THESIS

ANALYSIS OF NUTRIENT REMOVAL AT THE DRAKE WATER RECLAMATION FACILITY

Submitted by

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ABSTRACT

ANALYSIS OF NUTRIENT REMOVAL AT THE DRAKE WATER RECLAMATION FACILITY

Since the 1960's, the Federal Government through the United States Environmental Protection Agency (USEPA) has been working to create and enforce regulations to protect and counteract the degradation experienced in the nation's waterways due to increased nutrient loading (primarily phosphorus and nitrogen). The eutrophication caused by excess levels of these nutrients is not only an aesthetic issue, but is toxic to aquatic life and can also create issues detrimental to human health. In 2007, the Colorado Department of Public Health and Environment began working on new nutrient regulations for state dischargers, particularly larger Publicly Owned Treatment Works (POTWs) like the City of Fort Collins and its two wastewater treatment plants, Mulberry Water Reclamation Facility (MWRF) and Drake Water Reclamation Facility (DWRF). Since 2008, The City of Fort Collins has been upgrading its secondary treatment systems to Biological Nutrient Removal (BNR) in preparation for National Pollutant Discharge Elimination System (NPDES) permit compliance in 2020. Early in the design process, it was determined that DWRF suffered from a limitation in influent carbon for adequate nutrient removal and carbon addition would need to be considered. The City analyzed various local carbon sources and has been working to determine the viability of beer waste from local breweries as a viable carbon source. The overarching goal of this work is to evaluate the current nutrient removal efforts at DWRF to help determine if adjustments are required to the wastewater treatment Master Plan to consistently meet Colorado’s Regulation 85 nutrient discharge limits.

This study included monitoring of nutrient water quality values at specific points in the treatment system while adding beer waste at varying flow rates and durations to determine its effect on the system. Different automated control strategies were tested using several dosage schemes including Oxidation Reduction Potential (ORP) values. Finally, water quality data was analyzed and compared alongside historical nitrogen and phosphorus values to evaluate the effects of the beer waste addition to effluent quality and plant removal performance.

The initial values for effluent total inorganic nitrogen showed promise, averaging 9.79 mg/L in comparison to 12.05 mg/L when beer waste was not added. However, a mass balance comparison with influent nitrogen values showed no significant difference in BNR process performance for nitrogen with the beer addition. Effluent phosphorus values averaged 2.24 mg/L-P which was slightly lower than without beer waste addition (2.42 mg/L), but not considered a statistically significant decrease. During the study, an observation was made that adjusting time-of-day and flowrate of the dewatering centrate return significantly decreased effluent phosphorus concentrations down to 1.1 mg/L, significantly lower than P concentrations without beer addition ($p < 0.05$). An analysis of phosphorus removal at DWRF also highlighted the historical improvement of phosphorus removal as BNR improvements are brought on-line, even though the required effluent limits required by Regulation 85 have not been achieved yet. Overall, carbon addition via beer waste has shown to have positive impact on DWRF’s ability to remove nutrients. Lower effluent concentrations of nitrogen were achieved when beer waste was added to DWRF and lower effluent P concentrations were also achieved as long as centrate return flow was controlled. Additional study is required for long-term control of centrate return flows which may include the analysis of side-stream treatment solutions. Additional analysis to determine the role of beer waste addition independent of centrate flow returns is also recommended.

ACKNOWLEDGEMENTS

I would like to first thank my advisor, Dr. Sybil Sharvelle for her knowledge and support in helping me to achieve this goal. Her guidance in assisting me to work through a study of real-time conditions helped me to complete the project despite the inevitable issues that arose in dealing with biological processes.

I would also like to express my gratitude to Owen Randall, Carol Webb, and Kevin Gertig with the City of Fort Collins Utilities for making it possible both financially through the Utilities' tuition assistance program and flexibility with my schedule to complete this work.

I would also like to acknowledge all the help and support from the plant staff at Drake Water Reclamation Facility. This project would have been short-lived without their assistance in testing, troubleshooting, and maintaining and operating the pilot test. A special thanks to Ramon Arguello for his support in the whole pilot process and his years of insight in treatment processes which helped considerably when results were not as anticipated.

Most importantly I'd like to express my love and appreciation to my wife, Nancy, and daughters, Rebecca and Cassandra, for supporting me through this entire endeavor. Without their love and extreme patience this would not have been possible.

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1 INTRODUCTION

1.1 Research Motivation

In 2007 the State of Colorado, under pressure from the United States Environmental Protection Agency (USEPA), began working on stricter nutrient effluent limits for wastewater treatment facilities. Concentrating on phosphorus and nitrogen removal, the Colorado Department of Public Health and Environment (CDPHE) began a multi-year process with stakeholder groups to develop technology-based standards that would balance the need for environmental protection with the financial impacts of the new requirements. Adopted in June 2012, the Nutrients Management Control Regulation (Reg 85) required plants the size of the City of Fort Collins' to meet an annual median of 1.0 mg/L or less Total Phosphorus and 15 mg/L or less Total Inorganic Nitrogen (TIN). TIN is the sum of Nitrate (NO_3) as N, Nitrite (NO_2) as N, and Ammonia (NH_3) as N.

Due to the impending failure of treatment processes at the City of Fort Collins' Mulberry Water Reclamation Facility (MWRF), the City was unable to wait for the final regulations to be completed and with the help of the City's consulting engineer, MWH Global, made a reasonable attempt to predict and design for the future regulations. The was converted between 2008 and 2011 to a Biological Nutrient Removal (BNR) process from the Trickling Filter/Activated Sludge Process that had been in place since the 1940's. Drake Water Reclamation Facilities' (DWRF) North Process Train was converted in 2012 to BNR from a traditional activated sludge process. DWRF's South Process Train, also a traditional activated sludge process, has just been upgraded to BNR.

One major challenge with BNR is the need for additional organic carbon to fuel the additional biological processes. Both Biological Phosphorus Removal (BioP) and denitrification require additional carbon with BioP requiring specific types of carbon high in Volatile Fatty Acids (VFAs). During the upgrade of MWRF, the primary clarifiers were removed from the treatment system and other upgrades completed so that most of the maximum amount of influent carbon is sent to the secondary process. DWRF's configuration and need for primary sludge for the anaerobic system precluded this solution. The 2009 Master Plan predicted this carbon limitation from the characterization analysis of the plant's influent. Starting in 2010, Fort Collins began looking at its industrial clients for possible local sources of high strength carbon. Several local breweries high strength liquid waste appeared to fit the bill and a multi-year study of the potential use of this material began.

From the bench-scale tests at the Utilities' Pollution Control Lab and through a short-term pilot at MWRF, the Utility learned by trial and error the idiosyncrasies of working with beer waste. In 2012 and 2013 two phases of pilot-scale testing were conducted at DWRF with beer waste. The ability to properly dose the additional carbon seemed to be one of the larger challenges to this carbon addition practice.

1.2 Research Objectives

This research effort is designed to evaluate the current nutrient removal efforts at DWRF to help determine if adjustments are required to the overall wastewater treatment Master Plan to consistently meet Colorado's Regulation 85 nutrient discharge limits. The City of Fort Collins anticipates receiving its next National Pollutant Discharge Elimination System (NPDES) Permit by the end of 2015 with a compliance schedule for meeting phosphorus and nitrogen discharge limits. The specific objectives are as follows:

- Assess water quality plant-wide at each key stage of the process as it relates to nutrient removal. To meet this objective, an extensive sampling effort will be conducted over a six week period and historical data will be reviewed and analyzed.
- Monitor the quality and quantity available for the beer waste currently being utilized as a potential long-term carbon source. Sampling of beer waste carbon and VFA values both in the trucks delivering the product and in the storage tank will be conducted. Daily beer waste delivery volumes and frequency will also be recorded.
- Evaluate dosing options for controlling the feed rate of carbon addition to meet nutrient removal parameters without adversely affecting process. To meet this objective nitrate and ORP probes will be continuously monitored to evaluate the relationships between denitrification, ORP, carbon dosing and effluent quality.

2 BACKGROUND AND LITERATURE REVIEW

2.1 National Nutrient Timeline

While phosphorus and nitrogen are the building blocks of organic life, high concentrations in lakes, reservoirs, and receiving waters can lead to lower dissolved oxygen levels, poison aquatic life and eutrophication (Figure 2-1) In the mid-1960’s, the Federal government enacted environmental legislative reforms to facilitate the control of nutrient pollution (primarily phosphorus at the time) to obtain a consistent approach to pollution control.

Figure 2-1 Extracted from Examples of Pollution (Field Studies Council, 2015)

The 1970’s brought us the amendments to the Federal Water Pollution Control Act, now known at the Clean Water Act. This also brought into play billions of dollars in grants and loans to upgrade Publicly Owned Treatment Works (POTWs) and allowed not only substantial increase in wastewater treatment technology, but provided a basis for wastewater discharge control in the

United States. Coming out of the 1990's and into the 21st century, most POTW's provided good secondary process removal of Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), and Ammonia, but did little to removal phosphorus and other nitrogen species from the effluent.

Continued problems with eutrophication and nitrates in drinking water sources caused the United States Environmental Protection Agency (USEPA) to push States to enact more stringent nutrient removal standards. While high levels of phosphorus are generally attributed to driving eutrophication in surface waters, health risks and toxicity to aquatic life are the motivation for stricter regulations of ammonia in receiving waters. Nitrate and nitrite are regulated due to concern for drinking water quality and human health impacts.

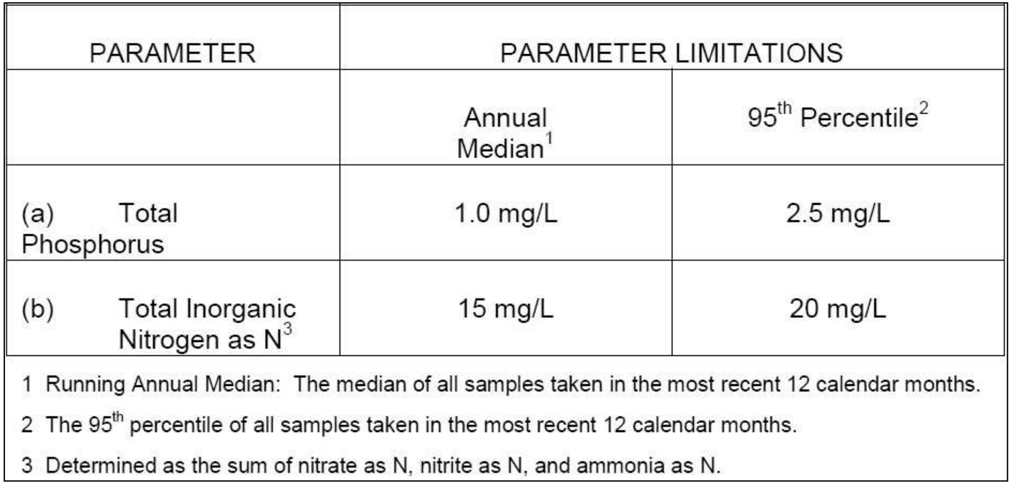
2.2 Health Effects of Nitrate and Nitrite

In 1974 Congress passed the Clean Water Act that requires the EPA, to set limits for certain contaminants for drinking water to be safe for consumption. In 1992, the Phase II rule set limits on Nitrite and Nitrate in drinking water. The Maximum Contaminant Level (MCL) for Nitrite was set at 1 mg/L primarily due to the risk of Methemoglobinemia. This is a syndrome in human infants where nitrite combines with hemoglobin and inhibits the transport of oxygen. Nitrite levels rarely reach or sustain these levels in drinking source waters, but nitrate can be reduced to nitrite in the non-acidic stomachs of infants causing the syndrome so the MCL for nitrate is 10 mg/L (Brezonik, 2011)

2.3 Colorado Regulations

In 2007, CDPHE's impending Regulation 85 for nutrient removal was the reason for Fort Collins' pre-emptive development of its nutrient removal facilities. Table 2-1 shows the published limits for existing domestic wastewater treatment plants identified prior to May 31, 2012.

Table 2-1 Regulation 85 limits for existing facilities (Colorado Department of Public Health and Evironment, 2012)



PARAMETER	PARAMETER LIMITATIONS	
	Annual Median[1]	95th Percentile[2]
(a) Total Phosphorus	1.0 mg/L	2.5 mg/L
(b) Total Inorganic Nitrogen as N[3]	15 mg/L	20 mg/L

1 Running Annual Median: The median of all samples taken in the most recent 12 calendar months.

2 The 95th percentile of all samples taken in the most recent 12 calendar months.

3 Determined as the sum of nitrate as N, nitrite as N, and ammonia as N.

Both MWRF and DWRF's North Process Train were designed prior to the final ruling on Regulation 85, but it was projected that set nutrient discharge limits would take into consideration the limits of technology and Biological Nutrient Removal (BNR) could be utilized without the requirement for chemical addition. Unfortunately, while this was the case for the nitrogen limits, phosphorus removal would treatment modifications (e.g. physicochemical phosphorus removal, carbon addition to BNR etc.).

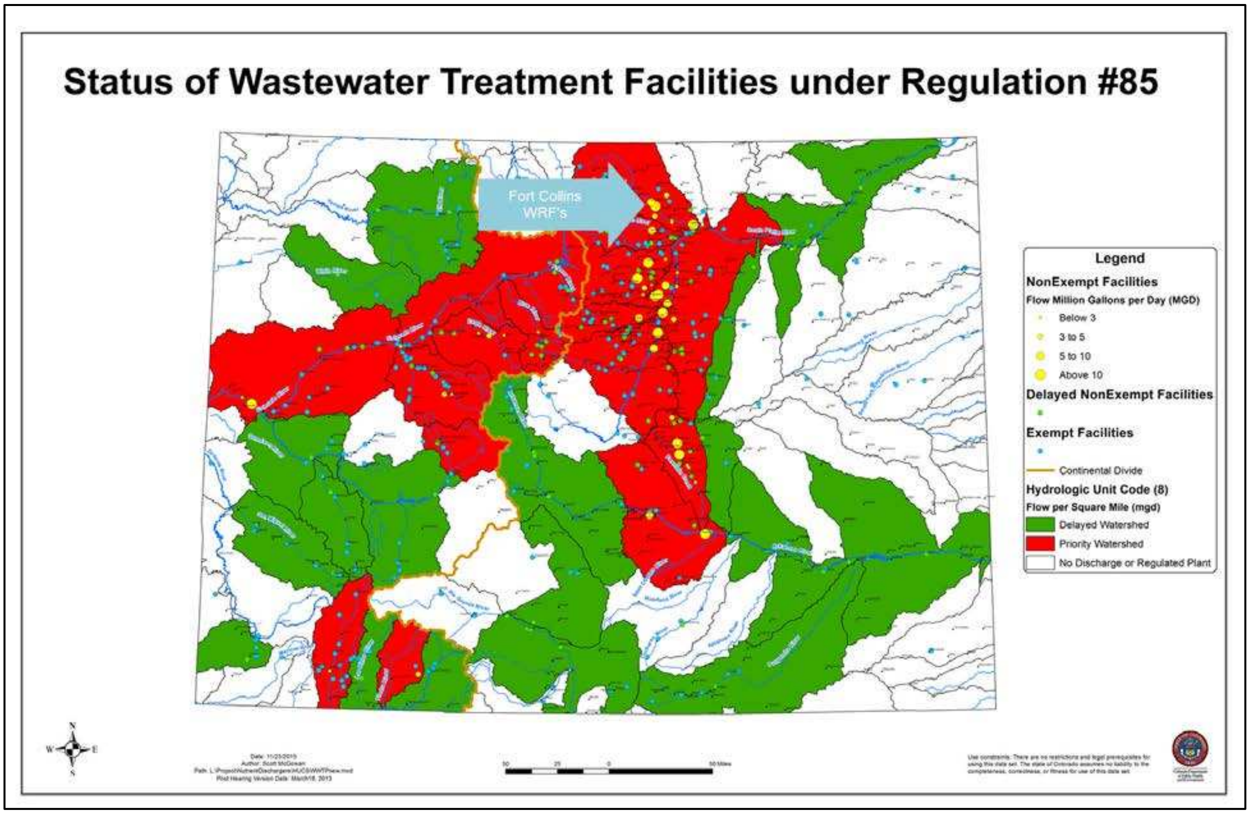


Figure 2-2 Map of Regulation 85 Affected Watersheds and Facilities (Colorado Department of Public Health and Environment, 2012)

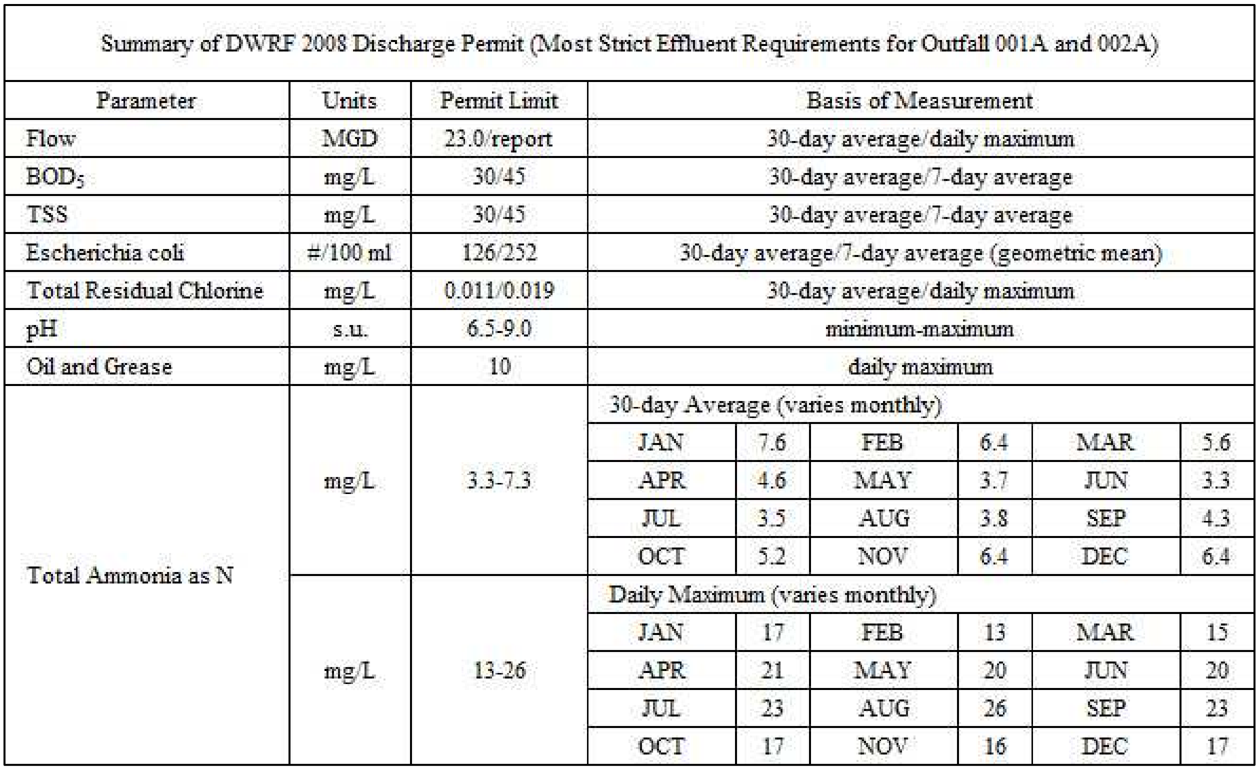
Arguments were made to wait on implementing nutrient removal until the State finalized the proposed limits. However, as two of the larger plants in the priority watersheds (Figure 2-2), it was theorized that both Fort Collins' wastewater treatments plants would be among the first plants required to upgrade to the Regulation 85 standards. Waiting could potentially cost the rate payers of Fort Collins considerably more if the required upgrades to both plants did not take nutrient removal into consideration.

Both MWRF and DWRF's NPDES permits are on administration hold until the South Platte basin Regulation 31 hearings are completed. At that time the Permits section of the Water Quality Control Division (WQCD) will commence negotiating permits within the basin to meet the Regulation 85 limits. It is anticipated that the permit negotiations will begin for the City by Fall 2015 with the potential for a new permit by Spring 2016. The most likely scenario is that a compliance schedule will be granted to allow the City to finish any remaining improvements required to meet the new nutrient limits.

2.4 Current Limits and Performance

Table 2.1 shows the current limits in the City's 2012 permit. The limits shown are the most stringent limits in permits. Discharge limits for ammonia and chlorine residual for DWRF's discharge into the Fossil Creek Reservoir Inlet Ditch (FCRID) are much more lenient.

Table 2-2 DWRF Permit Limits



Summary of DWRF 2008 Discharge Permit (Most Strict Effluent Requirements for Outfall 001A and 002A)								
Parameter	Units	Permit Limit	Basis of Measurement					
Flow	MGD	23.0/report	30-day average/daily maximum					
BOD$_5$	mg/L	30/45	30-day average/7-day average					
TSS	mg/L	30/45	30-day average/7-day average					
Escherichia coli	#/100 ml	126/252	30-day average/7-day average (geometric mean)					
Total Residual Chlorine	mg/L	0.011/0.019	30-day average/daily maximum					
pH	s.u.	6.5-9.0	minimum-maximum					
Oil and Grease	mg/L	10	daily maximum					
Total Ammonia as N	mg/L	3.3-7.3	30-day Average (varies monthly)					
			JAN	7.6	FEB	6.4	MAR	5.6
			APR	4.6	MAY	3.7	JUN	3.3
			JUL	3.5	AUG	3.8	SEP	4.3
			OCT	5.2	NOV	6.4	DEC	6.4
	mg/L	13-26	Daily Maximum (varies monthly)					
			JAN	17	FEB	13	MAR	15
			APR	21	MAY	20	JUN	20
			JUL	23	AUG	26	SEP	23
			OCT	17	NOV	16	DEC	17

Typically plant staff has little trouble meeting the ammonia permit limits (Table 2.1) during the warmer months of the year. The colder winter months tend to be more challenging in maintaining nitrification due to maintaining adequate populations of nitrifying microorganisms at lower temperatures.

2.5 Nutrient Removal Process Selection

During the development of the design for MWRF and the 2009 Master Plan from 2007-2009, various nutrient removal processes were analyzed. MWRF's processes and infrastructure had been rapidly failing between the years 2004-2007 primarily due to several low pH events that killed the plant's trickling filter and accelerated the failure of the 60-year old infrastructure. Pressure was on the City to come up with a design and construct a new facility prior to actually knowing the ultimate limits that would be imposed on the plant. In the end, a three-stage Anaerobic Anoxic, Oxic (A2O) process was selected (Figure 2-3). The three primary reasons for the selection of this style of process were:

- It could meet the nutrient removal criteria proposed at the time
- The process could easily be incorporated into existing infrastructure
- The process could be easily expanded to a 5-stage Bardenpho process in the event that Enhanced Biological Nutrient Removal (EBNR) was required.

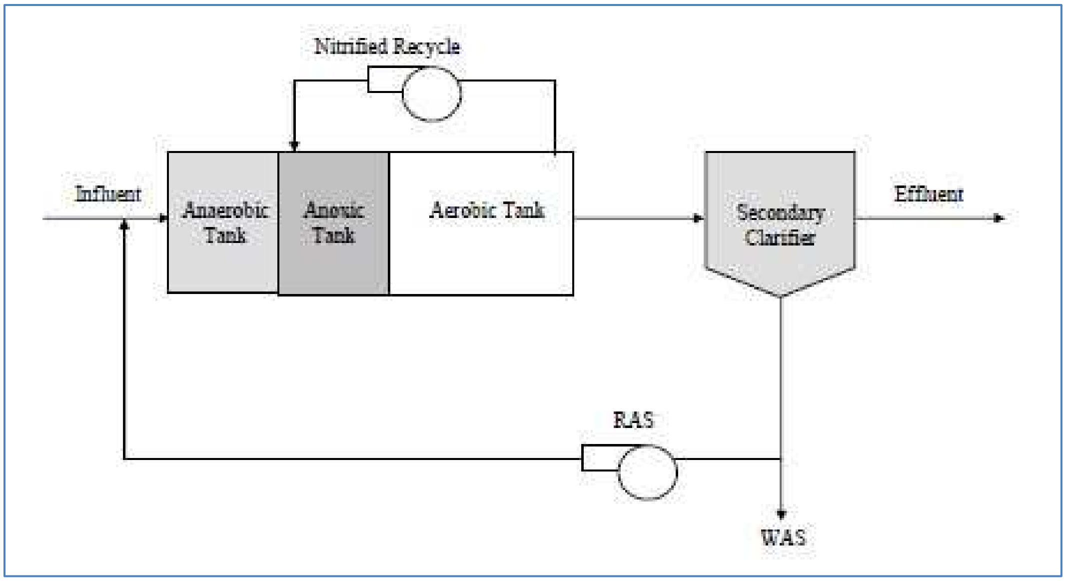


Figure 2-3 A2O process schematic excerpt from Municipal Wastewater Treatment Technologies (U.S. Environmental Protection Agency, 2008)

As shown in Figure 2-3, the A2O provides for simultaneous biological nutrient removal and denitrification. While additional pumping and piping is required, the reduced need for additional concrete tankage more than makes up for the additional mechanical costs.

