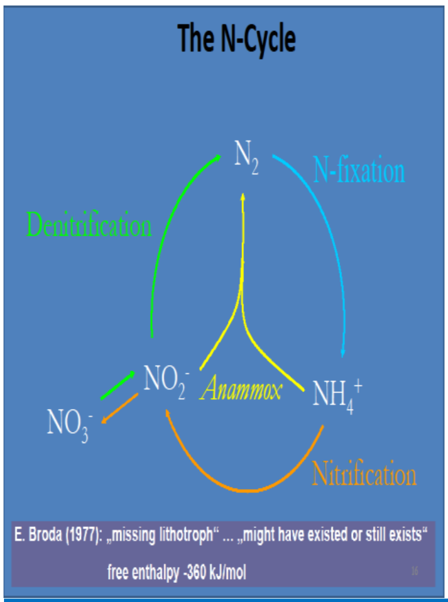
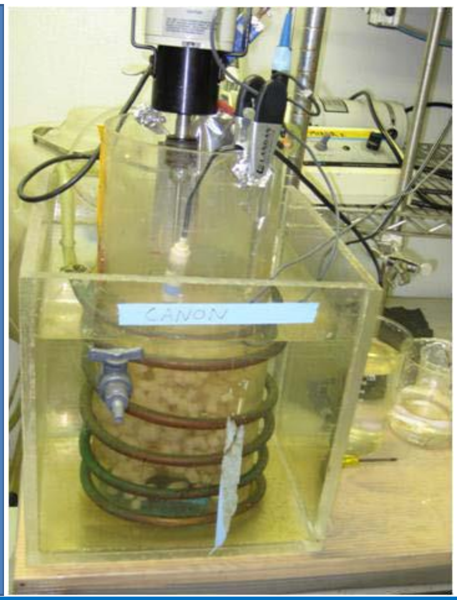
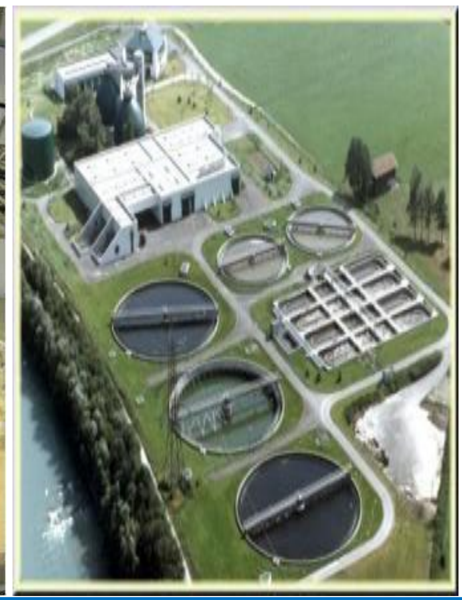
# Real World Wastewater Technologies Workshop:
## *Advancing the World We Live In - Exploring Cutting Edge Wastewater Treatment Technologies*

## Wednesday, May 16, 2012
## Richmond, Virginia

## STAC Workshop Report



| THEORY | PILOTING | OPERATION |
|---|---|---|

**Workshop Sponsored by:**
**The Chesapeake Bay Program's**
**Scientific & Technical Advisory Committee (STAC)**
**And the Wastewater Treatment Work Group**

**Co-sponsored by:**
**DC Water**
**Hampton Roads Sanitation District**
**Metropolitan Washington Council of Governments**
**Water Environment Research Foundation**

**About the Scientific and Technical Advisory Committee**
The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program (CBP) on measures to restore and protect the Chesapeake Bay. Since its creation in December 1984, STAC has worked to enhance scientific communication and outreach throughout the Chesapeake Bay Watershed and beyond. STAC provides scientific and technical advice in various ways, including (1) technical reports and papers, (2) discussion groups, (3) assistance in organizing merit reviews of CBP programs and projects, (4) technical workshops, and (5) interaction between STAC members and the CBP. Through professional and academic contacts and organizational networks of its members, STAC ensures close cooperation among and between the various research institutions and management agencies represented in the Watershed. For additional information about STAC, please visit the STAC website at www.chesapeake.org/stac.

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**Cover photos courtesy of:**
4. Nitrogen process graphic – Charles Bott, Hampton Roads Sanitation District
5. Photo of pilot testing apparatus – Kartik Chandran, Columbia University
6. Photo of wastewater plant – Bernard Wett, ARAConsult, Inc.



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# EXECUTIVE SUMMARY

## Purpose and Scope of Workshop

Given the scope of technologies that could be addressed versus the available time, it was agreed that this workshop should focus on nitrogen removal technologies. To better distinguish this effort from other technical efforts, this workshop focused on technologies that: a) were being implemented at large pilot[1] or full-scale levels[2]; b) could be implemented in the Bay watershed; and c) resulted in innovative or multiple benefits. Because the performance of these cutting-edge technologies varies widely at very low nutrient levels, the workshop also addressed the associated regulatory challenges. Finally, to enable operations staff to attend and get the maximum benefit from this STAC-sponsored workshop, the workshop agenda and speakers were chosen to complement the Virginia Water Environment Association's (VWEA) 2012 Education Seminar the following day focusing on optimization of nutrient removal processes.

## Technical Presentations

Presentations were made covering the technologies and case studies of pilot- and full-scale testing. Included in the presentations was an overview of the suite of technologies currently utilized, from variations of conventional processes to innovative side-stream processes, as well as an overview of the regulatory challenges these facilities must operate under. The presentations also addressed what is known about the multiple environmental benefits and impacts of these technologies.

## Key Findings: Opportunities and Challenges

At the end of the workshop the presentations and discussions were summarized. While many useful technical points were made during each presentation and subsequent discussion, the following major items emerged from the workshop:

**A. The Good News – These Cutting Edge Technologies are Proving to be Effective**
1. Innovating nitrogen removal by using new species (algae, bacteria, etc.) and pathways such as Anammox
2. Nitrite shunt and deammonification, both in side-stream and mainstream applications, are very promising technologies
3. Algae-based technologies also look promising (for certain types of applications)

**B. Additional Benefits – Or More Reasons to Pursue These Technologies**
1. Successful implementation can help address emerging contaminants
2. Successful implementation can have climate change benefits

**C. Pursuing Innovation and Managing Risk – How to Achieve the Right Balance?**
1. Good instrumentation, process control, and skilled operators are critical
2. Need to recognize inherent variability of these processes
3. Need for holistic, systems approach
4. Cannot innovate if no tolerance for risk
5. Critical need for additional funding and collaboration to support development and deployment of new treatment technologies, including research

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[1]Within the context of this workshop, a 15-20 MGD plant was generally considered average size.
[2]Full-scale applications addressed in this workshop included both side-stream <u>and</u> mainstream processes.

## Recommendations - Summary

Based on the various presentations and discussions, the following recommendations emerged to address the opportunities and challenges identified during the workshop. Because of the broad range of issues that need to be addressed, these recommendations are directed to federal agencies, particularly the Environmental Protection Agency; the states/jurisdictions within the Bay Partnership; the boards and managers of wastewater facilities; universities and colleges; as well as the general public, ratepayers, and environmental advocacy groups.

