NITROGEN & PHOSPHORUS REMOVAL AT THE COOKEVILLE, CROSSVILLE, AND LIVINGSTON WASTEWATER TREATMENT PLANTS

SUBMITTED TO THE UPPER CUMBERLAND DEVELOPMENT DISTRICT

FINAL REPORT

AUGUST 24, 2015

PREPARED BY

THE WATER PLANET COMPANY

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COMPLETED OBJECTIVES AND MILESTONES

A.1. All services and deliverables have been provided.

A.2.a SOPs for all three plants are included in the Final Report. The Cookeville SOP is written as process guidelines, the Crossville SOP is a brief report on an anticipated facility upgrade, and the Livingston SOP describes the barriers encountered and the opportunities for optimization.

A.2.b Written plans and guidance are included in the SOPs and are included in the Final Report, specifically in the site visit reports.

A.3.a One-day training (with CEUs) at Fleming Training Center held at onset of the contract period on November 13, 2014.

Central Office training for TDEC and technical assistance to TDEC permitting January 23, 2015.

Tennessee Water Resources Symposium presentation of Nutrient Removal Optimization April 2, 2015.

End of project ½-day training at Fleming Training Center held on July 9, 2015.

A.3.b.1 Four visits were made to the Cookeville wastewater treatment plant on November 18, 2014, January 21, 2015, March 31, 2015, and July 7, 2015.

Two visits were made to the Crossville wastewater treatment plant on November 17, 2014 and January 21, 2015.

Four visits were made to the Livingston wastewater treatment plant on November 14, 2014, January 22, 2015, March 31, 2015, and July 7, 2015.

A.3.b.2 Monthly reports were reviewed, diagnostic equipment was distributed, plant staff utilized diagnostic equipment to collect baseline information on each treatment facility.

A.3.b.3 Initial site visit meetings were held each facility's lead operator and operating strategies were developed and executed as described in the Final Report.

A.3.b.4 Follow-up meetings were held with each facility's lead operator and SOPs containing optimized operational strategies were developed and are enclosed with the Final Report.

A.3.c. SOPs for each plant were prepared and are being distributed along with the Final Report.

A.3.d Diagnostic equipment and supplies were purchased and used, documentation is provided in the Final Report.

A.3.e Three Quarterly Reports were submitted: January 5, 2015, March 20, 2015, and June 29, 2015. Copies are enclosed.

A.3.f Onsite and remote technical assistance was provided for the period November 2014 through July 2015.

A.3.g A Final Report follows; it includes SOPs for Extended Aeration Activated Sludge, Sequencing Batch Reactor, and Oxidation Ditch wastewater treatment facilities.

A.4 The tasks delineated in the Milestones listing were performed on the dates listed below.

<u>October 2014</u>

One-day training session was held November 13, 2014

Initial site visits were conducted November 14, 17 & 18.

Sampling directions were provided each plant.

Diagnostic equipment was ordered by each plant.

<u>December 2014</u>

First Quarterly Report was submitted January 5, 2015.

<u>January 2015</u>

Second round of site visits were conducted on January 21 & 22, 2015.

<u>March 2015</u>

Third round of site visits were conducted March 31 and April 1, 2015.

Second Quarterly Report was submitted March 20, 2015.

<u>June 2015</u>

Fourth and final round of site visits were conducted July 7 & 8, 2015.

Third Quarterly Report was submitted June 29, 2015.

<u>July 2015</u>

District-wide wastewater operator training class was held at the Fleming Training Center and broadcast to TDEC's Cookeville Field Office July 9, 2015.

<u>August 2015</u>

Detailed Final Report including written Standard Operating Procedures follows.

PROJECT OVERVIEW

The project had an ambitious goal: working with plant staffs to change the day-to-day operations of three municipal wastewater treatment plants in order to significantly reduce the discharge of nutrients without any capital expenditures. A nitrogen removal goal of 50% and a phosphorus reduction goal of 75% were established.

As discussed in detail in the pages that follow, the goal was realized at Cookeville, effective phosphorus removal was achieved was not sustained at Livingston, and Crossville's optimization efforts were confounded by a stockpiling of solids.

In execution of the contract, the consultant provided: (i) classroom and other training, (ii) equipment for in-house testing, and (ii) in-plant technical support. The support of plant staff was a major factor in the success of the project.

As the project has progressed, additional work elements were added at no expense to the client. The additional tasks included two days of meetings with TDEC staff (January 23, 2015 at TDEC Nashville office and July 9, 2015 at the Fleming Training Center in Murfreesboro) and a co-presentation with TDEC at the Tennessee AWRA meeting at Montgomery Bell State Park April 2, 2015.

A description of the work performed follows.

Training

The contract called for one day of classroom training; a one-day session at the Fleming Training Center at the onset of the contract period. In fact, at no additional charge, four training sessions were provided, as described below.

November 13, 2014. A day long training class was held at the Fleming Training Center (Murfreesboro) on November 13, 2014. The presentation was broadcast to TDEC regional offices in Memphis, Jackson, Columbia, Cookeville, Knoxville, Chattanooga, and Johnson City. In total, over 170 people attended.

The presentation was made as a kickoff to the wastewater treatment plant optimization project. Participants were primarily municipal treatment plant operators / administrators and state personnel. Also in attendance were a few educators, consultants, and EPA personnel.

The purpose of the presentation was motivational. People with an oversight responsibility for wastewater treatment were introduced to the notion of optimization. The conventional approach to meeting new permit requirements (for example; nutrients – nitrogen and phosphorus) is to design and construct new equipment at significant capital expense. The presenter, Grant Weaver, shared experiences gained from working with the staffs of over 25 municipal wastewater treatment plants to creatively achieve remarkable reductions in total-N and total-P; including more than a dozen plants not designed for nutrient removal.

As examples of what is possible, the following were given as case studies. Three New England municipal treatment plants with design flows averaging 5 MGD achieved nitrogen removal at a savings of $100,000,000. Three other facilities of similar size are removing more nitrogen and phosphorus while realizing O&M savings of over $1,000,000 per year. Copies of the slides used in the presentation are attached as attachments to the Final Report.

The following agenda/syllabus was followed:

- *Nitrogen Removal*
  - Basics of Nitrogen Removal
    - Creating the right habitats for biological N-removal
    - Basic science (N-removal)
    - Basic design theory
  - Case Studies: POTWs that have improved N-Removal by changing O&M
- *Phosphorus Removal*
  - Basics of Phosphorus Removal
    - Creating the right habitats for biological P-removal
    - Basic science (P-removal)
    - Basic design theory
  - Case Studies: POTWs that have improved P-Removal by changing O&M
- *Money Saving Ideas*
  - Opportunities for producing less sludge
  - Using fewer chemicals & less electricity: Case Studies

January 23, 2015. A series of meetings were held at TDEC's Nashville offices on January 23, 2015. One of the meetings, a two hour discussion of wastewater permit writing for nutrient removal, was broadcast to TDEC's regional offices. It, and some of the earlier in-house discussions, was attended by a contingency of four EPA Region 4 representatives.

Traditional nutrient permits contain strict limits for nitrogen and phosphorus expressed either as mg/L or lbs/day; such an approach all but forces municipalities to engage design engineers and construct capital intensive construction projects. More subjective language such as the following (taken from permits written by EPA Region 1 staff) was presented. The first of the two excerpts is from the wastewater discharge permit issued to Montague, MA (#MA0100137). The second is from Palmer, Massachusetts' permit (#MA0101168).

Montague, Massachusetts

"PART 1. H. SPECIAL CONDITIONS

Within one year of the effective date of the permit, the permittee shall complete an evaluation of alternative methods of operating the existing wastewater treatment facility to optimize the removal of nitrogen, and submit a report to EPA and MassDEP documenting this evaluation and presenting a description of recommended operational changes. The methods to be evaluated include, but are not limited to, operational changes designed to enhance nitrification (seasonal and year round), incorporation of anoxic zones, septage receiving policies and procedures, and side stream management. The permittee shall implement the recommended operational changes in order to maintain the existing mass discharge loading of total nitrogen. The annual average total nitrogen load from this facility (2004 – 2005) is estimated to be 172 lbs/day.

The permittee shall also submit an annual report to EPA and MassDEP, by February 1 each year, that summarizes activities related to optimizing nitrogen removal efficiencies, documents the annual nitrogen discharge load from the facility, and tracks trends relative to the previous year.

Palmer, Massachusetts

B. SPECIAL CONDITIONS

Within one year of the effective date of the permit, the permittee shall complete an evaluation of alternative methods of operating the existing wastewater treatment facility to optimize the removal of nitrogen, and submit a report to EPA and MassDEP documenting this evaluation and presenting a description of recommended operational changes. The methods to be evaluated include, but are not limited to, operational changes designed to enhance nitrification (seasonal and year round), incorporation of anoxic zones, septage receiving policies and procedures, and side stream management. The permittee shall implement the recommended operational changes in order to maintain the mass discharge of total nitrogen less than the existing annual average discharge load. The annual average total nitrogen load from this facility is estimated to be 376 lbs/day, based on data reported from 2004 through 2005.

