Final Report
Wastewater Nutrient Optimization Project

December 14, 2016

Overview

Training and technical support was given to TDEC and municipal employees to assist them in the optimization of nutrient removal at municipal wastewater treatment plants.

TDEC staff training and technical support was provided as classroom training, video conferences, meetings, site visits, email, and telephone.

Municipal wastewater treatment plant support was similarly provided as classroom training, video conferences, meetings, site visits, email, and telephone.

As the training was being provided, the following results were achieved. Using newly acquired knowledge, ongoing technical support, and by challenging themselves to operate existing equipment differently, two-thirds of the municipal wastewater facilities involved in the 2016 and 2015 training efforts are meeting anticipated nitrogen and phosphorus nutrient limits or have demonstrated the capability to do so.

	Nitrogen Removal	Phosphorus Removal
2016 Study		
Baileyton	[solid green]	[shaded green]
Chattanooga Moccasin Bend		
Collierville Shelton Road	[solid green]	
Humboldt	**x**	
Lafayette	**x**	**w/o chemicals** [shaded green]
LaFollette	**x**	**w/o chemicals** [shaded green]
Millington	[shaded green]	**x**
Nashville Dry Creek	[shaded green]	**x**
Norris	**x**	[shaded green]
Oak Ridge		
2015 Study		
Athens North Mouse Creek	**x**	[shaded green]
Athens Oostanaula	**x**	**w/o chemicals** [solid green]
Cookeville	[solid green]	[solid green]
Crossville	**x**	[shaded green]
Livingston	**x**	[shaded green]

Pre-existing nutrient removal noted with an "x"
Nutrient removal following optimization: solid green box
Nutrient removal strategy identified but not yet realized: shaded green box

Training Overview

In providing TDEC staff training and technical support, Water Planet made available on-line training resources (webinars and documents), provided classroom training, facilitated meetings, maintained email communications, and participated in dozens of telephone calls.

A listing of the on-site training follows.

On-Site Training

January 5&6, 2016: two-day classroom training session in Knoxville
- Day 1: Tennessee Department of Human Services' Knoxville office
- Day 2: TDEC Knoxville Field Office

January 8-14, 2016: first of three rounds of East/Middle Tennessee in-plant training and technical support sessions
- January 8, 2016: Oak Ridge Main wastewater treatment plant
- January 11, 2016: LaFollette wastewater treatment plant
- January 13, 2016: Norris wastewater treatment plant
- January 14, 2016: Baileyton wastewater treatment plant

January 20, 2016: day-long follow-up training discussion at TDEC's Knoxville Field Office

February 2&3, 2016 two-day classroom training session in Jackson
- Day 1: Jackson Energy Authority's Training Center
- Day 2: TDEC Jackson Field Office

February 5-12, 2016: first of three rounds of West/Middle Tennessee in-plant training and technical support sessions
- February 5, 2016: Humboldt wastewater treatment plant
- February 8, 2016: Chattanooga Moccasin Bend wastewater treatment plant
- February 9, 2016: Lafayette wastewater treatment plant
- February 10, 2016: Nashville Dry Creek wastewater treatment plant
- February 11, 2016: Millington wastewater treatment plant
- February 12, 2016: Collierville Shelton Road wastewater treatment plant

February 17, 2016: day-long follow-up training discussion at TDEC's Jackson Field Office

February 18, 2016: meetings with TDEC staff at the Nashville Central Office

April 18-20. 2016: second of three rounds of West/Middle Tennessee in-plant training and technical support sessions
- April 18, 2016: Lafayette and Nashville Dry Creek wastewater treatment plants
- April 19, 2016: Humboldt wastewater treatment plant
- April 20, 2016: Millington and Collierville Shelton Road wastewater treatment plants

April 21, 2016: day-long training discussion following second round of in-plant training and technical support at TDEC's Jackson Field Office

April 22-27. 2016: second of three rounds of East/Middle Tennessee in-plant training and technical support sessions
- April 22, 2016: Norris wastewater treatment plant
- April 25, 2016: Chattanooga Moccasin Bend wastewater treatment plants
- April 26, 2016: Oak Ridge wastewater treatment plant
- April 27, 2016: Baileyton and Lafollette wastewater treatment plants

April 28, 2016: day-long training discussion following second round of in-plant training and technical support at TDEC's Knoxville Field Office

October 13-20: third of three rounds of in-plant training and technical support sessions
- October 13, 2016: LaFollette wastewater treatment plant
- October 14, 2016: Norris and Baileyton wastewater treatment plants
- October 17, 2016: Millington and Collierville Shelton Road wastewater treatment plants
- October 18, 2016: TDEC Jackson Field Office with Humboldt wastewater treatment plant Superintendent
- October 19, 2016: Nashville Dry Creek and Lafayette wastewater treatment plants
- October 20, 2016: Chattanooga Moccasin Bend wastewater treatment plant

October 21, 2016: half-day training discussion following final round of in-plant training and technical support at TDEC's Chattanooga Field Office and video conferenced to all field offices

October 25, 2016: end-of-project technical discussions at TDEC's Central Office in Nashville, including a presentation that was video conferenced to all Division of Water personnel

Water Planet accompanied TDEC staff in making three visits to each of the ten municipal treatment facilities on the dates listed above. This approach provided simultaneous training of TDEC and municipal personnel.

Water Planet provided specifications for field testing instruments to Barbara Loudermilk. Field testing instruments were purchased and supplied to each of TDEC's eight field offices (Chattanooga, Columbia, Cookeville, Jackson, Johnson City, Knoxville, Memphis and Nashville). TDEC staff were trained in the use of the instruments at a May 3rd class at the Fleming Training Center; training was provided by Hach Instruments and TDEC's Barbara Loudermilk.

Municipal wastewater treatment plant staff were given access to the same on-line training resources (webinars and documents) that were made available to TDEC staff. Municipal personnel were active participants in all of the on-site training with the following exceptions. Two days were spent providing technical support to TDEC's Nashville Central Office staff on February 18 and October 25. And, after meeting with both TDEC and municipal participants following the first and second round of in-plant visits, municipal participants departed and training discussions were held with TDEC field personnel in Knoxville on January 20 and again on April 28 as well as in Jackson on February 17 and April 21.

Remote Technical Support

Beginning November 24, 2015, hour long conference calls were held twice monthly for TDEC staff to share the experiences they were gaining as participants in the year-long wastewater nutrient optimization effort. The calls, organized and facilitated by TDEC's Karina Bynum, were open to all eight TDEC field offices and Central Office staff. During each call, a brief update of each of the ten participating municipal wastewater treatment plants was made and Water Planet provided technical support. Over twenty such calls were made.

TDEC staff were encouraged to make at least one monthly visit to each wastewater treatment plant. Water Planet actively monitored TDEC staff activities and the optimization efforts employed at each of the ten participating plant by telephone and email. Hundreds of emails were sent, hundreds of emails were received, and dozens of telephone discussions were held with TDEC and wastewater treatment plant personnel.

Training Documents

In addition to on-site and web-based training, Water Planet provided TDEC with the following documents. Copies are attached as Appendices.

Nitrogen Removal:

Nitrogen Primer
Nitrogen Forms
Nitrogen Chemistry
Nitrogen Capital Avoidance Strategies
Nitrogen Removal Decision Tree

Phosphorus Removal:

Phosphorus Primer
Phosphorus Chemistry
Biological Phosphorus Removal
Phosphorus Capital Avoidance Strategies
Phosphorus Removal Checklist

Wastewater Treatment Plant Visits

Water Planet joined TDEC staff in making thirty wastewater treatment plant visits during the year. TDEC staff accompanied Water Planet in meeting with plant staff, reviewing operations, developing nutrient optimization strategies, and discussing optimization efforts.

Baileyton: January 14, April 27 & October 14
Chattanooga Moccasin Bend: February 8, April 25 & October 20
Collierville Shelton Road: February 12, April 20 & October 17
Humboldt: February 5, April 19 & October 18 at TDEC's Jackson Field Office
Lafayette: February 9, April 18 & October 19
LaFollette: January 11, April 27 & October 13
Nashville Dry Creek: February 10, April 18 & October 19
Millington: February 11, April 20 & October 17
Norris: January 13, April 22 & October 14
Oak Ridge Main Plant: January 8, April 26 & October 13

Water Planet's technical support approach was to identify opportunities for changing the day-to-day operations of each of the ten participating wastewater treatment plants, discuss concepts with TDEC and plant personnel, and support both parties in implementation. By actively engaging with treatment plant personnel in a proactive manner, TDEC staff not only gave much needed support to risk-adverse plant operations staff, TDEC employees fortified already strong partnership relationships. The result: cleaner water at economic and environmental savings.

In addition to realizing the nutrient removal improvements summarized in the table on page one, the majority of the treatment facilities realized additional environmental benefits. In changing the day-to-day operations of the facilities in order to create optimal habitats for biological nitrogen and phosphorus removal, most of the plants are (or will, when optimization is complete) see reductions in electrical consumption, chemical use, and/or sludge production: results which make the facilities more sustainable. A summary of the environmental benefits is presented in the table that follows.

	Environmental Benefits		
	Reduced Electricity	**Reduced Chemicals**	**Less Sludge**
2016 Study			
Baileyton			
Chattanooga Moccasin Bend			
Collierville Shelton Road			
Humboldt			
Lafayette			
LaFollette			
Millington			
Nashville Dry Creek			
Norris			
Oak Ridge			
2015 Study			
Athens North Mouse Creek			
Athens Oostanaula			
Cookeville			
Crossville			
Livingston			

Environmental benefits resulting from nutrient optimization: solid green box
Environmental benefits identified but not yet realized: shaded green box

None of the facilities found it necessary to increase electrical consumption, increase chemical use, or produce more sludge in order to improve nitrogen and phosphorus removal. In fact, as a result of the environmental benefits, half of the facilities have reduced their operating costs as shown in the first table on the following page. And,, as shown in the table at the bottom of the next page, approximately two-thirds of the municipalities involved will – as a result of the optimization effort – realize a savings in the scope of the facility upgrades associated with nutrient removal.

Given that optimization efforts are ongoing, there is not yet enough data to quantify any of the findings. For this reason, the tables illustrate the outcome qualitatively versus quantitatively.

Operations & Maintenance Dollar Savings

2016 Study	
Baileyton	[solid green]
Chattanooga Moccasin Bend	[yellow]
Collierville Shelton Road	[yellow]
Humboldt	[yellow]
Lafayette	[solid green]
LaFollette	[shaded green]
Millington	[yellow]
Nashville Dry Creek	[solid green]
Norris	[solid green]
Oak Ridge	[solid green]
2015 Study	
Athens North Mouse Creek	[shaded green]
Athens Oostanaula	[solid green]
Cookeville	[solid green]
Crossville	[yellow]
Livingston	[yellow]

Impact of Study on Financial Cost of Nutrient Removal Facility Upgrade

2016 Study	
Baileyton	[solid green]
Chattanooga Moccasin Bend	[yellow]
Collierville Shelton Road	[shaded green]
Humboldt	[yellow]
Lafayette	[shaded green]
LaFollette	[shaded green]
Millington	[yellow]
Nashville Dry Creek	[shaded green]
Norris	[solid green]
Oak Ridge	[shaded green]
2015 Study	
Athens North Mouse Creek	[solid green]
Athens Oostanaula	[solid green]
Cookeville	[solid green]
Crossville	[shaded green]
Livingston	[shaded green]

Cost savings resulting from nutrient optimization: solid green box
Cost savings but not yet realized: shaded green box
No cost savings: yellow box

TDEC Staff Involvement

Empowered by the positive experiences realized in working with the participating municipalities, TDEC staff members, in several cases, engaged with other municipalities and sewer authorities on optimization initiatives. Among the municipal wastewater treatment facilities not in the program that have worked on nutrient optimization are: Arlington, Bartlett, Collierville's second plant (Northwest), Nashville Metro White's Creek, and West Knoxville Utility District.

TDEC's Karina Bynum has organized biweekly conference calls for the eight field offices, central office personnel, and Water Planet's Grant Weaver.

Without the support and active involvement of TDEC's Central Office, the project would not have been anywhere near the success it was. By encouraging the municipal participants to change their day-to-day plant operations in ways not envisioned with the plants' Operation and Maintenance Manuals were written, TDEC not only demonstrated the regulatory agency's interest in making the nutrient optimization program work (a huge departure from the position of many regulatory agencies), TDEC gained invaluable training experience.

TDEC's upper management involved all units of the Division of Water in the effort. The biggest involvement has been that of the field inspectors, the majority of whom embrace their new role of working with plant staff on optimization strategies. Others in the organization share their enthusiasm. Permit writers are including optimization requirements as a first step towards nutrient removal. Engineers on TDEC's plan review staff are better informed and work with consultants to ensure that designs provide flexibility and data gathering functions to assist treatment plant personnel in making their facilities operate at peak performance as requirements change to meet changing water quality priorities.

Acknowledgements

Active involvement by the participants was key to the success of the optimization. Had not TDEC staff engaged, had municipal wastewater treatment plant operators resisted, none of the successes would have been realized. The foundation for the success of the optimization program was engagement. By conveying a "we'd like you to try this" relationship with the municipal wastewater treatment plant staff, TDEC personnel are responsible and deserve recognition for their role in bringing about the improvements. And, by engaging EPA Region 4 staff, TDEC was able to enlist additional regulatory support for the optimization efforts.

