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MEMORANDUM

From: P. S. Arora, P.E.
Director of Wastewater Utilities

To: Mario Canizares, Assistant City Manager

CC: Kenneth Banks, General Manager Utilities

Date: May 11, 2018

Subject: WET Magazine Article on Real Time Phosphorous Control at PCWRP

The Water Environment Association of Texas publishes Texas WET magazine. The Denton Pecan Creek Water Reclamation Plant phosphorous removal project was profiled in the current publication of the magazine (See attached). The article titled "Real Time Phosphorous Control Leads to Optimized Chemical Dosage and Cost Savings at City of Denton's Pecan Creek Water Reclamation Plant" discusses the first in Texas use of real time monitoring of phosphorous levels in the process stream to optimize the application of ferric chloride for phosphorous removal.

The plant has to meet 0.5 mg per liter phosphorous limit per the discharge permit criteria. Preliminary design and present worth analysis of available phosphorous removal processes, led to recommendation and use of chemical removal of phosphorous to meet the discharge permit. Jar testing led to recommendation of Ferric Chloride use to precipitate and removal of phosphorous. The use of real time analysis of phosphorous levels in the process stream using the HACH Phosphax units was a cutting edge application. This real time analysis allows very precise tuning of the ferric feed rate, resulting in optimized chemical cost, as well as optimized solids production.

Texas WET

LEADERSHIP FOR THE WATER ENVIRONMENT IN TEXAS

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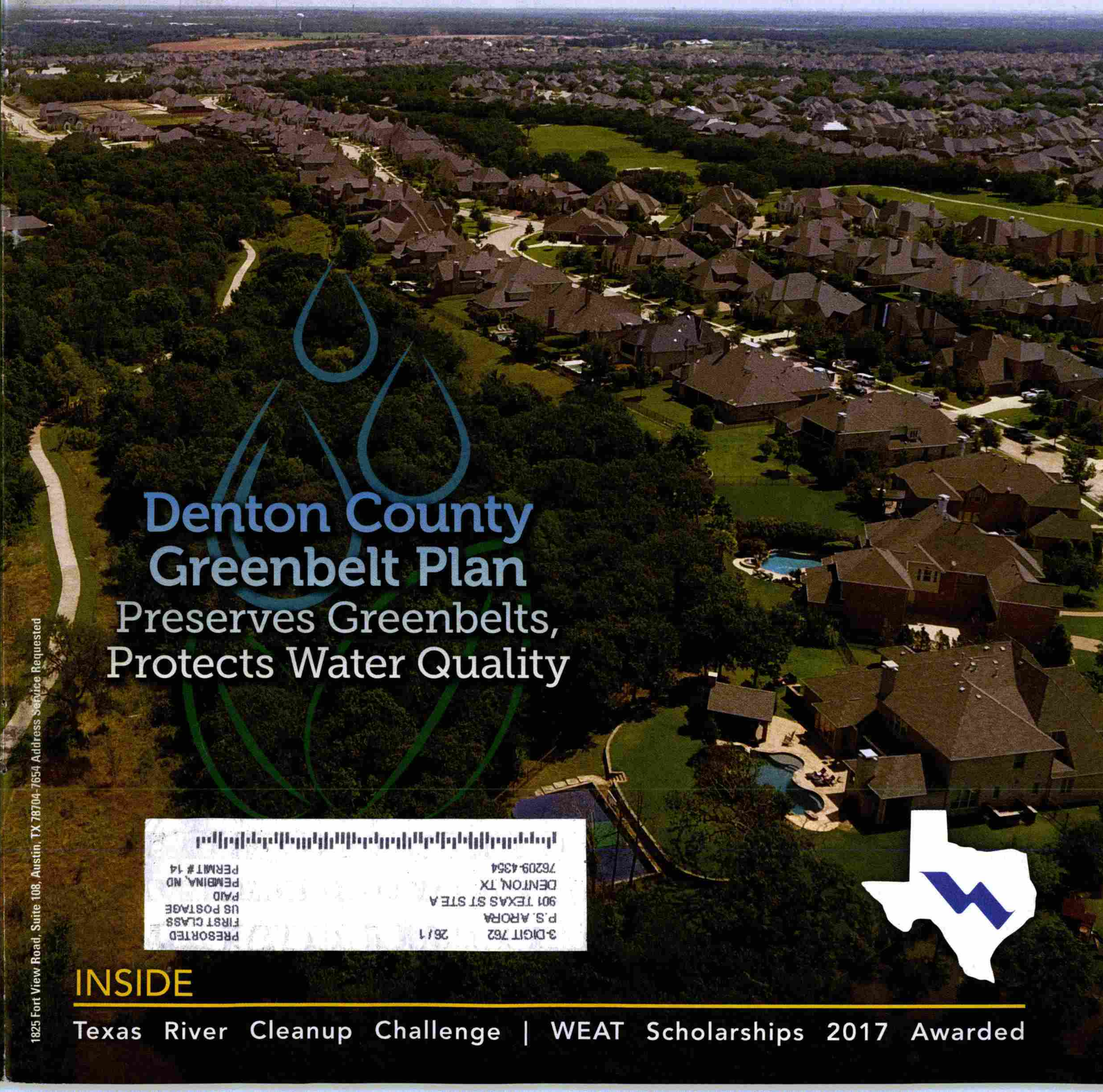

