REDUCING NUTRIENTS IN THE SAN FRANCISCO BAY THROUGH ADDITIONAL WASTEWATER TREATMENT PLANT SIDESTREAM TREATMENT

Prepared By: East Bay Municipal Utility District (EBMUD) and Project Partners

Prepared For:

U.S. Environmental Protection Agency Region 9

Funding Opportunity No. EPA-R9-WTR3-13-001

Grant No. 99T07401

April 28, 2017

Primary and Contributing Authors

Yun Shang, Ph.D., P.E.
Phoebe Grow, P.E.
Martin Musabyimana, Ph.D.
East Bay Municipal Utility District

Mike Falk, Ph.D., P.E.
JB Neethling, Ph.D., P.E.
Mario Benisch, P.E.
Glen Lischeske
HDR, Inc.

Rusty Holleman, Ph.D.
San Francisco Estuary Institute

David Graham, P.E.
Doménéc Jolis, Ph.D., P.E.
San Francisco Public Utilities Commission

Jimmy Dang, P.E.
Oro Loma Sanitary District

Amanda Roa
Delta Diablo

Robert Collison, Ph.D.
Collison Engineering

Alex Johnson
Erik Ringelberg
Chris Thomas
The Freshwater Trust

Project Team Contact

Yun Shang, Ph.D., P.E.
Principal Investigator
375 11th Street, MS 702
Oakland, CA 94607
Email: *yshang@ebmud.com*

EPA Project Managers

Terrence Fleming
Email: fleming.terrence@epa.gov

Luisa Valiela
Email: valiela.luisa@epa.gov
EPA Region 9 (WTR-3)
75 Hawthorne Street
San Francisco, CA 94105

Table of Contents

List of Figures

List of Tables

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to the U.S. EPA Region 9 for providing grant funding, and in particular to Terrence Fleming and Luisa Valiela for overseeing the study, Joe Eidelberg for reviewing the Quality Assurance Project Plan.

The authors would like to extend a special thanks to all the project partners for providing significant in-kind contributions, and staff support for operating the pilot units, including Nick Steiner, Gary Van Pelt, Abel Palacio, and the operations staff from Delta Diablo, with technical support provided by Craig Criddle, Zhiyue Wang, Sunggeun Woo, and Yaniv Scherson from Stanford University; the Board of Directors, Jason Warner, and other staff at the Oro Loma Sanitary District; Doménéc Jolis, Manisha Berde, and Southeast Plant Operations, Maintenance, and Lab staff at the San Francisco Public Utilities Commission; Mike Connor from East Bay Dischargers Authority; James Ervin from San Jose/Santa Clara Regional Wastewater Facility; Timothy Grillo and Connie Li from Union Sanitary District; Dan Frost and Jean-Marc Petit from Central Contra Costa Sanitary District; and David Senn from San Francisco Estuary Institute.

The authors also acknowledge the efforts of staff from the East Bay Municipal Utility District, including Chris Dembiczak for being the quality assurance manager for this project, Martin Musabyimana for conducting pilot testing, Donald Gray, Mark Chien, Erika Gardner, and other operations and maintenance staff of John Corriea, Kevin Dickison, Leon Duan, Jose Duarte, Grant Gilley, Mike Gomez, Huyen Hoang, Keith Louis, Gerald Ogden, Todd Trinta, and Linda Winters for project support. The laboratory staff of Sue Berg, Nirmela Arsem, and Antoine Chamsi for coordinating sample analyses and review of the Quality Assurance Project Plan. Lisa Servande and Sofia Kolidas for providing clerical support, and Bennett Horenstein and Vincent De Lange for providing critical insight into the project approach.

Further, the authors extend their special thanks to David Williams, Sherry Hull, and Lorien Fono from the Bay Area Clean Water Agencies for coordinating sidestream sampling and cost estimation effort with its member agencies.

LIST OF ACRONYMS

AOB	Ammonia-oxidizing bacteria
AACE	Association for the Advancement of Cost Engineering
AMR	Ammonia Recovery Process
Anammox	Anaerobic ammonia oxidation
ARP	Ammonia Recovery Process
BACWA	Bay Area Clean Water Agencies
BAY	San Francisco Bay
BOD	Biochemical Oxygen Demand
CANDO	Coupled Aerobic-anoxic Nitrous Decomposition Operation
CCCSD	Central Contra Costa Sanitary District
CCMP	Comprehensive Conservation and Management Plan
CEC	Cation Exchange Capacity
COC	Chain of Custody
COD	Chemical Oxygen Demand
CSTR	Continuous Stirred Tank Reactor
CWA	Clean Water Act
DD	Delta Diablo
DIN	Dissolved Inorganic Nitrogen
DO	Dissolved Oxygen
DMR	Discharge Monitoring Report
EBDA	East Bay Dischargers Authority
EBMUD	East Bay Municipal Utility District
ELAP	Environmental Laboratory Accreditation Program
EPA	Environmental Protection Agency
FOG	Fats, Oils and Grease
FTE	Full Time Employee
GHG	Greenhouse Gas
HRSD	Hampton Roads Sanitation District
HRT	Hydraulic Retention Time
IFAS	Integrated Fixed-film Activated Sludge
MAD	Mesophilic Anaerobic Digestion
MBBR	Moving Bed Biofilm Reactor
MLSS	Mixed Liquor Suspended Solids
MWWTP	EBMUD's Main Wastewater Treatment Plant
NARR	North American Regional Reanalysis
N Rem	Nitrogen Removal
NDN	Nitrification and Denitrification
Nit/Denit	Nitrification/Denitrification

NMS	San Francisco Bay Nutrient Management Strategy
NOB	Nitrite-oxidizing Bacteria
NPDES	National Pollutant Discharge Elimination System
NSBR	Nitrifying Sequencing Batch Reactor
O&M	Operation and Maintenance
OLSD	Oro Loma Sanitary District
POTW	Publicly Owned Treatment Work
PLC	Programmable Logic Controller
PS	Primary Sludge
PV	Present Value
RMP	Regional Monitoring Program
QA/QC	Quality Assurance/Quality Control
QAO	Quality Assurance Officer
QAPP	Quality Assurance Project Plan
RAS	Return Activated Sludge
ReNUWIt	Re-inventing the Nation's Urban Water Infrastructure
SBR	Sequencing Batch Reactor
SEP	SFPUC's Southeast Plant
SFEI	San Francisco Estuary Institute
SFPUC	San Francisco Public Utilities Commission
SJSC	San Jose/Santa Clara Regional Wastewater Facility
SM	Standard Methods
SOP	Standard Operating Procedure
SRF	State Revolving Funds
SRT	Solids Retention Time
SWRCB	State Water Resources Control Board
TFT	The Freshwater Trust
THP	Thermal Hydrolysis Pretreatment
TIN	Total Inorganic Nitrogen
TKN	Total Kjeldhal Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TPAD	Temperature-Phased Anaerobic Digestion
TSS	Total Suspended Solids
TWAS	Thickened Waste Activated Sludge
UASB	Upflow Anaerobic Sludge Blanket
USD	Union Sanitary District
USGS	United States Geological Survey
VA	York River Wastewater Treatment Plant
VFA	Volatile Fatty Acid

VSS	Volatile Suspended Solids
WDR	Waste Discharge Requirements
WERF	Water Environment Research Foundation
WWTP	Wastewater Treatment Plant
WY	Water Year

EXECUTIVE SUMMARY

A growing body of evidence suggests that the historic resilience of the San Francisco Bay (Bay) to nutrient enrichment could be weakening. This has generated increased concern for regulators and stakeholders, and has prompted the development of strategies to manage nutrient loads.

This study evaluates nutrient management load reduction strategies at wastewater treatment plants (WWTPs) which constitutes about two-thirds of the load contributions to San Francisco Bay. Specifically, this study focuses on a nutrient-rich stream at WWTPs known as the “sidestream”. The sidestream is an internal waste stream cycled within the plant that typically accounts for a significant nutrient load in the plant discharge, but less than 1 percent of plant flow. If nutrient removal is required at Bay Area WWTPS in the future, sidestream treatment could potentially be used as a cost-effective option, whereby it could serve as the initial step in an adaptive management stepwise approach, and/or as part of the full-plant nutrient upgrades.

This report presents the findings of a regional collaborative effort to investigate nutrient removal by sidestream treatment at wastewater treatment plants in the Bay Area. Innovative sidestream treatment technologies have been pilot tested at multiple locations. Potential nutrient load reductions and costs have been quantified at the planning level to understand the extent of sidestream treatment in reducing overall wastewater nutrient discharges to the Bay. Subsequent modeling has been conducted to simulate possible water quality improvement (in terms of nitrogen concentrations) in the Bay due to sidestream treatment. Additionally, this report discusses the high-level challenges and opportunities for developing and implementing a watershed-based nutrient trading program, compared to a “command-and-control” approach.

The high-level findings from this study include:

- A preliminary assessment indicates that the majority of the 37 Bay Area WWTPs are potential candidates for sidestream treatment (16 or 25 WWTPs, depending on whether ammonia or total nitrogen is selected as the reduction objection for the Bay)
- If all candidate plants implement sidestream treatment, the ammonia and total nitrogen load reduction can be up to 21 percent and 17 percent of WWTPs nitrogen discharges to the Bay, respectively
- Pilot testing of four new cost-effective biological nitrogen removal technologies at four sites has demonstrated that anammox can be used to treat sidestreams. Process upsets were experienced when treating unconventional (more concentrated) sidestreams at two test sites, resulting in little to no anammox activity. Nitrite accumulation was observed, but the root cause cannot be determined based on the data collected
- Additional pilot testing is required of the Coupled Aerobic-anoxic Nitrous Decomposition Operation (CANDO) technology before any definitive conclusions can be made about its viability as a sidestream treatment technology.

While performance goals were not achieved during the grant period (the pilot is ongoing), the CANDO team believes that with additional time and funding, desired performance goals can be demonstrated. Additionally, important operational and scientifically significant information was learned during the pilot testing

- Initial hydrodynamic and water quality simulation in the Bay suggests that a reduction in nitrogen load input to the Bay, through sidestream treatment, would yield comparable percentage reductions in concentration and nutrient transport to the coastal ocean. Variability in, and the balance between, transport and concentration was dependent on proximity to sources and the coastal ocean. Variability is significant depending on subembayment and season
- Planning level cost estimates show that the cost of sidestream treatment is significantly lower than the cost of mainstream upgrades for nutrient removal (ongoing Optimization/Upgrades Study for the Regional Nutrient Watershed Permit)
- A watershed-based nutrient trading program could be a potential management option, providing nutrient load reductions for the Bay at a reduced cost to the dischargers

Based on the findings from this study, we recommend the continued evaluation of potential sidestream treatment for nutrient removal, or recovery, as part of an ongoing regional, collaborative fact-finding nutrient management effort.

We also recommend that a conceptual nutrient trading program continue to be developed in conjunction with the regional scientific and engineering studies, to allow Bay Area wastewater dischargers to identify flexible and cost-effective nutrient load management solutions when they are deemed necessary.

Chapter 8 presents a summary of key project accomplishments, findings, recommendations, environmental outcomes, and lessons learned.

CHAPTER 1 – INTRODUCTION

1.1 Background

The San Francisco Bay (Bay) is a shallow estuary that drains water from approximately 40 percent of California to the Pacific Ocean. Over seven million people live in the area, generating a significant nutrient load (i.e., nitrogen, phosphorus) to the Bay.

Excess nutrients affect water quality in many estuaries around the world. Until recently, the Bay appeared to be immune to these negative effects. However, a growing body of evidence suggests that the historic resilience of the Bay to elevated nutrient concentrations could be weakening. Nutrient discharge to the Bay has emerged as a key area of interest, and is generating increasing concern from regulators, scientists, environmental organizations, and the wastewater community in the Bay Area, prompting research to determine whether nutrient reduction is necessary.

Municipal wastewater treatment plants (WWTPs) contribute a significant portion of the nutrient load to the Bay. Collectively, Bay Area WWTPs discharge over 50 tons of dissolved inorganic nitrogen (DIN), and approximately four tons of phosphorus, from approximately 450 million gallons of treated effluent daily (HDR, 2016). If nutrient upgrades are required, estimated capital costs would be in the billions of dollars. Nutrient removal will be one of the greatest financial and management challenges for Bay Area wastewater agencies in the future.

At WWTPs, a nutrient-rich "sidestream" (an internal waste stream cycled within the plant as shown in **Figure 1-1**) typically accounts for 15 to 20 percent of the nutrient load in the plant discharge, but less than 1 percent of plant flow. This concentrated characteristic can make nutrient removal or recovery from sidestream treatment a cost-effective option that can be used as an adaptive stepwise management approach and/or as part of future full-plant nutrient upgrades.

In 2013, EBMUD proposed a regional collaborative effort, including wastewater agencies, scientists, engineers, and regulators, to investigate nutrient reduction through the treatment of wastewater sidestreams. On January 31, 2014, EBMUD and its team (**Figure 1-2**) was awarded a $517,650 grant by the Environmental Protection Agency (EPA), as part of the EPA FY2013 San Francisco Bay Area Water Quality Improvement Fund, to partially cover the cost of this regional sidestream nutrient removal study. To complete the three year project, EBMUD, and its local Publicly Owned Treatment Work (POTW) partners, contributed a significant amount of in-kind support in the form of pilot testing, equipment purchases, facility access, laboratory analysis, and staff time. The key focus of this study was on ammonia and nitrogen reduction.

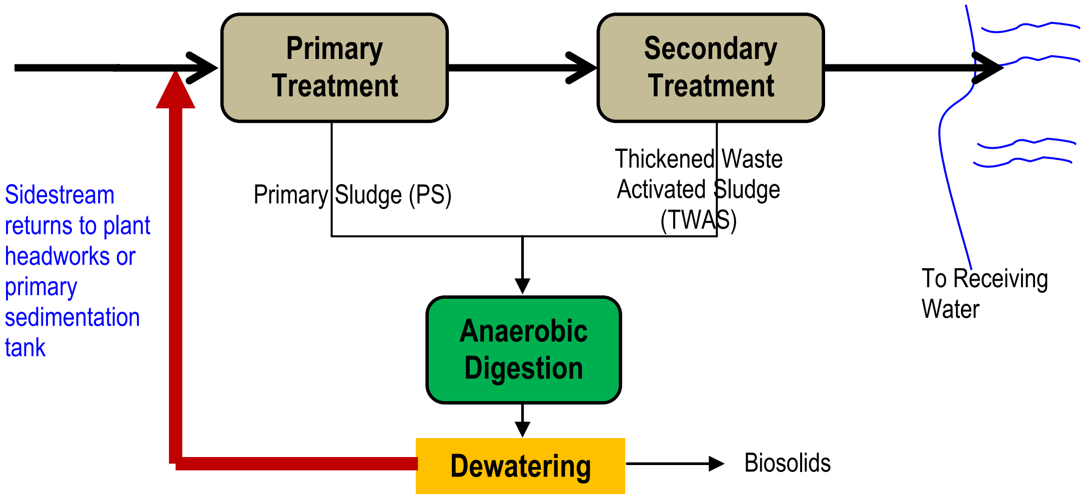


Figure 1-1. Typical Sidestream Generation at Wastewater Treatment Plants

1.2 Purpose

The purposes of this EPA grant-funded regional sidestream nutrient removal study were to:

- Evaluate and pilot-test new cost-effective and environmentally-sustainable sidestream treatment technologies at multiple WWTPs
- Identify candidate WWTPs for sidestream treatment, and estimate nutrient load reduction potentials, as well as costs associated with nutrient removal by sidestream treatment at WWTPs in the Bay Area
- Simulate possible Bay water quality improvements, in terms of nitrogen concentration, if sidestream treatment were to be implemented at WWTPs for nutrient (nitrogen) removal
- Develop a Conceptual Nutrient Trading Program through which interested Bay Area wastewater dischargers could collaborate to find cost-effective ways to manage nutrient discharges

1.3 Project Approach

The following approach was employed for this study:

- **Sidestream treatment technology evaluation**
  A comprehensive literature review of available sidestream nutrient removal technologies was conducted. Four innovative nitrogen removal technologies: two emerging—suspended and attached anaerobic ammonia oxidation (anammox), and two embryonic—zeolite anammox and Coupled Aerobic-anoxic Nitrous Decomposition Operation (CANDO), were pilot tested at four WWTPs since early 2014, as shown in **Figure 3-1**. These technologies are attractive due to their simplicity, resiliency, fast start-up, energy recovery potential, and potential low

cost relative to alternative technologies. Prior to starting the pilot testing, the project team prepared a comprehensive Quality Assurance Project Plan (QAPP) that covers test plan, data collection, Quality Assurance/Quality Control (QA/QC), data analyzing, and audit. The QAPP was reviewed and approved by the EPA Quality Assurance Officer (QAO) in July 2014.

- **Sidestream treatment load reduction and cost estimation**

  While the pilot testing was underway, parallel efforts were taken to distribute a sidestream questionnaire to 37 participating WWTPs in the Bay Area to identify potential candidates for sidestream treatment. Due to a lack of existing data, three large-scale sampling events were coordinated to collect sidestream samples from over 30 WWTPs to analyze key sidestream nutrient parameters. Using this information, the project team was able to better quantify the potential nutrient load reduction from sidestream treatment. A plant site investigation team, composed of process and operational experts, performed site visits to the 37 participating WWTPs to verify the information collected, and discuss treatment options with plant staff. This allowed the development of more refined sidestream treatment capital, and operational & maintenance (O&M) costs.

  In addition, to allow WWTPs to estimate sidestream treatment needs, a model was built to provide rough estimates of key treatment performance metrics (ammonia/nitrogen removal efficiency), design parameters (tank volume, aeration/power demand, chemical additions), O&M costs (power, chemical, and labor), with specific input sidestream composition and flow. The model was developed based on a combination of BioWin® modeling and engineering estimations. To encourage the wide usage of this modeling tool, an excel interface was built so that all WWTPs could use it on their own. The users can also select six different sidestream treatment technologies, ranging from the conventional nitrification/denitrification (NDN) to the emerging anammox processes. The Greenhouse Gas (GHG) emissions associated with sidestream treatment energy and chemical consumption are estimated using a user input energy source for their plant.

- **Potential Bay water quality improvements due to sidestream treatment**

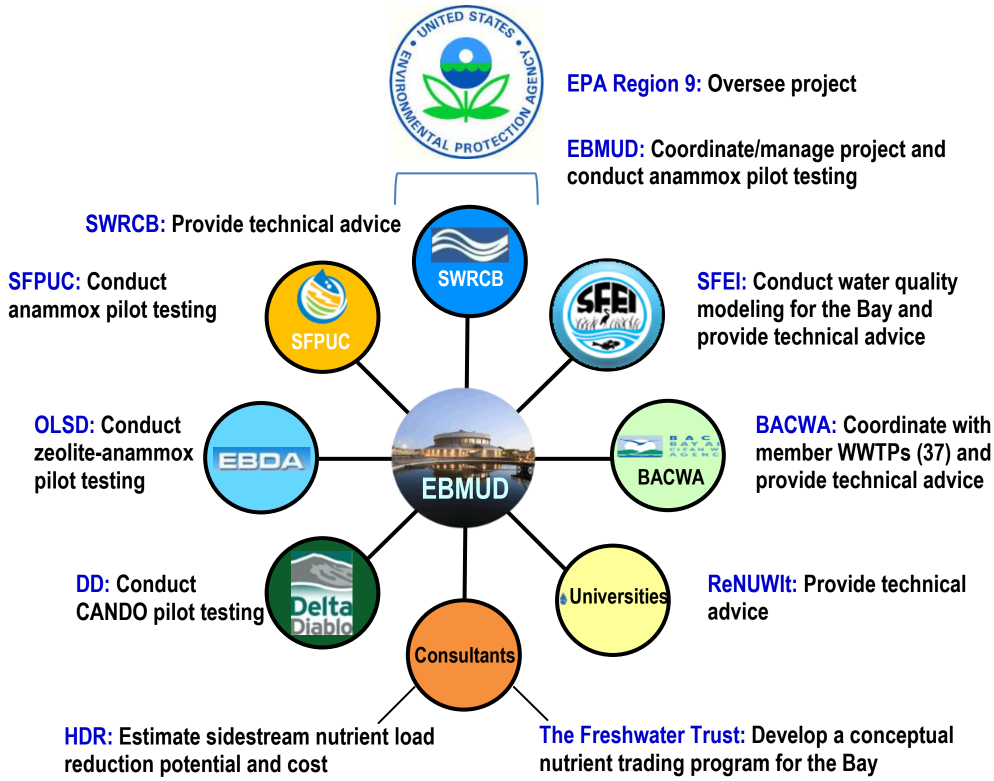
  Model simulation was performed to estimate the effects of WWTP sidestream treatment on ambient nutrient (both reactive and conservative nitrogen) concentrations throughout the Bay. The current San Francisco Estuary Institute's (SFEI) water quality model was used for this project. This existing model is hydro-dynamically calibrated for the 2013 Water Year (WY), and includes nitrification and denitrification reactions. Prior to the simulation, the model was updated with more recent WWTP nutrient discharge data (July 2012 to June 2016), collected under the 13267 Letter and the Regional Nutrient Watershed Permit (San Francisco Bay Regional Water Quality Board, 2014). A more complete and sophisticated model will be developed over the next few years.

- **Conceptual nutrient trading program for the Bay**
  A high-level assessment of challenges and opportunities for developing and implementing a nutrient trading program in the Bay was performed, and a Conceptual Nutrient Trading Program was developed. A number of hypothetical scenarios were developed to explain how this conceptual trading program would work. Potential environmental and economic benefits associated with a nutrient trading program, compared to a command-and-control approach, were estimated. In addition, the feasibility of adding non-point source dischargers into a point source-based trading program was explored.

The project was implemented through a collaborative effort, including participation from Bay Area wastewater agencies, scientists, engineers, non-profit organizations, and regulators, as shown in **Figure 1-2**.

1.4 Report Organization

This report discusses the execution and documents findings of the study, and is organized into eight chapters as shown in **Table 1-1**.



Anammox = anaerobic ammonia oxidation; BACWA = Bay Area Clean Water Agencies; CANDO = Coupled Aerobic-anoxic Nitrous Decomposition Operation; DD = Delta Diablo; EBDA = East Bay Dischargers Authority; EBMUD = East Bay Municipal Utility District; OLSD = Oro Loma Sanitary District; SFPUC = San Francisco Public Utilities Commission; SFEI = San Francisco Estuary Institute; SWRCB = San Francisco Regional Water Quality Control Board; ReNUWIt = Re-inventing the Nation's Urban Water Infrastructure

Figure 1-2. Project Team

Table 1-1. Report Organization

Chapter No.	Content Summary	Authors
1	Provides background, introduces the objectives, and describes the approach employed for the regional sidestream nutrient reduction study, conducted under the EPA FY2013 San Francisco Bay Area Water Quality Improvement Fund.	Yun Shang, EBMUD
2	Summarizes the literature review findings of the established, emerging, and embryonic sidestream treatment technologies. A detailed literature review report is included in the **Appendix A** of this report.	Mike Falk and JB Neethling, HDR
3	Provides a summary of the pilot tests conducted of cost-effective sidestream nitrogen removal treatment technologies at four wastewater treatment plants in the Bay Area. The technologies tested included suspended-growth, attached-growth, and zeolite anammox, as well as the CANDO. A quality assurance audit report is included in **Appendix B**.	Yun Shang, EBMUD With input from Martin Musabyimana (EBMUD), David Graham (SFPUC), Jimmy Dang (OLSD), Amanda Roa (DD), and Robert Collison
4	Describes the process to identify potential candidates for sidestream treatment, and presents sidestream nutrient concentration data measured for over 30 Bay Area WWTPs for the first time. Discusses planning level estimates of nutrient discharge load reduction, as well as sidestream treatment facility needs, and corresponding costs. Detailed sidestream data for individual plants are included in **Appendix C**.	Mike Falk, JB Neethling, and Glen Lischeske, HDR
5	Presents a sidestream treatment model that WWTPs can use to estimate key treatment performance metrics, design parameters, and O&M costs associated with six different sidestream treatment technologies (**Appendix D**).	Mike Falk, JB Neethling, and Mario Benisch, HDR
6	Presents the model simulation results of potential water quality improvements to the Bay, assuming sidestream treatment is implemented at the WWTPs identified as potential sidestream treatment candidates. Additional charts can be found at **Appendix E**.	Rusty Holleman, SFEI
7	Presents the findings regarding the development of a Conceptual Nutrient Trading Program, through which interested Bay Area WWTPs could participate collaboratively to find cost-effective ways to manage nutrient discharges. Detailed task reports are included in **Appendix F**.	Phoebe Grow, EBMUD With input from Alex Johnson, Erik Ringelberg, and Chris Thomas (TFT)
8	Presents a summary of key project accomplishments, findings, recommendations, environmental outcomes, and lessons learned.	Yun Shang, EBMUD

CHAPTER 2 – LITERATURE REVIEW OF SIDESTREAM TREATMENT TECHNOLOGIES

2.1 Introduction

This chapter summarizes the literature review findings on sidestream treatment technologies, including established, emerging, and embryonic technologies. The detailed literature review report is included in the **Appendix A** of this report.

At wastewater treatment plants (WWTPs), sidestreams result from liquid/solid separation by thickening, dewatering, decanting, etc. During such processes, the nutrient-rich liquid is separated and recycled back to plant headworks, primary clarifiers, or directly to secondary treatment. At plants with anaerobic digestion, the combined sidestream may constitute approximately 15 to 20 percent of the influent nitrogen load (Fux & Siegrist, 2004), and approximately 20 percent of the influent phosphorus load going into the activated sludge process (Khunjar & Fisher, 2014). At facilities that operate enhanced biological phosphorous removal, the recycle phosphorus loads can reach 100 percent of the influent load (Neethling et al., 2005).

2.2 Objectives

The key objectives of this literature review were to:

- Compile and screen sidestream treatment technologies
- Select and evaluate potentially viable technologies

The screening approach is used to select representative nitrogen removal technologies that cover the gamut from established technologies to research status technologies.

2.3 Biological Nitrogen Removal Summary

There are several biological pathways through which ammonia/nitrogen are removed at WWTPs. The most common pathways in industry are commonly referred to as Nitrogen Removal 1.0, 2.0, and 3.0. A summary of Nitrogen Removal 1.0, 2.0, and 3.0 pathways is presented in **Figure 2-1**.

A comparison of key unit parameters is captured in **Table 2-1**. The key points are that the oxygen/energy demand, carbon demand, biomass yields, and alkalinity demands are inversely related to the nitrogen removal pathway number (e.g., Nitrogen Removal 3.0). This reduced demand is attributed to the short cut in nitrogen removal pathways for Nitrogen Removal 2.0 and 3.0, compared to Nitrogen Removal 1.0.

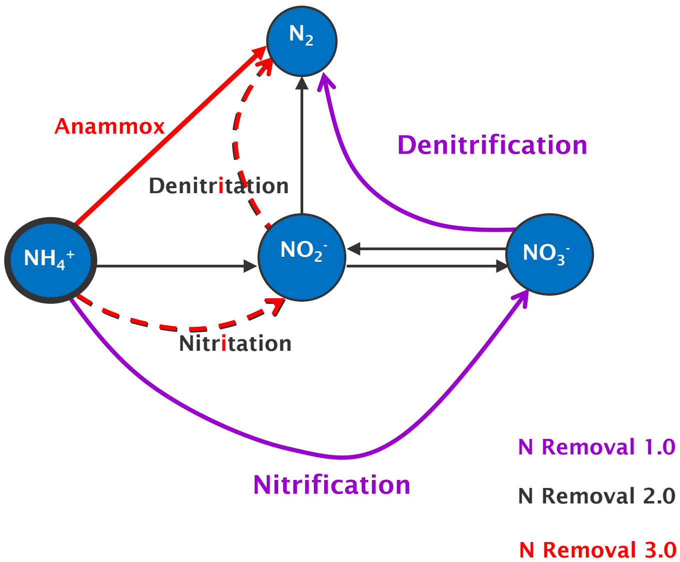


Figure 2-1. Nitrogen Removal Pathways (1.0, 2.0, 3.0)

Despite the operations and maintenance (O&M) benefits, WWTPs are reluctant in the United States to implement Nitrogen Removal 2.0 and 3.0 technologies due to concerns over risk and the perception that they are more difficult to operate than Nitrogen Removal 1.0 technologies. In order to compare and contrast all three nitrogen removal pathways, the selected technologies evaluated for this literature review include all three nitrogen removal pathways.

Table 2-1. Comparison for Nitrogen Removal 1.0, 2.0, and 3.0

Parameter	Units	Nitrogen Removal 1.0	Nitrogen Removal 2.0	Nitrogen Removal 3.0
Oxygen Required	lb O_2/lb NH_4-N Removed	4.6	3.4	1.9
Carbon Required (if acetate used)	lb COD/lb N Removed	6.6	4.5	0.0
Yield	lb VSS/lb N Removed	1.9	1.5	0.1
Alkalinity Required	lb Alk as $CaCO_3$/ lb NH_4-N Removed	7.1	7.1	3.6

A key question to consider is whether additional nitrogen removal pathways exist. Nitrogen removal 2.5 is presented in this literature review with a research technology (e.g., CANDO). This technology is a part of the selected technologies for further evaluation and will be further discussed below.

Background information on phosphorus removal pathways is provided in **Appendix A**.

2.4 Technology Status Classification

Sidestream treatment technologies may be classified according to the technology development status as described in **Table 2-2** and **Figure 2-2**. Many of the more progressive technologies have been conceived and established in Europe, in particular deammonification. Asia has been quick to adopt these progressive technologies. North America has been slower to adopt the cutting-edge technologies in wastewater treatment.

Table 2-2. Technology Status Classification Definition (Tetra Tech, 2013)

Technology Classification	Definition	Bench-Scale Testing	Pilot-Scale Testing	Full-Scale Installations	Comment
Established	Technology used at >1 percent of full-scale facilities (150) in the US	Yes	Yes	Yes	May include technologies that are widely used although recently introduced in the US
Innovative	Technology that meets one of the following criteria: - Some degree of initial use (i.e., <1 percent full-scale facilities (150) in the US - Available and implemented in the US for <5 years - Established overseas	Yes	Yes	Yes[1]	
Emerging	Technology has been tested at a pilot- or demonstration-scale, or has been implemented at full-scale	Yes	Yes	Yes[2]	
Research	Technology is at the development stage and/or has been tested at laboratory- or bench-scale.	Maybe	No	No	Technology that has reached demonstration-scale overseas are considered to be research technologies for US applications

1. Might be limited to outside the US
2. ≤3 installations or operated for <1 year

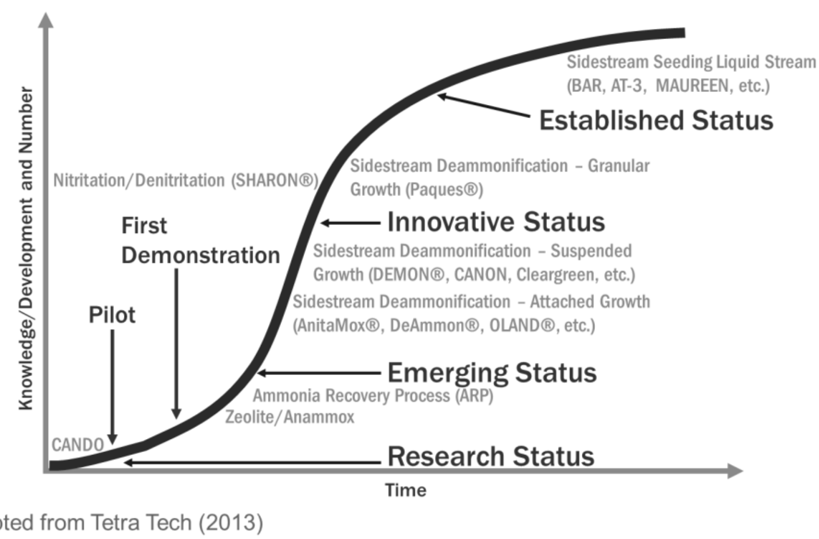


Figure 2-1. Technology Status Classification

2.5 Sidestream Treatment Technologies Selection

An overview of the sidestream treatment technologies grouped by nitrogen removal mechanism is provided in **Figure 2-3**. This list does not identify vendor specific technologies, unless the removal pathway is limited to a single technology. For example, DEMON® represents one of several Deammonification Technologies.

In order to identify attractive technologies for this study, each nitrogen removal mechanism is discussed separately, followed by a recommendation of technologies to evaluate. It is important to note that the evaluation criteria for selecting technologies consider plant-wide impact. For example, the Nitrogen Removal 2.5 CANDO technology requires that the plant has a cogeneration facility to recover the energy from their biogas. Otherwise, the benefit of the CANDO technology on energy is lost.

Details and background on the listed sidestream technologies in **Figure 2-3** is provided in the full literature review (see **Appendix A**). A comparison of the biological treatment technologies evaluated is provided in **Table 2-3**. The table lists the technology status, whether alkalinity and an external carbon source are required, and the relative energy demand.

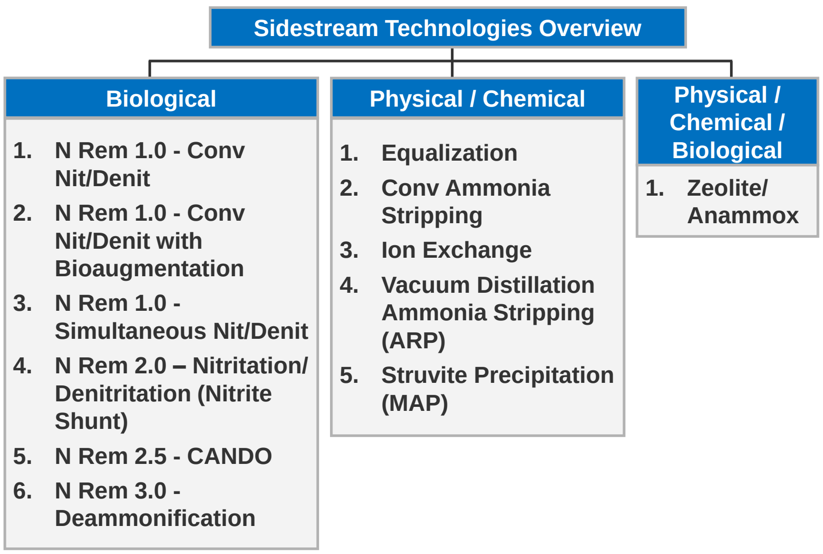


Figure 2-3. Sidestream Technologies Grouped by Nitrogen Removal Mechanism

Table 2-3. Biological Nitrogen Removal Technologies Comparison

Sidestream Treatment Technology	Technology Status[1]	Alkalinity Addition	External Carbon Source	Relative Energy Demand	Comment
N Rem 1.0 – Conventional Nit/Denit	Established	Yes	Yes	High	If just nitrification, the nitrate can be used for liquid stream odor control
N Rem 1.0 – Conventional Nit/Denit with Bioaugmentation	Established	Yes	Yes	High	Same as above
N Rem 1.0 – Simultaneous Nit/Denit	Innovative	Yes	Yes	High	Same as above
N Rem 2.0 – Nitritation/Denitritation (Nitrite Shunt)	Innovative	Maybe	Yes	Medium	Similar to above except nitrite can be used for liquid stream odor control
N Rem 2.5 – CANDO	Research	Yes	No[2]	Low	Benefits limited to WWTPs that recover energy from their biogas
N Rem 3.0 – Deammonification	Innovative	No	No	Low	Currently limited to waters >18°C

[1] Classifications according to technology status definitions by Tetra Tech (2013)
[2] CANDO requires soluble carbon to select for a microbial community that can store soluble carbon as polyhydroxybutyrate (PHB). The bench-top and demonstration scale have successfully used an external carbon source, acetic acid, in order to select for PHB accumulating organisms. A next step is evaluating whether an internal soluble carbon source, such as fermented raw solids, can be used to meet this soluble carbon demand.

2.6 Sidestream Treatment Technologies Evaluation

Nine selected nitrogen removal technologies are evaluated in this section. The full evaluation provided in **Appendix A** includes a technology description, important implementation and operational considerations (if applicable), advantages and disadvantages, and installation locations.

2.6.1 Established Sidestream Treatment Technologies

Nitrifying Sequencing Batch Reactor – Nitrogen Removal 1.0

The nitrifying sequencing batch reactor (NSBR) is a fill-and-draw activated sludge system for wastewater treatment. In this system, wastewater is added to a single “batch” reactor, treated to remove pollutants, and then discharged. Equalization, aeration, and clarification can all be achieved using a single batch reactor. There are five operational steps in a SBR: fill, react, settle, decant, and idle. Because both treatment and settling occur in the same reactor, secondary clarifiers, as well as return activated sludge (RAS), are unnecessary (Tchobanoglous et al., 2014). **Figure 2-4** displays the sequence of operational steps for a NSBR.

For nitrification-only operation, the react period is completely aerobic and additional alkalinity addition may be required. For operation incorporating denitrification for nitrogen removal, a supplemental carbon source is required due to the low Biochemical Oxygen Demand (BOD)/Total Kjeldhal Nitrogen (TKN) ratio of typical anaerobic digester centrate. Depending on the ammonia loading to the NSBR, this may result in high operating costs due to the cost of an external carbon source, such as methanol. Rather than denitrifying in the sidestream treatment reactor, the nitrite/nitrate produced in the sidestream treatment process can be returned to the plant headworks and denitrified in either the headworks and/or primary clarifiers. The benefits of denitrifying in the main plant are there should be sufficient carbon, and the oxygen released during denitrification can potentially combat odors. The reduced nitrate provides oxygen which can oxidize odorous sulfides to sulfate.

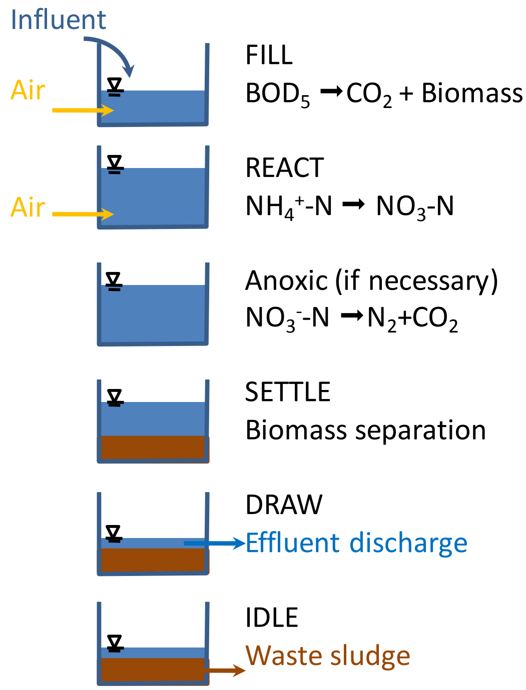


Figure 2-4. Nitrifying Sequencing Batch Reactor (SBR) Operational Steps

Most of the advantages for this process relate to the available design criteria, and operations experience for the SBR technology. Piloting the NSBR for sidestream applications is not necessary as the NSBR is a well-understood, established technology. NSBR performance can be modeled and accurately predicted with present-day mechanistic activated sludge simulation models such as with the proprietary modeling software BioWin®.

Conventional Nitrification/Denitrification with Liquid (Main) Stream Bioaugmentation – Nitrogen Removal 1.0

A sidestream treatment and bioaugmentation process that is integrated with liquid stream treatment may offer advantages to plants with liquid stream nitrification. Bioaugmentation is the addition or "augmentation" of specific microorganisms to a treatment process in order to perform a function that would not otherwise be possible without the added microorganisms. The majority of WWTPs in the Bay Area do not currently have a liquid stream nitrogen removal process; however, given the potential for future nitrogen limits, consideration of a sidestream treatment approach that may enhance liquid stream treatment via bioaugmentation is warranted.

Two different bioaugmentation approaches are available: in situ or external bioaugmentation. In situ bioaugmentation is achieved by integrating the sidestream return flows into the liquid stream process; nitrifier seed, as well as treated sidestream, are returned to the liquid stream process. This combination provides a way to handle the high strength sidestream, and provide an integrated ammonia reduction process. An advantage of in situ bioaugmentation is that nitrifier seed is better acclimated to liquid stream conditions due to the integration of the two processes. An alternative to in situ bioaugmentation, external bioaugmentation consists of growing nitrifiers in an external treatment process, and seeding liquid stream nitrification. The seed can be grown in a parallel treatment plant or with the sidestream flow.

The efficiency of nitrification enhancement by bioaugmentation is dependent upon the difference between liquid stream and sidestream growth environments (i.e., temperature, pH, ionic strength). Certain operating conditions will select for a specific nitrifying population tailored to those conditions. Sidestream-selected nitrifiers grown at higher sidestream temperatures will have a competitive disadvantage in the liquid stream environment.

The main disadvantage of the external bioaugmentation is the need for alkalinity supplementation. However, in cases where alkalinity supplementation is required for main stream nitrification there may be no impact on the total operation cost.

2.6.2 Innovative Sidestream Treatment Technologies

Nitritation/Denitritation (Nitrite Shunt) – Nitrogen Removal 2.0

Nitritation/denitritation is a short-cut nitrogen removal process whereby ammonia is partially nitrified to nitrite, and nitrite is subsequently denitrified to nitrogen gas. This process results in energy and carbon savings of 25 percent and 40 percent, respectively, in comparison to Nitrogen Removal 1.0 technologies. Nitritation/denitritation can be applied for nitrogen removal in the sidestream, but requires the addition of external carbon for denitritation. Alternatively, nitritation-only can be applied to the sidestream, and the nitrite produced may be recycled back to headworks, and/or primary clarifiers for denitritation using carbon available in the raw influent. This approach has the added benefit of potential odor control as previously discussed.

The SHARON® is a nitritation/denitritation process that takes advantage of the lower maximum specific growth rate of nitrite-oxidizing bacteria (NOB) as compared to ammonia-oxidizing bacteria (AOB) at temperatures above 28 ºC. NOB growth is effectively suppressed by operation at high temperatures; therefore, below a certain SRT threshold, AOB biomass is sustained, but NOB mass is selectively washed out. A process flow diagram of SHARON® is shown below in **Figure 2-5**.

The SHARON® reactor can be a single or dual stage completely mixed reactor. In the single-stage reactor, intermittent aeration is applied to allow for periods of nitritation and denitritation. In dual stage reactors, the nitritation and denitritation steps occur in separate stages. Similar to the Nitrogen Removal 1.0 technologies, alkalinity is typically required to oxidize ammonia to nitrite. An external carbon source must also be added for denitritation. Most installations have been dual stage due to enhanced process control.

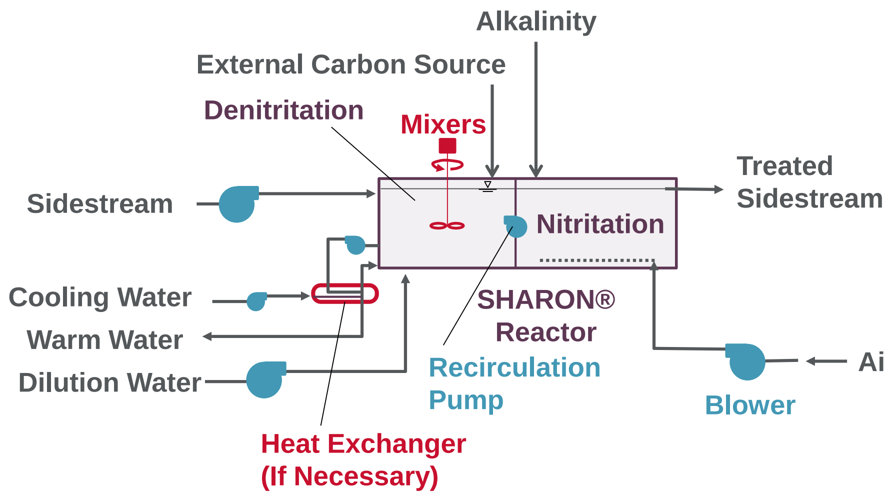
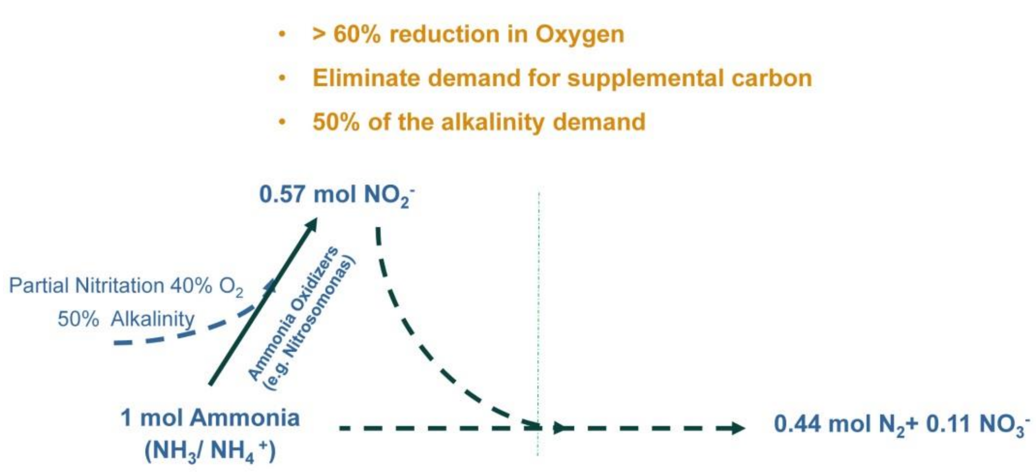


Figure 2-5. SHARON® Treatment Process (adapted from Bowden et al., 2014)

Deammonification: Suspended Growth, Granular Sludge, and Attached Growth – Nitrogen Removal 3.0

The bacterial strain specific to Nitrogen Removal 3.0 is referred to as the anaerobic ammonium oxidation (anammox) bacterial strain. The anammox bacterial strain oxidizes ammonium, while simultaneously reducing nitrite. Anammox bacteria are autotrophic and do not require a carbon source, like denitrifying organisms for nitrite or nitrate reduction. A schematic displaying the carbon and oxygen requirements for the deammonification process is shown below in **Figure 2-6**. Only half the ammonia load needs to be oxidized to nitrite, which thus reduces the oxygen requirement by approximately 60 percent when compared to Nitrogen Removal 1.0 for ammonia removal.



Developed by Wett et al., 2007

Figure 2-6. Schematic of Deammonification with Anammox Bacteria

Discovery of anammox in wastewater has paved the way for significant advancements in energy efficiency and waste reduction at treatment plants. Process configurations for Nitrogen Removal 3.0 (deammonification) have consisted primarily of granular sludge reactors, suspended growth SBRs that maintain anammox by granulation (referred to as suspended growth from herein), and attached growth moving bed biofilm reactors (MBBRs). Rotating biological contactors (attached growth) have also been used. Each process configuration has up to several patented treatment technologies, with trademarked names. These technologies differ in their control strategy, configuration, and method of concentrating and retaining Anammox bacteria.

The first generation of full-scale deammonification reactors struggled with long reactor start-up periods (up to several years) due to the slow growth rate of anammox bacteria. This long process was accelerated by seeding with anammox bacteria, and controlling the nitrogen loading rates. The more recent installations have not suffered from the long reactor start-up periods. Though deammonification technologies have become a roubst and reliable process, operational upsets do occur from the toxic inhibition of AOB, equipment failure, shock pH changes, and high influent solids concentration (Joss et al., 2011; Lackner et al., 2014). It is currently unclear from the literature if, from a process standpoint, which type of deammonification treatment configuration is most advantageous for treating high strength sidestream ammonia loads.

Variations in Deammonification Technology

The predominant type of suspended growth deammonification reactor is the sequencing batch reactor (SBR). In suspended growth SBRs, microorganisms are maintained in suspension for the removal of pollutants from water. The anammox microorganisms form granular solids that can be readily separated from NOBs and maintained in the system. Some suspended growth SBRs take advantage of these properties by separating the granular sludge and returning it to the reactor, which results in a much longer anaerobic SRT when compared to aerobic SRT. The treated wastewater is decanted from the SBR after a sedimentation phase. The predominant suspended growth configurations are DEMON®, Cleargreen®, and a SBR developed in collaboration with Swiss Federal Institute of Aquatic Science and Technology (EAWAG) (Joss et al., 2009).

Granular sludge deammonification technologies have been developed primarily in the Netherlands and China, and are typically single- and two-stage upflow anaerobic sludge blanket (UASB) reactors. The newer installations prefer single-stage reactors over two-stage. In two-stage suspended growth deammonification configurations, the nitritation reaction occurs in the first stage, followed by the ANAMMOX® reactor in the second stage. In the single-stage configuration, nitritation and the anammox reactions occur synergistically in a single reactor. Single-stage reactors are made possible because Anammox bacteria are reversibly inhibited by oxygen (Strous, 1997). Technologies include two-stage Nitritation/ANAMMOX®, and single-stage ANAMMOX®, both by Paques, BV in The Netherlands.

Lastly, the development of attached growth deammonification processes shortly followed the suspended growth SBR and granular sludge UASB process configurations. In an attached growth treatment process, microorganisms attach to some type of medium to form a biofilm. **Figure 2-7** displays the anammox biofilm formed on carrier media.

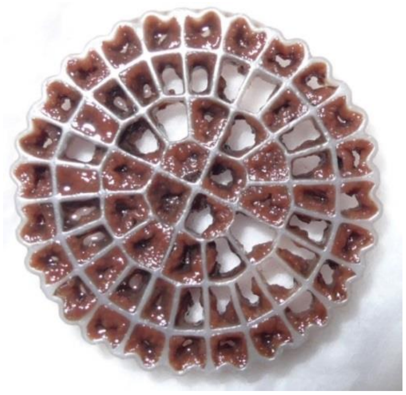


Figure 2-7. Anammox Biofilm on Carrier Media

Attached growth deammonification is made possible by the excessive formation of extracellular polymeric substances by anammox bacteria, allowing for ready attachment to surfaces. As for other biological treatment processes utilizing fixed film carrier media, the use of carrier media creates a higher equivalent Mixed Liquor Suspended Solids (MLSS) concentration, increasing the capacity of the treatment process, or decreasing the treatment process footprint. The retention of biomass as a biofilm on carrier media provides the necessary long SRT, and the ability to retain anammox for successful operation is considered more forgiving than other technologies. Attached growth deammonification configurations have primarily consisted of MBBR technologies. The performance of attached growth deammonification is similar to suspended growth; however, the energy demands have generally been greater for attached growth deammonification processes.

2.6.3 Emerging Sidestream Treatment Technologies

Ammonia Recovery Processes – Physical/Chemical Process

Notable emerging technologies are the Ammonia Recovery Process (ARP) by ThermoEnergy® and the Ammonia Recovery Process (AMR) by Anaergia®. Both technologies rely on increasing the pH to greater than 10 to volatilize the ammonium. Rather than strip out ammonia gas in a stripping tower, the ARP technology mists the stream to increase surface area and applies a vacuum pressure all within an enclosed vessel to draw out the ammonia gas. Once separated, the ammonia gas is condensed back to the liquid form using sulfuric acid to form reagent grade ammonium sulfate. The ammonium sulfate is then sold as a fertilizer (40 percent strength ammonium sulfate) and in turn creates a revenue stream. According to the vendor, ARP reduces the operating and capital costs of traditional ammonia recovery processes. The AMR produces a similar ammonium sulfate product but relies on a different acid scrubbing process to recover the volatilized ammonium.

Application of ammonia air stripping for higher strength sidestream ammonia levels may be advantageous due to an enhanced driving force for diffusive/mass transfer from the liquid phase to the gaseous phase; however, potential cost advantages have not been quantified.

Zeolite-Anammox Technology – Nitrogen Removal 3.0

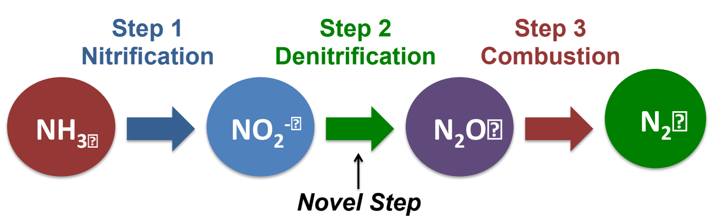
Zeolite-Anammox is a hybrid technology that leverages the benefits of zeolite and anammox bacteria. The technology performs nitrogen removal with applications for sidestream treatment, liquid stream treatment, and water reuse. Zeolite (clinoptilolite) is a microporous, aluminosilicate mineral that has a high cation exchange capacity (CEC). This high CEC preferentially adsorbs ammonium which is immobilized on the ion exchange sites. The immobilization step also concentrates ammonium for advantageous growth of a bacterial biofilm. A biofilm rich with anammox and AOBs coats the zeolite, and as the zeolite adsorbs ammonium the biofilm continuously regenerates the zeolite by converting the adsorbed ammonium to nitrogen gas.

There are two arrangements for the Zeolite-Anammox Technology, with and without blowers, for the high-rate and low-rate process, respectively. The low-rate (without blowers) arrangement harnesses the ability of the porous zeolite to wick up water like a sponge, providing a wetted surface that is orders of magnitude greater than the surface area of the tank. The high-rate (with blower) arrangement uses blowers or re-circulating trickling filters to provide oxygen more efficiently to reduce footprint required without comprising performance.

2.6.4 Research Sidestream Treatment Technologies

Coupled Aerobic-anoxic Nitrous Decomposition Operation (CANDO) – Nitrogen Removal 2.5

The CANDO is a new process for wastewater treatment that removes nitrogen from wastewater and recovers energy from the nitrogen in three steps: (1) ammonium is oxidized to nitrite via nitritation; (2) nitrite is reduced by denitrifying organisms to nitrous oxide (N_2O); and (3) energy is then extracted from the conversion of N_2O to N_2 by co-oxidation of N_2O with methane (CH_4), or by decomposition of N_2O over a metal oxide catalyst. The series of CANDO nitrogen transformation steps are as follows:



Step 1: Nitritation of NH_4^+ to NO_2^-, Step 2: Anoxic reduction of NO_2^- to N_2O, Step 3: N_2O conversion to N_2 with energy recovery (Gao et al., 2014)

Figure 2-8. CANDO Process

Unlike other nitrogen removal technologies developed to date, CANDO is the sole technology that allows for direct energy recovery from waste nitrogen in the form of nitrous oxide. For this reason, the CANDO nitrogen removal pathway is considered Nitrogen Removal 2.5. The CANDO process is in the very early stages of development. CANDO is an energetically advantageous process in comparison to Nitrogen Removal 1.0 (nitrification/denitrification) and 2.0 (nitrite shunt); but not to Nitrogen Removal 3.0 (deammonification) in terms of energy recovery and biosolids production reduction. CANDO may allow for a reduced footprint due to a lower operating SRT, as compared to deammonification. CANDO inventors note that CANDO may offer other benefits related to fast start-up (without a seed), robustness, simple operation, possible phosphorus recovery, and may circumvent certain issues associated with the use of deammonification.

2.7 Summary

This literature review investigates sidestream treatment technologies for Bay Area WWTPs. Nine technologies were evaluated in this sidestream treatment literature review, grouped by technology status. A comparison matrix of the key technology advantages, key disadvantages and data gaps that summarize the findings is provided in **Appendix A**. An additional comparative matrix that compares relative costs, footprint, performance, energy demand, and operational reliability among all considered technologies is also provided in **Appendix A**.

CHAPTER 3 – SUMMARY OF SIDESTREAM TREATMENT PILOT TESTING AT MULTIPLE SITES

3.1 Introduction

This chapter presents the summary results of pilot tests conducted at multiple wastewater treatment plants to evaluate new cost-effective and environmentally-sustainable sidestream treatment technologies identified in the literature review discussed in **Chapter 2**. Prior to starting the pilot testing, a comprehensive Quality Assurance Project Plan (QAPP) that covers test plan, data collection and Quality Assurance/Quality Control (QA/QC), data analysis and audit was prepared by the project team. The QAPP was reviewed and approved by the EPA Quality Assurance Officer (QAO).

3.2 Objective

Specifically, the objectives of the pilot testing were to evaluate the new nitrogen removal technologies of anammox and Coupled Aerobic-anoxic Nitrous Decomposition Operation (CANDO) for:

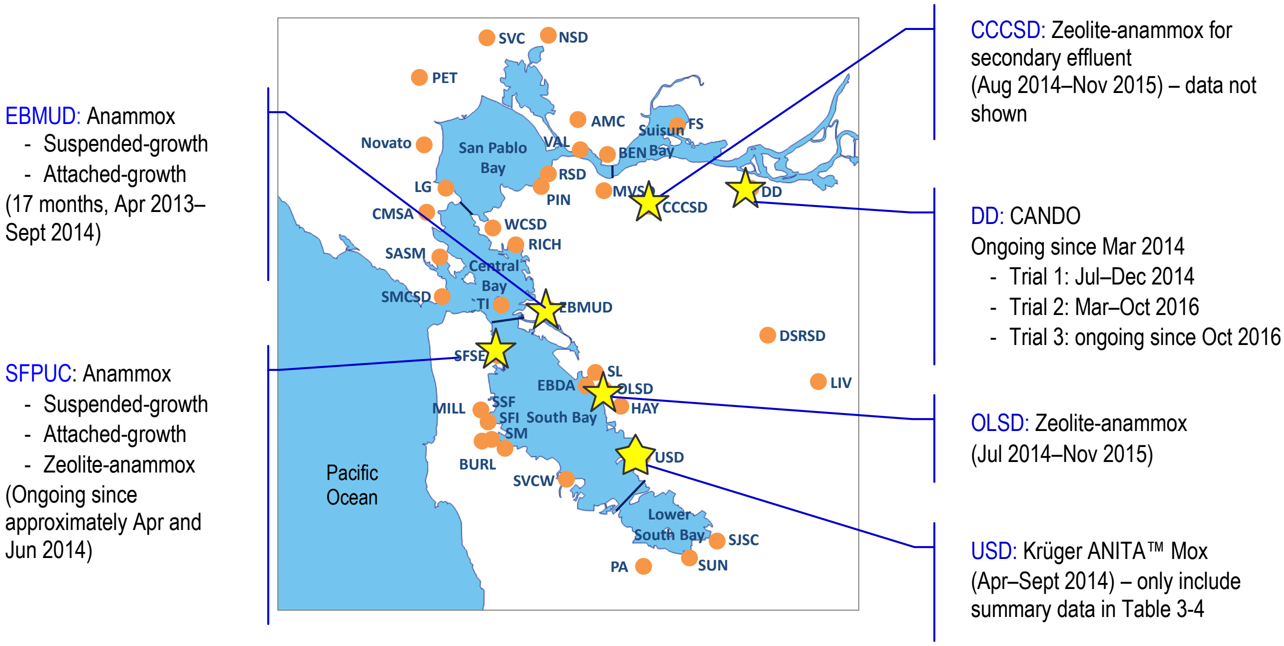
- Treating sidestreams with various ammonia concentrations and characteristics
- Feasibility of growing anammox bacteria from activated sludge
- Optimal process control and operational parameters
- Process performance in terms of ammonia loading and nitrogen removal efficiencies
- Factors important for potential future full-scale application

The zeolite-anammox and CANDO processes evaluated in this study have been scaled-up from the previous bench testing phase for the first time.

3.3 Methodology

3.3.1 Test Sites

Pilot testing was conducted at multiple WWTPs in the Bay Area as shown in **Figure 3-1**.



CANDO = Coupled Aerobic-anoxic Nitrous Decomposition Operation process, CCCSD = Central Contra Costa Sanitary District, DD = Delta Diablo, EBMUD = East Bay Municipal Utility District; OLSD = Oro Loma Sanitary District; SFPUC = San Francisco Public Utilities Commission (at the Southeast Plant); USD = Union Sanitary District

Figure 3-1. Map of Pilot Testing Sites

3.3.2 Sidestream Generation and Characteristics

Table 3-1 shows the quantity and source of sidestream generation at each test site. Sidestream is generated from dewatering of anaerobically digested sludge, and it is returned either to the plant headworks or primary treatment.

Table 3-1. Sidestream Generation

Test Site	Anaerobic Digestion	Dewatering Equipment	Sidestream Flow (avg.)	Sidestream Term Referred in This Study
EBMUD	Thermophilic AD of PS, TWAS and trucked high-strength organic wastes	Centrifuge	~0.7 mgd	Unconventional (due to trucked waste addition to AD)
SFPUC Southeast Plant (SEP)	Current: Two-stage mesophilic digestion of PS and TWAS Future: THP -> mesophilic AD	Centrifuge	~0.5 mgd	Conventional Unconventional
OLSD	Mesophilic AD of PS and TWAS	Belt press	~0.25 mgd diluted at ~1:1 ratio*	Conventional (diluted)
DD	Mesophilic AD of PS and TWAS	Centrifuge	~0.15 mgd	Conventional

AD = Anaerobic Digestion; PS = Primary Sludge; TWAS = Thickened Waste Activated Sludge; THP = Thermal Hydrolysis Pretreatment. * Blend of washwater with digested biosolids for operating a belt filter press

3.3.3 Pilot Testing Systems Setup Process Control, Seeding and Start-up

The pilot testing system setups are shown in **Figure 3-2 (a-d).** The reactor size, seeding, operation, and control information is summarized in **Table 3-2**.

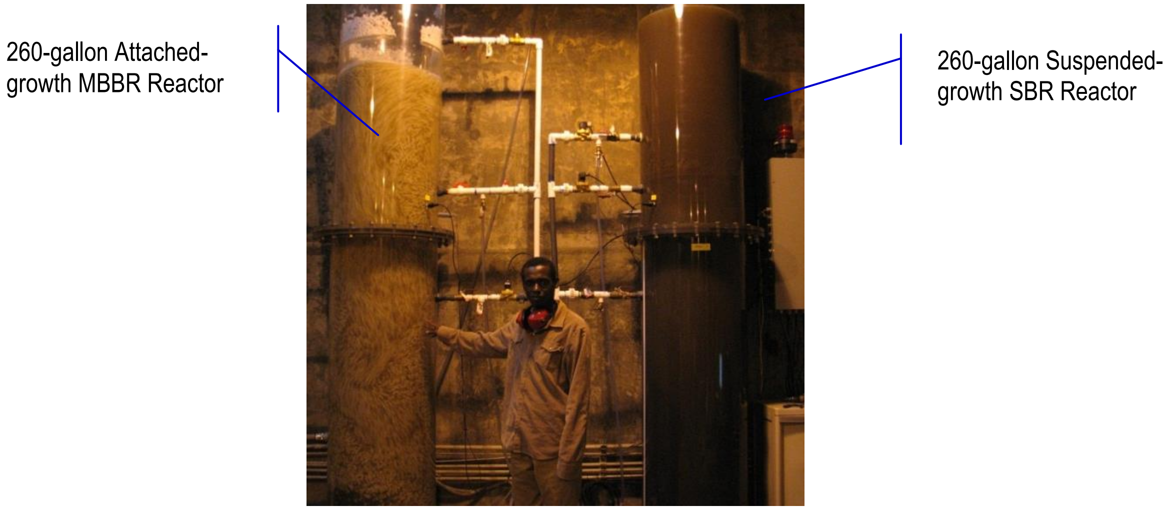


Figure 3-2a. Anammox Pilot Testing at EBMUD: Suspended-growth and Attached-growth Anammox

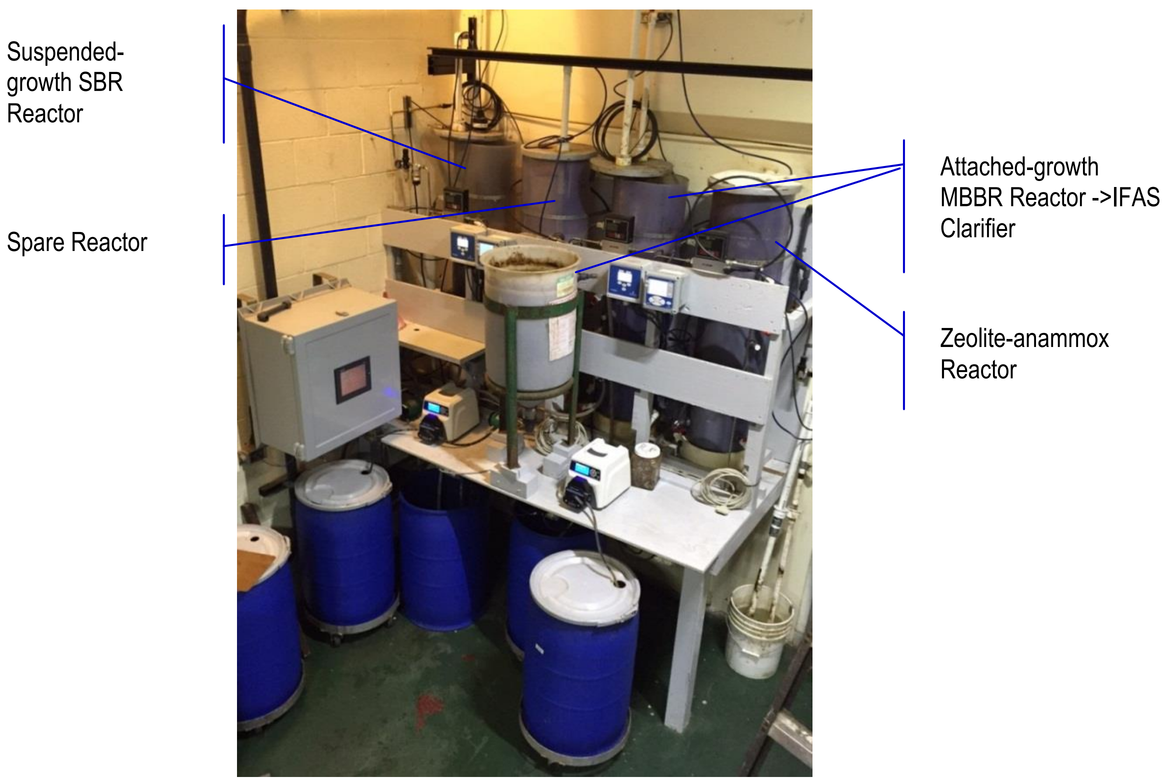


Figure 3-2b. Anammox Pilot Testing at SFPUC: Suspended-growth, Attached-growth, and Zeolite-anammox

Figure 3-2c. Zeolite-anammox Pilot Testing at OLSD

Figure 3-2d. CANDO Pilot Testing at DD

CSTR = Continuous Stirred Tank Reactor; IFAS = Integrated Fixed Film Activated Sludge Reactor; MBBR = Moving Bed Biofilm Reactor; SBR = Sequencing Batch Reactor

Figure 3-2. Pictures of the Pilot Testing Systems at: a) EBMUD, b) SFPUC, c) OLSD, and d) DD

3.3.3.1 EBMUD site (Anammox)

Setup: Two 260-gallon reactors were set up side-by-side to test the suspended- and attached-growth anammox processes (**Figure 3-2a**). Centrate, stored onsite in a 100-gallon tote, was fed to both reactors.

Control: A pH-based control strategy, i.e., maintaining pH in a tight band (typically about Δ0.02 S.U. between lower and upper setpoints), was used to control the duration of aerobic and anoxic periods that were linked to sidestream feeding, nitritation and anammox/denitrification reactions. Nitritation depresses pH while sidestream feeding and anammox/denitrification elevate the pH. The control was achieved by using a centralized control system using a Programmable Logic Controller (PLC) integrating measurements from pressure (for reactor liquid level), pH and dissolved oxygen (DO) sensors to control reactor feed and withdrawal, aeration and mixing.

Seeding and start-up: The suspended-growth reactor was initially seeded with 40 gallons of Return Activated Sludge (RAS) from a local nitrifying wastewater treatment plant, and was operated for nitritation in the first two months. After successfully reaching a targeted nitrogen species composition (roughly 46 percent ammonia, 47 percent nitrite, 7 percent nitrate) in reactor effluent, the reactor was fed with diluted centrate to reduce the concentration of nitrogen species to a level that would be tolerated by anammox bacteria. Once the nitrite concentration was below 20 mg-N/L, the reactor was inoculated with 3.5 L (about 1 gallon) of anammox seed sludge donated by York River Wastewater Treatment Plant (VA).

The attached-growth reactor, containing 30 percent of Kaldnes K1 plastic media (by volume), was seeded with 32 L nitrifying sludge (8.5 gallons) obtained from the same plant. This reactor was operated as an anammox reactor from the start using the pH-based control strategy. In the beginning, the reactor was fed with diluted centrate and operated as an SBR to minimize solids losses. After about one month, the reactor was fed with undiluted centrate and the reactor operation was changed from an SBR mode to a semi-continuous mode.

3.3.3.2 SFPUC site (Anammox)

Setup: Four 1-foot diameter by 4-foot tall anammox reactors (24 gallons each, including a spare reactor) were set up for side-by-side comparison of three anammox processes, as illustrated in **Figure 3-2b**. It is worth noting that the attached-growth reactor, filled with AnoxKaldnes K5 media (approximately 50 percent) was initially setup in June 2014 to functionally simulate an MBBR, then was later converted into an IFAS configuration after MBBR design loadings were reached in March 2015. A 55-L (14.5 gallons) clarifier was added to collect effluent from the MBBR reactor, and settled solids within the clarifier were periodically returned to the MBBR reactor.

Control: Three control strategies were instituted: 1) continuous feed with semi-continuous aeration, 2) continuous feed with DO control and timed aeration, and 3) a pH-based strategy. The first two strategies were found to be unstable and were abandoned. The third control strategy was instituted for all three reactors and provided a more stable environment for anammox growth. Similar to EBMUD's pilot, this pH-based control consisted of maintaining reactor pH within lower and upper setpoints (typically ±0.05 S.U.) using nitritation (e.g., aeration), sidestream feeding, and anammox/denitrification. Nitritation decreases pH while the latter increases pH as they are applied. When the pH hit the low setpoint after aeration, sidestream feeding would commence until the upper setpoint was reached. This could be done either anoxically or aerobically depending on operator preference. Aeration was also controlled via a timer to prevent over aeration of the suspended-growth SBR reactor. Each reactor also had a recirculation pump for mixing and/or sludge recirculation however this was not used for the SBR as it tended to shear the granules and thus aeration was the main mode of mixing. For the attached-growth MBBR/IFAS and zeolite-anammox reactors, sidestream feeding was typically done during aerobic periods as both were mostly operated with continuous aeration. A PLC was used to control aeration, sidestream feeding, SBR operation (e.g., level/decant, mixing/sludge recirculation for IFAS only) while continuously monitoring pH, DO, level and feed runtimes.

Seeding and start-up: The suspended-growth SBR reactor was started up in late April of 2014 with 2 gallons (approximately 10 percent reactor active volume) of seed from the EBMUD pilot reactor. The attached-growth reactor was started in June 2014 with mixed seeds composed of seeded plastic media provided by Veolia®, 5 gallons of nitrifying activated sludge from the San José-Santa Clara Regional Wastewater Facility, and 5 gallons of effluent from the EBMUD pilot reactor. At the start, these two reactors were both operated under low loading conditions e.g. low airflow rates to encourage anammox growth. Then, the airflow was gradually increased until design loading conditions were reached.

The zeolite anammox reactor was initially seeded in April 2014 with colonized ¾" diameter biozeolite provided by Collison Engineering, filled to approximately 42" of the reactor height (or 87.5 percent full). The ammonia-oxidizing bacteria (AOB)-seeded biozeolite (about 31 percent) and anammox-seeded biozeolite (about 69 percent) were packed separately into the reactor as the top and bottom layers respectively. Dewatering sidestream was fed into the top portion of the reactor and allowed to flow by gravity down through the reactor and out an overflow at roughly the same liquid level as the column of media. A mix pump periodically recirculated the reactor contents from the bottom of the reactor back to the top to ensure thorough dispersion of the liquid and maintain reactor temperature.

3.3.3.3 OLSD site (Zeolite-anammox)

Setup: A 21,000-gallon steel tank containing 18,000 gallons of zeolite media (with approximately half submerged in liquid) was used as the zeolite-anammox reactor operated as a recirculating trickling filter (**Figure 3-2c**). Sidestream stored in an 8,000-gallon tank was fed to the reactor at approximately 8 gpm and re-circulation flow was kept at approximately 30–50 gpm (on a timer). The reactor temperature was maintained in the range of 21–27 °C, approximate the temperatures expected of a full-scale installation.

Control: The process is primarily self-regulating based on a physico-chemical-biological equilibrium between zeolite adsorption/desorption and nitrifier-anammox symbiosis. The appropriate degree of aeration, controlled by a timer, was set during the project initiation phase when the nitrifying bacteria approach maturity. Once approximate equilibrium had been achieved between nitrifiers and anammox, the system became self-regulating. pH and alkalinity were measured weekly or biweekly. If necessary, pH was adjusted by varying the influent flow. During the entire project period, the timer was adjusted only once, and the influent flow rate was adjusted less than ten times.

Seeding and start-up: The zeolite anammox reactor was initially seeded with less than 2 percent of the colonized biozeolite (to the total volume of zeolite in the tank) grown from a bench-scale test completed earlier.

3.3.3.4 DD site (CANDO)

Setup: The CANDO pilot system consists of a 1,000-gallon centrate feed tank and two biological reactors (**Figure 3-2d**). Reactor 1 was a 1,000-gallon (650-gallon working volume) nitritation reactor operated as a continuous stirred tank reactor to convert NH_4^+ in centrate to NO_2^-. Reactor 2 was a 1,800-gallon (500-gallon working volume) CANDO reactor operated as a SBR to reduce NO_2^- produced in the liquid of Reactor 1 to N_2O.

Control: Both Reactors 1 and 2 were controlled using a PLC with feedbacks from integrated probes.

- For Reactor 1, a pH greater than 7.0 (with sodium hydroxide base addition) and a target temperature range of 25–35 °C was maintained. Air was pulsed into the reactor through a diffuser and aeration was operated on an ON/OFF cycle with a startup duration set at 1 minute ON and 5 minutes OFF. Air flow rate and aeration ON/OFF cycle time were adjusted manually based on centrate feed rate as well as ammonia and nitrate concentrations in the reactor.
- The SBR cycle for Reactor 2 consisted 1) an anaerobic phase (approximately 12 hrs) where carbon (in the form of acetate) was pulsed, 2) an anoxic phase (approximately 11 hrs) where effluent from Reactor 1 (containing mainly nitrite) was pulsed, 3) an 1-hr purging of liquid nitrous oxide, produced during the anoxic phase, with nitrogen gas, and 4) a settling and decant step (approximately 1 hr). Reactor pH was initially kept under 9.0 (via acid addition) to prevent potential high-pH induced inhibition and later was maintained at 7.5 to allow optimum conversion of nitrite to nitrous oxide.

Seeding and Start-up: In the most recent trial, Reactor 1 was inoculated with 55 gallons of nitrifying sludge from the City of Brentwood WWTP. The centrate feed rate along with the air flow rate was slowly ramped up with a goal of keeping ammonia below 200 mg-N/L, ideally in the range of 100–200 mg-N/L. It took three weeks to reach a loading rate of 12.4 gal/hr centrate feed (or 0.69 kg-N/m^3/d) and the corresponding aeration scheme was 20 scfm air flow with a 150-second ON and 300-second OFF aeration cycle. Reactor 2 was seeded with concentrated biomass from Reactor 1; however, Reactor 2 has been plagued with equipment and probe failures hindering the decoupling process of nitrite reduction and COD consumption. Reactor 2 is still running in an effort to improve the process and maximize the loading rate.

Table 3-2. Pilot Testing System Summary

	EBMUD Anammox		SFPUC Anammox			OLSD Anammox	DD	
	Suspended	Attached	Suspended	Attached	Biozeolite	Biozeolite	Reactor 1: Nitritation	Reactor 2: CANDO
Reactor feed	Centrate from a 100-gal storage tote	Same as left	30-gal	30-gal	30-gal	Filtrate from 8,000-gal feed tank	Centrate from an 1,000-gal storage tank	Reactor 1 Effluent
Size (working volume)	260-gal	260-gal	24-gal (19-gal, 80 percent active)	24-gal (~19-gal)	24-gal (~20-gal)	21,000-gal tank packed with 18,000-gal zeolite (9,000-gal submerged in liquid)	1,000-gal (650-gal)	1,800-gal (500-gal)
Carrier (media) (percent of reactor volume filled)	None	Kaldnes plastic media K1 (30 percent)	None	Kaldnes plastic media K5 (50 percent)	3/4" diameter biozeolite (~87.5 percent)	¼”x1” Pure Zeolite	None	None
Initial seed sludge	40-gal Activated Sludge[1] to start the reactor for nitritation; 1-gallon anammox[2] ~2 months later	8.5-gal Activated Sludge[1]	2-gal anammox seed from EBMUD pilot[3]	5-gal from EBMUD pilot[3], seeded media by Veolia®, and 5-gal of nitrifying activated sludge from SJSC[4]	0.85 CF AOB[5] seeded zeolite and 2 CF anammox seeded zeolite packed separately as the as top and bottom layers	Biozeolite[6] <2 percent (v/v) of the total zeolite in the tank	55-gal Nitrifying Sludge	Reactor 1 Effluent
Reactor operation	SBR	MBBR (semi- or continuous flow)	SBR	MBBR/IFAS (semi- or continuous flow)	semi- or continuous flow	Recirculating trickling filter (continuous flow)	CSTR	SBR
Reactor feeding	When pH is ≤ Lower Setpoint	Same as left	When pH is ≤ Lower Setpoint	same as left	same as left	Continuous	Continuous	Every 24 hours
Aeration	Intermittent during aerobic period	Intermittent during aerobic period	Intermittent during aerobic period	Continuous	Continuous	On a timer	Intermittent	None
Controlled process	Feed/withdraw, Aeration, Mixing	Same as left	Feed/withdraw /Level/Aeration	Feed/Aeration/Sludge Recirculation	Feed/Aeration	Self-regulating, Feed flow rate	Feed/withdraw, Aeration	Feed, acetate addition, N_2 generator
Key process control strategy	pH band (Lower and Upper pH set points) and DO <0.5 mg/L	Same as left	pH-based (pH Lower and Upper setpoints)	pH-based (pH Lower and Upper setpoints)	pH-based (pH Lower and Upper setpoints)	pH monitoring, Maintain pH > 6.5	pH (<7.0) with base addition, Temp, ammonia conc.	Time, pH (<7.5) with acid addition, COD
Control signal and instrument	Pressure (level), DO, and pH sensors, PLC	Same as left	Level, feed, DO, and pH sensors, PLC	Feed, DO, and pH sensors, PLC	Same as left		pH, DO, Temp, ammonia and nitrate sensors, PLC	pH, Temp, nitrite, nitrate, dissolved N_2O sensors, PLC

SBR = Sequencing Batch Reactor; MBBR = Moving Bed Biofilm Reactor; CSTR = Continuous Stirred Tank Reactor

1. Return activated sludge (RAS) obtained from the West County Wastewater District, Richmond, CA (a nitrifying plant), was used to seed the reactor; 2. From Hampton Roads Sanitation District (HRSD) full-scale sidestream DEMON® anammox process at its York River plant; 3. From the suspended-growth anammox pilot reactor at EBMUD; 4. Nitrifying activated sludge was from the San José-Santa Clara Regional Wastewater Facility (SJSC); 5. CF = cubic feet, AOB = Ammonia-oxidizing bacteria; 6. 300-gallon nitrifying and anammox biozeolite from an initial OLSD bench test was used to seed this pilot testing

3.3.4 Laboratory Analysis and Field Measurements

The sample analyses were categorized as critical and non-critical analytes per the QAPP developed and approved by the EPA at the beginning of the project. The critical parameters were identified as those essential for understanding centrate characteristics and quantifying the pilot performances. The critical analytes of ammonia, nitrite and nitrate were analyzed by California state accredited environmental testing laboratories. Non-critical parameters were analyzed by using either a lab method or measured by test kits and in-situ probes. In addition, field measurements were conducted to collect data of TKN, ammonia, nitrite, nitrate, DO, pH, temperature, liquid level, and air flow rate, etc. needed for process control and monitoring.

3.3.5 Data Analysis and Calculation

The following methods were used to calculate the key process performance parameters.

Specific Ammonia Loading Rate, NH_4^+-N Load (kg/m^3 active reactor/d) = $\frac{[NH_4^+]_{\inf} \times Q_{\inf}}{10^6 \times V_{active}}$

Where: $[NH_4^+]_{inf}$: Influent ammonia concentration (include both ammonia and ammonium), mg-N/L
V_{active}: Active volume of reactor, or reaction system in m^3
Q: Flow rate, L/d

Ammonia Removal Efficiency (%) = $\left(1 - \frac{[NH_4^+]_{eff}}{[NH_4^+]_{\inf}}\right) \times 100$

Inorganic Nitrogen Removal Efficiency (%) = $\left(1 - \frac{[NH_4^+]_{eff} + [NO_2^-]_{eff} + [NO_3^-]_{eff}}{[NH_4^+]_{\inf}}\right) \times 100$

Where: $[NH_4^+]_{eff}$, $[NO_2^-]_{eff}$, $[NO_3^-]_{eff}$: Effluent concentrations of ammonia, nitrite and nitrate, mg-N/L, respectively
$[NH_4^+]_{inf}$: Influent ammonia concentration, mg-N/L

Total Nitrogen Removal Efficiency (%) = $\left(1 - \frac{(TN)_{eff}}{(TN)_{\inf}}\right) \times 100$

Where: TN_{inf}: Influent Nitrogen (TKN) (kg/day)
TN_{eff}: Total Effluent Nitrogen (TKN + NO_2^- + NO_3^-) (kg/day)

3.4 Results and Discussions

The key characteristics of the sidestream feed, control parameters, chemical addition, and pilot performance in terms of ammonia loading rate and nitrogen removal results are summarized in **Table 3-3**. **Table 3-3** summarizes pilot reactor performance data during stable operation; however, the CANDO pilot testing at DD is progressing towards targets and stable operation has not been reached yet; therefore, results from prior bench-scale testing have been included. In addition, the anammox pilot test at EBMUD was terminated due to an irreversible process upset (see discussions later), and best data obtained prior to the upset are included.

Feed Characteristics and Impact on Process Performance

Ammonia concentration: The average ammonia concentration in sidestreams tested at the multiple sites in this study ranged from approximately 500 to approximately 2,000 mg-N/L, slightly higher than the 500–1,500 mg-N/L (mostly approximately 1,000 mg-N/L) reported for full-scale anammox plants (Lackner et al., 2014). The low ammonia concentration in OLSD sidestream was due to dilution of filtrate for struvite control as part of their normal dewatering operation. The relatively high ammonia in EBMUD sidestream was the result of accepting trucked nitrogen-rich wastes for co-digestion to increase renewable energy production.

The ammonia concentration of the sidestream generated from the SFPUC current operations was approximately 1,600 mg-N/L (conventional sidestream), but generally ranged from 2,000–3,000 mg-N/L for the pilot THP/Mesophilic Anaerobic Digestion process (THP sidestream). The THP centrate was first diluted with conventional sidestream to acclimate the biomass. Feed ammonia concentrations for annamox reactor were in the range of 1,600–2,900 mg-N/L once undiluted THP sidestream was introduced. As the test with undiluted THP centrate is still ongoing, results will be provided once completed.

Alkalinity/Ammonia-N ratio (Alk/N): Lower than 4:1 Alk/N ratio may require supplemental alkalinity for anammox technology. Alk/N ratio in the EBMUD centrate was relatively consistent and averaged at 4:1; therefore, no additional alkalinity was necessary. Supplemental alkalinity was added for the SFPUC pilot, due to a reduced Alk/N ratio from ferric addition prior to dewatering. The Alk/N ratio in the OLSD filtrate generally fell between 2:1 and 3:1. During the rare periods of very low influent alkalinity (i.e., 2:1), the sidestream feed flow rate was increased to maintain the reactor pH above 6.5, and no supplemental alkalinity was used. At DD, previous data indicated that the Alk/N ratio averaged around 3.3:1; data on the current pilot has not yet been collected as steady state has not yet been reached. CANDO technology requires supplemental alkalinity to Reactor 1 to maintain pH > 7.0 as nitritation reaction consumes alkalinity as expected.

Soluble COD/Ammonia-N ratio (sCOD/N): High sCOD/N ratios may lead to denitrifiers outcompeting Anammox bacteria. It has been suggested that the sCOD/N ratio should be below 0.5 for deammonification to occur (Daigger, 2014). Similar parameter (BOD/N ratio) was also used as one of the design criteria by commercial vendors. While competition between denitrifiers and anammox bacteria was not examined specifically for this study, EBMUD found that the relatively high sCOD/N ratio (approximately 0.7) of its sidestream could have potentially supported growth of denitrifiers to denitrify residual oxidized nitrogen (nitrite and nitrate, or NOx) using the influent sCOD. This may explain the high total inorganic nitrogen (TIN) removal obtained from the EBMUD pilot test.

The sCOD/N ratio for the SFPUC pilot ranged from 0.3 to 2.4 (avg. 0.8) for conventional sidestream and from 0.5 to approximately 3 (avg. 1.2) for THP sidestream. The treatment

of conventional sidestream at the SFPUC was found to be similar to EBMUD with relatively high TIN removals obtained.
Significant denitrification was unlikely for the zeolite-anammox process, based on a low sCOD/N ratio of 0.48 (at OLSD site). In addition, most sCOD was likely removed in the top aerated layer of the zeolite media before it was available for the denitrifying bacteria in the bottom non-aerated layer.

For CANDO technology being tested at the DD, a low sCOD/N ratio indicates more organic carbon source supplement is necessary for the partial denitrification process (Step 2). Previous data collected at DD indicated that the sCOD/N ratio averaged at 0.36.

TSS: Influent solids concentration can have high impact on anammox system. Seventy percent of the anammox plants surveyed by Lackner et al. reported high impact or operational problems with high and varying influent solids. EBMUD sidestream showed significant variations in TSS levels (up to 4,000 mg/L being measured). The average TSS concentration in SFPUC sidestream was approximately 600 mg/L but peaked at 4,600 mg/L. Zeolite media exhibited clogging near the top layer for the zeolite-anammox system at OLSD (limited data showing a significant variation of sidestream TSS from 40 to 4,000 mg/L). Previously collected data at DD indicated an average sidestream TSS of 300 mg/L. High TSS did have a negative effect on Reactor 2 of the CANDO process, however, operational issues have been minimized by settling the centrate in tank prior to feeding Reactor 1.

In summary, the average TSS in sidestreams ranged from 150 to 1,190 mg-TSS/L across the multiple test sites, much higher than the 240 to 330 mg-TS/L (limited data) reported for full-scale anammox plants (Lackner et al., 2014). In addition, for this pilot study, TSS samples were taken from temporary sidestream feed holding tanks, which allowed some solids settling, the actual TSS concentration generated in sidestreams is likely to be higher. The potential impact of high TSS in sidestreams should be considered and mitigated for future full-scale application of anammox technology for sidestream treatment.

Others: Algae growth was observed in the zeolite-anammox pilot system at OLSD. The algae combined with biofilm and TSS had formed a waterproof layer in the zeolite media that affected the zeolite-anammox reactor. Excluding direct sunlight to the reactor effectively resolved this issue.

Anammox Biomass Growth

The growth of anammox bacteria was a lengthy process, as expected, as they are known to have an extremely low growth rate even under optimal conditions. In addition to this common process disadvantage, there were some challenges specific to this study, which included: 1) limitations in pilot system setup to facilitate enrichment of the slow-growth anammox and promote granulation of anammox biomass such as availability of plastic carrier with a higher surface area/volume ratio (for EBMUD test), 2) less than ideal reactor dimensions, e.g. high surface-area-to-volume-ratio causing DO intrusion (for SFPUC test), and 3) short circuiting in treatment induced by high TSS in sidestream feed (for OLSD site). Other challenges associated with pilot testing and possibly affecting full-scale operation, such as malfunctions and limitations of equipment and instruments, adjustment of control systems, and power outages. Despite these challenges, substantial progress has been made as discussed below.

EBMUD: After about a 5 to 6 month latent period following reactor seeding and control system tuning (approximately two months), significant anammox growth was observed as demonstrated by the process ability to handle ammonia loading increases without any decrease in removal efficiency. From January to June 2014, the volumetric ammonia loading rate increased from 0.06 to 0.55 kg-N/m^3/d for the suspended-growth reactor, and from 0.02 to 0.70 kg-N/m^3/d for the attached-growth reactor.

SFPUC: The pilot start-up phase began in April 2014 for the suspended and zeolite-anammox reactors and June 2014 for the attached-growth reactor. By late 2014, the volumetric ammonia loading rates gradually increased and met the design targets of 0.5 and 0.8 kg-N/m^3/d for the suspended- and attached-growth reactors, respectively. The zeolite-anammox reactor, which had an average loading rate of 0.46 kg-N/m^3/d during stable operation, didn't reach the design target of 1.0 kg-N/m^3/d. Overall, it took 3 to 6 months to reach the design loads for these reactors after a proper control strategy was implemented. This is somewhat typical for optimally seeded (>2 percent) anammox reactors.

OLSD: Due to limited quantity of the biozeolite initial seed available (<2 percent), it took almost 12 months for the pilot reactor to reach its target loading and performance. In addition, a disruption to the biofilms, formed around biozeolite, caused by the placement method employed for initial seeding may had also contributed to the lengthy start-up time. The colonized biozeolite (seed) was poured into the reactor through the 10-foot openings on top of the reactor, causing shearing of the biofilm already established in the biozeolite seed. With careful planning, this issue can be avoided for future start-ups.

Volumetric Ammonia Loading Rate

Suspended-growth anammox: The average volumetric ammonia loading rate was 0.36 and 0.53 kg-N/m^3/d for the suspended-growth anammox reactors at EBMUD and SFPUC, respectively. These loading rates achieved are comparable to the design loading rate for a DEMON® system without a patented cyclone device (0.5 kg-N/m^3/d) (Personal conversation with Dr. Bernhard Wett), but lower than that with a cyclone (up to 1.0 kg-N/m^3/d). The ammonia loading rates for full-scale SBR anammox plants were reported to be in the range of 0.04–0.65 kg-N/m^3/d (Lackner et al., 2014).

Starting in October 2015, THP centrate was diluted and introduced to the suspended-growth SBR reactor for the SFPUC test at a 20:80 (THP: conventional centrate, v/v) mixture. After 19 days of stable operation, the reactor feed was changed to a less diluted THP centrate (THP: conventional of 50:50). The reactor was fed with this 50:50 mixture for 20 days before a process upset occurred resulting in little to no anammox activity. The loading rate applied during the THP feeding scenarios was 0.75 kg-N/m^3/d, significantly higher than loadings achieved with conventional centrate feed.

Following the process upset, the suspended-growth SBR reactor was restarted using the same biomass by decanting the majority of the liquid within the reactor and DI water to dilute the concentrations of NOx within the reactor. Following this, the reactor was fed with conventional sidestream until early August 2016 when diluted THP sidestream feed commenced again. The dilution gradually decreased until late September when undiluted THP sidestream was fed to the reactor. The average load with undiluted THP sidestream was 0.53 kg-N/m^3/d, which is less than that of the previous THP period (0.75 kg-N/m^3/d). It should be noted that the lower loading rate found during this period is possibly from a reduced aeration intensity during aerated periods since one of the goals was to prevent another process upset. Regardless, the removal efficiencies obtained during this period were found to be slightly lower, with nitrite steadily building up over time which could be indicative of inhibition of some of the biomass possibly leading to a process upset. Further study would be required to determine the cause of inhibition.

Evaluation of the IFAS process in treating THP sidestream was ongoing as of the writing of this report and data will be provided once collected.

Attached-growth anammox: The ammonia loading rates obtained by the attached-growth reactors were 0.56 at EBMUD and 0.98 kg-N/m^3/d at SFPUC (MBBR). The loading rate found by EBMUD is comparable to the design loading rate (0.6 kg-N/m^3/d) for an ANITA™ Mox MBBR with K1 plastic media (WERF, 2014). At SFPUC, installation of a clarifier (March 2015) following the attached-growth reactor had significantly increased its ammonia loading rate to an average of 2.82 kg-N/m^3/d (peak of 3.6 kg-N/m^3/d), which is comparable to the ANITA™ Mox IFAS N-loading rate. If accounting for the clarifier volume, the volumetric ammonia loading rate for the system was approximately 1.63 kg-N/m^3/d on average (2.08 kg-N/m^3/d peak).

Zeolite-anammox: The anammox loading rate based on total zeolite media of 18,000 gallons was estimated to be approximately 0.32 kg-N/m^3/d (feeding with 8 gpm of sidestream containing 500 mg-N/L ammonia), when the reactor at OLSD was fully functional after 12 months.

The SFPUC zeolite-anammox reactor reached an average ammonia loading rate of 0.46 kg-N/m^3/d and a peak of approximately 0.68 kg/m^3/d. Under constant flow conditions, higher loading rates were achieved but resulted in less than optimal removals and process instability. The process instability issue was resolved after the pH-based control was instituted in November 2014, which reduced the reactor feed flow and loading rate.

CANDO: Pilot testing of the CANDO process is still ongoing and the process has not yet been optimized. Since Reactor 2 is not yet fully operational the total volumetric ammonia loading rate cannot be calculated. Currently, the ammonia loading rate for Reactor 1 is 0.64–0.73 kg-N/m^3/d. During prior bench-scale studies designed to optimize removal rates rather than loading rates, the total volumetric ammonia loading rate was 0.085 kg-N/m^3/d. One of the major goals of the ongoing pilot test is to increase the loading rate of the two reactors of the CANDO system.

Pilot Performance of Ammonia, TIN and TN Removals

EBMUD: Both the suspended- and attached-growth anammox reactors at EBMUD consistently showed a TN removal above 80 percent (with few exceptions considered as outliers). EBMUD sidestream had sufficient COD that could be used to remove anammox-generated nitrate through denitrification. The TIN and ammonia removal percentages were both high at above 90 percent and they were also very close due to low nitrite and nitrate in the treated effluent.

SFPUC: Similar to EBMUD's experience, TIN and ammonia removal percentages were both being at or above 70 percent and 85 percent, respectively, with low nitrite and typical nitrate concentrations in the effluent. Removals were highly dependent upon the amount of alkalinity available which varied greatly in the SFPUC's pilot due to manual addition of baking soda. Full-scale facilities would likely not experience this issue and have higher and more consistent removal performances.

OLSD: The sidestream containing approximately 500 mg-N/L ammonia, the system was operated to meet arbitrary effluent goals of 100 mg-N/L ammonia and 100 mg-N/L nitrate, corresponding to 80 percent ammonia removal, and 60 percent TIN removal, through controlling contact/detention time. The actual ammonia and TIN removal obtained (Phase 3) was approximately 47 and 48 percent respectively, lower than the targets. This was because by the time the anammox was mature in Phase 3, the nitrifying efficiency had dropped off due to partial clogging of the aerated layer. This indicates that the symbiosis of nitrifiers and anammox is a key component of the zeolite-anammox system.

DD: Pilot testing of the CANDO process is still ongoing and the process has not yet been optimized. Results of bench-scale studies conducted in 2013-14 demonstrated an ammonia removal of 95 percent, a nitrite to nitrous oxide conversion of 78 percent and a total nitrogen removal efficiency of 98 percent. Initial testing of the un-optimized pilot-scale system demonstrated nitrite removal of 60 to 70 percent, with 70 to 85 percent conversion to N_2O.

Process Stability and Upset

EBMUD: The pilot experienced an irrecoverable process upset in late June of 2014 (12 months after initial anammox or RAS seeding) during which project staff was still trying to grow anammox and increase the ammonia loading rate. Accumulation of nitrite concentrations from 16 mg-N/L to as high as 160 mg-N/L was observed over a one-week period. This nitrite level was significantly higher than the normal operational target of 20 mg-N/L. In response, aeration time and ammonia loading rate were reduced during that period, but appeared insufficient. A subsequent shutdown of the sidestream feed and aeration to both reactors eventually reduced the nitrite level down to below 20 mg-N/L; however, a sharp drop in nitrogen removal efficiencies suggested that anammox activity might have been already lost after this unfortunate event. Attempts to recover the anammox activity for the subsequent three months were unsuccessful and the pilot testing was therefore terminated in September 2014. With the data collected around this catastrophic process upset, the root cause leading to the nitrite accumulation was never determined. Potential factors may include: changes or toxicities in the sidestream feed; a significant increase of ammonia loading rates about 7 to 10 days prior to the upset (switching from diluted sidestream to undiluted sidestream); potential vulnerability to process upset due to the lack of established or granular biomass; and other unknown causes.

Anammox process upsets like these are not unprecedented and highlight the need for careful process monitoring and further process automation especially for nitrite concentration, which has been reported as the most crucial parameter to monitor. About 50 percent of full-scale plants have reported process upset issues related to nitrite build-up (Lackner et al., 2014). However, based on literature reviews, there is no consensus on what should be considered as safe nitrite levels and exposure duration for the anammox process. The reported concentrations span over a wide range from <5 mg-N/L for DEMON® SBR (Wett, 2006) to higher than 182 mg-N/L (Egli et al., 2001).

SFPUC: No process upsets occurred when feeding conventional sidestream (approximately 1,600 mg-N/L); however, after feeding a 50:50 (THP:conventional, v/v) mixture to the suspended-growth reactor for 20 days, significant reduction in removal performance occurred with almost no anammox activity after roughly one week. Ammonia and nitrite concentrations increased from 323 and 2.71 mg-N/L respectively to 771 and 652 mg-N/L. Average ammonia feed concentration with the 50:50 mix was 1,797 mg-N/L with an average and peak ammonia load of 0.75 and 0.925 kg-N/m^3/day. No changes were made to the pH setpoints, aeration/anoxic times, or fill/react times. Although the ammonia loads were much higher than previously found, they were typical for the 20-day period during which this feed source was used. Other measured parameters during this period including total and soluble CODs, TSS, VSS, PO_4, and alkalinity were all around typical values. Because nearly a week went by before the upset was found, the exact cause of this upset is unclear.

In August 2016, SFPUC replicated at slightly lower ammonia loading conditions while increasing the frequency of analysis performed to provide a more detailed look at conditions within the reactor during THP sidestream feeding. During this testing, the system did not experience a similar process upset to the prior event, though it was loaded to a lesser degree (average 0.47 and peak 0.64 kg-N/m^3/day). Nitrite levels were found to be increasing as THP sidestream in the feed mixture increased, with nitrite increasing from 6 mg-N/L initially to over 300 mg-N/L when undiluted THP sidestream was fed. The reactor was fed undiluted THP sidestream for nearly one month and it is unclear if the nitrite levels would have eventually reached a high enough level to cause inhibition. Since it’s unclear the cause of the inhibition, design of future sidestream treatment processes treating THP sidestream would require careful consideration of means of mitigating inhibition effects on the biomass.

OLSD: A combination of high influent TSS loading from sidestream feed and algal growth in the top layer of the zeolite media caused short-circuiting in treatment for some parts of the zeolite-anammox reactor. However, pretreating sidestream with a coneshaped clarifier removed TSS effectively, and covering the zeolite-anammox reactor tank prevented algal growth.

DD: Pilot testing of the CANDO technology is not complete. Thus far there have been several perturbations in the process such as inefficiencies due to probe malfunctions, equipment failures, and power outages that have caused missed dosing of acetate in Reactor 2 and high level of COD in Reactor 1 that have prevented the decoupling of nitrite reduction and COD consumption in Reactor 2.

Table 3-3. Pilot Test Results Summary

	Typical Range for Anammox Application	EBMUD Anammox[1]		SFPUC Anammox (Treating Conventional Sidestream)			OLSD	DD CANDO[2] (Test ongoing, stable operation not reached yet)		
		Suspended	**Attached**	**Suspended**	**Attached**	**Biozeolite**	**Biozeolite**	**Reactor 1: Nitritation**	**Reactor 2: CANDO**	**Combined System**
Key sidestream characteristics[3]										
Ammonia-N concentration (mg-N/L)	200–2,000	1,940 ±161		1,597 ±143			478 ±74 (Phase 3)	1,355–1,630		
Alkalinity concentration (mg/L as $CaCO_3$)		7,742 ±437		5,384 ±641 (w $NaHCO_3$ addition of ~800-1,700 mg/L as $CaCO_3$)[4]			1,200–1,500	5,000–5,300		
Alkalinity/Ammonia-N ratio	>4	4.0 ±0.4					2–3[6]	3.2–3.3		
Temperature (°C)	20–35	ambient, ~20		ambient			21–27	30–35		
Total COD (mg/L)		5,711 ±3,005		2,238 ±1,146			N/A	950–1,120		
Soluble COD (mg/L)		1,168 ±272		1,350 ±617			200[5] (37[5] for BOD)	470–552		
Soluble COD/Ammonia-N ratio	<1	0.6 ±0.1		0.85			0.48[5, 6]	<0.5		
TSS (mg/L)	<2,000	1,190 ±1,341		TSS 626 ±276 VSS (509±189)			150[7] (40–4,000)	85–323		
Process Control										
pH range		7.5–7.53		6.99–7.25	6.94–7.25	6.90–7.25	6.5–7.5		<9.0	
DO range		0–0.5		0-5 being measured			0.1–8			
Temperature (°C)	30–35 (>20)	~30		30–35			21–27	30–35	22–28	
Others		NO_2^- Conc.								Acetate Conc.

	Typical Range for Anammox Application	EBMUD Aanmmox[1]		SFPUC Anammox (Treating Conventional Sidestream)			OLSD	DD CANDO[2] (Test ongoing, stable operation not reached yet)		
		Suspended	Attached	Suspended	Attached	Biozeolite	Biozeolite	Reactor 1: Nitritation	Reactor 2: CANDO	Combined System
Process performance										
Specific/volumetric ammonia loading rate (kg-N/m[3]-reactor/day)	DEMON® SBR design 0.6–0.75–1.0 MBBR design 1.0	0.36 ±0.14 (0.6 peak)	0.56 ±0.10 (0.7 peak)	0.53 (1.1 peak)	MBBR: 0.98 avg (1.23 peak) MBBR/IFAS (MBBR reactor only): 2.82 avg (3.6 peak) MBBR/IFAS system: 1.63 avg (2.08 peak)	0.46 avg (0.68 peak)	~0.32	0.64—0.73	TBD	TBD (Bench 0.085)
Ammonia removal efficiency (%)	DEMON® typical 90% MBBR typical 80–85%	95 ±3%	97±2%	86%	84%	87%	80% (target) 47% (actual Phase 3[8])	TBD	TBD	TBD (Bench 95%)
Inorganic Nitrogen removal efficiency (%)	DEMON® typical 80% MBBR typical 70–75%	92 ±4%	95 ±3%	78%	75%	87%	60–80% (target) ~48% (Phase 3[8])	TBD	TBD	TBD (Bench 95%)
Total Nitrogen removal efficiency (%)	75-–85%	84 ±6%	89 ±5%	71%	68%	79%	60% (target)	TBD	TBD	TBD (Bench 98%)
Chemical additions	Alkalinity Org. Carbon	No No	No No	Yes[4] No	Same as left	Same as left	No No	Yes	 Yes	Yes Yes

1. Results presented here (March 3–June 30, 2014) were obtained prior to an irreversible process upset occurred in late June 2014 that terminated the pilot testing in September 2014; 2. Pilot test is still progressing and steady-state has not been reached yet. TBD = To Be Determined. Results listed are from previous bench-scale testing; 3. Results here are measured for samples taken from the sidestream feed storage tanks used for pilot testing; 4. Supplemental alkalinity was necessary due to $FeCl_3$ addition prior to dewatering at SFPUC's Southeast Plant; 5. Based on a single measurement at the beginning of the pilot project; 6. The Alk/N ratio averaged at 4.3 and sCOD/N ratio averaged at 0.38 during the three sidestream sampling events conducted in July 2015 for undiluted sidestream; 7. Insufficient data to determine TSS within reasonable confidence limits (40–4000 mg/L for Phase I, 44–475 mg/L for phase 2); 8. The actual removal obtained (Phase 3) was lower than the targets. This was because by the time the anammox was mature in Phase 3, the nitrifying efficiency had dropped off due to partial clogging of the aerated layer. This indicates that the symbiosis of nitrifiers and anammox is a key component of the zeolite-anammox system.

3.5 Conclusions

To date, the anammox pilot testing at the EBMUD and OLSD sites have been completed, while the pilot testing at SFPUC (on anammox process for THP sidestream treatment) and DD (on CANDO process) are still ongoing (**Figure 3-2**). Detailed pilot testing results are shown in **Table 3-3** and a high-level summary of the findings is presented in **Table 3-4**. The data from demonstration test of Krüger's ANITA™ Mox conducted at the USD is also included in **Table 3-4** for comparison purpose.

EBMUD test of the suspended- and attached-growth anammox found that:

- Anammox bacteria grew well on EBMUD sidestream containing approximately 2,000 mg-N/L ammonia prior to the process upset, during which high ammonia (>90 percent) and TN removals (>80 percent) were obtained at ammonia loading rates of 0.36 and 0.56 kg-N/m^3/d for the suspended- and attached-growth reactors, respectively
- Anammox bacteria can be grown from nitrifying activated sludge using the EBMUD start-up strategy, reached an ammonia loading rate of approximately 0.5 kg-N/m^3/d in approximately 11 and 8 months for the suspended- and attached-growth anammox reactors, respectively
- The attached-growth anammox reactor allowed a higher ammonia loading rate in a shorter time compared to the suspended-growth reactor; however, neither process was optimized
- Operating anammox pilot reactors required a high level of monitoring and continuous adjustment, which highlighted the need for further process automation
- Anammox pilot was not as resilient as expected—the reactors could not recover from a process upset despite a three-month recovery effort
- Further testing is recommended to ensure the resiliency and reliability of anammox processes under various feed and operating conditions

SFPUC test of suspended-, attached- and zeolite-anammox processes found that:

- Anammox processes performed well when treating conventional sidestream with an average ammonia concentration of approximately 1,600 mg-N/L, during which high ammonia (approximately 85 percent) and TN removals (68 to 79 percent) were obtained, with the attached growth reactor having the highest loading of the three processes
- A pH-based control strategy was found to provide a stable environment for anammox growth and is a relatively easy control strategy to implement
- Operating anammox pilot reactors requires a high level of monitoring and continuous adjustment, which highlights the need for further process automation
- Test on sidestream generated from a THP-pretreatment digestion process is still ongoing. Process upset experienced but cause is unclear. Further testing is recommended to ensure the resiliency and reliability of anammox processes under various feed and operating conditions

- Design of future sidestream treatment processes treating THP sidestream would require careful consideration to mitigate potential inhibition effects on biomass

OLSD test on the zeolite-anammox showed that:

- Anammox bacteria grew well on OLSD sidestream (with 1:1 dilution when generated) containing about 500 mg-N/L ammonia
- The start-up period was heavily dependent on the volume of initial biozeolite media and can range from 7 weeks with 10 percent biozeolite seed (bench test) to 12 months with <2 percent seed (pilot test)
- Operating the zeolite-anammox reactor required a low level of monitoring and adjustments—the process was primarily self-regulating after reaching maturity
- High concentrations of TSS and/or soluble COD in sidestream feed tend to block the zeolite media—removing them will be necessary for future full-scale application to prevent short-circuiting in treatment
- Algae affected this system by combining with biofilm and TSS to form a waterproof layer—excluding direct sunlight solved the issue effectively
- The anammox bacteria in the zeolite-anammox system were much more resilient than expected (based on earlier research and tests conducted during 2010 to 2013)

DD preliminary results on the ongoing CANDO test showed that:

Nitritation Reactor (i.e., Reactor 1)

- Start-up time was 3 weeks from the day of inoculation of the nitritation reactor with nitrifying activated sludge seed (55 gallons) to stable operation at a loading of 0.64–0.73 kg-N/m^3/d of ammonia
- The nitritation reactor showed reproducible performance with high conversion of ammonia to nitrite (>90%) and partial removal of total nitrogen (~35%), likely as nitrous oxide
- Analysis of the ammonia-oxidizing microbial community provided strong evidence for heterotrophic nitritation, with *Xanthomonas* species enriched over autotrophic ammonia oxidizing bacteria, *Nitrosomonas* at temperatures of 30–35 ^{0}C. Nitritation was generally robust and able to withstand extended durations without aeration, ammonia feed or power. Restart and recovery of the reactor was rapid
- High levels of ammonia removal were experienced over a broad range of pH values from 6.5 to 9. A pH set point of 7.0 was used during most of the pilot testing
- Ammonia oxidation stopped when a pH probe failed, and pH decreased to 6 for an extended period of time (>24 hours)
- Actual DO concentration is not critical for control as long as nitrate concentrations remain below 2–3% of TKN, however pulsing of the aeration is critical

- Controlling ammonia concentration is not critical as long as ammonia levels are less than 400 mg/L, once initial AOB bacteria is cultivated
- Maintaining a temperature of 30–35 ^{0}C is critical for optimum ammonia removal, however, high levels of ammonia removal were observed with temperatures as low as 20 ^{0}C
- The nitritation reactor currently requires the addition of Sodium Hydroxide (base) for pH control, which could become costly at full scale
- Centrate feed line to Reactor 1 was frequently plugged causing inconsistent feeding due to struvite formation and solids settling in the centrate feed. However, when centrate was continually mixed, struvite and plugging issues were not present. Mixing was stopped due to TSS and COD carryover to Reactor 2

CANDO Reactor (i.e., Reactor 2)

- Minimum duration of each cycle for the CANDO reactor has not been identified. At startup, cycles ranged from as high as 24 hours to as short as 11 hours
- Accurate dosages of nitrite and COD during start-up are critical to decouple nitrite reduction and COD consumption
- Decoupling of nitrite reduction and COD consumption is critical to the selection and production of nitrous oxide over nitrogen
- Reactor 2 is mixed constantly, except during a one (1) hour decant step
- There are a lot of settings and controls related to Reactor 2 operation which increases the possibility of equipment or system failures
- No temperature control is necessary for Reactor 2
- Air or nitrogen gas must be used at the end of each batch to strip nitrous oxide from the liquid
- Biodegradable COD carryover from the nitritation reactor can prevent the decoupling of nitrite reduction with COD consumption in the CANDO reactor leading to complete reduction of nitrite to nitrogen rather than nitrous oxide
- Reactor 2 currently requires the addition of Sodium Acetate (COD source) as well as Hydrochloric Acid (pH control) which could be costly in a full scale operation. It is envisioned that fermented waste activated sludge could be used as the COD source, but this has not yet been tested
- CANDO reactor pilot scale has been unable to reproduce results shown in bench scale. Further testing is necessary to learn how to select nitrous oxide producing bacteria
- A potential source of carryover COD from the nitritation reactor is the polyamine coagulant used in the digestate dewatering process

Table 3-4. Summary of Pilot Test Findings

	Suspended-growth Anammox (EBMUD; SFPUC[1])	Attached-growth Anammox (EBMUD; SFPUC[1])	Zeolite-anammox (OLSD; SFPUC[1])	Attached-growth Anammox (Krüger ANITA™ Mox) (USD)
Ammonia conc. tested (mg-N/L)	1,940; 1,597	1,940; 1,597	478; 1,597	1,224
Ammonia loading rate achieved (kg-N/m³/day)	0.36; 0.53	0.56; 0.98	~0.32; 0.46	0.86
Ammonia-N removal (%)	95; 86	97; 84	47 (target 80); 87	84
TIN removal (%)	92; 78	95; 75	~48 (target 60); 87	72
TN removal (%)	84; 71	89; 68	Not available; 79	71
Chemical addition - alkalinity - carbon	 No; Yes No; No	 No; Yes No; No	 No; Yes No; No	 No No
Start-up time (months) to reach a certain ammonia loading rate (initial seeding)	11[2] to reach 0.5 kg-N/m³/day (seeded with 15% RAS and 0.38% anammox); ~3[3] to reach 0.8 kg-N/m³/day (50% mixed seed)	8[2] to reach 0.5 kg-N/m³/day (seeded with 3% RAS); ~3[3] to reach 0.8 kg-N/m³/day (seeded with ~50% mixed RAS and anammox seed)	12[4] to reach 0.32 kg-N/m³/day (seeded with <2% biozeolite); 3 to reach 0.46 kg-N/m³/day (100% biozeolite seed)	0.5 (reactor was filled with pre-colonized Anoxkaldnes biofilm carriers with anammox activity, corresponding to 50% of the overall reactor volume)
Process upset experienced	Yes; No with conventional centrate, but Yes with 50:50 (THP and conventional centrate) mixture	Yes; No with conventional centrate	Yes due to media clogging; No with conventional centrate	Demonstrated great resilience to process upsets and varying operational conditions
Factors to consider for future scale-up	-Removal of sidestream TSS -Sidestream dilution or not -Process reliability -Temperature	Same as left	- Removal of sidestream TSS and sCOD - Sunlight undesirable	The continuous, undiluted centrate feed flow mode offers superior performance in ammonia and TIN removal, compared to the other operational conditions tested (e.g., intermittent and/or diluted feed)

1. Data here are from SFPUC tests with conventional sidestream
2. Time to reach an ammonia loading rate of approximately 0.5 kg-N/m³/d at EBMUD site
   - For the suspended-growth reactor: counting from the initial anammox seeding
   - For the attached-growth reactor: counting from one month after the initial RAS seeding (time spent to implement proper control strategy)
3. After a proper control strategy was implemented to reach the design loads at SFPUC site
4. During OLSD's Phase 1 test, six 50-gallon reactors were seeded with –10 percent biozeolite (by volume). The system was fully operational after 7 weeks (data not shown)

Results showed that these new cost-effective nitrogen removal technologies can treat sidestreams with average ammonia concentrations ranging from approximately 500 to 2,000 mg-N/L. The start-up time required for anammox-type processes was 3 to 12 months, depending on the amount and type of initial seed available. The anammox processes can handle average ammonia loading rates of 0.32 to 0.98 kg-N/m^3 reactor/d and provide 47 to 97 percent ammonia and 48 to 95 percent inorganic nitrogen removals. Significant increase of ammonia loading to 1.63 kg-N/m^3 reactor/d was obtained with the MBBR/IFAS setup. Process upsets were experienced for the anammox pilot testing at both the EBMUD and SFPUC sites when treating unconventional sidestreams.

Future work is recommended to:

- Ensure the resiliency and reliability of anammox processes under various feed and operating conditions especially for treating the unconventional sidestreams at relative high ammonia loading rates
- Optimize and automate process monitoring and control system
- Further evaluate the need for pretreatment of incoming TSS in sidestream feed
- Mitigate potential inhibition effects when design future sidestream treatment processes treating unconventional sidestreams
- Consider process reliability and lengthy time needed to restart when process upsets occur

In addition, potential impact of sidestream temperature (especially following thermophilic digestion) on process performance was not evaluated in this study, but should be considered in full-scale application.

CHAPTER 4 – SIDESTREAM NUTRIENT LOAD REDUCTION AND COST ESTIMATION

4.1 Introduction

To support the larger regional effort in evaluating nutrient reduction strategies to the San Francisco Bay, potential nutrient load reduction and costs are quantified for sidestream treatment if it were implemented by Bay Area Wastewater Treatment Plants (WWTPs). This chapter summarizes the findings for identifying WWTPs that are potentially amenable for sidestream treatment, the corresponding potential load reductions, and the costs.

4.2 Objectives

The objectives of this chapter are as follows:

- Develop a systematic strategy to identify potential WWTP candidates for sidestream treatment
- Quantify the extent of nutrient discharge load reduction via sidestream treatment to each Subembayment and the overall Bay
- Develop a list of sidestream treatment facility needs and corresponding unit costs for WWTPs deemed amenable to sidestream treatment

The nitrogen removal costs developed for sidestream treatment can be compared against other nutrient load reduction strategies (such as wastewater treatment plant optimization and upgrades) currently under development for the region. In addition, coordinating the nutrient reduction assessment effort for all 37 participating WWTPs in the Bay Area provides a uniform assessment of strategies and costs to help make informed decisions if nutrient removal is required in the future.

4.3 Methodology

This section outlines the approach and methodology employed (**Figure 4-1)** to address this effort.

A questionnaire was developed and distributed to all 37 participating WWTPs (shown in **Figure 4-2**), through coordination with the Bay Area Clean Water Agencies (BACWA), to request general plant information, historical plant performance data, a description of discharge requirements, and relevant operational information. This information was used to determine if the WWTP generates a nutrient-rich sidestream, and therefore could be a potential candidate for sidestream treatment from an initial screening (32 out of 37 WWTPs identified).

Following the compilation of information, a subsequent data inquiry and sampling request were issued to 32 WWTPs. The information gathered on biosolids operations (e.g., dewatering frequency) from this subsequent request was used to further identify WWTPs potentially amenable to sidestream treatment. The sampling request was to address the lack of existing nutrient data in sidestreams. Three massive sampling events were coordinated in July 2015 to collect sidestream samples from these 32 WWTPs to analyze key nutrient parameters in their respective sidestreams. In addition to collecting data through questionnaires, a plant site investigation team composed of process and operational experts performed site visits to all the participating WWTPs to better understand each plant and verify information collected.

Started with all 37 BACWA participating WWTPs

Collect plant and sidestream data (via questionnaire and site visits)
- Flow, with or without washwater
- Nutrient concentration
- Temperature, other relevant data (e.g., pH)
- Dewatering operation schedule, such as seasonally or year-round, # of days/week, etc.

Identify potential sidestream treatment candidate WWTPs
Assumed it is a sidestream treatment candidate if the plant
- Generates year-round sidestream flow, and
- Dewaters at least 4 days per week (to produce a steady flow without requiring a large amount of equalization volume)

Estimate sidestream nutrient load
- Sidestream flow
- Nutrient concentrations

Conducted three sampling events from each of the 32 potentially eligible WWTPs
- Soluble COD
- Alkalinity
- Ammonia, TKN
- Total Phosphorus
- Orthophosphate
- pH
- Temperature

Quantify nitrogen load reduction potential due to sidestream treatment based on
- List of candidate WWTPs for sidestream treatment
- Sidestream nutrient loads for the candidate WWTPs
- Nitrogen removal efficiency assumed

Assumed Treatment Technology and Nitrogen Removal Efficiency
- Assumed anammox-type of treatment technologies, or conventional nitrification if there is a concern on sidestream temperature being relatively low (e.g., <20 ^{0}C).
- Assumed nitrogen removal by sidestream treatment **(Table 4-3)**

Estimate costs for sidestream treatment ($/lb N removal)
- Capital
- O&M

Chemical Oxygen Demand (COD) using Standard Methods SM 5220D, Alkalinity (SM 2320B), Total Kjeldahl Nitrogen (TKN) (SM 4500Norg B), Total Phosphorus (SM 4500-P E), and Orthophosphate (EPA Method 300.0)

Figure 4-1. Sidestream Nutrient Load Reduction and Costs Estimation for 37 WWTPs in the Bay Area

4.4 Results and Discussions

4.4.1 Plants Eligible for Sidestream Treatment

Table 4-1 presents the potentially eligible plants for sidestream treatment based on Total Nitrogen (TN) and ammonia removal goals, divided by Subembayment. The preliminary findings suggest that 25 out of 37 WWTP are candidates for sidestream treatment, if reducing total nitrogen in WWTP effluent discharge to the Bay is the goal. The plants not deemed candidates were attributed to: no sidestream to treat, or infrequent dewatering options (i.e., seasonal sidestreams and/or insufficient dewatering days per week), and/or water quality characteristics not amenable to sidestream treatment (e.g., pH greater than 10 from lime stabilization), or others. However, if reducing ammonia is the goal, 16 of the 37 WWTPs are candidates for sidestream treatment. These plants further excluded those already fully nitrify (but do not denitrify), because nitrifying plants are unlikely to benefit from sidestream treatment in reducing additional ammonia discharge load, as sidestream is normally returned back to the plant headworks or after the primary clarification and hence would be nitrified in the main liquid stream treatment.

Table 4-1. Potential Eligible Plants for Sidestream Treatment by Subembayment

Subembayment[1]	Initial Screen: Eligible for Ammonia Reduction	Refined Estimate[2]	
		Eligible for Ammonia Discharge Reduction to the Bay	Eligible for Total Nitrogen Discharge Reduction to the Bay
Suisun Bay	4	1	3
San Pablo Bay	9	1	4
Central Bay	5	4	5
South Bay	12	10	11
Lower South Bay	2	0	2
Total	**32**	**16**	**25**

1. Refer to **Figure 4-3** for subembayment
2. Preliminary pending WWTP review. Refer to **Appendix C** for details

4.4.2 Sidestream Nutrient Load

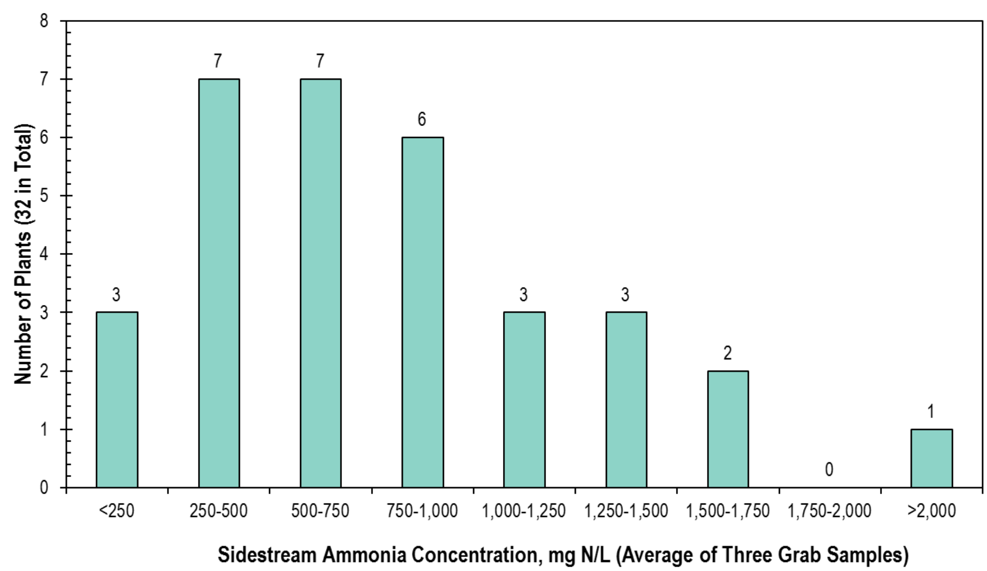
Table 4-2 summarizes the sidestream nutrient concentrations measured for the 32 WWTPs from the three massive sampling events coordinated in July 2015. The results indicated a wide range for all the parameters being measured. The ammonia concentration results are presented as a distribution in **Figure 4-2**.

Table 4-2. Sidestream Characteristics of 32 Bay Area WWTPs (non-weighted)

Parameter	Units	Average	Range
Ammonia	mg-N/L	832	67—2,224
TKN	mg-N/L	1,286	84—4,000
Soluble COD (sCOD)	mg/L	598	66—6,400
Alkalinity	mg/L as $CaCO_3$	3,513	500—15,000
Ortho-Phosphate	mg-P/L	98	0.3—816
Total Phosphorus	mg-P/L	228	4.4—1,300
sCOD/Ammonia-N	unitless	1.2	0.2—10
Ammonia/TKN	%	71%	11—120
Ortho-P/TP	%	57%	2—151
Alkalinity/Ammonia-N	unitless	5.4	2—91
Temperature[1]	^0C	31	20—45

Samples were analyzed by Alpha Analytical Laboratories, Ukiah, CA

1. Measured in-situ by WWTPs staff



July 2015 Sampling Events

Figure 4-2. Bay Area 32 WWTPs Sidestream Ammonia Concentration Distribution

The current sidestream flow rate information was collected in the questionnaire, projected to the plant permitted capacity using the current average annual sidestream flow with respect to the raw plant influent flow.

$$SidestreamFlow_{Permitted} = \frac{SidestreamFlow_{Current}}{PlantFlow_{Current}} \times PlantFlow_{Permitted}$$

The sidestream nutrient loads were quantified using the sidestream flow and nutrient concentration data.

