# Taking Denitrification to the Next Level:
## An Upgrade of Proven Technology with 21st Century I&C

This paper discusses the integration of new technologies, the operational benefits, and the startup coordination needed to reliably meet new operating permit limits.

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InTech

Published in InTech
(an ISA Publication)
December, 2014

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Taking Denitrification to the Next Level: An Upgrade of Proven Technology with 21st Century I&C

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## KEYWORDS

Instrumentation, Automation, SCADA, Denitrification, Case Study, Wastewater, Water Reclamation

## ABSTRACT

In 2006, one of the largest water reclamation facilities in the northern Virginia area recognized the need to expand the facility from 18 to 24 million gallons per day (mgd) to support future growth in Prince William County, Virginia. At the same time, new regulations necessitated an upgrade to improve nutrient removal capabilities of the plant. The new wasteload allocations for total nitrogen (TN) were to be based upon permitted discharge flows on December 31st, 2010 with a 3 mg/L TN concentration. The Prince William County Service Authority (PWCSA) recognized the need to simultaneously increase flow and nutrient removal capabilities to meet the future growth demands of the region. At the same time, there was a need to replace their plant-wide data acquisition and control system (DACS), with a new modern supervisory control and data acquisition (SCADA) system.

This design-build project provided enhanced nutrient removal and an increase in capacity; the existing aeration basin volume was doubled and reconfigured to allow operation in either 4-stage Bardenpho or Modified Ludzack – Ettinger (MLE) modes; 14 new deep bed denitrification filters were implemented for a total of 24; and methanol feed to the filters was automated to be nitrate load paced and controlled by a proprietary software calculation algorithm. Furthermore, an additional online analyzer for controlling the methanol feed to the filters was installed for redundancy purposes.

The proprietary software calculation algorithm for control is feed-forward/feed-back based upon flow and influent and effluent nitrate concentrations. This enhanced the operation and reliability of the process and also reduced the risk of methanol overdose by more closely matching the methanol feed to the actual demand. Consistent methanol dose control is challenging when trying to meet low effluent TN and simultaneously maintaining a low effluent carbonaceous biochemical oxygen demand (CBOD).

This plant is currently in full operation and in compliance with the effluent requirements. This paper discusses the integration of new technologies, the operational benefits, and the startup coordination required to reliably meet the new operating permit limits. Furthermore, it explains process efficiencies, which require less chemical (i.e. methanol), translating into an economic benefit for plant operations.

Figure 1 shows an aerial view of the plant before the upgrade and a rendering of the plant after the upgrade.

**Figure 1 – H.L. Mooney Advanced WRF aerial view before the upgrade and plant rendering after the upgrade**

## THE CHALLENGE

The 2000 Chesapeake Bay Agreement committed Maryland, Virginia, Pennsylvania, and the District of Columbia to achieving common interest goals to restore and protect the bay. The Virginia Department of Environmental Quality (DEQ) Water Quality Management Planning Regulation 9VAC-25-720 established nutrient load allocations for point source discharges from treatment plants above a certain capacity threshold, identified as "significant plants." The wasteload allocation was based on the permitted average daily discharge capacity as of December 31st, 2010. For the H.L. Mooney Advanced Water Reclamation Facility in Woodbridge, VA, this equated to an annual average concentration limit of 3 mg/L at 68,137 $m^3$/day (18 mgd) – existing average day flow permit limit – or the same concentration at 90,850 $m^3$/day (24 mgd) if the plant achieved a certificate to operate (CTO) at its expanded flow of 90,850 $m^3$/day (24 mgd). During 2009 and 2010, the annual average TN discharges were 5.86 mg/L and 3.93 mg/L respectively, which were well below the previous voluntary limit of 8 mg/L.

Therefore, the primary goal was to make the appropriate changes required to reduce effluent TN discharge on an annual basis to 3 mg/L and receive a CTO at 90,850 $m^3$/day (24 mgd) by December 31st, 2010. Also, the main objectives were to identify the process areas that needed to be modified; identify the specific modifications to each specific area; and identify the appropriate technology that would provide the best control methodology, performance, and monitoring capabilities.

## DESIGN CONSIDERATIONS

### Process Enhancements

In 2006, PWCSA recognized the need to expand the H. L. Mooney Advanced Water Reclamation Facility from 68,137 $m^3$/day (18 mgd) to 90,850 $m^3$/day (24 mgd) to obtain the full wasteload allocation, to meet new regulations, and because the average daily flows were reaching 85% to 90% of design average daily flows.

**Figure 2 – New denitrification filters**

Prior to the expansion, the plant operated with 10 denitrification filters that had insufficient surface area to process the full plant capacity of 18 mgd in denitrification mode. During the period when the filters were operated in the denitrifying mode, flows beyond 12 mgd bypassed the filters to prevent hydraulic overloading. Even though the filters were capable of hydraulically passing the full plant flow, denitrification could not be achieved at higher flows.

Based on the processing limitations and operational cost savings, the filters were often operated on a seasonal basis, with methanol being added only during the winter due to the additional dentirification needed to meet effluent TN requirements. During summer, the plant had sufficient denitrification capability in the secondary treatment (aeration basins) to meet effluent TN requirements and the filters would operate in a “polishing” mode without methanol addition to remove suspended solids.