**A. Technologies** – Are promising, but need to:

1. **Identify additional and dedicated/long-term funding for research, development, and demonstration** (i.e., including new technologies, full-scale and pilot testing, multiple environmental benefits, effectiveness at small/medium-sized plants (generally less than 20 million gallon per day (MGD) and unique process applications); and
2. **Make consideration of multiple benefits (e.g., greenhouse gas (GHG) emissions, emerging contaminants) part of design and operating considerations, as well as permit/regulatory considerations.**

**B. Operational Challenges –** Successful application of these advanced technologies is still highly variable, dependent on many factors, and requires advanced tools/skills to be successfully implemented, so there is a need to:

1. **Quantify greater permit/compliance risks, benefits, and costs;** and
2. **Design instrumentation and train support staff to meet new demands.**

**C. Regulations –** The realities of operating these cutting-edge technologies require that state/federal regulators need to:

1. **Write appropriate permit conditions;**
2. **Consider stochastic rather than completely deterministic permit limits, and allow for outliers;** and
3. **Utilize regulatory flexibility to allow for the testing and evaluation of new technologies.**

## Background

This workshop was conceived by the Chesapeake Bay Program's (CBP) Wastewater Treatment Workgroup, and funded by the CBP's Scientific and Technical Advisory Committee (STAC). A key role of STAC is to provide independent scientific and technical advice to aid the CBP partners in their ongoing efforts to restore the Chesapeake Bay, including supporting workshops that advance the technical knowledge and understanding of how additional nutrient and sediment reductions can be achieved in various sectors. The Wastewater Treatment Workgroup also supports the Bay restoration effort as a technical resource and forum for discussions among and between Federal agencies, state agencies/jurisdictions, and local government/utility wastewater treatment plant operators regarding all aspects of nutrient removal technologies. In fulfilling those roles, the Wastewater Treatment Workgroup submitted a proposal and STAC agreed to fund a workshop to specifically address 'cutting edge' wastewater technologies. The objective was to identify new and innovative technologies being successfully implemented and to discover what factors either helped or hindered the successful implementation of those technologies in the Bay watershed.

The steering committee to organize the workshop included members representing wastewater plant operators, consultants, local governments, state regulators, and advocacy groups. Committee members were:

- Charles Bott, Hampton Roads Sanitation District (HRSD) (STAC member)
- Allan Brockenbrough, VA-DEQ (Wastewater Treatment Workgroup member)
- Natalie Gardner, STAC Staff
- Matthew Johnston, STAC Coordinator
- Jeff McInnis, AECOM (Virginia Water Environment Association liaison)
- Sudhir Murthy, District of Columbia Water and Sewer Authority (DC Water)
- Vikram M. Pattarkine, PEACE USA (STAC workshop lead)
- Amit Pramanik, Water Environment Research Foundation (WERF)
- Tanya T. Spano, Metropolitan Washington Council of Governments (MWCOG) (Chair, Wastewater Treatment Workgroup)

Leading experts were invited to make presentations at the workshop and participate in discussion. The specific topics presented were:

- **Microbial Nitrogen Transformations**– Kartik Chandran, Columbia University
- **Nitrogen Removal: 1.0 to 3.0**– Charles Bott, Hampton Roads Sanitation District (HRSD)
- **Overview**– **Review of Deammonification Projects and Key Results**– Sudhir Murthy, DC Water, Bernard Wett, ARAConsult Inc., Austria, and Charles Bott, HRSD
- **A Survey of Global and National Nutrient Regulatory Approaches** – Dave Clark, HDR Engineering, Inc., and Peter Vanrolleghem, Université Laval, Quebec, Canada
- **At the Intersection of Nitrogen Transformations and Pharmaceuticals** – Nancy Love, University of Michigan
- **Balancing Nutrient Limits with Net Environmental Benefits** – J.B. Neethling, HDR Engineering, Inc.
- **Development of Algae-Based Nitrogen Removal Technologies** – Margie Mulholland, Old Dominion University

Because the objective was to make this a learning workshop, adequate time was built into the agenda for facilitated discussions during the day, as well as a very lively and informative summary session with the speakers and the audience at the end of the workshop.

## The Wastewater Challenge

The wastewater sector has successfully implemented advanced nutrient (phosphorus and nitrogen) reduction technologies since the mid-1980swhich have resulted in significant reductions in nutrient loads to, and consequent improvements in, the quality of several water bodies including the Chesapeake Bay. While the nutrient assimilation capacity of these receiving water bodies remains constant, the nutrient loads entering them have continued to increase because of increasing population and related commercial and industrial development. The regulatory agencies have thus had no choice but to make nutrient reduction requirements increasingly stringent. The challenge therefore is to find new and innovative ways to not only sustain but improve these nutrient reduction levels to meet the increasingly stringent permit conditions. At the same time, construction and operating costs have increased and other water quality and environmental demands (e.g., reducing greenhouse gases and addressing emerging contaminants) have been identified. As a result, wastewater facilities will have to be designed and operated cost-effectively, using less energy and chemicals, yet ensure reliable performance while minimizing greenhouse gas (GHG) emissions.

## Purpose and Scope of Workshop

This workshop was aimed at identifying viable nitrogen removal technologies and to begin a dialogue between practitioners, designers, and regulators on how these technologies could be successfully implemented in the Bay watershed. The intended audience for this workshop was the local governments and utilities that operate wastewater treatment plants (WWTPs) in the Bay watershed, as well as the state and federal agencies that regulate those plants.

## Workshop Presentations

Sixty-seven participants from over 40 organizations attended the workshop, with several others participating via webinar. Participants included representatives from local government and utility wastewater operators, state and federal regulators, and experts from academia and engineering consulting firms.

Each of the presentations contained extensive technical information about a wide range of new technologies, pilot studies, and example projects. One must review each presentation to fully appreciate the wealth of information that was presented at the workshop, so the links to each presentation are embedded below, along with a listing of some of the most significant points raised during each presentation. These presentations were directed toward experienced wastewater professionals and most presume those participating had an extensive background in wastewater treatment processes.

## I. **Microbial Nitrogen Transformations** – Kartik Chandran, Columbia University

http://www.chesapeake.org/stac/presentations/211_Chandran_Microbial%20nitrogen%20transformations.pdf

### Summary

Chandran's presentation provided an overview of the current scientific understanding about nitrogen transformations and pathways. He showed how current research is helping to better understand these mechanisms, while also noting that there is much fundamental research still needed to fully understand these biological processes. Chandran also discussed how this research is helping practitioners design more effective/cost-effective processes, as well as help improve nitrogen removal processes.

