Advanced Biological Filtration:

Proactive WWTP Design and Innovation Improves Health of Chesapeake Bay Watershed

By Kacey King-McRae

Operations Specialist
Department of Environmental Services
Water Pollution Control Bureau
Arlington, Virginia

Introduction

Located on 35 acres less than a mile west of Ronald Reagan Washington National Airport, Arlington County's Water Pollution Control Plant (WPCP) in South Arlington, Va., treats flows from nearly all of Arlington. Twenty percent of the plant's flow comes from neighboring municipalities such as Alexandria, Fairfax County and Falls Church. Effluent from the plant is discharged into Four Mile Run stream to the south, which feeds into the Potomac River and, ultimately, the Chesapeake Bay.

Originally constructed in 1937, the facility was upgraded several times in the 1950s, 1960s, 1970s and 1990s. In 2001, Arlington County officials recognized the need to address several long-term challenges. A growing population in the county's residential and business communities was straining the aging WPCP infrastructure. There was insufficient treatment capacity to handle wet weather events that could increase flows nearly fourfold. Additionally, site space constraints that included adjacent residential and commercial developments would present a challenge to the required huge construction effort.

Nitrogen and phosphorous are beneficial to life up to a point, beyond which they are considered "nutrient pollution." Excessive amounts of nitrogen and phosphorous can cause hypoxia and harmful algal blooms in aquatic settings, leading to elevated toxins, bacterial overgrowth and a contaminated ecosystem. The largest estuary in the United States, Chesapeake Bay supports life for thousands of plant and animal species, as well as 13.6 million people living in its watershed. Decreasing nitrogen and phosphorous effluent is a responsibility for every entity that discharges water into the Chesapeake Bay and its tributaries.

DE NORA

In a forward-looking approach and to assume its share of responsibility to reducing pollution in the Chesapeake Bay watershed, the county board decided in January 2003 to proactively upgrade the plant's treatment process to provide "limit of technology" nutrient removal in advance of any requirements to do so. This would require upgrading the plant's biological nutrient removal (BNR) 8 mg/l total nitrogen (TN) capability to meet an anticipated TN limit of approximately 3 mg/l with a concurrent low total phosphorous limit of 0.18 mg/l.

The resulting planning, design and construction project was a $568 million, decade-long upgrade of the WPCP that would expand the plant's capacity from 30 mgd to 40 mgd while also reducing nitrogen and phosphorous to the limit of technology.

Massive project divided into two phases

Virtually every process and structure was renovated, expanded or upgraded for this complex project, and the project was therefore executed in two phases.

Phase one included building two pre-stressed concrete flow-equalization tanks with a combined capacity of 12 million gallons, a 30,000-sq.-ft. filtration and disinfection facility equipped with 17 deep bed denitrification filters and two chlorine contact tanks.

Phase two included three new 140-ft.-diameter secondary clarifiers, two new advanced aeration tanks, a new pump station, a preliminary treatment bypass facility, two mixed liquor distribution structures and a primary effluent channel.

Additional equipment incorporated in the main contracts included two odor control scrubbers, two chemical feed facilities and upgrades to the bulk of the electrical distribution network. Other equipment upgrades included six secondary clarifiers, six primary clarifiers, an operation controls building, a blower building, a pump station, backwash waste tanks, electrical distribution centers and a chemical feed system.

Maintaining uninterrupted plant operation was critical and non-negotiable throughout construction. Therefore, improvements were implemented in multiple construction batches, each designed to allow the treatment process to stay in continuous operation. Fru-Con Construction Company, the project's general contractor, and plant staff coordinated more than 240 scheduled shutdowns to enable new facilities and systems to be brought on line. As a result of these efforts, the plant remained fully operational over the project's entire 46-month duration.