During the design phase of the plant upgrade, MLE, 4-stage Bardenpho, 5-stage Bardenpho, membrane bioreactors (MBR), and the step-feed biological nutrient removal (BNR) alternatives were considered. The MLE and the 4-stage Bardenpho processes were ultimately selected for implementation based on a wide range of criteria including capital cost, overall cost, net present value, land requirements, effluent quality, operability, maintainability, and schedule.

The plant was also required to reduce effluent total phosphorus (TP) to 0.18 mg/l. The plant currently achieves phosphorus removal through the use of chemically enhanced primary treatment (CEPT), which includes ferric chloride addition. If additional phosphorus removal is needed, ferric chloride is added ahead of the secondary clarifiers. Although the denitrification filters will remove small amounts of particulate phosphorus, they are not really designed to meet effluent total phosphorus requirements.

Phosphoric acid addition capability is provided in the filter’s area in the event the filters become “phosphorus limited.” In this case, denitrification removal rates will drop such that they will not occur fast enough in the filters. In order to avoid this, it may become necessary for the plant to reduce ferric chloride feed rates to the secondary clarifiers or to add phosphoric acid prior to the filters. It was anticipated that any phosphorus allowed to bleed through to the filters or added to the secondary effluent will be removed by the denitrification filters and permit limits will not be exceeded. However, provisions were provided for future implementation of phosphoric acid feed.

Additional denitrification filters were also a design consideration. Ultimately, the number of denitrification filters was increased from 10 to 24 to meet the new projected demands and to be able to handle when filters are off-line due to either backwashing, bumping, or for maintenance/repair.

**Figure 3 – New PLC cabinet**

## Plant-Wide Control System Replacement

As part of this design-build project, PWCSA also recognized the need to upgrade and replace their existing plant-wide DACS. The existing DACS was installed in 1996 and was obsolete with key components of the system no longer available from the manufacturer. In addition, overall support to maintain the DACS was no longer acceptable other than from one local support person. Finally, the upcoming plant upgrade needed to expand the DACS to create a plant-wide control system. As the existing system was obsolete, upgrading its components was not practical.

The existing DACS was transitioned to a new modern SCADA system, which was carried out as part of the overall project design-build implementation, including designing a system with both new process area control panels and upgrade of existing control panels.

The final build out of this system has about 5,000 input / output points, 25 programmable logic controllers (PLC) with a self-healing fiber optic ring, an object oriented human machine interface (HMI) system, and a historian interfaced with reporting software that integrates the SCADA and laboratory databases.

As part of the design-build implementation, the engineer of record provided construction management services and quality assurance/quality control (QA/QC) for the new SCADA system and the field instrumentation portion of the project. Some of the activities included QA/QC for the new instruments that were provided, start-up coordination between PWCSA and the subcontractor, onsite response to design/implementation questions/clarifications, development of maintenance of plant operations (MOPO) plans for the transition of existing and in-service systems to the new SCADA system with the objective of minimizing the impact on plant operations, and the development and continually updating of the SCADA project schedule.

Furthermore, towards the end of the project, the engineer of record also guided, witnessed and approved the testing procedures and results for the SCADA system as a whole. This activity included network testing, uninterruptible power supply (UPS) testing, software testing, PLC programming testing, loop testing (operational and readiness test – ORT) performed by the subcontractor and functional demonstration test (FDT) performed by the subcontractor with coordination with PWCSA and witnessed and approved by the engineer of record.

## Automation of the Methanol Feed System

As part of the new denitrification filters implementation, methanol feed to the filters was automated to be controlled by the proprietary TETRAPace® calculation algorithms. The TETRAPace® primary method of operation is feed-forward/feed-back based upon flow and influent and effluent nitrate concentrations.

As part of the TETRAPace® calculation algorithm, measurements of the influent and effluent nitrate concentrations are needed. For this purpose, the existing ChemScan unit was used. However, during the plant expansion, it was decided to have a second ChemScan unit installed for redundancy purposes and to eliminate the risk of methanol overdose in the event that one of the units is unavailable. If there was only one unit installed and unavailable, the typical programming is to utilize the last known readings; however, this could result in significant overdosing or under dosing of methanol if the characteristics of the wastewater change, potentially resulting in permit violations for CBOD or TN. Also, overdosing methonal to the denitrification filters may occur due to the variations in the secondary effluent nitrate levels while the Chemscan unit is out of service. This increase of the effluent CBOD level may result in a permit violation.


Figure 4 – Redundant ChemScan units

### Instrumentation

When designing critical process systems, the decision to use redundant systems and newer or additional devices for the upgrade was made after discussions with plant staff. When permit limits of such stringent levels are implemented, operations must use the instruments to optimize the facility and then rely on the electronics components to work reliably over time to enable compliance. The ChemScan system is a multi-parameter, multi-sample line analyzer that was already being used by the Authority for some time and the plant staff is used to working with it, keeping the system accurate and responsive.