### Topics Covered

- Transformations - An overview was presented of the novel nitrogen transformation pathways that have been recently elucidated and how nitrogen removal processes are engineered, and cost implications. These included:
  - Discussion of parallel and often competing interactions and pathways that occur in a process reactor
  - Review of how Ammonia Oxidizing Bacteria (AOB) transform nitrogen, and the opportunities to biologically produce methanol
  - Discussion of the role of ammonia oxidation by Archaea
- Biological Communities –A review of various communities (e.g., methylotropic populations), their carbon source preferences during specific process phases, and the preferential use of carbon sources in an engineered denitrification system was provided. These included Methanol, Ethanol, and Glycerol.
- Conventional versus Cutting-Edge Process Comparisons - A review of conventional Biological Nutrient Removal (BNR) versus Anammox bioreactors was made, noting that there have only been two pilot-scale applications of Anammoxin the United States. Details included:
  - Presentation of performance data, noting that these process results do not directly provide information regarding the ecology or abundance of bacterial communities that produce the results; and that abundance data do not directly provide information on actual biological activity
  - Noting that performance actually reflects the community of organisms present, and implications of that concept on how systems are designed
  - A review of Red Hook Water Pollution Control Plant (New York City) pilot testing and how Anammox activity was measured.
    - Noted that Anammox microbial communities in various European sites clearly varied (using genetic expression/typing)
- Process Considerations –Content included a review of the impact of:
  - $CO_2$ limitation on nitrite oxidizing bacteria (NOB) performance and process impacts, recognition that considerable pure culture research remains to be done to appropriately characterize *Nitrospira* spp. versus *Nitrobacter* spp.
  - Anammox reactor conditions on NOB
- Emissions - Delivery included a review of the higher $N_2O$emissions from aerated process zones versus non-aerated zones, respectively noting:

- The impacts of short changes in Dissolved Oxygen on $N_2O$ emissions and
- That AOB can produce but not consume $N_2O$

- Design Input – How this bio kinetic information can be used to help design processes, including:
  - Functional gene expression and bacterial activity and
  - A specific example of correlations to methanol denitrification rates.

## II. Nitrogen Removal: 1.0 to 3.0

1. **General Overview – Nitrogen Removal 1.0 to 3.0** — Charles Bott, HRSD
2. **Review of Deammonification Projects & Key Results:**
   a. District of Columbia (Blue Plains) – Sudhir Murthy, DC Water
   b. Austria/Switzerland (Strass) –Bernhard Wett, ARAConsult Inc.
   c. Virginia (HRSD) –Charles Bott, HRSD

http://www.chesapeake.org/stac/presentations/211_Bott_Nitrogen%20Removal%201.0%20to%203.0.pdf
http://www.chesapeake.org/stac/presentations/211_Wett_Review%20of%20deammonification%20projects%2 and%20key%20results.pdf

### Summary

Bott's presentation provided an overview of the most widely used engineered process for removing nitrogen from wastewater, which currently involves nitrification and denitrification – and outlined more conventional processes, versus newer processes, as well as the most cutting edge technologies (i.e., Nitrogen Removal 1.0 , 2.0 and 3.0).

Nitrification is the sequential biological oxidation of ammonia ($NH_3$) to nitrite ($NO_2^-$) by AOB and $NO_2^-$ to nitrate ($NO_3^-$) by NOB, as follows:

$$2NH_4^+ + 3O_2 \xrightarrow{(AOB)} 2NO_2^- + 4H^+ + 2H_2O$$
$$2NO_2^- + O_2 \xrightarrow{(NOB)} 2NO_3^-$$

As the equations above indicate, nitrification requires oxygen supply to the system. For wastewater treatment plants treating typical domestic waste streams, nitrification oxygen requirement can be as much as that for removing organic matter, thus doubling the power requirements for aeration. Nitrification also consumes alkalinity, as $H^+$ is released in the process. This can result in significant caustic requirements for alkalinity-limited wastewaters.

Denitrification involves the reduction of oxidized nitrogen species such as $NO_3^-$ and $NO_2^-$ to nitrogen gas ($N_2$), catalyzed by denitrifiers, as follows:

$$6NO_3^- + 2CH_3OH \rightarrow 6NO_2^- + 2CO_2 + 4H_2O$$
$$6NO_2^- + 3CH_3OH \rightarrow 3N_2 + 3CO_2 + 3H_2O + 6OH^-$$

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$$6NO_3^- + 5CH_3OH \rightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^-$$

To achieve adequate N-removal via denitrification, often fossil fuel-consuming supplemental organic carbon is needed (typically methanol, as shown above), which also constitutes a significant economic and environmental burden. For instance, the annual methanol costs for DC Water, located in Washington, District of Columbia,approximate$6 million.

Nitrogen removal can thus result in a substantial increase in the total energy and chemical requirements at a wastewater treatment facility. Given the increasingly stringent nutrient discharge standards, there is a critical need to develop and implement more energy- and cost-efficient processes than those currently used.

One of the primary approaches to removing nitrogen energy- and cost-efficiently relies upon short-cut nitrogen removal (ScBNR). This involves *partial* oxidation of $NH_3$ to $NO_2^-$ (termed *nitritation*) by AOB, followed by reduction of the nitrite thus produced to $N_2$ (termed, *denitritation*).

$$2NH_4^+ + 3O_2 \xrightarrow{(Nitritation)} 2NO_2^- + 4H^+ + 2H_2O$$
$$6NO_2^- + 3CH_3OH \xrightarrow{(Denitritation)} 3N_2 + 3CO_2 + 3H_2O + 6OH^-$$

The application of nitritation and denitritation (also known as nitrite shunt) confers additional BNR process flexibility with concomitant energy and cost savings. Complete nitritation followed by heterotrophic denitritation can result in up to 25% savings in aeration power (for nitritation) and 40% savings in external carbon supply (for denitritation). If, on the other hand, denitritation is accomplished by anaerobic ammonia oxidizing bacteria (AMX or Anammox), the savings can be even higher.

$$NH_4^+ + NO_2^- \xrightarrow{(AMX)} N_2 + 2H_2O$$

Since AMX use ammonia instead of external carbon source for denitritation, only a portion of ammonia needs to be oxidized to nitrite (partial nitritation), resulting in a 62.5% savings in aeration based on stoichiometry. The savings in external carbon supply is 100%, because the need for $CH_3OH$ is completely eliminated by AMX.

Deammonification is presently being applied to treat concentrated nitrogen side-streams generated internally during wastewater treatment, including anaerobic digestion filtrate or centrate. Side-stream deammonification, however, is applicable only to BNR plants with anaerobic digestion. Moreover, such side-streams constitute only about 25% of typical influent nitrogen loading to a given BNR plant. Thus, the deammonification process is currently applicable to only a relatively small fraction of the existing WWTPs, and at those plants it can be applied to only one fourth of the nitrogen load entering the plant. Consequently, there is a critical need to develop ways to expand the use of nitritation shunt and deammonification to the ‘mainstream’ wastewater flows, so that these energy and cost efficient processes could be applied to the total wastewater nitrogen load and to all municipal WWTPs whether or not the treatment processes include primary sludge processing. Further, the application of mainstream deammonification for *nitrogen conversion* leaves room for *anaerobic and/or thermal biogenic organic carbon conversion* for energy production rather than for BNR. Any internal carbon used for denitrification can then be diverted for energy production. Therefore, the application of mainstream deammonification has the potential to be a true ‘game-changer’ and a new model for cost-efficient, space-saving, and energy-neutral wastewater treatment.

