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January 31, 2020

Ed Hampston, P.E.
Director, Bureau of Water Compliance
New York State Department of Environmental Protection
625 Broadway, 4th Floor
Albany, NY 12233-3506

Re: First Amended Nitrogen Consent Judgment, Index No. 04-402174
(Supreme Court, New York County, J. Schlesinger)
Submittal of the Jamaica Bay Feasibility Study

Dear Mr. Hampston,

In accordance with Section VII.C of the First Amended Nitrogen Consent Judgment, the New York City Department of Environmental Protection (DEP) is hereby transmitting the Final Jamaica Bay Feasibility Study (Study). On July 31, 2019, a draft of the Study was made available for public comment. The public comment period ended on October 15, 2019, with no comments received.

Should you require further information, please contact me at 718-595-4194.

Sincerely,

Dimitrios Katehis, Ph.D., P.E.
Nitrogen Consent Judgement
Project Manager

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City of New York
Department of Environmental Protection

Jamaica Bay Feasibility Study

January 31, 2020

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EX. Executive Summary

On June 27, 2011, the State of New York, New York State Department of Environmental Conservation (DEC) and the DEC Commissioner (collectively the State) and the New York City Department of Environmental Protection (NYCDEP), its Commissioner and the City of New York (collectively the City) entered into the First Amended Nitrogen Consent Judgment (FANCJ). The FANCJ requires, among other things, that the City upgrade its four Jamaica Bay Wastewater Resource Recovery Facilities (WRRFs)1, for improved removal of nitrogen from the treated effluent discharged from those plants through a process known as biological nitrogen removal (BNR). Pursuant to Section VII.C of the FANCJ, DEP is to a conduct a feasibility study designed to evaluate the available nitrogen-removal technologies, and optimization techniques for existing infrastructure, to identify potential measures to reduce nitrogen discharges from the Jamaica Bay WRRFs and improve DO water quality in Jamaica Bay (the Jamaica Bay Feasibility Study).

In accordance with the FANCJ, the four Jamaica Bay WRRFs are required to meet a 12-month rolling average aggregate performance-based nitrogen limit, as shown in **Table EX-1**. The nitrogen limits for Jamaica Bay are established following a 6-month optimization period and 12-month performance period after the achievement of a FANCJ milestone (e.g., 18 months after commencement of operation of the Level 2 BNR upgrade at the 26th Ward WRRF, the new limit will be calculated and will go into effect the following month). The final performance-based nitrogen limit will go into effect 19 months following the construction completion of the nitrogen control upgrades (Level 1 BNR) at the Coney Island WRRF.

Table EX-1: Performance Based Nitrogen Limits Required in Jamaica Bay

Effective Date of Limit	Combined Nitrogen Limit for JB WRRFs (lbN/d)
January 1, 2009	45,300
November 1, 2009	41,600
January 1, 2012	36,500
November 1, 2013	36,400
August 1, 2017 (current)	31,118
19 months after the last of: (a) construction completion of the Level 1 BNR upgrade at the Coney Island WRRF; or (b) construction completion of the Level 1 BNR upgrade at the Rockaway WRRF	TBD

The performance-based nitrogen limits are based on the effluent quality observed at each of the four Jamaica Bay WRRFs during a 12-month performance evaluation period. The most recent performance as of this report is provided in **Figure EX-**, demonstrating continuous compliance with each performance based interim nitrogen limit. Seasonal variations in effluent loads show lower effluent nitrogen in the summer and higher effluent nitrogen in the winter, primarily driven by the temperature sensitivity exhibited by the biological nitrogen removal process. A summary description of each facility, BNR

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1 The City’s four Jamaica Bay WRRFs are 26th Ward, Jamaica, Coney Island, and Rockaway.

implementation schedules, proposed ammonia (NH_3) limits and the aggregate effluent Total Nitrogen (TN) limit is provided in **Table EX-2.**

Table EX-2: Summary of Facility Information

Facility	Design Dry Weather Flow	Facility Description	Current/Future BNR Treatment*	Nitrogen Limit (TN and NH_3)	Status
26th Ward WRRF	85 MGD	• Step-feed BNR plant • Centralized dewatering facility • Integrated separate centrate treatment (SCT) process • Supplemental chemical addition (glycerol and caustic) for optimized denitrification performance and overall nitrogen removal	Level 3 BNR	**NH_3 (Interim SPDES):** 13 mg/L **NH_3 (Proposed SPDES):** 1.25 mg/L (May – Oct) 1.30 mg/L (Nov – Apr)	**Level 2 BNR Completion:** June 1, 2010 **Interim Chemical Addition in SCT Process:** December 28, 2011 **Level 3 BNR Completion:** December 28, 2015
Jamaica WRRF	100 MGD	• Step-feed BNR plant • Supplemental carbon (glycerol) addition for optimized denitrification performance and overall nitrogen removal	Level 3 BNR	**NH_3 (Interim SPDES):** 18 mg/L **NH_3 (Proposed SPDES):** 3.4 mg/L (May – Oct) 3.7 mg/L (Nov – Apr)	**Level 2 BNR Completion:** December 31, 2014 **Level 2+ BNR Completion:** August 26, 2016
Rockaway WRRF	45 MGD	• Future Step-feed BNR plant	Level 1 BNR (Construction in Progress)	**NH_3 (SPDES):** Monitor	**Level 1 BNR NTP:** July 20, 2017 **Level 1 BNR Completion:** Projected in 2020
Coney Island WRRF	110 MGD	• Future Step-feed BNR plant	Level 1 BNR (Construction in Progress)	**NH_3 (SPDES):** Monitor	**Level 1 BNR NTP:** February 22, 2018 **Level 1 BNR Completion:** Projected end of 2022

***BNR Treatment Levels explained in Chapter 3**

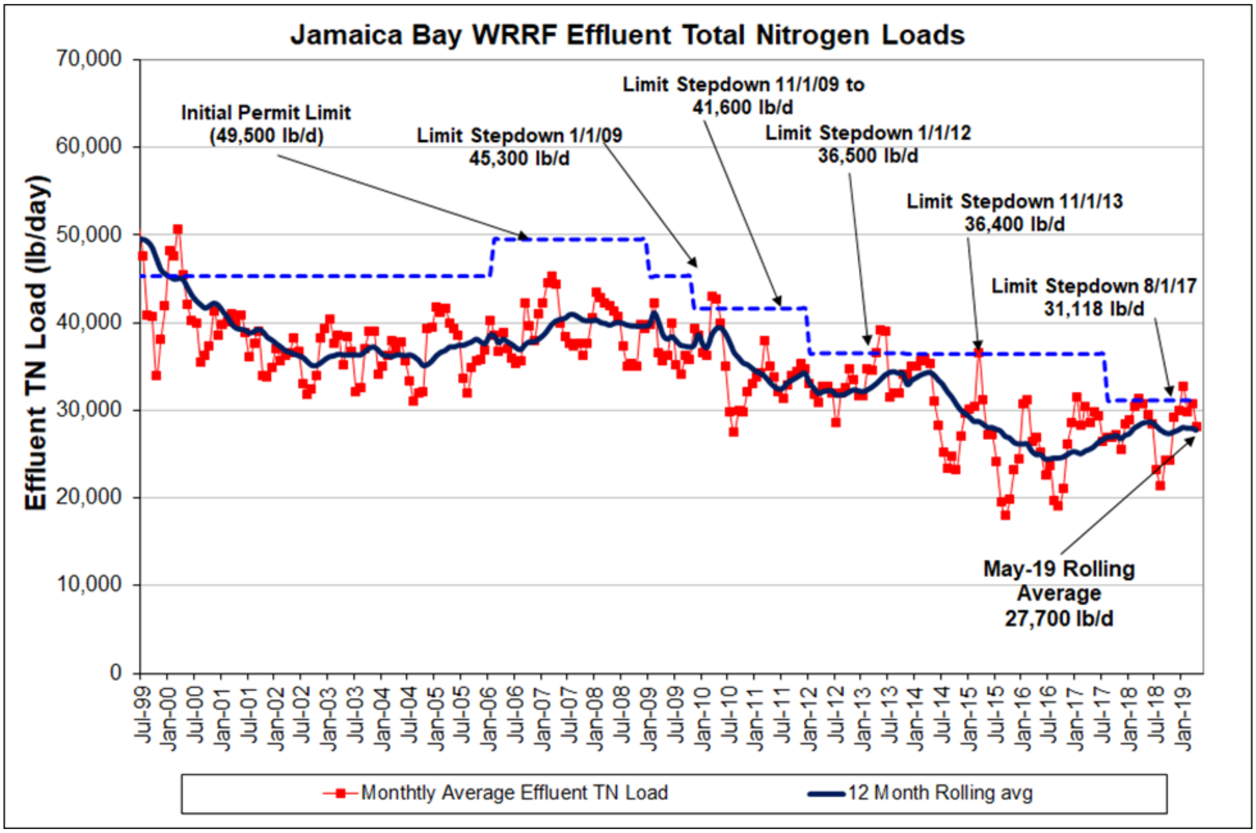


Figure EX-3: Jamaica Bay WRRF Effluent Total Nitrogen Loads

Nitrogen Control Technology Evaluation

Under the FANCJ, the City and NYCDEP committed to conduct the Jamaica Bay Feasibility Study in order to assess optimization opportunities and review available conventional technologies that may be applicable for achieving higher levels of treatment in Jamaica Bay, as well as providing a summary of more ecologically focused alternatives. The City conducted an assessment of conventional and innovative mainstream and sidestream nitrogen removal technologies that could be implemented at the WRRFs, and summarized applied research activities that target the development of new technologies or optimization of existing nitrogen removal technologies.

To execute the technology assessment, NYCDEP applied the Innovative Technology Evaluation Protocol (ITEP) developed under the PO-88 Applied Research Project (See *Managing Innovation: Optimizing Resource Allocation Using New York City's Innovative Technology Prioritization Tool*, presented at WEFTEC 2010). The ITEP-based evaluation represents a snapshot of our understanding of the rapidly evolving technologies evaluated. Multiple technologies were rated relatively low and were not carried forward for further evaluation at this time because the specific technologies have not been demonstrated at adequately large scale or lack a long term track record. These technologies are rapidly maturing, and it is likely that within the next few years the ratings would be modified materially as technologies such as mainstream deammonification, in-Dense and aerated granular sludge, mature and are deployed in large, footprint constrained WRRFs (similar to NYC WRRFs) in the US.

Within the noted limitations due to the rapid changes in BNR technology that are currently occurring, all of the technologies shortlisted in this study were deemed appropriate for further assessment at specific Jamaica Bay WRRFs and would be able to meet or exceed the treatment goals at each plant. At least one of the final technologies selected for each plant would be able to achieve Limit of Technology (LOT) treatment level resulting in an effluent TN of 3-4 mgN/L. Further assessment would be required to estimate the cost of the shortlisted options and the systemwide impacts in terms of additional biosolids production, greenhouse gas emission increases and workforce capabilities/headcount, among others. The shortlisted options would be compatible with further centralization of liquid and solids treatment within the JB WRRFs. At the Jamaica and 26th Ward WRRFs, the shortlisted technologies would also be able to meet the proposed effluent ammonia limits.

Table EX-2. Summary of Shortlisted Mainstream and Sidestream N Removal Technologies

WRRF	Shortlisted Mainstream Technologies		Shortlisted Sidestream Technologies
26th Ward	SND with Dynamic Aeration Control w/ add-on Denitrification Process (3 ATs in Operation, new SCT Process)	Level 2/3/4 BNR w/ Add-on Denitrification Process (3ATs in Operation, new SCT Process)	Deammonification (Granular or Fixed Film)
Jamaica	SND with Dynamic Aeration Control w/ Add-on Denitrification Process	Level 2/3/4 BNR with add-on Denitrification Process	N/A

Coney Island	Step Feed BNR Level 3	Simultaneous Nitrification/ Denitrification w/ Dynamic Aeration Control	N/A
Rockaway	Step Feed BNR Level 3	Simultaneous Nitrification/ Denitrification with Dynamic Aeration Control	N/A

As shown in **Table EX-2**, the Step Feed BNR process remains the core treatment process for nitrogen removal at the Jamaica Bay WRRFs at this time. The footprint limitations of the facilities, coupled with the configuration of the existing reactors and in-plant conveyance of major flows, makes it impractical to implement significant process reconfigurations using technologies that are well developed at this time. The mainstream treatment options identified for all four plants reflect varying levels of optimization of the step feed nitrogen removal process, with aeration enhancements and controls to allow for simultaneous nitrification/denitrification and the addition of a denitrification add-on process figuring prominently amongst the options. Should options that include step feed BNR be moved forward for further evaluation, the level of nitrogen removal that is achieved via the step feed process versus the nitrogen removal that is attained in the tertiary process would need to be evaluated and optimized based on cost, treatment reliability and triple bottom line considerations.

Sidestream treatment for removal of nitrogen from the anaerobically digested dewatering reject liquor stream is only applicable for the 26th Ward WRRF, where the Dewatering Facility is operated. Deammonifcation based technologies were identified as the most applicable for the sidestream, as they are now well developed with WRRFs of the same size as 26th Ward now in place in the US (DCWater, AlexRenew, Metro Water Reclamation District of Greater Chicago, DenverMetro). Deammonification represents a major stride in the sustainability of nitrogen removal technology, consuming one third the energy of conventional nitrogen removal and eliminating the need for supplemental carbon and supplemental alkalinity addition. This results in a process configuration that reduces the environmental, social and economic impacts of nitrogen removal, as heavy truck traffic is eliminated and the carbon footprint of the operation is reduced to less than a third of conventional nitrification/denitrification.

There are currently active research and development programs throughout the world focusing on transitioning deammonification from treatment of the dewatering sidestream to treatment of the mainstream flow. Preliminary data from some facilities such as AlexRenew in Alexandria, VA, the Strass-im-Zillertal WRRF in Austria, and Singapore’s Changi WRRF have shown active deammonification in the mainstream process. However, these efforts each use different forms of the basic deammonification technology and are still in the research and development stage, with no design criteria available to allow for transfer of the technology to other facilities, such as NYCDEP’s step feed BNR facilities. In order to successfully transfer this technology to the Jamaica Bay WRRFs, adaptation of the deammonification process to reactors configured in a step feed mode will be necessary. As deammonification and aerated granular technologies mature, it is likely that they would be attractive alternatives for the JB WRRFs in terms of both deployment cost and overall sustainability of operations. Should a further reduction in nitrogen discharges from the JB WRRFs be considered, a detailed assessment of deammonification based options should be conducted, as it is likely that mainstream treatment configurations will be available in the near future.

Optimization Techniques to Enhance Nitrogen Removal

The Jamaica Bay Feasibility Study identifies a wide array of optimization measures that NYCDEP has implemented for existing and future BNR related wastewater infrastructure to reduce nitrogen discharged. Using the flexibility afforded by the step feed nitrogen removal process, a series of optimization opportunities for the WRRFs were identified, starting from the current baseline and progressing towards increased levels of control and automation. The operation of both the mainstream and sidestream treatment process is reviewed and the impact of key operational controls is outlined. Focus points include:

- the need to maintain an adequate aerobic solids retention time to allow for stable nitrification, while balancing the need to maximize unaerated anoxic volume for denitrification
- providing optimal primary effluent flow distribution to manage seasonal changes in wastewater temperature and wet weather flow management
- adding precisely enough supplemental carbon to drive denitrification while avoiding excessive glycerin –derived biomass that will reduce nitrification performance and hamper wet weather solids clarification performance.
- controlling the proliferation of filamentous microbial biomass which induces severe operational problems in both the mainstream treatment and the solids processing facilities (thickening and anaerobic digestion)
- preventing breakpoint chlorination that is triggered by low ammonia in the effluent, and results in excessive hypochlorite addition and reduced disinfection performance.

Recognizing that the dynamic nature of the WRRFs operations will result in intervals of reduced performance a proactive Contingency Sampling program is outlined, to allow operators to rapidly recognize the potential for a process upset and initiate mitigation activities.

In order to support optimization activities in-situ analyzers for key parameters are required, including on-line TSS, pH and DO analyzers, in-situ nitrogen speciation analyzers for nitrate, and in the future ammonia analyzers as that technology matures.

Bench Scale Testing

Recognizing the rapid transformations in technology occurring in the nitrogen removal realm, NYCDEP is making significant investments in fundamental and applied research and optimization. By leveraging a combination of the talent afforded by local universities such as The City University of New York and Columbia University and research grants from the Water Environment Research Foundation and NYSERDA, NYCDEP has advanced the state of the art in nitrogen removal technologies. Contributions range from using glycerin in lieu of methanol for supplemental carbon addition to developing stable deammonification technology platforms for centralized dewatering applications.

The research results have allowed NYCDEP to adapt next generation technologies such as deammonification for deployment in its unique centralized dewatering facilities, while also laying the groundwork for adaptation of aerated granular sludge in a form compatible with NYCDEP's step-feed nitrogen removal reactors. Recognizing the limitations of the technology screening that was conducted under the Jamaica Feasibility study four core areas of continued R&D acivities were identified:

Simultaneous Nitrification/Denitrification (SND) allows for concurrent nitrification and denitrification to occur in the same tank at lower DO levels than what is used for conventional nitrification/denitrification. However, operational control over an SND system is challenging, particularly in high rate systems such as NYCDEP's step feed process. R&D to adapt SND to NYCDEP's facilities would allow NYCDEP to extract greater value out of its step feed facilities, given the lower reaction rates are exhibited by SND systems.

Ammonia Based Aeration Control (ABAC) systems rely on a feedback control based on oxygen and/or ammonia as the controlled variable. Continued development of these control strategies has identified a promising avenue of research into also using nitrite and nitrate in the control scheme to maximize the nitrogen removal capacity that can be obtained from a given facility.

Membrane Aerated Bioreactors (MABR) is a treatment technology consisting of a gas transfer membrane to deliver oxygen to a biofilm that is attached to the surface of the membrane. This process provides simultaneous nitrification and denitrification and requires less aeration energy than conventional BNR processes while reducing sludge production. Like most advanced processes, MABR require that fine screening be provided upstream of the reactors to avoid litter damaging the membranes.

Mainstream Deammonification at low temperatures and more dilute wastewater characteristics is an emerging operational application of sidestream deammonification, which is currently successfully conducted at high temperatures and concentrations (sidestream). NYCDEP would benefit from testing a seeding process, whereby biomass from the sidestream reactor(s) could be directed to the mainstream process to encourage mainstream deammonification in a granular form.

Ecologically Focused Nitrogen Removal Reduction

NYC DEP has long recognized that deployment of conventional gray infrastructure represents only one facet of a sustainable nitrogen management strategy for Jamaica Bay. As such, NYCDEP has focused resources on a range of ecologically focused interventions that are directly targeting the development of a healthy wetland ecosystem. Key among those are:

- **Algal Turf Scrubber Pilot.** Designed to mimic a stream ecosystem in a constructed environment that promotes algal growth. Nutrients in effluent wastewater are removed via algal photosynthesis.
- **Sea Lettuce Harvesting Pilot.** NYCDEP trash skimmer boats used to harvest sea lettuce where it amasses in the waters of Jamaica Bay to determine if this approach is feasible and to chemically analyze sea lettuce for its use as a source of biofuel.
- **Eel Grass Study.** The Cornell Cooperative Extension (CCE), in cooperation with NYCDEP, conducted a series of test plantings of eelgrass in multiple locations in Jamaica Bay.
- **Oyster Bed Pilot.** NYCDEP conducted two oyster reintroduction pilot studies within Jamaica Bay – the design and construction of an oyster bed off Dubos Point, Queens, and the placement of

oyster reef balls in Gerritsen Creek, Brooklyn**.** Monitoring activities included discrete and continuous water quality sampling, photo/video documentation, site maintenance, and investigation of sediment and current patterns.

- **Head of Bay Oyster Project.** A floating "nursery reef" containing 50,000 adult oysters will serve primarily as the supply of oyster larvae. 30 sampling locations were established throughout eastern Jamaica Bay to monitor for the settlement of oyster larvae. Monitoring activities include water quality sampling, adult oyster health, growth, reproduction and recruitment.
- **Ribbed Mussel Pilot.** Artificial structures were constructed in Fresh Creek, a tributary to Jamaica Bay, to encourage the growth of ribbed mussels. The study monitored mussel growth and qualitative water quality improvements to measure the effectiveness of ribbed mussels in removing nutrients and particulate organic matter from the water. This study has been expanded to include a phased research program, starting with fundamental research, culminating with a planned large scale demonstration in Jamaica Bay.
- **Paerdegat Basin Restoration.** NYCDEP established 52 acres of restored wetlands, including a public Ecology Park, along the shores of Paerdegat Basin.
- **Marsh Island Wave Attenuator Study.** A floating wave attenuator was installed at Brant Point, along the southern shoreline of Jamaica Bay near a severely degraded and actively eroding wetland edge. The wave attenuator deflects and reduces the energy of incoming waves, allowing for the accumulation of important wetland building sediments. These temporary structures are a proxy for future oyster beds around wetlands to evaluate the wave energy reduction and sediment capture potential.

1. Introduction

On June 27, 2011, the State of New York, New York State Department of Environmental Conservation (DEC) and the DEC Commissioner (collectively the State) and the New York City Department of Environmental Protection (NYCDEP), its Commissioner and the City of New York (collectively the City) entered into the First Amended Nitrogen Consent Judgment (FANCJ). The FANCJ requires, among other things, that the City upgrade its four Jamaica Bay Wastewater Resource Recovery Facilities (WRRFs), for improved removal of nitrogen from the treated effluent discharged from those plants through a process known as biological nitrogen removal (BNR). Pursuant to Section VII.C of the FANCJ, DEP is to a conduct a feasibility study designed to evaluate the available nitrogen-removal technologies, and optimization techniques for existing infrastructure, to identify potential measures to reduce nitrogen discharges from the Jamaica Bay WRRFs and improve DO water quality in Jamaica Bay (the Jamaica Bay Feasibility Study).

The Jamaica Bay Feasibility Study is organized in four core sections:

Section 2. Facility Information, provides a description of the City WRRFs located in the Jamaica Bay and Coney Island, along with the nitrogen removal that they are achieving as a result of the upgrades and optimization efforts that NYCDEP has undertaken for more than a decade.

Section 3. Technology Evaluation, describes the protocol used to screen technologies that may be applicable to nitrogen removal for the Jamaica Bay and Coney Island WRRFs, and identifies a shortlist of technologies that can be considered for further development if significant upgrades to the facilities are considered in the future.

Section 4. Optimization Techniques, identifies the operating variables that drive the nitrogen removal process in the WRRFs, and defines opportunities to enhance performance through operational and relatively minor capital improvements.

Section 5. Bench Scale Testing, describes the bench scale, pilot scale and demonstration scale studies that the NYCDEP has executed to better understand the fundamentals of novel treatment processes such as deammonification, and allow for a better understanding of the research and technology development needs that will allow for integration of these processes into the JB WRRFs.

Section 6. Nitrogen Reduction Efforts in Jamaica Bay, summarizes the novel ecologically focused investments that NYCDEP has made in Jamaica Bay to enhance water quality.

2. Facility Information

2.1 Introduction

This section of the Jamaica Bay Feasibility Study provides background information on each of the four New York City Department of Environmental Protection Wastewater Resource Recovery Facilities(NYCDEP WRRFs) that discharge to Jamaica Bay: 26th Ward, Jamaica, Coney Island, and Rockaway, including a brief facility history, description and status of the most recent Biological Nitrogen Removal (BNR) upgrades, overview of the treatment process, and effluent permit limits for nitrogen (including total nitrogen loading and future numerical ammonia limits). Current BNR practices are also documented.

On June 27, 2011, the DEC and the DEP entered into the First Amended Nitrogen Consent Judgment (FANCJ), in part to reduce nitrogen discharges from the City's Jamaica Bay WRRFs, thereby protecting and improving water quality and the environment of Jamaica Bay.

In accordance with the FANCJ milestones, the four Jamaica Bay WRRFs (26th Ward, Jamaica, Coney Island, and Rockaway) are required to meet a 12-month rolling average aggregate performance-based nitrogen limit, as shown in **Table EX-1**. The nitrogen limits for Jamaica Bay are established following a 6-month optimization period and 12-month performance period after the achievement of a BNR milestone (e.g., 18 months after commencement of operation of the Level 2 BNR upgrade at the 26th Ward WRRF, the new limit will be calculated and will go into effect the following month). The specific milestones are provided in Appendix C2 of the FANCJ. The final performance-based nitrogen limit will go into effect 19 months following the construction completion of Level 1 BNR at the Coney Island WRRF.

Table 2-1: Performance Based Nitrogen Limits Required in Jamaica Bay

Effective Date of Limit	Combined Nitrogen Limit for JB WRRFs (lbN/d)
January 1, 2009	45,300
November 1, 2009	41,600
January 1, 2012	36,500
November 1, 2013	36,400
August 1, 2017 (current)	31,118
19 months after the last of: (a) construction completion of the Level 1 BNR upgrade at the Coney Island WRRF; or (b) construction completion of the Level 1 BNR upgrade at the Rockaway WRRF	TBD

The performance-based nitrogen limits are based on the effluent quality observed at each of the four JB WRRFs during the 12-month performance period. The most recent performance as of this report is provided in **Figure EX-**, demonstrating continuous compliance with each nitrogen limit. Seasonal variations in effluent loads show lower effluent nitrogen in the summer and higher effluent nitrogen in the winter. These variations are expected due to the biological nature of BNR treatment. A summarized description of each facility, BNR implementation schedules, and effluent Total Nitrogen (TN) and ammonia (NH_3) limits is provided in **Table EX-2.**

Table 2-2: Summary of Facility Information

Facility	Size	Facility Description	Current/Future BNR Treatment*	Nitrogen Limit (TN and NH_3)	Status
26th Ward WRRF	85 MGD	• Step-feed BNR plant • Integrated separate centrate treatment (SCT) process • Supplemental chemical addition (glycerol and caustic) for optimized denitrification performance and overall nitrogen removal	Level 3 BNR	**TN Limit:** See **Table EX-1** **NH_3 (Interim SPDES):** 13 mg/L **NH_3 (SPDES):** 1.25 mg/L (May – Oct) 1.30 mg/L (Nov – Apr)	**Level 2 BNR Completion:** June 1, 2010 **Interim Chemical Addition in SCT Process:** December 28, 2011 **Level 3 BNR Completion:** December 28, 2015
Jamaica WRRF	100 MGD	• Step-feed BNR plant • Supplemental carbon (glycerol) addition optimized denitrification performance and overall nitrogen removal	Level 2+ BNR	**TN Limit:** See **Table EX-1** **NH_3 (Interim SPDES):** 18 mg/L **NH_3 (SPDES):** 3.4 mg/L (May – Oct) 3.7 mg/L (Nov – Apr)	**Level 2 BNR Completion:** December 31, 2014 **Level 2+ BNR Completion:** August 26, 2016
Rockaway WRRF	45 MGD	• Future Step-feed BNR plant	Level 1 BNR (Construction in Progress)	**TN Limit:** See **Table EX-1** **NH_3 (SPDES):** Monitor	**Level 1 BNR NTP:** July 20, 2017 **Level 1 BNR Completion:** December 31, 2019
Coney Island WRRF	110 MGD	• Future Step-feed BNR plant	Level 1 BNR (Construction in Progress)	**TN Limit:** See **Table EX-1** **NH_3 (SPDES):** Monitor	**Level 1 BNR NTP:** February 22, 2018 **Level 1 BNR Completion:** October 31, 2022

***BNR Treatment Levels explained in Chapter 3**

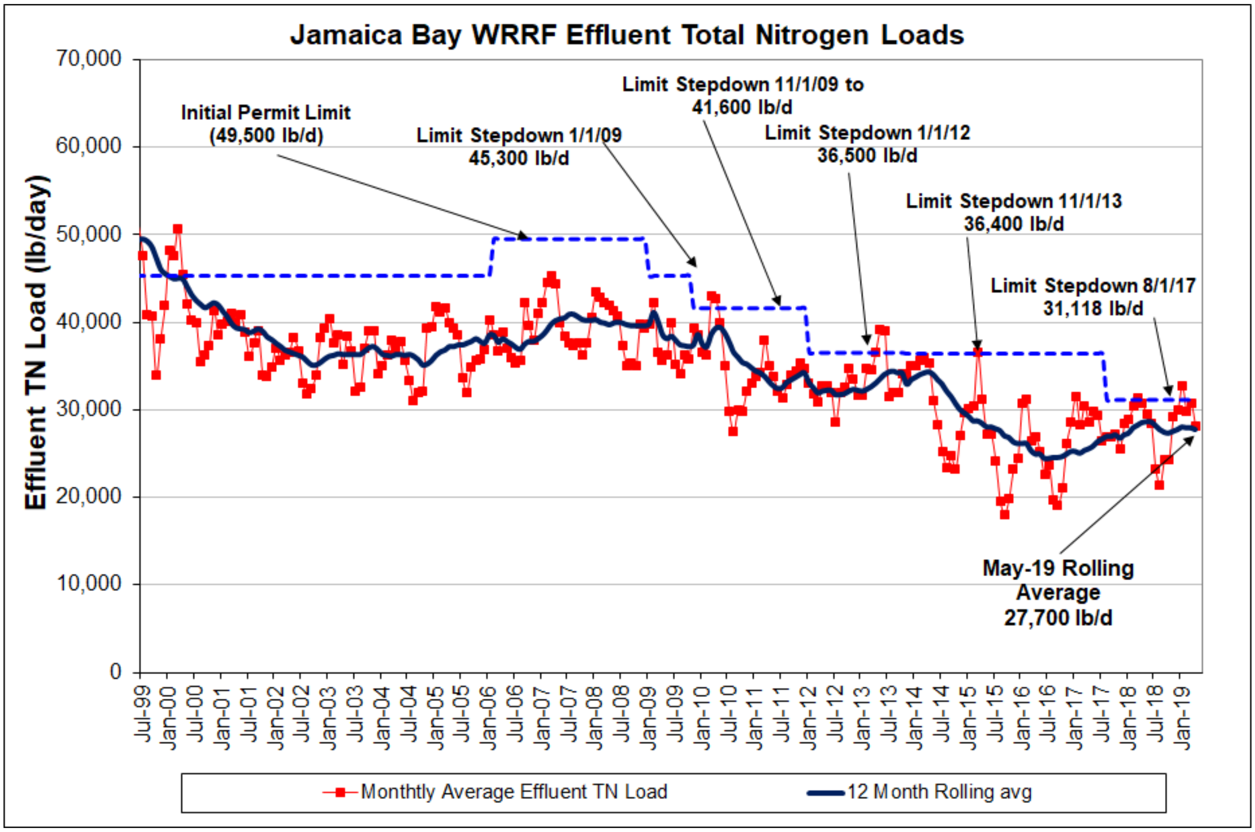


Figure 2-1: **Jamaica Bay WRRF Effluent Total Nitrogen Loads**

2.2 26TH WARD WRRF

2.2.1 Plant History

The 26th Ward WRRF is located on a 57.3-acre site on Flatlands Avenue, Brooklyn, New York. The site is adjacent to the Hendrix Street Canal in Southeast Brooklyn, as shown in **Figure 2-2**. The facility serves an area of 6,000-acres that is almost exclusively combined sewers. The first sewers in the area were constructed in the late 1800s and more than half of the sewers were in place by the early 1900s. The entire system is a gravity flow system, with three regulators in the sewer system tributary. The facility is currently permitted through New York State Department of Environmental Conservation (NYSDEC) State Pollutant Discharge Elimination System (SPDES) permit NY-0026212.