The permittee shall also submit an annual report to EPA and the MassDEP, by February 1st each year, that summarizes activities related to optimizing nitrogen removal efficiencies, documents the annual nitrogen discharge load from the facility, and tracks trends relative to the previous year.

April 2, 2015. TDEC's Karina Bynum and The Water Planet Company's Grant Weaver co-presented a paper at the 2015 Tennessee Water Resources Symposium meeting at Montgomery Bell State Park, titled "Nitrogen and Phosphorus Removal Using Existing Wastewater Treatment Equipment: The Tennessee Experience." As described in the abstract submitted for presentation:

> *"The implementation of Tennessee's Nutrient Reduction Framework encompasses best management practice strategy for non-point sources as well as point source nutrient reduction strategy through performance standards, policy and permitting within the watershed.*
>
> *As a first step in the point source nutrient strategy, wastewater treatment plants are encouraged to evaluate and operate existing equipment differently in order to determine and utilize their current capability for nitrogen and phosphorus removal. Fine-tuning wastewater treatment processes to optimize the use of the existing capacity requires the creation of optimal biological habitats for nutrient removal. Using targeted monitoring of key operational parameters, wastewater operators are able to combine the new information with their knowledge of wastewater treatment. Motivated, informed wastewater operators equipped with timely, in-plant data are expected to be able to achieve notable results at three wastewater plant types: oxidation ditch, extended aeration and a sequencing batch reactor.*
>
> *For these three types of wastewater treatment plants we will: (a) present the basic operating procedures, (b) discuss the changes that were identified for optimization (including the constraints of each plant type for nitrogen and phosphorus removal), (c) share the preliminary results of removals achieved, (d) relate the operators' experiences, and (e) comment on the lessons learned throughout the optimization process."*

A copy of the Power Point slide show is attached to the Final Report.

July 9, 2015. An end-of-project presentation was held at TDEC's Fleming Training Center in Murfreesboro on July 9, 2015. The presentation was broadcast to TDEC regional offices in Memphis, Jackson, Columbia, Cookeville, Knoxville, Chattanooga, and Johnson City. Over 50 people attended.

At the onset of the program, TDEC staff briefly discussed the status of Tennessee's nutrient program and gave an overview of energy audit programs available to wastewater facilities. After which the consultant described the approach taken and the results achieved in optimizing nutrient removal at the wastewater treatment plants that participated in the project. An interactive discussion featuring the Cookeville wastewater treatment plant staff followed the consultant's presentation. A copy of the consultant's Power Point slide show is attached to the Final Report.

August 2015. At the conclusion of the project, a news article was prepared for submission to the Upper Cumberland Business Journal. The article features the success enjoyed by the City of Cookeville. A copy of the draft that was presented for review follows.

> COOKEVILLE – Thanks to the creative efforts of the City of Cookeville, the South Jefferson Avenue wastewater treatment plant is using far less electricity and making much cleaner water than a year ago.

A year-long cooperative effort to remove nutrients from three area treatment plants was administered by the Upper Cumberland Development District using EPA/TDEC grant funds. Working with UCDD's consultant, Wastewater Plant Superintendent Tom Graham, Assistant Supervisor John Buford, and staff found a way to modify use existing plant equipment differently to remove 75% more nitrogen and phosphorus. And, in doing so, are now using some 13,000 KWH less per day; almost enough electricity every day to power the typical Upper Cumberland home for an entire year.

Karina Bynum, Cookeville TDEC Field Office Environmental Engineer, considers the City of Cookeville staff to be TDEC's "poster child" for innovation. City personnel embraced and one-upped the advice provided by Grant Weaver of The Water Planet Company (New London, Connecticut) to fine-tune the City's already well-run treatment facility. Instead of powering all of the plant equipment all the time as the plant was designed to do, select motors are now cycled on and off for appropriate periods of time in order to create optimal biological habitats for the bacteria that convert sewage into clean water. As a result, the water leaving the facility contains less than 5 parts per million nitrogen and only 0.5 ppm phosphorus.

The changes in day-to-day operations provide better treatment in all conditions. The rains of early July resulted in record flows at the treatment plant, yet, according to Water & Sewer Director Ronnie Kelly, plant staff were able process two and one-half times the plant's designed flow without incident. Now that Cookeville's wastewater treatment facility is effectively removing nitrogen and phosphorus, there is no need to spend $4,000,000 on nutrient removal equipment. Electrical savings have resulted in operating expenses that are $250,000 per year less than before the optimization study began.

Livingston and Crossville also participated in the $85,800 UCDD study. Optimization opportunities were identified in both communities. As a result of the consultant's review, the scope of a planned $800,000 repair of the Crossville wastewater treatment facility was cut in one-half. Experiments conducted at the Livingston wastewater treatment plant demonstrated an ability to reduce phosphorus by more than 75% to as low as 0.2 mg/L. Buoyed by the successes, TDEC is identifying wastewater treatment plants across Tennessee to participate in a training program so that TDEC staff and municipal volunteers can help interested municipalities sustainably improve the quality of the state's water resources.

WASTEWATER TREATMENT PLANT VISITS

The wastewater treatment plants were visited on four occasions: November 14-18, 2014, January 21-22, 2015, March 31, 2015, and July 7, 2015. The Cookeville and Livingston wastewater treatment facilities were both visited four times, the Crossville wastewater treatment plant was visited twice. A summary of each site visit follows.

Cookeville

Exciting improvements were achieved in Cookeville. As discussed below, significant reductions in total-nitrogen and total-phosphorus have been observed as a result of process changes made during the first half of 2015. Plant personnel are optimistic that treatment efficiency will continue through the fall and winter months; however, until the challenges of wet weather and lower air and water temperatures are addressed, the anticipated long-term, year-round effectiveness of the plant optimization efforts remain to be fully proven.

November 18, 2014. Tom Graham and John Buford of the City of Cookeville, Brett Ward of the University of Tennessee, and Grant Weaver of The Water Planet Company. Plant staff led the attendees on a tour of the Cookeville facility, reviewed data, and discussed process strategies.

Plant staff, in an attempt to remove nitrate-nitrogen in order to reduce effluent total-nitrogen, implemented the following changes in an effort to create an anoxic zone for nitrate-nitrogen removal while retaining sufficient aerobic conditions to continue the excellent ammonia removal enjoyed by the Cookeville facility.

In Oxidation Ditch 4

- Aeration brushes B, C and D continued to operate as normal (aerobic zone).
- Aeration brushes E, F, and A were turned off (anoxic zone).

To monitor the process

- Using the portable ORP probe, plant staff monitored ORP at the following locations:
  - From the catwalk @ aeration brush E
  - From the sidewall between aeration brush A and B
  - Sludge selector
- Using the spectrophotometer, plant staff tested samples collected from the following locations:
  - Secondary Clarifier #3 Effluent (baseline info)
    - Ammonia (NH_4)
    - Nitrate (NO_3)
    - Nitrite (NO_2)
    - Phosphate phosphorus (PO_4 as P) – (once per week only)
  - Secondary Clarifier #4 Effluent (full scale trial info)
    - Ammonia (NH_4)
    - Nitrate (NO_3)
    - Nitrite (NO_2)
    - Phosphate phosphorus (PO_4 as P) – (once per week only)

A series of process control strategies were developed to provide for as much experimentation as possible without causing permit violations. Several such strategies are listed below.

Process control considerations

If Secondary Clarifier #4 effluent Ammonia (NH_4) concentration increases to more than 0.57 mg/L, turn on one or more of aeration brushes E, F or A.

If Secondary Clarifier #4 effluent TSS concentration increases to more than 15 mg/L, develop a plan to periodically suspend oxidation ditch settled solids in advance of peak flow surges.

After two weeks of operating Oxidation Ditch #4 in the new mode, data were reviewed and plant staff made the following changes in an effort to strengthen the anoxic zone and improve nitrate-nitrogen removal.

Aeration brush B was turned off in Oxidation Ditch #4 so that A, B, E and F are off and only C and D are on. In addition, in Oxidation Ditch #2, aeration brushes A, B, E and F were also turned off. With these changes, two of Cookeville's four ditches are currently operating with four of six aerators off. The other two ditches (1 and 3) are operating with all six aeration brushes on, as has been standard practice for the past several years.

January 21, 2015. Tom Graham and John Buford of the City of Cookeville and Grant Weaver of The Water Planet Company. The impact of the changes made in November were reviewed and discussed. During the January site visit a lot of surface float was evident on Ditch #4. This was a result of staff following Water Planet's recommendation to not run the aerators. After being idle for two months, a significant amount of surface float had developed. The material was put back into solution by running the idle aerator for less than an hour.

Following the meeting, the process changes made to Oxidation Ditch #4 were implemented in all four ditches as discussed below.