Dr. Karina Bynum, PE was TDEC's project coordinator. Other TDEC participants include the following: Bob Alexander, Michael Atchley, Jason Benton, Tisha Benton, Eddie Bouzeid, Joellyn Brazile, Jonathan Burr, Karina Bynum, Bryan Carter, Jen Dodd, David Duhl, Souraya, Fathi, Jordan Fey, Conner Franklin, Amy Fritz, George Garden, Sherry Glass, April Grippo, Oakley Hall, Natalie Harris, Tim Hill, Brandon Hulette, Greta Hurst, Jennifer Innes, Vojin Janjic, Barbara Loudermilk, Bob Martineau, Shari Meghreblian, Regan McGahen, Greg Mize, Yatasha Moore, Jessica Murphy, Michael Murphy, Wade Murphy, Roger Orgain, Greg Overstreet, Steve Owens, Jessica Rader, Rob Ramsey, Chris Rhodes, Kevin Rice, Hassan Sanaat, Alan Schwendimann, Brad Smith, Sherwin Smith, Woody Smith, Maybelle Sparks, Robert Tipton, Sandra Vance, Johnny Walker, Sherry Wang, Erich Webber, Ariel Wessel-Fuss, John West, Maylynne Wilbert, and Angela Young. USEPA Region 4 staff was very supportive,

particularly: Amy Feingold, Bob Freeman, Brendan Held, and Craig Hesterlee. Larry Moore of the University of Memphis and Brett Ward of the University of Tennessee provided invaluable technical support.

But. Without the municipal participants, the training would have remained an academic exercise. Credit is due the following. From Athens: Russell Coleman, Jill Davis, Stef Farrell (consultant), Greg Hayes, and John Sullivan. From Baileyton: Danny Neely and Jason Smith. From Bartlett: Larry Gamblin and Will Kain. From Chattanooga: Brian Lessman, Mike Patrick, and Jeff Rose. From Collierville: Dave Harrison, Clay Holabird, and Tim Overly. From Cookeville: John Buford, Tom Graham, and Ronnie Kelly. From Crossville: Clark Annis. From Gatlinburg: Bill Ehrenbeck, Dale Phelps, and Keith Webb. From Humboldt: Scott Daniel and Jane Leatherland (consultant). From Lafayette: Rocky Hudson and Jack Hauskins. From LaFollette: Nick Cowan. From Livingston: Danny Langford, Jeremy Mars, and Steve Sims. From Millington: David Dunn, Chris Max, Shane Swindle, and Dave Wolle. From Nashville: Johnny McDonald, Jeff McGuire, Carl Marsh, Ken Schnaars (consultant), and David Tucker. From Norris: Doug Snelson and Tony Wilkerson. From Oak Ridge: Bob Currier, Lamar Dunn (consultant), Terry Howard, Scott Jackson, and Zachariah Seiden.

Contract Obligations

At project onset, a work plan was developed (contract item A2); it is provided on the following page. When the work plan was created, it was envisioned that all of the instrumentation would be purchased prior to any plant visits (contract items A5c, A7, and A8). However, the equipment did not arrive until after the second round of site visits in late April 2016. The equipment vendor joined TDEC staff in conducting a day long class at the Fleming Training Center May 3, 2016. As of the writing of this report, some TDEC staff are just beginning to put the equipment to use.

Also at project onset, it was envisioned that two calendar months would pass before the first round of treatment plant visits; and that the visits would first be conducted in West/Middle Tennessee. In fact, the first round of plant visits occurred within two weeks of contract award in East (not West/Middle) Tennessee. All of which means that the project ran ahead of schedule and took advantage of the seasonal fluctuations (albeit, with a delay in the use of beneficial monitoring instrumentation). Which meant that the ten municipal wastewater treatment plants participating in the project received more months of technical support than originally envisioned.

Municipal Participants

Ten municipalities volunteered to participate in the 2016 optimization effort: Baileyton, Chattanooga (Moccasin Bend plant), Collierville (Shelton Road plant), Humboldt, Lafayette, LaFollette, Millington, Nashville Metro (Dry Creek plant), Norris, and Oak Ridge (Main Plant). Five municipal facilities participated in the 2015 effort: Athens (Oostanula and North Mouse Creek plants), Cookeville, Crossville, and Livingston. Reports on the 2016 participants follow.

2015/2016 TDEC Nutrient Optimization Training Program		First Quarter (Dec 2015-Feb 2016)			Second Quarter (Mar-May 2016)			Third Quarter (Jun-Aug 2016)			Fourth Quarter (Sep-Nov 2016)		
Work Plan		**Dec '15**	**Jan '16**	**Feb '16**	**Mar '16**	**Apr '16**	**May '16**	**Jun '16**	**Jul '16**	**Aug '16**	**Sep '16**	**Oct '16**	**Nov '16**
A2	Develop workplan	X	X										
A3	ID and select volunteers												
	WWTPs												
	5 in West/Middle TN	X	X										
	5 in East/Middle TN	X	X										
	As necessary, others	X	X										
	Municipal wwtp volunteers	X	X										
A4	Training support for TDEC staff at 2016 statewide staff mtg												X
A5a	Initial training: two, 2-day classes in East/Middle and West/Middle TN		X	X									
A6	Oversight of TDEC and wwtp / volunteers (field)												
	Plant visits												
A6a	Initial visits												
	West/Middle TN			X									
	East/Middle TN				X								
A6b	Second visit												
	West/Middle TN							X					
	East/Middle TN							X					
A6b	Final visit												
	West/Middle TN												X
	East/Middle TN												X
A6c	Oversight of TDEC and wwtp / volunteers (remote)												
	Remote review and support		X	X	X	X	X	X	X	X	X	X	X
A5c & A7	Consultation re procurement and deployment of equipment	X	X										
A8	Develop wwtp nutrient removal training documents												
A8a	N&P resource materials	X	X										X
A8b	Plant optimization checklists and methods for N&P removal		X		X	X	X						X
A8c	Equipment checklists and methods for N&P removal	X	X										X
A9	Technical assistance when necessary												
A9a	Design criteria and plans review			X	X			X					X
A9b	Permit language			X	X			X					X
A9c	Other TDEC goals/functions relating to plant optimization			X	X			X					X
NA	Reports												
	Quarterly Reports				X			X			X		
	Final Report												X

Baileyton

TDEC's Johnson City field office staff was very active in assisting Baileyton with nutrient removal: Sandra Vance, Robert Tipton and Bryan Carter made numerous visits to Baileyton and actively interacted at all levels. Brett Ward of the University of Tennessee provided Baileyton with invaluable technical support. Baileyton's Danny Neely and operator Jason Smith were fully engaged with the optimization effort.

Baileyton successfully reduced nitrogen to low concentrations by cycling aeration equipment on and off throughout the day to create alternating aerobic conditions for ammonia conversion to nitrate (nitrification) and anoxic conditions for nitrate conversion to nitrogen gas (denitrification). The one in-service blower operates approximately 11 hours per day for a monthly electrical savings of approximately $500. Effluent nitrogen is consistently below 10 mg/L; before optimization it was typically greater than 50 mg/L.

Phosphorus removal has been more difficult to achieve. The pre-aeration tank has been converted to a pre-anaerobic tank and mixed liquor is piped into the now pre-anaerobic tank for VFA (volatile fatty acid) production and uptake by PAOs (phosphate accumulating organisms), but effective biological phosphorus removal has not been realized.

During the last visit of the contract, Baileyton was encouraged to make the following process changes in an ongoing effort to optimize phosphorus removal: decant the sludge holding tank / sludge digester weekly or more frequently in order to reduce the shock loadings of phosphorus that is released during digestion, slightly opening a valve on the air header in the pre-aeration fermenter enough to the keep the tank mixed but not so much that the contents become aerobic, and operating the aeration tanks such that the ORP cycles up to at least +150 mV most every cycle and shortening the aeration tank air-off cycles such that the air is not off for more than two hours at a time.

Given these changes and plant staff's commitment to optimize, Baileyton's wastewater treatment facility is now operated more sustainably at a reduced operating cost and the facility is expected to be able to meet anticipated nitrogen and phosphorus limits without a facility upgrade.

Chattanooga Moccasin Bend

Turnovers in the Moccasin Bend staff combined with significant mid-year mechanical issues have limited Chattanooga's ability to modify plant operations. Yet, Chattanooga's Mike Patrick and Jeff Rose along with TDEC's Angela Young and Jessica Rader have taken part in the training.

Dilution (presumably resulting from stormwater) has historically allowed the Moccasin Bend facility to meet its effluent ammonia limit even though the plant was purposefully operated with a short mean cell residence time (MCRT) so as to not nitrify. 2016's unusually dry summer has made it difficult for the 140 MGD facility to meet its ammonia limit. With the active support of University of Memphis professor Dr. Larry Moore Chattanooga's staff has considered options to address this.

The loss of one of two oxygenators this summer required Chattanooga staff to operate the plant differently than has traditionally been the practice. In response, Chattanooga's operational staff took creative actions to respond to the shortage of oxygen, an experience that has – in a manner similar to the optimization experiences of other facilities in the program – changed the plant's view regarding day-to-day operations. Which is this: given the tools to measure and the knowledge to respond, plant staff in Chattanooga – like staffs at other participating facilities – found their municipal wastewater treatment plants to be a lot more flexible than previously believed.

Collierville Shelton Road

Eddy Bouzeid of TDEC's Memphis field office was perhaps the most active field office participant in the optimization program.

Collierville staff likewise. City staff – Dave Harrison, Clay Holabird, and Tim Overly – continue to be fully engaged in optimizing nutrient removal at the Shelton Road treatment plant and are applying the knowledge gained at the larger facility to the similar Northwest treatment facility (both plants are oxidation ditch facilities). At Shelton Road, plant staff have installed an in-line ORP probe connected to SCADA to track conditions in the oxidation ditches. With this tool they are learning how to control both ammonia-nitrogen and nitrate-nitrogen in order to optimize total-nitrogen removal.

Years ago, plant staff realized that they could recover alkalinity lost during aeration by cycling the rotors in their oxidation ditches on and off. During the optimization effort, the cycles were adjusted in order to create optimal conditions for ammonia removal during the air-on cycles and nitrate removal during the air-off cycles. Conditions continue to be tracked using an in-line ORP probe and plant staff are working to establish optimal cycles.

At the recommendation of University of Memphis professor Dr. Larry Moore, plant staff have creatively reduced the RAS (return activated sludge) pumping rate in order to create anaerobic conditions in the plant's gravity thickener so that it will ferment sludge for biological phosphorus removal. Despite ongoing monitoring and considerable effort on behalf of the participants, phosphorus removal is not as effective as desired. Efforts to optimize are ongoing.

Nitrogen removal is well understood and controlled. Phosphorus removal continues to be a struggle. But, given the competency and intensity of Collierville's effort, the performance of the city's treatment facilities is being fully optimized.

Given the intensity of effort, this facility will almost surely be producing an effluent with low nutrients. Other than some chemical phosphorus polishing, it is unlikely that the Sheldon Road plant will need any upgrades to meet forthcoming nutrient limits.

Humboldt

Data collected for the optimization study revealed that the plant's equalization basin – a huge facultative lagoon – is providing two-thirds of the BOD and TSS removal as well as the majority of the influent nitrogen and phosphorus; the activated sludge portion of the facility appears to be providing almost no treatment. The primary clarifier and pre-aeration tricking filter are providing almost all of the treatment that occurs after the lagoon.

Given the above, it was recommended that the city explore opportunities to maximize lagoon treatment while evaluating long-term treatment options. City staff however seem committed to constructing a new SBR (sequencing batch reactor) facility and taking the lagoon out of routine use.

Lafayette

Oakley Hall of TDEC's Cookeville field office has been a very active participant in the optimization program. Lafayette's Jack Hauskins and Rocky Hudson have likewise been all in. As a result, a lot has been learned; a lot has been accomplished.

Using two portable OPR probes and meters, plant staff collected data which was formatted, graphed and distributed by Water Planet to TDEC and plant staff for review and discussion on a weekly basis. The data have been used to maintain excellent nitrogen removal while improving biological phosphorus removal. All involved have gained a strong awareness of the conditions that support and hinder phosphorus removal. Notwithstanding a number of actions, the high influent dissolved oxygen concentration and the small size of the pre-selector have limited plant staff's ability to create sufficiently anaerobic conditions in the selector to provide the desired level of biological phosphorus removal.

The weekly emails between the three parties (Lafayette, TDEC and consultant) empowered plant staff to the point that their facility is not only optimized, they reached out to the plant designer and discussed its limitations with them – and – are looking forward to operating the soon to be installed pre-equalization tank in such a way as to improve biological phosphorus removal so that it will no longer be necessary to ever add ferric chloride to maintain compliance with effluent phosphorus limits.

Given the staff's commitment, it appears likely that Lafayette will be able to dial in nutrient removal such that the facility will meet all anticipated nutrient limits without further facility upgrades.

LaFollette

Erich Webber of TDEC's Knoxville field office made numerous visits to LaFollette. Late in the year, LaFollette's recently promoted Chief Operator Nick Cowan began work on optimizing biological phosphorus removal by turning off one of two mixers in each of the two pre-anaerobic zones in an effort to strengthen fermentation.

LaFollette's facility is an oxidation ditch. It is equipped with a pre-anaerobic zone, presumably as a selector or biological phosphorus pre-anaerobic zone. The rotors have historically been operated intermittently. Extending the air-on and air-off cycle times to strengthen the aerobic and anoxic conditions in the ditches for nitrogen removal has been recommended.

Encouraging opportunities exist. With TDEC's ongoing support, there is every reason to expect that LaFollette will achieve significant BNR (biological nutrient removal) improvements;

hopefully to the point that chemical addition will no longer be necessary. And almost certainly such that no additional facility upgrades will be required to meet nutrient limits.