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REAL-TIME PHOSPHORUS CONTROL LEADS TO OPTIMIZED CHEMICAL DOSAGE AND COST SAVINGS AT CITY OF DENTON'S PECAN CREEK WATER RECLAMATION PLANT

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KEYWORDS
Nutrients; phosphorous removal; online analyzers; real-time control

INTRODUCTION

With several utilities in Texas being issued phosphorus limits as part of their permit renewal, phosphorus removal is becoming one of the important treatment process for wastewater treatment plants (WWTPs). Historically, phosphorus removal has been mostly based on plant flow or phosphorus load to the plant without optimization to account for biological removal of phosphorus. However, new technologies and analyzers provide in-situ phosphorus monitoring capabilities that can be utilized for real-time phosphorus control – thereby aiding in the optimization of the phosphorus removal process, providing cost savings in chemical consumption as well as in lower chemical sludge production. This article discusses implementation of phosphorus removal and real-time phosphorus control at the City of Denton's Pecan Creek Water Reclamation Plant (WRP).

The Pecan Creek WRP is owned and operated by the City of Denton, and consists of two separate process trains referred to as the North Plant and South Plant. Originally consisting of only its North Plant facility, the Pecan Creek WRP was originally constructed in 1961, with the South Plant facility being added in 1980. Several miscellaneous upgrades to the Pecan Creek WRP were made in 1992. During the latest improvements in 2001, the Pecan Creek WRP's treatment capacity was increased to an average annual daily flow of 21 MGD, maximum month flow of 25 MGD, and 2-hour peak flow of 46 MGD.

The Pecan Creek WRP is a conventional activated sludge wastewater treatment facility consisting of coarse screens, grit removal, primary clarification, activated sludge biological

Table 1. Flow and Loading Characteristics

Parameter	Average Flow and Loading	Maximum Month Flow and Loading
Flow, mgd	21	25
BOD5, lb/d (mg/L)	33,977 (194)	39,955 (192)
TSS, lb/d (mg/L)	42,080 (240)	55,538 (266)
P, lb/d (mg/L)	1,074 (6.13)	1,088 (5.22)

Table 2. Permit Limits

Parameter	Daily Average mg/L (lbs/day)	Effluent Discharge Limits (mg/l) 7-Day Average	Daily Maximum	Single Grab mg/L
Flow, mgd	Report	N/A	Report	N/A
CBOD (5-day)	7 (1226)	11	17	32
Total Suspended	15	25	40	60
Solids	(2627)			
Ammonia - Nitrogen April-October November-March	 2 (350) 3 (525)	 5 6	 10 10	 15 15
Total Phosphorus	0.5 (88)	1	2	3
E. Coli [colonies per 100 ml]	[126]	N/A	[394]	N/A
Dissolved Oxygen	5	5	5	5

reactors, secondary clarification, tertiary filtration and ultraviolet (UV) disinfection. In addition, the Pecan Creek WRP uses anaerobic digestion for sludge, which is then dewatered and composted for commercial resale. The North Plant includes four primary clarifiers, five aeration basins and four secondary clarifiers. The South Plant consists of three primary clarifiers, three aeration basins and four secondary clarifiers. The effluent from both plants is combined prior to tertiary filtration and disinfection. The treated effluent from the plant discharges into Pecan Creek, which eventually flows into Lake Lewisville.