4.4.3 Quantify Nutrient Load Reduction via Sidestream Treatment Across the Bay

Two different nitrogen removal technologies were considered for removing nitrogen from the sidestream, deammonification or conventional nitrification treatment technologies. Deammonification was the default technology due to its well documented energy and chemical savings. However, if a low sidestream temperature (e.g., less than 20 $^{\circ}$C) is anticipated, conventional nitrification was used as the deammonification process prefers a relatively high temperature (e.g., 25 to 35 $^{\circ}$C optimal). It is worth noting that the technologies considered here were limited to these two, solely for the purpose of estimating nutrient load reduction potential and costs.

For both technologies, a 90 percent ammonia removal and 80 percent total inorganic nitrogen removal were assumed for calculating nitrogen removals for sidestream treatment. These removals are industry accepted performance values and in the range of what were obtained from the pilot testing (refer to **Table 3-4**). An example calculation of the nutrient (nitrogen) load reduction by sidestream treatment for nitrogen removal is provided in **Table 4-3**. In this example, the organic nitrogen component is assumed to be inert.

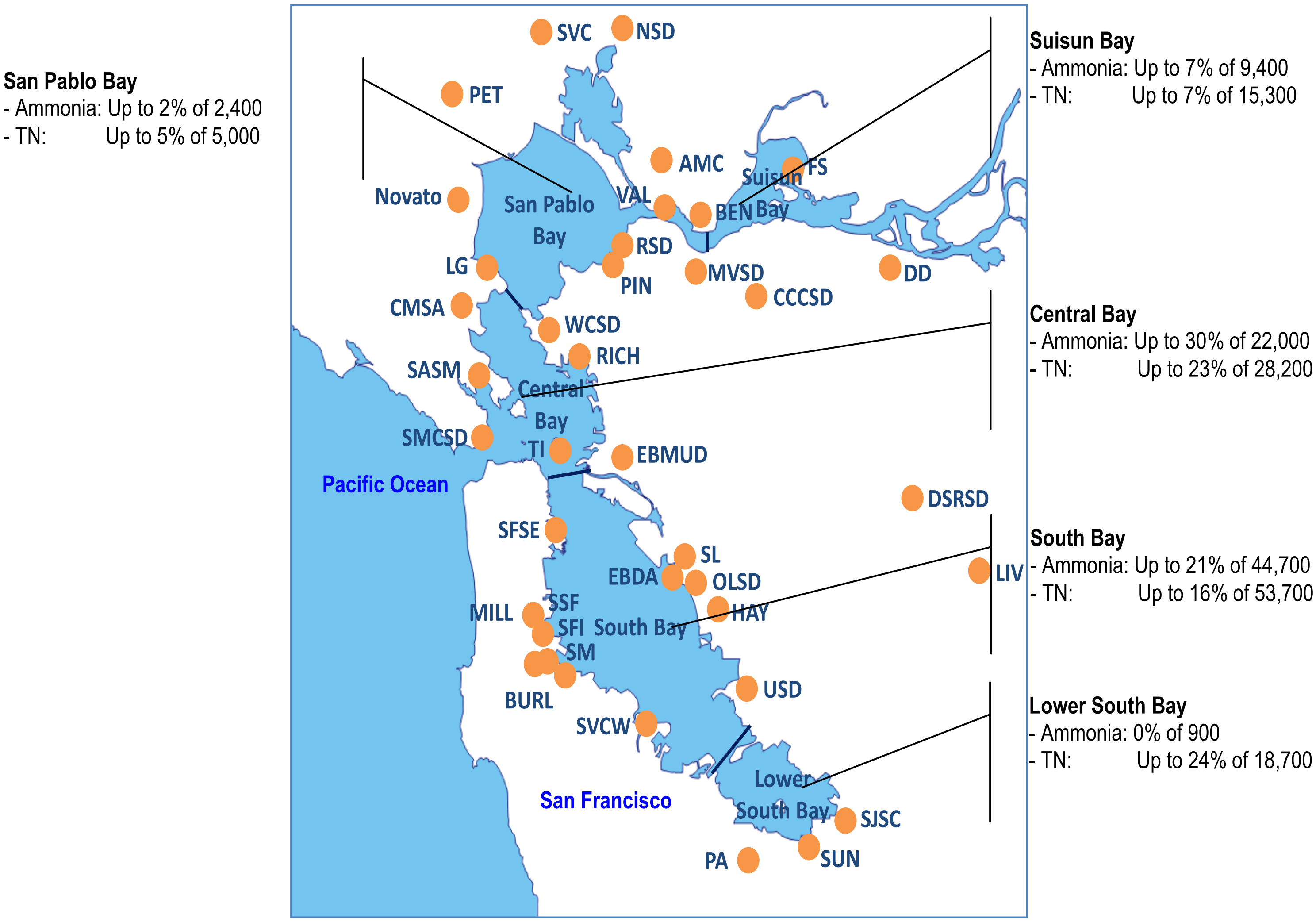
Table 4-3. Example Nitrogen Load Reduction Calculation for Sidestream Treatment

Parameter	Units	Ammonia[1]	Organic Nitrogen	TKN (Ammonia + Org N)	Nitrite + Nitrate (NOx)	Inorganic Nitrogen[2] (Ammonia + NOx)	Total Nitrogen[2] (TKN + NOx)
Sidestream Feed	kg N	100	35	135	0	100	135
Sidestream Effluent	kg N	10	35	45	10	20	55
% Reduction	%	90%	0%	67%	–	80%	59%

1. Assumes 90% ammonia removal in sidestream treatment reactor which is an industry accepted performance value (Bowden and Stensel, 2015)
2. Assumes 80% total inorganic nitrogen removal in sidestream treatment reactor which is an industry accepted performance value (Bowden and Stensel, 2015)

Figure 4-3 presents the potential ammonia and total nitrogen load reduction by sidestream treatment in comparison to the current WWTP nutrient discharges to the Bay (BACWA/HDR, 2016). The potential ammonia load reduction varies widely by Subembayment. The Lower South Bay has a value of zero as all three plants currently fully nitrify, thus implementing sidestream treatment would not reduce their ammonia discharge loads. The total nitrogen load reduction if all candidate plants implemented sidestream treatment is estimated to be up to 17 percent across the Bay.

San Francisco Bay Wide
(Potential load reduction with sidestream treatment percent of the rounded current nitrogen discharge loads[1])
- Ammonia[2]: Up to 21% of 79,400 lb N/d, or 16,800 lb N/d
- TN[2]: Up to 17% of 121,000 lb N/d, or 21,000 lb N/d



1. Source: Group Annual Report (BACWA/HDR, 2016) Average of 2012–2016 (https://bacwa.org/wp-content/uploads/2016/09/Group-Annual-Report-2016_Final.pdf)
2. Refer to **Appendix C** for details

Figure 4-3. Preliminary Ammonia and TN Discharge Load Reduction Potential with Wastewater Sidestream Treatment in the San Francisco Bay Region

4.4.4 Sidestream Treatment Cost Estimation

The order-of-magnitude capital and O&M costs were estimated for sidestream treatment using either deammonification or conventional nitrification technology. The cost estimate was developed based on a 5 to 10 percent project definition and has an expected accuracy

range of -30 to +50 percent (refer to Cost Estimate Classification System by Association for the Advancement of Cost Engineering [AACE International], Class 4).
The facility needs of key process components and equipment that would be required to implement sidestream treatment were identified and listed in **Table 4-4**. Some plants may have existing facilities that can be used to reduce construction costs. For example, a few of the WWTPs have empty tanks that may be retrofitted to accept dewatering reject water and serve as a sidestream treatment basin. This analysis assumed new tankage for sidestream treatment.

The sidestream facilities were sized for a maximum month condition, whereby the peaking factor used to translate between average annual to maximum month was based on the current raw plant influent flow peaking factors (maximum month to average annual). The O&M costs include power, chemicals, and labor, not rehabilitation and replacement cost. Unit chemical costs were developed using information from the Bay Area Chemical Consortia. The sidestream facility needs and O&M costs were estimated to reflect the sidestream flow and nutrient loads at each WWTP's permitted capacity.

Table 4-4. Sidestream Treatment Facility Needs Assumption

Construction Elements	Deammonification Technology	Conventional Nitrification Technology
Feed Pumping	Yes	Yes
Feed Flow Equalization	Maybe; Dependent on Dewatering Operations	Maybe; Dependent on Dewatering Operations
Pretreatment Screens	Yes	Yes
Biological Reactor	Yes	Yes
Aeration Equipment	Yes	Yes
Alkalinity Supply/Storage	Maybe; most likely not unless the alkalinity to ammonia ratio is atypical	Yes

In order to compare sidestream treatment costs among WWTPs, and against other nutrient load reduction strategies as well as published literature values, the sidestream treatment cost (including both capital and O&M) is presented in the $ per pound nitrogen removal in the present value (PV) over the project life. This unit cost was calculated by assuming a project life-cycle of 30 years and 2 percent real discount rate. The annualized cost was divided by the mid-point average nutrient load reduction between current and permitted capacity.

Cost curves were developed independently for deammonification and conventional nitrification treatment options, and each considered five different values that covered the ammonia loading range of the sidestream treatment candidate WWTPs. It is well documented that the ability to provide sufficient aeration for municipal sidestream reactors is the limiting factor for sizing, which is why ammonia load was the chosen governing parameter.

Table 4-5 provides these estimated unit costs and they range from just under $1 per lb N removal to approximately $25 per lb N removal. The wide range is attributed to the different technologies coupled with economies of scale. The economies of scale is wide for this effort as the WWTPs range in permitted capacity from just over 1 mgd to 167 mgd in terms of the average dry weather flow. The cost curve developed will be consistently applied to each of the potential sidestream treatment candidate WWTPs for this study.

Table 4-5. Cost Curve for Sidestream Treatment with Various Design Loadings

Ammonia Loadings (lb N/d)	**# of WWTPs** (Ammonia/TN as the Load Reduction Objective for the Bay)	**Deammonification Technology** ($/lb N Removed)	**Conventional Nitrification Technology** ($/lb N Removed)
<250	3/6	15–17	22–25
250–1,000	4/5	3–5	6–8
1,000–2,500	4/8	1–3	3–5
2,500–8,000	3/3	1–2	2–3
>8,000	2/3	0.5–1.0	1–3

- Based on 30 years life cycle, 2 percent real discount rate
- The cost estimate was developed based on a 5 to 10 percent project definition and has an expected accuracy range of -30 to +50 percent (refer to Cost Estimate Classification System by Association for the Advancement of Cost Engineering (AACE International), Class 4)
- The O&M costs include power ($0.17/kWh), chemicals, and labor ($150/hr loaded rate). Unit chemical costs were developed using information from the Bay Area Chemical Consortia

It is important to note that this cost analysis assumed a Greenfield facility and didn't include land cost, site restriction, and plant specific requirements. In the future, a more thorough investigation and refined estimates of site-specific sidestream treatment capital and O&M costs are highly recommended. In addition to the cost, many other factors such as process reliability, regulatory implications, environmental sustainability, and nutrient removal versus recovery should be considered to make informed management decisions for nutrient load reduction.

4.5 Conclusions

Potential nutrient load reductions and costs are being quantified for the region to understand the extent of sidestream treatment in reducing overall wastewater nutrient discharges to the Bay. The preliminary findings suggest that 16 of the 37 WWTPs are candidates for sidestream treatment if reducing ammonia discharge loads is the objective. The plants not deemed candidates were attributed to a combination of those already fully nitrifying, no sidestream, infrequent dewatering options (i.e., seasonal sidestreams and/or insufficient days per week), sidestream wastewater characteristics not amenable to biological treatment (e.g., pH greater than 10 from lime stabilization), and others. The ammonia load reduction if the all candidate plants implemented sidestream treatment is up to 21 percent across the Bay.

The preliminary findings suggest that 25 out of 37 WWTPs are candidates for sidestream treatment if reducing total nitrogen loads is the objective. The plants not deemed candidates had similar attributes as those not amenable to ammonia load reduction (except full nitrification). The total nitrogen load reduction if all the candidate plants implemented sidestream treatment is up to 17 percent across the Bay.

Cost curves were developed for deammonification and conventional nitrifying technologies that ranged from under $1 to $25 per lb N removed (Class IV estimate) with the deammonification removal pathway being more cost effective than conventional nitrification. The conventional nitrification option assumed that nitrate formed in the sidestream would be removed biologically in the main plant headworks and/or primaries. The wide ranging unit cost was attributed to a combination of technology type and economies of scale as the WWTPs range in size from just above 1 mgd to 167 mgd permitted capacity.

Coordinating the nutrient reduction assessment effort for all 37 WWTPs provides a uniform assessment of strategies and costs for nutrient reduction to the Bay. The cost curves developed for nitrogen removal via sidestream treatment can be compared against other nutrient load reduction strategies under the Regional Nutrient Watershed Permit (San Francisco Bay Regional Water Quality Board, 2014). A unit cost comparison for the various permit requirements (e.g., sidestream treatment and plant upgrades) will provide invaluable information to help make informed decisions if nutrient removal is required in the future.

Besides unit cost and potential load reduction, additional factors should be considered to make an informed decision, such as:

- Process reliability, regulatory implications
- Siting options and space for sidestream deammonification or conventional nitrification
- Future plan for liquid stream nitrogen removal: is it more cost-effective to upgrade for both sidestream and mainstream treatment or mainstream treatment alone?
- Environmental sustainability
- Priorities in comparison to other planned capital improvement projects
- Resource recovery (P and/or N recovery)
- Solids processing modifications (THP, Combined Heat and Power, Thermophilic)
- Others

CHAPTER 5 – MODELING SIDESTREAM TREATMENT AT WWTP – BIOWIN/EXCEL TOOL

5.1 Introduction

This chapter presents a sidestream treatment modeling tool developed for Bay Area Wastewater Treatment Plants (WWTPs) to evaluate implementation of sidestream treatment technologies at their particular plant. The planning level process modeling tool estimates the treatment efficacy, design parameters, and Operation and Maintenance (O&M) costs associated with six different sidestream treatment technologies.

The tool and a user guidance manual are included in **Appendix D** of this report.

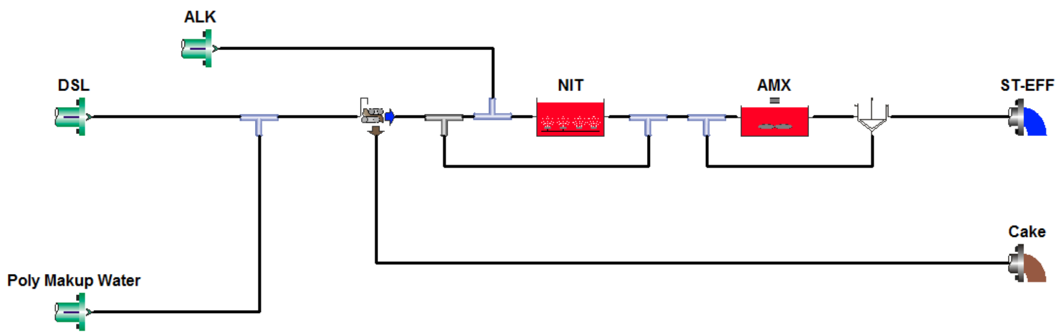
5.2 BioWin® Modeling

A series of process models were developed to simulate the following sidestream treatment technologies, using the industry accepted wastewater treatment process modeling software, BioWin®:

- Conventional Nitrification (SBR)
- Conventional Nitrification and Denitrification (SBR)
- Single reactor system for High activity Ammonium Removal Over Nitrite (SHARON®) Process (Nitritation and Denitritation)
- Deammonification (Suspended Growth)
- Deammonification (Attached Growth)
- Deammonification (Granular Growth)

BioWin® is based on the International Water Association Activated Sludge Model Number 2 and can simulate the activated sludge process performance under variable loading and operating conditions. It is used world-wide to design, upgrade, and optimize wastewater treatment plants.

For each technology, a BioWin® model was developed and calibrated using empirical performance parameters at typical operating conditions. A screen capture of the sidestream treatment model in BioWin® is provided in **Figure 5-1**.



DSL = Digested Solids; Alk = Alkalinity; NIT = Nitritation; AMX = Deammonification; ST-EFF = Sidestream Treatment Effluent

Figure 5-1. Screen Capture of a Sidestream Treatment Model in BioWin®

While BioWin® has been used widely to simulate a wide array of wastewater treatment unit processes, it has limitations on predicting emerging sidestream technology performance with reasonable accuracy. This became apparent as the team performed modeling simulations. Modeling of deammonification and anaerobic digestion systems in BioWin® is still in early developmental stages and requires many assumptions and professional judgments to arrive at a defensible result. Deammonification models are typically manipulated to match the empirical performance of existing facilities, as opposed to predicting effluent quality based on given unit process sizing and default kinetics. In addition, most WWTPs do not have access to BioWin® software. As a result, the team developed a static MS Excel model to fill an industry void and make an evaluation tool easily available to interested utilities.

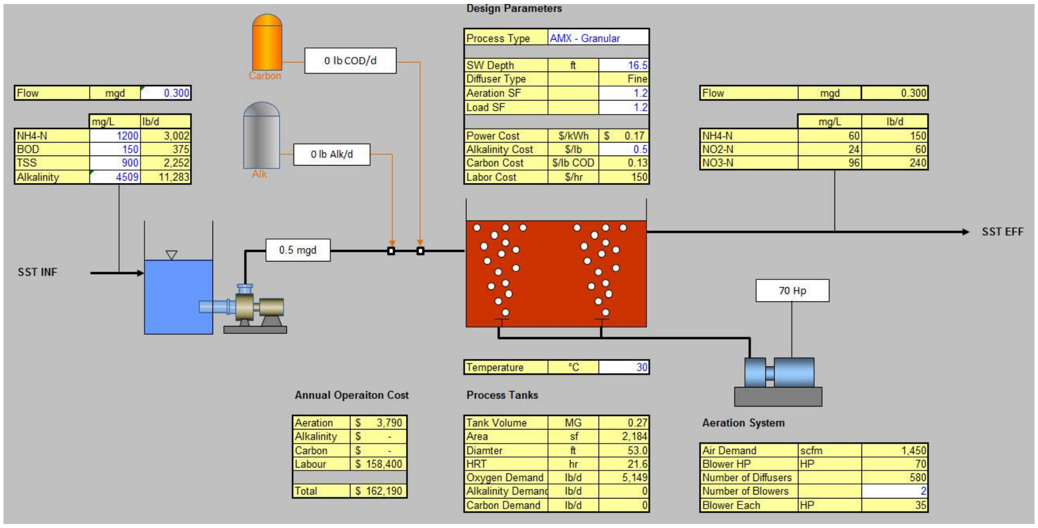
5.3 The Excel/BioWin® Sidestream Treatment Model

A picture of the static spreadsheet model is presented in **Figure 5-2**.

5.3.1 Excel/BioWin® Sidestream Treatment Model Development

The static spreadsheet model for assessing implementation of deammonification was developed in two steps summarized below:

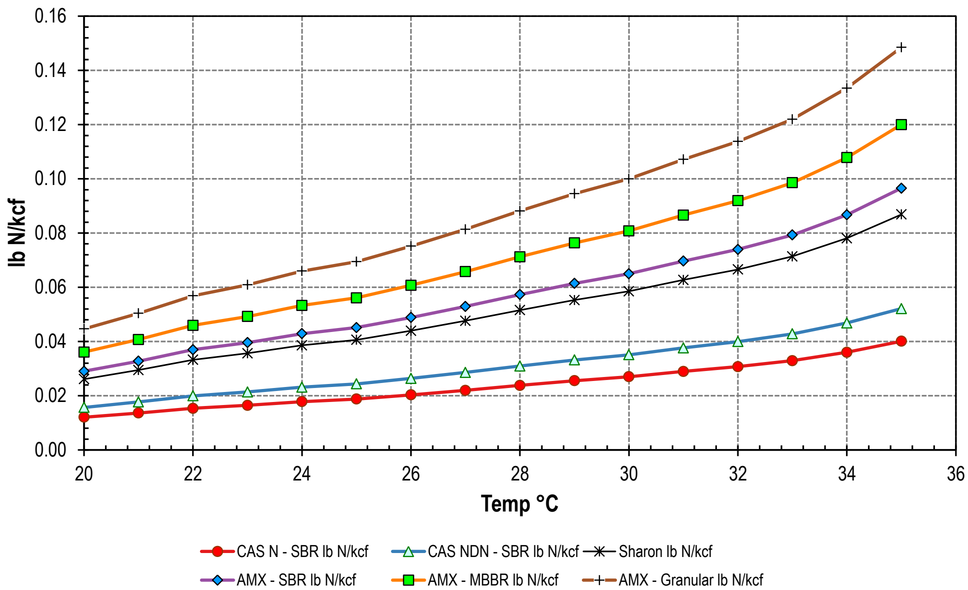
- **Step 1:** Establish temperature dependent volumetric nitrogen loading rates for each technology. The BioWin® model was simulated for different temperatures to develop the volumetric nitrogen loading rate versus temperature curve (**Figure 5-3**). This loading curve then becomes the basis for the reactor sizing.
- **Step 2:** Operational costs were determined through variable mass balance based calculations. The calculations are simplified by assuming certain removal or reaction rates that are representative for each technology.



See **Appendix D** for the model

Figure 5-2. Static Spreadsheet Model Screen Capture

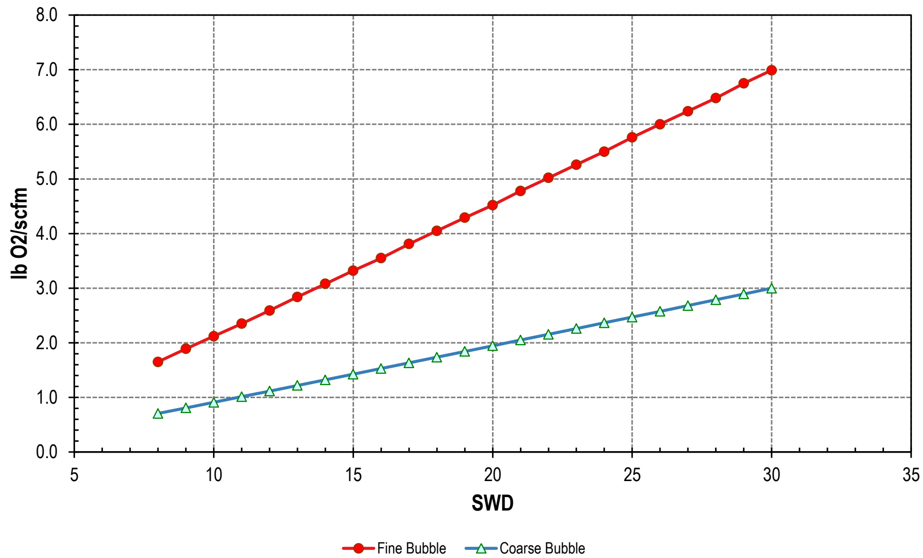
An example volumetric loading curve used in Step 1 is presented in **Figure 5-3**. All BioWin® model simulations were conducted using default parameters provided in BioWin®, as any movement away from the default parameters requires expert judgment.



CASN = Conventional Activated Sludge for Nitrification; CAS NDN = Conventional Activated Sludge for Nitrification/Denitrification; SHARON = Single reactor system for High activity Ammonium Removal Over Nitrite; AMX = Deammonification; SBR = Sequencing Batch Reactor; MBBR = Moving Bed Biofilm Reactor

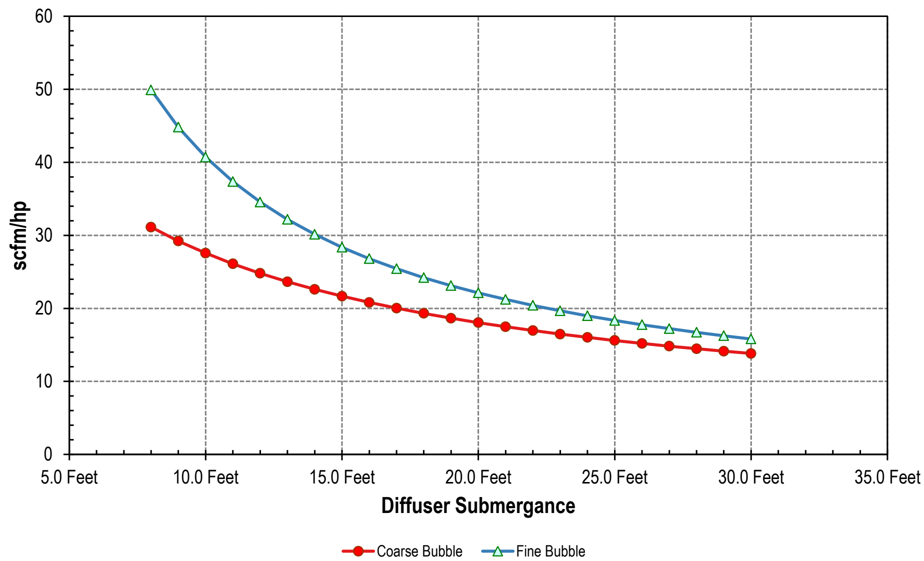
Figure 5-3. Volumetric Nitrogen Loading Rate Curves

To calculate operational costs as part of Step 2, equipment and facility needs, such as pumping, mixing, chemicals, and blower requirements, are estimated and translated to energy and chemical demands. For example, to estimate aeration requirements, oxygen demand is converted to an aeration requirement using representative curves for oxygen transfer versus depth (**Figure 5-4**). The oxygen transfer rates are based on fine bubble curves of standard 9-inch membrane diffusers. The power-to-airflow vs. depth curve (**Figure 5-5**) is then used to estimate the relative power requirement and operational costs associated with basin aeration. All other costs (alkalinity and carbon supplement) are directly calculated from the mass balance. The labor cost is linked to the size of the system. Any of the unit cost values can be overwritten by the user to match the local cost structure.



SWD = Side Water Depth; Includes Aeration System Parameters (i.e. alpha, beta, etc.)

Figure 5-4. Oxygen Transfer Relative to Basin Depth



Includes Aeration System Parameters (i.e. alpha, beta, etc.)

Figure 5-5. Power Requirement Relative to Airflow and Diffuser Submergence

5.3.2 Excel/BioWin® Sidestream Treatment Model Use

The static spreadsheet model contains a Read Me worksheet that provides step-by-step instructions on how to use the static model. Furthermore, a sequential approach for using the workbook is provided in **Appendix D.**

The spreadsheet model consists of two sheets: Overview (**Figure 5-2**) and Default Parameters. The Overview sheet provides the overall process design parameters and results for comparing process scenarios. To fine-tune a particular alterative for a specific application, the user must modify the underlying assumptions on the Default Parameters sheet. Parameters that can be modified include:

- Rates for power, chemicals, and labor
- Aeration settings such as blower efficiency or diffuser headloss
- Removal or reaction rates for the alkalinity mass balance
- Labor factors (Full Time Employee (FTE) relative to size)
- Diffuser types (coarse vs. fine)

5.4 Conclusions

A sidestream treatment modeling tool was developed to provide Bay Area WWTPs with the ability to assess sidestream treatment application with no additional software requirements. The Excel/BioWin Sidestream Treatment Model can provide planning level process sizing and operational cost estimates. The model uses empirical performance data from existing facilities to estimate volumetric loading rates, and removal efficiency to output treatment proficiency, relevant design parameters, and O&M costs related to six different sidestream treatment processes. In addition, the provided Read Me worksheet can support utilities with the steps associated with using the Excel/Biowin Sidestream Treatment Model to complete a preliminary evaluation of sidestream technologies.

CHAPTER 6 – MODELING WATER QUALITY IMPACT TO THE BAY FROM WWTP SIDESTREAM TREATMENT

6.1 Introduction

As an early step toward exploring how sidestream treatment as one of the various management options could influence ambient nutrient concentrations, model simulations were conducted to compare ambient nutrient (nitrogen, N) concentrations throughout the San Francisco Bay (Bay), assuming sidestream treatment was implemented by Bay Area Wastewater Treatment Plants (WWTPs).

A coupled hydrodynamic-biogeochemical model was used to simulate N concentrations in San Francisco Bay under two scenarios: (A) Current loads from wastewater treatment plants (Baseline), and (B) Projected decreased loads achieved through implementing sidestream treatment at a subset of WWTPs (Sidestream Treatment).

Section 6.2 describes the model setup, including major assumptions and limitations. **Section 6.3** presents Results and Discussion, including comparison of spatially-resolved predicted ambient nutrient concentrations for Scenarios A and B, and the predicted nutrient fate.

The current San Francisco Estuary Institute (SFEI) water quality model was used for this project. A more complete and sophisticated model will be developed over the next few years. While the model setup used here does not yet include some important components of nitrogen cycling, the output serves as a starting place for a first-order estimate of ambient concentrations and differences between scenarios.

6.2 Methodology

Nutrient simulations were carried out using a one-way coupled hydrodynamic-water quality model. Water year 2013 was chosen for the simulation period as (i) the model has been previously validated for hydrodynamics in this period, (ii) high-quality nutrient load data from POTWs are available, and (iii) drought conditions were not as severe as in subsequent years.

6.2.1 Hydrodynamics

Tides, currents, transport, and mixing were modeled using the SUNTANS 3-D hydrodynamics code (Fringer *et al.*, 2006). This code solves the shallow water equations on an unstructured triangular grid, allowing a coarse coastal ocean to seamlessly join with a highly-resolved representation of the Bay.

The San Francisco Bay implementation of SUNTANS used in this study (see **Figure 6-1**) is derived from the model of Holleman *et al.*, 2013. Grid resolutions in this model range from 250 m in South San Francisco Bay and 500 m in North Bay, to a coarse 5 km in the coastal ocean. The model domain extends to Chipps Island in the north, beyond which a pair of "false" deltas approximate the tidal characteristics of the Delta. The ocean boundary lies in the coastal ocean 100 km from the Golden Gate.

The hydrodynamic model incorporates forcing from tides, river flow, wind, evaporation, precipitation, and discharges associated with Publicly Owned Treatment Works (POTWs) and refineries. Tidal forcing is applied at the ocean boundary using observations from Point Reyes, with a minor shift in amplitude and timing to account for the spatial offset between Point Reyes and the model boundary. River flows are estimated from United States Geological Survey (USGS) streamflow gages where possible, and extrapolated from nearby gages in the case of ungaged watersheds. Delta outflow is taken from DAYFLOW (www.water.ca.gov/dayflow) and split between the two false deltas based on the ratio of Sacramento and San Joaquin reported by DAYFLOW. Winds are highly simplified with observed winds at Alameda used to define a spatially-constant wind field. Precipitation and evaporation rates over water are extracted from North American Regional Reanalysis (NARR) monthly mean reanalysis products (www.esrl.noaa.gov/psd/data/gridded/data.narr.html).

POTW discharge data is particularly relevant for the hydrodynamics as these discharges are a significant freshwater source, especially in the lagoon-like South Bay. POTW discharge flows were taken from data collected under the Regional Nutrient Watershed Permit requirements, supplied by HDR as part of the present study (San Francisco Bay Regional Water Quality Board, 2014).

Flows from refineries are much smaller, but were included nonetheless and estimated following the methods and data in "External Nutrient Loads to San Francisco Bay" (SFEI #704 2014). In cases where flow data was missing, values were extrapolated based on the superposition of a monthly climatology and a long-term interannual trend. Due to a limitation in the current hydrodynamic model, flows from outfalls located away from the shore were introduced at the surface rather than the bed. Tests on the vertical distribution of tracers show that these vertical gradients are mixed out over the course of a single tidal cycle, indicating that for the goals of the current project, the vertical location of the effluent discharge is inconsequential.

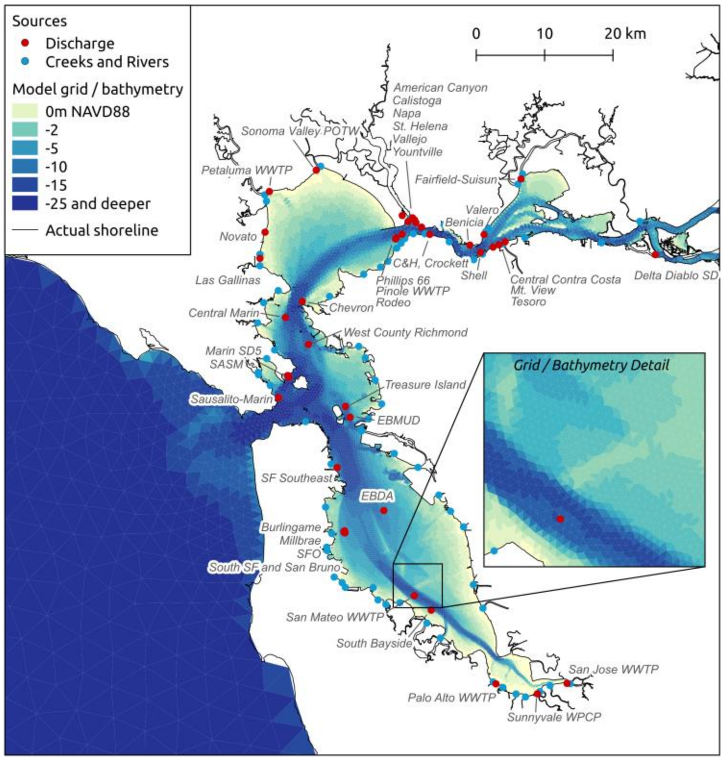


Figure 6-1. Central Model Domain for Hydrodynamics and Water Quality

<u>6.2.2 Water Quality Model</u>

A simplified water quality model was used for the present study to focus on the dominant controls on ambient inorganic nitrogen concentrations. For N cycling, the simulations included ammonium (NH_4^+, hereafter simply ammonia) and nitrate (NO_3^-, hereafter simply nitrate) loads, transport, nitrification (conversion of ammonia to nitrate), denitrification (conversion of nitrate to N_2). Nutrient uptake by phytoplankton was not included in the simulations. In San Francisco Bay, assimilation of N by phytoplankton is generally small compared to dilution, transport, and denitrification, and as such the model omits the considerable complexity and uncertainty related to phytoplankton modeling.

Formulation of nitrification

The process of nitrification is formulated as a temperature- and oxygen-corrected first-order process transforming ammonium and oxygen to nitrate. The mathematical formulation is:

$$R_{nit} = f_{ox} \times k_{nit} \times C_{NH4} \quad \text{(units of mg/L/day N)}$$

where the oxygen limitation factor is
$f_{ox} = (C_{ox} - C_{ox,crit}) / (C_{ox,opt} - C_{ox,crit})$, subject to $f_{ox} \in [0,1]$, and the first order rate constant is $k_{nit} = (0.1 \text{ day}^{-1}) \times 1.07^{(T-20)}$

Parameter values for the oxygen limitation are such that nitrification stops below 1 mg/L dissolved oxygen, and is not oxygen-limited for oxygen levels above 5 mg/L. These values and k_{nit} are based on default literature-derived values and confirmed to yield reasonable results in simulations of San Francisco Bay.

Formulation of denitrification
Denitrification is assumed to be significant only at the sediment-water interface where oxygen levels can be low and harvesting oxygen from nitrate is energetically favorable for microbes. This region of low oxygen is not modeled directly, but instead imposed as a nitrate loss term on an area basis, with the nitrate mass removed from the bottom of the water column.

The denitrification flux (i.e., loss) is first-order with respect to the nitrate concentration, and calculated as

$$F_{NO3} = (0.1 \text{ m day}^{-1}) \times 1.12^{T-20} \times C_{NO3}$$

which has units of g-N/m^2/day.

While the time constants for nitrification and denitrification appear the same (0.1), the effective, depth-averaged, denitrification rate has an inverse dependence on depth, such that nitrification and denitrification would proceed at equal rates only for 1 meter depth. When the depth is greater than 1 meter (typical in San Francisco Bay), nitrification will have greater effective rate than denitrification.

The model also includes a formulation for reaeration of dissolved oxygen. However, given the secondary relevance of oxygen in controlling the nutrient transformations as parameterized, the mathematical details have been omitted for brevity. The model calculates concentrations throughout the domain at a time interval of 30 minutes, though for practical reasons the output is generated only daily. Further details on all of the numerical implementations are in the Delft Water Quality Processes Technical Reference (content.oss.deltares.nl/delft3d/manuals).

6.3 Results and Discussions

The water quality simulations produce daily, three-dimensional distributions for ammonia and nitrate. In some figures the model output is shown as Dissolved Inorganic Nitrogen (DIN = NH_4 + NO_3). Flux data has also been calculated for a cross-section at the Golden Gate. This section presents a subset of these results in spatial and temporal plots.

6.3.1 Concentrations throughout the Bay

Figure 6-2 shows modeled, vertically-averaged DIN concentrations in the Bay for a winter month and a summer month. The figure is broken out into panels showing the baseline scenario, the sidestream scenario, and the difference between the two scenarios expressed as a percent reduction in concentration relative to baseline. Analogous results for ammonia and nitrate are shown in **Figures 6-3** and **6-4**.

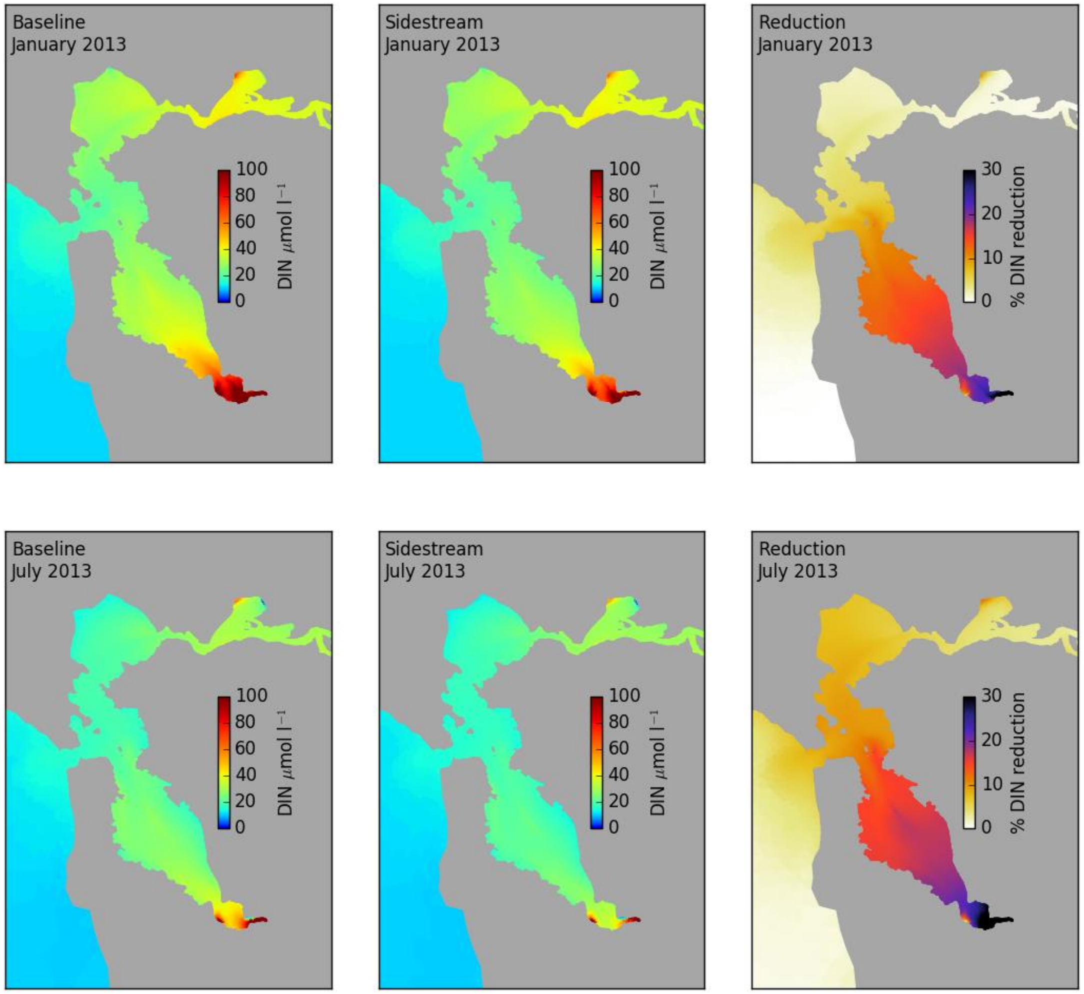


Figure 6-2. DIN Concentrations for the Baseline and Sidestream Treatment Scenarios, Averaged Over Depth, for January (upper) and July (lower)

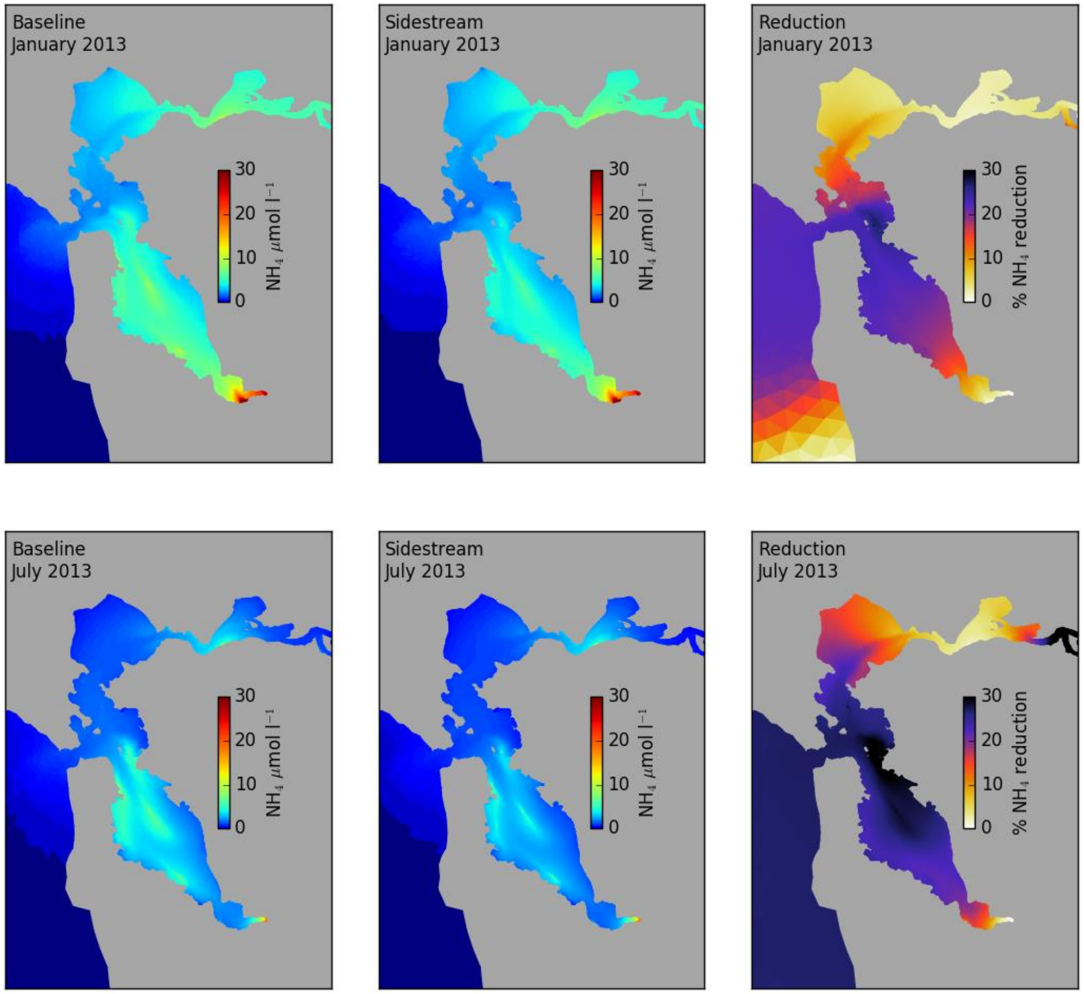


Figure 6-3. Ammonia Concentrations for the Baseline and Sidestream Treatment Scenarios, Averaged Over Depth, for January (upper) and July (lower)

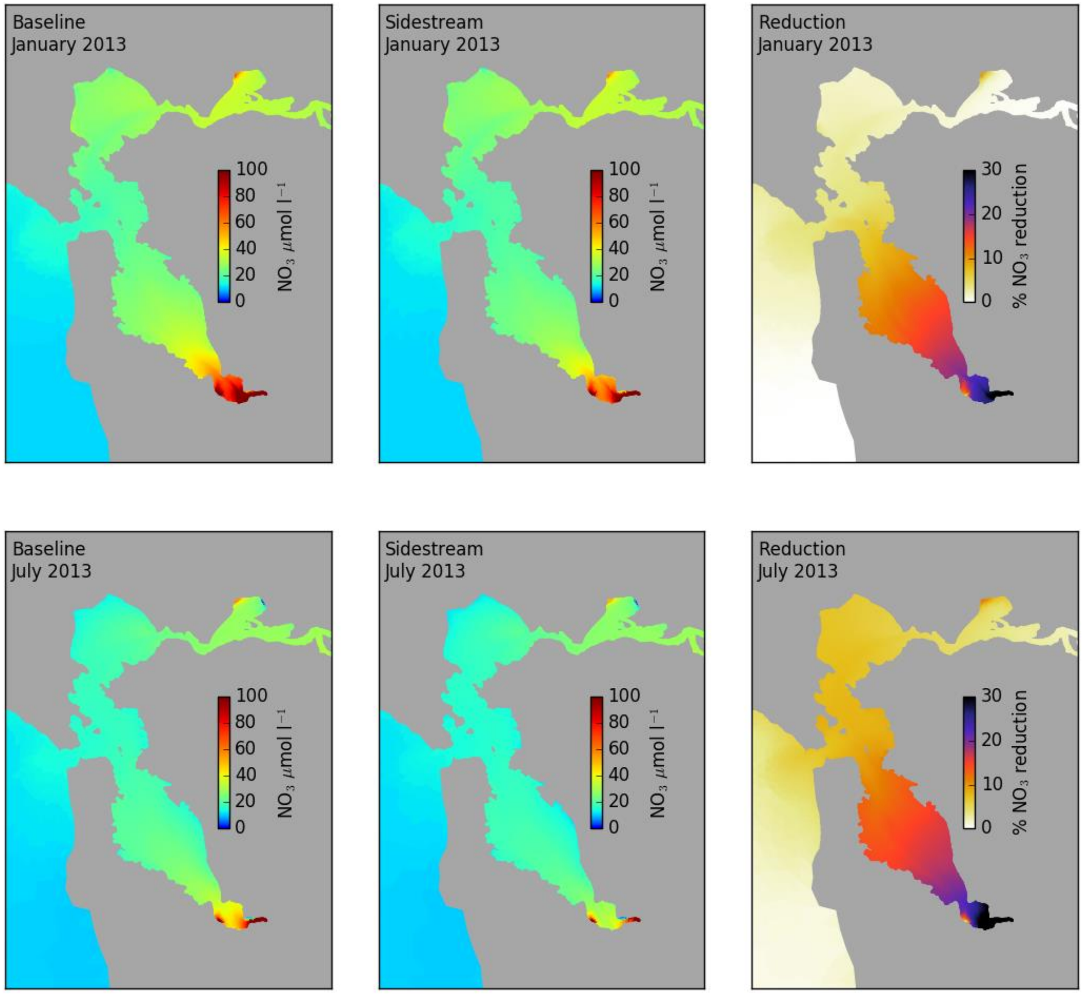


Figure 6-4. Nitrate Concentrations for the Baseline and Sidestream Treatment Scenarios, Averaged Over Depth, for January (upper) and July (lower)

Spatial variations tended to be more significant than differences between scenarios, but point-by-point comparisons (right-hand pair of panels for each of **Figure 6-2**, **6-3**, **6-4**) reveal up to 30 percent reductions in local concentrations for DIN, nitrate and ammonia. At larger spatial scales, typical values are 20 percent reduction in ammonia concentrations and 15 percent reduction in DIN and nitrate.

To quantify differences at the regional scale and over time, DIN concentrations were spatially averaged following the Regional Monitoring Program (RMP) subembayment delineations shown in **Figure 6-5**. Results for DIN, ammonia and nitrate are shown in **Figures 6-6**, **6-7** and **6-8**, respectively.

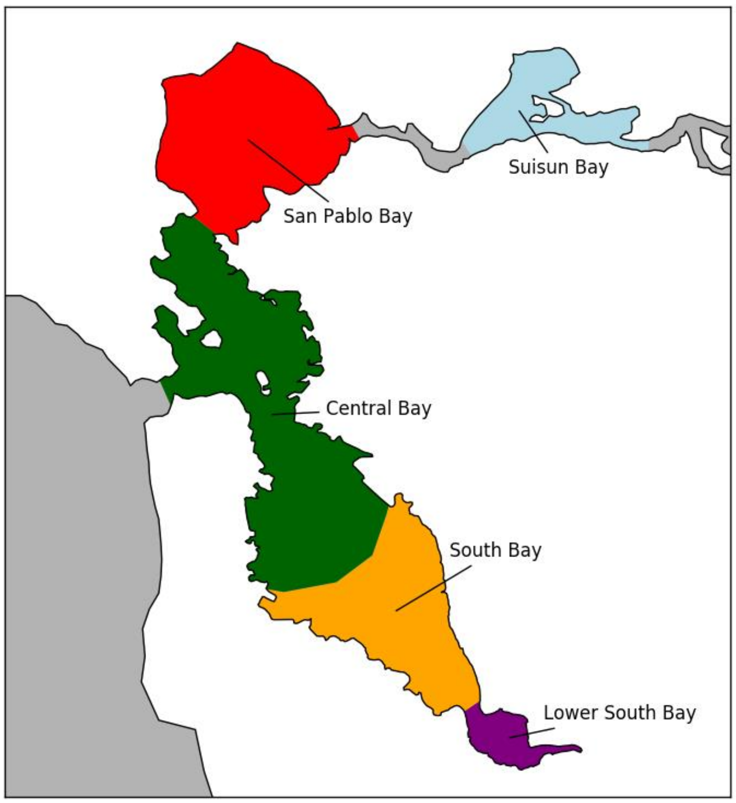


Figure 6-5. Subembayment Delineations Used in Summarizing Model Results

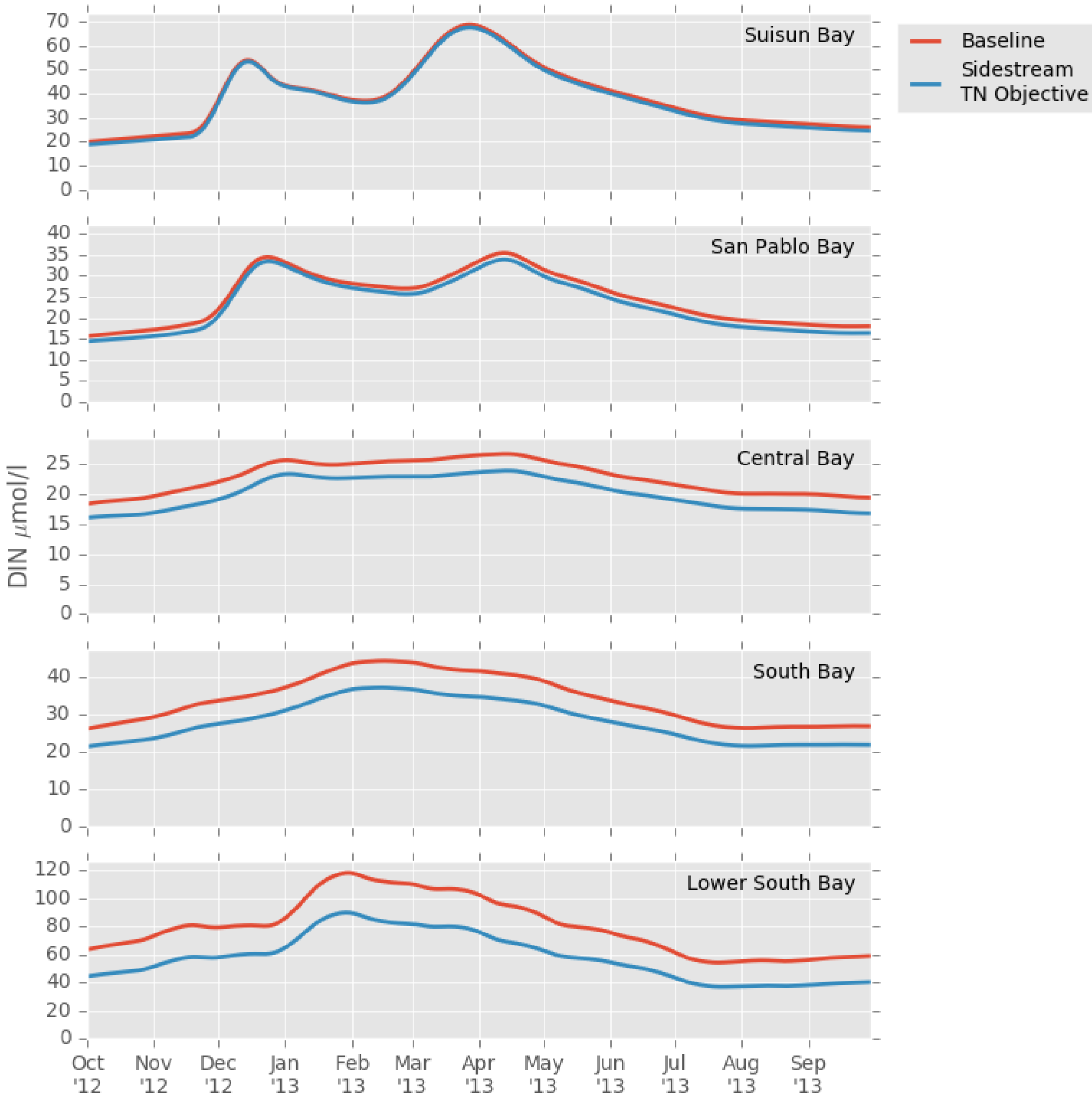


Figure 6-6. Time Series of DIN in the Baseline and Sidestream Treatment Scenarios, Averaged within Each Subembayment

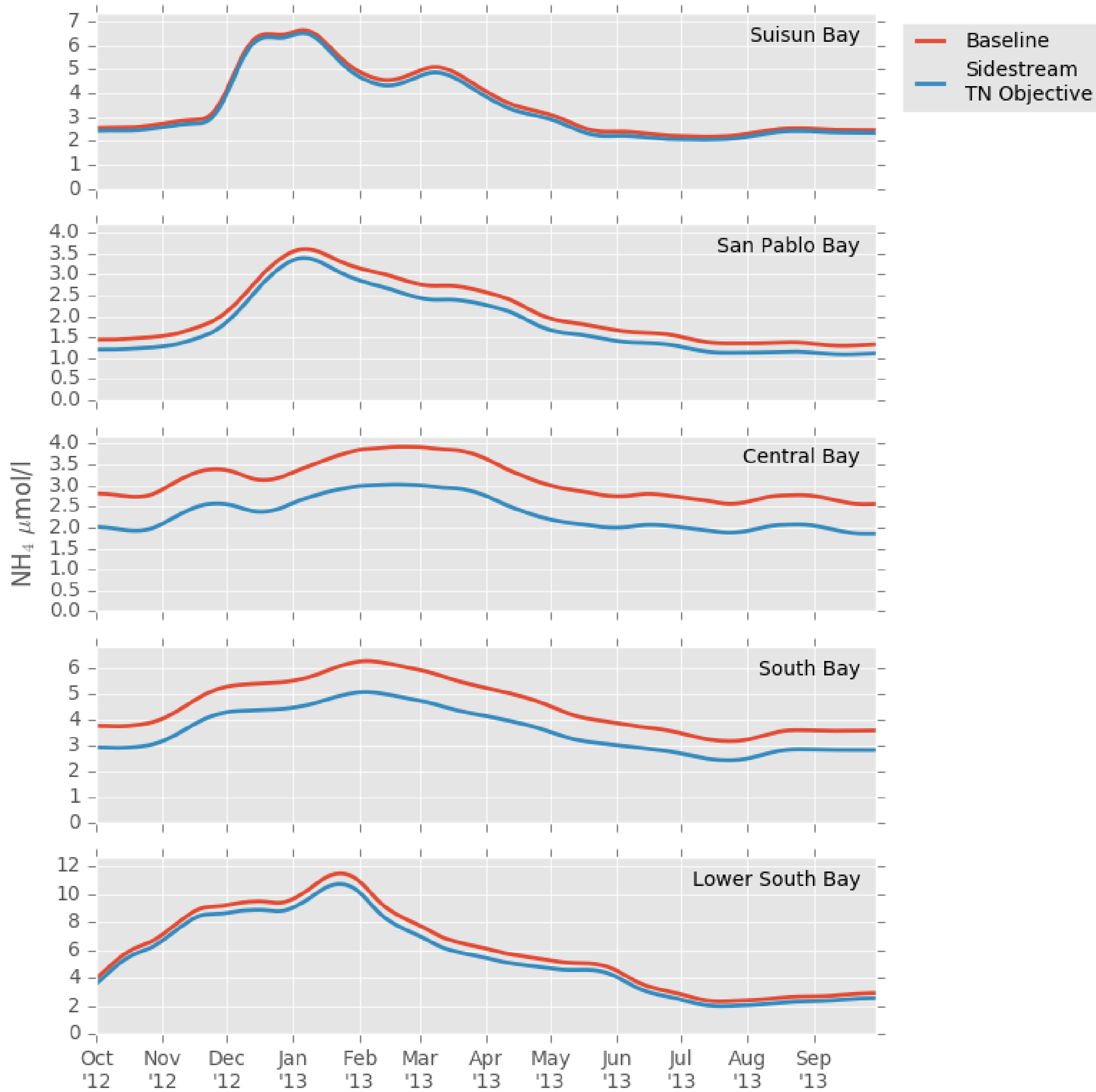


Figure 6-7. Time Series of Ammonia in the Baseline and Sidestream Treatment Scenarios, Averaged within Each Subembayment

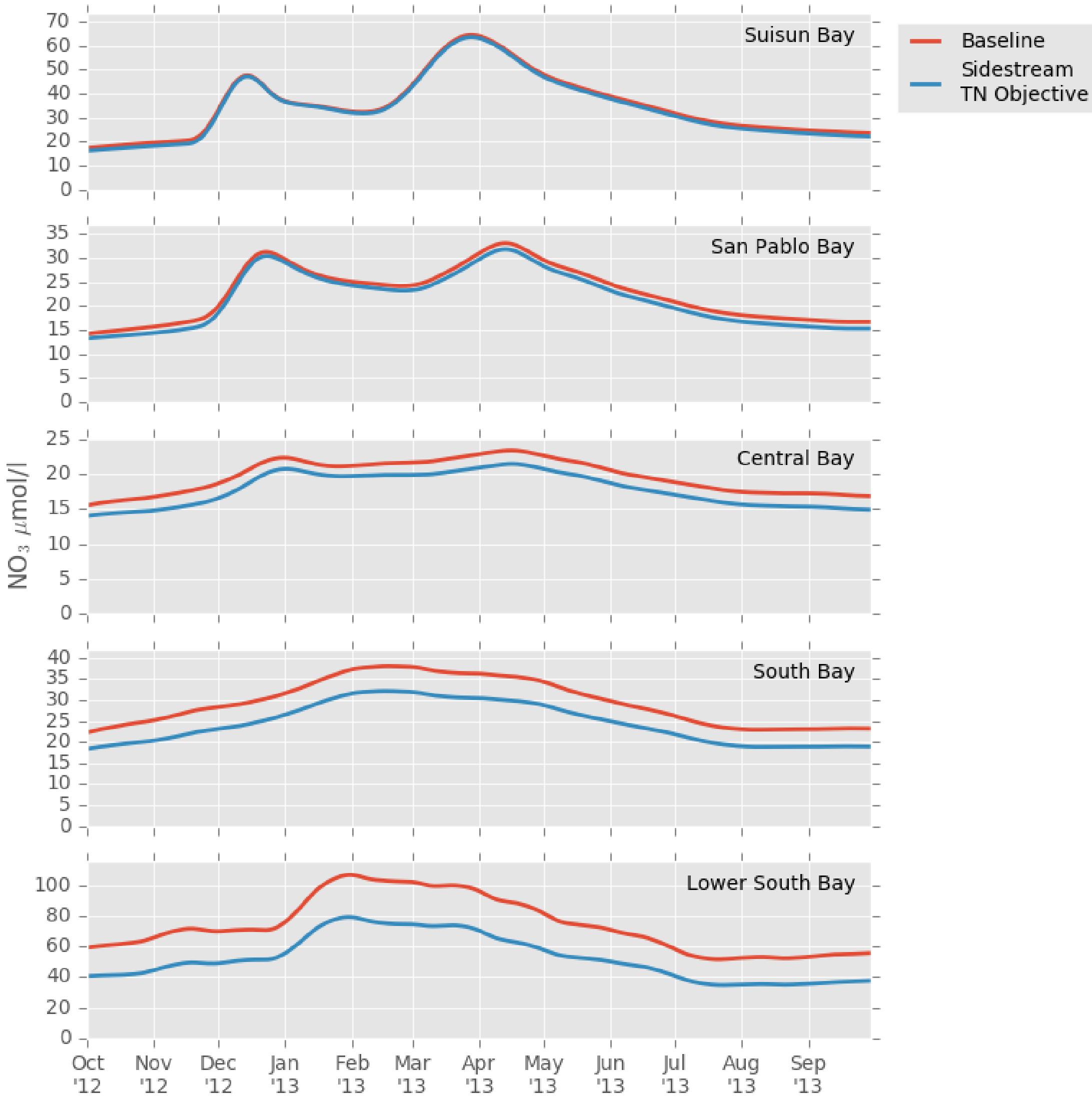


Figure 6-8. Time Series of Nitrate in the Baseline and Sidestream Treatment Scenarios, Averaged Within Each Subembayment

A comparison between the region-averaged baseline and sidestream TN objective scenarios in **Figure 6-6** shows that reductions of DIN are significant in Lower South Bay, minimal in Suisun Bay, and somewhere in between in the remaining three embayments. This pattern is largely explained by the location of reductions in loads in conjunction with the size/residence time of receiving waters. Furthermore, ambient concentrations in Suisun Bay are largely driven by sources upstream of the model domain in the Delta, and beyond the scope of the load reduction scenarios. **Figure 6-7** shows a distinct pattern for ammonia, with the greatest reductions in Central Bay. This spatial shift is driven by the fact that a larger fraction of the nitrogen loads south of the Bay Bridge are nitrified, and the ammonia compont of these discharges was not reduced in the sidestream scenario. Similar plots of nitrate are shown in **Figure 6-8**, with the patterns generally mirroring those of DIN in **Figure 6-6**.

A basic DIN budget for a fixed portion of the domain can be estimated from the model output. In order to relate these calculations to loads, we have framed the budget in terms of average daily "movement" of nitrogen in the model. The terms in this mass balance are:

- Load – the sum of nitrogen introduced to the Bay from the Delta and dischargers.
- Export – the flux of nitrogen leaving the Bay by way of the Golden Gate. Tidal fluctuations have been removed; i.e., the values represent the tidally-averaged export of nitrogen. Negative values indicate export of nitrogen from the Bay to the ocean, and positive values indicate import of nitrogen into the Bay.
- Change in storage – there are seasonal and event driven variations in the mass of nitrogen in the open Bay. Day-to-day changes in this mass are reported in this term, where positive values indicate accumulation of nitrogen in the Bay, and negative values a depletion.
- Gain or loss by reaction – denitrification causes a loss of N mass in the budget. In the case of DIN, there are no source reactions, so this term will always be negative (a similar plot for nitrate would include nitrification as a source, and the gain/loss term would be positive when nitrification outpaced denitrification).

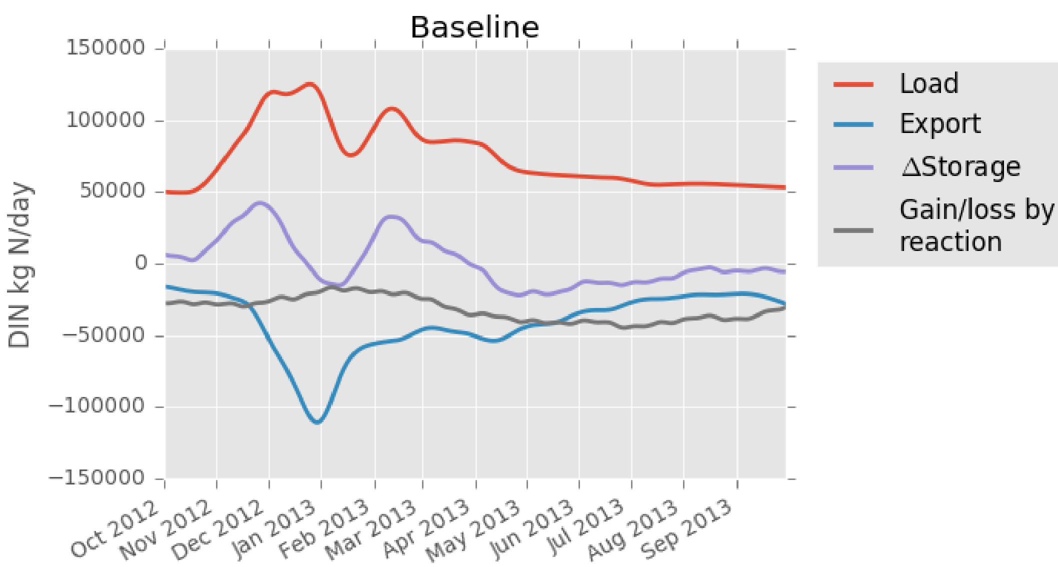


Figure 6-9. Time Series of DIN Budget for Baseline Scenario

Figure 6-9 shows the evolution of the DIN budget over WY2013. Following simple intuition, wet weather loads (Dec-Mar, red) are correlated to net accumulation of nutrients in the Bay (i.e., the change in storage is positive for most of this period). The maximum export of nitrogen to the coastal ocean lags slightly behind the loads with a peak export 2 to 4 weeks after the peak load. The role of denitrification is visible in the gray line, showing a relatively constant loss of DIN throughout the year. The main factors controlling the denitrification losses are temperature (favoring greater losses in the summer), ambient concentrations (favoring greater losses in the winter), and residence time (favoring summer, low-flow conditions). The seasonal pattern of DIN loss indicates that the combination of temperature and residence time has a greater net effect, based on the model results showing Bay-wide loss rates in the summer almost double the winter minimum rates. Relative to loads, the winter/summer contrast in denitrification losses is even starker with denitrification losses equal to roughly 90 percent of DIN loads in the summer.

Budget estimates were also compiled for ammonia and nitrate, and the water year averaged results are summarized in **Table 6-1**. Since the first order control on the change in the terms of the budget is the change in loads, the export and loss terms have been reported both in absolute terms (i.e., kg N/day), and as a percentage, normalized to the loads. This normalization results in budgets for the two cases which are nearly indistinguishable, suggesting that with the distribution sidestream treatment in the TN-objective scenario, the Bay-wide nitrogen response to sidestream treatment is essentially proportional to the changes in loads. The most significant change is in the loss of nitrate, which is estimated to go from just 5 percent of nitrate loads to 12 percent of loads. Interpretation of these numbers calls for some nuance, however, as nitrate loads are only about half of the nitrate introduced to the system, with the balance from nitrification of ammonia. For example, the baseline case includes 30,444 kg N/d nitrification, and 34,138 kg N/day of nitrate directly from discharges. In approximate terms, nitrate loads, sources from nitrification, exports and losses to denitrification are all of the same order.

Table 6-1. Summary of San Francisco Bay Nitrogen Budget for WY2013

	Baseline			Sidestream Treatment		
	Load	Export	Net Loss	Load	Export	Net Loss
Dissolved Inorganic Nitrogen	74,692	41,799 56%	32,056 43%	64,104	34,632 54%	28,773 45%
Ammonia	40,554	10,160 25%	30,444 75%	32,505	7,536 23%	25,005 77%
Nitrate	34,138	31,639 93%	1,611 5%	31,600	27,096 86%	3,767 12%

Fluxes in kg N/day; Nitrate loss reflects net effect of nitrification and denitrification.

6.3.2 Proportional Response

Nitrification and denitrification are both formulated as first-order processes with respect to ammonia and nitrate concentrations. This formulation implies that a uniform decrease in concentrations in the model inputs (initial conditions, ocean boundary, and effluent concentrations) yields a proportional decrease in the simulated ambient concentrations. In other words, if loads are cut by X percent, we should expect that concentrations, exports to the coastal ocean, and losses to denitrification will be reduced by X percent of respective baseline levels at the full-Bay scale. There are two distinct ways in which the model results can diverge from this simple proportional response (July 2015 Sampling Events): spatial variation in reductions and interactions with the coastal ocean.

Spatial variations in source

The sidestream scenario is not a uniform reduction in nutrient loads, but rather a selective reduction which differs between plants and the proportion of ammonia and nitrate. One way of looking at the integrated effects of the reductions is to consider the flux of nutrients through the Golden Gate. Considering first the baseline scenario and the mass balance of ammonia in **Table 6-1**, there is roughly a 75:25 split between ammonia lost to nitrification (75 percent) versus exported to the coastal ocean (25 percent). A similar budget for the sidestream scenario yields nearly the same results, with the split becoming 77 percent nitrification, 23 percent export.

An analogous look at DIN fluxes shows that in the baseline case export is about 56 percent of loads and transformation (denitrification) is 43 percent. Results from the sidestream treatment simulation are again similar, with 54 percent of loads being exported through the Golden Gate and 45 percent lost to denitrification. Though small, these differences are consistent with load reductions in Central Bay. Loads discharged into Central Bay have the least residence time within the Bay, and the least chance for denitrification. Along the same lines, discharges into deeper waters have less of a chance to experience denitrification. Reductions at these discharges shift the Bay-wide denitrification efficiency higher.

Interactions with the coastal ocean

In the simulations, the coastal ocean is initialized with spatially constant nutrient concentrations of 2 μmol/L for ammonia and 10 μmol/L for nitrate. In portions of the model domain highly influenced by exchange with the coastal ocean, i.e., Central Bay, ambient concentrations are tempered by exchange with the coastal reservoir of nitrogen and show a modest response to changes in loads. These exchange-related effects are more pronounced for nitrate than for ammonia, as the coastal nitrogen reservoir is primarily nitrate. This can be seen in **Figures 6-3** and **6-4**, where **Figure 6-3** shows coastal ocean ammonia concentrations near zero, leading to little coastal exchange effects and a broad, central region of nearly 20 percent ammonia reduction. In contrast, **Figure 6-4** shows significant nitrate concentrations in the coastal ocean, and a modest reduction in Central Bay nitrate of around 10 percent.

6.4 Conclusions

The nutrient model incorporates a well-resolved transport field and simplified representations of nitrification and denitrification. For each scenario, the model permits a means for estimating mass balances for nitrate and ammonia, as well as visualizing the distributions of these nutrients throughout the Bay. To first order and when considered at the full-Bay scale, the model suggests that both concentrations and individual terms of the mass balance are linearly related to the loads. As such, a fixed percentage reduction in loads yields comparable percentage reductions in concentration and in nutrients transported to the coastal ocean. That said, sidestream load reductions would *not* be an across-the-board fixed percentage reduction, and this spatial variation in reductions leads to localized effects in the simulations.

CHAPTER 7 – DEVELOPMENT OF A CONCEPTUAL NUTRIENT TRADING PROGRAM FOR SAN FRANCISCO BAY

7.1 Introduction

As part of this U.S. EPA grant-funded study, EBMUD worked with U.S. EPA to develop a scope of work to develop a conceptual nutrient trading program for the San Francisco Bay. Water quality trading, in coordination with ongoing water quality studies and modeling efforts, could allow for regional nutrient management solutions that are more economical and environmentally beneficial than the aggregate impact of implementing upgrades at individual Wastewater Treatment Plants (WWTPs).

The objective of this work was to develop a common understanding among key stakeholders of what a regional nutrient trading program could look like for the Bay. The conceptual nutrient trading program is a high-level analysis and, unlike the bulk of the work done under the grant, it is inclusive of nutrient reduction levels beyond that which could be achieved with sidestream treatment alone. The focus of this work was on trading nutrient "credits" between point sources (WWTPs specifically), but the potential inclusion of nonpoint sources was also examined. memoranda Task memoranda prepared in association with this work are included in **Appendix F** and are briefly:

- **Task 1:** Basics of Point-to-Point Source Water Quality Trading Programs for Compliance with Nutrient Discharge Limits (content incorporated in **Sections 7.2 – 7.5** of this report)
- **Task 2:** Assessment of Challenges and Opportunities Related to a Point Source Nutrient Trading Program in the San Francisco Bay (content incorporated in **Sections 7.4, 7.5** and **7.7)**
- **Task 3:** Components of a Conceptual Point-to-Point Source Nutrient Trading Program (**Sections 7.4, 7.5** and **7.7)**
- **Task 4:** Hypothetical Trading Scenario Assessment (**Section 7.6)**
- **Task 5:** Incorporating Nonpoint Sources into a Point Source Nutrient Trading Program for the San Francisco Bay (**Section 7.8)**

7.2 Current Regulatory Status of Nutrient Discharges to the San Francisco Bay

In 2014, the San Francisco Regional Water Quality Control Board adopted Order No. R2-2014-0014, which established Waste Discharge Requirements (WDRs) for nutrient discharges to the Bay from 34 outfalls for treated municipal wastewater.[1] That order, commonly referred to the Nutrient Watershed Permit, sets forth a regional framework to

[1] S.F. Bay Regional Water Quality Control Board, Order No. R2-2014-0014, Permit No. CA0038873, Waste Discharge Requirements for Nutrients from Municipal Wastewater Dischargers to San Francisco Bay, available at: http://www.waterboards.ca.gov/sanfranciscobay/board_decisions/adopted_orders/2014/R2-2014-0014.pdf One of these 34 outfalls is the outfall for the East Bay Dischargers Association (EBDA) which discharges effluent from seven distinct treatment facilities.

facilitate collaboration on studies that will inform future management decisions and regulatory strategies.

The 2014 Nutrient Watershed Permit contains effluent monitoring requirements but does not include effluent limits. It stated that in future reissuances of the Watershed Permit:

> *…the Regional Water Board anticipates considering the establishment of performance-based effluent limits for nutrients and may require implementation of treatment optimization or other means to reduce loads or increase assimilative capacity if scientific studies show results that warrant such activities. The Regional Water Board will also consider load offsets between Dischargers with and between subembayments if permissible.*

As such, nutrient trading (or "load offsets between Dischargers") has already been acknowledged as a potential compliance strategy if nutrient effluent limitations are enacted in future permits.[2]

The Nutrient Watershed Permit also requires that the dischargers both evaluate the cost of treatment upgrades for nutrient control and support region-wide efforts to model nutrient impacts in the Bay. If a nutrient trading program is ever to be developed for the Bay, this cost information and the water quality modeling capability will form an essential foundation for such a program. Early results of the cost estimating efforts indicate that the cost for nutrient removal varies greatly between Bay Area WWTPs. As such, the potential for water quality trading to allow nutrient loading reductions at a reduced cost is likely high.

7.3 Federal and State Authorization for Water Quality Trading

Water quality trading, and nutrient trading specifically, is well supported by federal regulations and guidance. Although California has not adopted any statewide regulations or policies concerning water quality trading, the discretion vested in the State Water Resources Control Board (SWRCB) and the Regional Water Quality Control Boards (Regional Water Boards) enables the development of water quality trading programs. This section provides an overview of the Federal and California State authorizations for water quality trading as well as an introduction to the main organizational features of trading programs.

7.3.1 Federal Authorization and Guidance for Water Quality Trading

In 2003, the U.S. EPA published a final water quality trading policy (EPA Trading Policy) outlining how water quality trading can be used as a flexible approach for Clean Water Act (CWA) compliance.[3] The EPA Trading Policy provides a framework for water quality trading consistent with the CWA's anti-backsliding policy, compliance and

[2] *Id*. at page F-9

[3] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. 1608(Jan. 13, 2003), *available at* https://www.gpo.gov/fdsys/pkg/FR-2003-01-13/pdf/03-620.pdf

enforcement provisions, and public notice and comment procedures. The EPA Trading Policy also explicitly endorses trading for nutrients among other pollutants. To further support water quality trading, the EPA issued the *Water Quality Trading Toolkit for Permit Writers* in 2007.[4]

EPA guidance does not require a Total Maximum Daily Load (TMDL) as a prerequisite to water quality trading.[5] Although not a requirement, a majority of trading activities do take place under existing TMDLs. This is because trading requires a firm understanding of the water quality conditions in the waterbody. In the absence of a TMDL, water quality trading requires a TMDL-like watershed analysis capable of properly dividing load between sources and clarifying the watershed's characteristics, thereby creating the baseline necessary for trading activities.

Water quality trading requires that credit sellers reduce pollution beyond what would have occurred in the absence of a trading program, a concept known as additionality.[6] Financial additionality ensures that money used to generate credits is not money that would have benefited the environment otherwise.[7] Guaranteeing that financial additionality is satisfied in the context of point-to-point source trading essentially looks to the underlying purpose of the sources of funding, ensuring that the finances were not intended for a non-compliance purpose. Only money raised or allocated for CWA compliance actions may be used for credit generation or the purchase of credits. Importantly, this restriction does not extend to public loans intended to be used for capital improvements of public water systems—this funding is intended to help achieve regulatory compliance and therefore does not result in any additionality issue. Generally, State Revolving Funds (SRF) can be used for credit-generating projects. [8]

---

[4] U.S. EPA, Water Quality Trading Toolkit for Permit Writers, EPA 833-R-07-004 (Aug. 2007, updated June 2009), *available at* www.epa.gov/npdes/pubs/wqtradingtoolkit.pdf

[5] "EPA supports implementation of water quality trading by states, interstate agencies and tribes where trading…[a]chieves early reductions and progress towards water quality standards pending development of TMDLs for impaired waters." U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1609.

[6] U.S. EPA, Technical Memorandum: Components of Credit Calculation, at 9 (May 14, 2014), available at: http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/TradingTMs/CreditCalculationTM_FINAL_5_14_14.pdf.

[7] WILLAMETTE PARTNERSHIP, ECOSYSTEM CREDIT ACCOUNTING SYSTEM: GENERAL CREDITING PROTOCOL VERSION 2.0 (Nov. 1, 2013), http://willamettepartnership.org/wp-content/uploads/2014/09/General-Crediting-Protocol-2.0.pdf

[8] For a detailed discussion on the interplay between water quality trading and the use of Clean Water State Revolving Funds, *see* U.S. EPA, WATER QUALITY TRADING TOOLKIT FOR PERMIT WRITERS, EPA 833-R-07-004, Appendix D: Use of Cost Share (Aug. 2007, updated June 2009). For a discussion of the savings calculus as applied to the Long Island Sound Nutrient Exchange, *see* NAT'L ENVTL. TRADING NETWORK, LONG ISLAND SOUND PROGRAM DESCRIPTION, SECTION J (last visited Nov. 2016), http://www.envtn.org/Long_Island_Sound.html

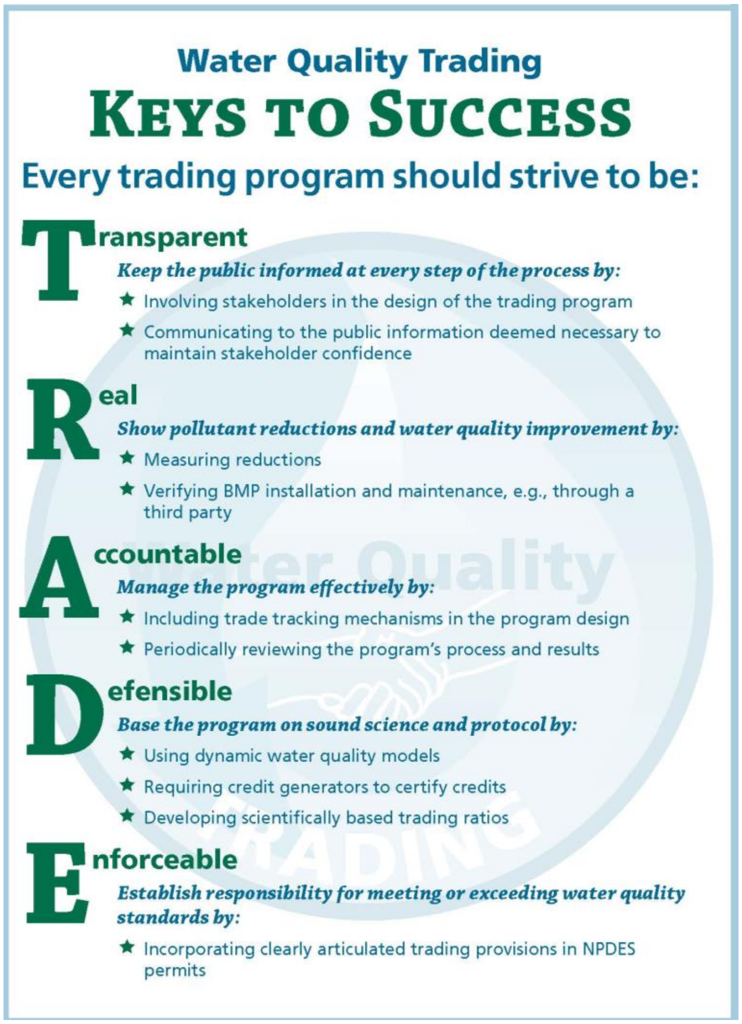


Figure 7-1. Keys to Water Quality Trading Success[9]

7.3.2 California State Authorization for Water Quality Trading

Although California has not implemented any statewide regulations concerning water quality trading, there are no regulatory barriers to water quality trading in California or in the Bay Area specifically. As noted earlier, the Nutrient Watershed Permit explicitly mentions trading as a potential offset program and, as discussed in in **Section 7.5**, water quality trading programs have already been implemented in California.

While it does not mention water quality trading specifically, the SWRCB's 2005 *Water Quality Control Policy for Addressing Impaired Waters* states the "Water Boards are committed to [using] all means to ensure that the waters of the state are protected" and goes on to discuss the "wide latitude" and "numerous options" available to the Regional

[9] U.S. EPA, Water Quality Trading Toolkit for Permit Writers, EPA 833-R-07-04 (Aug. 2007, updated June 2009).

Water Quality Control Boards to address impaired waters.[10] Furthermore, a 2001 memo from SWRCB's legal counsel stated that even in the absence of a TMDL, trading programs appeared consistent with water quality regulations so long as those programs complied with the applicable water quality standards.[11] A follow-up memo from the SWRCB's legal counsel further clarified that:

> *The use of offsets, pollutant trading, or other market-based mechanisms . . .is clearly appropriate when implemented in the context of a TMDL, in which case, substantial flexibility exists to achieve [water quality standards].*[12]

Although there are not presently (and may never be) any nutrient TMDLs for the San Francisco Bay, the Regional Water Boards have sufficient discretion allow National Pollutant Discharge Elimination System (NPDES) permit compliance through trading, even in the absence of a TMDL.

7.4 Overview of Trading Program Organization

There are several general categories of water quality trading programs based on the types of participants:

- *Point source-to-point source trading* occurs between regulated point sources, such as wastewater treatment plants or industrial dischargers. EPA considers point-to-point source trading "the most basic form of water quality trading" because it is "relatively straightforward, easily measurable, and directly enforceable".[13] For this reason, and because WWTPs contribute the majority of the nutrient loading to the Bay, the focus of the conceptual nutrient trading assessment has been on point-to-point source trading.
- *Point source-to-nonpoint source trading* occurs when a regulated point source offsets a portion of its discharges through environmental restoration or related action that addresses nonpoint source pollution. Nationally, point-to-nonpoint trading is the most common form of water quality trading. The Laguna de Santa Rosa Nutrient Offset Program (see **Section 7.5**) is an example of a point-to-nonpoint trading program. The potential for including nonpoint sources in a San Francisco Bay nutrient trading program is discussed in **Section 7.8**.

[10] CAL. CODE REGS. tit. 23, § 2917; Cal. State Water Resources Control Bd., Res. No. 2005-0050: Water Quality Control Policy for Addressing Impaired Waters: Regulatory Structure and Options (June 16, 2005), *available at* swrcb.ca.gov/water_issues/programs/tmdl/docs/iw_policy.pdf.
[11] Memorandum from Craig Wilson, Chief Counsel, Cal. State Water Resources Control Bd., to Arthur G. Baggett, Jr., Chair, Cal. State Water Resources Control Bd., on Legal Authority for Offsets, Pollutant Trading, and Market Programs to Supplement Water Quality Regulation in California's Impaired Waters (Oct. 16, 2001), *available at* waterboards.ca.gov/water_issues/programs/tmdl/docs/iwguide_apxb.pdf.
[12] Memorandum from Michael A.M. Lauffer, Chief Counsel, Cal. State Water Resources Control Bd., to Arthur G. Baggett, Jr., Chair, Cal. State Water Resources Control Bd., on Updated Legal Authority for Offsets, Pollutant Trading, and Market Programs to Supplement Water Quality Regulation in California's Impaired Waters With Established Total Maximum Daily Loads (Nov. 22, 2006).
[13] U.S. EPA, Water Quality Trading Toolkit for Permit Writers, 15, EPA 833-R-07-004 (Aug. 2007, updated June 2009).

- *Nonpoint-to-nonpoint source trading.* The last type of trading program involves trades between multiple nonpoint sources, such as municipal separate storm sewers. Two nonpoint-to-nonpoint trading programs are discussed briefly in **Section 7.8** and in more detail in **Appendix F (Task 5)**.

For point-to-point trading, the focus of this study, the EPA identifies three primary models: (1) trading between two point sources; (2) multiple facility trading without a central exchange; and (3) trading through a point source credit exchange.[14] All three models could potentially be used by WWTPs in the San Francisco Bay Area. **Figure 7-2** below provides brief descriptions from the EPA Water Quality Trading Toolkit of these trading models.

[14] U.S. EPA, Water Quality Trading Toolkit for Permit Writers, 15–17, EPA 833-R-07-004 (Aug. 2007, updated June 2009).

Trading Between Two Point Sources

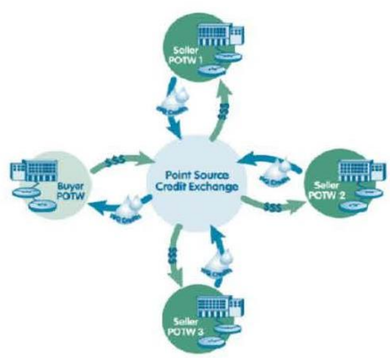
Single point source–single point source trades generally involve a trade agreement[1] between two point sources. In this type of trade, one point source is the credit generator and the other is the credit purchaser. For point source–point source trades, a single permit can be issued that incorporates or references the trade agreement and includes both point sources as co-permittees. Alternatively, each discharger can be issued an individual permit with trading provisions placed in each permit.

Multiple Facility Point Source Trading/No Exchange

Multiple facility point source trades involve a group of point sources operating under a single trade agreement. The agreement can establish ground rules for trading to allow point sources to trade among themselves as needed. The trade agreement can specifically identify the point sources that may participate in water quality trading, or it can identify a geographic boundary (typically a watershed) or a type of discharger, or both, and allow qualifying point sources to participate in trading as desired or appropriate. An overall limit or cap set by the permit regulates all trades. Point sources trading under a multiple facility trade agreement are sometimes organized under a group that facilitates and oversees trading among the members.

Point Source Credit Exchanges

Another type of multiple facility point source trade involves a group of point sources that may purchase credits from a central exchange as needed to comply with individual effluent limitations. The credit exchange is maintained by a separate entity, which may be a state agency, a conservation district, or other organization established to administer the credit exchange. Credits in the exchange are generated by point sources that over control their discharges. The trade agreement can specify how credits may be generated and purchased, how trade ratios are calculated, and individual and group responsibilities for meeting effluent limitations and overall pollutant loading caps. Credit exchanges do not hold credits for longer than the reconciliation period, which typically corresponds to the type of effluent limitation. For example, the reconciliation period for trades to meet monthly average effluent limitations for phosphorus would be one month. For each reconciliation period, new credits are generated for purchase. The credit exchange would likely have to be either operated by or approved and overseen by a state regulatory agency.



[1] A trade agreement is a document that specifies the overall trading policies that a buyer and a seller must follow to participate in trading. The NPDES permitting authority could approve the trade agreement and either reference the terms of the trade agreement in the NPDES permit or include the trade agreement as part of the permit for each point source participating in a trade.

Source: U.S. EPA, Water Quality Trading Toolkit for Permit Writers, 15–17, EPA 833-R-07-004 (Aug. 2007, updated June 2009), available at www.epa.gov/npdes/pubs/wqtradingtoolkit.pdf

Figure 7-2. Three Programmatic Options for a Point-to-Point Source Trading Program Identified by the EPA

7.5 Existing Trading Programs in the United States

Water quality trading has been implemented within jurisdictions throughout the nation, including point-to-point nutrient trading programs in large, complex watersheds. Within California, however, existing trading programs do not include point-to-point source trades. Two of the largest point-to-point nutrient trading programs in the U.S., those for the Chesapeake Bay and the Long Island Sound, are described below along with brief descriptions of existing California water quality trading programs.

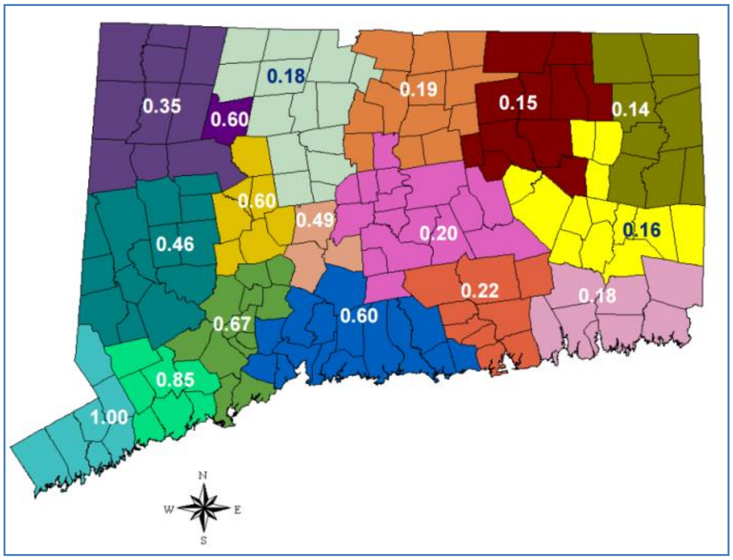
7.5.1 Long Island Sound Nutrient Credit Exchange

In 1990, Connecticut, New York, and the EPA adopted a Comprehensive Conservation and Management Plan (CCMP) for the Long Island Sound which called for reducing nitrogen to address decreased levels of dissolved oxygen.[15] A 2001 TMDL prepared jointly by the New York State Department of Environmental Conservation and the Connecticut Department of Energy and Environmental Protection included wasteload allocations that reflected a 58.5 percent decrease in nitrogen loading from the 1990 baseline established in the CCMP.[16]

In January 2002, Connecticut's Department of Energy and Environmental Protection issued a General Permit for Nitrogen Discharges to implement the TMDL and establish a voluntary nutrient trading program with a central exchange.[17] This permit has been reissued with revised discharge limits several times and remains in effect today.[18] Through the nutrient trading program, which is administered by an advisory board and the Connecticut Department of Energy and Environmental Protection, the 79 WWTPs discharging directly or indirectly to the Long Island Sound may purchase credits needed to achieve their individual limits or sell credits that they may have in excess of their individual limits.[19]

Connecticut adopted broadly applicable trading ratios for regions of the state based on approximate attenuation and equivalency for those areas (**Figure 7-3**). Trading ratios are used to account for a number of concerns, such as uncertainty, attenuation of water quality benefits between locations, and to build a credit reserve. For trades between two permitted point sources, the EPA accepts trading ratios as low as 1-to-1 (sometimes expressed as a percentage) because these trades involve little uncertainty. However, in large trading areas with geographically dispersed participants, trades may require a higher ratio, even when trading between permitted point sources. This is because nutrient credits generated by a distant point source are not likely to have the same level of actual nutrient reduction at the location of a permittee's credit use.

[15] LONG ISLAND SOUND STUDY, THE COMPREHENSIVE CONSERVATION AND MANAGEMENT PLAN (Mar. 1994), http://longislandsoundstudy.net/wp-content/uploads/2011/10/management_plan.pdf.
[16] N.Y. Dep't of Envtl. Conservation & Conn. Dep't of Envtl. Prot., A Total Maximum Daily Load Analysis to Achieve Water Quality Standards for Dissolved Oxygen in the Long Island Sound (Dec. 2000).
[17] 2001 CONN. LEGIS. SERV. 01-180 (S.S.B. 1012) (West).
[18] Conn. Dep't of Energy & Envtl. Prot., General Permit for Nitrogen Dischargers (Jan 1, 2016).
[19] CONN. GEN STAT ANN. § 22a-523 (West 2015).



These ratios are based on the attenuation between these areas and the point of highest impact. The ratios apply to all credits generated within that reach. Source: Connecticut Department of Energy and Environmental Protection, presentation "Connecticut's Nitrogen Trading Program" (Sept 2014). Available at: http://www.ct.gov/deep/lib/deep/water/municipal_wastewater/9_17_14_pres_futureplans_ntp.pdf

Figure 7-3. Connecticut's Trading Ratios

Connecticut's permit and the trading program it facilitated have resulted in a 65 percent reduction in nitrogen from the 1990 levels.[20] Under this program, the state operates as a central exchange, thereby serving as an intermediary for all trading activities. The state sets the credit price, purchases all credits generated, and sells credits to facilities discharging beyond their individual allocations. Thus, all credit transactions are directly with the state agency. Through this process it is estimated that Connecticut municipalities have saved $300 to $400 million dollars in WWTP upgrades that would have been implemented in the absence of a trading program.[21]

7.5.2 Chesapeake Bay Nutrient Credit Exchange

In 2000, Virginia, Pennsylvania, Maryland, the District of Columbia, and the EPA signed an agreement to cooperatively work to improve Chesapeake Bay's water quality. Virginia and Pennsylvania developed trading programs in order to make progress towards these goals and allow dischargers flexibility in achieving compliance with permit limits. While the trading programs were established in advance of the Chesapeake Bay TMDL, a TMDL for nitrogen, phosphorus, and sediment was eventually adopted.[22] The trading programs developed by the states continue to operate within the framework of this TMDL.

[20] CONN. DEP'T OF ENERGY & ENVTL. PROT., REPORT OF THE NITROGEN CREDIT ADVISORY BOARD FOR CALENDAR YEAR 2013 TO THE JOINT STANDING ENVIRONMENT COMMITTEE OF THE GENERAL ASSEMBLY (Sept. 30, 2014), *available at* http://www.ct.gov/deep/lib/deep/water/municipal_wastewater/nitrogen_report_2013.pdf.

[21] Connecticut Department of Energy & Environmental Protection, Nitrogen Control Program for Long Island Sound, *available at* http://www.ct.gov/deep/cwp/view.asp?a=2719&q=325572&deepNav_GID=1635%20

[22] U.S. EPA, Chesapeake Bay Total Maximum Daily Load for Nitrogen, Phosphorus and Sediment (Dec. 2010).

Virginia utilized a similar methodology for TMDL compliance as was employed in Connecticut. Virginia issued a general permit for all WWTPs, assigned individual effluent allocations to each facility, and established a trading program with a voluntary central exchange.[23] If a WWTP is unable to comply with its individual limit, it may purchase credits either from individual facilities or through the Virginia Nutrient Credit Exchange Association, a voluntary association operated by a third-party nonprofit industry group that functions as a central exchange.

Virginia also maintains a state-run water quality improvement fund, which facilities unable to buy credits on the market may pay into in order to offset the permit exceedance.[24] The use of the water quality improvement fund has not been necessary in recent years, as even large exceedances, such as the 172,000 pound nitrogen exceedance by Richmond's WWTP in 2015, have been offset using nutrient credits.[25]

In the Chesapeake Bay, the jurisdictions with point-to-point source trading programs use the Chesapeake Bay Watershed Model to estimate the individual trading ratios needed for specific trading partners.[26] This model generates a custom ratio for each trade to accurately account for attenuation without undermining the financial viability of trades. Furthermore, Virginia uses an additional 1-to-1.3 ratio for trades between certain basins

Virginia's trading program has notably decreased nutrient loading from Virginian point sources into the Chesapeake Bay.[27] The success of this trading program led EPA Administrator Gina McCarthy to remark that EPA "encourage[s] states to look at Virginia as a model and a resource as they adopt similar programs."[28] Pennsylvania's program has not seen the objective success that has been generated by Virginia's program.[29] This is likely due to regulatory decisions that have impeded trading, such as the use of individual permits rather than general permits that bring all potential trading partners under a single regulatory document.

7.5.3 California Water Quality Trading Programs

The Laguna de Santa Rosa Nutrient Offset Program saw its first trade in 2012. The Santa Rosa Subregional Water Reclamation Facility discharges into the Laguna de Santa Rosa watershed—a CWA section 303(d) listed waterbody impaired by nutrients, metals,

[23] VA. CODE ANN. §§ 62.1-44.19:12–19 (2015).
[24] 9 VA. ADMIN. CODE § 25-820-70(J)(3).
[25] Va. Dep't of Envtl. Quality, 2015 Nutrient Load Analysis (Mar. 2016), *available at* http://www.deq.virginia.gov/Portals/0/DEQ/Water/PollutionDischargeElimination/Watershed%20GP/2015%20Published%20Loads%203_31_16.pdf
[26] VA. DEP'T OF ENVTL. QUALITY, NUTRIENT CREDIT TRADING RATIO STUDY REPORT (Dec. 23, 2014), *available at* www.deq.virginia.gov/ Portals/0/DEQ/Water/PollutionDischargeElimination/TradingRatioFinalReport12-23-2014.pdf. *See also* Jennifer Vogel, U. VA. ENVTL. LAW, *Trading Ratios Used for Generation of Credits in Water Quality Trading Programs* (July 2012), *available at* www.deq.virginia.gov/Portals/0/DEQ/Water/PollutionDischargeElimination/UVA_Trading_Ratios_Study.pdf.
[27] Reductions in wastewater pollutants have been and remain ahead of schedule for nitrogen, phosphorus, and sediment. See U.S. EPA, Fact Sheet: EPA Evaluation of Virginia's 2014-2015 Milestone Progress (June 2016).
[28] U.S. Dep't of Agric., Office of Commc'n, News Release: Federal Agencies Support Virginia's Innovative Market-based Approach to Improving Water Quality in the Chesapeake Bay, No. 0270.14 (Dec. 2014).
[29] U.S. EPA, Fact Sheet: EPA Evaluation of Pennsylvania's 2014-2015 Milestone Progress (June 2016).

bacteria, sediment, and temperature. To address the impairment, the North Coast Regional Water Board imposed a "no net loading" nutrient limit in Santa Rosa's NPDES permit.[30] Rather than install costly technology, Santa Rosa pursued a trading program that allows for quantified and credited mitigation at select agricultural sites in the basin to reduce the animal waste and fertilizer runoff entering the waterway.

Santa Rosa's trading program operates under a general framework adopted by the North Coast Regional Water Board.[31] Currently, the framework is undergoing a process of revision to strengthen the program and facilitate more credit generating activities. To date, the program has relied on individual offset projects that have been individually approved by the North Coast Regional Water Board. The anticipated revisions seek to streamline the program, allowing for greater credit generation from a broader range of activities.

The Grasslands Bypass Trading Project is another California trading program. In 1996, San Joaquin Valley drainage districts needed to address elevated selenium levels in the waterways in order to obtain approval to use Bureau of Reclamation's San Luis Drain.[32] To get approval, an agreement was struck that imposed numeric selenium limits.[33] All of the participants received WDRs that included selenium load allocations, which became more stringent annually until eventually equaling TMDL load allocations.[34] Each drainage district had flexibility to determine how to meet the limits and could pay other districts to make further reductions. Several districts did partake in trades, though in recent years other compliance options have made trading unnecessary.

The Los Angeles Municipal Separate Storm Sewer System (MS4) NPDES Permit applies to 84 distinct entities with jurisdiction over stormwater and allows them to collaboratively establish watershed management programs to meet water quality goals.[35] While not strictly a water quality trading program, it is similar in that off-site pollutant reductions can help establish NPDES permit compliance.

[30] "No net loading" means the facility has a numeric discharges limit for nutrients equal to zero. The permit expressly allows this limit to be met by reducing discharges elsewhere in the watershed, though the North Coast RWQCB did require this to be accomplished pursuant to an approved offset plan. See N. Coast Reg'l Water Quality Control Bd., Order No. R1-2006-0045, Permit No. CA0022764, Waste Discharge Requirements & Master Reclamation Permit for the Santa Rosa Subregional Water Reclamation System, at 13, n. 5 (2006, rev. July 2008, Apr. 2009).

[31] N. Coast Reg'l Water Quality Control Bd., Res. No. R1-2008-0061: Approving Santa Rosa Nutrient Program (July 24, 2008).

[32] U.S. EPA, Grassland Bypass Project: Economic Incentives Program Helps to Improve Water Quality (Aug. 2012).

[33] U.S. Dep't of the Interior, Bureau of Reclamation, Agreement for Use of the San Luis Drain, No. 01-WC-20-2075 (Sept. 2001), *available at* www.usbr.gov/mp/sccao_new/west_sjv/grassland/documents/index.html.

[34] Waste Discharge Requirements are similar to NPDES permits but issued by the California SWRCB under the California Porter-Cologne Water Quality Act, which regulates more sources than the CWA. HANNA L. BREETZ, ET AL., WATER QUALITY TRADING AND OFFSET INITIATIVES IN THE U.S.: A COMPREHENSIVE STUDY 10 (Aug. 5, 2005).

[35] L.A. Reg'l Water Quality Control Bd., Order No. R4-2012-0175, Permit No. CAS004001, Waste Discharge Requirements for MS4 Dischargers within Coastal Watersheds of Los Angeles County (2012, rev. July 2015).

7.6 Hypothetical Scenario Analysis

Quantifying the potential financial and environmental benefits of a nutrient trading program in the San Francisco Bay requires a robust understanding of the costs associated with treatment plant upgrades for nutrient management. As mentioned above, the current Nutrient Watershed Permit requires that the dischargers develop cost estimates for various treatment plant upgrades and that final results of the evaluations be presented to the Regional Board by July 1, 2018. At the present time, only preliminary cost estimates, pending further evaluation, are available for approximately half of the Bay wastewater treatment plants. Nevertheless, the preliminary data shows that nutrient removal is significantly less expensive at some plants than others with cost varying between $1/lb of nitrogen removed to upwards of $50/lb of nitrogen removed.

Using this preliminary cost estimate information, augmented with fictional information where necessary, several potential trading scenarios that could arise across two synthetic subembayments under a nutrient trading program involving eleven fictional dischargers and EBMUD were analyzed. Although this analysis was constrained by available data, it still serves to provide broad insight into the potential benefits of water quality trading for nutrients in the San Francisco Bay. The scenario analysis is discussed in detail in **Appendix F (Task 4)**.

These hypothetical scenarios were constructed to minimize the total expenditure necessary to meet several tiers of nitrogen load reductions for the fictional watershed as a whole, but not necessarily to optimize expenditures for individual facilities. While individual facility economic optimization would occur under an actual trading program, an economic analysis of that nature would require additional facility information that is currently unavailable, such as the ongoing expenses associated with different treatment technologies. Moreover, that type of precise analysis requires insight into individual facilities' willingness to take on particular risk(s), ability to pay for advance credits, and general economic position. While constrained by the lack of specifics, the analysis demonstrates more broadly the mechanics of trading and what types of opportunities likely exist for trading based on the cost differentials for technological upgrades between facilities.

7.7 Preliminary Recommendations

The next step in developing a nutrient trading program for the San Francisco Bay is certainly to conduct scenario analyses with actual data rather than the hypothetical information that was necessarily used in the scenario analyses discussed above. Using the actual data in scenario analyses will reveal the extent of the benefits that could be realized through trading and will also guide the program structure. The necessary cost data is currently being developed through studies required in the Nutrient Watershed Permit.

Although analysis of specific and realistic trading scenarios is needed, there is no reason that water quality trading can't be as successful in the San Francisco Bay as it has been in other large, complex watersheds such as the Long Island Sound and the Chesapeake Bay. The considerations below represent preliminary recommendations for the permitting structure, program type, and administration of nutrient trading in the San Francisco Bay. These recommendations would need to be revisited after a scenario analysis can be completed with data on estimated costs of nutrient removal for individual dischargers and with a better understanding of water quality issues, hydrodynamics, and potential nutrient impairment in the San Francisco Bay.

7.7.1 Permitting Structure

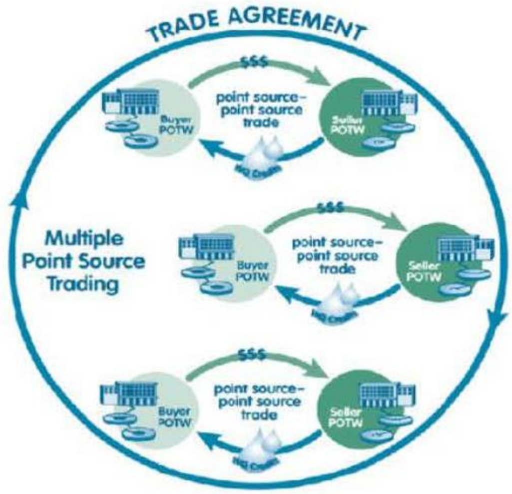
The existing Nutrient Watershed Permit jointly regulates the WWTPs in the San Francisco Bay and could be modified to incorporate trading provisions directly or by reference to another document in future reissuances. This approach aligns with the EPA's existing guidance documents and avoids the confusion that could arise if nutrient trading is implemented in individual permits.

While the next reissuance (2019) of the Nutrient Watershed Permit is not expected to include nutrient effluent limits, future reissuances of the permit are likely to include requirements for measurable nutrient load reductions, either cumulatively for the entire Bay or individually for the delineated subembayments. In addition to these overarching limits, the Watershed Permit could also include nutrient allocations for individual dischargers to allow for baseline determinations. The combined and individual limits could also include compliance schedules, if necessary and warranted.

7.7.2 Programmatic Type

A nutrient trading program for WWTPs in the San Francisco Bay could utilize a 'Multiple Facility Trading Program' structure with a trade agreement but without a central exchange. Operating without a true central exchange offers parties more leeway to design individual trade transactions that better suit their individual needs. Thus, individual dischargers would have the flexibility to enter into credit contracts formulated to be responsive to existing and anticipated conditions for those specific facilities, with negotiated clauses detailing mutually beneficial provisions for issues such as risk minimization, the results of breaching the agreement, and transaction timing. The trade agreement would be between the dischargers to the San Francisco Bay and would establish a single framework for all trading activities that all trades must comply with. The trade agreement would resolve much of the potential uncertainty in a trading program by explicitly and unambiguously defining the various components and characteristics of the program for all participants in one place, along with repercussions for failure to perform.

The trade agreement could be incorporated into the Nutrient Watershed Permit by reference, with some of the more important terms (i.e., trading area, reconciliation period, and baseline limits) included directly in the Watershed Permit. This approach allows for greater flexibility in refining the components of the trading program, as the parties and regulators could make amendments to the trade agreement in response to new information without having to reopen the general overlay permit. Importantly, such an agreement lowers transactional costs by defining the trading process and key components, which also makes participation easier.



Source: U.S. EPA, Water Quality Trading Toolkit for Permit Writers, EPA 833-R-07-04 (Aug. 2007, updated June 2009).

Figure 7-4. Multiple Facility Point Source Trading without an Central Exchange

7.7.3 Program Administration

A third-party broker could assist with trading forecasting, transaction documentation, reporting and credit accounting. Unlike a central exchange, the third-party broker will not act as an intermediary to buy and sell credits. Instead, the broker helps to anticipate credit supply and facilitate individual trades between two or more dischargers. Using a broker streamlines the trading process, lowering transaction costs and helping to minimize risk. This third-party broker should help to complete the documentation of individual trades required by regulators and should be responsible for maintaining a credit registry to track credit creation, serialization, transactions and custody.

Using a third-party broker significantly lowers the risk of noncompliance by providing a reliable mechanism for ensuring that credits are valid and properly documented before releasing them for compliance purposes. Moreover, a broker may be able to help direct trades in a way that further lowers risk and cost. For example, a broker can collaborate between multiple participants to forecast credit supply and demand, and facilitate future buy contracts—both of which can help minimize the capital exposure for potential credit sellers before they make costly upgrades. Of particular note, unlike a central exchange, a third-party broker may have as much or as little involvement in trading as the parties' to the trade agreement desire. Thus, a broker provides greater flexibility to individual parties as well as the certainty that comes with having an objective entity engaged in the process.

7.7.4 Additional Program Considerations

Although discrete program aspects will be completed in conjunction with stakeholders and the regulators, following components would likely be part of a successful trading program:

- **The trading area should likely include the entire San Francisco Bay with all of the subembayments, using trading ratios derived through bay-wide studies to account for attenuation of benefits between the subembayments**. Addressing impairment for the entire Bay represents the most holistic approach and, as such, has the greatest potential to improve conditions for the entire area. Similarly, a broader trading area allows for more participant permutations, which may also lead to further cost reduction opportunities.
- **The trade agreement should include a methodology for establishing trading ratios.** It is clear that a minimum 1-to-1 trading ratio would be required for nutrient trades between two point sources. Depending on the final trading area composition, higher ratios may be necessary to account for attenuation. One option is to use a 1-to-1 ratio for trades within a subembayment and create higher ratios for trading between subembayments. Another option is to tier ratios to the distance between subembayments. It would be preferable to develop a modeling tool like the trading programs in the Chesapeake use in order to generate appropriate ratios for individual trades.
- **Compliance should likely be determined on an annual basis, with credit duration matching this compliance period.** Water quality trading credits usually have a duration that aligns with the compliance period (i.e., a monthly compliance period would have credits with a one month duration). As such, the period of compliance impacts the transactional costs associated with credit trading—too short a period leads to high administrative expenses due to frequent trading, too long a period creates credits that are too expensive and generates too much uncertainty. An annual period allows for accurate forecasting of credit supply and demand while avoiding the issues associated with compliance periods that are too short or too long. The annual compliance period has proven workable in both the Virginia and Connecticut trading programs.
- **A reconciliation period should be adopted for achieving compliance with annual nutrient obligations.** End-of-pipe discharge monitoring should continue to be required by individual dischargers along with receiving water monitoring. In addition to the monthly Discharge Monitoring Reports (DMRs), all participating parties would be responsible for an end-of-year compliance report that documents annual reductions and trades. This report should not be due until several months after the close of the previous reporting year, as credit buyers will need time to reconcile credit needs based on actual discharges, and then acquire a sufficient volume of credits to offset any exceedances. Likewise, credit sellers will need time to properly account for and document the credits generated and sold. This approach is important for the purposes of individual facility risk minimization, as money is only exchanged after effluent reductions are achieved and credits are verified. This method also has less transactional costs than real-time reconciliation.

7.8 Feasibility of Including Non-Point Sources

As noted in the Nutrient Watershed Permit, estimates show that municipal WWTPs account for 63 percent of the annual average total nitrogen load to San Francisco Bay. While these estimates are continuing to be refined, it is evident that, as shown **Table 7-1**, the contribution from POTWs and other point sources varies significantly across the subembayments. POTWs account for the majority of nitrogen loading in the southern and central portions of the Bay and while stormwater and Delta efflux contribute the majority of nitrogen loading in the northern subembayments.

Table 7-1. Annual Average Loads for Dissolved Inorganic Nitrogen, kg/day[36]

Embayment	Municipal	Refinery	Stormwater	Delta	Total	POTW %
Lower South Bay	6,805	n/a	539	n/a	7,344	93
South Bay	19,401	n/a	670	n/a	20,071	97
Central Bay	11,667	n/a	159	n/a	11,826	99
San Pablo Bay & Carquinez Strait	2,721	842	7,484	n/a	11,047	25
Suisun Bay	5,618	130	1,968	15,930	23,646	24
Baywide	46,212	972	10,820	15,930	73,934	63

Although POTWs contribute most of the nitrogen loading to the Bay, the contributions from nonpoint sources (stormwater and non-point contributions in the Delta efflux) are large enough to warrant considering including nonpoint sources in the trading program. While credit supply would be largest in the upper subembayments, the nonpoint source credits could be transferable between subembayments using trading ratios to account for attenuation and uncertainty. This would provide a greater supply of credits that, in some instances, may be more cost effective while producing meaningful environmental benefits.

Expanding the potential point-to-point program to include nonpoint trading would not require significant revisions to an existing point-to-point trading program. The nonpoint source trading framework should be developed independently of the trade agreement for point-to-point trading before being incorporated by reference into that trade agreement. This enables participants to formulate and operate a point source trading program first and to add nonpoint source trading later, possibly avoiding the need to reopen the Watershed Permit if the point source trade agreement has already been adequately incorporated into the permit. This provides flexibility for parties to collaboratively develop a robust system that benefits all stakeholders.

[36] S.F. Bay Regional Water Quality Control Board, Order No. R2-2014-0014, Permit No. CA0038873, Waste Discharge Requirements for Nutrients from Municipal Wastewater Dischargers to San Francisco Bay. Data from San Francisco Estuary Institute, External Nutrient Loads to San Francisco Bay, Table 6, Draft, April 9, 2013. Final document (January 2014) available at: http://sfbaynutrients.sfei.org/sites/default/files/NutrientLoadsFINAL_FINAL_Jan232014.pdf . This report notes that: "the stormwater loads are highly uncertain, but nonetheless serve as order of magnitude estimates for comparison with other sources." (page 2).

A nonpoint source trading framework would be created to govern nonpoint source credit generation and accounting. This framework would identify all pertinent considerations, such as the eligible activities, the project quality standards, accounting process, etc. As nonpoint source crediting has a much higher degree of inherent uncertainty than point source crediting, providing clarity regarding the methodologies underlying nonpoint source credits is of the utmost importance. The framework document should be developed through a collaborative process involving the trading participants, the Regional Board, the EPA, and other interested stakeholders.

A central exchange is recommendable for nonpoint credits, even if no such exchange is created for credits generated by point sources. This central exchange could be operated by the broker that facilitates point-to-point source trades, or by an independent entity such as a third-party or the regulatory authority. Using an exchange would allow credit buyers to avoid the confusion and uncertainty inherent in nonpoint source trading. The exchange would deal with credit generators, providing point sources with the ability to purchase verified and certified credits directly from the central exchange. The expertise and experience of the exchange will lower transactional expenses, keeping credit costs to a minimum. The central exchange would bear the responsibility for ensuring the ongoing maintenance and monitoring required to maintain the validity of nonpoint source credits. This option provides the greatest level of certainty and oversight for nonpoint trading.

The nonpoint central exchange could also oversee a nonpoint source restoration fund. Dischargers unable to acquire credits to offset their exceedance could pay into the fund to achieve permit compliance and the fund would finance future restoration activities. The use of such a nonpoint source restoration fund as a component of a point source trading program could likely be helpful due to the certainty and risk minimization it provides to regulated entities. This type of fund constitutes a permanent pool of financing that the central exchange can manage and distribute to pay for nonpoint source credit generating activities. This offsets permit exceedances that would otherwise result in noncompliance with the discharge permit and generates greater environmental benefit that would otherwise be realized. Virginia's Chesapeake Bay Nutrient Trading Program uses this type of fund, and it has proven a valued tool to insure against unexpected credit shortages.[37]

[37] The Virginia Water Quality Improvement Act of 1997 established the Water Quality Improvement Fund (WQIF) to finance nutrient reduction strategies in the Chesapeake Bay and its tributaries. The WQIF is a permanent, non-reverting fund that point sources unable to acquire sufficient credits to offset exceedances may pay into in order to achieve permit compliance. The fund is used to finance point and nonpoint source nutrient reduction actions, thereby generating a net benefit to the local water quality. VA. CODE ANN. § 10.1-2117–2134 (2016). *See also* L.P. Bryant, Jr., Office of the Governor, Sec. of Nat. Res., Virginia Water Quality Improvement Fund Guidelines (Nov. 2006, updated May 2012), *available at* www.deq.virginia.gov/Portals/0/DEQ/Water/ChesapeakeBay/Nov2006WQIFGuidelines-updated_5-15-12.pdf.

CHAPTER 8 – PROJECT SUMMARY AND EVALUATION

8.1 Accomplishments

The key accomplishments for this study include:

- Conducted literature research on established, emerging, and embryonic sidestream treatment technologies
- Evaluated and pilot tested new cost-effective and environmentally sustainable sidestream treatment technologies at multiple wastewater treatment plants (WWTPs) to treat conventional, and more challenging, concentrated unconventional sidestreams
- Identified candidate WWTPs for sidestream treatment and estimated nutrient load reduction potentials, as well as costs associated with nutrient removal by sidestream treatment at WWTPs in the San Francisco Bay (Bay) Area
- Developed a sidestream treatment modeling tool for Bay Area WWTPs to assess planning level process sizing, and operational cost estimates for implementing sidestream treatment, at their facilities
- Simulated possible Bay water quality improvements, in terms of a decrease in nitrogen concentrations, if sidestream treatment were to be implemented at WWTPs for nitrogen removal
- Scanned the high-level challenges and opportunities in developing and implementing a watershed-based nutrient trading program, through which interested Bay Area wastewater dischargers could collaborate to find cost-effective ways to manage nutrient discharges

8.2 Summary and Findings

Pilot Test Results of Sidestream Nutrient Treatment Technologies (Chapter 3)

Pilot testing of nonproprietary anaerobic ammonia oxidation (anammox) (suspended-growth, attached-growth, zeolite-anammox), and the embryonic technology of coupled aerobic-anoxic nitrous decomposition operation (CANDO), was conducted at four WWTPs around the Bay (**Figure 3-1**). These new sustainable and cost-effective nitrogen removal technologies were evaluated for treating conventional and unconventional (more concentrated) wastewater sidestreams (**Table 3-1**). Unconventional sidestream was generated from the co-digestion of high organic strength trucked wastes at the East Bay Municipal Utility District (EBMUD) site, and from a more efficient digestion process due to the addition of sludge pre-treatment at the San Francisco Public Utilities Commission (SFPUC) site.

Pilot testing has shown that:

- The anammox-type processes can treat sidestreams containing approximately 500 to 2,000 mg NH_4^+-N/L, with a start-up time of three to twelve months, using various amounts of initial seeds at different pilot system scales

- The suspended- and attached-growth anammox processes tested by EBMUD and SFPUC handled average ammonia loading rates of approximately 0.36 to 0.98 kg-N/m^3-reactor/d, and achieved removal averages of 84 to 97 percent ammonia, 75 to 95 percent inorganic nitrogen, and 68 to 89 percent total nitrogen. Higher ammonia loading was obtained when a clarifier was installed following the addition of an attached-growth anammox reactor at the SFPUC site to retain biomass in the system. These results are comparable to those obtained from the pilot test of Krüger's ANITA™ Mox system performed by the Union Sanitary District
- Process upsets were experienced when treating unconventional sidestreams at two test sites, EBMUD and SFPUC, resulting in little to no anammox activity. Nitrite accumulation was observed, but the root cause cannot be determined based on the data collected
- The zeolite anammox test at the Oro Loma Sanitary District (OLSD) site handled an average ammonia loading rate of 0.32 kg-N/m^3-reactor/d, and achieved 47 and 48 percent reduction in ammonia and inorganic nitrogen, respectively. A higher ammonia loading rate (0.46 kg-N/m^3-reactor/d) and ammonia/inorganic nitrogen removal (87 percent) was obtained at the SFPUC site with a smaller reactor
- The CANDO pilot at the Delta Diablo site is ongoing, and further work is needed to demonstrate its viability as a cost-effective sidestream treatment technology. While greater insights on various nitrifying and denitrifying bacteria have been achieved, the pilot has not yet successfully replicated the previous bench-scale results of greater than 90 percent removal of ammonia and inorganic nitrogen. This is due to various equipment failures and control system issues that resulted from the limited budget available for pilot design and construction. Additional challenges arose from the increased variability of centrate characteristics that were encountered at the pilot scale, but were not seen previously at the bench scale study. Variability resulted from changing digester feedstocks (i.e., fats, oils and grease (FOG), food waste), differences in centrifuge operation, and individual digester performance. With additional funding and time (6 to 12 months), the CANDO team believes that the operational issues can be overcome and bench-scale results replicated. Preliminary data also indicates that there is a potential for this technology to be a one reactor system, which would greatly increase operational ease and cost-effectiveness; however, additional funding and time would be needed to demonstrate the feasibility
- Operating biological nutrient removal systems requires skilled manpower, continuous monitoring, and frequent adjustment

<u>Sidestream Load Reduction and Cost Estimation (Chapter 4)</u>

Potential nutrient load reductions and costs are being quantified to understand the extent of sidestream treatment in reducing overall wastewater nutrient discharge to the Bay. A total of 37 WWTPs were included in this assessment.

- Preliminary estimates indicate that
  - If all of the 16 candidate plants implemented sidestream treatment, the ammonia load reduction could be up to 21 percent across the Bay (**Figure 4-3** and **Appendix C**)
  - If all of the 25 candidate plants implemented sidestream treatment, the total nitrogen load reduction could be up to 17 percent across the Bay (**Figure 4-3** and **Appendix C**)
- Life-cycle costs for sidestream treatments are estimated to be $640 Million (in present value). These cost estimates were developed assuming greenfield facilities, with a 30-year project life and a 2 percent discount rate, and were based on a 5 to 10 percent project definition. They have an expected accuracy range of -30 to +50 percent
- Depending on ammonia mass loading, the order-of-magnitude unit cost for sidestream treatment using anammox or traditional nitrification technology ranges from <$1/lb to approximately $25/lb N removal (in present value) (**Table 4-5**). The wide range is largely attributed to the economies of scale, as the WWTP sizes range from approximately 1 to 167 mgd
- Both the total and unit cost of sidestream treatment will be significantly lower than that of mainstream upgrades for nutrient removal, as expected. The unit cost ($/lb N removal) for sidestream treatment is about one third of the mainstream cost (see the ongoing Optimization/Upgrades Study for the Regional Nutrient Watershed Permit)

Potential Bay Water Quality Improvement due to Sidestream Treatment (Chapter 6)

Model simulation was performed to estimate the effect of WWTP sidestream treatment on ambient nutrient (nitrogen) concentrations throughout the Bay, using the current San Francisco Estuary Institute (SFEI) model and the most recent WWTP nutrient discharge data available (July 2012 to June 2016). This existing nutrient model is hydro-dynamically calibrated and incorporates the simplified representation of nitrification and denitrification. For each scenario, the model permits a means for estimating the mass balance of nitrate and ammonia, as well as visualizing the distribution of these nutrients throughout the Bay.

The model suggests that both the concentrations, and the specifics of the mass balances, are directly related to the nitrogen load input to the Bay. As such, a fixed percentage reduction in loads through sidestream treatment would yield a similar percentage reduction in the concentration and transport of nutrients to the coastal ocean. However, sidestream load reductions would not be across-the-board fixed percentage reductions; the spatial variations in reduction lead to localized effects in the simulations, with reduction near the Golden Gate having a greater effect on transport to the coastal ocean and, on balance, less effect on ambient concentrations.

