the benchmark. Overall, efficiency improved by 36%.

Table 11 – Energy Efficiency – Pre vs Post Optimization

	Energy Efficiency - kWh/lb TPErem		
Facility	**Pre-Optimization**	**Post-Optimization**	**% Improvement**
Boonville	0.52	0.23	56%
Duckett Cr	0.35	0.23	35%
Herculaneum	1.98	0.86	56%
Independence	0.46	0.47	-3%
Jeff City	0.14	0.12	14%
Oak Grove	0.22	0.25	-16%
St Charles	0.38	0.44	-14%
St Peters	0.35	0.20	44%
Average	0.55	0.35	36%

Energy use (kWh) and energy cost ($) alone are often not the best measures of energy associated with nutrient reduction. Energy use generally tracks with weather – with costs peaking in the warmer summer months. For the Pilot project, several facilities also chose to increase aeration to higher than historical levels during the unusually cold periods in January and February due to scum formation at the tops of their basins.

Energy costs are questionable performance measures for several reasons outside of an operator's control. Costs can rise due to rate increases, energy use during peak periods (peaking, or peak demand charges), or higher rainfall resulting in additional pumping costs. Wet weather costs can be particularly significant for WWTFs with extraneous flow basins if high flows are pumped to the basin during wet weather, then pumped back from the basin for treatment during drier periods. As noted earlier, during the Pilot Project period more precipitation occurred than in previous years and most facilities saw higher flows.

Table 12 provides energy use(kWh) and cost data per million gallons treated for pre and-post optimization. Note this differs from Table 3 which provided the actual energy use and cost values. Evaluating on a use or cost per MG basis provides a better mechanism to assess the effects of optimization since they are not affected by higher or lower flows – they are rates. Overall, energy use per MG showed a significant decrease of 16%, with several facilities showing notable decreases: Boonville 33%, Herculaneum 28%, and St Peters 25%.

Overall, costs per MG were down 8% between pre- and post-optimization, illustrating that even with reduced energy use, costs can increase due to rate increases and/or peak demand charges. Oak Grove is a good example where energy use was decreased by 7%, but costs increased by 1%.

Boonville is notable in terms of energy use and energy cost, with each decreasing by 33% and 29%, respectively. With energy savings of around $2,070 per month ($24,845 per year), the City was able to pay for an upgraded SCADA system to more precisely control their aeration and have more consistent treatment.

Table 12 – kWh and Cost per MG – Pre vs Post Optimization

	Pre-Optimization		Post-Optimization		% Improvement	
Facility	kWh/MG	$/MG	kWh/MG	$/MG	kWh/MG	Cost/MG
Boonville	4,050	314	2,705	224	33%	29%
Duckett Cr	2,589	197	2,345	181	9%	8%
Herculaneum	3,595	282	2,601	228	28%	19%
Independence	1,325	188	1,433	237	-8%	-26%
Jeff City	1,215	107	1,214	104	0%	-1%
Oak Grove	3,343	278	3,164	266	7%	3%
St Charles	2,734	194	2,564	193	6%	0%
St Peters	2,633	198	1,984	162	25%	18%
Total	21,562	1,758	18,011	1,610	16%	8%

The aggregate cost savings for all facilities were $102,748 per year based on the cost per million gallons treated. Independence was the only facility that used significantly more energy per MG treated. Couple that with the fact Independence pays a combined $0.16/kWh, while the facilities pay anywhere between $0.07 to $0.09/kWh, greatly skews overall energy costs. Without Independence included, the other 7 facilities saved $190,608.

The aggregate energy demand for all facilities decreased by nearly 3,000,000 kWh per year. According to the US Energy Information Administration, the average U.S. residence uses 30 kWh per day[5]. Thus, the energy saved would power around 270 residences per year.

Economics

The entire cost for the Missouri Pilot Project is estimated to be less than $352,000 including the consultant fees, plus the labor and equipment costs reported by the Pilot facilities. Those costs were offset by an overall $102,748 energy savings. Therefore, the total cost of the project was $248,896 ($351,644 - $102,748) making the average total per facility cost less than $31,000 for the 18-month Project. The effort resulted in around 308 tons per year (616,000 lb/year) of additional nitrogen reduction and 18 tons per year (36,000 lb/year) of additional phosphorus reduction attributed to optimization at the eight non-upgraded, conventional wastewater facilities in the Pilot Project. Dividing the total cost by the addition pounds of TN and TP reduced is about thirty-eight cents ($0.38) per pound. For facilities likely to comply with the MoDNR goals for TN and TP, that is essentially a

[5] How much electricity does an American home use? https://www.eia.gov/tools/faqs/faq.php?id=97&t=3

one time, one year cost. With no additional construction costs, those facilities would also save money in the future due to reduced energy bills.

Three ways to contrast the cost of this project to construction include:

- The price of nutrient trading credits observed elsewhere in the country.
- The cost of construction for removing nutrients on a cost per pound basis.
- The cost of construction on a dollar per MGD basis.