2.6 City of Fort Collins Water Reclamation Facility Layout and Process Descriptions

2.6.1 Overall Treatment System Layout

The City's original wastewater treatment plant, MWRF is located on the east side of Fort Collins at the intersection of E. Mulberry Street and Riverside Drive (Figure 2-4). In 1984, MWRF's anaerobic digesters were decommissioned and all solids

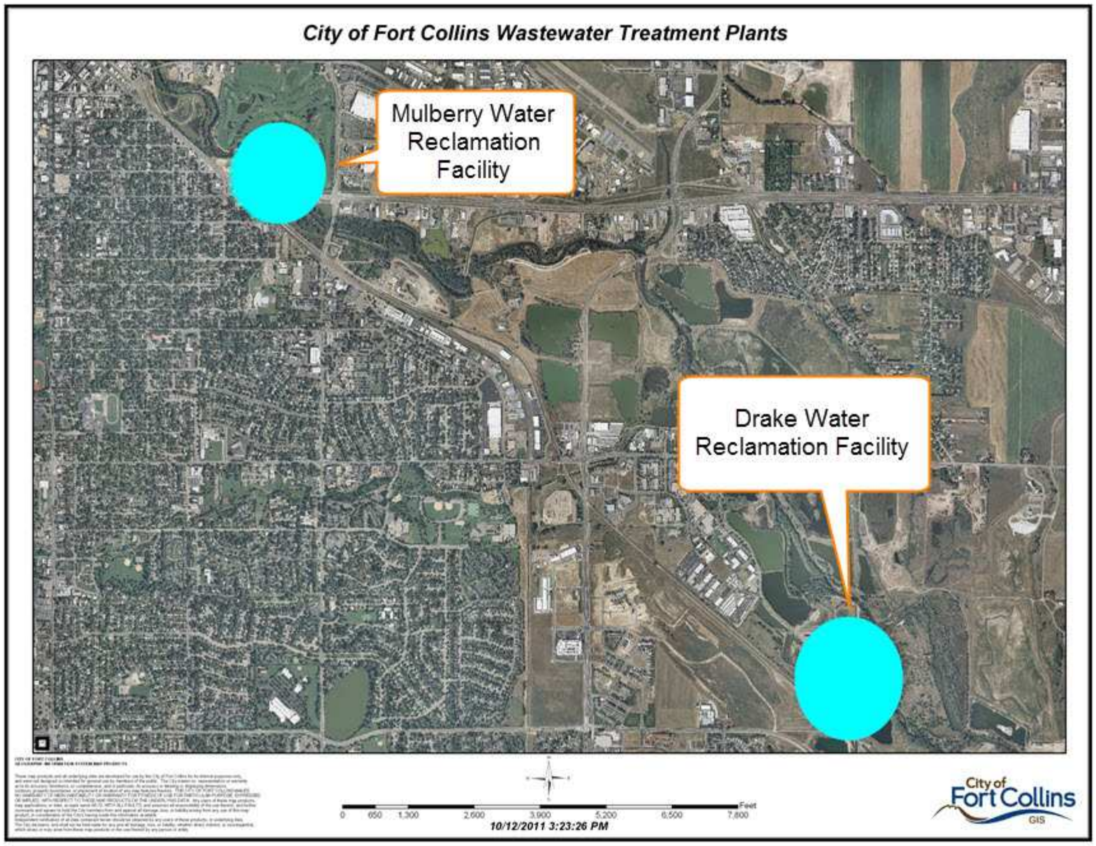


Figure 2-4 Fort Collins Wastewater Plant Locations (Map from City of Fort Collins GIS)

generated at MWRF were sent down a 42-inch transmission line to the City's second wastewater treatment plant, DWRF located approximately 3 miles southeast of MWRF.

2.6.2 Mulberry Water Reclamation Facility Process Flow Diagram

At MWRF, primary treatment was eliminated in the new BNR process (Figure 2-5) to maximize the influent carbon to the secondary system. The process flow diagram shows the

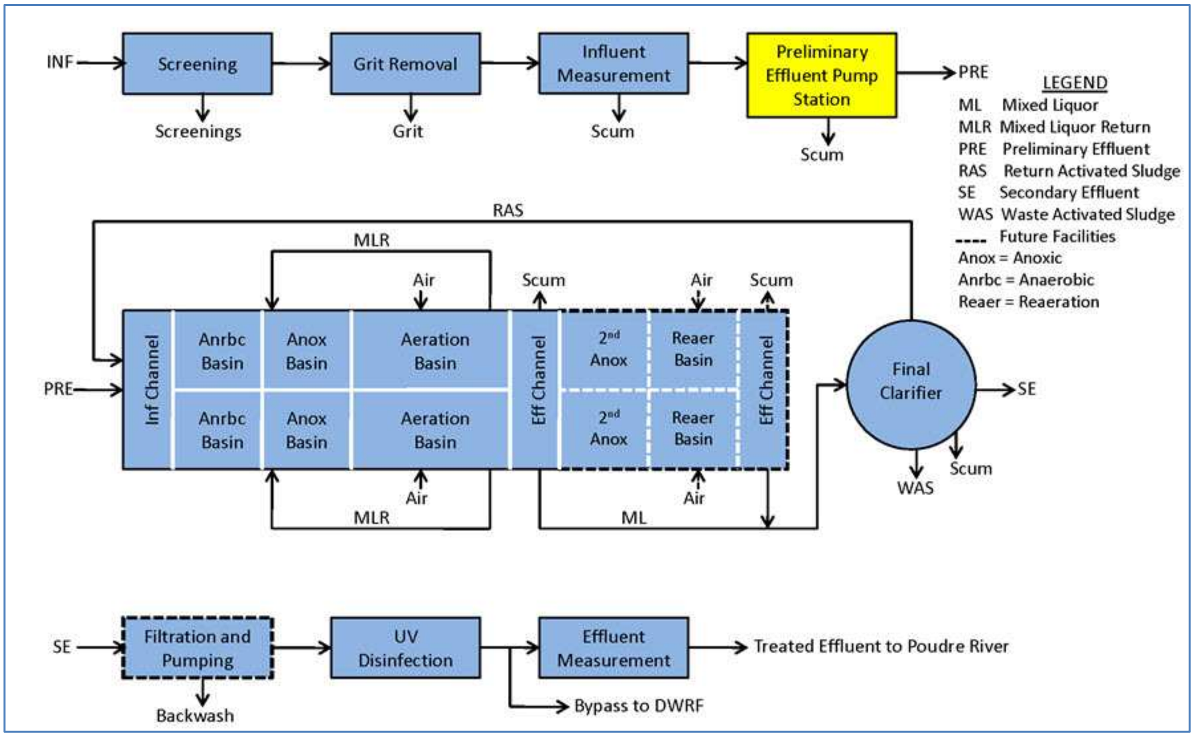


Figure 2-5 Mulberry Water Reclamation Facility Process Flow Diagram (MWH Global Process Design Report 2009)

future reactors necessary to convert this 3-stage A2O process into a 5-stage Bardenpho process. All scum and waste activated sludge (WAS) discharges from this system enter the 42-inch transmission main and flow down to DWRF.

2.6.3 Drake Water Reclamation Facility Process Flow Diagram

Figure 2-6 shows the process flow diagram for the entire DWRF facility. During the sampling period for this study the area clouded in green was under construction and all flows coming to the plant were sent to the North Process Trains (NPT).

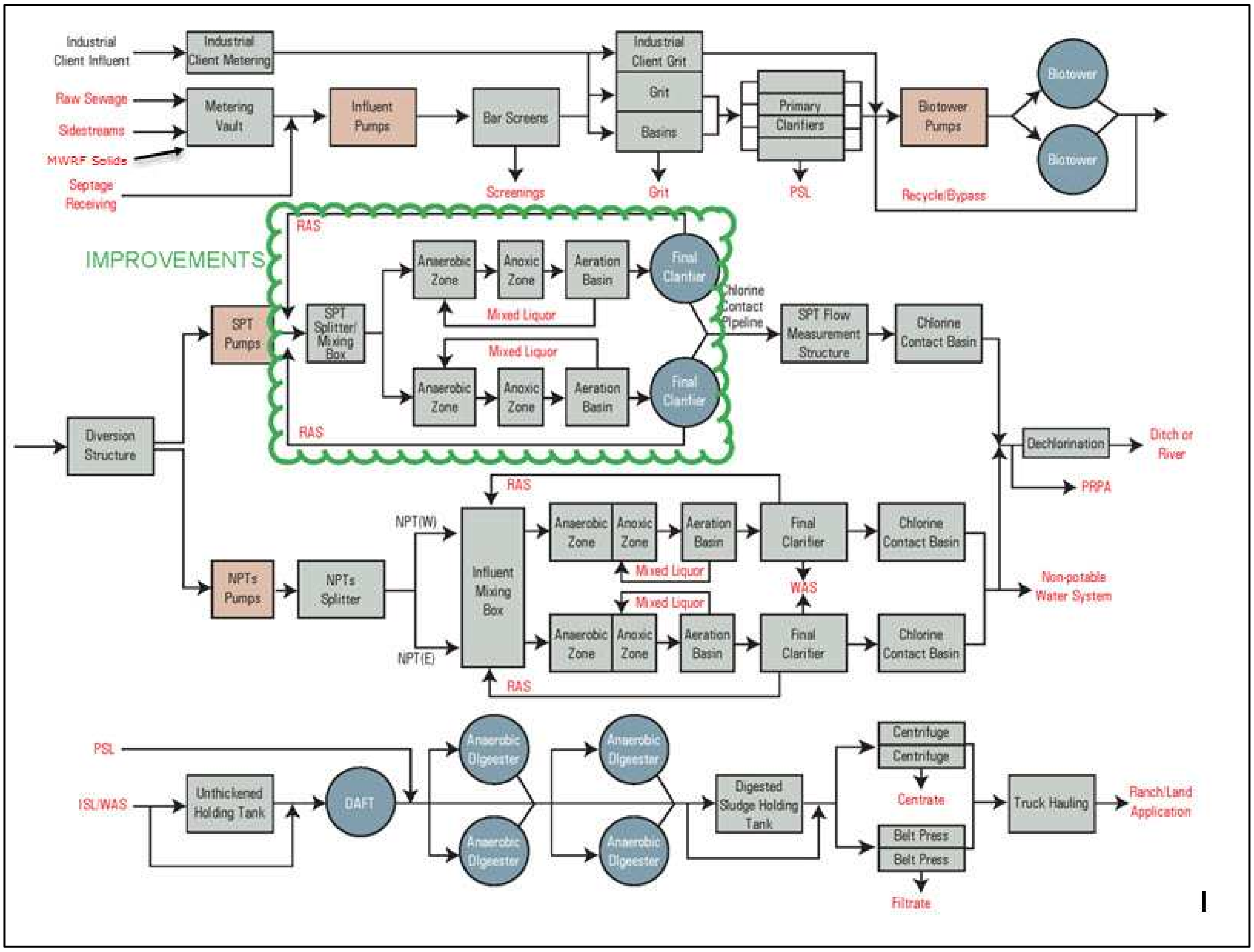


Figure 2-6 Drake Water Reclamation Facility Process Flow Diagram (MWH Global SPT Process Design Report, 2014)

Two items to note in the process flow diagram for DWRF (Figure 2-6) are the MWRF solids coming into the influent metering vault and the plant headworks. This actually is combined with the raw sewage in the transmission line, but shown separately here for clarity. Another item to point out is the centrate discharge from the centrifuges re-enters the system in the sidestreams that return to the influent metering vault.

2.7 Biological Phosphorus Removal

2.7.1 Introduction

In the 1970's scientists in the United States and South Africa advanced development of Biological Phosphorus Removal (Barnard 2006). Barnard theorized, and then proved, that alternating anaerobic zones with aerobic zones enhanced phosphorus removal by stimulating the growth of Polyphosphate Accumulating Organisms (PAO). Traditional activated sludge processes removed carbon by the creation of biomass which is then removed from the system by wasting. Phosphorus makes of a 2.67 percent of traditional activated sludge by mass. Enhanced biological phosphorus removal systems that are designed to promote the use and growth of PAO's can increase that percent removal by 2-5 times that of traditional activated sludge. Several microorganisms identified as PAOs include *Accumulibacter phosphatis, Actinobacteria, and Malikia* (Prescott, 2005). Figure 2-7 shows PAOs existing in DWRF's North Process Train

Figure 2-7 Phosphorus Accumulating Organisms (Photo Credit: Cindy Wright-Jones)

The dark nodules within the floc are the accumulated phosphate within the organisms. Weekly observations of microbiology within the aeration basins at DWRF and MWRF show that the darker the nodule, the more phosphorus is accumulated within the floc that is wasted.

2.7.2 Biological Phosphorus Removal Biochemistry

Because the mechanism of biological phosphorus removal involves cycling between anaerobic and aerobic environments, it is impossible to isolate the effects of PAO and its biochemistry (Water Environment Federation, 2011). However, there are key biochemical reactions that can be observed in a well-operated enhanced biological phosphorus (Bio-P) process (Figure 2-8)

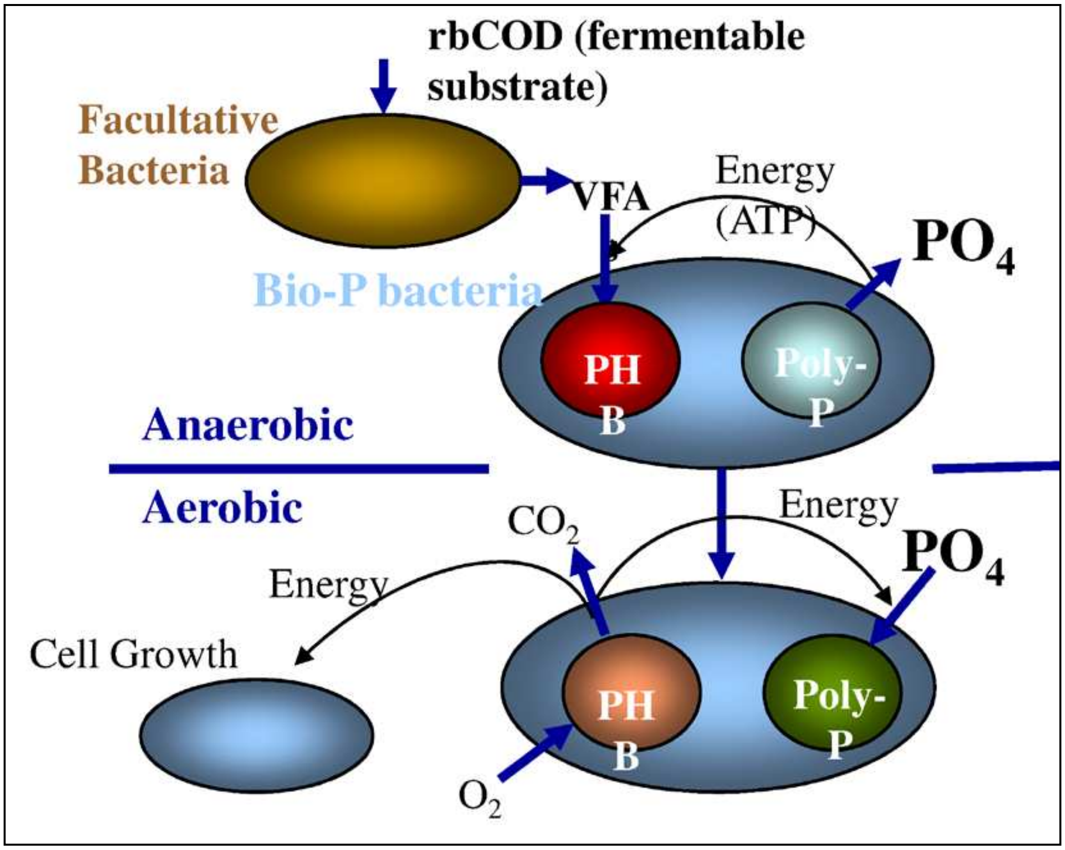


Figure 2-8 - Schematic of Biological Phosphorus Removal Process (MWH Global 2010)

Short-chain fatty acids trigger phosphorus release as the PAO’s utilize Adenosine Triphosphate (ATP) for energy to sequester the carbon as poly-*B*-hydroxybutyrate (PHB). These volatile fatty acids (VFA) include acetate, propionate, butyrate, and valeric acid. Their creation is facilitated by fermentation of readily biodegradable carbon in the anaerobic zone.

The presence of free oxygen or nitrate will inhibit the production of PHB. Since the PAOs are facultative heterotrophs, they will utilize the oxygen as a terminal electron acceptor reverting to aerobic metabolism and reduce PHB storage. Oxygen and nitrate in the anaerobic zone will also reduce the fermentation processes that help produce the VFAs.

Accumulation of stored energy gives the PAOs a competitive advantage in the aerobic zone.

During the aerobic phase the PAOs utilize the PHB for growth and reproduction. This depletion of PHB drives the uptake of soluble phosphorus, and since the PAO population has increased, the cumulative removal of phosphorus in the aerobic zone is greater than that released in the anaerobic zone.

2.7.3 BNR Facility Design for Phosphorus Removal

In the A20 process the anaerobic zones are first reactors in the process after the mixing of the Recycled Activated Sludge (RAS) with the effluent from the primary clarifier. Hydraulic retention times (HRT) for these reactors are typically designed for 45 minutes to 1 hour (Rittmann, 2001). This gives time for hydrolysis and fermentation of the readily biodegradable COD (rbCOD) into VFAs and for the PAO's to absorb the VFAs, producing PHB in the process. A key indicator that this process is working is the increase in orthophosphate concentration across the basin.

Another design element that takes careful consideration is mixing. Care must be taken not to introduce additional free oxygen into the anaerobic system. Floating mixers are a popular choice for mixing in non-aerated zones at several plants in Colorado. Colorado Springs, Boulder and Fort Collins utilized Aqua-Aerobics floating mixers in the anaerobic zones. Mixing helps maintain a homogeneous concentration throughout the basin which is important in higher solids concentration systems with total suspended solids (TSS) concentrations ranging from 2100-3300 mg/L. Finally, designers must also look at low flow scenarios within the anaerobic zone. If the PAO's remain too long in an anaerobic environment after the depletion of VFA's, secondary phosphorus release can occur. This potential is one of the reasons for DWRF's North Process

Trains anaerobic zones having a 45 minute detention time at average day flow. The other reason is that both the anaerobic and anoxic zones needed to be contained in the process trains original primary clarifiers so the designer had to balance the available area between the anaerobic and anoxic zones. While obviously important to the enhanced Bio-P process, no structural or mechanical changes were deemed necessary for either the aerobic or final clarifier processes. Process modifications to the dissolved oxygen (DO) concentrations within the three aeration basin aeration zones and sludge blanket depths are adjusted to optimize the process.

2.8 Nitrogen Removal

2.8.1 Introduction

The other nutrient of concern in the upcoming Regulation 85 requirements is nitrogen. Nitrogen enters the plant through the introduction of organic matter, ammonia produced by the breakdown of organic matter within the collection system, or from industrial sources such as nitric acid or ammonia-based cleaners. Another significant source of nitrogen is actually generated within the plant boundaries itself. Centrate generated from the dewatering of anaerobically digested sludge has ammonia concentrations as high as 950 mg/L. The centrate is collected in a storage tank and metered back to the head of the plant (Figure 2-6) and must be taken into account when designing nitrogen removal.

At DWRF, one additional source of nitrogen species is MWRF. MWRF discharges its Waste Activated Sludge (WAS) into the collection system served by DWRF, so organic nitrogen from the wasted biomass and some nitrate from the final clarifier can also be present. This results in an additional source of nitrogen in centrate. The City’s 2001 NPDES permit was the last that combined both DWRF and MWRF's discharges in a single permit. It required a "report only" for ammonia. The State set a limit on the amount of ammonia allowed in DWRF's effluent, requiring improvements to the plant's secondary processes. The driver was ammonia's effects on the receiving water quality. Ammonia is toxic to aquatic life and has an oxygen demand of 4.57 g O_2/g NH_3-N. This high DO demand can be a leading cause of eutrophication in receiving waters. There was not a regulatory requirement for ammonia removal that drove the conversion of the plant's North Process Train mechanical mixing systems to fine-bubble diffusion in 1992. The existing secondary process was a complete mix system with a total of 8-100 HP mechanical mixers. The primary reasons for this improvement were for energy efficiency and a better activated sludge process based on industry improvements and future changes (Tomerlin, 2015). These improvements converted DWRF to a designed nitrification system.

2.8.2 Nitrification

Nitrification is the first of two steps in biological nitrogen removal, in the process sense, if not the physical sense. The process of nitrification involves microbes to oxidize ammonia into nitrate via several steps (Figure 2-6)

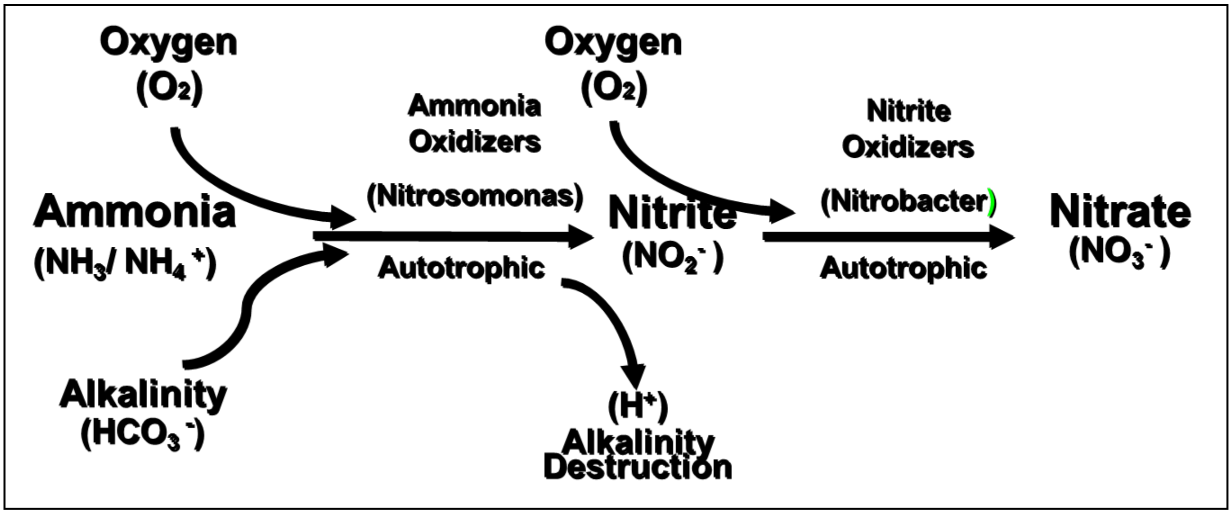


Figure 2-9 Nitrification Schematic (MWH Global)

As stated above, ammonia oxidation has a high dissolved oxygen demand, but also a high alkalinity demand. Because the ammonia oxidation process results in an increase in hydrogen ions, bicarbonate is lost due to its reaction to the hydrogen ions in the amount of 7.14 g of alkalinity (as CaCO3) per gram of NH_3 oxidized. This leads to plant operational issues because the 2012 permit modifications increased DWRF's minimum discharge pH from 6.0 to 6.5. In order to combat alkalinity loss, $Mg(OH)_2$ is added to increase the alkalinity in the aeration basin. This addition has led to increased struvite scaling in the dewatering centrate system. The BNR improvements installed in DWRF's NPT in 2011-2012 also have the capability of compensating for the alkalinity loss. This will be explained in Section 2.8.6.

Figure 2-10 shows the Ammonia Oxidizing Bacteria (AOB), an example being *Nitrosomanas,* oxidize ammonia to nitrite and Figure 2-11 shows Nitrite Oxidizing Bacteria (NOB), an example being *Nitrobacter,* oxidize nitrite to nitrate.