Prior to the widespread implementation of mainstream deammonification, some key technical challenges need to be addressed. First, the growth of NOBs needs to be suppressed or eliminated. It is difficult to repress or washout (outselect) NOBs in colder (12 – 20$^oC$), low-strength wastewaters (defined in

Tchobanoglous et al. 2003).[3] NOB repression and washout in warmer, higher strength[3] wastewater can be achieved using free ammonia or free nitrous acid inhibition, but these inhibition approaches are not applicable to mainstream treatment using existing methodologies. Therefore, new design and operational strategies need to be developed before mainstream nitritation-denitritation or mainstream deammonification, or some combination thereof, can be effectively implemented. Second, Anammox organisms are very slow growing and the development of methodologies that washout NOBs yet retain Anammox in large quantities must be developed before mainstream deammonification is possible. Alternatively, approaches that effectively utilize bioaugmention of Anammox from a side-stream deammonification process must be developed.

Summarizing, successful implementation of mainstream deammonification requires development of techniques that accomplish the following objectives:

1. Outselection (washout) of NOB growth to enable reduction of aeration energy and organic carbon requirements through short-cut BNR (ScBNR) and deammonification processes.
2. Maximization of energy recovery by redirecting organic carbon away from energy intensive processes (denitrification) to energy producing processes such as methane or methanol production. This would have the added advantage of allowing substantially smaller tank volumes for mainstream treatment of wastewaters (capital cost savings through smaller concrete tanks and related equipment)
3. Optimization of Anammox organism retention such that Anammox solids retention time (SRT) can be independently controlled.
4. Development and optimization of strategies to overcome flocculant biomass settleability limitations currently associated with ScBNR and autotrophic nitrogen removal processes.

DC Water and HRSD have already embarked upon a preliminary piloting program aimed at field-scale optimization of mainstream deammonification and nitrite shunting at the Blue Plains and the HRSD Chesapeake-Elizabeth Treatment Plants, respectively, but much work remains, and there is a need to use what has been learned so far to dramatically expand the scope of this early work. Successful accomplishment of these objectives would result in biological treatment processes that could meet stringent permit limits by autotrophic effluent polishing, while requiring lesser or no supplemental organic carbon.

## Topics Covered

1. **<u>General Overview</u>- Nitrogen Removal 1.0 to 3.0**

- Hampton Roads Sanitation District (HRSD) Overview
  - Key features of HRSD and its facilities [9 large plants, with combined capacity of 249 MGD]
  - Nutrient loads assigned under HRSD’s ‘bubble permit’ (2011)
  - Chesapeake Bay TMDL and Virginia Watershed Implementation Plan
    - List of pound loads, specific load allocations to each facility, and process features
  - HRSD’s Research and Development Program Focus
    - Resource utilization (e.g., energy, chemicals, all forms of labor, concrete, land)
    - Resource recovery (e.g., water, phosphorus, nitrogen, biogas, heat, hydraulic

[3]Reference: Tchobanoglous, G., F.L. Burton, and H.D. Stensel. 2003. Metcalf and Eddy - Wastewater Engineering: Treatment and Reuse, 4th Edition. McGraw Hill.

energy, chemicals, components of biosolids)

- HRSD's Research and Development Efforts in BNR
  - List of projects related to minimization of energy, chemicals (alkalinity and carbon), and aeration tank and clarifier volumes; side-stream deammonification; mainstream nitrite shunt and deammonification; advanced aeration controls; settling improvements; and urine separation.
  - Motivation for conducting pilot work (e.g., potential capital and Operations and Management cost savings, and limited land availability)
    - Chesapeake-Elizabeth treatment plant – review of process schematic, current BNR process plans, and partners involved in four-year pilot study

- **Key Concepts: Overview of Nitrification/Denitrification Processes – 1.0, 2.0, and 3.0**(definitions on p. 7)
  - **1.0 = conventional nitrification + denitrification**
  - **2.0 = nitrite shunt = nitritation + denitritation; requires NOB repression or outselection (washout)**
  - **3.0 = deammonification = partial nitritation + Anammox; requires NOB repression or outselection and Anammox retention**
  - **Review of conventional, mainstream, and emerging technologies**
    - Side-stream Treatment of Anaerobically Digested Sludge Dewatering Liquor – 1.0, 2.0, 3.0 (all established)
    - **<u>Mainstream</u> Treatment:**[4]
      - **1.0 (established)**
      - **2.0 (established with caveats)**
        - Relationship to SND(Simultaneous Nitrification/Denitrification)Process
        - A/B Process
          - Stage A –high rate activated sludge for 60-70% COD removal (40-50% soluble COD removal)
          - Stage B – Modified Ludzack-Ettinger (MLE) in SND mode (N removal 2.0)
        - HRSD Pilot A/B Process
        - $NH_4$-based Aeration Control
        - NOB Repression or Outselection
      - **3.0 (emerging)**
        - Alternative configurations
        - Carbon Flow
        - HRSD Pilot 3.0 - separate stage without bioaugmentation
    - Several other emerging ideas (3.1)

- **Review of Technologies – <u>Side-stream</u> Treatment (1.0, 2.0, and 3.0)**
  - Graphics presented the various treatment process features, kinetics, speciation involved, associated operating conditions
    - Introduced the concept of 'new' vocabulary needed to address these new process understandings:
      - Nitr*<u>a</u>*tation= oxidation of nitrite to nitrate by NOB

[4]At this time there are no full-scale mainstream 2.0 or 3.0 processes on-line, although there is pilot plant/research work being conducted by HRSD, DC Water, WERF, and others to evaluate these processes.

        - Nitr*i*tation= oxidation of ammonia to nitrite by AOB
        - Denitr*a*tation= reduction of nitrate to nitrite by heterotrophs
  - Denitr*i*tation= reduction of nitrite to nitrogen gas by heterotrophs. Key Fe*a*tures and Examples – Provided an overview/examples of each category of treatment technologies, including:
    - Process mechanisms utilized
    - Major process configurations and parameters
    - Process effectiveness and limitations
  - Comparison of Side-stream Processes Options - Provided comparisons of how range of various processes address biological nitrogen removal versus physical-chemical nitrogen and phosphorus removal/recovery
  - Review of Anammox and Related Process Options – Provided overview of key features for a wide range of actual operating systems across Europe and those under construction elsewhere
  - Benefits/Risks:
    - Side-stream Deammonification
      - No chemicals needed, less energy and well demonstrated in Europe – but slow start-up in US, requires robust process control, and need a successful American example

        **List of Projects:**[5]
        - Pilot projects in US that are underway or pending
        - Projects in design and in construction
        - HRSD York River Plant – full-scale side-stream deammonification (DEMON®) process started October 2012
- **Review of Technologies – Mainstream Treatment 1.0 (established)**
  - Graphics presented the various treatment process features, kinetics, speciation involved, associated operating conditions
- **Review of Technologies – Mainstream Treatment 2.0 (established with caveats)**
  - Simultaneous Nitrification/Denitrification (SND)
    - Discussion regarding application of SND in mainstream BNR processes and difficulty in assessing/applying in larger plants (due to several process/design constraints), information needs, and efforts to optimize
    - Overview of questions/mechanisms that need to be explored and references made to several of next day's VWEA seminar presentations that would address optimization issues
    - Detailed technical overview of pilot testing- concepts, schematics, process parameters, flow rates, removal rates, ammonia-based DO control performance, NOB repression and potential influences (e.g., Chemical Oxygen Demand (COD) and Mixed Liquor Suspended Solids (MLSS)), nitrogen processing rates, and other process features
- **Review of Technologies – Mainstream Treatment 2.0 and 3.0 (emerging)**
  - Objectives for 2.0 and 3.0 Technologies:
    - Redirect Carbon/COD to Anaerobic Digestion/Treatment

[5]There are approximately 70 full-scale side-stream processes worldwide (both 3.0 and 2.0 types), with the HRSD York River Plant (15 MGD) the only one now operating full-scale in North America (as of October 2012), although others are planned/under construction.