Conceptual Nutrient Trading Program for the Bay (Chapter 7)

A high-level analysis was performed to develop a common understanding among key stakeholders of what a regional nutrient trading program could look like for the Bay. While cost information for different levels of nutrient removal at individual Bay Area WWTPs is not yet fully available, preliminary estimates indicate that costs will vary significantly between dischargers. This, plus the absence of regulatory barriers and the success of trading programs in other analogous watersheds across the country, indicates that a nutrient trading program could potentially provide nutrient load reductions for the Bay at a reduced cost to the dischargers.

8.3 Recommendations

Based on the findings from this study, we recommend the continued evaluation of potential sidestream treatment as part of the ongoing regional, collaborative fact-finding nutrient management effort.

We also recommend that a conceptual nutrient trading program continue to be developed, in conjunction with regional scientific and engineering studies, to allow Bay Area wastewater dischargers to identify flexible and cost-effective nutrient load management solutions when they are deemed necessary.

Detailed recommendations for sidestream investigations include:

- Continue evaluating the potential full-scale application of innovative sidestream nutrient treatment technologies (anammox) to ensure process resiliency and reliability under various feed and operating conditions, especially for treating the more concentrated unconventional sidestreams at relative high ammonia loading rates
- Consider the mitigation of potential inhibition effects, process reliability, and the necessary lengthy start-up time for anammox-type technologies
- Further evaluate the need for the pretreatment of incoming total suspended solids (TSS) in the sidestream feed
- Consider potential impact of sidestream temperature (can be relatively high for thermophilic digestion) on biological process (which has not been evaluated in this study)
- Investigate nutrient recovery technologies from nutrient-rich sidestreams and assess the potential market for recovered material in the Region (which has not been evaluated in this study)
- Refine planning-level nutrient load reduction and cost estimates for sidestream treatment by Bay Area WWTPs, and consider site-specific conditions and plans at individual plants
- Conduct an engineering analysis to determine if, and at what conditions, it is more cost-effective to upgrade the WWTPs for both sidestream and mainstream treatment, or for mainstream treatment alone

- Simulate possible water quality improvements in the Bay when the more complete and sophisticated model becomes available over the next few years

Preliminary recommendations for a nutrient trading program include:

- Create a Bay-wide nutrient trading agreement that would outline the trading program's administration and compliance mechanisms
- At least initially, it is not recommended that that a "central exchange" be created as has been done in other major nutrient trading programs in the United States. Operating without a true central exchange offers parties more leeway to design trade transactions that better suit their individual needs
- Analyze potential trading scenarios, varying levels of nutrient load reduction and different degrees of trading across subembayments, after the necessary nutrient removal cost information for WWTPs becomes available through the work currently being conducted under the Nutrient Watershed Permit (San Francisco Bay Regional Water Quality Board, 2014)

8.4 Environmental Outcomes

A planning level assessment indicates that the majority of the 37 Bay Area WWTPs are potential candidates for sidestream treatment. If all candidate plants implemented sidestream treatment, the ammonia and total nitrogen load reduction across the Bay is up to 21 percent and 17 percent of the WWTP discharges, respectively (**Figure 4-3**).

This project has met the short-term (1–5 years) and long-term (5–20^+ years) environmental outcome goals described in the SF Bay Water Quality Improvement Fund Progress Report (2008–2014) (U.S. EPA Pacific Southwest/Region 9).

8.5 Lessons Learned

Challenges and lessons learned include:

- Pilot testing can take a significantly longer time, and much more effort, than originally planned, especially when evaluating emerging and embryonic technologies
- Pilot testing remains necessary in order to evaluate the key parameters involved in future full-scale application, especially for emerging and embryonic technologies
- Coordinated pilot testing is beneficial to Bay Area WWTPs because it offers cost and time savings when compared to individual treatment plants conducting individual, and possibly duplicative, testing
- Sharing study results in an open and transparent way is important to inform the ongoing nutrient management efforts led by the regulators, scientists, and stakeholders in the Bay Area

REFERENCES

Diaz, R. J. and Rosenberg, R. (2008) Spreading dead zones and consequences for marine ecosystems. Science, 321(5891), 926–9.

Dodds, W. K., Bouska, W. W., Eitzmann, J. L., Pilger, T. J., Pitts, K. L., Riley, A. J., et al. (2009) Eutrophication of U. S. Freshwaters: Analysis of Potential Economic Damages. Environmental Science & Technology, 43(1), 12–19.

Fux, C and Siegrist, H. (2004) Nitrogen removal from sludge digester liquids by nitrification/denitrification or partial nitritation/anammox: environmental and economical considerations. Water Science and Technology, 50(10):19-26.

HDR (2016) Bay Area Clean Water Agencies Nutrient Reduction Study Group Annual Report Nutrient Watershed Permit Annual Report (2015 and 2016): http://bacwa.org/wp-content/uploads/2015/11/Group-Annual-Report-2015_FINAL_20151111.pdf

http://bacwa.org/wp-content/uploads/2016/09/Group-Annual-Report-2016_Final.pdf

J.B. Neethling, B. Bakke, M. Benisch, A. Gu, Stephens, H.D. Stensel, R. Moore (2005). Factors Influencing the Reliability of Enhanced Biological Phosphorus Removal Facilities. WERF Report 01-CTS-3 (2005)

Joss, A., Salzgeber, D., Eugster, J., König, R., Rottermann, K., Burger, S., Fabijan, P., Leumann, S., Mohn, J., Siegrist, H. (2009). Full-scale nitrogen removal from digester liquid with partial nitritation and anammox in one SBR. Environmental Science and Technology, 43(14):5301-5306.

Joss, A., Derlon, N., Cyprien, C., Burger, S., Szivak, I., Traber, J., Morgenroth, E., 2011, Combined nitritation–anammox: advances in understanding process stability. Environmental Science and Technology, 45(22):9735-9742.

Khunjar, K. and Fisher, J. (2014). Nutrient Recovery in the Global Water Industry. From the Water Environment Association of Texas (WEAT) 2014 Eckenfelder Lecture Series. Hazen and Sawyer, CH2MHill, and Water Environment Research Foundation.

Lackner, S., Gilbert, E. M., Vlaeminck, S. E., Joss, A., Horn, H., and van Loosdrecht, M. (2014). Full-scale partial nitritation/anammox experiences–An application survey. Water Research, 55:292-303.

Regional Nutrient Watershed Permit issued by the San Francisco Bay Regional Water Quality Board, 2014 (Order No. R2-2014-0014).

Scherson, Y. D., Wells, G. F., Woo, S.-G., Lee, J., Park, J., Cantwell, B. J., et al. (2013) Nitrogen Removal with Energy Recovery Through N2O Decomposition. Energy and Environmental Science, 52, 547–556.

Tchobanoglous, G., Stensel, D., Tsuchihashi, R., Burton, F. (2014). Wastewater Engineering: Treatment and Resource Recovery, 5th Edition. Metcalf and Eddy, AECOM. McGraw-Hill Education.

Wett B., 2006; Solved upscaling problems for implementing deammonification of rejection water, Water Science and Technology 53(12): 121-128.

APPENDIX A – LITERATURE REVIEW OF SIDESTREAM TREATMENT TECHNOLOGIES

Literature Review

EPA Grant - Sidestream Treatment

EBMUD Led Sidestream Treatment Grant

Oakland, CA

February 8, 2017

Contents

List of Figures

List of Tables

Introduction

Nutrient levels in the San Francisco Bay are a growing concern for the Bay Area water quality. Historically, the San Francisco Bay has not been adversely impacted by nutrient loading, although there are indications that its historic resilience to the effects of nutrient enrichment may be weakening. While the definition of impairment has not been reached, there is concern that the San Francisco Bay has reached a tipping point that might lead to impairment.

Numerous scientific studies are being conducted, such as the Nutrient Numeric Endpoints (NNE), to understand the impact of nutrients on the San Francisco Bay. Initial findings have indicated that an estimated 63 percent of the annual average total nitrogen load to the San Francisco Bay is from publically owned treatment works (POTWs) which are known collectively as Bay Area Clean Water Agencies (BACWA) (Novick and Senn, 2013). As the science addresses the issue(s), BACWA POTWs are evaluating strategies to reduce their nutrient discharges to the Bay.

A pragmatic first step in evaluating nutrient load reduction opportunities at BACWA member agencies is by investigating nutrient removal opportunities at POTWs. One such potentially attractive strategy is treating the biosolids return sidestreams that are typically returned to the liquid stream, commonly referred to as the return sidestreams. The return sidestreams from digestion and dewatering are of interest since they are a source of high nitrogen loads. The sidestreams typically represent about 15 to 20 percent of the total nitrogen load discharged from a POTW (Fux and Siegriest, 2004). Furthermore, the sidestream is a low flow (typically a few percent of raw influent) and highly concentrated with nutrients (>500 mg N/L), which is ideal for cost effective and compact nitrogen removal.

This literature review investigates return sidestream treatment technologies as a part of the EPA Regional Grant to evaluate return sidestream treatment for BACWA POTWs. A graphic depicting the grant organization is provided in Figure 1.

Figure 1. EPA Region 9 Sponsored Sidestream Nutrient Removal Study Organizational Chart

The EPA Grant is being led by East Bay Municipal Utility District (EBMUD) with support from other BACWA POTWs, State Water Regional Control Board (SWRCB), academics/universities, San Francisco Estuarine Institute (SFEI), and consultants.

Literature Review Objectives and Approach

The key objectives of this literature review are as follows:

1. Create and screen return sidestream treatment technologies
2. Select and evaluate potentially viable technologies for BACWA POTWs

The screening approach is to elect representative nitrogen removal technologies that cover the gamut from established technologies to research status technologies.

The approach in evaluating the selected technologies is to include a brief technology description, present a process flowsheet, provide a list of installations (location, design flow, contact info), compile historical performance data (if available), identify knowledge and data gaps, list key advantages/disadvantages, and prepare a "fact sheet."

The 1-2 page fact sheet is a short document with key design information related to each technology and brief background material. For example, a fact sheet will include the following information:

- Pictures and schematics of the technology
- Brief background
- Capital and operations and maintenance (O&M) costs available
- Number of installations
- Equipment providers

Biological Nitrogen Removal Background

This section discusses various biological nitrogen removal pathways, referred to as Nitrogen Removal 1.0, 2.0, and 3.0. All three of these nitrogen removal pathways are shown under the nitrogen cycle shown in Figure 2. The removal of nitrogen during wastewater treatment is primarily achieved by (a) assimilation of nitrogen into biomass and (b) biochemical oxidation/reduction processes that convert organic nitrogen and ammonia to oxidized forms (nitrite and nitrate). The oxidized nitrogen forms are subsequently reduced to nitrogen gas for nitrogen removal.

Details for each nitrogen removal pathway are provided in the sub-sections below.

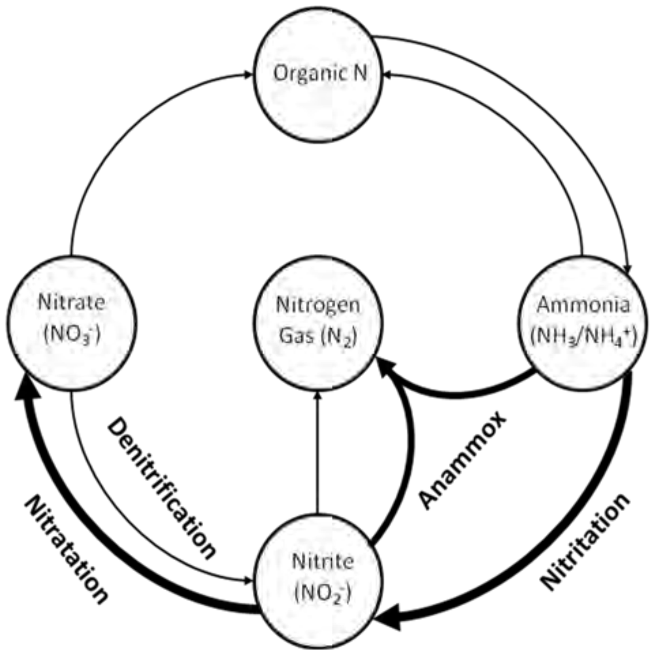


Figure 2. Primary Biological Nitrogen Transformations

Nitrogen Removal 1.0 - Nitrification/Denitrification

Nitrogen Removal 1.0 represents conventional nitrification and denitrification. Nitrification is an aerobic, two-step process where ammonia (NH_3/NH_4^+) is first oxidized to nitrite (NO_2^-) (nitritation) using ammonia oxidizing bacteria (AOBs), followed by nitrite oxidation to nitrate (NO_3^-) (nitratation) using nitrite oxidizing bacteria (NOBs). The two-step process is carried out by autotrophic nitrifying organisms (AOBs and NOBs) and is commonly referred to as nitrification. The overall process stoichiometry is as follows:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+ \quad (1)$$

The nitrate end-point of nitrification can be followed by denitrification if the treatment objective is to remove nitrogen. Denitrification is a biological process where heterotrophic, denitrifying bacteria reduce nitrate first to nitrite, followed by subsequent reduction of nitrite to nitrogen gas. Denitrification requires a carbon source (such as biochemical oxygen demand (BOD)) as the electron donor for reduction of nitrate and nitrite. Overall, the process stoichiometry with methanol as the carbon source is as follows:

$$6NO_3^- + 5CH_3OH + CO_2 \rightarrow 3N_{2(g)} + 6HCO_3^- + 7H_2O \quad (2)$$

Combined nitrification and denitrification configurations are used in activated sludge wastewater treatment plants to remove nitrogen. A more detailed discussion on nitrification/denitrification, as well as the various treatment configurations can be found in the WEF Nutrient Removal Manual (2010). Figure 3 below displays the stepwise carbon and oxygen requirements for oxidation and reduction in the nitrification and denitrification process. The carbon demand for denitrification will vary depending on the carbon source utilized.

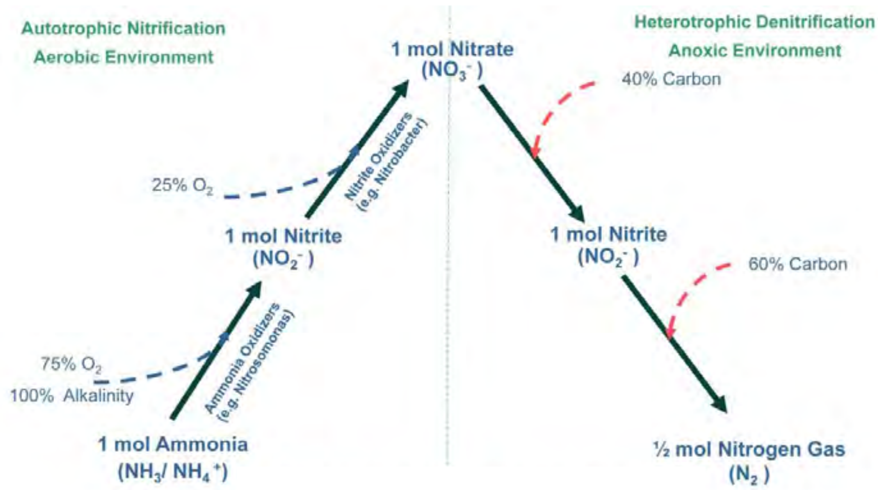


Figure 3. Schematic of Carbon, Oxygen, and Alkalinity Requirements for Nitrification/Denitrification

Nitrogen Removal 2.0 - Nitritation/Denitritation (Nitrite Shunt)

Nitrogen Removal 2.0 represents a short-cut over conventional nitrification and denitrification (Nitrogen Removal 1.0) and it thus requires less energy and chemicals. The ammonia oxidation step stops at nitrite (known as nitritation), which is subsequently reduced to nitrogen gas as follows (known as denitritation; shown with methanol as the carbon source):

$$NH_4^+ + 1.5O_2 \rightarrow NO_2^- + H_2O + 2H^+ \quad (3)$$

$$10NO_2^- + \ 5CH_3OH \rightarrow 5N_{2(g)} + 5CO_2 + \ 5H_2O + 10OH^- \quad (4)$$

In order to stop the ammonia oxidation step at nitrite (Equation 3), the NOBs must be suppressed which is commonly referred to as “nitrite shunt”. A schematic displaying the carbon and oxygen requirements for the nitritation/denitritation process is shown below in Figure 4.

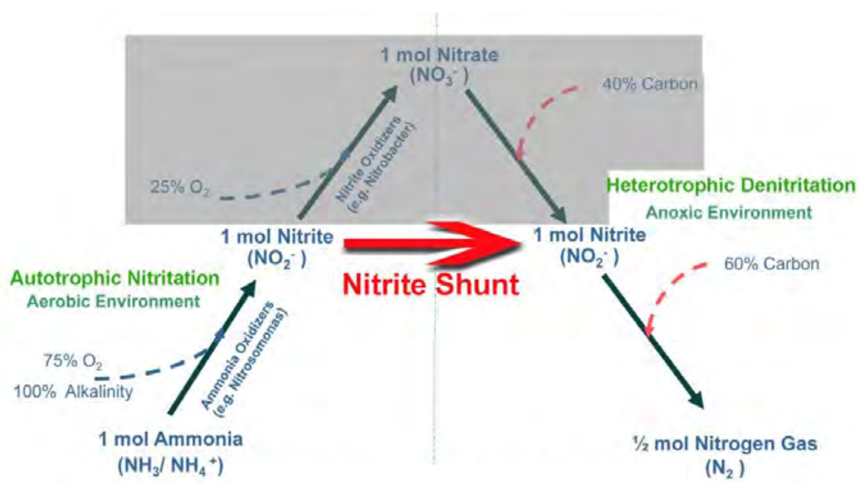


Figure 4. Schematic of Carbon, Oxygen, and Alkalinity Requirements for Nitritation/Denitritation

By stopping the ammonia oxidation at nitrite reduces both oxygen and carbon requirements by 25 percent and 40 percent, respectively. Additionally, biomass production is reduced by 40 percent in comparison to conventional nitrification/denitrification (Nitrogen Removal 1.0).

Nitrogen Removal 3.0 - Deammonification

Nitrogen Removal 3.0 represents a further enhanced short-cut over Nitrogen Removal 1.0 and 2.0. Nitrogen Removal 3.0, known as deammonification, is a two-step process that during the first step converts about half the ammonia load to nitrite using nitritation:

$$NH_4^+ + 1.5O_2 \rightarrow NO_2^- + H_2O + 2H^+ \qquad (5)$$

The subsequent second step removes the formed nitrite and the remaining ammonia load simultaneously to form nitrogen gas using anaerobic ammonia oxidizing (anammox) bacteria:

$$NH_4^+ + NO_2^- \rightarrow N_{2(g)} + 2H_2O \qquad (6)$$

Combined, the two steps of nitritation and anammox are known as deammonification. The inherent advantage of deammonification compared to Nitrogen Removal 1.0 reduces power consumption (about 60 percent less per pound N removed), requires little or no external carbon source, a low biomass yield (<0.15 lb TSS/lb N removed), and reduced CO_2 emissions.

Anammox bacteria are autotrophic and do not require a carbon source like denitrifying organisms for nitrite reduction. A schematic displaying the carbon and oxygen requirements for the deammonification process is shown below in Figure 5. Only half the ammonia load needs to be oxidized to nitrite which thus reduces the oxygen requirement by approximately 60 percent when compared to Nitrogen Removal 1.0.

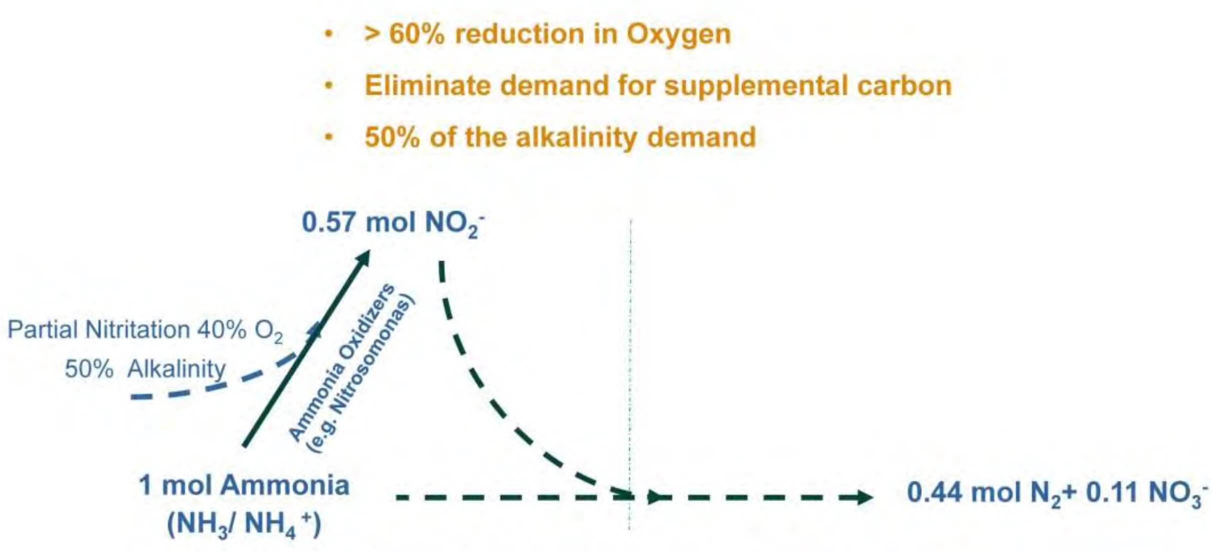


Figure 5. Schematic of Deammonification with Anammox Bacteria (Developed by Wett et al, 2007)

Biological Nitrogen Removal Summary

A summary of Nitrogen Removal 1.0 to 3.0 pathways is presented in Figure 6.

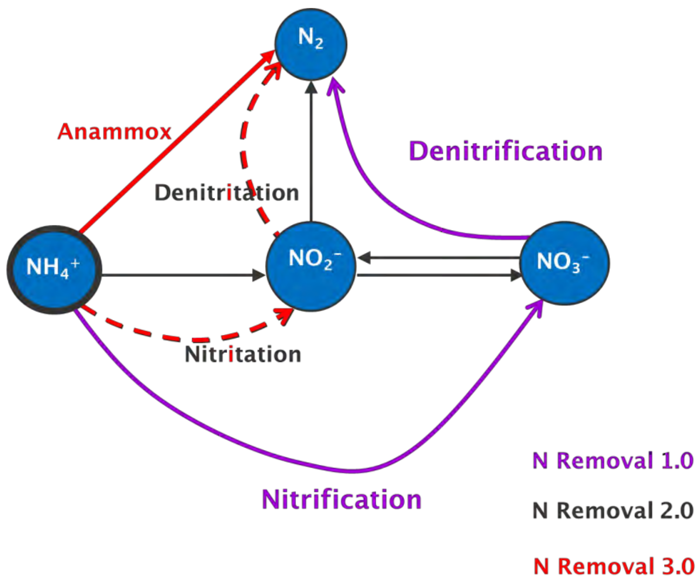


Figure 6. Nitrogen Removal Pathways (1.0, 2.0, 3.0)

A comparison of key unit parameters is captured in Table 1. The key points are the oxygen/energy demand, carbon demand, yields, and alkalinity demands are inversely related to the nitrogen removal pathway number (e.g., Nitrogen Removal 3.0). This reduced demand is attributed to the short-cut in nitrogen removal pathways for Nitrogen Removal 2.0 and 3.0 compared to Nitrogen Removal 1.0.

Despite the operations and maintenance (O&M) benefits, POTWs are reluctant in the United States to implement Nitrogen Removal 2.0 and 3.0 technologies due to concerns over risk and the perception that they are more difficult to operate than Nitrogen Removal 1.0 technologies. In order to compare and contrast all three nitrogen removal pathways, the selected technologies to evaluate for this literature review will include all three nitrogen removal pathways.

Table 1. Comparison for Nitrogen Removal 1.0, 2.0, and 3.0

Parameter	Units	Nitrogen Removal 1.0	Nitrogen Removal 2.0	Nitrogen Removal 3.0
Oxygen Required	lb O_2/lb NH_4-N Removed	4.6	3.4	1.9
Carbon Required (if acetate used)	lb COD/lb N Removed	6.6	4.5	0.0
Yield	lb VSS/lb N Removed	1.9	1.5	0.1
Alkalinity Required	lb Alk as $CaCO_3$/ lb NH_4-N Removed	7.1	7.1	3.6

A key question to consider is whether additional nitrogen removal pathways exist. Nitrogen removal 2.5 is presented in this literature review with a research technology. This technology is a part of the selected technologies for further evaluation and will be further discussed below.

Phosphorus Removal Background

The EPA Grant focuses on nitrogen removal but it is worthwhile to provide background on phosphorus removal as BACWA member agencies are currently tasked with evaluating phosphorus removal at their plants. Phosphorous can be removed from POTWs by biological and/or chemical/physical means. Biological phosphorous removal methods involve (a) assimilation of phosphorous (macro-nutrient) into cellular mass, and (b) enhanced phosphorus uptake by culturing phosphorus accumulating organisms (PAOs) in a sequential anaerobic-aerobic process. The latter is carried out in activated sludge processes configured for phosphorus removal, generally called Enhanced Biological Phosphorus Removal (EBPR). Phosphorus is removed from the treated effluent stream by wasting PAO-containing sludge. Average phosphorus content of EBPR sludge is in the range of 3 to 6 percent. Typically, biological phosphorus removal is implemented in the liquid stream. A more detailed discussion on biological phosphorus removal can be found in the WEF Nutrient Removal Manual (2010).

Chemical precipitation using a metal salt, such as alum or ferric, is used to reliably meet low effluent TP levels (TP <0.1 mg P/L). Chemical addition will precipitate inorganic phosphorus. The extent of phosphorus precipitation is largely governed by pH, alkalinity, and the metal dose to orthophosphate ratio. The appropriate pH operating range is based on the coagulant used, whereby alum has a tighter operating range than ferric. Recent work has shown that the metal/phosphorus chemistry is closely tied to hydroxide formation and that covalent bonding to metal hydroxides forms the major mechanism for phosphorus removal. A more detailed discussion on the fundamentals of phosphorus chemical precipitation can be found in Smith et al. (2008).

As it was mentioned before, phosphorus removal is typically applied as a part of the secondary treatment at the plant rather than specifically for treatment of centrate/filtrate. However, the dewatering centrate mostly from the plant with EBPR in the secondary treatment is an attractive location for phosphorus recovery. Phosphorus can be extracted and recovered as a marketable fertilizer in both the sidestream and the liquid stream. Phosphorus recovery is achieved by subjecting sludge or activated sludge recycle streams to anaerobic conditions for phosphorus release and subsequent crystallization from the solution.

Extractive recovery of phosphorus from plant sidestream flows has primarily been as struvite through a crystallization process. Many proprietary technologies are available for struvite recovery, such as Ostara Pearl®, PHOSPAQ™, and AirPrex®. The extracted struvite is sold as a fertilizer, with typical payback periods for the struvite installation ranging from 15 to 20 years (Khunjar & Fisher, 2014). Extractive phosphorus recovery from sidestream flows can significantly reduce recycle loadings of phosphorus and partially nitrogen, with orthophosphate sidestream recovery ranging from 80 – 90 percent and ammonia recovery ranging from 15 – 30 percent (Khunjar & Fisher, 2014). Struvite recovery is also attractive due to potential cost savings resulting from increased operational efficiency (from reduced nuisance struvite formation), reduced ferric/alum addition (where liquid stream chemical P removal is applied), and reduced nitrification aeration requirements (where liquid stream nitrification is utilized). A more detailed discussion on the fundamentals of extractive recovery of phosphorus can be found in Valsami-Jones (2004).

Sidestream Treatment

This section defines the sidestream and explains the benefits of sidestream treatment compared to liquid stream treatment.

Return Flows Characterization

At wastewater treatment facilities, sidestreams result from liquid/solid separation by thickening, dewatering, decanting, etc. During such processes, the nutrient-rich liquid is separated and recycled back to plant headworks, primary clarifiers, or directly to secondary treatment. The combined sidestream may constitute approximately 15 to 20 percent of the influent nitrogen load (Fux & Siegrist, 2004) and approximately 20 percent of the influent phosphorus load going into the activated sludge process (Khunjar & Fisher, 2014).

Multiple sidestreams are typically generated during the wastewater treatment process, each with different characteristics and impacts to the activated sludge wastewater treatment. The return flow characteristics from solids processing will vary with the type of thickening, digestion, and dewatering processes utilized for sludge treatment. Typical sidestream characteristics associated with anaerobic digestion are shown below in Table 2.

Return flows with significant nutrient loads include dewatering recycle from anaerobic digestion, anaerobic lagoons decant, and fermenter overflows. Return flows with low nutrient concentrations are those from primary sludge and waste activated sludge thickening, aerobic digested sludge dewatering, or returns from aerated lagoons.

Table 2 does not capture the intermittent nature of biosolids handling processes. A significant portion of POTWs, especially the smaller plants, do not operate their biosolids handling processing 24 hours per day, 7 days per week. As a result, the return sidestream loads are magnified during periods of operation. An example “magnification factor” calculation is presented below for a plant that operates their dewatering 3 days per week at 5 hours per day (while in operation):

$$\frac{\frac{7\ days}{week} X \frac{24\ hr}{day}}{\frac{3\ days}{week} X \frac{5\ hr}{day}} = 11\ times\ magnification\ factor$$

The impact of operating a solids handling process on magnifying the return sidestream loads needs to be managed for plants considering sidestream treatment.

Table 2. Typical Wastewater Characteristics[1]

Operation	Flowrate, Percent of Raw Influent	TSS mg/L	BOD mg/L	TKN mg N/L	NH_4-N mg N/L	NOx mg N/L	Total P mg P/L	Ortho-P mg P/L
Raw Influent	-	130 – 390	130 – 400	24 – 70	14 – 40	0	3.7 – 11	1.6 – 4.7
Anaerobic digestion supernatant (two-stage, high-rate)	0.1 – 0.5	1,000 – 11,500	500 – 5,000	850 – 1,800	800 – 1,300	0	110 – 470	100 – 350
Centrifuge dewatering centrate:								
Two-stage, high rate anaerobic digestion	0.5 – 1	200 – 20,000	100 – 2,000	810 – 2,100	800 – 1,300	0	100 – 550	100 – 350
Thermal hydrolysis + single stage mesophilic anaerobic digestion	0.2 – 0.5	1,500 – 10,000	1,500 – 3,000	2,200 – 3,700	2,000 – 3,000	0	220 – 800	200 – 700
Belt-filter press filtrate: Two-stage high rate anaerobic digestion, including belt washwater	1 – 2	100 – 2,000	50 – 500	410 – 730	400 – 650	0	50 – 200	50 – 180

[1] Adapted from Tchobanoglous et al., 2014

Benefits of Sidestream Treatment

The advent of more stringent discharge limits has led researchers to consider various locations in the plant for nutrient load reduction. In most cases, sidestream treatment of nutrient loads may be more economical and effective than liquid stream treatment due to high nutrient concentrations in the return flows from anaerobic digestion and dewatering. Such a sidestream is advantageous because the dewatering centrate/filtrate stream from anaerobic digestion has warmer water than the liquid stream which is more suitable for Nitrogen Removal 2.0 and 3.0 technologies. These short-cut nitrogen removal processes greatly reduce unit energy and operating costs as compared to the biological process utilized for liquid stream treatment nitrogen removal (Table 1).

Table 3 demonstrates the difference in unit cost for nitrogen removal in the liquid stream versus sidestream treatment. The table includes operation and maintenance (O&M) costs for two different deammonification sidestream treatment processes: DEMON® and AnitaMox®, which are described in the Section Deammonification: Suspended Growth, Granular Sludge, and Attached Growth below. Both the capital and O&M costs are significantly lower for sidestream treatment. According to the examples in Table 3, the use of sidestream treatment reduces capital costs by approximately 60 percent and O&M costs from 20 to 75 percent.

Table 3. Capital and Operations and Maintenance (O&M) Cost Comparison for Liquid Stream and Sidestream Nitrogen Treatment

Location	Unit	Cost (Capital)[1]	Annualized O&M Cost[1]	Cost (Capital + O&M)[1]	Configuration	Reference
Liquid Stream	$/lb N	0.9-1.6	1.7-1.8	2.7-3.3	5-stage Bardenpho + Denite Filters[2]	Bilyk et al. (2012)
Sidestream	$/lb N	0.5-0.7	0.4	0.9-1.1	DEMON[2]	Bilyk et al. (2012)
Sidestream	$/lb N	0.5-0.6	1.0	1.5-1.6	Nitritation/ Denitritation	Bilyk et al. (2012)
Sidestream	$/lb N	0.3-0.8	1.3	1.6-2.1	Bioaugmentation (e.g., BABE)	Bilyk et al. (2012)
DC Water Sidestream	$/lb N	0.4	Not available	--	DEMON®[3]	deBarbadillo (2014)

[1] Economics based on 20 years, 5% cost of financing, and 3% cost of inflation

[2] Installations at Hampton Roads Sanitation District (HRSD), Norfolk, VA

[3] Dilution water required to dilute high strength loads from CAMBI® process

Technology Status Classification

Sidestream treatment technologies may be classified according to the technology development status as described in Table 4. Many of the more progressive technologies have been conceived and established in Europe, in particular deammonification. Asia has been quick to adopt these progressive technologies. North America has been slower to adopt the cutting-edge technologies in wastewater treatment.

Table 4. Technology Status Classification Definition (Tetra Tech, 2013)

Technology Classification	Definition	Bench-Scale Testing	Pilot-Scale Testing	Full-Scale Installations	Comment
Established	Technology used at >1 percent of full-scale facilities (150) in the US	Yes	Yes	Yes	May include technologies that are widely used although recently introduced in the US
Innovative	Technology that meets one of the following criteria: • Some degree of initial use (i.e., <1% full-scale facilities (150) in the US • Available and implemented in the US for <5 years • Established overseas	Yes	Yes	Yes[a]	
Emerging	Technology has been tested at a pilot- or demonstration-scale, or has been implemented at full-scale	Yes	Yes	Yes[b]	
Research	Technology is at the development stage and/or has been tested at laboratory- or bench-scale.	Maybe	No	No	Technology that has reached demonstration-scale overseas are considered to be research technologies for US applications

[a] Might be limited to outside the US
[b] ≤3 installations or operated for <1 year

Sidestream Treatment Technologies Selection

An overview of the sidestream treatment technologies grouped by nitrogen removal mechanism is provided in Figure 7. This list does not identify vendor specific technologies (unless it the removal pathway is limited to a single technology). For example, DEMON® represents one of several Deammonification Technologies.

In order to identify attractive technologies for the EPA Grant, each nitrogen removal mechanism are discussed separately, followed by a recommendation of technologies to evaluate. It is important to note that the evaluation for selecting technologies considers the plant-wide impacts as this might influence the technology selection. For example, the Nitrogen Removal 2.5 CANDO technology requires that the plant has a cogeneration facility to recovery the energy from their biogas. Otherwise, the benefit of the CANDO technology on energy is lost.

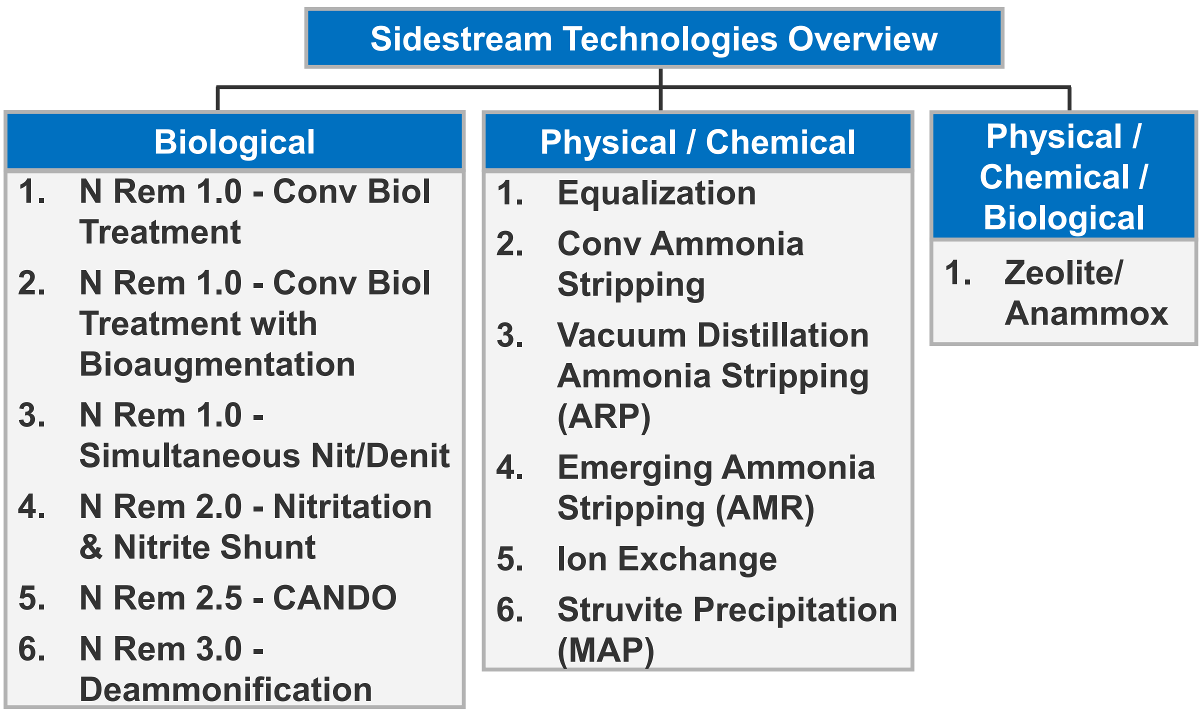


Figure 7. Sidestream Technologies Grouped by Nitrogen Removal Mechanism

Biological Treatment

A comparison of the biological treatment technologies presented in Figure 7 is provided in Table 5. The table lists the technology status, whether alkalinity and an external carbon source are required, and the relative energy demand.

Table 5. Biological Nitrogen Removal Technologies Comparison

Sidestream Treatment Technology	Technology Status[1]	Alkalinity Addition	External Carbon Source	Relative Energy Demand	Comment
N Rem 1.0 - Conventional Nit/Denit	Established	Yes	Yes	High	If just nitrification, the nitrate can be used for liquid stream odor control
N Rem 1.0 - Conventional Nit/Denit with Bioaugmentation	Established	Yes	Yes	High	Same as above
N Rem 1.0 - Simultaneous Nit/Denit	Innovative	Yes	Yes	High	Same as above
N Rem 2.0 – Nitritation/ Denitritation (Nitrite Shunt)	Innovative	Maybe	Yes	Medium	Similar to above except nitrite can be used for liquid stream odor control
N Rem 2.5 – CANDO	Research	Yes	No[2]	Low	Benefits limited to POTWs that recover energy from their biogas
N Rem 3.0 – Deammonification	Innovative	No	No	Low	Currently limited to waters >18°C

[1] Classifications according to technology status definitions by Tetra Tech (2013)

[2] CANDO requires soluble carbon to select for a microbial community that can store soluble carbon as polyhydroxybutyrate (PHB). The bench-top and demonstration scale have successfully used an external carbon source, acetic acid, in order to select for PHB accumulating organisms. A next step is evaluating whether an internal soluble carbon source, such as fermented raw solids, can be used to meet this soluble carbon demand.

The comparison in Table 5 complements the Section on Biological Nitrogen Removal Background, whereby the chemical and energy demands is inversely related to nitrogen removal pathways (e.g., Nitrogen Removal 3.0). Given the benefits of deammonification and CANDO (i.e., low energy and no additional chemicals), these two alternatives are recommended for further evaluation.

Although the Nitrogen Removal 1.0 and 2.0 technologies require additional chemicals and are highest in energy demand, the technologies offer the potential to help with odor control in the liquid stream. Several POTWs invest significant funds in headworks and primary odor control. If the ammonia is just oxidized to nitrate or nitrite for either Nitrogen Removal 1.0 or 2.0, respectively, the nitrate or nitrite can be used as an oxygen source to help mitigate odorous sulfides at the headworks and primaries. As a result, Nitrogen Removal 1.0 and 2.0 technologies are recommended for the evaluation. Additionally, having representation from each nitrogen removal pathway can serve as a benchmark against deammonification and CANDO.

Physical/Chemical Treatment

A comparison of the physical/chemical treatment technologies presented in Figure 7 is provided in Table 6. The table lists the technology status, whether pH adjustment is required, whether harmful chemical by-products need to be handled, the relative energy demand, and comments.

Table 6. Physical/Chemical Nitrogen Removal Technologies Comparison

Sidestream Treatment Technology	Technology Status[1]	pH Adjust Chemicals	Harmful Chemical By-Product	Relative Energy Demand	Comment
Equalization	Established	No	No	Low	Negligible costs if empty tankage is available
Conventional Ammonia Stripping[2]	Established	Yes	No	Medium	Releasing ammonia gas to the atmosphere might be a regulatory hurdle
Ion Exchange	Established	No	Yes	Medium	Harsh chemical by-products are a concern
Vacuum Distillation Ammonia Stripping [Ammonia Recovery Process (ARP) Technology][2]	Emerging	Yes	No	High	
Emerging Ammonia Stripping [Ammonia Recovery (AMR) Technology][2]	Emerging	No	No	High	
Struvite Precipitation[2]	Innovative	Yes	No	Medium	Nitrogen removal represents a small fraction of the sidestream nitrogen load (up to 44%)

[1] Classifications according to technology status definitions by Tetra Tech (2013)
[2] Nutrient recovery application that requires a demand to reliably unload the recovered material

The equalization alternative is more of a sidestream management approach and not a technology, per se. As a result, it is not carried any further. It is important to note that managing the sidestreams with equalization might be a viable option for plants with available tankage to equalize the flow and return during periods of low nitrogen concentrations. It is important to note that alkalinity and carbon demands might increase for this management strategy. During the return periods, the return streams do not typically provide sufficient alkalinity or carbon so the chemical demands have the potential to increase. This needs to be considered while evaluating this management style and sidestream treatment technologies.

Conventional ammonia stripping is a dated technology that is rarely, if ever, considered. The technology relies on increasing the pH to values above 10 or so (12 preferred) where total ammonia is converted to ammonia gas. The ammonia gas is stripped out of solution using an aerated media tower. The technology is rarely considered due to the chemical requirements for pH adjustment, the cost for constructing and operating a media tower, and the release of nitrogen as ammonia is a regulatory hurdle. For these reasons, conventional ammonia stripping was not considered any further.

Ion exchange technologies rely on replacing ammonium with other cationic ions using a resin or material with a high cationic exchange capacity (e.g., zeolite). At some point, the resin or media become saturated and must be regenerated. The chemicals required to regenerate the ion exchange resin are typically harsh and result in a chemical by-product that requires special handling. This technology was not considered further due to the concerns over handling the chemical by-products.

Two ammonia recovery processes are listed, ARP and AMR, which rely on vacuum distillation and stripping technologies. Both technologies convert total ammonia (NH_4^+ + NH_3) to ammonia by increasing the pH in a similar fashion to conventional ammonia stripping. The key difference in the two technologies is how the pH is increased and the strategy to separate ammonia gas. The ARP uses a strong base to increase the pH, whereas the AMR relies on CO_2 stripping facilitated by turbulence. Once the pH is raised, both technologies condense and recover ammonia using sulfuric acid to form ammonium sulfate (about 40 percent by volume). Similar to conventional ammonia stripping, both technologies suffer from high chemical (limited to ARP) and energy requirements. However, the ability to recover nitrogen in a form that can be taken to the marketplace makes this alternative attractive and it is thus recommended for further evaluation.

Struvite precipitation removes ammonium by precipitating with magnesium ammonium phosphate crystals (commonly referred to as struvite or MAP). The MAP crystals simultaneously remove ammonia and phosphate (theoretically 0.44 lb N per lb P removed), achieve near complete phosphate removal and provide partial nitrogen removal in the sidestream. MAP is harvested and used for beneficial purposes, such as agricultural fertilizer. Although attractive for recovering both ammonia and phosphate, the technology removes up to 44 percent of the sidestream ammonia load which translates to about 10 percent of the liquid stream nitrogen load. Given that it only removes about half the ammonia load compared to the other alternatives, it is not recommended for further evaluation.

Biological/Physical/Chemical Treatment

There is a single technology, Zeolite/anammox, under the biological/physical/chemical treatment grouping. This emerging technology takes advantage of ion exchange using the zeolite to remove ammonium out of solution. Once removed, biomass growing on the zeolite removes the ammonia to nitrogen gas. The biomass performing nitrogen removal treatment regenerates the zeolite media and thus reduces any concerns/risk associated with using harsh chemicals to regenerate the zeolite.

Zeolite/anammox offers both aerated and non-aerated options. The benefits of the non-aerated option include relatively low unit energy demand (blowers are not required) and no alkalinity/carbon requirements. Despite such overwhelming benefits, the technology requires the largest footprint of any technology discussed up to this point. Given the benefits, this technology is recommended for further evaluation.

Selected Sidestream Treatment Technologies

Nine different technologies were selected for further evaluation based on the reasons stated above. The selected technologies include those across all technology development statuses:

Established Technologies:

1. Nitrifying Sequencing Batch Reactor (Nitrogen Removal 1.0): Serves as benchmark
2. Sidestream Treatment with Liquid Stream Bioaugmentation (Nitrogen Removal 1.0)

Innovative Technologies:

3. Nitritation/Denitritation (Nitrogen Removal 2.0)
4. Suspended Growth Deammonification (Nitrogen Removal 3.0)
5. Granular Growth Deammonification (Nitrogen Removal 3.0)
6. Attached Growth Deammonification (Nitrogen Removal 3.0)

Emerging Technologies:

7. Ammonia Recovery Processes (ARP and AMR) (Physical/Chemical Removal Mechanism)
8. Zeolite/anammox (Nitrogen Removal 3.0)

Research Technology:

9. CANDO (Coupled Aerobic-anoxic Nitrous Decomposition Operation) (Nitrogen Removal 2.5)

Though less-established, the research, emerging, and innovative technologies offer the greatest potential benefits for cost and energy savings. The established technologies are low-risk investments, but are often not the most cost-effective. By selecting the established Nitrogen Removal 1.0 technologies, they can serve as a bench-mark against Nitrogen Removal 3.0 technologies and were thus recommended.

Sidestream Treatment Technologies Evaluation

The nine selected nitrogen removal technologies are evaluated in this section. The evaluation includes a technology description, important implementation and operational considerations (if applicable), advantages and disadvantages, and installation locations. Following the presentation of all technologies, two summary matrixes are given. One provides a summary of all advantages and disadvantages and data gaps for the selected technologies; the other compares relative costs, footprint, performance, energy demand, and operational reliability among all considered technologies.

Established Sidestream Treatment Technologies

As previously stated, two established technologies were considered attractive options for implementation by BACWA member agencies: (1) nitrifying sequencing batch reactor and (2) sidestream treatment with liquid stream bioaugmentation. Evaluations for these two established technologies are given below.

Nitrifying Sequencing Batch Reactor – Nitrogen Removal 1.0

The nitrifying sequencing batch reactor (NSBR) is a fill-and draw activated sludge system for wastewater treatment. In this system, wastewater is added to a single "batch" reactor, treated to remove pollutants, and then discharged. Equalization, aeration, and clarification can all be achieved using a single batch reactor. There are five operational steps in a SBR: fill, react, settle, decant, and idle. Because both treatment and settling occur in the same reactor, secondary clarifiers, as well as return activated sludge (RAS), are unnecessary (Tchobanoglous et al., 2014). Figure 8 displays the sequence of operational steps for a NBSR.

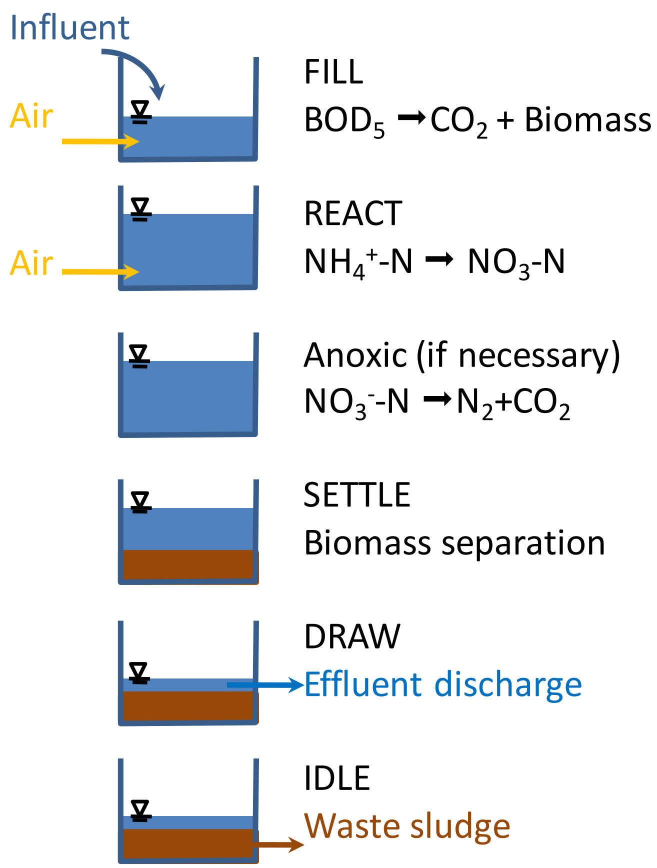


Figure 8. Nitrifying Sequencing Batch Reactor Operational Steps

The NSBR is an established technology that has been in use for decades since the first installations in the 1960s. It was not until the 1980s that NSBRs became widely accepted and implemented. The SBR configuration has been the most commonly utilized reactor configuration for sidestream treatment.

A hypothetical process flow diagram illustrating the application of a NSBR as a sidestream treatment process is shown below in Figure 9.

Based on a U.S. Environmental Protection Agency (EPA) survey (1992), there are approximately 170 wastewater treatment facilities in the United States that employ the SBR technology (EPA). Approximately 40 of those are operated for biological nitrogen removal (BNR). SBRs can be operated for only nitrification, or for both nitrification and denitrification. For nitrification-only operation, the react period is completely aerobic and additional alkalinity addition may be required. Two moles of bicarbonate are needed to neutralize the acidity generated per mole of nitrified ammonium. Blowers can be pH-controlled or can be operated at pre-determined on/off setpoints.

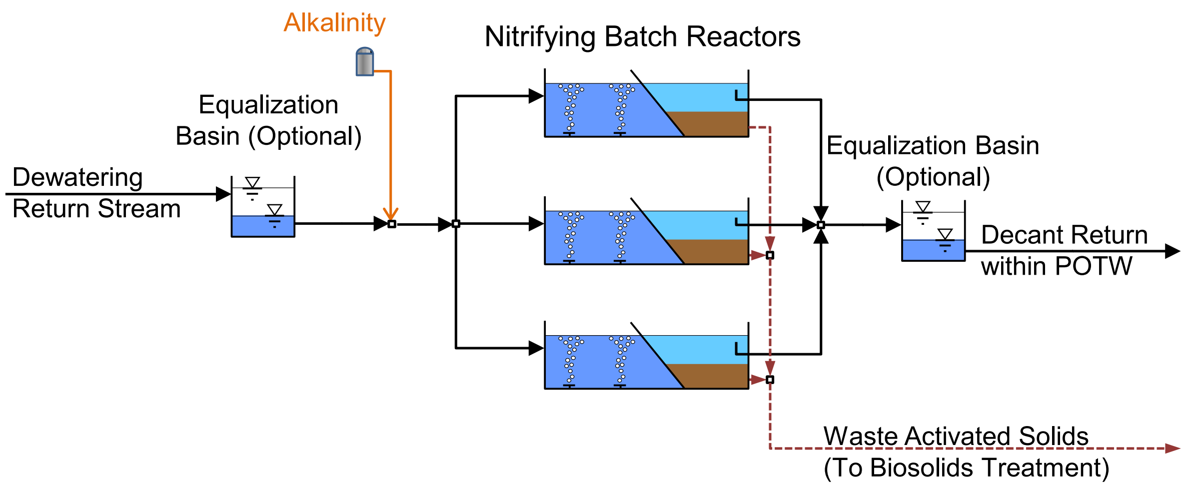


Figure 9. Hypothetical Sidestream Treatment Process Flow Diagram using a Nitrifying SBR

For operation incorporating denitrification for nitrogen removal, a supplemental carbon source is required due to the low BOD/TKN ratio of typical anaerobic digester centrate. Depending on the ammonia loading to the SBR, this may result in high operating costs due to the cost of an external carbon source such as methanol.

Rather than denitrifying in the sidestream reactor, the nitrite/nitrate produced in the sidestream process can be recycled to plant headworks to combat odors. Nitrite/Nitrate is preferentially reduced over sulfate and thus prevents formation of hydrogen sulfide (Zhang, et al., 2008). The reduced nitrate also provides oxygen which can oxidize odorous sulfides to sulfate. The odor control from nitrite/nitrate is a two-step biological process as follows:

If nitrite is present, it requires 1.2 lb NO_2^--N/lb HS^--S:

$$\text{Step 1} \rightarrow 2NO_2^- + 3HS^- + H_2O = 5S + N_2 + 5OH^- \quad (7)$$

Step 2 → $3S + 6NO_2^- = 3SO_4^{2-} + 3N_2$ (8)

If nitrate is present, it requires 0.7 lb NO_3^--N/lb HS^--S:

Step 1 → $2NO_3^- + 5HS^- + H_2O = 5S + N_2 + 7OH^-$ (9)

Step 2 → $5S + 6NO_3^- + 4OH^- = 5SO_4^{2-} + 3N_2 + 2H_2O$ (10)

Any nitrite/nitrate not reduced in the headworks should be removed in downstream primary clarifiers using influent BOD as the carbon source.

The practice of using nitrite/nitrate to control odors by way of sidestream treatment is in practice at treatment plants on the same scale as the largest BACWA plants (e.g., 91st Avenue Multi-Cities Wastewater Treatment Plant, Phoenix, AZ; 230 mgd design capacity). 91st Avenue has an in-plant return sidestream treatment facility to convert the centrate ammonia load to nitrite/nitrate. The nitrite/nitrate producing facility at 91st Avenue is a conventional activated sludge facility (basins, clarifiers, return activated sludge and waste activated sludge pumps). Although a different technology than NSBR, the treated water will have comparable nitrite/nitrate production results and thus combats odors in a similar fashion.

For plants interested in evaluating odor control potential, a rapid full-scale treatability experiment that requires a few testing hours can be tested as follows:

- Purchase tote(s) of commercially available odor control chemical that uses nitrate for combatting odors (e.g., Bioxide®). The number of totes required should match the nitrate load that could be produced over a few hours if sidestream treatment were implemented.
- Testing steps:
    - Measure sulfide levels at the headworks just before and during the few hours testing period.
    - After beginning the sulfide measurements, stop sending centrate to the headworks by storing or turning off dewatering for the few hours testing period.
    - Once the centrate return line is stopped, begin pumping the odor control chemical laden with nitrate in the centrate return stream line.
    - Continue pumping the odor control chemical during the few hours testing period while monitoring sulfide levels at the headworks.
    - Consider testing variable odor control chemical and raw wastewater contact times by taking grab samples at the headworks. This additional test will evaluate the role of contact time on headworks odor control.
- Results: Compare the sulfide levels for normal operation and during the testing period. This should serve as an indicator on how effective nitrate produced with sidestream treatment can assist with headworks odor control.

Most of the advantages for this process relate to the available design criteria and operations experience for the SBR technology. Piloting the NSBR for sidestream applications is not necessary as the NSBR is a well-understood, established technology. NSBR performance can be modeled and accurately predicted with present-day mechanistic activated sludge simulation models such as with the proprietary modeling software BioWin®.

Several NSBR installations are provided in Table 7. The three plants listed on top are NSBR facilities that treat the sidestream, whereas the remaining are liquid stream installations. The basis for presenting both sidestream and liquid stream facilities is to highlight that this technology has been implemented at all different sized plants and locations.

Table 7. Select Nitrifying Sequencing Batch Reactor Installations

Location	Location in Treatment Train	Description	Contact Information
Winnipeg, Manitoba	Sidestream	Centrate nitrifying-denitrifying as single stage SBRs. 1.5 mgd SBR.	Jong Hyuk Hwang City Engineer (204) 986-6268
Goddards Green, Southern Water, England	Sidestream	0.32 mgd (includes thickening filtrate, digested sludge centrate, and cake storage bays run-off. Influent - 400 mg N/L TKN	Jim Hawkins Senior Process Scientist (011) 44 1273-663234, jim.hawkins@southernwater.co.uk
Newthorpe, Severn Trent Water, England	Sidestream	0.09 mgd. The liquor is composed of digested sludge centrate only. Influent - 630 mg N/L TKN	Peter Wright Area manager Peter.Wright@severntrent.co.uk
Taneytown, MD	Liquid stream	Domestic wastewater with a 1.65 mgd flow for BOD removal and nitrification (Aqua-aerobic equipment)	Kevin Sneak Plant Manager (410) 984-4829
Fruitland, MD	Liquid stream	Domestic wastewater with a 1 mgd flow for nitrification (Siemens equipment)	George Calloway Superintendent (410) 548-2806
South Dayton, NV	Liquid stream	The domestic Rolling A wastewater plants nitrifies 1.5 mgd flow (ABJ equipment). Currently treating 0.7 mgd	Mark Tookey Utilities Electronical/Mechanical Superintendent (775) 246-5596 mtockey@lyon-county.org
Dublin, Ireland	Liquid Stream	Domestic wastewater with a 250 mgd flow for BOD removal and nitrification (ITT equipment)	Mark Driver Managing Director Celtic-Anglian Water Ringsend WWTW (01) 618 5800

Data from the Winnipeg, Canada high purity oxygen plant that treats their dewatering centrate with an NSBR is shown in Figure 10. Although the influent and effluent data do not occur at the same time, discussions with Nick Szoke, Branch Head - Wastewater Planning & Projects Delivery, City of Winnipeg, Water and Waste Department, Engineering Division revealed that the influent NSBR ammonia concentration is typically 700 mg N/L throughout the year. Although a couple effluent data points were greater than 200 mg/L as nitrogen, all the other data points are less 25 mg N/L leaving the NSBR.

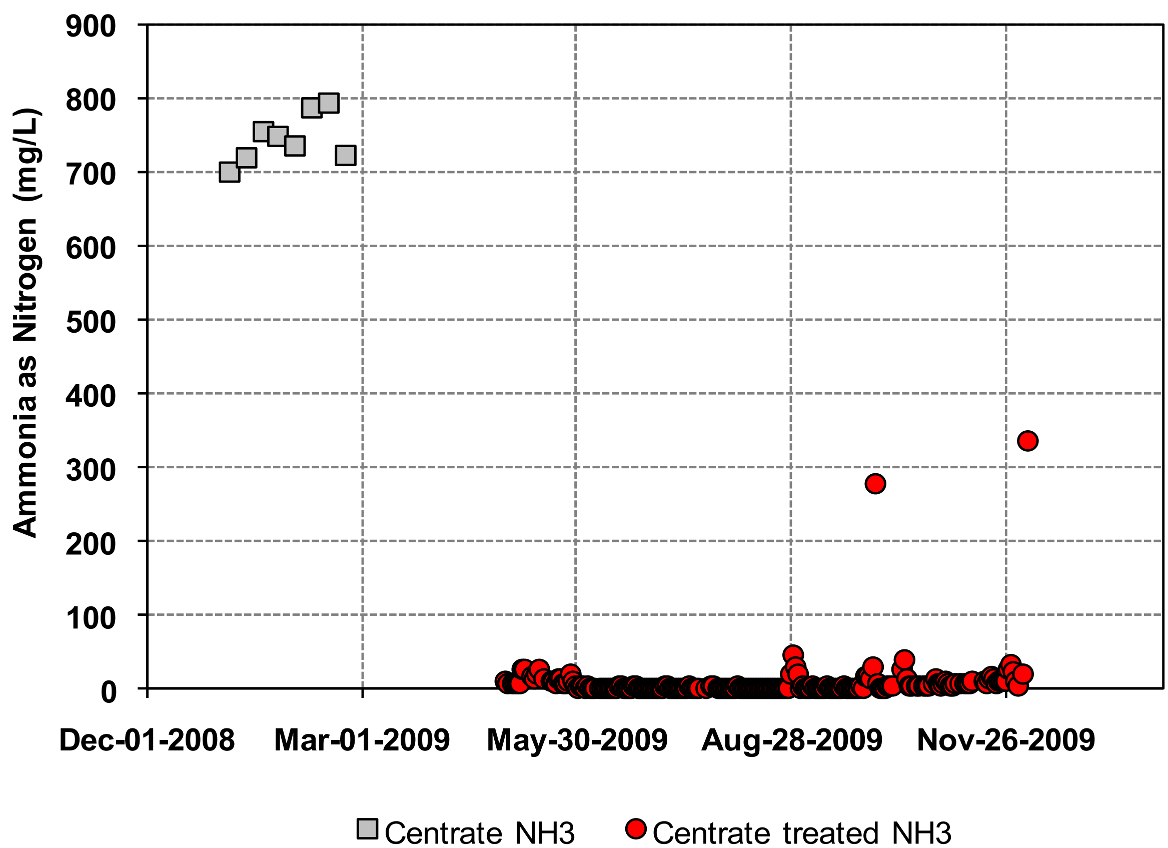


Figure 10. Nitrifying Sequencing Batch Reactor Data Treating Centrate from Winnipeg, Canada

The advantages, disadvantages, and data gaps for SBRs are outlined in Table 8.

Table 8. Advantages, Disadvantages and Data Gaps in Nitrifying Sequencing Batch Reactors

Parameter	Description
Advantages	• Established technology • Stable operating process • Single reactor vessel • No proprietary licensing • High operational flexibility and adaptation to changing wastewater loads • Tolerates peak flows and BOD shock loads • High retrofit flexibility: expand or upgrade for meeting future regulations • Ability to retrofit in the future for some of the currently emerging technologies (e.g., deammonification), as the technology becomes established) • Odor control at liquid stream headworks
Disadvantages	• Most energy intensive process (about 3 to 6 kWh/kg-N removed) • External carbon source required for complete nitrogen removal which poses a safety risk if methanol is used • Alkalinity addition typically required to convert all of the ammonia to nitrate • Complex instrumentation and control system • Potential for large reactor volume due to oxygen transfer limitations • Potential of washing out non-settled biomass during the decant phase • Potential for poor settling due to low heterotrophic population • Increased solids production due to complete nitrification to nitrate
Data Gaps	• This is an established and proven technology with minimal data gaps • Limited datasets for odor control at the headworks

Conventional Nitrification/Denitrification with Liquid Stream Bioaugmentation – Nitrogen Removal 1.0

A sidestream treatment and bioaugmentation process that is integrated with liquid stream treatment may offer advantages to plants with liquid stream nitrification. Bioaugmentation is the addition or "augmentation" of specific microorganisms to a treatment process in order to perform a function that would not otherwise be possible without the added microorganisms. The majority of BACWA member agencies do not currently have a liquid stream nitrogen removal process; however, given the potential for future nitrogen limits, consideration of a sidestream treatment approach that may enhance liquid stream treatment via bioaugmentation is warranted.

Two different bioaugmentation approaches are available: in situ or external bioaugmentation. In situ bioaugmentation is achieved by integrating the sidestream return flows into the liquid stream process; nitrifier seed, as well as treated sidestream, are returned to the liquid stream process. This combination provides a way to handle the high strength sidestream and provide an integrated ammonia reduction process. An advantage of in situ bioaugmentation is that nitrifier seed is better acclimated to liquid stream conditions due to the integration of the two processes. An alternative to in situ bioaugmentation, external bioaugmentation consists of growing nitrifiers in an external treatment process and seeding liquid stream nitrification. The seed can be grown in a parallel treatment plant or with the sidestream flow. For a more detailed comparison and literature review on in situ and external bioaugmentation see Parker and Wanner (2007).

A hypothetical process flow diagram illustrating the application of sidestream treatment with liquid stream bioaugmentation is shown below in Figure 11. The nitrifying organisms in the return flows from sidestream treatment can enhance the rate of nitrification in liquid stream nitrification and consequently reduce the liquid stream tank volume.

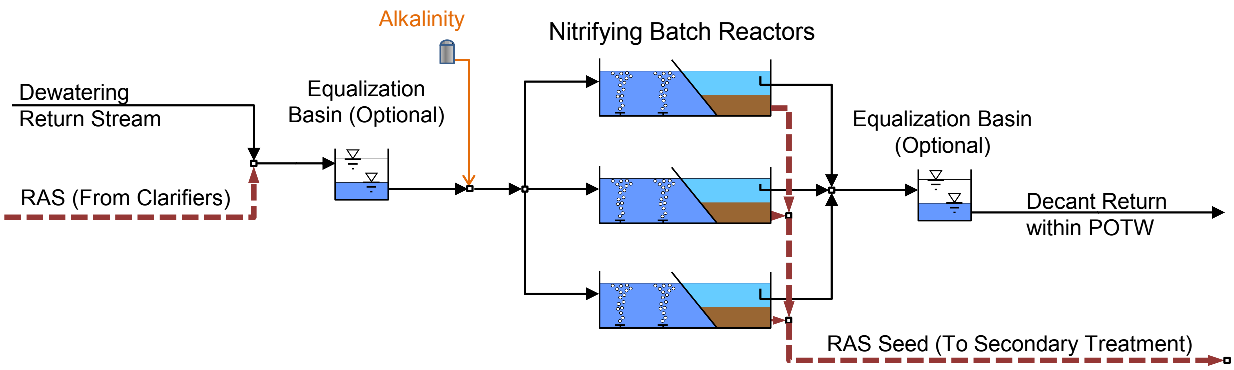


Figure 11. Hypothetical Sidestream Treatment Process Flow Diagram for Bioaugmentation

The efficiency of nitrification enhancement by bioaugmentation is dependent upon the difference between liquid stream and sidestream growth environments (i.e. temperature, pH, ionic strength); the effects have not been quantified over a wide range of operating conditions (Bowden et al., 2014; Munz et al., 2012). Therefore, certain operating conditions will select for a specific nitrifying population tailored to those conditions. A loss of seeding efficiency occurs between sidestream and liquid stream treatment due to the selection of differing nitrifying populations characterized by different kinetic parameters (Head et al., 2004; Wett, 2011). Sidestream-selected nitrifiers grown at higher sidestream temperatures will have a competitive disadvantage in the liquid stream environment. Therefore, sidestream treatment/ bioaugmentation processes that integrate more liquid stream recycle flows, such as liquid stream RAS, into the sidestream reactor result in enhanced nitrifier acclimation and seeding efficiency. Bioaugmentation technologies that have been utilized to enhance liquid stream nitrification are presented in Table 9. Select installations are presented in Table 10.

A dataset from the prenitrification reactor in Lincoln, NE is presented in Figure 12. The centrate is blended with RAS at Lincoln and subsequently nitrified in a separate aeration tank. This operating strategy creates sufficient nitrifiers in the prenitrifying tank to reduce the overall tank volume in the aeration basins.

A list of the advantages, disadvantages, and data gaps of sidestream treatment with liquid stream bioaugmentation are outlined in Table 11.

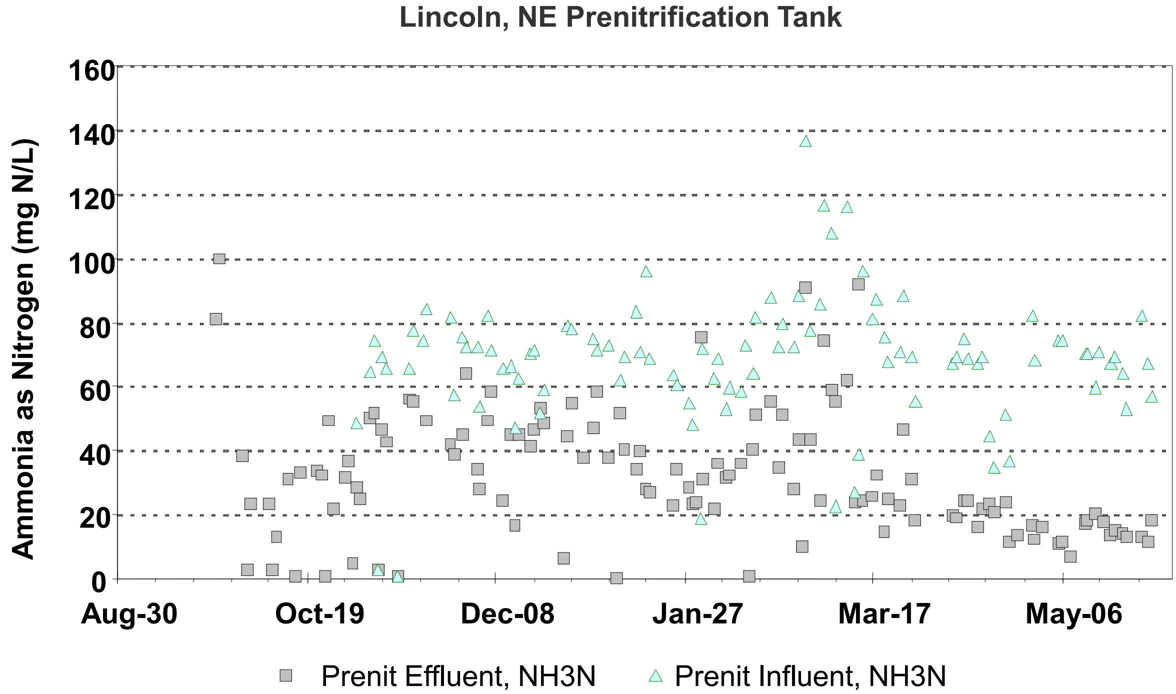


Figure 12. Ammonia Performance Data at the Lincoln, NE Prenitrification Tank that Treats RAS and Centrate

Table 9. Technologies for Sidestream Treatment with Liquid Stream Bioaugmentation

Technology	Process Overview	Advantages	Disadvantages
BABE® (Biological Augmentation Batch-Enhanced)	• Sidestream nitrifying SBR reactor • Returns nitrifier seed to liquid stream • A portion of the liquid stream RAS directed to the BABE reactor • Can operate for denitrification with external BOD addition	• Reduces liquid stream nitrification volume • Enhanced nitrifier acclimation	• Nitrogen Removal 1.0 • Requires external BOD addition for Denitrification
AT-3 (Aeration Tank 3 at the 26th Ward WWTP in Brooklyn, NY)	• A portion of liquid stream RAS directed to the sidestream 4-pass plug-flow tank • Alternating aerobic and anoxic zones • Caustic soda added for nitrification • Includes sidestream internal recycle	• Reduces liquid stream nitrification volume • Greater nitrogen removal in sidestream • Enhanced nitrifier acclimation	• Nitrogen Removal 1.0 • Requires external BOD addition for Denitrification
MAUREEN® (Mainstream Autotrophic Recycle Enabling Enhanced N-removal)	• Plug-flow reactor with two stages for nitrification and denitrification • A portion of the liquid stream RAS directed to the MAUREEN reactor	• Reduces liquid stream nitrification volume • Greater nitrogen removal in sidestream • Enhanced nitrifier acclimation • Seed contains methytrophs in addition to nitrifiers	• Nitrogen Removal 1.0 • Requires external BOD addition for Denitrification
InNitri® (Inexpensive NITRIfication)	• CSTR sidestream reactor • Does not incorporate liquid stream RAS addition to sidestream reactor	• Reduces liquid stream nitrification volume	• Nitrogen Removal 1.0 • Requires external BOD addition for denitrification • Sidestream nitrifiers not acclimated to liquid stream environment
BAR (BioAugmentation Reaeration)	• All liquid stream RAS directed to plug-flow sidestream reactor • Sidestream ammonia diluted by 50 to 100-fold; similar to liquid stream conditions • Can operate denitrification with BOD addition	• Reduces liquid stream nitrification volume • Enhanced nitrifier acclimation	• Nitrogen Removal 1.0 • Requires external BOD addition for denitrification
Prenitrification	• All RAS and centrate directed to plug-flow sidestream reactor	• Reduces liquid stream nitrification volume • Enhanced nitrifier acclimation	• Nitrogen Removal 1.0 • Not configured for denitrification

Table 10. Select Sidestream Treatment with Liquid Stream Bioaugmentation Installations

Installation Type	Location	Description	Contact Information
AT-3	New York, NY 26th Ward	85 mgd plant using centrate combined with RAS for nitrification. The secondary process is step-feed BNR that uses prenitrification on centrate to reduce aeration requirements within the secondary process. The nitrified centrate is sent to the headworks to promote denitification prior to the secondary process.	Mauro Orpianesi NYC Dept. of Environ morpianesi@dep.nyc.gov
BABE®	Groningen, Netherlands	First BABE process (operational since 2002); 1/3 filtrate mixes with 1/3 RAS for Nit/Denit in sidestream prenitrification/predenitrification process SBR. Effluent is combined with liquid stream RAS line prior to re-introduction into liquid stream secondary process.	Debby Berends Consulting Engineer +31 33 468 2483 debby.berends@dhv.com
BAR	Appleton, WI	14 mgd facility designed in 1989 using filtrate combined with RAS for nitrification. Achieves >90 percent nitrification on the filtrate.	Bob Kennedy Operations Supervisor (920) 832-5943 wastewater@appleton.org

Table 11. Advantages, Disadvantages and Data Gaps in Conventional Nitrification/Denitrification with Liquid Stream Bioaugmentation

Parameter	Description
Advantages	• Those listed for the Nitrifying Sequencing Batch Reactor • Reduces volume, footprint required for main liquid stream nitrification • Enhanced odor control at headworks due to recycled NO_3^- from sidestream nitrification
Disadvantages	• Those listed for the Nitrifying Sequencing Batch Reactor • Energy intensive: requires aeration energy for complete nitrification to NO_3^- • External carbon source required for complete denitrification (if sidestream total nitrogen removal is desired) • Alkalinity addition required for nitrification-only
Data Gaps	• Lack of information on how much seed is required to reliably nitrify in the liquid stream • Technology is based on more on anecdotal evidence than science • Enough installations to be considered an established technology, but designs based largely on anecdotal evidence • Lack of performance data on meeting stringent ammonia/nitrogen limits

Innovative Sidestream Treatment Technologies

Four innovative technologies are evaluated for possible implementation by BACWA member agencies as follows: (1) Nitritation/Denitritation, (2) Suspended Growth Deammonification, (3) Granular Growth Deammonification, and (4) Attached Growth Deammonification. These technologies are presented and described below.

Nitritation/Denitritation (Nitrite Shunt) – Nitrogen Removal 2.0

As described in the Biological Nitrogen Removal Background Section, nitritation/denitritation is a short-cut nitrogen removal process whereby ammonia is partially nitrified to nitrite, and nitrite is subsequently denitrified to nitrogen gas. This process results in energy and carbon savings of 25 percent and 40 percent, respectively, in comparison to Nitrogen Removal 1.0 technologies (see Table 5).

Nitritation/denitritation can be applied for nitrogen removal in the sidestream, but requires the addition of external carbon for denitritation. Alternatively, nitritation-only can be applied to the sidestream, and nitrite produced may be recycled back to headworks and/or primary clarifiers for denitritation using carbon available in the raw influent. This approach has the added benefit of odor control as previously discussed in the Nitrifying Sequencing Batch Reactor – Nitrogen Removal 1.0 Section.

Application of nitritation/denitritation for sidestream treatment was developed in the 1990s at the Delft University of Technology in The Netherlands (Hellinga et al. 1998) and was named SHARON® (Stable-reactor, High-Activity ammonia Removal Over Nitrite). The SHARON® process takes advantage of the lower maximum specific growth rate of NOB as compared to ammonia-oxidizing bacteria (AOB) at temperatures above 28ºC. NOB growth is effectively suppressed by operation at high temperatures; therefore, below a certain SRT threshold, AOB biomass is sustained but NOB mass is selectively washed out.

A process flow diagram of SHARON® is shown below in Figure 13.

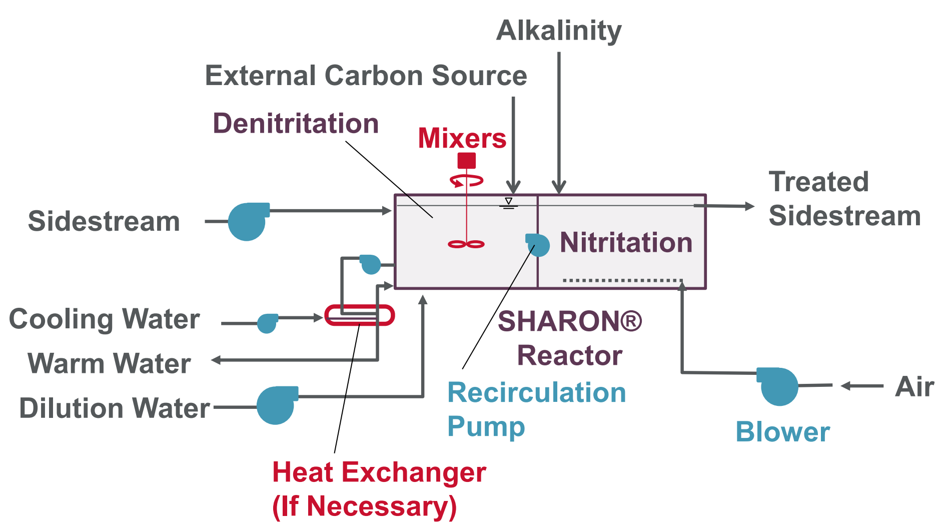


Figure 13. SHARON® Treatment Process (adapted from Bowden et al., 2014)

The SHARON® reactor can be a single or dual-stage completely mixed reactor. In the single-stage reactor, intermittent aeration is applied to allow for periods of nitritation and denitritation. In dual-stage reactors, the nitritation and Denitritation steps occur in separate stages. An external carbon source must be added for denitritation. Most installations have been dual-stage due to enhanced process control.

A hypothetical process flow diagram illustrating the application of sidestream treatment with nitritation/denitritation treatment process is shown in Figure 14.

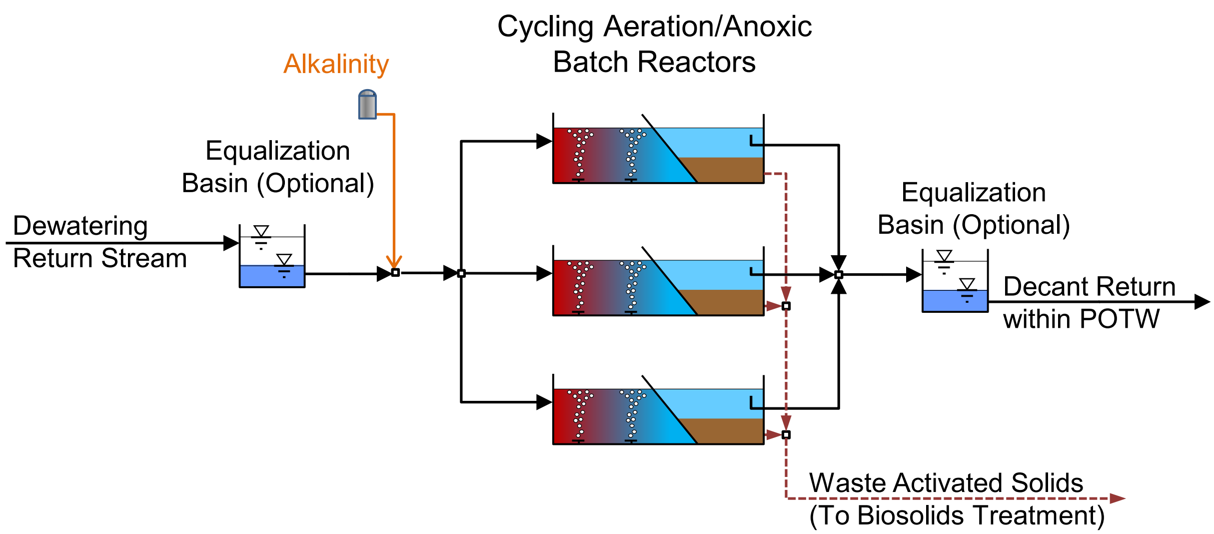


Figure 14. Hypothetical Nitritation/Denitritation Process Flow Diagram

Select nitritation/denitritation installations are provided in Table 12. There have been no municipal installations since 2010 as utilities are moving towards Nitrogen Removal 3.0 (deammonification) technologies.

Table 12. Select SHARON® Installations and Design Loading[1]

SHARON® Facility	Year	N Load (lb-N/day)
Utrecht (NL)	1997	1,980
Rotterdam (NL)[2]	1999	1,870
The Hague-Houtrust (NL)	2005	2,860
Geneva (CH)	2009	4,180
MVPC Shell Green, Manchester (GB)	2010	3,520
Wards Island WPCP, New York City (US)	2010	12,540
Linnkoping (SE)	2010	1,980

[1] Table adapted from Bowden et al., 2014.
[2] SHARON® tank at Rotterdam was converted to a two-stage deammonification process in 2002.

A list of the advantages, disadvantages, and data gaps for Nitritation/Denitritation (Nitrite Shunt) are outlined in Table 13.

Table 13. Advantages, Disadvantages and Data Gaps in Nitritation/Denitritation (Nitrite Shunt)

Parameter	Description
Advantages	• Reduction in aeration energy by 25 percent as compared to Nitrogen Removal 1.0 technologies • Reduction in external carbon addition by 40 percent as compared to Nitrogen Removal 1.0 technologies • Biomass production reduced by 40 percent as compared to Nitrogen Removal 1.0 technologies
Disadvantages	• Requires more aeration energy than Nitrogen Removal 3.0 technologies • Requires an external carbon addition for nitrogen removal • An emerging technology in the U.S. • Technology installations on the decline due to favor for Nitrogen Removal 3.0 technologies • Requires more sophisticated process control than Nitrogen Removal 1.0 technologies • New technology for operators
Data Gaps	• Limited installations in the U.S. • Dataset is expanding at a low rate due to more interest in Deammonification technologies • Installations limited to use of methanol as an external carbon source • The technology controls are key to the technology as these are improving faster than the technology(s)

Deammonification: Suspended Growth, Granular Sludge, and Attached Growth – Nitrogen Removal 3.0

TECHNOLOGY OVERVIEW

The origins of Nitrogen Removal 3.0 research in the wastewater sector dates back to the 1990's. The bacterial strain specific to Nitrogen Removal 3.0 is referred to as the anaerobic ammonium oxidation (anammox) bacterial strain. The anammox bacterial strain oxidizes ammonium while simultaneously reducing nitrite (Step 2 in Nitrogen Removal 3.0; Equation 6). The anammox bacterial strain was first reported in wastewater at the Delft University of Technology (Mulder, 1995). Discovery of anammox in wastewater has paved the way for significant advancements in energy efficiency and waste reduction at treatment plants. A comparison of deammonification to conventional nitrification/denitrification is presented in Table 14.

The first full-scale deammonification facilities were constructed from 2001 to 2002 in Germany and the Netherlands (Tchobanoglous et al., 2014). Approximately 100 full-scale worldwide deammonification facilities have been constructed or are under design as of 2014 (Lackner et al., 2014). The majority of installations are in Europe, with several locations also in Asia. The United States has been slower to adopt deammonification as a wastewater treatment strategy. As of 2014, only two full-scale municipal deammonification facilities were in operation in the U.S.

Both facilities are operated by Hampton Road Sanitation District (HRSD) at their York River and James River Plants. However, several other deammonification facilities are in the piloting and design/construction phases in the U.S. including DEMON® configurations at the District of Columbia Water and Sewer Authority (DC Water), at the Blue Plains Advanced Wastewater Treatment Plant (Figdore et al., 2011) and at the Alexandria Sanitation Authority Water Resource Facility (Daigger et al., 2011).

Table 14. Comparison of Nitrogen Removal 3.0 (Deammonification) to Nitrogen Removal 1.0 (Nitrification/ Denitrification) Sidestream Treatment Design Parameters

Parameter	Units	Conventional Nitrification/ Denitrification (Nitrogen Rem 1.0)	Deammonification (Nitrogen Rem 3.0)
Loading Rate	kg N/m^3/d	0.1 – 0.3	0.3 – 7.0 (most frequently seen values are 1.2 and 1.7)
HRT	hr	24 – 48	4 - 24
SRT	d	1 – 2	Depends on process control strategy (nitritation: 1 – 2 d; anammox strain: >30 d)
Energy Demand[1]	kWh/kg-N	3 – 6	0.8 – 2.0
Oxygen Demand	lb O2/ lb NH_4-N Removed	4.6	1.9
Carbon Demand	lb COD/ lb N Removed	6.6	0.0
Yield	lb VSS/ lb N Removed	1.9	0.1
Alkalinity Demand	lb Alk as CaCO3/ lb NH_4-N Removed	7.1	3.6
Ammonia Reduction	Percent	90 – 95	90 – 95
TIN Reduction	Percent	Dependent on available carbon	80 – 85*

[1] Lackner et al., 2014 and Wett, 2010

* Values can potentially increase if there is available carbon for heterotrophic denitrification

Process configurations for Nitrogen Removal 3.0 (deammonification) have consisted primarily of granular sludge reactors, suspended growth SBRs, and attached growth moving bed biofilm reactors (MBBRs). Rotating biological contactors (attached growth) have also been used. Each process configuration has up to several patented treatment technologies with trademarked names. These technologies differ in their control strategy, configuration, and method of concentrating and retaining Anammox bacteria.

A comparison of these configurations is provided in Table 15. The key differences in the configurations are volume, energy demand, and controls (further discussed with each technologies sub-section below).

Table 15. Comparison of Suspended, Granular Sludge, and Attached Growth Deammonification Treatment Configurations [a]

Parameter	Units	Suspended Growth	Granular Sludge	Attached Growth
Loading Rate	kg $N/m^3/d$	0.35 – 0.75	0.3 – 7.0[a]	0.4 - 1.2[b]
Energy Demand [c]	kWh/kg-N	1.0 – 1.3	1.2 – 1.8	1.4 – 1.8
Oxygen Demand	lb O_2/lb NH_4-N Removed	1.8	1.8	1.8
Carbon Demand	lb COD/lb N Removed	0	0	0
Yield	lb VSS/lb N Removed	0.1	0.1	0.1
Alkalinity Demand	lb Alk as CaCO3/ lb NH_4-N Removed	3.6	3.6	3.6
Ammonia Reduction	Percent	~90	~90	~90
Total N Reduction	Percent	~85	~85	~85

[a] Bench-scale data for industrial applications suggests loading rates can reach upwards of 90 kg $N/m^3/d$ (Tang et al., 2011; Chen et al., 2011).
[b] Loading rate can be increased to values > 3.2 if an integrated fixed-film attached system technology is used.
[c] Data from Stinson, B (2013)

The SBR configuration has been the most frequent full-scale installation, representing more than 50 percent of all full-scale installations (Lackner et al., 2014). The installation numbers of the SBR is followed by granular and then MBBR systems. Granular sludge systems have been mostly utilized for treatment of sidestreams with the highest N loads (Lackner, et al., 2014). Suspended, granular, and attached growth deammonification configurations for sidestream treatment are discussed in detail after the discussion of general deammonification process considerations below.

Although promising, the application of deammonification technology is currently limited to the dewatering facility sidestream (i.e., centrate/filtrate) treatment. Deammonification in the mainstream is in the very early stages of investigation under WERF and results have thus far been promising (Winkler et al., 2012; Regmi et al., 2012; Wett, et al., 2013; Hu et al., 2013; Al-Omari et al., 2012). Mainstream deammonification requires the use of a different strategy to suppress NOB growth due to operation at lower temperatures and lower ammonia concentrations. Mainstream nitrogen removal by deammonification is advantageous for wastewater facilities that do not already have anaerobic digestion; therefore, this strategy was not presently investigated. However, should mainstream nutrient removal be required in the future for BACWA member agencies, consideration may be given to mainstream deammonification.

PROCESS CONSIDERATION

Important process control considerations for successful deammonification are pre-treatment by removing surplus solids, maintaining sufficient alkalinity for AOB activity, suppression of NOBs, and providing sufficient SRT for growth and retention of Anammox bacteria. Solids pre-treatment using screens and/or sedimentation upstream of the biological process is case specific that depends on the upstream dewatering solids capture percentage. In order to maintain sufficient alkalinity for AOB, the process is operated in a pH range that maximizes the availability of inorganic carbon (primarily as bicarbonate, HCO_3^-, around a neutral pH) (Wett et al., 2010). NOB growth has been suppressed by operation at low DO concentrations and at higher temperatures to take advantage of the slower growth rate of NOB under these conditions. Strategies to maintain a sufficient SRT for Anammox bacteria have consisted of the formation of dense granules, attached growth processes for biomass retention, or the use of a hydrocyclone for selective sludge wasting to concentrate and retain dense anammox granules (Wett et al., 2010).

Due to the settling properties of granular sludge, Anammox bacteria can also be selectively enhanced during suspended growth and granular sludge operations. Anammox sludge granules form due to excessive formation of exocellular polymeric substances (Cirpus et al., 2006) and have a distinctive red color as shown below in Figure 15. Granular Anammox bacteria can have settling velocities upwards of 100 m/h (Bowden et al., 2014), compared to settling velocities of approximately 3 m/h for conventional flocculated activated sludge (Tchobanoglous et al., 2014); these settling velocities are based on a limited data set. The dense nature of the granules allows for straightforward separation from flocculated solids, providing a method to selectively retain Anammox bacteria.

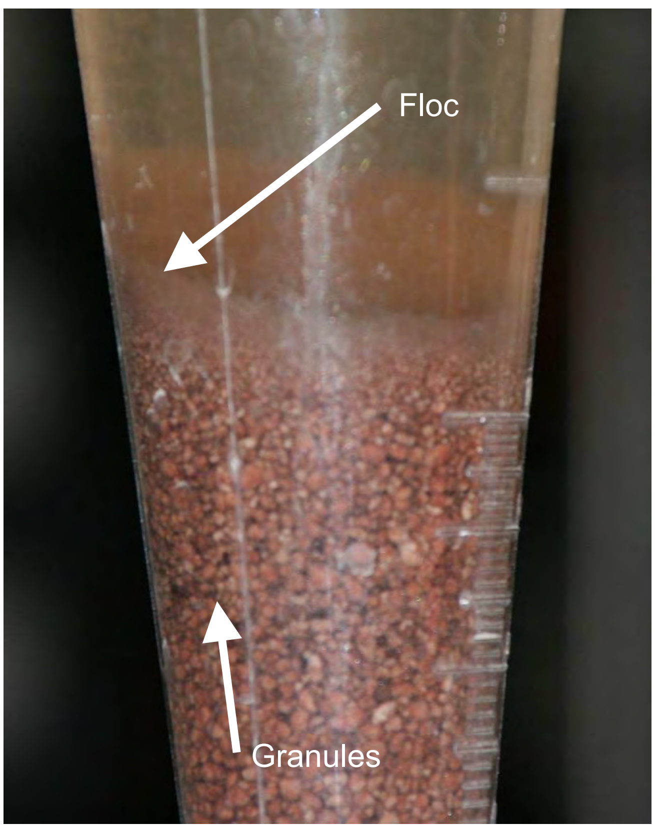


Figure 15. Anammox Granules – The Granules must be Maintained in the Basin while Wasting Competing Bacteria (Bowden et al., 2014)

A significant challenge in past anammox operations have been the long reactor start-up period (up to several years) required due to the slow growth rate of Anammox bacteria. The maximum specific growth rate of Anammox bacteria is less than one-tenth the rate of AOB, resulting in a doubling time of approximately two weeks (Strous et al., 1998). Transfer of sufficient seed sludge has proven to accelerate the start-up period (Strous et al., 1998). Their research suggests anammox activity increases once critical bacteria levels are reached. A possible reason for this phenomenon is that anammox activity does not accelerate until small anammox flocs form (Van Hulle et al., 2010). The ammonia oxidation intermediate hydrazine diffuses quickly from the anammox floc to the bulk liquid. The addition of hydroxylamine or hydrazine was found to accelerate anammox bacteria activity (Van Hulle et al., 2010).

The start-up period is dependent upon the mass of seed sludge and the nitrogen loading rates. Typical start-up periods prior to stable operation are now no more than several months (Joss, 2011). A DEMON® SBR seeded with Anammox bacteria demonstrated a start-up period of only 50 days (Wett, 2007). In a case study, Jardin and Hennerkes (2012) achieved start-up of a SBR (Plettenberg Plant in 2007) within only 1 day by using seeding sludge from the Strass Plant.

Though anammox is increasingly considered a reliable process, operational upsets do occur from toxic inhibition of AOB, equipment failure, shock pH changes, and high influent solids concentration (Joss et al., 2011; Lackner et al., 2014). However, a recent survey of 14 full-scale deammonification plants in Europe found that the majority surveyed have not experienced operational upsets and that for plants that do experience operational upsets, typically only 10-20 percent of the affected plants report an impact on process performance (Lackner et al., 2014).

It is currently unclear from the literature if, from a process standpoint, suspended, granular, or attached deammonification is more ideal for treating very high sidestream ammonia loads. Granulated suspended growth deammonification appears to have been utilized more frequently for treatment of the highest ammonia loads (Lackner et al., 2014; Bowden et al., 2014).

A list of the advantages, disadvantages and data needs for all deammonification technologies is presented in Table 16.

Table 16. Advantages, Disadvantages and Data Gaps in All Deammonification Technology

Parameter	Description
Advantages	• Reduced capital and operating cost compared to Nitrogen Removal 1.0 and 2.0 technologies • Highest net energy savings of biological processes (reduction of 60 percent) due to use of Anammox bacteria (reduced oxygen demand) • No carbon source required for TIN removal • Only 50 percent of the ammonia load needs to be nitrified to nitrite • Alkalinity demand reduced by about 45 percent • Innovative technology status (over 100 deammonification reactors globally) • Proprietary deammonification technologies have refined process control • Smallest footprint compared to other biological processes • Reduces biomass production and sludge hauling cost • Able to handle high ammonia loads
Disadvantages	• New technology for operators • Requires more sophisticated and precise process control • Many process configurations are proprietary technologies that require a license fee
Data Gaps	• Stress testing on the nitrogen loading rate • Limited datasets for US installations (dozens of datasets for Europe/Asia) • Recovery time period in the case of anammox or AOB wash-out • Test the nitrogen concentration upper limits with reliable operation. This relates to the anammox strain sensitivity to nitrite. • Test the temperature lower limits with reliable operation. • Metrics to establish reliable correlation between seed volume and start-up time

SUSPENDED GROWTH DEAMMONIFICATION TECHNOLOGY

The predominant type of suspended growth deammonification reactor is the sequencing batch reactor (SBR). In suspended growth SBRs, microorganisms are maintained in suspension for removal of pollutants from water. The microorganisms form flocculent settleable solids that can be readily removed due to the properties of the tightly aggregated granules as discussed above. Some suspended growth SBRs take advantage of these properties by separating the granular sludge and returning it to the reactor, which results in a much longer anaerobic SRT when compared to aerobic SRT. The treated wastewater is decanted from the SBR after a sedimentation phase.

A flow diagram demonstrating the application of suspended growth deammonification technology is shown below in Figure 16.

There are many proprietary suspended growth deammonification technologies; the primary technologies are summarized in Table 18. This literature review provides a general overview of suspended growth deammonification and does not provide a detailed description of each proprietary process. The predominant suspended growth configurations are DEMON®, Cleargreen®, and a SBR developed in collaboration with Swiss Federal Institute of Aquatic Science and Technology (EAWAG) (Joss et al., 2009).

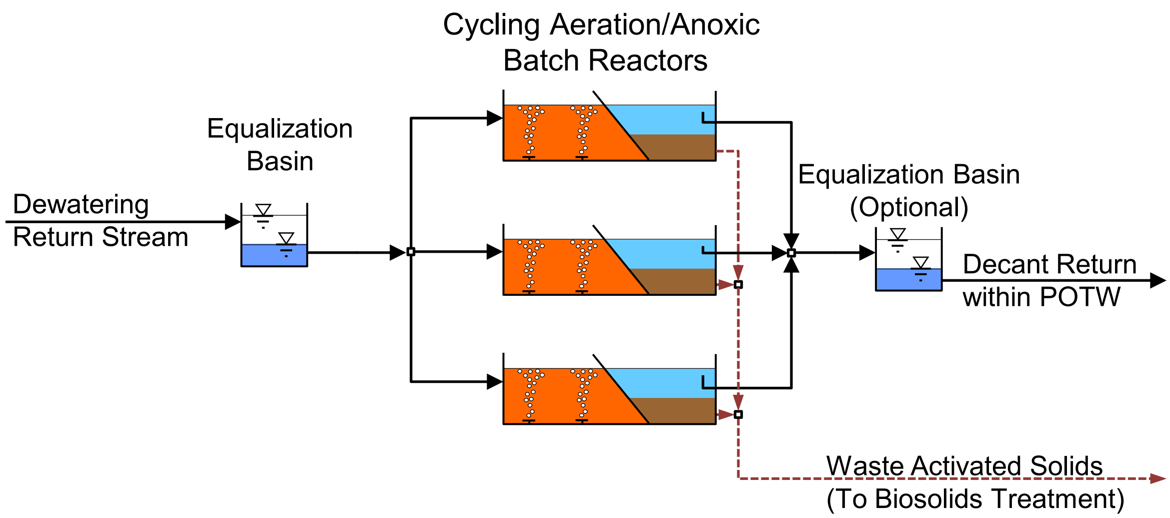


Figure 16. Hypothetical Process Flow Diagram for Suspended Growth Deammonification

The DEMON® configuration is utilized at greater than 80 percent of all full-scale SBR deammonification facilities (Lackner et al., 2014). The well-known Strass WWTP in Austria and the Hampton Roads Sanitation District (HRSD) York River Plant both utilize DEMON® for sidestream nutrient removal. In order to suppress NOB growth in DEMON®, the reactor is operated with intermittent aeration and low DO concentrations during the aerobic phase (0.3 mg/L) (Wett, 2007). Additionally, to maintain the slow growing Anammox bacteria, DEMON® relies on a hydrocyclone to enrich and recycle anammox biomass as shown in Figure 17. In the U.S., several other DEMON® facilities are in the design phase such as the DC Water Blue Plains WWTP (see Figdore et al., 2011 for piloting report) and Pierce County, WA (see Klein et al., 2012 for Pierce County piloting report).

Figure 17. Image of DEMON® Hydrocyclone at HRSD York River Plant.

Figure 18 and Figure 19 show the performance test data from two plants in Switzerland that operate sidestream DEMON® process. The maximum flow is under 0.08 mgd and nitrogen loading presented is 640 lb N/d for facility shown in Figure 18. The maximum flow is under 0.05 mgd and nitrogen loading presented is 460 lb N/d for facility shown in Figure 19. Both facilities achieve average TIN removal of 70 to 85%.

Though DEMON® is the most prevalent of the SBR technologies, SBR deammonification technologies other than DEMON® have been developed. The next most prevalent of the SBR deammonification technologies was developed in collaboration with Swiss Federal Institute of Aquatic Science and Technology (EAWAG) (Joss et al., 2009). The SBR developed by EAWAG has been installed at five locations in Switzerland since 2007 (Bowden et al., 2014). This technology is referred to as SBR EAWAG from herein. In this process, the SBR is continuously aerated at a DO concentration of 0.1 mg/L for simultaneous nitritation/deammonification. An on-line ammonia measurement is utilized to control process loading. The

The ClearGreen® SBR technology is gaining traction because it does not require seeding. The equipment provider claims the free ammonia process control selects for anammox bacteria in a more rapid fashion than their competitors controls. As a result, seed is not required and data suggests a 1-2 month start-up period.

Select suspended growth deammonification installations are provided in Table 19.

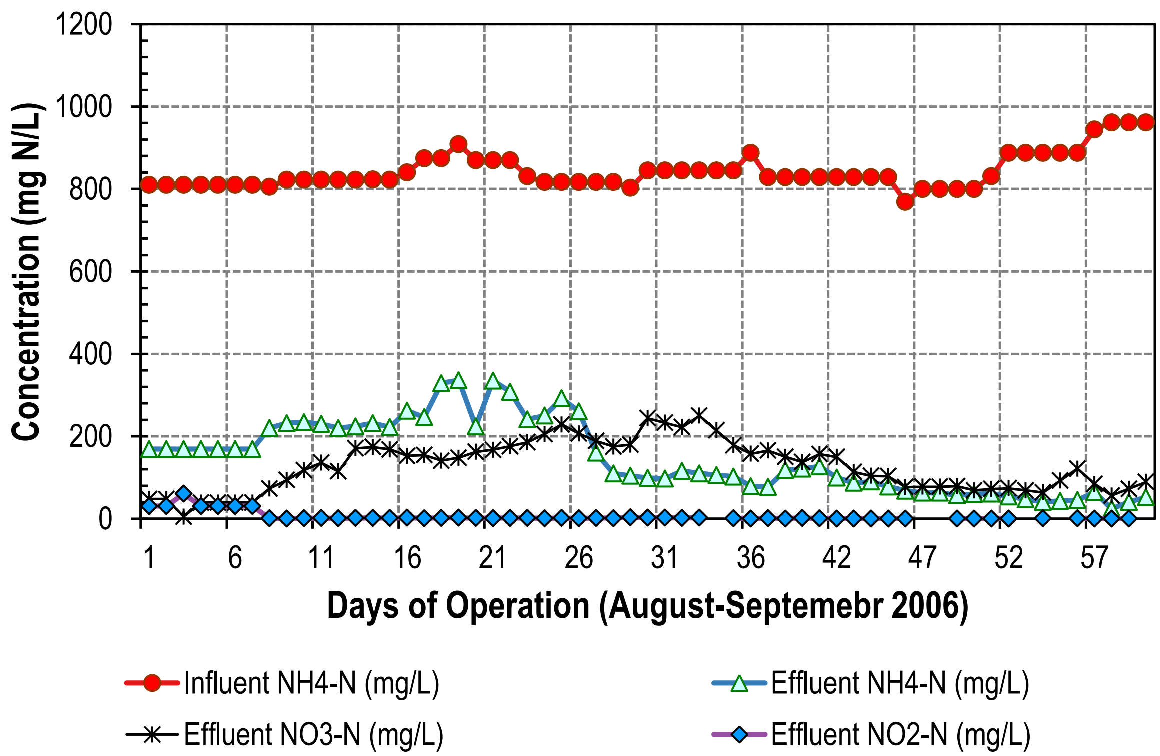


Figure 18. DEMON®- Anlage Glarnerland (Switzerland), Sludge wastewater Treatment Performance Test

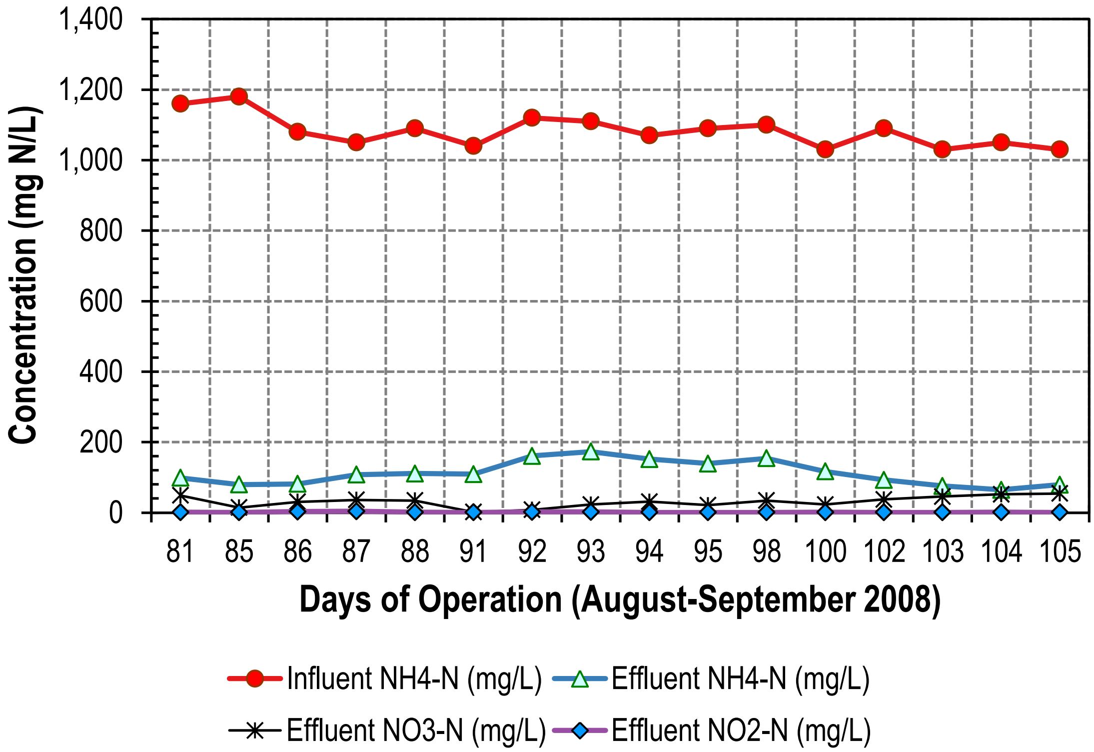


Figure 19. DEMON®- Anlage Thun (Switzerland). Separate Sludge Wastewater Treatment Performance Test

A list of the advantages, disadvantages, and data gaps for the suspended growth deammonification is provided in Table 17.

Table 17. Advantages, Disadvantages and Data Gaps in Suspended Growth Deammonification Technology

Parameter	Description
Advantages	• (See Deammonification)
Disadvantages	• Larger footprint than granular sludge and attached growth deammonification technologies • Susceptible to process upsets • Substantial amounts of seed anammox bacteria may be required for short start-up periods • Long start-up periods (months to years) may be required if adequate seed bacteria is not available Wash-out of anammox bacteria due to poor sludge settleability
Data Gaps	• (See Deammonification Technologies)

Table 18. Summary of Suspended Growth Deammonification Technologies

Process Name	Process Overview	Number of Full-Scale Installations	First Installation	Design N Load, lb N/day	Design Unit N Load, kg N/m^3/d	Advantages	Disadvantages
Cleargreen®	SBR operation with ammonia controlled aeration system Settling used to enrich and recycle anammox biomass No seed required	2 installations under design/ construction in Spain	--	270 - 860	0.55 – 0.70	Single reactor; No seed required due to robust process controls Simple design	Lower end of Deammonification loading rates; No full-scale installations
DEMON®	SBR operation with patented pH-controlled aeration system (Wett 2007). Hydrocyclone used to enrich and recycle anammox biomass (Wett, 2010). Seed required	37+	2004	110 - 27,000	0.40 – 0.70	Single reactor; Proven control system as evidenced by number of installations	Lower end of Deammonification loading rates; Seed required
SBR (EAWAG) *	SBR reactor with traditional sedimentation and decant of supernatant; foam control; complete cycle through aeration, mixing, sedimentation and decant phases lasts 6 to 24 h (Joss, et. al., 2009) Seed required	6	2007	120 – 2,800	0.35 – 0.45	Single reactor; Simple design and controls (e.g., no pH control)	Lower end of Deammonification loading rates; Seed required

* No hyperlink available

Table 19. Select Suspended Growth Deammonification Installations[1]

Process	Year	Installation	Country	Design N load, lb N/d	Design Unit N Load, kg N/m^3/d
ClearGreen®	Design/ Construct	Burgos[2]	Spain	860	0.70
ClearGreen®	Design/ Construct	Ourense[2]	Spain	270	0.55
DEMON®	2004	Strass	Austria	1,100	
DEMON®	2007	Glarnerland	Switzerland	550	0.40
DEMON®	2007	Plettenberg	Germany	176	50 kg
DEMON®	2008	Heidelberg	Germany	1,366	
DEMON®	2008	Thun	Switzerland	859	0.67
DEMON®	2008	Gengenbach	Germany	110	
DEMON®	2009	Etappi Oy	Finland	2,182	
DEMON®	2009	Balingen	Germany	423	
DEMON®	2009	Apeldoorn	Netherlands	3,637	0.66
DEMON®	2010	Zalaegerszeg	Hungary	353	
DEMON®	2010	Limmattal	Switzerland	550	
DEMON®	2010	Alltech	Serbia	5,290	
DEMON®	2012	York River, VA	USA	525	
DEMON®	2013	Biogas Plant, FL	USA	1,550	
DEMON®	2013	Leoben[3]	Austria	1,400	
DEMON®	Design/ Construct	Blue Plains, DC Water[4]	USA	27,000	0.60
DEMON®	Design/ Construct	Alexandria, VA	USA	4,000	0.42
DEMON®	Design/ Construct	Guelph	Canada	920	
DEMON®	Design/ Construct	Greeley, CO	USA	781	
DEMON®	Design/ Construct	Philadelphia, PA	USA	9,514	
DEMON®	Design/ Construct	Pierce County, WA	USA	3,260	0.75
SBR (EAWAG)	2007	Zürich	Switzerland	2,800	0.45
SBR (EAWAG)	2008	Zürich 2	Switzerland	1,380	0.45
SBR (EAWAG)	2007	St. Gallen 1	Switzerland	240	0.36
SBR (EAWAG)	2008	St. Gallen 2	Switzerland	240	0.36
SBR (EAWAG)	2008	Niederglatt	Switzerland	120	0.35
SBR (EAWAG)	2012	Pfannenstiel	Switzerland	170	
SBR	Design/ Construct	Dendermonde	Belgium	660	

[1] Contact Info: ClearGreen® - Mudit Gangal, Infilco Degremont, Inc. (Mudit.GANGAL@infilcodegremont.com);
DEMON® - Chandler Johnson, World Water Works, Inc. (CJohnson@worldwaterworks.com);

[2] No seed sludge required

[3] Treats centrate from co-digestion

[4] Treats centrate from thermal hydrolysis process

GRANULAR SLUDGE DEAMMONIFICATION TECHNOLOGY

Granular sludge deammonification technologies have been developed primarily in the Netherlands and China and are typically single- and two-stage upflow anaerobic sludge blanket (UASB) reactors. Granular sludge processes have consisted of both two-stage and single-stage configurations. In two-stage suspended growth deammonification configurations, the nitritation reaction occurs in the first stage, followed by the ANAMMOX® reactor in the second stage. In the single-stage configuration, nitritation and the anammox reactions occur synergistically in a single reactor. Single-stage reactors are made possible because Anammox bacteria are reversibly inhibited by oxygen (Strous, 1997). Technologies include two-stage Nitritation/ ANAMMOX®, and single-stage ANAMMOX®, both by Paques, BV in The Netherlands.

High-rate ANAMMOX® UASB reactors have exhibited a nitrogen removal rate of 74.3–76.7 kg-N/m^3/d at hydraulic retention time (HRT) of 0.16 h in lab-scale reactors. This is the highest nitrogen removal performance of any nitrogen removal technology in the world (Ali et. al., 2013). Design loading rates vary widely and are included in Table 21, which lists select granular sludge deammonification installations.

The packing of sludge granules can be used to illustrate nitrogen removal performance and can be described mathematically using sludge concentration and nitrogen loading as variables. Below a sludge concentration of 38 g/L, ANAMMOX® UASB reactor performance is more sensitive to sludge concentration while above this value, reactor performance is more sensitive to substrate loading rate (Ali et. al., 2013). A reactor operating with a higher solids inventory has a higher potential for overall process stability.

A notable two-stage granulated sludge reactor is the first full-scale deammonification reactor located in Rotterdam, Netherlands. The process consists of a first stage SHARON® nitritation reactor and a second stage ANAMMOX® reactor designed by Paques. The second stage removed 90 to 95 percent of the nitrogen load (10 kg/m^3/d) after 3.5 years of startup (Zumbrägel et al., 2006). Paques's granular system includes a lamella settler for granule retention. The two-stage reactor has a very compact footprint as seen in the image shown below in Figure 20.

Two-stage granulated sludge operations have largely been replaced with single-stage granulated sludge configurations due to the reduced cost of a single reactor and the overall smaller volume (Lackner et al., 2014). In the single-stage granulated sludge reactor, different control strategies are employed for efficient partial nitritation and anammox reactions. The single-stage ANAMMOX® process incorporates one or more gas-liquid-solids separator(s) in the upper portion of the upflow reactor. There are currently no Paques installations at municipalities in the U.S. and this is not likely to change over the next few years.

Figure 20. Two-Stage Granulated Sludge Reactor at Rotterdam, Netherlands

A list of the advantages, disadvantages and data gaps for granular sludge deammonification is provided in Table 20. One notable disadvantage of granular sludge UASBs is the potential for wash-out of the Anammox bacteria due to the flotation of the sludge granules (Ali et. al., 2013).

Table 20. Advantages, Disadvantages and Data Gaps in Granular Sludge Deammonification Technology

Parameter	Description
Advantages	• Potentially the most compact footprint of all biological processes
Disadvantages	• All those listed for suspended growth SBRs • In two-stage process, tight process controls are required to avoid elevated nitrite concentrations, which are toxic to the Anammox bacteria in the stage-two reactor • Wash-out of anammox bacteria due to sludge flotation
Data Gaps	• (See Deammonification Technologies)

Table 21. Select Granular Sludge Deammonification Installations[1]

Process	Year	Installation	Country	Design N Load, lb N/d	Design Unit N Load, kg/m³/d	No. Of Stages
ANAMMOX®	2002	WSHD, Rotterdam	Netherlands	1,100	7.0	Dual Stage
ANAMMOX®	2008	ARA Niederglatt, Niederglatt	Switzerland	100	0.3	Single Stage
ANAMMOX®	2009	Meihua I, Tongliao[2]	China	24,300	1.7	Single Stage
ANAMMOX®	2010	Meihua II, Tongliao[2]	China	19,800	2.2	Single Stage
ANAMMOX®	2011	Severn Trent, Minworth	United Kingdom	8,800	2.3	Single Stage
ANAMMOX®	2010	Waterschap Groot Salland, Zwolle	Netherlands	1,300	1.4	Single Stage

[1] Contact Info: W. Driessen (w.driessen@paques.nl); Paques BV, The Netherlands

[2] Plants treat industrial wastewater from monosodium glutamate production process

Table 22. Summary of Granular Sludge Deammonification Technologies

Process Name	Process Overview	No. of Installations	First Installation	Design N Load, lb N/day	Design Unit N Load, kg N/m³/d	Advantages	Disadvantages
Dual-Stage Nitritation/ ANAMMOX®	• Two-reactor system with partial-nitritation by SHARON® process in first reactor, followed by anammox in second reactor (Van dogen, 2001; Van Der Star, 2007).	1	2001	1,100	7.0	Tight process control by two separate reactors.	Two reactors to maintain Large reactor volume
Single-Stage ANAMMOX® and Canon®	• Partial-nitritation/anammox occur synergistically on granulated biomass. • Utilizes proprietary separator that settles and returns granulated solids to reactor.	22+	2002	100 - 24,300	0.3 – 2.3	Small reactor volume.	Process control more challenging to maintain nitritation and anammox.

ATTACHED GROWTH DEAMMONIFICATION TECHNOLOGY

The development of attached growth deammonification processes shortly followed the suspended growth SBR and granular sludge UASB process configurations. In an attached growth treatment process, microorganisms attach to some type of medium to form a biofilm. Attached growth deammonification is made possible by the excessive formation of exocellular polymeric substances by Anammox bacteria, allowing for ready attachment to surfaces. As for other biological treatment processes utilizing fixed film carrier media, the use of carrier media creates a higher equivalent MLSS concentration, increasing the capacity of the treatment process (or decreasing the treatment process footprint). The retention of biomass as a biofilm on carrier media provides the long SRT necessary for successful anammox operation. There are numerous proprietary attached growth deammonification technologies; the primary technologies are summarized below in Table 24. This literature review provides a general overview of attached growth deammonification.

Attached growth deammonification configurations have primarily consisted of Moving Bed Biofilm Reactor (MBBR) technologies. The anammox and nitritation reactions occur simultaneously within the biofilm that is attached to carrier media. The carrier media has a high surface area to volume ratio to maximize biofilm mass (e.g., 500 m^2/m^3 for Kaldnes K1 media by AnoxKaldnes). The biofilm is stratified over time with AOBs colonizing the outer biofilm surface (aerobic), followed by Anammox bacteria colonizing the interior biofilm layer (anoxic/anaerobic). The ammonia is subjected to nitritation in the aerobic layer, followed by anammox reactions in the interior. An image of the biofilm layer is shown below in Figure 21. Figure 22 displays the anammox biofilm formed on carrier media.

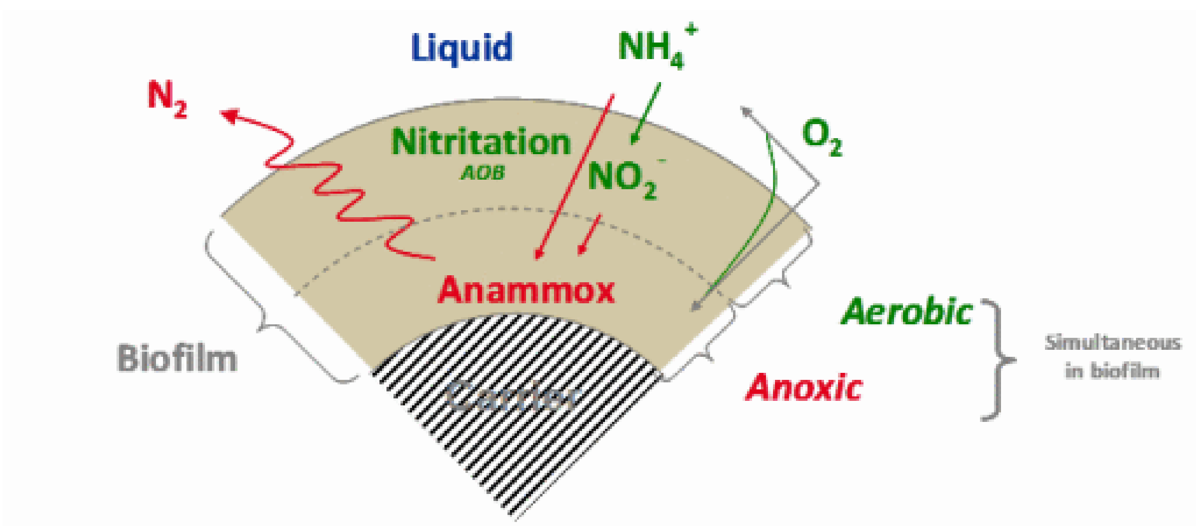


Figure 21. Deammonification Process in a Biofilm. Image Courtesy of AnoxKaldnes

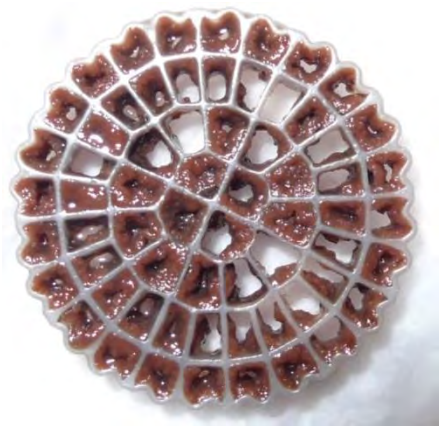


Figure 22. Anammox Biofilm on Carrier Media (Left) and AnitaMox™ Reactor (Right)

Unlike the suspended growth systems, the attached growth systems are unable to effectively control wasting. This is a concern for suppressing denitrifying organisms that can out-compete Anammox bacteria for nitrite/nitrate, especially for streams with higher BOD concentrations. Anecdotally, the data suggests this is not an issue but it is something to consider while designing these systems. Lackner et al. (2013) reported that an MBBR configuration demonstrated enhanced performance over the SBR configuration for sidestream with high C/N ratio sidestream of 3:1. The MBBR configuration sustained higher volumetric nitrogen removal rates and greater stability/resilience to process upsets.

The performance of attached growth deammonification is similar to suspended growth. At James River ANITA™ Mox reactor was able to achieve up to 83% TIN removal (Figure 23), while the unit mass loading to the reactor was upwards of 1.2 kg N/m^3/d compared to previously shown suspended growth that ranged between 0.4 to 0.7 kg N/m^3/d. This higher loading rate results in a smaller reactor footprint when compared to a suspended growth SBR.

Technology vendors are attempting to modify the MBBR operational configuration to an integrated fixed-film activated sludge (IFAS). The key different between MBBR and IFAS is the IFAS includes RAS in the operational mode. The benefit of operating in an IFAS mode over MBBR mode is the ability to increase biomass and in turn the design loading rates. While attractive, the IFAS operational mode is more challenging to control proliferation of NOBs. As a result, the MBBR is still the preferred design mode at this time.

Energy demands have generally been greater for attached growth deammonification processes as compared to suspended growth processes, due to operation at a higher DO concentration, uses coarse-bubble rather than fine-bubble diffusion, and the media must be kept in suspension (see Table 15).

A list of the advantages, disadvantages, and data gaps for the attached growth deammonification process is presented in Table 23.

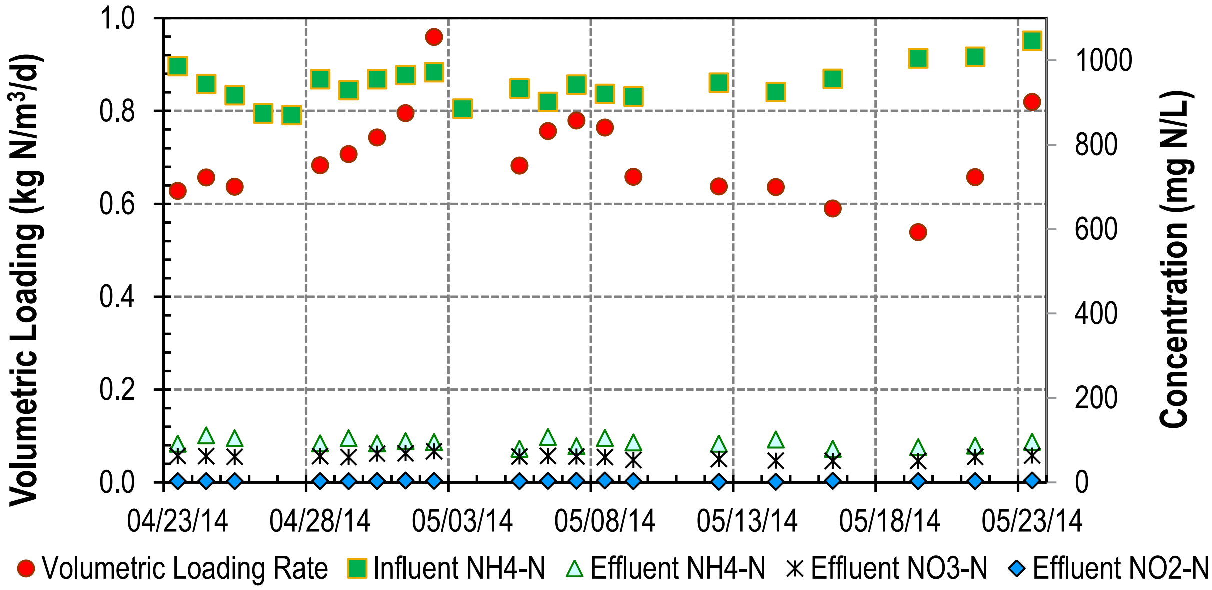


Figure 23. ANITA™ Mox Centrate Treatment Performance at James River, VA HRSD POTW

Table 23. Advantages, Disadvantages and Data Gaps in Attached Growth Deammonification Technology

Parameter	Description
Advantages	• Reduced footprint in comparison to suspended growth deammonification. • Less sludge production than suspended growth system due to high solids associated with attached growth; associated reduced sludge hauling cost • Generated solids can be removed through clarification, filtration, or flotation • Greater process stability • Robust biomass retention due to biofilm growth of both anammox and AOBs on carrier • No RAS pumping or lines required unless operating as an IFAS reactor. • Anammox bacteria
Disadvantages	• Higher operational energy demand, therefore cost, than suspended growth systems due to operation at higher DO concentrations and the need to keep media in suspension • Higher capital cost than suspended growth deammonification due to cost of carrier media which typically exceeds any savings associated with a smaller footprint • Occasional operational upsets have occurred • Does not allow for selective wasting of heterotrophic, non-Anammox bacteria • Requires screens to prevent clogging of media and media-capture screen
Data Gaps	• More robust data for nitrogen loading and unit energy demand • Concerns over an attached growth process from operators

Table 24. Summary of Attached Growth Deammonification Technologies.