Millington

Eddy Bouzeid of TDEC's Memphis field office has worked very closely with Millington Superintendent David Dunn and staff (Chris Max, Shane Swindle, and Dave Wolle). Brett Ward of the University of Tennessee and Larry Moore of the University of Memphis have both contributed their expertise to assist in the optimization of Millington's oxidation ditch wastewater treatment facility. This facility has received a lot of support!

Plant staff have cycled aeration rotors on and off at Millington's unique oxidation ditch plant in an effort to improve nitrogen removal by. Biological phosphorus removal has historically been good to excellent thanks to incomplete mixing and the creation of anaerobic sludge blankets in the oxidation ditches.

As the study was ongoing, Millington was repairing and replacing rotors with a new design that does not provide the same mixing as the original rotors. At project's end, it was decided to operate all rotors for a period of weeks to suspend all of the deposition that resulted from having rotors out-of-service for months. Once the material has been thoroughly resuspended, controlled on-off cycling will be implemented in an effort to bring down total-nitrogen and consistently manage total-phosphorus. With TDEC's technical support, Millington should be able to meet upcoming nitrogen and phosphorus limits without a facility upgrade.

Nashville Metro Dry Creek

Jordan Fey of TDEC's Nashville field office was, to the extent his schedule allowed, a very effective, active participant in the optimization program. Likewise, plant superintendent Johnnie McDonald and Metro's staff including Jeff McGuire, Carl Marsh, Dave Tucker, and Ken Schnaars (consultant) were fully engaged. Strong team!

Given the large size of the facility (42 MGD), and the fact that none of the aeration valves are automated, Nashville staff worked with one of six parallel trains. The air in the first one-third of the first pass of the two-pass, plug-flow aeration tank is always off. Designed as a biological selector for filament control, the zone provides anaerobic conditions for bio-P removal. The remainder of the first pass is continuously aerated in order to provide biological phosphorus uptake. The air in the second pass is cycled on and off versus always on as has been conventional practice. The operational strategy is intended to preserve the facility's historically excellent total-P removal (effluent averages 0.2-0.3 mg/L) while providing alternating aerobic conditions for ammonia conversion to nitrate and anoxic conditions for nitrate conversion to nitrogen gas in the second train.

In seeking to optimize nutrient removal, Metro has taken primary clarifiers off line in an effort to beneficially increase the organic loading on aeration tanks. Plant staff also incorporated step feed to send a portion of the primary effluent flow to the second pass of aeration to boost denitrification when the air is cycled off. These actions have provided encouraging results. Total-nitrogen dropped by approximately 50% in the optimized train and a measurable decline in electrical consumption was observed.

Metro is considering investing in equipment that will allow all six passes to be operated automatically to provide complete nitrogen removal and save electricity. Thanks to the willingness of Metro (with the support of their design consultant!) to make the process changes described above, Metro will save many millions of dollars on future upgrades as the Dry Creek facility can be made to remove nutrients to low concentrations with minimal capital investment.

Norris

TDEC's Knoxville field office actively participated in optimizing nutrient removal at the Norris wastewater treatment plant; participants included Greg Mize, Rob Ramsey, and John West. Norris' Doug Snead and Tony Wilkerson were enthusiastically involved. Brett Ward of UT provided a kick-start to the nitrogen removal and his help was invaluable.

The Norris wastewater treatment facility is a plate steel pre-fabricated plant that is 30 years old. A plug flow aeration tank surrounds a circular clarifier. Sludge is digested in a nearby concrete tank. The facility was designed for neither total-N nor total-P removal.

By project's end, Norris' small staff gained an incredibly strong understanding of nitrogen removal and is able to operate the facility such that the effluent is very low in nitrogen. A creative effort to biologically remove phosphorus has so far been unsuccessful but staff are continuing to seek modifications.

By cycling aeration equipment in the plug flow treatment facility, Norris staff reduced effluent total-N to below 5 mg/L by mid-summer. Since then, plant staff have been working on a mechanism to reduce total-P. The first attempt at biological phosphorus removal proved ineffective and detrimental to total-N removal. The failed effort involved cycling the aeration blower off long enough to create fermentative conditions in the resulting sludge blanket in the aeration tank.

The current strategy involves the use of two used 325-gallon chemical as fermenters. Mixed liquor is pumped into the totes and allowed to sit overnight before being returned to the aeration tank. Early trials have not been successful. Sufficiently fermentive conditions have been created and the desired phosphorus release is occurring in the fermenters but the uptake is not happening when the contents are discharged to the aeration tank even though the tanks are emptied when the aeration tanks are aerating to optimize phosphorus uptake. At times, the effluent total-P has been higher than before the optimization effort was initiated.

Given plant staff's interest, commitment, and intellect – given their informed use of TDEC supplied equipment – Norris is certain to produce fantastically clean water once optimized such that no facility upgrade will be required to meet anticipated nutrient limits.

Oak Ridge Main Plant

Leading TDEC's Knoxville field office involvement was John West; Rob Ramsey and Greg Mize have also been active. A number of city staff have worked with TDEC on the optimization effort, including: Bob Currier, Terry Howard, Scott Jackson, Zachariah Seiden, and consultant Lamar Dunn.

Prior to the optimization effort, city staff took the primary clarifiers out of service. Even without primary clarification, the City's organically under-loaded facility struggles to provide enough BOD to effectively convert nitrate-nitrogen to nitrogen gas. It took months of effort to establish a pre-anoxic zone strong enough to denitrify. By turning one of two blowers off and by working to reduce the dissolved oxygen concentration in the final two of the four-pass, plug-flow aeration tank, the first two aeration tanks were successfully made anoxic at summer's end as the project was reaching completion. A temporary pump was installed at the end of aeration in one of the two trains.

Nitrogen removal was the focus of the optimization effort. No attempt was made to biologically remove phosphorus. Although not successful at achieving consistent total-nitrogen or total-phosphorus removal, TDEC and Oak Ridge staff have gain invaluable experience that illustrates what does and doesn't need to be considered in a facility upgrade. The end result will be better operating facilities (vis-à-vis nitrogen and phosphorus removal), O&M and capital savings.

Contact Obligations

A1. The Contractor shall provide all goods or services and deliverables as required, described, and detailed below and shall meet all service and delivery timelines as specified by this Contract.
Complete.

A2. The Contractor, in conjunction with State Division of Water Resources (DWR) personnel, shall develop a work plan with detailed milestones and timeline of activities.
Task is complete: the work plan was attached to the first quarterly report.

A3. The Contractor shall work with DWR to identify and select ten volunteer major or minor waste water treatment plants (WWTP) for plant optimization:

a. Work DWR staff to identify WWTPs that are good candidates for plant optimization and are distributed as evenly as possible between the State's Environmental Field Offices.
Task is complete: ten volunteers were selected.
b. Initially select up to five WWTPs for plant optimization from candidates proposed by Johnson City, Knoxville, Chattanooga, and Cookeville Environmental Field Office areas.
Task is complete: the West/Middle Tennessee volunteers were Collierville, Humboldt, Lafayette, Millington, and Nashville Metro Dry Creek.
c. Initially select up to five WWTPs for plant optimization from candidates proposed by Memphis, Jackson, Nashville, and Columbia Environmental Field Office areas.
Task is complete: the East/Middle Tennessee volunteers were Baileyton, Chattanooga Moccasin Bend, LaFollette, Norris, and Oak Ridge.
d. If necessary to reach the goal of ten WWTPs, select additional WWTPs from all regions of the state.
Task is complete: ten volunteers were selected.

A4. The Contractor shall provide training of DWR personnel at a statewide staff meeting:

a. Present Plant Optimization via oral presentation

Task is complete: training was held October 27 in Nashville and video conferenced to all field offices (training originally scheduled for October 26 & 27 at annual TDEC staff meeting at Fall Creek Falls but rescheduled by TDEC as a result of the effects of the summer's drought on Fall Creek Falls water supply).

b. Meet with staff from Environmental Field Offices to discuss training results and set future directions.
Task is complete: training was held October 21 in Chattanooga and video conferenced to all field offices.

A5. The Contractor shall train DWR personnel to implement plant optimization at the selected WWTP facilities. Training will consist of the following elements:

a. Two (2) two-day in-person training sessions for regional EFO staff.
Task is complete: two-day training classes were held at Knoxville Field Office (January 5&6, 2016) and Jackson Field Office (February 2&3, 2016)
b. WWTP nutrient removal lectures, and
Task is complete: TDEC staff were given access to a series of recorded webinars describing WWTP nutrient removal practices.
c. Instrument use training lectures.
Task is complete: TDEC and volunteers were instructed in the use and application of instrumentation (ORP meters and spectrophotometers) during the initial two-day training classes and the initial site visits. Additional training was provided by the vendor and TDEC staff on May 3rd at the Fleming Training Center.

A6. The Contractor shall provide oversight of DWR personnel and WWTP personnel for plant optimization. Oversight shall consist of:

a. An initial visit with DWR personnel at each WWTP
Task is complete: initial visits with TDEC staff occurred on the following dates – Oak Ridge (1/8/16), LaFollette (1/11/16), Norris (1/13/16), Baileyton (1/14/16), Humboldt (2/5/16), Chattanooga Moccasin Bend (2/8/16), Lafayette (2/9/16), Nashville Metro Dry Creek (2/10/16), Millington (2/11/16), and Collierville (2/12/16).
b. A minimum of two (2) follow-up visits with DWR personnel at each WWTP
Task is complete: follow-up site visits with TDEC staff took place on the following dates – Baileyton (4/27/16 & 11/14/16), Chattanooga Moccasin Bend (4/25/16 & 11/20/16), Collierville (4/20/16 & 11/17/16), Humboldt (4/19/16 & 11/18/16), Lafayette (4/18/16 & 11/19/16), LaFollette (4/27/16 & 11/13/16), Millington (4/20/16 & 11/17/16), Nashville Metro Dry Creek (4/18/16 & 11/19/16), Norris (4/22/16 & 11/14/16), and Oak Ridge (4/26/16 & 11/13/16).
c. Remote review of DWR personnel and WWTP data sets and recommendations
Task is complete: throughout the contract period TDEC was given a monthly inventory of emails containing remote review and support for TDEC staff and the staff of the ten volunteer facilities.

A7. The Contractor shall provide consultation to DWR personnel about the procurement and deployment of equipment used for successful plant optimization.
Task is complete: specifications for the purchase of ORP meters and spectrophotometers with sampling vials were submitted. Equipment was ordered and put to use; TDEC chose to

purchase Hach SL1000 instruments instead of the recommended Hach HQ40d meters and probes.

A8. The Contractor shall develop WWTP nutrient removal training documents. The documents shall include:

a. Resource materials for nitrogen and phosphorus removal
Task is complete: nitrogen and phosphorus removal webinars were posted on the Contractor's website and made available to TDEC staff.
b. Plant optimization checklist and methods for nitrogen and phosphorus removal
Task is complete: a plant optimization checklist with methods for nitrogen was provided. Technical information on phosphorus removal was provided.
c. Equipment checklist and methods for nitrogen and phosphorus removal.
Task is complete: a plant optimization checklist with methods for nitrogen was provided. Technical information on phosphorus removal was provided.

A9. The Contractor shall provide technical assistance when necessary. Technical assistance may include:

a. Design criteria and plan reviews for WWTPs
Task is complete: TDEC staff and Contractor discussed design criteria and plan reviews for WWTPs on January 5 & 6, 2016 at the Knoxville Field Office, February 18, 2016 at the Central Office and exchanged numerous emails.
b. Finalizing permit language for plant optimization at WWTPs
Task is complete: TDEC staff and Contractor discussed permit language for plant optimization at WWTPs on January 5, 2016 at the Knoxville Field Office and February 18, 2016 at the Central Office.
c. Other goals related to plant optimization.
Task is complete: TDEC staff and Contractor discussed other goals related to plant optimization at the January 5, 6 & 20, 2016 Knoxville Field Office meetings, at the February 2, 3 &17 meetings at the Jackson Field Office, at the February 18, 2016 Central Office meeting, and in innumerable emails.

A10. The Contractor's goods, services, and deliverables shall be classified into monthly milestones as set out in the 2015/2016 TDEC Nutrient Optimization Training Program Work Schedule and Budget.
Task is complete: the work plan included in this Final Report includes monthly milestones.

Appendix

Training Documents

NITROGEN REMOVAL FROM WASTEWATER
A PRIMER

GRANT WEAVER, PE & WASTEWATER OPERATOR
PRESIDENT, THE WATER PLANET COMPANY

OVERVIEW. Municipal wastewater treatment plants biologically remove nitrogen in two ways.

ONE. Somewhere on the order of 10 mg/L of influent nitrogen is typically converted to the bacteria that end up as sludge. Because nitrogen makes up about twelve percent of the dry weight of secondary sludge, and a slightly smaller percentage of primary sludge, every 8-10 mg/L of effluent TSS contains one mg/L of "suspended" nitrogen. The TSS nitrogen is organic-N.

TWO. Treatment plants convert the majority of the incoming nitrogen to nitrogen gas in a three step biological process.

> Step 1. Organic-nitrogen is converted to ammonia-nitrogen (NH_4) by a mostly anaerobic process called Ammonification.
>
> Step 2. Ammonia-nitrogen (NH_4) is converted to nitrate-nitrogen (NO_3) by an aerobic biological process called nitrification.
>
> Step 3. Nitrate-nitrogen (NO_3) is converted to nitrogen gas biologically in a low-oxygen (anoxic) environment. During denitrification, nitrogen gas bubbles harmlessly out of wastewater into the atmosphere.