DESIGN FLOW, LOADING AND PERMIT LIMITS

Table 1 presents the annual average and maximum month flow and loading data from January 2010 through July 2013.

The new discharge permit limits for the Pecan Creek WRP are presented in **Table 2.** The permit shall utilize an ultraviolet Light (UV) system for disinfection purposes. An equivalent method of disinfection may be substituted only with prior approval of the Executive Director.

1. The pH shall not be less than 6.0 standard units nor greater than 9.0 standard units and shall be monitored once per day by grab sample.
2. There shall be no discharge of floating solids or visible foam in other than trace amounts and no discharge of visible oil.
3. Effluent monitoring samples shall be taken at the following location(s): Following the final treatment unit.
4. The effluent shall contain a minimum dissolved oxygen of 5.0 mg/l and shall be monitored once per day by grab sample.
5. The annual average flow and maximum 2 hour peak flow shall be reported monthly.

OVERVIEW OF EXISTING TREATMENT PROCESS

The Pecan Creek WRP receives raw sewage at the raw sewage pump station. Two mechanical bar screens are used to remove large debris from the incoming raw sewage. The screened influent raw sewage is then pumped to a raw sewage flow splitter box where the flow is distributed to two grit removal systems. The de-gritted influent flow is sent to a de-gritted influent flow splitter box where the flow is distributed to the North and South Plants. The flow to the North Plant is sent to the North Plant splitter box, which distributes flow to the four primary clarifiers. The primary clarifier effluent is sent to the aeration basin influent channel and then distributed to the five North Plant aeration basins. The flow from the aeration basins is sent to four North Plant secondary clarifiers. The flow to the South Plant is sent to the South Plant splitter box, which distributes flow to three primary clarifiers. The primary clarifier effluent is sent to the aeration basin influent channel and is distributed to the three South Plant aeration basins. The flow from the aeration basins is sent to four South Plant secondary clarifiers. The secondary clarifier effluent from the North and South Plants is combined before tertiary filtration. The combined clarifier secondary effluent is filtered and disinfected using UV disinfection before discharging into the Pecan Creek.

PHOSPHORUS REMOVAL PROCESSES

The City of Denton's Pecan Creek WRP is one of the first cities to be issued a phosphorus discharge limit under the new TCEQ regulations. The City's discharge permit was renewed in June of 2013. The renewed permit included a total phosphorus discharge limit of 0.5 mg/L. A study was conducted to assess the City's options for addressing the new phosphorous limit. Treatment processes assessed for the removal of phosphorus to meet the new phosphorus discharge permit limits are as follows:

- Chemical Processes – For phosphorus removal, addition of alum or iron based coagulants is effectively used at several wastewater plants. For this study, addition of ferric chloride for the removal of phosphorus was evaluated.
- Biological Processes – For phosphorus removal, the biological nutrient removal (BNR) process involves the addition of an anaerobic fermentation zone that promotes the growth of phosphorus accumulating organisms (PAO), which provide enhanced phosphorus removal in the activated sludge process. For the Pecan Creek WRP, BNR process evaluation determined that chemical phosphorus removal as a polishing step was also required to account for removal variations pertaining to biological process efficiency.

A biological nutrient removal (BNR) process utilizing anaerobic, anoxic and oxic zone (AAO process) – with and without struvite recovery – was also evaluated. Based on the evaluation, it was determined that the BNR process was not cost effective, and therefore chemical phosphorus removal using ferric chloride was selected.