Nitrogen Removal. Three rotors in each of the four basins were turned off: rotors E, F, and A. Three of the six rotors in each basin remained on: rotors B, C, and D. The aeration equipment was turned off over a period of weeks. This was done so that there wasn't a sudden, plant-wide drop in the plant's biological population. The aerators were shut off one ditch at a time until all four were operating with one-half of the aeration.

When and as necessary, plant staff turned on the aerators for short periods of time in order to perform preventive maintenance work on the rotor drives or whenever surface float was seen to accumulate.

Plant staff continued to collect samples and perform the sampling discussed during the first site visit in November but without the "control" testing since all four ditches operated the same.

The process changes were designed to drop the system-wide DO (dissolved oxygen) concentration sufficiently to push the selector tank into anoxic conditions for nitrate-nitrogen removal. And, perhaps, create low-oxygen zones in each of the four ditches in order to stimulate denitrification (nitrate removal) in the individual ditches as well.

Phosphorus Removal. To improve biological phosphorus removal, plant staff wanted to experiment with returning waste sludge back into the wastestream as follows. The blower in the big sludge holding tank was put on a timer in an attempt to create fermentive conditions during the off time and to resuspend solids as well as keep odors down during the on-time. (At too low of an ORP hydrogen sulfide odors can develop. Textbooks put the number at around -300 mV but The Water Planet Company's experience is odors can occur at an ORP of -200 mV in some plants and in others, not occur even with ORP readings of -400 mV. The only way to find out the limits in Cookeville is to experiment and monitor.)

If conditions allow the ORP to be kept strongly negative, VFAs (volatile fatty acids) should get produced in the sludge holding tanks and PAOs (phosphate accumulating organisms) should feed on the VFAs. Recirculating energized PAO bacteria bugs back into the oxidation ditches should result in a significant drop in effluent total-P.

As general guidance, plant staff was advised to attempt to return approximately 10% of the WAS (waste activated sludge) mass in order to keep the PAO bacteria moving between the aerobic and anaerobic (actually fermentive) conditions. A system-wide rise in bacterial population (MLSS, mixed liquor suspended solids) was considered to be advantageous, but plant staff increased wasting to big holding tank and found they did not have enough wasting capacity to accomplish this. Finally, to help drive the sludge holding tank ORP into strongly negative numbers, plant staff has been experimenting with pumping the trucked-in hog blood into the sludge holding tank instead of offloading it at the septage receiving station.

March 31, 2015. Tom Graham and John Buford of the City of Cookeville and Grant Weaver of The Water Planet Company.

Considerable improvements in nitrogen and phosphorus removal were reported by plant staff. Plant staff reported the following.

Nitrogen Removal. Timers were installed on all 24 aeration rotors and they were operated with two on at a time, a 2/3 reduction in electricity use. Effluent total-N has dropped from 20+ mg/L to 5 mg/L.

Phosphorus Removal. Plant staff has been experimenting creating anoxic zones within the ditch to create fermentive environment with some success. Effluent total-P, formerly 2 mg/L is now reportedly averaging 1.0 mg/L and dropping. To get these results, plant staff experimented with on-off times on the aerators and found a sequence that appears to work for them.

Fermentive conditions were created in the sludge holding tanks by cycling the sludge holding tank blowers on and off. In the larger of the two sludge tanks, a 100 HP blower typically operates 4 ½ hours a day from 11 AM to 1 PM; it used to operate 24/7. In the other sludge tank, a 75 HP blower typically operates 11 hours per day from 3 AM to 1 PM and again for an hour at 7-8 PM; it too used to operate 24/7. By creating the fermentive conditions and recycling sludge through the plant, effluent total-P dropped to as low as 0.2 mg/L.

July 7, 2015. Ronnie Kelly, Tom Graham and John Buford of the City of Cookeville, Karina Bynum of TDEC, and Grant Weaver of The Water Planet Company.

The facility is operating more sustainably at substantially lower expense. The changes at the Cookeville wastewater treatment plant save almost enough electricity every day (13,400 KWH) to power one Tennessee home for a year (typical usage: 14,600 KWH/yr). Instead of operating twenty-four 40-HP mechanical aerators around-the-clock as the plant was designed to do, eight rotors are now used. Additional savings are realized by cycling the sludge holding tank blowers on and off. Instead of operating 24 hours per day, the 100 HP sludge holding tank blower now operates 8.5 hours per day and the 75 HP sludge holding tank blower runs 11 hours daily.

Computing the electrical savings:

24 rotors x 40 HP x 0.75 KWH/HP x 24 hrs/day =	11,520 KWH/day
1 blower x 100 HP x 0.75 KWH/HP x (24-8.5) hrs/day =	1,163 KWH/day
1 blower x 75 HP x 0.75 KWH/HP x (24-11) hrs/day =	731 KWH/day
Total savings (approximate)	13,414 KWH/day

The project goal was nutrient removal, not electrical savings. The reduced electrical consumption was a side benefit of creating the environmental habitats to support biological nutrient removal. Yet, ironically, the nutrient reduction effort, resulting in ten times the electrical savings than were realized as a result of the City's electric conservation initiative.

Plant staff optimized nitrogen removal such that the effluent total-Nitrogen for June 2014 averaged less than 5 mg/L; before the onset of the project, it was typically greater than 20 mg/L. Phosphorus removal has also improved; before optimization effluent total-P was typically greater than 2.0 mg/L, now it averaging around 1.0 mg/L with occasional drops to less than 0.2 mg/L.

By embracing optimization, Cookeville has demonstrated the opportunities available when informed, motivated, effective people (plant staff and administration) apply their talents. By making targeted changes to the day-to-day operations, Cookeville personnel have – as described below – created optimal habitats for nitrogen and phosphorus removal.

By operating two adjacent aerator rotors out of the six in each oxidation ditch, Cookeville staff maintains three distinct stratified habitats. The surface layer (approximately one-third of the 12 foot depth of their ditches) remains aerobic. Excellent BOD removal is provided (June 2014 CBOD averaged (1.7 mg/L)) and complete nitrification occurs (June 2015 NH_3 maximum: (0.04 mg/L)). The middle one-third of each tank is sufficiently anoxic to provide complete denitrification; during June 2014 the effluent total-Nitrogen concentration averaged less than 5 mg/L. The bottom layer is anaerobic with an ORP of -250 mV. Inconsistent but vastly improved phosphorus removal is now occurring. During June the effluent total-P was as low as 0.17 mg/L but was as high at 2.14 mg/L.

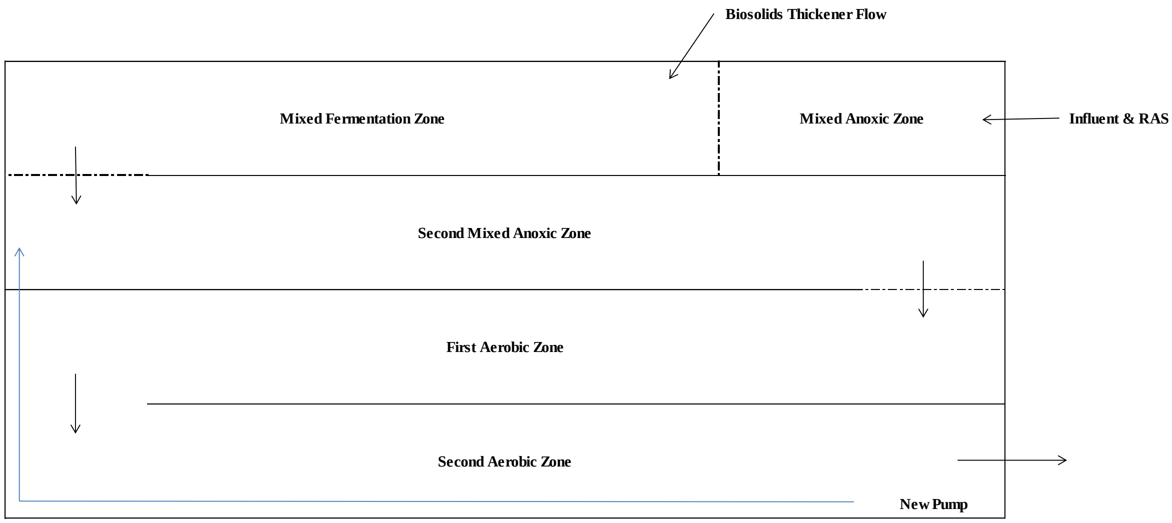
Intermittent aeration of the sludge holding tanks, coupled with a feeding of animal rendering plant wastes has created excellent conditions for nitrate removal (denitrification). As a result, the belt filter press filtrate contains almost zero nitrate; prior to the changes the nitrate concentration was often greater than 100 mg/L.

Crossville

November 17, 2014. Clark Annis of Veolia (operator of Crossville's wastewater treatment facility) and Grant Weaver of The Water Planet Company met, toured the plant, and reviewed data.