AMMONIFICATION. The majority of the nitrogen contained in raw sewage (urea and fecal material) is converted from organic-nitrogen to ammonia (NH_4) as it travels through sewer pipes. As a result, the majority of the influent nitrogen is ammonia (NH_4), although some organic-nitrogen remains. In most plants, less than 2 mg/L of organic-nitrogen passes through the treatment plant untreated. The rest is converted to ammonia (NH_4).

Ammonification is mostly an anaerobic process. It is sometimes called hydrolysis.

Most treatment plants do nothing to enhance organic-nitrogen removal; it is not managed. However, treatment facilities with total-nitrogen effluent limits can oftentimes reduce the organic nitrogen to less than one mg/L by subjecting wastewater to strongly anaerobic and organically-rich conditions.

NITRIFICATION. Ammonia removal is a strictly aerobic biological process. Technically, bacteria convert ammonia (NH_4) to nitrate (NO_3); it isn't really "removed." Nitrification only works on ammonia (NH_4). Organic-nitrogen is not converted directly to nitrate (NO_3); it must first be converted to ammonia (NH_4), and the ammonia (NH_4) converted to nitrite (NO_2) and then nitrate (NO_3).

Nitrifying bacteria are slower growing and more sensitive to environmental upset than BOD removing bacteria. Generally, nitrification occurs only under aerobic conditions at dissolved oxygen levels of more than 1.0 mg/L. In activated sludge facilities, nitrification requires a long retention time, a low food to microorganism ratio (F:M), a high mean cell residence time (measured as MCRT or Sludge Age), and adequate pH buffering (alkalinity). A plug-flow, extended aeration tank is ideal. In trickling filter plants, it is generally best to operate in series with BOD removal in the first trickling filter and ammonia (NH_4) removal in the second filter.

The nitrification process produces acid. The acid lowers the pH of the biological population and is – unless buffered – toxic to the nitrifying bacteria. An aeration tank (or trickling filter) alkalinity of at least 60 mg/L is generally required. If there isn't enough alkalinity present in the wastewater, bacteria will not complete the nitrification process; nearly all of the ammonia (NH_4) will be converted to nitrite (NO_2) but not all of the nitrite (NO_2) will be converted to nitrate (NO_3). At concentrations of more than 0.5 mg/L nitrite (NO_2) can interfere with chlorine disinfection. At concentrations of a few milligrams per liter, nitrite (NO_2) can exhibit toxicity and provide process upsets.

Water temperature also affects the rate of nitrification. At temperatures below 20 degrees C, nitrification proceeds at a slower rate, but will continue at temperatures below 10^{o}C. However, if nitrification is lost, it will not resume until the temperature increases to well over 10^{o}C.

DENITRIFICATION. Wastewater cannot be denitrified unless it is first nitrified. The biological reduction of nitrate (NO_3) to nitrogen gas is performed by bacteria that live in a low-oxygen environment. To thrive, the bacteria need BOD – soluble BOD. Particulate BOD needs to be broken down into solution before it is of value.

Denitrifying organisms are generally less sensitive to toxic chemicals than nitrifiers, and recover from toxic shock loads quicker than nitrifiers. However, most facilities have more difficulty with nitrate (NO_3) removal (denitrification) than ammonia (NH_4) removal (nitrification) for two principal reasons.

At low temperatures, it becomes more difficult to drive down the dissolved oxygen concentration and keep the ORP values at desired negative millivolt levels. Variations in BOD loadings also make it difficult to maintain consistent nitrate (NO_3) removal. Denitrifying bacteria require a considerable amount of soluble BOD (some five times as much as the amount of nitrate (NO_3) being denitrified) and many facilities find it difficult to provide an ongoing supply of readily digestible BOD.

NITROGEN REMOVAL FROM WASTEWATER
NITROGEN FORMS

GRANT WEAVER, PE & WASTEWATER OPERATOR
PRESIDENT, THE WATER PLANET COMPANY

Nitrogen exists in several forms. The principal nitrogen types of concern to wastewater treatment are: total Nitrogen (t-N), Total Kejeldahl Nitrogen (TKN), Ammonia (NH_4), Organic Nitrogen (org-N), Nitrate (NO_3), and Nitrite (NO_2). Concentrations are reported in mg/L, as Nitrogen (N).

The relationships of the various forms are confusing, but important to understand.

total-Nitrogen (total-N). In order to determine the total-Nitrogen concentration, laboratory testing of TKN, Nitrate (NO_3) and Nitrite (NO_2) is required. The results of the three tests are added together. Many labs perform a cost saving nitrite + nitrate test.

$$\text{total-N} = \text{TKN} + NO_3 + NO_2$$

Total Kejeldahl Nitrogen (TKN). TKN is made up of Ammonia (NH_4) and organic-Nitrogen. A municipal wastewater treatment plant with an effluent containing more than 5 mg/L TKN is not fully nitrifying.

$$\text{TKN} = NH_4 + \text{org-N}$$

Ammonia (NH_3 or NH_4). When the pH of the wastewater is acidic or neutral, the majority of the nitrogen is ammonium (NH_4^+); however, it is typically called ammonia, not ammonium. When the pH increases over 8.0, the nitrogen is mostly ammonia (NH_3).

A municipal wastewater treatment plant with an effluent containing more than 1 mg/L of ammonia (NH_4) is not fully nitrifying.

organic-Nitrogen (org-N). A small fraction, typically one or two milligrams per liter, of the organic-Nitrogen is not amenable to biological treatment and passes through the treatment facility unchanged. A municipal wastewater treatment plant that is effectively nitrifying generally contains less than 3 mg/L organic-Nitrogen.

Nitrate (NO_3). Two types of effluents contain low nitrate (NO_3) concentrations: (i) wastewaters with excellent nitrogen removal and (ii) wastewaters with poor nitrogen removal. In the first scenario ammonia is converted to nitrate, and the nitrate is converted to nitrogen gas, and very little nitrate remains. In the second scenario, little to no ammonia is converted to nitrate, and as a result, there is very little nitrate produced. As a result, effluent nitrate (NO_3) concentrations of less than 3 mg/L exist in wastewaters that are fully nitrified and denitrified as well as in effluents with no nitrogen removal at all.

An effluent that is fully nitrified but has not been denitrified will generally contain a nitrate (NO_3) concentration of approximately 20 mg/L.

Nitrite (NO_2). Municipal wastewater effluents generally contain less than 0.5 mg/L nitrite (NO_2). Greater concentrations are found when a facility is partially nitrifying. Nitrite (NO_2) uses up a lot of chlorine and interferes with disinfection in plants using chlorine gas or hypochlorite.

Nitrogen Gas (N_2). The air we breathe is 78% nitrogen gas (N_2) and only 21% oxygen. The remaining one percent is argon and other inert materials.

NITROGEN REMOVAL FROM WASTEWATER
NITROGEN CHEMISTRY

An overview of the chemical reactions that describe biological nitrogen removal in municipal wastewater treatment plants follows.

AMMONIFICATION. While traveling through sewer pipes, the majority of the nitrogen contained in raw sewage is converted from organic-nitrogen (urea and fecal material) to ammonia through a process called hydrolysis. The process is anaerobic and is described by the simplified equation below.

$$NH_2COHN_2 + H_2O + 7H^+ \longrightarrow 3NH_4^+ + CO_2$$

The equation shows the conversion of urea to ammonium, not ammonia. The ratio of ammonia (NH_3) versus ammonium (NH_4^+) is affected by pH and temperature. At conditions typical for most municipal wastewater treatment plants (pH of 6 to7, and temperatures of 10 to 20 degrees Celsius), almost all is created as ammonium and almost no ammonia is produced. Since ammonia and ammonium behave similarly, this fact is of no real consequence to treatment plant designers and operators.

And, as is normal in the industry, Water Planet uses the term "ammonia" to describe the chemical in our literature but accompanies the term with the chemical symbol for ammonium, NH_4.

NITRIFICATION. The biological conversion of ammonia to nitrate is called Nitrification. Nitrification is a two-step process. Bacteria known as *Nitrosomonas* (and others) convert ammonia (NH_4) nitrite (NO_2). Next, bacteria called *Nitrobacter* (and others) finish the conversion of nitrite (NO_2) to nitrate (NO_3). The reactions are generally coupled and precede rapidly to the nitrate (NO_3) form; therefore, nitrite (NO_2) levels at any given time are usually below 0.5 mg/L.

These bacteria, known as "nitrifiers," are strict "aerobes;" meaning, they must have free dissolved oxygen to perform their work. Nitrification occurs only under aerobic conditions with a sufficiently positive oxidation reduction potential (ORP). Nitrification requires a long retention time, a low food to microorganism ratio (F:M), a high mean cell residence time (measured as MCRT or Sludge Age), and adequate buffering (alkalinity). Temperature, as discussed below, also plays a role.

The nitrification process produces acid. This acid formation lowers the pH of the biological population in the aeration tank and, because it is toxic to nitrifiers – particularly those that convert nitrite (NO_2) to nitrate (NO_3) – can cause a reduction of the growth rate of nitrifying bacteria. The optimum pH for *Nitrosomonas* and *Nitrobacter* is between 7.5 and 8.5; however most treatment plants are able to effectively nitrify with a pH of 6.5 to 7.0. Nitrification becomes inhibited at a pH below 6.5 and stops at a pH of 6.0. The nitrification reaction (that is, the conversion of ammonia (NH_4) to nitrate (NO_3)) consumes 7.1 mg/L of alkalinity (as $CaCO_3$) for each mg/L of ammonia (NH_4) nitrogen oxidized. An alkalinity of 60 mg/L in the biological reactor (aeration tank, trickling filter, RBC, etc.) is generally required to insure adequate buffering.

Water temperature also affects the rate of nitrification. Nitrification reaches a maximum rate at temperatures between 30 and 35 degrees C (86^oF and 95^oF). At temperatures of 40^oC (104^oF) and higher, nitrification rates fall to near zero. At temperatures below 20 degrees C, nitrification proceeds at a slower rate, but will continue at temperatures of less than 10 degrees C but will not resume if alkalinity is lost until the wastewater temperature increases to almost 15^oC.

Some of the most toxic compounds to nitrifiers include cyanide, thiourea, phenol and heavy metals such as silver, mercury, nickel, chromium, copper and zinc. Nitrifying bacteria can also be inhibited by nitrous acid and high concentrations of free ammonia (NH_4).

The following equations describe the nitrification process. Organic-nitrogen must first be converted to ammonia to be nitrified. Unless converted to ammonia, organic-nitrogen will pass through a treatment plant unchanged.

<u>Alkalinity buffering equation</u>

$$H_20 + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow HCO_3 + H^+ \leftrightarrow CO_3 + 2H+$$

<u>Nitrification equations</u>

$$NH_4^+ + 1.5O_2 \longrightarrow 2H^+ + 2H_2O + NO_2^-$$

$$NO_2^- + 0.5O_2 \longrightarrow NO_3^-$$

$$NH_4^+ + 1.83\ O_2 + 1.98\ HCO3^- \longrightarrow 0.021\ C_5H_70_2N + 0.98\ NO_3^- + 1.041\ H_2O + 1.88\ H_2CO_3^-$$

$$NH_4+ + 1.9O_2 + 2HCO3^- \longrightarrow 1.9\ CO_2 + 2.9\ H_2O + 0.1\ CH_2$$

From the above equations, it can be calculated that for every pound of ammonia (NH_4) oxidized to nitrate (NO_3), the following occurs:

> 4.18 pounds of oxygen are consumed and
>
> 7.14 pounds of alkalinity are consumed measured as calcium carbonate ($CaCO_3$) – or – 12 pounds of alkalinity measured as sodium bicarbonate ($NaHCO_3$)

DENITRIFICATION. The biological reduction of nitrate (NO_3^-) to nitrogen gas (N_2) by facultative heterotrophic bacteria is called Denitrification. "Heterotrophic" bacteria need a carbon source as food to live. "Facultative" bacteria can get their oxygen by "breathing" free dissolved oxygen (O_2) or by removing bound oxygen from nitrate (NO_3) or other molecules.

Denitrification occurs when oxygen levels are depleted and nitrate becomes the primary oxygen source for microorganisms. The process is performed under anoxic conditions; that is, when the dissolved oxygen concentration is less than 0.5 mg/L, ideally less than 0.2. A better measure is ORP, with -100 mV or lower being ideal. When bacteria break apart nitrate (NO_3^-) to gain the oxygen (O_2), the nitrate (NO_3) is reduced to nitrous oxide (N_2O), and, in turn, to nitrogen gas (N_2). Since nitrous oxide and nitrogen gas both have low water solubility, they escape into the atmosphere as gas bubbles. Free nitrogen is the major component of air, thus its release does not cause any environmental concern.

The formula describing the denitrification reaction follows:

$$6NO_3- + 5CH_3OH \longrightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH'$$

A carbon source (shown in the above equation as CH_3OH) is required for denitrification to occur. Optimum pH values for denitrification are between 7.0 and 8.5. Denitrification is an alkalinity producing process; it beneficially raises the pH. Approximately 3.0 to 3.6 pounds of alkalinity (as $CaCO_3$) is produced per pound of nitrate (NO_3), thus partially mitigating the lowering of pH caused by nitrification in the mixed liquor – approximately one-half of the alkalinity consumed during nitrification is returned during denitrification.

Since denitrifying bacteria are facultative organisms, they can use either dissolved oxygen or nitrate (NO_3) as an oxygen source for metabolism and oxidation of organic matter. If dissolved oxygen and nitrate (NO_3) are present, bacteria will use the dissolved oxygen firs and will not lower the nitrate (NO_3) concentration. Denitrification occurs only under anoxic, low-oxygen conditions.