Special challenge: No elbow room

Presenting a particular challenge for the construction team was the site of the plant – surrounded by residential development, roadways, overhead power lines and the Four Mile Run waterway. This demanded the design of a very compact treatment process. In cooperation with the engineer (Malcolm Pirnie, the water division of ARCADIS), the final design took many plant layout iterations to accommodate the filters. The compact site also required creative approaches to construction, which, according to one team member, was like "building a ship in a bottle." To save space, De Nora designed a common effluent channel below a common influent channel, instead of piping. To maintain the required steady concrete flow during the equalization tank pour, work was scheduled for 32 straight hours over a weekend when normally heavy traffic would be minimized. To maintain flow while existing facilities were demolished to make room for new facilities, engineers constructed two temporary 72-in.-diameter pipes under the new aeration basins. Temporarily constructed power generation facilities provided continuous power during construction while the entire electrical system was being rebuilt. Two 2-acre tracts approximately five miles from the job site were used for storage due to limited space on site.

Pilot testing two denitrification filter technologies

Malcolm Pirnie engineers conducted pilot testing to assess the ability of two denitrification filter technologies to achieve total nitrogen effluent limits and removal of effluent total suspended solids (TSS) to ensure low effluent phosphorus concentrations. The tests were conducted in side-by-side conditions under various flows and loads, testing performance at average and peak conditions and influent phosphorus concentrations. After concluding the pilot tests, the company decided to replace the plant's existing tertiary filters with DE NORA TETRA® Denite® deepbed denitrification filters from De Nora. Seventeen Denite filters, each 12' 6" x 72' 4" with a total surface area of 15,370 sq. ft., were designed to address the treatment requirements of the WPCP.

The DE NORA TETRA filtration system is a fixed-film biological denitrification process that also serves as a deep bed filtration system capable of removing oxidized nitrogen (NOx-N), total phosphorous (TP) and suspended solids (SS) to meet a high standard of effluent discharge. DE NORA TETRA Denite system is a single treatment solution that addresses multiple wastewater treatment plant process needs by offering an economical, small footprint and virtually maintenance-free operation.

Fundamental to the DE NORA TETRA Denite system is the specially sized and shaped granular media used in the fixed-film biological filters. The high solids loading capacity of the media is ideal for retaining biological solids produced by the denitrification process, and the powerful backwash of the Denite filter system removes these solids periodically. The surface area of the 2-3 mm-diameter sand particles is very large, providing 650 m2/m3 contact between the wastewater supply and the biomass. The media allows for heavy capture of solids – at least one pound of solids per square foot of filter surface area before backwashing is required. The high solids capture permits extended operating periods and easily handles peak flow or plant upsets.

During the denitrification process, wastewater is forced to flow around nitrogen gas bubbles that accumulate in media voids in the filtration vessel, improving biomass contact and filtration efficiency. Effective removal of NOx-N is accomplished by introducing an external carbon source such as methanol, using an automatic dosing control scheme. This dosing control scheme is based on an influent flow signal combined with an influent and effluent NOx-N concentration analyzer. An alternative to this system is one incorporating either a flow-paced or feed-forward or feedback system. The advantages of tighter methanol control can be significant if the plant has a stringent BOD limit in combination with a low TN limit. Under these conditions, the tighter control and reduced risk can be a critical component in ensuring the plant meets limits reliably.

A "bump" operation is employed to remove or purge accumulated nitrogen gas that builds up in the filter media bed. If desired, this "bumping" can be accomplished without removing the reactor from service using the patented SpeedBump process, which applies backwash water to the bottom of the filter, releasing the entrapped gas into the atmosphere and reducing head loss.

An added benefit of the Denite system is the removal of phosphorus, which is assimilated as a nutrient in the biomass and removed via filtration of solids containing phosphorus. The trapped solids are backwashed out of the filter by a simultaneous injection of air and water and returned to the upstream biological treatment units at the end of each cycle. By operating in a down flow mode, excellent levels of solids removal are achieved, eliminating the need for additional effluent polishing filters.