CHEMICAL PHOSPHORUS REMOVAL USING FERRIC CHLORIDE

Ferric chloride reacts with phosphate present in the water. The equation for this reaction is:

$FeCl_3 + PO4^{3-}$ □ $FePO_4$ (□) + 3Cl-

Based on the chemical reaction presented above one mole of ferric chloride is required for removal of one mole of phosphorus which is equivalent to approximately 5.2 lbs. of ferric chloride per lb. of phosphorus (or 5.2 mg/l of ferric chloride per mg/l of phosphorus removed). In addition to the above reaction, ferric chloride rapidly hydrolyzes and forms ferric hydroxide. Approximately 10mg/l of ferric chloride is utilized to form ferric hydroxide. Therefore, approximately 15.2 mg/l of ferric chloride is required per mg/l of phosphorus removed. Phosphate is adsorbed onto the ferric hydroxide and precipitates. This phosphate rich ferric hydroxide floc can be removed by settling in primary clarifiers, secondary clarifiers or in tertiary filters.

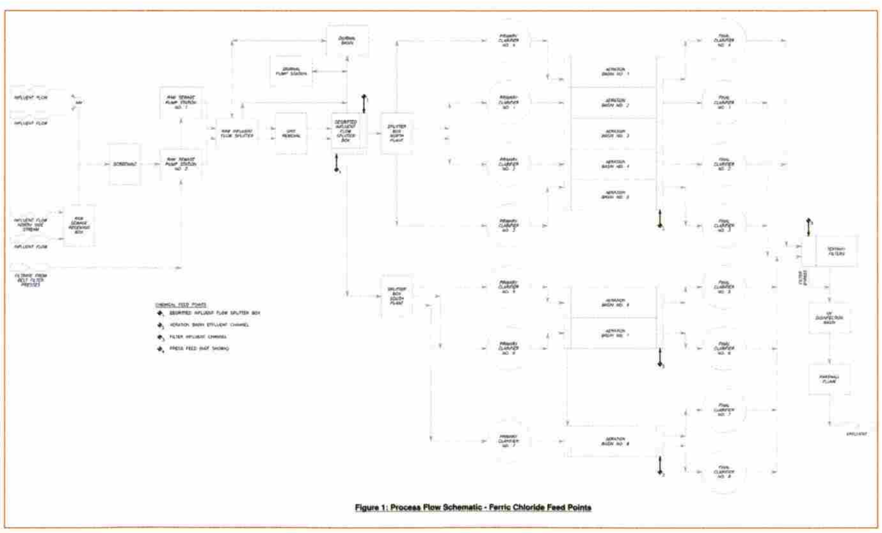

Figure 1 – Process Flow Schematic: Chemical Feed Points

Figure 2 – Chemical Feed and Storage Facility

Figure 3 – Ferric Chloride Feed Pump Skid

Thus, chemical phosphorus involves the following mechanisms:

- Chemical precipitation of phosphate (PO43-)
- Coagulation/flocculation of particulate phosphorus
- Adsorption of PO43- onto ferric hydroxide
- Precipitation of phosphate rich solids

Since the chemical phosphorus removal is achieved by removal of phosphorus rich solids, ferric chloride feed is provided at a well- mixed location upstream of solids settling or separation process units. Ferric chloride addition was provided at the following locations in the Plant. Process flow diagram with ferric chloride feed locations is provided in **Figure 1**.

- De-gritted influent flow splitter box (South and North Plant) – Upstream of Primary Clarifiers
- Aeration basin effluent channel (South and North Plant) – Upstream of Secondary Clarifiers
- Tertiary filters influent

Figure 2 above shows ferric chloride chemical storage and feed facility at Pecan Creek WRP.

Ferric chloride feed pump skid is shown in **Figure 3** above.

FERRIC CHLORIDE FEED AND CONTROL SYSTEM

The ferric chloride feed system consists of seven Variable Frequency Drive (VFD) driven chemical feed hose pumps with six pumps providing feed to six feed locations mentioned above and one pump as a back up to other pumps. The ferric chloride feed system consists of a Programmable Logic Controller (PLC) based control system and utilizes flow paced dosage and real-time phosphorus control dosage.