The ChemScan is essentially a lab spectrometer that is automated to read over 254 wavelengths thru a process sample from before and after the denitrification filters common inlet and effluent troughs. The sample pumps deliver a small stream to the analyzer constantly and the system alternates between each sample line in a continuous sequence to monitor ammonia, nitrate, nitrite and ortho-phosphorous.

The system also self-calibrates with a zero standard of deionized water and self-cleans with an acidic solution to keep the TSS and hardness from fouling the flow through the cell and other components in the plumbing manifold. Detection limits and process trends need to be understood and data excursions must be vetted by plant staff regularly to insure the expectations of the operators are met with confidence.

The data presented in Figure 5 shows a nitrite excursion during start-up that indicates an upset in the process which allows the operators to react to the situation, adjust upstream processes, and adjust chemical feed systems, if necessary. Figure 5 also displays how the data from the ChemScan analyzers and the grab samples are very close to each other confirming the calibration of the instrumentation.

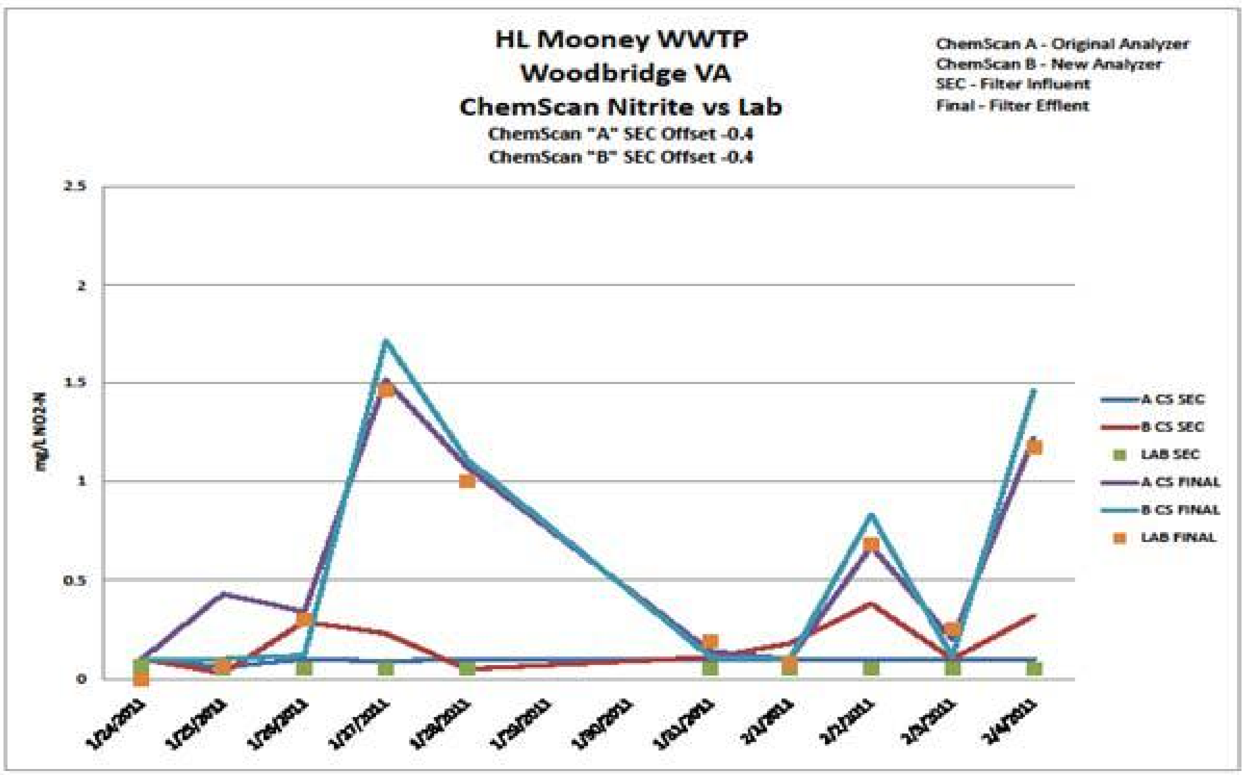


**Figure 5 – ChemScan nitrite analysis during startup**

Online analyzers mainly provide intermittent data which gives the effect of sharp high and low points in graphical terms, so operators must understand that these peaks and valleys are much smoother and time depressed than seen here. Process control decisions cannot be made on single points of data that stand uncorroborated. Patterns with repeatable trends and occasional outliers in the data are used to make rational decisions with and after vetting equipment.

Online monitoring devices can help run a facility better, but they are not foolproof and need regular care and inspection. Maintenance instructions and protection of transient electrical power surges must be done to protect the investment in this data gathering infrastructure.

At the same time, and as part of the design-build expansion project, a backup methanol feed pump was installed so that the loss of methanol feed to the denitrification filters (when running in denitrification mode) will be minimized in the event of a failure or scheduled maintenance for the main feed pump. Also, as part of the plant-wide DACS replacement, the network backbone was designed with a self-healing fiber optic ring to minimize the risk of losing the SCADA system and with UPS systems preventing spikes and brownouts from damaging the critical equipment of the control system.