Technology	Process Overview	Number of Installations[1]	First Installation[1]	Design N Load, lb N/day[1]	Design Unit N Load, kg N/m³/d	Comment
ANITA™Mox	• Single-stage deammonification MBBR system by AnoxKaldnes/Veolia. • Continuously aerated with DO setpoint between 0.5 mg/L and 1.5 mg/L.	6 (1 additional under design)	2010	950	1.0 – 1.2	
Terra-N®	• Single or dual-stage MBBR process with bentonite, rather than plastic, for support media. • Includes gravity clarification. • Requires solids removal pretreatment.	5	2008	1,500	0.4 – 1.1	• Larger footprint than ANITA™Mox.
DeAmmon®	• Purac's single or dual train reactor system with three stages per reactor and intermittent aeration. • Carrier media (typically Kaldnes K1) fill volume of 40 percent.	3	200	4,900	0.6	• Larger footprint than ANITA™Mox.

[1] Information from Neethling et al., 2014 or Lackner et al., 2014.

Table 25. Select Attached Growth Deammonification Installations[1]

Process	Year	Installation	Country	Design N load lb N/d[a]	Comment	Contact Information
ANITA™Mox	2010	Sjőlunda WWTP, Malmő	Sweden	440	Reject water, K3, Anox™K5; Biofilmchip™M	Magnus Christensson +46 46 18 21 57 magnus.christensson@anoxkaldnes.com
ANITA™Mox	2011	Sundet WWTP, Växjő	Sweden	950	Reject water, Anox™K5	Same as above
ANITA™Mox	2012	Holbeak WWTP	Denmark	260	Reject water, landfill, K3	Henrik Thygesen +45 30 10 36 42 het@holfor.dk
ANITA™Mox	2012	Grindsted	Denmark	235	Reject water	Bjame Bro +45 50 85 45 18 bb@billundvand.dk
ANITA™Mox	2012	Sarreguemines	France	150	Reject water	Brad Mrdjenovich 412-352-0975 brad.mrdjenovich@veolia.com
ANITA™Mox	2013	James River	VA, USA	560	Reject water	Charles Bott, HRSD Chief of Research and Development (757) 460-4228 CBOTT@hrsd.com
ANITA™Mox	Design/Construct	South Durham	NC, USA	670	Reject water	Donald F. Greeley Director of the Department of Water Management (919) 560-4479 don.Greeley@durhamnc.gov
ANITA™Mox	Design/Construct	Chicago	IL, USA	2,070	Reject water	Justine Gambala & Lou Storino MWRD Engineers (312) 751-5836 justine.gembala@mwrd.org louis.storino@mwrd.org
DeAmmon®	2001	Hattingen WWTP	Germany	260	Reject water, single (40 percent)	http://purac.se/?page_id=446
DeAmmon®	2007	Himmerfjärden WWTP Stockholm	Sweden	1,500	Reject water, dual (32 percent)	http://purac.se/?page_id=446

DeAmmon®	2009	Dailan XiaJiaHe	China	4,900[b]		http://purac.se/?page_id=446
MBBR	2011	Oslo/Bekkelaget	Norway	1,600[b]	Reject water	http://purac.se/?page_id=446
Terra-N®	2008	Fulda Gläserzell	Germany	880	Reject water, dual stage	Clariant/SÜD Chemie AG
Terra-N®	2010	Landshut	Germany	750	Reject water, dual stage	Clariant/SÜD Chemie AG
Terra-N®	2011	Klaranlage Rheda	Germany	1,500	Reject water, dual stage	Clariant/SÜD Chemie AG
Terra-N®	2012	KA North Potsdam	Germany	350	Reject water, dual stage	Clariant/SÜD Chemie AG
Terra-N®	2012	KA Rintein	Germany	180	Reject water, SBR	Clariant/SÜD Chemie AG

[1] Table adapted from Bowden et al., 2014.
[a] Loading rate is based on the maximum design loading.
[b] Loading information from Lackner et al., 2014.

Emerging Sidestream Treatment Technologies

As previously stated, two emerging technologies were considered attractive options by BACWA member agencies: (1) ammonia recovery processes (e.g., ARP and AMR) and (2) zeolite/anammox. Evaluations for these two emerging technology types are provided below.

Ammonia Recovery Processes – Physical/Chemical Process

This section will focus on the ARP technology as the AMR technology is a more recent technology in the market place.

Though biological treatment has been the dominant form of ammonia removal for municipal wastewater treatment, the physiochemical removal of ammonia is a proven technology that has been practiced at full-scale. Traditional physiochemical methods of ammonia removal include air stripping and acid absorption, steam stripping, and air stripping with thermocatalytic destruction of ammonia (Tchobanoglous et al., 2014). In order to strip ammonia from a liquid stream, the pH is increased to greater than 10 (preferably 12) shifts equilibrium from the ammonium ion (NH_4^+) towards the volatile form of ammonia (NH_3) (pK_a = 9.25). Air stripping and acid absorption allow for the recovery of ammonia as a marketable fertilizer, such as ammonium sulfate. Historically, concerns over fluctuating market conditions for sale of recovered ammonia fertilizer have deterred the adoption of ammonia recovery in municipal wastewater treatment.

Ammonia stripping is currently rarely applied to POTWs due to the amount of chemicals and/or energy required to increase the pH and the subsequent costs and operational issues associated with a stripping tower. However, there are emerging technologies for ammonia recovery not yet implemented at full-scale in the United States that may somewhat mitigate the disadvantages associated with older generation ammonia stripping technologies. Notable emerging technologies are the ARP by ThermoEnergy® and AMR by Anaergia.

ARP is a novel technology that uses the chemistry associated with ammonia stripping by increasing the pH to greater than 10 to volatilize the ammonium. Rather than strip out ammonia gas in a stripping tower, the ARP technology mists the stream to increase surface area and applies a vacuum pressure all within an enclosed vessel to draw out the ammonia gas. To begin the ammonia removal and recovery process, the wastewater is conditioned so that neither suspended solids nor precipitates can reach the ammonia removal operations. An image of an ARP reactor and rendering provided by ThermoEnergy® is shown in Figure 24.

Once separated, the ammonia gas is condensed back to the liquid form using sulfuric acid to form reagent grade ammonium sulfate. The ammonium sulfate is then sold as a fertilizer (40 percent strength ammonium sulfate) and in turn creates a revenue stream. The AMR process produces a similar ammonium sulfate product but relies on a different acid scrubbing process to recover the volatilized ammonium.

According to the vendor, ARP reduces the operating and capital costs of traditional ammonia recovery processes. Additionally, the footprint of the ammonia recovery process is reduced for the ARP system. A cost analysis was performed for the 26th Ward Water Pollution Plant in Brooklyn, New York (1.2 mgd design centrate flow) and found that the capital cost of ARP was

30 percent less than the cost to implement the SHARON process for ammonia reduction (ThermoEnergy®). This cost estimate did not include the equipment required to remove solids upstream of the ARP process.

Figure 24. Image of an ARP Reactor (Top) and Process Rendering by ThermoEnergy® (Bottom)

Application of ammonia air stripping for higher strength sidestream ammonia levels may be advantageous due to an enhanced driving force for diffusive/mass transfer from the liquid phase to the gaseous phase; however, potential cost advantages have not been quantified.

For plants interested in ARP, the initial step is to send a sidestream sample to ThermoEnergy® for chemical requirements analysis. The analysis evaluates water chemistry to determine the required caustic dose to increase pH. If the initial analysis is attractive in terms of ARP implementation, the plant should consider piloting the technology as the ARP installations are limited to industrial streams at this time (>60 full-scale industrial installations).

Important considerations for an ammonia recovery process are product demand and market conditions for the ammonium sulfate fertilizer. Overall demand for fertilizer in the U.S. has been steady over the past 10 years; however, demand for fertilizers has increased in specific regions, including on the West Coast in California, Oregon, and Washington (Khunjar & Fisher, 2014). Current market prices for nitrogen fertilizers are lower than for phosphorus fertilizers at approximately $312 to $429 per metric ton and $550 to $628 per metric ton, respectively (Khunjar & Fisher, 2014). Before further consideration of ARP, an assessment should be performed to determine if a satisfactory market exists for the ammonium sulfate fertilizer within an economical distance from the BACWA member facilities, making adoption of ARP a cost-effective strategy. The ARP process requires that the adopter take on some risk due to dependency on favorable market conditions for sale of the fertilizer. The District of Columbia Water and Sewer Authority (DC Water) performed an evaluation of ARP for sidestream treatment at the Blue Plains Wastewater Treatment Plant (a 370 mgd capacity facility), and though favorable market conditions were found, the technology was not selected due to the inherent risk of reliance upon market conditions (Figdore et al., 2010).

A process flow diagram demonstrating the application of the ARP process for sidestream treatment application is given below in Figure 25. A list of the advantages, disadvantages, and data gaps for ARP is outlined in Table 26.

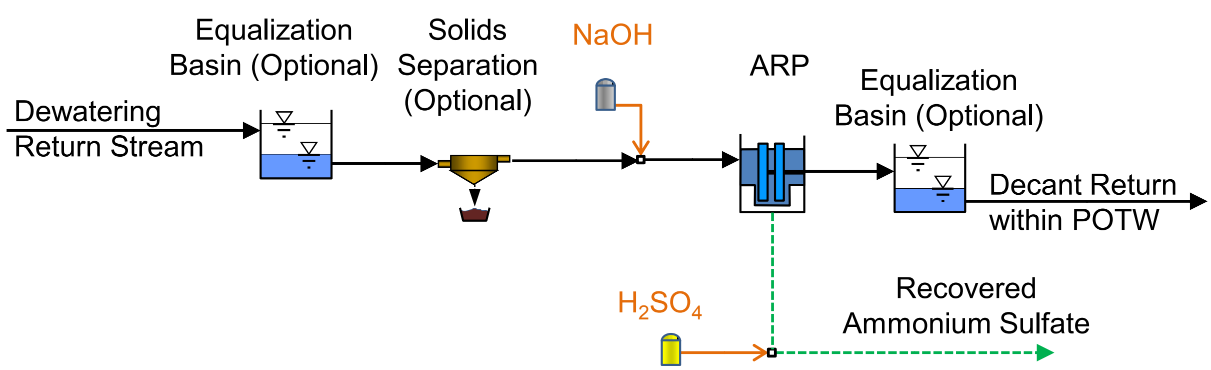


Figure 25. Wastewater Facility Process Flow Diagram with ARP Sidestream Treatment

Table 26. Advantages, Disadvantages and Data Gaps in Ammonia Recovery Process

Parameter	Description
Advantages	• Ammonia is recovered as marketable fertilizer, generating a revenue stream • Reduced footprint as compared to traditional physiochemical ammonia recovery • Reduced operating cost as compared to traditional physiochemical ammonia recovery • Technology independent of nutrient loading variability (based on alkalinity/pH) • Ease of developing design criteria
Disadvantages	• Risk incurred by reliance upon market conditions for favorable revenue stream • Emerging technology not yet implemented at full-scale • Requires the use of chemicals such as caustic soda or lime and sulfuric acid • Energy intensive process
Data Gaps	• Lack of municipal cost estimates (limited to one pilot) • Lack of municipal installations in US and globally • Lack of experience in marketing and selling the product • Design criteria by and large limited to water chemistry • Lack of data supporting reliable nitrogen removal performance • Robust municipal dataset that considers the plant wide impacts on alkalinity and carbon balance

Zeolite/Anammox – Nitrogen Removal 3.0

Zeolite/anammox is an emerging technology that was developed in Northern California by Dr. Robert Collison. It is a hybrid technology that leverages the benefits of zeolite and Anammox bacteria. The technology performs nitrogen removal with applications for sidestream treatment, liquid stream treatment, and water reuse.

Zeolite (clinoptilolite) is a microporous, aluminosilicate mineral that has a high cation exchange capacity (CEC). A picture of zeolite mineral is provided in Figure 26. This high CEC preferentially adsorbs ammonium which is immobilized on the ion exchange sites. The immobilization step also concentrates ammonium for advantageous growth of a bacterial biofilm.

Figure 26. Zeolite Media on Left and Zeolite/anammox Pilot Plant on Right

The use of zeolite for ammonium removal from wastewater using CEC has been in practice for decades. Truckee Meadows Water Reclamation Facility (TMWRF) used zeolite to remove ammonium following secondary treatment for approximately 30 years. TMWRF had reliable performance with ammonium levels leaving the zeolite technology at less than 1 mg NH_4^+-N/L. Despite reliable ammonium removal, zeolite media has to be regenerated (i.e., ammonium removed) once all the zeolite ion exchange sites are saturated. Regeneration at TMWRF was performed using high strength brine, with sodium replacing the ammonium ions. However, once ammonium adsorption is re-initiated following regeneration, sodium ions are released. Therefore the utility was faced with a TDS limit as well as managing a highly concentrated ammonium slurry. As a result, TMWRF decided to replace the zeolite technology with nitrification/denitrification in the early 2000's.

The Zeolite/Anammox Technology avoids the disadvantages of earlier zeolite-based ammonium removal systems by using continuous biological regeneration of the zeolite media. The technology relies on zeolite serving as medium to adsorb ammonium and biofilm growth. A biofilm rich with anammox and AOBs coats the zeolite, and as the zeolite adsorbs ammonium the biofilm continuously regenerates the zeolite by converting the adsorbed ammonium to nitrogen gas. A graphic depicting this process is provided in Figure 27. The end products in the process are nitrogen gas and water.

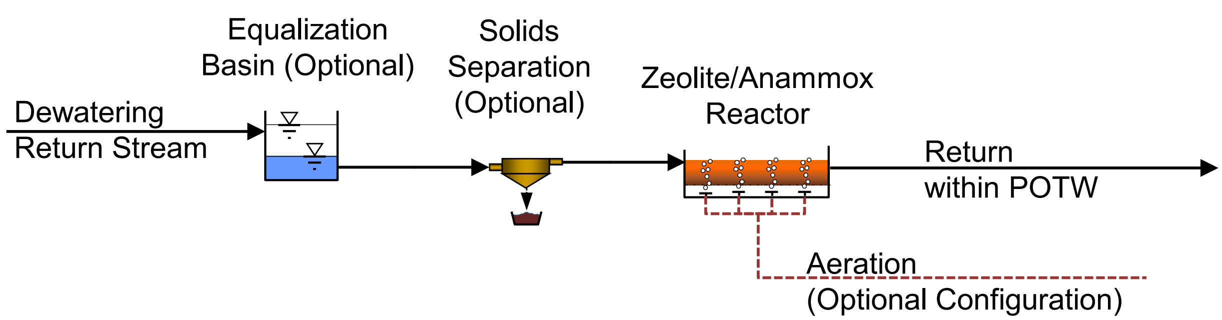


Figure 27. Graphic Illustrating the Removal of Nitrogen by the Zeolite/Anammox Technology

Despite being an emerging technology, the Zeolite/Anammox Technology has had several pilot installations in Northern California. A listing of prior and on-going efforts is provided in Table 27.

There are two arrangements for the Zeolite/Anammox Technology, with and without blowers, for the high-rate and low-rate process, respectively. The low-rate (without blowers) arrangement harnesses the ability of the porous zeolite to wick up water like a sponge, providing a wetted surface that is orders of magnitude greater than the surface area of the tank. The wetted zeolite results in a highly efficient atmospheric aeration system with no blower requirements. The low-rate arrangement is used for low ammonia concentrations (less than 100 mg N/L) typically seen in the liquid stream. The high-rate (with blower) arrangement uses blowers or re-circulating trickling filters to provide oxygen more efficiently to reduce footprint required without comprising performance. Depending on the tank depth the aerated option typically requires only 5 to 10 percent of the non-aerated footprint. The high-rate arrangement is used for high ammonia concentrations (greater than 100 mg N/L) such as the sidestream. As a result, the high-rate arrangement is assumed from herein for this report.

Table 27. Zeolite/Anammox Piloting and Full-Scale Installations.

Location	Description	Contact Information
Union Sanitary District (USD)	A pilot was located at Hayward Marsh to treat approximately 3,000 to 5,000 gpd of liquid stream final effluent (~40 mg N/L). The pilot removed greater than 90 percent of total inorganic nitrogen (TIN).	Tim Grillo T&D Research & Support Team Coach (510)477-7500 timg@unionsanitary.ca.gov
Oro Loma Sanitation District	A pilot tested treatment viability for filtrate sidestream (500 mg N/L ammonia feed with 60% TIN removal) Following the successful pilot, a 20,000 gallon demonstration facility was constructed to treat 10% of the sidestream flow/load.	Jason Warner General Manager/ Treasurer (510)276-4700 jwarner@oroloma.org
Central Contra Costa Sanitary District	A pilot project treating 3,000 to 5,000 gpd of secondary effluent using high-rate arrangement was constructed in September, 2014. An additional low-rate arrangement pilot is scheduled for October 2014.	Jean Marc Petit, District Engineer (925) 229-7112 jmpetit@centralsan.org
San Francisco Public Utilities Commission	A pilot project ongoing to treat a high-strength ammonia sidestream (2,000 to 3,000 mg N/L).	Domenec Jolis (415)920-4914 djolis@sfwater.org

A picture of the Zeolite/Anammox Technology at Union Sanitary District (USD) is presented in Figure 28. The USD pilot was operated at Hayward Marsh where USD sends about 3 mgd of treated secondary effluent for natural polishing in the marsh. The Zeolite/Anammox pilot treated a portion of the USD secondary effluent that serves as Hayward Marsh feed water.

Results from the Oro Loma sidestream pilot are provided in Figure 29. From the beginning, the ammonia was removed. Within six weeks of operation, the nitrate levels were removed which suggests denitrifying or anammox activity. It is likely anammox activity as the available soluble carbon in sidestreams is typically not sufficient to support denitrification. The corresponding TIN removal rate is 0.35 kg N /m^3/day.

Figure 28. Zeolite/anammox Pilot Beds at Union Sanitary District in 2012.

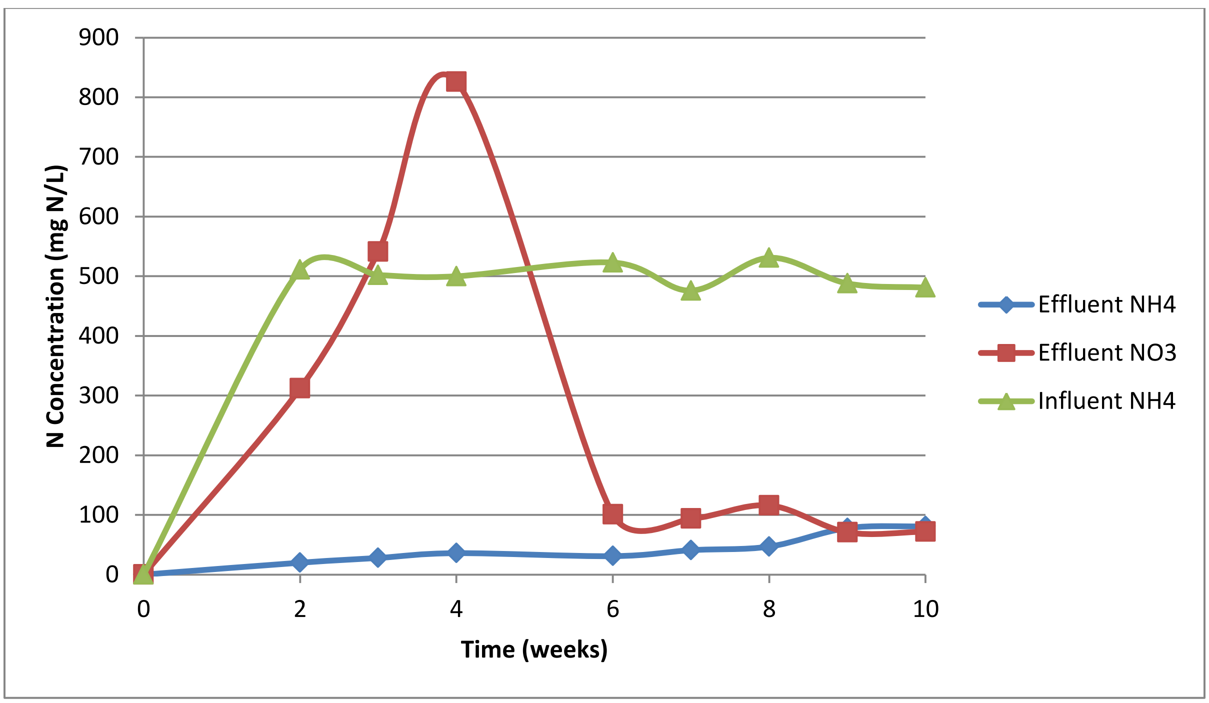


Figure 29. Zeolite/anammox Sidestream Pilot Showing Nitrification Peak at Week 4 and anammox Maturation after Week 6 at Oro Loma Sanitary District

Ammonium spatial results along the length of the reactor from USD are provided in Figure 30. The results highlight the lack of ammonium breakthrough over time. The effluent TIN data is not shown, but the data was always less than 5 mg N/L. The nitrogen removal rate for the Zeolite/Anammox Technology (aerated) using an influent ammonium concentration of 35 mg N/L was 0.1 kg N/m^3/day.

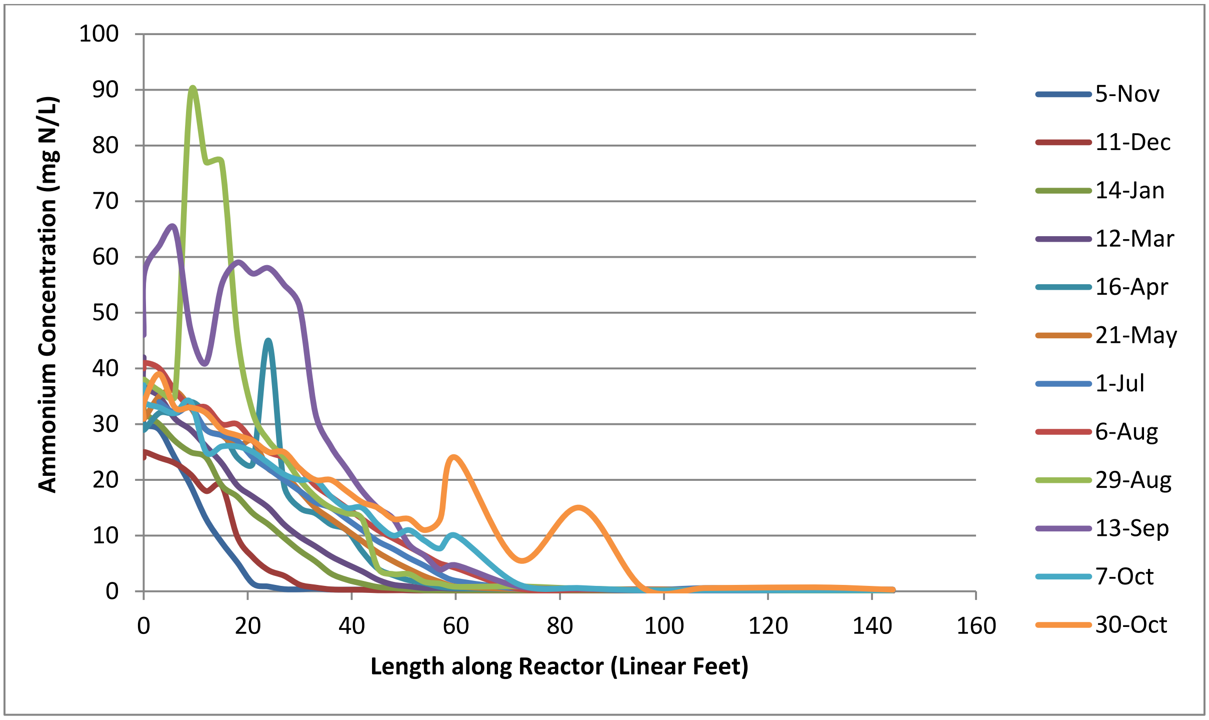


Figure 30. Zeolite/anammox Spatial Plot of Ammonium Concentration along the Reactor Length over Time at Union Sanitary District

Advantages, disadvantages, and data gaps of the Zeolite/Anammox Technology are presented in Table 28.

Table 28. Advantages, Disadvantages and Data Gaps in Zeolite/anammox Technologies

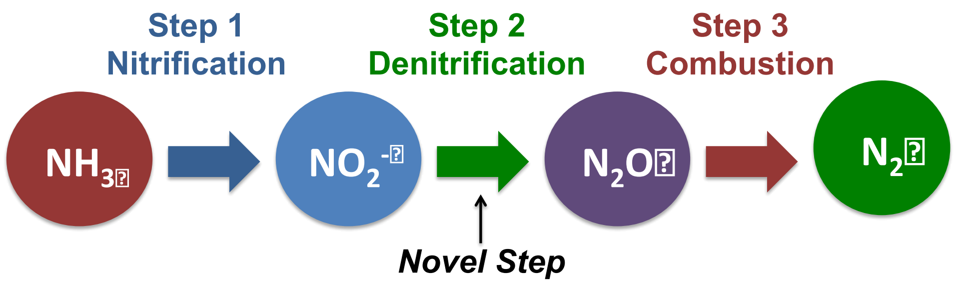
Parameter	Description
Advantages	• Low energy demand: highest net energy savings of biological processes due to use of zeolite and nitrogen removal 3.0 (deammonification) • Operationally simple/simple reactors (ponds, raised berms, etc.) • Low biosolids production • Relatively low cost • Versatility for treating a range of low to high strength ammonia concentrations (e.g., sidestream treatment, mainstream secondary effluent, liquid stream polishing and reuse) • Ability to remove ammonium and total nitrogen in a single process • No supplemental alkalinity required as it relies adsorption and anammox removal processes • No supplemental carbon required as it uses anammox removal processes • Uses a proven technology to remove ammonium, zeolite. The biological zeolite recharge strategy is novel. • Minimal maintenance (self-regulating process)
Disadvantages	• Emerging technology not yet demonstrated at full-scale • Relatively large footprint compared to other sidestream technologies (e.g., Nitrogen Removal 1.0, 2.0, and 3.0 technologies)
Data Gaps	• Strategy to suppress NOB in zeolite/anammox configuration. The system appears to be self-regulating but more data is recommended to confirm. • System start-up time: length of time/ease of anammox colonization on zeolite. Preliminary data (not shown) suggests a six month start-up period if seeded with 1% by volume and six weeks if seeded with 10% by volume. • A database for required sizing (should land availability for pond-type treatment not be possible), as compared to other short-cut nitrogen removal processes. Preliminary data from Oro Loma have a nitrogen loading rate of 0.35 kg N/m^3/day. • Cost estimation and comparison to typical deammonification technologies. The cost of zeolite is known and it varies based on economies of scale. The cost to engineer, design, and construct is still unclear at this stage. It is anticipated to be more affordable than other deammonification technologies as there is less specialized equipment. • Information on how this technology will be configured at a typical WWTP. The data supports a wide range of configurations (e.g., retrofit old digesters). • Defining key process operating parameters. The piloting data suggests it is a self-regulating system but this is limited to a data pilots. • Details on how sufficient aeration is maintained for nitritation. The aeration control strategy is controlled by effluent ammonia and nitrate.

Research Sidestream Treatment Technologies

One technology under the research category was considered in the evaluation and the detailed write-up on this technology is provided below.

Coupled Aerobic-anoxic Nitrous Decomposition Operation (CANDO) – Nitrogen Removal 2.5

The CANDO is a new process for wastewater treatment that removes nitrogen from wastewater and recovers energy from the nitrogen in three steps: (1) ammonium is oxidized to nitrite via nitritation; (2) nitrite is reduced by denitrifying organisms to nitrous oxide (N_2O); and (3) energy is then extracted from the conversion of N_2O to N_2 by co-oxidation of N_2O with methane (CH_4), or by decomposition of N_2O over a metal oxide catalyst. The series of CANDO nitrogen transformation steps are as follows:



Step 1: Nitritation of NH_4^+ to NO_2^- (as previously given in equation 3)
Step 2: Anoxic reduction of NO_2^- to N_2O (Novel Step)
Step 3: N_2O conversion to N_2 with energy recovery (Scherson et al., 2014)

Unlike other nitrogen removal technologies developed to date, CANDO is the sole technology that allows for direct energy recovery from waste nitrogen in the form of nitrous oxide. Nitrous oxide is an energetically potent oxidant and its combustion with methane releases 30 percent more energy than the combustion of oxygen with methane (Scherson et al., 2014). For this reason, the CANDO nitrogen removal pathway is considered Nitrogen Removal 2.5.

A hypothetical process flow diagram illustrating the integration of CANDO into a sidestream treatment process is shown below in in Figure 31.

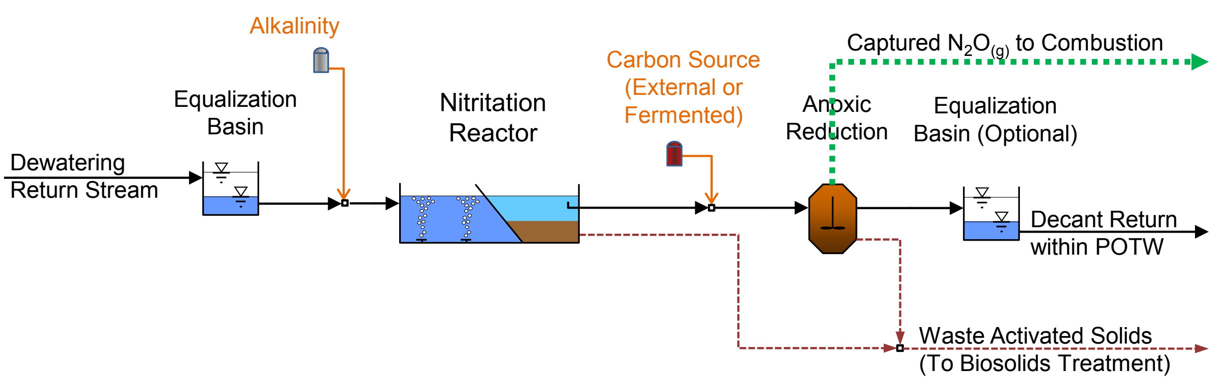


Figure 31. Hypothetical Wastewater Facility Process Flow Diagram for Coupled Aerobic-Anoxic Nitrous Decomposition Operation (CANDO)

The CANDO process is in the very early stages of development. The process was conceived in 2010 and later developed at bench-scale as part of an interdisciplinary doctoral research effort between the departments of Aeronautics and Astronautics and Civil and Environmental Engineering at Stanford University. The second step in CANDO, anoxic reduction of NO_2^- to N_2O, is novel. The first (NH_4^+ oxidation to NO_2^-) and third (CH_4 combustion with N_2O) steps in CANDO are well established. As such, CANDO systems have focused on demonstrating the second step with maximum conversion of NO_2^- to N_2O and maximum NO_2^- removal.

A first bench-scale unit operated in the Stanford laboratory and treated synthetic centrate at an influent process flowrate of approximately 1 L/day (Scherson et al., 2013). This system achieved 60-65% conversion of NO_2^- to N_2O and concluded that N_2O is the major end product of denitrification when electrons are supplied by endogenous carbon, namely polyhydroxybuterate (PHB).

A second bench-scale unit operated at the Delta Diablo wastewater treatment plant treated plant centrate (Scherson et al., 2014). A continuous-flow nitritation reactor oxidized NH_4^+ to NO_2^- with an HRT of 2 days (Step 1 reactor). The liquid from this reactor was supplied to a partial denitrifying SBR where the NO_2^- was reduced to N_2O (Step 2 reactor). The SBR was operated with alternating pulses of acetate and NO_2^-. Acetate was pulsed at the beginning of an anaerobic phase and nitrite at the beginning of an anoxic phase. During the anaerobic phase, the organisms stored the acetate as intracellular PHB, similar to the process control strategy for biological phosphorus removal. During the anoxic phase, the organisms oxidized the PHB and reduced NO_2^- to N_2O. The COD:N ratio in the partial denitrifying reactor was found to be a key operating parameter for efficient denitrification. In this system, 75-80% of the NO_2^- was converted to N_2O, with the remaining nitrogen presumably assimilated into cell biomass, and over 95% of the nitrogen was removed. There was also preliminary evidence of simultaneous phosphorus uptake.

The success of the initial bench-scale studies has resulted in upsizing the unit from bench-scale to pilot-scale at Delta Diablo for this project. The influent process flowrate is upwards of 320 gpd. Images of the pilot-scale study are shown below in Figure 32 and Figure 33.

Energy recovery from N_2O (Step 3) was tested at Silicon Valley Clean Water (SVCW; formerly South Bayside System Authority (SBSA)) in a full-scale biogas fed internal combustion engine that normally combusts biogas (about 60 percent methane) with oxygen present in air. N_2O was fed to the combustion engine at flow rates expected from a full-scale CANDO system at different molar ratios with methane. Power output from the combustion engine increased by 5.7 to 7.3 percent with the N_2O addition. However, this full-scale study utilized pure N_2O for injection, rather than biologically generated N_2O in CANDO process. Extraction and treatment of the biologically generated N_2O for use in combustion has yet to be demonstrated. A picture of the setup and results at SVCW are shown in Figure 34.

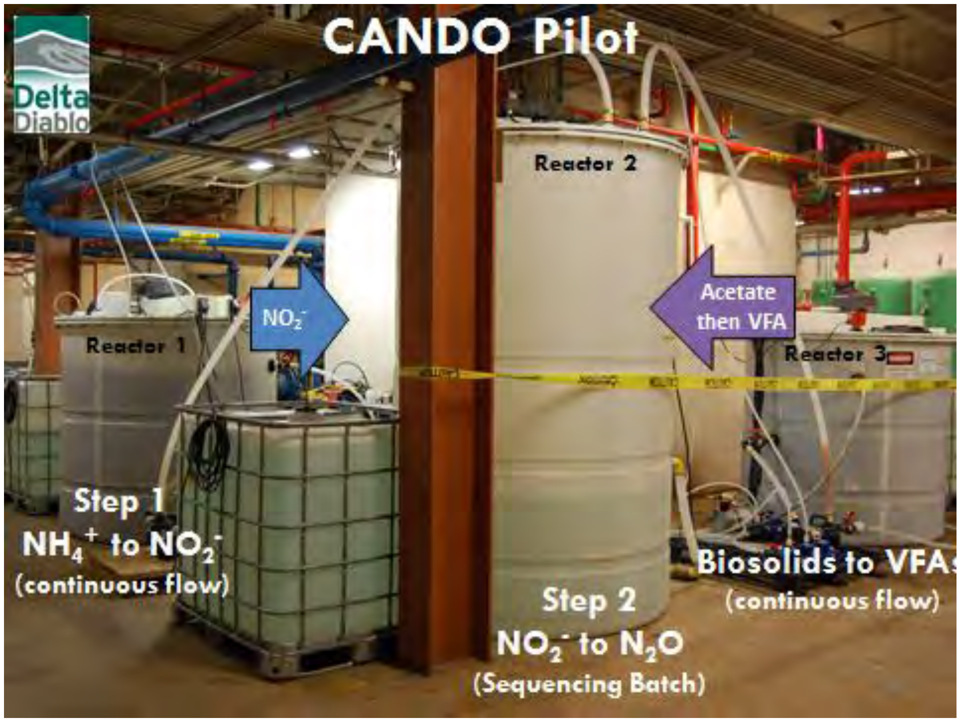


Figure 32. CANDO Pilot-Scale Study at Delta Diablo. The Nitritation Reactor (Step 1) is on the Left and the Anoxic Reduction to N_2O (Step 2) is on the Right

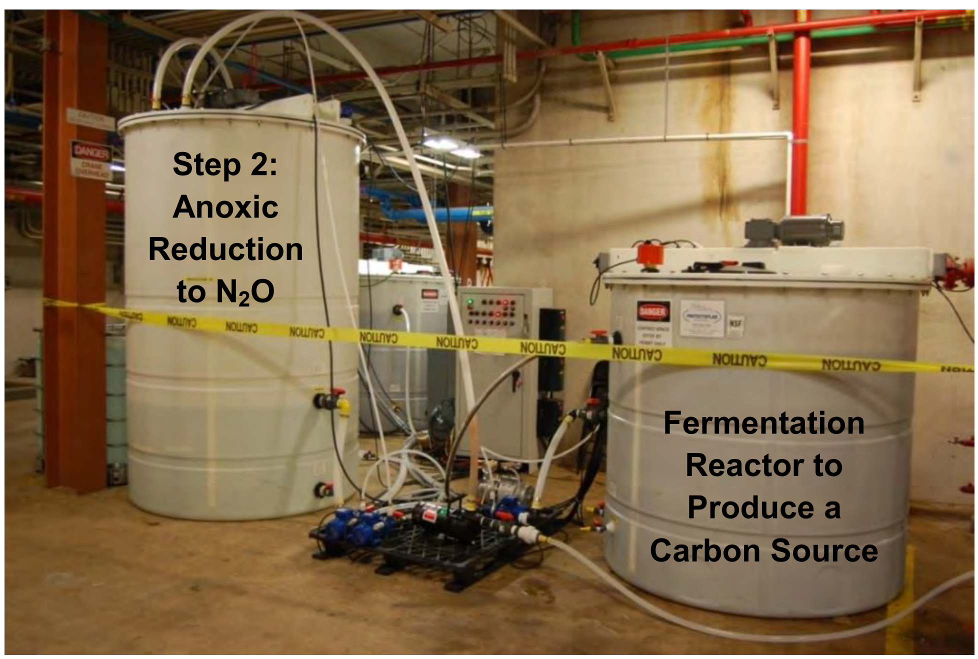
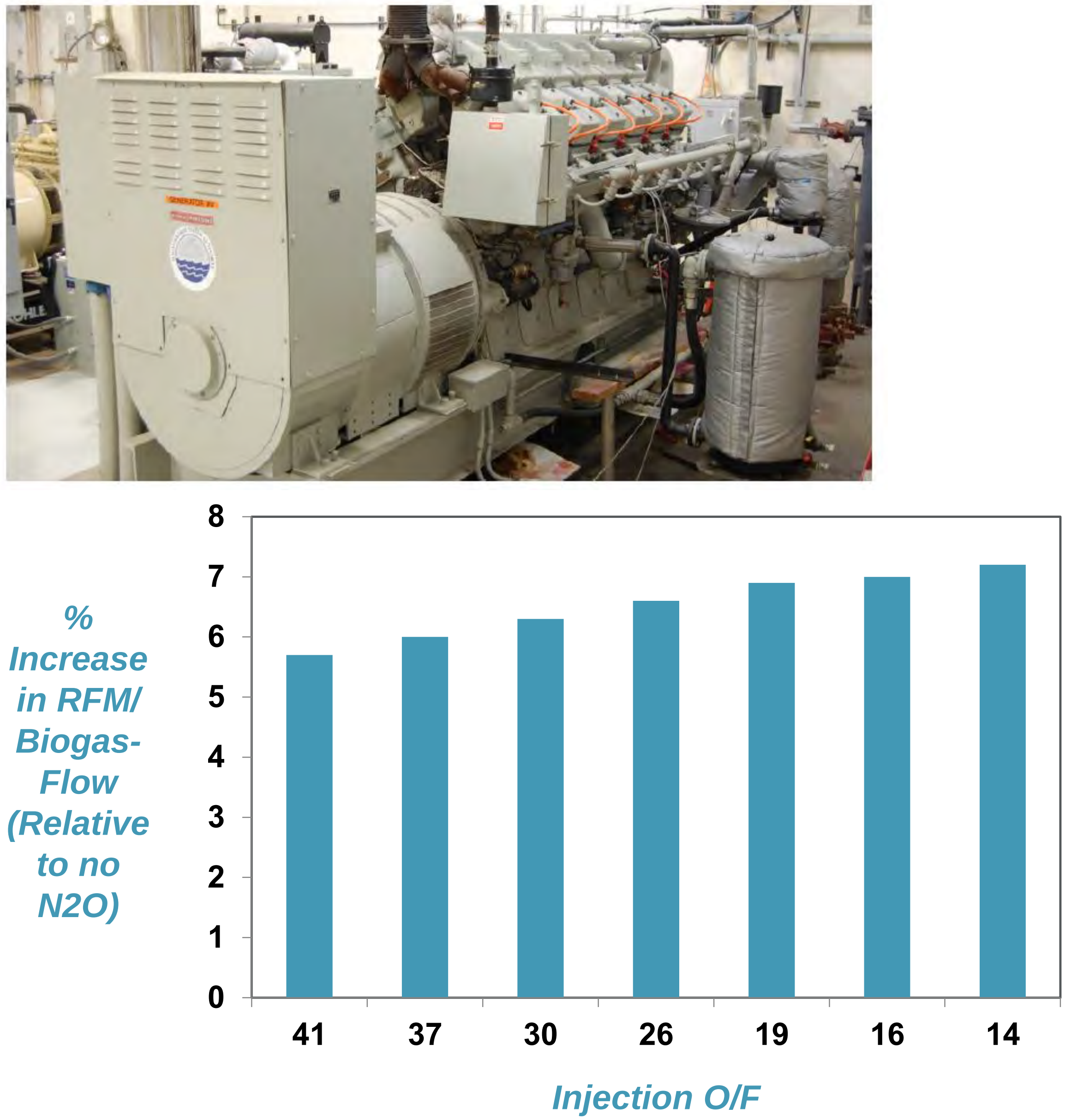


Figure 33. CANDO Pilot-scale Study at Delta Diablo. The Anoxic Reduction to N_2O (Step 2) is on the Left and a Fermentation Reactor to Provide a Carbon Source is on the Right.



Note: Stoichiometric O/F = 4

Figure 34. CANDO Step 3 Testing Setup at SVCW (Top) and the Increase in Energy Production (Bottom)

Table 29 displays a comparison of energy and biosolids related metrics of five nitrogen removal processes. CANDO is an energetically advantageous process in comparison to Nitrogen Removal 1.0 (nitrification/denitrification) and 2.0 (nitrite shunt); but not to Nitrogen Removal 3.0 (deammonification) in terms of energy recovery and biosolids production reduction.

Table 29. Comparison of Theoretical Energy and Biosolids Metrics for Nitrogen Removal Processes (Adapted from Gao, et al., 2014)

Parameter	Nitrogen Removal 1.0 - Nitrification-Denitrification	Nitrogen Removal 2.0 - Nitritation-Denitritation	Nitrogen Removal 3.0 - Deammonification	Current CANDO (heterotrophic)	Future CANDO (autotrophic)[1]
O_2 Consumed (mol)	1.8	1.3	0.7	1.3	0.7
Reducing Equivalents from Organics	9	5.5	1	3.5	0
Biosolids Produced (g VSS)	28	18	7	12	8
Energy Recovery from Nitrogen (kJ)	0	0	0	41	41

[1]These values are based on theoretical calculation for autotrophic denitrification of NO_2^- via "nitritation-denitritation", or NO_2^- reduction via NO to N_2O by autotrophic AOB.
Note: calculations based on reported biomass yield and typical SRT for each process type.

Scherson, et al. (2013) note that Nitrogen Removal 3.0 (deammonification) consumes less energy and produces slightly fewer biosolids than CANDO. This discrepancy is attributed to CANDO requires conversion of all the ammonia to nitrite during Step 1, as well as use of heterotrophic denitrifying organisms to reduce nitrite to nitrous oxide (Step 2). The energy recovered from nitrous oxide combustion along with methane offsets some of these short-comings, and in some cases all, of the additional aeration energy. Based on theoretical calculations, should autotrophic CANDO be developed in the future, this process would offer significant advantages in overall energy recovery.

Despite that the current CANDO process does not have the highest theoretical energy recovery of the listed nitrogen removal processes; this process may offer other advantages. CANDO may allow for a reduced footprint due to a lower operating SRT, as compared to deammonification. CANDO inventors note that CANDO may offer other benefits related to fast start-up (without a seed), robustness, simple operation, possible phosphorus recovery, and may circumvent certain issues associated with the use of deammonification. These shortcomings include slow growth rate of Anammox bacteria, sensitivity of Anammox bacteria to toxic substances (i.e. heavy metals, pharmaceuticals), and occasional process instability in nitritation/anammox systems (Gao et al., 2014; Scherson et al., 2014). Additionally, incorporation of biological phosphorus removal may be possible with CANDO, although authors did not observe significant growth of phosphorus-accumulating organisms (PAOs) in the bench-scale study.

A list of the advantages, disadvantages, and data gaps for the CANDO technology is provided in Table 30.

Table 30. Advantages, Disadvantages and Data Gaps in Coupled Aerobic-anoxic Nitrous Decomposition Operation (CANDO)

Parameter	Description
Advantages	• Energy is directly recovered from waste nitrogen • Reduced biosolids production and energy demands (compared to Nitrogen Removal 1.0 and 2.0) • Substantial net energy savings when N_2O gas is combusted • Process instabilities associated with Anammox bacteria are avoided (i.e. slow growth rates, inhibition due to toxic compounds) • N_2O emissions to the atmosphere are mitigated, in comparison to processes involving denitrifying organisms • May reduce overall sidestream treatment footprint due to reduced process SRT (yet to be demonstrated at full-scale) • Possible phosphorus removal (on-going research)
Disadvantages	• Emerging technology not yet demonstrated at full-scale • External carbon source required at this stage of technology development • Increased oxygen demand (in comparison to nitritation/anammox) • Current technology less energetically favorable than deammonification. • Increased biosolids production (in comparison to nitritation/anammox) Supplemental alkalinity needed (all the ammonia oxidized to nitrite)
Data Gaps	• Several uncertainties associated with CANDO have yet to be resolved, and have unknown implications at the commercial-scale. The combustion of N_2O in the bench-scale study was found to generate NOx (Scherson et al., 2014), or nitric oxide (NO) and nitrogen dioxide (NO_2), which are air pollutants of concern. The potential environmental impact of NOx generation from CANDO has yet to be quantified. • Integration of the N_2O gas stream into methane biogas infrastructure for combustion at a wastewater treatment facility has not been demonstrated. CANDO must include a process to extract dissolved N_2O from the liquid stream, such as air stripping. Additionally, N_2O biogas must be purified prior to combustion. As these processes have not been integrated concurrently with CANDO biological processes, questions remain as to the overall ease and cost of CANDO implementation. Complete life-cycle cost comparisons of CANDO to other competitive sidestream treatments technologies are currently unavailable as CANDO is in the early development stage. • Unknown implications at the commercial-scale • Integration of the N_2O gas stream into methane biogas infrastructure • Concurrent phosphorus removal • Complete life-cycle cost comparisons • Concurrent phosphorus removal may be possible (not yet demonstrated)

Process Controls

Background

Process controls are an integral component for most of the listed technologies. For many of the proprietary technologies that are driving wastewater operations to the next level, the process controls and instrumentation are one of the most critical components for success. In particular, the Nitrogen Removal 2.0 and 3.0 technologies rely on sophisticated instrumentation and process controls.

Process Controls Overview

The most widely applied control theory for dynamic systems such as wastewater treatment processes is feedback control. Feedback control requires accurate and reliable measurement of a “controlled variable” or a “measured variable”, which is the parameter that drives the actions of the controller itself. A controlled variable is known to react in a certain manner to a particular process or operational change, often referred to as a “manipulated variable”. The type of adjustment to this manipulated value and its magnitude are controlled with some form of programmable logic controller (PLC). The “error” is calculated from the difference between the measured variable and the “setpoint” and is used as the feedback input to the controller. Using the calculated error, the controller program will make the adjustments to the manipulated variable in an attempt to match the measured variable to the setpoint. One of the key components to an effective feedback controller is the tuning of the programming to ensure that adjustments made to the manipulated variable don’t cause extreme changes to the measured variable, commonly referred to as “overshooting”. A poorly tuned controller can result in process instability or upsets, and potential violation of treatment objectives or permits.

A simplified control schematic for a feedback process control loop is provided in Figure 35. In the schematic, the solid lines represent the input and output of the actual process being controlled, while the dashed lines represent control signals. The process output represents the measured variable, which is monitored by an online analyzer or other form of instrumentation. The PLC calculates the error and inputs this to the controller, which initiates a process adjustment (a change to the manipulated variable) based on its programming.

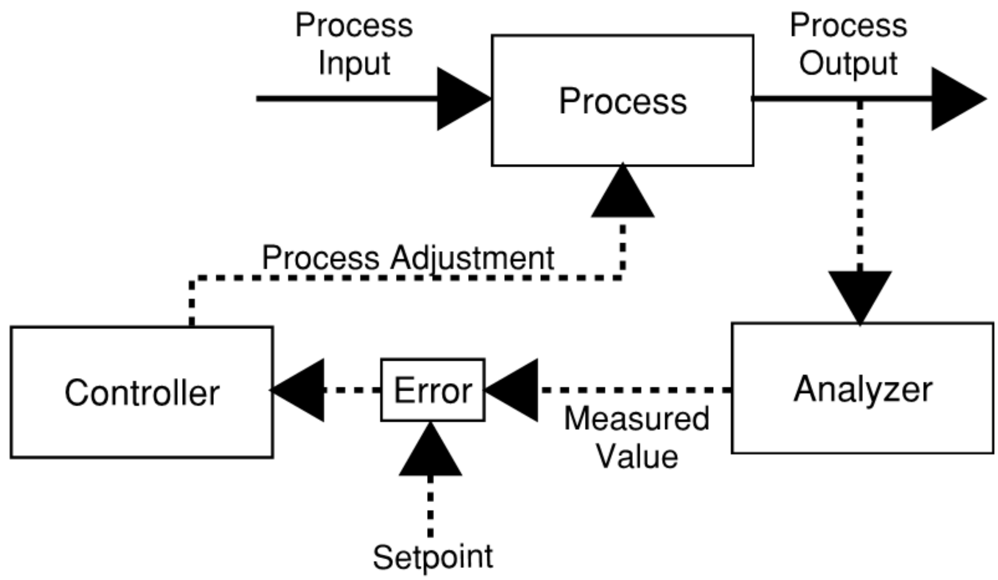


Figure 35. Feedback Control Schematic

Another control theory which has demonstrated benefits to dynamic system control in certain situations is feedforward control. With this control method, the adjustment to the manipulated variable is not based on an error measurement, but instead requires the development of a mathematical model. The mathematical model requires a thorough understanding of the system, and the adjustments to the manipulated variable that will result in the desired process output. As opposed to feedback control, feedforward control relies on a measured variable from the process input. This form of control is useful when the input to a process is highly variable and the process will benefit from a preemptive adjustment to the manipulated variable based on anticipated operating conditions. Due to the complexity of programming a mathematical model and the fact that the process output is not known, feedforward control alone is not commonly applied to wastewater treatment processes.

A simplified control schematic for a feedforward process control loop is provided in Figure 36. Again, the solid lines represent the input and output of the actual process being controlled, while the dashed lines represent control signals. The process input represents the measured variable, which is monitored by an online analyzer or other form of instrumentation. When the PLC detects a disturbance in the process input, the controller initiates a process adjustment (a change to the manipulated variable) based on the programmed mathematical model.

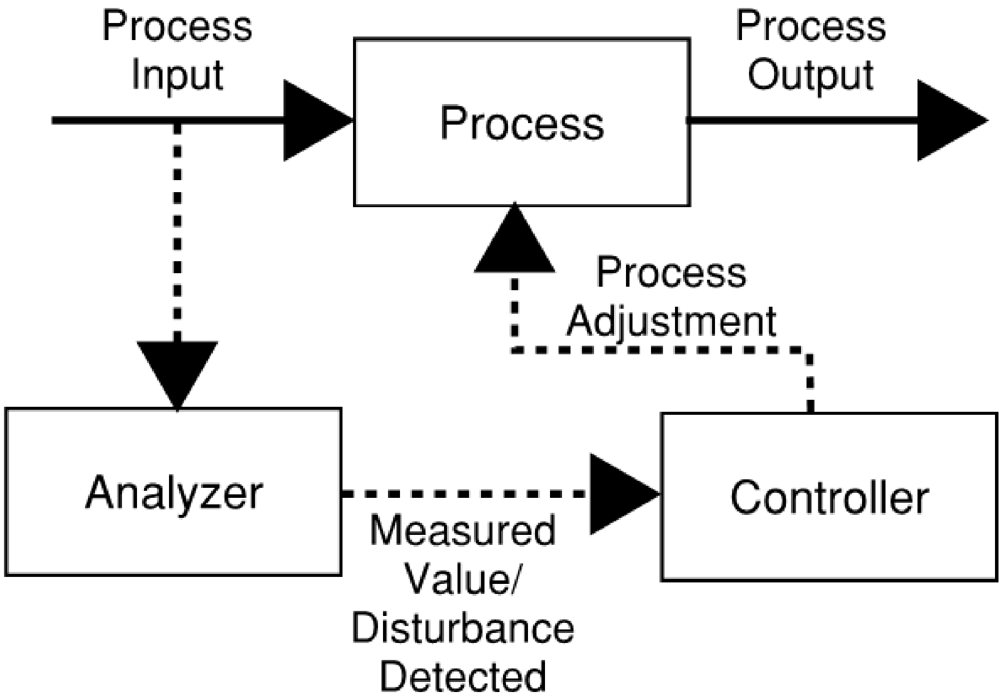


Figure 36. Feedforward Control Schematic

Feedforward control is typically most effective when paired with feedback control and can result in improved stability of certain processes. When these two control theories work together, the manipulated variable is adjusted to maintain a setpoint value in the process output, but at the same time, the process input is being monitored for disturbances or peak conditions. This allows the control system to dynamically adjust to changes in the process influent, while ensuring that the process effluent is meeting the setpoint.

A simplified control schematic for a combined feedback and feedforward process control loop is provided in Figure 37. In this system, both the process input and process output provide measured variables to the PLC, which are monitored by online analyzers or another form of instrumentation. Under normal operating conditions, the PLC calculates the error adjusts the manipulated variable accordingly to maintain the setpoint in the process output. In addition, when the PLC detects a disturbance in the process input, the controller will initiate a process adjustment based on the programmed mathematical model.

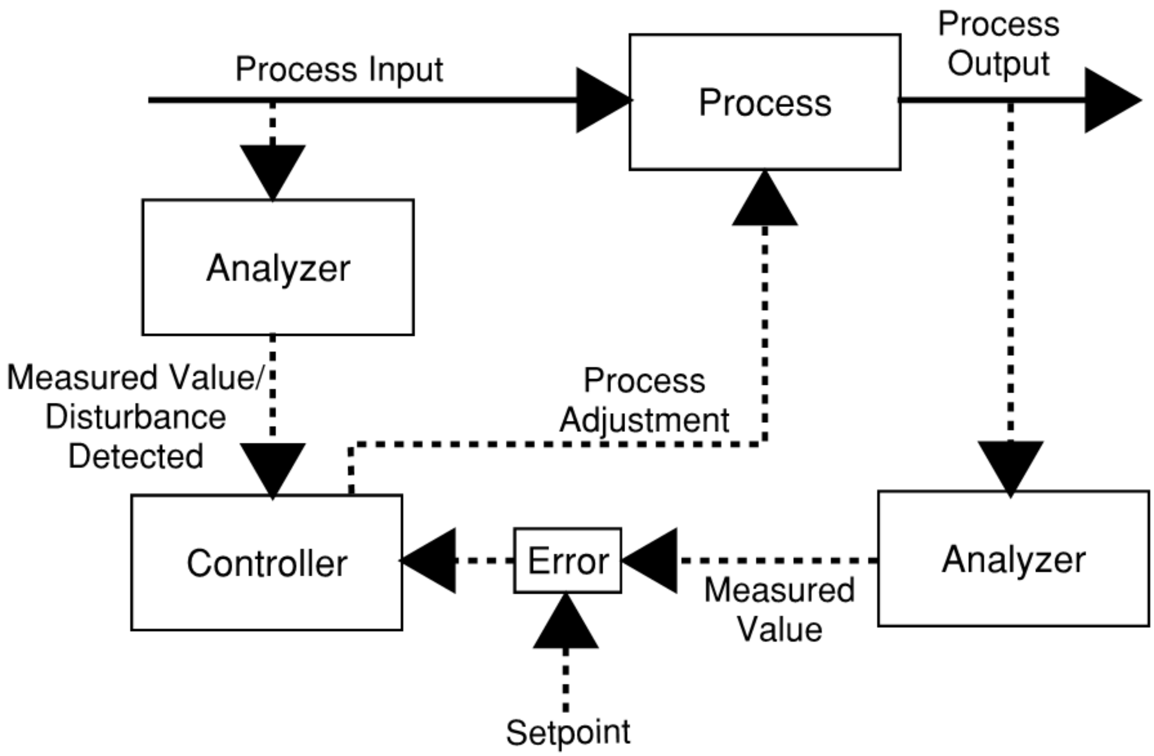


Figure 37. Feedback and Feedforward Control Schematic

With conventional wastewater treatment processes, feedback control alone is typically adequate for the required level of process control. However, for processes that experience highly dynamic process inputs, the combination of feedback and feedforward controls can help maintain process stability.

Sample of Process Controls for Deammonification

Two common control strategies are pH based control and free ammonia. This section will focus on pH-based control as there is a larger dataset with lessons learned. Regardless of control strategy type, the strategies are most stable under consistent loading conditions, so upstream equalization of the influent flow is typically incorporated into the design. This allows for the use of feedback control only, without the need for the more complicated feedforward control theory.

The pH control strategy for deammonification processes was originally developed by Bernhard Wett (Wett, 2007). The strategy uses pH as the control variable and the aeration time is the manipulated variable. During aeration, the DO is maintained at a setpoint value using a feedback PID controller. Under such operation, the cycle duration and schedule is determined during startup of the process. Each cycle consists of aeration, feeding with anoxic mixing, and anoxic mixing periods. The length of the intervals is controlled based on either timers or pH setpoints.

Setpoints for both high and low pH provide robust process control. When aerated, the process is achieving nitritation by creating the appropriate conditions for AOB to oxidize ammonia to nitrite, a reaction which consumes alkalinity and decreases pH. The low pH setpoint is determined during startup based on the desired level of ammonia conversion. Once this low pH setpoint is reached, the system switches to anoxic operation. Influent flow is fed for a portion of the anoxic period. During the anoxic periods, anammox activity produces alkalinity, driving the pH up. The influent feed to the process during the anoxic cycle provides additional alkalinity. In addition to alkalinity, the feed will also typically contain sCOD, which provides a carbon source for denitrification of the nitrate generated by anammox. Anoxic operation is maintained until the high pH setpoint, or a time interval setpoint, is achieved. This trend can be observed in Figure 38 (Nifong, 2013). The pH fluctuation indicates a stable system and can be used to gauge process performance. Systems that do not exhibit this clear pH pattern may be inhibited or limited by substrate, DO, or alkalinity and will require attention.

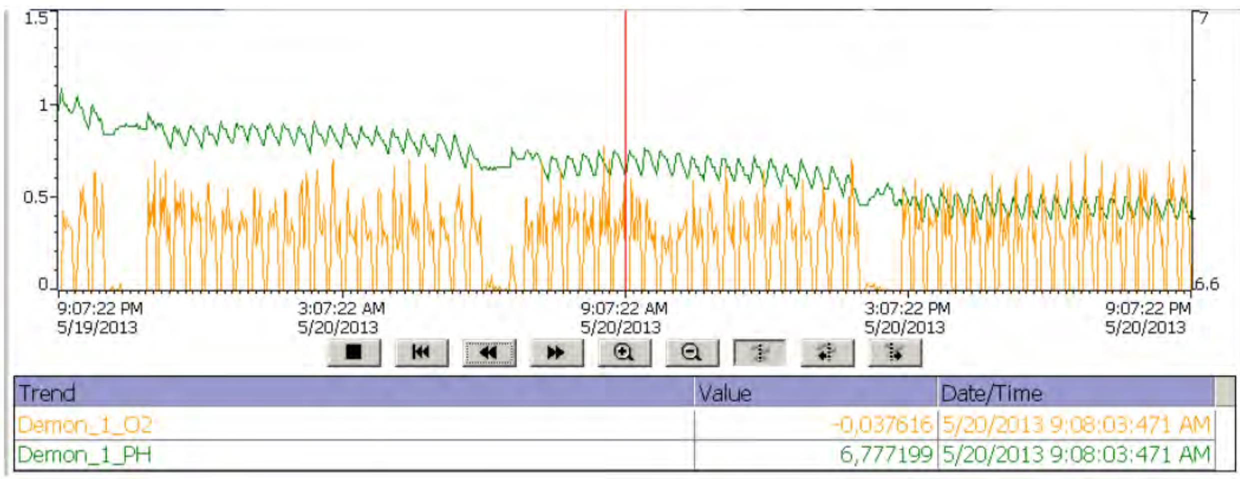


Figure 38. DO and pH Trending Screen (Nifong, 2013)

Other deammonification technologies operate with a form of pH-based control, such as using the DO concentration as the manipulated variable. With this control concept, the DO within the process is adjusted to maintain a setpoint pH value as seen in Figure 39. The pH setpoint is determined during startup to target a performance objective. Since this is an attached growth process with an inner anammox biofilm layer and an outer AOB layer, diffusion of oxygen through the biofilm layer will limit anammox activity. However, the AOB require oxygen to generate the nitrite required for anammox. If the measured pH is dropping below the setpoint, this indicates that the bulk DO concentration is too high. This is caused by consumption of alkalinity by AOB and reversible inhibition of anammox bacteria due to excess oxygen diffusion through the biofilm. As a result, the PID controller will decrease the DO concentration to bring the measured pH value closer to the setpoint. If the measured pH is increasing above the setpoint due to increasing alkalinity, this suggests reduced nitrite production by AOB caused by inadequate DO availability. As a result, the PID controller will increase the DO concentration to bring the measured pH value closer to the setpoint. In a stable system, the nitrite production and alkalinity consumption by AOB is balanced with the nitrite conversion and alkalinity generation by anammox by adjusting the DO to maintain a setpoint pH.

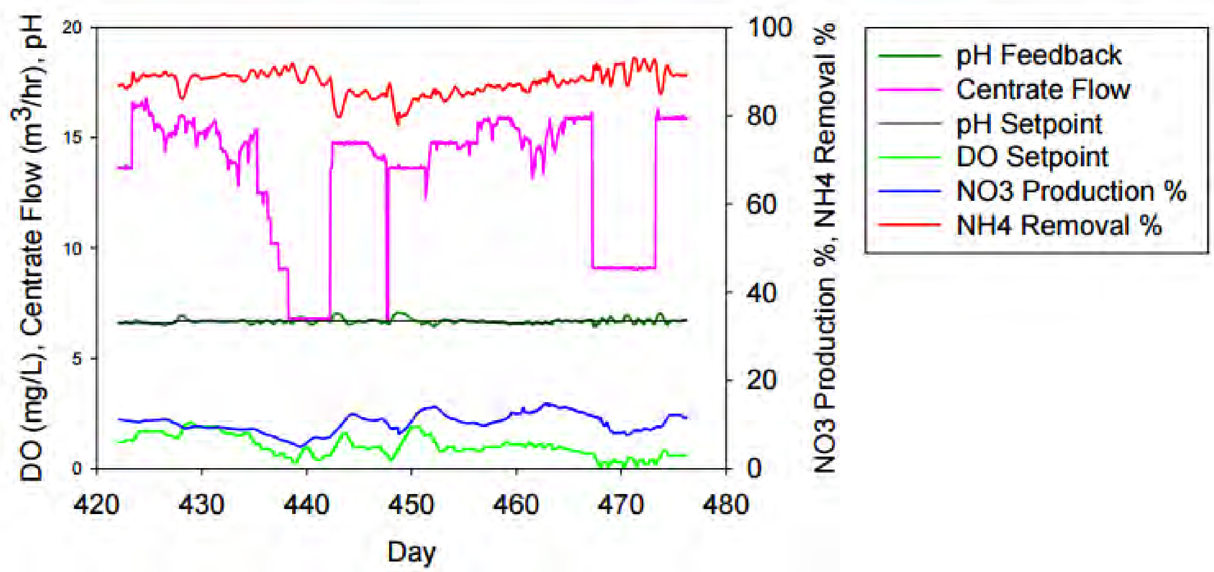


Figure 39. Sample of a pH-based Aeration Control (Klaus, 2015)

With either pH based control strategy described, only DO and pH instruments are required. Both of these instruments technologies are stable, reliable, and require infrequent calibration/maintenance. However, several other probes are recommended for process monitoring, including conductivity, ammonia, and nitrate. Proper placement of these instruments within the process is required for accurate and representative measurements.

Nutrient analyzers are more maintenance intensive and require greater attention in order to provide accurate data. Additionally, they are not typically provided as part of the vendor's packages, as they are not required for control. For these reasons, ammonia and nitrate are only used for these systems when the owner desires this additional level of monitoring. There are a number of different options for nutrient analyzers, so the final selections are typically based on owner preference. Some of the most commonly used instruments and the parameters they measure are summarized in Table 31 and Figure 40 shows a cabinet style instrument installation for ex situ analysis, while Figure 41 shows sample images of an online ammonia/nitrate probe and a field-mounted controller/transmitter.

Conductivity is used as a trending tool and represents the measure of all relevant ions. This has been found to be a useful monitoring tool and is typically included as part of the standard package provided by several vendors. For example, the accumulation of nitrite in the system would suggest reduced anammox activity, which could be caused by excessive aeration.

Table 31. Nutrient Analyzer Summary

Instrument	Ammonia	Nitrate	Nitrite
Hach AN-ISE	Yes	Yes	No
Hach A-ISE	Yes	No	No
Hach Nitratax	No	Yes	No
WTW VARiON®Plus 700 IQ	Yes	Yes	No
S::CAN Spectro::lyser	No	Yes	Yes
S::CAN Ammo::lyser	Yes	No	No
ASA ChemScan[1]	Yes	Yes	Yes

[1] ChemScan is an ex situ wet chemistry analyzer

Figure 40. ASA ChemScan Multi-Parameter Analyzer

Figure 41. Hach AN-ISE Ammonia and Nitrate Probe (Left) with Field-Mounted SC200 Universal Controller (Right)

Although probe selection is an important first step, equally important is the maintenance and calibration requirements associated with this instrumentation. An example sensor management plan is provided in Table 32.

Table 32. Example Instrumentation Management Summary

Instrument	Calibration Frequency	Maintenance	Function
pH	Quarterly, Max	Weekly Cleaning	Control
DO	Annual	Weekly Cleaning/ Air Blast	Control
Conductivity	Annual	No issue	Monitoring
Ammonia/Nitrate	As needed compared to lab values	Air Blast	Monitoring

Source: Klaus, 2015

Ensuring that personnel are trained on each process and the instrumentation associated with it is another vital component of these technologies. Lessons learned from the first generation of deammonification installations in the US are summarized below (Klaus, 2015):

- The entire plant staff should be trained on the basic process theory, components, analytical requirements and the process controls, with a smaller group trained on in depth theory, troubleshooting, and process control.
- During startup, the plant staff and vendor should have daily meetings to monitor startup progress and process performance. These can become less frequent as the team becomes more familiar with the system and operations stabilize.

Although the pH-based control strategy has been proven effective by both of these vendors at a number of installations, each facility startup requires careful attention to detail, frequent meetings and discussion, and a thorough understanding of the process and its controls. This knowledge and experience must be carried into the eventual normal operations, as this is a dynamic process which will need occasional adjustments based on a comprehensive understanding of the system (as often as once or twice a week).

Summary and Next Steps

This literature review investigates return sidestream treatment technologies as a part of the EPA Regional Grant for BACWA POTWs. Sidestreams represent a pragmatic first step in evaluating nutrient load reduction opportunities at BACWA member agencies. The return sidestreams from digestion and dewatering are of interest since they are a source of high nitrogen loads (about 15 to 20 percent of the total nitrogen discharge load).

Nine technologies were evaluated in this sidestream treatment literature review, grouped by technology status as follows:

Established Technologies:

1. Nitrifying Sequencing Batch Reactor (Nitrogen Removal 1.0) – served as the benchmark technology
2. Sidestream Treatment with Liquid Stream Bioaugmentation (Nitrogen Removal 1.0)
   Innovative Technologies:
3. Nitritation/Denitritation (Nitrogen Removal 2.0)
4. Suspended Growth Deammonification (Nitrogen Removal 3.0)
5. Granular Growth Deammonification (Nitrogen Removal 3.0)
6. Attached Growth Deammonification (Nitrogen Removal 3.0)
   Emerging Technologies:
7. Ammonia Recovery Processes (ARP and AMR with an emphasis on ARP) (Physical/Chemical Removal Mechanism)
8. Zeolite/anammox (Nitrogen Removal 3.0)
   Research Technology:
9. CANDO (Coupled Aerobic-Anoxic Nitrous Decomposition Operation) (Nitrogen Removal 2.5)

A comparison matrix of the key advantages, key disadvantages and data gaps that summarize the findings is provided in

Table 33. An additional comparative matrix that compares relative costs, footprint, performance, energy demand, and operational reliability among all considered technologies is provided in Table 34.

The evaluation considered technologies that represent biological nitrogen removal, physical/chemical nitrogen removal, and physical/chemical/biological nitrogen removal. The emphasis was on biological nitrogen removal as this is the most common removal approach implemented for municipal applications.

Table 33. Summary of Advantages, Disadvantages and Data Gaps Comparison Matrix

Parameter (Technology Status; Removal Mechanism)	Advantages	Disadvantages	Data Gaps
Nitrifying SBR (Established Technol.; Nitrogen Removal 1.0)	• Established technology • Stable operating process • Single reactor vessel • No proprietary licensing • High flexibility/ able to retrofit • Tolerates peak flows and BOD shock loads • Odor control	• Energy intensive • External carbon source can be needed • Alkalinity addition can be needed • Complex instrumentation / controls • Large reactor volume • Washout possible • Poor settling possible • Increased solids production	• Minimal data gaps • Liquid stream odor control
Bioaugmentation (Established Technol.; Nitrogen Removal 1.0)	• Those listed for the NSBR • Reduced volume / footprint • Odor control	• Those listed for the NSBR	• Amount of seed required • Scientific basis for design • Performance data on meeting stringent ammonia/nitrogen limits
Nitritation/Denitritation (Innovative Technol.; Nitrogen Removal 2.0)	• Aeration energy reduced compared to Nitrogen Removal 1.0 • External carbon reduced • Biomass production reduced	• Aeration energy more than Nitrogen Removal 3.0 • External carbon addition for nitrogen removal • Emerging technology in U.S. • Installations on the decline • Sophisticated process control • New technology for operators	• Limited installations in the U.S. • Dataset not expanding • External carbon sources other than methanol • Technology controls

Parameter (Technology Status; Removal Mechanism)	Advantages	Disadvantages	Data Gaps
Deammonification (Innovative Technol.; Nitrogen Removal 3.0)	• Highest net energy savings of biological processes • No carbon source required for TIN removal • Alkalinity demand reduced • Refined process control • Small footprint • Biomass production reduced	• New technology for operators • Sophisticated and precise process control required • License fee may be required	• Stress testing nitrogen loading rate • Limited datasets for US installations • Wash-out recovery time • Nitrogen concentration upper limits • Temperature lower limits
Suspended Growth Deammonification (Innovative Technol.; Nitrogen Removal 3.0)	• High ammonia loads • Reduced costs	• Process upsets • Larger footprint than attached growth deammonification • Wash-out	• (See Deammonification)
Granular Sludge Deammonification (Innovative Technol.; Nitrogen Removal 3.0)	• Very compact footprint	• All those listed for suspended growth SBRs • Tight process controls	• (See Deammonification)
Attached Growth Deammonification (Innovative Technol.; Nitrogen Removal 3.0)	• Reduced footprint compared to suspended growth deammonification • Sludge production reduced compared to suspended growth system • Solids removal via clarification, filtration, or flotation • No RAS pumping or lines (unless operating as an IFAS configuration)	• Higher operational energy demand than the suspended growth deammonification • Higher capital cost than suspended growth deammonification • Occasional operational upsets have occurred • No selective wasting of unwanted bacteria • Screens required	• Nitrogen loading data • Unit energy demand data • Operators concerned about process operation

Parameter (Technology Status; Removal Mechanism)	Advantages	Disadvantages	Data Gaps
ARP (Emerging Technol.; Phys/Chem Removal)	• Ammonia fertilizer recovered • Reduced footprint compared to traditional physiochemical ammonia recovery • Reduced operating cost as compared to traditional physiochemical ammonia recovery • Independent of nutrient loading variability • Ease of developing design criteria	• Reliance on fertilizer market conditions • Not yet implemented at full-scale • Chemicals • Energy intensive	• Limited costs for municipal installations • Lack of installations • Lack of experience • Design criteria limited to water chemistry • Nitrogen removal performance data • Plant wide impacts on alkalinity and carbon balance
Zeolite/Anammox (Emerging Technol.; Phys/Chem/Biol Rem)	• Low energy demand • Operationally simple • Low biosolids production • Low cost • Versatility • Single process NH3/TN removal • No supplemental alkalinity required • No supplemental carbon required • Minimal maintenance (self-regulating process)	• Emerging technology / biological process • Relatively large footprint	• Strategy to suppress NOB • System start-up time • Required footprint • Cost estimation and comparison • Technology configuration • Key process operating parameters • Sufficient aeration for nitritation

Parameter (Technology Status; Removal Mechanism)	Advantages	Disadvantages	Data Gaps
CANDO (Research Technol.; Nitrogen Removal 2.5)	• Energy recovered • N_2O emissions mitigated • Reduced biosolids production compared to nitritation-denitritation • Reduced energy demand compared to nitritation-denitritation • Process instabilities avoided • Reduced process SRT	• Emerging technology • External carbon source required • Increased oxygen demand compared to nitritation/anammox • Increased biosolids production compared to nitritation/anammox • Less energetically favorable than deammonification • Supplemental alkalinity needed	• Commercial-scale implications • Integration of N_2O gas stream • Concurrent phosphorus removal • Environmental impact of NO_x • Life-cycle cost comparisons

Table 34. Comparison Matrix Showing Relative Costs and Operational Considerations among All Considered Technologies

Parameter (units)	Nitrogen Removal Technology [a]								
	1	2	3	4	5	6	7	8	9
Relative Capital Cost	High	High	Medium	Low	Low	Low	Low	Low	Unknown
Relative Operational Cost (Energy & Chemicals)	High	High	Medium	Low	Low	Low	Medium	Low	Medium
Energy Demand (kWh/kg-N removed)	3 - 6	3 - 6	2 - 3	1.0 – 1.3	1.2 – 1.8	1.4 – 1.8	9	<2	Unknown
N Loading Rates (kg N/m^3/d)	0.3 - 0.4	0.4 - 0.5	< 0.7	0.35 – 0.75	0.3 – 7.0	0.4 - 1.2	1.2 - 1.6	?	Lowest (Step 2 is limiting)
Ammonia Removal (%)	>90	>90	>90	>90	>90	>90	>90	>90	>90
Nitrogen Removal (%)	80-90[b]	80-90[b]	80-90[b]	80-90	80-90	80-90	80-90	80-90	~65
Solids Yield	1.9	1.9	1.5	0.1	0.1	0.1	[c]	0.1	0.2
Nitrogen Byproducts	NO_x, N_2O	NO_x, N_2O	N_2, N_2O	N_2, NO_x, N_2O	N_2, NO_x, N_2O	N_2, NO_x N_2O	--	N_2, NO_x, N_2O	N_2, NO_x
Energy Recovery (kJ/mole N)	0	0	0	0	0	0	0	0	41
Nutrient Recovery	No	No	No	No	No	No	Yes	No	No
Ability to Expand	High	Medium	High	High	High	High	Medium	High	Unknown
Proprietary Nature	None	Medium	Medium	High	High	High	High	Medium	High
Flexibility to Meet Future Nutrient Regulations [d]	Low	Low	Medium	High	High	High	High	High	Medium
Operational Complexity	Medium	Medium	High	High	High	High	Medium	Low	High
Operational Reliability	High	High	Medium	Medium	Medium	Medium	High	High	Unknown

[a] 1 = NSBR; 2 = Bioaugmentation; 3 = Nitritation/Denitritation; 4 = Suspended Growth Deammonification; 5 = Granular Growth Deammonification; 6 = Attached Growth Deammonification; 7 = ARP; 8 = Zeolite/Anammox; 9 = CANDO

[b] If denitrification implemented; using the NOx for odor control at the headworks might be more viable than sidestream N removal

[c] Possibly, with lime addition

[d] Based on whether alkalinity and/or an external carbon source would be required to meet more stringent nitrogen limits

[e] Bioaugmentation potential for mainstream deammonification

[f] Could treat mainstream

Biological Nitrogen Removal

For the biological nitrogen removal technologies, the key differentiator amongst the technologies was the nitrogen removal pathways, Nitrogen Removal 1.0, 2.0, 2.5, and 3.0. A comparison of key parameters the nitrogen removal pathways is provided in Table 35. The key points are the oxygen/energy demand, carbon demand, yields, and alkalinity demands are inversely related to the nitrogen removal pathway number (e.g., Nitrogen Removal 3.0). This reduced demand is attributed to the short-cut in nitrogen removal pathways for Nitrogen Removal 2.0 and 3.0 compared to Nitrogen Removal 1.0.

Table 35. Comparison for Nitrogen Removal 1.0, 2.0, 2.5, and 3.0

Parameter	Units	Nitrogen Removal 1.0	Nitrogen Removal 2.0	Nitrogen Removal 2.5	Nitrogen Removal 3.0
Oxygen Required	lb O_2/ lb NH4-N Removed	4.6	3.4	3.4	1.9
Carbon Required (if acetate used)	lb COD/ lb N Removed	6.6	4.5	? *	0.0
Yield	lb VSS/ lb N Removed	1.9	1.5	0.2 **	0.1
Alkalinity Required	lb Alk as $CaCO_3$/ lb NH_4-N Removed	7.1	7.1	7.1	3.6
Energy Recovery	kJ/mole N Removed	0	0	41	0

* Currently unknown; this depends on if the carbon source is externally or internally provided on the process controls.
** Gao et al. (2014)

Nitrogen Removal 1.0 technologies are the industry standard. Despite the energy, chemical, and footprint benefits, plants are reluctant in the U.S. to implement Nitrogen Removal 2.0, 2.5, and 3.0 technologies. This stems from concerns over risk and the perception that they are more difficult to operate than Nitrogen Removal 1.0 technologies. The Nitrogen Removal 1.0 technologies are established, does not require any piloting, can reliably work at low temperatures (<20°C), and the produced nitrite/nitrate can assist with odor control at the headworks. The experimental steps for evaluating the viability odor control at a plant were highlighted in the Nitrifying Sequencing Batch Reactor – Nitrogen Removal 1.0 Section.

For the Nitrogen Removal 2.0, 2.5, and 3.0 technologies, Nitrogen Removal 3.0 is the most attractive at this time due to the energy, chemical, and biosolids yield benefits coupled with the number of installations (>100 globally). Nitrogen Removal 2.0 technologies have become less attractive over time. The operational challenge most common with Nitrogen Removal 2.0 and 3.0 technologies is the ability to stop ammonia at nitrite. For this reason coupled with the energy, chemical, and biosolids yield benefits, utilities are more likely to consider Nitrogen Removal 3.0 over 2.0. The Nitrogen Removal 2.5 technology, CANDO, is typically not considered as it is in the early development stage with no full-scale installations.

Nitrogen Removal 3.0 deammonification technologies has been shown to be technically and economically feasible. Several technology options have been tested and commercialized to provide the appropriate environment and control to provide stable operation. There are more than 100 full-scale installations since the first full scale facility was constructed in 2001. The majority of installations have shown stable operation.

Given the benefits for Nitrogen Removal 3.0 technologies, what is the bottleneck for plants selecting it over Nitrogen Removal 1.0 technologies? The literature review as well as experiences with plants point towards the following reasons:

- Most plant management and operators are hesitant to adopt innovative technologies due to risk in reliably meeting discharge requirements
- Long start-up period (early installations took more than a year): this has been reduced with seeding or modified process controls, but it still takes at longer than 1-month. There are several approaches to accumulate sufficient anammox bacteria necessary for the process. These processes differ in terms of the method to grow and retain the anammox bacteria, number of stages, the configuration of the process, and control strategies implemented (Bowden et al., 2014)
- Operational complexity: most of the technologies have complex control strategies that rely on pH, free ammonia, nitrite, DO, and other probes to control aeration and cycling. The controls have increased tremendously in recent years. With time, such concerns should be further abated until they are established.
- Lack of installations: there are about a dozen municipal plants in the U.S. under design/construction (two operational full-scale installations). It should be noted that there are >100 global installations with the majority in Europe and Asia.
- Operator attention
- Licensing fee
- Seeding requirements
- Piloting requirements

The key data gaps for Nitrogen Removal 3.0 technologies that should assist these technologies in transitioning from innovative to established technology status are as follows:

- Improve the overall process reliability. The parameters imperative for reliable performance are maintaining the appropriate pH, free ammonia, DO, nitrite, NOB suppression, and sufficient SRT for anammox bacteria. The performance data from installations is promising but there is concern over how to handle process disruption, such as instances when high nitrite levels poison the anammox bacteria.
- Reduce reactor start-up. These technologies have made monumental strides in recent years by seeding which has reduced start-up on the order of years to a little over a month. Data suggests that a couple month start-up is possible without seeding by controlling aeration by free ammonia. Coupling seeding and controlling aeration with free ammonia might further reduce the start-up time.

- Demonstrate the ability to reliably perform nitrogen removal under cold weather conditions (less than 15 degrees C). This is not critical for Bay Area utilities but is a concern in colder climates whose sidestream is cooled to ambient levels prior to treatment.
- Identify the upper nitrogen loading rate (kg $N/m^3/d$).Research using single-stage Anammox® to treat high-strength industrial loads supports loading the units up to 90 kg $N/m^3/d$ (Chen et al., 2011; Teng et al., 2011). Is there potential to load municipal streams to greater levels than seen at current installations (<<5 kg $N/m^3/d$)?

As the cumulative experience with Nitrogen Removal 3.0 deammonification technologies continues to grow, these technologies will transition to an established technology that can provide a consistent treated effluent quality and deliver the promised energy and chemical savings.

Physical/Chemical Nitrogen Removal

The physical and chemical nitrogen removal technologies evaluated for ammonia recovery were ARP by ThermoEnergy® and AMR by Anaergia, with an emphasis on ARP. ARP uses traditional air stripping by raising the pH and applying vacuum distillation. The stream is polished with ion exchange to remove any residual ammonia. The evaporated and sorbed ammonia is recovered with a strong base to form ammonium sulfate (40 percent by volume). This technology was considered as it recovers the nitrogen which can subsequently be used as a fertilizer.

Despite the ability to recover nitrogen, there are no full-scale municipal installations (piloted in New York, NY). The product demand and market conditions are challenging for nitrogen fertilizers. Commercially available nitrogen fertilizers are affordable and difficult to compete with. Additionally, there is an inherent risk of reliance upon market conditions (Figdore et al., 2010). For these reasons, the technology has yet to gain traction at municipalities.

Physical/Chemical/Biological Nitrogen Removal

The physical, chemical, and biological nitrogen removal technology evaluated was Zeolite/Anammox. The technology relies on zeolite serving as a medium to adsorb ammonium and biofilm growth. A biofilm rich with anammox and AOBs coats the zeolite, and as the zeolite adsorbs ammonium the biofilm continuously regenerates the zeolite by converting the adsorbed ammonium to nitrogen gas.

There are currently no full-scale installations, but the technology has several on-going piloting efforts in the Bay Area (Union Sanitary District, Oro Loma Sanitary District, Central Contra Costa Sanitary District, and San Francisco Public Utilities Commission).

Similar to the Nitrogen Removal 3.0 deammonification technologies, Zeolite/Anammox does not require supplemental alkalinity or an external carbon source. The technology has simpler controls as it is self-regulating and it requires less mechanically intensive equipment than other Nitrogen Removal 3.0 deammonification technologies.

The key data gaps that need to be addressed before the technology can transition from emerging to innovative are the following:

- A more robust database with nitrogen loading rates and performance data. Preliminary data from Oro Loma suggests a nitrogen loading rate of 0.35 kg N/m^3/day which is within the same magnitude of most existing deammonification installations.
- Cost estimation and comparison to typical deammonification technologies. The cost of zeolite is known and it varies based on economies of scale. The cost to engineer, design, and construct is still unclear at this stage. It is anticipated to be more affordable than other deammonification technologies as there is less specialized equipment.
- Full-scale installations

Next Steps

The next steps under this EPA Regional Grant are as follows:

- Compile and analyze on-going piloting results
- Identify BACWA POTWs that are candidates for sidestream treatment
- Estimate potential nitrogen load reductions to each sub-embayment of the San Francisco Bay if all the candidates implemented sidestream treatment
- Perform a planning level cost estimate for BACWA POTWs that are candidates for sidestream treatment

While preparing this literature review, participating BACWA member agencies have hosted several pilots: Nitrogen Removal 3.0 deammonification technologies, CANDO, and Zeolite/Anammox. The piloting results will be compiled as data is received.

A questionnaire was sent to BACWA members that had a series of questions to identify BACWA POTWs that are candidates for sidestream treatment. As part of the questionnaire, data was requested to estimate potential nitrogen load reductions for POTWs that are candidates for sidestream treatment. The nitrogen load reduction considers both current and permitted capacity conditions.

A planning level cost estimate will be provided for each POTW that is a candidate for sidestream treatment. Each POTW will have the option of receiving a Nitrogen Removal 1.0 or 3.0 planning level cost estimate (plants discretion).

If the science-based Nutrient Numeric Endpoints (NNE) results support nutrient load reductions to San Francisco Bay, information gathered, generated, analyzed, and disseminated under this EPA Regional Grant can be used by BACWA members to assist in their decision making on whether to implement sidestream treatment.

References

Ali, M, Chai, L-Y., Tang, C-J., Zheng, P., Min, X-B., Yang, Z-H., Xiong, L. and Song, Y-X. The Increasing Interest of ANAMMOX Research in China: Bacteria, Process Development, and Application. BioMed Research International, Hindawi Publishing Corporation, 134914:1-22.

Al-Omari, A., Han, M., Wett, B., Dockett, N., Stinson, B., Okogi, S., Bott, C. and Murthy, S. (2012). Main-stream deammonification evaluation at Blue Plains Advanced Wastewater Treatment Plant (AWTP). Proceedings of the Water Environment Federation Annual Conference, 15:1959-1967.

Bowden, G., Stensel, H.D. and Tsuchihashi, R. (2014) Technologies for sidestream nitrogen removal. WERF Nutrient Challenge Report NUTR1R06.

Chen, T., Zheng, P., Tang, C., Wang, S. and Ding, S. (2011) Performance of ANAMMOX-EGSB reactor. Desalination, 278(1-3):281–287.

Christensson, M., Ekström, S., Lemaire, R., Le Vaillant, E., Bundgaard, E., Chauzy, J. and Ekenberg, M. (2011). ANITA™ Mox–A biofarm solution for fast start-up of deammonifying MBBRs. Proceedings of the Water Environment Federation Annual Conference, 18:265-282.

Cirpus, I.E., Geerts, W., Hermans, J.H., Op den Camp, H.J., Strous, M., Kuenen, J.G. and Jetten, M.S. (2006). Challenging protein purification from Anammox bacteria. International yJournal of Biological Macromolecules, 39(1):88-94.

Daigger, G. T., Sanjines, P., Pallansch, K., Sizemore, J., and Wett, B. (2011). Implementation of a full-scale anammox-based facility to treat an anaerobic digestion sidestream at the Alexandria sanitation authority water resource facility. Water Practice and Technology, 6.

Dapena-Mora, A., Fernandez, I., Campos, J. L., Mosquera-Corral, A., Mendez, R., and Jetten, M. S. M. (2007). Evaluation of activity and inhibition effects on anammox process by batch tests based on the nitrogen gas production. Enzyme and Microbial Technology, 40(4):859-865.

Figdore, B., Bowden, G., Bodniewicz, B., Bailey, W., Derminassian, R., Kharkar, S., and Murthy, S. (2010). Impact of thermal hydrolysis solids pretreatment on sidestream treatment process selection at the DC Water Blue Plains AWTP. Proceedings of the Water Environment Federation Annual Conference, 2010(10):5927-5949.

Figdore, B., Bowden, G., Stinson, B., Wett, B., Hell, M., Bailey, W., Carr, J., Der Minassian, R., Murthy, S. (2011). Treatment of dewatering sidestream from a thermal hydrolysis-mesophilic anaerobic digestion process with a single-sludge deammonification process. Proceedings of the Water Environment Federation, WEFTEC 2011: Session 1 through Session 10, (16): 249-264.

Fux, C and Siegrist, H. (2004) Nitrogen removal from sludge digester liquids by nitrification/denitrification or partial nitritation/anammox: environmental and economical considerations. Water Science and Technology, 50(10):19-26.

Gao, H., Scherson, Y.D., Wells, G.F. (2014). Towards energy neutral wastewater treatment: methodology and start of the art. Royal Society of Chemistry, 16:1223-1246.

Gu, A. Z., and Onnis-Hayden, A. (2010) Protocol to evaluate alternative external carbon sources for denitrification at full-scale wastewater treatment plants. Water Environment Research Foundation, NUTR1R06b.

Head, M. A., and Oleszkiewicz, J. A. (2004). Bioaugmentation for nitrification at cold temperatures. Water Research, 38(3):523-530.

Hellinga, C., Schellen, A. A. J. C., Mulder, J. W., Van Loosdrecht, M. C. M., and Heijnen, J. J. (1998). The SHARON process: an innovative method for nitrogen removal from ammonium-rich waste water. Water Science and Technology, 37(9):135-142.

Hu, Z., Lotti, T., de Kreuk, M., Kleerebezem, R., van Loosdrecht, M., Kruit, J., ... and Kartal, B. (2013). Nitrogen removal by a nitritation-anammox bioreactor at low temperature. Applied and Environmental Microbiology, 79(8):2807-2812.

Jardin, N. and Hennerkes, J. (2012) Full-scale experience with the deammonification process to treat high strength sludge water -- a case study. Water Science and Technology, 65(3):447-55.

Joss, A., Salzgeber, D., Eugster, J., Kön g, R., Rottermann, K., Burger, S., Fabijan, P., Leumann, S., Mohn, J., Siegrist, H. (2009). Full-scale nitrogen removal from digester liquid with partial nitritation and anammox in one SBR. Environmental Science and Technology, 43(14):5301-5306.

Joss, A., Derlon, N., Cyprien, C., Burger, S., Szivak, I., Traber, J., Morgenroth, E., 2011, Combined nitritation–anammox: advances in understanding process stability. Environmental Science and Technology, 45(22):9735-9742.

Khunjar, W. O., Bilyk, K., Bruton, T., Yi, P., Latimer, R., Pitt, P., & Grandstaff, J. (2013). Use of Free Ammonia and Dissolved Oxygen for Process Control of a Sidestream Deammonification Sequential Batch Reactor. Proceedings of the Water Environment Federation, WEFTEC 2013: 1995-2000.

Khunjar, K. and Fisher, J. (2014). Nutrient Recovery in the Global Water Industry. From the Water Environment Association of Texas (WEAT) 2014 Eckenfelder Lecture Series. Hazen and Sawyer, CH2MHill, and Water Environment Research Foundation.

Klaus, S., Nifong, A., Nelson, A., Rutherford, B., Baumler, R., & Bott, C. (2015). Recommendations and Lessons Learned from the Startup of the First Two Full-Scale

Sidestream Deammonification Processes in North America: DEMON® and ANITA™ Mox. Proceedings of the Water Environment Federation, WEFTEC 2015: 2961-2980.

Klein, A., Ekstrom, L., Summers, A., Wan, J., Wett, B., Johnson, C. and Melcer, H. (2012). Results of the large-scale pilot investigation of the DEMON® nitrogen removal system in Pierce County, Washington. Proceedings of the Water Environment Federation Annual Conference, 2012(17):470-483.

Lackner, S., and Horn, H. (2013). Comparing the performance and operation stability of an SBR and MBBR for single-stage nitritation-anammox treating wastewater with high organic load. Environmental Technology, 34(10):1319-1328.

Lackner, S., Gilbert, E. M., Vlaeminck, S. E., Joss, A., Horn, H., and van Loosdrecht, M. (2014). Full-scale partial nitritation/anammox experiences–An application survey. Water Research, 55:292-303.

Mulder, A., Graaf, A. A., Robertson, L. A., and Kuenen, J. G. (1995). Anaerobic ammonium oxidation discovered in a denitrifying fluidized bed reactor. FEMS Microbiology Ecology, 16(3):177-184.

Munz, G., Szoke, N., and Oleszkiewicz, J. A. (2012). Effect of ammonia oxidizing bacteria (AOB) kinetics on bioaugmentation. Bioresource Technology, 125:88-96.

Neethling, J.B., Bott, C., Bowden, G., Goel, R., Murthy, S., Pramanik, A., Sandino, J., Stensel, D., Tsuchihashi, R. (2014). Deammonification Compendium. Water Environment Research Foundation, NUTR1R06.

Nifong, A., Nelson, A., Johnson, C., and Bott, C. (2013). Performance of a Full-Scale Sidestream DEMON® Deammonification Installation. Proceedings of the Water Environment Federation, WEFTEC 2013: 3686-3709.

Novick, E. and Senn, D. (2014) External nutrient loads to San Francisco Bay. San Francisco Estaurine Institute.

Parker, D. S., and Wanner, J. (2007). Improving nitrification through bioaugmentation. Proceedings of the Water Environment Federation, 2007(2):740-765.

Regmi, P., Miller, M. W., Bunce, R., Hingley, D. M., Kinnear, D., and Deammonification, B. (2012). Nitrogen Removal 3.0: A pilot study to evaluate the feasibility of mainstream deammonification. Proceedings of the Water Environment Federation, 2012(15):1994-2017.

Rosenwinkel, K. H., and Cornelius, A. (2005). Deammonification in the moving-bed process for the treatment of wastewater with high ammonia content. Chemical Engineering and Technology, 28(1):49-52.

Sagberg, P. Ryrfors, P. and Berg, K.G. (2006) 10 Years of operation of an integrated nutrient removal treatment plant: ups and downs. Water Science and Technology, 53 (12):83-90.

Scherson, Y., Woo, S. G., and Criddle, C. S. (2014). Production of nitrous oxide from anaerobic digester centrate and its use as a co-oxidant of biogas to enhance energy recovery. Environmental Science and Technology, 48(10):5612-5619.

Scherson, Y D., Wells, G.F., Woo, S., Lee, J.;Park, J., Cantwellc, B.J., Criddle, C.S. (2012), Nitrogen removal with energy recovery through N2O decomposition. Energy and Environmental Science. 6:241-248.

Stinson, B. (2013) Sidestream Treatment Processes. In Nutrient Treatment Technology Symposium. 2013. San Francisco: Bay Area Clean Water Agencies.

Strous, M., Van Gerven, E., Kuenen, J. G., and Jetten, M. (1997). Effects of aerobic and microaerobic conditions on anaerobic ammonium-oxidizing (anammox) sludge. Applied and Environmental Microbiology, 63(6):2446-2448.

Strous, M., Heijnen, J. J., Kuenen, J. G., and Jetten, M. S. M. (1998). The sequencing batch reactor as a powerful tool for the study of slowly growing anaerobic ammonium-oxidizing microorganisms. Applied Microbiology and Biotechnology, 50(5):589-596.

Tang,C.-J., Zheng, P., Wang, C.-H., Mahmood, Q., Zhang J.-Q., Chen, X.-G., Zhang, L. and Chen, J.-W. (2011) Performance of high-loaded ANAMMOX UASB reactors containing granular sludge. Water Research, 45(1):135–144.

Tchobanoglous, G., Stensel, D., Tsuchihashi, R., Burton, F. (2014). Wastewater Engineering: Treatment and Resource Recovery, 5th Edition. Metcalf and Eddy, AECOM. McGraw-Hill Education.

Tetra Tech, Inc. (2013) Emerging technologies for wastewater treatment and in-plant wet weather management. Prepared for the United States Environmental Protection Agency, EPA 832-R-12-011, Washington, DC.

Tsushima, I., Ogasawara, Y., Kindaichi, T., Satoh, H., and Okabe, S. (2007). Development of high-rate anaerobic ammonium-oxidizing (anammox) biofilm reactors. Water Research, 41(8):1623-1634.

United States Environmental Protection Agency. Sequencing batch reactors for nitrification and nutrient removal. (1992).Office of Water. EPA 832 R-92-002.

Valsami-Jones, E. (Ed.). (2004). Phosphorus in environmental technologies: Principles and applications. IWA Publishing.

Van der Star, W. R., Abma, W. R., Blommers, D., Mulder, J. W., Tokutomi, T., Strous, M., ... and Van Loosdrecht, M. (2007). Startup of reactors for anoxic ammonium oxidation: experiences from the first full-scale anammox reactor in Rotterdam. Water Research, 41(18):4149-4163.

Van Dongen, U. G. J. M., Jetten, M. S., and Van Loosdrecht, M. C. M. (2001). The SHARON®-anammox® process for treatment of ammonium rich wastewater. Water Science and Technology, 44(1):153-160.

Van Hulle, S.W.H., H.J.P. Vandeweyer, B.D. Meesschaert, P.A. Vanrolleghem, P. Dejans, and A. Dumoulin (2010) Engineering aspects and practical application of autotrophic nitrogen removal from nitrogen rich streams. Chemical Engineering Journal, 162(1):1-20.

Wett, B., Omari, A., Podmirseg, S. M., Han, M., Akintayo, O., Brandón, M. G., ... and O'Shaughnessy, M. (2013). Going for mainstream deammonification from bench-to full-scale for maximized resource efficiency. Water Science and Technology, 68(2):283-289.

Water Environment Federation (2010) Biological and Chemical Systems for Nutrient Removal, Special Publication. Water Environment Federation: Alexandria, Virginia.

Wett, B., Buchauer, K., and Fimml, C. (2007, June). Energy self-sufficiency as a feasible concept for wastewater treatment systems. In IWA Leading Edge Technology Conference (pp. 21-24). Singapore: Asian Water.

Wett, B. (2007). Development and implementation of a robust deammonification process. Water Science and Technology, 56(7):81-88.

Wett, B., Murthy, S., Takács, I., Hell, M., Bowden, G., Deur, A., and O'Shaughnessy, M. (2007). Key parameters for control of DEMON deammonification process. Water Practice, 1(5):1-11.

Wett, B., Nyhuis, G., Takács, I., and Murthy, S. (2010). Development of enhanced deammonification selector. Proceedings of the Water Environment Federation, 2010(10):5917-5926.

Wett, B., Jimenez, J. A., Takacs, I., Murthy, S., Bratby, J. R., Holm, N. C., and Ronner-Holm, S. G. E. (2011). Models for nitrification process design: one or two AOB populations?. Water Science and Technology, 64(3), 568-578.

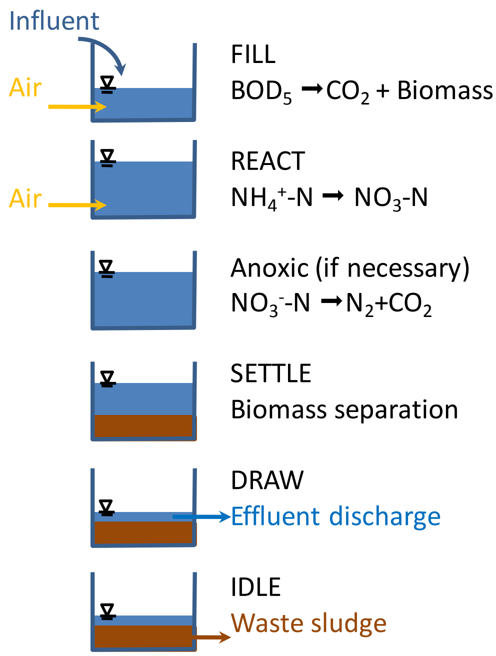
Winkler, M. K., Kleerebezem, R., and Van Loosdrecht, M. C. M. (2012). Integration of anammox into the aerobic granular sludge process for main stream wastewater treatment at ambient temperatures. Water Research, 46(1), 136-144.

Zhang, L., De Schryver, P., De Gusseme, B., De Muynck, W., Boon, N., and Verstraete, W. (2008). Chemical and biological technologies for hydrogen sulfide emission control in sewer systems: a review. Water Research, 42(1), 1-12

Zumbrägel, M., Abma, W.R., Schultz, C.E., Mulder, J.W., van Loosdrecht, M.C.M., van der Star, W.R.L., Strous, M., Tokutomi, T. (2006). Full scale granular sludge ANAMMOX process. In: 6. Aachener Tagung. Stickstoffrückbelastung. Aachen.

Appendix A – Fact Sheets

Nitrifying Sequencing Batch Reactor

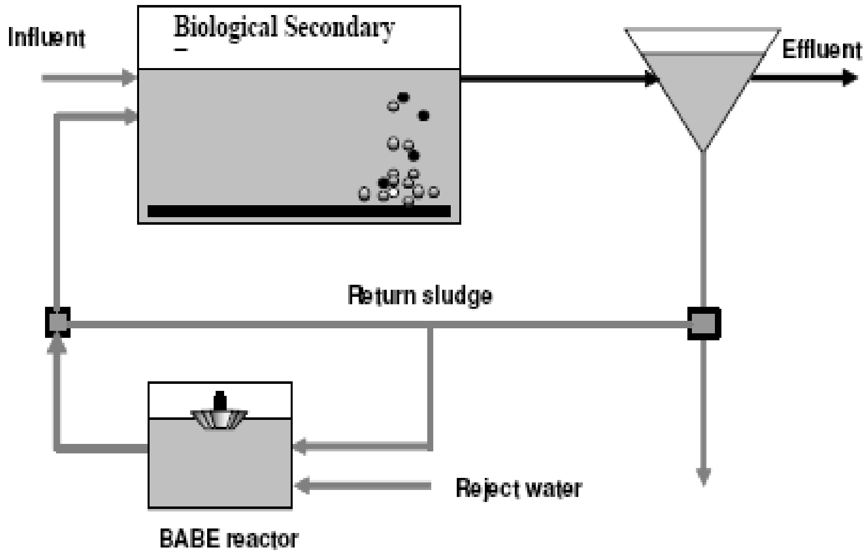


TECHNOLOGY:	NITRIFYING SEQUENCING BATCH REACTOR (NSBR)
DESCRIPTION:	Sequencing batch reactor (SBR) is a fill-and-draw wastewater treatment system, in which a series of conventional activated sludge (CAS) biological treatment steps (i.e., aeration and clarification) are carried out sequentially in the same tank. SBR operation involves Fill, React, Settle, Draw and Idle steps. The React step is typically mixed and aerated. When biological nutrient removal (BNR) is desired, the steps in the cycle are adjusted to provide anoxic or anaerobic periods.
APPLICATION POINTS:	SBR is applicable for both liquid and sidestream
CONSTITUENTS REMOVED:	TSS, BOD, Ammonia, Total Nitrogen, and ortho-Phosphate
DEVELOPMENT STATUS:	Based on EPA survey (1992), there were approximately 170 wastewater treatment facilities in the United States which employ the SBR technology. Approximately 40 of those are operated for BNR. Established technology, mainly small plants.
PERFORMANCE	Completely nitrifies and denitrifies (if carbon source provided and anoxic phase)
RELIABILITY:	Established technology

BENEFITS:	• High operational flexibility and adaptation to changing wastewater loads • Tolerates peak flows and BOD shock loads • Simple to expand or upgrade • No need for return activated sludge pumping and secondary clarifier. • Small footprint
LIMITATIONS:	• Complex instrumentation and control system • Some sludge might be discharged during draw phase. • Solids separation could be problem for sidestream treatment.
PROCESS ADAPTABILITY:	Sidestream or liquid stream applications
PRETREATMENT:	Grit removal, primary treatment, secondary treatment (if use for tertiary treatment). No additional pretreatment for sidestream return flow treatment.
EQUIPMENT:	Mixers, aeration, electrical, controls, pumps, etc.
POTENTIAL FATAL FLAWS	Settleability of treated centrate
FOOTPRINT:	Approximately 6,000 sf/mgd (average) for sidestream
COST:	Operational cost from energy usage: 3-6 kWh/kg-N removed
RESIDUALS:	Waste activated sludge
TYPICAL DESIGN CRITERIA:	<u>Parameter</u> / <u>Units</u> / <u>NSBR</u> Oxygen Required / lb O_2/lb NH_4-N Removed / 4.6 Oxygen Uptake Rate / mg/L/hr / 75 Alkalinity Required / lb Alk as $CaCO_3$/ lb NH_4-N Removed / 7.1 Maintain Alkalinity / mg/L as $CaCO_3$ / 100 Carbon Required[1] / lb COD/lb N Removed / 6.6 Yield / lb VSS/lb N Removed / 1.9 [1] *If acetate used*
O & M CONSIDERATIONS	• Minimize operation and maintenance requirements associated with conventional RAS pumps clarifiers • Process automated to go through aeration/decant cycles • Similar operational effort as activated sludge
VENDORS:	Several (to name a few): Aqua-aerobic®, Siemens®, ABJ®, and others
FACILITIES (to name a few):	Sidestream Applications: Winnipeg, Manitoba – 1.5 mgd centrate flow for Nit/Denit of centrate with biomass used as seed for secondary process; Goddards Green, Southern Water, England – 0.32 mgd (thickening filtrate, digested sludge centrate, and cake storage bays run-off) Newthorpe, Severn Trent Water, England – 0.09 mgd (centrate)
PUBLICATIONS:	United States Environmental Protection Agency. Sequencing Batch Reactors for Nitrification and Nutrient Removal. (1992).Office of Water. EPA 832 R-92-002

	Lackner, S., Gilbert, E. M., Vlaeminck, S. E., Joss, A., Horn, H., & van Loosdrecht, M. (2014). Full-scale partial nitritation/Anammox experiences– An application survey. Water Research, 55:292-303

In Situ Bioaugmentation BABE Process



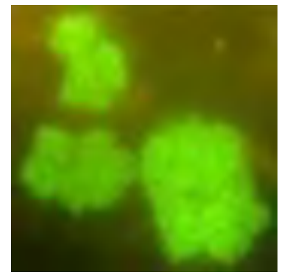


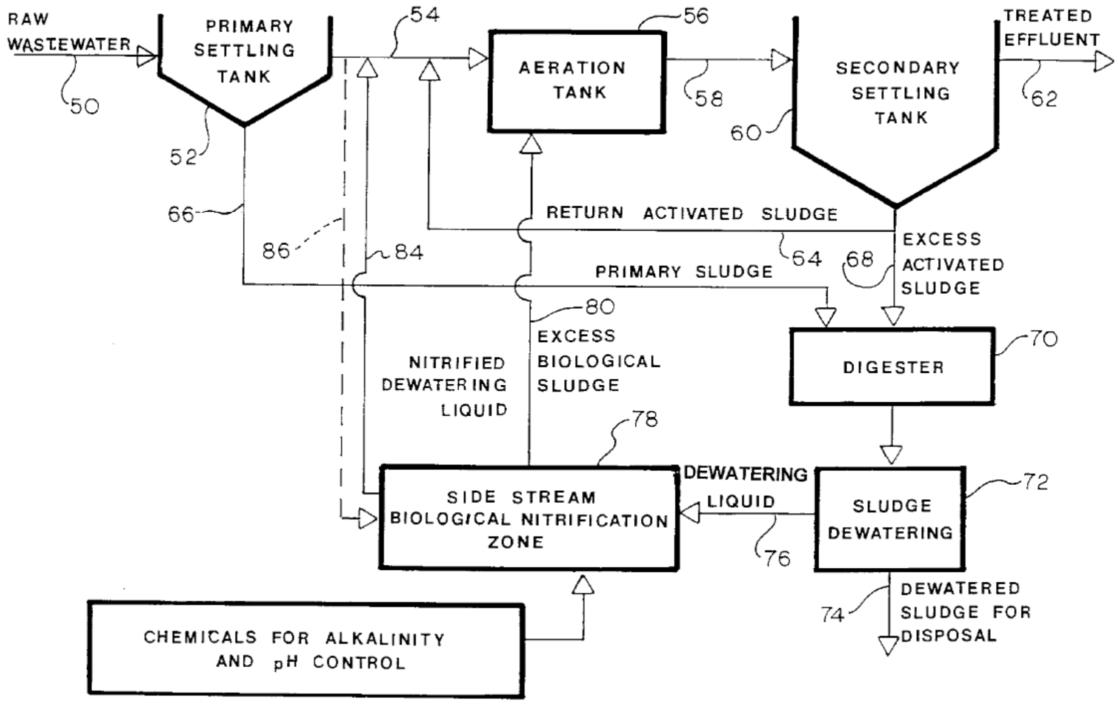
Figure 1. Fluorescently labeled BABE flocs

TECHNOLOGY:	Bio-Augmentation Batch Enhanced (BABE)
DESCRIPTION:	The concept of In Situ Bioaugmentation for nitrification in wastewater treatment involves seeding of the activated sludge reactor with a biological seed to perform a function that would not occur without the seed. In the case of BABE, the centrate return sidestream is combined with a portion of RAS or WAS to perform nitrification and grow nitrifier seed in a sequencing batch reactor. The nitrified BABE effluent contains the nitrifier seed and is returned upstream of the activated sludge process. The added nitrifier seeding enhances the rate of nitrification, allowing for a lower solids retention time (SRT). This is useful for systems with limited tank volume and SRT, which often have this issue of restricted nitrification capacity. Denitrification can also be performed in the BABE reactor if desired by the addition of an external carbon substrate (e.g., Methanol). Otherwise, the nitrified BABE effluent can be denitrified in the initial zone of the activated sludge process. BABE is a proprietary name; several other technologies exist that are slightly different, such as Prenitrification, BAR, and MAUREEN. The Prenitrification process and BAR (Bio-Augmentation Reaeration) entail combining a portion of RAS or WAS plus centrate like BABE, but the processes are flow through. As for MAUREEN (Mainstream Autotrophic Recycle Enabling Enhanced N-removal), the process operates as a plug flow reactor with two stages used for nitrification followed by denitrification.
APPLICATION POINTS:	Solids processing return side-streams and industrial waste streams with high ammonia levels
CONSTITUENTS REMOVED:	Ammonia, Total Nitrogen with carbon addition
DEVELOPMENT	This technology is fully developed, with installations at wastewater treatment

STATUS:	facilities world-wide.
PERFORMANCE (expected):	Greater than 80 percent nitrification of the high-strength side stream.
RELIABILITY:	Stable operation
BENEFITS:	• Reduced volume of main liquid treatment reactors required • Supplemental nitrifying/methylotrophic populations generated to seed the secondary treatment system
LIMITATIONS:	• Limited to return side stream and industrial applications with high ammonia levels • Increase in main stream capacity is a function of the percentage nitrogen load from the side streams • Supplemental Alkalinity (for nitrification) and Carbon (for denitrification) may be needed
PROCESS ADAPTABILITY:	Intercept return stream.
PRETREATMENT:	None
EQUIPMENT:	Tankage, pumps, air, mixers (for anoxic zones, if applicable)
POTENTIAL FATAL FLAWS	
FOOTPRINT	Typically the size of one aeration tank
COST:	
RESIDUALS:	Minimal
TYPICAL DESIGN CRITERIA:	Parameter / Units / BABE Oxygen Required / lb O_2/lb NH_4-N Removed / 4.6 Alkalinity Required / lb Alk as $CaCO_3$/lb NH_4-N Removed / 7.1 Carbon Required[1] / lb COD/lb N Removed / 6.6 Yield / lb VSS/lb N Removed / 1.9 [1] *If acetate used*
O&M CONSIDERATIONS:	• Ability to pump sufficient RAS to the side-stream treatment tank • Chemical addition in the form of alkalinity for nitrification, and supplemental carbon for denitrification
VENDORS:	
FACILITIES:	• New York, NY (In Situ Bioaugmentation): 26th Ward – 85 mgd using centrate combined with RAS for nitrification • Appleton, WI (In Situ Bioaugmentation): 14 mgd facility using filtrate combined with RAS for nitrification • Lincoln, NE (In Situ Bioaugmentation): 13 mgd plant using filtrate combined with RAS for Nit/Denit • Groningen, Netherlands (BABE): First BABE process; 1/3 filtrate mixes with 1/3 RAS for Nit/Denit in SBR
REFERENCES	• Berends D.H.J.G., Hommel B., Claessen V., van der Zandt E. (2005). “First outing for the BABE process”. *Water* 21, April 2005, 36-37.

	• Salem S., Berends D., van Loosdrecht M.C.M. and Heijnen J.J. (2003). Bio-augmentation by nitrification with return sludge. *Wat. Res.* 37(8), pp 1794-1804. • Salem S., Berends D.H.J.B., van der Roest H.F., van der Kuij R.J., van Loosdrecht M.C.M. (2004). Full scale application of the BABE technology . *Wat. Sci. Tech.* 50(7), pp 87-96. • Head, M. A., & Oleszkiewicz, J. A. (2004). Bioaugmentation for nitrification at cold temperatures. Water Research, 38(3), 523-530 • Wett, B., Jimenez, J. A., Takacs, I., Murthy, S., Bratby, J. R., Holm, N. C., & Ronner-Holm, S. G. E. (2011). Models for nitrification process design: one or two AOB populations. Water Science & Technology, 64(3), 568-578 • Parker, D. S., & Wanner, J. (2007). Improving nitrification through bioaugmentation. Proceedings of the Water Environment Federation, 2007(2), 740-765.

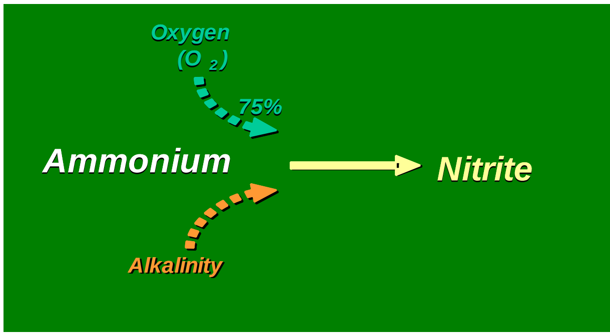
InNitri Process

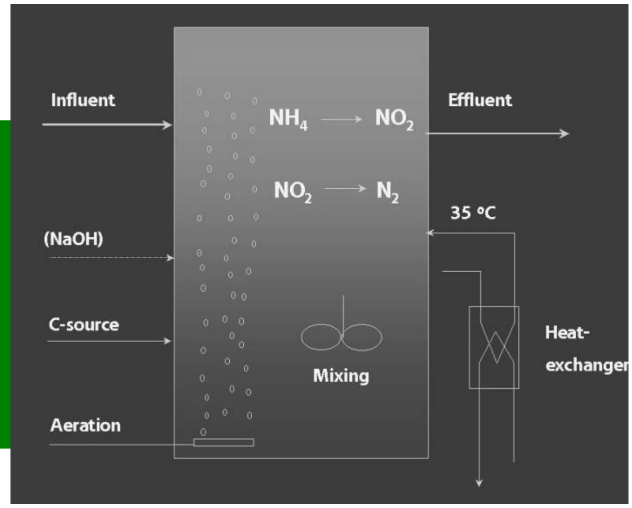


TECHNOLOGY:	INNITRI PROCESS
DESCRIPTION:	The InNitri process is a patented option where sidestream flow is used to grow nitrifiers. The nitrifiers are then used to seed the mainstream nitrification process. The liquid stream basin volume is reduced when seeding with nitrifying biomass introduced by the InNitri process. The InNitri process can be used for cold weather applications to meet effluent ammonia limits under cold weather operations.
APPLICATION POINTS:	Treat side streams to grow nitrifiers use to seed the liquid stream process
CONSTITUENTS REMOVED:	Nitrification of side stream.
DEVELOPMENT STATUS:	The process has very limited installations in the US
PERFORMANCE (expected):	Liquid stream modified to achieve nitrification desired (<1 mg/L NH_4-N).
RELIABILITY:	The process has not been field tested sufficiently to know its reliability.
BENEFITS:	• Independent side stream process is easy to implement • Integrate into existing facilities • Can phase modification to meet effluent targets

LIMITATIONS:	• Few full scale applications. • Influent is not heated (an InNitri claimed benefit)
PROCESS ADAPTABILITY:	Implement as separate treatment unit seeding mainstream nitrification.
PRETREATMENT:	Construct new activated sludge process to treat side streams and grow nitrifiers.
EQUIPMENT:	Biological reactors, clarifiers, blowers, recycle pumps. Modify mainstream treatment for enhanced nitrification.
POTENTIAL FATAL FLAWS	None
FOOTPRINT:	Small
COST:	
RESIDUALS:	None – send to mainstream treatment.
TYPICAL DESIGN CRITERIA	<u>Parameter</u> / <u>Units</u> / <u>InNitri</u> Oxygen Required / lb O_2/lb NH_4-N Removed / 4.6 Alkalinity Required / lb Alk as $CaCO_3$/ lb NH_4-N Removed / 7.1 Carbon Required[1] / lb COD/lb N Removed / 6.6 Yield / lb VSS/lb N Removed / 1.9 [1] *If acetate used*
O&M CONSIDERATIONS:	Operators will operate two treatment plants that are tied together. The INITRI activated sludge will need to have backup to provide continuous seeding to mainstream treatment.
VENDORS:	Sole source provider – M2T technologies.
FACILITIES:	City of Richmond, Virginia- In design (2,850 lb N/day) Tucson, AZ- Demonstration project (2,050 lb N/day)
PUBLICATIONS:	http://www.m2ttech.com/innitri.html

Nitritation Process



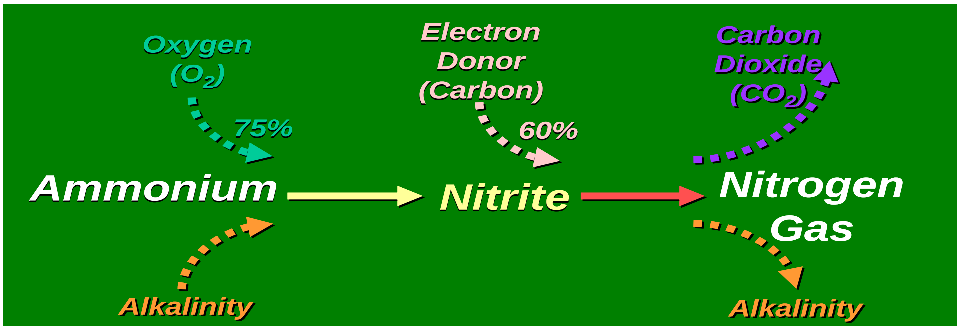


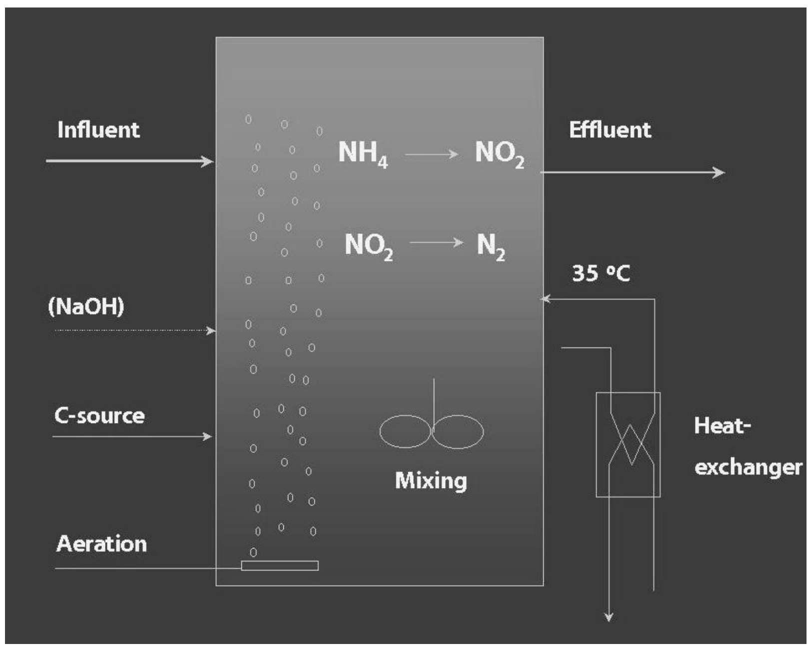
TECHNOLOGY:	Nitritation (Partial Nitrification)
DESCRIPTION:	In the Nitritation process, the ammonia load in the sidestream is partially nitrified to nitrite prior to sending back to the liquid stream. The ammonia oxidation is stopped at the nitrite step by operating the process at an elevated temperature and low SRT. At higher temperatures, the ammonia oxidizers grow faster than the nitrite-oxidizing bacteria. Due to this, the slower-growing nitrite oxidizers are washed out of the system. Depending on the ammonia concentrations in the sidestream being treated and final effluent limitations, the SRT/HRT may range from 1 to 2 days. Nitritation: $NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + H_2O + 2\ H^+$
APPLICATION POINTS:	Separate Centrate Treatment; SSB return
CONSTITUENTS REMOVED:	Ammonia
DEVELOPMENT STATUS:	Widely used in Europe as the first step of SHARON® process and centrate nitrogen removal. New York completed largest SHARON® facility in North America
PERFORMANCE (expected):	Ammonia removal efficiencies from centrate recycle streams of greater than 90 percent have been observed where the influent flow contains ammonia at 600-1000 mg N/L
RELIABILITY:	Proven reliable at smaller scales in Europe; North American data pending
BENEFITS:	• Saves 25percent of the oxygen demand and • Low O&M cost

LIMITATIONS:	• Limited to return side stream • Supplemental alkalinity required to drive the process to full nitritation. Otherwise, the process stops as the pH is depressed to ~6.5. • High capital cost • Patented technology/single source contracting may be a barrier for some municipalities • Operability at large scale unknown
PROCESS ADAPTABILITY:	Flexible process. Partially nitrified effluent can be routed to head of the plant, aeration tanks, or other application points within the plant
PRETREATMENT:	Heat (depends on feed water temperature); Alkalinity; Can accept centrate at a variety of return flow concentrations
EQUIPMENT	• Centrate pumping and controls; • Aerated reactor tanks; • Blowers and process air piping, distribution grid and diffuser; • Heat Exchangers and cooling water pumps; • Alkalinity storage and pumping station; • Electrical power substation (possible)
POTENTIAL FATAL FLAWS	Side stream nitritation only.
FOOTPRINT:	Smaller than conventional bioaugmentation facilities for high-strength waste stream ammonia removal
COST:	• Cost estimated as 1.5 euro/ kg NH4-N removed, or $1/lb of NH4-N (the Netherlands). Used the same cost values as SHARON (nitritation by itself is expected to be cheaper with a smaller basin and no MeOH addition).
RESIDUALS:	Waste activated sludge
TYPICAL DESIGN CRITERIA:	• Operates at temperatures between 30 and 35 degrees Celsius. • HRT may range from 1 to 2 days • pH from 7-8
	<u>Parameter</u> / <u>Units</u> / <u>Nitritation</u> Oxygen Required / lb O_2/lb NH_4-N Removed / 3.4 Carbon Required[1] / lb COD/lb N Removed / 4.5 Yield / lb VSS/lb N Removed / 1.5 Alkalinity Required / lb Alk as $CaCO_3$/lb NH_4-N Removed / 7.1 [1] *If acetate used*
O&M CONSIDERATIONS:	• Good temperature control is necessary • HRT control must be implemented to wash out nitrite oxidizing bacteria
VENDORS:	No vendors for just Nitritation, but for SHARON® Process: M2T – (http://www.m2ttech.com/)
FACILITIES	Ward's Island WPCP, New York City, NY Several installations in Europe
PUBLICATIONS:	• Hellinga, C., Schellen, A.A.J.C., Mulder, J.W., Van Loosdrecht, M.C.M. and Heijnen, J.J. (1998) The SHARON process: an innovative method for nitrogen removal from ammonium-rich waste water. *Wat. Sci. & Technol.* 37, 135-142 • Mulder, J.W., Van Loosdrecht, M.C.M., Hellinga, C., Van Kempen, R.