According to data supplied by Veolia Project Manager Clark Annis, Crossville's effluent total-Nitrogen averages 9.4 mg/L with spikes to 12 & 13 mg/L; values that are not compliant with the 5 mg/L total-N limits that TDEC will likely impose. Effluent total-Phosphorus averages 0.88 mg/L but is often up in the 2-3 mg/L range. The long term goal for the facility is believed to be 0.5 mg/L.

For the facility to bring about better, more consistent total-N removal while reducing total-phosphorus to less than 0.5 mg/L, the discussion shifted from experimenting with optimization strategies to a discussion of changes to a planned upgrade. The consultant recommended changing the design of the upgrade to accommodate the Modified Johannesburg Process by altering the work planned for the first two passes of the aeration tank. A description and schematic of the process we discussed was shared with Crossville plant staff and is provided below.



The following design recommendations were shared with the city's operator (Veolia) for transmittal to the city's design engineer. In designing changes to the first aeration tank, it was recommended that Crossville consider the following:

(1) Remove the accumulated solids as planned
(2) Install two new walls in the first aeration tank
(3) Install an internal recycle pump with piping
(4) Install piping so that flow can be sent from the Gravity Biosolids Thickeners to the inlet end of the Fermentation zone
(5) Install mixers in the anoxic and anaerobic tanks as already planned

Items (1) and (5) are self-explanatory. A brief discussion of items (2)-(4) follows.

(2) Walls. As an alternative to poured-in-place concrete walls, the construction of fiberglass or plastic baffle walls is recommended. The first wall should be installed about one-fifth to one-quarter of the way in from the inlet end of the air-OFF aeration tank in order to create an initial anoxic zone of sufficient size to strip the nitrates out of the RAS. The second wall should be installed as an extension of the center wall of air-OFF aeration tank in order to divide the fermentation zone from the second anoxic zone; the tank should be big enough to create -200 mV ORP (oxidation reduction potential) conditions in order to support biological phosphorus removal.

The walls can be permeable, fence-like structures. They should be built so that floating solids can pass over the top. If funds are available, it is recommended that the gate that connects the two aeration tanks be reconfigured such that flow passes over and into the tank instead of through a submerged opening so that solids will pass through the aeration tanks and into the secondary clarifier for removal.

(3) The ideal location for an internal recycle pump is at the outlet end of the second air-ON tank but other options are worth consideration.

(4)(a) Gravity Biosolids Thickeners piping. Among other things, the Gravity Biosolids Thickeners produce volatile fatty acids (VFAs), a food source for the bacteria that remove phosphorus. The VFAs are present in the supernatant as well as the sludge. To optimize bio-P removal, piping needs to be installed so that the VFAs can fuel the bio-P bugs while bypassing the first anoxic zone so that denitrifying bacteria don't eat the VFAs.

And, if some waste sludge (vs. supernatant) is pumped back into the system bacteria will break a portion of the waste material down to carbon dioxide and water and thereby reduce the amount of sludge that has to be trucked off site. This is something that should be kept in mind when designing the pumping/piping system.

(4)(b) Internal recycle pump and piping. Because a very high flow rate is required, axial flow pumps are typically used for this purpose. It is recommended that the pump be equipped with a variable frequency drive (VFD) and be constructed so that in-tank instrumentation can be used to automatically control the pumping rate. The pump should be sized so it can pump as low as 0.5 times the average daily plant flow to 3-3.5 times the average flow. Based on experience with a number of such designs, it is likely that plant staff will find the ideal pumping rate to be something close to 100% of influent flow. The outlet of the internal recycle piping should be at the inlet end of the second anoxic zone.

January 21, 2015. Clark Annis of Veolia and Grant Weaver of The Water Planet Company with a trip to City Hall to meet with City Manager David Rutherford. During the visit and subsequent email exchanges, it was agreed that optimization opportunities are currently limited. One of Crossville's two aeration tanks is full of solids and until the solids are removed, there is little that Crossville can do to optimize operations. The tank became filled with solids as a result of successful experimentation to improve the quality of the Obed River by (a) reducing effluent TSS and (b) reducing effluent nitrogen.

During a recent plant upgrade, it was not possible to clean and drain the first section of the aeration tanks due to record rainfalls and high risk of permit violations during construction. Other tasks removed from the upgrade: aeration tank mixers and piping modifications.

In order to minimize the risk of being non-compliant with Crossville's discharge permit and not knowing what the nutrient permit requirements would be, Crossville staff decided to leave the solids in place with modified operational risk and follow up with an subsequent minimum cost upgrade that would allow for ongoing biological nutrient removal (including ammonia-nitrogen) as well as achieve lower cBOD and TSS.

In an effort to minimize the release of solids, years ago Crossville staff began turning off aeration equipment during high flows in order to keep waste material from washing out of the plant. With two aeration tanks operating in series, during peak flow the first aeration tank was shut off for extended periods of time to capture solids. Effluent TSS was beneficially reduced with no adverse impact on treatment.

Seeing the benefits associated with the temporary holding of solids, a few years ago Crossville staff experimented with holding solids in the first aeration tank to assist with nitrogen removal. By keeping the first in a low-oxygen ("anoxic") condition, a percentage of nitrate-nitrogen was beneficially removed from the wastestream. During an unusually long period of wet weather a few years back, Crossville staff "parked" solids in the first aeration tank for so long that when the tank was mixed, the solids released ammonia-nitrogen. And, Crossville was at risk of violating its permitting discharge. As a result, the first aeration tank has not been aerated for several years and is now nearly full of solids. The accumulation of solids occupies one-half of the plant's aeration tankage. Removing the solids will essentially double the plant's capacity.

Before optimization can be attempted, the accumulated solids must be removed from the aeration tank – thus, no further plant visits were scheduled. Once the solids are removed, the aeration tank can be utilized and the plant can be optimized for nutrient removal as discussed below.

Nitrogen Removal. A number of options exist for nitrogen removal once the solids are removed. The least-costly, quickest and easiest way to implement nitrogen removal at the Crossville plant is likely an SBR-like cycling of aeration equipment. That is, operate the aeration tanks either in series or parallel and run the aeration for long enough periods of time to convert ammonia-nitrogen to nitrate-nitrogen, followed by air-off cycles to convert nitrate-nitrogen to nitrogen gas. The objective being to make the activated sludge plant operate in a sequencing batch reactor (SBR) mode of operation.

Another possibility is to operate the two aeration tanks in parallel and to cycle aeration between the two such that one is being aerated while the other is not. Given the existing piping configuration (all of the RAS flows to one aeration tank), this option is more difficult to set up. Therefore, the SBR-like cycling should be tried before this option.

Phosphorus Removal. A number of options exist for phosphorus removal, once the solids are removed. The simplest way for Crossville to implement bio-P removal is to capitalize on the fermentative conditions that almost surely exist in the gravity thickeners. Return approximately 10% of the WAS (waste activated sludge) to the aeration tank; concurrently increase wasting so as to not increase the bacterial concentration (MLSS). The cycling of bacteria from the fermentative conditions in the gravity thickeners to aerobic conditions in the aeration tanks will allow the PAOs to take in soluble ortho-P and thereby reduce effluent total-phosphorus.

Given the findings presented above, Crossville staff has reduced the scope of a planned upgrade from an $800,000 project to a $400,000 project. As a reminder of the opportunities for optimization, a letter was mailed to Crossville's City Manager on August 4, 2015. A copy of the letter is provided as an attachment to this report.

Livingston

November 14, 2014. Jeremy Mars and Steve Sims of the City of Livingston and Grant Weaver of The Water Planet Company. Superintendent Danny Langford was recovering from an accident and not available to attend.

The following ideas were discussed with plant staff. However, in light of the Superintendent's absence and the ongoing draining and repair of the SBR aeration ports, implementation was postponed until the January 2015 visit. The following issues were discussed with plant staff:

(1) Bypassing the polishing ponds.
(2) Changing out the aerobic digester diffusers, installing piping so that the smaller blowers can be used instead of the 75 Hp blowers, and installing timers so that aeration can be intermittent instead of continuous.
(3) Recycling fermented waste activated sludge to
   (a) biologically remove phosphorus and
   (b) reduce the amount of sludge that needs to be hauled off-site.
(4) Routinely monitor nitrogen removal in the SBR (in addition to final effluent compliance monitoring).

(1) *Polishing ponds*. Years of sludge accumulation in the polishing ponds causes the water going out of the ponds and into Town Creek to oftentimes be of lower quality than the water discharged out of the SBRs and into the polishing ponds. During the November site visit floating solids were observed to be forming and flowing out of the polishing pond and into the receiving water. This observation – and plant staff's findings that summertime ammonia levels are much higher in the polishing pond effluent than in the SBR effluent – raises the following questions: (a) Is complete denitrification is happening in the SBR or in the polishing pond? (b) Might effluent quality be improved if there were no polishing ponds and SBR effluent were instead piped directly to Town Creek?

The equipment that Livingston purchased for this study with TDEC support provided plant staff with the tools to both answer the question about denitrification and, if nitrate removal is not consistently occurring in the SBR, modify operations to achieve total-N removal. By the end of the study, enough data should be made available to demonstrate whether the polishing lagoons improve or degrade water quality following treatment in the SBR tanks.