Trading Costs

Missouri has acknowledged water quality trading (WQT) as an option for meeting future NPDES permit limits for nutrients. The theory behind WQT is that it may be an alternative to constructing technological treatment plant upgrades. This is accomplished by allowing dischargers to purchase nutrient reduction credits to comply with regulatory requirements. Nutrient credits can be generated by point sources or nonpoint sources and sold to others to comply with regulatory requirements (Arden, et al., 2025). The belief is that point sources (in this case, wastewater treatment plants) will purchase credits if they are cheaper than new construction. Therefore, the cost of credits would approximate the tipping point where a WWTF owner would choose to upgrade infrastructure. There are a handful of trading programs nationally that have established costs for credits:

- Virginia has established a nutrient trading regulation. It allows the purchase of credits to offset permitted limits. If nutrient credits are not available, WWTF owners can pay into a Nutrient Offset Fund – a payment in lieu of meeting permit-required reductions. The costs are established at $5.08/lb for TN and $11.15/lb for TP. WWTF owners need to decide whether it is cheaper to upgrade their facilities or pay the offset cost.[6]
- Connecticut's program focused on TN in Long Island Sound. In 2021, the cost of a TN credit was $4.84/lb.[7]
- In a paper by Arden, et al., theoretical TP trading costs were evaluated for several Wisconsin facilities. The cost for TP credits was estimated at around $70/lb. Note: the cost of a "credit" was estimated at $85 per credit, however Wisconsin applies a trade ratio of 1.2:1. Trade ratios are important considerations. When trading with nonpoint sources, it is assumed that there is uncertainty in terms of actual nutrient reductions, therefore trade ratios of 2:1 or more are often used. This means that for every pound of nutrient reduction needed by a point source, a higher amount must be reduced by the nonpoint source generating the credit. For a 2:1 trade ratio, the nonpoint source must provide two pounds of nutrient reduction for every pound required of the point source.

The cost of credits can be highly variable and depend on factors such as the actual cost of the reduction practice, the location of the watershed, policy frameworks (particularly trade ratios, and proximity to the discharger), and transaction costs. Transaction costs are often higher than the actual cost of the practice to reduce nutrients. However, with TN credits around $5 per pound and TP credits being $11 or more per pound, the 38 cents per pound cost calculated for the optimization project is cheap.

Construction Cost – Per Pound

While upgrade and new construction costs are facility specific, others have studied the costs of add-on or replacement treatment to achieve nutrient reduction. Those studies can be used as high-level

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[6] Virginia Administrative Code 9VAC25-820-70. https://law.lis.virginia.gov/admincode/title9/agency25/chapter820/section70/

[7] Cost of Equalized Nitrogen Credit for Buyers 2021. https://portal.ct.gov/-/media/deep/water/nitrogen_credit_advisory_board/cost-of-equalized-nitrogen-credits-for-buyers-2021.pdf?rev=602d20bb9ab64b529b34bddafc8419e6&hash=5FE627F16714BF57E6EC449687D2D1EA

estimates of potential costs to contrast with optimization costs. One study was conducted by JJ Environmental LLC for a group of smaller New England municipal wastewater treatment facilities (JJ Environmental, 2015). Normalized to 2025 dollars, the cost per pound of nitrogen reduction – both capital and operation and maintenance over a 20-year period - was around $2.10 per pound. The New England study only looked at total nitrogen cost which is typically less expensive than phosphorus reduction costs.

A second study was conducted to assess nutrient reduction costs for facilities in the state of Utah (CH2MHill, 2010). The Utah study looked at both total nitrogen and total phosphorus. Total nitrogen and phosphorus costs for one of the Utah scenarios were based on targets of 20 mg/L TN and 1.0 mg/L TP. Capital costs annualized over 20 years plus operation/maintenance was $5.40 per pound in 2025 dollars. Note this estimate is likely low since the TN goal was 20 mg/L versus the Missouri goal of 10 mg/L.

A more recent study looked at new construction and operating costs to reduce phosphorus (Bashar, et al., 2018). Although the study focused on phosphorus reduction, one process evaluated also reduced nitrogen to about the same concentration as the MoDNR goal. The study estimated concentrations of total inorganic nitrogen (TIN) = 7.48 mg/L (approximately 10 mg/L TN) and TP of 0.9 mg/L for a technology aimed at nutrient reduction. The estimated cost of nitrogen and phosphorus reduction was $6.50 per pound. Again, this study was for new construction, whereas the other two studies looked at some combination of new construction and upgrade of existing infrastructure.

Construction Cost – Per MGD

Another way to look at cost was noted in the Executive Summary – cost per million gallons. A Midwest environmental engineering firm estimates the cost for construction at $13.5 million per design MGD. Regardless of assessing dollars per million gallons, or cost per pound of pollutant removed, optimization offers a much lower cost path for many. For some, there is little to no capital cost.

Optimization offers the potential for large cost savings, contrasted to the cost of building new infrastructure. At a fraction of the cost of construction, optimization may achieve desired nutrient reduction goals. Thus, it makes economic sense to first try optimization. It could save a community and its wastewater ratepayers millions of dollars.

SUMMARY

The Missouri Municipal Nutrient Optimization Pilot Project demonstrated that nutrient reduction at facilities not designed for nutrient reduction is possible. Over a very short period, an estimated 652,000 additional pounds of nutrients were kept out of Missouri waters annually and those of downstream states. The cost for optimizing was minimal – around $31,000 per facility over the 18-month project – demonstrating that for some, optimization can meet the MoDNR targets at a fraction of the cost of construction. At such a minimal cost, all Missouri mechanical WWTFs should explore optimization. Optimization can be both financially rewarding and improve the quality of Missouri's waters as well as those of downstream states.

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APPENDIX A – CASE STUDIES