Another important aspect of denitrification is the requirement for carbon; there needs to be enough soluble organic matter to drive the denitrification reaction. Organic matter may be in the form of raw wastewater, or it can be added as an alcohol, acetic acid (vinegar), or some other form of supplemental carbon.

The carbon – typically measured as BOD – needs to be in a readily digestible; not all BOD is the same. Denitrifying bacteria need the BOD to be in a soluble form; short-chained carbon molecules are preferred to complex, long-chained compounds.

Conditions that affect the efficiency of denitrification include nitrate (NO_3) concentration, anoxic conditions (DO and ORP), presence of organic matter, pH, temperature, alkalinity and the effects of trace metals. Denitrifying organisms are generally less sensitive to toxic chemicals than nitrifiers, and recover from toxic shock loads quicker than nitrifiers.

Temperature affects the growth rate of denitrifying organisms, with greater growth rate at higher temperatures. Denitrification can occur between 5 and 30^oC (41^oF to 86^oF), and these rates increase with temperature and type of organic source present. The highest growth rate can be found when using methanol or acetic acid. A slightly lower rate using raw wastewater will occur, and the lowest growth rates are found when relying on endogenous carbon sources at low water temperatures.

Wastewater cannot be denitrified unless it is first nitrified, and organic-nitrogen must be converted to ammonia (NH_4) in order to be nitrified.

NITROGEN REMOVAL FROM WASTEWATER
CAPITAL AVOIDANCE STRATEGIES

For little to no cost, most treatment plants can make process changes in order to provide nitrogen removal. A discussion of various strategies follows.

Enhanced Ammonification. Because effluent organic-nitrogen concentrations are typically quite low (generally less than 2 mg/L), few treatment plants seek to reduce organic-N.

Nonetheless, treatment facilities with total-Nitrogen limits can oftentimes – with little effort and little cost – improve ammonification to provide an extra 0.5 to 1.5 mg/L reduction in total-Nitrogen.

This is done by creating a BOD-rich anaerobic zone at the front end of the treatment plant. We've done it in MLE (Modified Ludzack-Ettinger) activated sludge plants by converting pre-anoxic denitrification tanks to fully anaerobic conditions by reducing the internal recycle rate and managing the dissolved oxygen (DO) in the aeration tanks. Another tactic is to organically overload primary clarifiers so that they ferment wastewater. We've also recycled material from gravity thickeners and sludge storage tanks.

Enhanced Nitrification. Nitrification needs lots of air, not necessarily the 2 mg/L that is often recommended, but a goodly amount. Our favored approach is to monitor aerobic conditions with ORP but adjust aeration using DO. Once consistent ammonia removal has been achieved, we slowly make small reductions in the DO setting until we see an adverse impact on ammonia removal. We then restore complete nitrification and monitor conditions using ORP.

Nitrifiers grow slowly and generally need a hydraulic retention time of at least 6 hours, more at temperatures below 15^{o}C. Nitrification requires a high mean cell residence time (sludge age); typically a MCRT of 8 days or more. Nitrification needs alkalinity; if there isn't enough alkalinity in the raw wastewater to maintain at least 60 mg/L, it has to be added.

To implement ammonia removal, the first consideration – in an activated sludge plant – is mixed liquor concentration: which, as a general rule, we like to raise as high as can be maintained given existing conditions (e.g., clarifier blankets). The second is oxygen: which, as a general rule, we like to keep as low as possible – just enough to support complete ammonia removal. The third is alkalinity / pH. Every mg/L of ammonia converted to nitrate consumes 7.1 mg/L of alkalinity. The least expensive way of adding alkalinity is to create it during denitrification. Denitrification adds back about 50% of the alkalinity removed during nitrification. In instances where the conditions are favorable for nitrification, but the reaction is incomplete, ammonia removal might be improved by generating alkalinity by cycling the air off in order to create periods of anoxic conditions. Caution: If dissolved oxygen or retention time is limiting nitrification, this strategy will worsen, not improve nitrification.

In small treatment facilities, 50-pound bags of baking soda (sodium bicarbonate) can be mixed with 100 or more gallons of water in day tanks and pumped into the wastestream using chemical feed pumps. In larger plants, tanker truck deliveries of liquid magnesium hydroxide can be transferred to holding tanks and pumped into the wastestream with chemical feed pumps. Chemicals such as sodium hydroxide are widely used but do present safety concerns.

Nitrification design standards are generally very conservative. It is good to recognize and understand them, but don't allow the textbook "requirements" inhibit experimentation. Most treatment facilities can do more with less.

In order to establish and maintain nitrification it is important to monitor Dissolved Oxygen (D.O.), Alkalinity, TKN (and/or Ammonia), and Nitrate daily. Same day results are important! The daily use of test strips such as those manufactured by Hach may be sufficient. The ideal monitoring practice is to use in-line instrumentation connected to a SCADA system.

Regardless of how the data is collected, it won't be of much value unless it is regularly reviewed and used in making process adjustments. Written Standard Operating Procedures (SOPs) can be an invaluable tool.

It has been our experience that once a plant has been set up to effectively nitrify, it continues to do so unless (a) a toxin is discharged into the sanitary sewers, (b) equipment failure, or (c) temperatures fall very low. Facilities that struggle with consistent nitrification are those very few with influent nitrogen concentrations of 75 mg/L or more, or facilities where the basics – e.g., air, alkalinity – are ignored.

Denitrification. For denitrification to occur, nitrified wastewater needs to reside 1-2 hours in a low-oxygen, high BOD environment. The easiest way to create such a space is to cycle the aeration tank air. Another way is to create an a low oxygen area of sufficient size ahead of the aeration tank(s) and to pipe all return activated sludge to the inlet end of the anoxic tank so that it mixes with the incoming wastewater.

The two key parameters for denitrification are low DO (less than 0.5 mg/L) and surplus BOD (ideally around 5 mg/L of soluble BOD per mg/L of nitrate produced during nitrification). It is also important to mix the contents of the anoxic tank. This can be done using mixers, or if it is possible to direct influent flow into the settled layer of mixed liquor during the aeration-off cycle, it may be done without the need for any mechanical mixing.

The effectiveness of pre-anoxic denitrification tanks are often limited by the amount of available BOD. Any number of strategies are available to improve BOD availability. The fact is, not all BOD is the same to denitrifying bacteria. Particulate BOD (that included with TSS) is of little use. Of the soluble forms of BOD, denitrifying bacteria most effectively utilize volatile fatty acids (VFAs) and simple carbon chains such as alcohols.

Sufficient BOD often exists in influent. If too much BOD is being removed during primary treatment to provide the 5:1 ratio, better results may be obtained by taking one or more primary clarifiers out of service.

If enough BOD exists, but it is largely insoluble, it may be necessary to provide a short period of aeration prior to the anoxic stage. The pre-aeration period will allow for the particulate BOD to be made soluble and therefore available to the denitrifying bacteria.

If there isn't enough BOD coming in to satisfy demand, it may be possible to supplement using internal waste streams. One practice is to create fermentation tanks. "Fermentation" is essentially the same thing as anaerobic treatment except that the waste gets just enough air to prevent methane production. This can be done by periodically (for example, an hour per day) aerating the anaerobic waste.

The most common sources of fermented waste are primary gravity thickeners and recycled waste sludge from sludge holding tanks. Another excellent source is septage. Septage contains a significant quantity of volatile fatty acids. Volatile fatty acids (VFAs) are not only good food for denitrifying bacteria, VFAs promote biological phosphorus removal. Treatment facilities that receive septage take in a BOD source that is well suited to denitrification. The challenge is to pace the septage flow and to divert it to where it is most needed.

When denitrification tanks are established ahead of aeration tanks, design manuals typically call for the internal recycling of 300% of the influent flow to move the nitrified mixed liquor into the anoxic zone at a rate of 300% of influent flow. We've found this rate to be much too high. It is not only possible to denitrify with no internal recycling (under the right conditions), we have found it almost commonplace for treatment plants to recycle so much flow that denitrification is inhibited. Too high of an internal recycle rate brings in too much oxygen and reduces the anoxic retention time below what is necessary for denitrification to occur.

It has been our experience that effective denitrification enhances operations. It almost always creates a mixed liquor with less foaming, and a bacterial population that settles better in clarifiers. And, denitrification adds back alkalinity, which in turns assists nitrification.

Although a hardier biochemical process, we've found that the denitrification process in many facilities requires more day-to-day fine tuning than is required to maintain effective nitrification. A loss of denitrification – unlike restoring nitrification, a process than can take weeks to accomplish – can typically be remedied in two or three day's time. If denitrification is lost, it may be necessary to temporarily provide the nitrification tank with a dose of chemical alkalinity to compensate for the alkalinity that would have been returned if denitrification were ongoing. This, because denitrification adds 3.5 mg/L of alkalinity for every mg/L of nitrate converted to nitrogen gas.

PHOSPHORUS REMOVAL FROM WASTEWATER
A PRIMER

GRANT WEAVER, PE & WASTEWATER OPERATOR
PRESIDENT, THE WATER PLANET COMPANY

During conventional treatment (BOD removal), approximately 2 mg/L of phosphorus is removed from the wastestream and converted to bacterial mass. The influent total-P concentration is generally around 6 mg/L; therefore a typical effluent total-P concentration is 4 mg/L.

Two methods of enhanced phosphorus removal are available to wastewater treatment facilities: biological and chemical. Whether phosphorus is removed biologically, chemically, or both – influent phosphorus is converted from a liquid (generally ortho-P) to a solid (sludge). Effluent TSS (total suspended solids) contains approximately 5% phosphorus; therefore, there are two factors that control phosphorus removal: (i) the conversion of soluble phosphorus to a solid and (ii) TSS removal. Phosphorus can be chemically removed using a number of compounds as described on a companion white paper.

BIOLOGICAL PHOSPHORUS REMOVAL. The environmental conditions which provide enhanced biological phosphorus removal are: initially, a period of anaerobic treatment (zero oxygen), followed by aerobic treatment. The anaerobic zone cannot be a digester; anaerobic digesters destroy the acids that are needed to promote biological phosphorus removal. PAOs, phosphate accumulating organisms, take in volatile fatty acids (VFAs) that are created in anaerobic conditions. The VFAs are used as an energy source. In taking in VFAs, PAOs release phosphorus and temporarily increase the ortho-P concentration. Under highly aerobic conditions with a pH of 7.0 or higher, the PAOs take in large amounts of phosphorus, tripling (or more) the amount of phosphorus in their cells. Phosphorus is removed with the bacteria as waste sludge.

It is generally possible to attain effluent phosphorus concentrations of less than 0.5 mg/L using biological phosphorus removal. But, only when effluent suspended solids concentrations are very low. This, because each mg/L TSS effluent contains approximately 0.05 mg/L phosphorus.

Since anaerobic conditions followed by aerobic conditions promote biological phosphorus removal, any of the following will promote phosphorus removal: adding septic tank pump-out waste into the aeration tank, returning fermented (but not anaerobically digested) sludge (RAS or WAS) into the wastestream, or creating a pre-anaerobic zone for the wastewater to pass through.

CHEMICAL PHOSPHORUS REMOVAL. Chemical phosphorus removal is accomplished by the coagulation and precipitation of phosphorus. Three categories of chemicals are commonly used for phosphorus removal: iron compounds, aluminum compounds, and lime.

Iron salts. Iron is commercially available in three forms: ferric chloride, ferrous chloride, and ferrous sulfate. All are corrosive and, as such, pose a safety hazard.

Aluminum salts. Aluminum is commercially available in five forms. Aluminum sulfate (alum) and poly-aluminum chloride (PAC) are the most common. Also available are aluminum chloride, aluminum chlorohydrate, and sodium aluminate.

Lime. Wastewater treatment plants can, but generally do not, use lime. Lime dosage is more influenced by alkalinity than phosphorus concentration; the pH must be raised to 10.5 for phosphorus removal to occur. The amount of lime required is approximately 1.5 times the alkalinity concentration in mg/L. Lime must be “slaked” – put into solution – to be of use.

ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL

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Phosphorus is an essential nutrient in the growth of all living things. During conventional wastewater treatment, some 2 mg/L of phosphorus is typically removed from the wastestream and converted to bacterial mass. By weight, bacteria are approximately 1.5 percent phosphorus. Meaning, for every dry ton of waste sludge, 30 pounds of phosphorus is biologically removed from wastewater.

"Enhanced" biological phosphorus removal increases the dry weight component of phosphorus to as high as five percent, maybe more. Wastewater professionals who understand the process can quadruple phosphorus removal without the use of chemicals.

Enhanced biological phosphorus removal is a two step process: a period of anaerobic treatment (zero oxygen), followed by highly aerobic treatment at neutral or higher pH. Volatile fatty acids (VFAs) drive the process. VFAs are produced in anaerobic conditions.

The anaerobic treatment cannot be a digester; VFAs are destroyed during anaerobic digestion, they are converted to methane gas. In fact, the undesirable "acid" in the acid/alkalinity ratio that is used to monitor the effectiveness of anaerobic digesters is VFA. For enhanced biological phosphorus removal, it is important to ferment and not completely digest waste so that (i) a supply of volatile fatty acids are created in advance of an aerobic zone and (ii) a family of bacteria called PAOs, phosphate-accumulating organisms, take in the VFAs. The wastewater needs to contain approximately 25 times as much BOD as phosphorus in order to support biological phosphorus removal. During fermentation, the bacteria (PAOs) temporarily release a lot of the phosphorus stored within their cells into the wastestream.

When the PAO bacteria enter an aeration tank with high a high dissolved oxygen content and neutral pH (both conditions are very important for biological phosphorus removal) they use the VFAs as an energy source and take in all but 0.05 mg/L (or less) of the soluble ortho-phosphorus. The phosphorus is removed with the bacteria as waste sludge. There is a temporary increase in phosphorus concentration in anaerobic tanks.