            - A stage high rate activated sludge (HRAS), which is designated as part of the well-known A/B two-sludge process (A/B).
                - Reinventing HRAS
                - Controlling COD removal
            - Chemically enhanced primary treatment (CEPT)
            - Anaerobic treatment (upflow anaerobic sludge blanket or anaerobic membrane bioreactor)
            - Primary clarifier
        - Repress or outselect NOBs under challenging conditions
            - Low temperature
            - Low $NH_4$
        - Retain Anammox [high solids retention time (SRT) for Anammox]
    - Overview of the challenges, objectives, risks, and potentials of mainstream deammonification
        - Review of several possible process approaches to research (citing Strass WWTP demonstration as example, plus others), noting key operational parameters (e.g., process schematics, assessment of control schemes, nitrogen speciation, effects of influent soluble carbonaceous oxygen demand,  processing rates, potential use of Nitritation, dissolved oxygen control, and ideal process configuration)
            - A.  Bioaugment Anammox and AOB from side-stream deammonification process; one step suspended growth process with transient anoxia and selective Anammox retention
            - B.  One-step process without bioaugmentation
            - C.  Two-step process without bioaugmentation
    - Research Ideas for 3.1 Technologies:
        - Nitrite + Methane –MethanotrophicDenitritation
        - Sulfide-driven Autotrophic Denitritation/Denitratation
        - Nitritation
        - Is Anammox required?

**2. <u>Review of Deammonification Projects and Key Results</u>**

- Emerging Technologies and Innovation - Overview of transition from conventional to emerging technologies, and the resulting increase in the levels of innovation
- DEMON® Side-stream Process – Review of key features and full-scale applications in Europe
    - Incentive – Resource savings
    - Performance test results and energy savings
    - Potential applications for process (several examples provided):
        - Reject water
        - Leachate from landfills
        - Biogas plants
        - Petrochemical industry
        - Pharmaceutical
        - Aquaculture, fish farming
        - Waste air treatment
        - Domestic sewage treatment
- **WERF Mainstream Deammonification Project**

- Project description – demonstration projects at Strass WWTP and Glarnerland WWTP, and to validate/advance Blue Plains bench-scale work
- Status of project work, areas of focus, and objectives
    - Mainstream deammonification
    - Basic process mechanisms
    - Main process components
- Strass Pilot – Detailed review of process details
    - Configurations
    - Parameter data
    - Process features
    - System responses under full-scale piloting, peak loads, and various flow/temperature/loadings regimes
    - Impact of bioaugmentation on performance
    - GHG emission responses to varying process modifications
    - Schematic showing modeled configuration of original versus new process scheme
    - Key finding - Successful process operation and NOB repression depend on two parameters:
        - Competition between AOB and NOB for oxygen expressed by $K_o$, the half saturation coefficient describing oxygen affinity
        - Competition between Anammox and NOB for nitrite expressed by $K_s$, the half saturation coefficient describing substrate affinity
    - Schematic showing mass-balance for various parameters
- Overlap in findings bench-scale vs. full-scale operation mode and aeration regime
    - Bench-scale reactor A (intermittent aeration) was more successful in NOB-repression and Anammox enrichment compared to the continuously aerated control
    - During full-scale testing, the intermittent aeration pattern (either along the flow-path or the time axis) creating transient anoxic conditions was found more effective for repressing NOBs
    - NOB seem to be able to adapt to low DO conditions, therefore, low DO operation is not successful
- Recipe for mainstream NOB outselection is emerging

## III. A Survey of Global and National Nutrient Regulatory Approaches - Dave Clark, HDR, Engineering, Inc., Peter Vanrolleghem, Université Laval

http://www.chesapeake.org/stac/presentations/211_Clark_Survey%20of%20global%20and%20national%20nutrient%20regulatory%20approaches.pdf

### Summary

Clark provided an overview of regulatory approaches around the world indicates how vast the scope of the issues is, as well as the complexities involved in addressing them. Clark noted that many technical and water quality challenges need to be considered when determining appropriate, reasonable, and protective requirements. Clark also summarized many of the regulatory mechanisms that the states and

EPA use as they work to balance risk factors; noting that it is important to do proper assessments in determining what level of protection is needed, as well as in determining compliance, especially since cost implications can be significant. These efforts are still evolving as nutrient standards are being implemented across the country.

**Topics Covered**

- The presentation covered four main topics: Nutrient Water Quality Issues, US Nutrient Regulations, International Nutrient Regulations, and US Regulatory Solutions
- **Nutrient Water Quality Issues**
    - Summary of the 415 world-wide hypoxic and eutrophic coastal areas, of which only 13 systems are deemed to be in recovery
    - Overview of the scope of nutrient-related impairments in the United States
        - 14,000 nutrient-related impairment listings in 49 states
        - 47% of streams – medium to high phosphorus levels
        - 53% of streams – medium to high nitrogen levels
        - 78% of assessed coastal waters exhibit eutrophication
        - Efforts are underway to address, but collectively inadequate at state/national level
- **US Nutrient Regulations**
    - EPA’s national strategy for the development of Regional Nutrient Criteria (June 1998)
        - EPA and State Roles
        - Key elements of the strategy
        - Highlights of various EPA memoranda (2007 and 2011)
            - Focused on establishment of numeric standards/criteria
    - Overview of state development and adoption of numeric criteria for nitrogen and phosphorus
        - Technical challenges in establishing criteria, including:
            - Identifying threshold of harm to beneficial uses
            - Translation of in-stream criteria to effluent discharge permit limits
    - Challenges in meeting low effluent nutrient discharge permit limits
        - In-stream nutrient criteria are low concentrations
        - Traditional permitting approaches are complex, often developed based on different pollutant basis (i.e., toxics), and are very conservative
    - Interpreting/translating National Pollutant Discharge Elimination System(NPDES) permitting regulations (i.e., from in-stream standards to discharge requirements)
        - Challenging/complex process with many conditions/situations to assess
        - Those interpretations have a significant impact on the design and operation of facilities and the resulting costs for building and operating them
    - Review of Nutrient Discharge Permit Limits to meet Chesapeake Bay TMDL – comparison of current limitations versus those defined in EPA’s Final Phase I Watershed Implementation Plans (WIPSs)
    - Review of how water quality-based effluent limits are calculated from criteria
- **International Nutrient Regulations**
    - Canada – overview of regulations, strategies, and proposed effluent standards

- European Union – overview of basic requirements for Urban Waste Water Directive, as well as for directives for Sensitive Areas, responsibilities, and estimated costs to implement the directive (€35 Billion)
  - Poland
  - Italy
  - France (warned of non-compliance via the EU Urban Waste Water Directive, resulting action 2007)
- Japan – overview of effluent limitations and policies
- China – overview of effluent limitations and water body designations