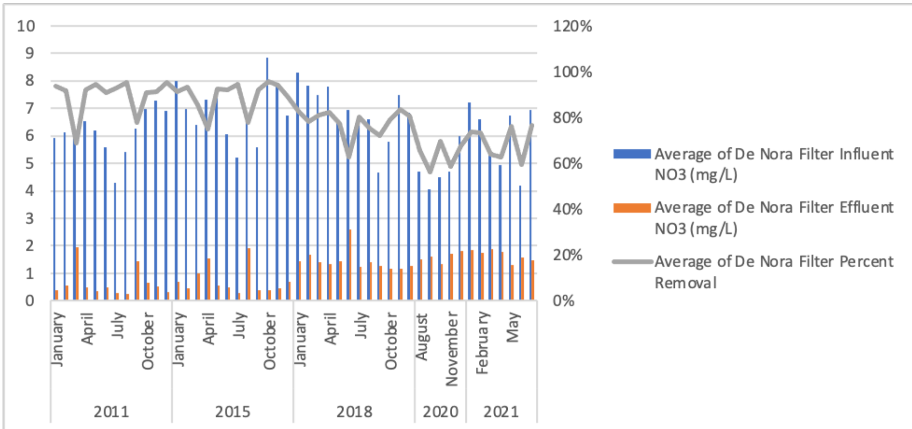
Award-winning plant design goes beyond the “Limit of Technology”

The Arlington County plant, which treats an average annual daily flow of 25 mgd, with an influent BOD around 260 mg/L, is one of the first major effluent denitrification facilities to achieve effluent TN < 3.0 mg/l and TP < 0.18 mg/l. Seventeen DE NORA TETRA Denite filters measuring 12’-6” x 72’-4” were installed in 2010 downstream of an MLE step feed process. Approximately 800 gallons per day of methanol is used to treat about 1400 lbs. per day of nitrate.

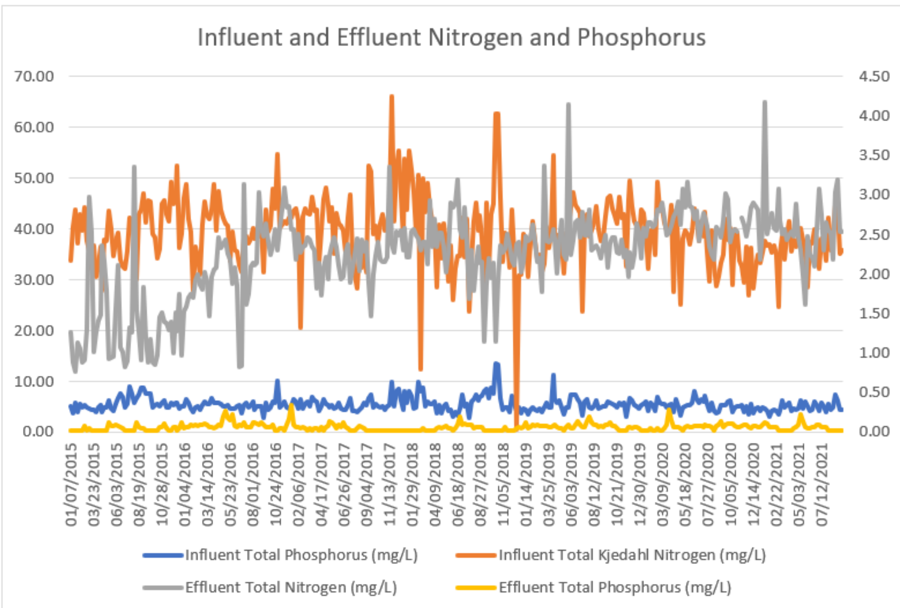
Since June 2010, the plant has realized an average annual effluent TN = 1.2 mg/l TN and TP<0.1 mg/l. This has been accomplished by replacing effluent filters and modifying all upstream processes. For example, to protect the treatment process against wide fluctuations in flow during wet weather, the plant’s design included increased equalization basin tankage and other primary treatment modifications.