(2&3) *Aerobic digesters*. Operating Livingston's aerobic digesters as fermenters with little to no aeration would provide a number of benefits: biological phosphorus removal, monetary savings on electricity, and labor/monetary savings on sludge disposal. As-is, the electrical cost for using one 75 Hp blower 24/7 to aerate the sludge is costing something on the order of $50,000/year. If the existing coarse bubble diffusers were replaced with no-clog diffusers, if the blower were cycled on and off, and if an existing, smaller blower were used instead of one of the 75 horsepower units … annual electrical savings of $30-45,000 would be possible. Not only will money be saved, treatment will be improved. Converting from aerobic sludge digestion to fermentive digestion should provide Livingston with a reliable, effective means of biological phosphorus removal. To bring about bio-P removal, the sludge digester air would be shut off the majority of the time in order to maintain a tank ORP concentration of approximately -20 mV and something on the order of 10% of the sludge wasted daily would be returned to the SBRs – ideally during the aerobic cycle, but anytime would work. Another benefit: by returning sludge to the SBR for bio-P removal, a lot of the sludge would be destroyed, reducing the amount of sludge that needs to be trucked off site.

(4) *Nitrogen Removal in the SBRs*. Nitrogen removal involves multiple steps (the two primary ones being ammonia-N conversion to nitrate-N and nitrate-N conversion to nitrogen gas). The site visit focused primarily on ammonia-nitrogen removal, there was little discussion about nitrate-nitrogen removal. With the new monitoring tools (ORP meter and spectrophotometer), it should be fairly easy for plant staff to regularly compile information on ammonia, nitrite and nitrate in and out of the SBRs. If nitrate removal is less than ideal (as is likely the case), one of the topics for future site visits will be working with plant staff to adjust the SBR process to

optimize total-N removal. In addition, if 10% of the sludge were to be returned to the SBR as recommended above, the extra BOD contained in the sludge should enhance nitrate removal.

As discussed with staff, given the ongoing effort to drain and clean the SBRs, given the staff shortage, they were advised to forgo spending too much time with new testing protocols until the SBRs are both back on line. Subsequent to the visit (after the SBRs were both cleaned and back in normal operating mode), the following testing protocols were discussed with plant staff.

On at least five days during January 2015, plant staff agreed to collect a grab sample of the water leaving the SBR and a grab sample of the water leaving the polishing ponds and using the spectrophotometer, test both samples for ammonia, nitrite, and nitrate. And, time permitting, to perform a limited amount of ortho-P testing in both sampling locations as well.

To become accustomed to ORP, plant staff were advised to collect data from various locations around the plant: ORP/DO at beginning, middle, and end of SBR cycles; ORP/DO in influent end, mid-point and outfall of polishing ponds; ORP/DO in idle polishing pond; ORP/DO in sludge holding tanks (inlet and outlet ends); and ORP/DO in the influent.

January 22, 2015. Danny Langford and Jeremy Mars and Steve Sims of the City of Livingston, Brian Mayo of TDEC, and Grant Weaver of The Water Planet Company.

A continuation of the discussion initiated during the November 2014 site visit included the following items:

(1) Bypassing the polishing ponds.
(2) Changing out the aerobic digester diffusers, installing piping so that the smaller blowers can be used instead of the 75 hp blowers, and installing timers so that aeration can be intermittent instead of continuous.
(3) Recycling fermented waste activated sludge to
    (a) biologically remove phosphorus and
    (b) reduce the amount of sludge that needs to be hauled off-site.
(4) Routinely monitor nitrogen removal in the SBR (in addition to final effluent compliance monitoring).

(1) *Polishing ponds*. After considerable discussion about the pros and cons of the polishing ponds, plant staff concluded that the benefits of maintaining the ponds outweigh the disadvantages. Livingston is committed to cleaning out the sludge accumulation and keeping the ponds in service.

(2) *Aerobic digester blowers and piping*. The potential for significant energy savings exists; however, given the recent return of the injured Superintendent and ongoing work at the plant, the follow-up discussion about blower sizing was postponed until the March visit. To bring about bio-P removal, the sludge digester air would be shut off the majority of the time in order to maintain a tank ORP concentration of approximately -20 mV and something on the order of 10% of the sludge wasted daily would be returned to the SBRs – ideally during the aerobic cycle, but anytime would work.

(3) *Recycling fermented waste for phosphorus removal*. With the ORP (oxidation reduction potential) meter purchased as a part of this study, Livingston staff found that the sludge thickener (a former clarifier) contains marginally sufficient fermentive conditions to support biological phosphorus removal. A strategy for returning fermented sludge to the plant's SBRs (sequencing batch reactors) was discussed with plant staff.

(4) *Nitrogen Removal in the SBRs*. Using the ORP meter purchased as part of this study, plant staff have found that the wastewater appears to be over-aerated. An ORP of +300 to +400 mV is being observed at the end of the aeration cycle. It should climb to +150 mV at the end of the air ON cycle and drop to -100 mV during the air OFF cycle.

Given the high ORP readings, plant staff was advised to undertake one of the following actions, record data and then reassess.

(1) Increase the air OFF cycle by at least 15 minutes.
(2) Reduce the air ON cycle by at least 15 minutes.
(3) Lower the DO setting by 0.5 mg/L.
(4) If available and if practical to do so, it was recommended that a smaller horsepower blower might be used to aerate the SBRs.

March 31, 2015. Danny Langford and Jeremy Mars and Steve Sims of the City of Livingston, Brian Mayo of TDEC, and Grant Weaver of The Water Planet Company.

Continuing with the same issues as explored during the first site visit, a discussion of each follows:

(1) Bypassing the polishing ponds.
(2) Changing out the aerobic digester diffusers, installing piping so that the smaller blowers can be used instead of the 75 hp blowers, and installing timers so that aeration can be intermittent instead of continuous.
(3) Recycling fermented waste activated sludge to
 (a) biologically remove phosphorus and
 (b) reduce the amount of sludge that needs to be hauled off-site.
(4) Routinely monitor nitrogen removal in the SBR (in addition to final effluent compliance monitoring).

(1) *Polishing ponds*. When warmer, drier weather makes it possible to do so, plant staff is making plans to clean the sludge accumulation out of the ponds to minimize the nitrogen and phosphorus release that has been observed. Doing so will provide Livingston with the advantages of the ponds – flow equalization and the removal of fine solids that periodically escape the treatment plant – without the disadvantages – periodic release of floating solids, ammonia-nitrogen, and phosphorus.

(2) *Aerobic digester blowers and piping*. A discussion about blower sizing was held but the focus of the site visit was biological-P removal by the recycling of fermented waste sludge (item #3 below). And, no action was contemplated.

(3) *Recycling fermented waste for phosphorus removal*. A portable pump was installed to transfer waste sludge to the screw pump inlet for (a) biological phosphorus removal and (b) sludge reduction.

Approximately 5,000 GPD of thickened sludge was pumped from the sludge thickener (ORP approximately -140 mV) to the SBR tanks. The volume of sludge wasted from the SBR to the thickener was increased in order to maintain the desired bacterial concentration (MLSS, mixed liquor suspended solids) in the SBR tanks. Samples were collected and data obtained from the spectrophotometer purchased (in part) using grant funds provided by this project were recorded.

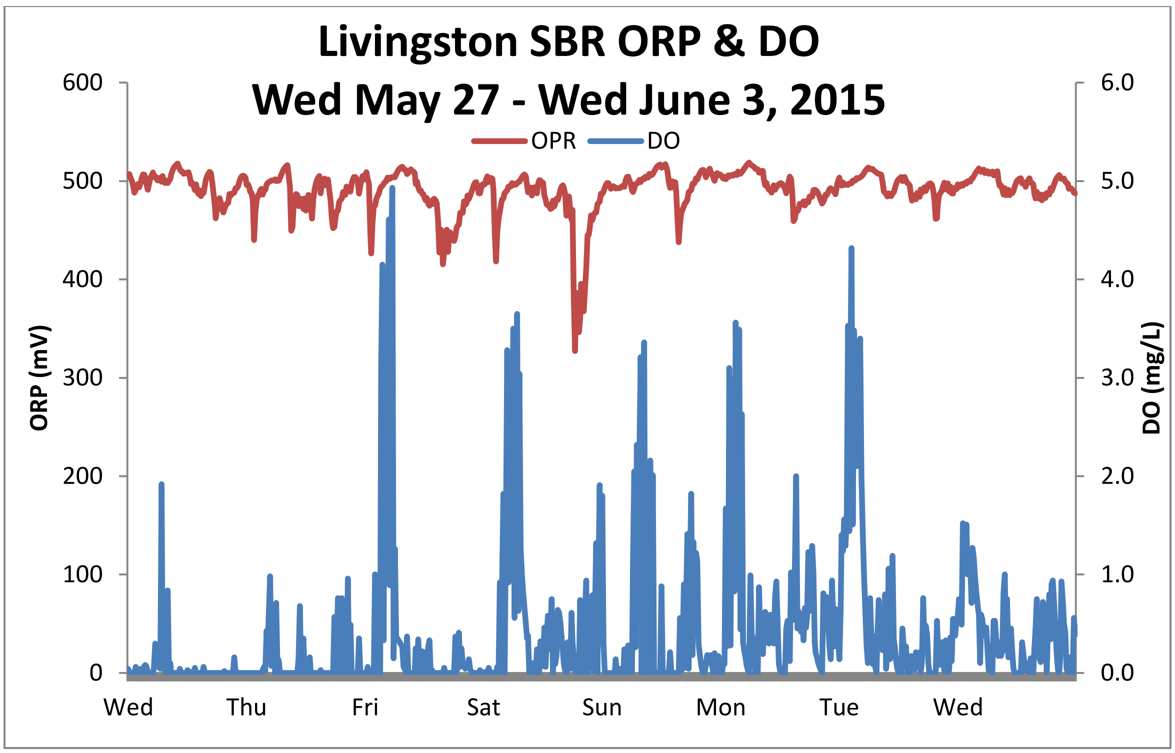
The pumping transferred enough PAO bacteria (phosphorus accumulating organisms) between aerobic (oxygen rich) conditions in the SBR and fermentive (no oxygen) conditions in the sludge thickener to markedly reduce effluent total-P as shown in the table that accompanies the Livingston SOP. However, floating debris interfered with pump operations and alternative methods of pumping were discussed.