- **US Regulatory Solutions**
  - State Remedies – mix of solutions: Issuance of a) interim treatment technology standards, b) water quality variances, c) affordability tests, and d) response criteria
    - Specific details for four case studies were presented:
      - Wisconsin
      - Colorado
      - Montana and
      - Maine
  - Highlights of National Resources Defense Council (NRDC) petition (2007) on Secondary Treatment Standards (i.e., that EPA must assess whether nutrient removal constitutes 'secondary treatment' standard)
    - EPA had not responded to the NRDC Petition (as of March 2012)

## IV. At the Intersection of Nitrogen Transformations and Pharmaceuticals–Nancy Love, University of Michigan

http://www.chesapeake.org/stac/presentations/211_Love_At%20the%20intersection%20of%20nitrogen%20transformation%20and%20pharmaceuticals.pdf

### Summary

Love's presentation showed that the prevalence and potential implications of pharmaceuticals in the environment and their impact on water quality have increased over the past 30-40 years. Love noted that these issues can be complex because: a) there are many chemicals to consider; b) there is still much that is not understood regarding impacts, to biological systems and human health; c) detection limits are so low that they create uncertainty about the presence and impact of these chemicals; and d) there is a need to assess the impacts of not only particular chemicals but also the biotransformations/by-products of those chemicals as well as mixtures of many chemicals. The good news is that many advanced nutrient removal processes can also treat these pharmaceuticals. Love summarized that much of the research in this area is still evolving, and much is still unknown about the ultimate fate or impact of these chemicals; Love noted that the role of source separation to minimize the presence of these chemicals in incoming sewage may still need to be pursued in addition to advances in these promising treatment technologies.

### Topics Covered

- Global Chemical Production – snapshot over time and projected into the future
  - Recognition that chemical pollution is a 'planetary boundary' that is currently not quantified (i.e., that the scope and extent of this pollution is planet-wide and present in multiple

environmental media)

- Presence of Pharmaceuticals in Environment - Highlights of technical papers and reports over time that have raised awareness of pharmaceuticals and their presence and affects in the environment:
  - German paper/articles (1977/1998) – noting presence in sewage (waste) water and effects on trout, as well as occurrence of drugs at plants and in rivers
  - Environmental Health Perspectives (1995) – article assessing toxicity
  - USGS report (2002) – A National Reconnaissance (i.e., a contaminants survey)
  - Graph showing significant increase in publications/citations over time (1970 to 2010)
  - PNAS paper (2007) – assessing 'Collapse of Fish Population After Exposure to a Synthetic Estrogen'
  - Int. J. Environ. Res. Public Health paper (2010) – human health risk assessment
- Graphic showing wide range of concentrations for a wide range of pollutants based on various studies
  - Noting that with the wide range of treatment efficiencies in the studies that not much is understood about the treatment conditions that actually influence biotransformation
- Impact of Cutting Edge Technologies on Pharmaceuticals in Wastewater - Highlights of various studies/reports that have shown that nitrification/nitrogen removal processes with longer SRTs have higher removal efficiencies for some pharmaceuticals
- Biochemical Mechanisms - Review of the biochemical mechanisms that are hypothesized to biotransform pharmaceuticals in wastewater treatment processes
  - Focusing on the aromatic rings that are common in many pharmaceuticals
  - Noting the relative roles of various bacteria in these biotransformations, and where they occur in the process
- Transformation of Estrogens - Comparison of conditions under which estrogens are biotransformed
  - Discussing denitrification, nitrification, and Anammox process mechanisms
  - Under ammonia-limited conditions and ammonia-sufficient conditions, and the resulting competition between estrogen and ammonia in these processes
  - Consideration of microaerobic environments, process mechanisms, and effects on biotransformation rates (e.g., oxygenase activity, redox environments, impacts of dissolved oxygen levels)
- Highlights of Select Studies:
  - DEMON® process (microaerobic nitritation plus Anammox) that showed very good estrogenicity removal
  - Survey of hormone and pharmaceutical removals during various treatment processes
  - Effects of ultraviolet (UV) irradiation on oxidation of trace organic chemicals
- Treatment Plant of the Future - Graphic describing the possible features of the 'Treatment Plant of the Future'
  - Source separation as a sustainable waste management solution (e.g., gray water, black water, yellow water)

## V. **Balancing Nutrient Limits with Net Environmental Benefits** - J.B.Neethling, HDR

http://www.chesapeake.org/stac/presentations/211_Neethling%202012%20Balancing%20Nutrient%20Limits%20with%20Net%20Environmental%20Benefits%20STAC%20Richmond%20VA%2020120516.pdf

## Summary

Neethling presented a thorough overview of a WERF-sponsored study that evaluated the effectiveness and reliability of nitrogen and phosphorus removals at several wastewater treatment plants. The study analyzed not only average and median performance values but also 'best' versus 'reliable' performance results, as well as examining permit violations and the resulting standard deviations in the performance data (both for the primary nutrients and species). The study included a close examination of the frequency of violations occurring (e.g., daily, weekly, monthly, annually) as a way to evaluate an 'acceptable' level of risk for determining permit limits and compliance requirements. The additional facilities, chemicals, and monitoring necessary for improving reliability require substantial additional costs. The study used the triple-bottom-line (environmental, economic, and social) analysis to assess nutrient removal versus sustainability and GHG emissions. Neethling concluded with a comparison of the potential range of capital and operating costs for a hypothetical 10 MGD plant based on various nutrient effluent conditions.

As with an earlier presentation, the averaging period used clearly has important implications for how risk is assigned, in terms of making design decisions, assessing operational reliability, and determining the potential for permit violations. All of these factors need to be evaluated closely because all factor into the ultimate capital and operating costs for a facility. The need for regulatory flexibility is critical for the management of risk and to achieve the necessary balance between all of these factors.

## Topics Covered

- Provided an overview of key questions about cutting edge technologies and their effectiveness based on results of WERF study.
  1. How reliably do good operating plants perform?
  2. What are the costs/features/break points of nutrient removal?
  3. What are the benefits/impacts of nutrient removal limits?
- How well do 'good' operating plants perform?
  - Graphic of datasets showing variability of low/high/average performance values
  - Graphics comparing ideal/median/reliable performance on a statistical basis
    - Statistical correlation of performance to concepts of ideal/median/reliable performance
    - Assessment of variations with 14-day rolling averages
  - List of nitrogen process types evaluated
    - Graphic of results of total nitrogen removal performance variability by process
  - List of phosphorus process types evaluated
    - Graphic of results of total nitrogen removal performance variability by process
  - Summary
    - Technology performance statistics allow for rational approach to data analysis and technology assessment
    - Data from well operated nutrient removal plants demonstrated the variability in performance (e.g., for nitrogen versus phosphorus removal)
  - Tables showing permit periods and resulting process reliability
    - Question – Whether a once a year exceedance is deemed to be an acceptable risk?
  - Tables summarizing reliability at the permit limit for total phosphorus and total nitrogen
  - What factors are controlling nutrient removal technologies?