Shown below is the ten-year history of the filter performance, showing approximately 70% removal of the nitrate over this time period.

Average Influent and Effluent Nitrate



Below, find the overall plant performance over the last 5 years, showing the removal of total nitrogen, Kjeldahl nitrogen, and phosphorous.



Typical maintenance schedule

Several maintenance tasks, such as a routine backwash and a routine filter bump, are automated to occur at scheduled intervals. Manual maintenance tasks are generally implemented when monitoring the system, if there is an indication that the filters are beginning to clog, or when there is wet weather event coming to the area and an anticipated increase in influent total suspended solids (TSS).

Task	Frequency	Maintenance Type
Automated Backwash	Once Every 96 hours	Routine
Operator Initiated Backwash	As Needed	Corrective
Automated Filter Bump	Once Every 4 hours	Routine
Operator Initiated Filter Bump	As Needed	Corrective
Manual Filter Wall Cleaning	As Needed	Corrective
Resetting Level Indicator	As Needed	Corrective

Backwashing filters to prevent clogging

A backwash is the process of making water and air flow upward through the filter to remove accumulated solids that would eventually create a buildup of pressure within the filter media. After an initial air scour, the backwash water is started and flows co-currently with backwash air. The backwash water acts as a transport medium to carry solids up and out of the filter bed and into the backwash trough. The backwash will continue with simultaneous application of air and water for up to 15 minutes.

Without a backwash, the filter has the potential to clog and lead to insufficient treatment and eventual overflow. For efficiency and to ensure that every filter is regularly backwashed, the system uses a filter backwash queue. The queue uses average monthly conditions to determine the frequency of filter backwash. At present, with 17 filters, each filter gets backwashed approximately once every four days. Once a filter's backwash is completed, that filter moves to the back of the queue.

Plant Flow Rates			
Design Average	Actual Average	Maximum 7-Day	Peak Hour
40 mgd	25 mgd	86.4 mgd	120 mgd

The plant monitors the level for the filter bed (> 7ft) to determine if a manual backwash is necessary.

Using methanol to achieve low nitrogen discharge

Methanol is an excellent source of readily available carbon ("food") which produce energy source for denitrifying microorganisms. Methanol provides the energy necessary for microorganisms to convert nitrates (NO_3) to nitrogen (N_2) gas. This process reduces the total nitrogen in the treated wastewater, thus allowing the Arlington plant (ACWPCP) to meet its discharge permit for that parameter.

Methanol is a simple organic alcohol easily broken down by the anoxic denitrifying bacteria to use as an energy or carbon source as they convert nitrate nitrogen (NO_3) into nitrogen gas (N_2). The denitrification process is driven by the effluent nitrate removal required to achieve the total nitrogen limit of 3.0 mg/L. This usually requires effluent nitrate to be reduced from 0.5 to 1.5 mg/L. The plant monitors the influent and effluent NO_3, and controls the methanol dosing based on meeting an effluent nitrate setpoint.

Project success is demonstrated by the following:

- Design and construction of the project were completed within budget, and major components were completed approximately 18 months ahead of schedule.
- The plant today is discharging <2.0 milligrams of nitrogen per liter of water and <0.1 milligrams of phosphorous per liter into the Four Mile Run stream compared to 19.6 milligrams of nitrogen in 1985 before nitrogen reduction efforts commenced.
- The plant is so successful, in fact, that it has earned "pollution credits," which are units of phosphorus and/or nitrogen that it removes from the wastewater over and above what is required. The plant is able to offer the credits to other facilities who cannot meet the limits and can benefit from the plant's exceptional treatment.
- Malcolm Pirnie won the Excellence in Environmental Engineering competition's 2011 Grand Prize in Design. The competition is sponsored by the American Academy of Environmental Engineers.

As one of the first major wastewater treatment plants in the Chesapeake Bay watershed to achieve enhanced nutrient removal, the Arlington County plant is a major contributor to the Bay's environmental quality goals and the health of the surrounding ecosystem.