(4) *Nitrogen Removal in the SBRs*. Using the ORP meter purchased as part of this study, plant staff have found that the wastewater appears to be over-aerated. An ORP of +300 to +400 mV is being observed at the end of the aeration cycle. It should climb to +150 mV at the end of the air ON cycle and drop to -100 mV during the air OFF cycle.

Given the high ORP readings, plant staff was advised to undertake one of the following actions, record data and then reassess.

(1) Increase the air OFF cycle by at least 15 minutes.
(2) Reduce the air ON cycle by at least 15 minutes.
(3) Lower the DO setting by 0.5 mg/L.
(4) If available and if practical to do so, it was recommended that a smaller horsepower blower might be used to aerate the SBRs.

A graph illustrating one week of results follows.



July 7, 2015. Danny Langford and Jeremy Mars and Steve Sims of the City of Livingston, Karina Bynum and Brian Mayo of TDEC, and Grant Weaver of The Water Planet Company.

Continuing with the same issues as explored during the previous site visits, a discussion of each follows:

(1) Bypassing the polishing ponds.

(2) Changing out the aerobic digester diffusers, installing piping so that the smaller blowers can be used instead of the 75 hp blowers, and installing timers so that aeration can be intermittent instead of continuous.

(3) Recycling fermented waste activated sludge to

(a) biologically remove phosphorus and

(b) reduce the amount of sludge that needs to be hauled off-site.

(4) Routinely monitor nitrogen removal in the SBR (in addition to final effluent compliance monitoring).

(1) *Polishing ponds*. Efforts to dewater the sludge are ongoing but have – to date – been unsuccessful.

(2) *Aerobic digester blowers and piping*. Plant staff said that nothing could be done without the input of the City's engineering consultant.

(3) *Recycling fermented waste for phosphorus removal*. Ongoing problems with the portable pumping arrangement resulted in a discontinuation of the experiment. Plant staff said that it would not be possible to install a more robust pumping system without the input of the City's engineering consultant.

(4) *Nitrogen Removal in the SBRs*. Additional ORP data was recorded and reviewed. Plant staff was advised that a more interactive version of the computer upgrade installed a few years' back by the SBR manufacturer (Fluidyne) is recommended. Something the plant staff said would need to be discussed with the City's engineering consultant.

As a follow-up to the meeting, TDEC's optimization consultant wrote the Mayor advising him of the opportunities for (i) improved treatment and (ii) cost savings. The letter is attached to the Final Report.

INSTRUMENTATION PURCHASES

The initial three participants – Cookeville, Crossville, and Livingston – purchased the instrumentation detailed in the contract, as summarized below.

Price quotations are also appended to the report. Based on this information, the consultant reimbursed each community $3,400.00 for the instrumentation. The consultant's $10,200.00 out-of-pocket expense was invoiced UCDD and has long ago been reimbursed by UCDD.

	# plants	# units/plant	price ea	total	part #
Benchtop Spectrophotomer					
DR 3900	3	1	$3,370.00	$10,110.00	LPV440.99.00012
TNT vials - enough for **195 tests** at each of four plants					
TKN	3	6	$105.00	$1,890.00	TNT880
Ammonia	3	6	$45.00	$810.00	TNT830,831,832
Nitrate (NO3)	3	6	$35.00	$630.00	TNT835,836
Nitrite (NO2)	3	6	$30.00	$540.00	TNT839,840
ortho-P	3	6	$30.00	$540.00	TNT846
Portable DO/ORP w/thumb drive					
HQ 40D	3	1	$850.00	$2,550.00	HQ40D53000000
LDO probe & 5m cable	3	1	$640.00	$1,920.00	LDO10105
ORP probe & 5m cable	3	1	$470.00	$1,410.00	MTC10105
Total					
Spectrophotometers & TNT vials	3	NA		***$14,520.00***	
DO/ORP meters and probes	3	NA		***$5,880.00***	
				$20,400.00	
Portion to be paid using grant funds				$10,200.00	
Portion to be paid by participating wastewater treatmen plants				$10,200.00	

NITROGEN REMOVAL
STANDARD OPERATING PROCEDURE

JULY 2015

Nitrogen removal is optimized by creating strongly aerobic conditions for Ammonia-Nitrogen (NH_4) conversion to Nitrate-Nitrogen (NO_3) – a process called nitrification – along with the creation of low-oxygen, anoxic, conditions for the conversion of Nitrate-Nitrogen (NO_3) to Nitrogen Gas (N_2); denitrification.

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.

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^oC. However, if nitrification is lost, it will not resume until the temperature increases to well over 10^oC.

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.

OPTIMIZING NITROGEN REMOVAL: GENERAL GUIDANCE. 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.

UNDERSTANDING NITROGEN FORMS. A discussion of the various forms of nitrogen follows.

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.

AMMONIFICATION SCIENCE. 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 SCIENCE. 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 SCIENCE. 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.

PHOSPHORUS REMOVAL
STANDARD OPERATING PROCEDURE

JULY 2015

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.

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.

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.

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

<u>Ferrous chloride</u> ($FeCl_2$)

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

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

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

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

<u>Ferrous sulfate</u> ($FeSO_4$)

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

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

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

@ 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.

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

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

Optimizing Nutrient Removal at the Cookeville Wastewater Treatment Facility
Standard Operating Procedure

July 2015

General. By operating two adjacent aerator rotors out of the six in each oxidation ditch, Cookeville staff maintains three distinct stratified habitats. The surface layer (approximately one-third of the 12 foot depth of their ditches) remains aerobic. Excellent BOD removal is provided (June 2014 CBOD averaged 1.7 mg/L) and complete nitrification occurs (June 2015 maximum: NH_3 (0.04 mg/L). The middle one-third of each tank is sufficiently anoxic to provide complete denitrification; during June 2014 the effluent total-Nitrogen concentration averaged less than 5 mg/L. The bottom layer is anaerobic with an ORP of -250 mV. Inconsistent but vastly improved phosphorus removal is now occurring. During June the effluent total-P was as low as 0.17 mg/L but was as high at 2.14 mg/L.

Intermittent aeration of the sludge holding tanks, coupled with a feeding of animal rendering plant wastes has created excellent conditions for nitrate removal (denitrification). As a result, the belt filter press filtrate contains almost zero nitrate; prior to the changes the nitrate concentration was often greater than 100 mg/L.

Given that plant staff continue to optimize nutrient removal, the guidance that follows should be considered more a snapshot of current operating practices than strict procedures to be followed in day-to-day operations.

Optimizing Nitrogen Removal. As discussed in great depth in the Nitrogen Removal Standard Operating Procedure, effective nitrogen removal requires (1) ammonia conversion to nitrate first and (2) nitrate conversion to nitrogen gas second. The procedures for creating these habitats to support biological nitrogen removal at the Cookeville plant are discussed below.

To provide better monitoring and control, it may in the future prove advantageous to install DO and ORP probes in multiple locations (horizontal and vertical) in each oxidation ditch to provide around-the-clock information. One in-line ammonia probe in the final effluent or, better, one in-line ammonia probe after each final clarifier connected to a computerized SCADA (supervisory control and data acquisition) system might also be installed to provide around-the-clock monitoring of ammonia removal efficiency. To optimize nitrate removal it may prove advantageous to supplement the oxidation ditch ORP probes with in-line nitrate probes in the effluent channels of each oxidation ditch. Finally, it may prove advantageous to install ORP and nitrate probes in the sludge holding tanks.