	(2001) Full-scale application of the SHARON process for treatment of rejection water of digested sludge dewatering. *Water Sci. Technol*. **43**, 127–134 • Bowden, G., Stensel, H.D., and Tsuchihashi, R. (2014) "Technologies for Sidestream Nitrogen Removal" WERF Nutrient Challenge Report NUTR1R06 (in press)

SHARON Process





TECHNOLOGY:	Single Reactor System for High Ammonia Removal over Nitrate (SHARON)
DESCRIPTION:	In the SHARON process, two independent reactions occur: i) nitritation and ii) denitritation with nitrite as the electron acceptor. The ammonia oxidation is stopped at the nitrite step by operating the process at an elevated temperature and low SRT. At higher temperatures, the ammonia oxidizers grow faster than the nitrite-oxidizing bacteria. Due to this, the slower-growing nitrite oxidizers are washed out of the system. Methanol is added as a carbon source to fuel the process. Depending on the ammonia concentrations in the sidestream being treated and final effluent limitations, the SRT/HRT may range from 1 to 2 days. The stoichiometric equations governing SHARON® are: Nitritation: $NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + H_2O + 2\ H^+$ Denitritation: $NO_2^- + 0.5\ CH_3OH \rightarrow 0.5\ N_2 + 0.5\ CO_2 + 0.5\ H_2O + OH^-$
APPLICATION POINTS:	Separate Centrate Treatment; SSB Return
CONSTITUENTS REMOVED:	Nitrogen
DEVELOPMENT STATUS:	Widely used in Europe, New York completed largest facility in North America; The technology is overlooked these days for Nitrogen Removal 3.0 deammonification technologies.
PERFORMANCE (expected):	Ammonia removal efficiencies from centrate recycle streams of greater than 90 percent have been observed where the influent flow contains ammonia at 600-1000 mg N/L. Total Nitrogen removals of 80 percent from the centrate recycle stream are expected at the New York City installation at the Wards Island WPCP
RELIABILITY:	Proven reliable at smaller scales in Europe; North American data pending
BENEFITS:	• Saves 33 percent of the oxygen demand and • Uses 40 percent less supplemental carbon for denitrification. • Alkalinity is produced through denitrification. Although some additional alkalinity is still required for nitritation, it is 80-90 percent less of that which is needed when compared to other centrate nitrification processes • Low O&M cost
LIMITATIONS:	• Limited to return side stream • High capital cost • Patented technology/single source contracting may be a barrier for some municipalities • Operability at large scale unknown
PROCESS ADAPTABILITY:	Flexible process. SHARON effluent can be routed to head of the plant, aeration tanks, or other application points within the plant
PRETREATMENT:	Heat (optional depending on feed water temperature) and alkalinity, external carbon source. Can accept centrate at a variety of BRF return flow concentrations

<table>
<tr><td>EQUIPMENT</td><td>

- Centrate pumping and controls;
- Reactor tanks with both aerated and anoxic zones;
- Blowers and process air piping, distribution grid and diffuser;
- Recycle pumps; Mixers for the denitrification zone;
- Heat Exchangers and cooling water pumps;
- Alkalinity storage and pumping station;
- Methanol storage and pumping station;
- Electrical power substation (possible)

</td></tr>
<tr><td>POTENTIAL FATAL FLAWS</td><td></td></tr>
<tr><td>FOOTPRINT:</td><td>Smaller than conventional bioaugmentation facilities for high-strength waste stream nitrogen removal</td></tr>
<tr><td>COST:</td><td>

- Cost estimated as 1.5 euro/ kg N removed, or $1/lb of Nitrogen removed (cost in Netherlands from EPA (2008))

</td></tr>
<tr><td>RESIDUALS:</td><td>NA</td></tr>
<tr><td>TYPICAL DESIGN CRITERIA:</td><td>

- Operates at temperatures between 30 and 35 degrees Celsius.
- HRT may range from 1 to 2 days
- pH from 7-8

<table>
<tr><th>Parameter</th><th>Units</th><th>SHARON®</th></tr>
<tr><td>Oxygen Required</td><td>lb O_2/lb NH_4-N Removed</td><td>3.4</td></tr>
<tr><td>Carbon Required[1]</td><td>lb COD/lb N Removed</td><td>4.5</td></tr>
<tr><td>Yield</td><td>lb VSS/lb N Removed</td><td>1.5</td></tr>
<tr><td>Alkalinity Required</td><td>lb Alk as $CaCO_3$/lb NH_4-N Removed</td><td>7.1</td></tr>
</table>

[1] *If acetate used*

</td></tr>
<tr><td>O&M CONSIDERATIONS:</td><td>

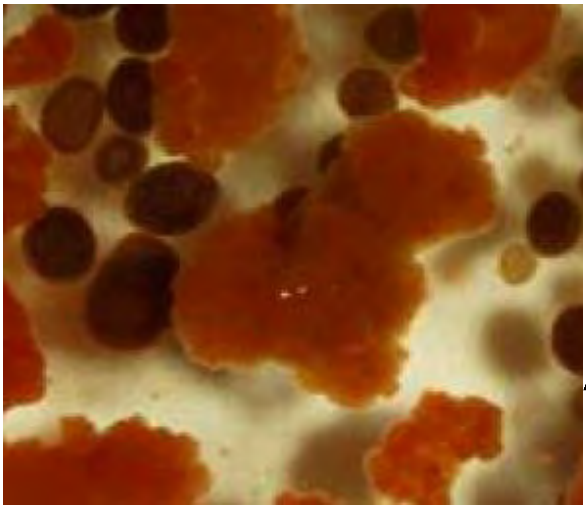
- Good temperature control is necessary
- HRT control must be implemented to wash out nitrite oxidizing bacteria

</td></tr>
<tr><td>VENDORS:</td><td>SHARON Process: M2T – (http://www.m2ttech.com/)
Grontmij Consulting Engineers</td></tr>
<tr><td>FACILITIES</td><td>Ward's Island WPCP, New York City, NY
Several installations in Europe</td></tr>
<tr><td>PUBLICATIONS:</td><td>

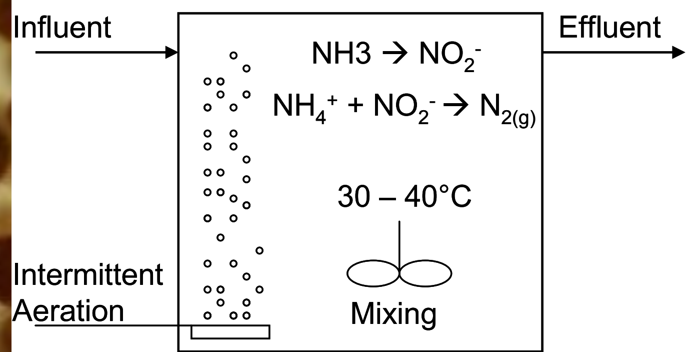
- Hellinga, C., Schellen, A.A.J.C., Mulder, J.W., Van Loosdrecht, M.C.M. and Heijnen, J.J. (1998) The SHARON process: an innovative method for nitrogen removal from ammonium-rich waste water. *Wat. Sci. & Technol.* 37, 135-142
- Mulder, J.W., Van Loosdrecht, M.C.M., Hellinga, C., Van Kempen, R. (2001) Full-scale application of the SHARON process for treatment of rejection water of digested sludge dewatering. *Water Sci. Technol*. **43**, 127–134
- Bowden, G., Stensel, H.D., and Tsuchihashi, R. (2014) "Technologies for Sidestream Nitrogen Removal" WERF Nutrient Challenge Report NUTR1R06 (in press)
- USEPA (2008) Wastewater Technology Fact Sheet- Side Stream Nutrient Removal

</td></tr>
</table>

Deammonification



Anammox Granulates (Photos by Paque Engr)



Anammox Schematic as a Sequencing Batch Reactor (SBR)

Anammox Granulate Samples Olburgen, NL

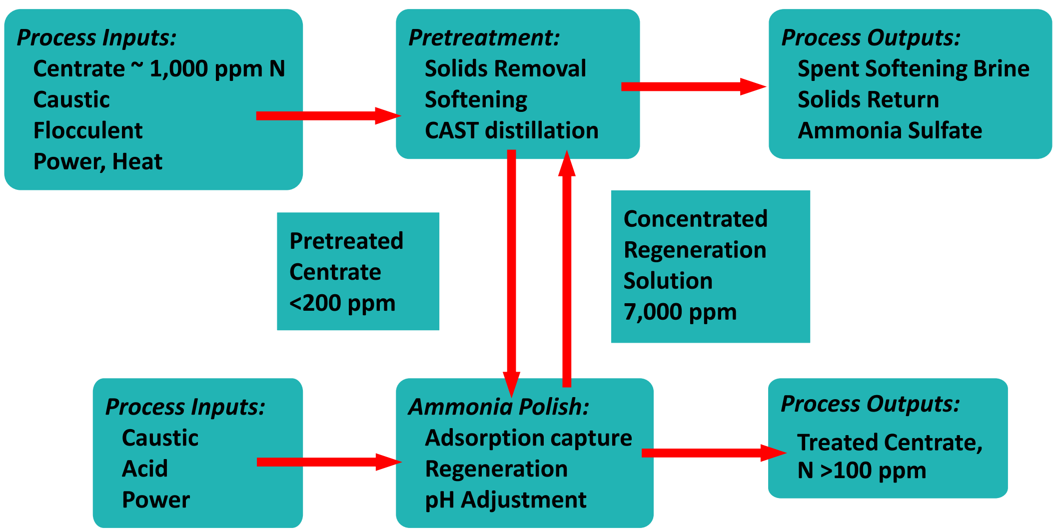
On top of Anammox Reactor of Olburgen WWTP

TECHNOLOGY:	Deammonification
DESCRIPTION:	The single stage process consists of two primary biological reactions: i) nitritation and ii) Anammox. Roughly 50 percent of the ammonia is converted to nitrite (nitritation), whereby the remaining ammonia/nitrite is converted to nitrogen gas by Anammox bacteria that use the ammonia and nitrite as the electron donor and acceptor, respectively. The reactor temperature should be 36°C to ensure partial nitrification and the reaction is governed by pH. Additionally, external carbon source is not required unless the ratio of ammonia/nitrite is less than desired for Anammox. $NH_4^+ + 1.32NO_2^- + 0.066HCO_3^- + 0.13H^+ \rightarrow 1.02N_{2(g)} + 0.26NO_3^- + 0.066CH_2O_{0.5}N_{0.15} + 2.03H_2O$ Anammox bacteria produce an exorbitant amount of extracellular polymeric substance that facilitates the formation of granular sludge (see floc images above) or attach to carrier media. Deammonification processes differ in terms of the method to grow and retain the anammox bacteria, number of stages, the configuration of the process, and control strategies implemented. Configurations include granular sludge reactors (ANNAMOX® single and two-step), suspended growth sequencing batch reactors (SBRs) (DEMON®, ClearGreen®, SBR EAWAG), moving bed biofilm reactors (ANITA^{TM}Mox, DeAmmon® and Terra-N®, and rotating biological contactors.
APPLICATION POINTS:	Solids processing return side-streams and industrial waste streams with high ammonia levels
CONSTITUENTS REMOVED:	Nitrogen
DEVELOPMENT STATUS:	The SHARON®/Anammox Process was originally developed at Delft University (Netherlands). Paques Engineering acquired the worldwide license in 1999. The first full-scale SHARON®/ANAMMOX® (two-stage) facility was commissioned in 2002 at Rotterdam Dokhaven WWTP in the Netherlands. Technology has evolved significantly since its first installation. The latest design features a single stage ANAMMOX®, making the dual stage process obsolete. As of 2014, over 100 full scale and pilot scale implementations of this technology exist. Most of these are in Europe and Asia (about 12 units are under design/construction in the U.S.).
PERFORMANCE (expected):	Greater than 80 percent nitrogen removal in the return side stream
RELIABILITY:	Plots from SCADA systems at Rotterdam and Olburgen, NL indicate stable operation and high levels of nitrogen removal (~80 percent).
BENEFITS:	• No external C-source required • Power consumption reduced by ~ 60 percent • CO_2 emission reduced by ~ 90 percent • Limited production of excess sludge • Compact • Good settling characteristic of granulate sludge • Greenhouse gas emissions are less than conventional BNR: greater than 4.7 ton CO_2/ton N versus 0.7 ton CO_2/ton N with SHARON®/ANAMMOX® (Stowa, 2001).

<table>
<tr><td>LIMITATIONS:</td><td>Limited to return side stream and industrial applications with high ammonia levels with proper alkalinity:ammonium molar ratios and pH close to neutral.</td></tr>
<tr><td>PROCESS ADAPTABILITY:</td><td>Intercept return stream and supply unit</td></tr>
<tr><td>PRETREATMENT:</td><td>• Additional heating may be required to raise water temperature</td></tr>
<tr><td>EQUIPMENT:</td><td>Tankage, pumps, air (SHARON step), mixers, heat exchangers, plumb heat source</td></tr>
<tr><td>POTENTIAL FATAL FLAWS AT SRWTP</td><td>• Molar ratio $HCO_3^-:NH_4^+$ (1.1:1) (Hellinga et al.., 1998)
• Ability to achieve 20-30 percent ammonia reduction</td></tr>
<tr><td>FOOTPRINT</td><td>Depends on process configuration, smallest footprint is for the attached growth reactors</td></tr>
<tr><td>COST:</td><td>Construction and operating costs are very site and technology specific</td></tr>
<tr><td>RESIDUALS:</td><td>Minimal due to exceptionally low yield (0.05 kg VSS/kg N)</td></tr>
<tr><td>TYPICAL DESIGN CRITERIA:</td><td>
<table>
<tr><th>Parameter</th><th>Units</th><th>Deammonification</th></tr>
<tr><td>Design Temperature</td><td>°C</td><td>36</td></tr>
<tr><td>HRT</td><td>hr</td><td>4 – 6</td></tr>
<tr><td>SRT</td><td>d</td><td>Depends on process control strategy (nitritation: 1 – 2 d; Anammox strain: >30 d)</td></tr>
<tr><td>Reactor Depth</td><td>ft</td><td>20 – 40</td></tr>
<tr><td>$N\text{-}NH_4$ Loading</td><td>kg N/m^3/d</td><td>0.3 – 7 (Technology Specific)</td></tr>
<tr><td>Oxygen Demand</td><td>lb O_2/lb NH4-N Removed</td><td>1.8</td></tr>
<tr><td>Carbon Required</td><td>lb COD/lb N Removed</td><td>0.0</td></tr>
<tr><td>Yield</td><td>lb VSS/lb N</td><td>0.1</td></tr>
<tr><td>Alkalinity Required</td><td>lb Alk as CaCO3/lb NH4-N Removed</td><td>3.6</td></tr>
</table>
[1] If acetate used</td></tr>
<tr><td>O&M CONSIDERATIONS:</td><td>• Reactor start-up issues (Anammox growth doubling rate 11 to 16 d)
• Molar ratio $HCO_3^-:NH_4^+$ (1.1:1) (Hellinga et al.., 1998)
• Ability to HEAT influent stream to 36°C (if necessary)
• Protozoan grazers can significantly reduce partial nitrification rates (Stowa, 1996a)
• Nitrite bleed through upon introduction into liquid stream
• Maintaining Anammox bacteria that are exceptionally slow-growers (11 to 16 d doubling rate)</td></tr>
<tr><td>VENDORS:</td><td>World Water Works – () DEMON®
M2T – (http://www.m2ttech.com/) SHARON®
Paques - (http://www.paques.nl/?pid=46&parentid=41) Anammox®
AnoxKaldnes –(http://www.anoxkaldnes.com/news-resources/technology-information/anita-mox.htm) ANITA™ Mox</td></tr>
</table>

	Grontmij- (http://www.grontmij.com/DEMON) DEMON® Degremont-(http://www.degremont-technologies.com/dgtech.php?article1084) Cleargreen™ HydroThane- (http://www.hydrothane-stp.com/DeAmmon-nitrogen-removal.php) DeAmmon®
FACILITIES:	York River Plant, HRSD - DEMON®, 525 lb N/d James River Plant, HRSD – ANITA™Mox, 560 lb N/d DC Water DEMON® (Under Construction) >25,000 lb N/d China has several large ANNAMOX® installations >20,000 lb N/d Numerous installations throughout Europe
• PUBLICATIONS:	• Jardin N, Hennerkes J. (2012) Full-scale experience with the deammonification process to treat high strength sludge water -- a case study. Water Sci Technol. 65(3):447-55 • Jaroszynski LW, Oleszkiewicz JA. (2011) "Autotrophic ammonium removal from reject water: partial nitrification and anammox in one-reactor versus two-reactor systems". Environ. Technol. 32(3-4):289-94 • Hellinga, C., Schellen, A.A.J.C., Mulder, J.W., Van Loosdrecht, M.C.M. and Heijnen, J.J. (1998) The SHARON process: an innovative method for nitrogen removal from ammonium-rich waste water. Wat. Sci. & Technol. 37, 135-142 • Jetten, M.S.M., Strous, M. Van de Pas-Schoonen, K.T., Schalk, J., Van Dongen, L.G.J.M., Van de Graaf, A.A., Logemann, S., Muyzer, G., Van Loosdrecht, M.C.M. and Kuenen, J.G. (1999) The anaerobic oxidation of ammonium. FEMS Microbiol. Rev. 22, 421-437. • STOWA (1996a) One-reactor system for ammonium removal via nitrite. Report no 96-01. STOWA, Utrecht, The Netherlands. ISBN 90 74476 39 2. • STOWA (1996b) Removal of ammonium from sludge water with the Anammox process. Feasibility study. Report no 96-21. STOWA, Utrecht, The Netherlands. ISBN 90 74476 55 4. • STOWA (2001) The combined Sharon/Anammox process. Report no 2000-25. STOWA, Utrecht, The Netherlands. ISBN 90 5773 104 5. • van Dongen, U., M.S.M. Jetten and M.C.M. van Loosdrecht (2001) The SHARON®-Anammox® process for treatment of ammonium rich wastewater. Water Sci. Technol. 44 (44) 153-160. • van der Star, W.R.L., Miclea, A.I., van Dongen, U.G.J.M., Muyzer, G., Picioreanu, C., van Loosdrecht, M.C.M. (2008) The membrane bioreactor: A novel tool to grow Anammox bacteria as free cell. Biotechnol. & Bioengr., 101, 286-294 • Wett, B. (2007) “Development and implementation of a robust deammonification process.” Water Science & Technology, 56 (7) 81-88. • Wett, B., S. Murthy, I. Takács, M. Hell, G. Bowden, A. Deur, M. O’Shaughnessy (2007) “Key Parameters for Control of DEMON Deammonification Process” Water Practice 1 (5). • Weissenbacher, N., Takacs, I., Murthy, S., Fuerhacker, M. and Wett, B. (2010) “Gaseous nitrogen and carbon emissions from a full-scale deammonification plant.” Water Environ Res 82(2) 169-175.

Ammonia Recovery Process (Representative ARP Technology Shown)



TECHNOLOGY:	Ammonia recovery via flash vacuum distillation
DESCRIPTION:	In the ARP process, the ammonia load in the sidestream is volatilized, distilled and recovered using an adsorption and regeneration process. Rather than strip out ammonia gas in a stripping tower, the ARP technology mists the stream to increase surface area and applies a vacuum pressure all within an enclosed vessel to draw out the ammonia gas. The physical principles used are (1) partial pressures to separate volatiles and (2) sensible heat of wastewater and high heat recovery to minimize thermal input. Distilled ammonia can be recovered as ammonium sulfate if ammonia vapor is scrubbed with sulfuric acid.
APPLICATION POINTS:	Separate treatment of sludge handling sidestreams (e.g., centrate, filtrate, digestate), leachate, manure wastes and other high ammonia bearing wastewaters
CONSTITUENTS REMOVED:	Ammonia

DEVELOPMENT STATUS:	Not commercialized yet
PERFORMANCE (expected):	• ≥80% ammonia nitrogen removal • Vacuum distillation to ~ 100 mg/L NH3-N • Ion exchange polishing to < 100 mg/L NH3-N
RELIABILITY:	There are no full-scale municipal installations on which to base reliability of performance.
BENEFITS:	• Most effective on wastewaters with high NH3-N (> 1000 mg/L) • Chemical process not prone to biological upsets • Can recover ammonia as a marketable fertilizer (ammonium sulfate) • May require less chemical input than some biological treatment alternatives
LIMITATIONS:	• Several pilot studies have been performed but the process has not been commercialized yet. • Different operating skills required compared to typical wastewater treatment operation skills
PROCESS ADAPTABILITY:	Flexible process. Pre-treated sidestream (<200 mg/L NH3-N) can be routed to head of the plant, aeration tanks, or other application points within the plant or polished for recovery of ammonium sulfate fertilizer.
PRETREATMENT:	Removal of suspended solids and precipitates (depending on feed water characteristics)
EQUIPMENT	• ARP vessels (vacuum still) • Ion exchange process (CAST®) feed tank • CAST® vessels
POTENTIAL FATAL FLAWS	How to distribute the recovered product
FOOTPRINT:	Much smaller than upgrading existing facilities to handle high-strength waste stream ammonia removal; also smaller than SHARON process.
COST:	• Thermo Energy 2010 capital cost estimate for a 100,000 gpd facility treating CFAO wastewater (500 to 1000 mg/L NH3-N) = $1 M. • Municipal application for 1.2 MGD sludge dewatering centrate - $12.5 M, 7000 sq ft building
RESIDUALS:	Spent softening brine; solids return; ammonium sulfate fertilizer
TYPICAL DESIGN CRITERIA:	• Strong base load dependent on feed water characteristics (feed water sample send to vendor to perform testing) • Feed 90-120°F • Process operating temperature 150-180°F • Distillate ~50°F • Vacuum of 26 to 29 inches • pH 10 to 12
O&M CONSIDERATIONS:	• Operating costs of $0.54 to $0.86 per lb nitrogen recovered
VENDORS:	ThermoEnergy® Corporation
FACILITIES	Pilot for New York City 26th Ward WPCP
PUBLICATIONS:	Limited to conference and marketing presentations

Zeolite-Anammox Process

TECHNOLOGY:	Zeolite-anammox (Total Inorganic Nitrogen Removal)
DESCRIPTION:	The zeolite-anammox process nitrifies approximately half the ammonia load in the influent to nitrite; then the nitrite is combined with the unused influent ammonium by anammox bacteria to form nitrogen gas and water. The symbiotic relationship between the nitrifiers and anammox is natural and largely self-regulating. (The system does not require continuous monitoring of D.O. and nitrite concentrations typical in other anammox systems). The system works most efficiently when ammonia and nitrite are balanced, but the DNRA ability of anammox can reduce excess nitrate back to nitrite. Temperature is important for determining treatment efficiency and retention time. For applications treating side-streams, typical retention times are 12 to 36hrs, depending on influent ammonia concentrations and final effluent limitations. The simplified equation is: $NH_4 + NO_2 \rightarrow N_2 + 2H_2O$
APPLICATION POINTS:	High strength side-stream; Mainstream; Water reuse.
CONSTITUENTS REMOVED:	Ammonia
DEVELOPMENT STATUS:	Treatments using zeolite, and treatments using anammox, both established for over 20 years. Combinations of zeolite and anammox operating since 2010.
PERFORMANCE (expected):	Ammonia removal efficiencies from centrate and filtrate recycle streams of 80% are readily achievable. Better than 99% removal from mainstream and water re-use is also readily achievable. Removal proportion directly linked to detention time.
RELIABILITY:	Fixed film reactor is very robust, and largely self-regulating. Clogging can be a concern, but easily addressed by appropriate design and operating procedures.

BENEFITS:	• Capital investment and infrastructure costs cut up to 50%. • Oxygen demand cut up to 66%. • Largely self-regulated → low O&M costs.
LIMITATIONS:	• Removal of ammonia. • Patented technology/single source contracting may be a barrier for some municipalities. • Operability at large scale unknown. • Footprint may be larger than competitors.
PROCESS ADAPTABILITY:	Flexible process.
PRETREATMENT:	Removal of suspended solids and precipitates (depending on feed water characteristics)
EQUIPMENT (SIDE-STREAMS)	• Centrate pumping and controls; • Aerated reactor tanks; • Blowers and process air piping, distribution grid and diffuser; • Heat Exchangers and cooling water pumps; • Alkalinity storage and pumping station; • Electrical power substation (possible)
POTENTIAL FATAL FLAWS	None
FOOTPRINT:	May require larger volume than other short-cut nitrogen removal technologies – depending on selected infrastructure (tall steel tanks → small footprint; lined earth berms → large footprint).
COST:	• Pending.
RESIDUALS:	NA
TYPICAL DESIGN CRITERIA:	Sidestreams: Operates at temperatures between 30 and 35 degrees Celsius; HRT may range from 1 to 2 days; pH from 7-8. Liquid stream: Ambient temperatures; HRT may range from 1 to 2 days; pH from 7-8. Volumetric Loading Rate: 0.35 kg $N/m^3/d$ (Oro Loma Sanitary District)
O&M CONSIDERATIONS:	• Control influent TSS
VENDORS:	Patent held by Collison Engineering. OLSD marketing bio-zeolite.
FACILITIES	Several pilot plants and small systems in Northern California
PUBLICATIONS:	• N/A

CANDO for Nitrogen Removal and Energy Recovery

The oupled erobic anoxic ecomposition peration CANDO) s a new astewater reatment process that removes and recovers energy from ammonia (NH_4^+) nitrogen in wastewater. The process consists of three steps: (1) NH_4^+ oxidation to nitrite (NO_2) in a bioreactor; (2) NO_2 reduction to nitrous oxide (N_2O) gas in a bioreactor; (3) N_2O conversion to N_2 with energy recovery through biogas combustion with N_2O as the oxidant.

Step 2 is the novel step in CANDO. Step 1 is demonstrated full scale by the SHARON process (NH_4^+ oxidation to NO_2) and Step 3 is well established in automotive and propulsion applications. Step 2 has been demonstrated in a bench scale system that treats anaerobic digester centrate at Delta Diablo in Antioch, CA. This system achieved >95% conversion of NH_4^+ to NO_2 (Step 1) and 75 80% conversion of NO_2 to N_2O (Step 2).

CANDO systems at Delta Diablo: bench-scale (left), pilot-scale (right).

A pilot scale CANDO system is being evaluated at Delta Diablo. The system will convert NH_4^+ in centrate to N_2O at a flow rate of approximately 300 gallons per day.

As compared to conventional nitrification denitrification, CANDO is expected to reduce oxygen requirements, reduce biomass production, recover energy from nitrogen, and possibly remove and recover phosphorus. As compared to other nitrogen short circuit processes, namely nitritation anammox, CANDO is expected to offer benefits with respect to process stability, operational simplicity, shorter solids residence time, and resistance to upsets and inhibition. The pilot study underway will evaluate these potential benefits.

If successfully scaled up, CANDO can be an attractive process for nitrogen removal with energy recovery from municipal anaerobic digesters, privately operated anaerobic digesters on farms, and landfill leachate.

APPENDIX B – QAPP AUDIT SUMMARY

APPENDIX B – QAPP AUDIT SUMMARY

The Project QA Manager developed the template at the end of this Appendix to conduct audits during the project when testing was being performed. The template contains relevant requirements from the QAPP after an extensive review of requirements. The template was presented to each site prior to performing audits at the test sites.

The Project QA Manager from EBMUD conducted audits at EBMUD, OLSD, and SFPUC. The audits were conducted when active processes were in place within the study timeframe. After each audit, the Project QA Manager notified the site of the audit results. Any deficiencies noted were corrected by the sites and follow-up documentation was sent to the Project QA Manager at EBMUD. No formal audit has been performed at DD. A site visit to DD was conducted by the Project QA Manager to familiarize the site with the QAPP expectations, but no formal audit was performed since much of the data was unavailable and being held by a third party at that time.

Audit records are maintained by EBMUD on its network.

The following pages contain the audit form developed to support the project.

EPA SIDESTREAM NUTRIENT REMOVAL PROJECT
GRANT NO. 99T07401
QUALITY ASSURANCE/QUALITY CONTROL AUDIT FORM

Auditor: ______________________________ **Date:** ______________________________

Test Site: ____ EBMUD (EB) - audit every 2 months ____SFPUC (SF) - audit every 2 months
____ Delta Diablo (DD) - audit monthly ____Oro Loma (OL) - audit quarterly

Audit Description

Requirement	QAPP Page	Y	N	NA	Comments
Field Review					
Spot check field sampling procedures (container cleanliness/labeling, sampling techniques)	30 (EB) 44 (SF) 58 (DD) 70 (OL)				
Check instrument testing, inspection, maintenance, calibration done per QAPP.	32 (EB) 45 (SF) 60 (DD) 73 (OL)				
Verify test kit results for NO2, NO3, NH3 with split samples sent to lab bimonthly. (EB)	31 (EB)				
Verify pH, DO, temp sensors to handheld meter (EB, OL)	31 (EB) 71 (OL)				
Verify loading-related measurements for site are recorded properly (EB, OL)	31 (EB) 71 (OL)				
Verify use of SOPs for sample collection and field sampling equipment works properly. (SF,DD)	44 (SF) 58 (DD)				
Verify NO2, NO3, NH3 field measurements are compared to specified secondary method. (DD)	59-60 (DD)				
Documentation Review					
Test site maintains logbook including daily flows, changes in batch feed, on-site instrument calibration info and other process parameters.	20				
Test site maintains documents below on a network or system with back-up capability:					
a. Field logbook (electronic)	19,20				
b. Excel file (or equivalent) with raw data	19,20				
c. Data analyses (charts, graphs, etc.)	19,21				
d. Laboratory reports (including COC, QA, and results)	19,21				

Requirement	QAPP Page	Y	N	NA	Comments
e. QA/QC reports by test site QAOs	19,21				
Verify calculations in Excel (or equivalent) are hand checked/verified (once in beginning, once in end of project).	32 (EB) 45 (SF) 60 (DD) 71 (OL)				
Review raw data trends in spreadsheet to identify errors.	30 (EB) 44 (SF) 58(DD) 70(OL)				
Sites follow the assessment and correction procedure to address any findings in audits (Figure C-1, page 75 of QAPP)	75				
Daily walkthroughs are conducted using checklist in QAPP (DD only)	62 (DD)				
At least one blind duplicate field sample to measure critical analytes at laboratory is analyzed and reported with test data.	16				
Laboratory Review					
Critical analytes being analyzed by labs with current accreditation (ELAP certification).	17				
Lab QAO has audited laboratory QA for project.	74				
Lab QA Manual and/or SOPs are up-to-date.	74-75				
Corrections made if findings are identified in Lab assessments.	75				

Recommendations:

APPENDIX C – SIDESTREAM TABLE BY BAY AREA WWTP

Nitrogen Load Reduction Potential to San Francisco Bay If Sidestream Treatment Is Implemented at All Candidate Plants (If Ammonia Is the Reduction Objective)

Plant Name	Subembayment	Current Discharge					Current Sidestream				Candidate for Sidestream if Ammonia Load Reduction is the Objective	Sidestream Load Reduction Potential (if implemented)		Load Reduction Potential		Discharge (if Implemented)	
		Flow mgd	Ammonia lb N/d	Total N lb N/d	Ammonia mg N/L	Total N mg N/L	Flow mgd	Ammonia*** mg N/L	Ammonia lb N/d	Total N lb N/d		Ammonia lb N/d	Total N lb N/d	Ammonia %	Total N %	Ammonia mg N/L	Total N mg N/L
American Canyon	San Pablo Bay	1.4	7	141	1	12	0.0000		*	*	Not a Candidate	0	0	0%	0%	1	12
Benicia	San Pablo Bay	2.1	406	496	24	29	0.0120	675	68	66	Deammonification	61	54	15%	11%	20	26
Burlingame	South Bay	2.9	598	954	24	39	0.0972	220	178	272	Conventional Nitrification	160	142	27%	15%	18	33
CCCSD	Suisun Bay	35.1	7,607	9,016	26	31	0.0000		*	*	Not a Candidate	0	0	0%	0%	26	31
CMSA	Central Bay	7.1	1,561	2,105	26	35	0.0561	931	436	465	Deammonification	392	348	25%	17%	20	29
Delta Diablo	Suisun Bay	6.9	1,780	3,350	31	58	0.0650	1,263	685	849	Deammonification	616	548	35%	16%	20	49
DSRSD **	South Bay	9.1	2,250	2,645	30	35	0.0000	233	*	*	Not a Candidate	0	0	0%	0%	30	35
EBMUD	Central Bay	55.3	18,636	23,114	40	50	0.6700	1,208	6,749	9,686	Deammonification	6,074	5,399	33%	23%	27	38
Fairfield-Suisun	Suisun Bay	12.8	4	2,642	0	25	0.0706	906	*	*	Not a Candidate	0	0	0%	0%	0	25
Hayward **	South Bay	10.3	2,208	2,791	26	32	0.1250	615	641	886	Conventional Nitrification	577	513	26%	18%	19	26
Las Gallinas	San Pablo Bay	1.4	33	362	3	32	0.0150	415	*	*	Not a Candidate	0	0	0%	0%	3	32
Livermore **	South Bay	4.3	1,610	1,711	45	48	0.0550	988	453	887	Deammonification	408	363	25%	21%	34	38
Millbrae	South Bay	1.5	527	608	42	48	0.0137	662	88	90	Conventional Nitrification	79	70	15%	12%	35	43
Mt View	Suisun Bay	1.3	5	276	1	26	0.0082	379	*	*	Not a Candidate	0	0	0%	0%	1	26
Napa	San Pablo Bay	5.2	46	479	1	11	0.0237	513	*	*	Not a Candidate	0	0	0%	0%	1	11
Novato	San Pablo Bay	3.1	23	353	1	14	0.0000	884	*	*	Not a Candidate	0	0	0%	0%	1	14
Oro Loma/Castro Valley **	South Bay	11.2	2,997	3,523	32	38	0.1250	906	944	2,016	Deammonification	850	756	28%	21%	23	30
Palo Alto	Lower South Bay	20.5	33	5,203	0	30	0.0000		*	*	Not a Candidate	0	0	0%	0%	0	30
Petaluma	San Pablo Bay	3.5	10	86	0	3	0.0310	1,290	*	*	Not a Candidate	0	0	0%	0%	0	3
Pinole	San Pablo Bay	2.5	486	727	23	34	0.0100	2,031	*	*	Not a Candidate	0	0	0%	0%	23	34
Richmond **	Central Bay	6.4	1,474	1,552	28	29	0.0226		156	240	Deammonification	140	125	10%	8%	25	27
Rodeo	San Pablo Bay	0.6	11	78	2	16	0.0133	502	*	*	Not a Candidate	0	0	0%	0%	2	16
SFO Airport	South Bay	1.1	398	415	43	45	0.0135	1,647	*	*	Not a Candidate	0	0	0%	0%	43	45
SFPUC Southeast Plant	South Bay	56.9	18,436	21,554	39	45	0.4360	1,263	4,592	5,576	Deammonification	4,132	3,673	22%	17%	30	38
San Jose/Santa Clara	Lower South Bay	85.1	503	11,698	1	16	0.8784	738	*	*	Not a Candidate	0	0	0%	0%	1	16
San Leandro **	South Bay	4.4	1,103	1,297	30	35	0.0295	1,153	284	567	Conventional Nitrification	256	227	23%	18%	23	29
San Mateo	South Bay	10.3	2,707	3,400	31	39	0.0740	804	*	*	Not a Candidate	0	0	0%	0%	31	39
SMCSD	Central Bay	1.3	103	317	9	29	0.0051	409	17	21	Deammonification	16	14	15%	4%	8	28
SASM	Central Bay	2.4	106	516	5	25	0.0073	478	*	*	Not a Candidate	0	0	0%	0%	5	25
SVCW	South Bay	13.0	4,680	4,996	43	46	0.1728	673	969	1,148	Deammonification	872	775	19%	16%	35	39
Sonoma Valley	San Pablo Bay	0.9	2	46	0	6	0.0000		*	*	Not a Candidate	0	0	0%	0%	0	6
South SF	South Bay	8.7	1,801	2,511	25	35	0.0581	1,098	532	1,131	Conventional Nitrification	479	426	27%	17%	18	29
Sunnyvale	Lower South Bay	10.5	322	1,848	4	21	0.0600	434	*	*	Not a Candidate	0	0	0%	0%	4	21
Treasure Island	Central Bay	0.3	11	37	4	14	0.0008	80	*	*	Not a Candidate	0	0	0%	0%	4	14
Union **	South Bay	21.2	5,414	7,282	31	41	0.1440	1,565	1,879	1,879	Deammonification	1,691	1,503	31%	21%	21	33
Vallejo	San Pablo Bay	9.9	1,414	2,231	17	27	0.1440	364	*	*	Not a Candidate	0	0	0%	0%	17	27
West County **	Central Bay	1.9	11	509	1	32	0.1970	371	*	*	Not a Candidate	0	0	0%	0%	1	32
SUM		**433**	**79,326**	**120,872**	**689**	**1,133**	**3.6341**		**18,671**	**25,777**	**16 Candidates**	**16,804**	**14,937**	**21%**	**12%**		

* Sidestream loads not quantified for those deemed not a potential candidate for sidestream treatment

** Values for individual EBDA members and the West County Outfall members are estimates. The sum of each member agency per respective outfall is approximately equal to the 2016 BACWA Group Annual Report.

*** Average of three grab samples from July 2015 sampleing events

Nitrogen Load Reduction Potential to San Francisco Bay If Sidestream Treatment Is Implemented at All Candidate Plants (If Total Nitrogen Is the Reduction Objective)

Plant Name	Subembayment	Current Discharge					Current Sidestream				Sidestream Technology to Consider if Total N Load Reduction is the Objective	Sidestream Load Reduction Potential (if implemented)		Load Reduction Potential		Discharge (if Implemented)	
		Flow mgd	Ammonia lb N/d	Total N lb N/d	Ammonia mg N/L	Total N mg N/L	Flow mgd	Ammonia*** mg N/L	Ammonia lb N/d	Total N lb N/d		Ammonia lb N/d	Total N lb N/d	Ammonia %	Total N %	Ammonia mg N/L	Total N mg N/L
American Canyon	San Pablo Bay	1.4	7	141	1	12	0.0000		*	*	Not a Candidate	0	0	0%	0%	1	12
Benicia	San Pablo Bay	2.1	406	496	24	29	0.0120	675	68	66	Deammonification	61	54	15%	11%	20	26
Burlingame	South Bay	2.9	598	954	24	39	0.0972	220	178	272	Conventional Nitrification	160	142	27%	15%	18	33
CCCSD	Suisun Bay	35.1	7,607	9,016	26	31	0.0000		*	*	Not a Candidate	0	0	0%	0%	26	31
CMSA	Central Bay	7.1	1,561	2,105	26	35	0.0561	931	436	465	Deammonification	392	348	25%	17%	20	29
Delta Diablo	Suisun Bay	6.9	1,780	3,350	31	58	0.0650	1,263	685	849	Deammonification	616	548	35%	16%	20	49
DSRSD **	South Bay	9.1	2,250	2,645	30	35	0.0000	233	*	*	Not a Candidate	0	0	0%	0%	30	35
EBMUD	Central Bay	55.3	18,636	23,114	40	50	0.6700	1,208	6,749	9,686	Deammonification	6,074	5,399	33%	23%	27	38
Fairfield-Suisun	Suisun Bay	12.8	4	2,642	0	25	0.0706	906	534	575	Deammonification	0	427	0%	16%	0	21
Hayward **	South Bay	10.3	2,208	2,791	26	32	0.1250	615	641	886	Conventional Nitrification	577	513	26%	18%	19	26
Las Gallinas	San Pablo Bay	1.4	33	362	3	32	0.0150	415	*	*	Not a Candidate	0	0	0%	0%	3	32
Livermore **	South Bay	4.3	1,610	1,711	45	48	0.0550	988	453	887	Deammonification	408	363	25%	21%	34	38
Millbrae	South Bay	1.5	527	608	42	48	0.0137	662	88	90	Conventional Nitrification	79	70	15%	12%	35	43
Mt View	Suisun Bay	1.3	5	276	1	26	0.0082	379	26	34	Deammonification	0	21	0%	8%	1	24
Napa	San Pablo Bay	5.2	46	479	1	11	0.0237	513	*	*	Not a Candidate	0	0	0%	0%	1	11
Novato	San Pablo Bay	3.1	23	353	1	14	0.0000	884	*	*	Not a Candidate	0	0	0%	0%	1	14
Oro Loma/Castro Valley **	South Bay	11.2	2,997	3,523	32	38	0.1250	906	944	2,016	Deammonification	850	756	28%	21%	23	30
Palo Alto	Lower South Bay	20.5	33	5,203	0	30	0.0000		*	*	Not a Candidate	0	0	0%	0%	0	30
Petaluma	San Pablo Bay	3.5	10	86	0	3	0.0310	1,290	334	870	Deammonification	0	20	0%	23%	0	2
Pinole	San Pablo Bay	2.5	486	727	23	34	0.0100	2,031	169	170	Deammonification	0	136	0%	19%	23	28
Richmond **	Central Bay	6.4	1,474	1,552	28	29	0.0226		156	240	Deammonification	140	125	10%	8%	25	27
Rodeo	San Pablo Bay	0.6	11	78	2	16	0.0133	502	56	67	Deammonification	0	45	0%	57%	2	7
SFO Airport	South Bay	1.1	398	415	43	45	0.0135	1,647	*	*	Not a Candidate	0	0	0%	0%	43	45
SFPUC Southeast Plant	South Bay	56.9	18,436	21,554	39	45	0.4360	1,263	4,592	5,576	Deammonification	4,132	3,673	22%	17%	30	38
San Jose/Santa Clara	Lower South Bay	85.1	503	11,698	1	16	0.8784	738	5,410	9,792	Deammonification	0	4,328	0%	37%	1	10
San Leandro **	South Bay	4.4	1,103	1,297	30	35	0.0295	1,153	284	567	Conventional Nitrification	256	227	23%	18%	23	29
San Mateo	South Bay	10.3	2,707	3,400	31	39	0.0740	804	496	702	Deammonification	0	397	0%	12%	31	35
SMCSD	Central Bay	1.3	103	317	9	29	0.0051	409	17	21	Deammonification	16	14	15%	4%	8	28
SASM	Central Bay	2.4	106	516	5	25	0.0073	478	*	*	Not a Candidate	0	0	0%	0%	5	25
SVCW	South Bay	13.0	4,680	4,996	43	46	0.1728	673	969	1,148	Deammonification	872	775	19%	16%	35	39
Sonoma Valley	San Pablo Bay	0.9	2	46	0	6	0.0000		*	*	Not a Candidate	0	0	0%	0%	0	6
South SF	South Bay	8.7	1,801	2,511	25	35	0.0581	1,098	532	1,131	Conventional Nitrification	479	426	27%	17%	18	29
Sunnyvale	Lower South Bay	10.5	322	1,848	4	21	0.0600	434	217	410	Deammonification	0	174	0%	9%	4	19
Treasure Island	Central Bay	0.3	11	37	4	14	0.0008	80	*	*	Not a Candidate	0	0	0%	0%	4	14
Union **	South Bay	21.2	5,414	7,282	31	41	0.1440	1,565	1,879	1,879	Deammonification	1,691	1,503	31%	21%	21	33
Vallejo	San Pablo Bay	9.9	1,414	2,231	17	27	0.1440	364	*	*	Not a Candidate	0	0	0%	0%	17	27
West County **	Central Bay	1.9	11	509	1	32	0.1970	371	609	865	Conventional Nitrification	0	487	0%	96%	1	1
SUM		**433**	**79,326**	**120,872**	**689**	**1,133**	**3.6341**		**26,521**	**39,263**	**25 Candidates**	**16,804**	**20,970**	**21%**	**17%**		

* Sidestream loads not quantified for those deemed not a potential candidate for sidestream treatment

** Values for individual EBDA members and the West County Outfall members are estimates. The sum of each member agency per respective outfall is approximately equal to the 2016 BACWA Group Annual Report.

*** Average of three grab samples from July 2015 sampleing events

APPENDIX D – EXCEL/BioWin® SIDESTREAM TREATMENT MODEL

APPENDIX E – ADDITIONAL SAN FRANCISCO BAY NUTRIENT MODELING CHARTS

ADDITIONAL NUTRIENT MODEL FIGURES

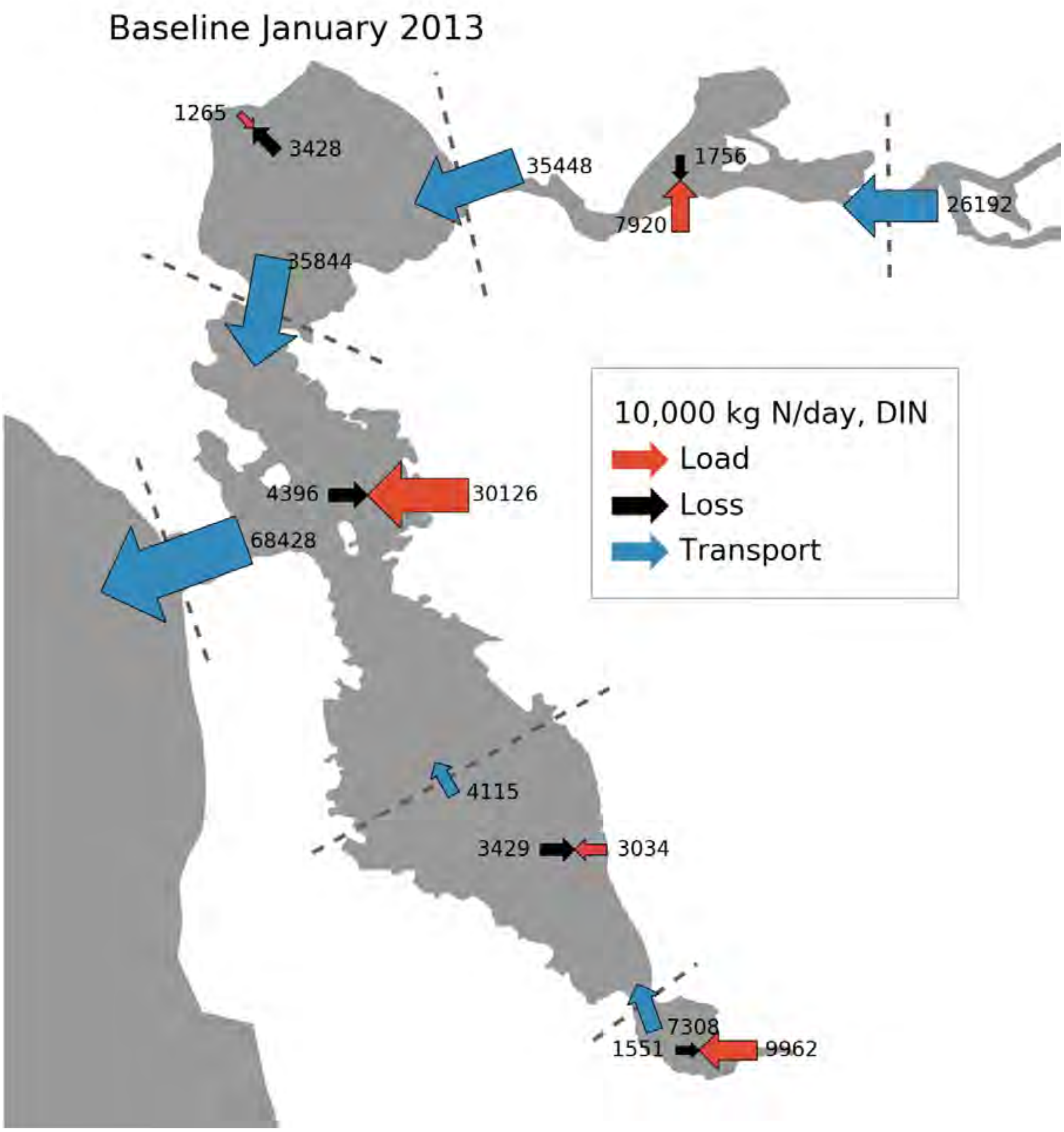


Figure 1. Wet season subembayment DIN fluxes for the baseline loading scenario. Arrows are labeled with average flux in kg N/day, where signs have been omitted to reduce clutter.

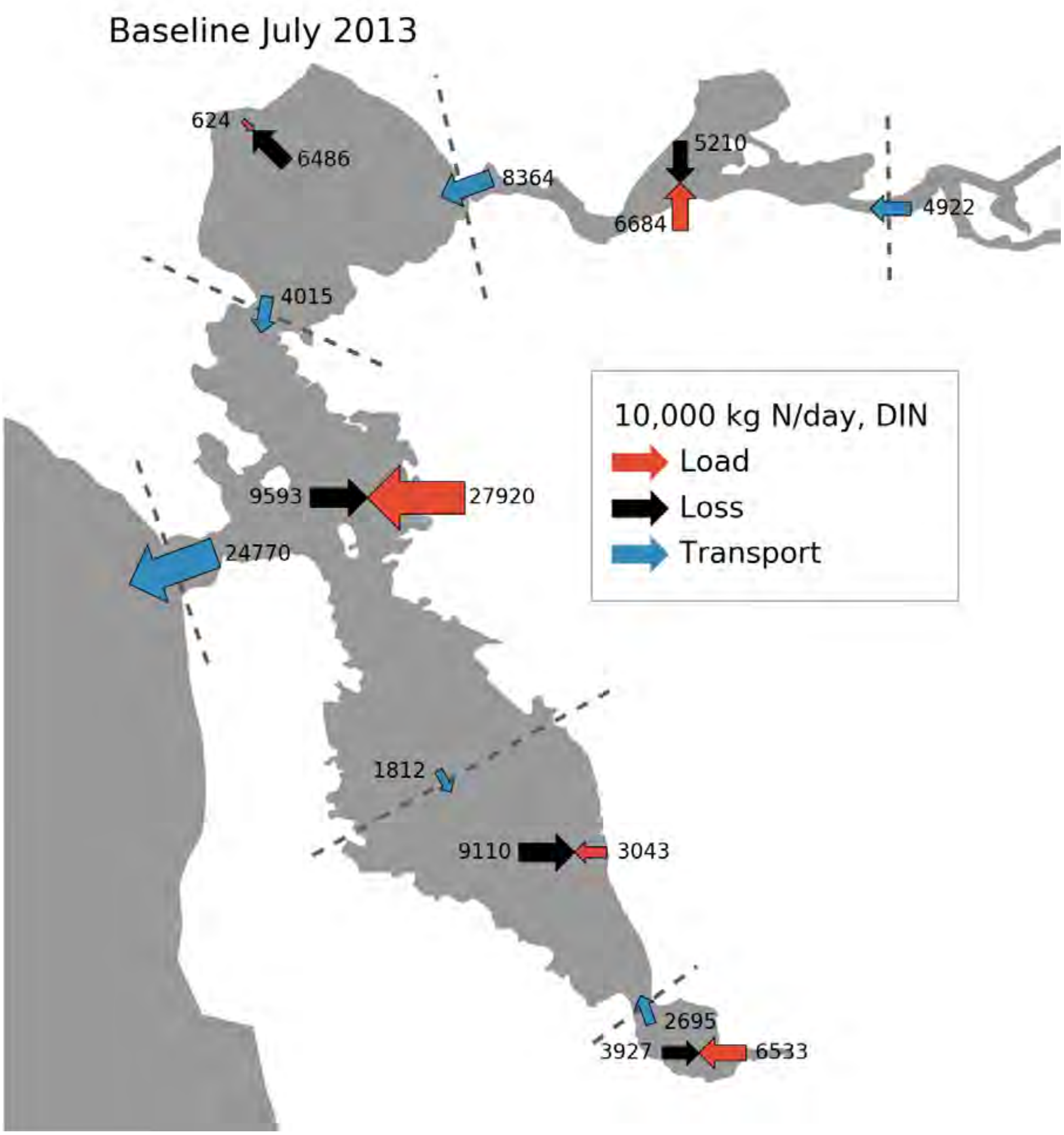


Figure 2. Dry season subembayment DIN fluxes for the baseline loading scenario.

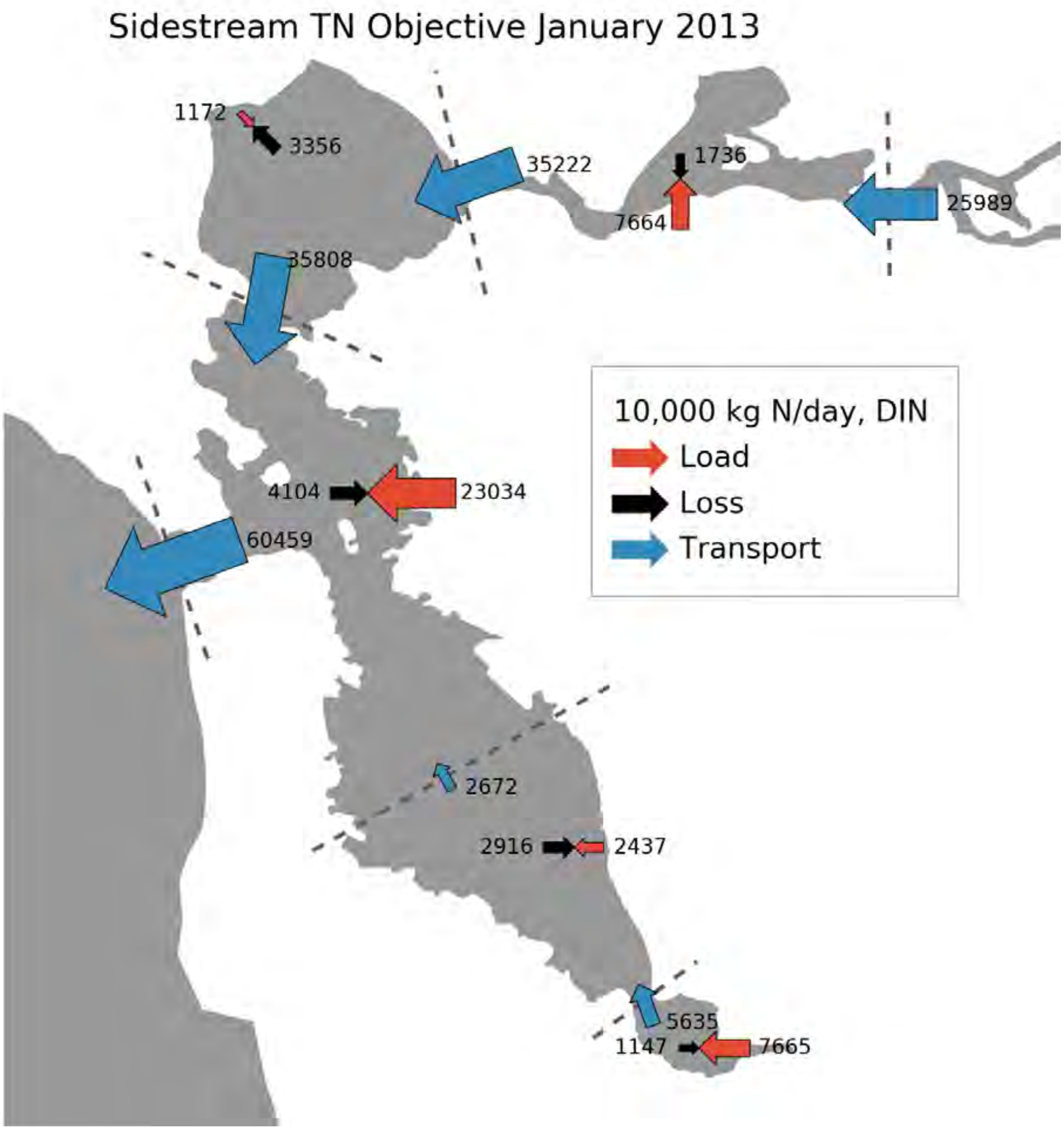


Figure 3. Wet season subembayment DIN fluxes for the TN objective sidestream loading scenario.

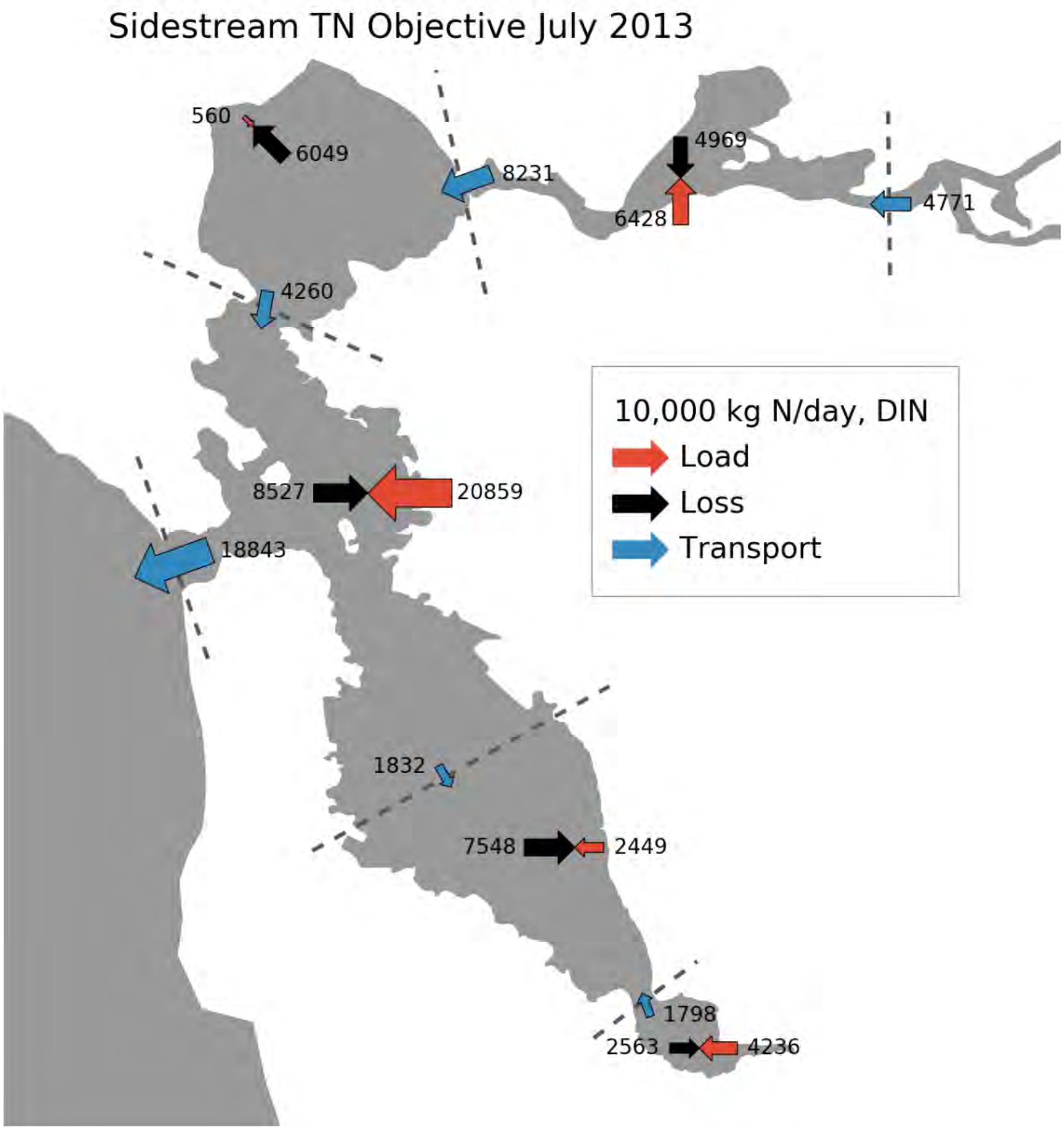


Figure 4. Dry season subembayment DIN fluxes for the TN objective sidestream loading scenario.

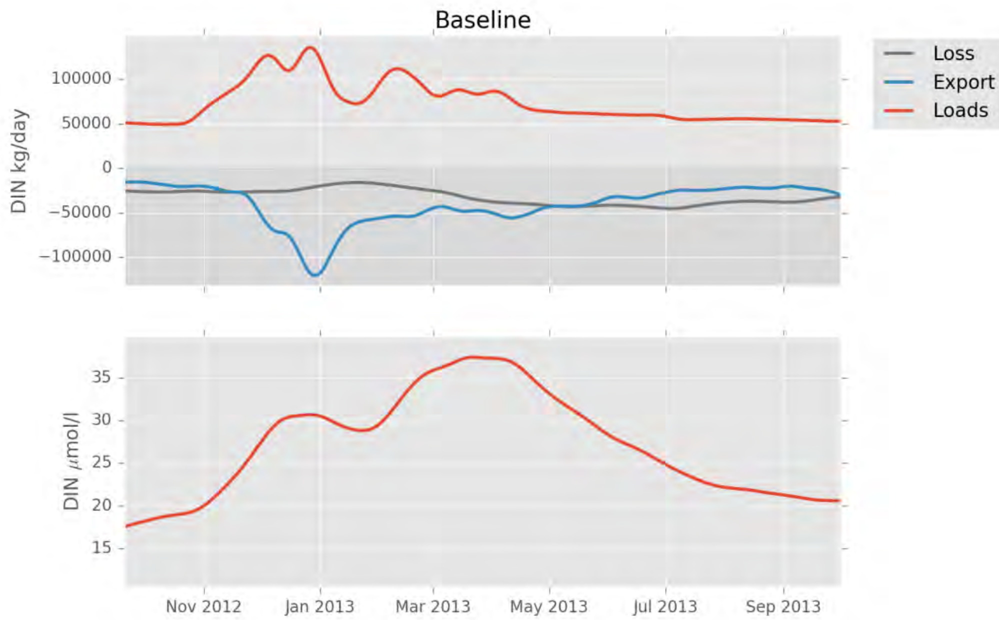


Figure 5. Time series DIN budget for the baseline loading case integrated over the region of the model landward of Golden Gate. The upper panel shows flux terms, including the export of DIN to the coastal ocean, loads from discharges within the bay, and denitrification losses. The lower panel shows the average DIN concentration, integrated across the same region.

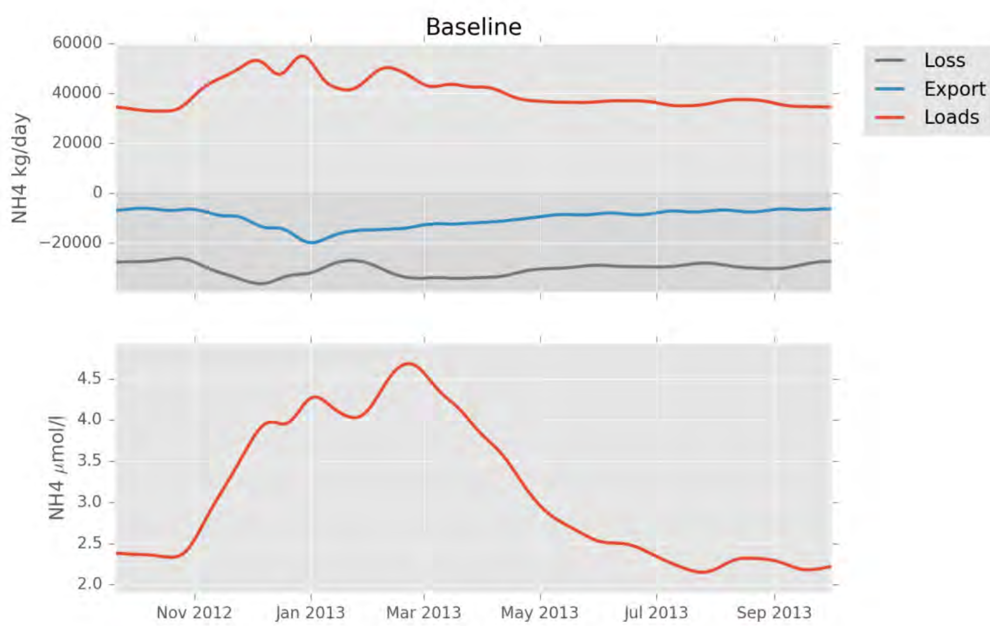


Figure 6. As in figure 5, but showing ammonium fluxes rather than DIN.

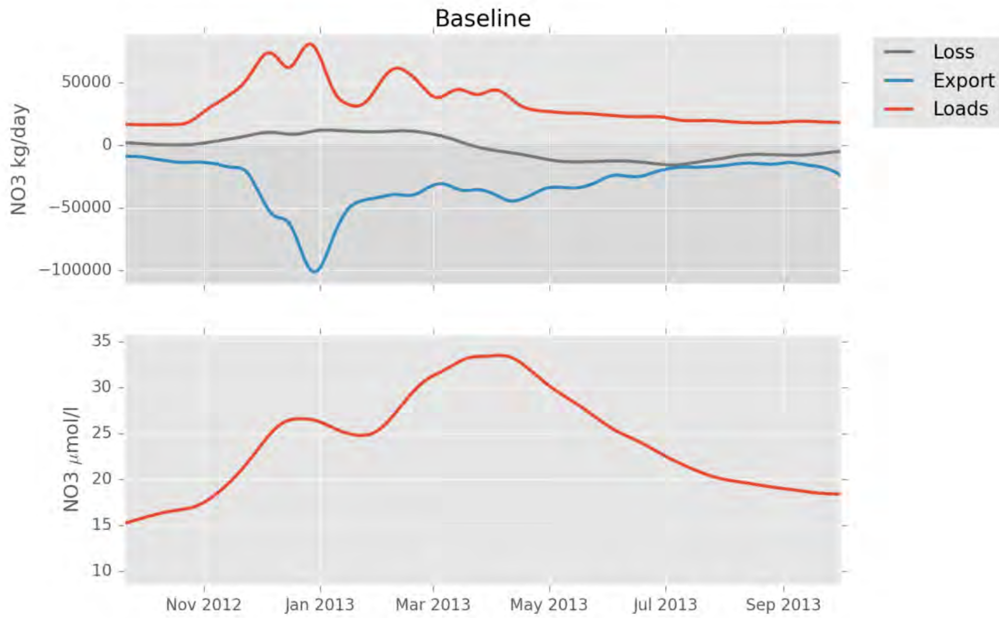


Figure 7. As in figure 5, but showing nitrate fluxes rather than DIN. Losses are the net result of nitrification and denitrification, where a positive loss indicates greater nitrification flux than denitrification flux.

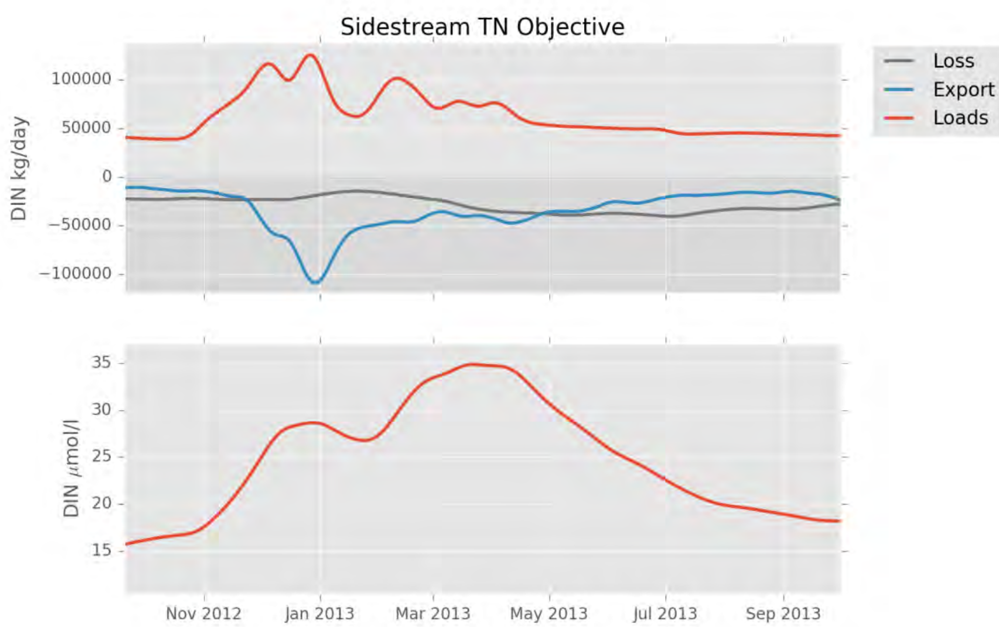


Figure 8. As in figure 5, but showing results from the TN objective loading scenario.

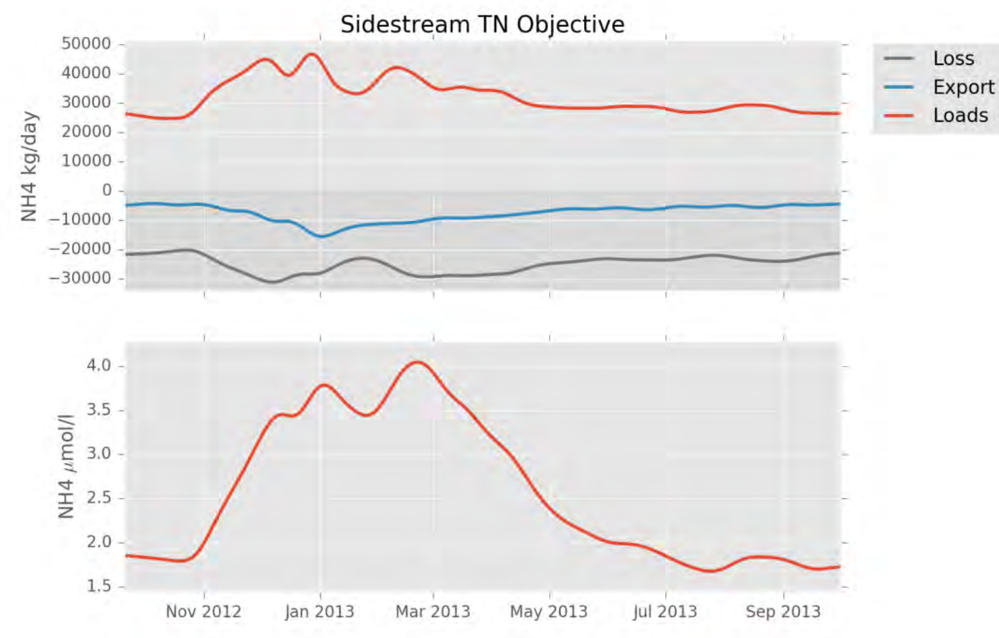


Figure 9. As in figure 5, but showing results from the TN objective loading scenario for ammonium.

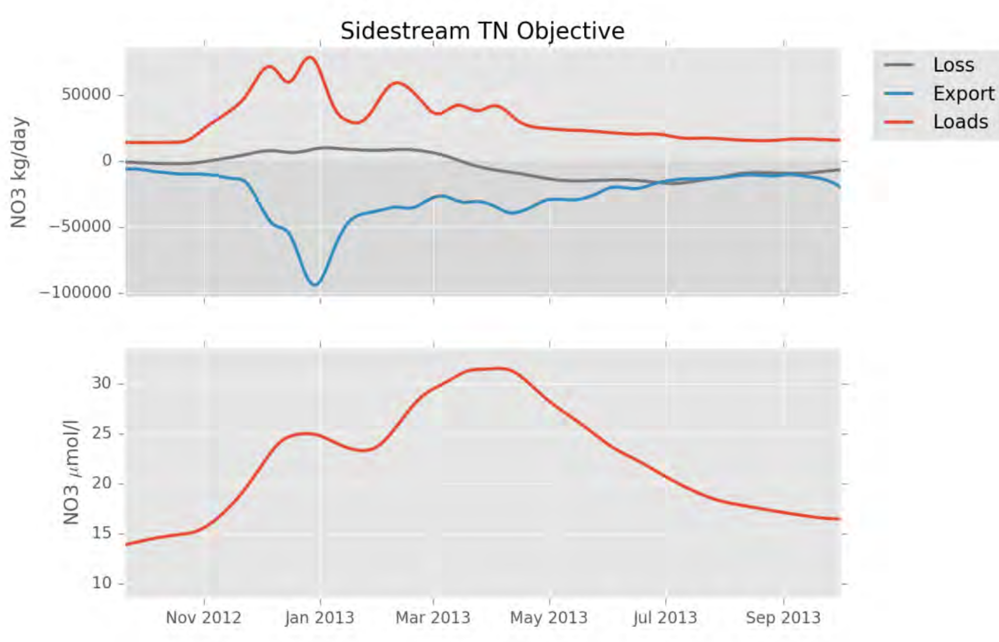


Figure 10. As in figure 5, but showing results from the TN objective loading scenario for nitrate.

APPENDIX F – MEMORANDA ON NUTRIENT TRADING

The Freshwater Trust®

January 30, 2017

Point-to-Point Source Water Quality Trading for Nutrients in the San Francisco Bay

Executive Summary: Assessing the Viability & Mechanics of a Nutrient Credit Trading Program

INTRODUCTION

Water quality trading (WQT) is a market-based Clean Water Act (CWA) compliance alternative that allows for exchanges between dischargers. Under a trading program, sources of nutrient loading may reduce their effluent below a pre-defined baseline and sell the excess reductions to other dischargers to offset effluent loads, thereby achieving compliance with the applicable discharge limits.[1] WQT often represents a more economical and environmentally beneficial alternative than traditional individual facility compliance methods. Large, complex watersheds across the country, notably the Long Island Sound and the Chesapeake Bay, have successfully implemented trading programs and seen meaningful water quality improvements and economic benefits through these flexible compliance solutions.

In light of the potential benefits of nutrient credit trading for wastewater utilities in the San Francisco Bay (the Bay), East Bay Municipal Utility District (EBMUD) enlisted The Freshwater Trust (TFT) to complete a five part evaluation of the viability of point-to-point source nutrient trading in the Bay. The specific tasks provide a foundational understanding of point-to-point source trading, highlight the key trading considerations in the watershed, and recommend advantageous components of a conceptual trading program based on TFT's findings and expertise.

As a result of these analyses, TFT believes that a watershed-based point-to-point source nutrient trading program represents a feasible tool to help dischargers comply with future permit limits while improving the water quality of the Bay in an efficient and cost effective manner. TFT provides several recommendations to reduce the risk and cost of applying a new approach to compliance within the Bay, to help ensure the success of a trading program in a complex environment, and to bolster certainty and predictability for participants.

SUMMARY OF THE FIVE TASKS

These analyses serve to provide a foundation of common language and principles, enabling stakeholders to assess WQT as a potential compliance mechanism for future nutrient discharge limits. Due to the wide range of possible trading structures and mechanisms, TFT formulated each of the five tasks to clarify the potential strengths and weakness of trading in the Bay, as well as the potential mechanisms for implementing such a program. The first task detailed the basic components of point-to-point source trading programs by identifying the regulatory parameters and evaluating notable existing trading programs. The second task assessed the opportunities and challenges facing a potential trading program in the San Francisco Bay. Task Three identified options and considerations for nutrient trading in the Bay, making discrete recommendations about program characteristics. To illustrate the mechanics and advantages of trading, Task Four constructed and analyzed several hypothetical trading scenarios. Lastly, Task Five detailed the potential opportunities for nonpoint source nutrient credit generation, and the mechanisms required to efficiently integrate nonpoint sources into a point-

[1] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. 1608 (Jan. 13, 2003), www.gpo.gov/fdsys/pkg/FR-2003-01-13/pdf/03-620.pdf.

to-point source program. Together, these tasks provide the foundational initial understanding necessary for stakeholders and regulators in the Bay to collaboratively develop the elements of a nutrient trading program that reflects local conditions and needs, if they so choose. The work conducted under these tasks is detailed in memos attached to this document.

AUTHORIZATION FOR TRADING AND BASIC POLICIES

The U.S. Environmental Protection Agency (USEPA) supports the use of WQT programs to achieve NPDES permit compliance for a number of pollutants, including nutrients. However, the USEPA requires trading advance some basic policies: trading should more effectively accomplish regulatory and ecosystem goals, rely on sound science, entail sufficient accountability, and not result in localized water impairments. To further clarify the agency's position on trading, the USEPA issued a comprehensive guidance document detailing the required components of a trading program.[2] Even with the federal guidance, flexibility remains for states to formulate the components of individual WQT programs. California has not issued state rules or guidance on trading, opting instead to develop and approve programs on a case-by-case basis. A number of entities active in trading have also issued informational guidelines to help inform program development.[3]

TOTAL MAXIMUM DAILY LOADS AND WATER QUALITY TRADING

As an initial matter, federal policies require trading programs be based upon and guided by scientifically defensible watershed-based studies. Often, Total Maximum Daily Loads (TMDLs) provide the requisite scientific basis, though other studies can satisfy this need. In the San Francisco Bay, no TMDL has been developed for nutrients. However, the ongoing scientific studies on nutrient pollution, both under the nutrient permit[4] and by other entities,[5] will likely provide the necessary technical support. Importantly, pre-TMDL trading programs have the potential to obviate the need for a TMDL even before water quality issues are remedied, if such a program is reasonably "expected to result in the attainment of an applicable water quality standards[.]"[6]

CHALLENGES & OPPORTUNITIES FOR SAN FRANCISCO BAY NUTRIENT TRADING

A point-to-point source nutrient trading program in the Bay faces some challenges as detailed in Task Two. California lacks regulatory guidance for trading, requiring clarification and approval for a trading program from the Regional Water Quality Control Boards. The legal and financial structure of credits and trading must be defined in the initial stages of trade agreement development. Moreover, at an early stage, the participants must determine a fair allocation of costs for developing and implementing a trading program. These logistical issues aside, the specific trading components need to be collaboratively developed in order to ensure program viability. Otherwise, the risk is that a program will be developed but never used by the intended participants. The transactional risk involved in a trading system (e.g., buyer not paying for credits or seller not generating the credits previously contracted for) may be mitigated through the use of standard contracting mechanisms designed to allocate risk according to the agreement reached in negotiations between the participants to an individual credit trade.

---

[2] U.S. EPA, WATER QUALITY TRADING TOOLKIT FOR PERMIT WRITERS, EPA 833-R-07-004 (Aug. 2007, updated June 2009), *available at* www.epa.gov/npdes/pubs/wqtradingtoolkit.pdf.

[3] *See, e.g.*, ASS'N OF CLEAN WATER ADM'RS & WILLAMETTE P'SHIP, THE WATER QUALITY TRADING TOOLKIT, V1.0 (Aug. 2016); WILLAMETTE P'SHIP & THE FRESHWATER TRUST, DRAFT REGIONAL RECOMMENDATIONS FOR THE PACIFIC NORTHWEST ON WATER QUALITY TRADING (2014); NAT'L NETWORK ON WATER QUALITY TRADING, BUILDING A WATER QUALITY TRADING PROGRAM: OPTIONS & CONSIDERATIONS (2015).

[4] S.F. Bay Reg'l Water Quality Control Bd., Order No. R2-2014-0014, Permit No. CA0038873, Waste Discharge Requirements for Nutrients from Municipal Wastewater Dischargers to San Francisco Bay (Apr. 2014).

[5] *See, e.g.*, Cal. State Water Res. Control Bd., Surface Water Ambient Monitoring Program, Fact Sheet: San Francisco Bay Regional Water Quality Control Board (Mar. 2013); Emily Novick, et al., REG'L MONITORING PROGRAM FOR WATER QUALITY IN THE S.F. BAY: NUTRIENT SCIENCE PROGRAM FY 2015 PROGRESS UPDATE (2016), *available at* http://www.sfei.org/rmp/nutrients.

[6] ERIC MONSCHEIN & LAURIE MANN, U.S. EPA, OFFICE OF WATER, CATEGORY 4B – A REGULATORY ALTERNATIVE TO TMDLS (2007); ERIC MONSCHEIN & SHERA REEMS, CATEGORY 4B – CURRENT NATIONAL STATUS AND TRENDS (2009).

Despite these obstacles, fundamental in any transactional system, considerable opportunity for a trading program exists. The USEPA, State Water Resources Control Board, and the Regional Water Quality Control Board have shown an inclination to support trading as a means to efficiently prioritize facility upgrades. The existing nutrient permit for the Bay also lays the groundwork for a trading program.[7] Furthermore, other trading programs, both in California and nationwide, provide insight into the specific aspects of trading programs that have led to success elsewhere. In particular, the presence of the Bay Area Clean Water Agencies group, which has experience working with the regulators and potential participants, presents a valuable foundation for point source collaboration on a trading program.

PROGRAMMATIC ELEMENTS OF A TRADING PROGRAM

As the Task Three memo details, when designing a trading program, there are two major programmatic decisions. The first is which type of point-to-point source trading model to pursue. In their guidance documents, the EPA identifies three primary models:

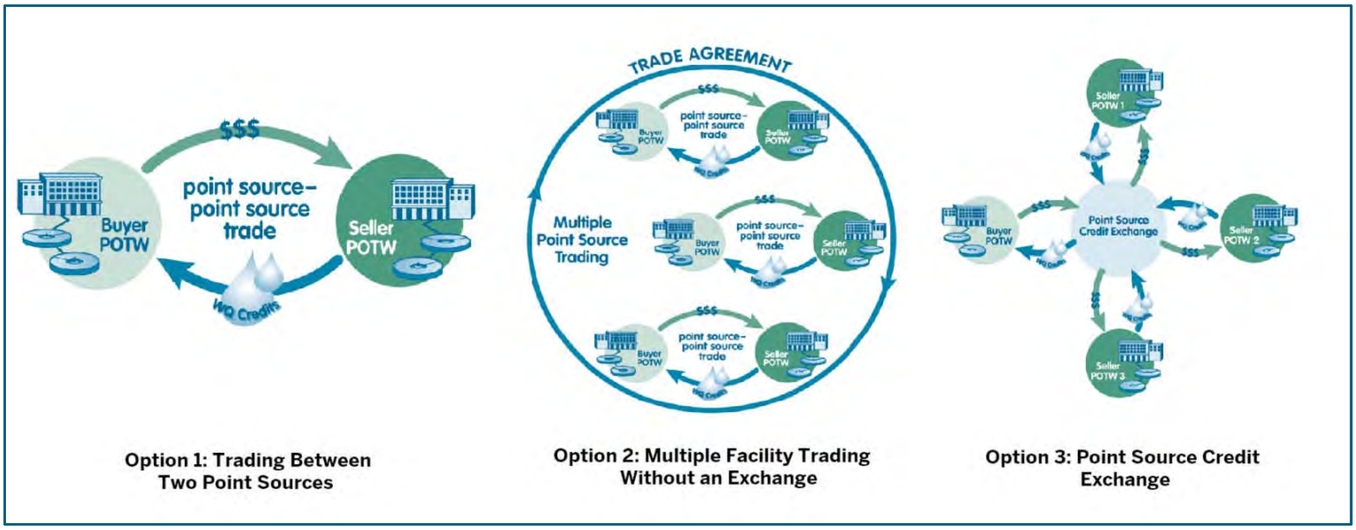


Figure 1. *Three Programmatic Options from the USEPA's Water Quality Trading Toolkit.*

Trading between two point sources provides less certainty for the participants but a great deal of flexibility to design individual trades in a beneficial manner. Multiple facility trading without an exchange has more high-level regulatory guidance and usually relies on an intermediary to facilitate and document trades, thus it is less flexible than peer-to-peer trading but provides a greater level of certainty and replicability. The third option uses a central exchange to serve as an intermediary in credit transactions. This provides the least flexibility for participants and may entail higher administrative costs, but also leads to greater certainty and risk minimization. These are by no means the only options, they simply represent the overarching program structure categories.

The choice of a trading model should be considered in tandem with the second decision, the type of permitting structure. The two major permit options are:

1. **Individual Permit** for all participants that contain the specific terms to govern trading; or
2. **Watershed General Permit** covering all potential trading participants.

Individual permits can be tailored to discharger-specific circumstances, but lack a watershed-based perspective. As each trading participants' individual permit may need to incorporate numerous trading guidance documents, there is great potential for uncertainty and inconsistency between permits given the different renewal dates.

---

[7] The nutrient permit requires dischargers to report nutrient loading in order to "establish baseline loads by subembayment and the potential for nutrient load trading." S.F. Bay Reg'l Water Quality Control Bd., Order No. R2-2014-0014, Permit No. CA0038873, Waste Discharge Requirements for Nutrients from Municipal Wastewater Dischargers to San Francisco Bay, at F-19 (Apr. 2014).

Conversely, a single watershed general permit, especially one that only covers the pollutants eligible for trading, minimizes uncertainty by uniformly addressing trading issues in a single regulatory document for all participants. Furthermore, a single watershed-based general permit often provides greater flexibility, as issuing or amending a general permit in response to new information or other needs is easier than making changes to all individual permits that regulate discharges.

CHARACTERISTICS OF A WATER QUALITY TRADING PROGRAM

The first step in implementing a trading program is to formulate the specific aspects of a trading program. As discussed in both Tasks One and Three, these program components may be included in the CWA permit directly or developed in an independent document that is incorporated in the permit by reference. Regardless of the structure for detailing these mechanisms, formal approval by the Regional Water Quality Control Board will be needed for the specific components and the trading program as a whole.

There are standard elements found in every trading program. For one, a *trading area*—a discrete geographic region that encompasses all trading activities—must be identified. Moreover, for point-to-point source trading the participants must have numeric effluent limits to establish minimum requirements for credit generation. This *baseline* prohibits entities from generating credits unless and until they have satisfied all legal mandates related to water quality. Any reductions beyond the baseline can be credited and sold. It is also necessary to unequivocally define the *credit characteristics*. This explicitly describes the units of trade, usually in rates or mass per unit of time as appropriate to align with the NPDES permit. Based on the units of trade, it is also necessary to define the methodology for quantifying credits and the duration, or lifespan, of the credits.

To account for uncertainty and the attenuation of benefits the EPA requires the adoption of a discount factor, known as a *trading ratio*. Of particular importance, a *credit accounting* methodology and process is needed to ensure that the program entails sufficient accountability and clarity. Overall, these considerations constitute the main elements of a trading program, though other issues may also be resolved in conjunction with these issues in order to provide sufficient certainty and accountability for trading participants.

SPECIFIC RECOMMENDATIONS FOR TRADING PROGRAM COMPONENTS

TFT has several programmatic recommendations that will lead to a trading program that is economically efficient and entails minimal risk. First, TFT recommends that the **existing permitting structure continue to be used**—the watershed nutrient permit applies to all dischargers and future permit iterations could include the required trading language. Furthermore, TFT recommends designing a **Multiple Facility Trading Program *without* a Central Exchange** and collaboratively **developing an overarching Trade Agreement** to provide a single framework for trading. This trade agreement would include all pertinent rules and limitations and would be incorporated into the permit by reference, making it binding on any parties that wish to engage in WQT and lowering risk by providing clarity. Together these recommendations provide simplicity, certainty, and flexibility for participants to design and enter into trades in a manner that best suits the needs of that individual facility.

In order to minimize the risk inherent in trading without a central exchange, TFT also advises the use of a third-party entity to help facilitate the program and individual trades. This third-party facilitator, or broker, would not actively buy and sell credits like a central exchange, but would serve a supporting role for other participants. The broker would prospectively evaluate the credit supply and credit needs of each participant, connecting specific participants where their respective interests are most closely aligned. Those facilities could then contract with one another, negotiating the credit price and other terms of the agreement. This lowers the risk and uncertainty for participants but retains a level of flexibility for parties to enter into bilateral credit contracts that provide them with the greatest benefit at the lowest cost. Such a broker could have as much or as little involvement as the parties desire. If participants wanted assistance, the broker could provide support with transaction documentation, reporting, and credit accounting, thereby providing the objective oversight that minimizes risk. Again, by allowing the individual dischargers to define the level of broker involvement beyond the minimal credit forecasting, the dischargers retain more control than they would with a central exchange—each entity determines their optimal balance of risk and expense for each trade.

In addition to the program structure, TFT has various recommendations on specific components of a nutrient trading program identified in Tasks Three and Five. Although discrete program aspects will be collaboratively developed between stakeholders and the regulators, TFT recommends incorporating the following specific elements into a trade agreement for the Bay:

- **Trading Area** – The trading area for a point-to-point trading program should include the entire San Francisco Bay. To account for uncertainty and the attenuation of water quality benefits between subembayments, trading ratios should be developed for each subembayment.
- **Compliance Period & Credit Duration** – Permit compliance should be determined on an annual basis, with credit duration aligning with this period. While any other durations are allowable, this period of time allows for accurate forecasting of credit supply and demand while minimizing the number of transactions, thereby keeping the cost and risk to a minimum.
- **Reconciliation Period** – In order to make an annual compliance period function properly, a reconciliation period should be used. This is a short period of time, usually a few months, following the end of the annual compliance period to complete all accounting and transact in credits before compliance is formally determined. This gives trading participants some leeway to undertake all transactions once compliance needs are definitively known.
- **Nonpoint Source Restoration Fund** – The creation of a nonpoint source restoration fund should be explored. This type of fund allows dischargers unable to acquire sufficient point source credits to offset their exceedance by paying into the fund, with the money financing nonpoint source nutrient reduction activities. Ideally the trading broker, given its expertise and positioning, would oversee the management of the fund, the implementation of projects, and the necessary ongoing maintenance of the restoration site. This protects against noncompliance, minimizes the risk from credit supply fluctuations, and generates environmental benefits for the watershed.

POTENTIAL MECHANICS OF THE RECOMMENDED TRADING PROGRAM

The envisioned conceptual program would operate through a cooperative process involving the dischargers and a third-party broker. Prior to the establishment of this program, dischargers would likely look for initial trading relationships based on the existing facility upgrade cost data and potential attenuation ratios from the hydrodynamic modeling. Once a full trading program is established, the dischargers that voluntarily opt to participate would first provide the broker with background information (e.g., NPDES permit limit, discharge reports, potential upgrades, etc.). Based on this data, the broker would predict individual and cumulative credit supply and demand for the upcoming compliance cycle and would make recommendations about the most effective upgrades and actions. The broker would maintain ongoing communication with participants to stay apprised of the existing circumstances. At the end of the compliance period, the broker would evaluate the parties' discharge reports to calculate the specific credit supply or need and help to complete the accounting and registration of the credits. Once the credits are validated, the broker would connect individual buyers and sellers so those parties may negotiate the transaction details and enter into a credit contract. Lastly, the broker would assist, if the entities desired, to complete the regulatory documentation prior to the close of the reconciliation period. In the event that an insufficient credit supply existed, the broker, with regulatory approval, would accept payment into the nonpoint source restoration fund to undertake nonpoint source nutrient reduction actions sufficient to offset the discharge. Once all credit transacting is complete, the broker would evaluate the discharge reports to predict credit needs for the next cycle.

CONCLUSION

After reviewing the pertinent issues and considerations, The Freshwater Trust believes that WQT for nutrients in the San Francisco Bay may offer a viable and effective tool to achieve compliance with future effluent limits and best prioritize facility upgrades. Water quality trading represents an alternative to traditional, across-the-board requirements on point sources, providing participants with a greater level of flexibility to efficiently achieve nutrient load reductions collaboratively. This collaboration allows for facilities to realize greater nutrient reductions at a lower cost by working together to implement the most effective and economical upgrades in order to jointly achieve permit compliance.

Table of Contents

The Freshwater Trust®

1. Basics of Point-to-Point Source Water Quality Trading Programs for Compliance with Nutrient Discharge Limits

Task 1: Detailing the Components of Water Quality Trading Programs

Executive Summary – Task 1

More than 40 years following the adoption of the Clean Water Act (CWA), waterbodies around the country remain impaired by a number of pollutants. These problems are often caused by dispersed nonpoint sources of pollution, which are beyond the scope of the CWA in many states. This leaves point sources such as municipal wastewater treatment plants bearing primary responsibility for addressing water quality impairments, regardless of whether those sources meaningfully contribute to the pollution loading at issue. As a result, point sources face increasingly stringent discharge limits, leading to a conundrum whereby regulated facilities must install ever more costly technology to achieve minimal reductions in pollution—the classic diminishing returns problem. Given this reality, alternative CWA compliance methods such as water quality trading have grown more attractive in recent years.

Water quality trading is a market-based CWA compliance alternative that allows for exchanges among various sources of pollution. A trading program often represents the most economically viable compliance alternative while also resulting in greater environmental benefits than traditional compliance methods. Furthermore, many water quality trading programs are designed to remediate nonpoint source pollution, thereby addressing one of the greatest causes of water quality impairment. To advance water quality trading, the U.S. Environmental Protection Agency (EPA) has issued guidance documents supportive of these programs. The EPA also encouraged states to authorize trading, either in regulations or on a case-by-case basis for individual programs.

CATEGORIES OF WATER QUALITY TRADING PROGRAMS

There are several general categories of trading programs based on the types of participants. One common trading program, and the focus of this review, is point source to point source trading. These programs involve tradeoffs between regulated (NPDES-permitted) facilities. Specifically, one facility decreases its discharges below the permit limits, thereby generating credits representing the difference between effluent limits and actual effluent discharges. A different facility may purchase those credits and use them to offset discharges exceeding its applicable permit limits. Another type of trading program involves point source to nonpoint source trading, whereby a regulated facility offsets a portion of its discharges through environmental restoration or related action that addresses nonpoint source pollution. The last type of trading program involves trades between multiple nonpoint sources such as municipal storm sewers. This type of program is rare and does not garner much discussion here as it is beyond the scope of this review. Overall, programs involving point sources are most common, as the regulatory driver—CWA NPDES permits or the state equivalent—tend to impose strict and costly compliance obligations on point sources.

ELIGIBILITY TO PARTICIPATE IN WATER QUALITY TRADING

While supportive of trading programs, the EPA has outlined general and specific minimum requirements for an

acceptable trading program. The EPA has stated that trading should advance some basic policies. Specifically, trading should more effectively accomplish regulatory and ecosystem goals, rely on sound science, entail sufficient accountability, not result in localized water impairments ("hotspots"), and fit within the Clean Water Act's framework. Many states, including California, have approved trading programs that abide these policies, though fewer states have promulgated official guidance to facilitate broad adoption of trading.
Total maximum daily loads (TMDLs), CWA-mandated informational documents drafted to guide the remediation of water quality impairments, often trigger the demand for trading by resulting in more stringent effluent limits, though they are by no means a prerequisite to trading. However, TMDLs do help to facilitate trading by establishing a governing structure and defined load limits. The basin-scale scientific studies underlying TMDLs help resolve many of the uncertainties that constitute hurdles to implementing a trading program, such as sources of pollution, needs and assimilative capacity of the watershed, and allocations of acceptable loading for each source. Nevertheless, trading programs may arise in the absence of a TMDL. Trading may even result in improvements to water quality sufficient to negate the need for a TMDL. Importantly, when trading is pursued without an applicable TMDL it is necessary to undertake a TMDL-equivalent analysis of the basin to provide the needed foundational scientific certainty.

The existence of a TMDL aside, numerous other requirements dictate a facility's eligibility to participate in a trading program. Likewise, many elements of a trading program must be worked out to the satisfaction of EPA and the state before a program will garner approval. Turning to the eligibility issues first, it is worthwhile to note that not all pollutants are tradable. To date, EPA has confined water quality trading to nutrients, sediment, temperature, and oxygen-demanding parameters. The Agency has stated it will consider most other pollutants on a case-by-case basis.

The EPA does not limit participation in trading programs to any certain type of facility; all entities are eligible to trade. Although any facilities may trade, limits on the extent to which trading may be used for CWA compliance purposes exist. These limitations are based upon the effluent limits applicable to a facility. EPA does not allow trading for 'technology-based effluent limits'—those pollution control technologies EPA requires for entire industries. 'Water quality-based effluent limits', on the other hand, may be achieved though trading. These effluent limits are specifically designed to protect specific beneficial uses in a given waterbody. As such, they surpass technology limits, as the required technology failed to adequately protect the water quality and/or uses, necessitating the water quality-based limits. Facilities may engage in trading to achieve compliance with water quality-based effluent limits, but must first achieve the minimal technological limits.

ENSURING WATER QUALITY BENEFITS

The EPA also requires that trading result in water quality improvements. To accomplish this, the Agency requires some specific components be included in every trading program. Compliance with the antidegradation policies constitutes the most basic of these mandates. In short, the antidegradation rules restrict discharges that would result in a net increase of pollution, although trading may be used to offset increased discharge quantities or concentrations. Similarly, except in rare cases, any new or modified effluent limits must be as stringent as the previous effluent limits in order to comply with anti-backsliding rules. Furthermore, in order to ensure the receiving water benefits occur, a trading program is required to operate within defined geographic boundaries. This "trading area" encompasses all potential trading participants, as well as sufficient sources of pollution to enable trading to improve local water quality.

Analogous requirements apply to confirm that credit generating activities result in gains to water quality and the watershed. "Baseline" serves as a threshold requirement to credit generation. Baseline prohibits entities from generating credits unless and until they have satisfied all legal mandates related to water quality, mainly the terms of the applicable NPDES discharge permit. Any load reductions beyond those baseline requirements can be credited and sold. A related concept, “additionality”, is intended to ensure financial propriety by evaluating the underlying sources of project funding. Additionality prevents public funds from being used to generate credits unless those monies were allocated for CWA compliance activities. Money earmarked for actions besides compliance (e.g., environmental restoration, public education, etc.) may not be redirected to generate credits. In contrast, money intended for compliance such as Clean Water State Revolving Fund financing may help to achieve baseline or generate credits as this does not contravene the intent underlying those funds.

WATER QUALITY TRADING FRAMEWORK

In order for a trading program to become fully functional, it is necessary to develop a trading plan or framework that describes the specific components of a trading program. This framework does not necessarily need to be a stand-alone guidance document—though creating such a guidance document does have benefits. Incorporating it into an NPDES permit directly or by reference suffices so long as it garners formal agency approval. In any event, the trading plan must address issues related to the credits characteristics and the logistics of trading.

One of the fundamental considerations in a trading plan is the credit characteristics. This explicitly defines the units of trade, usually expressed in rates or mass per unit of time as appropriate to align with the NPDES permit, TMDL, or other regulatory requirement. Maintaining consistency between the credit units and the units used in the NPDES permit is preferable as it fosters simplicity. Based on the units of trade, the framework must also define the methodology for quantifying credits. For point-to-point source trading that uses the same units as the NPDES permit, quantification will ideally mirror the permit’s methodology, allowing the required discharge monitoring reports to facilitate credit quantification. Furthermore, the framework should detail the duration of credits, commonly known as the credit life. The most straightforward methodology for credit life is to tie it to the critical period identified in the TMDL or watershed analysis, a period often incorporated into the discharge permit. This can be weekly, monthly, seasonally, annually, or some other unit of time. In theory, a credit could remain valid so long as the credit generating reduction remains in place, though credits often have a finite lifespan in other trading programs, frequently one year, after which they must be recertified to prove the reductions remain valid and reissued. Clearly articulating these characteristics is critical.

Once the credit characteristics are defined, it is necessary to determine the trading ratios. A trading ratio constitutes a discount factor for the credits, often between 1-to-1 and 2-to-1, which accounts for uncertainties, attenuation between locations, and ensures environmental benefits. Though point-to-point source trading involves much less uncertainty than other trading programs, prudence weighs in favor of using a reasonable ratio to guarantee environmental benefit. Moreover, a portion of the credits discounted by the ratio may be set aside into a reserve pool that may be drawn upon in the event of an unanticipated exceedance.

The trading ratio, while an important consideration, nonetheless constitutes only one of the credit accounting considerations. Credit accounting broadly entails articulating and documenting credit generation, the trade itself, and the credit use with sufficient proof and transparency to withstand scrutiny. Some trading programs use credit exchanges, centralized entities that maintain the appropriate records and serve as a trade facilitator or credit bank. Other programs simply trade directly between participants and use an agency-approved method to document the trade. Whatever the method, maintaining adequate and transparent records is very important.

EXAMPLES OF WATER QUALITY TRADING PROGRAMS

Although point-to-point source trading is not quite as common as trades involving nonpoint sources, there are still numerous examples to draw upon for guidance. The two most successful examples are Connecticut’s Long

Island Sound Nutrient Credit Exchange and Virginia's Nutrient Credit Exchange. Both used a general permit to guide trading and assign effluent limits, but the specific trading provisions differ markedly.

Connecticut adopted its trading program to address low dissolved oxygen levels caused by nutrient overenrichment that lead to hypoxia issues. The state issued a single general permit for all treatment plants within the state, assigning them each individual limits and trading ratios while simultaneously creating a single combined limit for all regulated entities. The individual limits serve as the basis for credit generation and, if a facility will not achieve that effluent limit, clarify the credit need for that facility. Credits are purchased by a state-run credit bank. Compliance is determined on an annual basis: if the combined limit is achieved, then all facilities are deemed in compliance with the permit, if not then enforcement actions are taken based on the individual limits. Though the Sound remains impaired, significant improvements have directly resulted from this trading program.

Virginia utilized a similar methodology for nutrients, creating a general permit for all wastewater treatment facilities but assigning individual effluent allocations to each facility. If a facility is unable to comply with its individual limit, it may purchase credit either from individual facilities or on an industry-run exchange. Virginia also maintains a state-run fund, which facilities unable to garner credits on the market may pay into in order to finance nonpoint source restoration sufficient to offset the exceedance. Also of note, Virginia is unique in that it allows for the permanent sale of unused discharge allocations (wasteload allocations) to new or expanding facilities. This program has resulted in meaningful progress toward achieving the goals of the Chesapeake Bay TMDL.

Overall, water quality trading represents a viable alternative to achieving compliance with the Clean Water Act. These programs often provide more economically viable alternatives, especially given the diminishing returns associated with many technological compliance solutions. The associated environmental benefits can provide significant improvements to the local watershed by improving water quality and other ecosystem functions. While market-based compliance solutions may not be viable in all instances, the potential benefits warrant giving meaningful consideration to these programs.

1.1. Introduction

East Bay Municipal Utility District (EBMUD) has expressed interest in evaluating the viability of water quality trading (WQT) as a potentially cost effective means to achieve reductions in nutrient loading into San Francisco Bay. This document serves as an introduction to the major aspects and considerations of a WQT program and provides examples of other WQT programs across the United States. This understanding will provide the foundation for future analyses by The Freshwater Trust(TFT), which include the investigations into the specific challenges, opportunities, and the feasibility of a point-to-point source nutrient trading program in the San Francisco Bay that are described in the contract between EBMUD and TFT dated October 4, 2016. The Freshwater Trust does not intend for this document to provide a full analysis of WQT feasibility for EBMUD as it could potentially operate in the San Francisco Bay, nor does TFT intend for this document to be construed as legal advice.[1]

1.2. Background and Principles of Trading Programs

A. FEDERAL AUTHORIZATION OF WATER QUALITY TRADING

In 2003, the U.S. Environmental Protection Agency (EPA) published a final water quality trading policy (EPA Trading Policy) describing how point and nonpoint sources can participate in market-based approaches to achieve water quality standards at a reduced cost.[2] The 2003 EPA Trading Policy supports WQT as a flexible approach for Clean Water Act (CWA) compliance. The EPA Trading Policy took the position in the that WQT can realize improvements to water quality while simultaneously generating environmental benefits otherwise beyond the reach of traditional regulatory compliance approaches. The EPA Trading Policy serves to provide a framework for water quality credit trading consistent with the CWA's anti-backsliding policy, compliance and enforcement provisions, and public notice and comment procedures and explicitly endorses trading for nutrients. To further clarify the aspects of a trading program, the EPA also issued a Toolkit for Permit Writers to guide trading program implementation.[3] Based on these guidance documents, EPA has issued several permits within EPA Region 9 (Southwest) that include trading plans in some form, including in California.[4]

Generally, the EPA supports trading between point sources, known as point-to-point source trading. EPA considers point-to-point source trading "the most basic form of water quality trading [because it] is relatively straightforward, easily measurable, and directly enforceable."[5] The EPA describes these trades as "the easiest type of trading to implement, to measure reductions from, and to ensure compliance and enforcement with

---

[1] EBMUD should consult its attorneys on all matters related to the issues discussed in this document. Nothing herein should be construed as providing legal advice or recommendations.

[2] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. 1608, 1610 (Jan. 13, 2003), *available at* www.gpo.gov/fdsys/pkg/FR-2003-01-13/pdf/03-620.pdf.

[3] U.S. EPA, Water Quality Trading Toolkit for Permit Writers, 15–17, EPA 833-R-07-004 (Aug. 2007, updated June 2009), *available at* www.epa.gov/npdes/pubs/wqtradingtoolkit.pdf (EPA Trading Toolkit).

[4] *See, e.g.,* L.A. Reg'l Water Quality Control Bd., Order No. R4-2012-0175, Permit No. CAS004001, Waste Discharge Requirements for MS4 Dischargers within Coastal Watersheds of Los Angeles County (2012, rev. July 2015) *available at* www.waterboards.ca.gov/losangeles/water_issues/programs/stormwater/municipal/; Cal. State Water Res. Control Bd., Res. No. R1-2010-0026: Action Plan for Klamath River Total Maximum Daily Loads (Mar. 2010) *available at* www.waterboards.ca.gov/northcoast/water_issues/programs/tmdls/klamath_river; N. Coast Reg'l Water Quality Control Bd., Order No. R1-2006-0045, Permit No. CA0022764, Waste Discharge Requirements & Master Reclamation Permit for the Santa Rosa Subregional Water Reclamation System, at 13, n. 5 (2006, rev. July 2008, Apr. 2009), *available at* www.waterboards.ca.gov/northcoast/board_decisions/adopted_orders/pdf/2006/061003_0045_SantaRosaWDRs.pdf.

[5] EPA Trading Toolkit at 15.

because all sources have a permit, the effectiveness of removal technologies is relatively well known, and monitoring protocols are in place."[6] As such, EPA encourages states to develop and adopt WQT programs.

B. GUIDING PRINCIPLES FOR WATER QUALITY TRADING

The following outlines the core principles that constitute a legally and scientifically defensible water quality trading compliance program, according to the EPA Trading Policy and guidance documents.

1. **More Effectively Accomplishes Regulatory and Environmental Goals:** Water quality trading must enable sources to achieve NPDES permit compliance without negatively affecting other parts of the environment.[7] Additionally, water quality trading should result in water quality improvements beyond what would have occurred without trading.
2. **Based on Sound Science:** Water quality trading is supported when the goals, credit quantification methods, and adaptive management systems are based on scientifically replicable and defensible methods. Trading programs should monitor and evaluate outcomes to adaptively manage the program.
3. **Sufficiently Accountable**: Water quality trading guidance, frameworks, and plans should seek to foster transparency in all aspects of the trading programs, including trading processes, location, volume of transactions, and the effectiveness of trading over time. Trading documents should foster accountability by clearly articulating participants' responsibilities and providing a mechanism for identifying and correcting problems. Engaging the public early and often also improves trading accountability.
4. **No Localized Water Quality Problems Result:** WQT is not supported where it leads to localized water quality impairments[8] or exceedances of acute or chronic aquatic life or human health criteria beyond a zone of dilution or the edge of a mixing zone. Under no circumstances may WQT create "hotspots"—areas where water quality standards are exceeded.
5. **Consistent with the Clean Water Act's Regulatory Framework:** Water quality trading must be consistent with the CWA and its implementing regulations. This includes avoiding trading where it would circumvent the installation of required minimum technology-based treatment equipment, adversely affect drinking water quality or cause the exceedance of the combined TMDL allocations.

C. STATE AUTHORIZATION OF WATER QUALITY TRADING

The trading programs in California have been developed and permitted independently on a case-by-case basis.[9] California has not adopted any statewide regulations or official policies concerning water quality trading, but existing policies support WQT and the discretion vested in the State Water Resources Control Board (SWRCB) and the Regional Water Quality Control Boards (RWQCBs) enables the development and implementation of such a program. The SWRCB has, however, adopted a policy for addressing impaired waters that states the "Water Boards are committed to [using] all means to ensure that the waters of the state are protected" and goes on to discuss the "wide latitude" and "numerous options" available to RWQCBs to address impaired waters.[10]

---

[6] *Id.*
[7] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1611.
[8] Examples of localized impairments include, but are not limited to, thermal barriers to salmonid migration, thermal shock/lethality for salmonids, impairment of salmonid spawning habitat, algal blooms and areas of low dissolved oxygen.
[9] ENVTL. TRADING NETWORK, STATE TRADING PROGRAMS: CALIFORNIA (2011), *available at* www.envtn.org/State_Programs___Rules.html#California. *See also* NAT'L NETWORK ON WATER QUALITY TRADING, BUILDING A WATER QUALITY TRADING PROGRAM: OPTIONS & CONSIDERATIONS, 33–35 (2015).
[10] Without detailing the specific actions, this policy clarifies that regulatory and nonregulatory measures can be utilized to achieve compliance with the receiving water standards. CAL. CODE REGS. tit. 23, § 2917; Cal. State Water Resources Control Bd., Res. No. 2005-0050: Water Quality Control Policy for Addressing Impaired Waters: Regulatory Structure and Options (June 16, 2005), *available at* www.swrcb.ca.gov/water_issues/programs/tmdl/docs/iw_policy.pdf. Memorandum from Michael A.M. Lauffer, Chief Counsel, Cal. State Water Resources Control Bd., to Arthur G. Baggett, Jr., Chair, Cal. State Water Resources Control Bd., on Updated Legal Authority for

Furthermore, two memos from the SWRCB's legal counsel support using WQT and other offset programs. One of those memos clarified that "[t]he use of offsets, pollutant trading, or other market-based mechanisms . . . is clearly appropriate when implemented in the context of a TMDL, in which case, substantial flexibility exists to achieve [water quality standards]."[11] Together these proclamations demonstrate not only that trading constitutes a viable compliance option, but also that California regulators are actively "encouraged to be as innovative and creative as possible" in achieving a TMDL's goals.[12]

D. TYPES OF TRADING PROGRAMS

Each trading program is unique in response to the circumstances present in a given jurisdiction and watershed. Nevertheless, many commonalities exist, allowing the universe of trading programs to be roughly classified into several overarching groups. Any trading program that is undertaken within the context of a CWA NPDES permit will generally involve either trading between multiple point sources (point-to-point source trading) or trading between point sources and nonpoint sources (point-to-nonpoint source trading).[13] Trading between multiple participants, whether multiple point sources or nonpoint sources, may involve a broker or intermediary to facilitate to trades, though this is not required and does not change the underlying trading program, simply the accounting methodologies.

The EPA's Water Quality Trading Toolkit identifies three types of point-to-point trades: 1) a single point source trading with another point source; 2) a group of point sources within one basin operate under a single trade agreement; and 3) a group of point sources that purchase credits from a central exchange as needed to comply with individual effluent limitations.[14] The 2003 EPA Trading Policy also outlined a fourth alternative, the intra-plant trade option,[15] whereby multiple outfalls within a single facility may trade within the plant to achieve permit compliance on a facility-wide basis. There is much similarity between these types of trading programs—the distinctions mainly relate to the size of the program, the number of participants, and the permitting vehicle.

The smaller single point source trading programs are usually conducted under the separate NPDES permits of the facilities involved in the trading. All participants may receive individual permits with individual limits and may trade to satisfy some portion of their effluent limits. The larger programs, those involving multiple point sources, may entail each facility operating under an individual NPDES permit, or it may involve a broader, watershed-based permit.[16] Under a watershed-based permit, effluent limits are cumulatively established for all point sources within the basin. These cumulative limits allow for permit compliance to be achieved by all sources within the basin together. These joint permits also contain individual limits that provide the informational basis to set trading baselines and pursue individual enforcement actions when necessary.

Offsets, Pollutant Trading, and Market Programs to Supplement Water Quality Regulation in California's Impaired Waters With Established Total Maximum Daily Loads (Nov. 22, 2006).

[11] Memorandum from Craig Wilson, Chief Counsel, Cal. State Water Resources Control Bd., to Arthur G. Baggett, Jr., Chair, Cal. State Water Resources Control Bd., on Legal Authority for Offsets, Pollutant Trading, and Market Programs to Supplement Water Quality Regulation in California's Impaired Waters (Oct. 16, 2001), *available at* www.waterboards.ca.gov/water_issues/programs/tmdl/docs/iwguide_apxb.pdf.

[12] CAL. CODE REGS. tit. 23, § 2917; Cal. State Water Resources Control Bd., Res. No. 2005-0050: Water Quality Control Policy for Addressing Impaired Waters: Regulatory Structure and Options (June 16, 2005).

[13] Nonpoint-to-nonpoint source trading also exists, though it is quite rare due to the lack of a regulatory driver in most instances. However, one example of this is the Los Angeles MS4 Trading Program that allows for numerous stormwater agencies to engage in joint efforts to achieve combined permit compliance with the MS4 permit.

[14] EPA TRADING TOOLKIT at 15–17.

[15] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1610. This option allows for a "facility with multiple outfalls [to] receive a mass WLA" instead of specific effluent limits for each outfall, thereby allowing the facility to make trade-offs among the outfalls in order to achieve permit compliance for the entire facility. EPA TRADING TOOLKIT at 22–23.

[16] There is something of a modern trend towards watershed-based NPDES permits to facilitate trading, as these approaches take a more holistic perspective toward achieving watershed-scale environmental improvements.

E. TMDLS AND WATER QUALITY TRADING

When a waterbody fails to attain the applicable water quality standards, it is formally listed as impaired and placed on the '303(d) list'.[17] In order to guide efforts to fix the impairment and attain the water quality standards, regulators must develop and implement a Total Maximum Daily Load (TMDL). A TMDL "defines the specific maximum amount of a pollutant which can be discharged or 'loaded' into the waters at issue from all combined sources."[18] A TMDL allocates the total pollutant load for a single day between nonpoint and point sources, thus ensuring that if all sources abide their respective allocations, the waterbody will achieve its water quality standards.[19] Point sources receive 'wasteload allocations' (WLAs) that serve as the basis for the discharge limits incorporated into the applicable NPDES permit. TMDLs only serve an informational tools to guide the development of NPDES permits and water quality control plans—they do not directly impose any restrictions on dischargers until they are incorporated into other enforceable documents. Rather, they serve to bring together various sources of information and restrictions to create blueprints for the water quality restoration in an area.[20]

The EPA's guidance on WQT does not require a TMDL as a prerequisite to trading. One of the objectives of the EPA Trading Policy is to "achieve[] early reductions and progress towards water quality standards pending development of TMDLs for impaired waters."[21] Although not a requirement, a majority of trading activities do take place under existing TMDLs. This is because trading requires a firm understanding of the water quality conditions in the waterbody. This includes not simply the existing conditions, but also the reductions necessary to realize the underlying water quality standards not currently being attained, essentially all of the research that makes up the foundation of a TMDL.[22] Therefore, having an existing TMDL to serve as a blueprint for trading, though not mandatory, makes the design and implementation of a WQT program simpler.

In the absence of a TMDL, WQT ostensibly requires a TMDL-like watershed analysis capable of properly dividing load between sources, thereby creating the baseline necessary for trading activities. Such an analysis also helps to ensure that further impairment is avoided and environmental benefits result, thus making progress toward the attainment of water quality standards. This watershed analysis mirrors the TMDL process in that existing watershed loading is determined, loading necessary to achieve water quality standards is derived, and the necessary loads and reductions are divided among the existing sources. All of this should be consistent with the methodologies that would otherwise be used in the TMDL process to ensure credibility. The main difference is that no formal document needing EPA approval is generated, possibly streamlining the regulatory process.

1.3. Core Elements of Trading Programs

A. ELIGIBILITY TO PARTICIPATE IN A WQT PROGRAM

i. Pollutants Eligible for Trading

Not all pollutants may be eligible for trading pursuant to the EPA Trading Policy. To date, trading programs have been adopted for nutrients, temperature, oxygen-demanding parameters, and sediment. However, "EPA recognizes that trading of pollutants other than nutrients and sediments has the potential to improve water quality and achieve ancillary environmental benefits if trades and trading programs are properly designed."[23]

---

[17] 33 U.S.C. § 1313 (2012).

[18] Dioxin/Organochlorine Center v. Clarke, 57 F.3d 1517, 1520 (9th Cir. 1995).

[19] For a thorough discussion of TMDLs, see Mary. E. Christopher, *Time to Bite the Bullet: A Look at State Implementation of Total Maximum Daily Loads (TMDLs) Under Section 303(d) of the Clean Water Act*, 40 WASHBURN L.J. 480 (2001).

[20] Pronsolino v. Nastri, 291 F.3d 1123, 1129 (9th Cir. 2002).

[21] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1609.

[22] WILLAMETTE P'SHIP & THE FRESHWATER TRUST, DRAFT REGIONAL RECOMMENDATIONS FOR THE PACIFIC NORTHWEST ON WATER QUALITY TRADING, 64 (2014).

[23] 2003 U.S. EPA Water Quality Trading Policy, 68 Fed. Reg. at 1610.

Other pollutants may be eligible for trading on a case-by-case basis with EPA approval if they are not persistent bioaccumulative toxics.[24]

ii. Entities Eligible to Purchase Credits

All entities are eligible to purchase credits, though it is uncommon for entities to buy credits for any reason other than NPDES permit compliance. All potential point source dischargers are required to have an individual permit or be covered under a general NPDES permit.[25] To determine a discharge limit, regulators establish effluent limits, which cannot "cause, have the reasonable potential to cause, or contribute" to violations of water quality standards or criteria.[26] To meet these limits, NPDES permits include controls that reflect the stricter of two different kinds of effluent limitations: those based on the technology available to treat a pollutant (a technology-based effluent limit, or "TBEL"),[27] and those necessary to meet the applicable water quality standard(s) of the receiving waterbody (a water quality-based effluent limit, or "WQBEL").[28] TBELs "represent the minimum level of control that must be imposed in a permit,"[29] and are "developed independently of the potential impact of a discharge on the receiving water."[30] Where a point source's TBEL is insufficient to meet applicable water quality standards, or where no TBEL exists for a particular pollutant from a particular type of source, the permit will instead include WQBELs—including "alternative effluent control strategies" such as best management practices (BMPs) and other non-numeric limitations—to ensure water quality standards are met.

In the absence of a specific regulatory exception, the EPA Trading Policy provides that water quality trading cannot be used to comply with an existing federal TBEL.[31] Several memos from the SWRCB's legal counsel echo this restriction.[32] However, POTWs do not have federal TBELs for nutrients[33] and California has not adopted nutrient TBELs. Any nutrient limits in NPDES permits for POTWs in California will be WQBELs, and therefore constitute potentially tradable limits. TFT has found nothing in the California laws, regulations, or water quality plans that contravenes this conclusion. To the contrary, market-based approaches may be used to meet WQBELs or the wasteload allocations they are based upon as those "circumstances will promote (and not forestall) . . . attainment of water quality standards."[34]

---

[24] "EPA does not support trading of persistent bioaccumulative toxics (PBTs)." EPA TRADING TOOLKIT at 10.
[25] 33 U.S.C. § 1311(a); 40 C.F.R. § 122.28 (general permits).
[26] 40 C.F.R. § 122.44(d)(1). Anywhere that applicable TMDLs exist for the stream segments, a facility's permit limits need to be consistent with TMDL wasteload allocations. *See* 40 C.F.R. §§ 122.44(d)(1)(vii), 130.7(a).
[27] *See* 33 U.S.C. §§ 1311(b)(1)(A)–(B).
[28] *See id.* at §§ 1311(b)(1)(C), 1312(a).
[29] 40 C.F.R. § 125.3(a).
[30] U.S. EPA, NPDES PERMIT WRITERS' MANUAL, EPA-833-K-10-001, at 5-1 (Sept. 2010).
[31] "EPA does not support trading to comply with existing [TBELs] except as expressly authorized". U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1610–11. Although EPA "will consider including provisions for trading in the development of new and revised [TBEL] guidelines and other regulations" the existing POTWs policies lack such provisions. *Id.* at 1611.
[32] Memorandum from Michael J. Levy, Staff Counsel, Cal. State Water Resources Control Bd., to Stefan Lorenzato, TMDL Coordinator, Cal. State Water Resources Control Bd., on Guidance Regarding the Extent to which Effluent Limitations Set Forth in NPDES Permits can be Relaxed in Conjunction with a TMDL, 1 (Jan. 26, 2001) ("[TBELs] cannot be relaxed"); Memorandum from Craig Wilson, Counsel, Cal. State Water Resources Control Bd., to Arthur G. Baggett, Jr., Chair, Cal. State Water Resources Control Bd., on Legal Authority for Offsets, Pollutant Trading, and Market Programs to Supplement Water Quality Regulation in California's Impaired Waters, 2 (Oct. 16, 2001) ("no market system can . . . afford relief from TBELs").
[33] TBELs are derived by using industry-specific technology-based effluent guidelines have been promulgated for over 50 different industrial categories. *See* 40 C.F.R. pts. 405–99. The permitting entity can also rely on ad hoc best professional judgment to set TBELs if no effluent limit guidance exists. *See* 33 U.S.C. § 1342(a)(1); 40 C.F.R. § 125.3(a)(2). While TBELs exist for all sources, they do not exist for all pollutants from all sources. In the case of POTWs, TBELs are secondary treatment standards as defined in CWA. 33 U.S.C. § 1311(b)(1)(B). POTW facilities have TBELs for five-day biochemical oxygen demand (BOD), total suspended solids (TSS), and pH. 40 C.F.R. § 133.102. POTWs do not have secondary treatment TBELs for nutrient discharges. In late 2012, EPA rejected a rulemaking petition to include nitrogen and phosphorous removal standards within the national TBEL standards for POTWs. Letter from Michael H. Shapiro, U.S. EPA, Deputy Asst. Administrator, to Ann Alexander, Natural Resource Defense Council (Dec. 12, 2012).
[34] Memorandum from Craig Wilson, Chief Counsel, Cal. State Water Resources Control Bd., to Arthur G. Baggett, Jr., Chair, Cal. State Water Resources Control Bd., on Legal Authority for Offsets, Pollutant Trading, and Market Programs to Supplement Water Quality Regulation in

iii. Anti-Backsliding for Trading Participants

Point sources wishing to trade must comply with relevant federal and state "anti-backsliding" provisions related to effluent limits. Under these provisions, NPDES permits generally may not be renewed, reissued, or modified to contain less stringent effluent limitations than those found in the previous permit, unless specific conditions are met. Under federal law, this means that once an entity achieves a particular WQBEL, future permit iterations cannot contain less stringent limits, unless a CWA section 402(o)(2)[35] exception applies or section 303(d)(4) is met.[36] The EPA Trading Policy states:

> EPA believes that the anti-backsliding provisions of Section 303(d)(4) of the CWA[37] will generally be satisfied where a point source increases its discharge through the use of credits in accordance with alternate or variable water quality based effluent limits contained in an NPDES permit, in a manner consistent with provisions for trading under a TMDL, or consistent with the provisions for pre-TMDL trading included in a watershed plan. These anti-backsliding provisions will also generally be satisfied where a point source generates pollution reduction credits by reducing its discharge below a WQBEL that implements a TMDL or is otherwise established to meet water quality standards and it later decides to discontinue generating credits, *provided that the total pollutant load to the receiving water is not increased*, or is otherwise consistent with state or tribal anti-degradation policy.[38]

As legal counsel for the SWRCB has noted, state regulations allow the use of alternative compliance methods to relax WQBELs "only if they are consistent with the assumptions and requirements of the TMDL, and will not result in the violation of water quality standards."[39] Hence, if the underlying WLAs are satisfied, upholding the assumptions of the TMDL, trading represents a viable means to comply with the NPDES permit limits.