FLOW PACED DOSAGE

The flow paced dosage is based on grab sample analysis of the influent phosphorus, plant flow and the operator-entered dosage corresponding to the sampled phosphorus concentration. The pump feed in flow paced dosage is calculated as below.

$$FerricChlorideFeed\ Rate\ (mL/\min) = \frac{Dosage\ Setpoint\ (mg/L) * 3{,}786 * Flow\ Pacing\ Signal\ (mgd)}{1{,}440 * Specific\ Gravity * Chemical\ Percentage}$$

The above dosage depends on the operator-entered dosage set point. The dosage set point can be determined using the sampled phosphorus concentration and ferric chloride chemical required to form ferric phosphate and ferric hydroxide. For example, if the influent phosphate concentration is 7 mg/l, the effluent permit limit is 0.5 mg/l and if we assume that a 2 mg/l of phosphate is consumed in the biological process, the total phosphate to be removed is 4.5 mg/l. To remove 4.5 mg/l, ferric chloride dosage can be calculated as 4.5 mg/l*15.2 and can be used in the above equation to determine feed rate.

The above flow paced dosage is not efficient due to the following reasons and can result in overdosing or under dosing of ferric chloride:

- Influent phosphate concentration varies throughout the day
- Incoming phosphate concentrations are not proportional to flow
- Process conditions such as pH and temperature can influence ferric phosphate and ferric hydroxide formation and thus impact ferric chloride required
- Biological process also impacts the phosphate concentrations for chemical removal

"SINCE THE CHEMICAL PHOSPHORUS REMOVAL IS ACHIEVED BY REMOVAL OF PHOSPHORUS RICH SOLIDS, FERRIC CHLORIDE FEED IS PROVIDED AT A WELL-MIXED LOCATION UPSTREAM OF SOLIDS SETTLING OR SEPARATION PROCESS UNITS."

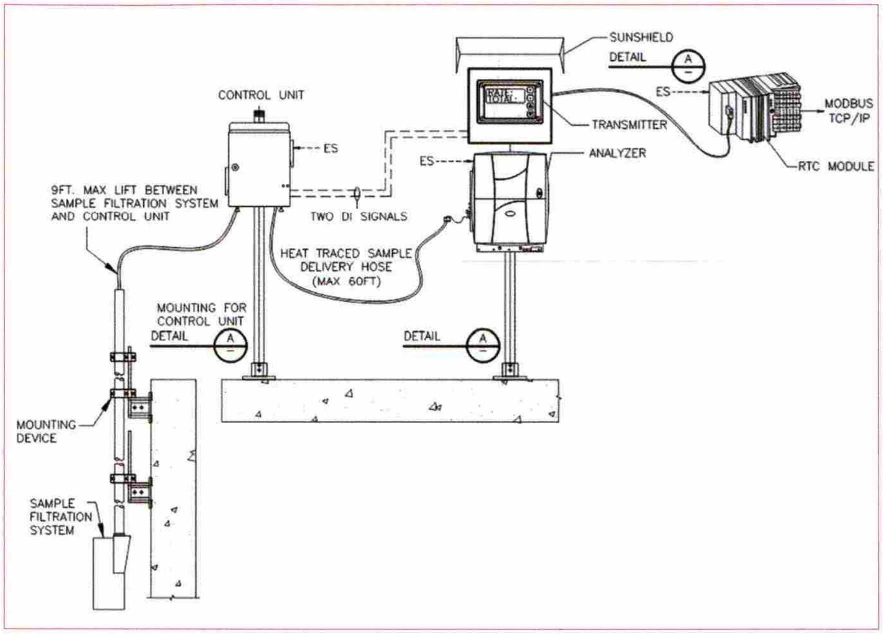

Figure 4 – Phosphate Analyzer System

In flow paced dosage, ferric chloride is added to remove worst case phosphorus loading to the plant, which can lead to overdosing of ferric chloride. Overdosing of ferric chloride can result in alkalinity consumption and removal of excessive amounts of TSS, BOD and other nutrients from wastewater and may result in nutrient deficiency in the downstream biological processes. Ferric chloride overdosing can coat the UV disinfection system bulbs and reduce the overall efficiency of the UV system. Overdosing will also result in increased sludge production and in higher chemical costs.