Figure 2-2: **26th Ward WRRF Site**

Although several sewage treatment facilities have existed at the 26th Ward site since the 1890s, the original activated sludge facility was constructed in 1949 with a design flow of 60 million gallons per day (MGD).

In the 1970s, the facility was expanded to its current capacity of 85 MGD. In 1992, regulations banning sludge dumping at sea resulted in the construction of a sludge dewatering facility, a third aeration tank, and an eighth final clarifier.

The current facility is designed for 85 percent removal of both biochemical oxygen demand (BOD) and total suspended solids (TSS), utilizing the step aeration activated sludge process. The facility is designed to treat a peak flow of 170 MGD (two times the design dry weather flow) through the plant headworks, primary treatment, and disinfection facilities and 127.5 MGD (1.5 times the design dry weather flow) through secondary treatment processes.

The facility currently treats an average daily flow of 46 MGD (2015 through 2018). Dry weather flows and regulated wet weather flows are conveyed to the facility's high level and low level wet wells. The low-level wet well receives flow from three sources, which include:

- The 60-inch Flatlands Avenue interceptor, which serves the western portion of the drainage area and transports flow from Williams Avenue Regulator 2 just north of Fresh Creek.
- The 60-inch diameter Vandalia Avenue interceptor serving the eastern section of the drainage area by conveying flow from the Autumn Avenue Regulator 3 just north of the Spring Creek Auxiliary WPCP.
- The 48-inch Starrett City Sewer. This is a separate sewer that does not pass through a regulator but connects directly to the inlet manhole for the Low-Level Screen Chamber.

During wet weather events, excess flow is directed from the Autumn Avenue and Jamaica Regulator 2 to the Spring Creek Combined Sewer Overflow (CSO) facility, where it is retained and eventually returned to the 26th Ward WRRF for treatment. When the storage capacity of the Spring Creek retention basins is exceeded, CSO is discharged from the Spring Creek CSO facility to Jamaica Bay. Additional CSOs from the Flatlands Avenue Interceptor discharge into Fresh Creek, where floatables are captured and removed through a netting facility. The high-level wet well receives flow exclusively from the Hendrix Street Canal interceptor, which services the central portion of the 26th Ward drainage area. CSOs from the Hendrix Street Regulator discharge directly into the Hendrix Street Canal and combine with plant effluent discharging to Jamaica Bay.

2.2.2 Treatment Process Description

The 26th Ward WRRF is a step-feed BNR plant, with an integrated separate centrate treatment (SCT) process, and supplemental chemical addition (carbon and caustic) for optimized denitrification performance and overall nitrogen removal.

The main plant consists of two aeration tanks (ATs); AT 1 and AT 2, treating primary effluent. Both aeration tanks receive treated centrate from the SCT tank (Aeration Tank 3) via Return Activated Sludge (RAS) addition line which discharges into Pass A of both AT1 and AT2. The treated centrate is directed to the combined RAS channel upstream of the RAS/Waste Activated Sludge (WAS) well. Treated flow leaves Pass D of each AT and enters the secondary clarifiers where the active biomass settles and is separated from the treated effluent. A portion of the settled biomass is returned to the head of the ATs

(Pass A) as RAS, while the remaining portion of the settled biomass is pumped to the gravity thickeners as WAS. Biomass can alternately be wasted directly from the surface of the AT through the surface waste activated sludge (SWAS) system and/or Mixed Liquor Suspended Solids (MLSS) leaving Pass D directly to the gravity thickeners. The treated effluent from the secondary clarifiers flows over weirs and enters the chlorine contact tanks (CCT) where it is disinfected with sodium hypochlorite and discharged to Jamaica Bay (JB). The plant is required to treat influent flow through the secondary BNR process up to 1.5 times the design dry weather capacity of 85 MGD.

Layouts of the main plant BNR ATs and SCT BNR AT are provided in **Figure 2-3** and **Figure 2-4**, respectively. A schematic of the 26W WRRF is shown in **Figure 2-5**.

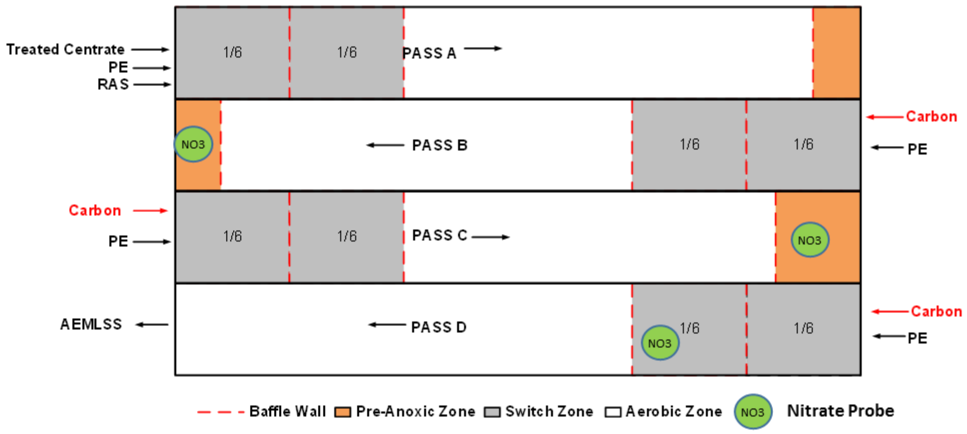


Figure 2-3: Schematic of 26th Ward Main Plant ATs 1 and 2

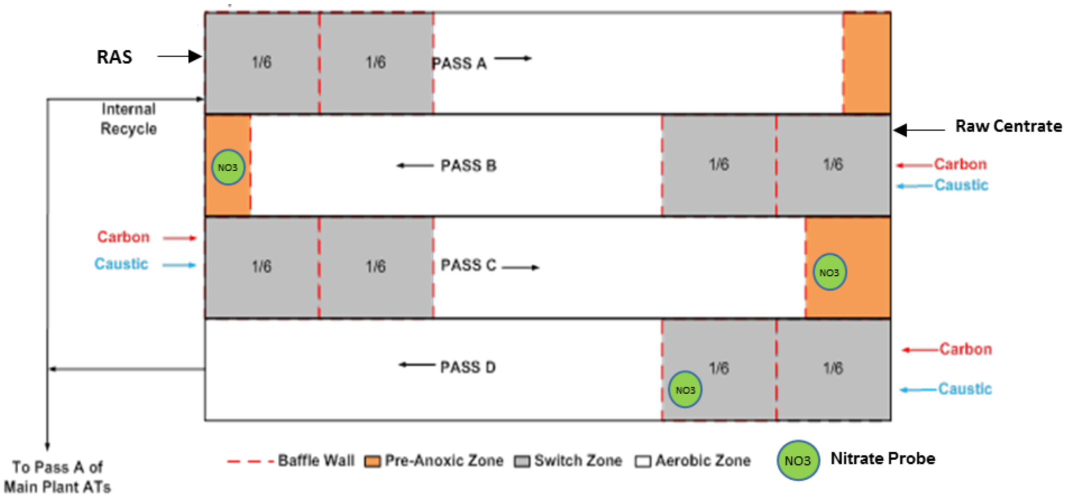


Figure 2-4: Schematic of 26th Ward SCT AT 3

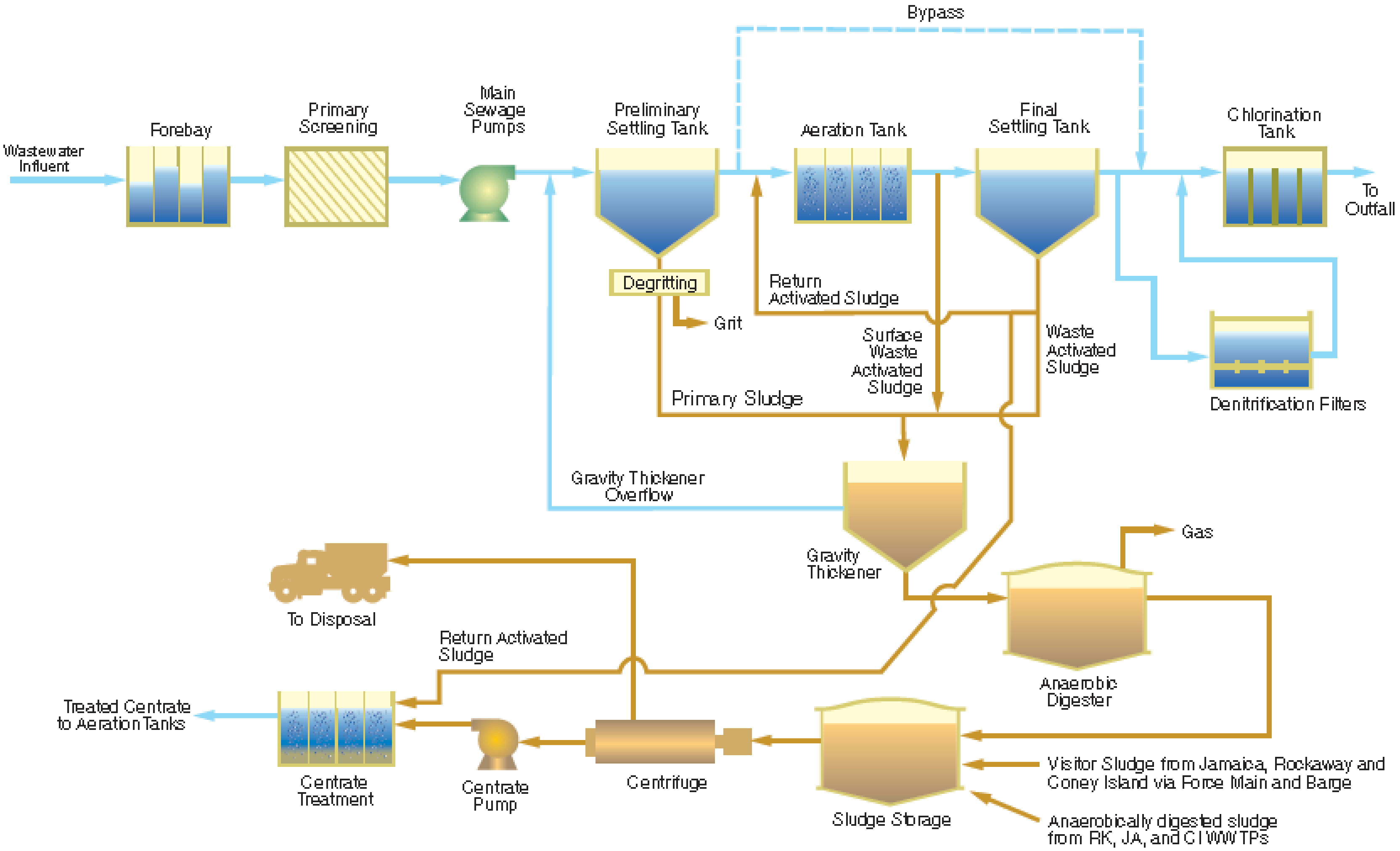


Figure 2-5: 26th Ward WRRF Process Flow Diagram

2.2.3 Status of BNR Upgrades

As part of the First Amended Nitrogen Consent Judgment, NYCDEP was required to upgrade the 26th Ward WRRF to Level 2 BNR treatment, i.e., Advanced Basic BNR. These upgrades were completed as of June 1, 2010.

Step-feed BNR implementation at the 26th Ward WRRF included the following upgrades:

- AT modification including rehabilitation of existing baffles, new mixers, new diffuser membranes, and a tapered diffuser layout.
- Process air system modification including electrical modifications to the existing air blowers and repair/replacement of process air headers.
- RAS/ WAS upgrade including increase RAS capacity, variable frequency drives, and metering controls.
- Froth control measures including chemical storage and feed facilities for sodium hypochlorite, AT surface wasting, and improved design and relocation of froth hoods.
- Alkalinity addition for SCT in AT 3.

As part of the FANCJ, NYCDEP was required to initiate interim supplemental carbon addition in AT-3, the dedicated AT for SCT at 26th Ward. Interim supplemental carbon addition was placed into operation on December 28, 2011.

Following the interim supplemental carbon addition upgrade at 26th Ward, NYCDEP was required to construct a permanent side-stream separate centrate treatment process at the 26th Ward WRRF to handle the high strength centrate stream from the dewatering process. This permanent side-stream treatment was originally proposed to be a 1.2 MGD Ammonia Removal Process (ARP), which is a chemical process that converts aqueous ammonia to ammonia gas under high temperature/low pressure conditions. Upon commencement of operation of SCT with supplemental carbon addition in AT-3, significant reductions in effluent TN loads (between 1,500 to 2,000 lbN/d) were observed when compared to pre-glycerol addition effluent quality. These overall nitrogen removals, in conjunction with the treatment plant operator's familiarity with this type of biological system, unfamiliarity with the ARP chemical process, and extremely high operating cost associated with ARP, led NYCDEP to re-evaluate their long-term dedicated centrate treatment strategy and whether there may be alternatives that would result in better, more cost-effective nitrogen removal.

After a detailed analysis which did not show a benefit of ARP over biological centrate treatment with supplemental glycerol addition in AT-3, a modification was made to the FANCJ that allowed NYCDEP to continue to operate AT-3 as an SCT process with supplemental glycerol addition instead of implementing ARP. As part of this modification, NYCDEP was required to develop a contingency plan to transship centrate/sludge from 26th Ward WRRF to the Port Richmond WRRF, if an AT needs to be taken out of service for an extended period of time. Additionally, NYCDEP was required to upgrade the Jamaica WWP to Level 2+ BNR. This modification was projected to reduce nitrogen discharges into Jamaica Bay by about 2,500 lbN/day.

Lastly, upgrades for plant-wide supplemental carbon addition to the 26th Ward were designed and implemented to optimize nitrogen removal and further reduce nitrogen discharges to Jamaica Bay. The supplemental carbon system includes six (6) glycerol storage tanks, each with a nominal capacity of 7,600 gallons, which accepts deliveries of glycerol that meet the NYCDEP glycerol specification. According to the specification, the delivered product must consist of a minimum percentage glycerol solution (typically 65 to 70%) with a minimum Chemical Oxygen Demand (COD) content of approximately 900,000 to 1,000,000 mg/L. Supplemental carbon addition was placed into operation on December 28, 2015.

2.2.4 Effluent Permit Limits

2.2.4.1 Effluent Total Nitrogen Load

As mentioned previously, the four Jamaica Bay (JB) WRRFs (26th Ward, Jamaica, Coney Island, and Rockaway) are required to meet a 12-month rolling average aggregate performance-based nitrogen limit, as shown in **Table EX-1** The nitrogen limits for Jamaica Bay are established following a 6-month optimization period and 12-month performance period after the achievement of a BNR milestone (e.g., 18 months after commencement of operation of the Level 2 BNR upgrade at the 26th Ward WRRF, the new limit will be calculated and will go into effect the following month). The specific milestones are provided in Appendix C2 of the FANCJ. The final performance-based nitrogen limit will go into effect 19 months following the construction completion of Level 1 BNR at the Coney Island WRRF.

2.2.4.2 Effluent Ammonia Concentration

NYSDEC has issued a draft revised SPDES permit for the 26th Ward WRRF that includes a strict monthly average effluent ammonia limit (as NH3) of 1.25 mgN/L from May through October and 1.30 mgN/L from November through April.

An interim monthly average ammonia limit of 13 mg/L is in effect while the facility complies with the compliance schedule provided in **Table 2-3**, as outlined in the compliance schedule section of the 26th Ward WRRF SPDES permit (NY0026212).

Table 2-3: 26th Ward Schedule of Compliance for Effluent Ammonia Limits

Compliance Action	Due Date	Status
The Permittee (NYCDEP) shall revise the Jamaica Bay Phase I Post Construction Monitoring (PMC) Plan, received on June 30, 2015, to include a three-year ambient water quality monitoring program to sample for un-ionized ammonia (NH3/NH4-N pH, temperature and salinity) at the edge of the DEC-approved chronic mixing zone for the 26th Ward WRRF discharge. The Jamaica Bay Phase I PCM plan shall address sampling and quality assurance/quality control for this sampling program.	Receipt of DEC comments on the Phase I PCM + 30 Days	Submitted March 20, 2017
The Permittee shall commence the ambient water quality monitoring program as part of the approved Jamaica Bay Phase I PCM in accordance with the FANCJ.	In accordance with FANCJ Appendix B Milestones	Commenced July 31, 2016
The Permittee shall undertake a 12-month performance evaluation to establish performance-based interim limits for ammonia beginning 6 months after commencement of operation of the Level 3 BNR at the 26th Ward WRRF. The Permittee shall submit the performance data from the performance evaluation period to the Department within 30 days of the end of the 12-month performance period. The Department shall calculate performance-based limit using methods consistent with TOG 1.3.3. The 95th Percentile value of the individual sampling data points will be used for the interim monthly average limit. Based upon this information, the Department may reopen the permit to revise the interim ammonia limit to reflect the limits.	Performance data due on July 30, 2017	Submitted
The Permittee shall submit the results of the three-year ambient water quality monitoring program in an approvable ambient water quality monitoring report to the Department in accordance with the approved Jamaica Bay Phase I PCM plan and the FANCJ.	In accordance with FANCJ Appendix B Milestones	TBD
Upon review and approval of this report, the Department will notify the Permittee in writing whether the ammonia water quality standard is met with the 26th Ward WRRF operating in accordance with the performance-based limits and will recalculate the seasonal ammonia limits. If the sampling results demonstrate that the ammonia water quality standard is being achieved while the 26th Ward WRRF is operating at the performance-based limits, the Department will evaluation making the performance-based limits the permit limits. Based on the results, the Department may reopen the permit to revise the ammonia limits.	Receipt of the ambient water quality monitoring report + 6 months	TBD
If the Department determines that the ambient water quality monitoring program demonstrates that the ammonia water quality standard is not met, the Department will use the data from the ambient water quality monitoring to recalculate the seasonal ammonia limits for the 26th Ward WRRF. Based upon this information, the Department may reopen the permit to revise the ammonia limits to include the recalculated limit. The Permittee shall conduct a feasibility study and engineering analysis of potential alternatives necessary to comply with the recalculated seasonal ammonia limits. The Permittee shall submit this information in an approvable report to the Department. As part of this submission, the Permittee may propose; and the Department will review in good faith; an effluent variance for ammonia, if any, pursuant to the FANCJ, Section IV; and in accordance with Part 750-1.7.	Department notification that WQ standard is not met + 24 months	TBD
If treatment system upgrades are determined to be necessary, the Permittee shall submit approvable final plans and specifications, as well as a schedule of construction, for the facilities described in the approved Engineering Report.	DEC Approval of Feasibility Study and Engineering Analysis Report + 36 months	TBD
The Permittee shall construct the facilities described in the approved report, plans and specifications and achieve compliance with the recalculated limit in accordance with the approved schedule of construction.	In accordance with the approved schedule	TBD

2.2.5 Current BNR Practices and Optimization Techniques

Table 2-4 summarizes the 26th Ward WRRF's current BNR practices and optimization techniques.

As one of the first NYCDEP facilities to operate BNR, 26th Ward plant staff have acquired substantial experience from day-to-day BNR operation. From this experience, plant staff practice optimized operational strategies for the various elements of BNR operation (e.g., solids inventory, aeration, chemical addition, etc.) best suited for 26th Ward based on the plant's specific BNR related equipment and configuration, including use of instrumentation for automated operation. Generally, 26th Ward has been operating within the BNR operational guidelines discussed in **Chapter 5**.

Additionally, since 26th Ward has been operating BNR since 2010, BNR related equipment has had time to 'age' and therefore NYCDEP has had the opportunity to develop and implement preventive maintenance plans based on experience from aging infrastructure to ensure that all equipment is in a SOGR.

NYCDEP performs preventative maintenance (PM) and corrective maintenance (CM), in accordance with manufacturer recommendations and the plant's operations and maintenance manuals on critical equipment. An annual report is submitted to NYSDEC that certifies that this PM/CM plan has been performed.

Table 2-4: 26th Ward Current BNR Practices

BNR Area of Focus	Current Operational Practice
Solids Inventory Management	• Solids inventory targets consistent with BNR operational guidelines in **Chapter 5**. • Wasting is primarily accomplished via SWAS system and AEMLSS channel.
Process Aeration/ATs	• Aeration targets consistent with BNR operational guidelines in **Chapter 5**.
PE Flow Splits	• Target PE flow splits are consistent with BNR operational guidelines in **Chapter 5**. • Flow splits are regularly monitored using TSS profiles and back-calculated flows per pass.
Foam Control	• Surface wasting is the main mechanism for foam prevention and control. • SWAS system operates with a diurnal SWAS control strategy, with manual settings that must be adjusted every 8 hours (once per shift) and during wet weather events.
SCT Operation	• Operational settings consistent with Supplemental Sampling Report results in **Chapter 5**.
Chemical Addition	• Nitrate probe strategy for glycerol addition. • Caustic added if supplemental sampling procedure deems it is required.
Wet Weather Strategy	• Pass D gates are motorized and are manually adjusted during wet weather events. • SWAS gates are raised during wet weather events.
Instrumentation	• NO3 probes are installed for automation of glycerol addition based on NO3 readings in ATs. • DO probes are installed for monitoring purposes.

2.2.6 Plant Nitrogen Removal Performance

Effluent nitrogen speciation from January 2008 through May 2018 is shown in **Figure 2-6**. From pre-BNR operation, effluent nitrogen loads from 26th Ward have decreased by 68 percent from an average of effluent TN load of 10,800 lb/d (January 1, 2008 through May 31, 2010) to an average effluent TN load of 3900 lb/d (January 1, 2016 through May 31, 2019) and overall nitrogen removal has increased from an average of 30% TN removal (January 1, 2008 through May 31, 2010) to an average of 77% TN removal (January 1, 2016 through May 31, 2019).

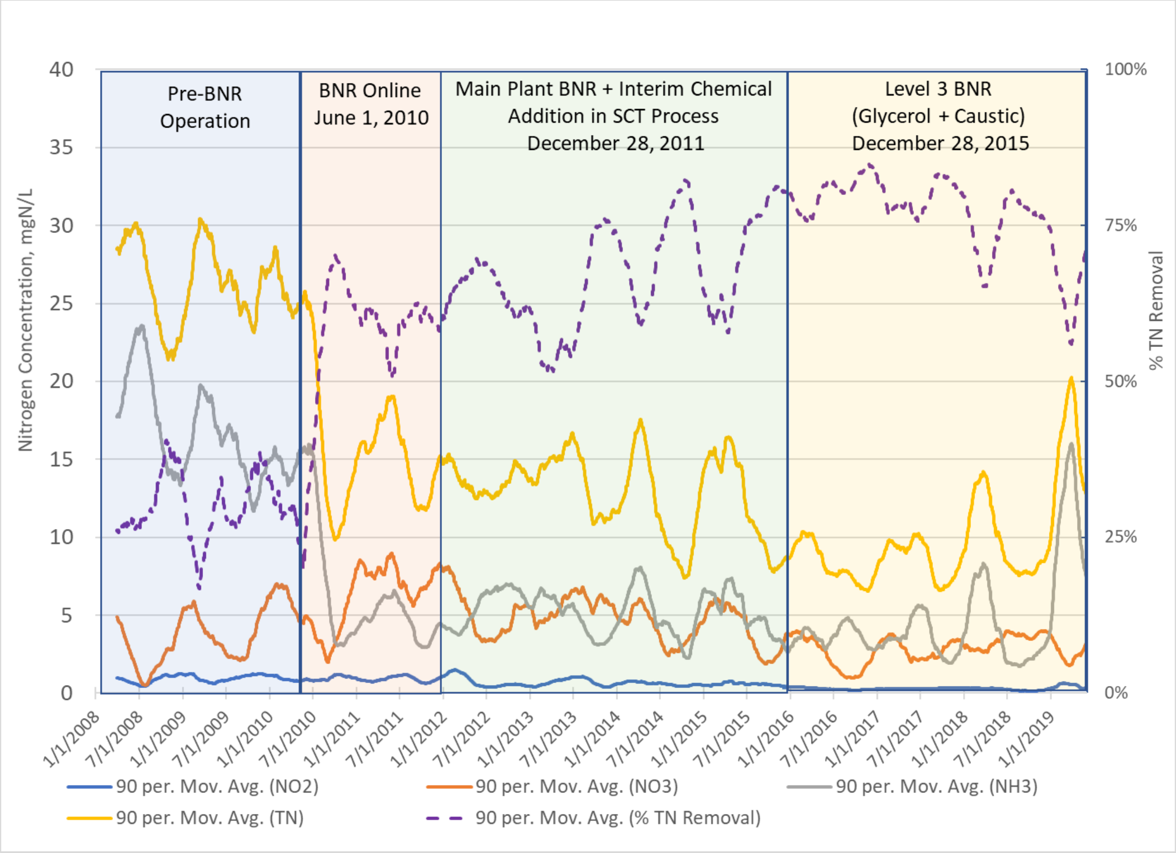


Figure 2-6: 26W Effluent Nitrogen Speciation and % TN Removal (inclusive of N load from visitor sludge) – January 2008 through May 2019

2.3 Jamaica WRRF

2.3.1 Plant History

The Jamaica WRRF is located on a 26-acre site at 15-20 134th Street, Queens, New York. The site is bordered by the Nassau Expressway to the north, 155th Avenue to the south, 130th Street to west, and 134th Street to the east, as shown in **Figure 2-7**. The facility serves an area of 25,528-acres, treating water from both separate and combined sewers from the Southern Section of Queens. The facility is currently permitted through NYSDEC SPDES permit number NY-0026115.