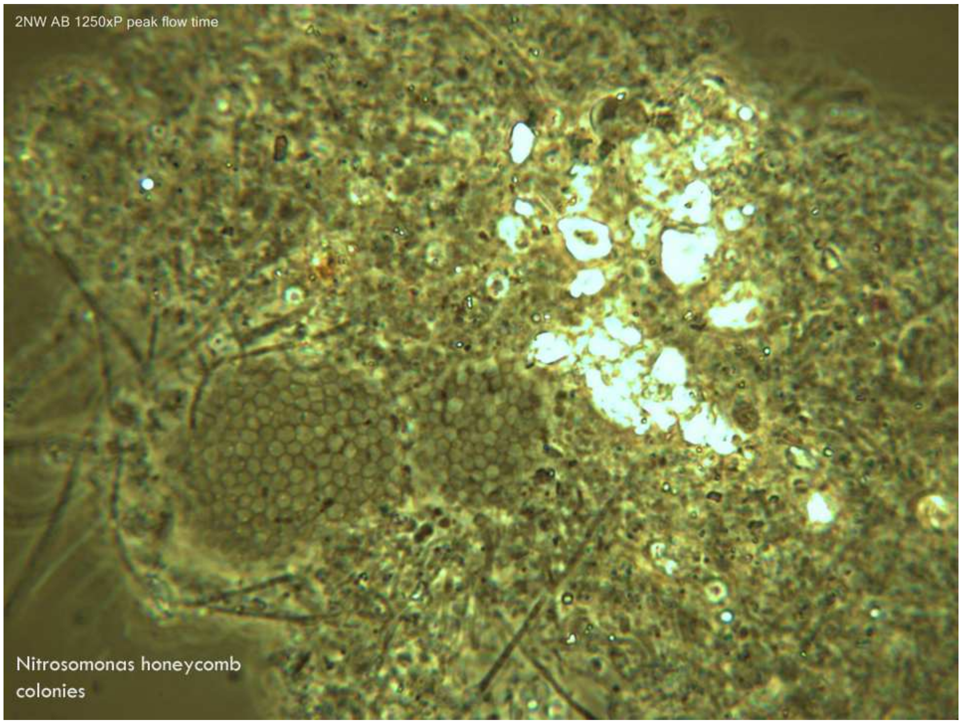


Figure 2-10 - Nitrosomonas Nitrifying Bacteria (Photo Credit: Cindy Wright-Jones)

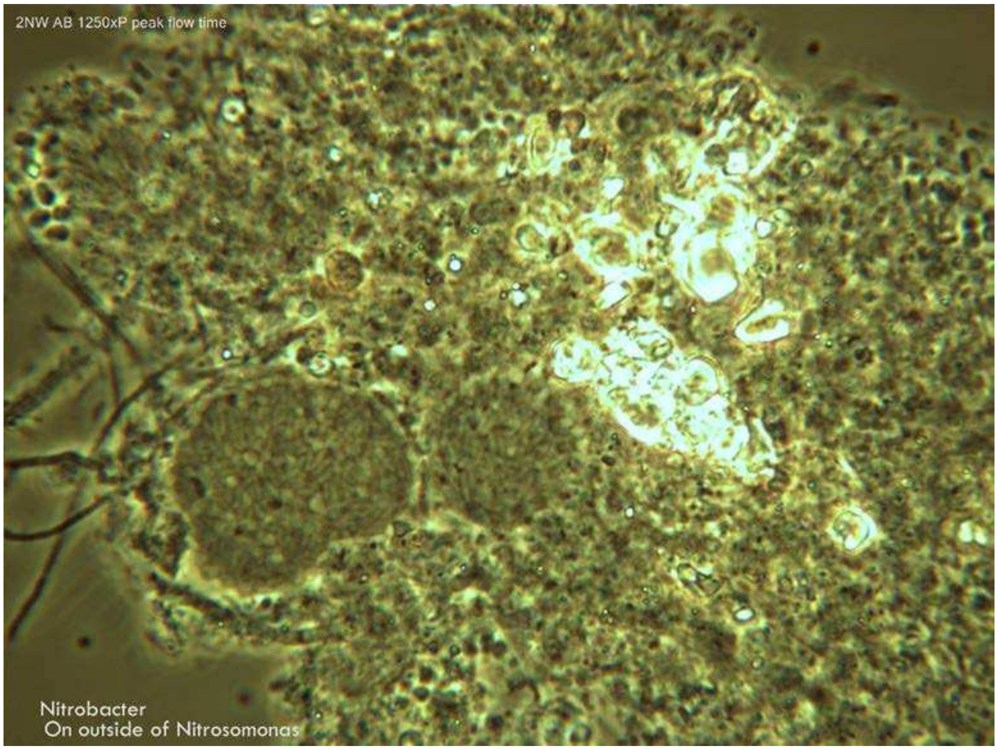


Figure 2-11 Nitrobacter Nitrifying Bacteria (Photo Credit: Cindy Wright-Jones)

2.8.3 Facility Design for Nitrification

DWRF NPT's 2 MG aeration basins (Figure 2-6) consist of two passes with a total of three aeration zones. The first pass is evenly divided between the first two aeration zones with the second pass consisting of the entire third aeration zone (Figure 2-12).

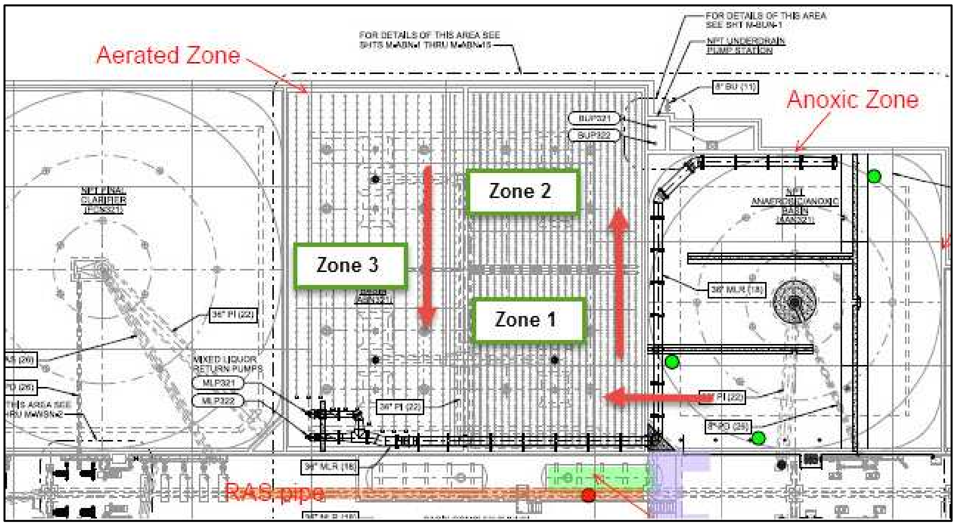


Figure 2-12 DWRF North Process Train Aeration Zones

The original Parkson diffuser system was replaced during the 2012 BNR improvements project with a Sanitaire system utilizing approximately 5,800 9-inch ceramic diffusers. Each aeration zone is controlled by Rotork automated valves with Sierra mass flow meters. The aeration zones are balanced utilizing a most open valve control program through the Siemen's blower master control panel.

2.8.4 Denitrification

When the Phase II ruling of the Safe Drinking Water Act was passed in 1991 nitrate and nitrite were assigned designated Maximum Contaminant Level Goals (MCLG) which was a signal to States and municipalities that more stringent nutrient limits were coming. Starting in 2005

DWRF plant staff was already considering modifying the plant process to include denitrification, more for the benefits of alkalinity recovery than reduced nutrient discharge. Between 2006 and 2012 the NPT and SPT operated in a “two-stage” denitrification mode where the first aeration zone was turned down to the minimum air flow required for mixing, thus creating on anoxic zone within the aeration basin. The Recycled Activated Sludge (RAS) flow rate was turned up to simulate Mixed Liquor Return (MLR) and this process modification not only significantly decreased the amount of Mg(OH)2 required for pH adjustment due to nitrification, but decreased power usage plant-wide due to lower aeration requirements.

2.8.5 Denitrification Microbiology

General discussions of denitrification theory usually include the heterotrophic organism’s reduction of nitrate to nitrite to nitrogen gas. In reality, the complete denitrification cycle consists of four reduction steps (Figure 2-13). All denitrifying bacteria are facultative aerobes (Rittmann, 2001) meaning they can utilize NO3 and NO2 if O2 becomes limiting. Common bacteria include *Pseudomonas, Paracoccus*, and *Halobacterium*. Plant microbiologist have indicated that denitrifying microorganisms are more difficult to identify under a microscope than nitrifiers, but *Hyphomicobium* can sometimes be seen (Figure 2-14).

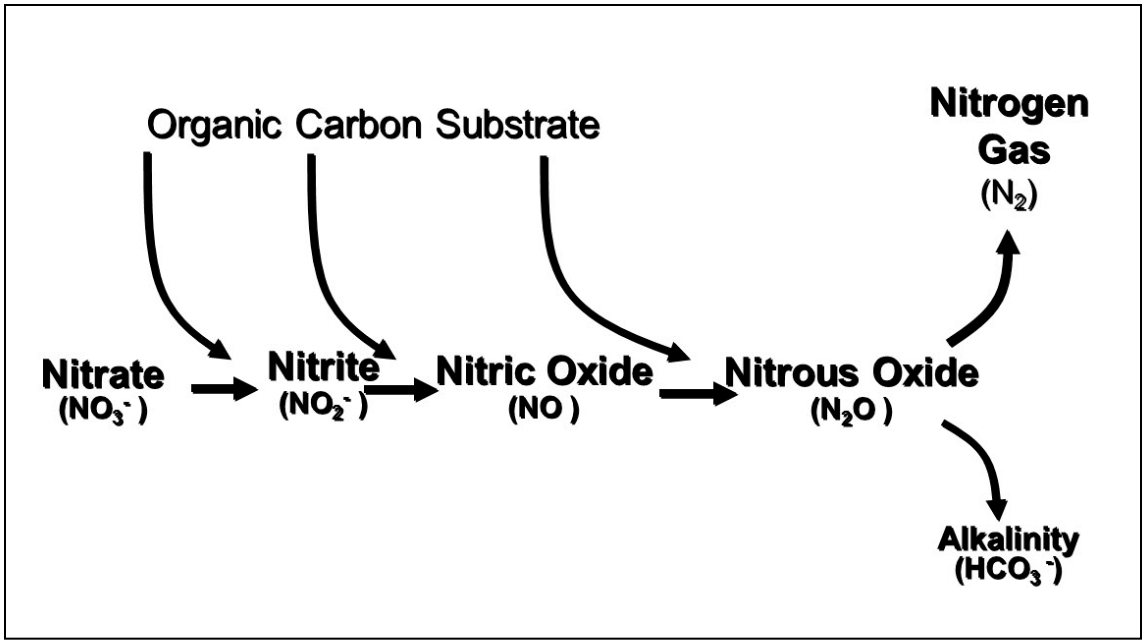


Figure 2-13 Schematic of Denitrification

Figure 2-14 Picture of Denitrifying Bacteria (Photo Credit: Cindy Wright-Jones)

While these organisms can be difficult to identify under the microscope, their effect on process makes it fairly easy to determine their existence. One example is when the operators determine that RAS chlorination is required for filament control. During this process, denitrification is usually the first process to drop out due the toxic effects of chlorine on the denitrifiers. The loss of these organisms is indicated by a decrease in available alkalinity in the aeration basin and a decrease in pH due to nitrification. Experience has shown that it typically takes 1-2 weeks for the denitrifying population to recover.

2.8.6 Facility Design for Denitrification

For the selected A2O process, denitrification takes place in the second stage of the BNR process, after the anaerobic zone, but before the aerobic zone. While denitrification prior to nitrification is not intuitive, the reason is to utilize the available carbon remaining in the process for denitrification while increasing the alkalinity of the mixed liquor prior to nitrification. Full denitrification recovers half of the alkalinity lost during the nitrification process and allows the plant to operate without adding additional chemicals for pH adjustment. DWRF's anoxic zone (Figure 2-15), comprised of approximately 2/3rd of the old intermediate clarifiers is set up in a three-pass serpentine channel to help facilitate plug flow.

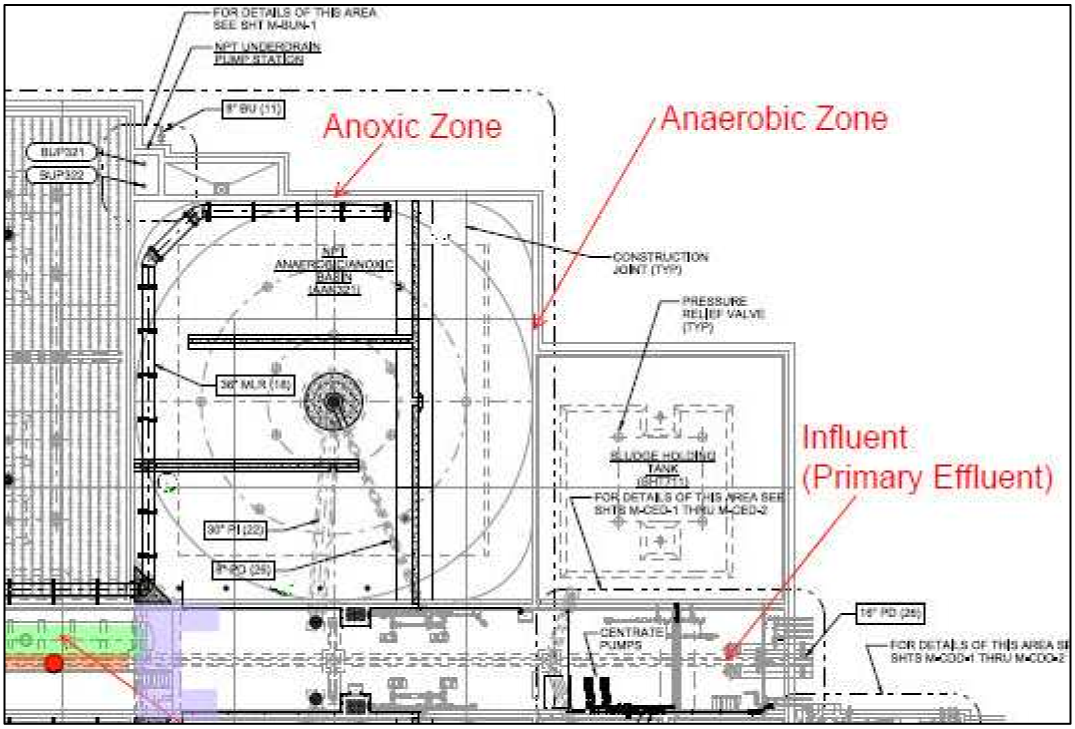


Figure 2-15 DWRF North Process Train Anaerobic and Anoxic Zones

Mixers in each pass help maintain the mixed liquor in suspension without adding additional DO into the process.

Another important part of the denitrification design is the mixed liquor return pumps and piping. 15-HP Flygt axial (or wall-fan) pumps were installed during the NPT's BNR improvements at the end of the aerobic basin (A-basin) to pull the nitrate-rich mixed liquor from the A-basin, prior to discharge to the final clarifiers, and return it to the front pass of the anoxic zone. Two instruments are located at the end of the anoxic zone for monitoring. A Hach ORP probe and a Hach Nitrate probe are located just upstream of the last anoxic pass.

One design issue that could possibly be inhibiting the denitrification process is the drop over the weir between the anaerobic zone and the anoxic zone. The weir was installed to facilitate the flow split between the east and west trains. The 1.3 foot drop appears to be aerating the mixed liquor which will inhibit denitrification until all free oxygen is consumed.

2.9 Previous Work to Address Carbon Limitations at DWRF

During the 2009 Master Plan development, BioWin modeling of the DWRF processes revealed that both DWRF and MWRF would suffer from carbon limitation in that not enough organic biodegradable carbon was available in the plant's influent stream to drive the nutrient removal process to the point where Regulation 85 limits could be met. Table 2-3 shows the restrictions predicted based upon the characterization study performed in 2008.

Table 2-3 Biological Phosphorus Removal Carbon Requirements

Parameter	Suggested Ratio (Water Environment Federation, 2011)	DWRF
COD:BOD	> 2:1	1.76
COD:TKN	> 12:1 for sufficient denitrification	10:1
COD:TP	45:1 for efficient Bio-P removal	51:1

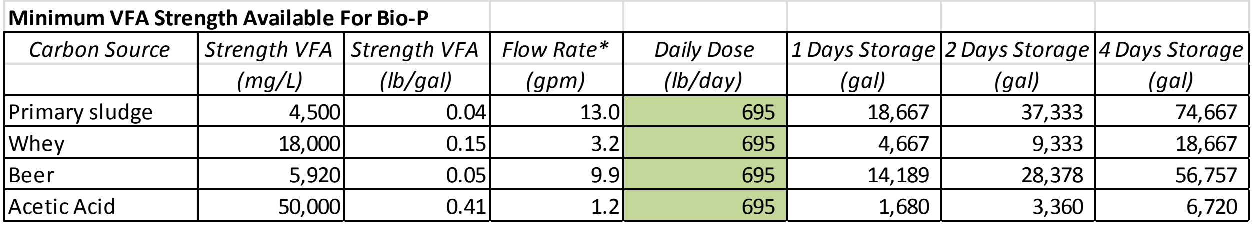
The process improvements completed at MWRF in 2011 were able to compensate for the lack of influent carbon by eliminating the primary clarifiers from the process flow. While this necessitated improvement of MWRF's preliminary treatment by upgrading to fine screens and improving the efficiency of the grit removal systems, adequate carbon appears to be available for MWRF to meet the Regulation 85 requirements under most circumstances.

These modifications were not deemed practical once the design phase for the NPT improvements commenced. DWRF is dependent on primary sludge for the gas production in the anaerobic digesters. Biogas produced in the digesters is used as fuel for the plant's two Cleaver-Brooks boilers to heat the digesting sludge to a thermophilic level of 95 degrees F. and provide a heat source for DWRF's glycol loop which heats approximately half of the facilities' buildings. The other reason was that the high ammonia and phosphorus concentrations recycled from the sludge dewatering operations would necessitate the addition of carbon to meet the limits imposed by Regulation 85. During the dewatering process, centrate from the centrifuge operations is directed to a centrate holding tank where the liquid is metered back the head of the process in an attempt to level out the ammonia and phosphorus load to the process. Ammonia levels of 950 mg/L – N and Total Phosphorus (TP) load of 120-130 mg/L-P are typical for the return flows accounting for 20-25 percent of the ammonia and phosphorus load to the plant. Research on different carbon sources including costs and safety concerns prompted plant staff and their consulting engineer to evaluate local carbon alternatives in hopes that a nearby source could be more economical, safe, and sustainable. Pilot studies utilizing an available local source were conducted.

2.9.1 Evaluation of Carbon Sources

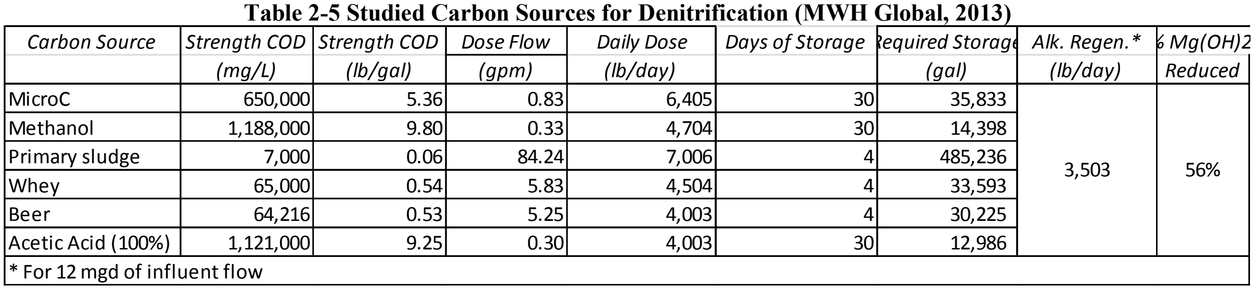
In 2011 a study for supplemental carbon sources was conducted by MWH. The direction was to find a sustainable source for additional carbon, preferably from a local vender. An evaluation was conducted of various carbon sources being used around the industry. Tables 2-4 and 2-5 show values for VFA Concentration and storage requirements for the forms of carbon that were evaluated.

Table 2-4 Studied Carbon Sources for Enhanced Bio-P (MWH Global, 2013)



Minimum VFA Strength Available For Bio-P							
Carbon Source	*Strength VFA (mg/L)*	*Strength VFA (lb/gal)*	*Flow Rate* (gpm)*	*Daily Dose (lb/day)*	*1 Days Storage (gal)*	*2 Days Storage (gal)*	*4 Days Storage (gal)*
Primary sludge	4,500	0.04	13.0	695	18,667	37,333	74,667
Whey	18,000	0.15	3.2	695	4,667	9,333	18,667
Beer	5,920	0.05	9.9	695	14,189	28,378	56,757
Acetic Acid	50,000	0.41	1.2	695	1,680	3,360	6,720

Table 2-5 Studied Carbon Sources for Denitrification (MWH Global, 2013)



Carbon Source	*Strength COD (mg/L)*	*Strength COD (lb/gal)*	*Dose Flow (gpm)*	*Daily Dose (lb/day)*	*Days of Storage*	*equired Storag (gal)*	*Alk. Regen.* (lb/day)*	*Mg(OH)2 Reduced*
MicroC	650,000	5.36	0.83	6,405	30	35,833	3,503	56%
Methanol	1,188,000	9.80	0.33	4,704	30	14,398		
Primary sludge	7,000	0.06	84.24	7,006	4	485,236		
Whey	65,000	0.54	5.83	4,504	4	33,593		
Beer	64,216	0.53	5.25	4,003	4	30,225		
Acetic Acid (100%)	1,121,000	9.25	0.30	4,003	30	12,986		

* For 12 mgd of influent flow

The City also indicated a preference for a carbon source that would work for nitrogen and phosphorus removal, eliminating Micro C and Methanol from the list. The amount of tankage required for primary sludge fermentation and the odor issues perceived with this form of supplemental carbon decreased the desirability of this option. Given the number of breweries existing in Fort Collins, the City wanted to explore the viability of using industrial waste streams from various breweries for supplemental carbon. Plant staff called the breweries and three were willing to provide samples of their various waste streams for analysis. Table 2-6 shows the laboratory analysis conducted on the waste streams. The truck waste from brewery 2 (Odell's)

Table 2-6 Water Quality Data for Studied Beer Waste Sources (MWH Global)

Brewery	Description	COD	sCOD	ffCOD	TKN	NH_3	NO_2	NO_3	TPO_4	OPO_4	SS	BOD_5	$sBOD_5$	VSS
No.		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
	Standard Method	5220D	5220D	5220D	351.2	350.1	353.2	353.2	365.1	365.1	2540D	5210B	5210B	160.4
1	post anaerobic treatment	1,223	224	192	73	60.5	0.1	<0.05	53	45.865	870	126	26	460
1	inlet to treatment	8,851	664	678	60	2.15	0.09	16.25	46	29.06	1420	5,239	>4,116	940
1	spent yeast	171,949	20,636	NA	105	10.73	0.11	0.8	897	269.523	72,500	88,092	45,649	68,500
2	truck waste (trub, spent yeast)	84,674	5,575	>50000	174	19.42	0.44	1.48	204	112.554	19,900	49,992	38,349	17,600
2	sanitary waste, floor drains	2,162	NA	>1000	22	1.33	0.09	<0.05	7	2.5	1,180	1,236	1,599	425
3	spent grain	89,670		15,652	32	4.09	0.05	1.24	419		51,400	37,094		49,800
3	still bottom	34,339	20,609	13,912	105	23.2	<0.05	0.11	294	131.808	15,230	14,587	9,247	14,620
3	spent yeast	341,632			95	49.7	<0.05	1.05	2,074		139,600	110,500	51,750	127,500
3	trub	245,133				0.49	<0.01	<0.01	3			91,250	60,500	

was selected as the experiment source because of it's high COD, relatively low nutrients, and lower suspended solids.

2.9.2 Beer Waste Bench-Scale Testing

Following the survey of local breweries, the City of Fort Collins began working with Odell's brewery to try using their brewery waste as a carbon source. The first bench-scale testing in the Summer of 2011 conducted by the City of Fort Collins Pollution Control Lab (PCL), showed that the beer waste was not only an excellent source for Chemical Oxygen Demand (COD), but provided propionic acid (Figure 2-16) which is a desirable source of VFA for BioP removal (Water Environment Federation, 2011). The bench-scale tests also showed indications of increased COD and propionic acid levels when the beer waste was allowed to ferment. The bench-scale tests gave indications that a 2-3 day detention time with adequate stirring achieved the highest values for COD and propionic acid.