Figure 6 is a plant process flow diagram where the red arrows represent the methanol application points and the green and blue arrows represent locations of the nutrient concentrations readings. The blue arrows are the sample points that feed the ChemScan units before and after the denitrification filters. The two green arrows on the right of Figure 6 show where the ChemScan units are physically located.

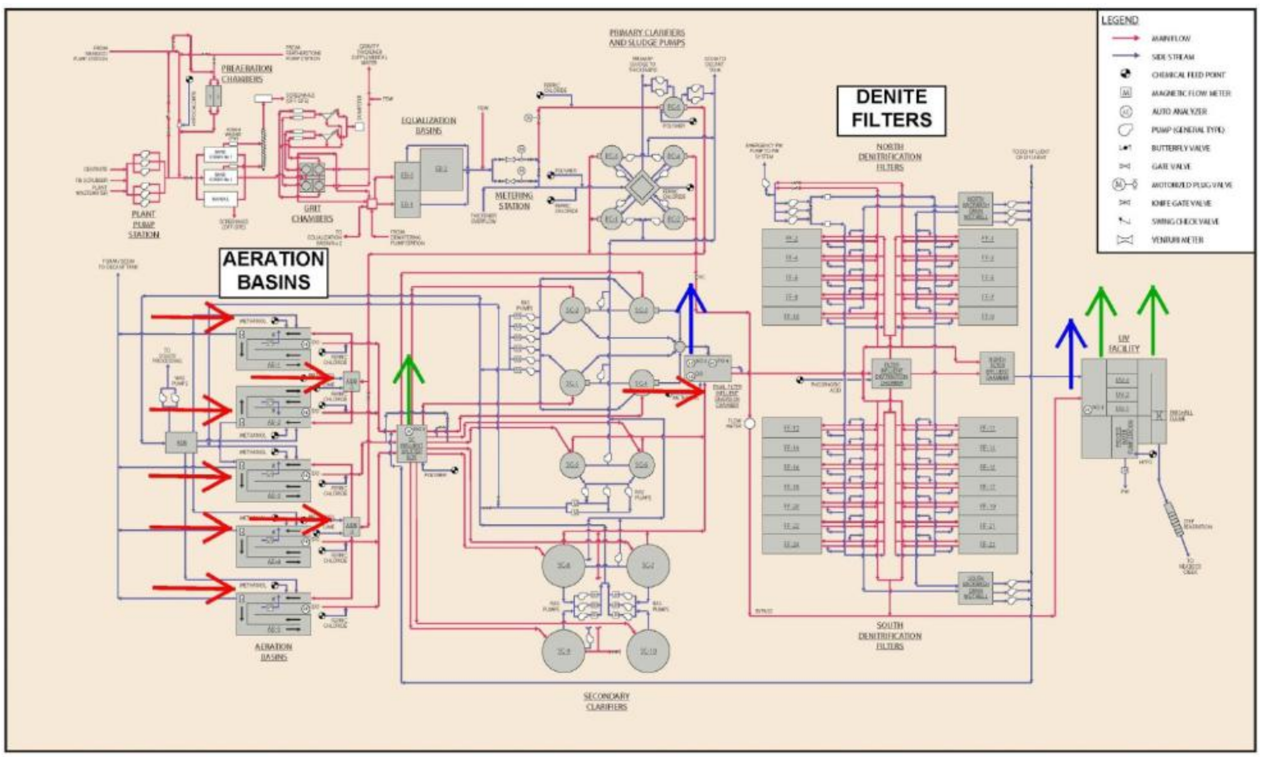


**Figure 6 – Methanol application points and nutrient sample points**

The other green arrow towards the left of Figure 6 is the representation of a separate nitrate analyzer that can be relocated to take nitrate readings at either of the 5 aeration basins or at the secondary influent distribution box (where shown in the figure). These six locations have provisions for such a case where an individual aeration basin requires the nitrate levels to be read.

This whole implementation enhanced the plant operations and reliability of the process and also reduced the risk of methanol overdose by more closely matching the methanol feed to the actual demand. Consistent methanol dose control is challenging when trying to meet low effluent TN while simultaneously maintaining a low CBOD.

Figure 7 shows constant methanol consumption (an average of about 412 gal/day) totally independent of the nitrate and nitrite changes. On the other hand, Figure 8 shows how the methanol feed follows the nitrate and nitrite changes and with a daily average methanol consumption of about 300 gal/day. From the operational perspective, this translated into minimizing the risk of methanol overdose by more closely matching the methanol feed to the actual nitrate and nitrite changes.