Municipal wastewater treatment plant staff can create volatile fatty acids in any number of ways. VFAs can also be imported; for example with septage.

The three textbook ways of creating VFAs are: (i) in a mainstream anaerobic tank located ahead of aeration, (ii) in a primary sludge fermenter, and (iii) in a return sludge selector. Once established, the biological process needs little to no attention. Simply allow moderate to high BOD to remain anaerobic for a period of an hour or longer. Aerobic digesters can be converted to fermenters by turning the air off. Similarly, sludge holding tanks, gravity thickeners, and other zones of zero oxygen and high-BOD can be made into fermenters.

A well operating biological phosphorus removing facility can reduce effluent phosphorus to 0.2 mg/L. To achieve this level of treatment, the effluent TSS (total suspended solids) concentration must be very low. Each mg/L of effluent TSS contains approximately 0.05 mg/L of phosphorus. To meet an effluent limit of 0.5 mg/L or less, effluent TSS and effluent ortho-P must be closely monitored and controlled.

PHOSPHORUS REMOVAL FROM WASTEWATER
PHOSPHORUS CHEMISTRY

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PHOSPHORUS REMOVAL - GENERAL. Whether done with chemicals or biologically, phosphorus is removed from wastewater by converting soluble phosphorus – the vast majority of which is ortho-phosphate (PO_4) to a solid. The solid becomes a part of the TSS (total suspended solids) and is removed as sludge.

There are two ways of reporting phosphorus: (i) as P, the more common method, and (ii) as PO_4. "As P" values are one-third of the "as PO_4" results. This, because the molecular weight of PO_4 (95) is three times that of P (31). When reviewing data, always make sure that the results are reported "as P."

BIOLOGICAL PHOSPHORUS REMOVAL. The chemistry behind biological phosphorus removal is complicated, not completely understood, and is therefore not shown.

The principal science is the need for fermentive conditions sufficient to both create volatile fatty acids (VFAs) such as acetic and propionic in advance of an aerobic (mixed liquor) zone and allow for VFA intake by a family of bacteria called PAOs, phosphate-accumulating organisms. For this to happen, the wastewater needs to contain approximately 25 times as much BOD as phosphorus. During fermentation, the bacteria (PAOs) release much of the phosphorus stored within their cells into the wastestream. When the PAO bacteria enter an aeration tank with high a high dissolved oxygen content and neutral pH (both conditions are very important for biological phosphorus removal) they use the VFAs as an energy source and take in all but 0.05 mg/L (or less) of the soluble ortho-phosphorus.

CHEMICAL PHOSPHORUS REMOVAL. Chemical phosphorus removal processes are better understood and are shown in the equations that follow.

Iron salts. Iron is commercially available in three forms: ferric chloride ($FeCl_3$), ferrous chloride ($FeCl_2$), and ferrous sulfate ($FeSO_4$). All are corrosive and therefore must be carefully handled.

Theoretically, 1.8 pounds of iron is required to remove one pound of phosphorus (as P). However, to achieve low phosphorus concentrations, much more is required. Approximately 1 mg/L of alkalinity is consumed for each mg/L of iron added; as a result, the wastewater pH drops approximately 0.1 per 10 mg/L of iron added. Iron works over a wide pH range. Iron salt solutions contain some trace metals: up to 75-100 mg/L depending on the product.

<u>Ferric chloride</u> ($FeCl_3$)

$FeCl_3 + PO_4 \longrightarrow Fe_3(PO_4)_2$

$Fe^{+3} + HCO_3 \longrightarrow FeOH_2$

@ 34.5% ferric chloride solution = 1.38 pounds of iron per gallon
@ 40% ferric chloride solution = 1.62 pounds of iron per gallon

Ferrous chloride ($FeCl_2$)

$FeCl_2 + PO_4 \longrightarrow Fe_3(PO_4)_2$

$Fe^{+2} \longrightarrow Fe^{+3}$

$Fe^{+3} + HCO_3 \longrightarrow FeOH_2$

@ 25% ferrous chloride solution = 1.18 pounds of iron per gallon

Ferrous sulfate ($FeSO_4$)

$FeSO_4 + PO_4 \longrightarrow Fe_3(PO_4)_2 + H_2SO_4$

$Fe^{+2} \longrightarrow Fe^{+3}$

$Fe^{+3} + HCO_3 \longrightarrow FeOH_2$

@ 16.3% $FeSO_4$ solution = 0.59 pounds of iron per gallon
@ 46.7% $(Fe_2SO_4)_3$ solution = 1.74 pounds of iron per gallon

Aluminum salts. Aluminum is commercially available in five forms: aluminum sulfate (alum) ($Al_2(SO_4)_3$), poly-aluminum chloride (PAC), aluminum chloride ($AlCl_3$), aluminum chlorohydrate, and sodium aluminate ($Na_2Al_2O_4$).

A simplified chemical equation illustrating aluminum precipitation of phosphorus is given below.

Theoretically, 0.87 pounds of aluminum removes one pound of phosphorus (as P). But, as with iron, much more will be required to meet low phosphorus limits.

The different aluminum forms consume differing amounts of alkalinity. Alum uses approximately 0.5 mg/L of alkalinity for each mg/L of aluminum added. Aluminum chloride uses 1 mg/l. PAC uses almost no alkalinity. The optimum pH is 6.5.

$Al^{+3} + PO_4^{-3} \longrightarrow Al(PO_4)$

$Al^{+3} + 3HCO_3 \longrightarrow AlOH_3$

@ 48.6% $Al_2(SO_4)_3$ solution = 0.49 pounds of aluminum per gallon
@ 28% $AlCl_3$ solution = 0.59 pounds of aluminum per gallon
@ 50% PAC solution = 0.54 pounds of aluminum per gallon
@ 70% PAC solution = 0.56 pounds of aluminum per gallon
@ 82% Aluminum chlorohydrate solution = 1.39 pounds of aluminum per gallon
@ 39% $Na_2Al_2O_4$ solution = 1.30 pounds of aluminum per gallon

Lime. The chemical equations for lime removal of phosphorus are given below. Lime dosage is more influenced by alkalinity than phosphorus concentration; the pH must be raised to 10.5 for phosphorus removal to occur. The amount of lime required is approximately 1.5 times the alkalinity concentration in mg/L.

Simplified stoichiometric equations are provided below.

$Ca(OH)_2 + HCO_3 \longrightarrow CaCO_3 + H_2O$

$5Ca^{+2} + 4OH^{-} + 3HPO_4^{-2} \longrightarrow Ca_5(OH)(PO_4)_3 + 3H_2O$

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PHOSPHORUS REMOVAL FROM WASTEWATER
CAPITAL AVOIDANCE STRATEGIES

In most wastewater treatment facilities, opportunities for significantly improving phosphorus removal without major capital investment exist. Biological phosphorus removal alone can oftentimes provide compliance with effluent limits of 0.5 mg/L total-phosphorus; sometimes lower. In order to consistently meet permit limits of less than 0.5 mg/L, effluent filtration and/or chemical treatment is generally necessary.

To optimize phosphorus removal, it generally makes sense to explore, experiment, and evaluate biological treatment options. That is, seek ways to either (a) establish a pre-anaerobic treatment zone, or (b) import an anaerobic sidestream back into the mainstream.

Bacteria release phosphorus in anaerobic conditions and then take up much more than was released during subsequent aerobic conditions. Exactly why this happens is complicated and subject to some scientific debate. Volatile Fatty Acids (VFAs) play a big part.

The anaerobic-aerobic cycle can either occur in the mainstream flow, or a sidestream waste can be subjected to anaerobic conditions and reintroduced to the mainstream flow. For sidestream wastes, it is best to keep the anaerobic treatment in a “fermentation” stage. This is done by periodically (say, daily for an hour) aerating the anaerobic tank to kill of the methane producing bacteria.

Biological Phosphorus Removal: pre-Anaerobic Zone

Facilities equipped with pre-anoxic treatment tanks are the easiest to convert to pre-anaerobic. To make the anaerobic, the dissolved oxygen (DO) needs to be reduced to zero. This can usually be done by: (a) reducing internal recycle pumping, (b) lowering aeration tank DO levels, and/or (c) eliminating all extraneous sources of oxygen. A dissolved oxygen meter can be used to confirm that a pre-anoxic tank is anaerobic. Even better is to use an ORP meter. An ORP reading of -250 at the pre-anaerobic tank outlet is typically sufficient.

Internal Recycle. Our experience with facilities that internally recycling three to four times the influent rate has not been good. We’ve found that better denitrification results from internally recycling one times the influent flow or less. A very effective way of reducing oxygen input is to reduce the internal recycle rate and, to the extent practical, RAS rates too. Minimizing these oxygen inputs is usually the quickest, easiest way to transform a pre-anoxic tank to pre-anaerobic.

Aeration DO. Aeration tanks require enough oxygen to provide complete BOD and ammonia removal. Once these objectives have been met, there is no need for further oxygen. Careful control of aeration tank DO not only saves money in reduced electrical expenditures, it improves pre-anoxic / pre-anaerobic treatment. Surplus oxygen, in fact, is recycled back to the pre-anoxic tank where it is toxic to the denitrification process.

Eliminate oxygen inputs. Oxygen enters the pre-anoxic tank in three ways: (1) with the influent, RAS, and/or internal recycle; (2) by mixing – air lift mixers, surface aeration, floor mount aeration; and (3) splashing of influent flows that introduce air. DO inputs need to be minimized to keep conditions anaerobic.

Finally, regarding pre-anaerobic treatment, the longer the retention time, the easier it is to maintain truly anaerobic conditions. The easiest ways to increase hydraulic retention time are to minimize internal recycling and/or add tanks. Minimizing RAS pumping may be something worth considering.

Biological Phosphorus Removal: Introducing Anaerobically treated waste

In situations where it is not practical to create an anaerobic treatment zone ahead of aeration, it is oftentimes possible to import or create an anaerobic waste that will provide the same quality of phosphorus removal. The following options exist: (a) trucking in septic pump-out waste (septage), and/or (b) returning a portion of anaerobically treated sludge, be it primary sludge, gravity thickener waste, RAS or WAS.

Septage. The processing of trucked-in septic tank waste can, for some facilities, provide sufficient anaerobically treated waste to allow for effective biological phosphorus removal. If the volume of septage is large relative to plant flow, the anaerobic waste may provide enough volatile fatty acids (VFAs) for the aeration tank bacteria to take up phosphorus to meet effluent phosphorus limits. Making it work may (or may not) involve some creative pretreatment, storage, pumping and piping to convey the waste to the aeration tank.

Return anaerobically treated sludge. Any form of anaerobically held sludge can be used as a source of VFAs: primary, secondary, mixed. As long as the sludge has been held long enough to become anaerobic, VFAs are formed. Fully anaerobically digested sludge, however, contains few VFAs; the acids are broken down and are not available for phosphorus removal. The ideal sludge treatment is to “ferment” the sludge long enough to create VFAs, but not so long as to break down the volatile fatty acids. This can be done by aerating the sludge holding tank for an hour per day.

If a portion of the waste activated sludge is returned, it will be necessary to increase the wasting rate. Otherwise the mixed liquor concentration will increase.

Chemical Phosphorus Removal

Various chemicals can be used to effectively remove phosphorus: iron solutions, aluminum solutions, or lime.

Each compound has its advantages and disadvantages as discussed below. To meet stringent phosphorus limits it is generally most cost effective to add chemicals to more than one location. In order to determine the best chemical(s) the typical practice is to perform jar testing with various chemicals prior to full-scale, in-plant trials. Most chemical supply companies will perform an such an evaluation for free.

When evaluating options, one thing to consider is the fact that chemical treatment only works on the soluble fraction. Particulate phosphorus – the phosphorus that is attached to effluent TSS particles – will not be removed by chemicals. If the effluent TSS is over 10 mg/L or if effluent total-phosphorus concentrations of less than 0.5 mg/l are required, an understanding of soluble vs. insoluble effluent total-P is important.

An important consideration in selecting chemicals is sludge disposal. The use of aluminum products creates a sludge with increased aluminum. Sludge incineration facilities can be adversely impacted by aluminum; it causes struvite to form as "clinkers." Some incinerators won't take aluminum laded sludge.

Some of the more common chemical addition points are: (a) influent (precipitant is removed in primary clarifiers), (b) aeration tanks – beginning, middle, end (precipitant is removed in secondary clarifiers), and (c) prior to filtration (precipitant is removed during filtration).

The advantages of using iron salts are: better dewatering, sulfate removal (odor control as a bonus), material can be stored out-of-doors, and BOD removal. The disadvantages of using iron salts are: safety (the material is highly corrosive), consumes alkalinity, and stains UV bulbs and reduces UV efficiency.

The advantages of using aluminum salts are: lower overall cost, less alkalinity is consumed, can be used as direct filtration aide, and is more tolerant to overfeeding. The disadvantages to using aluminum salts are: it must be stored inside and some incinerators will not accept aluminum treated sludge.

Lime is delivered as a powder in bulk. It is alkaline and difficult to work with. Because it needs to be slaked prior to use, it is not practical for facilities with flows of less than 5 MGD.

NITROGEN REMOVAL

DECISION TREE

SELECTING A STRATEGY FOR TOTAL-N REMOVAL

N1. Is the plant removing total-nitrogen?

N1A: ***Determine if the plant is removing total-N***.

N1A1: What is the annual average effluent total-Nitrogen?

If 5 mg/L or less, the plant is effectively removing nitrogen – go no further.

If greater than 5 mg/L, there may be room for improved nitrogen removal – go to next question (N1A2).