Figure 2-7: Jamaica WRRF Site

The Jamaica WRRF was originally constructed in 1903 and provided primary treatment to a design flow of 1 MGD. In 1943, the facility was expanded to an average dry weather capacity of 65 MGD and upgraded to modified aeration processes. In 1963 the facility was further expanded to its current treatment capacity, providing primary treatment and disinfection for annual average and peak flows of 100 and 200 MGD, respectively, and secondary treatment for flows up to 150 MGD. The 1963 upgrade also provided for 85 percent removal of BOD and TSS.

The facility currently treats an average daily flow of 77 MGD (2015 through 2017). Wastewater enters the WRRF through a junction structure (Chamber A) located at the intersection of 150th Avenue and 134th Street. Chamber A receives wastewater from two intercepting sewers which include:

- A 96-inch diameter intercepting sewer that serves the drainage area east of the Van Wyck Expressway
- A 72-inch diameter intercepting sewer that serves the drainage area west of the Van Wyck Expressway.

Most of the sewers in the eastern area are separate sanitary sewers, whereas the western area is served by combined sewers. The combined sewers in the system terminate at regulators that accept all dry weather flow and convey it to the intercepting sewers connected to the WRRF. During wet weather events, the regulators divert sanitary flow and storm water to the intercepting sewers until the WRRF reaches its permitted capacity. Flows in excess of 200 MGD discharge from the collection system regulators as CSO.

The Jamaica Redevelopment Zone, spanning over 1,770 acres, will create new business and residential districts that will increase sewage flows to the Jamaica WRRF. An analysis of the impact of increased flows on BNR operations, capacity, and effluent quality should be considered when the projected flows are calculated. The service area is served by three existing sanitary trunk sewers with significant capacity limitations during peak dry and wet weather conditions. As such, collection system capacity improvements are necessary to safely convey the additional flow associated with the new development to the Jamaica WRRF. The Jamaica WRRF Drainage Area Facility Planning project is being closely coordinated with the Jamaica Bay Long Term Control Plan (LTCP), which is currently evaluating a number of CSO control alternatives.

Over the years, the Jamaica WRRF has received numerous upgrades and modifications to its treatment process including providing for step aeration in 1978 and upgrades associated with the Stabilization Program in 1998. The Stabilization Program was implemented to upgrade the facility to meet the secondary treatment requirements in the SPDES permit and provide features that would facilitate a future conversion to BNR treatment. Under the Stabilization Program, the Jamaica WRRF received an additional primary settling tank, increased return sludge pumping capacity, and control instrumentation to allow for close monitoring of the BNR process.

2.3.2 Treatment Process Description

The Jamaica WRRF is a step-feed BNR plant, with a supplemental chemical addition (glycerol) for optimized denitrification performance and overall nitrogen removal. The plant consists of four ATs; ATs 1 through 4, treating primary effluent. Treated flow leaves Pass D of each AT and enters the secondary clarifiers where the active biomass settles and is separated from the treated effluent. A portion of the settled biomass is returned to the head of the ATs (Pass A) as RAS. Biomass can be wasted two ways: (1) via the settled biomass from the secondary clarifiers as Waste Activated Sludge (WAS) or (2) from the surface of the AT through the SWAS system in Pass A. Waste sludge is thickened in the Gravity Thickeners (GTs) and/or Gravity Belt Thickeners (GBTs). All sludge is digested and transported via Force Main to the 26th Ward WRRF for dewatering. The treated effluent from the secondary clarifiers flows over weirs and enters the CCT where it is disinfected with sodium hypochlorite and discharged to Jamaica Bay (JB). The plant is required to treat influent flow through the secondary BNR process up to 150 MG, 1.5 times the design dry weather capacity of 100 MGD.

A layout of an AT is shown in **Figure 2-8**. A process flow diagram for the Jamaica WRRF is provided in **Figure 2-9**

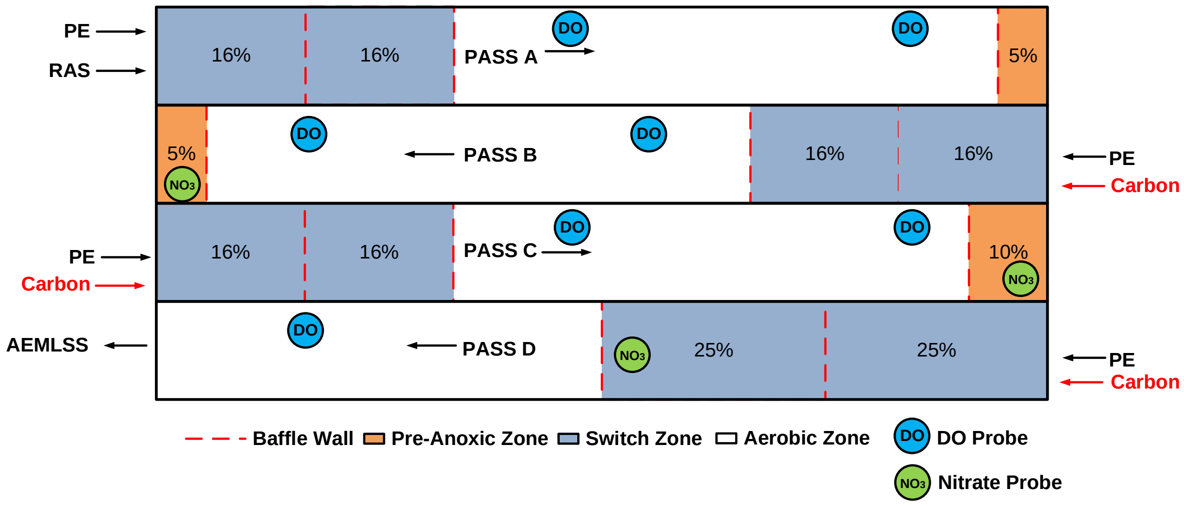


Figure 2-8: Schematic of Jamaica WRRF ATs

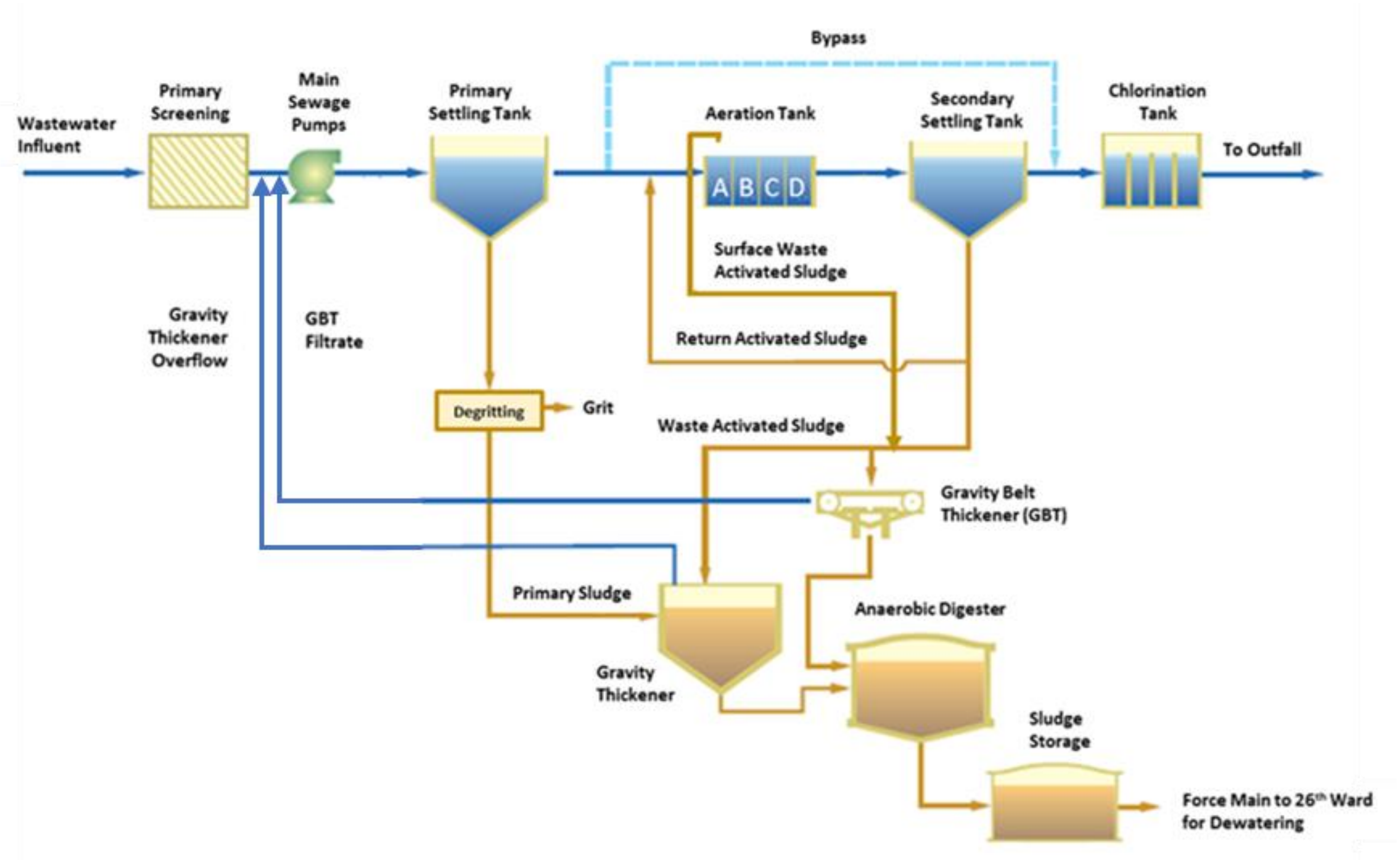


Figure 2-9: Jamaica WRRF Process Flow Diagram

2.3.3 Status of BNR Upgrades

As part of the FANCJ, NYCDEP was required to upgrade the Jamaica WRRF to Level 2 BNR treatment, i.e., Advanced Basic BNR. These upgrades completed as of December 31, 2014.

The following upgrades were made to convert the Jamaica WRRF to Advanced Basic BNR:

- Modifications to the existing process air blowers and air blower controls to improve DO control.
- Air distribution piping sized to accommodate the higher BNR air flow requirements.
- Air diffuser grid patterns modified to facilitate the installation of tank baffles and additional air diffuser drop pipes to accommodate the modified grids.
- Baffles installed within the ATs to establish specialized process zones (anoxic, switch, pre-anoxic, and oxic (also referred to as aerobic)).
- Hyperbolic mixers installed in the anoxic, switch, and pre-anoxic zones to allow for complete mixing without aeration.
- SWAS Pump Stations and other froth control modifications provided in the ATs.
- Secondary settling tank sludge collection mechanisms replaced with parabolic scrapers designed to rapidly collect settled solids.
- Sludge blanket indicators added to allow the sludge blanket level to be carefully managed and controlled.

Upgrades for supplemental carbon addition to the Jamaica WRRF were designed and implemented to optimize nitrogen removal and reduce nitrogen discharges to the sensitive Jamaica Bay water body.

The system includes three (3) glycerol storage tanks, each with a nominal capacity of 10,400 gallons, which accepts deliveries of glycerol that meet the NYCDEP glycerol specification. Depending upon the specification, the delivered product must consist of a minimum percentage glycerol solution (typically 65 to 70%) with a minimum COD content of approximately 900,000 to 1,000,000 mg/L.

These upgrades for supplemental carbon addition were placed into operation August 28, 2016.

2.3.4 Effluent Permit Limits

2.3.4.1 Effluent Total Nitrogen Load

See Section 2.2.4.1

2.3.4.2 Effluent Ammonia Concentration

NYSDEC has issued a draft revised SPDES permit for the Jamaica WRRF that includes a strict monthly average effluent ammonia limit (as NH_3) of 3.4 mgN/L from May through October and 3.70 mgN/L from November through April.

An interim monthly average ammonia limit of 18 mg/L is in effect while the facility complies with the compliance schedule provided **Table 2-6**, as outlined in the compliance schedule section of the Jamaica WRRF SPDES permit (NY-0026115).

2.3.5 Current BNR Practices and Optimization Techniques

Table 2-5 summarizes the Jamaica WRRF's current BNR practices and optimization techniques.

Jamaica plant staff identified operational strategies for the various elements of BNR operation (e.g., solids inventory, aeration, chemical addition, etc.) best suited for Jamaica WRRF based on the plant's specific BNR related equipment and configuration, including use of instrumentation for automated operation. Generally, Jamaica WRRF has been operating within the BNR operational guidelines discussed in **Chapter 5**.

Table 2-5: Jamaica WRRF Current BNR Practices

BNR Area of Focus	Current Operational Practice
Solids Inventory Management	• Solids inventory targets consistent with BNR operational guidelines in **Chapter 5**. • Wasting is primarily accomplished via SWAS system.
Process Aeration/ATs	• Aeration targets are consistent with BNR operational guidelines in **Chapter 5**. • Plant uses a constant pressure control strategy.
PE Flow Splits	• Target PE flow splits are consistent with BNR operational guidelines in **Chapter 5**.
Foam Control	• Surface wasting is plant's main mechanism for foam prevention and control.
Chemical Addition	• Nitrate probe strategy for glycerol addition.
Wet Weather Strategy	• Pass D gates are motorized and are manually adjusted during wet weather events.
Instrumentation	• NO3 probes are installed for automation of glycerol addition based on NO3 readings in ATs. • DO probes are installed to provide feedback information to control air required in each Pass of each AT.

2.3.6 Plant Nitrogen Removal Performance

Effluent nitrogen speciation from April 2010 through May 2019 is shown in **Figure 2-10**. From pre-BNR operation, effluent nitrogen loads from Jamaica WRRF have decreased by 56 percent from an average of effluent TN load of 13,300 lb/d (May 1, 2010 through December 31, 2014) to an average effluent TN load of 5,900 lb/d (August 31, 2016 through May 31, 2019) and overall nitrogen removal has increased from an average of 40% TN removal (April 1, 2010 through December 31, 2014) to an average of 75% TN removal (August 31, 2016 through May 31, 2019).

Table 2-6: Jamaica Schedule of Compliance for Effluent Ammonia Limits

Compliance Action	Due Date	Status
The Permittee (NYCDEP) shall revise the Jamaica Bay Phase I Post Construction Monitoring (PMC) Plan, received on June 30, 2015, to include a three-year ambient water quality monitoring program to sample for un-ionized ammonia (NH3/NH4-N pH, temperature and salinity) at the edge of the DEC-approved chronic mixing zone for the Jamaica WRRF discharge. The Jamaica Bay Phase I PCM plan shall address sampling and quality assurance/quality control for this sampling program.	Receipt of DEC comments on the Phase I PCM + 30 Days	Submitted March 20, 2017
The Permittee shall commence the ambient water quality monitoring program as part of the approved Jamaica Bay Phase I PCM in accordance with the FANCJ.	In accordance with FANCJ Appendix B Milestones	Commenced July 31, 2016
The Permittee shall undertake a 12-month performance evaluation to establish performance-based interim limits for ammonia beginning 6 months after commencement of operation of the Level 2 BNR upgrade at the Jamaica WRRF. The Permittee shall submit the performance data from the performance evaluation period to the Department within 30 days of the end of the 12-month performance period. The Department shall calculate performance-based limit using methods consistent with TOG 1.3.3. The 95th Percentile value of the individual sampling data points will be used for the interim monthly average limit. Based upon this information, the Department may reopen the permit to revise the interim ammonia limit to reflect the limits.	Performance data due on July 30, 2016	Submitted
The Permittee shall submit the results of the three-year ambient water quality monitoring program in an approvable ambient water quality monitoring report to the Department in accordance with the approved Jamaica Bay Phase I PCM plan and the FANCJ.	In accordance with FANCJ Appendix B Milestones	TBD
Upon review and approval of this report, the Department will notify the Permittee in writing whether the ammonia water quality standard is met with the Jamaica WRRF operating in accordance with the performance-based limits and will recalculate the seasonal ammonia limits. If the sampling results demonstrate that the ammonia water quality standard is being achieved while the Jamaica WRRF is operating at the performance-based limits, the Department will evaluation making the performance-based limits the permit limits. Based on the results, the Department may reopen the permit to revise the ammonia limits.	Receipt of the ambient water quality monitoring report + 6 months	TBD
If the Department determines that the ambient water quality monitoring program demonstrates that the ammonia water quality standard is not met, the Department will use the data from the ambient water quality monitoring to recalculate the seasonal ammonia limits for the Jamaica WRRF. Based upon this information, the Department may reopen the permit to revise the ammonia limits to include the recalculated limit. The Permittee shall conduct a feasibility study and engineering analysis of potential alternatives necessary to comply with the recalculated seasonal ammonia limits. The Permittee shall submit this information in an approvable report to the Department. As part of this submission, the Permittee may propose; and the Department will review in good faith; an effluent variance for ammonia, if any, pursuant to the FANCJ, Section IV; and in accordance with Part 750-1.7.	Department notification that WQ standard is not met + 24 months	TBD
If treatment system upgrades are determined to be necessary, the Permittee shall submit approvable final plans and specifications, as well as a schedule of construction, for the facilities described in the approved Engineering Report.	DEC Approval of Feasibility Study and Engineering Analysis Report + 36 months	TBD
The Permittee shall construct the facilities described in the approved report, plans and specifications and achieve compliance with the recalculated limit in accordance with the approved schedule of construction.	In accordance with the approved schedule	TBD

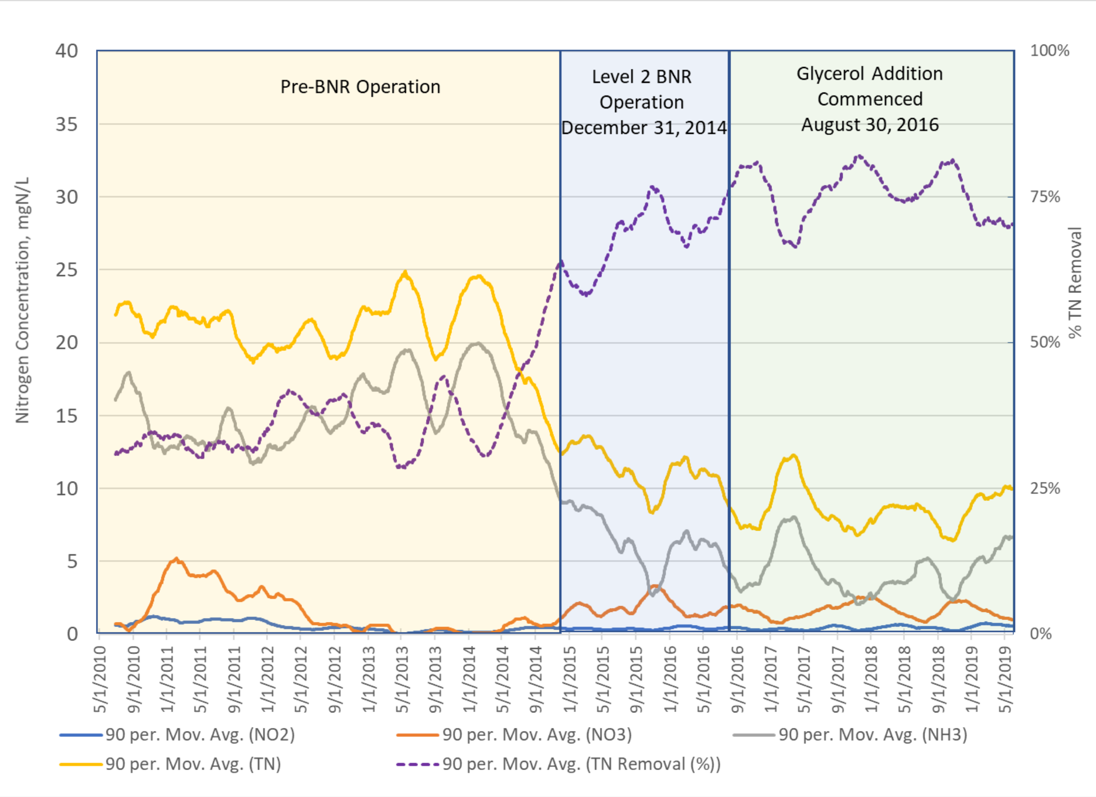


Figure 2-10: Jamaica WRRF Effluent Nitrogen Speciation – May 2010 through May 2019

2.4 Coney Island WRRF

2.4.1 Plant History

The Coney Island WRRF is located on a 30-acre site at 2591 Knapp Street in the Sheepshead Bay section of Brooklyn, NY, including 8-acres in use for public recreational facilities. The site borders Avenue Y to the north, Voorhies Avenue to the south, Coyle Street to the east, and Shell Bank Creek to the east, as shown in **Figure 2-11**. The facility serves an area of almost 15,000-acres, treating wastewater from a combined sewage collection system. The facility is permitted by the NYSDEC through SPDES permit number NY-0026182.

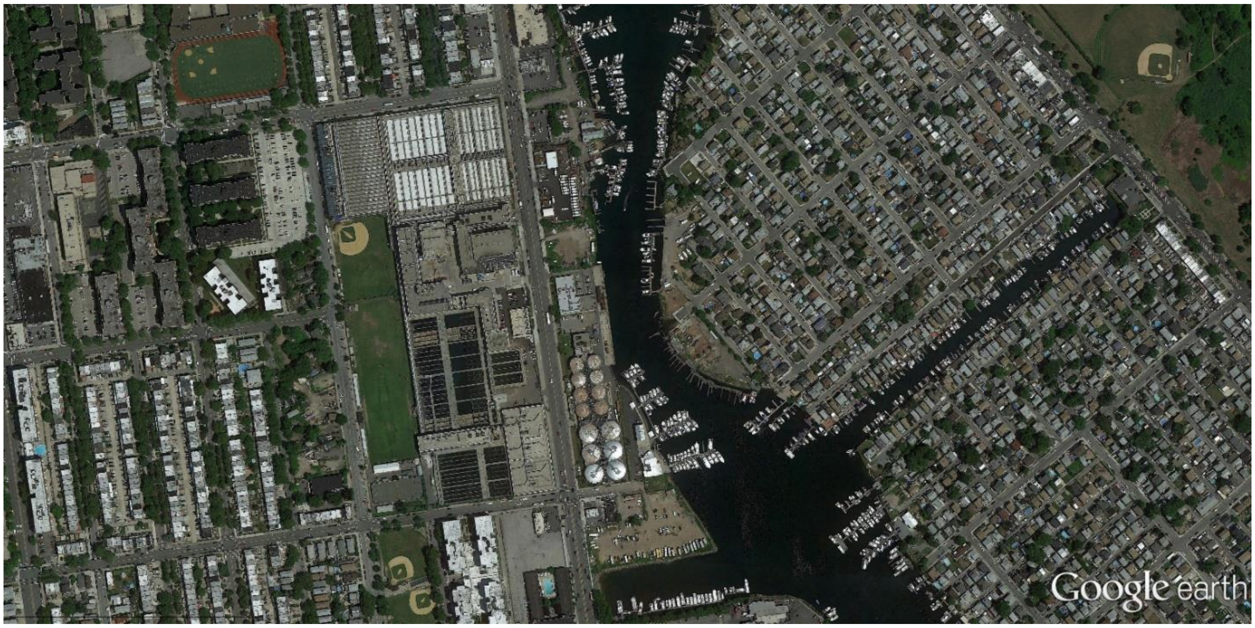


Figure 2-11: Coney Island WRRF Site

The facility was constructed in 1935 and has since undergone several upgrades. Originally the Coney Island WRRF operated with chemical treatment, sedimentation, and sludge digestion. In the 1940s, the sedimentation tanks, pump and blower house, and gas holders were upgraded. In 1958, the Coney Island WRRF was upgraded to include secondary treatment via a modified aeration process utilizing biological treatment to remove 50 percent of the influent BOD and TSS. Upgrades included enhancements to ATs, grit tanks, sedimentation tanks, raw sewage pumps, blowers, and sludge thickeners. The facility began full secondary upgrades from 1983 to 1993 in compliance with the Clean Water Act. Multiple improvements were made to the sludge handling facilities, which were comprised of primary sludge degritting, waste sludge screening, gravity thickeners, anaerobic digesters, gas holding tanks, and sludge storage. Other upgrades included new main sewage pumps, new screen chambers, rehabilitated grit tanks, new primary settling tanks, new hypochlorite contact tanks, as well as expanded aeration and final settling facilities

The current facility has a design dry weather flow (DDWF) of 110 MGD, with a maximum capacity of 220 MGD (two times DDWF). A total of 165 MGD (1.5 times DDWF) can receive secondary treatment, with excess flow treated through primary treatment and disinfection processes.

The facility currently treats an average daily flow of 88 MGD (2015 through 2017). The plant inflow is provided by two interceptors:

- A 120-inch diameter Paerdegat interceptor provides 70 percent of plant inflow from the regions north and east of the facility.
- An 84-inch interceptor provides remaining flow from the area to the west of the plant

The Coney Island WRRF has an in-line CSO storage facility, the Paerdegat Basin CSO Retention Facility. The facility was designed to capture and store up to 50 million gallon (MG) of CSO and return the CSO to the Coney Island WRRF after the wet weather event subsides. Stored CSO is pumped back through a pump station over a 24 to 48 hours period.

2.4.2 Treatment Process Description

Coney Island WRRF has four covered step-feed ATs, each with four passes, A through D, for secondary treatment. Treated flow leaves Pass D of each AT and enters the secondary clarifiers where the activated biomass settles and is separated from the treated effluent. A portion of the settled biomass is returned to the head of the ATs (Pass A) as RAS, while the remaining portion of the settled biomass is pumped to the gravity thickeners as WAS. A secondary bypass is available when system capacity is exceeded during a wet weather event. Primary sludge and WAS are sent to gravity thickeners following degritting and screening. Thickened sludge flow is directed to the primary and secondary digesters, then stored in sludge storage tanks. Anaerobically digested sludge is then pumped five miles via a 12-inch diameter force main to 26th Ward WRRF for dewatering. Treated effluent from the secondary clarifiers flows over weirs and enters the CCT where it is disinfected with sodium hypochlorite and discharged to Jamaica Bay. The plant is required to treat influent flow through the secondary BNR process up to 1.5 times the design dry weather capacity of 110 MGD (or 165 MGD).