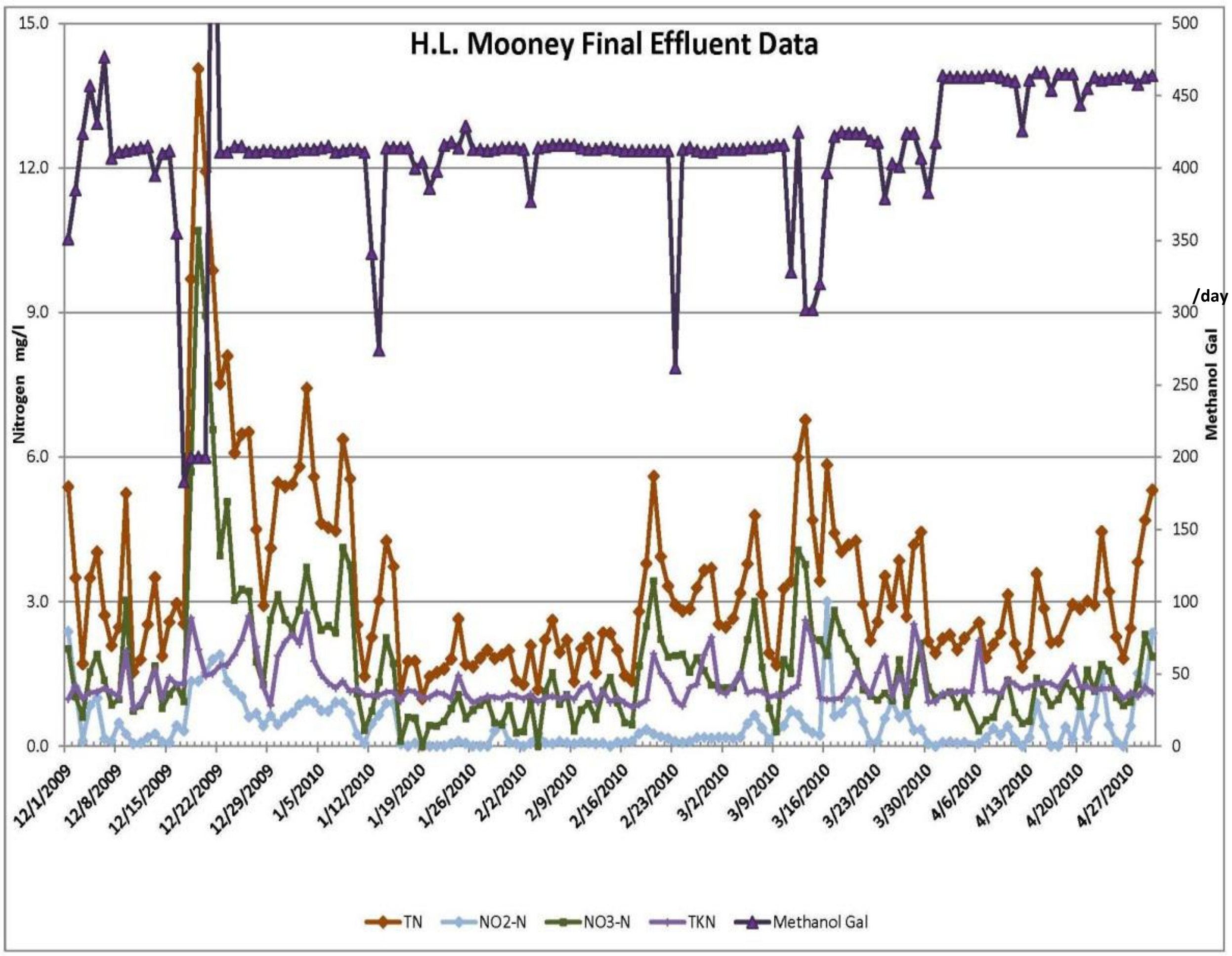


**Figure 7 – Effluent nitrate and nitrite concentrations, and methanol feed rates *BEFORE* the upgrade**

## DURING CONSTRUCTION

One of the biggest challenges during this plant upgrade was the coordination, planning, and execution of the MOPO plans. Since the plant must be kept online during this upgrade, there were many factors that had to be taken into consideration to minimize the plant downtime. One of the key factors was to perform testing of the hardware and software before it even was shipped to the plant. Once the equipment was onsite, another thorough test was executed to test the field connections and installation.