Ammonia Removal. Ammonia-nitrogen is converted to Nitrate-nitrogen in the aerobic portion of the oxidation ditches. Plant staff can ensure effective Ammonia removal by monitoring dissolved oxygen (DO) and oxygen-reduction-potential (ORP) values in the upper few feet of the oxidation ditches. Minimum DO and ORP targets can be established to ensure that the proper environmental conditions are maintained to support complete nitrification.

Currently, sufficiently high DO and ORP values are maintained by operating two consecutive rotors at a time in each of the four ditches. At periods of low-flow it may be possible to maintain ammonia removal with only one rotor operating. At other times it may prove advantageous to run three or more rotors.

Nitrate Removal. Nitrate-nitrogen is converted to nitrogen gas in two locations: the four oxidation ditches and the two sludge storage tanks. The layered operation of the oxidation ditches provides an optimal habitat (low DO, high BOD) for nitrate removal in the lower depths, particularly in those portions of the ditches that are most distant from the in-service rotors.

Currently, sufficiently low ORP values are maintained by operating two consecutive rotors at a time in each of the four ditches. During colder weather or extended periods of high flow it may be necessary to operate fewer than two rotors in order to drive out the dissolved oxygen and drop the ORP to sufficiently low levels. At periods of low flow it may prove advantageous to operate more than two rotors if low DO odors develop.

In addition to removing nitrate in the mainstream flow, the Cookeville plant removes nitrate from the sludge holding tanks so that the filtrate leaving the belt filter presses contains minimal nitrate. Timers have been installed on the blowers that aerate the sludge holding tanks and the tanks are kept anoxic to support denitrification. To provide denitrifying bacteria with the “food” to fuel nitrate removal, soluble BOD in the form of trucked-in rendering waste is off-loaded directly into the sludge tank.

Optimizing Phosphorus Removal. As discussed in great depth in the Phosphorus Removal Standard Operating Procedure, effective phosphorus removal involves three steps. Under fermentive conditions (1) one family of bacteria create a food source – VFAs; volatile fatty acids – for the bacteria that biologically remove soluble phosphorus while (2) another family of bacteria – PAOs; phosphate accumulating organisms – “eat” the VFAs and temporarily release additional phosphorus into solution. The energized PAOs must then (3) move out of the fermentive/anaerobic habitat and into a strongly aerobic environment where they bio-accumulate soluble phosphorus. The procedures for creating these habitats to support biological phosphorus removal at the Cookeville plant are discussed below.

As described below, optimizing biological phosphorus removal consists of optimizing ortho-P release / VFA uptake in fermentive conditions, maximizing ortho-P uptake in aerobic conditions, minimizing the re-release of ortho-P, and minimizing the amount of total suspended solids (TSS) in the effluent. As described below, Cookeville’s creative three-dimensional use of the oxidation ditches makes it difficult to troubleshoot phosphorus removal.

Volatile Fatty Acid Production. VFAs are produced in two locations: (a) in the near bottom depths of the oxidation ditches and (b) in the sludge holding tanks; the majority being formed in Cookeville’s oxidation ditches. Optimizing VFA production requires strongly fermentive conditions and significant soluble BOD. In the ditches the bottom few feet, particularly in those parts of the tanks that are far removed from the active surface aeration rotors, are anaerobic. VFAs are produced in the sludge blanket and as described below consumed by PAOs.

VFAs are also produced in the sludge holding tanks. Instead of operating the sludge holding tanks blowers around-the-clock as called for in the plant's O&M Manual, the air is cycled on long enough to mix the tanks' contents and keep the tanks from going septic (which also improves belt press operations and overall bio-solids performance)… And, turned off long enough to keep the tanks anoxic, if not fermentive.

Fueling PAOs with VFAs. Phosphate accumulating organisms consume the VFAs as they are produced in both the lowest depths of the oxidation ditches and inside the sludge holding tanks. The PAOs in the oxidation ditches are mixed up into upper layers as the mechanical rotors cycle on. The PAOs in the oxidation ditches are mixed when the aeration blowers cycle on. Ortho-phosphate is released from the PAOs as they take in the VFAs: the volatile fatty acid release being something that can, if desired, be measured in the sludge holding tanks but difficult to measure in the oxidation ditches because of the sludge blanket movement that occurs. As a process control tool, monitoring VFA concentration is not a priority.

Phosphorus Uptake by PAOs. The final step of biological phosphorus removal occurs in the upper layer of the oxidation ditches. Strongly aerobic, pH neutral conditions provide the right habitat for the VFA-energized PAOs to pull soluble phosphorus out of solution and into their cells. The major process control parameters to use in optimizing PAO uptake are DO and ORP. With time, plant staff should establish targets for both.

As mentioned above, Cookeville staff is handicapped in their efforts to manage phosphorus removal. Given the dynamics of the vertical PAO movement in the oxidation ditches, at times of less than stellar phosphorus removal it is difficult to assess whether the PAOs are receiving enough VFAs to fuel subsequent uptake or receiving too little oxygen to support complete ortho-P removal. With additional operating experience, a method of monitoring and therefore controlling the initial ortho-P release and uptake need to be developed.

OPTIMIZING NUTRIENT REMOVAL AT THE CROSSVILLE WASTEWATER TREATMENT FACILITY
STANDARD OPERATING PROCEDURE

JULY 2015

General. Optimization efforts have been postponed until the years' long accumulation of solids is removed from one of Crossville's two aeration tanks. Given the number of tanks, many of which are empty, numerous opportunities for optimization exist. Provided that interconnecting piping exists – or, even if additional piping is required – any number of existing tanks can be modified for nitrogen and/or phosphorus removal; the biggest opportunity being the creation of one or more fermenters to support biological phosphorus removal.

In light of the solids stockpile and Crossville's desire to proceed with a facility upgrade, a review of the pending upgrade was performed. The scope of the $800,000 was cut in half by suggesting the following. (1) The substitution of fiberglass, plastic, or other pre-fabricated permeable walls inside the aeration tanks as an alternative to poured-in-place concrete walls. (2) Evaluating alternative locations and designs for the internal recycle pumps to be installed for nitrogen removal. (3) Utilizing the existing gravity thickeners as fermenters for phosphorus removal.

Optimizing Nitrogen Removal. As discussed in great depth in the Nitrogen Removal Standard Operating Procedure, effective nitrogen removal requires (1) ammonia conversion to nitrate first and (2) nitrate conversion to nitrogen gas second. In light of the city's desire to first address the solids inventory in the aeration tank, procedures for creating these habitats to support biological nitrogen removal at the Crossville plant were not pursued.

Optimizing Phosphorus Removal. As discussed in great depth in the Phosphorus Removal Standard Operating Procedure, effective phosphorus removal involves three steps. Under fermentive conditions (1) one family of bacteria create a food source – VFAs; volatile fatty acids – for the bacteria that biologically remove soluble phosphorus while (2) another family of bacteria – PAOs; phosphate accumulating organisms – "eat" the VFAs and temporarily release additional phosphorus into solution. The energized PAOs must then (3) move out of the fermentive/anaerobic habitat and into a strongly aerobic environment where they bio-accumulate soluble phosphorus. In light of the city's desire to first address the solids inventory in the aeration tank, procedures for creating these habitats to support biological nitrogen removal at the Crossville plant were not pursued.

Optimizing Nutrient Removal at the Livingston Wastewater Treatment Facility
Standard Operating Procedure

July 2015

General. Optimization efforts – to the extent they were undertaken – were successful. Livingston's SBRs (sequencing batch reactors) provide effective, consistent nitrogen removal. By recycling fermented sludge from the sludge holding tank, Livingston was, on occasion, able to reduce the phosphorus from the plant's discharge from the historical average of more than 2 mg/L to less than 0.5 mg/L.

Three factors prevented Livingston from fully optimizing operations.

One, the plant superintendent suffered a serious accident shortly before the first site visit. Notwithstanding the rest of the staff's capabilities, it wasn't really appropriate for them to make significant process changes with their leader absent.

Two, mechanical difficulties. For a few months at the onset of the project, plant staff were draining and repairing the SBR aeration equipment, significantly limiting optimization efforts. Also, the sludge pump used to return fermented sludge to the SBR inlet for phosphorus removal plugged, became air bound, or otherwise malfunctioned as often as it worked.

Three, perhaps the biggest barrier to optimization, like many communities; Livingston's operators do not have the flexibility to make changes to their facility without the support of their consulting engineer – whether the need for outside approval is self-imposed or mandated by utility overseers.

Notwithstanding the barriers preventing optimization, Livingston staff made two important findings.

1. When the sludge return pump operated, they were able to reduce phosphorus to quite low levels: under 0.2 mg/L ortho-P as measured by in-house equipment.
2. More often than not, more nutrients leave the polishing ponds and flow into the receiving water than what is discharged from the treatment plant. This, presumably, is because some 20 years of organic debris has accumulated in the polishing ponds.