B. ENSURING ENVIRONMENTAL BENEFITS RESULT FROM WATER QUALITY TRADES

Several fundamental aspects of trading programs serve to ensure that trading programs result in benefits to the environment, in addition to being economically viable compliance alternatives. This consideration involves ensuring that the state and federal antidegradation policies, which prevent worsening a waterway's impairment or unacceptable degradation of high quality waters[40] are followed, making sure that credits are only generated by actions that go beyond the minimum legal requirements, public funds dedicated for restoration are not used for trading projects, and trading ratios minimize uncertainty and lead to ecosystem improvements.

California's Impaired Waters (Oct. 16, 2001); Memorandum from Michael A.M. Lauffer, Chief Counsel, Cal. State Water Resources Control Bd., to Arthur G. Baggett, Jr., Chair, Cal. State Water Resources Control Bd., on Updated Legal Authority for Offsets, Pollutant Trading, and Market Programs to Supplement Water Quality Regulation in California's Impaired Waters With Established Total Maximum Daily Loads (Nov. 22, 2006); N. Coast Reg'l Water Quality Control Bd., Res. No. R1-2008-0061: Approving Santa Rosa Nutrient Offset Program (July 24, 2008).

[35] 33 U.S.C. § 1342(o)(2).

[36] "EPA has consistently interpreted CWA section 402(o)(1) to allow relaxation of WQBELs . . . if the relaxation is consistent with the provisions of CWA section 303(d)(4) or if one of the exceptions in CWA section 402(o)(2) is met. The two provisions constitute independent exceptions to the prohibition against relaxation of effluent limitations. If either is met, relaxation is permissible." U.S. EPA, NPDES PERMIT WRITERS' MANUAL, EPA-833-K-10-001, at § 7.2.1.3 (Sept. 2010). CWA section 303(d)(4) is broken into two parts, the first of which applies to non-attaining waters and the second of which applies to attaining waters. For non-attaining waters, CWA section 303(d)(4)(A) allows a less stringent WQBEL if the permittee meets two conditions: 1) the existing limit is based on a TMDL or "other WLA established under [CWA § 303]"; and 2) the attainment of water quality standards will be ensured through the cumulative effect of the revised effluent limits or the designated use not being attained is removed in accordance with the UAA provisions of 40 C.F.R. § 131.10(g). 33 U.S.C. § 1313(d)(4)(A).

[37] 33 U.S.C. § 1313.

[38] *See* U.S. EPA Water Quality Trading Policy, 68 Fed. Reg. at 1611 (emphasis added).

[39] Memorandum from Michael J. Levy, Staff Counsel, Cal. State Water Resources Control Bd., to Stefan Lorenzato, TMDL Coordinator, Cal. State Water Resources Control Bd., on Guidance Regarding the Extent to which Effluent Limitations Set Forth in NPDES Permits can be Relaxed in Conjunction with a TMDL, at 1 (Jan. 26, 2001) (internal citations omitted).

[40] Cal. State Water Resources Control Bd., Res. No. 68-16: Statement of Policy with Respect to Maintaining High Quality of Waters in California (Oct. 28, 1968).

i. Consistency with Antidegradation Policies

Water quality programs and trades must comply with state antidegradation policies. In water-quality limited waters, states must maintain and protect existing attained designated uses.[41] EPA endorses trading so long as existing uses are preserved and protected.[42] EPA does not believe that antidegradation review should be triggered under its regulations when trades or the trading program achieves an overall "no net increase" of instream concentrations of the pollutant traded and when designated uses are not impaired.[43] The California antidegradation policy, which applies to "high quality surface and ground waters", is read as incorporating the federal policy.[44] Taken together, these provisions are designed to ensure that a waterbody will not be degraded by the permitted discharge except in limited circumstances.[45] No water quality degradation that would interfere with or become injurious to these uses is allowable. In the trading context, the antidegradation policies are usually satisfied where the result is both no net increase of nutrients entering the waterway and no change in localized impact of discharge, thereby maintaining the beneficial uses. Moreover, trading ratios are designed to result in greater environmental improvements than would otherwise be realized without trading.

ii. Considerations for Establishing a Trading Area

In order for credits to count against a facility's permit obligations, the credit-generating activities must occur within a defined "trading area." A defined and discrete trading area ensures that trades improve local water quality. The EPA maintains water quality trading should occur "within a watershed or a defined area for which a TMDL has been approved."[46] A trading area may align with the TMDL's geographic scope or it may encompass the watershed in whole or part. The watershed characteristics and type of trade proposed will influence the appropriate geographic scope.[47] These factors usually garner consideration in the TMDL.[48] In any event, a trading area should "encompass the universe of sources that contribute to a specific water quality problem" that WQT aims to address.[49]

There are several other pertinent considerations when defining the scope of a trading area. Larger trading areas likely increase the number of potential buyers and sellers who may engage in either point-to-point source

---

[41] 40 C.F.R. § 131.12(a)(1).

[42] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1610.

[43] *Id.* at 1611. EPA's position is consistent with the purposes of water quality standards (including anti-degradation). *See* 40 C.F.R. § 131.2 (water quality standards exist to "protect public health or welfare, enhance the quality of water and serve the purposes of the [CWA]"). It is also consistent with EPA regulations on allowable water quality degradation. *See id.* § 131.12 ("In allowing such degradation or lower water quality, the State shall assure water quality adequate to protect existing uses fully. Further, the State shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable [BMPs] for nonpoint source control.").

[44] Cal. State Water Resources Control Bd., Res. No. 68-16: Statement of Policy with Respect to Maintaining High Quality of Waters in California (Oct. 28, 1968). *See also* Memorandum from William Attwater, Chief Counsel, Cal. State Water Resources Control Bd., to Reg'l Bd. Executive Officers, on Federal Antidegradation Policy (Oct. 7, 1987), *available at* www.epa.gov/sites/production/files/2014-12/documents/ca-antidegradation-policy-memo.pdf (verifying that the California antidegradation policy incorporates the federal policy); CAL. STATE WATER RESOURCES CONTROL BD., A COMPILATION OF WATER QUALITY GOALS 17 (17 ed. 2016), www.waterboards.ca.gov/water_issues/programs/water_quality_goals/docs/wq_goals_text.pdf.

[45] To justify discharges that degrade a waterway, such action must be (i) consistent with the maximum benefit of the populace, (ii) not an unreasonable impairment of present and anticipated beneficial uses, and (iii) consistent with the applicable water quality plans and policies. Cal. State Water Resources Control Bd., Res. No. 68-16: Statement of Policy with Respect to Maintaining High Quality of Waters in California (Oct. 28, 1968).

[46] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1610.

[47] This analysis looks to the hydrogeologic conditions, fate and transport of pollutants, ecological parameters, location and type of point source(s), type of pollutant(s), and regulations and management structures.

[48] For instance, the Medford Trading Program on the Rogue River in Oregon has a trading area that is based upon the "Point of Maximum Impact.' *See* Or. Dep't of Envtl. Quality, Permit No. 100985: City of Medford NPDES Waste Discharge Permit (issued Dec. 13, 2011). The TMDL identified this point as the location on the river where the pollutant discharges have the greatest impact and below which the negative consequences wane. California has not adopted this requirement and the Malibu TMDL did not identify any analogous location.

[49] EPA TRADING TOOLKIT at 12.

trading or point-to-nonpoint source trading. On the other hand, smaller trading areas can direct nonpoint source credit production to locations that can best address the needed water quality and beneficial use impairments in that portion of the basin by focusing all efforts in a more discrete area. It is also important to consider the designated uses (i.e., aquatic life, recreation, etc.) impacted by discharges when setting a trading area because the benefits of a trade should be tied to those designated uses and the impairment of those uses. Once a trading area is established, point sources may purchase specific credits generated within that area for a variety of non-compliance related reasons.[50]

iii. Baseline for Credit Generation

"Trading baseline" is the threshold improvement that a credit-seller is required to meet before being able to generate credit to sell. Per the EPA Trading Policy, "[w]here a TMDL has been approved or established by EPA, the applicable point source waste load allocation or nonpoint source load allocation would establish the baselines for generating credits."[51] The 2007 U.S. EPA Trading Toolkit states that in the absence of a TMDL, baseline is equal to the pollutant control requirements that apply to a buyer and seller in the absence of trading.

For point-to-point source trading, dischargers that wish to generate credits must reduce their effluent below the most stringent permit limit. Therefore, the baseline is specified by the wasteload allocation in the TMDL and expressed as a water quality-based effluent limit in the facility's NPDES permit. Using this effluent limit as the baseline, any reductions in pollution beyond the reductions called for in the NPDES permit may potentially be quantified and traded to other sources. Because point sources have numeric standards measured at the end-of-pipe, it is not necessary to undertake any challenging translation to determine the applicable baseline.

iv. Additionality Requirements

Additionality describes the environmental benefit resulting from some funding source that would not have occurred in the absence of the trading market. Put simply, additionality ensures that money used to generate credits is not money that would have benefited the environment otherwise.[52] Guaranteeing that financial additionality is satisfied in the context of point-to-point source trading essentially looks to the underlying purpose of the sources of funding, ensuring that the finances were not intended for a non-compliance purpose. Only money raised or allocated for CWA compliance actions may be used for credit generation or the purchase of credits. For instance, funds originally dedicated for environmental restoration or public education (non-compliance purposes) could not be used to fund credit generation because those monies were not originally allocated for CWA compliance actions. Importantly, this restriction does not extend to public loans intended to be used for capital improvements of public water systems—this funding is intended to help achieve regulatory compliance and therefore does not result in any additionality issue.

C. CHARACTERISTICS OF WATER QUALITY CREDITS

i. Units of Trade for Water Quality Credits

Each trading plan or framework needs to define its own standardized units of trade, ideally using the same units as the NPDES effluent limits. "Clearly defined units of trade are necessary for trading to occur. Pollutant specific credits are examples of tradable units for water quality trading. These may be expressed in rates or mass per unit time (e.g. flow concentration or discharge load) as appropriate to be consistent with the time periods that

---

[50] For instance, a city may prefer to buy credits within its boundaries for civic reasons or from particular areas in high need of ecological improvement and investment.

[51] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1610. The Trading Policy also provides that "pollutant reductions [should be] greater than those required by a regulatory requirement or established under a TMDL." *Id.*

[52] WILLAMETTE PARTNERSHIP, ECOSYSTEM CREDIT ACCOUNTING SYSTEM: GENERAL CREDITING PROTOCOL VERSION 2.0 (Nov. 1, 2013), http://willamettepartnership.org/wp-content/uploads/2014/09/General-Crediting-Protocol-2.0.pdf.

are used to determine compliance with NPDES permit limitations or other regulatory requirements."[53] Standard units and a standard range of pricing per unit within a trading area or watershed will facilitate developer, seller, and buyer transactions so that they will be dealing in the same currency.

ii. Quantification of Tradable Credits

Quantification of the pollutant reductions and environmental benefit is the cornerstone of any crediting regime. To ensure the methodology utilized serves the intended purpose of adequately tracking the pollution reductions, the quantification should be accurate, repeatable, sensitive, and transparent, as well as practical and economical.[54] For point-to-point source trading that does not rely on any nonpoint source activities, credit quantification fits within the existing permit regime in terms of both pollutant units and monitoring. The point sources continue to monitor their discharges and submit the required Discharge Monitoring Reports (DMRs) as required by the NPDES permit. These DMRs will reveal any pollutant reductions that resulted in a facility discharging below its effluent limits, such that the facility may trade its unused pollutant allocations. In this way, the trading regime mirrors the NPDES permit, providing certainty and consistency.

iii. Trading Ratios to Account for Delivery and Attenuation

Ratios are a mechanism to support the realization of environmental benefits and safeguard against the uncertainty inherent in innovative compliance systems. The EPA Trading Policy calls for the use of ratios whenever trading involves nonpoint sources.[55] Trading ratios are commonly used to help to account for the uncertainty in nonpoint source load and reduction estimates. However, even for point-to-point source trading programs, which entail much less uncertainty than nonpoint source trades, trading ratios are encouraged in order to address a number of factors such as delivery, location, equivalency, uncertainty, and retirement.[56]

In the absence of a state policy, ratios must be established on a case-by-case basis. Based on the lessons learned from other water quality trading regimes and federal guidance documents, ratios may be needed to address the following factors:

- Degree of technical and logistical uncertainty associated with the credit generating method. These 'uncertainty ratios' are common with nonpoint trades.
- Whether the credits are calculated or measured. Generally, measured values will be more reliable than calculated values; uncertainty is greater when the calculation method is used.
- The fate and transport of the pollutant over the distance between the pollutant source, trade source, and points of regulatory compliance within the watershed. These 'delivery ratios' or 'location ratios' account for the fate and transport mechanisms of the pollutants.[57]
- Temporal variability of the pollutant load and of the pollutant reduction method. Credit ratios may be adjusted to compensate for variabilities in loading or treatment that may occur daily, monthly, seasonally, or annually as appropriate.
- The different forms of the same pollutant in terms of composition and impacts on the environment. These 'equivalency ratios' help account for the percent of the nutrients that are biologically available versus the nutrients that are less biologically accessible.

---

[53] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1612.

[54] WILLAMETTE P'SHIP & THE FRESHWATER TRUST, DRAFT REGIONAL RECOMMENDATIONS FOR THE PACIFIC NORTHWEST ON WATER QUALITY TRADING, 64 (2014).

[55] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1612.

[56] EPA TRADING TOOLKIT at 30–32 ("There is not set limit for how high a trading ratio can be. Trading ratios depend on the specific circumstances in the watershed").

[57] These ratios account for the transport characteristics of a pollutant, the unique characteristics of a watershed, distance, and time. *Id.* at 30–31. Delivery ratios account for both the transport of the pollutants into the watershed and within the waterway itself. *See* WILLAMETTE P'SHIP & THE FRESHWATER TRUST, DRAFT REGIONAL RECOMMENDATIONS FOR THE PACIFIC NORTHWEST ON WATER QUALITY TRADING, 75 (2014).

- Time lag between implementation of the technology or practice and full performance.[58]

Accounting for these factors, the EPA Trading Policy supports using trading ratios greater than 1-to-1.[59] For nonpoint-to-point source nutrient trading, a 2-to-1 ratio is common.[60] Furthermore, it is often prudent to maintain a reserve pool of credits that can be used to manage uncertainty. This reserve pool can be drawn from by trading participants to compensate for unanticipated shortfalls in the quantities of credits actually generated, thereby buffering against temporary compliance shortcomings.[61] One method to accomplish this is to increase the trading ratio slightly, setting aside this fraction of each traded credit into a reserve pool.

However, when establishing a ratio, caution is suggested to "avoid creating redundancy in uncertainty measures, compounding multipliers, or using excessively large factors" as this increases credit costs, impacting the economic calculus that underpins WQT.[62] Importantly, a number of the aforementioned factors may be addressed in different components of trading program development—not all of these factors necessarily need to be built into a ratio. Finding the proper balance is paramount to creating a defensible yet viable program.

iv. Credit Duration

Credit duration, commonly known as credit life, refers to the "length of time credits are expected to be used."[63] Put simply, this refers to the period between when a credit becomes usable as an offset and when the credit is no longer valid.[64] The EPA Trading Policy provides that "credits may be generated as long as the pollution controls or management practices are functioning as expected" and may be used to comply with an annual, seasonal, or monthly NPDES permit limit once they have been generated. [65] The most straightforward approach for determining the credit duration is to tie the credit's lifespan to the critical period defined in a TMDL or similar watershed analysis as detailed in the NPDES permit. For point-to-point source trading, this would mean that the credit is generated when one point source foregoes a discharge that it is allowed under a permit. Depending on the terms of the permit, this may occur on a daily, monthly, or seasonal basis. From that point, the credit could remain valid for as long as the reduction remains in effect.

Thus, for a joint NPDES permit, the credit could continue as a valid offset for the duration of the permit term so long as the reduction remained in place. The credit could even be capable of being carried from one term to another. Conversely, credits may only remain valid for a given reporting period. The credit duration in a trading program is determined by the regulators, taking into account the specific circumstances of that program and the anticipated projects. Considering that the kind of technology solutions that generate credits in a point-to-point source trading program are usually permanent, it is important to clearly articulate the lifespan of credits. Too short of a duration will remove the financial incentive to generate credits while too long of a duration results in fewer facility upgrades. The length of credit validity must be determined as a fundamental component of a trading program that is negotiated as part of the overarching trading plan or framework.

---

[58] *See e.g.*, COLO. DEPT. OF PUBLIC HEALTH AND ENV., COLORADO POLLUTANT TRADING POLICY (2004).
[59] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1612.
[60] For Chesapeake Bay nutrient trading programs, EPA Region 3 recommended at least a 2-to-1 ratio to account for uncertainty. EPA, REGION 3, ACCOUNTING FOR UNCERTAINTY IN OFFSET AND TRADING PROGRAMS, at 4–5 (2014), *available at* http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/TradingTMs/Final_Uncertainty_TM_2-12-14.pdf. Colorado likewise adopted a minimum 2-to-1 ratio for nutrient trades involving nonpoint sources. 5 COLO. CODE REGS. § 85.5(3)(d)(ii).
[61] NAT'L NETWORK ON WATER QUALITY TRADING, BUILDING A WATER QUALITY TRADING PROGRAM: OPTIONS & CONSIDERATIONS, 78–80 (2015), *available at* www.willamettepartnership.org/publications/.
[62] *Id.*
[63] OR. ADMIN. RULES § 340-039-0025(5)(f)(C).
[64] WILLAMETTE P'SHIP & THE FRESHWATER TRUST, DRAFT REGIONAL RECOMMENDATIONS FOR THE PACIFIC NORTHWEST ON WATER QUALITY TRADING, 87 (2014).
[65] 2003 EPA Water Quality Trading Policy, 68 Fed. Reg. at 1612.

v. Accounting of Credits Generated and Used

The most important aspect of point source trading credit characteristics is credit accounting. Accounting for credits entails tracking individual credits from their inception through their usage. This ensures that credits are only used for compliance one time and by one entity, thereby avoid the problem of double counting credits. Commonly a third-party centralized credit exchange serves as a broker for the credits and handles the accounting. These exchanges are neutral intermediaries that can verify the credit generation and track the sale and usage of the credits. On the other hand, in some instances trading participants handle the credit accounting with the regulatory body serving as an overseer as part of permit compliance monitoring. Regardless of the method utilized maintaining accurate records is quite important as it demonstrates permit compliance.

A major consideration in credit accounting is the quantity and timing of credits required for compliance. This deals with the "number of credits needed and any credit generation milestones[.]"[66] It is of utmost importance to have clarity regarding the compliance deadline and number of credits needed. These terms should be unambiguously included in the permit. Of note, in trading programs permits often rely on a compliance schedule that provides the permittee some leeway in achieving compliance with the final NPDES permit limits.[67] A compliance schedule stipulates the precise number of credits required to be generated by certain deadlines. While missing these deadlines constitutes a violation of the permit, achieving the most stringent discharge limits is postponed, providing a measure of leeway to permittees.

Overall, the issue of credit characteristics is not as problematic in the context of point-to-point source trading due to the quantifiable nature of the reductions being traded. Regardless, it is important to establish a uniform credit characteristics (quantification method, unit, duration) as well as a tracking and reporting system to accurately track all discharges from both the credit generator and the credit buyer. Tracking and reporting is essential in reducing the risk of double counting, paper credits,[68] and credit stacking.

1.4. Point-to-Point Source Trading Program Examples

Point-to-point source trading programs in other states illustrate how such trading has furthered the purposes of the Clean Water Act. Some trades have been one-time undertakings completed either as pilot programs or to provide flexibility for a point source to adopt a permanent solution to its water quality concerns. Many other trades are fully-established, continually-operating programs that support marked environmental improvements at lower costs than traditional technological solutions. Both one-off projects and fully baked programs offer lessons and insight that can guide the formulation of new water quality trading systems.

A. LONG ISLAND SOUND NUTRIENT CREDIT EXCHANGE – CONNECTICUT

The Long Island Nutrient Credit Exchange is a multiple source credit trading exchange. In 1990, Connecticut, New York, and the EPA adopted a Comprehensive Conservation and Management Plan (CCMP) for the Long Island Sound.[69] The CCMP calls for reducing nitrogen to address decreased levels of dissolved oxygen in Long Island Sound and mitigating related hypoxia damage to the Sound's ecosystem. To accomplish this, the CCMP establishes a baseline of dissolved oxygen concentrations at 1990 levels and calls for a 58.5% reduction within

---

[66] OR. ADMIN. RULES § 340-039-0025(5)(f)(A).

[67] This is because trading is most commonly adopted in response to the imposition of notably more stringent permit limits.

[68] "Paper credits" refer to credits that exist on paper but do not relate to actual pollution reductions in the environment. This undermines the efficacy of a trading program and opens it up to potential liability for CWA violations.

[69] LONG ISLAND SOUND STUDY, THE COMPREHENSIVE CONSERVATION AND MANAGEMENT PLAN (Mar. 1994), *available at* http://longislandsoundstudy.net/wp-content/uploads/2011/10/management_plan.pdf.

15 years. A 2001 TMDL included wasteload allocations for point sources and load allocations for non-point sources in the watershed that reflected this 58.5% decrease.[70]

One of the core strategies to achieve these reductions is using an innovative nitrogen trading program among 79 POTWs that discharge directly or indirectly into Long Island Sound. In January 2002, Connecticut's Department of Energy and Environmental Protection[71] issued a General Permit for Nitrogen Discharges to implement the TMDL and the trading program. This permit has been reissued with revised discharge limits several times since and remains in effect today.[72] That permit and the trading program it facilitated has resulted in a 65% reduction in nitrogen from the 1990 levels.[73]

Under the nitrogen trading program, participating POTWs must individually meet the annual average discharge limits in the permit. Conversely, the facilities may purchase the necessary credits to achieve their individual limits through the program, which is administered by an advisory board and the Connecticut Department of Energy and Environmental Protection.[74] POTWs performing better than required by their permit limits generate credits to sell through the program. The reconciliation period for this program is one year. Importantly, while the state had subsidized this program by purchasing excess credits, that subsidy recently ended as the program reached a point of self-sufficiency.[75]

B. CHESAPEAKE BAY NUTRIENT CREDIT EXCHANGE PROGRAM

Virginia, Pennsylvania, Maryland, the District of Columbia, and the EPA signed a cooperative agreement in 2000—the latest in a series of similar agreements—to cooperatively work to improve Chesapeake Bay's water quality. Virginia and Pennsylvania developed trading programs make progress towards these goals and allow dischargers flexibility in achieving compliance with permit limits. Despite these efforts and the modest water quality improvements, a TMDL was necessary to address the impairments caused by nitrogen, phosphorus, and sediment.[76] The TMDL continues to advance WQT as a means to achieve nutrient reduction efficiently and the trading programs developed by Virginia and Pennsylvania have become more robust as a result.[77]

i. Virginia Nutrient Credit Exchange Program

To accelerate the progress made under the cooperative agreement, the Virginia General Assembly passed the Chesapeake Bay Watershed Nutrient Credit Exchange Program in 2005.[78] This led to the passage of a watershed-based general permit[79] for all point sources that includes individual nutrient limits and combined limits

---

[70] N.Y. Dep't of Envtl. Conservation & Conn. Dep't of Envtl. Prot., A Total Maximum Daily Load Analysis to Achieve Water Quality Standards for Dissolved Oxygen in the Long Island Sound (Dec. 2000).
[71] 2001 CONN. LEGIS. SERV. 01-180 (S.S.B. 1012) (West).
[72] Conn. Dep't of Energy & Envtl. Prot., General Permit for Nitrogen Dischargers (Jan 1, 2016).
[73] CONN. DEP'T OF ENERGY & ENVTL. PROT., REPORT OF THE NITROGEN CREDIT ADVISORY BOARD FOR CALENDAR YEAR 2013 TO THE JOINT STANDING ENVIRONMENT COMMITTEE OF THE GENERAL ASSEMBLY (Sept. 30, 2014), *available at* http://www.ct.gov/deep/lib/deep/water/municipal_wastewater/nitrogen_report_2013.pdf.
[74] CONN. GEN STAT ANN. § 22a-523 (West 2015).
[75] 2015 Conn. Acts 15-38 (Reg. Sess.), https://www.cga.ct.gov/2015/act/pa/pdf/2015PA-00038-R00SB-00940-PA.pdf.
[76] U.S. EPA, Chesapeake Bay Total Maximum Daily Load for Nitrogen, Phosphorus and Sediment (Dec. 2010).
[77] *Id.* at § 10 ("EPA expects the jurisdictions to develop offset programs that are credible, transparent, consistent with [the TMDL], and subject to EPA and public oversight"); *Id.* at App. S.
[78] VA. CODE ANN. §§ 62.1-44.19:12–19 (2015). In passing this law, the General Assembly found that "adoption and utilization of a watershed general permit and market-based point source nutrient credit trading program will assist in (a) meeting these cap load allocations cost-effectively and as soon as possible in keeping with the 2010 timeline and objectives of the Chesapeake 2000 Agreement, (b) accommodating continued growth and economic development in the Chesapeake Bay watershed, and (c) providing a foundation for establishing market-based incentives to help achieve the Chesapeake Bay Program's nonpoint source reduction goals." *Id*. at § 62.1-44.19:12.
[79] Va. Dep't of Envtl. Quality, VPDES Watershed Permit for Nutrient Discharges to the Chesapeake Bay, 9 VA. ADMIN. CODE § 25-820 (2012); Va. State Water Control Bd., Fact Sheet: Modification of a General VPDES Permit to Discharge to State Waters (2012), www.deq.virginia.gov/Portals/0/DEQ/Water/PollutionDischargeElimination/VAN00FactSheet2012.pdf.

representing a watershed cap on all discharges.[80] The general permit and the trading program it encourages allows for trading between point sources operating under the watershed-based permit as one mechanism to improve environmental conditions.[81] While the trading program went into effect prior to the establishment of the TMDL, it continues to operate under the framework of the TMDL, albeit with more stringent discharge limits.

Virginia's trading program operates in two ways. First, existing point sources may generate credits by remaining under their nutrient allocations and by trading those credits with facilities in the same river basin to achieve year-end compliance.[82] The credits do not relieve the point source from the duty to comply with TBELs but allow flexibility in meeting WQBELs. If insufficient point source credits exist, a facility may pay into a general fund that is used to generate nonpoint source reductions.[83] However, while these existing sources may trade credits generated from unused allocations, they may not trade the actual allocations.[84]

The second set of trading provisions concerns new and expanding point sources. These sources do not receive nutrient allocations under the TMDL. Rather, they may purchase allocations from an existing source or fund long-term nonpoint source nutrient reductions.[85] Thus, Virginia allows for the transfer of WLAs for new sources.

This program has notably decreased nutrient loading from Virginian point sources into the Chesapeake Bay.[86] Virginia's "realistically aggressive" water quality goals continue to be met in large part due to this voluntary, market-based program.[87] The success of this trading program led EPA Administrator Gina McCarthy to remark that EPA "encourage[s] states to look at Virginia as a model and a resource as they adopt similar programs."[88]

ii. Pennsylvania Nutrient Credit Trading Program

Pennsylvania, also a signatory to the Chesapeake Bay Cooperative Agreement, approved a trading policy in 2006 that allows point sources to participate in a trading program.[89] The nutrient trading program was further strengthened by the passage of trading regulations in 2010.[90] While there have been some questions about the efficacy of the nonpoint source aspects of the Pennsylvania trading program,[91] it nevertheless serves as an informative example of point-to-point source trading.

The nutrient trading program allows point sources operating under individual NPDES permits to sell credits to other point sources using a centralized credit exchange. Credits are generated by any reduction below a facility's

---

[80] 9 VA. ADMIN. CODE § 62.1-44.19:14 ("An owner or operator of two or more facilities located in the same tributary may apply for and receive an aggregated [WLA for total nitrogen and total phosphorus] for multiple facilities reflecting the total of the water quality-based total nitrogen and total phosphorus [WLAs] established for such facilities individually").
[81] *Id.* at § 62.1-44.19:17 ("The permittees under the general permit may establish a nonstock corporation . . . , the Virginia Nutrient Credit Exchange Association, to coordinate and facilitate participation in the nutrient credit exchange program").
[82] 9 VA. ADMIN. CODE § 25-820-70(J) (2015). The credits also cannot be carried from one year to the next and are usually subject to a 1-to-1 trading ratio, though a 1-to-3 ratio may apply in some instances. *Id.* at § 25-820-70(J)(2)(b). *See also* U.S. EPA, FINAL REPORT: VIRGINIA'S TRADING AND OFFSET PROGRAMS REVIEW OBSERVATIONS (Feb. 2012).
[83] VA. CODE ANN. § 62.1-44.19:18.B (2015).
[84] Kurt Stephenson, et al., U. of Minn., Dep't of Applied Econ., *An Evaluation of the Virginia's Nutrient Credit Trading Program*, 5 (2006), *available at* http://ageconsearch.umn.edu/bitstream/21071/1/sp06st06.pdf.
[85] VA. CODE ANN. § 62.1- 44.19.15(B) (2015).
[86] Reductions in wastewater pollutants have been and remain ahead of schedule for nitrogen, phosphorus, and sediment. *See* U.S. EPA, Fact Sheet: EPA Evaluation of Virginia's 2014-2015 Milestone Progress (June 2016).
[87] Va. Nutrient Credit Exchange Ass'n, Exchange Compliance Plan: 2015 Annual Update, 1-1 (Feb. 2015).
[88] U.S. Dep't of Agric., Office of Commc'n, News Release: Federal Agencies Support Virginia's Innovative Market-based Approach to Improving Water Quality in the Chesapeake Bay, No. 0270.14 (Dec. 2014).
[89] Penn. Dep't of Envtl. Protection, Final Trading of Nutrient & Sediment Credits: Policy & Guidelines, 392-0900-001 (Dec. 2006).
[90] 25 PA. CODE § 96.8 (2015).
[91] The allegations of impropriety leveled at the Pennsylvania trading program relate to nonpoint source credit generation and the tracking of those nonpoint source credits, not the point-to-point source program discussed herein. Food & Water Watch, *Water Quality Trading: Polluting Public Waterways for Private Gain* (Nov. 2015).

WLA[92] and used for compliance with the applicable WQBELs.[93] New facilities that face a lack of sufficient WLAs may purchase credits sufficient to offset the new or increased discharge.[94] Wasteload allocations may not be sold to a different facility, but may be transferred between facilities with the same owner, subject to some conditions.[95] Conversely, the unused WLA could be sold as a credit, although permanent transfers are not allowed. This program has not seen the objective success that has been generated by Virginia's program.[96]

C. DIXIE DRAIN PHOSPHORUS REMOVAL PROJECT – IDAHO

The Dixie Drain Offset Project constitutes an intra-plant offset project, meaning that the facility seeking to offset its discharges is responsible for generating the offset credits. The City of Boise operates two separate POTWs that discharge into the Boise River. That waterway has been listed as impaired for phosphorus, largely due to phosphorus laden agricultural return flows.[97] Faced with the prospect of spending large sums of money to reduce its phosphorus discharges by 98%, the City opted to utilize an innovative offset program. The program requires the City to make significant reductions in phosphorus discharges at its wastewater facilities. Those reductions, however, are lower than what was called for in the absence of such a program, with the remaining required phosphorus reductions coming from the waterway itself, as described below.

To make the remaining required reductions, the City installed a new treatment facility on the Dixie Slough, an agricultural return drain (the "Dixie Drain"). The Dixie Drain transports a large portion of the phosphorus discharged from the Boise River into the Snake River—by some estimates up to 40% of the phosphorus loading into the Snake River.[98] That facility withdraws water from the Dixie Slough using a gravity-fed diversion. That water is treated, removing a majority of the phosphorus before discharging the treated water back into the Slough. These reductions offset the phosphorus exceedances from the City of Boise's other wastewater plants using a 1.5-to-1 ratio. Thus, for every pound of phosphorus discharged by the POTWs beyond their permit limit, 1.5 pounds are removed at the Dixie Drain Treatment Facility. This program aims to "yield a net environmental benefit by removing more phosphorus on an annual basis (approximately 5,000 lbs/year) from the Boise River and allow the City to treat an unregulated non-point source agricultural return drain."[99]

D. NEUSE RIVER BASIN SENSITIVE WATERS MANEGEMENT STRATEGY – NORTH CAROLINA

The Neuse River watershed is a 5,600 square mile basin located entirely within North Carolina. The watershed is listed as impaired due to nutrients, mainly total nitrogen (TN), which has caused eutrophication of the Neuse estuary.[100] In 1996, the North Carolina legislature set the goal of reducing nitrogen loading 30% by 2003,[101] leading to the development of the Neuse River Sensitive Waters Management Strategy to meet this goal.[102] The strategy establishes annual TN allocations for existing point source dischargers, allowing those dischargers to participate in a group compliance program in order to collectively meet their nitrogen permit limit.

---

[92] 25 PA CODE § 96.8(e)(3). This determination is based on the discharge monitoring reports required by the permit.
[93] Credits may not be used to comply with TBELs. Pa. Dep't of Envtl Protection, Phase 2 Watershed Implementation Plan Nutrient Trading Supplement (Rev. Feb. 2016).
[94] EVEN BRANOSKY, ET AL., WORLD RES. INSTITUTE, COMPARISON TABLES OF STATE NUTRIENT TRADING PROGRAMS IN THE CHESAPEAKE BAY (May 2011).
[95] Pa. Dep't of Envtl Protection, Phase 2 Watershed Implementation Plan Nutrient Trading Supplement (Rev. Feb. 2016).
[96] U.S. EPA, Fact Sheet: EPA Evaluation of Pennsylvania's 2014-2015 Milestone Progress (June 2016).
[97] Id. Dep't of Envtl. Quality, Idaho's 2012 Integrated Report (Jan. 2014) (2012 303(d) list of water impairment).
[98] Adam Cotterell, New Boise Project Seen as Innovative Way to Improve Water Quality, BOISE STATE PUB. Radio (Feb. 25, 2015), http://boisestatepublicradio.org/post/new-boise-project-seen-innovative-way-improve-water-quality#stream/0.
[99] U.S. EPA, Fact Sheet: Proposed Modification to West Boise Wastewater Treatment Facility NPDES Permit, ID-002398-1, *available at* https://www3.epa.gov/region10/pdf/permits/npdes/id/west_boise_dixie_mod_fs_id0023981_091312.pdf.
[100] U.S. EPA, Watershed-based Permitting Case Study: Neuse River Watershed, North Carolina (July 2007).
[101] 1995 N.C. Sess. Laws 559 (passing House Bill 1339: Nitrogen Reduction Goals).
[102] 15A N.C. ADMIN. CODE 02B.0233 (2015).

The major dischargers in the Neuse River Basin have a joint NPDES permit.[103] The 22 co-permittees under this watershed-based permit are collectively known as the Neuse River Compliance Association and are authorized to achieve permit compliance on a collective basis. Each participating entity has individual discharge limits for nitrogen, as well as equivalency factors to account for the attenuation of nutrients when trading; but the individual limits only come into play in the event that the association as a whole violates the combined limits. The program lacks a centralized exchange, though the association oversees transfers of unused nitrogen allocations among members, both on a temporary and permanent basis.[104] The program has proven a success and the permittees have reduced their nitrogen discharges to less than half of the amount authorized by the permit through a series of trades and incentivized actions.

E. MINNESOTA RIVER BASIN PHOSPHORUS TRADING PROGRAM – MINNESOTA

The Minnesota Pollution Control Agency has expressed long-standing interest in water quality trading as a means to address the state's widespread water quality impairment caused by nutrients. In 2005 the state authorized point-to-point source trading for nutrient impaired waterways by issuing a watershed-based permit to both improve water quality and accommodate future growth.[105] This permit was issued for the Lower Minnesota River Basin, which suffered low dissolved oxygen levels due to excess phosphorus. Two years later the agency commenced rulemaking to guide trading programs, but eventually abandoned this effort as unnecessary in light of a new 2014 law.[106]

The general permit for the Minnesota River Basin went into effect in 2005 and covered 40 significant wastewater treatment facilities in the watershed.[107] Under this permit and pursuant to the terms of the TMDL and its implementation plan,[108] the facilities constituting the major sources of phosphorus have the option of trading amongst themselves to meet their discharge limits. The facilities may generate credits by reducing their phosphorus discharge below the applicable permit limits and selling those credits to an individual buyer.[109] A trading ratio of either 1.1-to-1 or 1.2-to-1 applies to trades to ensure they result in environmental benefits and to account for attenuation.[110] Under this program there have been an average of 17 trades per year.[111] Not only has this proven to be a more cost-effective means of reducing phosphorus loading, but it has resulted in improvements to the watershed.[112]

---

[103] N.C. Dep't of Env't & Natural Res., National Pollutant Discharge Elimination System: The Neuse River Compliance Association and Its Co-Permittee Members, NCC000001 (Dec. 2014).

[104] NEUSE RIVER COMPLIANCE ASSN., 2014 ANNUAL REPORT (Mar. 2014).

[105] Minn. Pollution Control Agency, NPDES and State Disposal System Permit: General Authorization to Discharge Phosphorus to the Minnesota River Basin and Authorization to Transfer Jordan Trading Units, MNG420000 (Dec. 2005, rev. Dec. 2009). The permit appears to have been reissued then administratively extended, remaining in effect to date.

[106] 2014 MINN. LAWS 10846. The revised statutory section allows the permitting agency to authorize trading if it "achieves a net decrease in the pollutant loading to the receiving water." MINN. STAT. ANN. § 115.03 (West 2015).

[107] *Id.*; Minn. Pollution Control Agency, Minnesota River Basin General Phosphorus Permit – Phase I: Phosphorus Trading Overview, wq-b3-18 (Apr. 2007). The general permit served as an overlay to bring together the individual permits.

[108] Minn. Pollution Control Agency, Lower Minnesota River Dissolved Oxygen: Total Maximum Daily Load Report (May 2004); Minn. Pollution Control Agency, Lower Minnesota River Dissolved Oxygen: Total Maximum Daily Load Implementation Plan (Feb. 2006).

[109] Minn. Pollution Control Agency, NPDES and State Disposal System Permit: General Authorization to Discharge Phosphorus to the Minnesota River Basin, MNG420000, at 9 (Dec. 2005, rev. Dec. 2009).While the agency allowed permittees to form associations to facilitate trading, no associations have been formed.

[110] *Id*. *See also* Minn. Pollution Control Agency, Minnesota River Basin General Phosphorus Permit – Phase 1: Phosphorus Trading Overview, wq-b3-18 (Apr. 2007).

[111] MICHAEL N. ZAJICEK, WATER QUALITY TRADING ON THE MINNESOTA RIVER: LESSONS LEARNED FROM THE JORDAN TRADING PROGRAM, MASTER'S THESIS, U. OF MINN., 24 (Aug. 2013).

[112] Minn. Pollution Control Agency, Minnesota River Basin: Environment and Water Quality Achievements, (Feb 2009).

F. OTHER TRADING AND OFFSET PROGRAMS – CALIFORNIA

Several trading programs type have gained approval from California regulators and the EPA. In the absence of state guidance these programs have been developed individually. The main trading programs are the nonpoint source Grasslands Bypass Trading Program (1998) and the Laguna de Santa Rosa Offset Plan (2008). Several other watershed-based permits that share some similarities with WQT have also been approved.[113]

i. Los Angeles MS4 Watershed-based NPDES Permit

The prime example of a watershed-based permit in California is the Los Angeles Municipal Separate Storm Sewer System (MS4) NPDES Permit.[114] That permit applies to 84 distinct entities with jurisdiction over stormwater, allowing them to collaboratively establish Watershed Management Programs to meet water quality goals. This program allows permittees to establish permit compliance jointly on a watershed scale. While not a WQT program, it is similar in that off-site pollutant reductions can help establish NPDES permit compliance.

ii. Grasslands Bypass Nonpoint-to-Nonpoint Source Trading Project

The Grasslands Bypass Trading Project is another similar trading program. In 1996 San Joaquin Valley drainage districts needed to address elevated selenium levels in the waterways in order to obtain approval to use Bureau of Reclamation's San Luis Drain.[115] To get approval, an agreement was struck that imposed numeric selenium limits.[116] All of the participants received Waste Discharge Requirements (WDR) that included selenium load allocations, which became more stringent annually until eventually equaling TMDL load allocations.[117] Each drainage district had flexibility to determine how to meet the limits and could pay other districts to make further reductions. Most of the completed trades were retroactive as credits were needed to achieve compliance for the previous year. Several districts did partake in trades, though in recent years other compliance options made trading unnecessary.

iii. Laguna de Santa Rosa Nutrient Offset Program

The most recent and most analogous offset program is the 2008 Santa Rose Nutrient Offset Program, which saw its first trade in 2012.[118] The Santa Rosa Subregional Water Reclamation Facility discharges into the Laguna de Santa Rosa watershed—a CWA section 303(d) listed waterbody impaired by nutrients, metals, bacteria, sediment, and temperature.[119] To address the nutrient impairment, the RWQCB imposed a "no net loading" nutrient limit (both nitrogen and phosphorus) in Santa Rosa's NPDES permit.[120] The facility upgrades needed for

---

113 Watershed-based permits regulate multiple sources within a large geographic area under a single permit. Due to the jointly applicable limits, offsetting actions are easily implemented to allow for a form of credit trading between permittees.

114 L.A. Reg'l Water Quality Control Bd., Order No. R4-2012-0175, Permit No. CAS004001, Waste Discharge Requirements for MS4 Dischargers within Coastal Watersheds of Los Angeles County (2012, rev. July 2015).

115 U.S. EPA, *Grassland Bypass Project: Economic Incentives Program Helps to Improve Water Quality* (Aug. 2012).

116 U.S. Dep't of the Interior, Bureau of Reclamation, Agreement for Use of the San Luis Drain, No. 01-WC-20-2075 (Sept. 2001), *available at* www.usbr.gov/mp/sccao_new/west_sjv/grassland/documents/index.html.

117 Waste Discharge Requirements are similar to NPDES permits but issued by the California SWRCB under the California Porter-Cologne Water Quality Act, which regulates more sources than the CWA. HANNA L. BREETZ, ET AL., WATER QUALITY TRADING AND OFFSET INITIATIVES IN THE U.S.: A COMPREHENSIVE STUDY 10 (Aug. 5, 2005).

118 N. Coast Reg'l Water Quality Control Bd., Res. No. R1-2008-0061: Approving Santa Rosa Nutrient Offset Program (July 24, 2008), *available at* http://www.waterboards.ca.gov/northcoast/water_issues/programs/nutrient_offset_program/.

119 CAL. STATE WATER RES. CONTROL BD., 2010 INTEGRATED REPORT (CLEAN WATER ACT SECTION 303(D) / 305(B) REPORT) (2010). The waterway is also listed as impaired by Trash, Sulfates, Selenium, Invasive Species, Fish Barriers, and Unnatural Foam/Scum.

120 "No net loading" means the facility has a numeric discharges limit for nutrients equal to zero. The permit did expressly allow this limit to be met by reducing discharges elsewhere in the watershed, though the North Coast RWQCB did require this to be accomplished pursuant to an approved offset plan. *See* N. Coast Reg'l Water Quality Control Bd., Order No. R1-2006-0045, Permit No. CA0022764, Waste Discharge Requirements & Master Reclamation Permit for the Santa Rosa Subregional Water Reclamation System, at 13, n. 5 (2006, rev. July 2008, Apr. 2009).

compliance cost roughly $40 million.[121] Rather than install costly technology, Santa Rosa pursued a WQT program that allows for quantified and credited mitigation at select agricultural sites in the basin to reduce the animal waste and fertilizer runoff entering the waterway. With the support of the North Coast RWQCB, Santa Rosa continues to use WQT to achieve permit compliance at a fraction of the alternative cost.

Santa Rosa's WQT program operates under a general framework adopted by the North Coast RWQCB.[122] Currently, the framework is undergoing a process of revision to strengthen the program and more closely align it with national trading guidance. An updated framework is expected in the near future. Despite the anticipated updates, the existing framework still provides insight into the potential characteristics of a WQT program.

The existing Santa Rosa WQT Program measures NPDES permit compliance using an average of the actual nutrient discharge loads for the past three years. Thus, exceedances in one year can be offset in the next year using WQT. The program measures reductions in one of two ways. For directly measured reductions, the entire reduction minus a small margin of safety can be claimed. For actions with modeled reductions, credits are calculated using median effectiveness estimates minus the margin of safety, thus only a portion of the reductions are creditable. Operating within these confines, the facility has removed significant amounts of nutrients from the watershed, creating a variety of ancillary environmental benefits and meeting the NPDES permit limits in a cost effective manner.

G. LESSONS FROM OTHER TRADING PROGRAMS

An objective review of these examples, especially Connecticut's Long Island Sound Nutrient Credit Exchange and Virginia's Chesapeake Bay Nutrient Credit Exchange, provides some important insight into the aspects of successful point-to-point trading programs and potential applicability to the San Francisco Bay. Both of those programs demonstrate the importance of focusing on a discrete watershed and including an entire class of dischargers in that basin. By including all similar dischargers in a basin, it is possible to meaningfully address the water quality impairments while avoiding the free-rider problem.

The most efficient way to bring all of the similar sources together is through the issuance of a joint watershed-based permit, like both Virginia and Connecticut pursued. This permit defines a baseline level of pollution for the whole watershed from which decreases can be measured for all sources together. Mandatory reductions from this baseline level establish the driver for a trading program by requiring the participants to achieve reductions on a predetermined timeline. Importantly, this general permit also sets individual limits for each facility that serve as the basis for water quality credit generation and makes it possible to identify and enforce against individual permittees. By having this general permit with both shared and individual discharge limits, the facilities can make economically rational decisions about how to manage their operations and achieve the required pollutant reductions. None of these entities is required to participate in the trading program, they may opt to pursue technological solutions internally to meet the applicable individual limits. However, the flexibility and voluntary nature of such a program creates a situation wherein there is an incentive for cooperation among facilities out of individual self-interest.

Also, of utmost importance in a water quality trading program, is the guiding trading framework or plan. This plan may be developed as a section of the overarching general permit or developed independently as a standalone guidance document. In any event, the trading framework must be subject to public notice and comment. Regardless of the method chosen to frame out a program, it is important to incorporate the core components of a trading system such as the baseline, trading ratios, monitoring and reporting requirements,

[121] Keiser & Assoc., *City of Santa Rosa, California Nutrient Offset Compliance Project*, *available at* kieser-associates.com/uploaded/environmental_markets/city_of_santa_rosa_california_nutrient_offset_resolution_compliance_project.pd.

[122] N. Coast Reg'l Water Quality Control Bd., Res. No. R1-2008-0061: Approving Santa Rosa Nutrient Program (July 24, 2008).

compliance deadlines, and quantification methods. This plan or framework will also predetermine the specific means by which trading will occur—whether through a centralized exchange like in the Long Island Sound or by working with individual entities like Virginia's trading system. The important consideration is to establish these terms in a clear and definite manner. By unambiguously establishing these core components in conjunction with the potential trading participants, a transparent, effective, responsive, and resilient program is established.

1.5. Conclusion

Across the United States, many widely different water quality trading programs have been enacted with equally varying levels of success. Understanding the commonalities among trading programs and the core concepts present in all water quality trades helps to establish the mutual understanding necessary to formulate such a trading program. The Freshwater Trust's intent in this document is to provide a high-level summary of the most salient points to consider when articulating a water quality trading program and to introduce some examples of point-to-point trading in order to create the foundational understanding required to build a novel water quality trading system. This document should assist in creating the conditions for productive future conversations on water quality trading in the San Francisco Bay that will accompany the future deliverables.

2. Assessment of Challenges and Opportunities Related to a Point Source Nutrient Trading Program in the San Francisco Bay

Task 2: Review of Pertinent Regulatory, Jurisdictional, and Financial Considerations

Executive Summary – Task 2

Developing and implementing a water quality trading in the San Francisco Bay faces some challenges, though opportunities for such a program also exist. The challenges that must be overcome involve jurisdictional issues, financial concerns, and regulatory hurdles. The jurisdictional issues identified include a lack of guidance on water quality trading in California, the lack of a TMDL to guide trading activities, and the differences in authority of each water agency. Financial concerns include determining an equitable allocation of the expenses associated with developing and operating a trading program. The regulatory obstacles all involve determining the specific characteristics of a trading program for the watershed and resolving the scientific uncertainty.

Numerous opportunities exist in the Bay that support the development of a trading program. The existing Watershed Nutrient Permit helps to foster the underlying foundation for a trading program. Similarly, the scientific studies undertaken as part of that permit should resolve some of the scientific ambiguity that must be addressed prior to implementing a trading program. Furthermore, trading represents an opportunity to potentially avoid the need for a TMDL. The history of cooperation among the wastewater utilities in the Bay also presents an opportunity for a trading system as collaboration is a key requirement for both developing and implementing a trading program.

2.1. Introduction

This report constitutes the second task in a series of four tasks, all of which will be compiled into a single final report. This document seeks to identify some of the expected challenges to designing and implementing a successful point-to-point source water quality trading program for wastewater treatment plants in the San Francisco Bay. Although a point-to-point nutrient trading program could be expanded to include nonpoint source trading, the specifics of such an expansion and the components needed to incorporate nonpoint sources into a point source trading program, are beyond the scope of this analysis. Such information will be provided in a subsequent (Task 5) report. This report also aims to highlight the conditions in the Bay area that represent opportunities for a water quality trading program. While it is not possible to anticipate all potential challenges and opportunities, this report will identify and categorize the major considerations, both advantageous and problematic, as currently understood.[1]

2.2. Potential Challenges to a Trading Program

The following sections detail potential and current jurisdictional, financial, and regulatory issues that a new point-to-point source nutrient trading program would have to overcome.[2] Identifying and discussing these hurdles will ideally foster informed and strategic decision-making during the conception of a market-based compliance program.

A. JURISDICTIONAL HURDLES

The following challenges relate to potential jurisdictional issues. Put differently, these are issues that relate to regulatory authority to implement water quality trading broadly, and the ability of individual entities to participate in a trading program.

i. No State Policy on Water Quality Trading

Like most states, California has not adopted a uniform rule or policy framework to guide new trading programs.[3] Without such statewide direction, new programs must develop the core concepts and restrictions of a trading program on a case-by-case basis.

Despite this challenge, there are numerous sources of insight and guidance that can be drawn from to help shape this program. Federal, state, and nongovernmental guidance documents on water quality trading can provide some direction on core trading provisions. Specifically, the Environmental Protection Agency (EPA) has issued both an overarching water quality trading policy that presents the general requirements,[4] as well as more specific trading guidance.[5] Likewise, there are several documents, crafted by nonprofits and industry

---

[1] EBMUD should consult its attorneys on all matters related to the issues discussed in this document. Nothing herein should be construed as providing legal advice or recommendations.

[2] Some of the potential issues touch on several of these sections. The classifications used herein serve to provide clarity but should not be interpreted as concrete categories.

[3] Counsel for the State Water Resources Control Board has issued legal memorandum supportive of water quality trading under a TMDL and in pre-TMDL scenarios. Memorandum from Michael A.M. Lauffer, Chief Counsel, Cal. State Water Resources Control Bd., to Arthur G. Baggett, Jr., Chair, Cal. State Water Resources Control Bd., on Updated Legal Authority for Offsets, Pollutant Trading, and Market Programs to Supplement Water Quality Regulation in California's Impaired Waters With Established Total Maximum Daily Loads (Nov. 22, 2006); Memorandum from Craig Wilson, Chief Counsel, Cal. State Water Resources Control Bd., to Arthur G. Baggett, Jr., Chair, Cal. State Water Resources Control Bd., on Legal Authority for Offsets, Pollutant Trading, and Market Programs to Supplement Water Quality Regulation in California's Impaired Waters (Oct. 16, 2001), *available at* www.waterboards.ca.gov/water_issues/programs/tmdl/docs/iwguide_apxb.pdf.

[4] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. 1608, 1610 (Jan. 13, 2003), *available at* www.gpo.gov/fdsys/pkg/FR-2003-01-13/pdf/03-620.pdf.

[5] The Toolkit is arguably the most useful tool as it deals specifically with point-to-point trading, whereas many of the other sources of insight either address trading generally or focus on nonpoint source trading. U.S. EPA, WATER QUALITY TRADING TOOLKIT FOR PERMIT WRITERS, EPA

stakeholders, that lay out many of the options and considerations for a trading program, including the recent JOINT REGIONAL RECOMMENDATIONS FOR WATER QUALITY TRADING IN THE PACIFIC NORTHWEST,[6] and the NATIONAL NETWORK ON WATER QUALITY TRADING'S OPTIONS & Considerations.[7] These documents fill in the gaps left by the broad federal guidance, using examples to answer many of the lingering questions about trading and to make recommendations about the tradeoffs associated with programmatic decisions.

Despite the absence of a state policy, the Bay stakeholders can draw from several trading programs that have previously been established in California.[8] The State Water Resources Control Board's attorney has also issued a pair of memorandums on trading that broadly discuss the ability of Regional Boards to approve trading programs, lay out some overarching goals for trading, and guide the foundational components of programs.[9] Moreover, both the San Francisco Bay Basin Water Quality Control Plan and the watershed NPDES permit for Bay POTWs contain references to trading and offsets, indicating an openness on the part of the regulatory bodies to adopt such programs.[10] In addition, as described in Deliverable 1, lessons can be drawn from several other point-to-point programs from around the country, including the programs in Virginia and the Long Island Sound.

ii. No Total Maximum Daily Load Exists for Nutrients in the San Francisco Bay

According to EPA and the SWRCB, Total Maximum Daily Loads (TMDLs) are not a requirement for water quality trading,[11] though they are helpful in resolving many of the uncertainties concerning watershed conditions. Despite having a history of concern for nutrient overenrichment, the San Francisco Bay does not have nutrient water quality objectives or a TMDL for nutrients, nor has the Bay been officially designated as nutrient impaired. Without a TMDL, a watershed-scale study will likely be required to determine the various sources and scope of nutrient loading, and to identify how these different sources interact to affect ambient water quality and beneficial uses in the Bay. Likewise, individual discharger loadings will need to be determined in order to create the baseline for any credit generation and transfers. Therefore, a scientifically defensible watershed-scale understanding is needed to guide a potential trading program.

833-R-07-004 (Aug. 2007, rev. June 2009), *available at* www.epa.gov/npdes/pubs/wqtradingtoolkit.pdf; U.S. EPA, NPDES PERMIT WRITERS' MANUAL, EPA-833-K-10-001, at 5-1 (Sept. 2010).

[6] WILLAMETTE P'SHIP & THE FRESHWATER TRUST, DRAFT REGIONAL RECOMMENDATIONS FOR THE PACIFIC NORTHWEST ON WATER QUALITY TRADING, (2014).

[7] NAT'L NETWORK ON WATER QUALITY TRADING, BUILDING A WATER QUALITY TRADING PROGRAM: OPTIONS & CONSIDERATIONS (2015); WATER & ENVT. FOUND., ADVANCES IN WATER QUALITY TRADING AS A FLEXIBLE COMPLIANCE TOOL (2015).

[8] The Laguna de Santa Rosa Nutrient Offset Program is a point-to-nonpoint source trading program that allows a wastewater utility to achieve permit compliance by remediating nonpoint source pollution. N. Coast Reg'l Water Quality Control Bd., Res. No. R1-2008-0061: Approving Santa Rosa Nutrient Offset Program (July 24, 2008). There are also two nonpoint source trading programs. The Grasslands Bypass Selenium Trading Program was a nonpoint trading program involving several drainage districts that needed to cumulatively reduce selenium runoff to use a federal drain. U.S. Dep't of the Interior, Bureau of Reclamation, Agreement for Use of the San Luis Drain, No. 01-WC-20-2075 (Sept. 2001). Lastly, the Los Angeles MS4 Watershed-based permit allows for cooperation among the permittees to lower pollution in discharges to meet water quality standards. L.A. Reg'l Water Quality Control Bd., Order No. R4-2012-0175, Permit No. CAS004001, Waste Discharge Requirements for MS4 Dischargers within Coastal Watersheds of Los Angeles County (2012, rev. July 2015).

[9] *See supra*, note 3.

[10] *See e.g.*, CAL. REG'L WATER QUALITY CONTROL BD., S.F. BAY REGION, SAN FRANCISCO BAY BASIN WATER QUALITY CONTROL PLAN, 7-38 (Mar. 20, 2015); S.F. Bay Reg'l Water Quality Control Bd., Order No. R2-2014-0014, Permit No. CA0038873, Waste Discharge Requirements for Nutrients from Municipal Wastewater Dischargers to San Francisco Bay (Apr. 2014).

[11] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1610 ("EPA supports pre-TMDL trading in impaired waters to achieve progress towards or the attainment of water quality standards. EPA believes this may be accomplished by individual trades that achieve a net reduction of the pollutant traded or by watershed-scale trading programs that reduce loadings . . ."). "The extent to which [trading] may be employed varies greatly depending upon whether a TMDL has been adopted for an impaired water, although [trading] may be permissible in either context." SAN FRANCISCO REG'L WATER QUALITY CONTROL BD., SAN FRANCISCO BAY NUTRIENT MANAGEMENT STRATEGY (Nov. 2012); Cal. State Water Res. Control Bd., Final 2012 Integrated Report (CWA Section 303(d) List/305(b) Report), Res. 2015-0021 (Apr. 2015), *available at* http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2012.shtml.

The monitoring requirements associated with the existing nutrient watershed NPDES permit—which applies to more than 30 permittees, representing approximately two-thirds of all nutrient loading to the Bay[12]—should serve to resolve some of these uncertainties by generating the needed watershed-level data.[13] While future iterations of the watershed permit will likely include individual discharge allocations, thereby providing the source of baseline for potential trading participants,[14] more analysis will be required to understand how these discharges interact in the Bay. The ongoing studies undertaken by San Francisco Estuary Institute and funded by the Bay dischargers may provide the requisite understanding.

iii. Each Wastewater Facility is Governed by Different Local Authorities

The wastewater treatment facilities in the San Francisco Bay serve different localities and in some instances, differ in responsibilities and authorities, though they have largely similar missions. For example, the Central Contra Costa Sanitary District is a special enterprise district with a mission to protect public health and the environment by engaging in stewardship, sustainability, and wastewater treatment, whereas East Bay Municipal Utility District is a publicly-owned utility.[15] Other wastewater utilities in the Bay are organized in a number of ways, including as joint powers agencies, special act districts, and municipal agencies (i.e. Cities), to name a few. Despite many similarities between the management, authority, and responsibilities of the facilities, the differences may result in some difficulties as the entities collaborate to develop a trading program, though the history of cooperation may render this potential issue moot. Because of these differences, if trades are entered into by individual facilities, it may be necessary for participating treatment facilities to enter into Memorandums of Understanding (MOU), Agreement (MOA) or contracts to explicitly lay out the responsibilities and liabilities of each trading participant, to ensure no redundant efforts are made and the interests of all participants are protected, and to protect against inequitable distribution of costs and benefits. On the other hand, centralized credit banks or exchanges may eliminate the need for such agreements.

The existence of the Bay Area Clean Water Agencies (BACWA) can facilitate this effort by building upon the existing level of collaboration among the Bay area facilities. As a centralized entity accustomed to working with the various wastewater utilities and having a thorough understanding of its members needs and positions, BACWA is uniquely positioned to facilitate this process.[16] Just as it leads the annual group reporting under the nutrient permit,[17] BACWA could serve as a credit exchange, or at least as an inter-governmental agreement clearinghouse. Having a central entity to direct programmatic efforts could potentially negate the need for individual agreements, minimizing transaction costs.

B. FINANCIAL HURDLES

In order to justify the development of a trading program, the overall cost of trading generally should be cheaper or on-par with the cost of reductions from traditional compliance solutions. This calculus is especially difficult

[12] San Francisco Bay Regional Water Quality Control Board, San Francisco Bay Nutrients Project (2016), http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/planningtmdls/amendments/estuarynne.shtml.
[13] S.F. Bay Reg'l Water Quality Control Bd., Order No. R2-2014-0014, Permit No. CA0038873, Waste Discharge Requirements for Nutrients from Municipal Wastewater Dischargers to San Francisco Bay (Apr. 2014).
[14] The baseline for credit generation by point sources is "its most stringent applicable effluent limitation." U.S. EPA, Water Quality Trading Toolkit for Permit Writers, 6, EPA 833-R-07-004 (Aug. 2007, rev. June 2009).
[15] Central Contra Costa Sanitary District, www.centralsan.org/index.cfm?navId=63 (last visited Nov. 29, 2016); East Bay Municipal Utility District, www.ebmud.com/about-us/board-directors/governance/ (last visited Nov. 29, 2016).
[16] This undertaking would even advance BACWA's commitments and goals. Bay Area Clean Water Agencies, http://bacwa.org/about/vision/ (last visited Nov. 29, 2016).
[17] Bay Area Clean Water Agencies Nutrient Reduction Study, Group Annual Report: Nutrient Watershed Permit Annual Report 2016 (Oct. 2016), http://bacwa.org/wp-content/uploads/2016/09/Group-Annual-Report-2016_Final.pdf.

when the compliance options of multiples parties are at play, and the cost savings must be shared amongst a group of dischargers over a period of time.

i. Funding the Development of a Trading Program

Developing a trading program generally constitutes a somewhat intensive venture in terms of time and resources. Completing the necessary scientific analyses, especially in the absence of a TMDL, is no simple undertaking, though other programs have arisen in the absence of a TMDL. Likewise, formulating the specific components of a trading program requires ongoing negotiations and collaboration between the various stakeholders and the Regional Water Quality Control Board as well as the State Water Resources Control Board. All of this takes resources, both in terms of staff time and financial support.

Dividing this need among interested parties in a way that accounts for the differences in size and resources of the facilities is important to avoid potential conflicts. If only staff time is involved, each participant may choose the level of involvement they feel is necessary. However, if monetary contributions are required, the issue arises of how to equitably assign responsibility for these contributions while simultaneously avoiding the classic free-rider problem. Open dialogue on this issue as well as mutual collaboration and cooperation will be needed to avoid unfairly burdening some entities. In sum, the interested parties and anticipated participants will need to determine the appropriate level of involvement and division of resources at each stage of the program development: conceptualization, feasibility analysis, framework formulation, stakeholder outreach, and the finalization of the trading plan. It is worth mentioning that the Bay has significant resources already established that lay the groundwork for and generally assist with this effort, as well as BACWA as a strong collaborative.[18]

ii. Funding the Implementation and Operation of a Trading Program

The issue of resource demands that comes up in the context of program development also arises with regard to the implementation of a program. The costs of trading is exceedingly important, as a program is unlikely to succeed if its potential savings are not clear.[19] The question of economic viability touches on the specifics of program implementation and operation, the cost of credits, and the anticipated savings associated with trading compared to other solutions.

The amount of funding needed for trading program implementation varies widely based on the program details, credit requirements, and the region. For instance, trades from one facility to another without the involvement of an intermediary do not raise equity questions, as the participants bear their own expenses and an individual deal is negotiated in mutually beneficial terms. However, if a centralized exchange is used, then the exchange will need financial support to operate. This sometimes requires direct contributions. More often, an exchange operates using a sustainable, self-supporting business model. Such a business model could constitute the retention of a portion of each credit that passes through the exchange or a percent of all credit purchases (analogous to a sales tax). Another option is for the exchange to require a flat or prorated fee as a precondition to participating.

Overall, the implementation funding is less of an issue than the funding of program development as the level of participation tends to delineate the required level of programmatic support. Thus, if broad interest exists, then a centralized exchange using a tax or fee would likely make the most sense, whereas low levels of interest do not warrant a central exchange as individual efforts will be commensurate with the desired involvement.

---

[18] For instance, the San Francisco Estuary Institute has studied the Bay heavily and the existing General Nutrient Permit creates some baseline analysis. Numerous other studies have been completed as well. *See, e.g.*, Lester J. McKee, et al., *Numeric Nutrient Endpoint Development for San Francisco Bay Estuary: Literature Review and Date Gaps Analysis*, S. CAL. COASTAL RESEARCH PROJECT Rep. No 644 (2011).

[19] For instance, in Idaho a plan for trading was developed in conjunction with the TMDL. A nonprofit trading exchange was also created to facilitate credit transfers. Despite these efforts, no meaningful trading program has arisen. ID. DEP'T OF ENVTL. QUALITY, UPPER SNAKE RICK TMDL MODIFICATION (July 22, 2005).

The question of the economic viability of trading also differs based on the credit characteristics. The lifespan of a credit (usually based on the duration of the water quality benefit) especially impacts the economic valuation, as does the method of determining the credit price point. In all instances, the cost of a credit represents some proportional expense associated with generating that credit. In some instances, the cost of a credit is dictated by the market itself with the buyer and seller negotiating the individual credit price, taking the duration of the credit into account.[20] In other instances, the credit price is set by the central exchange based on the average cost of pollution reductions in terms of both capital costs and ongoing maintenance expenses.[21] For a program to be viable the value of the credit must be greater than the cost of generating it, and lower than the pollution reduction cost for the purchasing facility. Agreeing on a programmatic method for credit cost calculations, while an optional component of a trading framework, can provide a level of reassurance and predictability for trading participants.

The overarching question about the potential cost savings from adopting a trading program must also be addressed. A trading program's financial attractiveness takes into consideration the cost of removal technologies for a facility, the delayed capital and operational expenses for buyers, and the possibility of wholly avoiding the most advanced (and expensive) technological upgrades.[22] The comparative treatment costs versus effectiveness between facilities also constitutes a meaningful consideration. The estimated savings from other trading programs have accounted for these dynamics as well as the prioritization of incentives such as low-interest loans from State Revolving Funds.[23] Hence, when doing the financial calculus, it is important to take a broad perspective to account for all elements of the economics of trading, both now and in the future.

C. REGULATORY HURDLES

Formulating the guidance to facilitate trading represents one of the largest hurdles to the adoption of a market-based trading program. To date, trading programs in California have been developed and permitted independently on a case-by-case basis. This sort of individual trading plan development requires that the specific components of a trading program to be formulated and incorporated into a waste discharge permit or other legally-binding document approved by the local Regional Water Quality Control Board after public notice and comment. This document serves to frame the trading program and guide all activities undertaken as part of that program, from the initial credit generation through the credit issuance and usage for Clean Water Act compliance. The following points constitute the major issues that will require attention during the process.

---

[20] Virginia's nutrient trading program allows for trades directly between point sources, thereby creating a scenario where the cost of a credit is based in part on the expense of generating that reduction and in part on the willingness of the buyer to pay. For trades involving the intermediary Virginia Nutrient Credit Exchange Association, the Exchange values credits at prices "in the best interests of the Nutrient Exchange and its Participants." VA. NUTRIENT CREDIT EXCHANGE ASS'N, EXCHANGE COMPLIANCE PLAN: 2015 ANNUAL UPDATE, 8-11 (Feb. 2015), www.deq.virginia.gov/Portals/0/DEQ/Water/PollutionDischargeElimination/ExchangeCompliancePlan-2015AnnualUpdate.pdf.

[21] Connecticut's program derives the credit cost by dividing the total annual project cost (capital expenditures and ongoing operation and maintenance costs) by the reduction in equalized pounds of nitrogen. CONN. DEP'T OF ENERGY & ENVTL. PROT., REPORT OF THE NITROGEN CREDIT ADVISORY BOARD FOR CALENDAR YEAR 2013, 8 (Sept. 2013), *available at* www.ct.gov/deep/lib/deep/water/municipal_wastewater/nitrogen_report_2013.pdf.

[22] With adoption of ever-more expensive technological solutions, point sources face the issue of diminishing returns—upgrades are increasingly more expensive while achieving less nutrient reduction. A watershed-based focus fosters a more cooperative and holistic perspective where, as the most viable technology solutions in the basin are exhausted by the trading participants, nonpoint source reductions may be considered.

[23] For a detailed discussion on the interplay between water quality trading and the use of Clean Water State Revolving Funds, *see* U.S. EPA, WATER QUALITY TRADING TOOLKIT FOR PERMIT WRITERS, EPA 833-R-07-004, Appendix D: Use of Cost Share (Aug. 2007, updated June 2009). For a discussion of the savings calculus as applied to the Long Island Sound Nutrient Exchange, *see* NAT'L ENVTL. TRADING NETWORK, LONG ISLAND SOUND PROGRAM DESCRIPTION, SECTION J (last visited Nov. 2016), http://www.envtn.org/Long_Island_Sound.html.

i. Necessary Components of a Trading Framework for the Basin

In order to establish a robust and successful trading program, it is necessary to formulate an unambiguous regulatory trading framework.[24] Developing this guidance and its individual components stands as a hurdle to realizing a trading program. This framework should govern all activities within the water quality trading program and should delineate the regulatory mechanisms that will be utilized. It is essential that this framework also resolve questions regarding participant eligibility, the geographic scope, credit characteristics, and the means of calculating and utilizing compliance-grade credits, among other issues.[25] This framework should provide regulatory assurances that a trading program is scientifically sound and creates benefits for both the participants and the environment. Generating such a document constitutes a hurdle to overcome as no directly applicable guidelines currently exist in the San Francisco Bay area. Therefore, working with stakeholders and regulators to develop a mutually acceptable framework will be a necessity.

Some flexibility exists when deciding what form of trading program and framework to utilize. Based on existing trading programs, two general programmatic options exist: (1) issue a general NPDES permit for all dischargers that includes all pertinent trading language, or (2) develop a stand-alone trading framework that is incorporated into a general or individual NPDES permit by reference. A general NPDES permit with the trading terms applies equally to all participants, lowering the regulatory burden of developing such a framework but potentially eliminating the opportunity to adjust some factors (e.g., trading ratio) to individual circumstances. Conversely, a trading framework takes a larger regulatory lift but may enable some adjustments for the conditions faced by individual facilities. In the current circumstances, it will be necessary to collaboratively determine the most advantageous method to fit a trading program into the existing regulatory framework.

Trading Area

Delineating a trading area is an important, though not necessarily difficult, hurdle to overcome. Determining the trading area constitutes a foundational component of a program, as it sets the geographic scope of the program, thereby preliminarily defining who may participate. Larger trading areas often face attenuated benefits due to the distance between facilities.[26] Smaller areas may not include sufficient pollutant sources (i.e. trading partners) to make the program economically feasible. Thus, finding the right balance is important. The EPA recommends adopting a trading area that represents “a watershed or a defined area for which TMDL has been approved.”[27] However, adopting a trading area that does not align with an entire watershed is also acceptable, so long as the trading program helps to improve overall water quality at least as much as traditional alternatives.[28]

In the San Francisco Bay, determining the appropriate size of a trading area may prove somewhat problematic. This is due to the large size of the watershed and the lack of a TMDL. The existing nutrient watershed NPDES permit divides the Bay into five sub-watersheds, known as subembayments.[29] To establish a trading area, it will be necessary to determine what entities should be able to participate. Determining the hydrologic connection between the various portions of the Bay and potentially the Sacramento-San Joaquin Delta will also need to

---

[24] U.S. EPA, Water Quality Trading Toolkit for Permit Writers, EPA 833-R-07-004 (Aug. 2007, updated June 2009); Nat’l Network on Water Quality Trading, Building a Water Quality Trading Program: Options & Considerations, (2015).

[25] Willamette P’ship & The Freshwater Trust, Draft Regional Recommendations for the Pacific Northwest on Water Quality Trading, (2014).

[26] *Id.* at 45.

[27] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1610.

[28] For example, the Medford Temperature Trading Program in Oregon takes place in the Rogue River Basin but does not encompass the entire watershed. Medford Reg’l Water Reclamation Facility, Thermal Credit Trading Program, App. 1 (2011), http://www.deq.state.or.us/wq/trading/docs/MedfordThermalTrading.pdf.

[29] Those five subembayments are Suisun Bay, San Pablo Bay, Central bay, South Bay, and Lower South Bay. S.F. Bay Reg’l Water Quality Control Bd., Order No. R2-2014-0014, Permit No. CA0038873, Waste Discharge Requirements for Nutrients from Municipal Wastewater Dischargers to San Francisco Bay, E-4 (Apr. 2014).

occur because, based on this information, differing trading ratios may be adopted to account for the attenuation of water quality benefits. All told, the creation of a trading area will present one of the preliminary considerations to developing a trading program framework, though the existing nutrient permit should provide some insight to guide this process.

Credit Characteristics

Determine the characteristics of the credits also constitutes an important issue that must be addressed. This is more than simply the type of tradeable pollutants and the units of measurement—both easily resolved aspects of trading as they should directly align with the terms of the applicable discharge permit. The credit life, trading ratio, and reconciliation period[30] must all be resolved as well.

Credit duration is the length of time a credit is valid once generated. Duration is often a sticking point, as it directly impacts the economic and environmental viability of credit trading: too short a duration and the credits are not economically viable; too long and the credits do not generate sufficient environmental gain. Similarly, the trading ratio(s)[31] must be agreed upon in order to allow for accurate predictions of the credit needs and worth. Developing modeling tools to understand the attenuation of benefits between the subembayments will help to resolve the existing uncertainties about hydrologic transport of nutrients. The reconciliation period often amounts to an important consideration as well. This period is the length of time between when credits are generated and when they must be used before expiring. Like the balance for credit duration, the reconciliation should be long enough to foster an accurate prediction of credit availability and credit need, while not being so long that the water quality benefits become too attenuated. Often this period is one year, thereby allowing for purchase of credits to satisfy the past year's compliance, while preventing credits from being carried across multiple years. All told, these considerations are by no means insurmountable, they simply require attention in order to attain a balanced outcome.[32]

Baseline for Credit Generation and Purchase

The baseline for credit generation and purchase can be a sticky issue, though less so for strict point-to-point trading programs.[33] Because the Bay does not have a nutrient TMDL, there are no wasteload allocations to inform discharge limits and the current nutrient permit only requires monitoring, it does not assign any discharge limits. This is problematic because to generate credits reductions of a waste stream below the permit limits must be achieved. Likewise, to purchase and use credits, a facility must first satisfy the technological limits; credits may only satisfy the water quality-based portion of the effluent limits.[34] Without these limits no regulatory driver exists to dictate the baseline for credit generation and transfer.

Future iterations of the nutrient watershed permit may contain numeric limits on total nitrogen, thereby spurring and facilitating credit trading.[35] Prior to the realization of a trading program, numeric effluent limits for

---

[30] The reconciliation period is "period of time during which a seller generates water quality credits and a buyer may use those credits to offset a pollutant load that it discharges during that same period of time." U.S. EPA, WATER QUALITY TRADING TOOLKIT FOR PERMIT WRITERS, EPA 833-R-07-004, 34 (Aug. 2007, rev. June 2009).

[31] Ratios may differ for trades involving differing entities in order to account for different geographic distance between the sources and levels of attenuation. For instance, Virginia established trading ratios by rule based on the location of trading participants in the watershed. 9 VA. ADMIN. CODE § 25-820-70(J)(2).

[32] For a detailed discussion of the considerations that go into formulation of the credit characteristics, *see* Task 1.

[33] Point source trading is generally the easiest type of trading to implement and monitor "because all sources have a permit, the effectiveness of removal technologies is relatively well known, and monitoring protocols are in place." U.S. EPA, WATER QUALITY TRADING TOOLKIT FOR PERMIT WRITERS, EPA 833-R-07-004, 15 (Aug. 2007, rev. June 2009).

[34] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1610–11.

[35] S.F. Bay Reg'l Water Quality Control Bd., Order No. R2-2014-0014, Permit No. CA0038873, Waste Discharge Requirements for Nutrients from Municipal Wastewater Dischargers to San Francisco Bay, F-9 (Apr. 2014) ("In the 2019 permit reissuance, reissuance, the Regional Water Board anticipates considering establishment of performance-based effluent limits for nutrients").

nutrients will be required. If determined to be appropriate as a result of the studies performed under the nutrient watershed permit, these limits should be developed and incorporated into the nutrient watershed permit in such a way as to unambiguously convey the technology-based portions (if any) versus the water quality component.

Given the uncertainty by Bay stakeholders that such limits will be imposed in the foreseeable future, the timing of actions to develop a trading framework is somewhat uncertain. An advantage of developing a trading framework earlier will be to increase flexibility in achieving compliance with those limits from the moment they are incorporated into the discharge permit. Such efforts will also create the opportunity to incorporate terms for the pre-compliance generation of credits. This would allow for technological upgrades to wastewater facilities to receive some benefit for achieving early reductions in their nutrient discharges. Encouraging these early reductions generates the impetus to make investments in pollution control that are otherwise not warranted in the near-term.

Credit Accounting and Permit Compliance

The consideration of trading mechanisms also involves a number of logistical issues, the resolution of which stands as a hurdle to program realization. These issues include the method of transfer, the accounting methodology, the timing for compliance, and the supply of credits. To guarantee that a program is transparent and verifiable, the answers to these questions, both broadly and as they relate to specific credit transfers, should be clearly and publicly resolved. The next analysis (Task 3) will provide some examples and guidance on this issue, though the specific measures will still require attention to fine-tune those documents for the specific circumstances present in the Bay.

For a viable trade, either a centralized exchange, independent transfers from one facility to another, or a combination of both is acceptable. Participants must clearly articulate the chosen method and transparently maintain records. This is equally true for the methodology underlying credit calculation and the compliance timeline. Neither of these issues should pose a serious obstacle in the San Francisco Bay, as they tend to be inextricably linked to the monitoring and compliance reporting periods contained in the existing nutrient watershed permit. The credit calculation relies on the effluent limits—the 'credits' will reflect the units of measurement per a permit. Similarly, the period for compliance generally mirrors the reporting periods in the permit, regardless of whether credits remain viable for multiple reporting periods. Simply put, these issues are not usually overly complicated, but they must be agreed-upon and reported for transparency and accountability.

A larger potential issue is the transparent reporting and tracking of transactions across multiple participating agencies. Each agency likely has its own rules related to record retention, public access, and public transparency. To ensure that credits are only being used once, it is often prudent to develop a multi-party, web-based, publicly accessible registry (i.e., ledger) to track transactions and provide the public and regulators with confidence that the trades are yielding net benefits. While the discharge monitoring reports must contain information about the purchase and use of credits to show permit compliance, credit generation has the potential to be more opaque. To avoid this problem, and potential claims of impropriety, it is important to accurately and publicly report credit generation, transfer, and continuing use as well as any pertinent underlying information in a clear manner. A public credit registry may warrant consideration as it satisfies all of these issues. For example, Markit Environmental Registry is used for water quality credit trading by programs in Oregon, Ohio, Pennsylvania, and elsewhere.[36]

[36] IHS MARKIT, https://www.markit.com/Company/About-Markit (last visited Nov. 29, 2016).

The issue of credit supply also requires consideration. Guaranteeing an adequate supply of credits or having some safety mechanism in place is important to justify a trading program. Facilities counting on the ability to use credits to achieve permit compliance need some assurance that those credits will be available when needed. While it is possible to shift this risk through credit purchase contracts, it is sometimes preferable to have some method that entails less risk and a lower transactional cost. One mechanism to address this risk is through the use of a reserve pool of credits.[37] The reserve pool receives a portion of each credit traded or otherwise collects some adequate number of credits to use as an insurance policy that can be drawn from when needed. Another approach is to develop a nonpoint source restoration program that can be paid into when necessary in order to offset the permitted discharge.[38] A guaranteed market for credits whereby the state purchases all credits generated can also help to avoid this issue by incentivizing the production of excess credits.[39] Either of these methods can minimize the risk of an insufficient supply of credits, providing the assurance needed to justify participation in a trading program.

ii. Scientific Uncertainty Must be Resolved

The lack of a TMDL or similar watershed-scale analysis creates a hurdle to trading program development. A thorough grasp of the watershed conditions and inputs is a prerequisite to a trading program. The monitoring, modeling, research, and reporting regimes currently funded through the nutrient watershed permit make significant strides toward satisfying this requirement. Depending on the results of that ongoing work, more information may be necessary to resolve all outstanding questions. Fortuitously, existing entities in the Bay, such as BACWA and the San Francisco Estuary Institute, are positioned to quickly address this need. Likewise, one potential benefit of a robust trading program in a pre-TMDL environment is the possibility that the program negates the need for a TMDL at all.[40] In any event, the unresolved scientific uncertainty requires resolution before trading may proceed.

Necessary Reductions and Hotspots: Protecting Beneficial Uses

EPA regulations prohibit any discharge from impairing the waterway such that the beneficial uses are further degraded.[41] Water quality trading programs should result in pollution reductions that help to attain the beneficial uses. Trading constitutes a mechanism to allow for increases in discharges beyond what would be otherwise acceptable because the increases in pollutant reductions are offset elsewhere, resulting in a net reduction of pollution in the waterway.[42] Trading benefits a waterway, even if it allows for greater discharges of pollution from some sources. Even still, trading has limits and cannot be used to offset discharges beyond a certain point, even if there are ample credits available. One of these limitations involves "hotspots"—areas where the concentration of pollution exceeds some threshold such that it becomes toxic or otherwise problematic.

---

[37] U.S. EPA, WATER QUALITY TRADING TOOLKIT FOR PERMIT WRITERS, EPA 833-R-07-004, 102 (Aug. 2007, rev. June 2009).

[38] Virginia pursued this method, setting up the Water Quality Improvement Fund that allows permittees to make payments into the fund to finance nonpoint source restoration if point source nutrient credits are unavailable. 9 VA. ADMIN. CODE § 25-820-70.

[39] Connecticut used this method to ensure the Long Island Sound Trading Program operated as intended until recently. The regulatory body that oversees credits in Connecticut determined the program had reached a point of sustainability, whereby it was no longer necessary for the state to purchase the excess credits. 2015 Conn. Acts 15-38 (Reg. Sess.), https://www.cga.ct.gov/2015/act/pa/pdf/2015PA-00038-R00SB-00940-PA.pdf.

[40] Impaired waterbodies are listed by the state on the CWA section 303(d) list and assigned classifications based on the existence of a TMDL. One often overlooked classification, known as Category 4b, designates a waterway as impaired but not requiring a TMDL because other measures are addressing the impairment. *See* Eric Monschein & Laurie Mann, U.S. EPA, Office of Water, *Category 4b – A Regulatory Alternative to TMDLs* (2007), *available at* https://www.epa.gov/sites/production/files/2015-10/documents/2009_06_04_tmdl_results_36monschein_wef07_paper7.pdf.

[41] 40 C.F.R. § 122.44(d)(1) (2012).

[42] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1610.

To understand the reductions necessary to make progress toward attaining beneficial uses, it is necessary to fully comprehend the water quality necessary to protect those uses. This requires analyses to tease out the maximum pollutant loading in given areas that do not degrade the beneficial uses. Once this information is determined, the reductions from current pollution loading required to achieve that load can be discerned. This type of analysis is a core aspect of a TMDL. However, without a TMDL, the maximum allowable load and required reductions must be determined through other scientifically defensible studies. These studies should also inform the hotspots analysis by monitoring and studying the water conditions in the vicinity of existing discharges in order to determine the upper limit on the receiving water's near-field assimilative capacity. These studies will provide the scientific underpinnings required to ensure that trading neither impairs the watershed broadly or in a specific locale.

Subembayments and the Attenuation of Benefits

The current nutrient permit divides the San Francisco Bay into five subembayments. These classify discrete portions of the Bay, based on hydrodynamics and other factors, allowing for differentiation of water quality issues that occur in a subset of the overall Bay as well as divide dischargers into smaller groups for reporting purposes.[43] While the use of subembayments for regulatory purposes does not necessarily pose a problem, they do raise some questions regarding the attenuation of water quality benefits, especially in such a large watershed. For example, a trade involving two facilities located in different subembayments on opposite ends of the Bay will generate benefits that are attenuated due to the sheer distance and other fate and transport factors. If water quality benefits become too attenuated, then one of the underlying trading policies—to "achieve[] greater environmental benefits"[44]—is frustrated.

The main mechanism to avoid the attenuation problem is through the use of trading ratios. These ratios discount credits in order to account for factors including, but not limited to, the distance between two sources. Thus, to put it simply, two sources that are geographically distant will require a higher trading ratio than facilities located near one another. To determine the appropriate ratio, it is necessary to undertake scientific studies that will clarify the degree of attenuation that occurs between various portions of the Bay. These studies and the insight they provide will ensure that trading ratios are formulated that are protective of water quality benefits for trades between the subembayments and significantly benefit a potential trading program.

Antidegradation

Antidegradation ensures that water quality is not worsened by discharges and current instream beneficial uses are protected.[45] In the context of trading, this requires ensuring that there is "no net increase of the pollutant traded and [trades] do not result in any impairment of designated uses."[46] On a subembayment level this may require ambient water quality monitoring to protect against a localized impacts to water quality resulting from trading activities. Trading ratios often ensure that this obligation is upheld by requiring more pollutant reductions than allowable additional pollutant discharges. However, even if a full antidegradation review is not warranted by the specific circumstances, there should be a scientific basis to ensure benefits result. This is an obstacle likely resolved as part of the other required scientific studies.

---

[43] S.F. Bay Reg'l Water Quality Control Bd., Order No. R2-2014-0014, Permit No. CA0038873, Waste Discharge Requirements for Nutrients from Municipal Wastewater Dischargers to San Francisco Bay, E-4 (Apr. 2014).

[44] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1610.

[45] Cal. State Water Resources Control Bd., Res. No. 68-16: Statement of Policy with Respect to Maintaining High Quality of Waters in California (Oct. 28, 1968). *See also* Memorandum from William Attwater, Chief Counsel, Cal. State Water Resources Control Bd., to Reg'l Bd. Executive Officers, on Federal Antidegradation Policy (Oct. 7, 1987), *available at* www.epa.gov/sites/production/files/2014-12/documents/ca-antidegradation-policy-memo.pdf.

[46] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1611.

2.3. Opportunities for a Water Quality Trading Program

A. REGULATORY FOUNDATIONS FOR A TRADING PROGRAM

Even in the absence of a TMDL, the underpinnings of a successful trading program already exist in the San Francisco Bay, creating the opportunity for a trading program to arise. The nutrient watershed permit serves to help build the needed scientific groundwork, there is sufficient time before the next permit iteration to overcome the hurdles, and there are signs that the regulatory body is supportive of water quality trading. There are also numerous studies currently ongoing or contemplated for the future and several entities with expertise specific to the Bay that could quickly remedy the existing uncertainties.

i. San Francisco Bay Nutrient Watershed Permit and Ongoing Studies

The San Francisco Bay Nutrient Permit creates the foundation upon which to build a trading program. The monitoring regime that the permit requires should provide the basis for a trading program by helping to resolve many of the outstanding scientific uncertainties, or at least fostering the initial understanding required for trading even if more study is needed.[47] The permit states that the intention of the discharge reporting "is to establish baseline loads by subembayment and the potential for nutrient load trading."[48] Furthermore, that permit connects all dischargers under a single regulatory program, tying them together in a manner that is conducive to collaborative compliance methods like water quality trading. All told, the opportunity presented by the nutrient permit cannot be understated as it certainly appears to constitute the first step down the path to market-based compliance solutions.

Moreover, several ongoing and completed scientific studies present an opportunity for trading to take hold with less time and resources than is often required for pre-TMDL trading programs. These efforts, which include the Regional Monitoring Program Nutrient Strategy,[49] the Surface Water Ambient Monitoring Program,[50] and the San Francisco Bay Nutrient Numeric Endpoints studies[51] may provide the requisite scientific basis for a trading program. If correct, this would make the scientific analysis little more than a literature review to bring the current understandings together and use them to underpin a trading program.

ii. Regulatory Precedent for Water Quality Trading

Despite the fact that neither the state of California nor the regulatory bodies have adopted any detailed guidance for water quality trading, several trading programs of this type have garnered approval from California regulators and the EPA. These examples serve as useful regulatory precedent to demonstrate that trading is an acceptable compliance method. The main trading program is the Laguna de Santa Rosa Offset Program. Several other watershed-based permits that share some similarities with water quality trading programs have also been approved.[52]

---

[47] Bay Area Clean Water Agencies Nutrient Reduction Study, Group Annual Report: Nutrient Watershed Permit Annual Report 2016 (Oct. 2016), http://bacwa.org/wp-content/uploads/2016/09/Group-Annual-Report-2016_Final.pdf.

[48] S.F. Bay Reg'l Water Quality Control Bd., Order No. R2-2014-0014, Permit No. CA0038873, Waste Discharge Requirements for Nutrients from Municipal Wastewater Dischargers to San Francisco Bay, E-4 (Apr. 2014). This permit also states: "The Regional Water Board will also consider load offsets between Dischargers within and between subembayments if permissible." *Id.* at F-9.

[49] Emily Novick, et al., Reg'l Monitoring Program for Water Quality in the S.F. Bay: Nutrient Science Program FY 2015 Progress Update (2016), *available at* http://www.sfei.org/rmp/nutrients.

[50] Cal. State Water Res. Control Bd., Surface Water Ambient Monitoring Program, Fact Sheet: San Francisco Bay Regional Water Quality Control Board (Mar. 2013), www.waterboards.ca.gov/water_issues/programs/swamp/docs/factsheets/rb2_cw101.pdf.

[51] Lester J. McKee, et al., *Numeric Nutrient Endpoint Development for San Francisco Bay Estuary: Literature Review and Date Gaps Analysis*, S. Cal. Coastal Research Project Rep. No 644 (June 2011).

[52] Watershed-based permits regulate multiple sources within a large geographic area under a single permit. Due to the jointly applicable limits, offsetting actions are easily implemented to allow for a form of credit trading between permitees. *See* Task 1 for a discussion of other watershed-based permits and trading programs in California.

Turning to watershed-based programs, the best example is the recent Los Angeles Municipal Separate Storm Sewer System (MS4) NPDES Permit.[53] That permit applies to 84 distinct entities with jurisdiction over stormwater, allowing them to collaboratively establish Watershed Management Programs to meet water quality goals. This program allows permitees to establish permit compliance jointly on a watershed scale. While not a true trading program, it is similar in that off-site pollutant reductions can help establish permit compliance.

However, the most recent and most precedential trading program is the 2008 Santa Rosa Nutrient Offset Program, which saw its first trade in 2012.[54] The Santa Rosa Subregional Water Reclamation Facility discharges into the Laguna de Santa Rosa watershed—a CWA section 303(d) listed waterbody impaired by nutrients, metals, bacteria, sediment, and temperature.[55] To address the impairment, the RWQCB imposed a "no net loading" nutrient limit in Santa Rosa's NPDES permit.[56] The facility upgrades needed for compliance cost roughly $40 million.[57] Rather than install costly technology, Santa Rosa pursued a trading/offset program that allows for quantified and credited mitigation elsewhere in the basin. With the support of the North Coast RWQCB, Santa Rosa has used and continues to use trading to achieve permit compliance at a fraction of the alternative cost.

Santa Rosa's trading program occurs within the strictures of a general framework adopted by the North Coast RWQCB.[58] Currently, the framework is undergoing a process of revision to strengthen the program and more closely align it with national trading guidance. An updated framework is expected in the near future. Despite the anticipated updates, the existing framework still provides insight into possible trading program characteristics.

The existing Santa Rosa Trading Program measures NPDES permit compliance using an average of the actual nutrient discharge loads for the past three years. Thus, exceedances in one year can be offset in the next year using trading. The program measures reductions in one of two ways. For directly measurable (point source) reductions, the entire reduction minus a small margin of safety can be claimed. For actions with modeled (nonpoint source) reductions, credits are calculated using median effectiveness estimates minus the margin of safety, so only a portion of the reductions are creditable. Operating within these confines, the facility has removed significant amounts of nutrients from the watershed, creating a variety of ancillary environmental benefits and meeting the NPDES permit limits in a cost effective manner. Thus, while distinguishable, this program offers valuable insight for other trading programs, an opportunity that should not be understated.

B. PROGRESS TOWARD WATER QUALITY GOALS PRIOR TO TMDL

One major benefit of a pre-TMDL trading program is the potential for trading to make meaningful progress towards protection of beneficial uses. If sufficient progress can be realized, a trading program could potentially negate the need to list a waterbody as impaired. Another possible outcome is that, even if the waterbody is placed on the 303(d) list, a trading program could negate the need for a TMDL, even before the gains necessary

---

[53] L.A. Reg'l Water Quality Control Bd., Order No. R4-2012-0175, Permit No. CAS004001, Waste Discharge Requirements for MS4 Dischargers within Coastal Watersheds of Los Angeles County (2012, rev. July 2015).

[54] N. Coast Reg'l Water Quality Control Bd., Res. No. R1-2008-0061: Approving Santa Rosa Nutrient Offset Program (July 24, 2008), *available at* http://www.waterboards.ca.gov/northcoast/water_issues/programs/nutrient_offset_program/.

[55] CAL. STATE WATER RES. CONTROL BD., 2010 INTEGRATED REPORT (CLEAN WATER ACT SECTION 303(D) / 305(B) REPORT) (2010). The waterway is also listed as impaired by Trash, Sulfates, Selenium, Invasive Species, Fish Barriers, and Unnatural Foam/Scum.

[56] "No net loading" means the facility has a numeric discharges limit for nutrients equal to zero. The permit did expressly allow this limit to be met by reducing discharges elsewhere in the watershed, though the North Coast RWQCB did require this to be accomplished pursuant to an approved offset plan. *See* N. Coast Reg'l Water Quality Control Bd., Order No. R1-2006-0045, Permit No. CA0022764, Waste Discharge Requirements & Master Reclamation Permit for the Santa Rosa Subregional Water Reclamation System, at 13, n. 5 (2006, rev. July 2008, Apr. 2009), *available at* www.waterboards.ca.gov/northcoast/board_decisions/adopted_orders/pdf/2006/061003_0045_SantaRosaWDRs.pdf.

[57] Keiser & Assoc., *City of Santa Rosa, California Nutrient Offset Resolution Compliance Project*, *available at* www.kieser-associates.com/uploaded/environmental_markets/city_of_santa_rosa_california_nutrient_offset_resolution_compliance_project.pd.

[58] N. Coast Reg'l Water Quality Control Bd., Res. No. R1-2008-0061: Approving Santa Rosa Nutrient Offset Program (July 24, 2008).

to fully attain the water quality standards have been achieved.[59] The EPA has created a special category of impaired waters that, despite their impairment and subsequent placement on the 303(d) list, do not require a TMDL because “other pollutant control requirements are expected to result in the attainment of an applicable water quality standards[.]”[60] Thus, assuming that the San Francisco Bay or some portion thereof is eventually listed as impaired for nutrients, trading could avoid the need for a TMDL or at least make TMDL development and implementation more efficient.

C. COOPERATION AMONG BAY AREA UTILITIES ALREADY EXISTS

One of the most important yet least discussed components necessary to both develop and operate a trading program is cooperation. All participants must collaborate among themselves and with the regulatory bodies in order to conceptualize and implement a trading program. This can present an issue if animosity or a lack of trust exists between the stakeholders. A lack of cooperation is especially problematic in the absence of an objective, unifying entity that can serve to bring all of the parties together.

In the San Francisco Bay, the Bay Area Clean Water Agencies, a joint powers agency, may serve to bridge the divide between the potential participants. BACWA has already taken responsibility for reporting the discharges of its members required by the nutrient permit. This seemingly indicates a potential willingness to serve as a unifying force that will bring together the agencies to achieve economic and environmental benefits otherwise out of reach of any individual member.

2.4. Conclusion

A conceptual point-to-point source trading program for nutrients in San Francisco Bay faces a variety of hurdles before such a program can become a reality. A lack of statewide or regional regulatory guidance as well as jurisdictional dichotomies between potential participants must be overcome in the initial stages of framework development. Moreover, the question of fairly allocating the cost of developing and implementing a program will likely require resolution at an early stage in order to avoid concerns over unequal burdens being placed on certain entities. These logistical issues aside, the scientific underpinnings of a trading program must be developed in the absence of a TMDL and the specific components of a trading program need to be developed in order to ensure that the program will be viable. Otherwise, the risk is that a program will be developed that never gets used by the intended participants.

Even considering all of these obstacles, there is clear opportunity for a nutrient trading program. The regulatory body has shown an inclination, both through its actions and official documents, to support trading. The existing nutrient permit for the Bay also lays the groundwork for a trading program to arise. Furthermore, there are other examples of trading programs, both in California and nationwide that provide insight into the components of a trading system that lead to success. Such a trading system even presents the possibility to avoid the need for a TMDL. Lastly, the existence of an industry group that has already brought the potential participants together and has experience in working with the regulators, presents a meaningful opportunity. All told, despite the many hurdles that must be overcome, there is ample reason to believe a trading program could arise and thrive in the San Francisco Bay.

---

[59] U.S. EPA, WATER QUALITY TRADING TOOLKIT FOR PERMIT WRITERS, 21, EPA 833-R-07-004 (Aug. 2007, rev. June 2009).

[60] Eric Monschein & Laurie Mann, U.S. EPA, Office of Water, *Category 4b – A Regulatory Alternative to TMDLs* (2007); Eric Monschein & Shera Reems, Category 4b – Current National Status and Trends (2009), *available at* https://www.epa.gov/sites/production/files/2015-10/documents/11a.pdf.

3. Components of a Conceptual Point-to-Point Source Nutrient Trading Program

Task 3: Specific Options and Considerations for a Potential POTW Nutrient Trading Program in the San Francisco Bay

Executive Summary – Task 3

Water quality trading holds great promise for assisting wastewater utilities and other regulated entities to achieve compliance with clean water obligations, often with more environmental benefit at a lower overall cost.[1] Developing and implementing a water quality trading program that provides the necessary regulatory assurances along with certainty for permittees is no simple task—but with clear stakeholder understanding of the mechanisms of trading, program options, and lessons from other trading programs, building a robust point-to-point source trading program is very achievable.

When designing a trading program, the first major choice is which type of point-to-point source trading model to pursue. The EPA endorses three primary models for point-to-point source trading.

The first is "peer-to-peer trading" which involves two point sources trading directly between each other without an intermediary. This contractual arrangement affords participants the flexibility to design trades in the most beneficial terms, but without the predictability and assurances that come from working with an exchange or under an overarching trading framework.

The second option involves multiple facilities trading directly under a trading agreement or a multi-party general permit. This high-level regulatory guidance, commonly called a trade agreement (or trade framework), is developed by interested parties and incorporated into NPDES permits by reference. Unlike peer-to-peer trading, this trading model has more high-level regulatory guidance, and usually relies on an intermediary to facilitate and document trades. While less flexible than peer-to-peer trading, an overarching agreement provides a greater level of certainty and replicability.

The third option involves the use of a central intermediary, known as a credit exchange, to facilitate trades. Exchanges operate by either buying credits and then selling them to other point sources, or by serving as a central platform to enable trades among sources. Exchanges entail the least amount of flexibility of the three options, but this rigidity often creates a great deal of certainty and risk minimization for participants, and allows for optimum tracking and transparency.

The choice of a trading model should be considered in tandem with the number of permittees and permitting structure, as they are interrelated decisions. The two major permit options are: (1) individual permits that contain the specific terms to govern trading, or (2) a watershed general permit covering all potential trading

[1] "Successful water quality trading programs involving point source discharges have demonstrated that trading can provide much-needed flexibility, while generating more cost-effective environmental benefits than traditional regulatory approaches." Ken Kirk, Former Executive Director, National Association of Clean Water Agencies, quoted in NAT'L NETWORK ON WATER QUALITY TRADING, BUILDING A WATER QUALITY TRADING PROGRAM: OPTIONS AND CONSIDERATIONS, foreword (2015).

participants. Using the first approach allows for the tailoring of individual permits to discharger-specific circumstances, but can miss or undervalue a watershed-based perspective, and can require the incorporation by reference of numerous guidance documents into individual permits at different renewal dates, potentially leading to uncertainty and inconsistency between permits. Under the second scenario, a single permit (e.g. the nutrient watershed permit in the Bay) regulates every point source of a given type (e.g. POTWs) in a specific area. General permits may come in the form of an "overlay" permit that applies in addition to each facility's individual permits and regulates a pollutant not covered by the individual permit. Though not as neatly tailored as stand-alone individual permits, general permits can enable trading by dealing with all potential participants and uniformly addressing core issues in a single regulatory document. Furthermore, a single watershed-based general permit often provides greater flexibility, as issuing or amending a general permit in response to new information or other needs is easier than making changes to all individual permits that regulate discharges in an area. The general permit option has been used for most of the major existing point-to-point source trading programs around the country, with the exception of Pennsylvania.

Regardless of the trading model and permitting mechanism selected, when building a trading program, it is important to minimize risk and uncertainty. Even when using trading to achieve compliance, participants remain liable for complying with individual permit limits. Trading does not ultimately shift liability, nor does it relieve any party from liability for failing to acquire sufficient offsets, even if the potential buyer is unable to acquire credits through no fault of their own. This risk of credit shortfalls may be minimized or eliminated completely through the use of mechanisms such as: a credit reserve pool; a nonpoint source offset restoration fund; insurance; private indemnity agreements; or by adopting trading policies that encourage early pollution reductions.

Another important risk minimization consideration is avoiding sunk costs. In existing point source trading programs, money is only exchanged after effluent reductions are achieved and credits are verified. Individual permittees finance facility upgrades, and then recover some of this investment once the technology comes online and credits are sold. This approach protects credit buyers, but leaves potential credit sellers responsible for making costly upgrades with minimal assurances. To mitigate this problem, participants may enter into purchase contracts at an early stage, subsidies may be offered, or parties can collaborate to forecast credit supply and demand.

In addition to the program structure and strategies for minimizing uncertainty, all participants need to agree on the main components of a trading program. The first of these parts is the trading area, the development of which requires a firm grasp of regional hydrologic conditions in order to account for the attenuation of benefits throughout the watershed and to avoid localized impacts. In the San Francisco Bay, the trading area may therefore encompass some or all of the subembayments. The larger the trading area, the more important 'trading ratios' become. Trading ratios are used to account for concerns such as uncertainty, time lag, and/or to build a credit reserve. Moreover, when a large trading area is developed, trading partners may be far from one another, necessitating higher trading ratios to account for the attenuation of water quality benefits between locations.

Where there is no TMDL, as is the case for nutrients in the San Francisco Bay, the EPA states that the baseline for point-to-point source trading is established by the water quality-based effluent limit in the NPDES permit of the seller. In formulating applicable limits, the EPA recommends that regulators clearly articulate the discharge levels that apply to all potential credit buyers and sellers in the absence of trading, as well as when trading is used. Discharge monitoring reports then enable regulators and trading participants to track the generation of credits easily. Comparing the actual discharges with the permitted discharges illustrates supply and demand—

pollutant discharge below the permit limit generates credits, while pollutant discharge above the limit requires credits to offset and maintain compliance.

Even with a robust monitoring regime for end-of-pipe discharges, credits generated, purchased, and used must be accurately accounted for. Failure to do so may lead to the issue of 'double counting' credits, which can result in credit invalidation and permit noncompliance. Credit cycle management—which refers to the certification, registration, and tracking of credits from generation through usage—ensures that no improprieties arise that could lead to an enforcement action. Depending on the chosen program type, the accounting system for registering credits may differ. Although it is possible to operate a multi-party, point-to-point trading program without a singular accounting system, The Freshwater Trust recommends a registry for the assurances that it provides. A ledger serializes credits, helping to avoid duplicative use of credits and accounting problems. A registry may be a central exchange, as has arisen in Virginia, or it may be a more flexible third-party system whereby a facilitating party ensures propriety through a system of safeguards before accounting for or transferring credits.

A central exchange or third-party registry also avoids many credit tracking issues by bringing all trading documentation into a single location under the management of one entity. Specifically, an exchange will enter into binding agreements with all participants. The exchange will then quantify the credits generated or needed based on the discharge data submitted by participants. Once calculated, the exchange distributes the available credits, either pursuant to the terms of the exchange agreement or individual credit sale contracts, collecting funds from buyers and distributing back to the sellers. After that point, the exchange may prepare a report for the agency that certifies the sales or may leave that responsibility with the individual permittees. A third party registry accomplishes the same goal as a central exchange, though with a less direct role. A third party could serve to facilitate, document, and register trades in a credit registry such as Markit, but not actively direct them. In either form, this entity may communicate the trade to the regulators.

In light of these considerations, TFT has several programmatic recommendations. First, TFT recommends that the existing permitting scheme continue to be used—the watershed overlay permit applies to all dischargers and future permit iterations could include the required trading language and could incorporate a trade agreement by reference. Furthermore, TFT advises that a conceptual trading program for the Bay utilize a 'Multiple Facility Trading Program' with a trade agreement. The trade agreement outlines the core aspects and rules for a trading program, while the lack of a central exchange provides each facility with greater flexibility. TFT also recommends using a third party entity to help facilitate the trading program. In the absence of a central exchange, a third party entity could assist with credit forecasting, transaction documentation, reporting, and credit accounting, providing objective oversight and assistance to participants. Adoption of these overarching recommendations would foster a robust, reliable, and workable Bay trading program.

The complexity of the systems needed to operate a viable point-to-point trading program may be overwhelming at first glance, but once stakeholder agreement has been reached, these systems will become semi-permanent. Once established, the ultimate value of long-term assurance and clarity that comes with an effective trading program provides a solid foundation for viable compliance investments by permittees. In the end, if pursued in a considerate manner, trading represents a viable and advantageous compliance alternative for San Francisco Bay dischargers facing nutrient discharge limits in future permit iterations.

Table of Contents

3.1 Introduction

This report represents the third task by The Freshwater Trust (TFT) in a series of deliverables analyzing the viability of a point-to-point source trading program in the San Francisco Bay. The previous two tasks provided a summary of the basics of point source trading and identified the challenges and opportunities for trading in the San Francisco Bay, respectively. Building on those tasks, this deliverable includes specific options for major trading program components, and recommendations to minimize the risks and uncertainties associated with these compliance options. Specific examples of documentation and regulatory language from other successful point source trading programs are discussed, with full excerpts of important documents from those programs included as appendices.[2]

3.2 Program Structure Options

When designing a trading program, the first major choice is the type of point-to-point source trading model to pursue. The EPA identifies three primary models for point-to-point source trading. The mechanics and advantages of each option are described below, including blue call-out boxes that contain sample permit language and examples from other programs. The question of trading model and permitting structure are interrelated decisions that should be considered together. The San Francisco Regional Water Quality Control Board (Regional Board) may structure the NPDES permits in a manner appropriate for the chosen model. Following the discussion of trading models, the analysis examines the two basic permit models and their relative advantages and disadvantages.

A. POINT-TO-POINT TRADING MECHANISM OPTIONS

The EPA identifies three primary models for point-to-point source trading: (1) peer-to-peer trading between two point sources; (2) multiple facility trading without a central exchange; and (3) trading through a point source credit exchange.[3]

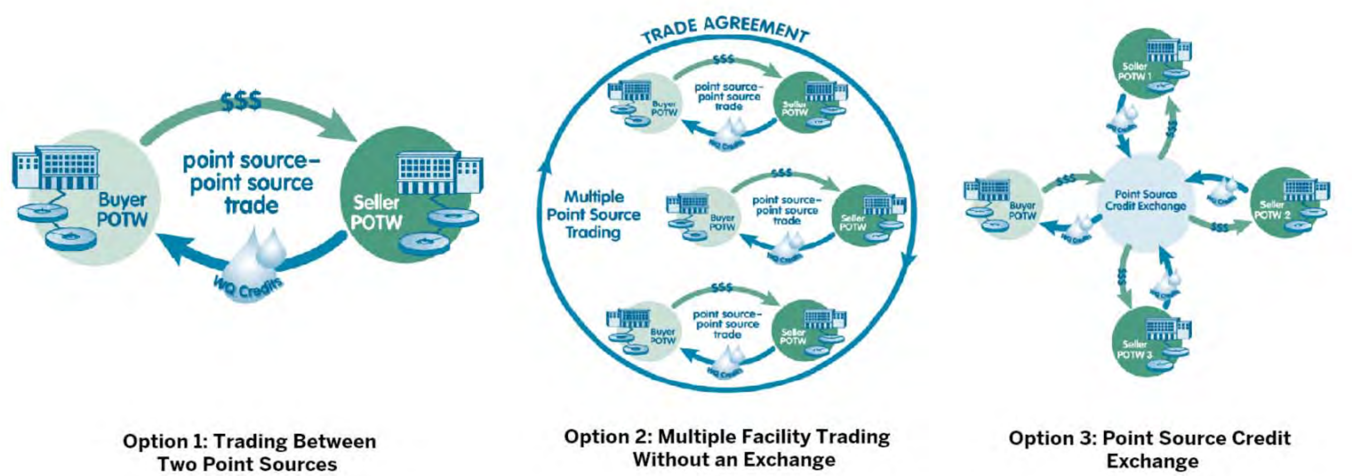


Figure 3.1: Programmatic Options for Point-to-Point Source Trading.[4]

---

[2] EBMUD should consult its attorneys on all matters related to the issues discussed in this document. Nothing in this document should be construed as providing legal advice or recommendations.

[3] U.S. EPA, Water Quality Trading Toolkit for Permit Writers, 15–17, EPA 833-R-07-004 (Aug. 2007, updated June 2009), *available at* www.epa.gov/npdes/pubs/wqtradingtoolkit.pdf (EPA TRADING TOOLKIT).

[4] *Id.*

The core differences between these models are based on the number of participants, the existence (or not) of a central exchange, and how much of the trading infrastructure is encapsulated in bilateral agreements between participants as opposed to trading frameworks.

i. Peer-to-Peer Trades

Under this option, two trading participants may operate under a single permit as co-permittees or, more commonly, under individual permits. The participants trade directly between each other without an exchange, negotiating and arranging the terms of the specific trade(s). The core components of the trade(s) must be included in the NPDES permits of all participants to clarify the regulatory constraints and requirements for the offset activity.[5] This leaves participants with the flexibility to design trades in the most beneficial terms, but without the predictability and assurances that come from working with an exchange or under an overarching trading framework.

Sample Permit Language – Trading Authorization

> The Discharger must meet, through treatment or trading, a mass-based effluent limitation for Pollutant A of XX per XX [this constitutes baseline for the point source]. If this effluent limitation is met through trading, the Discharger must purchase credits from authorized Sellers in an amount sufficient to compensate for the discharge of Pollutant A from Outfall 001 in excess of [baseline], but at no time shall the maximum mass discharge of Pollutant A during [averaging period] exceed the minimum control level of [minimum control]. Thus, the maximum mass discharge of Pollutant A to be offset through credit purchases is XX per XX [minimum control – baseline].

In this scenario, the transactional details of the trade between facilities would be contained in a "separate, written and signed contract" between the facilities.[6] Under these contracts, a purchasing facility would generally not agree to buy credits until the pollutant reductions have been realized. For a credit to be realized, the overseeing regulator (or designee of that regulator) typically needs to determine that the reduction has occurred (usually during a reconciliation period after receiving facility discharge reports), and define how long the credit can be used for (i.e., the "credit life").

Overarching regulatory frameworks that pre-establish these rules can expedite individual transactions. After reconciliation is completed, a purchased credit is valid for the previous compliance period (e.g., month, season or year—the Virginia and Connecticut programs use a 1-year compliance period).[7] Reductions cannot be "banked" to account for compliance periods preceding or following the current compliance period, though two facilities can engage in future buy contracts for later credits based on projected discharges over a period of time. If the capital cost of the upgrade at the selling facility is high, a credit buyer may opt to help finance pollution control technology at another facility in exchange for the rights to the anticipated credits generated. In this scenario the parties should ensure that the regulatory authority supports such an arrangement, perhaps in the form of a compliance schedule or variance included in both permits.

Importantly, peer-to-peer trading programs do not usually take a watershed-scale perspective. Instead of looking at all loading in a basin and encouraging water quality improvements to the watershed as a whole, this type of program focuses on the needs of individual entities who are usually in close proximity.[8] Therefore, peer-

---

[5] This includes the credit characteristics, the compliance period, the eligible constituents, baseline, etc.

[6] EPA TRADING TOOLKIT at 61. This includes things credit price, payment schedule, and consequences for contract breach.

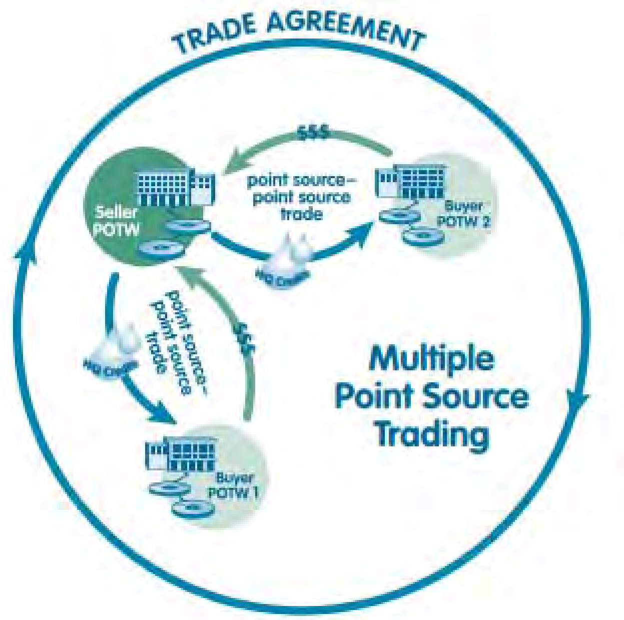
[7] 9 VA. ADMIN. CODE § 25-820-70(F); Conn. Dep't of Energy & Envtl. Prot., General Permit for Nitrogen Dischargers, DEEP-WP&S-GP-002 (Jan 1, 2016), www.ct.gov/deep/lib/deep/Permits_and_Licenses/Water_Discharge_General_Permits/nitrogen_gp.pdf.

[8] If the entities are not in close proximity, regulators and stakeholders are likely to attenuate, or discount, the benefits generated from the selling facility, which can undermine the financial viability of the transaction.

to-peer trades often assist a facility in balancing short-term compliance shortfalls through less expensive means. It is less common for this type of system to support a robust, long-term trading program. Thus, this type of program usually requires less effort to develop as it lacks the programmatic framework and involves fewer entities. The facilities' permit(s) needs to authorize trading and establish some basic requirements, but some details may be worked out between the participants for specific transactions.

ii. Multiple Facility Trading Without an Exchange

The second option entails multiple facilities trading among each other directly under a trade agreement (or a multi-party general permit creating a similar framework)—likely a more useful option for the parties in the San Francisco Bay than the first option. The trade agreement (or trade framework) is usually developed by the discharges in coordination with the regulatory agencies. While not necessarily a regulatory document, the trade agreement is often incorporated into individual NPDES permits either explicitly or by reference.[9]



Option 2: Multiple Facility Trading. All participants exchange credits directly, operating within the guidelines of a trade agreement.

Similar to peer-to-peer trading, individual trades are still negotiated between participants. However, many of the issues that require contractual attention in peer-to-peer trades are resolved by the overarching trade agreement. Trade agreements often set the ground rules for trading and either specifically identify the participants or define the eligibility requirements (e.g., geographic location and/or type of facility). The agreement should explicitly define a framework for credit life, reconciliation period, consequences of breach, compliance reporting obligations, and any other desired terms. Likewise, the trade agreement should have enough detail to provide the permitting authority with some certainty that cumulatively, trades will result in a net reduction of pollutants. Individual NPDES permits then incorporate the trading agreement or general permit terms directly or by reference.

<u>*Sample Permit Language – Incorporating a Trading Agreement into a NPDES Permit*</u>

The [Trade Agreement Title] is hereby incorporated as an enforceable provision of this NPDES permit by reference.

If the [Trading Agreement Title] is approved by the [State Agency] pursuant to applicable administrative processes, the terms of the [Trade Agreement Title] will become enforceable components of this NPDES permit by reference.

With the trade agreement in place, individual trades will likely occur via private contracts between the parties that satisfy the requirements in the trade agreement. In an effort to lessen transaction costs, the participants in this type of system may organize themselves as a group to facilitate trading among the members.[10] For example, several small credit buyers may band together to develop a contract with one large credit generator.

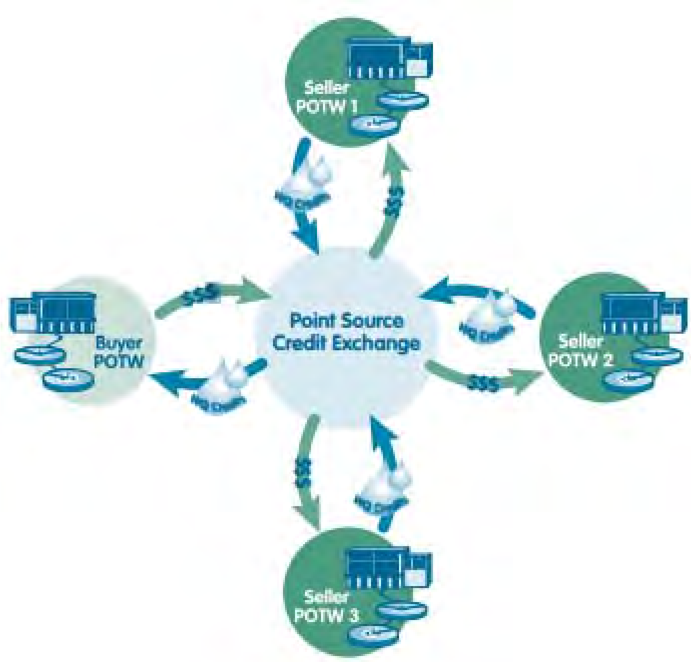
---

[9] EPA TRADING TOOLKIT at 81.
[10] *Id.* at 16.

iii. Trading through a Central Exchange

The credit exchange option is similar to the second option, except that trades occur through a central credit broker instead of directly between participants—this option is thus likely a better fit for the parties in the San Francisco Bay than the first option, though the second option has more flexibility. Often, the credit exchange option is the same as trading under a trade agreement, but participants have the additional option of using a third-party to facilitate and track trades.

> *Sample Permit Language – Authorizing Participation in an Exchange*
>
> The permittee is authorized to participate in water quality trading with the [Credit Exchange], as specified in the trade agreement, for the purposes of complying with the nitrogen effluent limitations of this permit.



Option 3: Central Credit Exchange. The central exchange may serve as an intermediary to facilitate trades or actively buy credits to sell.

Exchanges operate by either buying credits from credit generators (point source or nonpoint source) then selling them to other point sources or by serving as a central platform to facilitate trades among sources by maintaining a ledger of credits and potential trading partners (see Figure 3). An exchange may be a state agency, industry group, or other organization created to administer the program, and is "either operated by or approved and overseen by a state regulatory agency."[11] An exchange must craft internal bylaws to clearly govern its actions and define the exchange's role and responsibilities in a trading program.[12] In particular, exchange bylaws should address the specific reconciliation process and timing, as well as how and when money and credits will be transferred. Ideally, the exchange should also include a mechanism for predicting the supply of credits available in a given year and have a process in place for addressing shortfalls so that individual permittees are not punished for market-level issues.[13] Another important consideration is exchange funding. Some common solutions have been to charge a membership fee or retain a portion of the credit sale proceeds that pass through the exchange.

---

[11] EPA TRADING TOOLKIT at 17. EPA interviewed trading participants nationwide and found they commonly "praised the role of third-party administrators, primarily for their willingness to do the 'heavy lifting' necessary to keep programs running. For instance, on Great Miami, all the interviewees stressed the role of the Miami Conservancy District in initiating the program and handling the daily administrative demands. Other examples include the Neuse River Compliance Association and the Idaho Clean Water Cooperative on behalf of the Lower Boise." U.S. EPA, Final Report: Water Quality Trading Evaluation, 3-5 (Oct. 2008) .epa.gov/sites/production/files/2015-09/documents/epa-water-quality-trading-evaluation.pdf.

[12] *See* Appendix C for the Credit Exchange's internal guidance document.

[13] Virginia accomplishes this by using two tiers of credits: Class A for those pledged in advance, Class B for all other credits. The incentive to pledge credits in advance is the greater monetary value assigned to Class A credits. This helps to accurately predict the anticipated supply of credits, thereby avoiding shortfalls. *Id.*

There are numerous benefits to using a centralized exchange. Exchanges facilitate trading by serving as a single clearinghouse for compliance-grade[14] water quality credits, thereby increasing the predictability of credit supply across multiple entities. Exchanges also have the ability predict and minimize credit supply shortages by reserving some credits or using membership dues to finance "reserve" credit generating actions.[15] Exchanges have the potential to lower transaction costs by standardizing credit transfer agreements and reporting, serving as a single point of contact for buying and selling credits, and reporting all transactions to the regulatory body. Importantly, a central exchange, especially one with strong industry support, may help to direct facility upgrades by all participants in such a way as to realize the most economically feasible compliance strategies for all interested parties.[16]

POTOMAC Basin: Nitrogen Credit Ledger

Compliance Year:	2015	Credit Forecasts		Preliminary Use of Credits				Credit Exchange (Pounds)			
Facility Name	Delivered WLA	Expected Load	Expected Credits	In-Bubble Exchange	Private Exchange	WQIF-Held Credits	Expected Net Credits		Class A Sales	Class A* Purchases	Class B** (expected)
								PRICE:	$ 0.44	$ 3.05	$ 0.03
The Exchange (group)	3,346,561	2,656,178	690,383	-	(3,222)	(25,278)	661,883		270,198	(43,779)	435,464
ACSA-Fishersville	21,441	5,176	16,265	(888)	-	-	15,377		13,307	-	2,070
ACSA-Greenville	6,265	2,231	4,034	(4,034)	-	-	-		-	-	-
ACSA-Harriston	2,506	403	2,103	(2,103)	-	-	-		-	-	-
ACSA-Middle River	36,449	18,539	17,910	-	-	-	17,910		13,307	-	4,603
ACSA-Mt. Sidney	3,759	5,335	(1,576)	1,576	-	-	-		-	-	-
ACSA-Stuarts Draft	21,441	4,829	16,612	-	-	-	16,612		13,306	-	3,306
ACSA-Vesper View	2,506	1,141	1,365	(1,365)	-	-	-		-	-	-
ACSA-Weyers Cave	2,680	9,494	(6,814)	6,814	-	-	-		-	-	-
Alexandria Renew Ent.	493,381	493,381	-	-	-	-	-		-	-	-
Arlington Co.	365,467	190,271	175,196	-	(816)	-	174,380		-	-	174,380
Berryville	5,713	3,510	2,203	-	-	-	2,203		1,983	-	220
Broadway Regional	19,752	16,685	3,067	-	-	-	3,067		-	-	3,067
Fairfax Co-Noman Cole	612,158	423,942	188,216	-	-	-	188,216		75,286	-	112,930
FCWSA-Vint Hill	6,712	2,120	4,592	-	-	-	4,592		-	-	4,592
Front Royal	32,648	27,547	5,101	-	-	-	5,101		1,530	-	3,571
FWSA-Opequon	90,170	50,032	40,138	-	-	-	40,138		20,000	-	20,138
FWSA-Parkins Mill	45,074	21,185	23,889	-	-	-	23,889		6,000	-	17,889
HRRSA-North River	111,492	74,346	37,146	-	-	-	37,146		37,146	-	-
KGCSA-Dahlgren S.D.	9,137	7,309	1,828	(640)	-	-	1,188		-	-	1,188
KGCSA-Fairview Beach	1,827	822	1,005	(1,005)	-	-	-		-	-	-
KGCSA-Purkins Corner	1,096	2,741	(1,645)	1,645	-	-	-		-	-	-
Leesburg	101,113	55,207	45,906	-	-	(25,278)	20,628		-	-	20,628
Loudoun Water- Broad Run	111,224	80,890	30,334	-	-	-	30,334		27,301	-	3,033
Luray	8,576	3,498	5,078	-	-	-	5,078		4,824	-	254

Figure 3.2: Sample Ledger from Virginia Nutrient Credit Exchange Association 2015 Compliance Plan.