A process flow diagram for the Coney Island WRRF is provided in **Figure 2-12**

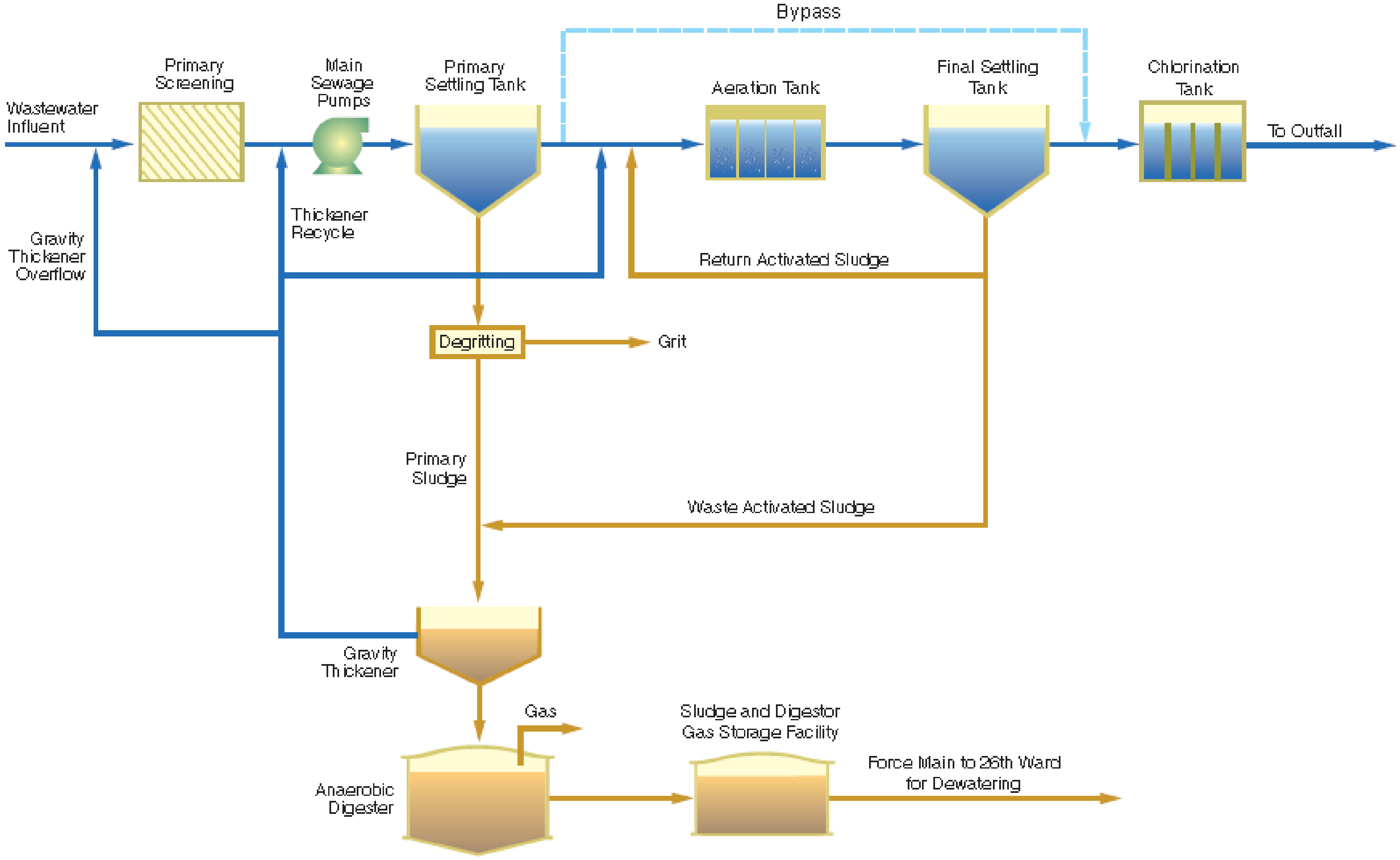


Figure 2-12: Coney Island WRRF Process Flow Diagram

2.4.3 Status of BNR Upgrades

As part of the FANCJ, NYCDEP is required to upgrade the Coney Island WRRF to Level 1 BNR treatment. These upgrades have a Consent Judgment Milestone completion date of October 31, 2022.

In accordance with DEC-approved designs, the Coney Island WRRF will receive the following upgrades to convert to Level 1 BNR:

- Installation of permanent baffle walls to create specialized process zones for nitrification and denitrification. There will be two zones (aerobic and anoxic) per pass. One baffle will be installed in each pass of the ATs to separate the two zones, for a total of four baffle walls per tank.
- Installation of hyperbolic mixers in each anoxic zone to provide sufficient mixing energy to keep mixed liquor solids in suspension, prevent stagnant pockets, and minimize surface turbulence.
- Installation of DO probes to improve DO control in the ATs.
- Modification of existing AT skimmer box to provide the plant the ability to surface waste from Passes A, B, and D of each AT.
- Polymer feed system and spray water system to combat anticipated foaming issues.
- Air diffuser grid patterns modified to facilitate the BNR tank configuration and installation of tank baffles.
- Modification of air distribution pipe to accommodate the new baffle wall zones.

A schematic layout of the proposed aeration tank zones and baffle location for Coney Island is shown in **Figure 2-13.**

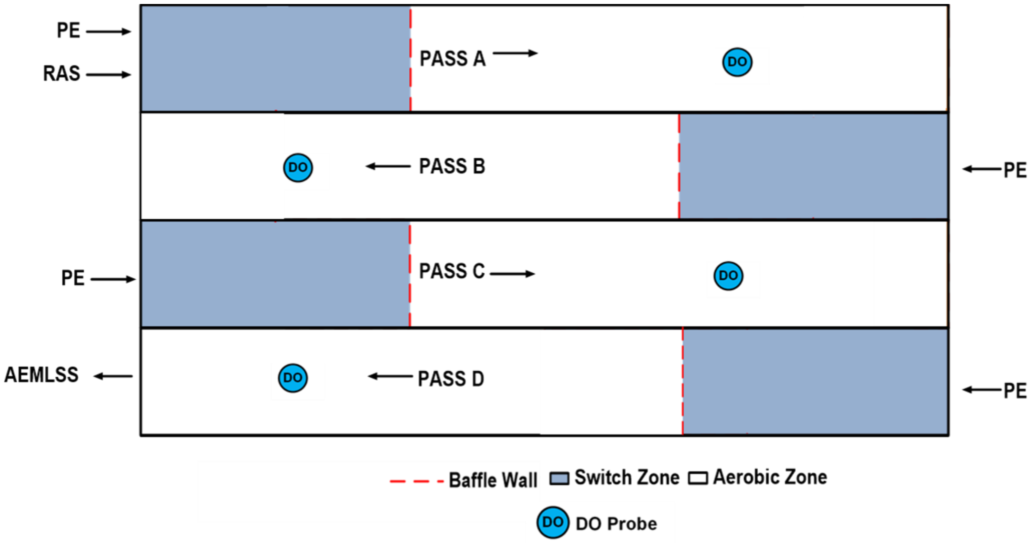


Figure 2-13: Coney Island WRRF Aeration Tank Schematic

2.4.4 Effluent Permit Limits

2.4.4.1 Effluent Total Nitrogen Load

See Section 2.2.4.1

2.4.4.2 Effluent Ammonia Concentration

The current NYS SPDES permit (NY-0026182) for the Coney Island WRRF does not have a monthly average effluent ammonia concentration limit, however, the plant is required to monitor effluent ammonia concentrations.

2.4.5 Current BNR Practices

Upgrades for Level 1 BNR operation are currently under construction. Currently, the plant is operating conventional biological treatment for BOD and TSS removal.

2.4.6 Plant Nitrogen Removal Performance

Effluent nitrogen speciation from May 2010 through May 2018 is shown in **Figure 2-14**. Although not yet a BNR facility, Coney Island removes on average 42% of the influent TN load and discharged an average effluent TN load of 13,400 lb/d from May 1, 2010 through May 31, 2018.

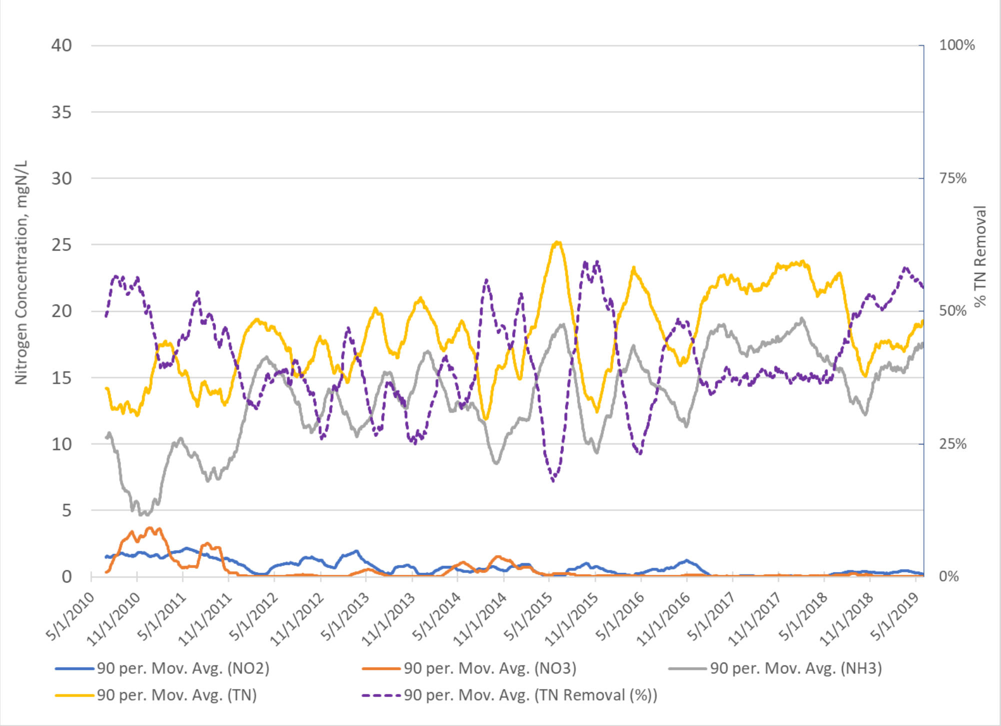


Figure 2-14: Coney Island WRRF Effluent Nitrogen Speciation – May 2010 through May 2019

2.5 Rockaway WRRF

2.5.1 Plant History

The Rockaway WRRF is located at 106-21 Beach Channel Drive, Rockaway, on the Rockaway Peninsula and borders the Rockaway Freeway in Queens, NY, as shown in **Figure 2-15.** The facility serves an area of 6,259-acre, treating wastewater from communities on the Rockaway Peninsula. The facility is currently permitted through NYSDEC SPDES permit number NY-0026221.

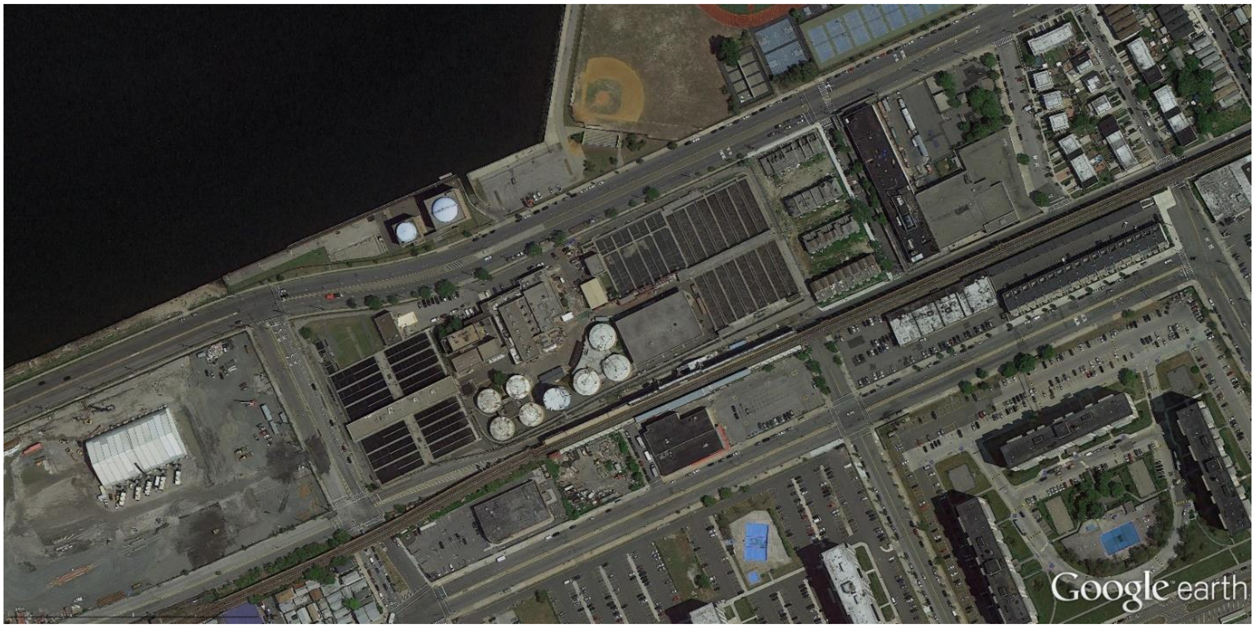


Figure 2-15: Rockaway WRRF Site

The facility was constructed in 1952 to treat 15 MGD. Upgrades in 1962 increased treatment capacity to 30 MGD. Notable modifications occurred in 1978, when a secondary treatment system was installed for a DDWF of 45 MGD with a 90 MGD (two times DDWF) peak hydraulic flow loading. The current plant specifications can achieve 67.5 MGD (one and a half times DDWF) through secondary treatment. Influent flows between 67.5 and 90 MGD undergo primary treatment and disinfection before discharge to Jamaica Bay. The facility currently averages a daily flow of 17 MGD (2015 through 2017).

2.5.2 Treatment Process Description

Rockaway WRRF has four step-feed ATs, each with four passes, A through D, for secondary treatment. Treated flow leaves Pass D of each AT and enters the secondary clarifiers where the activated biomass settles and is separate from the treated effluent. A portion of the settled biomass is returned to the head of the ATs (Pass A) as RAS, while the remaining portion of the settled biomass is pumped to the gravity thickeners as WAS. A secondary bypass is available when system capacity is exceeded during a wet weather event. Primary sludge and WAS are sent to gravity thickeners following degritting and screening. Thickened sludge flow is directed to the primary and secondary digesters, then stored in sludge storage tanks. Anaerobically digested sludge is delivered to 26th Ward WRRF for dewatering via boat. Treated effluent from the secondary clarifiers flows over weirs and enters the CCT where it is disinfected with sodium hypochlorite and discharged to Jamaica Bay).

A process flow diagram for the Rockaway WRRF is provided in **Figure 2-16**.

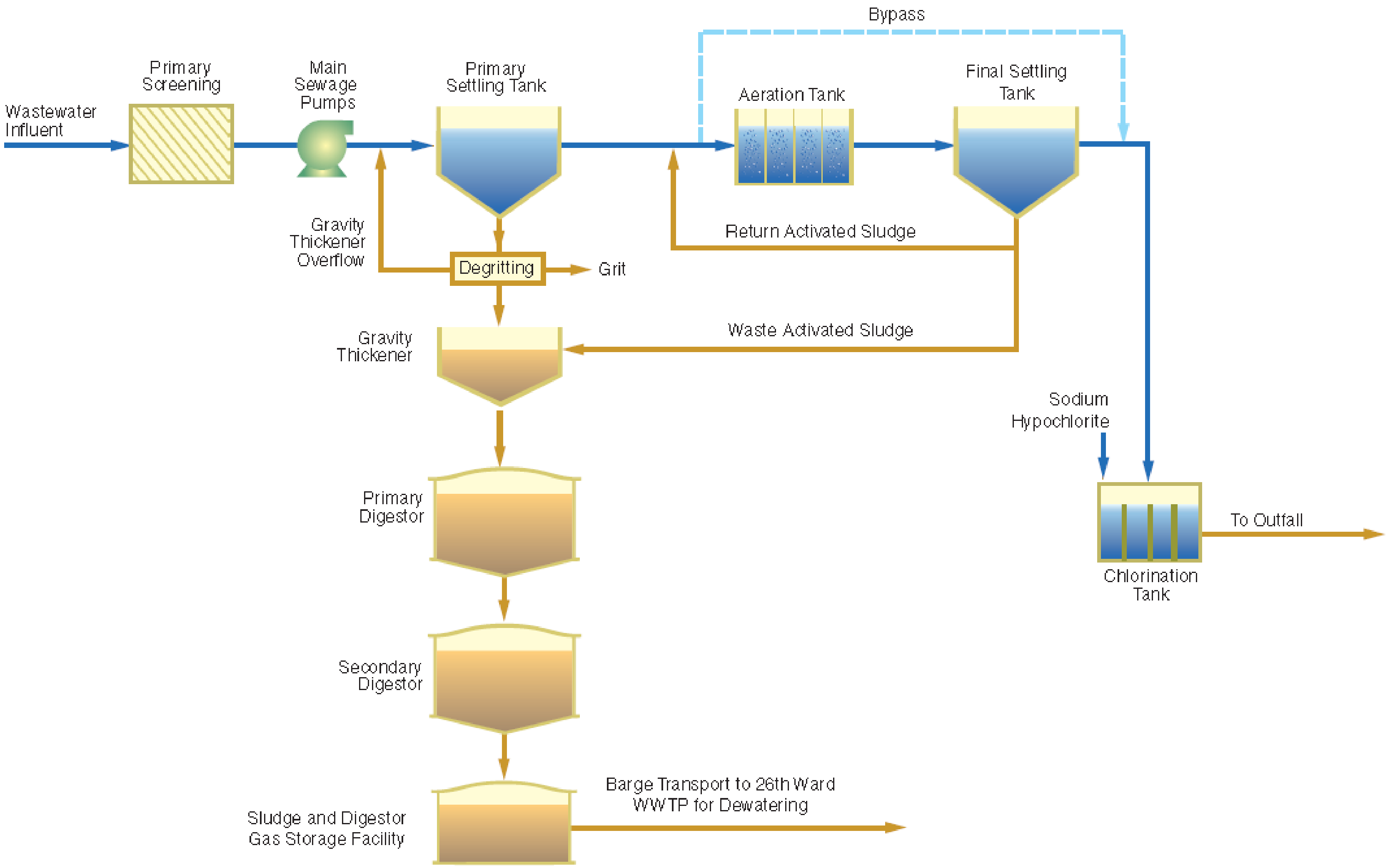


Figure 2-16: Rockaway WRRF Process Flow Diagram

2.5.3 Status of BNR Upgrades

As part of the FANCJ, NYCDEP was required to upgrade the Rockaway WRRF to Level 1 BNR treatment. These upgrades have a Consent Judgment Milestone completion date of December 31, 2019.

In accordance with DEC-approved designs, the following upgrades are currently under construction to convert the Rockaway WRRF to Level 1 BNR:

- Installation of permanent baffle walls to create specialized process zones for nitrification and denitrification.
- Installation of hyperbolic mixers in each anoxic zone to provide sufficient mixing energy to keep mixed liquor solids in suspension, prevent stagnant pockets, and minimize surface turbulence.
- Upgrades to valves for the existing RAS/WAS pumping system.
- Replacing existing spray water systems and addition of polymer feed system to combat the anticipated froth issues.
- Air diffuser grid patterns modified to facilitate the BNR tank configuration and installation of tank baffles.
- Modification of air distribution pipe to accommodate the new baffle wall zones.
- Installation of DO probes to improve DO control in the ATs.
- Polymer feed system and spray water system to combat anticipated foaming issues.

A schematic of the proposed aeration tank zones and baffle walls for Rockaway is shown in **Figure 2-17**.

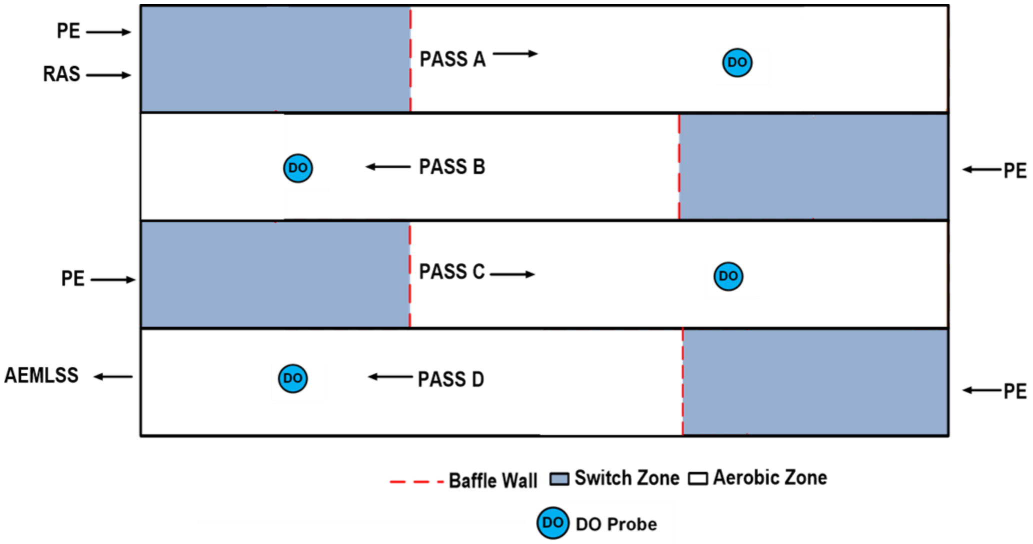


Figure 2-17: Rockaway WRRF Aeration Tank Schematic

2.5.4 Effluent Permit Limits

2.5.4.1 Effluent Total Nitrogen Load

See Section 2.2.4.1

2.5.4.2 Effluent Ammonia Concentration

The current NYS SPDES permit (NY-0026221) for the Rockaway WRRF does not have a monthly average effluent ammonia concentration limit; however, the plant is required to monitor effluent ammonia concentrations.

2.5.5 Current BNR Practices

Upgrades to Level 1 BNR are expected to be completed on December 31, 2019. Currently, the plant is operated as conventional biological treatment for BOD and TSS removal.

2.5.6 Plant Nitrogen Removal Performance

Effluent nitrogen speciation from May 2010 through May 2019 is shown in **Figure 2-18**. Although not yet a BNR facility, Rockaway removes on average 40% of the influent TN load and discharged an average effluent TN load of 1,900 lb/d from May 1, 2010 through May 31, 2018.

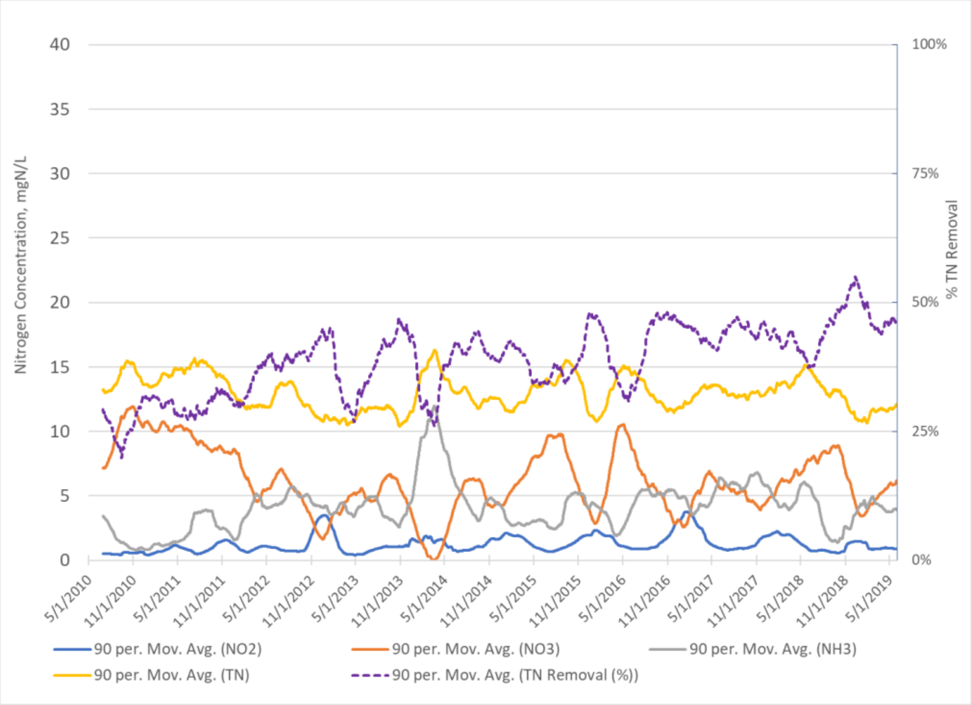


Figure 2-18: Rockaway WRRF Effluent Nitrogen Speciation – May 2010 through May 2019

3 Technology Evaluation

The objective of the Jamaica Bay Feasibility Study is to evaluate the applicability and potential performance of available nitrogen-removal technologies and optimization techniques at all four Jamaica Bay wastewater treatment facilities. Prior to the detailed technology evaluation, a list of existing BNR technologies encompassing both proven and emerging technologies for mainstream and sidestream treatment was developed. Subject matter experts were consulted and assisted in assembling the comprehensive lists of technologies. The listed mainstream and sidestream technologies are discussed further in Section 3.2 and 3.3 of this document, respectively. All listed technologies were evaluated using the Innovative Technology Evaluation Protocol (ITEP) developed under the PO-88 project (Managing Innovation: Optimizing Resource Allocation Using New York City's Innovative Technology Prioritization Tool, presented at WEFTEC 2010). The ITEP is discussed further in Section 3.1 of this document. All of the final technologies selected were deemed appropriate for implementation at specific Jamaica Bay WRRFs and would be able to meet or exceed the current TN and ammonia standards at each plant. At least one on the final technologies selected for each plant was able to achieve Limit of Technology (LOT) treatment level resulting in an effluent TN of 3-4 mgN/L.

Limit of Technology is defined as the lowest effluent concentration achievable by using any treatment technology or suite of technologies. As there is no regulatory definition or consensus for LOT, LOT for BNR is assumed to be 3 - 4 mg/l for total nitrogen (TN) based on existing nitrogen discharge permits in locations such as the Chesapeake Bay.

At the Jamaica and 26th Ward WRRFs, the selected technologies were also able to meet the proposed effluent ammonia limits. **Table 3-1** shows the current and projected effluent TN ranges for each Jamaica Bay WRRF, as well as the current permit ammonia standard.

Table 3-1: Total Nitrogen and Proposed Ammonia Effluent Targets/Standards for Jamaica Bay WRRFs

Plant	Current/Pending BNR Process	Predicted Effluent TN Range* (mgN/L)	Proposed Permitted Ammonia Limit** (mgN/L)
26th Ward	Full-step BNR with Carbon (Level 3 BNR)	5 - 9	1.3 *(Nov. – Apr.)* 1.25 *(May – Oct.)*
Jamaica	Full-step BNR with Carbon (Level 2+ BNR)	7-11	3.4 *(Nov. – Apr.)* 3.7 *(May – Oct.)*
Rockaway	Retrofit Level 1 BNR	12-16+	N/A
Coney Island	Retrofit Level 1 BNR	12-16+	N/A

*From the Amendment to the Comprehensive Jamaica Bay Report, April 2011

**Interim limit pending completion of scheduled Post Construction Monitoring and Performance Evaluation

+Projected effluent TN range once current BNR upgrades are completed.

3.1 Innovative Technology Evaluation Program (ITEP)

The ITEP was developed in 2009 under the NYCDEP's PO-88 Applied Research Project, with the purpose of serving as a standardized mechanism for DEP to objectively evaluate innovative technologies and provide continuity within the DEP knowledge base. Long-term experience with identification, evaluation, and implementation of innovative technologies has shown that a structured framework allows decision makers to select the most appropriate technologies for their specific needs. The ITEP focuses on assessing four general topic areas, with multiple questions (typically 5-10) for each specific topic area. The four general topic areas include:

- **Technology Fundamentals:** An assessment of the strength of the fundamental principles upon which the evaluated technology is based and the general acceptance of those principles by the scientific community.
- **Technology Maturity:** An evaluation of engineering and technical considerations related to the maturity of the technology in the wastewater treatment marketplace. This may include parameters related to the level of research and development (R&D) supporting the technology, the scale of technology testing and implementation, number of units in operation, etc.
- **Implementation within DEP:** An assessment of the applicability of the technology at DEP WRRFs with a focus on operational considerations and the ability to employ the technologies at specific Jamaica Bay facilities. This assessment will identifies and evaluates risks associated with the deployment of specific technologies in NYC, including site constraints, existing process limitations, local impacts, variability in operational expertise, and future permit limits.
- **Institutional Compatibility:** An evaluation of the ability of the technology to meet long-term institutional goals within NYC such as compatibility with other NYC programs and objectives (i.e. 35/20; 80/50, Energy Neutrality, health and safety requirements, etc.).