N1A2: What is the annual average effluent organic-Nitrogen (TKN minus Ammonia) concentration?

If 2.5 mg/L or less, the plant is effectively removing organic-nitrogen – go N1B.

If greater than 2.5 mg/L, there is a higher than normal amount of organic-Nitrogen in the effluent – go to next question (N1A3).

N1A3: What is the Total Inorganic Nitrogen (TIN = Ammonia + Nitrite + Nitrate) concentration?

If 2.5 mg/L or less, the plant is effectively removing nitrogen – go no further.

If greater than 2.5 mg/L, there may be room for improved nitrogen removal – go to next question (N1B).

N1B: ***Determine if the plant is nitrifying and denitrifying***.

N1B1: What is the annual average effluent Ammonia concentration?

If less than or equal to 1.0 mg/L, the plant is effectively nitrifying but not completely denitrifying – go to **N3. Nitrate Removal**.

If greater than 1.0 mg/L, the plant may not be effectively nitrifying – go to **N2. Ammonia Removal**.

N2. Ammonia Removal: the first step in total-N removal

N2A: ***Determine if the plant is nitrifying***.

N2A1: Is annual average effluent Ammonia 1.0 mg/L or less?

If YES, the plant is effectively nitrifying – go to **N3. Nitrate Removal**.

If NO, determine if the plant can be made to nitrify – go to next question (N2A2).

N2A2: Is the lowest monthly average effluent ammonia concentration 1.0 mg/L or less?

If YES, the plant is periodically nitrifying – go to next question (N2A3).

If NO, determine if the plant can be made to nitrify – go to N2B.

N2A3: Is wintertime effluent ammonia concentration typically both (a) four times or more than that of summer effluent ammonia and (b) greater than 2.0 mg/L?

Note: To determine the wintertime effluent ammonia concentration, find the maximum monthly average effluent ammonia concentration during the months November – March.

To determine the summertime effluent ammonia concentration, find the minimum monthly average effluent ammonia concentration during the months of May – October.

If YES, the plant is seasonally nitrifying – go to N2E.

If NO, determine if the plant can be made to nitrify – go to next question (N2B).

N2B: ***Determine if the pH is too low (too acidic) to support nitrification***.

N2B1: What is the aeration tank pH? What is the aeration tank alkalinity?

If UNKNOWN, measure pH and alkalinity and proceed.

If the pH is greater than 6.5 and the alkalinity is greater than 60 mg/L, the pH is probably high enough to support nitrification – go to N2C.

If the pH is 6.5 or less or if the alkalinity is 60 mg/L or less, the pH is probably too low to support nitrification – go to N2B2.

N2B2: Are pH adjusting chemicals being added?

If YES, where are pH adjusting chemicals being added?

If pH adjusting chemicals are added before or into aeration, the chemical dosage is too low and needs to be increased until the pH is greater than 6.5. Then, go back to N2A.

If pH adjusting chemicals are added after aeration, the point of addition needs to be relocated such that the chemicals are added before aeration or into aeration until the pH is greater than 6.5. Then, go back to N2A.

If NO, go to next question (N2B3).

N2B3: Is the available alkalinity 60 mg/L or less?

Available alkalinity = Influent alkalinity – (3.5 x Influent TKN).

Note: this calculation assumes complete denitrification follows ammonia removal.

If UNKNOWN, measure the unknowns, perform the calculation, and proceed.

If YES, the available alkalinity is too low to support complete ammonia removal and pH chemicals are required. Add pH adjusting chemicals until the pH is greater than 6.5 and the alkalinity is greater than 60 mg/L. Then, go back to N2A.

If NO, the available alkalinity is high enough to support complete ammonia removal and pH chemicals are probably not required – go to next question (N2B4).

N2B4: Without nitrate removal, is there enough alkalinity to fully nitrify; that is, is the available alkalinity 60 mg/L or greater using the following equation?

Ammonia removal only available alkalinity = Influent alkalinity – 7.0 x Influent TKN

If UNKNOWN, measure the unknowns, perform the calculation, and proceed.

If YES, the available alkalinity is high enough to support nitrification without capturing the alkalinity that is released into solution during denitrification when nitrate is removed – go to N2C.

If NO, the available alkalinity is too low to support ammonia removal without also removing nitrate unless pH chemicals are added – go to **N3. Nitrate Removal** and jointly optimize ammonia and nitrate removal.

N2C: ***Determine if the mixed liquor suspended solids (MLSS) concentration is too low to support nitrification***.

N2C1: What is the Food : Microorganism (F:M) ratio?
(To compute F:M divide the influent BOD (lbs/day) by the MLSS (lbs under aeration).

If the F:M Ratio is less than 0.15, there should be enough MLSS to support nitrification – go to N2D.

If the F:M Ratio is 0.15 or greater, it may be necessary to increase the MLSS concentration – go to N2C1a.

N2C1a: Raise the MLSS concentration by 10% per week until: (i) the ammonia concentration drops below 1.0 mg/L, or (ii) the F:M Ratio drops below 0.15, or (iii) the MLSS concentration is so high as to overwhelm the aeration equipment (see N2F), or until the solids loading threatens permit violation by (for example) building the secondary clarifier blanket too high, or some other adverse consequence results. Hold the MLSS concentration until the water temperature is 15 °C or higher for a period of six weeks and measure effluent ammonia concentration.

If the minimum ammonia concentration is 1.0 mg/L or less, the plant has been shown it can be made to nitrify – maintain the higher MLSS concentration and go to **N3. Nitrate Removal**.

If the minimum ammonia concentration is greater than 1.0 mg/L, further optimization is required – go to the next question, N2D.

N2D: ***Determine if the hydraulic retention time (HRT) is too low to support nitrification***.

N2D1: What is the aeration tank HRT?

(To compute HRT, divide the aeration tank volume (gallons) by the average daily flow (gallons/day) and multiply by 24 hours/day.

If the HRT is more than five hours, there should be enough HRT to support nitrification – go to N2E.

If the HRT is 5 hours or less, there may not be enough tankage in service to support nitrification – go to N2D1a.

N2D1a: Is additional aeration tankage available?

If YES, add aeration capacity to provide a minimum of five hours HRT for a period of six weeks at a water temperature of 15 °C or higher. Measure effluent ammonia concentration – go to the next question, N2E.

If NO, it may not be possible to fully nitrify without additional aeration tank capacity. To determine whether it is possible – go to the next question, N2E.

N2E: ***Determine if temperature is too low to support nitrification***.

N2E1: What is the average aeration tank water temperature (or, if not available, final effluent temperature) during the three months when the ammonia concentration is the highest?

If the answer to N2E1 is 8 °C (46 °F) or higher, the water temperature should be high enough to support year-around nitrification – go to the next question (N2F).

If the answer to N2E1 is lower than 8 °C (46 °F), the water temperature may be dropping too low in the winter to support year-around nitrification. And, it may be necessary to either seek opportunities for keeping the wastewater warmer during winter months (for example, reducing HRT so that the influent does not cool off as much while at the wastewater treatment plant and/or covering tanks) or proceeding with warm-weather-only nitrification. Regardless, forgo optimize nitrification during the coldest months and concentration on optimizing during the warmer months – go to the next question (N2F).

N2F: ***Determine if there is enough oxygen to support nitrification***.

N2F1: What is the aeration tank ORP?

If not known and an ORP is not available, go to N2F2.

If known, or if can be measured, see below.

If the aeration tank ORP is +150 mV or more, there is enough oxygen to support nitrification – go to N2G.

If the aeration tank ORP is less than +150 mV, there may not be enough oxygen to support nitrification – go to next question (N2F1a).

N2F1a: Does aeration capacity exist sufficient to raise the aeration tank dissolved oxygen concentration until the tank ORP is greater than +150 mV?

If YES, increase aeration until the aeration tank ORP is greater than +150 mV and return to N2A.

If NO, there isn't enough aeration capacity to raise the ORP to +150 mV, it may not be possible to fully nitrify – go to N2G.

N2F2: What is the aeration tank DO concentration? If not known, measure twice daily (morning and afternoon) for a period of one week.

If the answer is 2.0 mg/L or more, there should be sufficient oxygen to support nitrification – go to N2G.

If the answer is less than 2.0 mg/L, there may not be sufficient oxygen to support nitrification. Is it possible to raise the aeration tank dissolved oxygen concentration until the tank DO is greater than 2.0 mg/L?

If yes, do so and go to N2A.

If no, it may not be possible to fully nitrify. Measure effluent ammonia with aeration equipment operating at maximum – go to next question (N2F2a).

N2F2a. What is the effluent ammonia concentration?

If effluent ammonia concentration is 1.0 mg/L or less, ammonia removal is optimized – go to **N3. Nitrate Removal**.

If effluent ammonia is greater than 1.0 mg/L, the oxygen demand must be decreased before ammonia removal is optimized – go to the next question, N2F2b.

N2F2b. Can the BOD loading be reduced enough to lower the oxygen demand while maintaining a sufficient inventory of nitrifiers?

If yes, lower the BOD loading while maintaining maximum oxygen output. If the effluent ammonia concentration is 1.0 mg/L or less, ammonia removal is optimized – go to **N3. Nitrate Removal**.

If effluent ammonia remains greater than 1.0 mg/L at maximum oxygen output – go to the next question, N2F2c.

N2F2c. Can the MLSS concentration be reduced enough to lower the oxygen demand while maintaining a sufficient inventory of nitrifiers?

If yes, reduce the MLSS concentration sufficiently to reduce the oxygen demand but not so much as to bring the F:M ratio above 0.15. If the effluent ammonia concentration can be brought down to 1.0 mg/L or less, ammonia removal is optimized – go to **N3. Nitrate Removal**.

If effluent ammonia remains greater than 1.0 mg/L at maximum oxygen output – ammonia removal cannot be optimized without additional aeration capacity. The plant is optimized – go no further.

N2G: ***Determine if nitrite (NO_2) is at toxic levels in the aeration tank***.

N2G1: What is the final effluent nitrite (NO_2) concentration?

If the final effluent nitrite (NO_2) concentration is 1.0 mg/L or less, nitrite (NO_2) is not likely interfering with ammonia removal – go to N2H.

If the final effluent nitrite (NO_2) concentration is greater than 1.0 mg/L, the nitrite (NO_2) concentration in the aeration tank could be toxic to the nitrifiers and interfering with ammonia removal. Even more likely, for plants that disinfect with chlorine (liquid or gas), the elevated effluent nitrite (NO_2) concentration is consuming chlorine and may be interfering with disinfection – go to next question (N2G2).

N3G2: Typically, wastewater treatment plant effluents have a nitrite concentration that is considerably less than 1.0 mg/L.

Has the effluent nitrite (NO_2) concentration been 1.0 mg/L or greater for a week or more?

If NO, the nitrite lock is likely a short term situation while the plant transitions to consistent ammonia removal. If chlorine is used for disinfection, monitor the chlorine residual closely as nitrite (NO_2) consumes chlorine. Retest.

If nitrite (NO_2) drops below 1.0 mg/L – go to **N3. Nitrate Removal**.

If nitrite (NO_2) remains at 1.0 mg/L or above, nitrite lock is likely the result of low aeration tank pH – go back to N2B.

If YES, the nitrite lock is likely the result of low aeration tank pH – go back to N2B.

N2H: ***Determine if bristle worms or other life forms that feed on nitrifiers are present in the aeration tank MLSS.***

N2H1: Are bristle worms or other life forms that feed on nitrifiers present in the aeration tank MLSS?

If YES, change environmental conditions or otherwise kill those organisms that preferentially feed on nitrifiers, then – go back to N2A.

If NO – go to next question (N2I).

N2I: ***Determine if something else is interfering with ammonia removal***.

N2I1: Does the wastewater contain toxic levels of metals or other constituents?

Neutralize any known toxins that may exist, then go back to N2A.

If toxins cannot be neutralized or if none exist – go to next question (N2J).

N2J: ***Review data and determine under what conditions effluent ammonia is at a minimum and attempt to replicate those conditions***.

N2J1: Compile the following data for three time periods: (i) when ammonia removal is best, (ii) when it is worst, and (iii) when it is typical – pH, Alkalinity, MLSS, F:M, HRT, temperature, ORP, and DO.

Correlate and compare data in an effort to determine what parameters are having the greatest positive impact on ammonia removal and – to the extent possible – modify operations accordingly.

Ammonia removal is optimized – go to **N3. Nitrate Removal**.

N3. Nitrate (NO_3) Removal: the final step in total-N removal

N3A: ***Determine if the plant is Denitrifying***.

N3A1: What is the average effluent Nitrate concentration?

If 2 mg/L or less*, the plant is effectively denitrifying – **Go no further, the plant is optimized*.**

If greater than 2 mg/L, the plant may have the potential to do better – go to the next question (N3B).

**Nitrate is created as ammonia is removed. If ammonia is high, then nitrate has not been created and effluent nitrate will be low even though there is poor total-nitrogen removal.*

N3B: ***Determine if sufficiently anoxic conditions with adequate soluble BOD exist***

N3B1: Does the plant have a dedicated anoxic zone before or after aeration?

If NO – go to N3B2.

If YES – go to the next question (N3B1a).

N3B1a. Is the maximum ORP concentration of the anoxic zone(s) -100 mV or lower (that is, more negative than -100 mV)?

If UNKNOWN, measure.

If YES, the oxygen concentration should be low enough to support denitrification. Confirm by collecting a minimum of three grab samples from the discharge end of each anoxic tank, filter, and test for nitrate.

If the nitrate concentration at the discharge end of the anoxic zone is less than 2 mg/L, the tank is sufficiently anoxic – go to N3C.