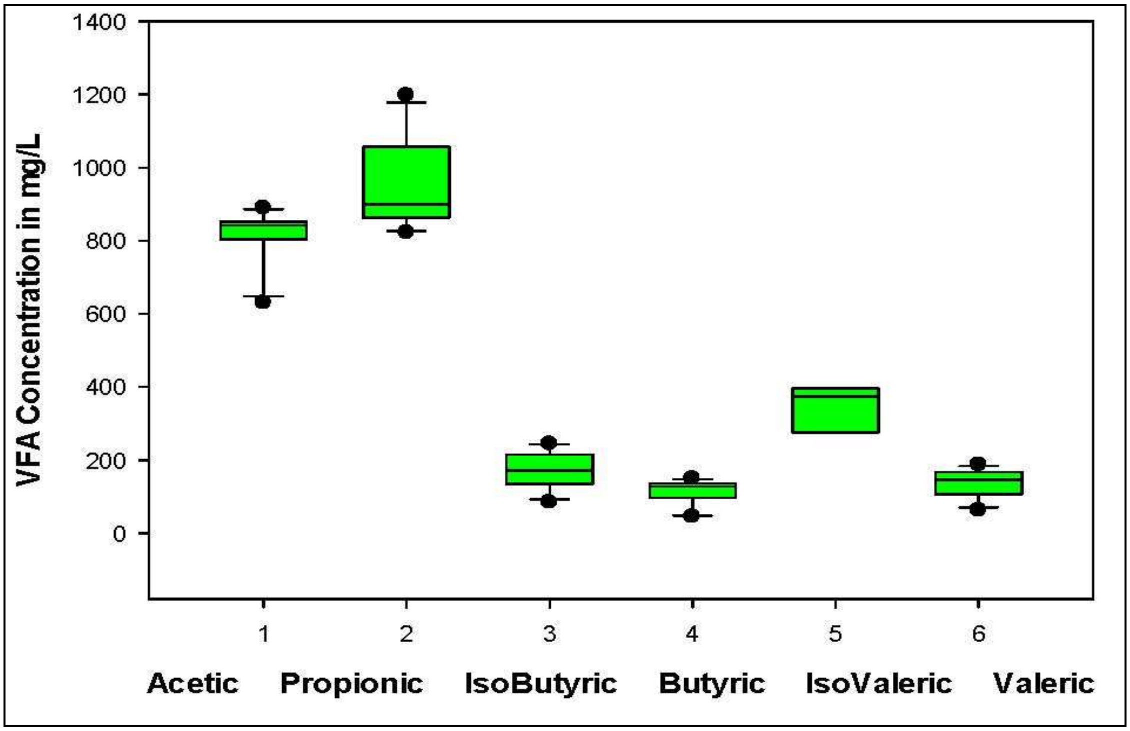


Figure 2-16 Acetic Acid Concentrations from Bench Scale Testing

2.9.3 Mulberry Water Reclamation Facility 2012 Pilot Test

MWRF's 3-stage BNR process came on-line in July 2011, giving the City an opportunity to test carbon addition at one of its own facilities. The elimination of MWRF's primary clarifiers and the replacement of preliminary treatment with improved screening and grit removal increased the concentration of BOD entering the plant's secondary system thus decreasing the need for supplemental carbon addition. It was hoped that the addition of supplemental carbon would help determine the benefits of the beer waste. A 5,000 gallon tanker trailer and a 1.0 hp pump were utilized to feed the waste into the influent stream just before the preliminary effluent pump station (PEPS). The 6-week study showed that the introduction of the beer waste decreased the effluent nitrogen on average from 5.1 mg/L to 0.5 mg/L. Effluent phosphorus decreased from 0.8

mg/L to 0.2 mg/L (MWH Global, 2012). It also revealed that more effort was required in the storage and feed systems due to the heavy sediment loads in the beer waste.

2.9.4 Drake Water Reclamation Facility Pilot 2013

DWRF's North Process Train conversion to a 3-stage BNR process was completed in September 2012. In February 2013, a 9-week pilot was conducted utilizing beer waste from Odell's Brewery. One of the train's two 16,000 gallon storage tanks was converted to beer waste holding and, learning from the MWRF pilot, 4 horizontally-mounted pumps were installed within the tank to provide constant mixing of the material. A Brendal SPX-25 peristaltic hose pump was temporarily borrowed from the magnesium hydroxide feed system to be utilized as a beer waste feed pump which discharged the beer waste directly into the RAS return as shown in Figure 2-17

Figure 2-17 Phase 2 Carbon Feed System

The results of this pilot were disappointing due to a number of factors:

- The pump rate of the Brendal SPX-25 used to feed the beer waste maxed out at 1.5 gpm and was insufficient to determine an optimal dosing rate.
- Beer waste supply was not always consistent during most weekends due to reduced production at the brewery so the beer waste flow rate had to be turned down or shut off because of low storage tank levels at the plant
- The Variable Frequency Drive (VFD) used to control the metering pump was not tied into the plant’s Supervisory Control and Data Acquisition (SCADA) system and needed operator intervention to adjust the dosing. During early morning low influent flow periods at DWRF, very low ORP values (< -300 mV) occurred in the anoxic zone and a floating scum layer appeared in the anaerobic zone.
- Finally, due to the lack of available beer waste, the increase in VFA’s due to extended detention times in the holding tank could not be realized. The 2013 pilot study did still show some promise of nutrient removal with decreased effluent phosphorus concentrations during periods of high beer waste flow (Figure 2-18), so plant staff were directed to continue studying the feasibility of using the beer waste. The two peaks of nitrogen species shown during the test period were the result of RAS chlorination required for filament control.

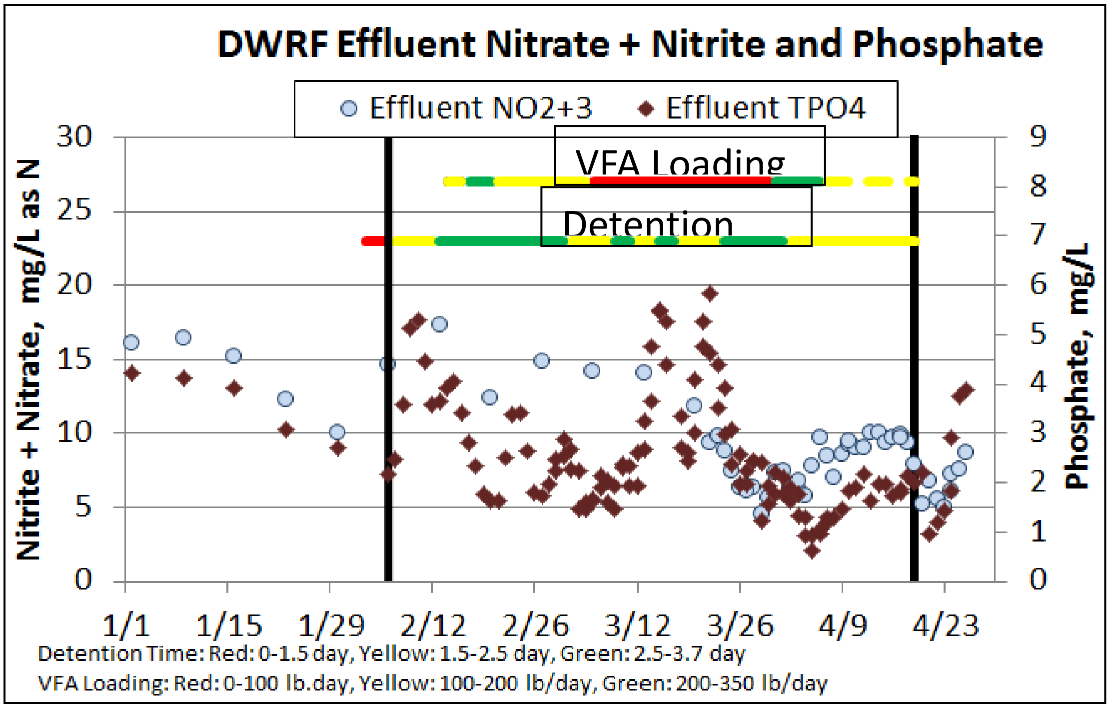


Figure 2-18 Nutrient Values From Phase 2 Study (MWH Global, 2013)

2.10 Carbon Dosing

One of the issues that needed to be overcome to successfully supplement beer waste to DWRF was adequate dosing control. The MWRF pilot attempted to utilize various types of valves to throttle the flow into the process. The City tried pinch valves, plug valves, and ball valves but all of these had a tendency to clog with the high sediment loads in the beer waste. During the first DWRF pilot, a VFD was incorporated in the system but had to be manually set by an operator. Since neither plant is manned 24 hours a day this setup did not allow for adjustments based upon plant loading. During the aborted pilot attempt in the spring of 2014, time step programing was introduced where the operator could input 4 different flow rates to begin at different times of the day. The difficulty is carbon dosing motivated investigation of alternative dosing methods such as the use of use of ORP to control dosing.

2.11 Use of Oxidation Reduction Potential for Carbon Dosing Control

2.11.1 Oxidation Reduction Potential Defined

In wastewater systems where biochemical reactions are taking place, electrons are being exchanged between different constituents in the reactions. Oxidation causes the loss of electrons by an element while reduction involves the gain of electrons. Since there cannot be a buildup of free electrons in a system (Brezonik, 2011) when a species is oxidized, another is reduced. Wastewater influent contains numerous constituents, so in each reactor vessel there are multitudes of oxidation and reduction half reactions occurring, making quantitative evaluation of the process state difficult to determine thermodynamically (Peddie, 1988).

Process design can facilitate the prediction of specific reactions such as denitrification in an anoxic zone. The potential for a specific reaction to occur is given in terms of E^o or Reduction Potential. This is the net reaction between the E^o for both the oxidation and reduction half-reactions shown in Equation 2.1

Equation 2-1 Reduction Potential Equation

$$E_{net}^{o} = E_{reduction}^{o} - E_{oxidation}^{o}$$

2.11.2 Historical Perspective on ORP

The earliest reference to the use of oxidation-reduction potential in the context of wastewater was 1906 (Dirasian, Molof, & Borchardt, 1963). In the 1940's, there was considerable excitement about the use of ORP in determining the condition of different processes, especially anaerobic and activated sludge (Hood, 1947). However, in the 1960's, due to the supposedly insurmountable task of being able to fully rationalize the theoretical aspects of ORP, the common belief that reliable ORP readings were difficult to obtain, and the advent of dissolved oxygen monitors, the use of ORP in wastewater processes was discouraged (Oldham, 1985). The late 1970's and 80's brought about the beginnings of full scale Biological Nutrient Removal (BNR) and thus the greater need for a way to monitor processes in environments where free oxygen is neither required or desired. Research began to indicate that although the exact values of ORP reflected all of the factors that contribute to electron activity (biological activity, influent substrate, pH, and temperature), for a given system, the pattern of ORP responses were reproducible (Peddie, 1988). A sensor similar to a pH probe was found to be most reliable instrument utilizing a platinum indicating sensor measured against an Ag/AgCl reference electrode with electrical contact maintained through a potassium chloride solution. The experimentation also concluded that the only reproducible and reliable method of taking measurements was *in-situ* monitoring (Oldham, 1985). The ORP probe electrode behavior can also be explained by expansion of Equation 2-1, into the Nernst Equation (Equation 2-2).

Equation 2-2 Nernst Equation

$$E = E_0 - \frac{\mathrm{R} \times \mathrm{T}}{\mathrm{n} \times \mathrm{F}} \ln \frac{\mathrm{C}_{ox}}{\mathrm{C}_{\mathrm{red}}}$$

Where:

E = measured potential (mV) between the platinum and the reference electrode

E_0 = measured potential (mV) between the platinum and the reference electrode at a concentration of Cox = Cred

R = Universal gas constant (R = 8.314 J mol-1 K-1)

T = Temperature in K (Kelvin), where T (K) = 273.15 + t°C and t is the temperature of the measured solution

F = Faraday constant (96485 C mol-1)

n = electrical charge of the ion

C_{ox} = oxidant concentration in moles/L

C_{red} = reductant concentration in moles/L.

2.11.3 ORP and Nitrates

As previously discussed, the removal of NO_3 is an important goal in DWRF's nutrient removal process. The ability to monitor denitrification in the anoxic zone to determine system performance is critical. Since denitrification involves the reduction (through several steps) of NO3 to N2, the resultant ORP readings for this portion of the process will be negative. Several past research articles provide guidance on the values desired.

In an article published in 1985 (Oldham, 1985), pilot plant process configurations are discussed that were attempting to separate an anaerobic zone in an activated sludge process into two sub-zones, a sludge conditioning zone that denitrified the sludge and a true anaerobic zone that facilitated the production of VFAs which at the time was thought to facilitate the phosphorus release portion of enhanced Bio-P removal. Figure 2-19 shows an interesting tendency that the

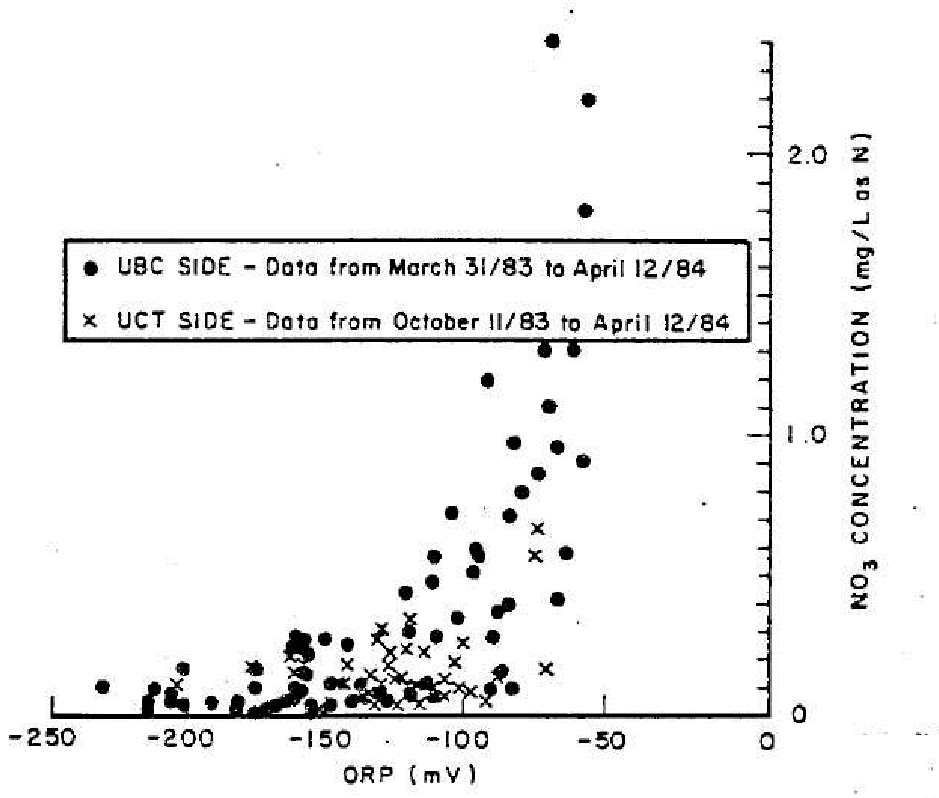


Fig. 6 Scatter plot of sludge conditioner nitrate vs. ORP data

Figure 2-19 ORP values within Sludge Conditioning Zone (Oldham, 1985)

lowest NO$_3$ values occur in the -150 mV to -250 mV range. The study also noted that the ORP readings seem to depend on the mass of nitrates entering the system via the RAS, and the amount of denitrification taking place which was also dependent on the influent waste strength. This information would seem to indicate a range to attempt to maintain for maximum denitrification. In the 1990’s several papers were written on studies attempting to utilize ORP readings to automatically control aeration in Sequencing Batch Reactors (SBR). The first study (Wareham, 1993) identified the nitrate breakpoints, or “knee’s” that occur through the SBR sequence. The first knee point during the aeration phase appeared to be the result of the completion of oxidation of NH3 and a signal to turn off the aeration (Figure 2-20).

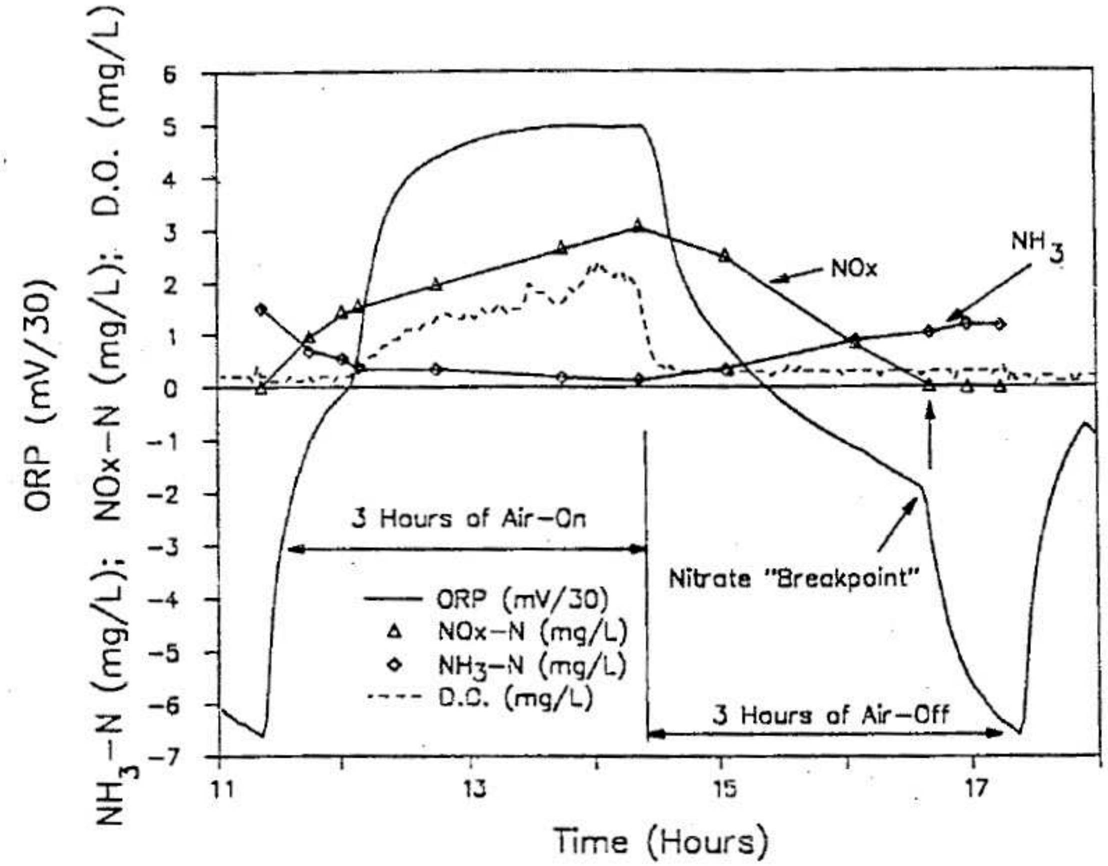


Fig. 1. Nitrate breakpoint occurring in ORP-time profile.

Figure 2-20 Chart showing Nitrate bend points

After the first knee, the ORP readings make a steep decline, indicating the reduction of the nitrate through the different species to nitrogen gas. At the completion of the denitrification the ORP readings then take an even sharper decline seeming to indicate a true anaerobic phase until the aeration was restarted. For the purposes of our investigation, this provides a distinct link between the ORP readings and the completion of denitrification.

Several years later, another study (Plisson-Saune, 1996) provided additional clarification to the ORP-nitrogen relationship. It was determined that the first ORP deflection point was not due primarily to the elimination of NH3, but due to the increase in DO after the oxidation of NH3 was complete. Another finding in this study was the reason for the sudden increase the negative slope of the ORP readings at the end of the denitrification period. After the elimination of nitrate, sulfate-reducing bacteria increase their reduction activity causing the downward trend. This will be a condition the current investigation will seek to avoid since not only will having the anoxic zone in this extremely low ORP condition be a waste of carbon, but the plant desires to minimize the excess production of sulfides to avoid odor and corrosion issues.

Based upon the research it appears that ORP can be a valid indication of successful denitrification. While exact measurements of ORP readings due not appear to be useful, past data appears to indicate that ORP readings are repeatable and can be used to indicate the state of nitrogen in an process environment. A control description for the beer waste dosage pump was programmed to increase or decrease its flow rate in an attempt to maintain an ORP value of -280 mV. If the ORP reading decreases to below -300 mV, the flow rate for the pump would decrease, reducing the carbon feed to the anaerobic and anoxic zones. If the ORP value increased to above -250 mV the beer waste flow would increase to add additional carbon to the system. The control description will be adjusted as necessary to optimize denitrification in the anoxic zone.

3 PILOT TESTING TO ANALYZE THE EFFECTIVENESS AND DOSAGE OF BEER WASTE ON AN ANAEROBIC ANOXIC OXIC (A2O) BIOLOGICAL NUTRIENT REMOVAL PROCESS

3.1 Introduction

The City of Fort Collins Water Reclamation Facilities Master Plan Update 2009 proposed an A2O process for the DWRF's North Process Train. The A2O processes major advantage over other BNR processes was its ability to be "easily" expanded to a 5-stage Bardenpho process in the event that more stringent regulations are implemented in the future. While the 3-stage A2O process can theoretically meet the nitrogen and phosphorus limits identified in the State's regulation 85, the second tier improvements that could come into play after the State's nutrient evaluation in 2023 could result in the need for enhanced nutrient removal (ENR) with the 5-state Bardenpho plus chemical additional and tertiary filtration for more phosphorus removal.

It was also determined that DWRF carbon limitations would impact ability to meet the Regulation 85 requirements (MWH Global, 2009) even with the A2O improvements. Some form of carbon addition capable of driving denitrification and enhanced BioP was going to be needed. Following the lead of the Colorado Springs Utilities (CSU), the City of Fort Collins, began a search of local industries to determine if there was a locally available carbon source to augment the secondary treatment process. In 2009, CSU began working with a local Colorado Springs dairy to utilize dairy whey to fuel their nutrient removal process (Brischke, Olds, Adams, Hardison, & Rieger, 2010).

The bench-scale testing discussed in Section 2.9.2 showed that beer waste could be a viable carbon source to provide the required substrate for meeting the nutrient limits set forth in Regulation 85. Starting from the lessons learned from the previous pilot phases, the 2015 pilot was modified and during the initial 6-week period added beer waste at different dosages, durations and times of the day to observe its impact on process performance.

3.2 DWRF Carbon Addition Pilot 2015 Setup

In July 2015 DWRF plant staff began the addition of beer waste to the North Process Train. Figure 3-1 shows the beer waste addition setup. Beer is loaded off the beer truck at the north chemical receiving dock. The 2000-gallon tanker truck used a pressure/vacuum pump to off-load the beer which travels approximately 200 feet down the north tunnel through a 3-inch fibercast pipe into the tank.

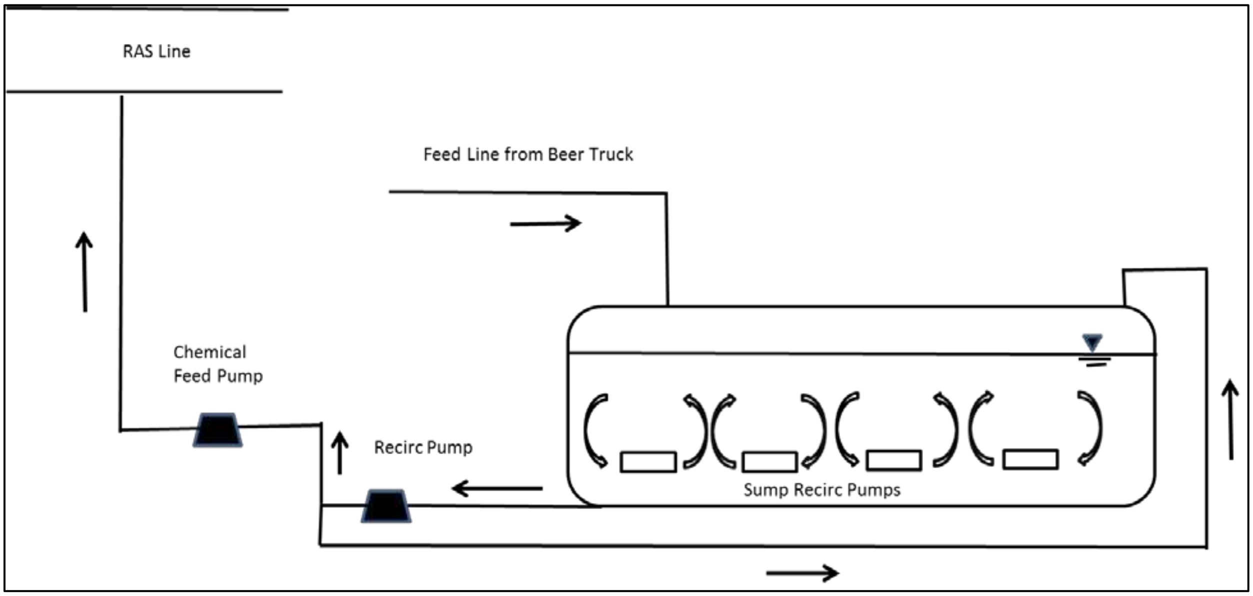


Figure 3-1 Schematic of Phase 3 Carbon Addition System

3.2.1 Beer Waste Addition Modifications

Lessons learned from the 2013 DWRF pilot and the aborted 2014 attempt at carbon addition led to numerous improvements for the 2015 attempt. The following is a list of improvements added:

- In addition to the existing recirculation pump which was an existing progressive cavity gear pump that draws off the bottom of the tank and discharges into the top of the far south end, four horizontally mounted 1-HP sump pumps were added. The pumps were positioned such that two adjacent pairs would discharge toward each other and create a vertical vortex mixing pattern. This setup should help prevent the solids deposition that occurred during the last attempts.
- The Chemical Feed Pump was upgraded from the SPX-25 to a Brendel SPX-40. The reasoning for this pump selection is that it is the same model and capacity of pump that is used in the polymer feed system and can be used as a spare. The pump rate span it larger than needed (2-13 gpm) but plant staff was able to decrease the motor frequency enough utilizing a Variable Frequency Drive (VFD) that a pump rate of 0.5 gpm could be achieved. Once a permanent system is installed, a more suitable pump for this application may be a Brendel SPX-32 with a range of 0.5- 9 gpm.
- The pump (VFD) was connected directly into the SCADA system allowing for system automation. The control schemes available were constant flow rate, timed-step flow, and variable flow based on ORP readings.
- The injection point for the beer waste was located on the east side of the RAS line during the Phase 2 pilot. Major differences in ORP readings during low beer waste flows or high RAS flows seemed to indicate that the carbon feed would favor the east train in

these conditions. During this phase, the carbon injection point was relocated to a point at the bottom of the RAS line approximately 20 feet closer to the mixing box. This helped divide the carbon addition more equally between the two basins during different flow conditions.