        - e.g., nutrient species, potential to remove, and removal efficiencies of individual species
        - Graphics showing removal efficiencies/percentiles for nitrogen and phosphorus species
    - Question – Can you ‘beat’ the statistics (ensure your outliers do not cause permit violations)?
        - Yes, but at a higher cost (i.e., list of cost elements), but there are limitations.
- Environmental Impacts and Benefits
    - Matrix of pollutant performance objectives for various levels of treatment
    - Matrix of treatment unit processes that characterize those treatment levels
    - Assessment made of tradeoffs between nutrient removal and sustainability
        - Assessed five treatment levels for a 10 MGD plant
        - Determined point of diminishing returns with increased treatment
        - Assessed triple-bottom-line impacts:
            - Economic
            - Environmental
            - Social
        - Graphics of:
            - System inputs
            - GHG emissions
            - Incremental GHG removal as a function of nitrogen or phosphorus removal
            - Comparison of algal versus GHG production
        - Table comparing project costs (i.e., total, operating, total present worth) versus various treatment levels
- Conclusions – Part I
    - Even well operating plants shows significant variation in performance
    - The average performance is about 2 times the ideal
    - The reliability of meeting a permit requirement depends on:
        - Averaging period
        - Factor of safety to meet permit (Owner risk tolerance)
    - Restrictive limits (lower and/or short periods) increase the need for redundant units, multiple barriers to meet permits reliably
- Conclusions– Part II
    - Efficient solids separation becomes critical for phosphorus removal
    - Chemical addition provides a tool to improve reliability
    - Chemical usage increases for restrictive limits
    - Ionic species removal drastically increases treatment costs and impacts
    - The benefit per mass N or P diminishes exponentially as the permits become more restrictive

## VI. **Development of Algae-Based Nitrogen Removal Technologies** — Margie Mulholland, ODU

http://www.chesapeake.org/stac/presentations/211_Filippino%20and%20Mulholland_Development%20of%20algae-based%20nitrogen%20removal%20technologies.pdf

## Summary

Mulholland presented the results of some new and very promising studies about algae-based technologies. Much of this work is still evolving. Most technologies have been developed for smaller facilities outside the United States, and are generally focused on dissolved inorganic phosphorus and ammonium treatment. Substantial research is currently focused on evaluating the potential for algae-based technologies for specific applications where conventional treatment options are limited or too costly. Mulholland provided an overview of the various control and operational elements used in algae-based technologies, which are different from those used in conventional treatment technologies (e.g., wave-lengths, choices in light-emitting diode types, algal species, and large surface area requirements). She concluded her presentation by noting that while promising, additional research is still needed to optimize treatment performance and making the technology more cost-effective.

## Topics Covered

- Phycoremediation (algae-based nitrogen removal) – pros and cons, state of technology, potential solutions
    - Current technologies for low total nitrogen removal commonly involve use of bacteria
    - Algae-based nitrogen removal – potential applications as replacements for BNR or post-BNR polishing; many applications and designs being utilized
    - Pros:
        - Rapid nitrogen removal
        - No need for supplemental carbon
        - Ability to simultaneously remove phosphorus
        - No gaseous nitrogen products
        - Inexpensive/simple/environmentally-friendly
    - Cons:
        - Requires light
        - Algae needs to be separated from treated wastewater stream
        - Requires continuous flow – chemostat reactors (e.g., short hydraulic retention times/high flow rates, washout concerns)
        - Requires space (i.e., large surface areas/light, large footprint versus conventional reactors)
    - Current state of design technology and applications
        - Most technologies developed outside of U.S.
        - None designed for large wastewater plant applications
        - Primarily focused on dissolved inorganic phosphorus and ammonium
    - Potential solutions
        - Immobilize algae to allow separation (e.g., though use of polymers, biofilms)
        - Increase light penetration (e.g., through use of submerged light sources, fiber optics, solar/light collectors, wavelength-specific light sources)
- Approach and experimental design
    - Key elements: algal separation, algal immobilization, nutrient removal, light penetration, and optimization
    - Detailed list of experimental design features and constants

- Results
  - Free algae like to grow in wastewater
    - Specifically - use of natural polymers is effective in helping to encapsulate algae while allowing diffusion of nutrients to the algae
  - Table of resulting nutrient reduction performance – for nitrogen and phosphorus
  - Graphics and tables showing performance of large-scale encapsulated algae application under varying conditions (e.g., light, pH, flow)
- Conclusions
  - Phycoremediation strategies are successful at hydraulic retention (HRTs) times of 6.5 and 12 hours
  - In bead-support systems for algae, 10% bead to effluent ratio is efficient for nitrate removal – potential to reduce more?
  - Coated biofilm carriers proved promising
  - Effluent ‘type’ (nutrient species, concentrations, source) will affect results
  - Significant $NO_x$-N removal was obtained, with levels reaching steady-state within 24 hours
  - Wavelength-specific submersible light-emitting diodes (LEDs)increase growth rates
  - Maintaining pH increases nitrogen and phosphorus removal efficiencies
  - Reality Check – Costs
    - Lights and alginate are greatest expense
    - Need to scale down amount/use/cost of LEDs
    - Need to find cheaper source for alginate for large-scale use
    - Must consider other chemical cost versus recycling and other performance costs
- Future Work
  - Decrease HRTs
  - Scale up[6]
  - Perform experiments in a series
  - Identify robust algal communities for plant settings
  - Determine optimal nitrogen: phosphorus ratios and possibilities for adjusting ratios in effluent discharge
  - More work on biofilm carriers (e.g., similar to moving bed biofilm reactor (MBBR) processes)
  - Evaluate potential for algal and polymer recycle streams

## Key Findings: Opportunities & Challenges

At the end of the workshop the day’s presentations and discussions were summarized. While many useful technical points were made during each presentation and subsequent discussion, the following major points emerged:

### A. The Good News – These Cutting-Edge Technologies are proving to be Effective

1. **Innovating by Using New Species and Pathways** - These successful technologies are often the result of new species (e.g., Archaea) and new pathways/processes (e.g., Anammox) that are just beginning to be investigated. Many of the technologies are promising and very effective, though the process mechanisms as well as the chemical and biological pathways need to be

[6] To-date, algal removal processes have been used in pond/lagoon systems and pilots of higher-rate engineered algae systems, but nothing full-scale has been implemented in North America, with the exception of a few Algae Turf Scrubbers.

better understood.

2. **Deammonification is a very Promising Technology** – Mainstream deammonification and nitrite shunting have the potential for a quick return, and the associated reductions in energy and supplemental carbon are strong drivers. In addition, side-stream deammonification is now a well-established process and can be more readily applied at existing wastewater plants.
3. **Algae-based Technologies Also Look Promising -** The application of algae technologies is not as advanced or widespread as other technologies, but they are showing some promising results and may well be applicable for some types of facilities.

**B. Additional Benefits – Or More Reasons to Pursue These Technologies**

1. **Successful Implementation Can Help Address Emerging Contaminants -** There is potential for ancillary benefits such as removal/reduction of trace organics and pharmaceuticals with these technologies. It will be important to closely monitor both the inputs and outputs of these compounds in order to advance our understanding of the mechanisms and their effectiveness.
2. **Successful Implementation Can Have Climate Change Benefits -** GHG emissions from wastewater plants can be substantially reduced if technologies such as deammonification and algal treatment are successfully implemented.