The ITEP matrix is in **Appendix A**. The left side of the matrix lists the topic area, category within the topic area, and associated question/description. The right side of the document provides the basis for scoring, with 0 being the lowest and 3 being the highest score achievable for each question. The scores for each topic area were weighted based on importance and applicability to DEP. Weightings for each topic were developed based on input from the NYCDEP, and are as follows:

Technology Fundamentals:	15 percent
Technology Maturity:	15 percent
Implementation at DEP:	40 percent
Institutional Compatibility:	30 percent

The maximum score achievable for each individual technology is 100 points. While the overall BNR process configuration for treatment needs to consider the entire plant as a whole and to provide an overall system score, the individual technology score is an important step in understanding the likely technologies that will fit within the overall system. The mainstream technologies that were evaluated, along with their associated ITEP scores are discussed in **Sections 3.2.1** and **3.2.2** of this document. Evaluated sidestream technologies and their associated ITEP scores are discussed in **Sections 3.3.1** and **3.3.2**. The top-scoring mainstream and sidestream technologies were screened for each Jamaica Bay WRRF (Rockaway, Jamaica, Coney Island, 26th Ward). In the ITEP evaluation process, 26th Ward and Jamaica were evaluated as a group since they each have relatively stringent proposed ammonia standards and both plants already have Level 2 BNR with carbon. Rockaway and Coney Island were also grouped together in the ITEP evaluation as they will both have Level 1/Retrofit BNR without carbon once current upgrades are completed and either plant has proposed ammonia limits. For each WRRF, at least one selected technology will result in effluent Total Nitrogen (TN) of 3-4 mgN/L. For Jamaica and 26th Ward, technologies that could alone meet the effluent ammonia standard were also included in the evaluation, as were combination technologies that could meet the proposed ammonia standard as well as a more stringent TN standard (e.g. Integrated Fixed Film Activated sludge with Denitrification filters). It should be noted that the proposed ammonia standards for 26th Ward and Jamaica will be re-evaluated based on the results from the FANCJ required post construction ambient water quality monitoring and the 12-month individual plant performance period, as detailed in the 26th Ward and Jamaica WRRF SPDES permit compliance schedules.

3.2 Mainstream Treatment Alternatives

The first task in evaluating nitrogen removal technologies for the Jamaica Bay Feasibility Study was to develop a list of mainstream treatment technologies. Subject matter experts were consulted during the development of the list of technologies, and the subject experts were also involved in evaluating the technologies using ITEP. The final list of mainstream technologies included 26 technologies, ranging from well-established Advanced Step BNR to emerging technologies such as NEREDA® and Membrane Aerated Biofilm Reactors, as shown in Error! Reference source not found.. Some of these technologies w ere not considered for specific plants, as those plants either already use the technology or the employ a technology the exceeds the performance of the technology. For examples, Jamaica has Level 2+ BNR and 26th Ward already has Level 3 BNR, so Advanced Step BNR (Level 2) and Full-Step BNR with Carbon (Level 3) were not evaluated for either Jamaica or 26th Ward. A brief description of each mainstream alternative is given in **Section 3.2.1**of this document.

Table 3-2: Mainstream Alternatives Summary

A/B Process	Mainstream Deammonification
Advanced Basic Step-feed BNR	Membrane Aerobic Biofilm Reactor (SABRE/MABR/Z-lung)
Ballasted Flocculation	Membrane Aerobic Biofilm Reactor + Denite Process (filters or MBBR)
Battery Level E Equivalent BNR	Membrane Bioreactor (MBR)
BNR with add-on Denitrification Process (filters, MBBR)	Moving Bed Biofilm Reactor (MBBR)
Chemically Enhanced Primary Treatment (CEPT) with full step feed BNR (with Carbon)	n-DAMO
Full Step-feed BNR with Carbon Addition	NEREDA
HYBACs	Nitrification/ Denitrification BAF
inDENSE®	Nitritation/ Denitritation
Integrated Fixed Film Activated Sludge (IFAS)	Partial Denitratation Deammonification (PDNA)
IFAS + Denite Process (filters or MBBR)	Reverse Osmosis (RO)
Ion Exchange	SND with Dynamic Aeration Control - ABAC and AvN
Mainstream anaerobic MBR + n-DAMO	Tertiary algae process

3.2.1 Mainstream Treatment Alternatives

The mainstream treatment alternatives as shown in Error! Reference source not found. are described in t his section. It is recognized that multiple permutations of processes can be developed; for clarity terminology used in the NYC BNR program is used where possible. Advanced primary treatment options that could be integrated into the core nitrogen removal processes are discussed, followed by the biological nitrogen process, and tertiary nitrogen removal treatment process.

3.2.1.1. Adsorption/Bio-oxidation (A-B) Process

The A/B process is a high rate carbon removal or A-stage followed by biological nutrient removal (BNR) or B-stage with ammonia-based cyclic aeration control. A-stage utilizes a very high rate activated sludge (HRAS), typically with 6-12 hours solid retention time (SRT), and 15-30 minutes hydraulic retention time (HRT) operated at a DO of 0.5-1 mg/L. The aim of the HRAS process is to provide a cost-effective means of removing carbon in the raw wastewater while decreasing aeration demand and volume required for the subsequent B-stage process, which is some form of BNR configuration.

The A-stage process consistently removes approximately 50-60% of the influent particulate and soluble COD and between 20-35% of total nitrogen. As much as 1/3rd -1/2 of carbon and nitrogen inventory can be redirected thus leveraging similar additional treatment capacity for B-stage BNR. Furthermore, plants that have sludge treatment capacity or are planned as resource recovery centers or have planned sidestream treatment should consider the A-B type approach from a system evaluation perspective. Typically, sidestream treatment is needed for A-B plants to autotrophically manage at least 15-20% of the nitrogen stream. The higher amounts of carbon redirected will need to be managed within the sludge stream. In the absence of sidestream deammonification, carbon removal in the A-stage results in B-stage denitrification operating in carbon-limited conditions. Thus, it may require the system to take advantage of simultaneous nitrification-denitrification (SND) and/or mainstream nitritation/denitritation (nitrite shunt) to avoid external carbon supplementation. The former is accomplished by ammonia-based cyclic aeration control (ABAC) system, the latter through a more refined control approach that integrates residual ammonia control and dissolved oxygen control. This control allows the reactors to maintain DO levels low enough to support SND and/or nitrite shunt, yet high enough to achieve nearly complete nitrification with effluent total inorganic nitrogen (TIN) values in the range of 4-6 mg-N/L, the majority of that being in the form of ammonia.

SND typically is not an appropriate solution for capacity limited plants as the low DO operations entail lower operating rates and higher capacity requirements. However, nitrite shunt with transient anoxia is more suitable. Here, the reactor moves between higher DO levels of > 1.5 mg/L (to maximize aerobic rates and minimize aerobic volume needed) and anoxic conditions to achieve the shunt. Voth NOx and ammonia values are managed through air cycling, to maximize treatment efficiency and capacity use. As the A/B process has matured since its original development in the early 70’s, multiple configurations have been developed, with the goal of facilitating its deployment within existing facilities. Thus, one type of A-stage process is the “Triple A” process where the A-stage is retrofitted within existing primary tanks of approximately 2 h of hydraulic retention time. A process flow diagram of a typical A/B process configuration is shown in **Figure 3-1.**

By achieving a significant reduction in BOD within the A-stage, the compatibility of the A/B process with future mainstream deammonification technologies is enhanced, whether using granular activated sludge or a moving bed bioreactor type configuration.

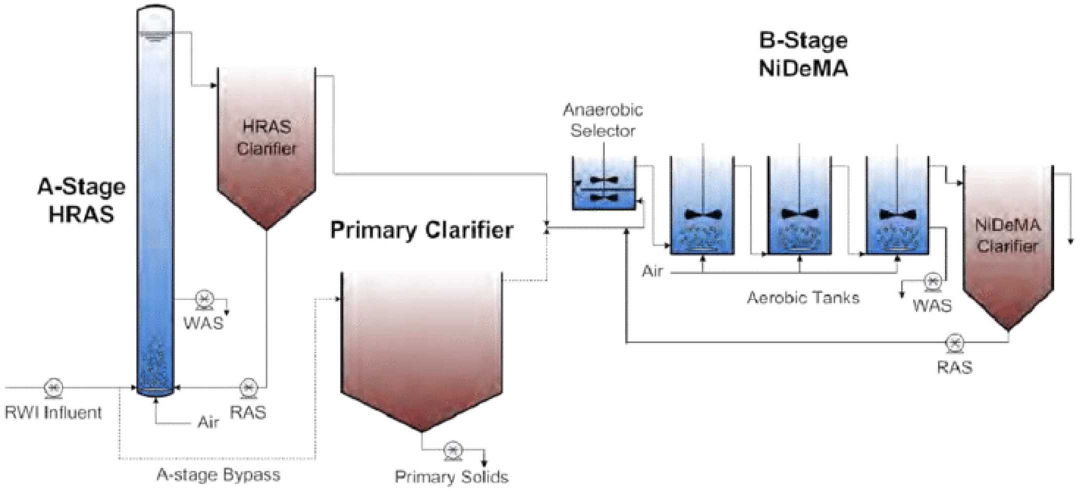


Figure 3-1: Schematic of the A/B Process Pilot Study Including the Primary Clarifier Bypass

3.2.1.2. Chemically Enhanced Primary Treatment (CEPT) with full step feed BNR with Carbon

CEPT employs chemical coagulants (such as metal salts) and flocculation to increase the settling velocity of suspended solids in sedimentation basins. Compared to conventional treatment processes, CEPT requires a smaller footprint for water treatment infrastructure, such as primary and aeration basins. · The CEPT process can achieve similar COD removals as A-stage with additional wet-weather handling capabilities. Due to the destruction of alkalinity by the coagulation chemicals (ferric chloride, $FeCl_3$, typically) a supplemental alkalinity source would be required (typically caustic soda, NaOH). However, CEPT discharges contain higher nitrogen concentrations than an A-stage process thus producing lower carbon to nitrogen ratios than needed to support BNR without external carbon. The addition of a Full Step-feed BNR in series would provide secondary nitrogen removal through carbon-enhanced nitrification and denitrification. Error! Reference source not found. shows a schematic of the CEPT p rocess.

The primary advantages for facilities that use CEPT within their process configuration is the higher primary solids removal rates, to include removal of colloidal material that normally will pass through the primary tanks as it would not settle. The key disadvantages relate to the need to transport, store and apply large volumes of corrosive chemicals (ferric chloride and caustic) in the process, the need to expand the solids handling facilities to handle the increased mass of inert chemical precipitates formed and the significant increase in biosolids produced that would need to be transported out of the plants.

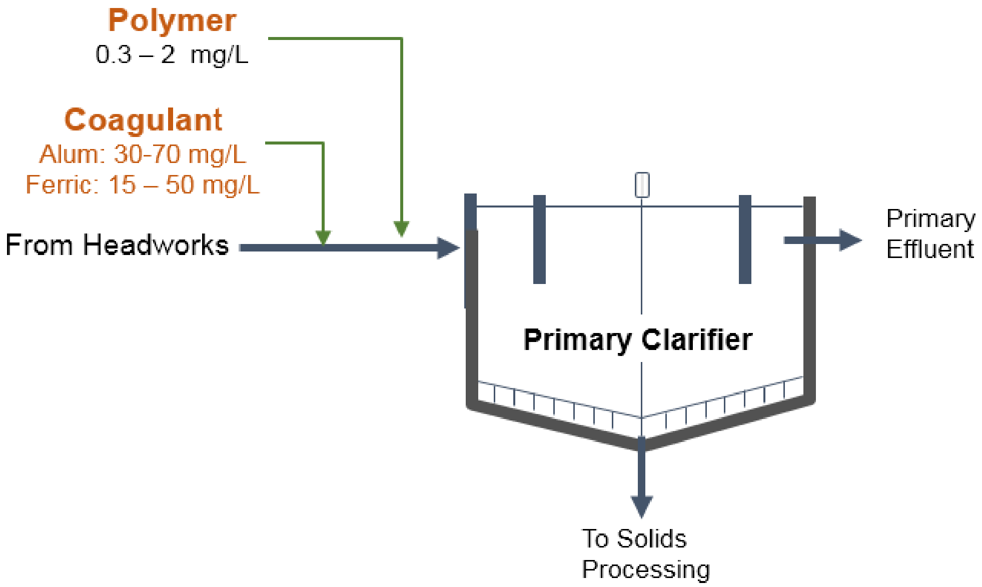


Figure 3-2: CEPT Schematic

3.2.1.3. Ballasted Flocculation

Ballasted flocculation is a high-rate, physical-chemical clarification process involving the fixing of flocs/suspended solids, onto ballast (micro-sand) with the aid of a polymer, which produces high-density floc that settles nearly 10 times faster, thus enhanced reduction of suspended solids and biochemical oxygen demand (BOD). Ballasted flocculation is a four-step process; coagulation, flocculation, clarification, and separation. As shown in Error! Reference source not found., screened influent water is mixed with coagulant in the first tank. Coagulated water flows to a flocculation tank and is mixed with polymer and micro-sand to form high-density floc. The floc settles in the clarifier and clarified water passes up through tube settlers and leave the system. Settled floc and sand are pumped to the hydrocyclone where sand is separated from solids. Solids are sent to waste/return and separated micro-sand is returned to the flocculation tank. Ballasted flocculation typically removes >85% TSS, 65% BOD, 25-35% nitrogen, and 80-90% phosphorus.

Ballasted Flocculation is primarily applicable to CSOs/SSOs treatment, but can be used to provide treatment for wet weather flows within the WRRFs. The primary advantages of Ballasted Flocculation lies in the small footprint requirements, as the process can be implemented in existing facilities to increase wet-weather treatment capacity at a fraction of surface area required in comparison to conventional treatment. For CSOs and SSOs, the process requires less footprint than a storage tank, operational costs are incurred only during usage, the process does not require conveyance of flow to wastewater treatment plants.. Among the primary disadvantages, this process requires deployment of staffing to what are typically remote sites during wet weather conditions, a specialized operator skillset that includes physicochemical treatment fundamentals, fine screening to prevent plugging of the hydrocyclones, and complex instrumentation and controls, O&M cost associated with pumping ballast recycle material, uses of chemical and more operation required in comparison to conventional CSO treatment process.

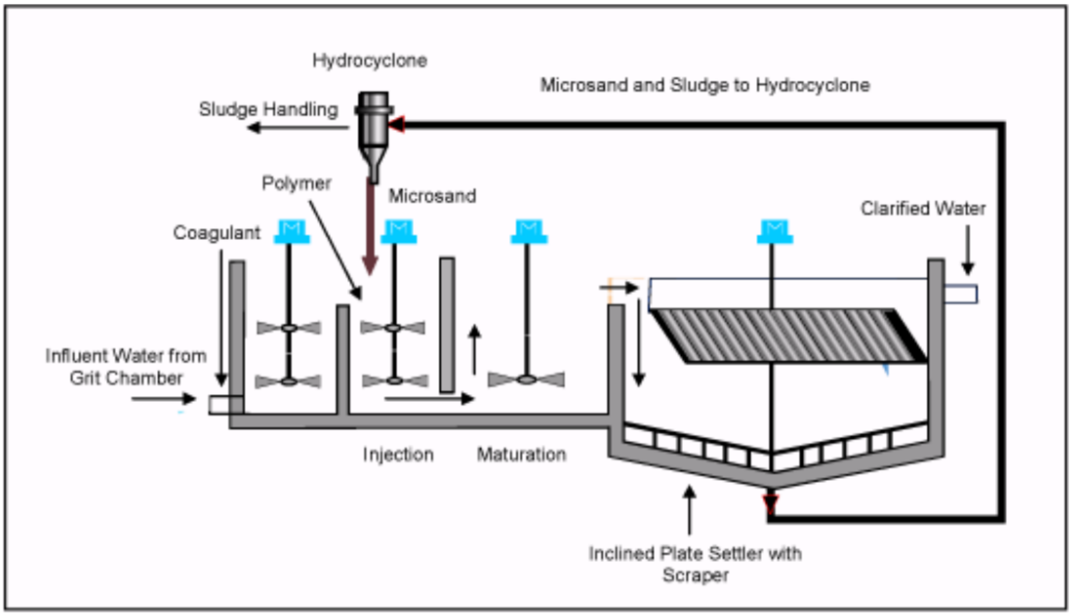


Figure 3-3: Schematic of Ballasted Flocculation Processes

3.2.1.4. Advanced Basic Step-Feed BNR (ABBNR/Level 2 BNR)

Advanced Basic Step-Feed BNR (Level 2 BNR) consists of a four-pass aeration tank system (Passes A-D) where primary effluent (PE) is fed to the head of each Pass. A wet-weather bypass is provided at Pass D, allowing PE to be fed to Pass D during wet weather events to prevent solids washout. PE gates at Passes A-C are manually operated while the gates in Pass D are motorized. RAS is fed to the head of the aeration tank and there is a RAS pumping capacity of 50-60 percent DDWF. Three baffles per Pass are installed – at approximately 16 percent and 33% of the tank (anoxic volume)for Passes A through C, with the third baffle separating the oxic zone from the deoxygenation zone, allowing for the creation of anoxic and oxic zones for denitrification and nitrification, respectively. In Pass D, the baffles are located at approximately 16% and 33% of the tank volume. One or more mixers are installed in anoxic zones, while oxic zones contain a dissolved oxygen delivery system (typically a fine bubble diffuser system). Switch zones may be applied in facilities where wintertime nitrification performance is limiting and would contain both air diffuser grids and mixers, and can function as either oxic or anoxic zones, providing flexibility in treatment processes. Biological froth is controlled via a combination of froth hoods in Passes A and B, RAS chlorination and surface wasting at the end of Pass A, and Pass B with the capacity to waste 100 percent of the wasting load via surface wasting. Monitoring requirements are as follows: blower status, air flow rates per pass, system pressure, DO concentrations, wet weather bypass flow, RAS, WAS, and SWAS flow. Effluent Total Nitrogen (TN) values from the ABBNR process can vary significantly depending on the specific reactor configuration, operating temperature, loadings and reactor volumes, ranging from 6-12 mgN/L.

The primary advantage of the Level 2 Step Feed BNR process outlined above is its compatibility with the existing reactor configuration and footprint available in the Jamaica Bay WRRFs. However, process performance will be limited by the available hydraulic retention times (i.e. reactor volumes versus flow) and secondary clarifier capacity, which will limit the solids inventory that the process can retain.

Whereas Level 2 BNR cannot achieve LOT, it may be coupled with one of the tertiary treatment processes described in the following sections, to attain LOT, if footprint for such as tertiary process is available.

3.2.1.5. Full Step-Feed BNR with Carbon Addition (FBNR – Level 3 BNR)

Full Step-feed BNR with Carbon Addition (Level 3 BNR) consists of a four-pass aeration tank system (Passes A-D) where PE feeds to the head of each pass. There is a wet weather bypass provided at Pass D, allowing PE to feed to Pass D during wet weather events to prevent solids washout. All PE gates are motorized. Passes A-C have 33 percent anoxic volume and 10 percent preanoxic volume while Pass D has 50 percent anoxic volume. A portion of the anoxic volume acts as a switch zone, containing both air diffuser grids and mixers, and can function as either oxic or anoxic zones, providing flexibility in treatment processes. Baffles separate each zone. A Full Step-Feed BNR schematic is shown in Error! Reference source not found.. RAS feeds to the head of the aeration tank, and there is optimized, site dependent RAS pumping capacity.

Chemical addition systems may include caustic, supplemental carbon in the form of glycerol, and polymer. A caustic addition system may be required to feed into Pass A of the aeration tank so the nitrification process is not alkalinity limited. Supplemental carbon addition, in the form of glycerol, to Passes B, C, and D is used to enhance the denitrification process and polymer can be added to the RAS line and spray water system to combat froth. Biological froth is controlled via froth hoods in Passes A and B, and RAS chlorination and surface wasting in each anoxic/preanoxic zone in Passes A and B with the capacity to waste 100 percent of the wasting load via SWAS is also required. Monitoring requirements are as follows: blower status, air flow rates per pass, system pressure, DO concentrations, wet weather bypass flow, RAS and WAS flow, pH, TSS, and NH_3/NO_3. Typical effluent TN values from the FBNR process are 6-10 mgN/L, but will be site specific, dependent on reactor and clarifier volumes and wastewater characteristics.

Whereas Level 3 BNR cannot achieve LOT, it may be coupled with one of the tertiary treatment processes described in the following sections, to attain LOT, if footprint for such as tertiary process is available.

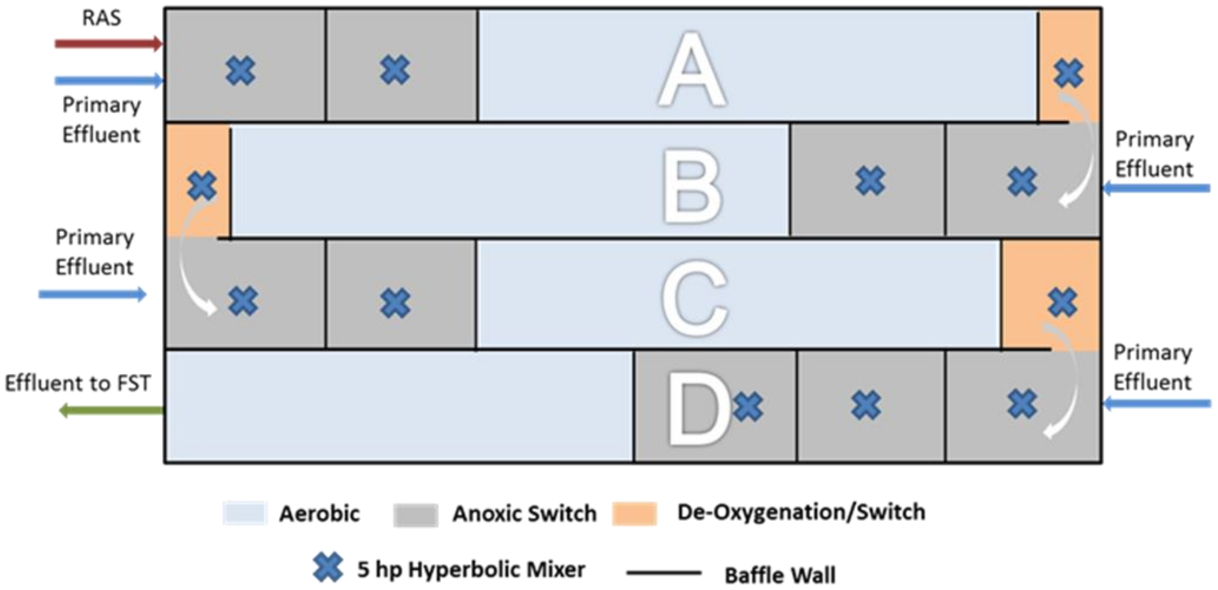


Figure 3-4:Full Step-Feed BNR Schematic

3.2.1.6. Battery E Equivalent BNR (Battery E BNR) (Level 4 BNR)

Battery E at Wards Island WRRF is a full-scale step-feed BNR system utilizing advanced operational features. Because of its advanced operation features, Battery E can be considered Level 4 BNR and outperforms both Advanced Basic Step-feed BNR and Full Step-feed BNR with effluent TNs of 4-5 mg/L, dependent on the available hydraulic retention time and allowable maximum SRT, which is a function of clarifier capacity. Therefore, Battery E BNR was considered as a mainstream technology that could be applied to other DEP WRRFs. Battery E BNR consists of a four-pass aeration tank system (Passes A-D) where PE is fed to the head of each Pass. A wet weather bypass is provided at Pass D, allowing PE to be preferentially fed to Pass D during wet weather events to prevent solids washout. All PE gates are automated. The four-pass system (Passes A-D) contains up to six zones in each pass: a combination of oxic zones for nitrification, pre-anoxic zones to prevent dissolved oxygen carryover into anoxic zones, and switch zones. Switch zones contain both air diffuser grids and mixers, and can function as either oxic or anoxic zones, providing flexibility in treatment processes. Baffles separate each zone. RAS is fed to the head of the aeration tank, and there is a RAS pumping capacity of 100 percent DDWF, although only a fraction of that RAS capacity is required for optimal operation.

Supplemental carbon addition in the form of glycerol to Passes A, B, C, and D is used to enhance the denitrification process and polymer can be added to the RAS line to combat froth. Froth is also controlled via froth hoods in Passes A and B, RAS chlorination, and surface wasting in each anoxic/preanoxic zone in Passes A and B with the capacity to waste 100 percent of the wasting load via surface waste activated sludge (SWAS).

Monitoring requirements are as follows: blower status, air flow rates per pass, system pressure, DO concentrations, wet weather bypass flow, RAS, WAS, and SWAS flow, pH, TSS, and NH_3/NO_3. Baffles are added to the final settling tanks (FSTs) to allow for increased solids loading to the tanks. Typical effluent TN values from the Battery E process less than 5 mgN/L. **Figure 3-5** shows a schematic of the Battery E BNR process.

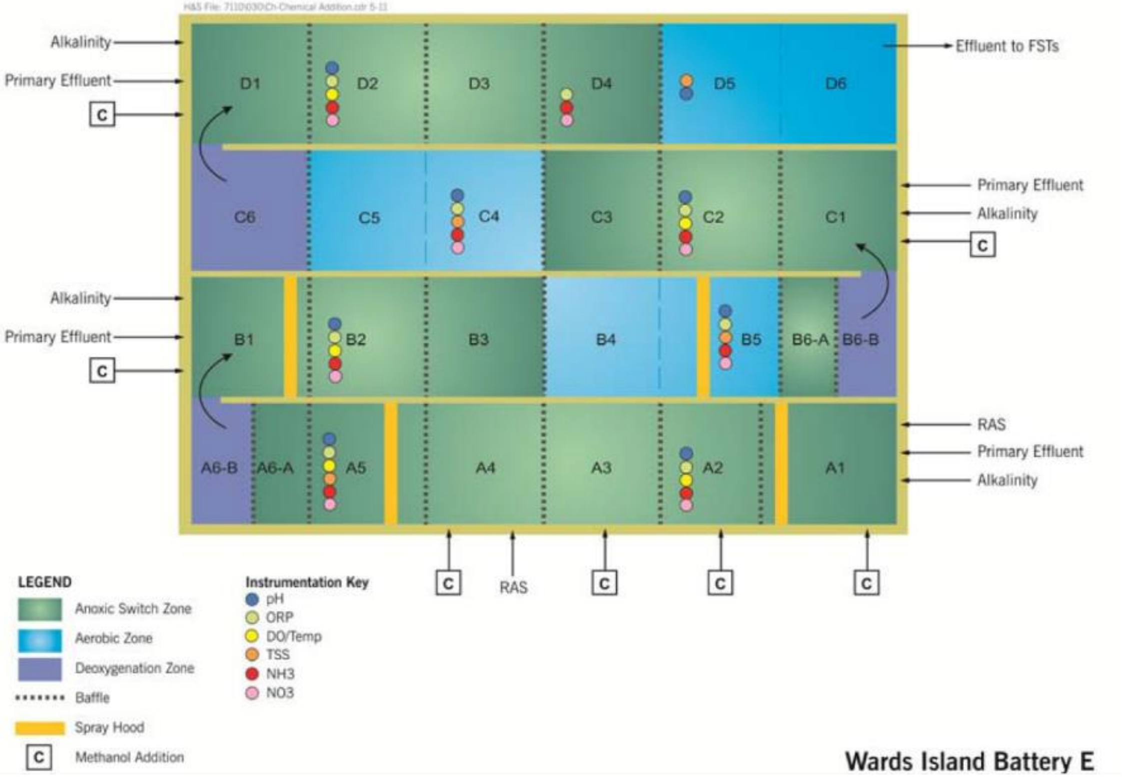


Figure 3-5: Battery E BNR Schematic

3.2.1.7. BNR with Add-On Denitrification Process

This technology option would include a step feed BNR configuration with or without carbon addition and an add-on denitrification process of either denitrification filters or MBBRs. Denitrification filters have been used for over thirty years to enhance nitrogen removal. They are typically paired with an activated sludge BNR process to attain low-effluent nitrogen levels and can be used to achieve limit-of-technology (LOT) treatment levels of 3-4 mg/l of effluent TN. Denitrification filters are used to treat clarified BNR process effluent, and act as both a fixed-film bioreactor and a deep-bed filter to remove both nitrate and TSS. Potentially an add-on to the BNR process, MBBRs would precede final clarification or would require a second clarification step. The advantage of MBBRs versus denitrification filers is the use of certain supplemental carbon sources (glycerol) with denite filters requires excessive backwashing due to the higher biomass yield, thus MBBRs can be a more effective denitrification polishing step compared to filters. Both technologies have the potential to be retrofitted in the future for anammox treatment in the partial denitrification anammox (PDNA) mode to reduce biomass yields and glycerol requirements, as this type of mainstream anammox technology further matures. The first full-scale implementation of mainstream PDNA is at a HRSD plant at York River, Virginia. A shunt process is used to provide a ratio of ammonia and NOx to the PDNA system. The filter is then operated at approximately 2.9 g COD/g NO3-N with methanol to produce sufficient nitrite for the anammox reaction. The filters are currently operated at a low loading of approximately 1 gpm/ft^2. Higher loadings can likely be achieved and will eventually be constrained by backwash frequency needed to remove turbidity while retaining anammox biomass.