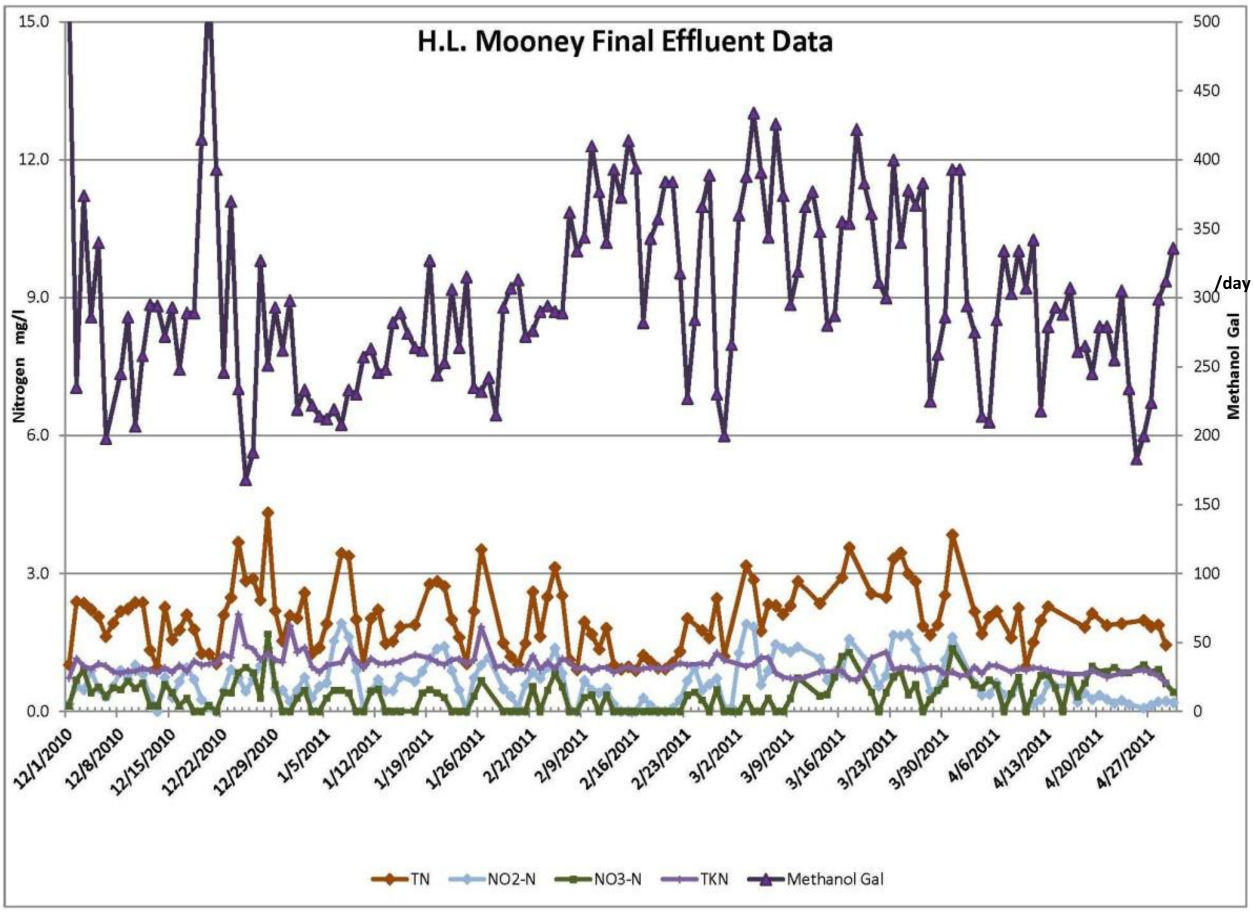


**Figure 8 – Effluent nitrate and nitrite concentrations, and methanol feed rates *AFTER* the upgrade**

The startup process was done in phases, taking into consideration that not only the instrumentation but the plant-wide control system was being transitioned and that there were construction aspects of the project that had to be considered as well. This led to an initial setup and calibration of the TETRAPace® calculation algorithms and the ChemScan units that later had to be changed to accommodate for the different conditions of the phased approach.

Due to the redundant ChemScan units setup, the PLC and HMI systems were programmed and configured to accommodate for this redundant system. A screen shot of the UV system area is displayed on Figure 9 where the readings of both ChemScan units are displayed.

At every operator workstation (OWS), which are distributed throughout the plant, the operators have the option to select which ChemScan unit readings to use in the TETRAPace® calculation algorithms.

Figure 10 shows a screen shot of the denitrification filters area where the operators can select which ChemScan unit readings to use for the TETRAPace® calculation algorithms. This also added flexibility for maintenance of the ChemScan units.