3.2.2 Proposed Sample Locations and Parameters

Analyzing wastewater characteristics before and after secondary treatment is important in determining what is happening in the secondary treatment process. Figure 3-2 is a layout diagram of DWRF identifying all of the major facilities. The sample locations identified are locations that have existing composite samplers that are utilized by the Pollution Control Lab (PCL) and plant staff for regulatory and process control sampling. These composite samplers are set up on a flow-paced sampling protocol where a solenoid valve opens and draws a set sample volume upon receiving a digital signal from a Programmable Logic Controller (PLC). The PLC sends the signal, or pulse, for every 10,000 gallons read on the influent metering flume.

The first location in the wastewater process that the pilot will be conducting additional tests is “2CINF” (Figure 3-2), or combined influent. On all plant sample locations, the “2” stands for Plant 2, or DWRF. "2CINF" is after the raw influent stream is mixed with the plant sidestreams and pumped up into the headworks, through the mechanical screens. Samples from this location showed the influence of the additional ammonia and phosphorus loads from centrate on the secondary system. This location also provided a level of influent carbon and helped calibrate the PCL’s BOD5 daily samples with Total and soluble COD sampling.

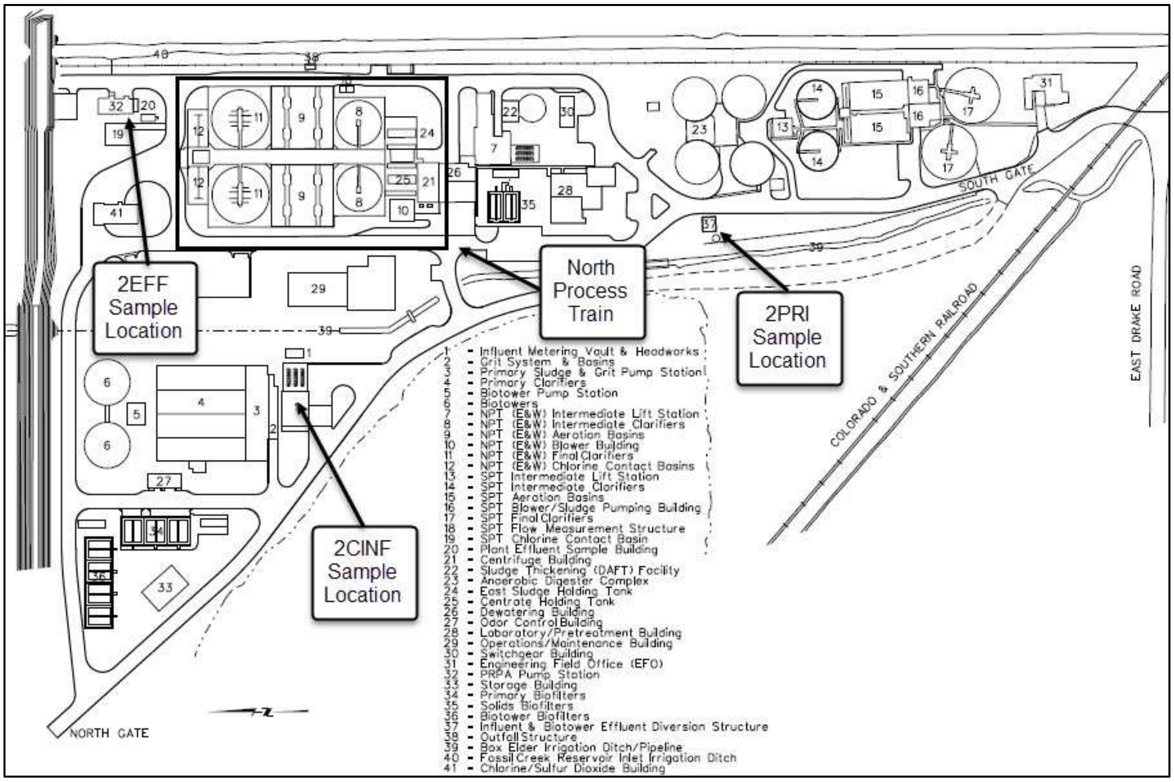


Figure 3-2 Diagram of DWRF excerpt from (MWH Global, 2009)

The next location was “2PRI”. This stands for Primary Effluent and was located after the primary clarifiers in the diversion structure where the primary effluent is split between the north and south process trains. This location provided information on wastewater characterization just prior to entering the secondary treatment processes. COD tests in this location showed the actual organic loading to the secondary processes prior to carbon addition.

The location “2EFF” is the plant’s effluent sampling station. The composite sampler in that location collected sample post-SO2 injection and is the plant’s regulatory discharge sample point. Since this is the location that will be used to collect nutrient water quality samples, it was logical to utilize it for determining the effectiveness of carbon addition.

3.2.3 North Process Train Layout and Sample Locations

The North Process Train as shown in Figure 3.3 was originally built as a traditional activated sludge plant in 1974, converted to BNR in 2012. The green dots show the grab sample locations for the pilot test. These grab samples were taken as the process flow entered the A2O process, leaving the anaerobic zones, and leaving the anoxic zones. Grab samples were also taken from the beer waste tank daily before any deliveries were added and a sample was taken from the delivery truck after several minutes of pumping to ensure that the sample did not contain a misrepresentative amount of sediment.

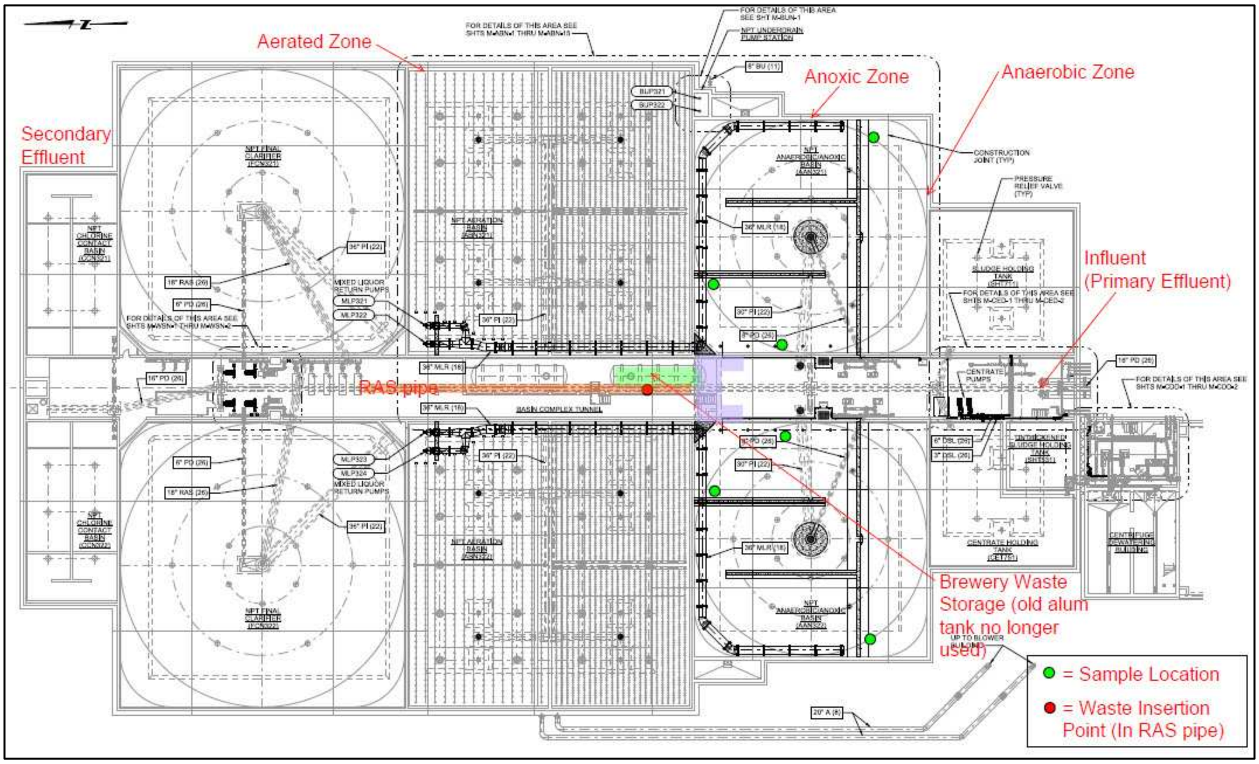


Figure 3-3 Diagram of DWRF North Process Train

3.3 Water Chemistry Testing

3.3.1 Wet Chemistry Testing Locations

Table 3.1 shows the locations and types of tests conducted during the data collection period of the pilot. When the area operators collected the composite samples, they would pour out a separate 125 ml sample for the pilot study and leave it in the composite refrigerator for pick up by the duty lab operator. The duty lab operator gathered the daily grab samples between 9:30-10:00 a.m. and set them in the lab refrigerator at 4 deg C until their other process duties were completed. The tests included total chemical oxygen demand (tCOD) and soluble chemical oxygen demand (sCOD) along with the orthophosphate (OPO_4) and Volatile Acids as acetic acid equivalents

Table 3-1Water Quality Sample Locations

Sample	Type	Description	sCOD	tCOD	OPO4	NH3-N	NO3-N	NO2-N	Volatile Acid
2CINF	Composite	Combined Plant Influent	x	x					
2PRI	Composite	Primary Effluent	x	x					
2EFF	Composite	Plant Effluent			x	x	x	x	
2NEINF	Grab	Northeast Influent Channel	x						
2NWINF	Grab	Northwest Influent Channel	x						
2NEAN	Grab	Northeast Anaerobic Zone	x						
2NWAN	Grab	Northwest Anaerobic Zone	x						
2NEAX	Grab	Northeast Anoxic Zone	x				x	x	
2NWAX	Grab	Northwest Anoxic Zone	x				x	x	
Beer Truck	Grab	Beer Truck discharge line	x						x
Beer Tank	Grab	Beer tank after flow meter	x						x

3.3.2 Process Water Chemistry Analytical Methods

The Chemical Oxygen Demand (COD) tests were done using the Hach mercury-free reactor digestion method 10236 (High-Range) with a HACH DR2800 spectrophotometer. The tCOD tests were done utilizing a well-mixed sample while the sCOD tests samples were taken after the samples were centrifuged for 3 minutes to settle out the solids instead of the usual 0.4 *u*m filter . The sample is heated for 2 hours with potassium dichromate. Oxidizable organics react, reducing the dichromate to a green chromic ion. The measurement wavelength is 605 nm (HACH Company, 2014)

Ammonia was analyzed using HACH low range ammonia method 10205 and a HACH DR2800. Since the effluent samples were immediately refrigerated and tested that day, no additional preservation was utilized. The ammonium ions react with hypochlorite and salicylate ions to form indophenol. The amount of color formed is directly proportional to the amount of ammonia nitrogen in the sample. The measurement wavelength is 690 nm (HACH Company, 2014). Nitrate tests were analyzed with HACH Nitrate – Dimethylphenol Method 10206 with a HACH 2800 spectrophotometer. Nitrate ions react with 2,6-dimethylphenol to form 4-nitro-2,6-dimethylphenol. The measurement wavelength is 345 nm. No additional preservation methods other than refrigeration were necessary.

Nitrite levels were measured using HACH Nitrite Method 10207 which is also the USEPA Diazotization Method. Because the samples were analyzed within 48 hours, no additional preservation was needed. The HACH DR 2800 was also used for this test. Nitrite reacts with a primary aromatic amine to form a diazonium salt, which combines with an aromatic compound to form a complex that has a color directly proportional to the nitrite in the sample. The wavelength measured is 515 nm (HACH Company, 2014).

Volatile Acids in the beer waste were analyzed with HACH Volatile Acids esterification method 10240 and the DR 2800. The beer waste from both the truck and the tank were sampled within 4 hours so no preservation other than refrigeration was required. The samples were centrifuged for 6 minutes to separate the solids and the supernatant was then analyzed. The volatile acids in the sample react with diols to form fatty acid esters. These are reduced with ferric to form red complexes. The wavelength measured is 497 nm (HACH Company, 2015).

3.3.3 Laboratory Water Quality Methods

The Pollution Control Lab uses either Standard Methods or EPA methods for their analysis of composite samples. The total phosphorus test method was EPA 365.1. NO_2 and NO_3 tests utilized EPA method 353.2 by Flow Injection. NH3 was measured using EPA method 350.1.

3.4 Water Quality Instrumentation

3.4.1 Water Quality Probe and Analyzer Locations

In addition to sample analysis in the laboratory, various water quality probes and wet chemistry analyzers existed in the North Process Train and Plant Effluent instrument system. Figure 3-4 shows the location of these instruments in the system. The majority of the pilot concentrates on data from the ORP probes, NITRATAX probes, and the online PHOSPHAX analyzer.

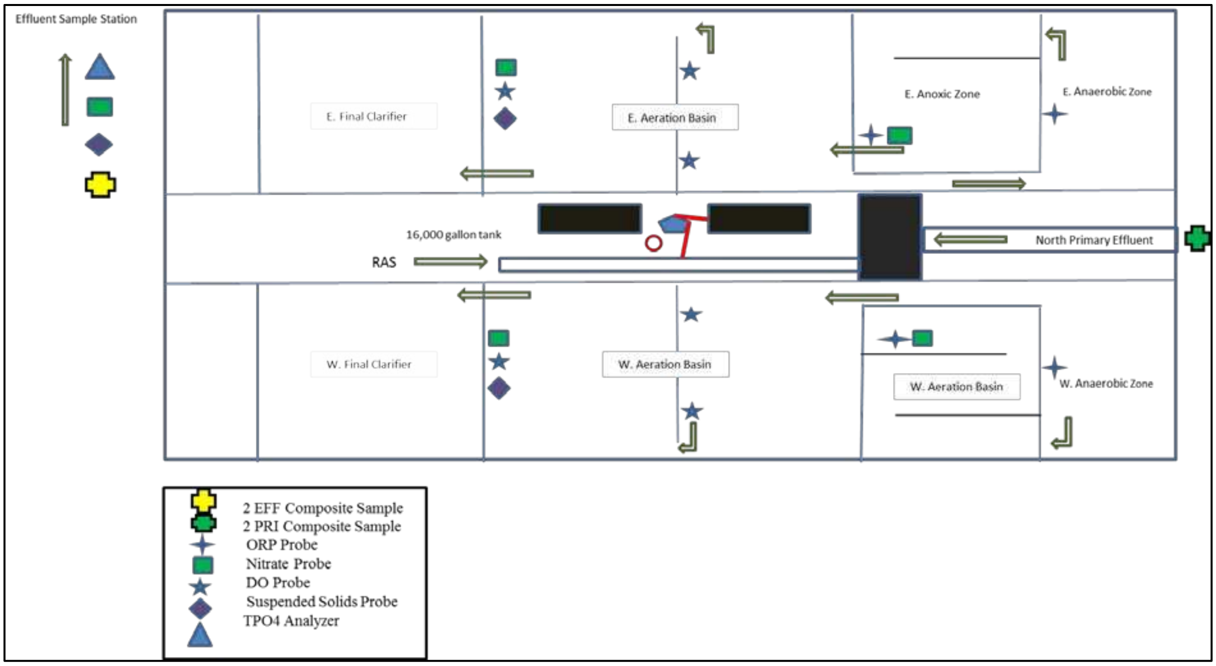
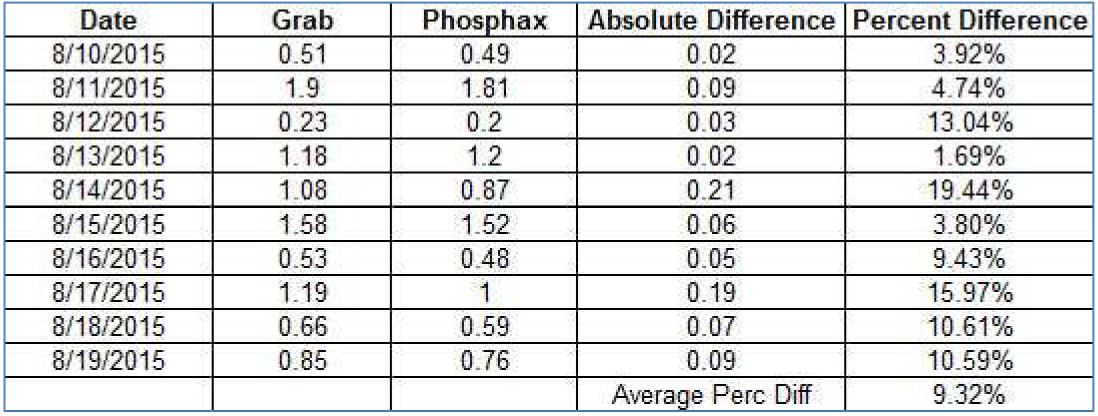


Figure 3-4 Water Quality Instrumentation Locations

The Hach PHOSPHAX^{TM} Phosphate Analyzer provides for continuous sampling of orthophosphate at 10 minute sampling intervals. The sample is drawn from the post chlorination sample line in DWRF's sample station and is filtered through a 0.2 *u*m filter before entering the unit. Because of this, particulate phosphorus is not measured, but it gives plant staff an indication of how the enhanced Bio-P process is operating. The unit uses the vanado-molybdate yellow colorimetric method for measurement (Hach Company, 2011). A comparison of the instrument readings of the PHOSPHAX was conducted during the sample period (Figure 3-2) by testing the instrument feed line utilizing the Hach low-range orthophosphorus tests. Readings were taken at different times of day and different effluent flow rates. Almost all of the grab sample readings were higher than the instrument readings and this can be attributed to the grab sample being taken prior to the instrument filter. The ~10% difference provides enough accuracy for process control.

Table 3-2 Comparison of Phosphax to Hach Ortho-Phosphorus Tests



Date	Grab	Phosphax	Absolute Difference	Percent Difference
8/10/2015	0.51	0.49	0.02	3.92%
8/11/2015	1.9	1.81	0.09	4.74%
8/12/2015	0.23	0.2	0.03	13.04%
8/13/2015	1.18	1.2	0.02	1.69%
8/14/2015	1.08	0.87	0.21	19.44%
8/15/2015	1.58	1.52	0.06	3.80%
8/16/2015	0.53	0.48	0.05	9.43%
8/17/2015	1.19	1	0.19	15.97%
8/18/2015	0.66	0.59	0.07	10.61%
8/19/2015	0.85	0.76	0.09	10.59%
			Average Perc Diff	9.32%

The Hach NITRATAX^{TM} sc UV Nitrate Sensor probes are located at the end of the anoxic zones and in the 3rd zone of the aeration basin. These immersion probes are lowered into the process flow and utilize ultraviolet (UV) adsorption technology to measure nitrate concentrations. The unit uses the principle that molecular bonds adsorb UV light to measure nitrate concentrations. A photometer measures the primary beam of UV light while a second beam provides a reference and corrects for turbidity interferences (Hach Company, 2011)

ORP is measured using Hach Differential ORP sensors. Plant staff prefers using this type of immersion probe for pH and ORP because of the durability and ease of maintenance. The ORP probes measure electron activity using platinum and reference electrodes. These probes are located mid-way through the anaerobic zones and at the end of the anoxic zones.

3.5 Statistical Tools

To help analysis the data, especially the weekly composite effluent testing conducted by the PCL, box plots are used. Figure 3-5 provides an explanation of the features of boxplots as used here.

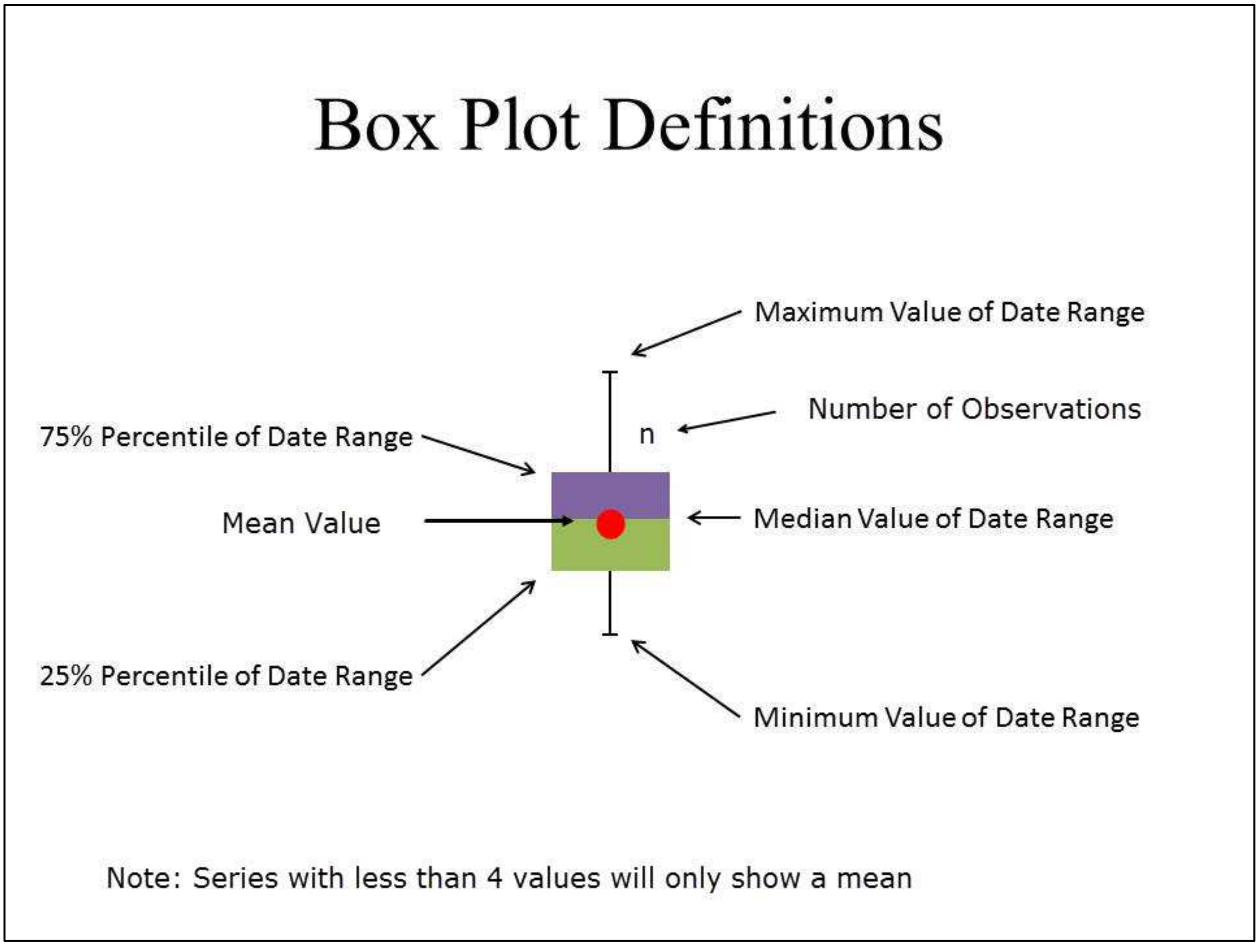


Figure 3-5 - Box Plot Definitions

Another tool used during this study is called a Student's t-test. This is a statistical hypothesis test used to determine if the differences between two sets of values are statistically significant. The differences in the means of the two sets, taking into account the standard deviations of the values, are used to evaluate whether the differences in the means are true or just by chance. Utilizing the null hypothesis that there is no significant difference between the data sets, the probability is calculated and if it is less than 0.05 than the null hypothesis is rejected and there is a significant difference between the data sets.

3.6 Results and Discussion

3.6.1 Drake Water Reclamation Facility Water Quality Results

3.6.1.1 Baseline Data

3.6.1.1.1 Timeframes of Sampling

The duration and timing of the process water quality sampling was determined by the location and tracked consistency of the results. Soluble COD testing in the anaerobic and anoxic zones along with process total and soluble COD tests in the combined influent (2CINF) and primary effluent (2PRI) were conducted from 7/6/2015 – 8/4/2015. Process monitoring of total inorganic nitrogen (TIN) continued an additional month through 9/11/2015 to attempt to obtain consistent results. Daily and weekly nitrogen and phosphorus data from the pollution control lab was monitored continuously through October 10, 2015 in an attempt to identify anomalies that will be discussed in Section 3.6.1.2.1.