As mentioned in the letter to Livingston's Mayor, copy attached, Livingston may find it beneficial to consider abandoning the polishing ponds and to instead discharge treated wastewater directly to Town Creek. Doing so will eliminate whatever nitrogen and phosphorus release from pond sediments that are now occurring. Descriptions of how the SBR can be modified to optimize end-of-treatment nitrogen and phosphorus follow.

Optimizing Nitrogen Removal. As discussed in great depth in the Nitrogen Removal Standard Operating Procedure, effective nitrogen removal requires (1) ammonia conversion to nitrate first and (2) nitrate conversion to nitrogen gas second. Livingston's sequencing batch reactors (SBRs) have been effectively removing nitrogen for years. OPR testing done by plant staff as part of the optimization effort indicate that – high quality effluent notwithstanding – SBR operations are not optimized. Better results may be attainable if the SBR cycles were to be adjusted based upon ORP and in-plant testing of ammonia, nitrite, and nitrate concentrations. A far less labor intensive and better method of optimizing SBR performance is to install in-line instruments (DO, ORP and perhaps nitrate and ammonia) to monitor and control the SBR cycles.

Optimizing Phosphorus Removal. As discussed in great depth in the Phosphorus Removal Standard Operating Procedure, effective phosphorus removal involves three steps. Under fermentive conditions (1) one family of bacteria create a food source – VFAs; volatile fatty acids – for the bacteria that biologically remove soluble phosphorus while (2) another family of bacteria – PAOs; phosphate accumulating organisms – "eat" the VFAs and temporarily release additional phosphorus into solution. The energized PAOs must then (3) move out of the fermentive/anaerobic habitat and into a strongly aerobic environment where they bio-accumulate soluble phosphorus.

Although the Livingston plant was not designed to remove phosphorus, plant staff was able to manipulate treatment to occasional do so. Sludge was pumped from the non-aerated holding tank – a former clarifier – back into the SBR unit. The holding tank contained an ORP of approximately -120 mV, enough to create VFAs (volatile fatty acids). Phosphate accumulating organisms (PAOs), bacteria that live in the mixed liquor, feed on the VFAs in fermentive conditions and, when cycled back into aerobic conditions, take soluble phosphorus out of the wastewater and into their cells.

Fundamental to the optimization of phosphorus removal is reliable pumping equipment, something Livingston does not currently have. Should reliable pumping become available, Livingston can optimize performance by monitoring phosphate release in the sludge holding tank and ortho-P concentration in the SBR effluent.

Livingston in-house data

Date	tN			Ammonia			Nitrite			Nitrate			ortho-P		
	Raw	SBR	Pond	Raw	SBR	Pond	Raw	SBR	Pond	Raw	SBR	Pond	Raw	SBR	Pond
12/30/2014		0.4	1.2		0.05	0.11		0.01	0.01		0.9	1.4			
1/2/2015					0.05	0.04		0.05	0.01		2.7	1.3			
1/7/2015					0.06	0.13		0.00	0.00		2.2	1.4			
1/12/2015					0.72	0.05		0.12	0.00		2.5	3.2			
1/14/2015				5.9		0.24									
1/15/2015		0.6	1.0	1.9		0.05		0.00	0.00		0.4	0.3		0.11	0.59
1/20/2015		4.1	6.0		0.89	0.53		0.71	0.19		4.2	3.2		1.35	1.80
2/12/2015	8.0	17.8	28.2	9.7	0.11	0.27	1.34	0.01	0.02	1.3	2.1	2.7	2.43	1.13	1.22
4/2/2015		11.1	13.9		0.19	1.43								1.95	1.09
4/14/2015					0.61	0.66		0.05	0.01		1.8	1.7		1.09	0.84
4/21/2015					0.11	0.23		0.01	0.01		1.3	0.9		0.13	0.46
5/5/2015					0.11	0.50		0.02	0.01		2.0	1.5		1.81	1.79
5/15/2015					0.03	0.59		0.02	0.03		1.6	2.0		1.38	1.59
6/9/2015					0.18	0.81		0.09	0.02		0.6	0.3		0.69	0.70

July 21, 2015

Mayor William Curtis Hayes, Jr.
City of Livingston
301 McHenry Circle
Livingston, TN 38570

RE: Wastewater Treatment Facility
Dear Mayor Hayes:

As a contractor for the Tennessee Department of Environmental Conservation (TDEC), I have visited the Livingston wastewater treatment facility on four occasions to work with plant staff to optimize nutrient removal. As described below, five opportunities for improved treatment / monetary savings were found.

Polishing ponds. Using equipment purchased in part with grant funds, plant staff found that the water quality leaving the polishing ponds (nitrogen and phosphorus) is frequently of lower quality that the water leaving the mechanical treatment plant. Historical data collected from the discharge end of the polishing ponds shows that late summertime ammonia can, at times, exceed Livingston's discharge permit limit.

To assist Livingston in most cost-effectively complying with existing and future nutrient limits, I recommend piping treated wastewater from the SBR (sequencing batch reactor) directly to Town Creek and abandoning the polishing ponds.

Sludge reduction. Using an existing pump and hose, plant staff successfully experimented with returning waste sludge to the mechanical treatment plant in an effort to digest the sludge onsite. A more robust pump/piping arrangement as discussed with plant staff will allow Livingston to reduce the amount of sludge that needs to be trucked off site. This will greatly benefit wastewater operations; as is, the plant becomes choked with sludge during late Spring.

Phosphorus removal. The sludge recycling experiment referenced above will also reduce phosphorus. While experimenting, plant staff on occasion produced an effluent with an ortho-phosphorus concentration of under 0.5 mg/L. A permanent sludge recycling system will defer the need to install additional treatment equipment to meet upcoming phosphorus limits for years, perhaps decades.

Electrical savings. The motors on the plant's aeration equipment are very energy intensive. With minor repiping it should be possible to reduce the plant's annual electric bill by $25,000 or more.

SBR optimization. The recently installed computerized controls by Fluidyne can, and I believe should, be upgraded after the above items are addressed in order to provide finer control of the treatment process and further reduce energy consumption. I suggest upgrading the SBR controls to include in-line instrumentation (DO, ORP, TSS & perhaps Nitrate) and integrate the information generated by the instruments with the SBR aeration, pumping, and equipment.

It was a real pleasure working with plant staff as they are knowledgeable and willing to experiment. During my last visit to the plant on July 7, there was a UPS delivery of sample bottles for the plant staff to use in order to the undertaking of a nutrient optimization study, the very task TDEC was providing the City at no cost other than the City's 50% share of some field testing equipment. In discussing with staff I detected some hesitancy to continue with the optimization work listed above because it was developed by someone other than the City's engineer.

The decision on how to proceed is certainly Livingston's to make but I can tell you this. By embracing TDEC's optimization support, the City of Cookeville has improve nitrogen removal by 75%, phosphorus removal by 50%, and has reduced their wastewater treatment plant's electrical bill by approximately $250,000 per year.

Thank you for considering my comments and best wishes to you and the people of Livingston in providing cost-effective wastewater treatment.

Sincerely,

Grant Weaver, PE
President

CC: Danny Langford, Livingston
Karina Bynum, TDEC

August 4, 2015

David A. Rutherford
City Manager
Crossville City Hall
392 N Main St
Crossville, TN 38555

RE: Wastewater Treatment Facility
Dear City Manager Rutherford:

As a contractor for the Tennessee Department of Environmental Conservation (TDEC), I had the pleasure of meeting you in January of this year when Veolia's Clark Annis and I spoke with you in your office. We gave you a brief verbal report on the wastewater optimization work I was hired to do for Crossville, Cookeville and Livingston. The project has now come to a close and I'm writing to provide a brief overview of the findings.

The combination a talented workforce and the number of unused tanks and other equipment at the treatment plant make Crossville an ideal candidate for optimization. It should be possible to use existing equipment differently in order to reduce nitrogen and phosphorus to levels that will satisfy TDEC for years to come with very little in the way of capital investment, as was done in Cookeville.

Because one of Crossville's critical treatment steps is unavailable for optimization until repairs are performed, we were not able to implement any of the optimization concepts. We were nonetheless able to recommend changes in the modifications which will allow the work to be done at much lower cost. Once the aeration tank modifications are made, it should be possible for Crossville to make changes in the day-to-day operations to improve treatment and reduce the day-to-day cost of wastewater treatment.

The decision on whether to proceed or not is certainly Crossville's to make but I can tell you this. By embracing TDEC's optimization support, the City of Cookeville has improve nitrogen removal by 75%, phosphorus removal by 50%, reduced their wastewater treatment plant's electrical consumption such that one day's reduction (13,400 KWH) is almost enough to power an Upper Cumberland home for a full year thereby reducing electrical expenses at the plant by approximately $250,000 per year, and eliminating the need for a $4,000,000 plant upgrade.

Best wishes to you and the people of Crossville in providing cost-effective wastewater treatment. If there is ever anything I can do to assist, please ask.

Sincerely,

Grant Weaver, PE
President

CC: Mayor James Mayberry
Clark Annis, Veolia
Karina Bynum, TDEC