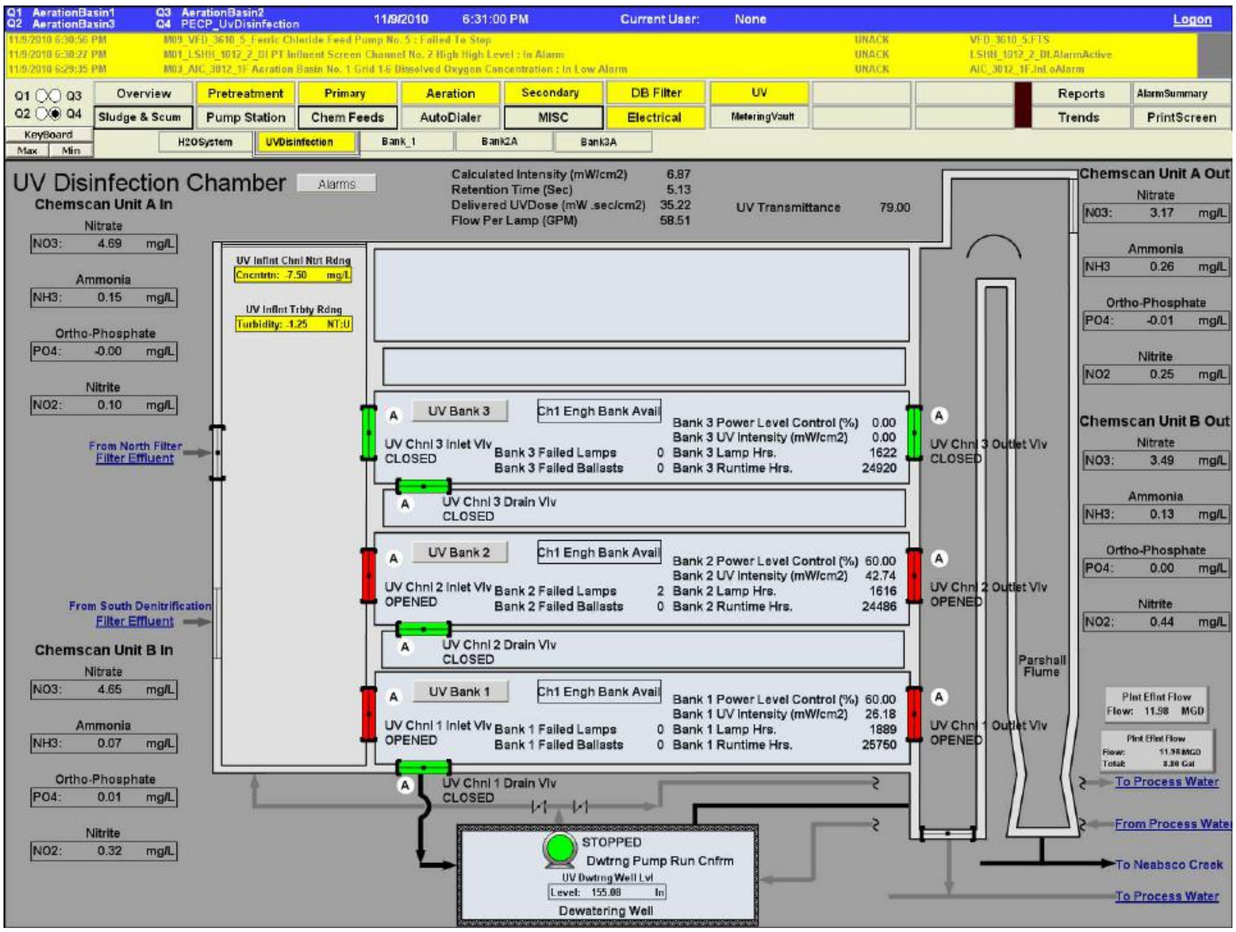

**Figure 9 – Filters influent and effluent ChemScan units readings**

Additionally, PLC programming and HMI development for the denitrification filters were implemented as an integral part of the overall plant-wide SCADA system instead of having a vendor system communicating to it. This provided the plant staff with a more standardized approach to facilitate future changes and maintenance to either of the systems.

## OPERATIONAL AND ECONOMIC BENEFITS

As it has been mentioned already, one of the main operational benefits is that the risk of methanol overdose was greatly reduced by more closely matching the methanol feed to the actual nitrate and nitrite changes when feeding methanol to the filters. This enhanced control simultaneously maintains a low CBOD and the denitrification filters can now denitrify meeting permit limits up to average day maximum month loading.

At the same time, and as a consequence of the improvements made to the aeration basins, plant operations fed methanol to the denitrification filters until about August 2011, very close to the substantial completion date of the project. Currently, the plant is able to completely denitrify to below 3.0 mg/L of TN consistently in the aeration basins. The fact that the plant is currently flowing about 50% capacity might be an important factor for this, but if the flows increase and there is the need for it, methanol can be fed to the filters again.