3.6.1.1.2 Effluent Diurnal Trends

During the first week of sampling, it was noted that the effluent phosphorus levels exhibited a very steady, distinct diurnal pattern (Figure 4-1). The peaks of this pattern will normally occur

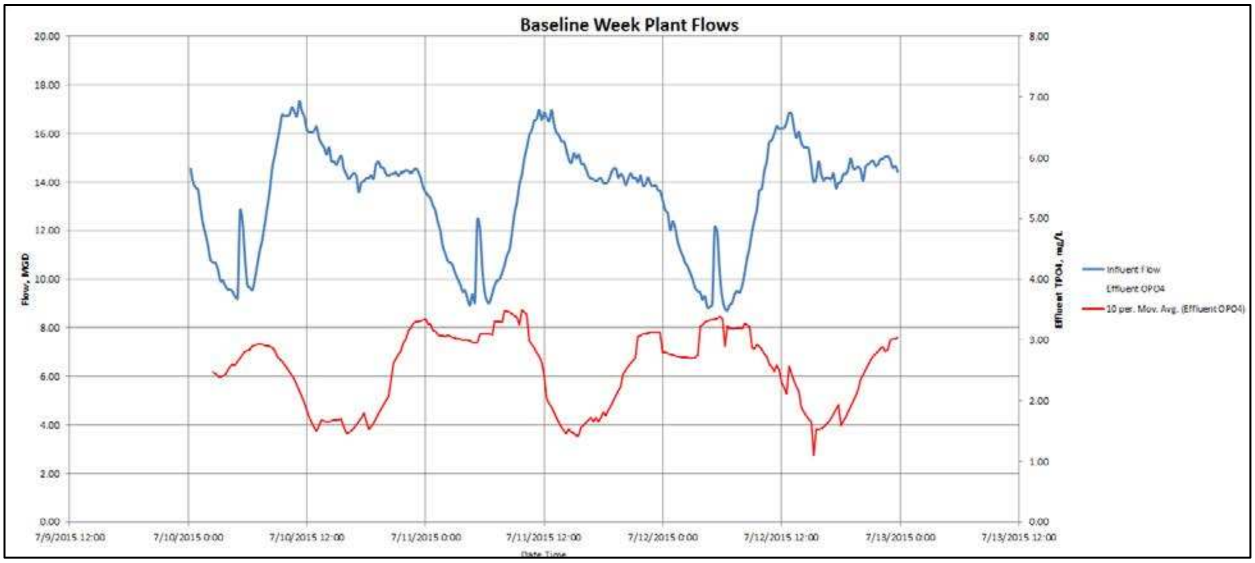


Figure 3-6 DWRF Baseline Flow Data

from midnight to 3 a.m.. The peak highs in effluent phosphorus coincide with low influent flows. As beer waste addition began, this phenomenon remained consistent and a flow profile through the plant did not completely account for the 12 hour lag in peak phosphorus to peak flow (Figure 3-7)

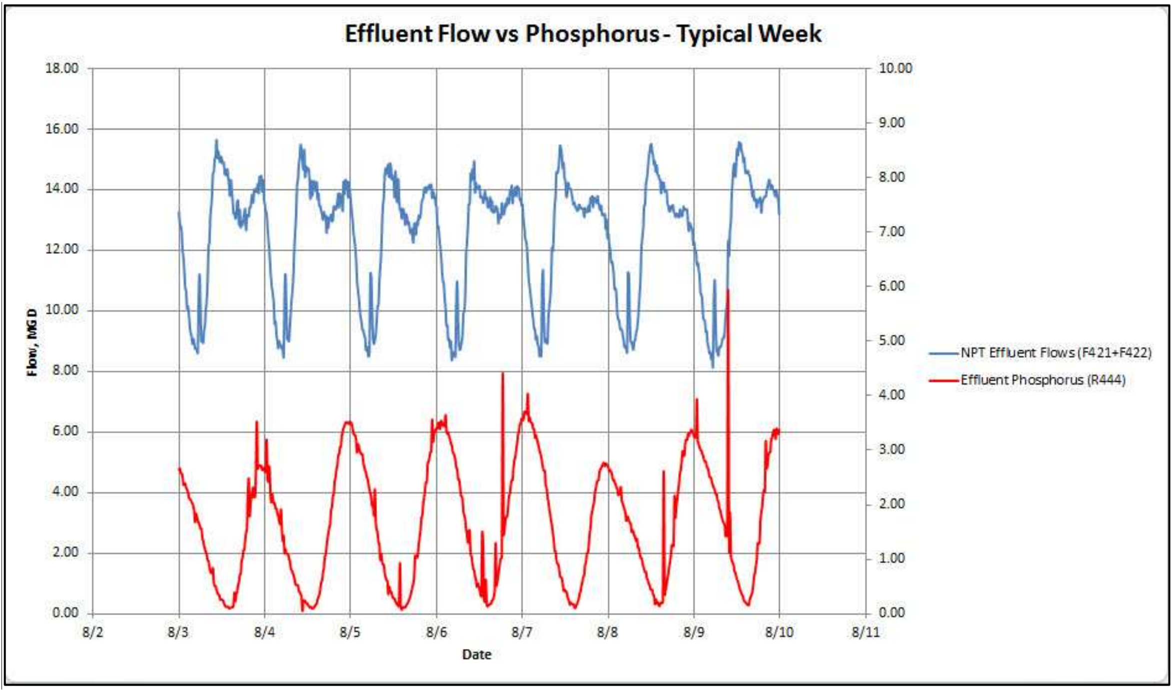


Figure 3-7 - Effluent Flow vs Phosphorus - Typical Week

3.6.1.1.3 Plant Baseline Phosphorus Profile

During the baseline week, where all samples were taken, but no beer waste addition occurred, the Pollution Control Lab (PCL) conducted additional phosphorus testing at the combined influent, primary effluent and plant effluent sampling locations. Figure 3-8 shows that approximately 1/3 of the influent phosphorus plus sidestreams is removed in the primary clarifiers and (without additional carbon) an additional 1/3 is removed in the BNR process. Effluent phosphorus levels range between 2-3 mg/L.

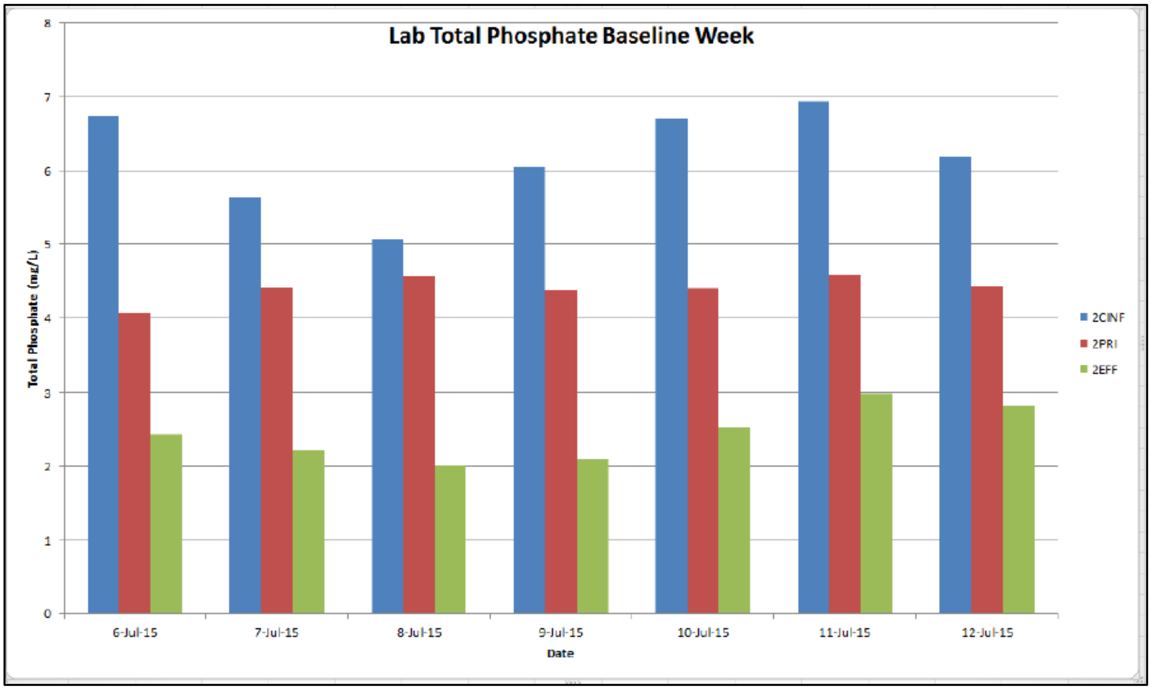


Figure 3-8 Baseline Phosphorus Profile (2CINF represents the combined influent, 2PRI is the primary effluent, and 2EFF is plant effluent)

3.6.1.2 Phosphorus Removal

Beer waste addition began on July 13, 2015 with the first week's dose set at the minimum (1 gpm) to acclimate the process to the carbon addition. After the initial acclimation period dosage rates were increased in increments of 1 gpm up to 4 gpm on a continuous feed basis. At this feed rate the daily beer waste requirements was 5760 gallons per day which was reaching the maximum delivery volume available (3 x 2000 gallon loads), when it was available. Five times during the study period, dosing had to be turned down to minimum flow because additional beer waste was not available.

Without any notable changes in effluent phosphorus concentration, a step feed approach was conducted for several weeks to attempt applying the carbon dose at the appropriate time during the day to offset the effluent phosphorus peaks. These adjustments in duration, timing and magnitude had little effect on the effluent phosphorus (Figure 3-9). The effluent values continued to range between 2-4 mg/L. This was very discouraging to the pilot study effort as the initial phases of the study showed promise in utilizing beer waste, with effluent P values below 1 mg/L.

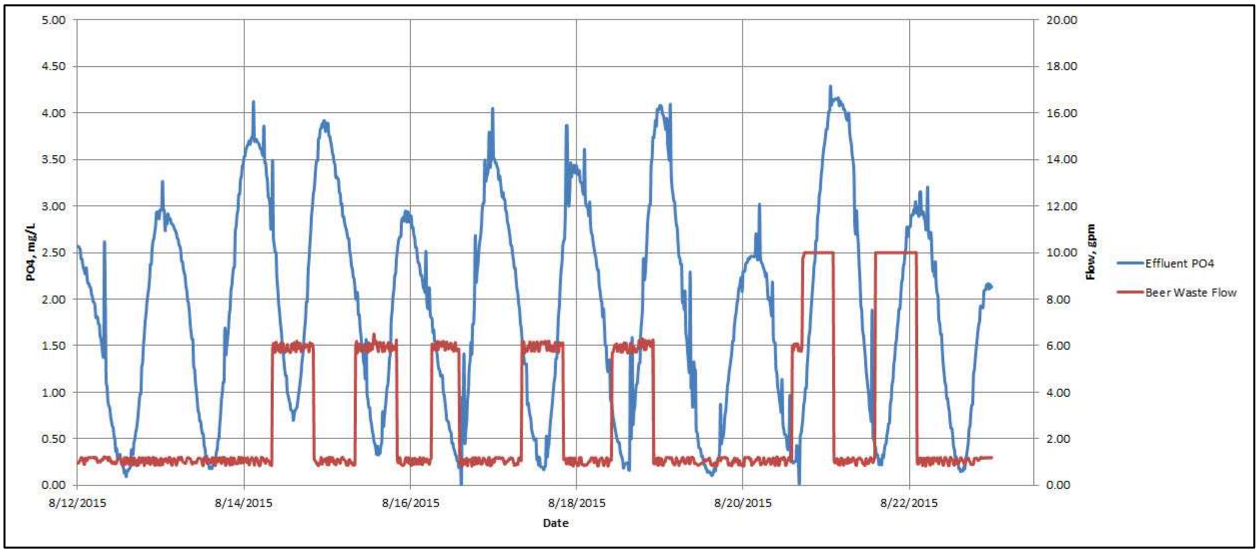


Figure 3-9 Beer Waste Flow vs Effluent PO4 - Typical Pilot Week

3.6.1.2.1 Centrate Influence

Because of the benefits the beer waste addition had on the nitrogen removal processes that will be discussed in Section 4.1.3.2, beer waste addition continued past the initial pilot stage into September and October 2015. A review of effluent phosphate values in the beginning of September 2015 revealed two events that showed effluent phosphate levels below 1 mg/L (Figure 4-4).

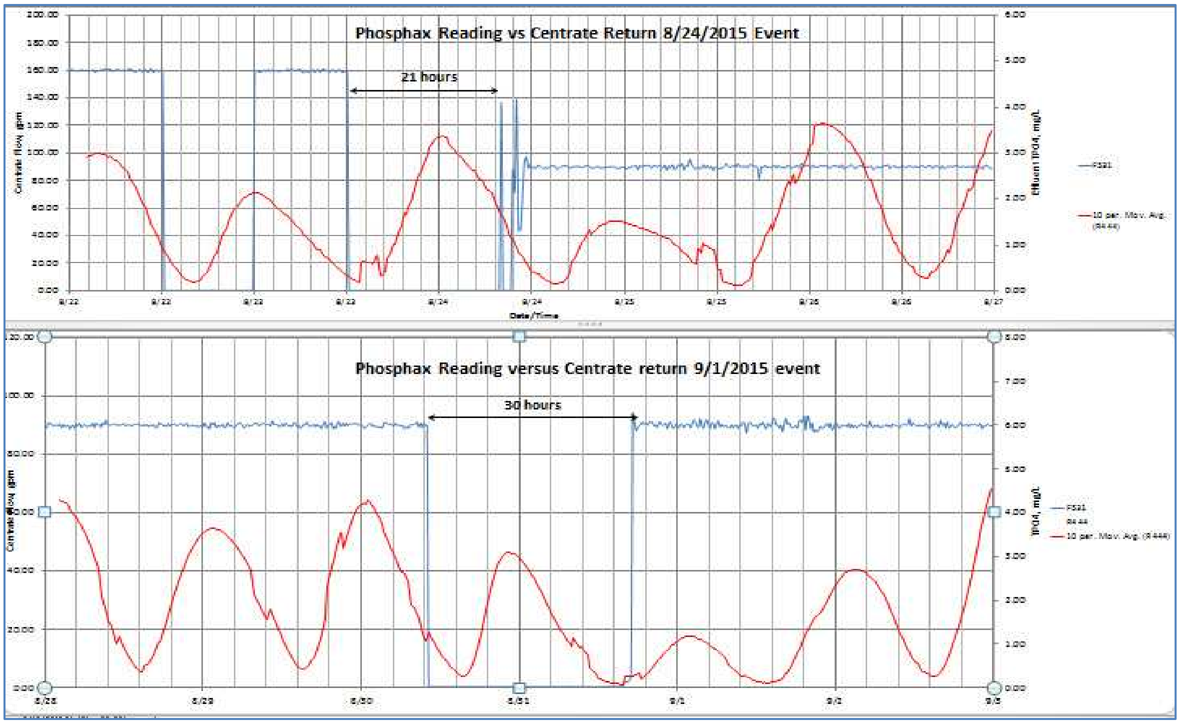


Figure 3-10 Centrate Flow vs Effluent PO_4 plots

A careful analysis of plant operations during these time periods revealed an extended period of time where centrate was not being pumped to the head of the plant. Centrate is the liquid supernatant from the plant's dewatering centrifuges which typically operate Monday through Friday for 5-6 hours a day. Centrate is stored in a holding tank and return flows are equalized throughout the week to minimize effects on plant processes. Typical nutrient values for centrate are 950 mg/L NH_3 and 130 mg/L P. Equalizing the flow addressed the primary concern of plant staff by minimizing the loss of nitrification due to overloading the secondary system with ammonia during peak flow hours. Over the weekends the centrate is drained back until the centrate storage tank reaches minimum level, then shuts off, normally sometime Sunday morning. Under normal circumstances, the duty centrifuge operator turns the centrate pumps back on at the beginning of the centrifuge cycle, but several new operators have been recently hired and forgot to turn the pumps on until later than normal on Monday.

Plant staff began experimenting with adjusting the flow timing, rate, and duration to see its effect on the effluent phosphorus concentrations. Adjusting the pump start times to begin in the early evening and continue into the early morning hours appears to provide the most benefit. Substantial improvement was made in the effluent phosphorus concentrations (Figure 3-11).

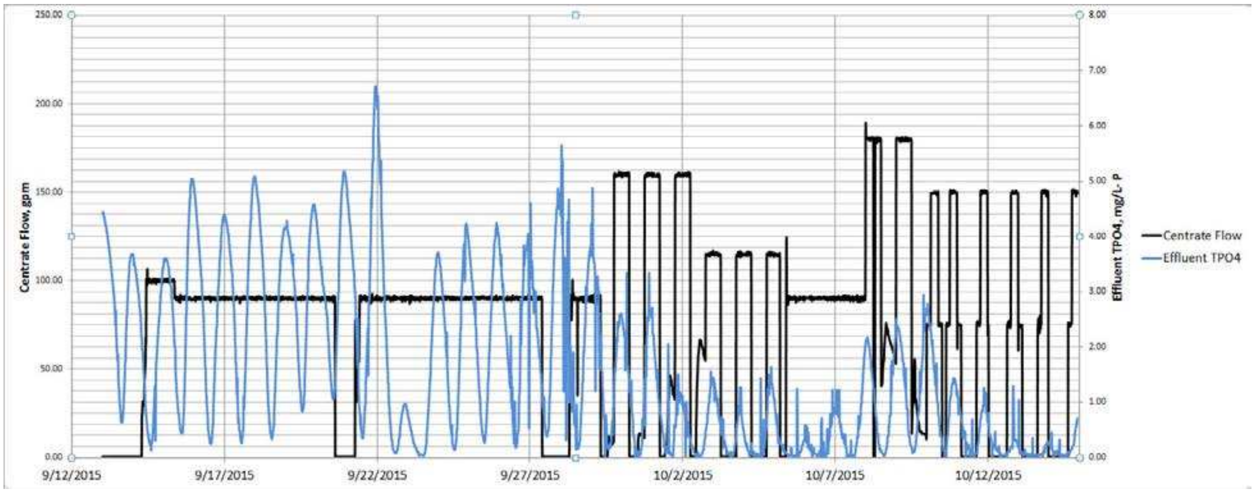


Figure 3-11 Centrate Timed Feed vs Effluent Phosphorus

Several different flow sequences were tried by plant staff. The most promising was a two-stage flow over the evening hours that minimized the total flow period.

3.6.1.2.2 Comparison of Experiment Phosphorus Data to Historical Data

3.6.1.2.2.1 Timeline Definitions

The lack of initial success in enhanced Bio-P removal necessitated a closer look at historical data for the DWRF effluent phosphorus levels. A review of the phosphorus data from January 2006 to present was conducted. Because of the influence of different plant configurations on effluent quality, the data was divided into six distinct time periods as follows:

- Pre-MWRF – This period is from January 2006 to July 2008. It represents the time period when both MWRF and DWRF were run as traditional activated sludge plants and all of MWRF's solids; both primary and secondary were routed to DWRF.
- MWRF Construction – From August 2008 to July 2011, all flow to MWRF was routed directly to DWRF during the construction of BNR improvements at MWRF.
- NPT Construction – This period between August 2011 to September 2012 had MWRF on-line as a BNR plant with only WAS being routed to DWRF. DWRF was operating with one NPT train and the SPT on-line. At this time, the SPT was a coarse air aeration system. The NPT was being upgraded to BNR.
- NPT – From October 2012 to June 2015 both MWRF and the NPT were on-line with BNR. The SPT was on-line for about one month in January 2013, but for the remainder of the time, was shut down.
- Pilot – The time period for the main 6 week study from July through August 2015
- Pilot w/ Centrate loading – The extended portion of the pilot study from September through October 2015 where centrate loading was manipulated.

3.6.1.2.3 Phosphorus Results

As depicted in Figure 3-12, effluent phosphorus values have been almost halved since the introduction of the BNR processes at DWRF and MWRF. Between the NPT timeframe and the Pilot, there is no significant difference in the effluent values. There was, however, a statistically significant decrease when the centrate loading was adjusted (Pilot w/ cent loading; $p < 0.05$).

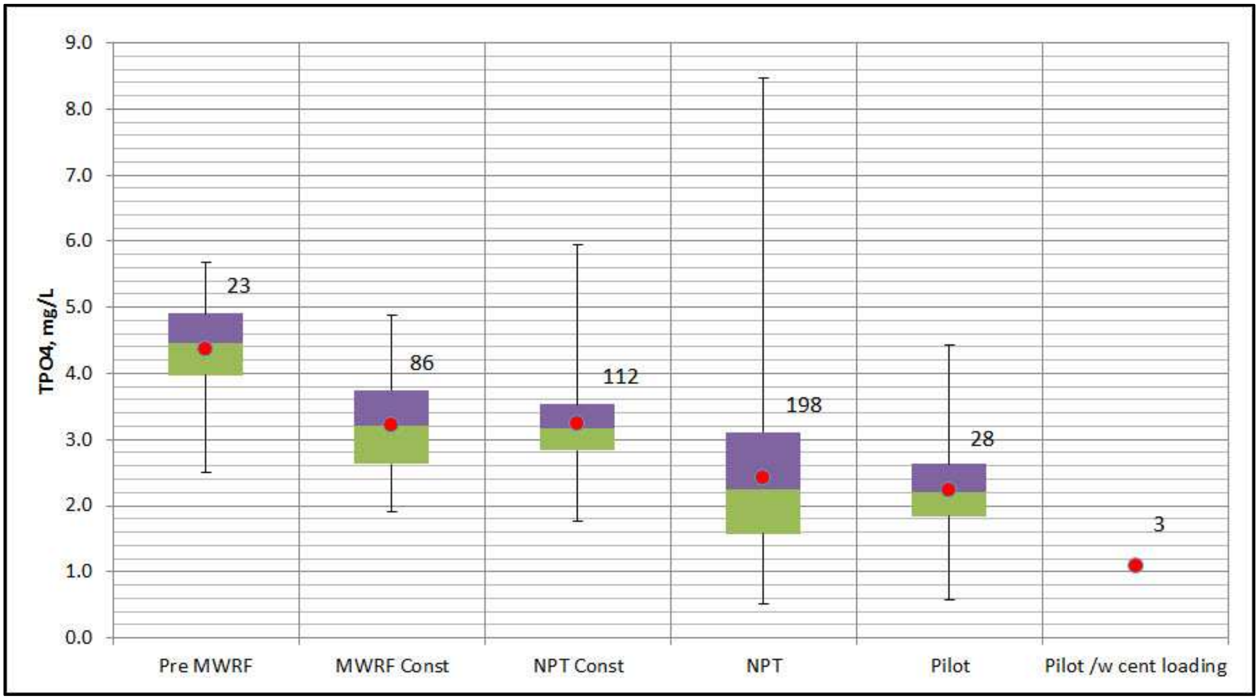


Figure 3-12 DWRF Effluent TPO4 History -Time periods, Pre-MWRF (1/06-7/08), MWRF Const (8/08-6/11), NPT Const (7/11-9/12), NPT (10/12-6/15), Pilot (7/15-8/15), Pilot /w cent loading (9/15-10/15)

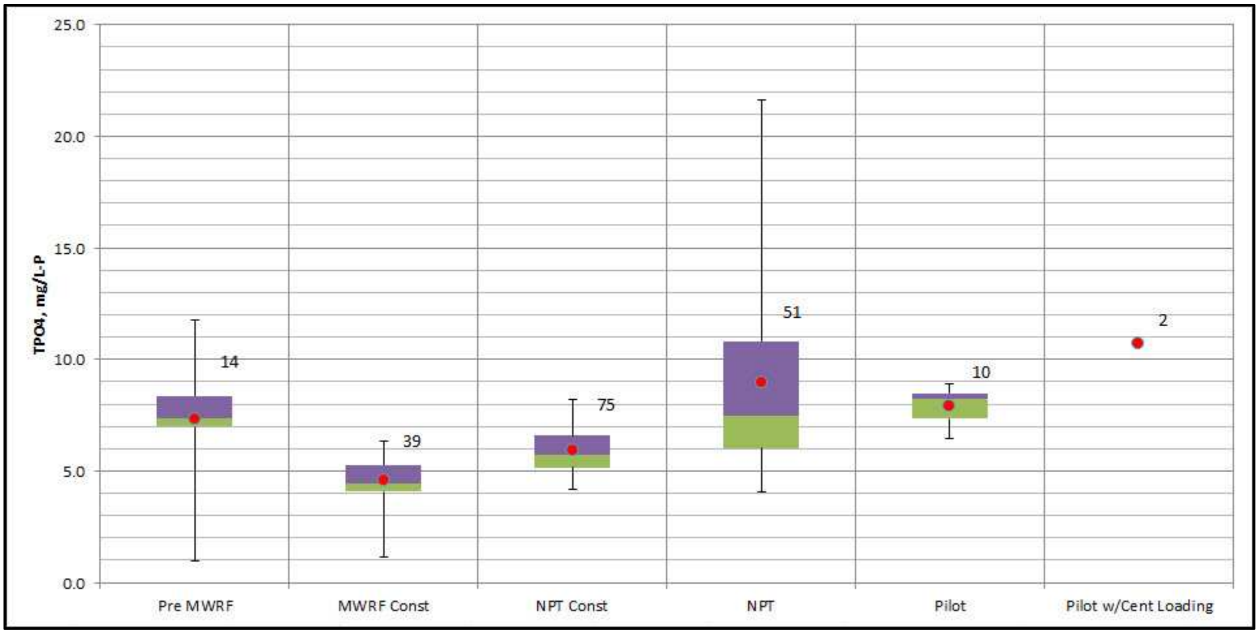


Figure 3-13 DWRF Influent TPO4 History - Time periods, Pre-MWRF (1/06-7/08), MWRF Const (8/08-6/11), NPT Const (7/11-9/12), NPT (10/12-6/15), Pilot (7/15-8/15)

Looking at the difference between Pre-MWRF and MWRF construction, the effluent concentration reduction may be the result of additional carbon from the MWRF services area flowing into DWRF. However, since the BNR facilities were not in place at DWRF NPT at that time, carbon addition probably would not have provided a notable decrease and is most likely the result of decreased influent phosphorus as shown in the next section. The decrease in effluent phosphorus once the NPT was brought on-line was expected, just not as much as hoped for during design. The wide range in values between minimum and maximum during this time period could be attributed to the NPT system slipping into and out of enhanced Bio-P depending on the amount of carbon in the system.