In flow paced dosage, since the phosphorus concentration varies throughout the day, adequate ferric chloride may not be added when the phosphorus concentration is above the set dosage set point and thus lead to under dosing of ferric chloride. Under dosing of ferric chloride can result in inadequate phosphate removal and not meeting the permit limits.

Historically, flow paced dosage has been the most common dosage method of phosphorus removal. The flow paced dosage method depends on frequent grab sample testing and can be labor intensive. Plants typically test sample once or twice a day and this testing does not provide for changing phosphorus concentrations coming into the Plant. New technologies and analyzers can provide in-situ real time phosphorus measurement and aid in monitoring and dosing of ferric chloride.

REAL-TIME PHOSPHORUS CONTROL DOSAGE

To address the inefficiencies associated with flow paced ferric chloride dosage discussed above, real-time phosphorus control was incorporated into the design. The real-time phosphorus control requires the following:

- In-situ analyzers
- Real-time controller (RTC) system
- Communication between Plant SCADA and real time controller
- Pump control from SCADA

Phosphorus Analyzers:

Phosphorus analyzers can measure the phosphorus concentrations and aid operators in monitoring phosphorus at critical locations. For the Pecan Creek WRP, the design included monitoring phosphate at locations downstream of solids separation processes [i.e., at influent to aeration basins (downstream of primary clarifiers) and influent to filters (downstream of secondary clarifiers)]. A phosphate analyzer system was also included to monitor Plant effluent. Each phosphate analyzer system consists of several components and is shown in **Figure 4. Figure 5** shows phosphate analyzer at the aeration basin influent.

Sample filtration systems consist of a plate membrane module and is located to be at least 6-inches submerged at the sample location. The filtered sample enters through the membranes into a tube, and two tube metering pumps housed in the control unit draw the sample through the sample tube and pump to the analyzer. The analyzer utilizes the vanadomolybdate yellow colorimetric method to measure phosphate concentrations. The response time for analyzing one sample is approximately five minutes. The frequency of sampling can be adjusted by the operator.

The measured phosphate concentrations are then fed to a controller, which can collect and log measurements. The controller can communicate with the Plant SCADA system or Plant PLC. For the Pecan Creek WRP design, a RTC system by Hach was used. The RTC system reads measurements from the controller and also obtains plant flow data from the Plant SCADA system. A phosphate concentration limit can be set at the RTC. The RTC uses real time flow data and concentration data to calculate ferric chloride dose required to meet set limit. The RTC adjusts the ferric dosage feed required by increasing and decreasing the chemical feed flow requirements and communicates the flow requirement with Plant SCADA. The Plant SCADA adjusts the VFD speed to pump ferric chloride dosage needed. Therefore, as the phosphate concentration changes, the ferric chloride feed flow is varied to correspond to the changing phosphate concentrations. Phosphate concentrations and ferric chloride feed at Pecan Creek WRP are monitored at a frequency of fifteen minutes. Monitoring data from one day of chemical feed operation (01/04/2018) was used to develop the chart above. The data for the chart is for phosphate measurements at the filter influent (downstream of secondary clarifiers) and ferric chloride feed at upstream treatment process, which is at the aeration basin effluent or secondary clarifier influent.

From the chart above, it can be observed that the ferric chloride feed rate follows the increase and decrease in the phosphate concentration. For the time periods when the phosphate concentration is below the set limit, no ferric chloride is dosed; thus avoiding unnecessary chemical dosage and increased sludge production. As the phosphate concentration increases, ferric chloride feed is increased to remove phosphate levels to meet permit; thus increasing reliability of the system to maintain optimal effluent phosphorus limits.