**C. Pursuing Innovation and Managing Risk – How to Achieve the Right Balance**

1. **Good Instrumentation, Process Control, and Skilled Operators are Critical -** It is essential that we have good dissolved oxygen/SRT control. The technologies exist, and there are many good examples in the United States as well as in Europe. Instrumentation and process control technologies are critical to achieve extremely low effluent nutrient levels. In addition, reliance on advanced instrumentation also requires operators with higher skills and increased training needs. It is recognized that more sophisticated instrumentation and controls will be needed for second and third generation nitrogen removal processes.
2. **Need to Recognize Inherent Variability of Processes -** The ability to meet stringent and low nutrient limits is challenging, as these cutting-edge technologies are operating in the range where there is no longer a significant margin of safety, and there is inherently greater risk of permit violations. Hence, permit conditions for these wastewater plants should provide some flexibility, manage the overall nutrient benefits, and recognize occasional permit violations. This is especially true for mainstream systems that are subject to greater flow variability[7];side-stream systems are not as susceptible to that variability.
3. **Need for Holistic, Systems Approach -** To be successful, a holistic or systems approach is needed on how these technologies are implemented, i.e., managed for overall results and also taking into consideration energy and environmental footprint.
4. **Cannot Innovate if No Tolerance for Risk -** Given the proper resources, many wastewater plants can implement these new innovative technologies to achieve very low effluent nutrient levels, but at much higher costs than in the past, and with much greater risk. That higher risk can be somewhat mitigated, but likely at a much higher cost. The net benefit of implementing these controls must therefore be weighed against the higher energy and operating costs. It is also clear that the maximum effectiveness of these technologies cannot be determined if no risk is tolerated when operating these processes.
5. **Critical Need for Additional Funding and Collaboration to Support Cutting-Edge Research and Process Development -** Conducting the necessary research and pilot-testing is not cost-effective if each facility has to act individually. Small to moderate-sized facilities are

[7]The impact of wet weather flows and flow variability on mainstream processes is the subject of on-going research.

unable to fund or staff such cutting-edge research. EPA and the states must therefore partner with plants and other organizations to find ways to fund and conduct applied research to advance the state of science for these new/cutting-edge technologies.[8]

## Recommendations

Based on the presentations and subsequent discussions, the following recommendations were developed to address the opportunities and challenges noted during the workshop. Because of the broad range of issues that need to be addressed, these recommendations are directed toward federal agencies, particularly the EPA; the states/jurisdictions within the Bay Partnership; the boards and managers of wastewater facilities; universities and colleges; as well as the general public, ratepayers, and environmental advocacy groups.

**A. Technologies are promising, but there is a need to**:

1. **Identify additional and dedicated/long-term funding for research**
    a. Evaluate the fundamentals of these new technologies to:
        i. Achieve greater standardization of testing protocols and therefore results;
        ii. Establish a baseline for treatment process efficiencies to aid design of wastewater plant upgrades/process enhancements; and
        iii. Define the process features of a 21st Centurywastewater treatment plant.
    b. Conduct pilot testing as well as full-scale testing at wastewater plants to assess actual operating conditions and effectiveness of these technologies;
    c. Evaluate not only total nitrogen reduction capabilities, but also the effectiveness of such processes for the reduction of emerging contaminants, and their ability to reduce GHG emissions. This requires integrating wastewater treatment with energy planning as well as addressing other water quality objectives;
    d. Evaluate these technologies at smaller and medium-sized plants that cannot support independent research on their own; and
    e. Evaluate the application of these technologies at wastewater plants that have unique needs/process constraints (e.g., industrial wastes, high incoming nutrient loads, etc.).
2. **Make multiple benefits (e.g., GHG emission reductions, removal of emerging contaminants) part of design and operating considerations, as well as permit/regulatory considerations.**

**B. Operational Challenges – Successful application of these advanced technologies is still highly variable, dependent on many factors, and requires advanced tools/skills to be successfully implemented, so there is a need to:**

1. **Quantify Greater Permit/Compliance Risks, Benefits, and Costs** - Recognizing these technologies are operating at their extreme limits, conventional performance safety factors are difficult to apply. Therefore, risks and benefits must be assessed against greater capital and operating costs when designing facilities.
2. **Design Instrumentation and Train Support Staff to Meet New Demands**
    a. Acknowledge that advanced levels of instrumentation and control are critical to successful operation of these technologies and must be part of any capital improvement project as well as operating and maintenance decisions and budgeting.

[8] For instance, at this time only the Strass plant in Austria is attempting to implement mainstream 3.0 processes and is part of on-going research with other partners to evaluate the potential at plants in North America.

b. Acknowledge that successful implementation of these technologies requires high level/skilled operators, instrument technicians, and other process control and engineering staff. These must be factored into any organizational planning and staffing assessments. These skill sets also need to be part of programs to train existing as well as future workers, whether through technical training or professional degrees.

**C. Regulations – The realities of operating these cutting edge technologies require that state/federal regulators need to:**

1. **Write Appropriate Permit Conditions** - Acknowledge inherent performance variability when writing permit conditions;
2. **Allow for Outliers** - Find ways to incorporate the occurrence of outliers in setting permit requirements; and
3. **Utilize Regulatory Flexibility**– Fully utilize existing regulatory flexibility in interpreting and implementing regulations so that innovation can continue to be supported.

## Participants

Participants represented over 40 different wastewater agencies, jurisdictions, consulting firms, organizations, and governmental agencies. They included operators, consultants, academics, local government representatives, state regulators, and wastewater advocacy groups (see list below).

| Last Name | First Name | Organization Name |
|---|---|---|
| **Amad** | **Sam** | Washington Suburban Sanitary Commission |
| **Bennett** | **Steve** | Prince William Co. Service Authority |
| **Bott** | **Charles** | HRSD |
| **Bowden** | **Greg** | AECOM |
| **Brockenbrough** | **Allan** | VADEQ |
| **Broderick** | **Tom** | Loudoun Water |
| **Bunce** | **Ryder** | ODU |
| **Bustamante** | **Heri** | DC Water |
| **Chandran** | **Kartik** | Columbia University |
| **Clark** | **David** | HDR |
| **Copithorn** | **Rhodes** | Stearns & Wheeler |
| **Cronin** | **Edward** | Greeley-Hansen |
| **Dair** | **Daniel** | World Water Works |
| **Degen** | **Marcia** | VDH |
| **Fancher** | **Adrienne** | Alexandria Sanitation Authority |
| **Fang** | **Yuan** | Greeley-Hansen |
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| Last Name | First Name | Organization Name |
|---|---|---|
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| **Miller** | **Mark** | Virginia Tech |
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| **Nifong** | **Andrea** | ODU |
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| **Owens** | **Steve** | Archaea Solutions |
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| **Phillips** | **Gary** | VA DEQ |
| **Pramanik** | **Amit** | WERF |
| **Randall** | **Cliff** | Virginia Tech |
| **Reardon** | **Rod** | Carollo Engineers, Inc. |
| **Regmi** | **Pusker** | ODU |
| **Rezai** | **Simin** | MDE |
| **Rieger** | **Leiv** | Enviroism |
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