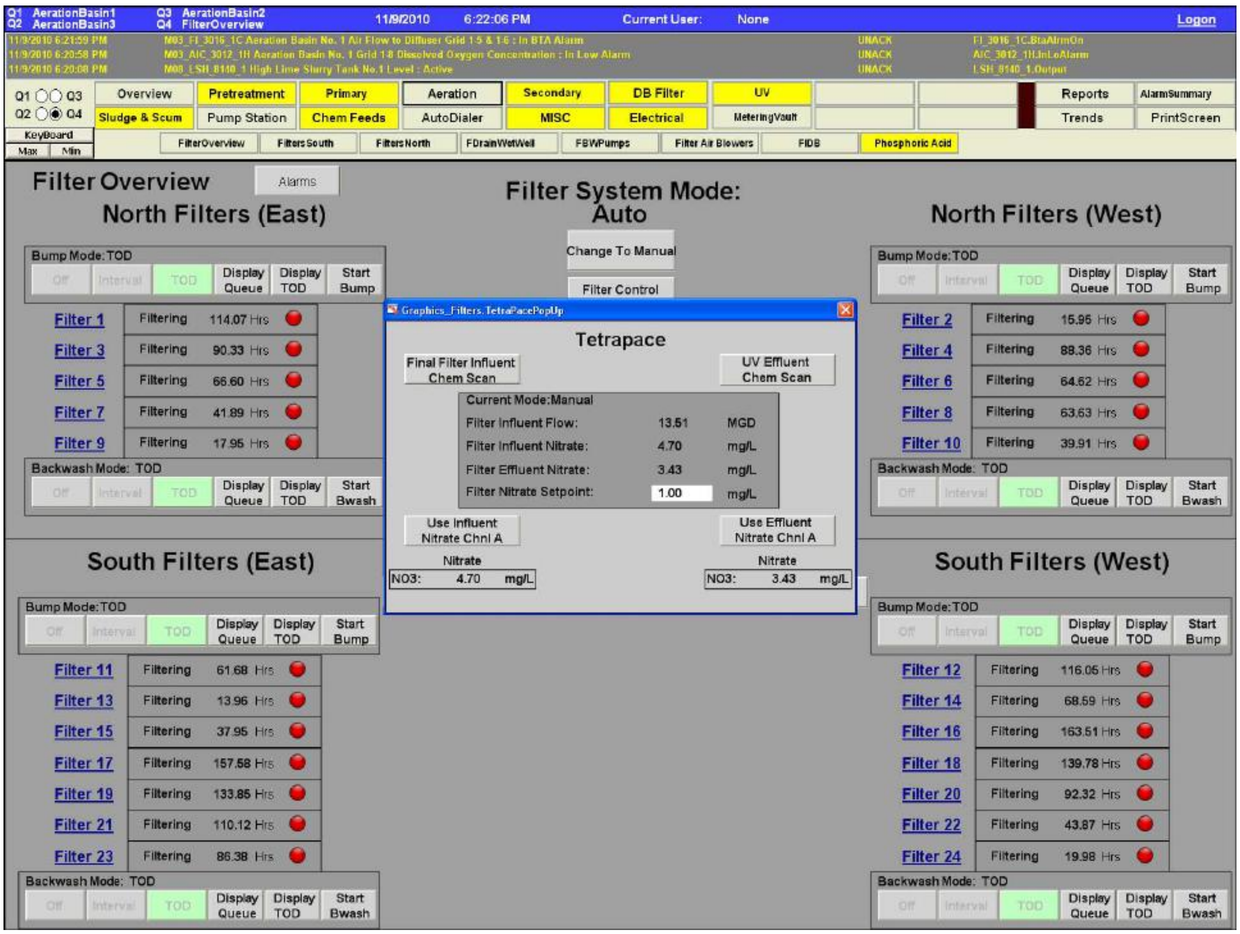


**Figure 10 – Filters TETRAPace® calculation and ChemScan readings selection**

With the lower flows through the aeration basins, the plant is able to operate year round in the 4-stage Bardenpho mode with maximum anoxic zones. The mode of operation still allows complete nitrification in the aeration basins and maximized volume available for denitrification. At the same time, with the higher retention times, the plant has been able to support a biological phosphorous accumulating organism in the aeration basins, allowing operations to stop all ferric chloride feed to the secondary system while maintaining ferric chloride feed to the primary clarifiers to meet the total phosphorus limit.

On the economic side, and as Figures 7 and 8 showed, the daily average methanol consumption to the filters went down from about 413 gal/day to close to 300 gal/day. Methanol is fed to the filters for an average of about 8 months a year, which translates to about 27,000 gallons less methanol used per year. Additionally, since currently sufficient denitrification is taking place in the aeration basins when operating in the 4-stage Banderpho mode and no methanol is being fed to the filters, this means that the methanol savings would be about 41,000 gallons per year, above the 300 gal/day of filter methanol that was moved to the aeration basins to improve the nitrate reduction. With the gallon of methanol being about $1.755, this translates into a yearly savings of about $71,955.

In other words, what was done before the upgrade to save money on methanol consumption by running the filters in "polishing" mode, has now become normal operations for the plant.

## SUMMARY

The H.L. Mooney Advanced WRF upgrades became necessary because the average daily flows were reaching 85% to 90% of the plant capacity and further growth was expected. Additionally, PWCSA wanted to maintain a wasteload allocation based upon 3 mg/L of effluent TN at the future flow capacity of 24 mgd. In addition to the process upgrades to the aeration basins and denitrifying filters, the upgrades included improved controls for the denitrifying filters allowing a reliable methanol feed control to minimize methanol costs while also ensuring adequate feed.

The modifications to the overall plant have allowed a significant reduction in overall chemical usage for both methanol and ferric chloride. Ferric chloride use was reduced due to the increased volume in the aeration basins resulting in biological phosphorus removal. Furthermore, the improved controls incorporated into the denitrification filters resulted in a reduction in methanol usage by approximately 25% while still meeting effluent nutrient loading criteria. Finally, the methanol reduction at the filters can be traced directly to the use of a load-based methanol addition algorithm for the denitrification filters.

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### List of Acronyms:

BNR..................biological nutrient removal
CBOD................carbonaceous biochemical oxygen demand
CEPT .................chemically enhanced primary treatment
CTO..................certificate to operate
DACS.................data acquisition and control system
DEQ ..................department of environmental quality
FDT ...................functional demonstration test
HMI...................human machine interface
I&C....................instrumentation and control
MBR..................membrane bioreactor
mgd ..................million gallons per day
MLE ..................modified ludzack ettinger
MOPO...............maintenance of plant operations
ORT...................operational and readiness test
OWS .................operator workstation

PLC....................programmable logic controller
PWCSA..............Prince William County Service Authority
QA/QC ..............quality assurance/quality control
SCADA ..............supervisory control and data acquisition
TN.....................total nitrogen
TP .....................total phosphorus
TSS....................total suspended solids
UPS ..................uninterruptible power supply

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