If the nitrate concentration at the discharge end of the anoxic zone is 2 mg/L or more, the tank is either not sufficiently anoxic or there isn't enough soluble BOD to support nitrate removal – go to N3B1b.

If NO, there may be too much oxygen in the anoxic zone(s). Determine whether nitrate removal is occurring by collecting a minimum of three grab samples from the discharge end of each anoxic tank, filter, and test for nitrate.

If the nitrate concentration at the discharge end of the anoxic zone is less than 2 mg/L, the tank is sufficiently anoxic – go to N3C.

If the nitrate concentration at the discharge end of the anoxic zone is 2 mg/L or more, the tank is either not sufficiently anoxic or there isn't enough soluble BOD to drive denitrification – go to N3B1b.

N3B1b. Is the plant equipped with one or more internal recycle pumps?

If YES, turn down the internal recycle pumping rate until the pre-anoxic ORP maintains an ORP value of -100 mV or lower (more negative). If the pumps are already at minimum speed or if the pumps are fixed speed, cycle them on an off in order to create sufficiently anoxic conditions; if available, use timers, but, if not, turn on and off manually during work hours. After cycling the recycle pumps for a week; collect a minimum of three grab samples from the discharge end of each anoxic tank, filter, and test for nitrate.

If the nitrate concentration at the discharge end of the anoxic zone is less than 2 mg/L, the tank is sufficiently anoxic and there is sufficient soluble BOD to support denitrification – go to N3C.

If the nitrate concentration at the discharge end of the anoxic zone is 2 mg/L or more, the tank is sufficiently anoxic but there is not enough soluble BOD to support denitrification – go to N3D.

If NO – go to the next question (N3B2).

N3B2: Does the plant cycle air on and off to provide alternating aerobic and anoxic conditions; for example, a sequencing batch reactor (SBR)?

If NO – go to N3B3.

If YES – go to the next question (N3B2a).

N3B2a. Is the minimum ORP concentration during the air off cycle (anoxic conditions) -100 mV or lower (more negative)?

If NO, the air-off cycle may be too short. Extend the air-off cycle by 15 minute increments until the end of air-off cycle ORP drops to -100 mV for 30 minutes, then – go back to N3A.

If YES – go to the next question (N3B2b).

N3B2b. Does the ORP remain below -100 mV for an average of at least 30 minutes during each anoxic cycle?

If UNKNOWN, measure.

If NO, the anoxic cycle may be too short. Extend the air-off cycle by 15 minute increments until the end of air-off cycle ORP drops to -100 mV for 30 minutes, then – go back to N3A.

If YES – the oxygen concentration is low enough, long enough to support denitrification – go to the next question (N3B3b).

N3B3: Is the plant an oxidation ditch?

If NO – go to N3B4.

If YES – go to the next question (N3B3a).

N3B3a: Is the ORP concentration always more positive than -100 mV everywhere in the tank?

If UNKNOWN, measure.

If YES, the tank may have too much oxygen to denitrify. Extend the air-off cycle by 15 minute increments until the end of air-off cycle ORP drops to -100 mV for 30 minutes, then – go back to N3A.

If NO, sufficiently anoxic conditions exist – go to the next question (N3B3b).

N3B3b. Does the ORP remain below -100 mV daily for periods of at least 30 consecutive minutes?

If UNKNOWN, measure.

If YES – the oxygen concentration is low enough, long enough to support denitrification – go to N3B4.

If NO, the anoxic cycle may be too short. Extend the air-off cycle by 15 minute increments until the end of air-off cycle ORP drops to -100 mV for 30 minutes, then – go back to N3A.

N3B4: Determine if nitrate removal is inhibited by a shortage of soluble BOD.

N3B4a: What is the ratio of the BOD concentration entering the anoxic tank to the influent TKN? If unknown, collect data and compute the ratio before proceeding.
(To compute the ratio, divide the BOD concentration by the influent TKN concentration.)

If there is 10 times as much BOD going into the anoxic zone as there is influent TKN, there is enough BOD to support Nitrate removal – go to N3C.

If there is less than 10 times as much BOD going into the anoxic zone as there is influent TKN, there may not be enough readily available soluble BOD to support Nitrate removal – go to the next question (N3B4b).

N3B4b: Perform the benchtop lab test described below.

Place magnetic stirrers in two settleometers, fill both to the 1000 mark with mixed liquor taken from the discharge end of the anoxic zone, and place on magnetic mixers. Add ¼ cup of household sugar to one of the settleometers. Grab a sample from each and test in-house for nitrate. Cover the containers with foil or plastic wrap to prevent aeration and turn the magnetic stirrers on very low speed. Grab samples every 15 minutes for two hours and test for nitrate.

Did the addition of BOD (sugar) result in a measurable drop in nitrate concentration?

If YES, nitrate removal is BOD limited – go to N3D.

If NO, nitrate removal is not BOD limited – go to the next question (N3C).

N3C: ***Experiment with cycling aeration tank equipment to create alternating aerobic conditions for ammonia removal and anoxic conditions for nitrate removal.***

N3C1: Cycle aeration equipment off for one hour during the morning and one hour during the afternoon; continue for a week. Do composite effluent samples show ammonia to remain at 1.0 mg/L or less and permit compliant with the air cycling on and off?

If NO, abandon the experiment. The plant is optimized – go no further.

If YES – go to the next question (N3C2).

N3C2: Adjust the aeration cycles in order to optimize nitrate removal while maintaining ammonia removal. To the extent possible, use the following rules of thumb in adjusting the cycles: (a) cycle the air on long enough to raise ORP to +150 mV for one hour or more and (b) cycle the air off long enough to drop the ORP to -100 mV for 45 minutes or more. Provided sufficient tank capacity exists, keep the air on / air off cycles short enough so that two, ideally three, complete on / air off cycles are performed during a period of time equal to the aeration tank's hydraulic retention time at average daily flow not including RAS or internal recycle. When the above conditions are met, collect an effluent composite sample and test for nitrate.

If effluent nitrate concentration is 2 mg/L or less, the plant is optimized – go no further.

If effluent nitrate concentration is greater than 2 mg/L, supplemental BOD may be required – go to next question (N3D).

N3D: ***Identify opportunities for feeding supplemental BOD in order to support denitrification***.

N3D1: Is the plant equipped with one or more primary clarifiers?

If YES, take a clarifier off line, overload one or more primary clarifiers by allowing sludge to build up, bypass some or all of the flow around the primary clarifiers, or otherwise "detune" primary treatment in order to increase the organic loading on the aeration tanks in order to provide additional BOD to improve nitrate removal. Then, collect a final effluent composite sample and test for nitrate.

If the effluent nitrate concentration is 2 mg/L or less, the plant is optimized – go no further.

If the effluent nitrate concentration is greater than 2 mg/L, additional BOD may be required – go to the next question (N3D2).

If NO – go to the next question (N3D2).

N3D2: Can waste sludge be returned to the plant flow such that the BOD loading on the aeration tanks is increased?

If YES, pump up to ten percent of the waste sludge back into the wastestream (taking care to increase wasting rates to compensate for the additional solids loading), collect a final effluent composite sample, and test for nitrate.

If the effluent nitrate concentration is 2 mg/L or less, the plant is optimized – go no further.

If the effluent nitrate concentration is greater than 2 mg/L, additional BOD may still be required – consider trucking in a soluble BOD source.

If NO – additional BOD may still be required – consider trucking in a soluble BOD source.

PHOSPHORUS REMOVAL CHECKLIST

Phosphorus Removal Checklist for Activated Sludge wwtps

Pre-checklist questions

If the effluent total-P is less than 0.5 mg/L, bio-P is optimized.

If the plant is not reducing ammonia to 1.0 mg/L or less, to right conditions for bio-P do not exist; optimize ammonia removal first.
If the plant influent does not contain 20 times as much BOD (mg/L) as total-P (mg/L), supplemental BOD will be required.
If the aeration tank DO is not above 6.9 or the aeration tank ORP is not above +125, additional oxygenation will be required.

1-1 Does the plant have a pre-anaerobic zone?

If yes, go to question 1-5

1-2 If no, can an existing tank be converted to a pre-aerobic zone?

If yes, convert and go to question 1-5

1-3 If no, can a side stream fermenter be created?

If yes, create side stream fermenter and go to question 1-5

1-4 If no, might it be possible to create anaerobic conditions in the bottom of a tank?

If yes, do so and go to question 1-5

If no, the plant cannot be made to biologically remove phosphorus.

1-5 Is the ortho-P concentration in the fermenter 2.5-3.5 times the influent total-P?

If yes, the anaerobic portion of bio-P removal is optimized, go to question 2-0

If no and if less than 2.5 times as much, go to question 1-6

If no and if greater than 2.5 times as much, go to question X

1-6 Is the tank ORP less (i.e., more negative) than -125 mV?

If yes, go to question 1-9

1-7 If no, can the ORP be lowered by increasing the organic loading?

If yes, do so and go to question 1-5

1-8 If no, can the hydraulic retention time be increased?

If yes, do so and go to question 1-5

If no, the plant cannot be made to biologically remove phosphorus.

1-9 Is the tank's influent BOD concentration at least 20 times the influent total-P concentration?

If yes, despite having the right conditions for phosphorus release, the plant is not able to biologically remove phosphorus.

If no, increase the BOD loading by taking primary clarifiers off line, feeding waste sludge into the pre-anaerobic zone, or otherwise supplementing BOD.

1-10 Can the excessive phosphorus release be reduced by lowering the hydraulic retention time or otherwise freshening the tank?

If yes, do so and go to question 1-5.

If no, excessive phosphorus release in the anaerobic zone will prevent optimizing bio-P removal.

2-1 Is the aeration tank pH 7.0 or greater?

If yes, go to question 2-2

2-2 If no, is the aeration tank DO 2.0 mg/L or higher?

If yes, go to question 2-3

If no, increase aeration until the DO reaches reaches 2.0 mg/L and go to question 2-3

2-3 Is the aeration tank ORP +150 mV or greater?

If yes, go to question 2-4

If no, increase aeration until the ORP reaches +150 mV and go to question 2-4

2-4 Is effluent ammonia consistently less than 1.0 mg/L?

If yes, conditions exist for bio-P removal - the plant is optimized.

If no, optimize ammonia removal and go to question 2-1

Note: Warm water interferes with bio-P; if the water temperature is above 15 ^{o}C, it may be necessary to postpone optimization efforts until the water cools.

INSTRUMENTATION RECOMMENDATIONS / SPECIFICATIONS

Instrumentation Recommendations / Specifications

At project onset, the following listing of instruments was developed such that each of TDEC's eight field offices would have (1) a spectrophotometer for field testing of nitrogen and phosphorus parameters and (2) a DO/ORP probe.

	# units	budget price ea	total budget	part #	range mg/L)
Benchtop Spectrophotomer					
DR 3900	8	$4,000.00	$32,000.00	LPV440.99.00012	NA
TNT vials - enough for **75 tests**					
TKN	16	$120.00	$1,920.00	TNT880	0-16
Ammonia					
	8	$50.00	$400.00	TNT831	
	16	$50.00	$800.00	TNT830	0.15-2
Nitrate (NO3)	24	$40.00	$960.00	TNT835	.23-13.5
Nitrite (NO2)					
	8	$35.00	$280.00	TNT839	.015-0.600
	8	$35.00	$280.00	TNT840	0.6-6.0
ortho-Phosphate					
	8	$35.00	$280.00	TNT846	1.6-30
	8	$35.00	$280.00	TNT844	0.5-5.0
	8	$35.00	$280.00	TNT843	0.05-1.5
Portable DO/ORP w/thumb drive					
HQ 40D	8	$1,000.00	$8,000.00	HQ40D53000000	NA
LDO probe & 5m cable	8	$750.00	$6,000.00	LDO10105	0-13
ORP probe & 5m cable	8	$650.00	$5,200.00	MTC10105	-400 to +400 mV
Total					
Spectrophotometer & TNT vials			***$37,480.00***		
DO/ORP meter and probes			***$19,200.00***		
			$56,680.00		

As guidance for regulators and wastewater treatment plant operators, the table on the following page was circulated. It identifies the types of instruments available to measure different wastewater parameters and their relative cost and accuracy/usefulness.

Options for Monitoring Nitrogen and Phosphorus Removal

	Cheapest	Good	Better	Best	Ideal
Environmental conditions					
DO	hand held membrane DO meter	hand held LDO meter	hand held LDO with thumb drive	in-line DO probe	in-line connected to SCADA
ORP	pen/stick measure	hand held ORP meter	hand held ORP meter with thumb drive	in-line ORP probe	in-line connected to SCADA
pH	test strips	pen/stick measure	benchtop pH	in-line pH probe	in-line connected to SCADA
Alkalinity	test strips	test strips	spectrophotometer	benchtop pH w/ titration	benchtop pH w/ titration
Nitrogen					
TKN	estimate: Ammonia + 2.0 mg/L	estimate: Ammonia + 2.0 mg/L	spectrophotometer	spectrophotometer	spectrophotometer
Ammonia	test strips	test strips	spectrophotometer	in-line instrument ($$)	in-line connected to SCADA ($$)
Nitrate	test strips	test strips	spectrophotometer	in-line instrument ($$)	in-line connected to SCADA ($$)
Nitrite	test strips	test strips	spectrophotometer	spectrophotometer	spectrophotometer
Phosphorus					
total-P	estimate: TSSx0.05 + test strips	estimate: TSSx0.05 + test strips	spectrophotometer	spectrophotometer	spectrophotometer
ortho-P	test strips	test strips	spectrophotometer	in-line instrument ($$)	in-line connected to SCADA ($$)