Influent phosphorus values appear to have increased steadily since 2011 (Figure 3-13). Since construction activities should not have affected the influent numbers, this increase could be the result of increased population growth or increased concentration due to water conservation activities.

The concentration increase between the MWRF Construction and the NPT Construction could also be the result of less primary sludge coming to DWRF from MWRF and more secondary sludge with the increased phosphorus being present in the biomass from MWRF.

Regardless of the reasons for the influent concentration increases, they call to question the validity of the effluent phosphorus analysis. A better approach was to look at the mass balance of the phosphorus as around the entire plant (Figure 3-14). There is no statistical difference between the NPT period and the Pilot Period, but the results are statistically significant when the centrate loading was being manipulated (Pilot w/ cent loading; $p < 0.05$).

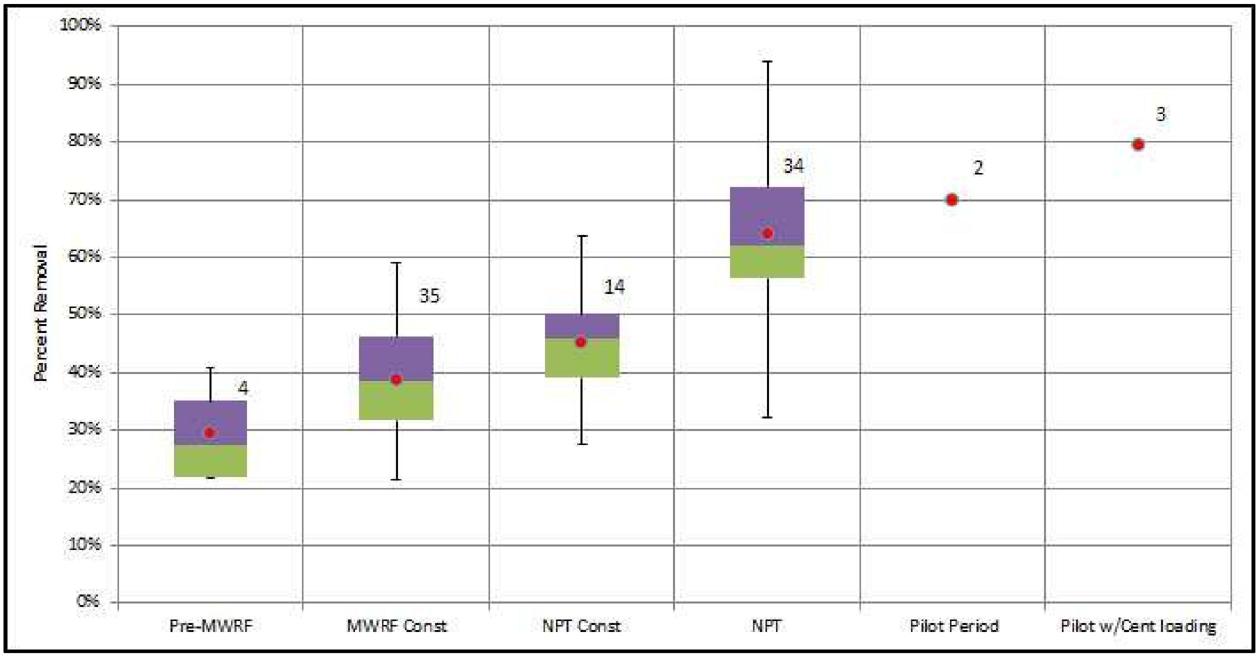


Figure 3-14 DWRF Phosphorus Removal Efficiency based on lbs TPO4 removed per day - Time periods, Pre-MWRF (1/06-7/08), MWRF Const (8/08-6/11), NPT Const (7/11-9/12), NPT (10/12-6/15), Pilot (7/15-8/15)

3.6.1.2.4 Phosphorus Summary

While results from the addition of the beer waste during the pilot time period did not show significantly lower effluent P concentration compared to operation without beer waste addition, the historical review of DWRF's phosphorus removal performance shows that BNR is having a positive impact on the effluent P concentrations. The mass balance review shows the true story of the phosphorus removal at the plant. It is unfortunate that the regulations focus on the effluent concentration and not the amount removed. The discovery that adjusting the centrate bleed-back to the head of the plant can have a positive effect on effluent phosphorus concentrations was important and may lead to additional evaluation and process improvements in the sidestream system.

3.6.1.3 Nitrogen Removal

3.6.1.3.1 Nitrogen Values

During Phase 2 of the pilot study the denitrification benefits of beer waste addition were proven and this last phase of the study appeared to show similar results (Figure 3-15). The addition of a peristaltic pump with a higher flow rate and providing time-step automation through the SCADA system helped to fine-tune the operation by giving the operators more control over the dosage rates. Reviewing the historical data, several trends in effluent TIN values become apparent. The difference in values between Pre-MWRF and MWRF Construction is most likely due to the additional carbon being sent to DWRF during the construction time period.

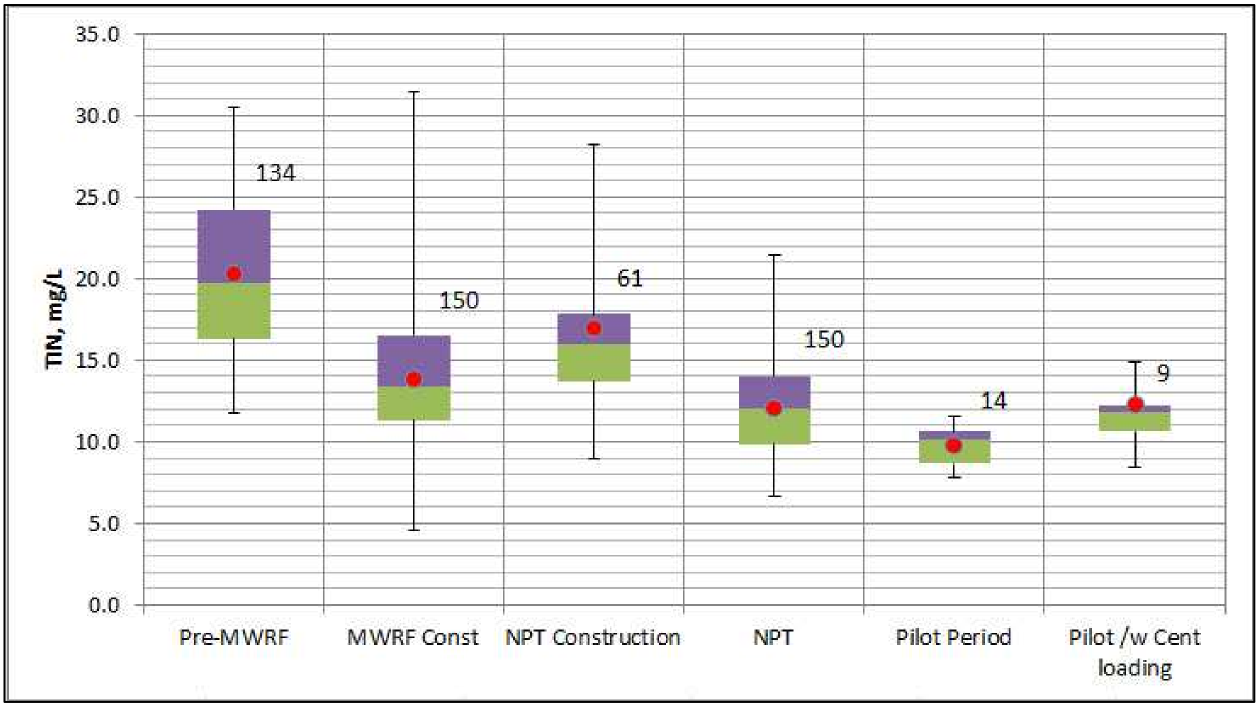


Figure 3-15 DWRF Effluent Total Inorganic Nitrogen (TIN) History - Time periods, Pre-MWRF (1/06-7/08), MWRF Const (8/08-6/11), NPT Const (7/11-9/12), NPT (10/12-6/15), Pilot (7/15-8/15), Pilot /w cent loading (9/15-10/15)

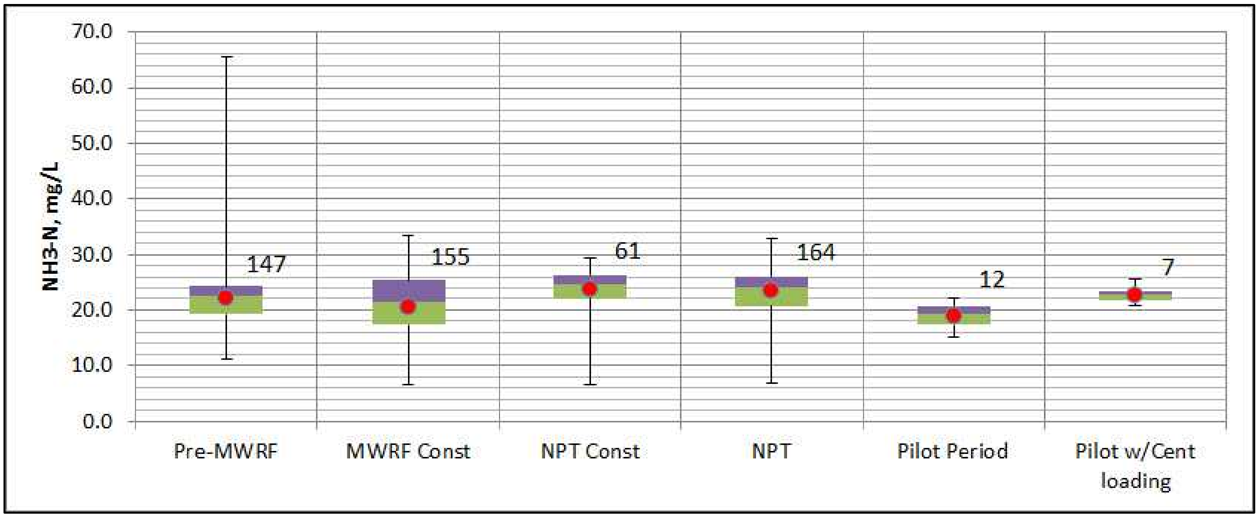


Figure 3-16 DWRF Influent NH3 History - Time periods, Pre-MWRF (1/06-7/08), MWRF Const (8/08-6/11), NPT Const (7/11-9/12), NPT (10/12-6/15), Pilot (7/15-8/15), Pilot /w cent loading (9/15-10/15)

While formal BNR was not in place at DWRF, the "two-stage denitrification" discussed in Section 2.8.4 was in operation and could take advantage of the additional carbon. The increase in effluent TIN during the NPT construction was the result of DWRF being run with only one NPT train and the SPT, with its coarse air diffusion. This decrease in aeration capacity along with the original SPT's propensity to bleed through ammonia during high flow periods increased the ammonia levels in the effluent during this timeframe.

The decrease in effluent TIN between the NPT time period and the Pilot Period appears to be statistically significant (Pilot Period; $p < 0.05$). However, similar to the Phosphorus analysis, the influent NH3 values also show a drop in concentration between these two time periods (Figure 4-10). Since the difference in values in the influent NH3 between the NPT time period and the Pilot Period was also statistically significant (Pilot Period; $p < 0.05$) , this appears to nullify the positive effluent TIN result. A mass balance for nitrogen comparing the influent NH3 values to the effluent TIN values was done (Figure 3-17). There appears to be a significant drop in

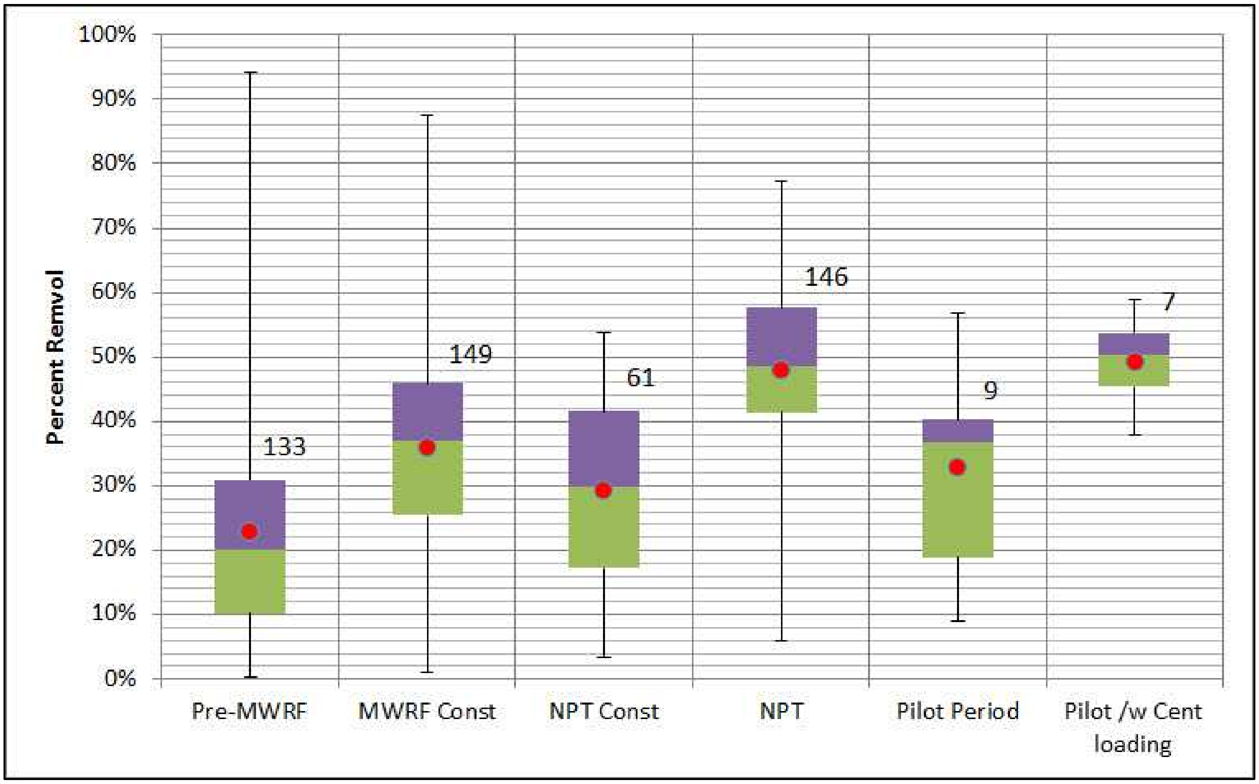


Figure 3-17 DWRF Nitrogen Removal Efficiency based on lbs N removed per day - Time periods, Pre-MWRF (1/06-7/08), MWRF Const (8/08-6/11), NPT Const (7/11-9/12), NPT (10/12-6/15), Pilot (7/15-8/15)

N removal efficiency (Pilot Period; $p < 0.05$) between the NPT time period and the Pilot Period and although the efficiency appears to recover during the Pilot w/ Centrate loading period the results are not statistically significant compared the NPT time period.

3.6.1.3.2 TIN Discussion

While the pilot results do not show a significant decrease in effluent N concentration due to the beer waste addition, the value's mean was far enough below the desired limit of 15 mg/L N to allow plant staff a comfortable buffer in the event of plant upsets. One possible reason that will be investigated is problems with the influent sampler causing increased organics in the composite sampler. This would increase the influent organic nitrogen component and show a reduction in the removal efficiency. An added benefit to this was the increase in alkalinity resulting in plant staff eliminating the addition of $Mg(OH)_2$ through most of the pilot time period. Although there is no easy way to determine it, reducing the concentration of Mg in the system should decrease the amount of struvite produced in the anaerobic digester, sludge holding tank, and centrate tank. During the time period that the centrate loading was being adjusted there was a slight increase in overall TIN values which is probably attributed to increased influent NH3. These effluent values are still below the desired TIN limit.

3.6.1.3.3 Nitrogen Summary

The historical review of effluent TIN values shows the improvements to effluent discharge achieved by the introduction of the BNR processes both in effluent concentration and removal efficiency. The addition of beer waste can provides more carbon for fueling the denitrification process, but also offers the added benefit of increased alkalinity. Adjustment of centrate loading will have to be carefully managed to optimize the process.

3.6.2 Beer Waste Monitoring

3.6.2.1 Introduction

Taft Hill Dairy provided beer waste delivery to DWRF throughout the pilot period. Between 7/13/2015 and 9/11/2015 samples were taken from the first truck delivery of the day. After 9/11/2015, weekly test samples were taken to monitor waste quality. Prior to receiving a delivery, plant staff took a sample of the beer waste storage tank for analysis this was done daily from 7/13/2015 to 9/11/2015.

3.6.2.2 *Beer Waste Chemical Oxygen Demand (COD)*

Figure 3-18 shows the COD values for both the beer truck and the beer tank throughout the pilot period. While there does appear to be a slight difference in values between the beer truck waste and the waste that has been held in the tank for several days, according to the t-tests, those differences are statistically insignificant. One phenomenon that does appear to be relevant is where there is a wide range in variation in beer truck COD values, those values appear to get evened out as the product is held in the beer tank.

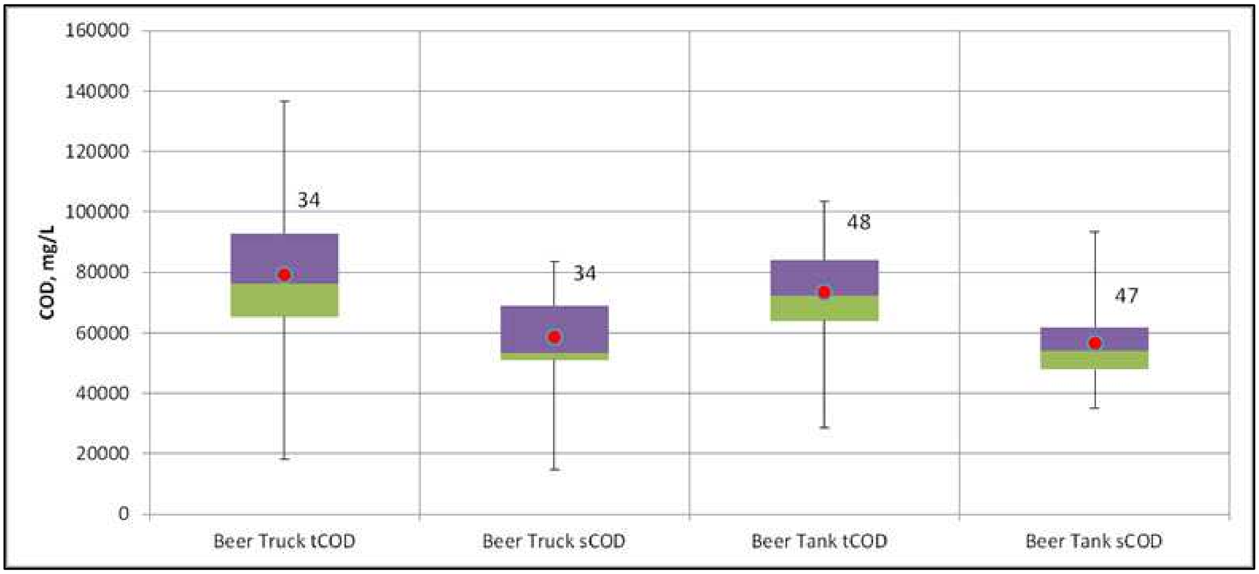


Figure 3-18 Beer Waste COD Values - (7/17-9/15)

3.6.2.3 *Beer Waste Volatile Fatty Acids (VFA)*

As was predicted in the bench-scale testing, the fermentation taking place during the retention time in the beer tank increases the VFA concentration. Figure 3-19 shows the VFA concentration

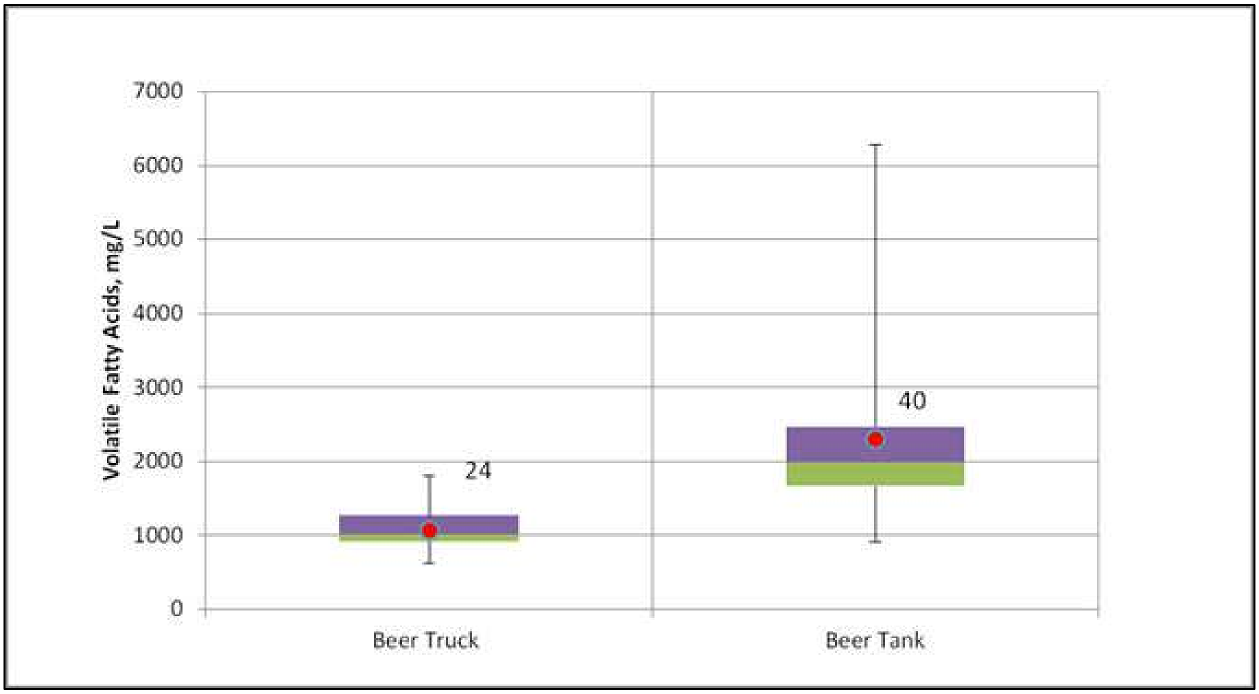


Figure 3-19 Beer Waste Volatile Fatty Acids - (7/15-9/15)

for both the beer truck and the beer tank. VFA values coming from Odell's were fairly consistent in comparison to the COD values. The almost doubling of the VFA values due to the holding time in the tank is statistically significant according to the t-test.

3.6.2.4 Beer Waste Quantity

Past phases of this pilot study suffered do to the adequate availability of the beer waste. Since the start of this study in 2011, Odell's production has increased substantially and with that, their beer waste volumes have increased. There were still 5 instances during the main pilot study where dosage rates had be stopped or set at a minimal 1 gpm due to lack of beer waste. Several factors were the cause of these outages. Odell's does not currently brew on the weekends which led to low volumes available early in the week. A four-day construction shutdown at Odell's for process improvements at the beginning of August was another factor. The final issue was the plant high usage rates during the third week in August when using 6-10 gpm dosage rates to attempt to influence effluent phosphorus values

3.6.2.5 Beer Waste Summary

Beer waste COD values appear to be sufficient to provide adequate denitrification for the system. While there does not appear to be adequate VFA's to provide meaningful enhanced Bio-P results during normal circumstances, the increase in VFA values is valuable data for future storage facilities. Finally, although there were still time periods when adequate beer waste supplies were unavailable, reasonable dosage rates, along with Odells' potential expansions bodes well for there being adequate carbon supplies in the future.

3.6.3 Carbon Dosing

3.6.3.1 Introduction

During phase 2 of this study, a definite need to control the dosing of beer waste was discovered. Inadvertent high flow rates caused thick scum buildup in the anaerobic and anoxic zones. It was also theorized that beer waste addition beyond that necessary for enhanced Bio-P and denitrification led to a rapid increase in heterotrophic microbes in the aeration basin causing a very rapid increase in system biomass. The rapid wasting of the biomass may have contributed to the 4-month foaming event in 2014. Plant staff is very motivated to avoid over dosing in the future.

3.6.3.2 ORP analysis

ORP and nitrate probe trends were plotted together with the results shown on Figure 3-20.