For wastewater treatment, there are two main process configurations for denitrification filters commercially available, downflow and upflow continuous backwash filters. Downflow filters are the most used denitrification filter configuration in the wastewater industry, especially for large flows (>5 MGD). Downflow denitrification filters operate in a conventional filtration mode; they consist of media and support gravel supported by an underdrain. Different denitrification filter systems that are commercially available include but are not limited to: Severn Trent's TETRA® Denite system; Leopold's elimi-NITE® filter system, Degremont's Deniflo® process and Evoqua's NxClear®. Each of these systems has proprietary instrumentation and process controls, flow control and backwash systems, block underdrain systems, and/or specialized media to enhance attachment and growth of denitrifying bacteria while providing effective solids removal.

Figure 3-6 shows a schematic of a typical post-BNR denitrification filter. Clarified BNR effluent enters a downflow filter over weirs both sides of the filter bed. Effluent is conveyed over a control weir into a clear well where it may be stored for backwashing. Backwashing is required at regular intervals to clear the filter of accumulated solids and excess denitrifying biofilm on the media. As water flows through the filter, nitrate is denitrified to nitrogen gas and TSS are removed via traditional filtration processes. Since the BNR effluent entering the filter does not have significant rbCOD, a supplemental carbon source (methanol, glycerol, or other) is needed to drive the denitrification process within the filter. Systems are equipped with nitrate probes and metering pumps for automated carbon dosing to optimize TN removal.

If deemed more appropriate, MBBRs can be used in lieu of denite filters. MBBR systems utilize plastic carriers to promote biofilm growth through attachment. These reactors must continuously mix to prevent settling of the carriers. Denite MBBRs operate as anoxic with mechanical mixing. Typically 2 or 3 MBBRs are needed in series to achieve the low nitrogen limits. Air can be added for oxygenation and removal of excess glycerol or methanol. The largest example of such a system is installed at Noman Cole AWTP, Virginia handling 67 MGD of flow. The system is compact and it does not require RAS due to the biomass retention on the plastic carriers. However a downstream clarification or filtration step is required if LOT levels of nitrogen are required. MBBRs are discussed further in Section 3.2.1.18.

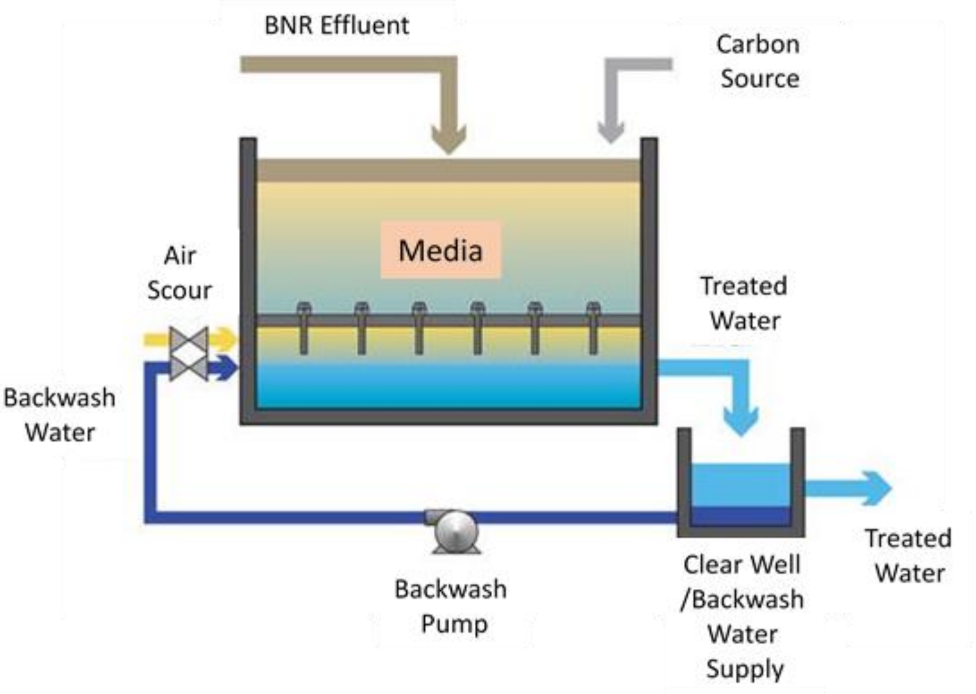


Figure 3-6: Schematic of Post BNR Downflow Denitrification Filter

3.2.1.8. HYBACS®

HYBACS® is a proprietary technology incorporating rotating biological contactors (RBCs), seen in **Figure 3-7**, in series with conventional biological treatment. The RBCs contain attached biomass on the shaft mounted reactors, contacting both the influent and the air as it rotates. RBCs have layers of biofilm on their contact faces, fostering both aerobic and anaerobic bacterial layers. It is available as a retrofit to existing facilities and is intended to reduce loadings to activated sludge tanks to improve final effluent quality.

Figure 3-7: HYBACS RBC System (Bluewater 2011)

3.2.1.9. inDENSE^{TM}

The inDENSE^{TM} technology uses hydrocyclones to generate separate sludge streams based on density. The lighter fraction, made up of poorer settling sludge, is wasted from the plant through the overflow while retaining the denser biomass through the underflow. This selective wasting practice can improve the wastewater treatment facility's sludge settling volume index (SVI). Furthermore, by preferentially selecting for the denser bacteria, organisms such as glycogen accumulating organisms (GAOs) are wasted and the heavier PAOs are naturally selected for, providing the opportunity to achieve biological phosphorus removal, if that is required. The inDENSE^{TM} system can provide a solution to poor settling mixed liquor suspended solids (MLSS) and increase the BNR treatment capacity by increasing the internal reactor inventory and clarifier loading without the need for new reactors and clarifiers. This technology can be incorporated into any of the activated sludge technologies noted above, where bulking sludge limits the plant's capacity/performance. inDENSE^{TM} technology cannot meaningfully increase the capacity in facilities where year-round good sludge settling characteristics are already exhibited (i.e. SVI's of less than 100 mL/gr). inDENSE^{TM} has been shown to improve and stabilize poor winter settling properties.

3.2.1.10. Integrated Fixed Film Activated Sludge (IFAS)

In IFAS systems, plastic growth media is added to activated sludge bioreactors to increase the amount of biomass that can be retained in the system, often as a retrofit to existing aeration tanks. The plastic growth media are free-floating in a well mixed tank with screens to retain the media. Designed with extensive interior surface area, the plastic media serves as an effective growth surface. **Figure 3-8** shows an example of a tank fitted with screens for plastic IFAS media. IFAS is typically applied for nitrification purposes, especially at facilities that have limited space for other technologies, as it can require a smaller footprint than other equivalently performing nitrification technologies. IFAS may be a stand-alone option for Jamaica and 26th Ward if the proposed ammonia limits are promulgated.

Integration of IFAS into existing reactors requires a significant retrofit of the facility with modification required to headworks (to provide fine screening), new aeration systems and the addition of retention screens to prevent media loss. Because of the application of coarse bubble aeration to allow for increased mixing, and the need to operate at higher DO than conventional activated sludge bioreactors, energy requirements are also higher in IFAS systems.

Figure 3-8: IFAS Installation with Growth Media (Gellner 2014)

3.2.1.11. Integrated Fixed Film Activated Sludge (IFAS) with Tertiary Denitrification Process

This option would combine the IFAS technology with Denitrification filters or MBBRs to consistently achieve effluent Ammonia limits at the 26th Ward and Jamaica WRRFs, while achieving limit of technology effluent TN levels. The IFAS process would allow for higher nitrification rates within existing aeration tank volumes, while the Denite filters or MBBRs would reduce residual nitrate in the IFAS/Activated sludge effluent. The IFAS retro-fit process is especially appealing for plants that have limited aeration capacity to meet seasonal ammonia limits, while not requiring the construction of new aeration tanks. IFAS systems typically produce poor settling sludge. At HRSD’s James River plant, an IFAS system is combined with inDENSE to leverage nitrification capacity in the media while leveraging heterotrophic capacity in the contained suspended growth process.

3.2.1.12. Ion Exchange

An ion exchange process consists of vessels containing resins that exchange positive or negative ions for those in the feed stream. High ammonium ion removal efficiency can be achieved using strong acid cationic resins. Ion exchange systems are also effective at removing metals and other ionic compounds. Removal of constituents are targeted by using different resins for different compounds. Pretreatment is typically necessary to optimize process performance. Ion exchange vessels are shown in **Figure 3-9**.

Figure 3-9: Ion Exchange Vessels (Gunderson 2014)

3.2.1.13. Mainstream Anaerobic MBR and n-DAMO

Anaerobic MBR (AnMBR) couples anaerobic biological treatment and membrane solids separation processes. The anaerobic reactor converts influent organics in wastewater to methane and carbon dioxide. This biogas is collected and can be used to generate energy (Visvanathan 2012). Error! Reference source not found. shows a schematic of an AnMBR system. The membrane recirculates solids to the reactor, increasing SRT, while allowing liquids to pass. By adding an n-DAMO system in series, the influent methane would be oxidized to reduce remaining ammonium, nitrate, and nitrite to dinitrogen gas. The n-DAMO process is described below in a separate section.

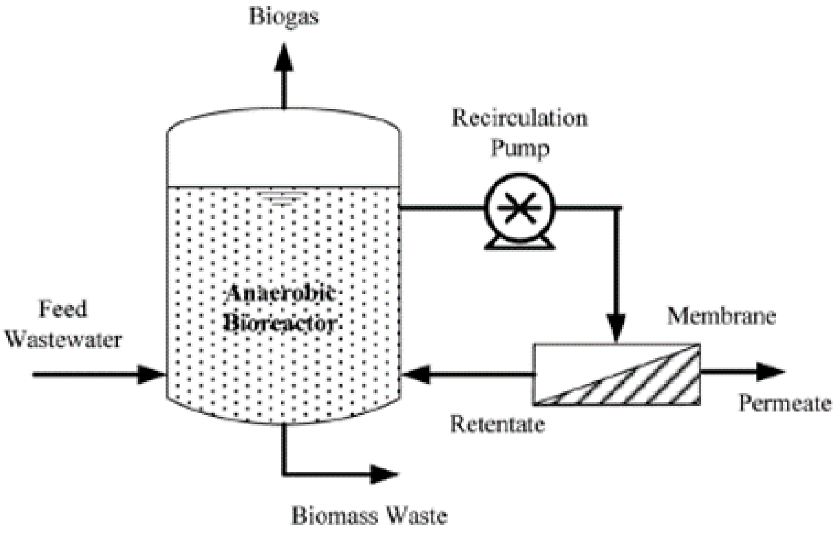


Figure 3-10: AnMBR Schematic (Visvanathan 2012)

3.2.1.14. Mainstream Deammonification

Biological treatments incorporating deammonification are established for sidestream treatment processes and are an emerging technology for mainstream application. Use of deammonification has the potential to reduce both oxygen requirements and the quantity of supplemental carbon added. Mainstream implementation must create a low-oxygen environment to foster the growth of ammonia-oxidizing bacteria over nitrite oxidizing bacteria, feeding the anammox process with the necessary nitrite as seen in **Figure 3-11**. Challenges for mainstream deammonification treatment include effective NOB suppression, low nitrogen concentrations as compared to sidestream concentrations, low operating temperatures, and sufficient SRT to retain the slow-growing anammox bacteria. One approach of mainstream deammonification combines a dual anammox system consisting of an upstream anoxic anammox IFAS reactor fed proportions of ammonia and NOx within a step feed BNR system. This anoxic IFAS can be operated in the nitrite shunt, PDNA or a combination of nitrite shunt and PDNA modes.

At this point in time, there are significant research efforts underway throughout the world to harness the benefits of mainstream deammonification technologies. However experience to date particularly for colder climates such as NYC has been limited, with only a single facility in the world (the Strass WWTP in Austria) having demonstrated mainstream deammonification at temperatures below 20°C.

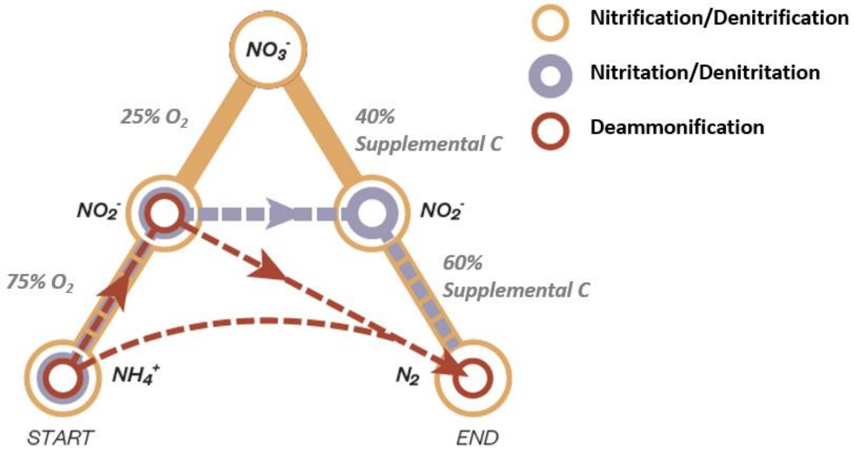


Figure 3-11: Deammonification Process

3.2.1.15. Membrane Aerated Biofilm Reactor (SABRE, MABR, Zee-Lung)

Membrane Aerated Biofilm Reactor processes consists of porous membranes that are placed in the aerobic section of a treatment process. The membrane is pressurized with air at 2-3 psi and oxygen diffuses through the membrane into the wastewater. A biofilm develops on the water side of the membrane containing nitrifying bacteria, and deeper into the water side an anoxic biofilm develops. This process provides simultaneous nitrification and denitrification (SND) and requires significantly less aeration energy than conventional BNR processes (typically one half to one third the aeration energy) while reducing sludge production. The process can be used for enhanced nitrification as well as SND. Membrane Aerated Biofilm Reactor systems can be retro-fitted into existing aeration tanks and may serve as a stand-alone option for improving nitrification at the Jamaica and 26th Ward WRRFs, which may face stringent ammonia standards soon. There are multiple proprietary membrane aerated biofilm technologies currently on the market or in development. SABRE® and Zee-Lung® are two of the leading technologies currently. An image of the SABRE® membrane is shown in **Figure 3-12**.

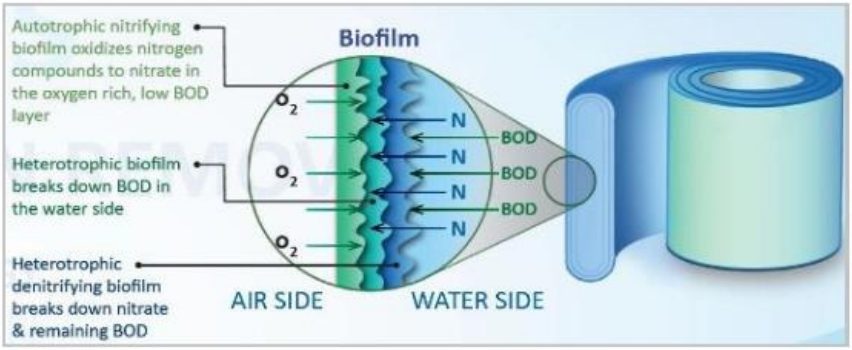


Figure 3-12: SABRE$^{®}$ Membrane (Emefcy)

3.2.1.16. Membrane Aerated Biofilm Reactor (SABRE, MABR, Zee-Lung) with Denite Process

This Technology combines MABR (described above) with denite filters (described above) or MBBRs (described below) to simultaneously achieve reliable full-nitrification and limit of technology TN removal (effluent TN = 3-4 mg/l). The aerated membrane systems would be installed into existing aeration tanks to enhance nitrification and SND, while the denite filters or MBBRs would be used to meet the overall TN effluent. This combination technology is attractive for plants that have limited aeration capacity and cannot accommodate additional aeration tanks due to costs or site constraints.

3.2.1.17. Membrane Bioreactor (MBR)

Membrane Bioreactors (MBRs) consist of a biological reactor with suspended biomass and solids separation by filtration membranes with pore sizes ranging from 0.1-0.4 µm. They can be used to separate biomass from treated wastewater in aeration tanks. The concept of MBR systems consists of utilizing an aeration tank and membrane filter to supplement secondary clarification (allowing operation at a higher solids inventory) and effluent filtration. Advantages of MBRs include (1) higher volumetric loading rates and shorter HRTs; (2) longer SRTs resulting in less sludge production; (3) operation at low DO concentrations, allowing for the possibility of simultaneous nitrification-denitrification in long SRT designs; (4) high quality effluent in terms of BOD, TSS, and turbidity; and (5) decreased footprint (Metcalf & Eddy, 2003). **Figure 3-13** shows a typical membrane cartridge.

Figure 3-13: Membrane Cartridge (www.GEwater.com)

3.2.1.18. Moving Bed Biofilm Reactor (MBBR)

MBBR systems utilize plastic carriers to promote biofilm growth through attachment. These reactors must continuously mix to prevent settling of the carriers. MBBRs can be aerobic, when using blowers for mixing, or anoxic with mechanical mixing. The systems are compact and do not require RAS due to the biomass retention on the plastic carriers. A schematic of a MBBR is shown in **Figure 3-14**.

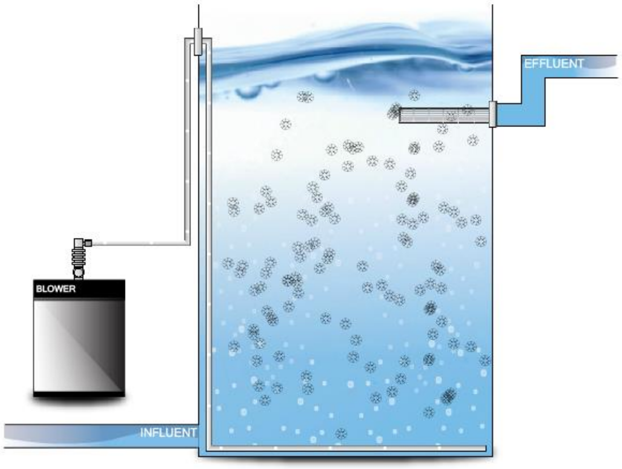


Figure 3-14: Moving Bed Biofilm Reactor (Headworks 2014)

3.2.1.19. n-DAMO

The n-DAMO (Nitrite-Dependent Anaerobic Oxidation of Methane) application to wastewater treatment involves the coupling of Anammox and methane oxidation, utilizing nitrite as an electron acceptor. As shown in **Figure 3-15**, DAMO archaea reduce nitrate, providing both Anammox and DAMO bacteria with substrate nitrite to generate dinitrogen gas from ammonium. The DAMO organisms generate carbon dioxide, a less harmful greenhouse gas than the methane substrate. In n-DAMO systems, supplemental oxygen is not required (Luesken 2011).

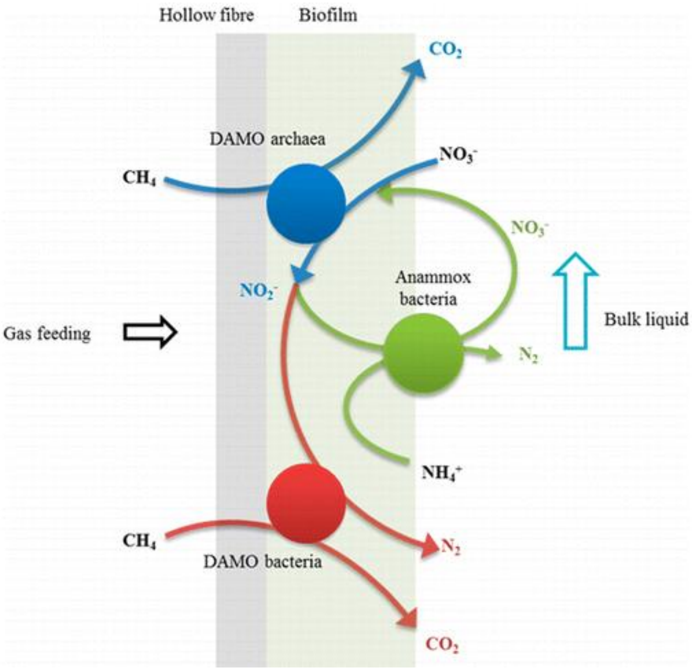


Figure 3-15: n-DAMO Chemical Processes (Luesken 2011)

3.2.1.20. NEREDA®

NEREDA® is a proprietary sequencing batch reactor technology that relies on bacterial treatment in sludge flocs. It is a three-step system consisting of a feed and discharge step, aeration, and settling. As seen in **Figure 3-16**, bacterial strata form in these flocs, with the inner layer fostering anaerobic nitrate reduction and phosphate removal. This is due to the oxygen gradient formed within the dense biomass granules. Due to the settling of the bacterial granules, the system retains solids and biomass for the next reaction sequence.

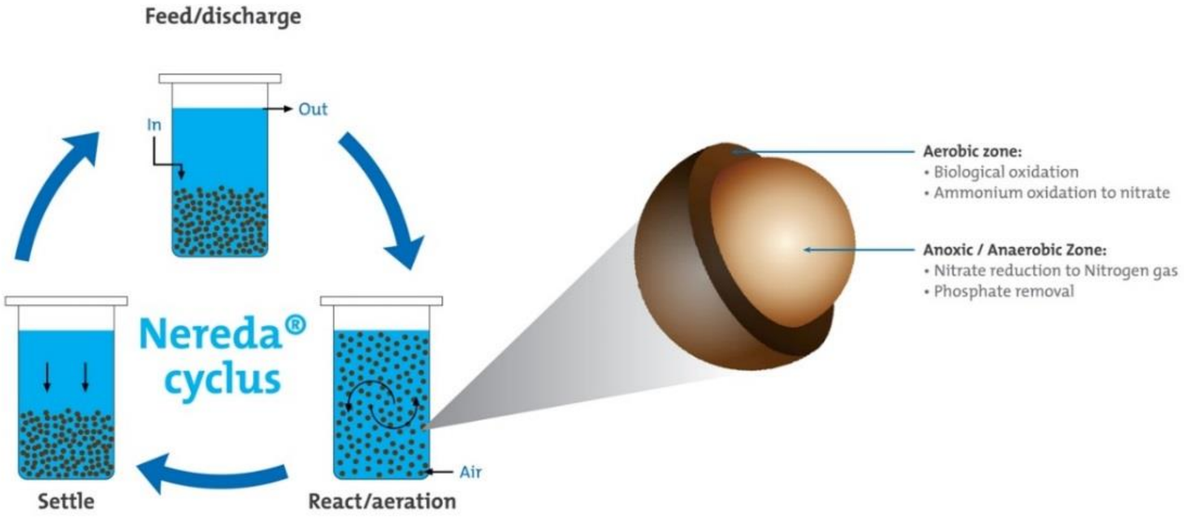


Figure 3-16: NEREDA Process (NEREDA 2013)

3.2.1.21. Nitrification/Denitrification Biological Aerated Filters (BAF)

Biological Aerated Filters (BAF) are compact, submerged biological filter systems. In an upflow BAF, such as the one in **Figure 3-17,** primary effluent forces upwards through a porous media. This media both removes suspended solids and fosters bacterial growth through attachment (Kruger 2013). Nitrification and denitrification can take place in the same reactor, due to changes in oxygen concentration throughout the reactor strata. BAFs can also be placed in series to allow for separate ammonia and nitrate degradation. The system can be employed for both secondary treatment and nitrogen polishing.

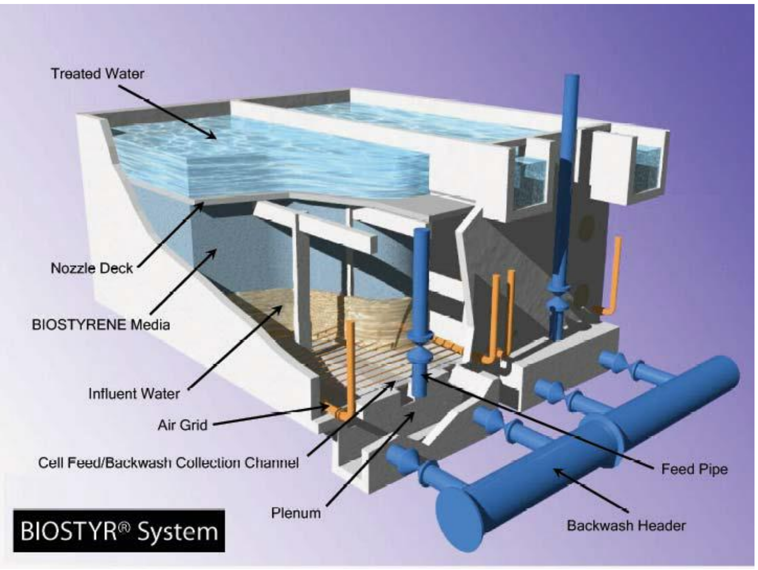


Figure 3-17: BIOSTYR Biological Aerated Filter (Kruger 2013)

3.2.1.22. Nitritation/Denitritation

Also known as “nitrite shunt”, nitritation-denitritation skips the oxidation of nitrite to nitrate, and the subsequent reduction back to nitrite. Illustrated in **Figure 3-18**, aerobic AOB generate nitrite from influent ammonia. Before further oxidation can take place, anoxic heterotrophic bacteria reduce nitrite to dinitrogen gas. This allows for less oxygen and carbon input to the system and a resulting reduction in biomass generation. Nitritation/Denitritation can be operated in the SND mode (described in a subsequent section) or in the alternating aerobic/anoxic mode or even within a step feed system as demonstrated at Changi in Singapore. The aerobic step in operated at a higher oxygen concentration > 1.5 mg/L and with a residual ammonia concentration. Step feed nitrite shunt can be combined with PDNA to leverage treatment capacity while achieving low TN effluents. Good process control will be needed to manage both residual ammonia for shunt (using a combination of AvN and ABAC as described in the next subsection) and residual nitrate for PDNA (as described in the next subsection). This approach can leverage capacity efficient existing step-feed infrastructure already present at DEP plants.

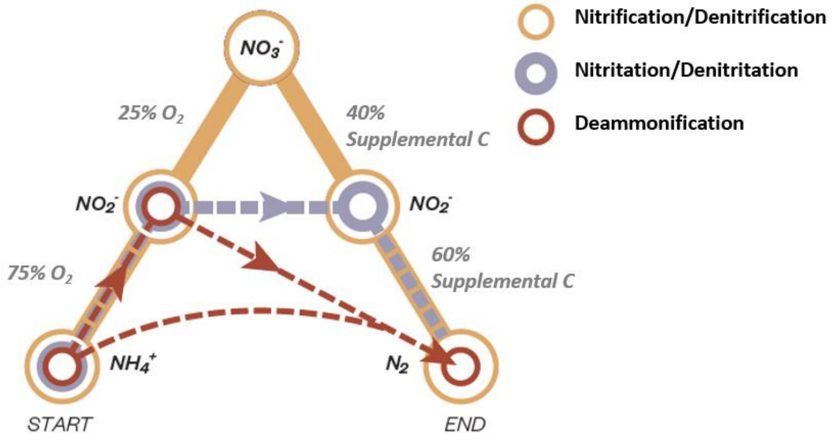


Figure 3-18: Nitritation/Denitritation Schematic

3.2.1.23. Partial Denitratation Anammox Process (PDNA)

The PDNA process relies on the conversion of 50% of the ammonia to nitrate via standard nitrification. The nitrate is then subjected to denitratation ($NO_3 \rightarrow NO_2$) using glycerol acclimated biomass (GAB), which are a specialized population that are observed to quickly convert nitrate to nitrite. Partial denitratation is followed by the simultaneous removal of ammonia and nitrite via anammox bacteria. This process could result in a 50% reduction in aeration and up to an 80% reduction in supplemental carbon compared to conventional nitrification/ denitrification processes. Unlike standard deammonification processes, the PDNA process does not require suppression of NOB activity, which can be challenging to control and is one of the main barriers to implementing deammonification in mainstream wastewater treatment. For mainstream BNR, PDNA has been able to remove of up to 85% of TN. This process was piloted at the 26th Ward WRRF (Discussed in Chapter 6.0) and it has shown promise as a possible retrofit, non-proprietary mainstream BNR process. The PDNA pathway to nitrogen removal is shown in **Figure 3-19**. To achieve stable PDNA either the nitrate residual needs to be managed (typically greater than 1-2 mg/L depending on diffusion limitations) or the SRT of the biomass needs to be managed to create a stable system.