In general, the benefits of using the real-time phosphorus control dosage are:

- Meet permit even during the period when phosphorus concentrations vary significantly
- Prevent under dosing and thus meet permit
- Prevent over dosing resulting in lower chemical costs and lower sludge production
- Reduce manual sampling

Operation and maintenance considerations:

- Periodic maintenance of membranes in sample filter system
- Periodic calibration of the analyzer
- Analyzer reagent costs

SUMMARY

Historically, chemical feed for phosphorus removal has been mostly flow paced or load paced; neither of which account for fluctuating phosphorus concentrations and other process parameters that impact the chemical phosphorus removal. Likewise, both are labor intensive as manual grab sample testing is required. New analyzer and control technologies are available that can provide in-situ and continuous online monitoring of phosphorus concentrations. Utilizing these technologies, real-time phosphorus control and chemical feed can be incorporated into the design. The real-time phosphorus control aids in preventing over dosing or under dosing of chemical, thus minimizing adverse impacts on the downstream processes, lowering chemical costs and decreasing sludge production. The real-time phosphorus control system optimizes the chemical feed by adjusting the chemical feed to varying phosphorus loading into the plant and provides a reliable system to meet permit limits.

ABOUT THE AUTHOR(S)

Sri Koduri is an environmental engineer with CDM Smith and has more than 14 years of experience in water and wastewater treatment plant design. He has worked on various phases of water and wastewater treatment projects including feasibility studies, piloting, preliminary design, detailed design and construction management. His wastewater treatment experience includes BNR, WWTP upgrades, greenfield treatment plant design and MBRs. He has also worked on digester evaluation, biogas utilization studies, pre-dewatering and thickening design for pre-THP solids treatment. He has Bachelor's Degree in chemical engineering from India and a Master's Degree in environmental engineering from the University of Mississippi.

P.S. Arora, P. E. is the Director of Wastewater Utilities for City of Denton

Rusty Willard has been with the City of Denton since 1999 and now serves as the Superintendent for The City of Denton's two Water Reclamation plants. Rusty, along with his management staff, has been heavily involved from the design phases through the construction phases of City of Denton wastewater projects. Having input into the process produces a feeling of ownership for the plant staff. The Pecan Creek Water Reclamation Plant was named Plant of the Year in 2015.

Figure 5 – Phosphate Analyzer at Aeration Basin Influent

"THE REAL-TIME PHOSPHORUS CONTROL AIDS IN PREVENTING OVER DOSING OR UNDER DOSING OF CHEMICAL, THUS MINIMIZING ADVERSE IMPACTS ON THE DOWNSTREAM PROCESSES, LOWERING CHEMICAL COSTS AND DECREASING SLUDGE PRODUCTION."

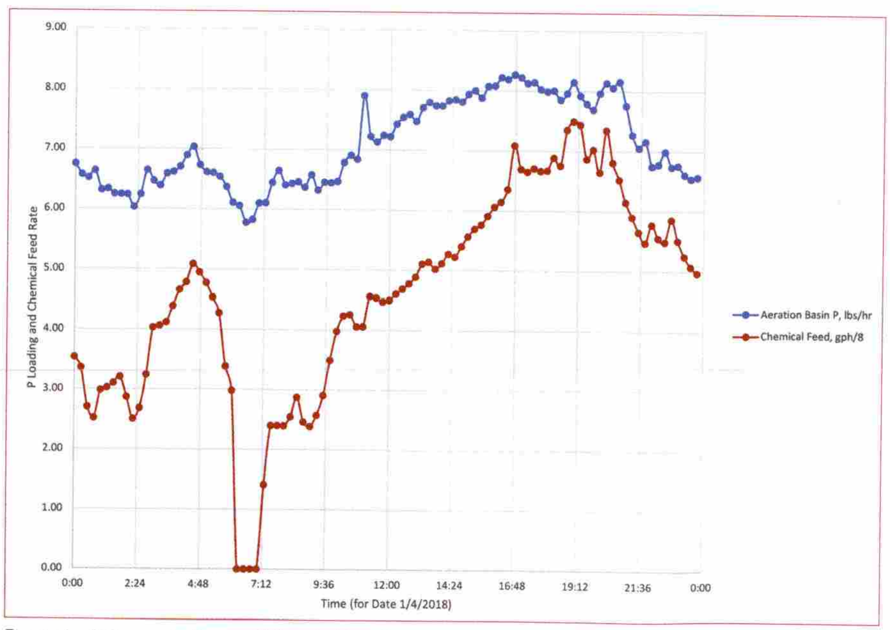

Figure 6 – P Concentration and Chemical Feed