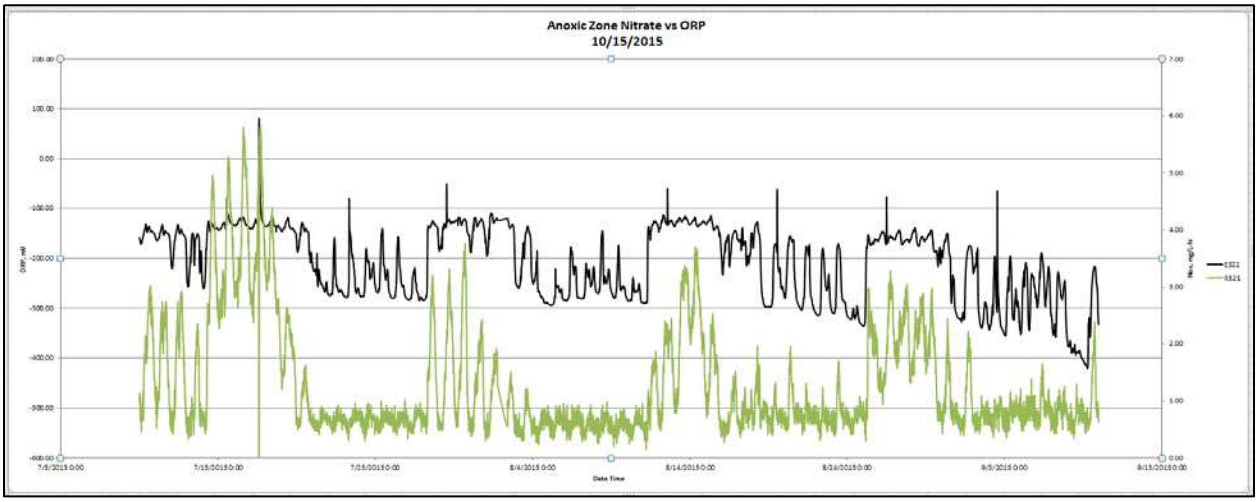


Figure 3-20 ORP vs Nitrate in Anoxic Zone

As shown above, when ORP values were in the -250 to -300 mV range, nitrate values where consistently below 1 mg/L. This trend corresponds to the literature review and was at first very promising. It also showed that the nitrate probe itself could be used as a dosage tool.

3.6.3.3 Dosing Summary

Efforts to program the dosing pump to consistently achieve ORP or nitrate readings within a specific range were unsuccessful. The primary reason was the delay due to hydraulic detention time between the dosage point and where the readings were taken. This 1-1 ½ hour delay meant that the program was constantly behind in dosage corrections. As discussed in Section (3.5.1.1.2), the water quality readings throughout the plant are tied to the trains hydraulic flow rate. Plant staff was able to set up a time step program where the dosage was adjusted based on the time of day and the operator’s experience. This method is used for other dosage scenarios (including centrate) and is widely accepted by plant staff.

4 CONCLUSION

The growing emphasis on increased water quality along with the decreased funding available to construct improvements is leading facility owners like the City of Fort Collins to search for innovative, low-cost, local solutions for nutrient removal. Historical data has shown that the construction of BNR has improved the removal of nutrients from DWRF's effluent, but the physical and mechanical facilities themselves are not all that is needed for an efficiently run BNR system. Fuel in the form of carbon and volatile fatty acids are required to drive the processes to peak performance.

The additions of beer waste as a carbon source appears to be beneficial for system phosphorus removal but not to the point where meeting Regulation 85 limits are met. For DWRF, the addition of beer waste does not appear to significantly improve biological nitrogen but does have a positive impact on plant process nonetheless. Adjustments in the plant's centrate return flows appear to be a key operational consideration for nutrient reduction. Timing of the duration and strength of the centrate can have positive effects on the system and this, in combination with the carbon and BNR improvements, should bring effluent phosphorus levels closer to the goal of 1 mg/L. This will be further investigated in the near future.

This study also brings to the point that the nutrient removal problem is not a "one system" solution. Because the dewatering centrate obviously plays such an important part in the phosphorus equation at DWRF, the next facility plan for the City should include analysis of side stream treatments to removal additional nutrients from the solids handling portion of the system.

This will be even more important if Regulation 31 rules come into effect in future years, lowering allowable nutrient discharge limits even further. The influence of MWRF’s solids discharging to DWRF also needs to be analyzed to determine the effect of the additional biomass on DWRF’s processes. DWRF’s digesters appear to be negatively impacted by the increase concentration of secondary sludge coming in to DWRF’s influent. Understanding how this affects DWRF’s secondary processes will be important to future plant operations.

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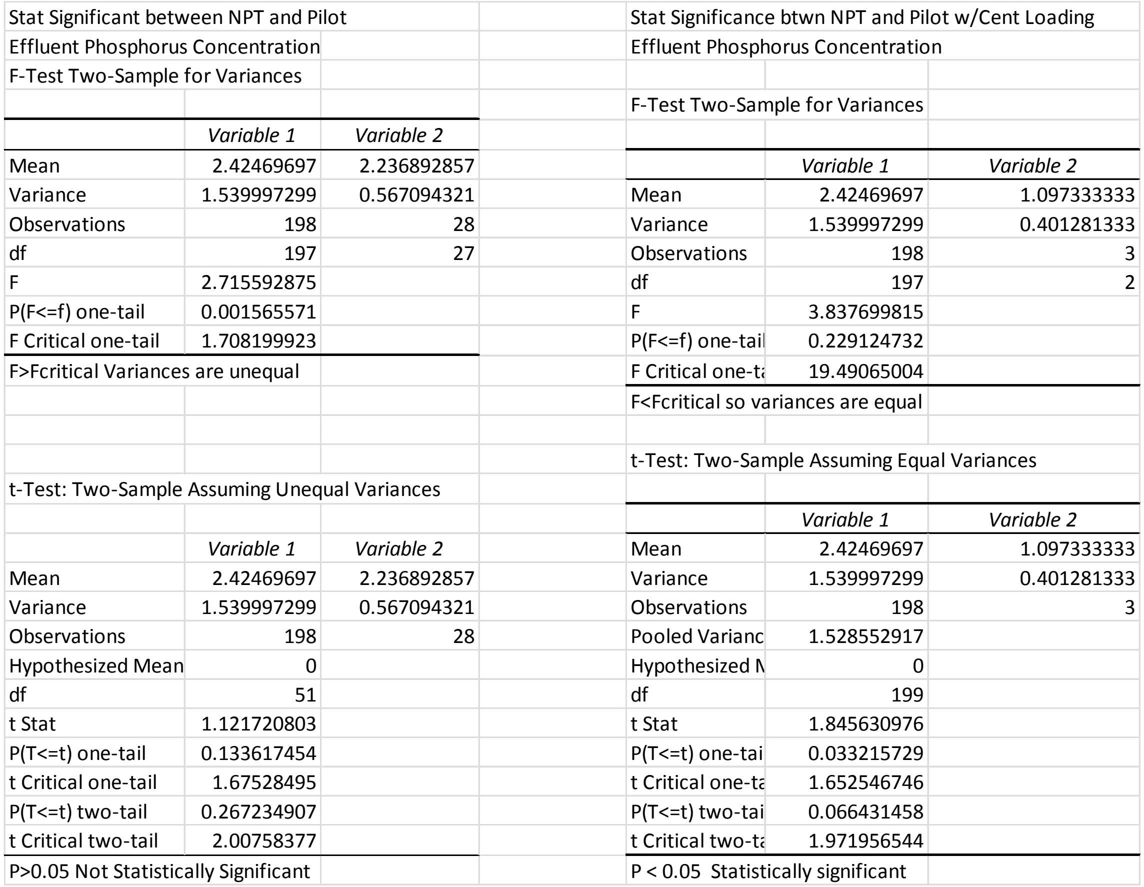
APPENDIX A: STATISTICAL T-TEST DATA

Effluent Phosphorus



Stat Significant between NPT and Pilot

Effluent Phosphorus Concentration

F-Test Two-Sample for Variances

	Variable 1	Variable 2
Mean	2.42469697	2.236892857
Variance	1.539997299	0.567094321
Observations	198	28
df	197	27
F	2.715592875	
P(F<=f) one-tail	0.001565571	
F Critical one-tail	1.708199923	

F>Fcritical Variances are unequal

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	2.42469697	2.236892857
Variance	1.539997299	0.567094321
Observations	198	28
Hypothesized Mean	0	
df	51	
t Stat	1.121720803	
P(T<=t) one-tail	0.133617454	
t Critical one-tail	1.67528495	
P(T<=t) two-tail	0.267234907	
t Critical two-tail	2.00758377	

P>0.05 Not Statistically Significant

Stat Significance btwn NPT and Pilot w/Cent Loading

Effluent Phosphorus Concentration

F-Test Two-Sample for Variances

	Variable 1	Variable 2
Mean	2.42469697	1.097333333
Variance	1.539997299	0.401281333
Observations	198	3
df	197	2
F	3.837699815	
P(F<=f) one-tail	0.229124732	
F Critical one-ta	19.49065004	

F<Fcritical so variances are equal

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	Variable 2
Mean	2.42469697	1.097333333
Variance	1.539997299	0.401281333
Observations	198	3
Pooled Varianc	1.528552917	
Hypothesized M	0	
df	199	
t Stat	1.845630976	
P(T<=t) one-tai	0.033215729	
t Critical one-ta	1.652546746	
P(T<=t) two-tai	0.066431458	
t Critical two-ta	1.971956544	

P < 0.05 Statistically significant

Effluent Nitrogen

Statistical Significance btwn NPT and Pilot Period

DWRF N Removal

F-Test Two-Sample for Variances

	Variable 1	*Variable 2*
Mean	32.69914386	47.98670224
Variance	260.0869149	177.4917974
Observations	9	146
df	8	145
F	1.46534611	
P(F<=f) one-tail	0.174774274	
F Critical one-tail	2.002798305	

F<Fcritical - variances are equal

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	32.69914386	47.98670224
Variance	260.0869149	177.4917974
Observations	9	146
Pooled Variance	181.8104964	
Hypothesized Mea	0	
df	153	
t Stat	-3.301113722	
P(T<=t) one-tail	0.000599261	
t Critical one-tail	1.654873847	
P(T<=t) two-tail	0.001198523	
t Critical two-tail	1.975590315	

P<0.05 Statistically Significant

Statistical Significance btwn NPT and Pilot w/ Cent loading

DWRF N Removal

F-Test Two-Sample for Variances

	Variable 1	*Variable 2*
Mean	37.38665202	47.98670224
Variance	377.8691816	177.4917974
Observations	452	146
df	451	145
F	2.128938842	
P(F<=f) one-tail	1.04381E-07	
F Critical one-tai	1.258629092	

F>Fcritical - variances are unequal

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	47.98670224	49.25406421
Variance	177.4917974	55.44060491
Observations	146	7
Hypothesized Me	0	
df	8	
t Stat	-0.419302803	
P(T<=t) one-tail	0.343013702	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.686027404	
t Critical two-tail	2.306004135	

P>0.05 Not Statistically Significant

Phosphorus Mass Balance

Statistical Significance btwn NPT to Pilot Period

DWRF P Removal

F-Test Two-Sample for Variances

	Variable 1	Variable 2
Mean	0.63993806	0.69994718
Variance	0.01806686	0.01043625
Observations	34	2
df	33	1
F	1.73116423	
P(F<=f) one-ta	0.54736748	
F Critical one-	250.475708	

F<Fcritical the variance are equal

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	Variable 2
Mean	0.63993806	0.69994718
Variance	0.01806686	0.01043625
Observations	34	2
Pooled Varian	0.01784243	
Hypothesized	0	
df	34	
t Stat	-0.6174381	
P(T<=t) one-ta	0.27052965	
t Critical one-	1.69092426	
P(T<=t) two-ta	0.5410593	
t Critical two-	2.03224451	

P>.05 so not statisticall significant

Statistical Significance btween NPT and Pilot w/cent loading

DWRF P Removal

F-Test Two-Sample for Variances

	Variable 1	Variable 2
Mean	0.639938061	0.793663
Variance	0.018066861	0.005329
Observations	34	3
df	33	2
F	3.390432203	
P(F<=f) one-ta	0.25348716	
F Critical one-	19.46543842	

F<Fcritical so variances are equal

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	Variable 2
Mean	0.639938061	0.793663
Variance	0.018066861	0.005329
Observations	34	3
Pooled Varian	0.01733897	
Hypothesized	0	
df	35	
t Stat	-1.938346943	
P(T<=t) one-ta	0.030339921	
t Critical one-	1.689572458	
P(T<=t) two-ta	0.060679842	
t Critical two-	2.030107928	

P<0.05 Statistically significant

Influent NH3

Statistical Significance btwn NPT and Pilot Period

Influent NH3 concentrations

F-Test Two-Sample for Variances

	Variable 1	Variable 2
Mean	23.37542683	18.98
Variance	18.0249035	5.392272727
Observations	164	12
df	163	11
F	3.342728458	
P(F<=f) one-tail	0.014702962	
F Critical one-tail	2.43668165	

F>Fcritical variances are unequal

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	23.37542683	18.98
Variance	18.0249035	5.392272727
Observations	164	12
Hypothesized Mean	0	
df	17	
t Stat	5.877499746	
P(T<=t) one-tail	9.13632E-06	
t Critical one-tail	1.739606726	
P(T<=t) two-tail	1.82726E-05	
t Critical two-tail	2.109815578	

P<0.05 Statistically Significant

Statistical Significance btwen NPT and Pilot w/Cent Loading

Influent NH3 concentrations

F-Test Two-Sample for Variances

	Variable 1	Variable 2
Mean	23.37542683	22.76714286
Variance	18.0249035	2.80372381
Observations	164	7
df	163	6
F	6.428915515	
P(F<=f) one-ta	0.012283921	
F Critical one-	3.695288747	

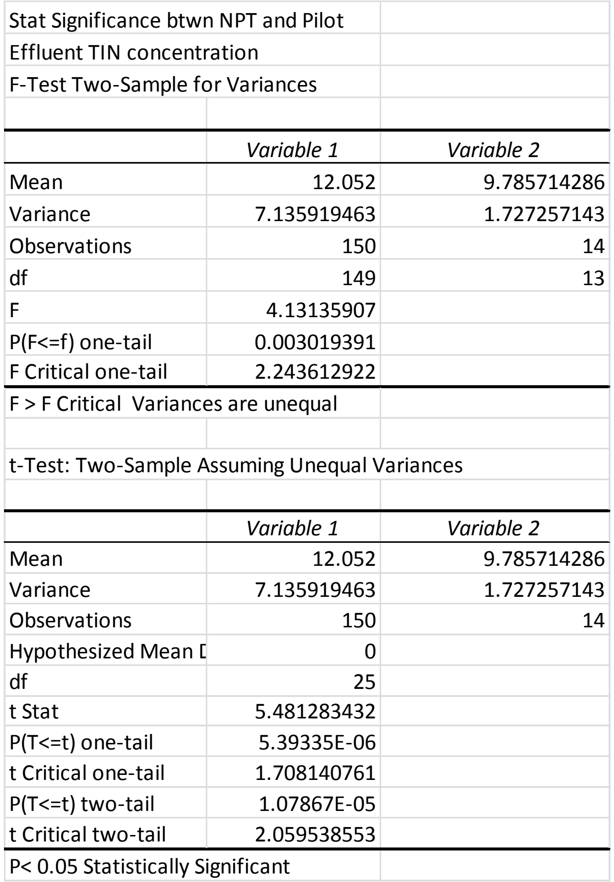
F>Fcritical variances are unequal

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	23.37542683	22.76714286
Variance	18.0249035	2.80372381
Observations	164	7
Hypothesized	0	
df	10	
t Stat	0.851400806	
P(T<=t) one-ta	0.207234931	
t Critical one-	1.812461123	
P(T<=t) two-ta	0.414469862	
t Critical two-	2.228138852	

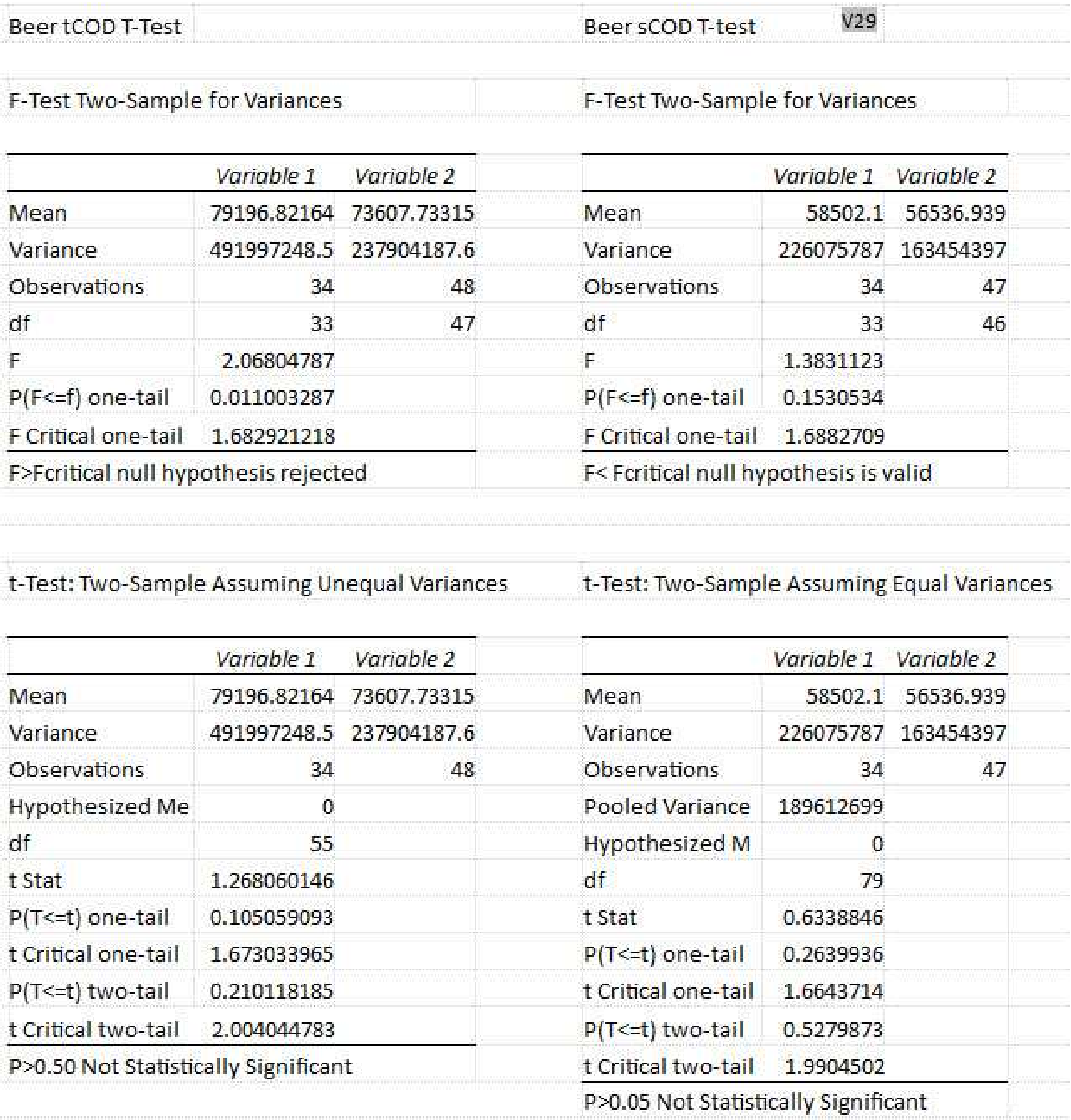
P>0.05 Not Statistically Significant

Effluent TIN



Stat Significance btwn NPT and Pilot		
Effluent TIN concentration		
F-Test Two-Sample for Variances		
	Variable 1	*Variable 2*
Mean	12.052	9.785714286
Variance	7.135919463	1.727257143
Observations	150	14
df	149	13
F	4.13135907	
P(F<=f) one-tail	0.003019391	
F Critical one-tail	2.243612922	
F > F Critical Variances are unequal		
t-Test: Two-Sample Assuming Unequal Variances		
	Variable 1	*Variable 2*
Mean	12.052	9.785714286
Variance	7.135919463	1.727257143
Observations	150	14
Hypothesized Mean D	0	
df	25	
t Stat	5.481283432	
P(T<=t) one-tail	5.39335E-06	
t Critical one-tail	1.708140761	
P(T<=t) two-tail	1.07867E-05	
t Critical two-tail	2.059538553	
P< 0.05 Statistically Significant		

Beer Waste COD



Beer tCOD T-Test

F-Test Two-Sample for Variances

	Variable 1	*Variable 2*
Mean	79196.82164	73607.73315
Variance	491997248.5	237904187.6
Observations	34	48
df	33	47
F	2.06804787	
P(F<=f) one-tail	0.011003287	
F Critical one-tail	1.682921218	

F>Fcritical null hypothesis rejected

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	79196.82164	73607.73315
Variance	491997248.5	237904187.6
Observations	34	48
Hypothesized Me	0	
df	55	
t Stat	1.268060146	
P(T<=t) one-tail	0.105059093	
t Critical one-tail	1.673033965	
P(T<=t) two-tail	0.210118185	
t Critical two-tail	2.004044783	

P>0.50 Not Statistically Significant

Beer sCOD T-test V29

F-Test Two-Sample for Variances

	Variable 1	*Variable 2*
Mean	58502.1	56536.939
Variance	226075787	163454397
Observations	34	47
df	33	46
F	1.3831123	
P(F<=f) one-tail	0.1530534	
F Critical one-tail	1.6882709	

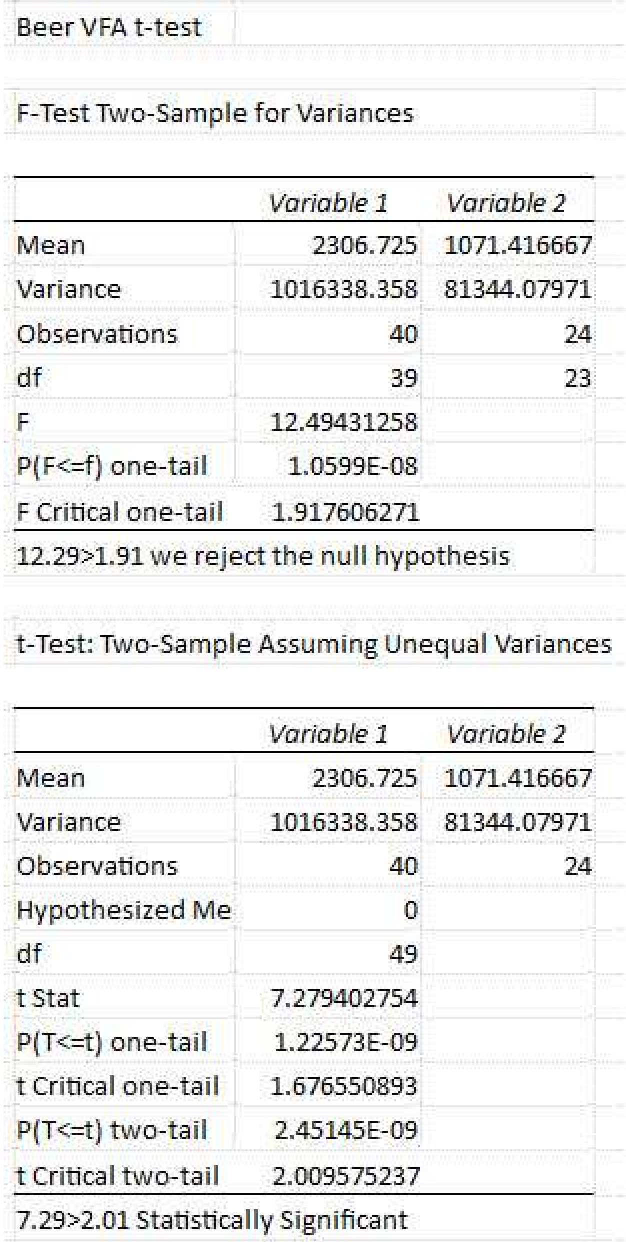
F< Fcritical null hypothesis is valid

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	58502.1	56536.939
Variance	226075787	163454397
Observations	34	47
Pooled Variance	189612699	
Hypothesized M	0	
df	79	
t Stat	0.6338846	
P(T<=t) one-tail	0.2639936	
t Critical one-tail	1.6643714	
P(T<=t) two-tail	0.5279873	
t Critical two-tail	1.9904502	

P>0.05 Not Statistically Significant

Beer Waste VFA



Beer VFA t-test

F-Test Two-Sample for Variances

	Variable 1	*Variable 2*
Mean	2306.725	1071.416667
Variance	1016338.358	81344.07971
Observations	40	24
df	39	23
F	12.49431258	
P(F<=f) one-tail	1.0599E-08	
F Critical one-tail	1.917606271	

12.29>1.91 we reject the null hypothesis

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	2306.725	1071.416667
Variance	1016338.358	81344.07971
Observations	40	24
Hypothesized Me	0	
df	49	
t Stat	7.279402754	
P(T<=t) one-tail	1.22573E-09	
t Critical one-tail	1.676550893	
P(T<=t) two-tail	2.45145E-09	
t Critical two-tail	2.009575237	

7.29>2.01 Statistically Significant