B. PERMIT STRUCTURE OPTIONS

Regardless of the trade type selected, all trading-based compliance solutions rely on NPDES permits to govern the compliance obligations of individual permittees. The specific regulatory and environmental circumstances heavily influence the appropriate permit structure.[17] The two major permit structure options are (1) individual permits that contain the specific terms to govern trading, or (2) a watershed general permit[18] covering all potential trading participants.

[14] 'Compliance-grade' credits are those capable of being used to achieve legal compliance with a regulatory program. It is not unheard of for entities to generate less than compliance-grade credits to test the viability of a program or for public benefits.

[15] 9 VA. ADMIN. CODE § 25-820-70(D).

[16] Va. Nutrient Credit Exchange Ass'n, Exchange Compliance Plan: 2015 Annual Update, 1-1 (Feb. 2015). "The initial focus of the Exchange Compliance Plan was on the construction of a large number of nutrient removal technology upgrades at Participants' facilities to achieve compliance with the new Chesapeake Bay nitrogen and phosphorus waste load allocations."

[17] NAT'L NETWORK ON WATER QUALITY TRADING, BUILDING A WATER QUALITY TRADING PROGRAM: OPTIONS AND CONSIDERATIONS, 26 (2015) ("there is no one-size-fits-all approach to effectuating trading").

[18] The watershed-specific general permit applies to multiple point sources within a defined area and may be drafted for a single pollutant or multiple pollutants. *Id.* For trading these permits are usually constrained by both facility type and geographic scope.

i. Individual Permits with an Independent Trading Framework

The first option is to incorporate trading agreement content into individual permits. Without a collective permit to guide action, these programs often rely on robust management by the regulatory agency or a central exchange to ensure proper program operation if trading is to be conducted at a level beyond a few peer-to-peer trades. Although this approach allows for individual permits to be tailored to discharger-specific circumstances, this approach can miss or undervalue a broader, watershed-based perspective.

25 Pa. Code § 96.8(h) – Use of Credits and Offsets to Meet NPDES Permit Requirements

(1) A permittee will only be authorized to use credits and offsets through the provisions of its NPDES permit. The permit conditions will require appropriate terms, such as recordkeeping, monitoring and tracking, and reporting in DMRs.

(2) Only credits and offsets generated from activities located within the Chesapeake Bay Watershed may be used to meet NPDES permit requirements related to the Chesapeake Bay. Credits generated in either the Susquehanna or Potomac basins may only be used in the basin in which they were generated, unless otherwise approved by the Department.

The individual permit option has been used in Pennsylvania's Chesapeake Bay nutrient trading program, a primarily point-to-point trading program which is governed by binding regulations and guidance but does not utilize a watershed general permit.[19]

To implement the trading program amongst point sources, the Pennsylvania Department of Environmental Protection includes trading provisions in the individual permits. The individual permits reference the guidance documents that detail basic trading actions and program components such as identifying participants, projecting credit availability, and registering credits.[20]

Pennsylvania NPDES Permit No. PA.0027057, Williamsport Sanitary Authority (Aug. 10, 2016)

1. Credits may be used for compliance with the Cap Loads when authorized under 25 Pa. Code § 96.8 (Use of offsets and tradable credits from pollution reduction activities in the Chesapeake Bay Watershed), including amendments, updates and revisions thereto; in accordance with DEP's Phase 2 WIP Wastewater Supplement; and in accordance with DEP's Phase 2 WIP Nutrient Trading Supplement [this guidance conveys the state's guidance on trading for POTWs].
2. Where effluent limitations for TN and/or TP are established in Part A of the permit for reasons other than the Cap Load assigned for protection of the Chesapeake Bay ("local nutrient limits"), the permittee may purchase and apply credits for compliance with the Cap Load(s) only when the permittee has demonstrated that local nutrient limits have been achieved.
3. Where local nutrient limits are established in Part A of the permit, the permittee may sell any credits generated only after the permittee has demonstrated that local nutrient limits have been achieved and those credits have been verified in accordance with the procedures established in the Phase 2 WIP Nutrient Trading Supplement.

---

[19] 25 Pa. Code § 96.8 (2015); *see also* Pa. Dep't of Envtl. Prot., Pennsylvania Chesapeake Watershed Implementation Plan: Phase 2 (Mar. 30, 2012); Pa. Dep't of Envtl. Prot., Phase 2 Watershed Implementation Plan: Nutrient Trading Supplement (Oct. 14, 2016).

[20] *See e.g.,* Penn. Dep't of Envtl. Prot., Projection of Future Credit Availability Based on 2014 Compliance Year Information (Apr. 2015), *available at* files.dep.state.pa.us/Water/BPNPSM/NutrientTrading/ProgramRequirements/Projection_of_Future_Credit_Availability.pdf; Penn. Dep't of Envtl. Prot., Nutrient Credit Registry, www.dep.pa.gov/Business/Water/PointNonPointMgmt/NutrientTrading/Pages/NutrientCreditRegistry.aspx.

While this approach affords more flexibility to tailor individual permit obligations, incorporating numerous guidance documents by reference into individual permits at different renewal dates may lead to uncertainty and inconsistency between permits. Changes to those documents could impact some permittees differently and at different times, potentially making it difficult to plan for and execute trades.

ii. Watershed General Permit with Trading Provisions

The second permitting option is a watershed general permit. In this scenario, a single permit is issued that regulates every point source of a given type (e.g. POTWs) in a specific area. Watershed general permits usually come in the form of "overlay" permits, meaning that the general permit applies in addition to each facility's individual permits and regulates a pollutant not covered by the individual permit.[21] The 2003 EPA Trading Policy advocates the use of watershed general permits to facilitate trading:

> EPA also encourages the use of watershed general permits, where appropriate, to establish pollutant-specific limitations for a group of sources in the same or similar categories to achieve net pollutant reductions or water quality goals through trading. Watershed permits issued to point sources should include facility specific effluent limitations or other conditions that would apply in the event the pollutant cap established by the watershed permit is exceeded.[22]

Watershed general permits can enable trading by dealing with all potential participants in a single regulatory document issued at one time. This approach creates uniform standards and terms for all trading participants, as well as a single source of requirements to govern all trading partners. Issuing or amending an overlay permit in response to new information or other needs is more expeditious than making changes to individual permits that regulate all of a facility's discharges.[23]

Both Virginia and Connecticut have issued watershed general permits to govern their trading programs. Virginia outlined the terms of its watershed general permit in regulations,[24] including monitoring requirements, wasteload allocations, compliance schedules, trading mechanisms, and options for compliance if no credits are available. All Virginia wastewater treatment facilities implicated by the rules must submit a registration statement to be included as a co-permittee.

Connecticut similarly issued a watershed general permit for nitrogen to all POTWs within the state,[25] with other pollutants are covered by individual NPDES permits. The Connecticut watershed general permit identifies all covered facilities and explicitly assigns each of them a trading ratio and a daily effluent limit, in addition to covering the required aspects of a permit like the monitoring, reporting, and method of determining compliance. Of note, unlike Virginia's regulations, Connecticut's watershed general permit does not lay out the mechanics of credit trading, instead referencing the statutory sections that govern the trading program.[26]

While Connecticut passed a law and Virginia adopted regulations to govern trading, it is not necessary to do so. It is entirely appropriate, and likely more efficient, to draft a watershed general permit that either contains the

---

[21] EPA Trading Toolkit at 41. EPA defines an overlay permit as "[a] NPDES permit issued to a group of point source dischargers that supplements individual permits . . . for one or more pollutant of concern that are not addressed in the existing individual permits." *Id.* at G-4. The existing San Francisco Bay nutrient permit is technically an overlay permit.

[22] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. 1608, 1611 (Jan. 13, 2003).

[23] A watershed-based general permit "provides greater flexibility for variation and adjustment over any trading period." Nat'l Network on Water Quality Trading, Building a Water Quality Trading Program: Options and Considerations, 27 (2015).

[24] Va. Dep't of Envtl. Quality, VPDES Watershed Permit for Nutrient Discharges to the Chesapeake Bay, 9 Va. Admin. Code § 25-820 (2012); Va. State Water Control Bd., Fact Sheet: Modification of a General VPDES Permit to Discharge to State Waters (2012), www.deq.virginia.gov/Portals/0/DEQ/Water/PollutionDischargeElimination/VAN00FactSheet2012.pdf. Guidance Memorandum No. 07-2008 from Ellen Gilinsky, Director of Va. Dep't of Envtl. Quality, to Deputy Reg'l Directors, on Permitting Considerations for Facilities in the Chesapeake Bay Watershed (Oct. 23, 2007).

[25] Conn. Dep't of Energy & Envtl. Prot., General Permit for Nitrogen Dischargers, DEEP-WP&S-GP-002 (Jan 1, 2016).

[26] *Id.*; CONN. GEN STAT ANN. § 22a-521 – 527 (West 2015).

provisions to govern trading or incorporates by reference a trade agreement or framework.[27] So long as the watershed general permit addresses effluent limits, explains the measurement and timing of compliance and reconciliation, dictates a trading area and any applicable ratios, and lays out the reporting requirements, then all additional terms to govern trading (e.g., trade agreement mechanics, pricing method, potential reserve pools, etc.) may be contained in an independent trade agreement or framework.

Given EPA's strong support for watershed general permits and the close-knit network of dischargers in Bay Area Clean Water Association (BACWA), this option is probably the best fit for a robust trading program in the San Francisco Bay

C. MANAGING RISK AND UNCERTAINTY

It is possible to minimize this risk and uncertainty by taking considerate steps when formulating a trading program, the underlying permit, and individual trades. Mechanisms such as a reserve ratio, credit prediction techniques, insurance, performance bonds, and indemnity agreements can lower the risks and uncertainties associated with trading. Taking thoughtful steps when developing a trading program can mitigate uncertainties, and therefore the risk associated with trading.

i. Permit Shield with Overlay Permit

Every NPDES permit provides the permittee with regulatory assurances. Specifically, the Clean Water Act (CWA) states that: "[c]ompliance with a permit issued pursuant to this section shall be deemed compliance" with the CWA for purposes of enforcement and citizen suits involving certain effluent limits, performance standards, and ocean discharges.[28] This safe harbor provision has been interpreted as applying if (1) the permittee complies with the explicit terms of the permit, and (2) the permittee only discharges pollutants reasonably contemplated by the permitting agency.[29]

Regulatory assurance under these provisions has some restrictions. Namely, the protection does not apply to discharges of pollutants not anticipated by the permitting agency when the permit was issued.[30] For individual permits, this exception rarely manifests because the permit application will identify all potential constituents to be discharged and will be based on past monitoring data. However, for broad general permits, this may be more problematic as the agency issuing the general permit may not contemplate certain pollutants. Issuing an overlay

> *9 VA. ADMIN. CODE § 25-820-70: General Permit for Nitrogen and Phosphorus Discharges and Nutrient Trading in the Chesapeake Watershed in Virginia*
>
> In compliance with the provisions of the Clean Water Act, as amended, and pursuant to the State Water Control Law and regulations adopted pursuant thereto, owners of facilities holding a VPDES individual permit or owners of facilities that otherwise meet the definition of an existing facility, with total nitrogen and/or total phosphorus discharges to the Chesapeake Bay or its tributaries, are authorized to discharge to surface waters and exchange credits for total nitrogen and/or total phosphorus.
>
> The authorized discharge shall be in accordance with the registration statement filed with DEQ, this cover page, Part I-Special Conditions Applicable to All Facilities, Part II-Special Conditions Applicable to New and Expanded Facilities, and Part III-Conditions Applicable to All VPDES Permits, as set forth herein.

---

[27] EPA Trading Toolkit at 8 ("Some states allow trading without having state trading rules, policy, or guidance specifically addressing pollutant trading. For example, the North Carolina . . . works with any watershed group interested in trading to develop a trading framework for that watershed and cover dischargers under an overlay permit").

[28] 33 U.S.C. § 1342(k). This does not apply top toxic discharges however.

[29] This is known as the *Piney Run* test. Nat. Res. Def. Council v. Cty. of L.A., 725 F.3d 1194 (9th Cir. 2013) (citing Piney Run Pres. Ass'n v. Cnty. Comm'r, 268 F.3d 255 (4th Cir. 2001)).

[30] "Section 402(k) also shields discharges of pollutants authorized under a general permit. EPA's position is that general permits authorize the discharge of all pollutants within the specified scope . . . so long as the permittee complies with all EPA application requirements." Memorandum from R. Perciasepe, EPA Adm'r for Water, on Scope of NPDES Permit Shield, to Reg'l Adm'rs (1994).

permit avoids the issue by restricting the scope of the general permit to a single or a select few pollutants. In an overlay scenario, individual permits will provide regulatory protection for the majority of a facility's discharges and the general overlay permit will provide protections for the discharge and actions taken pursuant to a trading program. By divorcing the protections for the individual permit and the general permit, this course of action provides assurance for nutrient trading.

Importantly, including an explicit reference to the safe harbor language in the permit is not required. The safe harbor provisions arise from the federal CWA and all permits issued by state agencies must comply with that law.[31] Therefore, even though "no statutory right to a 'safe harbor' provision [has] to be included as the term of a permit", those protections are implied.[32] A simple reference to the agency's authority to issue the permit suffices to trigger the safe harbor.

Sample Permit Language – Legal Authority

Legal Authorities

This Order is issued pursuant to the Clean Water Act section 402 and implementing regulations adopted by the U.S. EPA and chapter 5.5, division 7 of the California Water Code (commencing with section 13370).

ii. Individual Permittee Liability Minimization Techniques

Entities engaging in water quality trading retain responsibility for complying with their own effluent limits. Using water quality trading to achieve compliance with a NPDES permit does not shift liability from one party to another, nor does it relieve any party from the liability that arises from noncompliance with the terms of a permit.

Sample Permit Language from EPA Trading Toolkit – Individual Liability

Enforcement Liability

The permittee is liable for meeting its most stringent effluent limitation. No liability clauses contained in other legal documents (e.g., contracts) established between the permittee and other authorized buyers and sellers are enforceable under this permit.

As the EPA Trading Policy states: "In the event of default by another source generating credits, an NPDES permittee using those credits is responsible for complying with the effluent limitations that would apply if the trade had not occurred."[33] Even when trading programs operate under a single general permit that assigns one joint pollutant load to all sources, the EPA requires that individual limits exist for the purposes of assigning liability to specific sources if the combined load is exceeded. Individual liability related to water quality based effluent limits (WQBELs) cannot be avoided through the use of trading or contracts even if the shortfall is not the fault of the credit generator.[34]

---

[31] 33 U.S.C. §1342(b).

[32] City of Rancho Cucamonga v. Reg'l Water Quality Control Bd.-Santa Ana Region, 135 Cal. App. 4th 1377, 1388 (2006).

[33] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. 1608, 1612 (Jan. 13, 2003).

[34] The CWA and the implementing regulations contain affirmative defenses to unintentional noncompliance caused by a natural disturbance (the "upset" defense). *See* 40 C.F.R. § 122.41(m & n). However, this "upset" provision only provides an affirmative defense to an action brought against a permittee for temporary and unintentional non-compliance with TBELs beyond the reasonable control of the permittee. *See id.*; Public Interest Research Group of N.J. v. Hercules, 830 F. Supp. 1525, 40 (D.N.J. 1993) (recognizing an upset defense "when seven electrical failures combined with unusual heavy rainfall to cause an overflow of the Dicup skimmer pit[]" and "a temporary 150% increase in process water flows to the plant").

Virginia Nutrient Credit Exchange Association Policy for the Purchase and Sale of Nutrient Credits

6.3 Compliance with Watershed General Permit; Exchange Not Liable

Each Participant shall remain responsible for ensuring its own compliance with the Watershed General Permit. Neither the Nutrient Exchange, nor its officers, governors (directors), technical consultants or other advisors shall be responsible for assuring an adequate supply of Credits or for any other costs or damages of any kind related in any way to the operation of the Nutrient Exchange, including consequential damages

Several good options exist to mitigate this risk to credit purchasers. First, the regulatory entity has discretion to take the cause of and responsibility for noncompliance into consideration when deciding whether to undertake enforcement actions. In addition, other approaches can be implemented to mitigate liability risk. For instance, Pennsylvania has adopted a reserve pool approach. When calculating the amount of credits generated by a credit project, Pennsylvania requires that credit generators relinquish 10% of those credits to a state credit reserve, rather than sell them to credit buyers.[35] Virginia's trading program deals with this uncertainty by allowing permittees to pay into a state fund that uses the money to generate water quality benefits (generally by financing other point and nonpoint pollution reduction measures) in order to offset discharges in the event of point source credit shortages.[36]

9 VA. ADMIN. CODE § 25-820-70: General Permit for Nitrogen and Phosphorus Discharges and Nutrient Trading in the Chesapeake Watershed in Virginia

(J)(3) Credit acquisitions from the Water Quality Improvement Fund

Until such time as the board finds that no allocations are reasonably available in an individual tributary, permittees that cannot meet their total nitrogen or total phosphorus effluent limit may acquire nitrogen or phosphorus credits through payments made into the Virginia Water Quality Improvement Fund established in § 10.1-2128 of the Code of Virginia only if, no later than June 1 immediately following the calendar year in which the credits are to be applied, the permittee certifies on a form supplied by the department that he has diligently sought, but has been unable to acquire, sufficient credits to satisfy his compliance obligations through the acquisition of point source nitrogen or phosphorus credits with other permitted facilities, and that he has acquired sufficient credits to satisfy his compliance obligations through one or more payments made in accordance with the terms of this general permit.

Connecticut, on the other hand, opted to focus on encouraging an ample supply of credits by working with facility's to predict the credit supply and demand for the upcoming year as well as purchasing any unsold credits, thereby guaranteeing a financial return to credit generators. Connecticut also measures permit compliance at the year's end, thereby allowing for a greater level of anticipation for credit availability and need, and helping to minimize unanticipated shortages. The National Network's trading guidance also suggests pre-implementation certification—a process that quantifies credits prior to completion of the credit-generating project to provide certainty about the number of available credits.[37]

Although individual liability cannot be transferred from a permittee, this liability can be shifted contractually between trading partners. Per the EPA Trading Toolkit, this type of agreement, while not enforceable under the terms of the permit itself, it is enforceable under standard contract law. The credit purchase contract may be used to provide partial or full indemnification to the credit purchaser. Indemnification does not alter an enforcement action itself; it simply shifts the financial burden associated with the enforcement. For example,

[35] 25 Pa. Code §§ 96.8(a), (e)(3)(v) (2015).
[36] VA. CODE ANN. § 62.1-44.19:18.B (2015).
[37] Nat'l Network on Water Quality Trading, Building a Water Quality Trading Program: Options and Considerations, 89–94 (2015).

liability that is not the fault of any party may be split evenly, or entirely upon the credit seller if it fails to generate the agreed-upon credits.

Another potential risk minimization option is insurance. Although insurance has not been used in water quality trading, it has been used to minimize risk regarding carbon offsets in California's cap-and-trade program. This insurance product only insures risk that a credit will be invalidated as a result of being improperly created (e.g., if it is discovered that the credit has been "double counted" in both California and in some other offset program).[38] While this insurance does not cover catastrophic risks like floods or earthquakes, the cap-and-trade system has adopted a credit reserve system similar to the Pennsylvania program to cover those types of threats.[39] It may also be possible to acquire insurance to cover the liability that would arise in the event that credits are invalidated. In addition to formal insurance products, it is also possible for a credit purchaser to buy more credits than necessary in order to maintain an internal supply of credits to serve as insurance.

iii. Ensuring Investments are not Sunk Costs

In existing point-to-point source trading programs, money is only exchanged after the discharge reductions are achieved and credits are verified. Under this structure, individual permittees have to finance technological upgrades, and then recover some of this investment once the technology comes online and credits are sold. This approach protects credit buyers by ensuring that the credits purchased are verified and compliance-grade, but leaves potential credit sellers responsible for making costly upgrades without full assurance that the cost of these renovations will be partially recovered.

Several trading market mechanisms may provide a greater degree of certainty to credit sellers, especially if all of the participants are captured under on regulatory document (e.g., watershed general permit) and all are moving forward with compliance alternatives analysis at the same time. For example, the Virginia Nutrient Credit Exchange Association, the nonprofit association that facilitates trades for its members, requires each member to submit an annual report that specifies its expected credit supply and credit demand needs.[40]

Virginia Nutrient Credit Exchange Association Policy for the Purchase and Sale of Nutrient Credits

4.4 Expected Net Credits

For each of its Permitted Facilities included in the Plan, the Participant will be responsible for specifying the Delivered WLA (established by regulation), Expected Load (derived from projected flow and concentration data provided by the Participant), Expected Credits, Preliminary Uses of Credits, and Expected Net Credits. Expected Net Credits is a planning figure only, and no Participant is obligated solely by its specification thereof to generate Credits in a quantity equal to or greater than the Expected Net Credits for the Planning Period.

The Virginia Nutrient Credit Exchange Association also uses a tiered credit approach, with Class A and Class B credits. Class A credits are promised and purchased in advance of their generation[41] while Class B credits are anticipated but not promised. Class A credits are more certain and are therefore more expensive. Furthermore, the Association, which acts as a central exchange, pays sellers at the end of the reconciliation period for the number of credits submitted to the Association, not for the number of that seller's credits that were purchased.

---

[38] *See Parhelion Underwriting Ltd., Parhelion California ARB Offset Credit Invalidation Insurance (Apr. 2013), available at* http://www.parhelion.co.uk/pdf/Parhelion%20California%20ARB%20Offset%20Invalidation%20Insurance%20-%20Product%20Summary.pdf.

[39] CAL. CODE REGS. tit. 17, § 95983; Cal. EPA Air Res. Bd. *Compliance Offset Protocol, U.S. Forest Projects*, § 7, App. D (Oct. 2011).

[40] See Appendix C for The Virginia Nutrient Credit Exchange Association's Credit Exchange Policy.

[41] The Association does have a clause in the agreement that potentially relieves parties of their obligation to submit Class A credits in response to an upset or other issue beyond the reasonable control of the operators. *See* Appendix B.

Until recently, the Connecticut program used a simpler method for guarding against sunk costs by credit generators—Connecticut buys all the credits. This program sets the credit price based on the cost to achieve those reductions.[42] The state, acting as a central exchange, then bought all available credits at the set value and sold them to facilities discharging beyond their permit limits. In essence, the state subsidized the program by ensuring that the demand for credits always matched (or potentially exceeded) the supply of credits and ensuring that credit sellers received a credit price that offset the portion of the capital expenditures that generated credits. The state recently decided to stop this subsidy because the program is believed to have reached a point of sustainability whereby the credit demand sufficiently aligns with the credit generation and cost.

Another method for avoiding sunk costs is through the use of performance bonds and/or standard contracting mechanisms to allocate risk. Two facilities can contract to cooperatively fund the implementation of pollutant reduction technology at one facility in exchange for the excess reductions. That contract could contain language making clear that one party receives ownership of any credits generated, with the other party responsible for making all necessary efforts to ensure those credits are generated as anticipated. As part of this agreement, the buyer could require the seller to issue a performance bond that would compensate the buyer in the event the credits were not generated.[43]

iv. Early Reduction Protections

Pre-permit effluent reductions can improve water quality sooner while simultaneously resulting in a more robust and predictable supply of nutrient credits.[44] In fact, the existing San Francisco Bay Nutrient Watershed Permit states that the "Regional Water Board intends to recognize early actions and encourage early nutrient removal where opportunities exist."[45] However, it is risky for dischargers to invest in early technological or watershed improvements prior to the completion of a trading framework or the imposition of compliance obligations unless regulators provide protected incentives for that action.

One method to encourage early actions is through the use of a "look back period", incorporated into a trading framework or permit. A look back period establishes the base year for credit generation at some previous date, tying the baseline for credit generation to the discharge limits that applied at that time. By making any conforming credits generated during the look back period eligible for trade, entities that implement discharge reduction projects in anticipation of a trading program are better protected and reductions are incentivized.[46] If those projects are in conformance with the trading program—a requirement that is less problematic for point-to-point source trading due to the predictable nature of such investments—then those early action credits can be verified and sold.

---

[42] Cost of an equalized credit is derived by the following formula: *The value of an equalized credit = Capital Costs + Operational Costs / Total amount of equalized nitrogen reduced from project facilities.* Conn. Dep't of Energy & Envtl. Prot., Report of the Nitrogen Credit Advisory Board for Calendar Year 2014 and 2015 To the General Assembly (Sept. 30, 2016), *available at* http://www.ct.gov/deep/lib/deep/water/lis_water_quality/nitrogen_control_program/nitrogen_report_2014_2015.pdf.

[43] Such bonds are common in construction agreements and commodity contracts, two situations that share similarities with an agreement to co-finance technological upgrades in exchange for the credits generated.

[44] The EPA Trading Policy states that one goal of trading is to achieve "early reductions and progress towards water quality standards pending development of TMDLs for impaired waters." U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1611.

[45] S.F. Bay Reg'l Water Quality Control Bd., Order No. R2-2014-0014, Permit No. CA0038873, Waste Discharge Requirements for Nutrients from Municipal Wastewater Dischargers to San Francisco Bay, Fact Sheet, F-15 (Apr. 2014).

[46] Under this approach, "projects completed between the base year and the inception of the trading framework or plan must demonstrate conformity with trading guidance, framework, or plan requirements in order to be eligible to sell credits." Willamette P'ship & The Freshwater Trust, Draft Regional Recommendations for the Pacific Northwest on Water Quality Trading, 57 (2014).

Another method for incentivizing early reductions, and the creation of adequate credit supply, is through the use of lower trading ratios for projects implemented in advance of compliance obligations.[47] As discussed in the Section 3 below, discount ratios are often applied to water quality trades in order to address uncertainties, but reducing that discount ratio creates a direct incentive for early investment. For instance, if the trading ratio is normally 2 to 1 (two units purchased for one unit actually needed), the ratio for credits generated from early projects could be 1.5 to 1, meaning these credits could generate higher profits for the seller. For point-to-point trades, the question of credit duration that could arise with early projects does not pose an issue as the reductions from technological upgrades continue to generate credits. Thus, even though the credits that would otherwise be generated prior to the adoption of a trading program do not accrue to the facility owner because the trading program has not yet arisen, credits generated following the adoption of the program will offer greater economic benefit that will help to offset the upgrade expense.

Sample Trading Framework Options & Language – Base Year & Look Back Period

Project Timing

Fixed Base Year – "Projects are eligible to generate credits if installed after [base year] so long as those projects comply with the terms of this trading framework"

Eligibility Window – "Projects are eligible to generate credits if installed between [date range] if those projects comply with the terms of this trading framework."

Current Year – "Projects are eligible to generate credits after the adoption of this trading framework."

3.3 Technical Program Components

The following section seeks to inform the key components of a point-to-point trading program and provides examples of potential alternatives. These components should be developed through collaboration with all stakeholders in the region and regulators, as those entities have the necessary understanding of a basin's characteristics and the needs of the potential participants.

A. TRADING AREAS AND TRADING RATIOS

Water quality trading typically occurs within a geographic area that is simultaneously large enough to encompass enough sources to make a program viable and small enough to produce assured water quality benefits. As the EPA's Trading Policy states, the ideal trading area "ensure[s] that water quality standards are maintained or achieved throughout the trading area and contiguous waters." This requires a firm grasp of relevant hydrologic conditions, and proper consideration of how benefits will attenuate across the watershed and whether localized impacts may result.

i. Accounting for Subembayments, Tidal Impacts, and Mixing Zones

The EPA Trading Policy advises that trading areas should coincide with a watershed (or TMDL study area) in order to result in trades that affect the same waterway or stream segment. Within this discrete area, trades should be designed to result in a water quality improvement by defining a "point of compliance" (or points) where the water quality goals must be met. These points—which are usually identified in a TMDL or watershed-level analysis—do not necessarily refer to a specific location as they may instead refer to a sizeable geographic

[47] For an example of this, *see* Or. Dep't of Envtl. Quality, Internal Management Directive: Water Quality Trading Oregon, at 20 (Mar. 31, 2016), *available at* http://www.deq.state.or.us/wq/pubs/imds/WQTradingIMD.pdf.

area.[48] The relationship between the point(s) of discharge and the point of compliance help guide the creation of a trading area (see Figure 4).

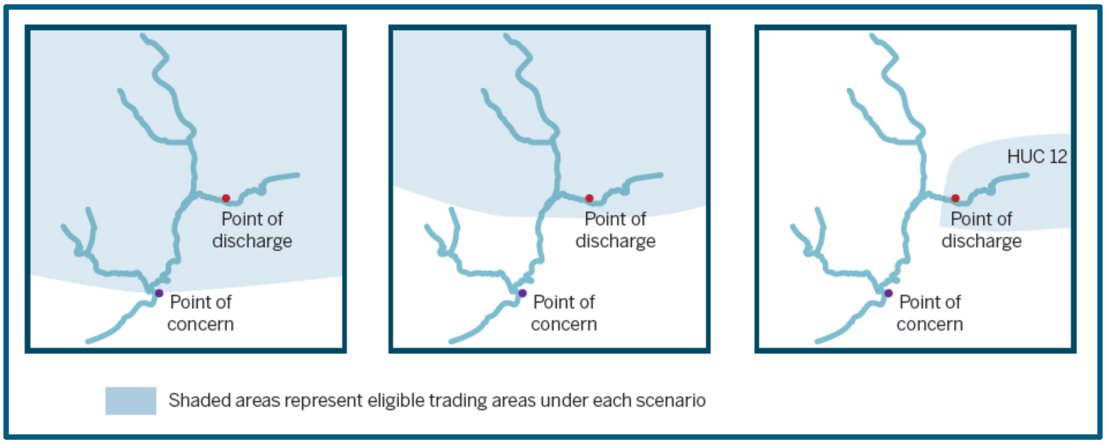


Figure 3.4: Example Trading Areas. This demonstrates the general options for trading areas as related to the overall watershed, the point of discharge, and the point of concern.

The San Francisco Bay constitutes a large, exceedingly complex and diverse watershed. The Bay is a tidally dominated waterbody that encompasses five subembayments—discrete portions of the greater watershed with distinct hydrological and environmental conditions (see Figure 5). These subembayments have differing rates of mixing that change based on a number of factors, such as tides, meteorology, reservoir releases, surface water withdrawals, and Delta outflows.

Figure3.5: Location of Dischargers and Subembayments. This shows the five subembayments and the major municipal dischargers.

A water quality trading area for the San Francisco Bay must account for these factors in order to ensure that water quality benefits are generated as a result of trading. Having a complete understanding of the hydrologic interactions is not necessary in order to develop a trading area, but enough must be known to ensure that trading does not result in a localized impairment of the water quality (a "hotspot"). Under no circumstances may a facility discharge more effluent than the receiving water can incorporate without unacceptable degradation, and the combined potential impact of multiple discharges must also be understood.

So long as no unacceptable near-field water quality degradation results, the trading area may be quite broad. The existing nutrient permit provides that the Regional Board will consider trades "within and between subembayments if permissible." Thus, while it appears acceptable to craft a single trading area that includes all of the subembayments, or a smaller subset of the subembayments, regulators and stakeholders will need to develop the technical justification for those decisions.

[48] For instance, the Pennsylvania Trading Program identifies the Chesapeake Bay as the point of concern. 25 PA. CODE § 96.8.

ii. Trading Ratios

Trading ratios are used to account for a number of concerns, such as uncertainty, attenuation of benefits between locations, and to build a credit reserve. For trades between two permitted point sources, the EPA accepts trading ratios greater than or equal to 1-to-1 (sometimes expressed as a percentage) because these trades may involve little uncertainty.[49] However, in large trading areas with geographically dispersed participants, trades may require a higher ratio, even when trading between permitted point sources. This is because nutrient credits generated by a distant point source are not likely to have the same level of actual nutrient effect on ambient concentrations or beneficial uses at the location of a permittee's credit use.

In the Chesapeake Bay, the jurisdictions with point-to-point source trading programs use the Chesapeake Bay Watershed Model to estimate the individual trading ratios needed for specific trading partners.[50] This model generates a custom ratio for each trade to accurately account for attenuation without undermining the financial viability of trades. Furthermore, Virginia uses an additional 1-to-1.3 ratio for trades between certain basins and Pennsylvania imposes an additional 10% reserve ratio (1-to-1.1).[51] Connecticut, on the other hand, adopted broadly applicable ratios for regions of the state based on approximate attenuation and equivalency for those areas (Figure 6).

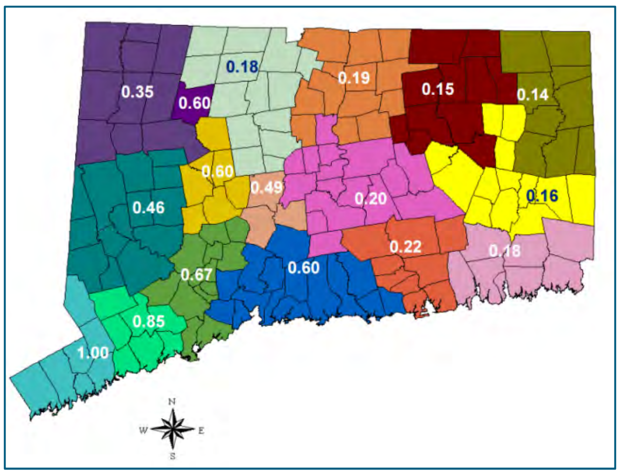


Figure 3.6: Connecticut's Ratios for Different Regions. These ratios are based on the attenuation between these areas and the point of highest impact. The ratios apply to all credits generated within that reach.

Applying these lessons to the San Francisco Bay, it is clear that a minimum 1-to-1 trading ratio would be required for nutrient trades between two point sources. Depending on the final trading area composition, higher ratios may be necessary to account for attenuation. One option is to use a 1-to-1 ratio for trades within a subembayment and create higher ratios for trading between subembayments. Another option is to tier ratios to the distance between subembayments. In a more complex model, water quality and ecological values could be "stacked," and thus reduce the ratio needed.[52] It would be preferable to develop a modeling tool like the Chesapeake applied in order to generate appropriate ratios for individual trades. If participants and/or regulators desire a reserve pool, a reserve ratio can be incorporated into individual trades. In any of these circumstances, it will be necessary to develop a technical basis such that the ratios are scientifically defensible.

B. PERMIT LIMITS AND BASELINE

NPDES permit effluent limits are the core driver for all trades. Discharge limits may include both a technology-based effluent limit (TBEL) component—a minimum level of technology required by all dischargers that cannot be satisfied by trading—and a water quality-based effluent limit (WQBEL) component. EPA states that the water

[49] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. 1608, 1611 (Jan. 13, 2003).
[50] Va. Dep't of Envtl. Quality, Nutrient Credit Trading Ratio Study Report (Dec. 23, 2014), *available at* www.deq.virginia.gov/Portals/0/DEQ/Water/PollutionDischargeElimination/TradingRatioFinalReport12-23-2014.pdf. *See also* Jennifer Vogel, U. Va. Envtl. Law, *Trading Ratios Used for Generation of Credits in Water Quality Trading Programs* (July 2012), *available at* www.deq.virginia.gov/Portals/0/DEQ/Water/PollutionDischargeElimination/UVA_Trading_Ratios_Study.pdf.
[51] *See e.g.,* 9 Va. Admin. Code § 25-820-70(J)(2)(b).
[52] For a primer on stacking, see Royal Gardner & Jessica Fox, *The Legal Status of Credit Staking*, 40 Ecology L. Q. 713 (Sept. 2013).

quality portion of the effluent limit is the only part that may be satisfied via trading. These numeric limits define the maximum concentration and/or the mass of a pollutant that each permittee may legally discharge if complying with the law individually.

Where there is no TMDL, as is the case here for the San Francisco Bay for nutrients, the EPA Trading Policy states that baseline for point-to-point source trading is established by the water quality based effluent limit contained in the NPDES permit of the selling entity. In other words, the seller's WQBEL for a pollutant constitutes its trading baseline—discharges below that limit can generate credits. If a facility discharges above that limit, it cannot sell credits, and must either buy credits or install technology to achieve permit compliance. Thus, while it is fine to adopt a single combined discharge limit for all point sources under a general permit, there must still be individual limits in order to establish the baseline for each source.

In formulating applicable WQBELs, EPA's Trading Toolkit recommends that regulators clearly articulate the discharge levels that apply to all potential credit buyers and sellers in the absence of trading, as well as when trading is used. In most instances, the minimum control level required for credit sellers is the lower of an applicable WQBEL or a TMDL wasteload allocation. The permitting authority also has the power to define some base control level that must be met before trading is allowed. This base level of control can serve to ensure that no localized water quality impairments (i.e., hotspots) result from a credit buyer's discharges. In the absence of an applicable base technological control, it is possible for permits to identify the limits for each facility, along with a narrative requirement that discharges not cause violation of local water quality standards.

C. COMPLIANCE SCHEDULES

NPDES permits may include compliance schedules. These schedules extend the time for permittees to achieve full compliance with new or stricter effluent limits upon showing that additional time is needed implement necessary effluent control measures.[53] With a compliance schedule, if the permittee abides by the schedule and achieves its interim effluent limits and enforceable milestones, it is considered in compliance with its permit even if it is not yet meeting the final effluent limit. These schedules require full compliance to be achieved "as soon as possible" and should not extend longer than 10 years.[54] Virginia's trading program allows for compliance schedules and Connecticut's permit contemplates compliance schedules as one reason the agency may reopen the permit prior to its expiration.

For the San Francisco Bay area, the appropriateness of compliance schedules will likely depend on the decision whether to adopt nutrient water quality objectives, the magnitude of those objectives, the strictness of the effluent limits, and whether time is necessary to install necessary technological upgrades. In light of the fact that it often takes years to design, permit, and build pollution control technology, compliance schedules may be useful tools to bridge the gap between the adoption of discharge limits and the completion of facility upgrades (and the subsequent availability of credits for the entities that plan to cover exceedances with credit purchases).

D. ONGOING MONITORING REQUIREMENTS

Discharge monitoring reports (DMRs) enable regulators and trading participants to track the generation and use of credits and assess overall permit compliance. In addition to end-of-pipe monitoring, ambient water quality monitoring can help demonstrate water quality improvements and show that unacceptable localized degradation of water quality has not resulted from trading activities.

---

[53] Cal. Code Regs. tit. 23, § 2918; State Water Resources Control Board Resolution No. 2008-0025
Cal. State Water Res. Control Bd., Policy for Compliance Schedules in NPDES Permits, Res. 2008-0025 (Apr. 2008).
[54] 40 C.F.R. § 122.47 (2012).

i. Effluent Monitoring Requirements

When monitoring methods and procedures (e.g., sampling protocols, monitoring frequencies) already exist, whether from federal regulations or in NPDES permits, they should continue to be used if applicable for measuring compliance for point source trading.[55] The existing San Francisco Bay Nutrient Watershed Permit, the SF Bay Regional Monitoring Program, as well as the individual permits for the POTWs, contain monitoring protocols that comply with state and federal rules and should largely suffice to support a trading program.

The Nutrient Watershed Permit first requires effluent monitoring at the co-permittees' individual outfalls. This calls for both 24-hour composite samples ("a minimum of four discrete grab samples" weighted for flow) collected between twice per year and twice per month, depending on design flow. Furthermore, the general permit calls for a collaborative receiving water monitoring program designed to provide a more holistic understanding of bay conditions. The individual permits also require monitoring specific constituents in varying frequencies, from continuously to annually.[56]

These existing requirements are similar to the monitoring regimes in other point-to-point trading programs, albeit less robust when it comes to frequency of sampling. For instance, the Virginia Nutrient Trading Program—which like the general nutrient permit tiers monitoring requirements based on facility size—mandates nutrient sampling between once per month and three times per week, with most facilities having to take a weekly sample.[57] Connecticut similarly requires sampling of effluent once or twice per week depending on design flow.[58]

In light of these examples, it is likely that the San Francisco Bay trading participants may need to increase the frequency of effluent monitoring for nutrients as part of a trading program, though other aspects of monitoring

Connecticut General Permit for Nitrogen Discharges

(d) Monitoring Requirements

(1) Effective upon issuance of this general permit, the permittee shall monitor total nitrogen in the final effluent in accordance with the following frequency:

(a) POTWs with a design flow rate specified in the individual permit for the facility of less than 10,000,000 gallons per day shall monitor the final effluent at a minimum frequency of weekly.

(b) POTWs with a design flow rate specified in the individual permit for the facility equal to or greater than 10,000,000 gallons per day shall monitor the final effluent at a minimum frequency of twice per week.

such as the location and methodology would likely remain unchanged. This will guarantee that the trading program has sufficient effluent monitoring and reporting to demonstrate credit supply and demand for all participants.

ii. Additional Monitoring Requirements for Trading

Even with a robust monitoring regime for end-of-pipe discharges, additional information is advantageous to a nutrient trading program. For one, it may be desirable to continue the receiving water monitoring currently being undertaken as part of the ongoing regional monitoring program and other regional scientific efforts. This information may not be required by future permit iterations, but would benefit the San Francisco Bay

[55] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. 1608, 1611 (Jan. 13, 2003).
[56] *See, e.g.,* S.F. Bay Reg'l Water Quality Control Bd., Order No. R2-2015-0018, Permit No. CA0037702, Waste Discharge Requirements for East Bay Municipal Utility District (May 2015).
[57] 9 Va. Admin. Code § 25-820-70(E).
[58] Conn. Dep't of Energy & Envtl. Prot., General Permit for Nitrogen Dischargers, DEEP-WP&S-GP-002, at (4)(d) (Jan 1, 2016).

permittees by providing a more thorough understanding of the receiving water characteristics and responses to changes in source loadings.

The currently required monitoring and reporting practices would likely suffice to prove credit surplus and shortage amounts. If credits are generated and used on an ongoing or recurring basis (e.g., monthly), then it would be necessary to monitor and report the generation, sale, and use of credits in the individual DMRs. However, a trading agreement that includes a reconciliation period to allow for backward-looking compliance likely negates the need for the review of monthly DMRs as the compliance review would only occur during the defined reconciliation period (see below).

Additional information would also be included in either the monthly DMRs or in the annual reports to demonstrate full permit compliance associated with trading. For instance, the comment section of the monthly DMR could contain a reference to the location where a credit registry/ledger and any associated project information is tracked. Information about any technological upgrades either under construction or recently implemented may also be included in a report to the permitting authority. Importantly, for point-to-point trades that do not use a central registry to transparently track all credit generation and trading, it is imperative that the generation and use of credits be closely monitored on an ongoing basis to protect against double counting of credits and other accounting mishaps.

E. COMPLIANCE AND MARKET ADMINISTRATION

A robust administrative framework for all trades, whether contained in a NPDES permit, a trade agreement or a central exchange, will ensure that compliance is achieved and adequately documented. Numerous options exist concerning the method of administering a trading program and demonstrating compliance with NPDES permit requirements.

i. Reconciliation Period for Compliance

Under normal NPDES permit terms, dischargers are responsible for complying with the effluent limits on an ongoing basis. Any exceedance above the limits subjects the facility to enforcement for permit violations. However, to facilitate trading, a "reconciliation period" is often incorporated into point-to-point NPDES permits. This period "allow buyers a window of time at the end of the compliance period to purchase needed credits . . . reduc[ing] risk to regulated sources of overbuying or under buying credits in any given year."[59] In essence, this is a compliance grace period for permittees to acquire the credits needed to compensate for exceedances.

Recognizing its importance, Virginia adopted a five month long reconciliation period. The Virginia general NPDES permit has an annual compliance period that requires dischargers to show permit compliance for the calendar year. They do not need to make this showing, however, until June 1st of the following year, providing the time to adequately complete and document credit generation and trades. Connecticut also uses a one year compliance period with a reconciliation period. TFT recommends such a reconciliation period for the San Francisco Bay, given the complexity of the expected market and the size, cost and timing of the expected facility upgrades.

[59] Ass'n of Clean water Adm'rs & Willamette P'ship, The Water Quality Trading Toolkit, V1.0, at 146 (Aug. 2016).

ii. Credit Cycle Administration

'Credit cycle management'—which refers to the certification, registration, and tracking of credits from generation through usage—ensures that no improprieties arise that could lead to an enforcement action. Certifying credits for point-to-point source trading is much more straightforward than water quality trading programs involving nonpoint sources. The credit generator simply must complete the required monitoring and reporting. Once reported, the reductions are shown and credits have been generated. If a central exchange is used, that entity will track all credits. In the absence of a central exchange, a credit registry—a third party platform that serves as a single location for parties to track credit generation and use—can resolve many of the uncertainties associated with credit accounting.

> *Sample Trading Framework Language – Establishing Permit Compliance*
>
> Compliance will be determined through the permittee's DMR and annual reports, which must demonstrate the permittee has secured sufficient credits and continues to hold a credit balance to meet its effluent limits. Enforcement of the trading program as detailed in this framework shall be consistent with applicable state and U.S. EPA enforcement policies and guidance.

Regardless of the method used, however, care must be taken to avoid double counting credits and to provide transparency. The sections below discuss how a credit registry operates either through a central exchange or a third-party administrator.

Central Exchange

A central exchange avoids many of the credit tracking issues by bringing all trading documentation into a single location under the management of a one entity. Exchanges use standardized documents to facilitate and track trades, lessening the potential for accounting errors. Specifically, an exchange will enter into binding agreements with all participants that lay out expectations and responsibilities. The exchange will then quantify the credits generated or needed based on the DMRs or other data submitted by all participants. Once calculated, the exchange distributes the available credits, either pursuant to the terms of the exchange agreement or individual credit sale contracts, collecting funds from buyers and distributing back to the sellers. After that point, the exchange may either prepare a report for the agency that certifies the sales or may leave that responsibility with the individual permittees.

For example, the Virginia Nutrient Credit Exchange Association (the Association) requires its members to provide an estimation of anticipated discharges (and thus credits) for the upcoming annual compliance period.[60] The members are given the option to pledge to buy or sell a set number of credits in the approaching year. At the end of the year, the facilities then submit an annual report to the agency and the Association that summarizes the DMRs for that year. With this information, the Association quantifies the credit market to create an initial reconciliation report.

[60] Participation in the exchange is voluntary and members may engage in independent trades, though members "shall provide reasonable advance notice to the Nutrient Exchange of all Private Exchanges." *See* Exchange Policy § 4.9, at Appendix C.

The Association then issues credit exchange confirmations to sellers to verify credit availability before sending similar confirmations to buyers. Once the buyers execute these forms, the exchange of compliance-grade credits is complete and buyers have the documentation needed to show permit compliance.[61] Following the transfers, the Association submits a final reconciliation report to the agency documenting the transactions and providing the transparency needed.

> *9 VA. ADMIN. CODE § 25-820-70: General Permit for Nitrogen and Phosphorus Discharges and Nutrient Trading in the Chesapeake Watershed in Virginia*
>
> **(F) Annual reporting**
> On or before February 1, annually, each permittee shall file a discharge monitoring report with the department identifying the annual mass load of total nitrogen and the annual mass load of total phosphorus discharged by the permitted facility during the previous calendar year.
> …
> **(J)(2)Compliance with Waste Load Allocations: Credit Acquisition from Permitted Facilities**
> f. No later than June 1 immediately following the calendar year in which the credits are applied, the permittee certifies on a credit exchange notification form . . . that he has acquired sufficient credits to satisfy his compliance obligations. The permittee shall comply with the terms and conditions contained in the credit exchange notification form submitted to the department.

Third-Party Accounting & Credit Registry

A third party registry accomplishes the same goal as a central exchange, though with less of a direct role.[62] A third party in this role could serve to facilitate, document, and register trades but not actively direct them. Unlike an exchange, use of a third party registry has more opportunity for trade negotiation to fit individual needs.[63] The relationship between permittees and the third party is more similar to a contractor or accountant, whereas an exchange is more like a seller to an auction house.

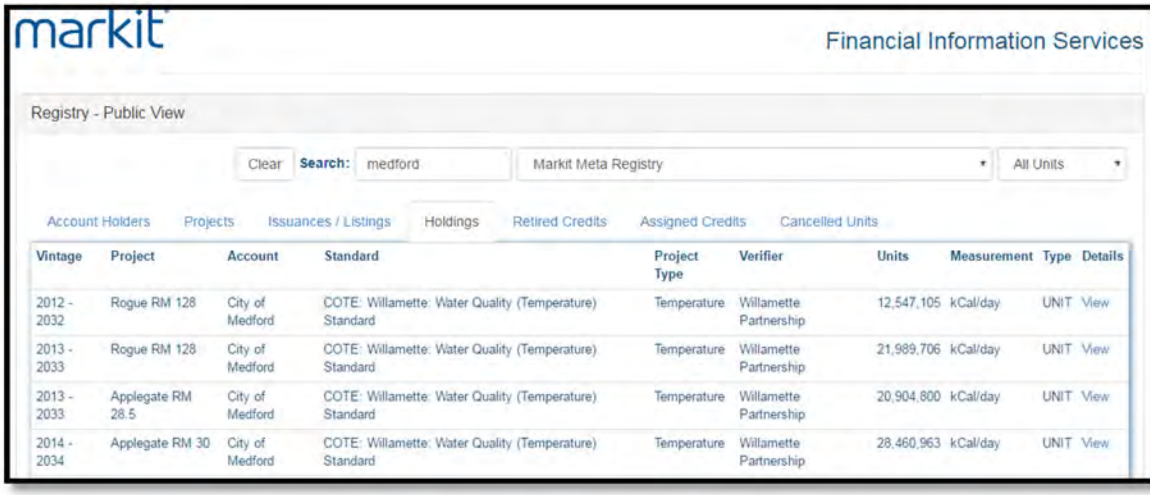
> *Sample Permit Language from EPA Trading Toolkit – Credit Registry*
>
> **Credit Registry to Track Credits**
> No trade is valid unless it is recorded in the [Credit Registry] electronic trade tracking system or equivalent system that records all trades and generates trading notification forms and a summary of all trades valid between [Date Range] of each year, in substantially the same format as forms approved by the state. The record-keeping system must be capable of ensuring that a particular credit is not sold to more than one trading participant. The trading notification forms and trading summary may be compiled by the Registry, but each permittee is responsible for the submittal of all documentation and reports. Trading notification forms for each trade must be submitted to the [Permitting Authority] by [Compliance Deadline].

Under this arrangement, a third party becomes involved in order to help complete trades. After reviewing the DMRs to quantify and certify the credits as valid, the third party then completes the registration of credits into a credit registry such as Markit (Figure 8). Entry into a public registry helps to protect against double counting (and potential invalidation) and allows for independent compliance monitoring. The third party may also communicate the trade to the permitting authority.

---

[61] See the Attachments to Appendix C for a copy of these forms.
[62] This credit cycle framework is essentially the "Multiple Facility Trading Without an Exchange" discussed in § 2(A)(1).
[63] Note: the third party responsibilities outlined here only provide an example of the potential duties, the parties negotiate an agreement that defines the parties' particular responsibilities.

The use of a third party becomes even more important if nonpoint source trading is incorporated into a point-to-point source trading program. Nonpoint source credit generation entails less certainty and includes more geographically dispersed projects. As a result, these types of trades require a greater degree of oversight and accounting to certify, register, and track the credits.



Vintage	Project	Account	Standard	Project Type	Verifier	Units	Measurement	Type	Details
2012 - 2032	Rogue RM 128	City of Medford	COTE: Willamette: Water Quality (Temperature) Standard	Temperature	Willamette Partnership	12,547,105	kCal/day	UNIT	View
2013 - 2033	Rogue RM 128	City of Medford	COTE: Willamette: Water Quality (Temperature) Standard	Temperature	Willamette Partnership	21,989,706	kCal/day	UNIT	View
2013 - 2033	Applegate RM 28.5	City of Medford	COTE: Willamette: Water Quality (Temperature) Standard	Temperature	Willamette Partnership	20,904,800	kCal/day	UNIT	View
2014 - 2034	Applegate RM 30	City of Medford	COTE: Willamette: Water Quality (Temperature) Standard	Temperature	Willamette Partnership	28,460,963	kCal/day	UNIT	View

***Figure 3.7**: Markit Environmental Credit Registry. This registry helps trading participants to transparently track credit generation and use.*

iii. Non-Compliance Ramifications

Like any CWA permitting program, noncompliance with the terms of either a watershed general permit or an individual permit that contains trading provisions can result in an enforcement action. These enforcement actions may be brought by the state agency or citizen plaintiffs. Ramifications include the potential for daily fines levied for each day the violation(s) occurred. For trading programs this can be quite daunting as compliance is often determined for a relatively long period of time such as one year. If insufficient credits exist for the past compliance period, a permittee could face multiple days of permit violations. While this has not occurred in other trading programs, this is the result of program mechanisms to prevent such shortages, such as the use of a credit reserve pool or water quality improvement fund.

In order to avoid noncompliance with a permit as it relates to water quality trading, it is important to maintain adequate transparency for the public and regulators, accurately document credits from generation through use, and communicate openly with the permitting authority. Failure to do so could lead to an enforcement action by private parties or state or federal regulators.

3.4 Conclusion & Recommendations

The municipal dischargers to the San Francisco Bay, EPA Region 9, the San Francisco Bay Regional Water Quality Control Board, and other pertinent Bay stakeholders should jointly develop and agree to the specific components of a water quality trading program for it to be a durable compliance alternative. This collaborative process would allow the participants and regulators to design a trading system using a trade agreement that has accountability and transparency, as well as the flexibility and clarity to ensure trading represents a secure and cost-effective compliance option for permitted entities that generates a net environmental benefit versus the non-trading alternative. The following recommendations should not supplant this collaborative process, but are instead intended to help inform and guide the discussions. Importantly, these recommendations should not be construed as legal advice—but rather as suggestions that must be discussed with legal counsel prior to making any decision related to regulatory compliance.

TFT recommends that the San Francisco Bay continue to utilize a watershed overlay permit that applies to all dischargers for the specific pollutant(s) where trading is relevant. The existing permit jointly regulates the wastewater treatment facilities in the San Francisco Bay and could be easily modified to incorporate nutrient trading provisions directly or by reference to another document. This approach aligns with the EPA's existing guidance documents and avoids the confusion that could arise if nutrient trading is implemented in individual permits. Likewise, by addressing nutrient trading in an overlay permit that only applies to nutrient discharges and not to other pollutants, the permit will entail a greater degree of clarity. The permit may set discharge limits cumulatively for the entire Bay or individually for the distinct subembayments. Such combined discharge limits provide an easier mechanism for achieving watershed-scale nutrient reductions. Significantly, even with these overarching limits, the permit must include individual nutrient allocations to allow for baseline determinations. These individual limits would likely only apply in the event that cumulative compliance is not achieved. The combined and individual limits could also include compliance schedules, if necessary and warranted.

Turning to the programmatic structure, TFT recommends that a nutrient trading program for wastewater utilities in the San Francisco Bay utilize a 'Multiple Facility Trading Program' with a trade agreement. A trade agreement outlines the core aspects of a trading program, establishing a single framework for all trading activities that all trades must comply with. The trade agreement would resolve much of the potential uncertainty in a trading program by explicitly and unambiguously defining the various components and characteristics of the program for all participants in one place, along with repercussions for failure to perform. The trade agreement would be incorporated into the watershed general permit by reference, with some of the more important terms (i.e., trading area, reconciliation period, and baseline limits) directly included in the overlay permit. This approach allows for greater flexibility in refining the components of the trading program, as the parties and regulators could make amendments to the trade agreement in response to new information without having to reopen the general overlay permit. Importantly, such an agreement lowers transactional costs by defining the trading process and key components, which also makes participation easier. This trade agreement would be between the dischargers to the San Francisco Bay, and would ensure that trades satisfy regulatory requirements.

TFT also recommends **using a third party entity to assist with trading forecasting, transaction documentation, reporting and credit accounting**. The downside to a Multiple Facility Trading Program with a trade agreement compared to a program using a central exchange is the lack of a central entity to direct trades and assist in trade tracking, documentation, etc. Though operating without a true central exchange offers parties more leeway to design individual trade transactions that better suit their individual needs, having a single party to help facilitate or broker individual trades between two or more dischargers will streamline the trading process. This third-party broker should help to complete the documentation of individual trades required by regulators and should be responsible for maintaining a credit registry to track credit creation, serialization, transactions and custody. This approach significantly lowers the risk of noncompliance by guaranteeing that credits are valid and properly documented before releasing them for compliance purposes. Moreover, a broker may be able to help direct trades in a way that further lowers risk and cost. For example, a broker can collaborate between multiple participants to forecast credit supply and demand, and facilitate future buy contracts—both of which can help minimize the capital exposure for potential credit sellers before they make costly upgrades. Of particular note, unlike a central exchange, a third party broker may have as much or as little involvement in trading as the parties' to the trade agreement desire. Thus, a broker provides greater flexibility to individual parties as well as the certainty that comes with having an objective entity engaged in the process.

In addition to broad program structure, TFT has various recommendations on specific components of a nutrient trading program. Although discrete program aspects will be completed in conjunction with stakeholders and the regulators, TFT believes the following component recommendations are critical to any successful program:

- ***The trading area should include the entire San Francisco Bay with all of the subembayments, using trading ratios derived through bay-wide studies to account for attenuation of benefits between the subembayments***. Addressing impairment for the entire Bay represents the most holistic approach and, as such, has the greatest potential to improve conditions for the entire area. Similarly, a broader trading area allows for more participant permutations, which may also lead to further cost reduction opportunities.
- ***Compliance should be determined on an annual basis, with credit duration matching this compliance period.*** Water quality trading credits usually have a duration that aligns with the compliance period (i.e., a monthly compliance period would have credits with a one month duration). As such, the period of compliance impacts the transactional costs associated with credit trading—too short a period leads to high administrative expenses due to frequent trading, too long a period creates credits that are too expensive and generates too much uncertainty. An annual period allows for accurate forecasting of credit supply and demand.
- ***A reconciliation period should be adopted for achieving compliance with annual nutrient obligations***. End-of-pipe discharge monitoring should continue to be required by individual dischargers along with receiving water monitoring performed by the regional monitoring program. In addition to the monthly DMRs, all participating parties would be responsible for an end-of-year compliance report that documents annual reductions and trades. This report should not be due until several months after the close of the previous reporting year, as dischargers will need time to reconcile credit needs based on actual discharges, and then acquire a sufficient volume of credits to offset any exceedances. This approach is important for the purposes of individual facility risk minimization, as money is only exchanged after effluent reductions are achieved and credits are verified. This method also has less transactional costs than real-time reconciliation.
- ***The baseline should be founded on the future individual discharge limits contained in the applicable permit,*** Credits may be generated by reducing effluent concentrations below the baseline. Conversely, credits may be purchased and used to offset effluent concentrations above the baseline, to the extent that no near-field impacts result. In the event that future permit limits contain a technology-based effluent limit component, trading would not represent a means to offset discharge beyond that limit. In that scenario, the technology-based effluent limit would serve as a baseline for credit purchase, though the baseline for credit generation would remain the same.
- ***A nonpoint source restoration fund should be established to allow dischargers unable to acquire sufficient credits to offset their effluent by paying into the fund.*** Such a fund would create a safety net for dischargers in the event of unexpected credit shortfalls. A facility unable to purchase sufficient credits to offset discharges due to a lack of supply is in noncompliance with its permit. With a nonpoint source restoration fund, dischargers facing this prospect would still be able to achieve compliance by directing the same amount that would have been spent on credits to a fund used to implement environmental restoration. The state (or a reputable third-party) would oversee the management of the fund, the implementation of projects, and the necessary ongoing maintenance of the restoration site. This protects against noncompliance, minimizes the risk from credit supply fluctuations, and generates environmental benefits for the watershed.

In the end, point-to-point source water quality trading programs require a level and type of documentation and management not ordinarily needed for traditional CWA compliance solutions. Yet, while trading programs may need more initial development, the potential benefits in time, money, and environmental outcomes often outweigh the expenses. Based on a review of successful point-to-point source trading, as well as organizational experience with point-to-nonpoint source trading, TFT believes these recommendations have good potential to result in the development of a successful nutrient trading program for San Francisco Bay.

4. Hypothetical Trading Scenario Assessment

Task 4: Using Hypothetical Scenarios to Demonstrate the Mechanics of a Point-to-Point Source Trading Program for the San Francisco Bay

Executive Summary – Task 4

This report uses existing information about discharges into the San Francisco Bay, supplemented with some underlying assumptions, to review several potential trading scenarios in the Bay. The scenarios evaluate nutrient trades between 11 fictional dischargers and EBMUD across two hypothetical subembayments. Although the gaps in the available information constrain the applicability of this assessment, this report still offers insight into the specific mechanics of a robust trading program. Moreover, this assessment demonstrates the potential economic effectiveness of trading, though the specific figures are rough estimates that may not accurately represent the potential savings to the dischargers.

The specific scenarios involved four hypothetical nutrient discharge reduction requirements. The specific reduction requirements were based on effluent concentrations but converted into mass required reductions as well. The scenarios sought to achieve the greatest cost savings for the watershed as a whole. This analysis demonstrates that as the required reductions become more stringent, the nutrient trading tends to become an increasingly viable option.

4.1. Introduction

This report analyzes several potential trading scenarios that could arise across two hypothetical subembayments under a nutrient trading program involving 11 fictional dischargers and EBMUD. The scenarios illustrate two tiers of effluent reductions beyond current nutrient loading. In order to demonstrate the potential viability and mechanics of trading, data was generated that mimics the conditions in the San Francisco Bay. This data is not derived directly from the Bay due to gaps in the information available, but is valuable to highlight the functionality and the potential economic viability of nutrient trading.

Importantly, this hypothetical scenario has been constructed to minimize the total expenditure necessary to meet several tiers of nitrogen load reductions for the fictional watershed as a whole, but not necessarily to optimize expenditures for individual facilities. While individual facility economic optimization would occur under an actual trading program, an economic analysis of that nature would require additional facility information that is currently unavailable, such as the ongoing expenses associated with different treatment technologies. Moreover, that type of precise analysis requires insight into individual facilities' willingness to take on particular risk(s), ability to pay for advance credits, and general economic position. While constrained by the lack of specifics, this report is meant to demonstrate more broadly the mechanics of trading and what types of opportunities likely exist for trading based on the cost differentials for technological upgrades between facilities.

4.2. Overarching Trading Mechanics

The specific mechanisms for trading will not differ between the scenarios analyzed. Therefore, the mechanisms and assumptions for trading are discussed in this section to avoid redundancy.

A. TRADING AREA & TRADING RATIO

In order to geographically delineate a trading program, a trading area must be designated. In this hypothetical, the trading area is comprised of two synthetic subembayments with facilities randomly assigned to one of these subembayments. In order to illustrate the accounting of the potential attenuation of water quality benefits, a trading ratio of 2-to-1 is used for trades between the subembayments. Trades within one subembayment use a 1-to-1 ratio.

B. CREDITS & COMPLIANCE PERIOD

In any trading program, it is important to clearly articulate the characteristics of a credit. Under this hypothetical, a credit constitutes one kilogram per day of total nitrogen (TN) reductions (beyond baseline), averaged for an entire year. This means that the kg/day reduction must be realized, on average, every day for the entire year to warrant crediting.

The compliance period for this illustration is one year, which means that compliance is determined at the end of the year for the previous year. This assumes a short reconciliation period (usually several months) to allow dischargers to complete the documentation required to show effluent loading, determine any credit needs or supply, and complete any credit trades prior to demonstrating compliance. At the end of this reconciliation period, the dischargers would submit the documentation to the regulatory authority demonstrating that compliance is achieved for the preceding year.

C. BASELINE

To generate credits, a facility must reduce its discharge below the applicable baseline. The baselines for these scenarios correspond to the TN load reductions necessary to meet discharge reductions. Thus, under the 30% reduction scenario, a facility may generate credits for any reductions beyond a 30% reduction of that facility's existing discharge. For instance, if a facility has an existing discharge of 1,000 kilograms of TN per day, any reductions below a 700 kilogram TN discharge per day would generate credits. Any nutrient reductions beyond this effluent limit constitute creditable discharges.

D. MARKET ADMINISTRATION

This hypothetical operates under the assumption that a third party broker is engaged to help direct trading activities and assist in completing the required documentation. The use of such a broker allows for the system to function completely efficiently—only the most economically effective trading scenarios are undertaken. Moreover, a broker ensures that the credits are equal cost across the entire trading area, generating the greatest economic savings while still achieving the required nutrient reductions.

E. SPECIFIC MECHANICS OF THE TRADING PROGRAM

To begin with, dischargers would supply the third party broker with the most current year's discharge monitoring reports (DMR), and any other pertinent information, in order to enable a projection of credit supply and demand for the upcoming year (or the discharger could complete this demand analysis internally). Likewise, the facilities will provide estimates on the cost of various treatment upgrades and the associated discharge reductions. Based on this information, the broker can calculate the anticipated credit needs and potential availability for the upcoming year. The broker then communicates with the facilities to direct implementation of the most efficient upgrades that will achieve the required reductions at the lowest combined cost.

Assuming these upgrades are implemented as directed, the facilities would then submit all DMRs to the broker at the end of the compliance year. The broker would then calculate the individual facility credit supply or need, as well as the cost of the individual credits based on the number of credits available and the cost to generate them. At that point, the broker then completes the necessary accounting, registering the validated credits on a transparent credit registry that serializes and assigns ownership of each individual credit.

Once the credits are calculated and registered, the broker would direct the parties' trading activities, connecting each credit seller with the nearest credit buyer(s) in order to minimize any attenuation of water quality benefits. The broker would assist these parties in completing any regulatory documentation, finalizing the credit contract, and transferring the credits. Once all transfers are completed and evidenced on the credit registry, the broker would assist the parties in generating the annual report and other records for the regulatory body before the end of the reconciliation period. When submitted, this information proves compliance for the individual entities and for the waterbody as a whole. The broker would then evaluate the credit supply and demand for the next compliance year based on the information submitted to the regulators and other insight from the facilities, working with the dischargers to direct any upgrades for the next compliance year.

4.3. Hypothetical Scenario Analysis

A. UNDERLYING DATA & CORE ASSUMPTIONS FOR ALL SCENARIOS

The scenario analysis is based upon a number of underlying assumptions that were necessary in order to demonstrate the mechanics of trading for nitrogen. First, it was necessary to generate and assign data and synthetic subembayments to the facilities (See Figure 1). This includes figures on permitted discharges, actual discharge flow, and average daily TN discharges by load (kg/day) as well as concentration (mg/L). This underlying facility data was generated to be an approximate representation of existing discharges to the Bay during the 2015–2016 compliance year, but is not assignable to real-world facilities.[1] The representative facility data was then paired with actual data on the capital costs[2] of implementing various levels of nutrient reduction

[1] BAY AREA CLEAN WATER AGENCIES NUTRIENT REDUCTION STUDY, GROUP ANNUAL REPORT: NUTRIENT WATERSHED PERMIT ANNUAL REPORT 2016 (Oct. 2016).

[2] The ongoing expenses required to maintain these treatment technologies was not available. In actual trading programs the ongoing expenses are factored into the credit costs so that the credit price accurately reflects the expenses of creating and maintaining the credits.

technologies at individual facilities, though this data was anonymized. Thus, the discharge and cost data was designed to be as representative of existing circumstances in the Bay as possible, while maintaining the anonymity of the existing facilities, in order to best illustrate the viability and mechanics of a trading program.

	Subembayment	Permitted Discharge (MGD)	Actual Flow 2015-2016	TN Average (kg/day)	TN Daily Average (mg/L)	No Net Loading (kg/d)	30% Reduction (kg/d)	50% Reduction (kg/d)
Discharge 1	1	167	79.3	5400	15	5400	1620	2700
Discharge 2	1	53.8	33.2	4000	30	4000	1200	2000
EBMUD	1	120	52.9	11000	49	11000	3300	5500
Discharge 3	1	7	2.9	240	14	240	72	120
Discharge 5	1	53.8	33.2	4200	30	4200	1260	2100
Discharge 6	1	2	0.3	13	11	13	3.9	6.5
Discharge 7	1	2.5	1.5	63	10	63	18.9	31.5
Discharge 10	2	15.5	9.7	840	22	840	252	420
Discharge 11	2	23.7	12.8	1300	27	1300	390	650
Discharge 12	2	4.5	2	220	26	220	66	110
Discharge 13	2	3.2	1.2	130	25	130	39	65
Discharge 16	2	39	21.6	2400	29	2400	720	1200
Total				29,806		29,806	8,942	14,903

Figure 4.1: *Randomly Assigned Facility Discharge Data and Effluent Limits*

Next, discharge limits to drive a theoretical trading program were created. As the current nutrient permit only requires monitoring and does not include any numeric effluent limitations, the limits necessary to create run a theoretical scenario were generated by TFT staff. These specific scenarios are: (1) No Net Load Increase, the existing discharges constitute the effluent limit, (2) 30% Reduction beyond the No Net Load Increase, and (3) 50% reduction beyond No Net Load Increase. These reductions apply to the total load discharges, but include some assumptions about concentration. Similar to the effluent limit methodology used by other trading programs,[3] these limits are applied to the Bay as a whole, allowing compliance to be achieved for the entire Bay regardless of individual discharges (Figure 2). However, individual discharge limits were assigned to guide the individual facility discharge compliance that drives trading programs (Figure 1). As discussed previously, individual limits only apply for enforcement purposes under these types of permits if cumulative discharges exceeded the Bay-wide nutrient limit.

Scenarios	Allowable Load (kg/d)	Bay-wide Reduction Needed (kg/d)	Subembayment 1 Reduction Needed (kg/d)	Subembayment 2 Reduction Needed (kg/d)
(1) No Net Load Increase	29,806	0	0	0
(2) 30% Load Reduction	20,864	8,942	7,475	1,467
(3) 50% Load Reduction	14,903	14,903	12,458	2,445

Figure 4.2*: Current Loading and Reductions Required in Different Scenarios.*

Importantly, to better demonstrate the mechanics of a trading program for the Bay, trading ratios were assigned.[4] Nutrient credit trades between facilities in the same subembayment used a 1-to-1 trading ratio as it is assumed that no discount factor was needed due to the geographic proximity of sources. For credit trades between two different subembayment a 2-to-1 ratio was used, requiring credit buyers to purchase twice as

---

For instance, Connecticut's program derives the credit cost by dividing the total annual project cost (capital expenditures plus ongoing operation and maintenance costs) by the reduction in equalized pounds of nitrogen. CONN. DEP'T OF ENERGY & ENVTL. PROT., REPORT OF NITROGEN CREDIT ADVISORY BOARD FOR 2013, 8 (Sept. 2013), www.ct.gov/deep/lib/deep/water/municipal_wastewater/nitrogen_report_2013.pdf.

[3] Va. Dep't of Envtl. Quality, VPDES Watershed Permit for Nutrient Discharges, 9 VA. ADMIN. CODE § 25-820 (2012).

[4] Trading ratios are discount factors applied to trades to ensure environmental benefits accrue and to account for uncertainty and the attenuation of water quality benefits between sources. U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. 1608, 1612 (Jan. 13, 2003), *available at* www.gpo.gov/fdsys/pkg/FR-2003-01-13/pdf/03-620.pdf.

many credits as actually needed for compliance to account for the attenuation of water quality benefits between distant facilities.

	Level 2 Upgrade Expense	Level 2 Treatment Cost ($/lb)	Level 3 Upgrade Expense	Level 3 Treatment Cost ($/lb)
Discharge 1	$ 18,000,000	-	$ 56,000,000	$ 1.70
Discharge 2	$ 28,000,000	$ 6.60	$ 28,000,000	$ 17.60
EBMUD	$ 1,173,000,000	$ 0.90	$ 1,231,000,000	$ 5.00
Discharge 3	$ 1,000,000	-	$ 31,000,000	$ 57.70
Discharge 5	$ 51,000,000	$ 63.00	$ 219,000,000	$ 5.00
Discharge 6	$ 34,000,000	-	$ 36,000,000	$ 24.90
Discharge 7	$ 84,000,000	-	$ 92,000,000	$ 6.50
Discharge 10	$ 43,000,000	$ 0.50	$ 56,000,000	$ 6.60
Discharge 11	$ 180,000,000	$ 0.40	$ 251,000,000	$ 4.00
Discharge 12	$ 110,000,000	$ 1.40	$ 120,000,000	$ 4.00
Discharge 13	$ 70,000,000	$ 1.10	$ 80,000,000	$ 3.00
Discharge 16	$ 28,000,000	$ 1.00	$ 52,000,000	$ 2.00
Total	**$ 1,820,000,000**		**$ 2,252,000,000**	

Figure 4.3: *Capital Expenses and Cost per Pound of Nutrient Reductions for Two Levels of Upgrades.*[5]

In addition to this data, a number of underlying assumptions were made in order to facilitate the generation and evaluation of several scenarios. The assumptions that apply generally include:

- Implementing Level 2 treatment results in a TN concentration of 15 mg/L for all facilities;
- Implementing Level 3 treatment results in a TN concentration of 6 mg/L for all facilities;
- A facility can implement Level 3 treatment without implementing Level 2 treatment;
- Implementing treatment technology results in all discharges from that facility having the same concentration of TN;
- No credit reserve ratio was assigned to retire credits; and
- Credit costs are derived to be uniform for trades across the entire trading area.

With these assumptions and the data assigned, TFT evaluated three hypothetical scenarios based on different fact patterns for the San Francisco Bay using the same trading mechanics for each.

[5] The data underlying this table is based on real facility upgrades expenses in the San Francisco Bay. The dashes represent facilities that already satisfy the effluent concentrations achievable by this level of technology, or gaps in the data available. In any event, these missing figures do not alter the results.

			Level 2 Upgrade							
	Subembayment	30% Reduction (kg/d)	Capital Cost	Treatment Cost of TN ($/GPD)	Treatment Cost of TN ($/lb)	TN Effluent with Level 2 Treatment (kg/day)	TN Load Reduction with Level 2 Treatment (kg/day)	Cost of Level 2 Upgrade ($/day)	Existing TN Credits (kg/day)	S1
Discharge 1	1	1620	$ 18,000,000	$ 0.70		4,503	0	0	0	
Discharge 2	1	1200	$ 28,000,000	$ 19.10	$ 6.60	1,885	2,115	30,778	0	
EBMUD	1	3300	$ 1,173,000,000	$ 9.80	$ 0.90	3,004	7,996	15,869	0	y
Discharge 3	1	72	$ 1,000,000	$ 0.20		154	0	0	26	c
Discharge 5	1	1260	$ 51,000,000	$ 0.30	$ 63.00	1,885	2,315	321,570	0	
Discharge 6	1	3.9	$ 34,000,000	$ 26.10		12	0	0	30	c
Discharge 7	1	18.9	$ 84,000,000	$ 5.40		57	0	0	47	c
Discharge 10	2	252	$ 43,000,000	$ 7.70	$ 0.50	551	289	319	0	
Discharge 11	2	390	$ 180,000,000	$ 3.40	$ 0.40	727	573	506	0	
Discharge 12	2	66	$ 110,000,000	$ 5.50	$ 1.40	114	106	329	0	y
Discharge 13	2	39	$ 70,000,000	$ 3.90	$ 1.10	68	62	150	0	
Discharge 16	2	720	$ 28,000,000	$ 1.40	$ 1.00	1,226	1,174	2,588	0	y
Total		**8,942**	**$ 1,820,000,000**			**14,185**	**14,630**	**372,107**	**104**	

Figure 4.4: *This selection of the scenario analysis identifies the required reductions and the potential reductions and expense for each facility to upgrade to Level 2 treatment. The last column shows the ideal trading scenario, with 'Y' indicating that entity would implement the technology thereby generating credits to trade, and 'C' showing the entities that would generate credits using existing technology.*

B. SCENARIO 1: 30% NITROGEN REDUCTION USING ONLY LEVEL 2 UPGRADES

The first scenario evaluated was based on a 30% reduction of nutrient loading into the Bay from the synthetic subembayments using only Level 2 technology. This level of reduction required a total nitrogen load reduction of 8,942 kg/day for the Bay. If every facility under this scenario was required to upgrade to Level 2 treatment, combined it would cost approximately $1.8 billion dollars using this approach. On average, it would cost each facility $151 million to implement the Level 2 technological upgrades, resulting in an overall reduction of over 14,000 kg/day with a total associated expense of $372,107 per day. This is well beyond the effluent reductions required to achieve a 30% decrease in TN loading across the Bay. Based on this finding, trading appeared to be a more viable compliance option.

Scenario 1 included one additional assumption: facilities with current TN concentrations less than 15 mg/L could produce credits without engaging in any upgrades because they already discharged below the concentration achieved by Level 2 upgrades. This demonstrates that, in limited circumstances, some facilities may be able to generate credits without implementing upgrades. However, only 104 credits were generated in this manner between three facilities, a minimal amount that did not meaningfully impact the results.

Assuming the broker directs upgrades so that only the most efficient scenario would arise, three facilities would implement Level 2 upgrades to achieve the required TN reductions: EBMUD and Dischargers 12 and 16. Although EBMUD has the highest capital expense to upgrade, it also generates the most total load reductions, resulting in one of the lowest costs per kg of TN reduced. Similarly, although Dischargers 12 and 16 are not strictly the cheapest source of nutrient load reductions, they are the most affordable option taking into account the quantity of credits needed.

Scenario 1	Load Reductions
Subembayment 1	7996 kg/day from EBMUD 104 Existing Reductions $15,868.61 per day
Subembayment 2	1280 kg/day from Dischargers 12 & 16 $2,916.20 per day
Total	8963 kg/day $18,784.81 per day $2.10 per credit (kg/day)

Figure 4.5: *Load Reductions and Expenses for Scenario 1*

Under this scenario, EBMUD would generate 7,996 kg/day of TN reductions in Subembayment 1. In subembayment 1, Dischargers 3, 6, and 7 would also generate a minor amount of credits based on the existing discharge concentrations, 104 kg/day to be precise. In Subembayment 2, Discharges 12 and 16 would generate 106 and 1,174 kg/day of TN reductions, respectively. As EBMUD would only need 3,300 kg/day to achieve compliance with its individual limit, it would have a surplus of 4,696 credits to trade. Discharger 12 has an individual permit limit (baseline) of 66 kg/day, leaving a surplus of 40 credits to trade, while Discharger 16 has a baseline of 720 kg/day, leaving a surplus of 454 credits.

	Subembayment	Required Reductions (kg/day)	Effluent Reductions (kg/day)	Existing Credits	Credits Generated	Credits Purchased
Discharge 1	1	1,620	-	-		1620
Discharge 2	1	1,200	-	-		1,200
EBMUD	1	3,300	7,996	-	4,696	-
Discharge 3	1	72	-	26		-
Discharge 5	1	1,260	-	-		1,260
Discharge 6	1	4	-	30		-
Discharge 7	1	19	-	47		-
Discharge 10	2	252	-	-		252
Discharge 11	2	390	-	-		390
Discharge 12	2	66	106	-	40	-
Discharge 13	2	39	-	-		39
Discharge 16	2	720	1,174	-	454	-

Figure 4.6*: Credits Generated and Purchased by Each Facility.*

Based on these upgrades, Subembayment 1 would have a total of 8,100 kg/day of TN reductions, generated at an expense of $15,869 per day per kilogram of TN. Subembayment 2 would generate 1,280 kg/day, costing $2,916 per day per kilogram removed. Cumulatively, these upgrades would cost $18,785 per day and generate 8,963 total credits, resulting in credits costing $2.10 per kilogram per day. Of note, for some of the Bay dischargers $2.10 per kg/day is more than the individual cost of compliance. But if these dischargers upgraded individually, there wouldn't be enough credits generated to lead to compliance at a Bay scale, so, for the purposes of this coarse analysis, it is assumed that the higher cost per unit would be covered through the savings to the collective. A more complex modeling exercise with specific site-level data could likely demonstrate viable trading without all of the dischargers participating, as may be the case in reality.

Trading within each subembayment would be prioritized. In Subembayment 1, the credits from EBMUD and the existing reductions would wholly satisfy the credit needs of the other dischargers within that subembayment. The parties within Subembayment 1 would contract individually to purchase credits between each other, leaving EBMUD with 626 credits remaining after all intra-subembayment trading was complete. In Subembayment 2, all of the credits generated would be traded with the dischargers in the same manner, but would nonetheless leave a deficit of 302 credits still needed to meet the total load reduction needed for Subembayment 2. To overcome this deficit, inter-subembayment trading would occur, using the 2-to-1 ratio. The remaining compliance would be achieved by purchasing the remaining credits from EBMUD, leaving a final surplus of 22 credits.

Using trading under this scenario would result in compliance for all of the dischargers. The total expense of all facilities upgrading to Level 2 treatment would have been $1.82 billion, but with trading the only three facilities would upgrade, costing $1.311 billion. These facilities would also have the upgrade expenses partially offset. For instance, EBMUD would generate over $3.5 million each year from trading. Therefore, under this hypothetical scenario, the dischargers would see a significant cost savings on an annual basis, while still generating the nutrient reductions needed to achieve compliance.

C. SCENARIO 2: 50% NITROGEN REDUCTION USING ONLY LEVEL 3 UPGRADES

The second scenario assumed a 50% required reduction of nutrient loading into the Bay from the synthetic subembayments using only Level 3 technology. This level of reduction required a total load reduction of 14,903 kg/day of TN to the Bay beyond the existing discharge levels. If every facility had to upgrade to Level 3 treatment, it would cost slightly more than $2.25 billion dollars. On average, each facility would have to spend $187.7 million to implement the Level 3 technological upgrades, resulting in an overall reduction of more than 24,000 kg/day with a total associated expense of $336,949 per day. This is well beyond the effluent reductions required to achieve a 50% decrease in TN loading across the Bay. Notably, this scenario did not include any existing reductions, as no facilities have effluent concentrations below the 6 mg/L TN concentration achievable through Level 3 treatment.

			Level 3 Upgrade									
	Subembayment	50% Reduction (kg/d)	Capital Cost	Treatment Cost of TN ($/GPD)	Treatment Cost of TN ($/lb)	TN Effluent with Level 3 Treatment (kg/day)	TN Load Reduction with Level 3 Treatment (kg/day)	Cost of Level 3 Upgrade ($/day)	S1	S2	S3	S4
Discharge 1	1	2700	$ 56,000,000	$ 2.30	$ 1.70	1,801	3,599	13,490		y	y	y
Discharge 2	1	2000	$ 28,000,000	$ 19.10	$ 17.60	754	3,246	125,969			2	
EBMUD	1	5500	$ 1,231,000,000	$ 10.30	$ 5.00	1,201	9,799	108,029		y	y	2
Discharge 3	1	120	$ 31,000,000	$ 4.40	$ 57.70	66	174	22,155		y	y	
Discharge 5	1	2100	$ 219,000,000	$ 1.30	$ 5.00	754	3,446	37,992		y		y
Discharge 6	1	6.5	$ 36,000,000	$ 27.60	$ 24.90	7	6	340		y		
Discharge 7	1	31.5	$ 92,000,000	$ 5.90	$ 6.50	34	29	415		y		
Discharge 10	2	420	$ 56,000,000	$ 10.00	$ 6.60	220	620	9,018			2	
Discharge 11	2	650	$ 251,000,000	$ 4.70	$ 4.00	291	1,009	8,902			2	
Discharge 12	2	110	$ 120,000,000	$ 6.00	$ 4.00	45	175	1,540		y		
Discharge 13	2	65	$ 80,000,000	$ 4.80	$ 3.00	27	103	680				
Discharge 16	2	1200	$ 52,000,000	$ 2.60	$ 2.00	491	1,909	8,421				2
Total		**14,903**	**$ 2,252,000,000**			**5,692**	**24,114**	**336,949**				

Figure 4.7*: This selection of the scenario analysis matrix identifies the required reductions and the potential reductions and expense for each facility to upgrade to Level 3 treatment. The last columns show the ideal trading situation under each scenario, with 'Y' indicating that entity would implement Level 3 technology and '2' indicating that facility would implement Level 2 technology.*

Assuming only the most efficient scenario would arise due to the direction of the intermediary broker, seven facilities would adopt Level 3 upgrades to achieve the required TN reductions: EBMUD and Dischargers 1, 3, 5, 6, 7 in Subembayment 1 and Discharger 12 in Subembayment 2. Like Scenario 1, although EBMUD has the highest capital expense to upgrade, it also generates the most nutrient reductions, resulting in one of the lower costs per unit of TN reduced. Similarly, although the other Dischargers are not always the most affordable source of pollution reductions, they are the most viable options when accounting for the quantity of credits needed.

In this scenario, the six facilities in Subembayment 1 that upgrade would generate 17,053 kg/day of TN reductions. In Subembayment 2, Discharger 12 would generate 175 kg/day of TN reductions. As the Dischargers in Subembayment 1 only require 10,458 kg/day to achieve compliance with the permit limits, together they would have a surplus of 6,595 credits to trade. Conversely, Discharger 12 in Subembayment 2 would only have enough reductions to generate 65 credits of the 2,445 kg/day required for the entire Subembayment.

Scenario 2	Load Reductions
Subembayment 1	17,053 kg/day $182,420 per day
Subembayment 2	175 kg/day $1,540 per day
Total	14,930 credits $183,959 per day $12.32 per credit (kg/day)

Figure 4.8: *Load Reductions and Expenses for Scenario 2*

Based on these upgrades, Subembayment 1 would have a total of 17,053 kg/day of TN reductions, generated at an expense of $182,420 per day per kilogram of TN. Subembayment 2 would generate 175 kg/day, costing $1,540 per day per kilogram removed. Cumulatively, these upgrades would cost $183,959 per day and generate 17,227 total credits. Taking into account the trading ratio that applies to inter-subembayment trading, individual credits would cost $12.32 per kilogram per day. Again, for some of the Bay dischargers, $12.32 per kg/day is more than the individual cost of compliance. But if these dischargers upgraded individually, there would be a shortage of available credits to achieve compliance at a Bay scale. Thus, for this coarse analysis it is assumed that the higher cost per unit would be covered through the savings to the collective. Again, a more complex modeling exercise with specific site-level data could demonstrate viable trading without full discharger engagement, as may be the case in reality.

Again, trading within each subembayment would be prioritized. In Subembayment 1, the reductions generated would wholly satisfy the required effluent reductions. Discharger 2 would contract individually to purchase credits from one of the other facilities, leaving a combined total of 4,595 surplus credits in Subembayment 1. In Subembayment 2, all of the credits generated by Discharger 12 would be sold, but a deficit of 2,270 credits would remain. The surplus credits from Subembayment 1 would be sold to facilities in Subembayment 2, as the 4,595 credit surplus would result in 2,297 available credits after factoring in the 2-to-1 trading ratio. Thus, inter-subembayment trading would overcome the deficit in Subembayment 2, with 27 credits to spare.

	Subembayment	Required Reductions (kg/day)	Effluent Reductions (kg/day)	Credits Generated	Credits Purchased
Discharge 1	1	2,700	3,599	899	-
Discharge 2	1	2,000	-	-	2,000
EBMUD	1	5,500	9,799	4,299	-
Discharge 3	1	120	174	54	-
Discharge 5	1	2,100	3,446	1,346	-
Discharge 6	1	7	6	-	1
Discharge 7	1	32	29	-	3
Discharge 10	2	420	-	-	420
Discharge 11	2	650	-	-	650
Discharge 12	2	110	175	65	-
Discharge 13	2	65	-	-	65
Discharge 16	2	1,200	-	-	1,200

Figure 4.9: *Credits Generated and Purchased by Each Facility in Scenario 2.*

Trading in Scenario 2 would result in compliance for all of the dischargers. The total expense of all facilities upgrading would have been $2.252 billion, but with trading the seven facility upgrades would cost $1.785 billion. Through trading, these facilities would also have the upgrade expenses partially offset, with the specific ratio of the offset depending on the quantity of credit generated and sold, as well as the expected lifespan and operation expenses for each upgrade. In any event, it is clear that under this scenario, the dischargers would realize an annual financial savings, while still achieving permit compliance.

D. SCENARIOS 3 & 4: 50% NITROGEN REDUCTION USING LEVEL 2 & 3 UPGRADES

Scenarios 3 and 4 analyze the same circumstances using different potential trading outcomes. Both hypotheticals evaluate the potential trade scenarios that could arise to satisfy a 50% required reduction using a combination of Level 2 and Level 3 treatment technologies. Together these scenarios demonstrate the meaningful differences in credit cost that can arise when a trading program lacks measures to ensure efficiency, namely a broker to direct technological upgrades and trading activities.

Identical to Scenario 2, a 50% reduction beyond No Net Load Increase would require a total of 14,903 kg/day of TN be removed from the watershed. Using only technological compliance alternatives at every facility, this would require more than $2.25 billion in investments and generate far more nutrient reductions than required by the effluent limits. Again, this scenario did not include any existing reductions, as no facilities currently attain the effluent concentrations achievable with Level 3 treatment.

Scenario 3	Load Reductions
Subembayment 1	15,686 kg/day $174,451 per day
Subembayment 2	862 kg/day $824 per day
Total	14,935 credits $175,276 per day $11.74 per credit (kg/day)

Figure 4.10: *Scenario 3Load Reductions and Expenses.*

	Subembayment	Required Reductions (kg/day)	Effluent Reductions (kg/day)	Credits Generated	Credits Purchased
Discharge 1	1	2,700	3,599	899	
Discharge 2	1	2,000	2,115	115	
EBMUD	1	5,500	9,799	4,299	
Discharge 3	1	120	174	54	
Discharge 5	1	2,100	-	-	2,100
Discharge 6	1	7	-	-	7
Discharge 7	1	32	-	-	32
Discharge 10	2	420	289	-	131
Discharge 11	2	650	573	-	77
Discharge 12	2	110	-	-	110
Discharge 13	2	65	-	-	65
Discharge 16	2	1,200	-	-	1,200

Figure 4.11: *Credits Generated and Purchased by Each Facility in Scenario 3.*

Under Scenario 3, six facilities would implement technological upgrades. In Subembayment 1 three facilities (EBMUD and Dischargers 1 and 3) would adopt Level 3 treatment and Discharger 2 would adopt Level 2 treatment. In Subembayment 2, Dischargers 10 and 11 would adopt Level 2 treatment. In Subembayment 1, these upgrades would generate a total of 15,686 kg/day of nutrient reductions at a total daily expense of $174,451. In Subembayment 2, 862 kg/day of TN reductions would arise with an associated cost of $824 per day. Together this would generate 14,935 kg/day of reductions at an expense of $175,276, resulting in an expense of $11.74 for each unit of reduction. For some of the dischargers this credit cost is more than the individual cost of the facility upgrade. However, if these dischargers upgraded individually, there would be a shortage of available credits to achieve compliance at a Bay scale. A more complex modeling exercise with specific site-level data could demonstrate viable trading without full discharger engagement, as may be the case in reality.

Trading within each subembayment would be given priority. In Subembayment 1, the reductions generated would wholly satisfy the effluent limits. The credit generators would contract individually to sell credits to the other facilities. Following this intra-subembayment trading, a combined total of 3,228 surplus credits would remain. In Subembayment 2, the Level 2 upgrades by Dischargers 10 and 11 would generate reductions of 862 kg/day, which would fall short of the 1,070 kg/day those facilities cumulatively need to comply with the 50% reduction requirement. Therefore, in this scenario even the facilities implementing upgrades would need to purchase credits from Subembayment 1. Together, Subembayment 2 facilities would need 1,583 kg/day worth of TN offsets from Subembayment 1 after accounting for the trading ratio. This contrasts with Scenario 4.

In Scenario 4, only four facilities would need to implement additional technological controls to reduce effluent concentrations. In Subembayment 1, EBMUD would adopt Level 2 treatment and Dischargers 1 and 5 would adopt Level 3 treatment. This would create 15,041 kg/day of TN reductions at an expense of $67,351 per day. In Subembayment 2, Discharger 16, the only facility upgrading, would adopt Level 2 treatment technology. This upgrade would lower TN discharges by 1,174 kg/day at a daily cost of $2,588. Together, the upgrades across both subembayments would reduce TN loading into the Bay by 14,923 kg/day at a daily cost of $69,938, resulting in the individual units of reduction costing $4.69, less than half of the credit costs in Scenario 3. To reiterate, for some of the facilities, $4.69 per kg/day is more than the individual cost of compliance. But if these dischargers upgraded individually, a shortage of available credits would arise for the other dischargers. Thus, for this coarse analysis, it is assumed that the higher cost per unit would be covered through the cumulative savings. A more intricate modeling exercise with specific site-level data could demonstrate viable trading without full discharger engagement.

Scenario 4	Load Reductions
Subembayment 1	15,041 kg/day $67,351 per day
Subembayment 2	1,174 kg/day $2,588 per day
Total	14,923 credits $69,938 per day $4.69 per credit (kg/day)

Figure 4.12: *Load Reductions and Expenses for Scenario 4*

The upgrades in Subembayment 1 would satisfy the required effluent reductions for all facilities in that subembayment. Some trading would occur within that subembayment to offset individual discharges from facilities that did not upgrade their technology. EBMUD and Dischargers 1 and 5 would enter into individual contracts to sell excess credits to the other facilities in that area, leaving a 2,583 surplus credits in Subembayment 1. In Subembayment 2, all of the nutrient reductions generated by Discharger 16 would be used by that facility to achieve the permit limits, though this would still leave Discharger 16 short of the effluent limits by 26 kg/day. Surplus credits from Subembayment 1 would be sold to facilities in Subembayment 2 to make up for the deficit of TN reductions. After applying the 2-to-1 trading ratio, there would be 1,292 credits available for trading. The dischargers from Subembayment 1 would enter into credit sales contracts with the individual facilities in Subembayment 2, resulting in compliance with the joint and individual permit limits, with 20 credits left unsold.

	Subembayment	Required Reductions (kg/day)	Effluent Reductions (kg/day)	Credits Generated	Credits Purchased
Discharge 1	1	2,700	3,599	899	-
Discharge 2	1	2,000	-	-	2,000
EBMUD	1	5,500	7,996	2,496	-
Discharge 3	1	120	-	-	120
Discharge 5	1	2,100	3,446	1,346	-
Discharge 6	1	7	-	-	7
Discharge 7	1	32	-	-	32
Discharge 10	2	420	-	-	420
Discharge 11	2	650	-	-	650
Discharge 12	2	110	-	-	110
Discharge 13	2	65	-	-	65
Discharge 16	2	1,200	1,174	-	26

Figure 4.13: *Credits Generated and Purchased by Each Facility in Scenario 4.*

Trading under either Scenario 3 or 4 would achieve permit compliance for all dischargers in this hypothetical scenario. The total expense of all facilities upgrading to Level 3 technology would have been $2.252 billion. However, with trading the technological upgrades only cost $1.569 billion under Scenario 3 and $1.476 billion under Scenario 4. These expenses would be offset by credit trading, as this enables each credit generator to recover some of the expenses incurred to upgrade technology. While the specific ratio of the offset depends on the quantity of credits generated and sold, as well as the expected lifespan and operation expenses for each upgrade, it is clear that trading represents a viable option to achieve permit compliance in the synthetic subembayments.

4.4. Conclusion

Although this analysis is somewhat constrained by available data, it still serves to provide broad insight into the potential benefits of water quality trading for nutrients in the San Francisco Bay. It is apparent in light of these findings that nutrient trading represents a cost-effective option for Bay dischargers to achieve compliance with nutrient effluent limits. When multiple facilities in the same waterway cooperate to generate a mutually gainful outcome, all participants stand to benefit.

As more information becomes available, this analysis may be revised to provide greater accuracy and granularity. Such additional information will allow for the evaluation of trading as it relates to individual facilities, in addition to the entire watershed. At a high level, this analysis demonstrates that trading represents a viable option and good financial opportunity to achieve permit compliance in the synthetic subembayments.

The Freshwater Trust

5. Incorporating Nonpoint Sources into a Point Source Nutrient Trading Program for the San Francisco Bay

Task 5: Preliminary Feasibility Assessment of Point-to-Nonpoint Source Nutrient Trading and Potential Mechanisms of Nonpoint Credit Trading

Executive Summary – Task 5

The San Francisco Bay, which historically has proven quite resilient to nutrient pollution, is increasingly showing signs of water quality degradation from nutrient loads.[1] A significant portion of the overall nutrient loading to the San Francisco Bay originates from point source municipal wastewater treatment facilities. A point-to-point trading program for the Bay offers a means to reduce these point source loadings in an economical and environmentally beneficial way, if such reductions are determined to be necessary. However, point-to-point trading will only partially address nutrient loadings to the Bay because a large amount of the nutrients entering the Bay also comes from diffuse nonpoint sources. This is especially true in the northern subembayments—the Suisun and the San Pablo Bays—as these areas receive nonpoint nutrient loading from the Sacramento-San Joaquin Delta and local agricultural lands.

As technological solutions to water quality issues necessarily become more advanced, they also become increasingly expensive and energy intensive, resulting in an issue of diminishing returns for municipal facilities. Although point-to-point trading offers a means to lessen or delay this potential economic burden, eventually point source upgrades may become less economically viable than non-point source credits. To reduce risk and expand credit supply, it is in the best interests of point-to-point trading participants to consider integrating nonpoint source credit generation in that program.

A trading program strictly involving point sources cannot address nonpoint source contributions, thereby leaving these sources of nutrients unresolved. In order to deal with nonpoint loadings, a point-to-point trading program could be expanded to allow for the inclusion of credits generated by nonpoint sources. Those credits would arise from *voluntary* actions and projects that reduce nonpoint source nutrient loadings above and beyond reductions otherwise required in TMDLs and WDRs. Credits generated through nonpoint source actions would offset point source permit exceedances in the same manner as credits generated by other point sources. This would create financial incentives for nonpoint sources to address nutrients, thereby expanding the universe of potential credit generating sites and activities. This would offer greater flexibility and credit supply to trading participants.

As an initial matter, incorporating nonpoint source crediting into an existing point source trading program would not require any additional permit issuances. The existing general watershed NPDES permit for point source

---

* EBMUD should consult its attorneys on all matters related to the issues discussed in this document. Nothing herein should be construed as providing legal advice or recommendations.

[1] E. Novick & D. Senn, S.F. Estuary Inst., External Nutrient Loads to the San Francisco Bay, No. 704, at 1 (Jan. 2014). Located at the bottom of a massive watershed, the San Francisco Delta would be eutrophic-mesotrophic under pre-settlement conditions. Yet, it is not going hypoxic due to low productivity despite the high nutrients. James E. Cloern, *Our Evolving Conceptual Model of the Coastal Eutrophication Problem*, 210 Marine Ecology Progress Series 223 (Jan. 2001), *available at* http://www.int-res.com/articles/meps/210/m210p223.pdf.

dischargers in the San Francisco Bay would continue to suffice. As the nonpoint sources are outside of the regulatory program governing municipal dischargers, no permit expansion would be required. Only minor changes to the fact sheet would be needed to appraise the public of the nonpoint source crediting potential. Otherwise, all programmatic alterations to facilitate nonpoint source credit generation would occur in the overarching point-to-point trade agreement, or in a stand-alone nonpoint source trading guidance document that is incorporated into the watershed permit by reference to make those guidelines binding.

Deciding what the ideal programmatic structure for incorporating point-to-nonpoint source trading into a point source trading program is the first and largest decision. The EPA identifies three categories of nonpoint source trading options, alternatives that roughly mirror the previously discussed programmatic choices for a point-to-point program. A point-to-nonpoint source program may entail either (1) Single Point-to-Nonpoint Source Trading, (2) a Third Party Broker, or (3) a Nonpoint Source Credit Exchange. These alternatives are provided for illustration; the chosen system may diverge from these options. In any case, if there is an existing point-to-point trading program, a nonpoint credit program should use a corresponding structure to be integrated as a component of the existing program for greatest efficiency and clarity.

The first option—Single Point-to-Nonpoint Source Trading—is analogous to the 'Trading Between Two Point Sources' Option for a point-to-point source trading program. Under this structure, individual point sources bear complete responsibility for locating potential projects and working with the nonpoint source to structure and implement the project. The point source would also have to undertake all credit accounting. While providing individual dischargers with the most control, this option also has the highest potential for problems and often the highest transaction costs.

The second option involves the use of a third party broker to facilitate single point-to-nonpoint source trades. The broker evaluates the watershed, identifying advantageous projects and making the necessary introductions between individual point and nonpoint sources to allow those parties to transact directly. The point and nonpoint source entities cooperate (to varying degrees based on the individual scenario) to implement and account for the credit generating project, albeit with the added benefit of an experienced broker to provide direction). This option offers participants a great deal of flexibility and lower risk than Option 1, but also has high transaction costs.

Lastly, a nonpoint source program could utilize a Credit Exchange, identical to the type of exchange that a point-to-point source trading program could use. Under this option, the Exchange would work with nonpoint sources to locate, structure, and implement credit generating projects. The Exchange would complete all accounting activities and purchase all certified nonpoint credits. The point source facilities would only buy fully established and valid credits from the Exchange—point sources would have minimal, if any, interaction with nonpoint sources. This provides point sources with less flexibility and control, but minimizes risk and likely lowers transactional costs through the economies of scale (if the transaction volume is sufficient) and the efficiencies that come with expertise. Moreover, a central exchange would be able to maintain the nonpoint source restoration fund TFT recommended as a means to avoid credit shortages in a point-to-point trading program.

In order to establish a nonpoint source nutrient credit trading program, it is necessary to develop a nonpoint source trade framework to address the issues unique to nonpoint programs. This could be created and included as one component of the overarching trade agreement, or it could be crafted independent from the point-to-point source trade agreement and incorporated into that document later as an addendum. Conversely, a framework could be independently incorporated into the permit by reference. Like the point-to-point trade agreement design, the development of a framework should entail a collaborative process involving potential participants, regulators, and stakeholders.

The framework needs to address a variety of issues. Importantly, the nonpoint trade framework should identify eligible project types and establish quality standards to guide the project implementation and management. Because nutrient reductions from many nonpoint source projects cannot be directly measured and must instead be modeled, ensuring that projects abide the quality standards is crucial to guaranteeing that the anticipated reductions occur. Similarly, because the nonpoint activities are diverse and occur at a variety of sites, the nonpoint framework should include mechanisms for evaluating the baseline and additionality for each project. The framework should also include some guidance for the type and timing of monitoring activities. To account for the attenuation and delivery of nutrients and to address the inherent uncertainty, the framework should identify the trading ratio(s). Lastly, the framework should explicitly define credit life—how long credits remain valid following implementation of the project and certification of the benefits—to provide participants and project developers with the certainty needed for economic forecasting.

The framework should also thoroughly detail nonpoint credit accounting requirements because, in light of the dispersed and inexact nature of nonpoint source credit generation, properly defining and carrying out the accounting is quite important. The first item for proper accounting is project validation, essentially a prescreening of the proposed project to ensure that it will satisfy the requirements to produce valid credits. Following project implementation, credits must be verified. To verify credits, an authorized verifier (a state agency, third party, or the permittee) visits the site to ensure that the project conforms to the applicable quality standards. Once a project is verified, then the credits can be certified. This often involves a written confirmation from the regulatory body stating that the credits conform to the applicable standards and have been properly accounted. When certified, credits are ready to be sold. To track credits—ensuring that credits are not double counted or improperly accounted—a third party registry is often used. This registry serializes the credits and maintains them in a ledger, providing transparency and accountability. After deciding these issues in a nonpoint trade framework and incorporating that framework into the existing trade agreement or permit, nonpoint source nutrient projects may begin to generate and sell credits.

TFT recommends that participants in a point-to-point source trading program for the San Francisco Bay incorporate provisions into the trade agreement to enable trading nonpoint source credits. This doesn't need to occur during initial formulation of a trading program, though parties should consider the components of a nonpoint source program when developing a point-to-point trading system to facilitate easy adoption of nonpoint trading later. When adopting a nonpoint trading system, TFT advises that the participants develop a nonpoint source trade framework to incorporate as part of the larger programmatic trade agreement. This document will resolve much of the ambiguity and create definite standards to guide project implementation and credit accounting. Lastly, TFT recommends that a nonpoint source trading program utilize a central exchange to handle all credit transactions. This provides a high level of certainty and ease as the exchange handles everything on the credit generation and purchase end, offering only fully established credits for sale to point sources. This exchange could operate the restoration fund TFT recommended for a point-to-point trading program in order to accept compliance payments from facilities unable to acquire credits, using the funds to implement environmental restoration. If followed, these recommendations will result in the creation of a robust, efficient, and accountable nonpoint source trading program.

5.1. Introduction

Nutrient discharges into the San Francisco Bay (the Bay) originate from many sources. Municipal wastewater utilities account for a majority of the overall nutrient loading to the Bay.[2] Even still, a significant amount of nutrients arise from nonpoint sources. In the lower subembayments, stormwater runoff from impervious surfaces and residential areas introduces a notable amount of nutrients to the watershed. The upper subembayments receive a large portion of all nutrient loading from agricultural sources within the Sacramento-San Joaquin Delta. These nonpoint sources of nutrients represent a potential source of nutrient reduction credits that could be generated through restoration or other nutrient control projects. Incorporating nonpoint source nutrient control activities into an existing point-to-point source trading program would not pose an overwhelming burden, though the differences between point and nonpoint source credit generation must be accounted for and addressed in a nonpoint source trade framework.

For greatest efficiency, the nonpoint program elements should be integrated into the program structure from the beginning to allow for expansion as needed beyond the initial point-to–point trading. Including some language in the permit or point-to-point trade agreement that references nonpoint source crediting would suffice as a regulatory placeholder. Furthermore, accounting for the potential inclusion of nonpoint sources when designing certain aspects of a point-to-point program (i.e., trading area, ratios, and accounting) will ensure that the later addition of nonpoint crediting is feasible. The specific nonpoint source trading framework will likely be developed independently of the point-to-point trading system, but including some nonpoint source language in the overarching trade agreement will allow the nonpoint source trade framework to be more easily appended.

Integrating nonpoint source nutrient credits into a point-to-point trading program offers several notable benefits. For one, the additional sources of credit generation provides greater flexibility to trading participants. Nonpoint source restoration projects may even minimize risk and uncertainty as those projects could be used in the same manner as a reserve pool of credits—when no point source generated credits are available, a facility needing to offset exceedances could pay into a fund that finances nonpoint source restoration activities and thereby be in compliance with their permit. Furthermore, if nutrient discharge limits become more stringent over time, the technological compliance solutions will grow increasingly expensive. In time, the economic calculus may shift such that nonpoint source restoration offers a more economically feasible and environmentally beneficial compliance solution.[3]

As the EPA has noted, "it is often less expensive to remove nutrients through the use of improved agricultural practices . . . than through upgraded municipal waste treatment."[4] This is equally true for other nonpoint source credit generation activities such as environmental restoration, stormwater control, or instream improvements. Lastly, many nonpoint source actions directly result in a number of ancillary environmental and social benefits to the watershed and the trading participants. Thus, although it will require minor additional effort and resources to incorporate the necessary provisions to govern nonpoint source trading into a point-to-point source trading program, such efforts are likely well worth the initial time given the eventual benefits to the trading participants.

---

[2] BAY AREA CLEAN WATER AGENCIES NUTRIENT REDUCTION STUDY, GROUP ANNUAL REPORT: NUTRIENT WATERSHED PERMIT ANNUAL REPORT 2016 (Oct. 2016), http://bacwa.org/wp-content/uploads/2016/09/Group-Annual-Report-2016_Final.pdf.

[3] Connecticut's Long Island Sound Nutrient Trading Program has run into this. Despite the significant point source nutrient discharge reductions achieved by trading, more reductions are needed to realize the goals of the TMDL, including added emphasis on stormwater and nonpoint source runoff. CONN. DEP'T OF ENERGY & ENVTL. PROT., REPORT OF THE NITROGEN CREDIT ADVISORY BOARD FOR CALENDAR YEAR 2014 AND 2015 TO THE GENERAL ASSEMBLY, at 6 (Sept. 30, 2016).

[4] U.S. EPA, Water Quality Trading Toolkit for Permit Writers, 17, EPA 833-R-07-004 (Aug. 2007, updated June 2009), *available at* www.epa.gov/npdes/pubs/wqtradingtoolkit.pdf (EPA TRADING TOOLKIT).

5.2. Sources of Nonpoint Source Nutrient Loading

Federal regulations allow for point sources to use offsets "credited to nonpoint source [pollution] abatement" in the event that "BMPs or other nonpoint source pollution controls make more stringent load allocations practicable[.]"[5] These measures include implementation of nonpoint source BMPs, restoration or creation and maintenance of wetlands, freshwater habitat restoration, pollution prevention or minimization programs, and modification of water diversion, delivery, or storage activities that reduce pollutant concentrations.[6] Depending on the specific source of nutrient loading, all or some of these nonpoint source pollution control activities have the potential to address sources of pollutants that would remain unresolved without nonpoint source trading.

The San Francisco Bay has a history of nutrient enrichment, though historically the Bay has not shown the kinds of problems common in similar nutrient enriched estuaries.[7] Those sorts of problems, such as increased phytoplankton and decreased dissolved oxygen, have begun to present themselves in the Bay, leading the San Francisco Estuary Institute to suggest that the Bay's "resistance to the harmful effects of nutrient overenrichment is weakening."[8] In recent years, the San Francisco Bay has experienced a red tide bloom for the first time and cyanobacteria blooms have grown more common, signaling changes in the ecosystem response and community composition.[9] In the Delta, nutrient levels have contributed to the spread of invasive vegetation that outcompetes native plants, degrading the quality of aquatic and riparian habitat, to the detriment of native species.[10]

These nutrient issues are exacerbated by a number of factors. For instance, the drought in California reduces flows into the Bay-Delta and increases water temperatures, fostering the conditions that lead to harmful algal blooms.[11] Water project development and operation alters the hydrological regime in the Delta. In time, climate change is likely to exacerbate the ecological conditions in the San Francisco Bay, making the watershed even less resistant to nutrient impairment.[12] Together, the environmental changes and ecosystem degradation, as well as the potential effects of climatic changes, will continue to exert pressure on the watershed.

In the San Francisco Bay, approximately 63% of all dissolved inorganic nitrogen loading comes from wastewater utilities.[13] The specific nutrient contribution differs between subembayments. Over 90% of dissolved nitrogen loading in the Lower South Bay, the South Bay, and the Central Bay come from wastewater utilities. In comparison, only about 25% of nitrogen loading in the Suisun Bay and San Pablo Bay result from wastewater

---

[5] Memorandum from Michael A.M. Lauffer, Chief Counsel, State Water Resources Control Bd., to Arthur G. Baggett, Jr., Chair, State Water Resources Control Bd., on Updated Legal Authority for Offsets, Pollutant Trading, and Market Programs to Supplement Water Quality Regulation in California's Impaired Waters With Established Total Maximum Daily Loads (Nov. 22, 2006) (internal citation omitted).

[6] *See e.g.*, CAL. WATER CODE § 16101(d)(5); MALIBU CREEK WATERSHED EWMP GROUP, ENHANCED WATERSHED MANAGEMENT PROGRAM FOR MALIBU CREEK WATERSHED 35-50 (June 25, 2015), *available at* www.swrcb.ca.gov/losangeles/water_issues/programs/stormwater/municipal/watershed_management/index.shtml.

[7] J. Cloern & A. Jassby, *Drivers of Change in Estuarine Coastal Ecosystems: Discoveries from four Decades of Study in San Francisco Bay*, 50 REVIEWS OF GEOPHYSICS (Oct. 2012), *available at* http://onlinelibrary.wiley.com/doi/10.1029/2012RG000397/epdf.

[8] E. Novick & D. Senn, S.F. ESTUARY INST., EXTERNAL NUTRIENT LOADS TO THE SAN FRANCISCO BAY, No. 704, at 1 (Jan. 2014).

[9] *Id.* citing J. Cloern, et al., *Heat Wave Brings an Unprecedented Red Tide to San Francisco Bay*, 86 AM. GEOPHYSICAL UNION 66 (2005); P.W. Lehman, et al., *The Influence of Environmental Conditions on the Seasonal Variation of Microsystis Cell Density and Microcystins Concentration in San Francisco Estuary*, 600 HYDROBIOLOGIA 187 (2008); P. M. Glibert, *Ecological Stoichiometry and its Implications for Aquatic Ecosystem Sustainability*, 4 CURRENT OPINION IN ENVTL. SUSTAINABILITY 272 (2012).

[10] Anna C. Tyler, et al., *Nitrogen Inputs Promote the Spread of an Invasive Marsh Grass*, 17 ECOLOGICAL APPLICATIONS 1886 (Oct. 2007).

[11] CÉCILE MIONI, ET AL., HARMFUL CYANOBACTERIA BLOOMS AND THEIR TOXINS IN CLEAR LAKE AND THE SACRAMENTO-SAN JOAQUIN DELTA, SURFACE WATER MONITORING PROGRAM, 10-058-150 (Mar. 31, 2012).

[12] James E. Cloern, et al*., Projected Evolution of California's San Francisco Bay-Delta-River System in a Century of Climate Change*, 6 PLOS ONE (Sept. 2011), *available at* http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0024465.

[13] S.F. Bay Reg'l Water Quality Control Bd., Order No. R2-2014-0014, Permit No. CA0038873, Waste Discharge Requirements for Nutrients from Municipal Wastewater Dischargers to San Francisco Bay, Fact Sheet, F-8 (Apr. 2014).

discharges.[14] As Figure 1 illustrates, the remaining load in Suisun Bay and San Pablo Bay is largely the result of upstream loading with stormwater runoff in the Bay playing a lesser role in the loadings.

The nutrient loading in the southern reaches of the Bay originate largely from point sources and stormwater. These stormwater issues result from the widespread development of the lower subembayments for residential, commercial, and industrial purposes, resulting in vast amounts of impervious areas and the associated rise in runoff. Conversely, a majority of nutrients in the northern reaches of the Bay originate from the Sacramento-San Joaquin Delta. While stormwater plays a role in nutrient loading to the northern subembayments, the bulk of these nutrients are from diffuse runoff, both from the Sacramento-San Joaquin Delta and the areas draining directly to the northern subembayments.

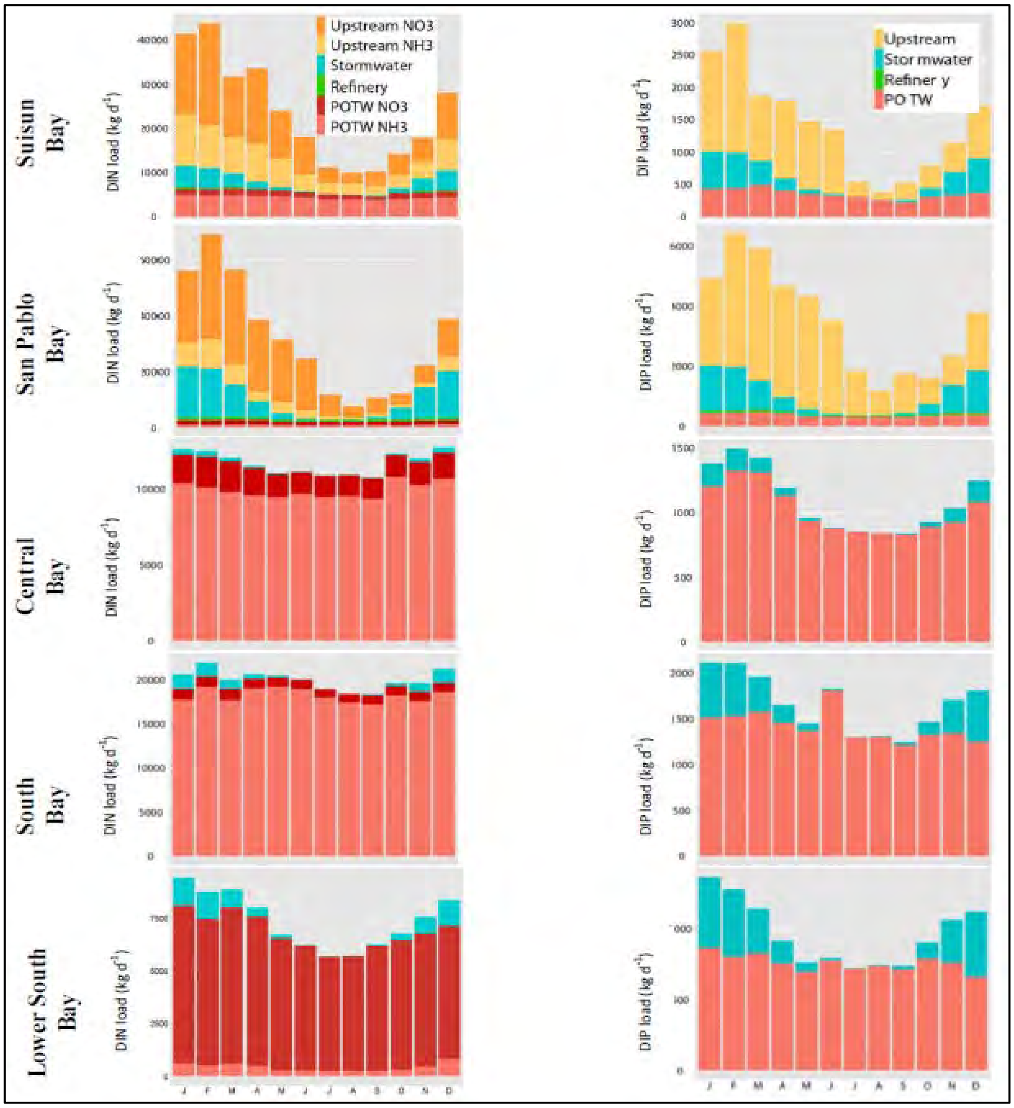


***Figure 5.1**: Average monthly DIN and DIP loads to each subembayment from 2006-2011.*

Water quality trading offers a potential tool for point source dischargers in the Bay to simultaneously achieve permit compliance and improve water quality and environmental conditions impaired by nonpoint source loading. While there is less opportunity for nonpoint source nutrient reductions in the lower subembayments, there is some potential for stormwater pollution reduction projects. Such projects could reduce stormwater runoff beyond the current regulatory requirements in order to generate water quality credits.

[14] Novick & D. Senn, S.F. ESTUARY INST., EXTERNAL NUTRIENT LOADS TO THE SAN FRANCISCO BAY, No. 704, at 24–30 (Jan. 2014).

Table 5.2: *Annual Average Loading of Dissolved Inorganic Nitrogen (kg/day)*

Embayment	Municipal	Refinery	Stormwater	Delta	Total	POTW %
Lower South Bay	6,805	n/a	539	n/a	7,344	93
South Bay	19,401	n/a	670	n/a	20,071	97
Central Bay	11,667	n/a	159	n/a	11,826	99
San Pablo Bay & Carquinez Strait	2,721	842	7,484	n/a	11,047	25
Suisun Bay	5,618	130	1,968	15,930	23,646	24
Baywide	46,212	972	10,820	15,930	73,934	63

In the northern subembayments greater potential for nonpoint source nutrient reduction projects exist given the large portion of the nutrient loading attributable to nonpoint sources. Credit generating projects could include activities aimed at reducing nonpoint source pollution loads directly entering the Bay, such as riparian buffer installation, ecologically designed detention basins, and improved agricultural management practices. It is also possible to implement projects intended to control upstream nutrient loading that occurs in the Delta. Such activities could include wetland creation and restoration, or aquatic restoration aimed at restoring the historic hydrologic conditions and improving the flow regime. These are only a few examples of potential nonpoint source controls that could help to address the nutrient loading into the Bay attributable to nonpoint sources.

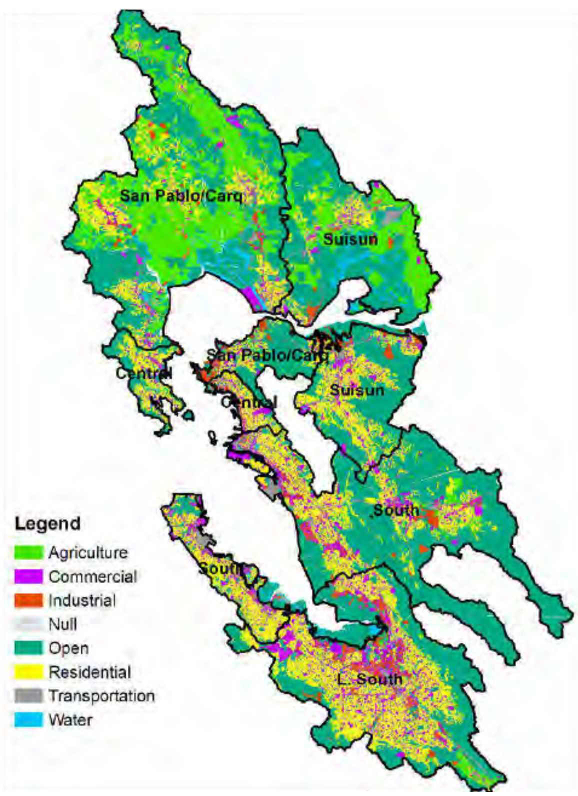


Figure 5.3: *Land Use in Watersheds that Contribute Nutrient Loads to the Bay.*

Given the findings of recent studies, it is clear that nutrients do not solely arise from the municipal wastewater treatment facilities discharging directly to the Bay. A significant source of nutrient loading and the associated problems that those nutrients may engender, comes from nonpoint sources. Addressing these nonpoint sources of nutrient loading as part of a point-to-point water quality trading program has the potential to notably improve conditions in the watershed.

5.3. Mechanics of Nonpoint Source Nutrient Trading

Nonpoint source credit generation often represents a beneficial and often more economically viable option than technological compliance solutions. The EPA has noted that with some nonpoint source trading programs, "point sources benefit by purchasing credits for required reductions at lower cost than technology upgrades; nonpoint sources benefit by gaining income from better resource management; and water quality improves."[15] However, point-to-nonpoint source trading entails much more inherent uncertainty than a strictly point-to-point trading program. As the EPA cautioned in the Water Quality Trading Toolkit, "extra care should be taken to ensure that nonpoint source load reduction uncertainty is addressed."[16] With these cautions, nonpoint source trading constitutes a potentially attractive programmatic extension for participants of a point-to-point trading program.

Incorporating nonpoint source trading into an existing point source trading program should not require any additional permitting action, as the sources of nonpoint source credits do not need to be regulated by the watershed general permit that regulates the municipalities. Yet, the permit fact sheet must include a brief description to "explain any trading provisions."[17] This explanation should address both the point and nonpoint source components of a trading program. Otherwise, nonpoint source credit generation does not necessitate any meaningful change to the permitting scheme and would fit well within a point-to-point trading program.

A. PROGRAMMATIC OPTIONS FOR NONPOINT SOURCE CREDITS

When building nonpoint source credit generation into an existing point-to-point source trading program, stakeholders must determine the specific programmatic structure for credit generation. This decision will govern the mechanics of credit generation and exchange and defining parties' roles and responsibilities. The three main options identified by the EPA are evaluated to identify the specific mechanics and to compare the benefits and drawbacks of each option. This programmatic structure does not need to occur independently of the point-to-point source trading structure—it is wholly possible and appropriate to use the same mechanisms to facilitate nonpoint credit generation and transactions, or to incorporate this system under the umbrella of the point-to-point system. Yet, it is also possible that a separate trading structure could be utilized in order to resolve the uncertainty inherent in nonpoint source trading. Ideally an existing point-to-point trading program would incorporate nonpoint source credit generation using the same or related trading mechanisms.

i. Single Point-to-Nonpoint Source Trading

One option for acquiring nonpoint source nutrient reduction credits is for individual point sources to complete the transaction independently. This provides dischargers with the greatest level of control over the credit generation. The point source would locate the potential nonpoint source of nutrient reductions and work with that source directly to implement and verify the reductions. In this way, the point source would have a more direct role in the crediting process from initiating the project through transacting the credits.[18]

Under this arrangement, an individual discharger enters into a trading contract with one or more nonpoint sources. This trade contract would dictate the terms of the transaction, from credit generation methodologies to risk allocation. In the Trading Toolkit, the EPA states that these types of trades "should be reflected in an individual permit for the point source that either references or incorporates the terms of the trade [contract]."[19]

---

[15] EPA TRADING TOOLKIT at 17.
[16] *Id.*
[17] *Id.* at 18.
[18] NAT'L NETWORK ON WATER QUALITY TRADING, BUILDING A WATER QUALITY TRADING PROGRAM: OPTIONS & CONSIDERATIONS, 173–4(2015), *available at* http://www.wri.org/sites/default/files/buiding-a-water-quality-trading-program-nn-wqt.pdf.
[19] EPA TRADING TOOLKIT at 18.