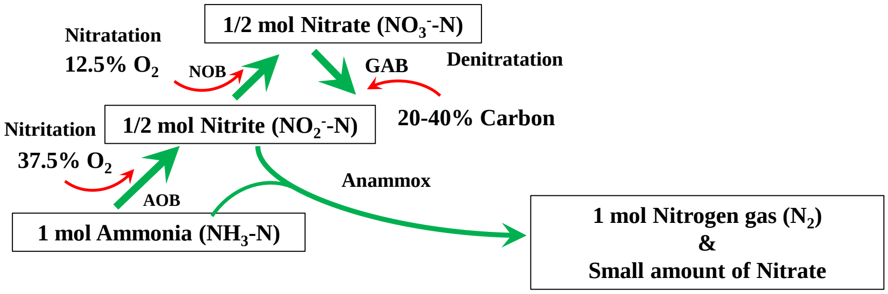


Figure 3-19: Partial Denitratation Anammox (PDNA) Process

3.2.1.24. Reverse Osmosis (RO)

Reverse osmosis (RO) systems force pressurized water through porous membranes, trapping unwanted dissolved molecules. Although conventionally used to produce potable water from saline sources, it can also be applied for removal of dissolved solids other than salts, including ammonia and phosphate. RO achieves high removals; however increased operating costs due to pumping and instrumentation can limit application. **Figure 3-20** shows a schematic of the RO process.

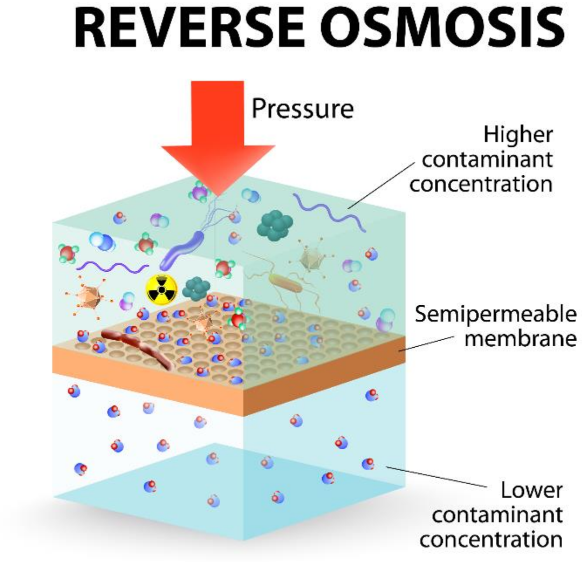


Figure 3-20: Schematic of Reverse Osmosis Process

3.2.1.25. Simultaneous Nitrification/Denitrification with Dynamic Aeration Control (ABAC and AvN)

Simultaneous Nitrification/Denitrification (SND) allows both nitrification and denitrification to occur in the same volume by operating at lower DO levels. SND occurs within flocs of organic material in WRRFs, as suggested by the DO gradient that forms within. The anoxic floc interior fosters denitrification, while the oxic exterior layer provides nitrification conditions. Ideally, DO control should be based on levels of ammonia, nitrate and nitrite in the system; however, access to reliable ammonia probes is limited and the chemical mechanisms of nitrogen removal are complex and not completely understood, rendering operational control over an SND system difficult. However, the lower DO operations for SND can reduce rates and thus capacity increase cannot be leveraged.

Two relatively new aeration control processes, Ammonia Based Aeration Control (ABAC) and Ammonia vs. NO_x (AvN) can be implemented to effectively control SND. ABAC combines DO control with ammonia sensors, reducing aeration when measured ammonia is low, and increasing when the measured ammonia is high. AvN is a new process control system offered by World Water Works that controls the important balance between Ammonia Oxidizing Bacteria (AOB) and Nitrite Oxidizing Bacteria (NOB).

AvN utilizes a patented process that applies selective pressure to aid in the accumulation of AOBs over NOBs, resulting in the preferential conversion of ammonia to nitrite, which can then be transformed directly to nitrogen gas in the denitrification process. This allows wastewater treatment systems to achieve more efficient removal of TN in the mainstream process at the lowest total energy cost possible. This technology could improve the operational control of SND process or in the alternating aerobic/anoxic process or the step feed BNR process by controlling the bacterial populations in the system to achieve the desired effluent ammonia, nitrate and nitrite concentration. Currently, aeration control systems can be designed to carry out both ABAC and AvN for SND or step feed modes.

SND type technologies have typically required the use of bioreactors with large hydraulic retention times (large volumes relative to the flow they treat) and have not been applicable to the higher rate bioreactors that are used in NYC WRRFs. With the advances in ABAC and AvN that have occurred over the past 5 years the application of the SND to bioreactors similar to NYC is being considered.

3.2.1.26. Tertiary Algae Process

Tertiary algae processes can be integrated into a conventional activated sludge system for energy and nutrient recovery from wastewater. A microalgae photobioreactor (PBR) could be introduced as tertiary treatment to improve treated water quality, with the produced biomass co-digested for biogas generation. As shown in **Figure 3-21**, digestant from anaerobic digestion could also diluted with secondary effluent in the PBR to grow microalgae biomass which can be used as bioenergy feedstock. Co-digestion of microalgae and sludge could improve the methane productivity and the hydrolysis efficiency compared to each substrate's mono-digestion (Zhen et al., 2016).

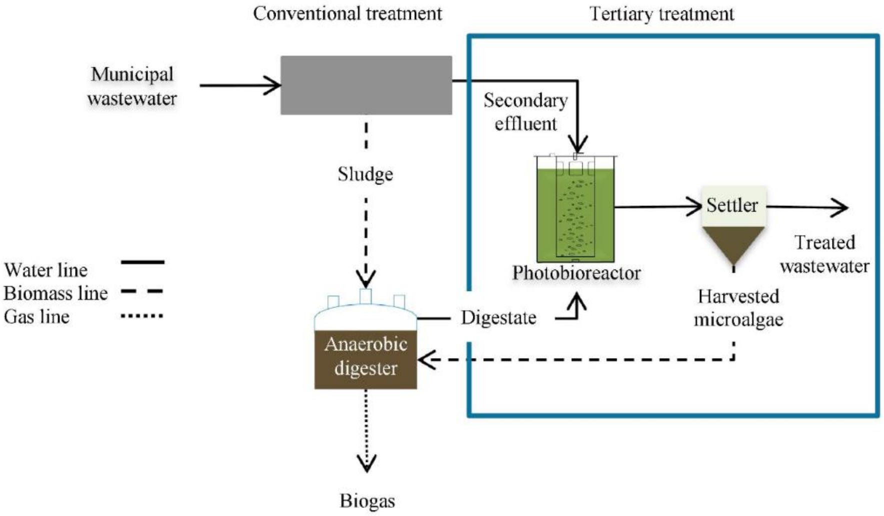


Figure 3-21: General Scheme of Tertiary Algae Process

3.2.2 Selected Mainstream Treatment Alternatives

All technologies listed in **Section 3.2.1** were evaluated using the ITEP as described in **Section 3.1.** The ITEP focuses on assessing four general topic areas, with multiple questions per topic area. The scores for each topic area were weighted based on importance and applicability to DEP. Weightings for each topic were determined by the NYCDEP and are as follows:

Technology Fundamentals:	15 percent
Technology Maturity:	15 percent
Implementation at DEP:	40 percent
Institutional Compatibility:	30 percent

The maximum score achievable was 100 points.

Table 3-3 shows the top six (6) technologies 26th Ward and Jamaica WRRFs based on the DEP weightings. **Table 3-4** shows the same scoring for Rockaway and Coney Island WRRFs. **Appendix A** shows the ITEP matrix with scores assigned to each question for each mainstream technology for all four plants.

It is recognized that the ITEP evaluation represents a snapshot of the Department's understanding of each technology evaluated. Multiple technologies were rated relatively low because the technologies have not been demonstrated at adequately large scale or lack a long term track record. These technologies are rapidly maturing, and it is likely that within the next few years the ratings would be modified materially as technologies such as mainstream deammonification, in-Dense and aerated granular sludge mature and are deployed in large WRRFs.

Table 3-3: Mainstream Technology ITEP Scores for the 26th Ward and Jamaica WRRFs

Weighted scores	**15%**	**15%**	**40%**	**30%**	**Total score (weighted)**
	Technology Fundamentals	Technology Maturity	Implementation at DEP	Institutional Compatibility	Total
SND With Dynamic Aeration Control	13	14	24	15	67
Level 4 BNR	15	15	20	15	65
Nitritation/ Denitritation	13	13	23	13	61
BNR with add-on Denite Process*	15	15	17	13	61
IFAS + Denite Process*	13	15	17	15	61
IFAS	13	15	21	12	61

*Long-term compliance with both TN and proposed ammonia limits

Table 3-4: Mainstream Technology ITEP Scores for the Rockaway and Coney Island WRRFs

Weighted scores	**15%**	**15%**	**40%**	**30%**	**Total score (weighted)**
	Technology Fundamentals	Technology Maturity	Implementation at DEP	Institutional Compatibility	Total
Advanced Basic Step-feed BNR	15	15	25	13	69
SND With Dynamic Aeration Control	13	15	25	15	69
Step Feed BNR (Level 4)*	15	15	21	15	66
Full Step-feed BNR with Carbon Addition	15	15	21	13	65
Integrated Fixed Film Activated Sludge (IFAS)	13	15	21	15	64

*limit of activated sludge technology TN 4-5 mgN/L

The following technologies are recommended to be further evaluated and potentially taken to conceptual design for the 26th Ward WRRF:

- SND with Dynamic Aeration Control (all three ATs in Operation, new SCT Process) with add-on Denitrification Process (Denite Filters)
- Level 2/3/4 BNR (all three ATs in Operation, new SCT Process) with add-on Denitrification Process (Denite Filters)

For the 26th Ward WRRF, the technologies identified are compatible with management of increased organics and nitrogen loadings should consolidation of liquid treatment and/or solids production be considered at this site. Design flows and loads would need to be modified to reflect consolidation of flows and/or solids, incorporating projected population growth.

The following technologies are recommended to be further evaluated and potentially taken to conceptual design for the Jamaica WRRF:

- SND with Dynamic Aeration Control with add-on Denitrification Process (Denite Filters)

  Level 2/3/4 BNR with add-on Denitrification Process (Denite Filters)

The following technologies are recommended to be further evaluated and potentially taken to conceptual design for the Coney Island WRRF, if LOT treatment is required, :

- Advanced Basic Step Feed BNR
- Simultaneous Nitrification/ Denitrification with Dynamic Aeration Control
- Battery E Equivalent (Level 4 BNR)

The following technologies are recommended to be further evaluated and potentially taken to conceptual design for the Rockaway WRRF:

- Advanced Basic Step Feed BNR
- Simultaneous Nitrification/ Denitrification with Dynamic Aeration Control
- Battery E Equivalent (Level 4 BNR)

3.3 Sidestream Treatment Alternatives

Treatment of sidestream process flows, such as centrate from dewatering operations, is typically performed to help manage the nutrient recycle load to the mainstream BNR process. Separate Centrate Treatment (SCT) is often economical due to the relatively low volume and high concentration of nutrients present in these flows. By removing nutrients in the sidestream, utilities can attain a higher factor of safety on mainstream BNR as sidestream treatment provides both equalization and a net reduction in nutrient load that is returned to the head of the plant (up to 85% reduction of TN). Other benefits SCT may provide include biomass (nitrifier) seeding from SCT to the main plant process and the ability to optimize SCT performance separate from the mainstream process.

Concurrent to developing a list of mainstream technologies, as discussed in **Section 3.2**, a list of sidestream treatment technologies was also developed. Subject matter experts were involved in developing and evaluating the technologies using ITEP. The final list of 18 technologies, ranging from well-established conventional SCT to emerging technologies, is shown in

Table ***3-5***. A brief description of each sidestream alternative is given in **Section 3.3.1** of this document.

Table 3-5: Sidestream Alternatives Summary

Deammonification - ANITA^{TM}Mox	Generic stream stripping
Deammonification - DEMON	High Rate Pure Oxygen Nitrification Reactor
Deammonification - ANAMMOX	Ion-exchange
Deammonification/Nitritation	Magneto (Bioelectrochemical NH3 recovery)
Bion	PNDA
CANDO (Coupled Aerobic-anoxic Nitrous Decomposition Operation)	P-Recovery and Anammox
Centrate Treatment with Bioaugmentation	SABRE/MABR/Z-lung
Conventional Separate Centrate Treatment	SHARON
Electrodialysis	Simultaneous Nitrification/ Denitrification
Aerobic Digestion (using existing storage tanks)	Aerobic Post-Digestion

3.3.1 Sidestream Treatment Alternatives

The SCT treatment alternatives as shown in are described below.

3.3.1.1. Deammonification – ANITA^{TM} Mox

ANITA^{TM} Mox is a proprietary moving bed biofilm reactor (MBBR) technology that treats high-ammonia waste streams using both aerobic nitrite-producing bacteria and Anammox bacteria. The MBBR is filled with suspended plastic media and is kept in uniform distribution through mixing. Mixing prevents washout of biomass, increases growth surface area, and allows the growth of consecutive biomass layers, as shown in **Figure 3-22**. The system does not use external carbon sources and consists of a single reactor.

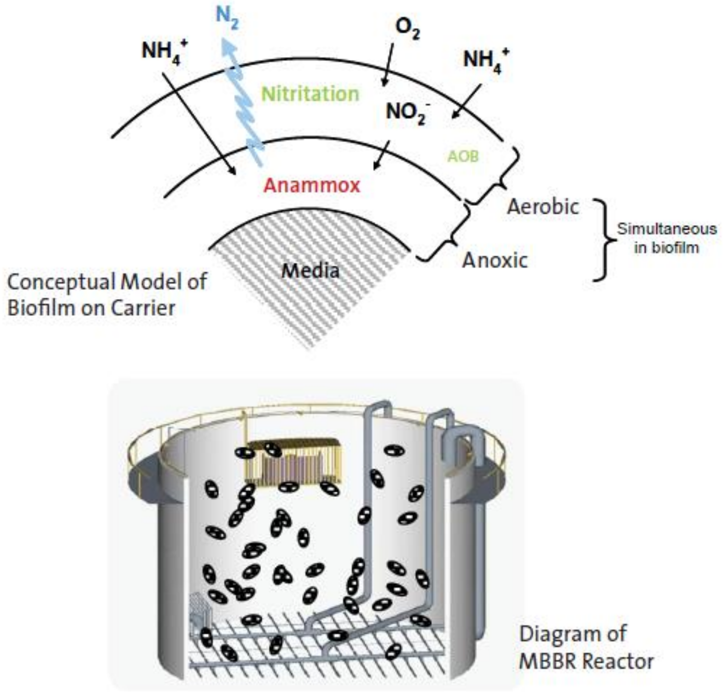


Figure 3-22: ANITA^{TM} Mox Biofilm model and Diagram of MBBR Reactor (Kruger 2013)

3.3.1.2. Deammonification – DEMON

DEMON is a continuous flow deammonification process utilizing granular anaerobic ammonium oxidizing bacteria (anammox) biomass for removing ammonia from digested sludge dewatering streams. The DEMON Process from World Water Works includes patented advanced biological process controls and physical separation (screens) to facilitate the growth and retention of the anammox bacteria which carry out anaerobic deammonification with no supplemental carbon and greatly reduced aeration. The process can achieve up to 90% removal of ammonia form high strength centrate streams while reducing aeration energy needs by more than 60%.

3.3.1.3. ANAMMOX® – Paques

ANAMMOX® is a proprietary flow through reactor system for removing ammonium from effluent, utilizing inclined plate settlers, as shown in **Figure 3-23.** The reactor system allows nitritation and anammox conversion occur simultaneous in one single process unit. The Anammox® can initiate in 3 weeks; the system can achieve greater than 90% Ammonia-A and greater than 85% Total Nitrogen removal.

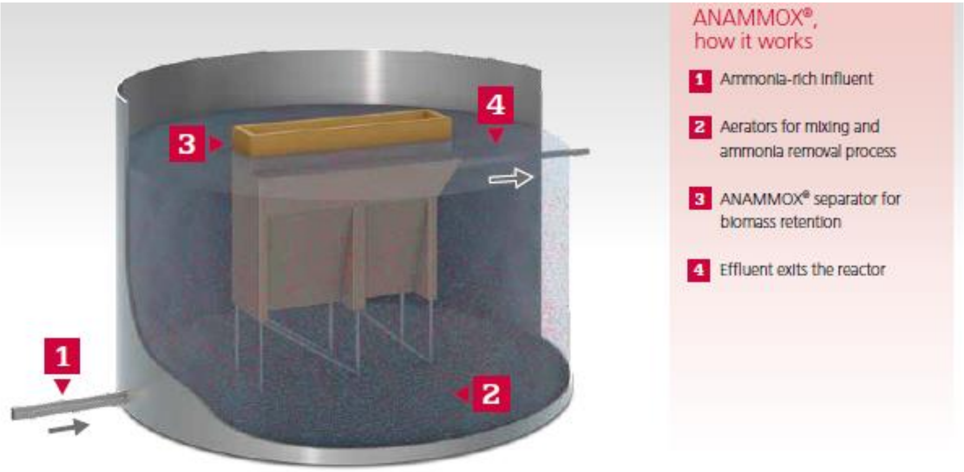


Figure 3-23: ANAMMOX® Process

3.3.1.4. Deammonification

An established sidestream nitrogen treatment technique, Anammox/nitritation bioreactors are typically applied to wastewaters of high temperature, high ammonium concentrations, and low carbon content. The process takes place in a low-oxygen reactor, with aerobic and anaerobic processes occurring in tandem inside floc particles. As shown in **Figure 3-24**, the ammonium oxidizing bacteria generate nitrite in the outer floc layer, which is converted to dinitrogen gas by Anammox bacteria in the anoxic inner floc. This would be a non-proprietary process designed and implemented by DEP with its own anammox retention technology and its own process control system.

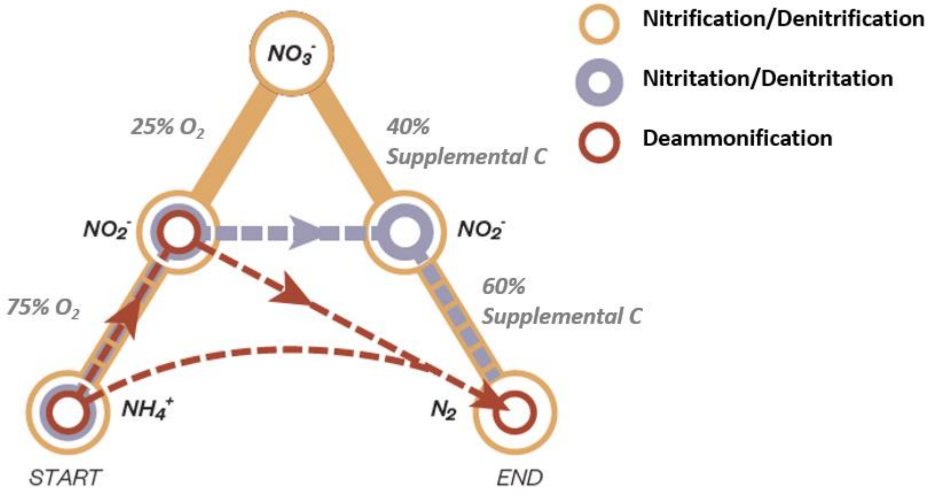


Figure 3-24: Anammox/Nitritation Schematic

3.3.1.5. Bion

Bion BNR waste management system is a biological nutrient removal process for removal of nitrogen and phosphorus from the waste stream. The waste is screened, solids are collected for composting or land application. The liquid is piped to a two-stage bioreactor where it first enters an anaerobic zone comprising about one tenth of the total bioreactor volume. After the anaerobic zone the stream enters an anoxic zone for further treatment. Liquid from the end of the bioreactor is sent to Sweco vibrating screens, then discharged serially to two lagoons and then land applied. **Figure 3-25** shows the process diagram for Bion BNR. Bion BNR waste management system can be operated to removed 74% of the total nitrogen and 79% of the phosphorus load. The system can also achieve air emission reduction of 99% for ammonia, 98% volatile organics (VOCs), 94% methane, 95% hydrogen sulfide, and 93% nitrogen.

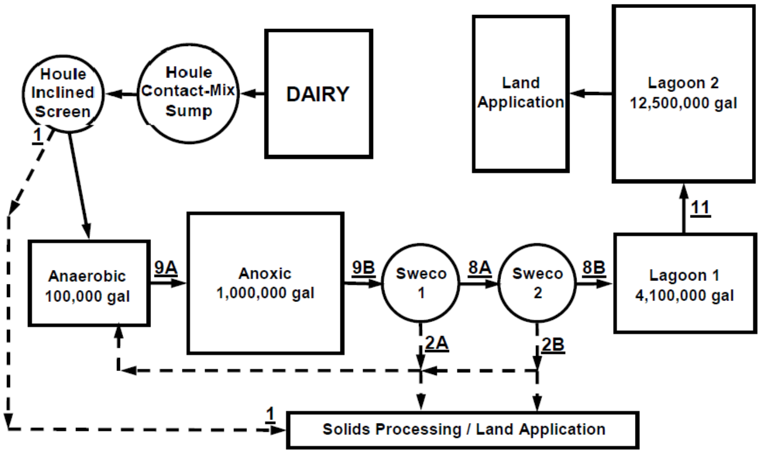


Figure 3-25: Bion BNR Process Flow Diagram

3.3.1.6. CANDO (Coupled Aerobic-anoxic Nitrous Decomposition Operation)

Coupled Aerobic-anoxic Nitrous Decomposition Operation (CANDO) is a nitrogen treatment technology developed at Stanford University intended to generate electricity from nitrous oxide off-gassing to reduce energy costs associated with wastewater treatment and nitrogen effluent compliance. After undergoing standard primary treatment, the process involves biological conversion of ammonia to nitrite and conversion of nitrite to nitrous oxide. The nitrous oxide from this process is captured and sent for energy recovery through combustion along with a co-fuel such as captured biogas, as seen in **Figure 3-26**.

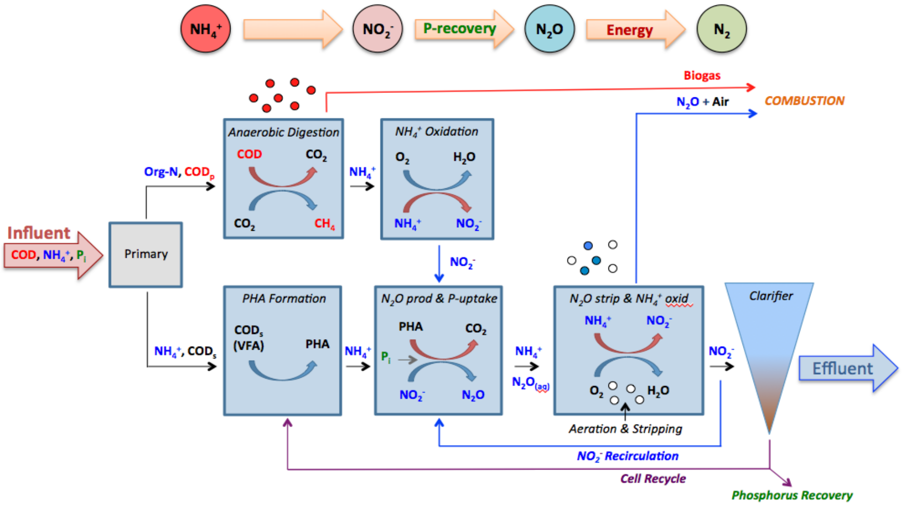


Figure 3-26: CANDO Chemical Process (Scherson 2013)

3.3.1.7. Electrodialysis

Electrodialysis is an electrochemical separation process in which ionic species are transported from one solution to another through an ion selective membrane using direct current as the driving force. Cation and anion membranes are arranged alternately between stacked spacers. An anode and cathode are attached to either side of the reactor creating electric potential to transport the ions. The membranes form barriers to the ions of the opposite charge, not allowing them to pass though the membrane. A filtration process is needed to remove solids prior to the liquid stream entering the electrodialysis reactor. An image of an electrodialysis installation is shown in **Figure 3-27**.

Figure 3-27: Electrolysis Installation (gewater.com)

3.3.1.8. Aerobic Post-Digestion

Aerobic post-digestion is a biological stabilization process operated in the presence of oxygen in which the remaining biodegradable products from anaerobic digestion are further oxidized to carbon dioxide and other products. This results in enhanced biosolids quality, while also allowing for removal of the ammonia that is produced in the anaerobic digestion process.

With respect to ammonia, simultaneous nitrification and denitrification occurs in the aerobic post-digester, resulting in concurrent ammonia oxidation and nitrate/nitrite reduction to nitrogen gas. An example of an aerobic digester is shown in **Figure 3-28**.

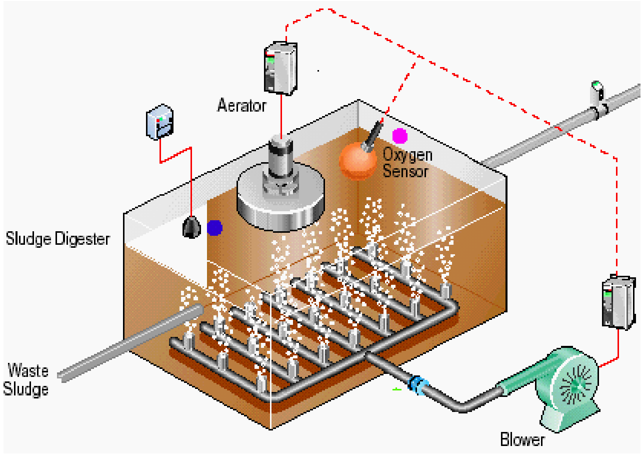


Figure 3-28: Schematic of an Aerobic Digester (electrical-engineering-portal.com)

3.3.1.9. Generic Steam Stripping

Stream stripping involves removing constituents from an influent liquid stream through contact with steam. The influent liquid steam flows downward through a packed column and it is contacted by upward-rising steam. Steam strips ammonia from the liquid steam and transfers it to the gas phase. The stripped liquid then exists the bottom of the tower and may be recycled through the process for additional treatment. Caustic is often added to increase pH, promoting the conversion of ammonium to ammonia. System works much like a traditional steam stripping column.

3.3.1.10. High Rate Pure Oxygen Nitrification Reactor (HPO-BNR)

HPO-BNR is an activated sludge process that utilizes pure oxygen instead of air for nutrient removal. The aeration process occurs in an enclosed biological reactor similar to that of **Figure 3-** and is followed by a clarifier. RAS feeds to the head of the reactor to ensure that the system maintains biomass levels. The high dissolved oxygen levels in the system make HPO-BNR suitable for high strength wastewater and for sites with limited construction space available.