While not expressly resolved by the EPA, independent generation of credits under the regulation of a general watershed permit may require independent approval from the Regional Water Quality Control Board, though it is possible that programmatic approval for all nonpoint source trading would suffice. In any event, this system offers point sources a greater degree of flexibility and control, but the complexity of nonpoint source reductions does create some risk for the permittee.

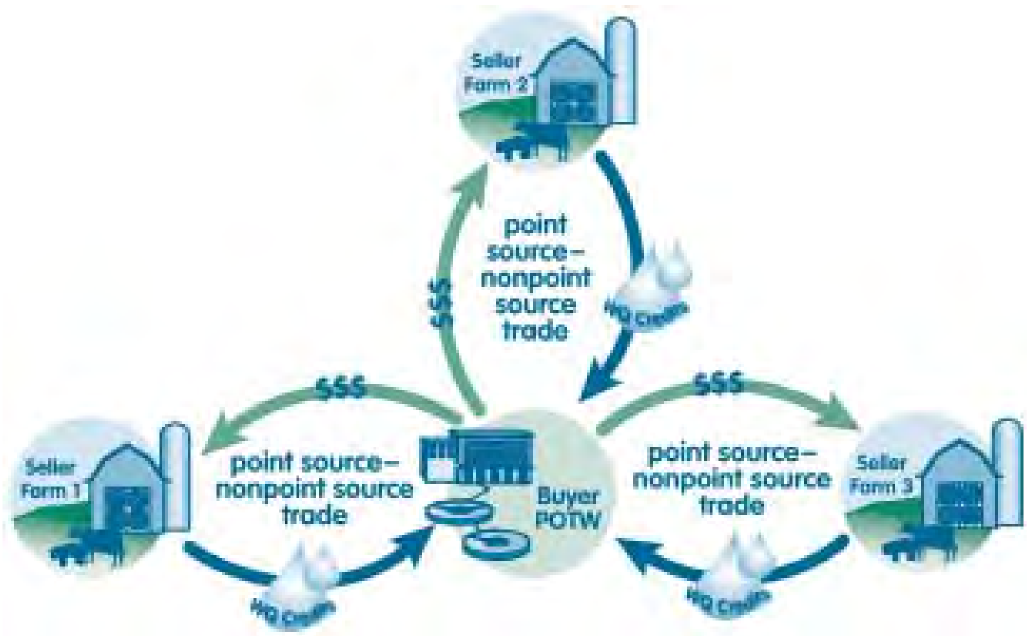


Figure 5.4: *Illustration of Single Point Source-Nonpoint Source Trading from the EPA Trading Toolkit.*

ii. Third Party Brokers

Another option for nonpoint source credit generation is to use third party brokers.[20] A broker may be the state, a conservation district, private company, nonprofit, or some other entity.[21] Brokers act to facilitate nonpoint source credit generation by connecting the point sources with potential sources of nonpoint source nutrient reductions. All trading happens directly between sources using a trade contract in the same manner as the Single Point-to-Nonpoint Source Trading option. However, the broker under this scenario may provide support to the parties in order to help facilitate the transaction. For one, the broker should identify the most beneficial nonpoint source projects with the highest potential for long-term success. The broker may also provide assistance in a variety of capacities, from the contracting and implementation to the quantification and verification of reductions. The level of broker involvement is entirely within the discretion of the individual point source. This option provides a high level of control and responsibility to the point source, but with the additional benefit of an experienced broker to help direct the activities.

---

[20] EPA TRADING TOOLKIT at 19.

[21] For instance, private companies act operate as brokers under the Endangered Species Act, maintaining banks of mitigation credits to offset adverse impacts to protected species. U.S. Fish & Wildlife Service, Conservation Banking (2012), https://www.fws.gov/endangered/esa-library/pdf/conservation_banking.pdf. Similar banks exist to compensate for impacts to wetlands for dredge and fill activities under CWA section 404. U.S. EPA, Establishment, Use and Operation of Mitigation Banks, 60 Fed. Reg. 58,605 (Nov. 28, 1995), *available at* www.epa.gov/cwa-404/federal-guidance-establishment-use-and-operation-mitigation-banks.

iii. Nonpoint Source Credit Exchange

Another option is to use a nonpoint source credit exchange.[22] Operated by a third party entity, the exchange would bear responsibility for acquiring nonpoint source credits. Independent nonpoint source credit sellers would generate load reductions using approved practices and sell those credits to the exchange. Point sources would purchase validated credits from the exchange without dealing directly with the nonpoint sources whatsoever. The exchange would maintain a bank of credits that could be purchased at a moment's notice.

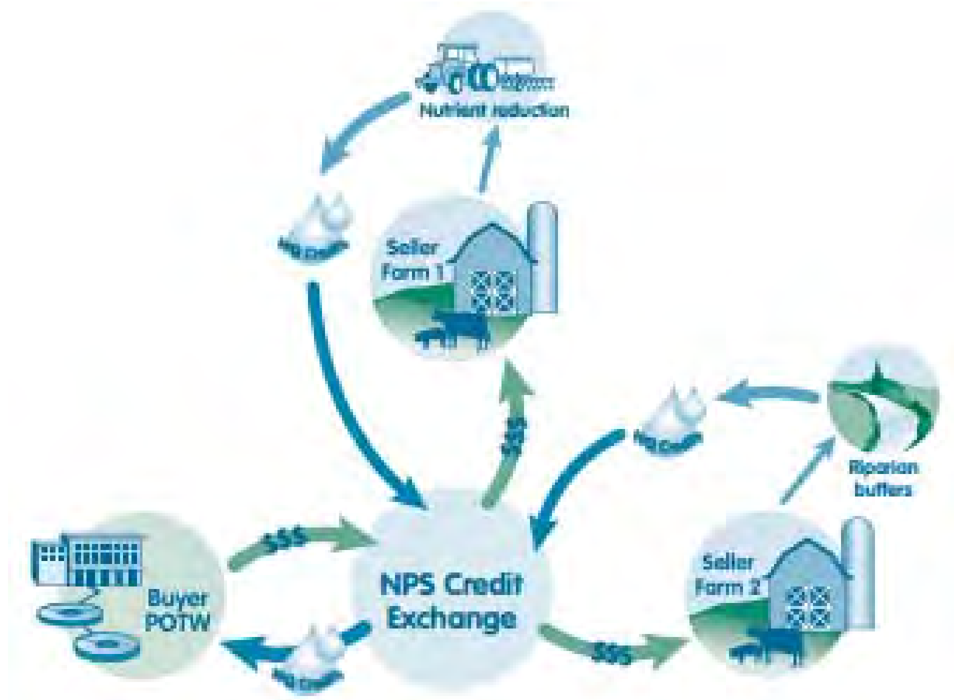


Figure 5.5: *Illustration of Nonpoint Source Credit Exchange from the EPA Trading Toolkit*

This option provides point sources without much flexibility or control but provides participants with certainty. An exchange often reduces transaction costs and administrative burden for point sources.[23] The exchange would likely handle all market administration and credit accounting, resulting in an efficient and simple process for trade participants. Notably, the exchange would potentially maintain a reserve pool of credits to provide assurance to point sources. The Exchange could be any number of entities, such as a nonprofit (like Virginia's Point Source Exchange), a private company, or the state regulatory agency (like Connecticut's Point Source Exchange). If an exchange or facilitator guides the point-to-point trading program, ideally that party would also act as a nonpoint credit exchange, directing or managing nonpoint source credit trading as well. In any event, an exchange must work closely with the Regional Board to ensure all credits are properly verified, accounted, and traded.

B. REQUIRED TRADING FRAMEWORK ELEMENTS

The reductions in nonpoint pollution often cannot be directly measured and must instead be modeled using representative sampling and ongoing monitoring. Thus, the practices and activities that generate nonpoint source credits require a more definite framework to operate within than point-to-point trading. This framework establishes binding guidance for credit generation and accounting that resolves the uncertainty surrounding

[22] EPA TRADING TOOLKIT at 19.

[23] If the transaction volume is sufficient to justify the cost of building, maintaining, and overseeing the exchange. NAT'L NETWORK ON WATER QUALITY TRADING, BUILDING A WATER QUALITY TRADING PROGRAM: OPTIONS & CONSIDERATIONS, 173 (2015).

nonpoint source trading. Although a framework may be developed for individual nonpoint trades, the more feasible option is to develop a programmatic nonpoint trading framework that avoids the need for individual project approvals. In this scenario, the regulating agency approves the nonpoint source trading framework and incorporates that document into the general watershed permit either directly or by reference. This framework could facilitate any of the programmatic options discussed previously, though the mechanics of such program should be included in the nonpoint source trading framework. The following subjects are all issues that should be resolved either directly in the watershed permit or in the nonpoint source trade framework.

i. Eligibility

The trade framework should resolve the issues of eligibility, specifically the questions of where nonpoint nutrient reductions may occur and what practices are eligible to generate nonpoint credits.

Trading Area

In order for nonpoint source actions to generate compliance-grade nutrient credits to offset point source discharges, the activities should occur within a defined "trading area." The San Francisco Bay receives flow, and thus nutrients, from an extensive watershed that encompasses the Sacramento River and San Joaquin River Basins. Given this size, a more discrete trading area will need to be determined that still encompasses sufficient nonpoint sources of nutrients.[24]

It is possible that the potential trading area for a point-to-point trading program in the Bay will suffice for nonpoint source actions as well. However, depending on the geographic scope of a point-to-point source trading program, it may be necessary to enlarge the trading area beyond the sub-embayments delineated in the Nutrient Watershed Permit. This could entail growing either the entire trading area or the scope of one or more subembayments in order to encompass a critical mass of nonpoint sources that justify the programmatic expansion.[25]

Eligible Projects

Federal regulations allow for point sources to use offsets "credited to nonpoint source [pollution] abatement" in the event that "nonpoint source pollution controls make more stringent load allocations practicable[.]"[26] These measures potentially include a suite of actions, including but not limited to: best management practices (BMPs), restoration or creation and maintenance of wetlands, freshwater habitat restoration, pollution prevention or minimization programs, and modification of water diversion, delivery, or storage activities that reduce pollutant concentrations.[27] However, given the variability of nonpoint source reductions, regulators must clarify what restoration or best management practices (BMPs) are eligible to generate credits. This is accomplished through the development of a list of specific activities that are eligible to generate credits along with a set of project quality guidelines that provide assurance that the actions are suitable and appropriate for the watershed. These restoration quality standards and BMP guidelines enable an objective evaluation of project implementation and performance while accounting for the specific circumstances at a project site. Additionally, the list of actions should include any necessary guidelines that will ensure the anticipated environmental benefits will be realized

---

[24] This analysis looks to the hydrogeologic conditions, fate and transport of pollutants, ecological parameters, location and type of point source(s), type of pollutant(s), and regulations and management structures. U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. 1608, 1611 (Jan. 13, 2003).
[25] The size of the trading area for nonpoint source credit generation will be a consideration in determining the appropriate delivery and attenuation ratios. EPA TRADING TOOLKIT at 13.
[26] Memorandum from Michael A.M. Lauffer, Chief Counsel, State Water Resources Control Bd., to Arthur G. Baggett, Jr., Chair, State Water Resources Control Bd., on Updated Legal Authority for Offsets, Pollutant Trading, and Market Programs to Supplement Water Quality Regulation in California's Impaired Waters With Established Total Maximum Daily Loads (Nov. 22, 2006), referencing 40 C.F.R. §§ 122.4, 122.44, 130.2 (2016).
[27] *See e.g.*, CAL. WATER CODE § 16101(d)(5) (2015).

as a result of project implementation, such as criteria to determine effectiveness, design and maintenance standards, project implementation standards, and standards for project performance. Depending on the specific activities, the guidelines may be applicable to upland actions for nutrient credits as well. Often these quality standards can be based on existing BMP or restoration standards promulgated by agencies such as the Natural Resources Conservation Service.

ii. Quantification of Water Quality Benefits

Whereas point source credits are easily determined by end-of-pipe discharge monitoring, nonpoint source credits arise from reducing diffuse pollutant loading, making them more difficult to quantify. Moreover, there must be a true water quality benefit that would not have occurred without trading to justify crediting a nonpoint project. There are several concepts that should be incorporated into a nonpoint source trade framework to address the uncertainty and ensure water quality benefits arise.

Additionality

"Additionality" relates to the crediting of water quality benefits generated from a nonpoint source activity.[28] The reduction benefits secured from a restoration action or BMP adoption are "additional" when the action is not already required, when funds or resources used to generate the benefits are authorized for water quality compliance purposes, and when the benefits of those actions have not already been credited for alternative regulatory program requirements.

In the implementation of a nonpoint source trading program in the San Francisco Bay, additionality would likely be considered in two ways. First, ensuring that the water quality benefits from a restoration project site are not generated contrary to legal restrictions associated with the funding source ("financial additionality" assessment). Second, confirmation that the restoration action proposed for the project site is not already required by existing affirmative land management obligations ("trading baseline").

As noted in the National Network on Water Quality Trading summary document, "trading programs should not shy away from applying multiple sources of funding, but need to be clear about which funding is generating which water quality benefits, and for whom."[29] Financial additionality is the evaluation of the funding sources for restoration actions and the benefits from which a permittee is seeking water quality credits. The analysis is meant to address two issues: first, whether there is authorization for the use of funding for credit-generating actions (e.g., funding is authorized for water quality compliance); and second, whether the benefits of those actions have already been credited for an alternative regulatory program and are therefore no longer available (e.g., avoiding "double-counting" the same benefits from a project for wetland mitigation under Clean Water Act Section 404 as well for water quality credits under Clean Water Act Section 401).[30] Essentially, if the source of funding was initially earmarked for compliance purposes and has not been used to generate existing credits for another program, then financial additionality is satisfied.

Baseline

One of the most important, and at times confusing, considerations for nonpoint source trading is the baseline for credit generation. "Trading baseline" refers to the threshold a source must meet before generating credits for sale. For nonpoint source actions, baseline can be understood as any affirmative obligations that apply to a parcel of land. In describing baseline, the EPA Trading Policy states "pollutant reductions [should be] greater

---

[28] WILLAMETTE P'SHIP & THE FRESHWATER TRUST, DRAFT REGIONAL RECOMMENDATIONS FOR THE PACIFIC NORTHWEST ON WATER QUALITY TRADING, 49 (2014) *available at* http://willamettepartnership.org/wp-content/uploads/2014/09/PNW-Joint-Regional-Recommendations-on-WQT_ThirdDraft_2014-08-05_full1.pdf.
[29] NAT'L NETWORK ON WATER QUALITY TRADING, BUILDING A WATER QUALITY TRADING PROGRAM: OPTIONS & CONSIDERATIONS, 63 (2015).
[30] *Id.* at 62–63.

than those required by a regulatory requirement or established under a TMDL."[31] The EPA Trading Toolkit states that where no TMDL exists, baseline is equal to the pollutant control requirements that apply to a buyer and seller without trading.[32] The EPA has noted that where a TMDL applies, the nonpoint source baseline "would be derived from the nonpoint source's load allocation."[33] However, because baseline applies at the individual site level, it is critical to translate these generic statements into more specific guidance. To assist in this effort, the National Network on Water Quality Trading developed the following flowchart[34]:

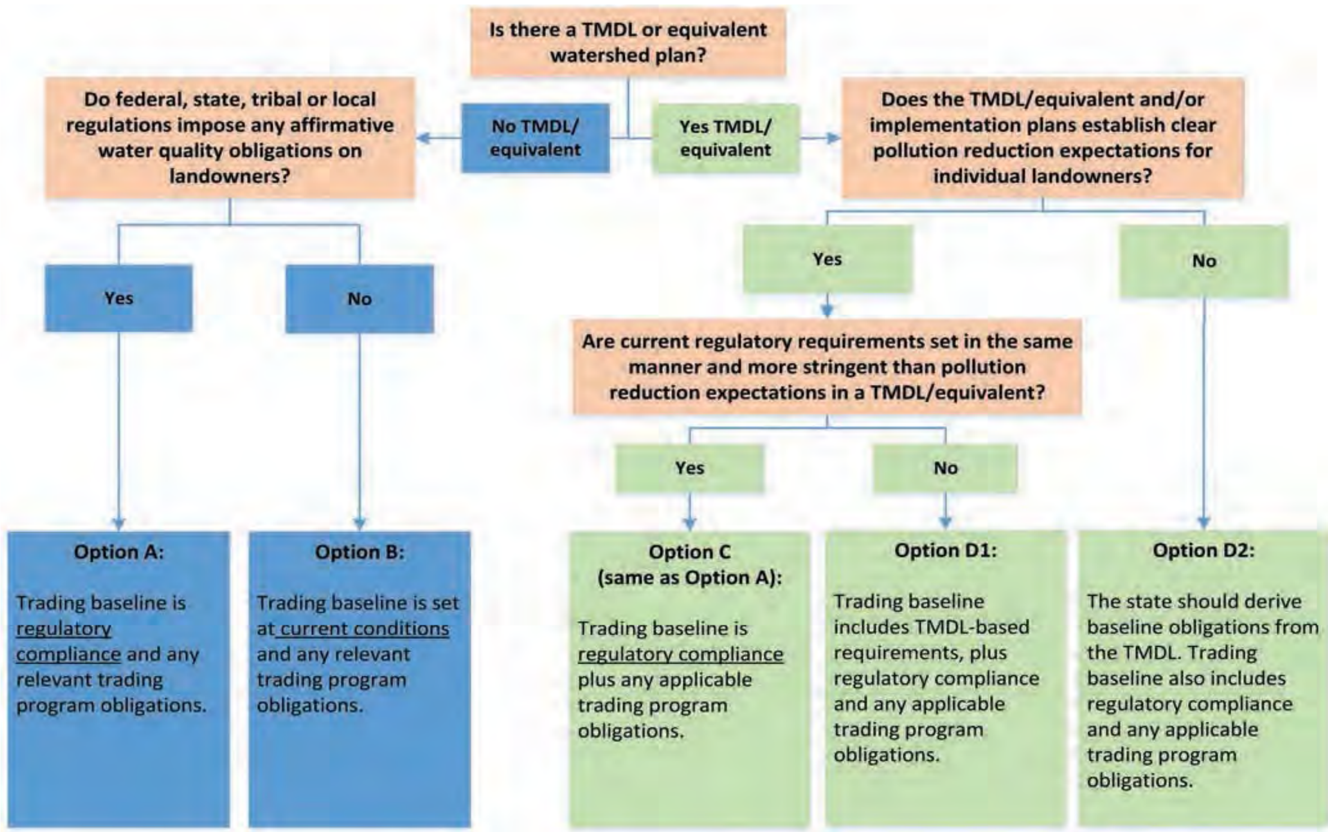


Figure 5.6*: Flowchart to Determine Sources of Baseline*

A screening review for baseline requirements will need to be undertaken on each site as the different locales and land uses often result in site-specific baseline requirements. Moreover, under California's Porter-Cologne Water Quality Act, many nonpoint sources that otherwise avoid federal CWA permitting nonetheless receive a waste discharge permit or a conditional waiver.[35] If a nonpoint source has received a permit or waiver, the requirements contained therein will inform baseline at the particular site where the permit or waiver applies. Beyond these requirements, specific types of sources (*e.g.*, stormwater sources, irrigated agriculture, and open space) may be implicated by other water quality obligations. In addition, local regulations establish a number of minimum operational practices. Depending on the location, the operation may be subject to constraints imposed by county or city comprehensive plans, zoning ordinances, subdivision ordinances or other code requirements. Baseline requirements at the county and city level may therefore vary depending on location, land use type, applicable overlay districts (if any) and the type of BMP employed to generate credits.

---

[31] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1610.
[32] *See* EPA TRADING TOOLKIT at 28–29.
[33] *See id.* at 29 & Glossary-1.
[34] *See* NAT'L NETWORK ON WATER QUALITY TRADING, BUILDING A WATER QUALITY TRADING PROGRAM: OPTIONS & CONSIDERATIONS, at 57, Fig. 3.2.1, (2015).
[35] CAL. WATER CODE § 13260 (2016).

While the wide array of baseline options may seem overwhelming, in many instances existing requirements do not include active restoration actions on specific sites. In other words, the proposed credit-generating actions are usually not already required. Nonetheless, it is important to assess the existing land use obligations associated with sites to ensure that this general presumption is true as applied to the specific proposed credit site.

Quantifying Water Quality Benefits at a Project Site

The environmental benefit provided by a project serves as the foundation of a water quality credit. Conversion of a project's benefits into units of environmental benefit (specifically the reduction in nutrient load) is necessary in order to compare those benefits against a numerically defined regulatory obligation. Benefit quantification methods are based on direct measurement of pollutant reduction, use of pre-determined project efficiency rates, or the best available information and modeling or calculations to predict reductions. To quantify a project's benefits, a project developer needs to estimate pre-project and post-project conditions, ideally using preapproved and standardized forms. These conditions can come in the form of direct measurements or technically viable assumptions to input into a model. Either way, an environmental benefit quantification methodology must be designed to incorporate site-specific information within a watershed context to quantify the water quality benefits associated with a nonpoint source project. Notably, in any water quality trading project, water quality benefits should be scientifically defensible, repeatable, conservative, transparent, and practical.

Monitoring Requirements

The EPA recommends additional monitoring for water quality trading programs in order to verify the generation and use of credits.[36] For trades involving nonpoint sources, the NPDES permit should "address the unique considerations for monitoring and reporting that will facilitate evaluating the effectiveness of BMPs used to generate pollutant reduction credits."[37] This often includes ongoing monitoring and modeling to show the pollutant reductions and inspections to verify the continuing validity of the pollutant reduction measures. Additionally, the amount, location, and method of credit generation should be consistently documented to demonstrate permit compliance.[38] This inspection may be undertaken by either the permittee or an approved third party. Often regulators require verification of project installation and performance before the credits may be used for compliance.

As an example, for the current Laguna de Santa Rosa Nutrient Offset Program, the North Coast Regional Board established monitoring and tracking requirements beyond those contained in the NPDES permit. The City of Santa Rosa operates without a broker, so the City must identify the location and proposed actions, model the pollutant reductions, detail the monitoring and reporting plan, and submit the findings for RWQCB approval.[39] Following implementation, Santa Rosa must submit annual reports documenting the pollutant discharges, the pollutants controlled by offset projects, and anticipated future reductions. While a preapproval process for each project is onerous compared to similar programs elsewhere, the monitoring requirements are representative of other programs nationwide.

Ideally, the compliance assurance measures minimize transaction costs and uncertainties from any potential trade. This is accomplished "by achieving consistent approval decisions—both in outcome and timing—based on

---

[36] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1612.
[37] EPA TRADING TOOLKIT at 22.
[38] "Permitting authorities should consider developing trade tracking forms and establishing discharger trade reporting requirements to monitor trading activities and any alternative compliance activities implemented if a BMP fails to perform as expected." *Id.* at 23.
[39] N. Coast Reg'l Water Quality Control Bd., Res. No. R1-2008-0061: Approving Santa Rosa Nutrient Offset Program (July 24, 2008), *available at* www.waterboards.ca.gov/northcoast/water_issues/programs/nutrient_offset_program/.

the data needed to ensure achievement of the required pollutant reductions" and the avoidance of localized impacts.[40] Thus, the establishment of a robust monitoring system tends to lower the transaction costs by providing the certainty needed to satisfy regulators and the public.

Ratios to Account for Attenuation & Delivery Factors

The 2003 EPA Trading Policy calls for the use of ratios whenever trading involves nonpoint sources because nonpoint source reductions can rarely be directly measured and trading ratios account for the uncertainty in nonpoint source reduction estimates.[41] The EPA Trading Toolkit likewise suggests that ratios may be necessary to address a number of factors such as delivery, location, and retirement.[42] In the absence of a California policy, ratios must be established on a case-by-case basis. Based on the lessons learned from other water quality trading regimes and federal guidance documents, ratios may need to address the following factors:

- Degree of technical and logistical uncertainty;[43]
- The fate and transport of the pollutant over the distance between the pollutant source, trade source, and points of regulatory compliance within the watershed;[44]
- Temporal variability of the pollutant load and of the pollutant reduction method;
- The different forms of the same pollutant in terms of composition and impacts on the environment;[45] and
- Time lag between implementation of the technology or practice and full performance.[46]

Accounting for these factors, the EPA Trading Policy supports using trading ratios greater than 1:1 between point and nonpoint sources,[47] although a 2:1 ratio is common in other trading programs.[48]

The trading ratio, whether adopted for individual projects or on a programmatic basis, must be determined based on the specific factors present in the area. In the San Francisco Bay, the specific nonpoint source credit trading ratio would probably apply on a subembayment level in order to account for the delivery and attenuation of water quality benefits. A nonpoint source trading ratio should increase commensurate with the distance upstream (or mixing zone effects). Thus, credits generated in the upper reaches of the San Francisco Bay watershed (including the Delta) would likely require a higher trading ratio than credits generated in the lower reaches.

iii. Credit Accounting

As is true with point source nutrient credits, one of the most important considerations for a water quality trade is the credit accounting. Robust accounting ensures that the reductions are achieved and the credits are accurately conveyed to purchasers. Some additional requirements and considerations arise for nonpoint source credits beyond those for point source credits.

---

[40] U.S. EPA, National Water Quality Trading Assessment Handbook, 53, EPA 841-B-04-001 (Nov. 2004), *available at* http://www.dep.state.fl.us/water/watersheds/docs/ptpac/national-wqt-handbook-2004.pdf.

[41] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1612.

[42] EPA Trading Toolkit at 30–32 ("There is not set limit for how high a trading ratio can be. Trading ratios depend on the specific circumstances in the watershed").

[43] *Id.* at 32. These 'uncertainty ratios' are common with nonpoint trades.

[44] These ratios account for the transport characteristics of a pollutant, the watershed characteristics, distance, and time. *Id.* at 30. Delivery ratios account for both the transport of the pollutants into the watershed and within the waterway itself. *See* Willamette P'ship & The Freshwater Trust, Draft Regional Recommendations for the Pacific Northwest on Water Quality Trading, 75 (2014).

[45] "Equivalency ratios" help account for the level of biologically available nutrients versus the nutrients that are less accessible.

[46] *See e.g.*, Colo. Dept. of Public Health and Env., Colorado Pollutant Trading Policy (2004).

[47] U.S. EPA, Water Quality Trading Policy, 68 Fed. Reg. at 1612.

[48] For Chesapeake Bay nutrient trading programs, EPA Region 3 recommended at least a 2:1 ratio to account for uncertainty. EPA, Region 3, Accounting for Uncertainty in Offset and Trading Programs, at 4–5 (2014), *available at* http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/TradingTMs/Final_Uncertainty_TM_2-12-14.pdf. Colorado likewise adopted a minimum 2:1 ratio for nutrient trades involving nonpoint sources. 5 Colo. Code Regs. § 85.5(3)(d)(ii) (2015).

Project Implementation & Quality Assurance Standards

For a project to be eligible to produce credits, it must be designed and implemented consistent with rigorous quality standards so that the project will produce intended reductions in nutrient loading. Each project type must have quality standards that define whether a project is implemented correctly, the mechanisms necessary to ensure that projects are adequately maintained, and any legal mechanisms necessary to protect a project that is in place.

The first step in this process is project site screening or "validation" to vet potential nonpoint source nutrient reduction projects for program eligibility. Depending on the program structure, this may be completed by the individual permittee, the facilitator, or the exchange. Validation of potential projects ensures that ineligible activities can be eliminated before time or resources are spent on implementation. This stage also allows project developers to evaluate a proposed project's consistency with any and all applicable laws and regulations. While it does not need to occur at the validation stage, at this point a developer should make the required showing of adequate legal protections and secure funding for the life of the project site. This may also be accomplished at later stages of the credit accounting process, but it must be demonstrated before credits are issued.

The list of eligible activities included in the nonpoint source trading framework should also set guidelines to explicitly define the design and performance standards for each action using quantitative metrics. These guidelines ensure that nonpoint source reduction projects are installed and maintained in a manner consistent with the underlying assumptions for the credit calculations. These guidelines also provide a means to ensure that activities remain consistent with applicable rules and regulations when implemented. The ideal guidelines provide a balance between flexibility in implementation methods and the certainty required for compliance programs.

For some nonpoint source credit generating activities, it may even make sense to incorporate specific project site design and management requirements into the framework. For example, many agricultural conservation BMPs have specific standards developed by the NRCS and adapted at a state level that ensure the project achieves its intended purpose.[49] Other projects, including many restoration activities, will require more flexibility to adapt to specific site conditions. When specific requirements cannot be applied to a class of projects, it is necessary for the project developer to create a management plan that, if followed, provides a level of assurance that the project will succeed in generating water quality benefits. This management plan has two components: a project design portion that describes the proposed activity, goals, and anticipated threats; and a stewardship plan that details how the activity will be maintained in the long-term.

Project Verification & Certification

Project verification is the final step before credits may issue from a nonpoint source project. In essence, verification confirms that a project is implemented according to the applicable quality standards, that the reductions have been quantified properly, and the project will be maintained such that it continues to function as designed over time. Even though some nonpoint source projects such as restoration may take years to become fully established, projects usually begin to generate credits following implementation so long as the long term maintenance is ensured. The entity that performs verification, whether the permittee, a third party, or the regulatory body, must be familiar with the performance metrics and the quantification methodologies in order to properly confirm that the site is designed, implemented, and performing as intended.

---

[49] Natural Resources Conservation Service, National Conservation Practice Standards (2015), *available at* https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/cp/ncps/.

Verification constitutes an important step because "point-nonpoint trades often involve various types of BMPs (each with its own unique requirements), installed at numerous and dispersed nonpoint source locations[.]"[50] Thus, verification serves to provide the level of assurance that arises from discharge monitoring for point source credits. This gives regulators and the public confidence that the expected water quality benefits will accrue.

Following verification, formal certification of the credits occurs. This administrative review ensures that all credits are valid and the appropriate documentation is complete. The certification stage constitutes the final review of projects to guarantee that the nutrient reductions have occurred and credits may be issued. Certification may be completed by the regulatory body, the permittee, or an approved third party. Once the review of an individual project is complete, the reviewing entity should issue a formal written certification to memorialize the decision. Once certified, the nonpoint source credits are ready for registration and transacting.

Project Tracking & Registration

Once a project's implementation is formally certified, credits are issued and tracked. Tracking is the process of following the status and ownership of credits as they are issued, used, retired, suspended, or cancelled. Information about credits used for NPDES permit compliance should be made available to the public to promote transparency and allow for review and oversight. Registering credits using an online registry platform provides a straightforward method for achieving transparency. Serializing and registering credits (both point and nonpoint source credits) provides additional assurance that each unit of water quality improvement is not being sold multiple times to different buyers (i.e., double counting).

An online registry for water quality credits provides the public and the regulatory agencies with the ability to track project site- and program-level success over time. This could be accomplished using a third-party environmental credit registry, such as Markit, that is used for several other trading programs across the country.[51] Of particular importance, ideally the chosen credit registry will be used to track credits generated by both point and nonpoint sources. This will simplify the accounting process and make the program transparent for participants, the regulators, and the public.

Credit Life

The standard "life" of a nonpoint source credit—the amount of time the credit remains valid to offset other discharges—has not been answered definitively in California.[52] For point sources, the credit life occurs on a repeated basis based on the compliance period. Thus, point source reductions below the permit limits will generate credits each compliance period. However, for nonpoint source credits, the decision of credit life must be determined from the start because the choice related to credit life for nonpoint source trading has long-term implications.

Allowing for the renewal of credits from ongoing BMPs may help to keep effective BMPs in place for longer periods of time, and therefore further solidify the ecological gains achieved in the first crediting cycle. When the water quality benefit generated from a site is no longer creditable, the credit buyer (whether the point source or exchange) will no longer pay for continued monitoring and maintenance or landowner lease payments.

---

[50] WILLAMETTE P'SHIP & THE FRESHWATER TRUST, DRAFT REGIONAL RECOMMENDATIONS FOR THE PACIFIC NORTHWEST ON WATER QUALITY TRADING, 104 (2014).

[51] EPRI's Ohio River Basin Nutrient Trading Program is hosted on Markit: https://mer.markit.com/br-reg/public/orb/index.jsp. Likewise, the City of Medford's temperature compliance program can be viewed here: https://mer.markit.com/br-reg/public/index.jsp?name=City%20of%20Medford&entity=holding&entity_domain=Markit,GoldStandard.

[52] No state policy or guidance on this issue has been formulated. However, the Santa Rosa Nutrient Offset Program approves credit life for each reduction project on a case-by-case basis based on the expected life of the crediting practice. *See e.g.*, N. Coast Reg'l Water Quality Control Bd., Notice of Approval: Nutrient Reduction Activities for the Nunes Ocean View Dairy Nutrient Offset Project (Jan. 24, 2013), *available at* www.waterboards.ca.gov/northcoast/water_issues/programs/nutrient_offset_program/.

However, many BMPs require ongoing investment and maintenance to sustain or even increase their water quality benefit (e.g., riparian wetland buffer restoration). Landowners may also require ongoing incentives to maintain BMPs on the land or to provide access to those responsible for maintaining them.

Without the ability to renew credits from ongoing BMPs, there is no guarantee that their positive functions will continue to accrue. A new BMP may not generate as much benefit for water quality as one that has been installed and maintained for enough time to allow for the full benefit of the BMPs to accrue. Finally, there are transaction costs associated with engaging new landowners and with the initial implementation of a BMP (e.g., development of a nutrient management plan, site preparation, and credit calculation costs).

Maintenance of BMPs over time can make improvements to water quality more cost effective than continual investment in new BMP installations. For example, the science associated with some types of restoration and weed management is constantly evolving. Therefore, it is beneficial to allow the renewal of some or all types of nonpoint source credits in subsequent years. This guarantees that the projects continue to remain in place and generate the reductions year after year.

Compliance Determinations

Nonpoint source trading distributes pollution reduction activities from the end-of-pipe to locations across the watershed, raising questions about how to ascertain compliance. A trading program must address issues such as the contents of a Discharge Monitoring Report, entry of credits into the CIWQS system (the California Integrated Water Quality System is a database for effluent monitoring data) required limits at the point of discharge with or without credits, and what happens if credit generating projects don't succeed. Yet, little difference exists between compliance determinations for trading and for other treatment processes. The only difference is the inclusion of additional documentation when submitting compliance documents with the regulators. Trading must include some evidence of the credits used to offset any exceedances. The agency will identify the specific methods to make this showing, but it will likely include providing the credit certifications and registrations to prove that the credits are valid and have been properly accounted.

5.4. Conclusion & Recommendations

The San Francisco Bay has sufficient documented evidence of nonpoint source nutrient pollution to warrant a programmatic expansion of a point-to-point source trading program to include nonpoint source nutrient trading. While credit supply is largest in the upper subembayments, the nonpoint source credits could be transferable between subembayments using trading ratios to account for attenuation and uncertainty. Moreover, such a programmatic expansion would not require significant revisions to an existing program as most of the existing compliance mechanisms would facilitate both point and nonpoint source trading activities. The existing permit would continue to govern, with very minor revisions to incorporate the guidelines needed to frame nonpoint credit generating activities. Those guidelines would likely be drafted independently of the trade agreement for point-to-point trading, enabling participants to formulate and operate a point source trading program first and to add nonpoint source trading later. This provides flexibility for parties to collaboratively develop a robust system that benefits all stakeholders. Accordingly, the following recommendations are not intended to supplant this collaborative process, but are instead intended to help inform and guide the discussions. Please note that these recommendations should not be construed as legal advice, but rather as suggestions that must be discussed with legal counsel prior to making any decisions related to regulatory compliance.

TFT recommends that **a point-to-point source trading program for the San Francisco Bay include nonpoint source trading using a central exchange**. The use of a central exchange for nonpoint credits, even if no such exchange exists for credit generated by point sources, allows credit buyers to avoid the confusion and uncertainty inherent in nonpoint source trading. Instead, the point sources would have the ability to purchase verified and certified credits directly from the central exchange. The expertise and experience of the exchange will lower transactional expenses, keeping credit costs to a minimum. Moreover, the exchange would bear the responsibility for ensuring the ongoing maintenance and monitoring required to maintain the validity of nonpoint source credits. This option provides the greatest level of certainty and oversight for nonpoint trading.

TFT recommends **developing an independent nonpoint source trading framework to govern all nonpoint source credit generation and accounting**. This framework can identify all pertinent considerations, such as the eligible activities, the project quality standards, accounting process, etc. As nonpoint source crediting has a much higher degree of inherent uncertainty, providing clarity regarding the methodologies underlying nonpoint source credits is of the utmost importance. This document should be developed through a collaborative process involving the trading participants, the Regional Board, the EPA, and other interested stakeholders and must be incorporated directly into the point-to-point trade agreement or into the watershed permit by reference. This virtually guarantees the nonpoint source actions generate the required benefits and are properly accounted.

The central exchange should oversee a nonpoint source restoration fund—dischargers unable to acquire credits to offset their exceedance could pay into the fund, which would finance future restoration activities. TFT recommends the **use of such a nonpoint source restoration fund as a component of a point source trading program due to the certainty and risk minimization it provides to regulated entities**. This type of fund constitutes a permanent pool of financing that the central exchange or regulatory body can manage and distribute to pay for nonpoint source (and potentially point source) credit generating activities. This offsets permit exceedances that would otherwise result in noncompliance with the discharge permit and generates greater environmental benefit that would otherwise be realized. Virginia's Chesapeake Bay Nutrient Trading Program uses this type of fund, and it has proven a valued tool to insure against unexpected credit shortages.[53]

In addition to broad programmatic recommendations, TFT has a few recommendations on specific aspects of a nonpoint source credit generating component of a larger point-to-point nutrient trading program. Although these specific program aspects will be determined through collaboration with stakeholders and regulators, TFT believes the following component recommendations are critical to any successful point-to-nonpoint source trading program:

- **Distinct trading ratios should be developed for nonpoint source credit generation activities that are higher than the trading ratio(s) applicable to point-to-point trades.** This provides a mechanism to address the uncertainty of nonpoint source credits, to account for the attenuation of benefits across the watershed, and to ensure water quality benefits accrue. Depending on the specific trading area adopted, it may be appropriate to adopt multiple trading ratios that apply to different scenarios, thereby ensuring the ratios are not too onerous, but are sufficient to protect against undesirable results.
- **Quality standards and performance metrics for project sites should be based on established guidance when possible.** Many state and federal agencies have adopted guidelines for various types of projects that may be eligible to generate nonpoint source credits. While these may not exist for every potential project, they should be used when available and appropriate.

[53] The Virginia Water Quality Improvement Act of 1997 established the Water Quality Improvement Fund (WQIF) to finance nutrient reduction strategies in the Chesapeake Bay and its tributaries. The WQIF is a permanent, non-reverting fund that point sources unable to acquire sufficient credits to offset exceedances may pay into in order to achieve permit compliance. The fund is used to finance point and nonpoint source nutrient reduction actions, thereby generating a net benefit to the local water quality. VA. CODE ANN. § 10.1-2117–2134 (2016). *See also* L.P. Bryant, Jr., Office of the Governor, Sec. of Nat. Res., Virginia Water Quality Improvement Fund Guidelines (Nov. 2006, updated May 2012), www.deq.virginia.gov/Portals/0/DEQ/Water/ChesapeakeBay/Nov2006WQIFGuidelines-updated_5-15-12.pdf.

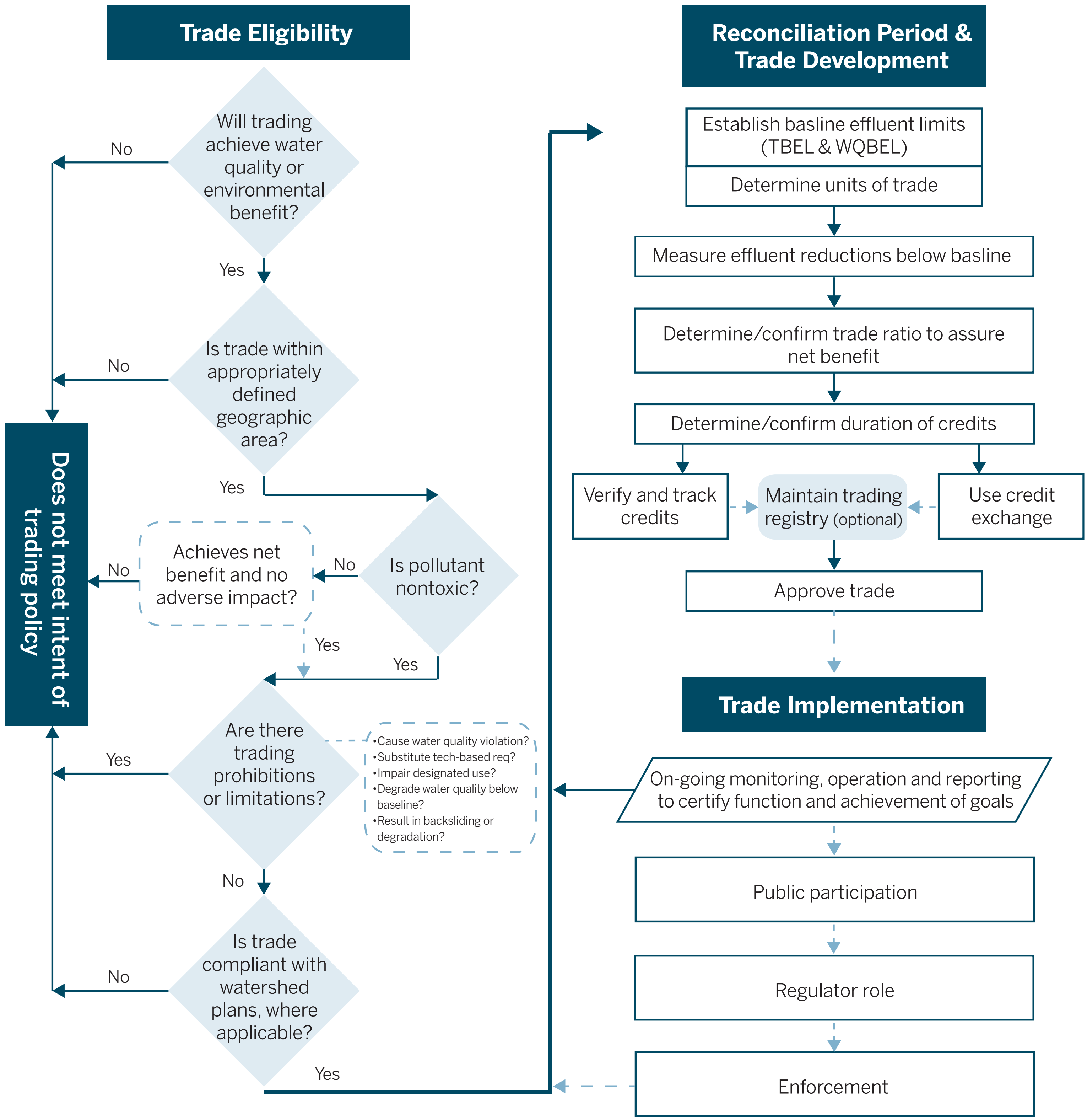
- **Agency-approved verifiers should be used in order to provide for independent, objective oversight of the project site implementation.** Having verifiers with expertise and objectivity provides a level of assurance to credit purchasers that the credit generating projects are properly vetted and the credits will not be invalidated.
- **An online credit registry, such as Markit Environmental Registry, should be used to track credits**. This provides a level of certainty and accountability to trade participants, guaranteeing that credits are valid and have not been double counted. Likewise, it creates transparency by enabling regulators and outside parties to evaluate credit usage and permit compliance.
- **Credits should have a definite credit life that, based on the type of project proposed, is long enough to justify implementing the project.** Depending on the type of project, the credit life may vary. However, the credit life should extend for several years to guarantee the benefit to water quality accrues and the project is worthwhile. This is especially important for nonpoint projects as the water quality benefits often increase as the project matures. For instance, riparian restoration generates greater pollution reduction benefits several years after implementation as the vegetation becomes more established.

Based on the foregoing, TFT believes that nonpoint source nutrient credit generation represents a viable and beneficial option for including in a point-to-point source trading program. Even with the greater degree of uncertainty, the advantages of such a program in terms of the environmental, economic, and social gains that are possible cannot be understated. Therefore, potential participants in trading program for the San Francisco Bay should seek to incorporate nonpoint trading as one aspect of a point-to-point source trading program moving forward.

Appendix A

Water Quality Trading Policy Framework

for point source to point source trading



The Freshwater Trust

Adapted from *Colorado Pollutant Trading Policy*, Colorado Department of Public Health and Environment, Water Quality Control Division, October 2004

Appendix B

NUTRIENT CREDIT SERVICES AGREEMENT

THIS NUTRIENT CREDIT SERVICES AGREEMENT (this "Agreement") made by and between the Virginia Nutrient Credit Exchange Association, Inc., (the "Nutrient Exchange") and the undersigned owner or operator of a Permitted Facility included in the Exchange Compliance Plan (the "Participant").

BACKGROUND

A. The Participant owns or operates a certain facility or facilities regulated under the General Virginia Pollutant Discharge Elimination System Watershed Permit Regulation for Total Nitrogen and Total Phosphorus Discharges and Nutrient Trading in the Chesapeake Bay Watershed in Virginia, 9 VAC 25-820, issued by the State Water Control Board and Department of Environmental Quality (collectively "DEQ") for a five-year permit term beginning January 1, 2007 or as hereafter modified or reissued from time to time (the "Watershed General Permit").

B. The Nutrient Exchange is a Virginia non-stock corporation comprised of permittees subject to the Watershed General Permit and is authorized by section 62.1-44.19:17 of the Code of Virginia to assist permittees with Watershed General Permit compliance and to facilitate voluntary nutrient credit trading.

C. Among other requirements, the Watershed General Permit (9 VAC 25-820-70, Part I B) imposes limitations on the discharge of two nutrients, total nitrogen and total phosphorus, from the Participant's Permitted Facility(ies), and requires the Participant to submit to DEQ by August 1, 2007 and each February 1 thereafter, either individually or through the Nutrient Exchange, a compliance plan (9 VAC 25-820-40 and -70 Part I D) identifying how its Permitted Facility(ies) will comply with such limitations.

D. On behalf of the Participants and based on the data provided and decisions made by the individual Participants, the Nutrient Exchange has developed, and intends to maintain by means of the Watershed General Permit-required annual Plan Updates, a compliance plan for each of Virginia's five major river basins (collectively the "Exchange Compliance Plan") to assist the Participants in complying with the Watershed General Permit compliance plan requirement.

E. In addition, Participants in the Exchange Compliance Plan have the option of exchanging nutrient Credits. The Exchange Compliance Plan identifies firm commitments for the purchase and sale of Class A Credits at the request of numerous individual Participants who have elected to participate as Class A Buyers or Class A Sellers, and further establishes a market for and provides all Participants with the option of later purchasing available Class B Credits on more flexible terms to assist in maintaining compliance during unanticipated circumstances.

F. The Nutrient Exchange serves as the central trading exchange to facilitate the execution and reporting of these voluntary nutrient Credit Exchanges by and among its Participants in accordance with its Credit Exchange Policy, the Watershed General Permit and, when applicable, Water Quality Improvement Fund Grant Agreements entered into by and between a Participant and DEQ.

AGREEMENT

NOW, THEREFORE, in consideration of the mutual covenants and conditions herein, the parties hereto agree as follows:

1. Annual Compliance Plan Updates. The Nutrient Exchange agrees to update the Exchange Compliance Plan annually and submit such Plan Update to DEQ for approval on or before the deadline (currently February 1 of each year) specified in Part I D of the Watershed General Permit. The Plan Update shall include updated information as provided by the Participant in accordance with the Credit Exchange Policy for its Permitted Facility(ies), including revisions to relevant facility-specific information. The Participant shall assist the Nutrient Exchange in the development of the Plan Update by providing information reasonably requested by the Nutrient Exchange in accordance with an annual Plan Update schedule to be established by the Nutrient Exchange.

2. Annual Reports. The Participant agrees to submit to the Nutrient Exchange a copy of the Participant's annual report to DEQ required by Part I F of the Watershed General Permit (9 VAC 25-820-70), and such other information as may be reasonably requested by the Nutrient Exchange to assist in the annual Reconciliation of Credit Exchanges for each Compliance Year.

3. Annual Credit Exchange Reconciliation. The Nutrient Exchange agrees to conduct an annual Reconciliation process for the timely execution of the Credit Exchanges elected by the Participants as specified in the Exchange Compliance Plan. The Participant agrees to implement any previously elected Class A Credit or Class B Credit Exchanges in accordance with the Credit Exchange Policy.

4. Incorporation of Credit Exchange Policy. The provisions of the Credit Exchange Policy are hereby incorporated as if such provisions were fully set out herein. For convenient reference, a copy of the current version of the Policy is attached hereto.

GENERAL PROVISIONS

5. Definitions. Terms not specifically defined herein shall have the definitions provided in the Credit Exchange Policy.

6. Term. The Agreement shall be in effect once signed by both parties and shall have an initial term through and including June 30, 2013. This term is coincident with the five year Planning Period covered by the current Exchange Compliance Plan (January 1, 2008 through December 31, 2012) plus a six month period (January 1, 2013 through June 30, 2013) for the Reconciliation process for the fifth Compliance Year (2012). Such term shall automatically extend by one year, without notice, upon submittal to DEQ of each annual update of the Exchange Compliance Plan beginning with the 2009 Annual Update due February 1, 2009,

unless (a) the Participant withdraws as provided herein or (b) the Nutrient Exchange provides notice to the Participant prior to completion of the Plan Update that it will not extend the term of this Agreement.

7. Amendments to Credit Exchange Policy and Exchange Compliance Plan. The Nutrient Exchange and the Participant acknowledge that the Credit Exchange Policy and the Exchange Compliance Plan may be amended from time to time as a result of changes desired by the Participants, the Exchange Board of Governors or DEQ, possible changes to law, and other factors. It is agreed that changes thereto shall become effective upon notice to the Participants or upon a later effective date as may be specified in such notice.

8. Withdrawal. The Participant shall have the following rights to withdraw from the Nutrient Exchange and the Exchange Compliance Plan.

(a) Withdrawal Upon End of Current Term. This Agreement shall not automatically extend for an additional year upon the Plan Update as provided in Paragraph 6 if the Participant elects to withdraw by providing notice of such election to the Nutrient Exchange at least four years and nine months (57 months) prior to the expiration of the term of this Agreement or before any later date as the Nutrient Exchange may specify during the Plan Update process. In the event of such withdrawal, the Nutrient Exchange shall omit the Participant and its Permitted Facilities from the additional Compliance Year (the new Year 5) added to the Plan during the Plan Update process for that year. For example, if a Participant in the Exchange Compliance Plan for the five year Planning Period covering January 1, 2008 through December 31, 2012 desires to withdraw and not extend this Agreement for an additional year (*i.e.*, through December 31, 2013), the Participant shall provide its withdrawal notice on or before October 1, 2008.

(b) Withdrawal During Term in Response to Policy or Plan Amendment. Notwithstanding any other provision of this Agreement, if any change to the Credit Exchange Policy or the Exchange Compliance Plan pursuant to Paragraph 7 would result in a material adverse effect on the Participant within the five year Planning Period covered by the Exchange Compliance Plan then in effect, the Participant may withdraw from the Agreement by written notice delivered to the Nutrient Exchange within sixty (60) days of such Participant's notice of the change, unless the Nutrient Exchange in its discretion further amends the Credit Exchange Policy or Exchange Compliance Plan within ninety (90) days of receiving such notice in a manner that eliminates the material adverse effect. Such withdrawal shall be effective January 1 of the Compliance Year for which the material adverse effect would first otherwise occur. The Participant shall participate in the Reconciliation and execute all Credit Exchanges planned for each Compliance Year prior to the effective date of withdrawal and pay all Credit costs or receive Credit revenue through and including such Compliance Year. In addition, the Participant shall continue to pay all applicable fees or dues in the ordinary course through the effective date of such withdrawal.

(c) Withdrawal During Term for Other Reasons. In addition to the right to withdraw during the term of this Agreement as provided in Subparagraph 8(b), the Participant shall have the right to withdraw during the term of this Agreement through the Plan Update process if the following conditions are satisfied: (i) the Board determines that the Participant's withdrawal, alone or in combination with other modification requests, would not have a material adverse effect during the Planning Period on the Nutrient Exchange or any non-withdrawing Participants, (ii) the Participant is and agrees to remain current on all fees and Credit purchase costs as are due or may come due through and including the time of completion of the Reconciliation process for the last Compliance Year for which its Permitted Facilities are covered by the Plan, and (iii) the Participant agrees to cooperate fully in the Reconciliation for the last Compliance Year for which its Permitted Facilities are covered by the Plan. Such withdrawal shall be effective subject to the foregoing conditions upon submittal of the Plan Update by the Nutrient Exchange to DEQ as provided in Paragraph 1 above.

9. Annual Fee. The Nutrient Exchange's obligations under this Agreement shall be contingent on the continued adequate funding of the Nutrient Exchange through fees applicable to and paid by the Participants. Following execution of this Agreement by both parties and by approximately November 2008, the Nutrient Exchange shall issue an invoice to the Participant in the amount shown on Attachment A under the column labeled "Nov. 2008." Such invoice shall also include the amount, if any, invoiced by the Nutrient Exchange to the Participant in approximately March 2008 (as shown under the column labeled "Mar. 2008") but not yet paid by the Participant. The Participant agrees to pay such invoice within forty-five (45) days of the invoice date. Beginning with the 2009 Plan Update, following submittal of each annual Plan Update to DEQ the Nutrient Exchange shall issue an invoice to the Participant for the annual fee. The Participant shall pay such invoice within forty-five (45) days of the invoice date or by July 31 of the calendar year in which the invoice is issued, whichever is later. The Nutrient Exchange agrees to periodically update such schedule to add the fee amount for future years and in so doing intends to keep the annual fees specified therein to the lowest level sufficient for proper operation in the discretion of the Board. The Board anticipates establishing annual fees associated with and payable after the 2009, 2010, 2011 and 2012 Plan Updates, respectively, at less than a maximum of twice the annual fee currently scheduled on Attachment A for Nov. 2008. If an annual fee associated with any Plan Update through and including the 2012 Plan Update were to exceed this maximum anticipated fee, in that event the Participant may withdraw in accordance with the same procedures provided in Paragraph 8(b) of this Agreement. For the 2009 Plan Update, the Board's current estimate is that the annual fee will be the same amount as the Nov. 2008 fee shown on Attachment A. Upon receipt of a written request from the Participant, the Nutrient Exchange agrees to provide the Participant with an accounting of its receipts and disbursements for the two fiscal years immediately preceding the fiscal year in which the written request is received. The Participant agrees to pay applicable fees when due. Failure to pay any annual fee invoice within forty-five (45) days shall result in an administrative charge of one hundred dollars ($100). In the event the Participant fails to pay any annual fee invoice within ninety (90) days of the invoice date, without limiting any other remedies, the Board in its discretion may terminate this Agreement and eliminate the Participant's Permitted Facilities from the Plan. Such termination shall not relieve the Participant of its obligation to pay any amounts due prior to the date of termination.

10. Waiver of Liability of the Nutrient Exchange. In recognition of the benefits derived by Participants and the nature of the Nutrient Exchange, to the extent permitted by law the Participant waives any causes of action and rights of recovery for liability of the Nutrient

Exchange and its Board of Governors, officers, employees, consultants and other advisors, for any losses or damage to the Participant, other than due to the gross negligence or intentional misconduct thereof.

11. Authorization of Signature. The Participant and the Nutrient Exchange each represent and warrant that its execution of this Agreement by the undersigned is fully authorized and validly performed.

12. No Partnership. Nothing contained in this Agreement shall create any partnership, trust, or joint venture with regard to the Nutrient Exchange and any or all Participants.

13. Third Party Beneficiaries. This Agreement is solely for the benefit of the Nutrient Exchange and its Participants and their permitted successors and assignees and shall not confer any rights or benefits on any other person.

14. Notices. Notices pursuant to Paragraphs 6 and 8 shall be delivered at the following address by U.S. Mail, certified with return receipt, and shall be deemed given when received (or delivery is refused) by the party to whom such notice or communication is directed. A party may change its address for such notice in writing as provided herein.

If to the Nutrient Exchange: Virginia Nutrient Credit Exchange Association, Inc.
ATTN: Secretary
P.O. Box 51
Richmond, Virginia 23218-0051

If to the Participant: ____
____
____
____

with a copy to the Participant's Designated Representative.

Any other notices and communications pursuant to this Agreement shall be made by or to the Participant's Designated Representative, or alternate when appropriate, each as designated the Participant from time to time in accordance with the Bylaws of the Nutrient Exchange.

15. Netting of Payments. The Nutrient Exchange may, but shall not be obligated to, net any payments to the Participant for such Participant's sales of Credits or otherwise with any fees past due, other authorized charges past due, or charges for Credits purchased past due to the Nutrient Exchange.

16. Integration. This Agreement (including the Credit Exchange Policy incorporated herein by reference) contains the entire agreement between the Nutrient Exchange and the Participant as to the subject matter hereof and supercedes all previous written and oral negotiations, commitments, proposals and writings, including those of counsel. Except as

otherwise provided herein or in the Credit Exchange Policy, no amendments may be made except by a writing signed by the parties.

17. Change in Law. Other than as specifically provided in the Credit Exchange Policy, in the event of any material change in applicable laws or regulations the parties shall work together to amend the Agreement to conform to such change in law, while maintaining as closely as practical the provisions and intent of this Agreement.

18. Governing Law; Severability. This Agreement shall be construed in accordance with and governed for all purposes by the laws of the Commonwealth of Virginia. If any term or provision of this Agreement, the deletion of which would not adversely affect the receipt of a material benefit by either party hereunder, shall be held by a court of competent jurisdiction to be invalid or unenforceable, the remainder of this Agreement shall not be affected thereby and each other term and provision of this Agreement shall remain valid and enforceable to the fullest extent permitted by law. It is the intent of the parties to this Agreement, and the parties agree, that in lieu of any term or provision of this Agreement that is illegal, invalid or unenforceable, the parties in good faith shall supply as part of this Agreement a legal, valid and enforceable term or provision as similar to such illegal, invalid or unenforceable term or provision as may be possible.

IN WITNESS WHEREOF, the parties have caused the execution of this Agreement as of the date first written above.

VIRGINIA NUTRIENT CREDIT EXCHANGE ASSOCIATION, INC.

By: ______________________________

Name: ______________________________

Title: ______________________________

Date: ______________________________

____

PARTICIPANT NAME

By: ______________________________

Name: ______________________________

Title: ______________________________

Date: ______________________________

Appendix C

CREDIT EXCHANGE POLICY FOR THE PURCHASE AND SALE OF CHESAPEAKE BAY NUTRIENT CREDITS

ARTICLE I
PURPOSE

This Credit Exchange Policy (this "Policy") of the Virginia Nutrient Credit Exchange Association, Inc. (the "Nutrient Exchange") is adopted pursuant to Article VII of the Bylaws for the purpose of coordinating and facilitating the participation of its Members in Virginia's Chesapeake Bay Nutrient Credit Exchange Program established by Virginia Code section 62.1-44.19:12 *et seq*. Accordingly, this Policy is intended to provide a framework for the Exchange of Credits by and among the Members and, in addition to other benefits, to satisfy the standard requirement of Virginia Water Quality Improvement Fund Grant Agreements made pursuant to Virginia Code section 10.1-2117 *et seq*. that the grantee make available for Exchange any Credits remaining after complying with its Watershed General Permit limits.

ARTICLE II
DEFINITIONS

Unless otherwise defined below or a different meaning is intended by the usage herein, all terms shall have the same definition as provided in section 9 VAC 25-820-10 of the Watershed General Permit.

Actual Class B Credits – In the Reconciliation Year, the quantity of Credits remaining for the Permitted Facility after adjusting Actual Net Credits for Class A Credit purchases and sales for the immediately preceding Compliance Year. This quantity equals Actual Net Credits plus any Class A Credit purchases and minus any Class A Credit sales for the Compliance Year.

Actual Credits – Credits actually generated during the Compliance Year prior to adjusting for Preliminary Uses of Credits. Actual Credits equal Delivered WLA minus Actual Load.

Actual Load – The Delivered Load actually discharged during the Compliance Year for one or more Permitted Facilities.

Actual Net Credits – Actual Credits minus the quantity of Credits not available due to Preliminary Uses of Credits.

Board of Governors (or Board) – The board of directors of the Nutrient Exchange.

Buyer – A Participant that purchases Credits for a given Compliance Year.

Class A Buyer – A Participant that requests the availability of, and agrees in advance to purchase, a specific quantity of Credits in accordance with this Policy. Except as otherwise provided herein, a Class A Buyer is committed to purchasing its requested and agreed amount of Class A Credits, even if the Class A Buyer actually needs a lesser amount based on actual performance of its Permit Facility in a Compliance Year.

Class A Credits – Credits for which an agreement for sale and purchase in a specific quantity is made in advance in accordance with this Policy.

Class A Pledge – The quantity of Class A Credits that the Seller specifies and agrees to sell to the Nutrient Exchange as Class A Credits in accordance with this Policy.

Class A Seller – A Participant that agrees in advance to sell Class A Credits to the Nutrient Exchange in accordance with this Policy. Except as otherwise provided herein, a Class A Seller is responsible for making up any shortfall in its agreed amount of Class A Credits for a given Compliance Year and completing such sale.

Class B Credits – Credits for which no agreement for sale and purchase in a specific quantity is made in advance but which are pledged to the Nutrient Exchange in accordance with this Policy.

Clearing Account – An account of the Nutrient Exchange used for segregating funds from Credit Exchanges from other funds of the Nutrient Exchange.

Compliance Year – Any specific calendar year for which Exchanges are planned or executed.

Credit – Each pound of TN or TP by which the Expected Load (projections) or Delivered Load (actual) is less than the Delivered WLA for a Permitted Facility (or Permitted Facility Bubble). Note that while Credits can exist only in positive quantities, for planning and implementation purposes certain Credit-related values may be stated as negative quantities. For example, when a Permitted Facility's Expected Load is projected to exceed its Delivered WLA, the Plan will show a negative quantity of Expected Credits. Additional examples may include Expected Net Credits, Actual Credits, Actual Net Credits, and Actual Class B Credits.

Delivered WLA – The TN or TP WLA assigned to a Permitted Facility, either under the Water Quality Management Planning ("WQMP") Regulation (9 VAC 25-720) or otherwise, and adjusted by the applicable delivery factor under the Watershed General Permit and expressed as pounds per year.

Delivered Load – The TN or TP load discharged by a Permitted Facility during a Compliance Year, adjusted by the applicable delivery factor under the Watershed General Permit and expressed as pounds per year.

DEQ – The Virginia Department of Environmental Quality or, where appropriate, the State Water Control Board to which the Department serves as staff.

Designated Representative – A person who is a fulltime employee of, and is designated in writing by, the Participant to act on its behalf.

Exchange – The purchase and sale of a Credit of any class.

Exchange Compliance Plan (or P lan) – The plan submitted by the Nutrient Exchange to DEQ pursuant to 9 VAC 25-820-40 A as updated periodically pursuant to 9 VAC 25-820-40 B and 9 VAC 25-820-70 Part I D of the Watershed General Permit.

Exchange Compliance Plan Update (or Plan Update) – The update of the Exchange Compliance Plan required pursuant to 9 VAC 25-820-40 B and 9 VAC 25-820-70 Part I D of the Watershed General Permit.

Expected Class B Credits – The quantity of Credits projected to be remaining for a Permitted Facility after adjusting Expected Net Credits for Class A Credit sales for the current or any future Compliance Year. This quantity equals Expected Net Credits minus any Class A Credits committed by a Class A Seller for a Compliance Year.

Expected Load – The projected Delivered Load for a given Compliance Year for one or more Permitted Facilities.

Expected Credits – The amount of Credits projected for a given Compliance Year as determined by subtracting the Expected Load from the Delivered WLA.

Expected Net Credits – Expected Credits minus the quantity of Credits projected to not be available due to Preliminary Uses of Credits.

In-Bubble Exchange – A Preliminary Use of Credits consisting of Credit use by and among the Permitted Facilities within a Permitted Facility Bubble included in the Exchange Compliance Plan. In accordance with 9 VAC 25-820-70 Part I B 2 e of the Watershed General Permit, In-Bubble Exchanges are not Exchanges or credit acquisitions as described in 9 VAC 25-820-70 Part I J 2 of the Watershed General Permit.

Neutral Participant – A Participant which projects a positive quantity of Expected Net Credits for its Permitted Facility in a given Compliance Year, but which has not elected to be a Class A Seller for that Compliance Year.

Non-Participant – An owner or operator of a Permitted Facility that is not a Participant.

Participant – A Member owner or operator of a Permitted Facility included in the Exchange Compliance Plan which has executed the Nutrient Credit Services Agreement.

Permitted Facility – A facility authorized to discharge under the Watershed General Permit. The singular refers to the plural (Permitted Facilities) where appropriate. This term also refers to a Permitted Facility Bubble where appropriate.

Permitted Facility Bubble – Multiple Permitted Facilities under common ownership or operation that are subject to aggregated WLAs pursuant to 9 VAC 25-820-70 Part I B 2 of the Watershed General Permit.

Planning Period – The rolling five-year period covered by the Exchange Compliance Plan (or Plan Update) beginning with the year in which the Plan is due to be submitted to DEQ. For example, for the Exchange Compliance Plan 2008 Annual Update due and submitted to DEQ on February 1, 2008, the Planning Period is January 1, 2008 through and including December 31, 2012.

Preliminary Use of Credits – Any of the following three planned or actual uses of Credits: In-Bubble Exchange, Private Exchange, or WQIF-Held.

Private Exchange – A Preliminary Use of Credits consisting of an Exchange planned or executed directly between or among Participants or Non-Participants rather than through the Nutrient Exchange.

Reconciliation – The process for executing Exchanges for a Compliance Year.

Reconciliation Year – For each Compliance Year, the year immediately following during which time Exchanges for the Compliance Year are executed. For example, for Compliance Year 2011, the associated Reconciliation Year is 2012.

Seller – A Participant that supplies Credits for a given Compliance Year.

TN – Total nitrogen, a pollutant the discharge of which is authorized and limited under the Watershed General Permit.

TP – Total phosphorus, a pollutant the discharge of which is authorized and limited under the Watershed General Permit.

Watershed General Permit – The General Virginia Pollutant Discharge Elimination System Watershed Permit Regulation for Total Nitrogen and Total Phosphorus Discharges and Nutrient Trading in the Chesapeake Bay Watershed in Virginia (9 VAC 25-820) issued by the State Water Control Board effective for a five-year permit term beginning January 1, 2007 or as hereafter modified or reissued from time to time. Among other requirements, the Watershed General Permit imposes limitations on the discharge of TN and TP from Permitted Facilities (9 VAC 25-820-70 Part I B), and requires each permittee to submit to DEQ by August 1, 2007 and annually thereafter (currently by each February 1) a compliance plan (9 VAC 25-820-40), either individually or through the Nutrient Exchange, indicating how its facility(ies) will comply with such limitations.

WLA – A Wasteload Allocation for TN or TP as established under the Water Quality Management Planning Regulation, 9 VAC 25-720, and implemented through the Watershed General Permit. A WLA may be expressed in pounds per year as either a discharged WLA (*i.e.* end-of-pipe gross pounds) or as a Delivered WLA (*i.e.*, the discharged WLA multiplied by the delivery factor applicable to the Permitted Facility as specified in the Watershed General Permit).

WQIF-Held – Pursuant to 9 VAC 25-820-70 Part I J 2 e of the Watershed General Permit, a Preliminary Use of Credits which consists of setting aside and not using within the Plan certain Credits associated with Permitted Facilities (or a portion thereof) not yet constructed and in operation. Such Credits are held in the Water Quality Improvement Fund administered by DEQ.

ARTICLE III
GUIDING PRINCIPLES & GENERAL APPROACH

3.1 Guiding Principles. This Policy has been developed and is to be implemented in accordance with the following guiding principles adopted by the Nutrient Exchange:

(a) Guiding Principle No. 1: Environment First. The Nutrient Exchange, including its Exchange Compliance Plan and this Policy, is designed to ensure environmental protection first and foremost. Environmental protection is fostered by means of full compliance with the Watershed General Permit issued by DEQ.

(b) Guiding Principle No. 2: Voluntary Participation. Under governing laws and regulations, there is generally no requirement for a Permitted Facility to trade, *i.e.*, Exchange, Credits with any other person. Accordingly, the Nutrient Exchange, including its Exchange Compliance Plan and this Policy, is premised on the voluntary participation of Participants and their Permitted Facilities subject to applicable laws and regulations and the policies and procedures established by the Nutrient Exchange.

(c) Guiding Principle No. 3: Benefits for All. Consistent with the concept of voluntary participation, the Nutrient Exchange, including its Exchange Compliance Plan and this Policy, is designed with the intent of benefitting all Participants whether as a Buyer, Seller or Neutral.

(d) Guiding Principle No. 4: Remember the "Base Case." This principle is a reminder that the Nutrient Exchange is a first-of-its-kind undertaking with the potential to provide significant benefits including water quality improvement, regulatory flexibility, and economic efficiency compared to the traditional regulatory approach lacking a trading option, and that the Nutrient Exchange intends to operate with this potential for broad benefit in mind.

3.2 General Approach. This Policy is designed to meet the following goals and objectives for the establishment of a successful Exchange Program: (a) a highly-structured, well-planned program, (b) a convenient and reliable Credit Exchange mechanism, (c) a practical legal structure that promotes participation by maintaining a high degree of flexibility for Participants, and (d) a fair and effective pricing methodology.

ARTICLE IV
COMPLIANCE AND CREDIT EXCHANGE PLANNING

4.1 Participant-Driven Exchange Compliance Plan. The Nutrient Exchange has developed the Exchange Compliance Plan on behalf of the Participants for each of Virginia's five major river basins in accordance with the Watershed General Permit and intends to update the Plan annually by submittal of Plan Updates to DEQ. The Nutrient Exchange Compliance Plan is now and will continue to be based on the individual data provided by, and individual decisions made by, Participants with respect to their own Permitted Facilities, including revisions to relevant facility-specific information related to Class A Credit and Class B Credit Exchanges or other information, in accordance with the schedule at Attachment A and subject to acceptance by the Nutrient Exchange in accordance with this Policy and further subject to approval by DEQ.

4.2 Five-Year Planning Period. The Plan including any Plan Updates shall cover a rolling five-year Planning Period. For each Planning Period each of the following Plan elements shall be on a firm basis and may not be modified by a Participant except as provided in Section 4.8 (Modifications Within Planning Period): (a) Class A Credit sales and purchases once elected by a Participant, (b) the Class A Credit purchase price paid by a Class A Buyer (Attachment B), and (c) the Participant's commitment pursuant to Section 4.7 (Class B Credit Pledge) to provide to the Nutrient Exchange its Actual Class B Credits. With each Plan Update, Year 1 of the preceding Planning Period shall be dropped (except for purposes of Reconciliation), Year 2 through Year 5 of the preceding Planning Period (Year 1 through Year 4 of the Plan Update) shall remain unchanged with respect to the Plan elements stated in this Section as firm, and a new Year 5 shall be added based on data and information determined by each Participant with respect to its Permitted Facility. For example, in 2012, the Nutrient Exchange, in coordination with the Participants, will conduct the Reconciliation process for Compliance Year 2011 and update the five-year Plan to cover a Planning Period of 2012 through and including 2016, with the new fifth year (2016) based on data and information determined and submitted by each Participant with respect to its Permitted Facility. Without limiting the foregoing, it is nevertheless the intent of the Nutrient Exchange to accommodate through each Plan Update certain modifications related to firm elements of the Plan for the remaining four years of the Planning Period, whenever some or all of such modifications are determined by the Board in its discretion to be feasible and in the best interests of the Nutrient Exchange, as provided below in Section 4.8. Notwithstanding the foregoing provisions of this Section, if DEQ were to extend the schedule of compliance in Part I C 1 of the Watershed General Permit for any tributary (river basin) and parameter combination, the obligation of Participants to execute Exchanges of Credits for Permitted Facilities in such tributary (river basin) and for such parameter (TN or TP) as provided in the Exchange Compliance Plan shall be waived for each year prior to the first year for which compliance is required.

4.3 Annual Participant Data Update. The Nutrient Exchange may request and each Participant shall provide in a timely manner information necessary or useful for updating or otherwise administering the Plan. For purposes of Plan Updates, the Nutrient Exchange anticipates continuing to utilize a Facility Data Checklist. The most recent form of the Facility Data Checklist is attached as Attachment C and may be revised by the Nutrient Exchange from time to time. The Nutrient Exchange anticipates continuing to utilize a Compliance Deadline

Statement prior to the expiration of the schedule of compliance in Part I C 1 of the Watershed General Permit. The most recent form of the Compliance Deadline Statement is attached as Attachment D and may be revised by the Nutrient Exchange from time to time. With respect to the new fifth year of the Planning Period covered by each Plan Update, the Plan shall be based on data and information determined by the Participant during the Plan Update process. To meet applicable regulatory deadlines, Participants shall submit the requested data pursuant to the schedule at Attachment A, which may be revised by the Nutrient Exchange from time to time. Failure to meet submittal deadlines may result in omission of a Participant and its Permitted Facilities from the Plan at the discretion of the Nutrient Exchange.

4.4 Expected Net Credits. For each of its Permitted Facilities included in the Plan, the Participant will be responsible for specifying the Delivered WLA (established by regulation), Expected Load (derived from projected flow and concentration data provided by the Participant), Expected Credits, Preliminary Uses of Credits, and Expected Net Credits. Expected Net Credits is a planning figure only, and no Participant is obligated solely by its specification thereof to generate Credits in a quantity equal to or greater than the Expected Net Credits for the Planning Period.

4.5 Class A Credit Sale Obligations. Participants with Permitted Facilities projecting to generate a positive quantity of Expected Net Credits shall have the option to sell Class A Credits for a Compliance Year in the Planning Period at the premium Class A Credit price. Each such Participant shall specify its Class A Pledge as a quantity of Credits ranging from zero (0) up to the quantity of its Expected Net Credits for each year of the Planning Period, such quantity to be determined in the discretion of the Participant. Such specification shall be made for the full initial Planning Period and thereafter annually for the new fifth year of the five-year Planning Period. The Participant shall be obligated to provide to the Nutrient Exchange such quantity of Class A Credits. The specified quantity of Class A Credits shall be set forth in the Plan. Unless waived pursuant to section 5.10 (Waiver of Class A Credit Sales Obligation), the Participant agrees to sell such quantity of Credits to the Nutrient Exchange regardless of its Actual Net Credits (*i.e.*, a Class A Seller is responsible for making up any shortfall in its agreed amount of Class A Credits for a given Compliance Year and completing such sale). A Participant projecting to generate a positive quantity of Expected Net Credits but electing to make no firm Class A Credit sales obligation (*i.e.*, a Neutral Participant) shall specify a Class A Pledge of zero.

4.6 Class A Credit Purchase Obligations. For Permitted Facilities projecting Expected Net Credits in a negative quantity, to demonstrate a plan for compliance the Participant shall be obligated to purchase Credits in such quantity at the Class A Credit purchase price shown on Attachment B. For example, a Permitted Facility projecting in the 2008 Plan Update to have Expected Net Credits of TN of negative 500 for Compliance Year 2011 shall be obligated to purchase 500 TN Credits at the Class A Credit price in effect for 2011 ($2.00 per Credit). This transaction shall be executed during the Reconciliation Year at which time the Credits shall be transferred and the price shall be paid. The Exchange Compliance Plan shall plan to meet this projected demand addressed in this Section through Class A Credit sales obligations under Section 4.5 to the extent available; however, to the extent that sufficient Class A Credits are not available, the Plan may address this demand by means of Class B Credits pledged by Participants. The Credit prices paid by a Buyer as shown on Attachment B are firm for the Planning Period and shall be updated annually to include such price for the new fifth year of the Plan Update.

4.7 Class B Credit Pledge. By participating in the Exchange Compliance Plan, each Participant pledges one hundred percent of its Expected Class B Credits and agrees to transfer one hundred percent of its Actual Class B Credits from its Permitted Facilities to the Nutrient Exchange. The quantity of Expected Class B Credits is a projection only and it accommodates Preliminary Uses of Credits, including Private Exchanges planned and disclosed by the Participant in accordance with Section 4.9. Without limiting this pledge requirement, it is acknowledged and understood that Actual Class B Credits are anticipated to vary from the projection of Expected Class B Credits and that the Participant has no obligation to provide Actual Class B Credits in the same quantity as Expected Class B Credits, so long as the Participant transfers all of its Actual Class B Credits to the Nutrient Exchange. Among other purposes, it is the intent of this Section to enable Participants, which have entered into or will enter into a Virginia Water Quality Improvement Fund Grant Agreement with DEQ (*i.e.*, the owners of eligible municipal wastewater treatment plants) to satisfy the following standard provision of the typical grant agreement: "To aid in implementing the Nutrient Credit Exchange Program, the Grantee shall make all Point Source Nitrogen and Phosphorus Credits generated in a calendar year available for nutrient allocation compliance." It is also the intent of this Section to include as Actual Class B Credits those Credits not identified as Expected Class B Credits due to any Preliminary Use of Credits but which are in fact available for Exchange through the Nutrient Exchange during the Reconciliation.

4.8 Modifications Within Planning Period. Notwithstanding the firm commitments for Class A Credits and Class B Credits provided in this Article IV, it is the intent of the Nutrient Exchange to accommodate through each Plan Update requests for modifications affecting the firm elements of the previous Planning Period, provided that the Board determines, in its discretion, that such modification is not reasonably expected to have a material adverse effect on the Nutrient Exchange or its Participants. Consistent with the guiding principles described above, the fact that a modification would result in a decrease in funds from Credit sales shall not preclude the Board from determining that a modification would not have a material adverse effect. In the event of multiple competing modification requests, (i) requests of existing Participants shall have priority over requests of potential new Participants, and (ii) to the extent that it is not feasible to honor all modification requests of existing Participants, the Nutrient Exchange generally intends to address the requests of existing Participants on a pro rata basis with respect to Credits. In order to manage requests for modifications within the Planning Period efficiently and fairly, the Nutrient Exchange shall establish annually a date by which Participants shall submit such requests. The modifications requested by any Participant, if accommodated in the Plan Update in whole or in part, shall be binding on such Participant.

(a) Class A Credit Sale Obligations. Notwithstanding the firm basis of Class A Credit sale obligations, a Class A Seller may decrease its Class A Credit sale obligations through the Plan Update to the extent the Board determines that a sufficient supply of Class A Credits is projected to remain to meet the existing Class A Credit demand of the existing Class A Buyers, and the Board, in its discretion, may accommodate further decreases taking into consideration Expected Class B Credit projections. Any Participant may increase its Class A

Credit sale obligation so long as the resulting Class A Credit supply does not exceed Class A Credit demand.

(b) Class A Credit Purchase Obligations. Notwithstanding the firm basis of Class A Credit purchase obligations, a Class A Buyer may decrease its Class A Credit purchase obligations to the extent the Board determines that Class A Credit demand exceeds Class A Credit supply. Any Participant may increase its Class A Credit purchase obligation to the extent of Class A Credit supply, and the Board, in its discretion, may accommodate further increases taking into consideration Expected Class B Credit projections.

(c) Class B Credits. As provided above in Section 4.7, Expected Class B Credits is a projection only and the Participant's obligation with respect to Class B Credits is limited to providing its Actual Class B Credits to the Nutrient Exchange. Accordingly, through each Plan Update, the Participant at its discretion may modify its projection of Expected Class B Credits for each and every year of the five-year Planning Period covered by the Plan Update.

(d) New Participants. The Nutrient Exchange intends to consider the admission of new Participants depending on whether the Nutrient Exchange anticipates a surplus of Credits or projects a need for or desires additional Credits during the Planning Period. Admission of new Participants shall be at the discretion of the Board and generally subject to the following conditions. When the Plan indicates a surplus of Class A Credits, a new Participant may be included subject to the condition that it may not sell Class B Credits until Year 3 and Class A Credits until Year 5 of the Plan Update that first includes the new Participant. When the Plan indicates a need for additional Class A Credits, a new Participant may be included subject to the condition that it may not purchase Credits until Year 5 of the Plan Update that first includes the new participant. These conditions may be waived or modified in whole or in part by the Board in its discretion.

4.9. Private Exchanges. Sections 4.4 (Expected Net Credits) and 4.7 (Class B Credit Pledge) notwithstanding, to facilitate adequate planning each Participant shall provide reasonable advance notice to the Nutrient Exchange of all Private Exchanges to which it is or will be a party. Such notice shall be made by the deadline in Attachment A for submitting the Facility Data Checklist during the Plan Update process and shall be effective for any Private Exchange for the Compliance Year beginning the next January 1 following such notice (or for any subsequent Compliance Year). The notice shall be on a form to be provided by the Nutrient Exchange and shall identify all parties and the quantity of Credits subject to the Private Exchange. For example, if a Participant desires to enter into a new Private Exchange for Compliance Year 2011, under the current schedule at Attachment A notice would be required by November 1, 2010 and such Private Exchange would be included in the Plan Update covering the Planning Period of Compliance Years 2011 through 2015. Nothing in this Section 4.9 shall affect the firm commitment as to Class A Credit purchases and sales once made by a Participant.

4.10 DEQ Approval. The Nutrient Exchange's goal is to maintain the Exchange Compliance Plan in a manner and form that best serves its Participants and complies with the terms and conditions of the Watershed General Permit. In the event that DEQ were to disapprove a Plan Update in whole or in part, the Nutrient Exchange shall be responsible only for continuing to endeavor, in consultation with the Participants, to obtain DEQ approval pursuant to 9 VAC 25-820-40 B.

ARTICLE V
CREDIT EXCHANGE RECONCILIATION

5.1 Administration of and Participation in Reconciliation. Beginning in 2012 for Compliance Year 2011, the Nutrient Exchange will administer and the Participants will participate in an annual Reconciliation pursuant to the Plan and this Policy for the preceding Compliance Year.

5.2 Annual Permitted Facility Reports. In accordance with the schedule at Attachment A, each Participant shall annually submit to the Nutrient Exchange a copy of the Participant's Annual Report to DEQ required by Part I F of the Watershed General Permit and such other information as may be reasonably requested by the Nutrient Exchange in administering the Reconciliation.

5.3 Initial Reconciliation Report. In accordance with the schedule at Attachment A, the Nutrient Exchange will prepare and distribute to the Participants the Initial Reconciliation Report for the immediately preceding Compliance Year. On a Permitted Facility and river basin-level basis for all Participants, the report shall present in ledger format an accounting of the generation and transfer of Credits within the Nutrient Exchange and among its Participants. The report shall specify for each Permitted Facility its Delivered WLA, Actual Load, Actual Credits, Preliminary Uses of Credits, Actual Net Credits, Class A Credit sales and purchases, and Actual Class B Credits, Credit prices, charges to Buyers, and revenues to Sellers. As applicable, the report will reflect application of the policies and procedures in Sections 5.9 (Initial Upgrades), 5.10 (Waiver of Class A Credit Sales Obligation), 5.11 (Option to Purchase Additional Credits During Reconciliation), and 5.12 (Credit Shortfall Management Procedures).

5.4 Credit Exchanges and Confirmations. The transfer of Credits from Sellers to the Nutrient Exchange, and from the Nutrient Exchange to Buyers, shall be implemented as follows.

(a) Credit Transfers from Sellers. Each year beginning 2012 (or one year later for each year by which DEQ extends the schedule of compliance for any tributary (river basin) and parameter (TN or TP) combination beyond January 1, 2011), Participants shall transfer to the Nutrient Exchange in accordance with the Initial Reconciliation Report and the schedule at Attachment A (i) the quantity of Class A Credits to which they have committed as Sellers and (ii) the quantity of their Actual Class B Credits, if any. Such transfer shall be effective without further action by the Participant and shall be confirmed by the Participant through execution by its Designated Representative of, and submittal to the Nutrient Exchange of, the Seller's Credit Exchange Confirmation Form (Attachment E).

(b) Credit Transfers to Buyers. Each year beginning 2012 (or one year later for each year by which DEQ extends the schedule of compliance for any tributary (river basin) and parameter (TN or TP) combination beyond January 1, 2011), the Nutrient Exchange shall transfer to Buyers in accordance with the Initial Reconciliation Report and the schedule at Attachment A the quantity of Credits committed to and requested by such Buyers subject to the terms and limitations of this Policy. Such transfer shall be accomplished and confirmed by the Nutrient Exchange through execution and submittal to Buyers of the Buyer's Credit Exchange Confirmation Form (Attachment F). In addition, the Nutrient Exchange shall invoice each Buyer for Credit purchases in accordance with the schedule at Attachment A, and each Buyer shall pay such invoice within forty-five (45) days of the invoice date. Failure to pay such invoice within such time shall require payment by the Participant of an administrative charge of one hundred dollars ($100.00) plus ten percent (10%) of the amount of the invoice.

5.5 Sales of Surplus Credits to Non-Participants. For any Compliance Year and associated Reconciliation Year, for any river basin and parameter (TN or TP) combination, if the Nutrient Exchange has satisfied all of the needs for Credits for Participants as specified in the Exchange Compliance Plan or as otherwise requested by Participants for Watershed General Permit compliance purposes, and has remaining Credits, the Nutrient Exchange may sell such remaining Credits, in the discretion of the Board, to any Non-Participants requesting and committing to the purchase of such Credits subject to terms established by the Board in accordance with this Policy. The revenue from any Credit sales to Non-Participants or others shall be distributed to the Participants in the manner provided in Section 5.8.

5.6 Final Reconciliation Report. In accordance with the schedule at Attachment A, the Nutrient Exchange will prepare and distribute to the Participants the Final Reconciliation Report for the immediately preceding Compliance Year to reflect any adjustments subsequent to the Initial Reconciliation Report for sales of surplus Credits to Non-Participants or as otherwise may be appropriate.

5.7 Sources of Funds. The sources of funds for the Nutrient Exchange's purchase of Credits from Sellers shall be the funds paid by Buyers, the funds paid by any Non-Participants or others purchasing Credits through the Nutrient Exchange, and any other revenues accruing to the Nutrient Exchange that the Board designates for this purpose.

(a) Clearing Account. All such funds shall be segregated for accounting purposes from any other funds of the Nutrient Exchange in a Clearing Account for the purposes of holding prior to distribution and of distributing such funds to Sellers in the manner provided in this Policy.

(b) Prices Paid by Buyers and Non-Participants. The prices for Credits shall be (i) for Buyers of Credits in the quantities scheduled in the Plan as Class A Credit purchases the Class A Credit price on Attachment B, (ii) for Participants making additional Credit purchases beyond those scheduled in the Plan as Class A Credit purchases, the Class A Credit Price from Attachment A multiplied by a premium of 1.5, and (iii) for any Non-Participant or others for purchases as provided in Section 5.5, the Class A Credit Price from Attachment A multiplied by a premium which shall be established by the Board but which shall not be less than 2.0, unless the Board in its discretion determines that a lesser premium is in the best interests of the Nutrient Exchange and its Participants.

5.8 Disbursement of Funds to Sellers. The Nutrient Exchange shall disburse funds to Sellers from the Clearing Account as follows.

(a) Timing. Funds shall be disbursed to Sellers each Reconciliation Year in accordance with the schedule at Attachment A, or as soon thereafter as may be practical.

(b) Amounts Paid to Sellers. Ninety (90) percent of the amount in the Clearing Account and due to the Nutrient Exchange from Buyers for each Compliance Year in the Reconciliation Year shall be paid to the Class A Sellers, pro rata in proportion to the quantity of such Class A Credits transferred by each. The remaining ten (10) percent shall be paid to those Participants transferring Class B Credits to the Nutrient Exchange, pro rata as to the quantity of such Class B Credits transferred by each. However, if under the preceding calculation the amount paid by the Nutrient Exchange for each Class B Credit would exceed the amount paid by the Nutrient Exchange for each Class A Credit, the amount paid for Class A and Class B Credits shall be equal and shall be paid to Sellers pro rata in proportion to the quantity of Credits transferred by each.

(c) Clearing Account Shortfalls Due to Non-Payment of Buyers. To the extent that any Buyer or other purchaser of Credits from the Nutrient Exchange fails to remit to the Nutrient Exchange any amounts for Credits when due, and such shortfall interferes with the distribution of funds as provided herein, in addition to the administrative charge provided in Paragraph 5.4(b) the Board may in its discretion (i) invalidate the Credit transfer to the non-paying person(s) and redistribute such Credits as provided in this Policy, (ii) extend additional time for payment on such terms as the Board may determine, or (iii) take other actions in the best interests of the Nutrient Exchange and the Participants. In any such event, the Board may further in its discretion either delay payments otherwise provided for in this Section 5.8, or make partial payments, pro rata as provided herein, pending resolution of such matters.

5.9 Initial Upgrades. The Nutrient Exchange and the Participants acknowledge that for the initial Permitted Facility wastewater treatment upgrades necessary to implement the Exchange Compliance Plan for any river basin beginning January 1, 2011 (or such later initial year for compliance as DEQ may approve), the availability of engineering design services, the availability of construction services, availability of Water Quality Improvement Fund grant funds, extreme weather and other factors may make a Participant's provision and transfer to the Nutrient Exchange of Class A Credits impracticable and beyond the reasonable control of such Participant. In any case in which such transfer to the Nutrient Exchange of Class A Credits is determined by the Board in its discretion to be impracticable and beyond the reasonable control of such Participant, such not-at-fault Participant shall be relieved of its obligations for the transfer to the Nutrient Exchange of Class A Credits, but only the extent that such Credits are actually not available to such Participant and only for the period of time of the initial unavailability. Any resulting Credit shortfalls impacting the ability to supply Credits to Class A Buyers shall be managed in accordance with Section 5.12 (Credit Shortfall Management Procedures). In addition, the Nutrient Exchange shall request DEQ's concurrence that neither the not-at-fault Class A Seller(s) as defined in this Section 5.9 nor the not-at-fault waiting Buyer(s) will be deemed to be in noncompliance or subject to enforcement solely because of such circumstances and related Credit supply impacts.

5.10 Waiver of Class A Credit Sales Obligation. If during the Reconciliation Year sufficient Credits exist to meet the demands of all Participants for the Compliance Year, a Class A Seller's Class A Credit sales obligation shall be waived to the extent of its Class A Credit shortfall.

5.11 Option to Purchase Additional Credits During Reconciliation. If during the Reconciliation Year sufficient Credits exist to meet the demands of all Participants for the Compliance Year, after waivers of Class A Credit sale obligations pursuant to Section 5.10 any Participant desiring to purchase additional Credits for unanticipated needs (*i.e.*, Credits required beyond the Participant's Class A Credit purchases scheduled in the Exchange Compliance Plan) may purchase such Credits from the Nutrient Exchange at the premium price applicable to Participants as specified in Paragraph 5.7(b)(ii) to meet its Watershed General Permit compliance obligations.

5.12 Credit Shortfall Management Procedures.

(a) If insufficient Credits exist to meet the demands of all Participants, Class A Buyers shall have priority access to available Credits to the extent provided in this Paragraph 5.12(a). To the extent of the available Credits, Credits shall first be transferred to Class A Buyers in a quantity sufficient to satisfy either the amount of Credits scheduled as a Class A Credit purchase in the Exchange Compliance Plan for each Class A Buyer or the amount of Credits actually needed by the Class A Buyer to comply with its Delivered WLA, whichever is less for each Class A Buyer (its "Class A Shortfall Distribution Quantity"). Such distribution to Class A Buyers and any subsequent distribution to Participants shall be implemented in accordance with either Paragraph 5.12(b) or Paragraph 5.12(c), as appropriate.

(b) If the distribution of available Credits pursuant to Subparagraph 5.12(a) is insufficient to satisfy all Class A Buyers in the manner and to the extent provided in Subparagraph 5.12(a), the following procedure shall apply: (i) all available Credits will be distributed among the Class A Buyers pro rata in proportion to the Class A Shortfall Distribution Quantity of each, and (ii) all Class A Sellers that failed to generate and transfer all of the Class A Credits that such Sellers had agreed to provide pursuant to Section 4.5 of this Policy and scheduled in the Plan shall make up their allocable share of any remaining shortfall of Class A Credits to the extent required to meet the total Class A Shortfall Distribution Quantity of all Class A Buyers, pro rata in proportion to each such Class A Seller's Class A Credit sales shortfall, by acquiring Credits from outside of the Nutrient Exchange, from the Water Quality Improvement Fund administered by DEQ, or as otherwise allowed under applicable law.

(c) If the distribution of available Credits pursuant to Subparagraph 5.12(a) is sufficient to satisfy all Class A Buyers in the manner and to the extent provided in Subparagraph 5.12(a), any remaining Credits shall be transferred in equal shares to all Participants who desire such Credits; provided, however, that no Participant may purchase more Credits than required for compliance of its Permitted Facility under the Watershed General Permit. Each Participant with a remaining need for Credits thereafter shall be solely responsible for acquiring sufficient additional Credits from outside of the Nutrient Exchange, from the Water Quality Improvement Fund administered by DEQ, or as otherwise allowed under applicable law.

(d) In the discretion of the Board, the Nutrient Exchange may assist the Participants in acquiring sufficient additional Credits from outside of the Nutrient Exchange, from the Water Quality Improvement Fund administered by DEQ, or as otherwise allowed under applicable law; however, the Nutrient Exchange shall have no liability whatsoever for or related to a Credit shortfall regardless of the cause thereof.

ARTICLE VI
MISCELLANEOUS PROVISIONS

6.1 Amendments. This Policy may be amended from time to time in accordance with Article VII of the Bylaws.

6.2 Administrative Obligations. As a condition of continuing participation and without limiting any other provision of this Policy, each Participant shall (a) execute and comply with terms of the Nutrient Credit Services Agreement; (b) pay any applicable fees in a timely manner, and (c) pay its Credit purchase costs as provided herein in a timely manner.

6.3 Compliance with Watershed General Permit; Exchange Not Liable. Each Participant shall remain responsible for ensuring its own compliance with the Watershed General Permit. Neither the Nutrient Exchange, nor its officers, governors (directors), technical consultants or other advisors shall be responsible for assuring an adequate supply of Credits or for any other costs or damages of any kind related in any way to the operation of the Nutrient Exchange, including consequential damages.

6.4 No Waiver. No failure to exercise, and no delay in exercising, any right, power or privilege under this Policy by the Nutrient Exchange shall operate as a waiver, nor shall any single or partial exercise of any right, power or privilege hereunder preclude the exercise of any other right, power or privilege. No waiver by the Nutrient Exchange of any breach of any provision shall be deemed to be a waiver of any preceding or succeeding breach of the same or any other provision, nor shall any waiver be implied from any course of dealing.

ATTACHMENTS

A Annual Schedule for Plan Update and Reconciliation Processes
B Credit Price Schedule
C Facility Data Checklist
D Compliance Deadline Statement
E Seller’s Credit Exchange Confirmation Form
F Buyer’s Credit Exchange Confirmation Form

ATTACHMENT A

ANNUAL SCHEDULE

Action	**Deadline**	**Party Responsible**	**Policy Section(s)**
Submit Class A Credit Sale/Purchase Obligation Change Requests (OPTIONAL) (only for changes proposed to current Planning Period, not for new Year 5)	Sept. 1	Participant	4.8
Submit Facility Data Checklist (Attachment C) for Plan Update Development	Sept. 1	Participant	4.3
Submit Annual Report to Nutrient Exchange (and DEQ per 9 VAC 25-820-70 Part I F)	Feb. 1	Participant	5.2
Submit Exchange Compliance Plan Update to DEQ	Feb. 1	Exchange	4.1, 4.10
Prepare Initial Reconciliation Report	Mar. 7	Exchange	5.3
Distribute Credit Exchange Confirmation Forms to Sellers	Mar. 15	Exchange	5.4(a)
Distribute Invoices to Buyers	Mar. 15	Exchange	5.4(b)
Submit Credit Exchange Confirmation Forms to Nutrient Exchange	April 15	Sellers	5.4(a)
Invoice Payments Due from Buyers	May 1	Buyers	5.4(b), 5.7
Distribute Signed Credit Exchange Confirmation Forms to Buyers	May 20	Exchange	5.5(b)
Certify Credit Purchases to DEQ (9 VAC 25-820-70 Part J 2 f)	June 1	Buyers	N/A
Prepare Final Reconciliation Report	June 15	Exchange	5.4
Disbursement of Funds to Participants for Credit Sales	Aug. 1	Exchange	5.8

<u>**ATTACHMENT B**</u>

CREDIT PRICE SCHEDULE

Compliance Year	**Reconciliation Year**	**Class A Credit Purchase Price ($/Credit)**		**Price Status (Firm or Estimate)**
		Nitrogen	***Phosphorus***	
2011	2012	$2.00	$4.00	Firm
2012	2013	$2.00	$4.00	Firm
2013	2014	$2.15	$4.30	Firm
2014	2015	$2.65	$4.60	Firm
2015	2016	$3.05	$4.93	Firm
2016	2017	$3.50	$5.27	Firm
2017	2018	$3.75	$5.65	Firm
2018	2019	$3.78	$5.70	Firm
2019	2020	$3.82	$5.76	Firm

Participant (Owner) Name: ______________________

Facility Name: ______________________

Designated Representative (or Alternate) Name: ______________________

Contact Phone: ______________________

Contact Email: ______________________

After completing the checklist, please save the file according to the following format: Participant Name-Facility Name dd-mm-year (where date in file name is date of email submittal) and email back to Cody Stanger, **cstanger@grg-ltd.com** (**NEW EMAIL**, note only one 'r' in last name)

(please enter information only in cells with blue text)

NITROGEN Data Checklist	New 5th Year	Es imates Beyond 5-year Planning Period		
	2019	**2020**	**2021**	**2022**
Projected Flow (mgd)	0.00	0.00	0.00	0.00
Projected mg/L (avg. annual)	0.00	0.00	0.00	0.00
End-of-Pipe Pounds	0	0	0	0
Delivery Factor[1]	0.00	0.00	0.00	0.00
Delivered Pounds	0	0	0	0
Delivered WLA[1]	0	0	0	0
Expected Credits	0	0	0	0
Adjustments In (Out)[2]	0	0	0	0
Net Expected Credits	0	0	0	0
Class A Sales (Purchases)[3]	**0**	**0**	**0**	**0**
Expected Class B Credits	*0*	*0*	*0*	*0*
Class A Purchase Price ($/lb)	$ 3.82			
Facility Class A Purchase Cost[5]	**$ -**			

PHOSPHORUS Data Checklist	New 5th Year	Estimates Beyond 5-year Planning Period		
	2019	**2020**	**2021**	**2022**
Projected Flow (mgd)[4]	0.00	0.00	0.00	0.00
Projected mg/L (avg. annual)	0.00	0.00	0.00	0.00
End-of-Pipe Pounds	0	0	0	0
Delivery Factor[1]	0.00	0.00	0.00	0.00
Delivered Pounds	0	0	0	0
Delivered WLA[1]	0	0	0	0
Expected Credits	0	0	0	0
Adjustments In (Out)	0	0	0	0
Net Expected Credits	0	0	0	0
Class A Sales (Purchases)	**0**	**0**	**0**	**0**
Expected Class B Credits	*0*	*0*	*0*	*0*
Class A Purchase Price ($/lb)	$ 5.76			
Facility Class A Purchase Cost[5]	**$ -**			

1 - Facility-specific Delivery Factors and Delivered WLAs as shown on DEQ's revised Watershed General Permit Registration List

2 - Adjustments include either positive or negative Credit amounts that reflect Private Exchanges, Bubble Exchanges, or WQIF-held Credits

3 - If showing positive value for Net Expected Credits, enter the number of Class A Credits committed for sale (enter 0 if no Class A Credits are committed for sale).

3 - If showing negative value for Net Expected Credits, enter the same value in this row to indicate Class A Credit purchase commitment (consistent with Credit Exchange Policy).

4 - Projected flows for the Phosphorus Credit forecast are set equal to those used to generate the Nitrogen Credit forecast

5 - Represents the total purchase cost to the facility (regardless of actual Credit need) based on the Credit purchase forecast and corresponding Class A purchase price

ATTACHMENT D

COMPLIANCE STATEMENT FOR FACILITIES SUBJECT TO REDUCED WASTELOAD ALLOCATIONS IN CHESAPEAKE BAY TMDL

Facility (Or Owner Bubble) Name: ____

Check One:
_____ James River TN Compliance
_____ York River TP Compliance

Compliance Information Required by 9 VAC 25-820-40 A 2 (Check Option 1 or Option 2)

_____ Option 1 (9 VAC 25-820-40 A 2 b): Permittee hereby requests WLA to be effective as of January 1, 2012.

_____ Option 2 (9 VAC 25-820-40 A 2 a): Additional capital project(s) is needed to ensure continued compliance with the WLA through the applicable compliance schedule deadline for the tributary. (Note: Checking Option 2 does not preclude use of credit purchase as means of compliance under II.B.)

If Option 2 is checked, briefly describe need for additional projects:
____
____
____

Implementation Schedule

1. Does permittee anticipate using credit purchase to comply?
   _____ NO _____ YES

2. Is permittee implementing a capital project to comply?
   _____ NO _____ YES
   (If YES, compliance is required as soon as possible but no later than the applicable tributary compliance schedule deadline.)

3. Capital Project Milestone Schedule (Specify estimated date for each milestone. For bubbles, specify facility name(s) and list multiple facility schedules if applicable.)

   Engineer selection ____________________
   PER/CER to DEQ ____________________
   Plans & Specifications to DEQ ____________________
   Commence construction ____________________
   Complete construction ____________________
   CTO Request to DEQ (POTWs only) ____________________

ATTACHMENT E

SELLER'S CREDIT EXCHANGE CONFIRMATION FORM
COMPLIANCE YEAR 20__

The execution of this Credit Exchange Confirmation Form confirms a Credit Transfer from the Participant to the Nutrient Exchange pursuant to the Section 5.4(a) of the Credit Exchange Policy of the Nutrient Exchange. Capitalized terms have the meanings provided in the Credit Exchange Policy.

In accordance with the provisions of and subject to the terms and limitations of the Credit Exchange Policy and the Nutrient Credit Services Agreement, the undersigned Participant hereby:

1. Acknowledges receipt of the Initial Reconciliation Report dated _____________.

2. Confirms and represents that the Initial Reconciliation Report correctly states for its Permitted Facility(ies) in the Exchange Compliance Plan the amounts of Class A Credits of TN and TP and Class B Credits of TN and TP transferred to the Nutrient Exchange.

3. Acknowledges and confirms the transfer of such Credits in such amounts to the Nutrient Exchange.

To be completed by Participant:

Participant Name (Organization): ___________________________________

Designated Representative (Print): ___________________________________

Designated Representative Signature: ___________________________________

Date: ___________________________________

No later than April 15 submit the signed original form to:
Virginia Nutrient Credit Exchange Association, Inc.
ATTN: Secretary
P.O. Box 51
Richmond, VA 23218-0051

ATTACHMENT F

BUYER'S CREDIT EXCHANGE CONFIRMATION FORM

The execution of this Credit Exchange Confirmation Form confirms a Credit Transfer to the Participant from the Nutrient Exchange pursuant to the Section 5.4(b) of the Credit Exchange Policy of the Nutrient Exchange. Capitalized terms have the meanings provided in the Credit Exchange Policy.

In accordance with the provisions of and subject to the terms and limitations of the Credit Exchange Policy and the Nutrient Credit Services Agreement, the Nutrient Exchange hereby transfers to the Participant identified herein the following amounts of Credits of TN and TP:

Participant Name (Organization): ____________________________________

River Basin (One Per Form): ____________________________________

Compliance Year: ____________________________________

TN Credits (Pounds): ____________________________________

TP Credits (Pounds): ____________________________________

VIRGINIA NUTRIENT CREDIT EXCHANGE ASSOCIATION, INC.

By: ____________________________________

Title: ____________________________________

Date: ____________________________________

For convenience, the next page of this form made be used, subject to DEQ's approval, by the Participant to make its required certification of credit acquisition to DEQ.

ATTACHMENT __

BUYER'S CREDIT EXCHANGE NOTIFICATION TO DEQ PURSUANT TO PART I J 2 f OF THE GENERAL PERMIT FOR TOTAL NITROGEN AND TOTAL PHOSPHORUS DISCHARGES AND NUTRIENT TRADING IN THE CHESAPEAKE BAY WATERSHED IN VIRGINIA 9 VAC 25-820-70

General Permit Registration No.: _______________________________________

Permittee Name: _______________________________________

Pursuant to Part I J 2 f of the Watershed General Permit, the above-named Permittee, a Participant in the Virginia Nutrient Credit Exchange Association, Inc., hereby certifies that it has acquired sufficient Credits to satisfy its compliance obligations. The Credit Exchange Confirmation Form on the reverse side of this notification form documents the quantity of Credits of TN and TP transferred from the Nutrient Exchange to the Participant for the Compliance Year.

I certify under penalty of law that this notification and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Principal Executive Officer
or Authorized Agent: _______________________________________

Typed or Printed Name: _______________________________________

Signature: _______________________________________

Area Code/Phone Number: _______________________________________

Date: _______________________________________

Appendix D

Memorandum of Understanding

Between

The Freshwater Trust and the Oregon Watershed Enhancement Board

PARTIES:

The Memorandum of Understanding (MOU) is hereby entered into by and between The Freshwater Trust ("TFT") and the Oregon Watershed Enhancement Board ("OWEB") (collectively, the "Parties").

PURPOSE AND SCOPE:

The purpose of this MOU is to articulate the Parties' intent to enter into a collaboration to demonstrate and test the ability of ecosystem service market-based infrastructure to quantify, track and monitor outcomes from voluntary restoration actions supported with public funds.

RECITALS:

1) TFT is an Oregon non-profit organization whose mission is to actively work to preserve and restore freshwater ecosystems. TFT is a private conservation organization that is developing contracts with regulated entities (e.g., National Pollutant Discharge Elimination System ("NPDES") permit holders regulated under the Clean Water Act) and conservation buyers to complete riparian restoration projects that produce quantified outcomes using Willamette Partnership's "Counting on the Environment" ("COTE") ecosystem service crediting standards. TFT has nearly 30 years of restoration experience in Oregon and is a national leader in the development workable transaction models for ecosystem services.
2) OWEB is an Oregon state agency whose mission is to help protect and restore healthy watersheds and natural habitats that support thriving communities and strong economies. OWEB is a leader in the conservation of Oregon's natural resources and enjoys strong public support for its contributions to community-based conservation, watershed health, and local economies. OWEB has long supported innovative strategies for habitat restoration and conservation.

WHEREAS, TFT secured $966,722 in funding from the Natural Resources Conservation Service ("NRCS") Conservation Innovation Grant Program to support the "Northwest Environmental Markets Initiative: Applying Proven Market Tools to Benefit Rural Communities and Farmers" proposal; and

WHEREAS, OWEB has initiated a Willamette Basin Ecosystem Services Project to test the ability to measure and track restoration outcomes—in the form of improvements to ecosystem processes and functions—through time by applying ecosystem services metrics, and explore the potential for private funding for restoration to complement awards made by OWEB and other public entities; and

WHEREAS, at its March 2010 Board meeting, the OWEB Board supported OWEB's participation in this collaboration by providing matching funds of up to $400,000 for the purchase of eligible, completed restoration projects with quantified ecological outcomes and the associated ecosystem service credits resulting from these projects, conducted within the Willamette Model Watershed Program framework of the Willamette Special Investment Partnership; and

WHEREAS, the Parties have agreed to enter into a collaboration to conduct this demonstration and test of ecosystem service market-based infrastructure using measurement, tracking and transaction protocols for thermal load reductions (i.e., shading) and, to the maximum extent practicable, nutrient reductions resulting from riparian restoration projects.

IT IS MUTUALLY AGREED AND UNDERSTOOD BY THE PARTIES THAT:

1) TFT will secure private capital to finance riparian restoration projects that meet the rigorous COTE standards in terms of site selection, baseline assessment, credit calculation, verification and registration activities.
2) TFT will use private funds to initiate, plan, implement, monitor and maintain riparian restoration projects in the Willamette Basin for a 20-year term, in conjunction with local restoration practitioners such as watershed councils and/or soil and watershed conservation districts, among others. TFT agrees that project development will begin immediately, with implementation of restoration projects to commence on or before May of 2013 and project completion scheduled on or before June of 2015, contingent upon execution of the formal grant agreement(s) referenced in Paragraphs 4 and 9.
3) OWEB agrees to the future purchase of restoration outcomes, in the form of completed restoration projects and associated ecosystem services credits, generated by TFT under the COTE protocols in the mutually agreed-upon service area specified.
4) OWEB will use subsequent grant agreements to provide funding for purchases of up to $400,000 worth of measured restoration outcomes emerging from these completed restoration projects and associated ecosystem service credits certified as meeting Version 1.1 COTE standards for thermal reductions and, to the maximum extent practicable, nutrient reductions.
5) Completed restoration projects and associated ecosystem service credits purchased by OWEB will be registered on an ecosystem service credit registry and immediately retired for conservation purposes, thus making them unavailable for sale or use for any compliance purpose in the future.
6) OWEB will assist TFT in outreach to Model Watershed Program coordinators to better identify projects for use in this pilot.
7) TFT will provide periodic progress reports and presentations to OWEB Board and staff to share updates about and findings from the Willamette Basin Ecosystem Services Project and the larger NRCS-funded Northwest Environmental Markets Initiative project.
8) The Parties agree to collaborate for the length of this partnership to demonstrate and test the market based model for the purchase of restoration outcomes from completed restoration projects, with the intent of testing the functionality and application of the infrastructure, protocols and procedures therein.

9) This MOU will become effective upon signature of TFT and OWEB and shall remain in effect until June 30, 2015. This memorandum can be modified or terminated at any time by mutual consent of the parties thereto, or can be terminated in whole, or in part by either party alone by giving 30-day notice in writing to the other. Formal grant agreement(s) with final terms will be executed by the Parties prior to TFT invoicing OWEB for completed restoration projects and associated ecosystem service credits.

AGREED:

By ____________________
Joe Whitworth, President
The Freshwater Trust

Date 4.2.2012

By ____________________
Tom Byler, Executive Director
Oregon Watershed Enhancement Board

Date 3/21/12

APPENDIX: Overview of Ecosystem Credit Accounting -- Pilot General Crediting Protocol: Willamette Basin Version 1.1

Appendix E

State of Wisconsin
Department of Natural Resources
101 South Webster Street
Madison, WI 53707

Notice of Intent to Conduct Water Quality Trading

Form 8700-nnn (R10/12)

Notice: Any personally identifiable information submitted on this form will be used for program purposes only, but is available for inspection and copying under Wisconsin's public records laws. This form should be completed by any permittee that intends to pursue pollutant trading as a method for complying with a permit limitation. Failure to complete this form would not result in penalties.

Applicant Information					
Permittee Name	Permit Number **WI-**		Facility Site Number		
Facility Address		City		State	ZIP Code
Project Contact Name(if applicable)	*Address*	*City*		*State*	*Zip Code*
Project Name					
Receiving Water Name	Parameter(s) being traded		HUC 12(s)		
Is the permittee in a point or nonpoint source dominated watershed? *(See PRESTO results- http://dnr.wi.gov/topic/surfacewater/presto.html)*		☐ Point source dominated ☐ Nonpoint source dominated			

Credit Generator Information		
Credit generator type (check all that apply):	☐ Permitted Discharge (non-MS4) ☐ Permitted MS4 ☐ Permitted CAFO	☐ Non-permitted urban discharge ☐ Agricultural nonpoint source discharge ☐ Other- Specify: ______________
Are any of the credit generators in a different HUC 12 than the applicant?	☐ Yes; HUC 12: ______________ ☐ No ☐ Unsure	
Are any of the credit generators downstream of the applicant?	☐ Yes ☐ No ☐ Unsure	

Will a broker/exchange be used to facilitate trade?	☐ Yes; Name: ____________________ ☐ No ☐ Unsure

Point to Point Trades (Traditional Municipal/Industrial Discharge, MS4, CAFO):

Discharge Type	Permit Number	Name	Contact Address	Is the PS currently in compliance with their permit requirements?
☐ Traditional ☐ MS4 ☐ CAFO				☐ Yes ☐ Unsure ☐ No
☐ Traditional ☐ MS4 ☐ CAFO				☐ Yes ☐ Unsure ☐ No
☐ Traditional ☐ MS4 ☐ CAFO				☐ Yes ☐ Unsure ☐ No
☐ Traditional ☐ MS4 ☐ CAFO				☐ Yes ☐ Unsure ☐ No
☐ Traditional ☐ MS4 ☐ CAFO				☐ Yes ☐ Unsure ☐ No

Point to Nonpoint Trades (Agricultural, Non-Permitted Urban, etc.):

Check all practices that will be used to generate credits:

Method for quantifying credits generated: ☐ Monitoring
☐ Modeling, Names: ____________________
☐ Other: ____________________

Projected date credits will be available:

The preparer certify all of the following:	
• I am familiar with the specifications submitted for this application, and I believe all applicable items in this checklist have been addressed. • I have completed this document to the best of my knowledge and have not excluded pertinent information.	
Signature of Preparer	Date Signed

Authorized Representative Signature:	
I certify under penalty of law that this document and all attachments were prepared under my direction or supervision. Based on my inquiry of those persons directly responsible for gathering and entering the information, the information is, to the best of my knowledge and belief, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.	
Signature of Authorized Representative	Date Signed

NOTE: The *Authorized Representative* is someone who is authorized to sign all applications, reports or other information submitted to the DNR. This person may be; for a corporation, a responsible corporate officer including a president, secretary, treasurer, vice president or manager; and for a municipality, a ranking elected official; for a corporation or a municipality, another person authorized by one of those officers or officials and who has responsibility for the overall operation of the facility or activity regulated by the permit. This is the person to whom we will send information regarding the application, the draft permit and permit reissuance.

Water Quality Trading Checklist

State of Wisconsin
Department of Natural Resources
101 South Webster Street
Madison, WI 53707

Water Quality Trading Checklist
Form 8700-nnn (R10/12)

Notice: Any personally identifiable information submitted on this form will be used for program purposes only, but is available for inspection and copying under Wisconsin's public records laws. This form should be completed by any permittee that intends to pursue pollutant trading as a method for complying with a permit limitation. Failure to complete this form would not result in penalties.

Applicant Information

Permittee Name	Permit Number **WI-**	Facility Site Number

Facility Address	City	State	ZIP Code

Project Contact Name(if applicable)	*Address*	*City*	*State*	*Zip Code*

Project Name

Receiving Water Name	Parameter(s) being traded	HUC 12(s)

Credit Generator Information

Credit generator type (check all that apply):
- ☐ Permitted Discharge (non-MS4)
- ☐ Permitted MS4
- ☐ CAFOs
- ☐ Non-permitted urban discharge
- ☐ Agricultural nonpoint source discharge
- ☐ Other- Specify: ____________________

Are any of the credit generators in a different HUC 12 than the applicant? ☐ Yes; HUC 12: ____________________ ☐ No

Are any of the credit generators downstream of the applicant? ☐ Yes ☐ No

Was a broker/exchange be used to facilitate trade? ☐ Yes *(include description and contact information in WQT plan)* ☐ No

Point to Point Trades (Traditional Municipal/Industrial Discharge, MS4, CAFO):

Are each of the point sources identified in this section are in compliance with their WDPES permit requirements? ☐ Yes ☐ No

Discharge Type	Permit Number	Name	Contact Information	Trade Agreement Number
☐ Traditional ☐ MS4 ☐ CAFO				
☐ Traditional ☐ MS4 ☐ CAFO				
☐ Traditional ☐ MS4 ☐ CAFO				

☐ Traditional ☐ MS4 ☐ CAFO				
☐ Traditional ☐ MS4 ☐ CAFO				

Does plan have a narrative that describes:				Plan Section
a.	Summary of discharge and existing treatment including optimization	☐ Yes	☐ No	
b.	Amount of credit being generated	☐ Yes	☐ No	
c.	Timeline for credits and agreements	☐ Yes	☐ No	
d.	Method for quantifying credits	☐ Yes	☐ No	
e.	Tracking and verification procedures	☐ Yes	☐ No	
f.	Location of credit generator in proximity to receiving water and credit user	☐ Yes	☐ No	
g.	Other: ___________________________________	☐ Yes	☐ No	

Point to Nonpoint Trades (Non-permitted urban, agricultural, other):

Type	Practices Used to Generate Credits	Method of Quantification	Trade Agreement Number	Have the practice(s) been formally registered?
☐ Urban NPS ☐ Agricultural NPS ☐ Other				☐ Yes ☐ No ☐ Only in part
☐ Urban NPS ☐ Agricultural NPS ☐ Other				☐ Yes ☐ No ☐ Only in part
☐ Urban NPS ☐ Agricultural NPS ☐ Other				☐ Yes ☐ No ☐ Only in part
☐ Urban NPS ☐ Agricultural NPS ☐ Other				☐ Yes ☐ No ☐ Only in part
☐ Urban NPS ☐ Agricultural NPS ☐ Other				☐ Yes ☐ No ☐ Only in part
☐ Urban NPS ☐ Agricultural NPS ☐ Other				☐ Yes ☐ No ☐ Only in part
☐ Urban NPS ☐ Agricultural NPS ☐ Other				☐ Yes ☐ No ☐ Only in part

☐ Urban NPS ☐ Agricultural NPS ☐ Other				☐ Yes ☐ No ☐ Only in part

Does plan have a narrative that describes:				Plan Section
a.	Description of existing land uses	☐ Yes	☐ No	
b.	Management practices used to generate credits	☐ Yes	☐ No	
c.	Amount of credit being generated	☐ Yes	☐ No	
d.	Description of applicable trade ratio per agreement/management practice	☐ Yes	☐ No	
e.	Location where credits will be generated	☐ Yes	☐ No	
f.	Timeline for credits and agreements	☐ Yes	☐ No	
g.	Method for quantifying credits	☐ Yes	☐ No	
h.	Tracking procedures	☐ Yes	☐ No	
i.	Conditions under which the management practices may be inspected	☐ Yes	☐ No	
j.	Reporting requirements should the management practice fail	☐ Yes	☐ No	
k.	Operation and maintenance plan for each management practice	☐ Yes	☐ No	
l.	Location of credit generator in proximity to receiving water and credit user	☐ Yes	☐ No	
m.	Practice registration documents, if available	☐ Yes	☐ No	
n.	History of project site(s)	☐ Yes	☐ No	
o.	Other: ______________________________	☐ Yes	☐ No	

The preparer and owner certify all of the following:

- I am familiar with the specifications submitted for this application, and I believe all applicable items in this checklist have been addressed.
- I have completed this document to the best of my knowledge and have not excluded pertinent information.
- I certify that the information in this document is true to the best of my knowledge.

Signature of Preparer	Date Signed

Authorized Representative Signature:

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision. Based on my inquiry of those persons directly responsible for gathering and entering the information, the information is, to the best of my knowledge and belief, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Signature of Authorized Representative	Date Signed

NOTE: The *Authorized Representative* is someone who is authorized to sign all applications, reports or other information submitted to the DNR. This person may be; for a corporation, a responsible corporate officer including a president, secretary, treasurer, vice president or manager; and for a municipality, a ranking elected official; for a corporation or a municipality, another person authorized by one of those officers or officials and who has responsibility for the overall operation of the facility or activity regulated by the permit. This is the person to whom we will send information regarding the application, the draft permit and permit reissuance.

Appendix F

Example Trade Agreement for Point to Point Source Trades

Notice

This is an example agreement and should be amended to meet the needs and conditions of the specific agreement. The Department does not require final trade agreements to be submitted with the trading plan. However, these documents must be presented upon request by the Department.

Credit User Information

Credit User Name (Permittee)	Credit User Permit Number **WI-**	Trade Agreement Number

Credit User Address	City	State	ZIP Code

Project Name

Credit User Receiving Water Name	HUC 12

Project Name

Credit Generator Information

Credit Generator Name (Permittee)	Credit User Permit Number **WI-**

Street Address	City	State	ZIP Code

Credit Generator Receiving Water Name	HUC 12

Method for Generating Credit

Pollutant Trade Agreement

The property described above is enrolled in a Water Quality Trade Agreement. Funds are provided to the credit generator in return for pollution credit generated from the installation, operation and maintenance of treatment technology. This agreement commits the credit generator to agree to, and comply with, more restrictive permit requirements so that credits are available for trading.

Credit Generator's applicable limit (TBEL, WQBEL, or TMDL-derived limit) prior to trade:

applicable limit post trade:

Credit Generator's applicable limit (TBEL, WQBEL, or TMDL-derived limit) prior to trade:

applicable limit post trade:

Pollutant	Quantity being Traded	Cost per Unit (including O & M)	Estimated Total Cost	Total Financial Reimbursement	Estimated Date Credits will be Available

Section A – General Requirements
Example:
A 1. This agreement may be amended by mutual agreement of either party, so long as the agreement has not yet expired.
A 2. This agreement is effective from the date signed by all parties through the end date of the permit terms.

Section B – Credit Generator Shall:
Example:
B 1. Design, install, operate and maintain treatment to comply with permit requirements consistent with this trade agreement.
B 2. Report treatment failures in a timely matter to WDNR and the credit user.

Section C – Grantee Shall:
Example:
C 1. Provide cost sharing to the credit generator consistent with this agreement.
C 2. Make cost-share payments to the credit generator upon permit reissuance once the credit generator's permit has been modified to reflect the trade.

TA Number	Typed Name of Credit Generator	Initials of Credit Generator	Date

Credit Generator

Signed this ______________________ day of ____________________________________, 20 _____.

____
Signature of Authorized Representative of Credit Generator

____
Typed Name of Authorized Representative of Credit Generator

STATE OF WISCONSIN)
) ss.
________________ County)

Personally came before me this _________ day of ________________________, 20 _____.

The above named ____ to me known to be the person(s) who executed the foregoing instrument and acknowledge the same.

_________________________ Signature of Notary Public

_________________________ Typed Name of Notary Public

Notary Public ________________________ County, Wisconsin

My commission (is permanent) (expires _________________).

Credit User

Signed this ______________________ day of ____________________________________, 20 _____.

____
Signature of Authorized Representative of Credit User

____
Typed Name of Authorized Representative of Credit User

STATE OF WISCONSIN)
) ss.
________________ County)

Personally came before me this _________ day of ________________________, 20 _____.

The above named ____ to me known to be the person(s) who executed the foregoing instrument and acknowledge the same.

_________________________ Signature of Notary Public

Notary Public ________________________ County, Wisconsin

My commission (is permanent) (expires _________________).

Other Signer- Specify title or relationship: ____________________________

Signed this ______________________ day of ____________________________________, 20 _____.

_________________________ Signature

_________________________ Signature

_________________________ Typed Name

_________________________ Typed Name

STATE OF WISCONSIN)
) ss.
________________ County)

Personally came before me this _________ day of ________________________, 20 _____.

The above named ____ to me known to be the person(s) who executed the foregoing instrument and acknowledge the same.

____