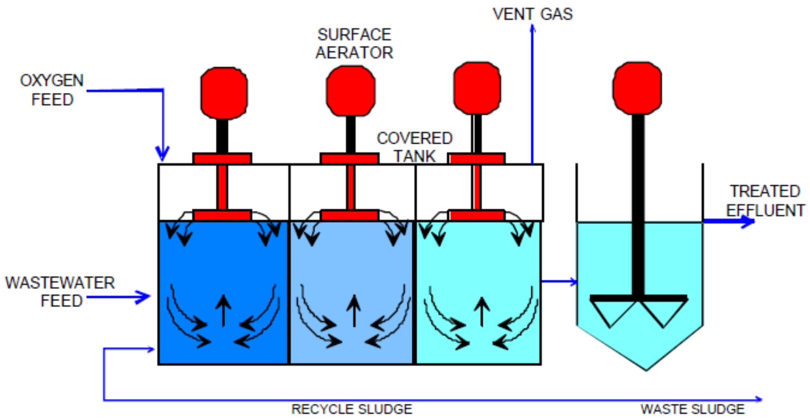


Figure 3-28: HPO-BNR Process Flow Diagram (Morin & Gilligan, n.d.)

3.3.1.11. Ion Exchange

An ion exchange process consists of vessels containing resins that exchange positive or negative ions for those in the feed stream. High ammonium ion removal efficiency can be achieved using strong acid cationic resins. Ion exchange systems are also effective at removing metals and other ionic compounds. Removal of constituents can be targeted by using different resins for different compounds. Pretreatment is typically necessary to optimize process performance. Ion exchange vessels are shown in **Figure 3-9**.

3.3.1.12. Magneto (Bioelectrochemical NH3 Recovery)

Magneto is a nutrient recovery process intended to recover phosphorus and ammonia from urine streams (ammonia rich streams) prior to dilution in sewers. A struvite recovery system is primarily implemented to recover phosphorus and some nitrogen, as seen in **Figure 3-**. Next, a bioelectrochemical system fosters biological oxidation of organics at a bio-anode. This process drives ammonium ions through a membrane, allowing nitrogen to be captured in the cathode. Additionally, alkaline compounds are produced, which also are to be recovered. The treated urine can then discharge to a sewer or WRRF with a much smaller nutrient loading.

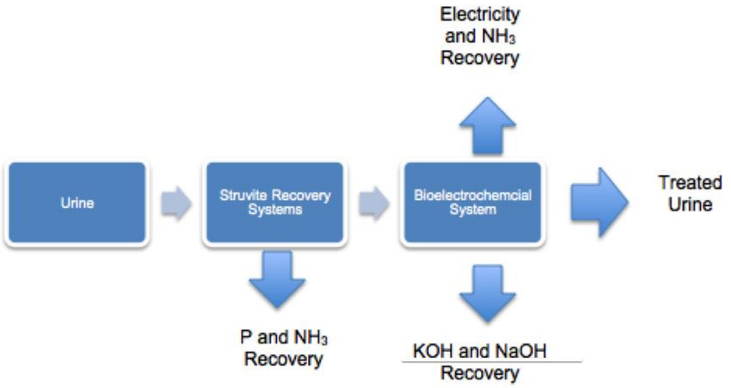


Figure 3-30: Magneto Process Summary (BlueTech 2014)

3.3.1.13. P-Recovery and Anammox

Combining an Anammox treatment technique with a struvite recovery technology, such as Ostara Pearl®, would offer more complete nitrogen removal in addition the benefits of phosphorus nutrient recovery. Anammox systems are effective at removing ammonia but a high concentration of phosphate remains in their outflow. Struvite recovery offers efficient phosphate removal with limited impact on nitrogen. Operating these technologies in series would provide a centrate effluent with low levels of both algal limiting nutrients. There are multiple technologies available to carry out both deammonification and p-recovery. This struvite technology is most favorable when both TN and TP are regulated or where plants have a serious struvite issue or to improve dewatering in Bio P plants.

3.3.1.14. Membrane Aerobic Bioreactor

Membrane Aerated Biofilm Reactor processes consists of breathable membranes that are placed in the aerobic section of a treatment process. Air flows through the membrane and oxygen diffuses through the membrane into the wastewater. A biofilm develops on the water side of the membrane containing nitrifying bacteria, and deeper into the water side an anoxic biofilm develops. This process provides simultaneous nitrification and denitrification (SND) and requires less aeration energy than conventional BNR processes while reducing sludge production. The process can be used for enhanced nitrification as well as SND. An image of the membrane is shown in **Figure 3-12**.

3.3.1.15. Partial Denitratation Anammox Process (PDNA)

The PDNA process relies on the conversion of 50% of the ammonia to nitrate via standard nitrification. The nitrate is then subjected to denitratation ($NO_3 \rightarrow NO_2$) using glycerol acclimated biomass (GAB), which are a specialized population that are observed to quickly convert nitrate to nitrite. Partial denitratation is followed by the simultaneous removal of ammonia and nitrite via anammox bacteria. This process could result in a 50% reduction in aeration and up to an 80% reduction in supplemental carbon compared to conventional nitrification/ denitrification processes. The PDNA pathway to nitrogen removal is shown in **Figure 3-19** in the previous section.

3.3.1.16. SHARON®

Stable High-Rate Ammonia Removal Over Nitrite (SHARON®) is a proprietary process consisting of a single heated reactor with a short residence time. This reactor contains an aerated zone and a mixed anoxic zone. The reactor operates at 30 - 40^{0}C to block the formation of nitrite oxidizers such as Nitrobacter, as ammonia to nitrite oxidizers Nitrosomonas outcompete them. This results in the buildup of nitrite. Denitrification occurs in the subsequent anoxic phase of the reactor, which is mechanically mixed. With the aid of carbon addition, the denitrifiers produce dinitrogen gas. A full-scale SHARON® facility is currently in operation at the Wards Island WRRF. **Figure 3-** shows a conceptual drawing of the SHARON® process.

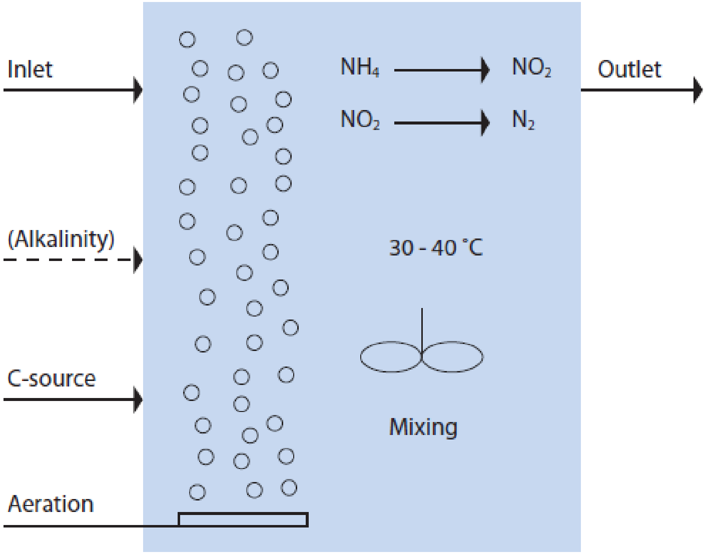


Figure 3-29: Conceptual Drawing of SHARON® Process

3.3.1.17. Simultaneous Nitrification/Denitrification

Simultaneous Nitrification/Denitrification (SND) allows both nitrification and denitrification to occur in the same tank at low DO levels. SND may occur within floc of organic material in WRRFs, as suggested by the DO gradient which forms within. The anoxic floc interior fosters anaerobic denitrification, while the oxic exterior layer provides nitrification conditions. SND does not require the construction of baffles like BNR systems, as the creation of oxic and anoxic zones is not required. However, the chemical mechanisms of nitrogen removal are complex and not completely understood, rendering operational control over an SND system difficult, especially in Centrate Treatment Processes when the ammonia and nitrite can be elevated.

3.3.2 Selected Sidestream Treatment Alternatives

All technologies listed in Section 3.3.1 were evaluated using the ITEP as described in Section 3.1. The ITEP focuses on assessing four general topic areas, with multiple questions per topic area. The scores for each topic area were weighted based on importance and applicability to DEP. Weightings for each topic are as follows:

- Technology Fundamentals: 15 percent
- Technology Maturity: 15 percent
- Implementation at DEP: 40 percent
- Institutional Compatibility: 30 percent

The maximum score achievable was 100 points. **Table 3-6** shows the top six technologies with both the topic scores and the final score based on DEP preferred weightings. **Appendix A** shows the ITEP matrix with scores assigned to each question for each technology.

Table 3-6: ITEP Scoring for SCT Treatment Technologies

Weighted scores	**15%**	**15%**	**40%**	**30%**	**Total score (weighted)**
	Technology Fundamentals	Technology Maturity	Implementation at DEP	Institutional Compatibility	Total
Deammonification	14	15	23	18	71
Deammonification-ANITA™ Mox	13	15	23	18	70
Deammonification - DEMON™	13	14	23	18	69
SHARON	13	15	22	18	68
ANAMMOX - Paques	13	13	23	18	68
SND	14	15	21	15	65
P-Recovery and Anammox	13	13	18	20	63
SABRE/MABR/Z-lung	11	13	18	15	57
CANDO	8	3	19	17	47
High Rate Pure Oxygen Nitrification Reactor	13	13	15	3	43
Generic stream stripping	15	14	7	7	43
Bion	7	4	10	13	34
Electrodialysis	8	3	11	10	32
Magneto	5	3	11	12	31

As can be seen, the three highest scoring SCT technologies are a non-proprietary Anammox Nitritation or the proprietary ANITA™ Mox or DEMON™. All of the highest scoring SCT processes were deammonification processes, which all utilize the same biological technology to remove nitrogen from centrate, and thus require essentially the same pretreatment, pumping capacities, and equalization tank and treatment reactor volumes. The only difference between these technologies is the proprietary equipment used to maintain the anammox biomass, and the instruments and controls needed to effectively operate the treatment systems. The ANITA™ Mox, ANAMMOX®, and DEMON™ technologies come with vendor specific operator training, performance guarantees and maintenance contracts.

Of the four WRRFs examined in this study, only 26th Ward WRRF performs sidestream treatment, as it is the only location where anaerobically digested biosolids are dewatered. The highest rated technologies were all deammonification processes. All these processes would require new treatment infrastructure, to allow for the current SCT aeration tank (AT3) to be available for mainstream treatment in order to achieve the ammonia limits and approach LOT level mainstream performance. If 26th Ward is required to meet a stringent ammonia limit (in the range of 1-3 mgN/L), all three ATs would be needed for main plant BNR, and centrate would have to be treated at a separate, stand-alone facility or transshipped to another plant for treatment. Thus, for any of the deammonification processes to be effectively implemented at 26th Ward, the SCT process would likely have to be built on the south side of the 26th

Ward site after proceeding through a multitude of steps for intenstification (i.e. controls, implementation, maintenance, etc.).

Any process improvements for mainstream or sidestream treatment should first consider complexity for implementation, thus first considering improvements in the following order: instrumentation and control changes, electrical changes, mechanical changes, hydraulic changes and civil/structural changes. Processes that entail fewer changes while providing large benefits to capacity increase should be prioritized as they promote rapid deployment.

4. Optimization Techniques

4.1 Introduction

This Chapter of the Jamaica Bay Feasibility Study identifies the wide array of optimization measures that NYCDEP has implemented for existing and future BNR related wastewater infrastructure to reduce nitrogen discharges and improve dissolved oxygen (DO) water quality in Jamaica Bay. A description of completed and future optimization measures will be provided for the BNR upgrades at each facility.

The following optimization measures will be covered and discussed in detail this Chapter:

- Initial Development of BNR Process Control Strategies
- Comprehensive Sampling Programs of the 26th Ward and Jamaica WRRFs
- Contingency Sampling
- Instrumentation Control
- Equipment Optimization

4.2 Initial Development of BNR Process Control Strategies

Initial development of BNR Process Control Strategies for the Jamaica Bay WRRFs was essential in allowing for a smooth transition into BNR operation. General target operational parameters for BNR operation were developed using a combination of process modeling, lessons learned from earlier NYCDEP WRRFs to come online in BNR mode (located along the Upper East River), and NYCDEP's pilot BNR demonstrations (Battery E Full-Scale BNR Demonstration Facility and 26th Ward BNR Pilot).

It should be noted that as BNR operation came online at the 26th Ward and Jamaica WRRFs, BNR operational targets were further refined for those individual facilities through the Comprehensive Sampling Programs, which will be discussed in the following sections of this Chapter.

4.2.1 Nitrification Control

The most challenging aspect of BNR operation is maintaining stable nitrification due to the slow growth and temperature sensitivity of nitrifying biomass. As nitrification is the first step in effective total nitrogen (TN) removal, the general approach is to maximize nitrification and then optimize denitrification to attain overall TN removal. To maintain nitrification under all operational conditions, longer solids retention times (SRT) are needed compared to a conventional biochemical oxygen demand (BOD) removal plant.

The operating goal for both the Main Plant and Separate Centrate Treatment (only applicable at the 26th Ward WRRF) is to maintain and maximize the nitrification process on a year-round basis. To maintain this operational goal for the Main Plant, there are three operational parameters that must be monitored and adjusted:

- Aerobic Solids Retention Time (SRT); which is impacted by:
    - Solids Inventory (controlled by RAS and WAS rates, and flow distribution)
    - Aerobic/Anoxic Zone Configuration
- Aerobic Zone DO Concentrations

- pH/Alkalinity

4.2.1.1 Aerobic SRT

Sufficient aerobic SRT is needed to maintain adequate nitrifying biomass in the system to maximize nitrification. Nitrifying biomass make up a relatively small fraction of the total biomass in the activated sludge of a BNR process and are slow-growing, especially at low temperatures. As shown in **Figure 4-1**, the minimum aerobic SRT requirement for nitrification performance is largely a function of seasonal temperature.

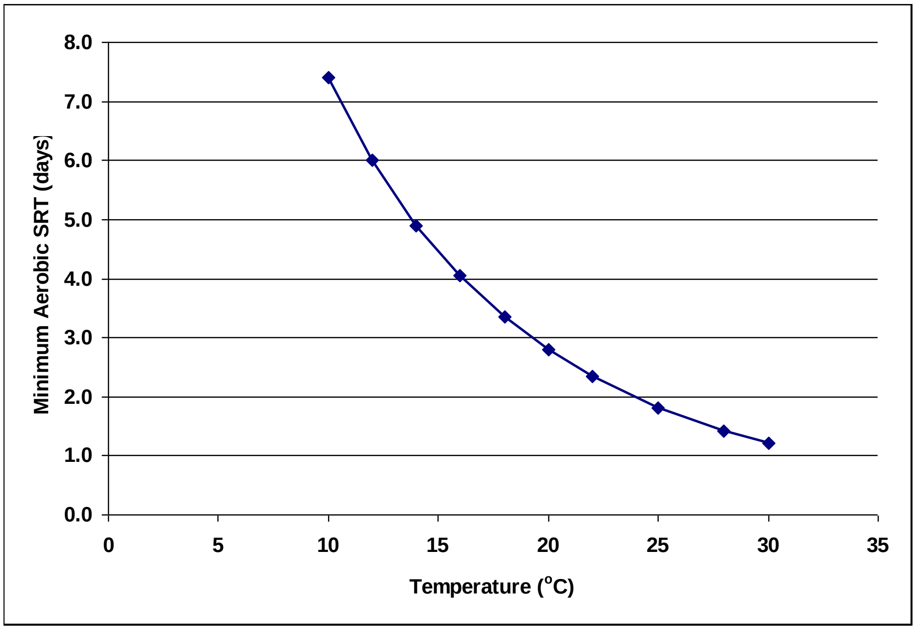


Figure 4-1: Aerobic SRT as a Function of Temperature

4.2.1.1.1 Solids Inventory

Aerobic SRT is impacted by the plant's solids inventory, which is controlled by RAS flow, WAS and SWAS flow, the primary effluent (PE) flow distribution, and the anoxic/oxic configuration of the aeration tanks. **Generally, an aerator effluent mixed liquor suspended solids (AEMLSS) concentration ranging from 2,000 mg/L to 2,500 mg/L is targeted to attain the minimum aerobic SRT requirement for nitrification. The operating mixed liquor levels may need to be reduced depending on the activated sludge settling characteristics.**

Return Activated Sludge (RAS)

The RAS flow rate is a key process control element in the step-feed BNR process. Typical **RAS rates for BNR systems are approximately 50 percent of the raw influent flow rate**. Target RAS rates should be assessed any time process changes are made that modify AEMLSS concentrations during average or peak flow conditions, or if there is a marked change to settling characteristics of the activated sludge (e.g., changes in Sludge Density Index (SDI)). In general, RAS rates will be increased and WAS rates will be decreased to elevate solids inventory in response to an event when significant solids are lost from the system and to increase inventory as the plant moves into colder operating temperatures and operating AEMLSS targets increase. If the plant implements surface wasting (SWAS) as part of its standard operating procedure, alterations to waste activated sludge (WAS) flow rates may be needed to maintain the target solids inventory. Care should be taken to make sure the balance of SWAS and WAS does not exceed daily wasting rates needed to attain target solids inventory and SRT. Finally, RAS rates may be altered during wet weather and bulking events as discussed in **Table 4-1.**

Table 4-1: Drivers for Modifying the RAS Flow Rate

Parameter	Impact of Increasing RAS Rate	Impact of Reducing RAS Rate
Clarifier Sludge Blanket	Enhances capture of poorly compacting sludge (**low SDI/high SVI***), resulting in lower blankets	Increases solids inventory for a given AEMLSS target by returning a concentrated biomass stream, but only applicable during periods of **high SDI/low SVI***
Wet Weather Inventory Management	**Prior to wet weather**, draws down sludge blankets and stores solids in Pass A of ATs	**During wet weather** (and when all other wet weather operating procedures are followed), increases the protected inventory of biomass by reducing diluted flow to Pass A of ATs

***Based on SVI and settling criteria from *Biological Wastewater Treatment, 3rd Edition, Table 2.2*:**

High SVI Conditions: > 150 mL/g; Low SVI Conditions: < 80 mL/g

Waste Activated Sludge (WAS)

At NYCDEP operated BNR facilities, sludge can be wasted from the RAS line and the surface wasting system. Biomass wasted from the RAS line is commonly referred to as WAS, while biomass wasted from the surface is commonly referred to as SWAS. Surface wasting should be performed continuously to prevent foam accumulation on the surface of the aeration tanks. Wasting from the surface allows for selective removal of the filamentous bacteria that are responsible for foam formation. Generally, foam is collected at the end of Pass A in each aeration tank through a weir gate.

The total amount of sludge wasted (SWAS + WAS) will impact the solids inventory and dictate the total SRT and the aerobic SRT of the system as shown in **Equations 1 and 2**.

$$Total\ SRT = SRT = \frac{(Mass_{anox} + Mass_{oxic})}{(Mw + ME)} \qquad (days) \qquad \boldsymbol{Eqn.1}$$

$$Aerobic\ SRT = SRToxic = \frac{(Mass_{oxic})SRT}{(Mass_{anox} + Mass_{oxic})} \qquad (days) \qquad \boldsymbol{Eqn.2}$$

Where:

$Mass_{oxic}$ = Biomass under aerobic conditions = V_{oxic} * $MLSS_{avg}$ * 8.34 (lbs)

$Mass_{anox}$ = Biomass under anoxic conditions = V_{anox} * $MLSS_{avg}$ * 8.34 (lbs)

M_w = Total load wasted per day = Q_{WAS} * TSS_{RAS} * 8.34 + Q_{SWAS} * TSS_{SWAS} * 8.34 (lbs/day)

ME = Load wasted in effluent per day = $TSS_{Effluent}$*$Q_{Effluent}$*8.34 (lbs/day)

$MLSS_{avg}$ = Average MLSS concentration in aeration tank (mg/L)

Q_{WAS} = WAS flow rate (MGD)
TSS_{RAS} = TSS of RAS (mg/L)
Q_{AEMLSS} = Wasted AEMLSS flow rate (MGD)
TSS_{AEMLSS} = Aerator Effluent MLSS (mg/L)
Q_{SWAS} = SWAS flow rate (MGD)
TSS_{SWAS} = Average TSS of SWAS (mg/L)
$Q_{Effluent}$ = Plant effluent flow rate (MGD)
$TSS_{Effluent}$ = TSS of plant effluent (mg/L)
8.34 = Conversion from MG*mg/L to lb

When utilizing the SWAS system, either intermittently or as part of daily operations, the total SWAS mass wasted on a daily basis needs to be properly accounted for in SRT calculations to ensure adequate solids are maintained in the system. **It is recommended that the SWAS system be operated to contribute at least 30% of the total wasted sludge load, and best results are attained when 100% of the total sludge wasted is through the SWAS system.**

Primary Effluent (PE) Flow Distribution

Consistent PE flow distribution to each main plant aeration tank (AT) is desirable for stable operation in terms of solids inventory management, as well maintaining nitrification performance and maximizing total nitrogen removal. To maintain optimal nitrogen removal performance, PE flow distribution should be checked periodically (weekly and after any operational changes that may impact PE flow distribution) using the mixed liquor dilution measurement technique, shown below in **Figure 4-2**. MLSS concentration in RAS and each AT Pass can be measured using a properly calibrated TSS probe.

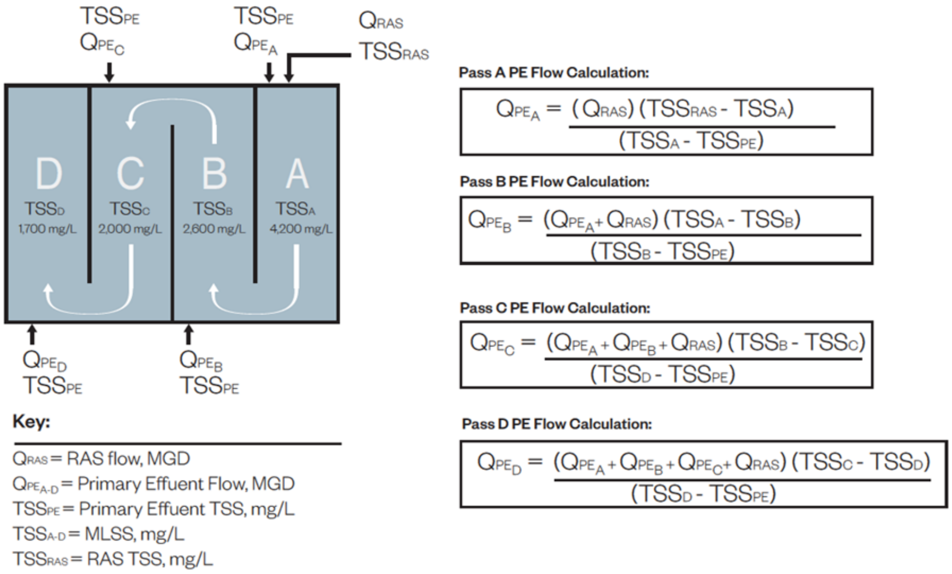


Figure 4-2: PE Flow Distribution Estimation – MLSS Dilution Method

A PE flow distribution of 10:40:30:20 percent to Passes A, B, C, and D, respectively, is recommended for optimal nitrification and denitrification in a four-pass step-feed BNR AT.

However, the PE flow distribution can and should be changed to allow for inventory management, particularly during wet weather events or protracted cold spells. By diverting more of the flow to the latter portions of the reactor during such limiting conditions, nitrification can be retained without necessarily sacrificing denitrification completely.

4.2.1.1.2 Aerobic/Anoxic Zone Configuration

A schematic of a typical four-pass, step-feed BNR AT is provided in **Figure 4-3**. At the head of each pass there is an anoxic zone to promote denitrification (conversion of nitrate, NO3-N to nitrogen gas, N2). The anoxic zones are followed by aerobic zones where nitrification (conversion of ammonia, NH3-N to nitrate, NO3-N) occurs. The anoxic zones can operate in aerobic mode when necessary and are referred to as “switch zones” given their ability to operate in either aerobic or anoxic mode. Switch zones provide the plant to maximize nitrification in the winter due to slower growth kinetics or to recover nitrification when effluent ammonia concentrations increase by converting anoxic zones to aerobic operation.

Typical seasonal anoxic/aerobic zone configuration targets are shown in

Table 4-2. Generally, as temperatures decrease, anoxic switch zones are converted to aerobic operation to increase the aerobic SRT due to slower nitrifier growth conditions. Where reactors allow for increased anoxic volumes in the last Pass (pass D), increasing anoxic volume in the summer and fall will maximize overall nitrogen removal by enhancing denitrification performance. For Pass D, anoxic volumes up to 66% of the Pass Volume should be targeted wherever physically possible, in the summer and fall months.

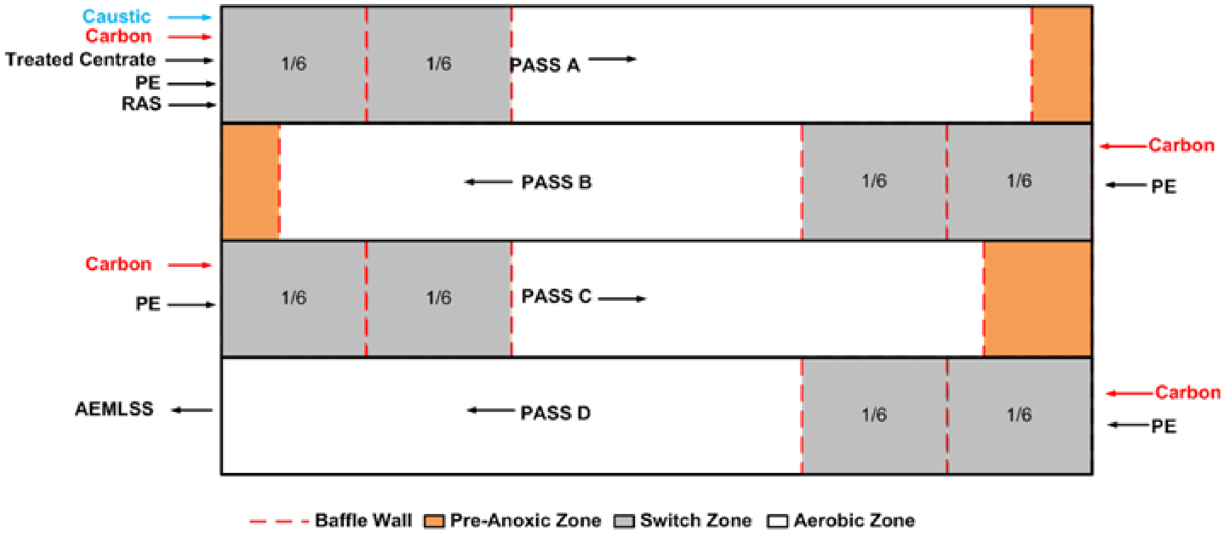


Figure 4-3: Typical AT Zone Configuration

Table 4-2: Typical Seasonal Anoxic/Aerobic Configuration Targets

Season	% Anoxic in Passes A/B/C/D
Summer	33/33/33/33
Spring	16/33/33/33
Fall	16/16/33/33
Winter	0/16/33/33

4.2.1.2 Dissolved Oxygen Concentrations

Maintaining healthy DO concentrations is integral to maintaining nitrification performance. The aerobic zones should have **between 1 and 4 mg/L of DO for effective nitrification**. If effluent NH_3 concentrations increase above 2 mg/L-N in the Spring and Summer, the target DO concentrations within the aerobic zones should increase to 3 mg/L or greater on average to improve and stabilize nitrification. During the Fall and Winter, if effluent NH_3 concentrations increase above 5 mg/L-N, DO concentrations within the aerobic zones should increase to 4 mg/L or greater, as the goal is nitrification process retention, rather than overall nitrogen removal.

4.2.1.3 pH and Alkalinity

The nitrification process requires 7.2 pounds of alkalinity as $CaCO_3$ per pound of NH_3-N oxidized, as shown in **Figure 4-4**. The **optimal target pH in the ATs should be between 6.8 and 7.2 to avoid nitrification inhibition**. Generally, alkalinity naturally present in NYC influent wastewater is sufficient to support nitrification. Therefore, the Jamaica WRRF is not equipped with a supplemental alkalinity system and the Coney Island and Rockaway WRRFs will not be equipped with supplemental alkalinity systems as part of the planned Level 1 BNR upgrades.

Supplemental alkalinity is typically needed to support nitrification in SCT processes due to the high ammonia loading conditions in centrate with contributions from visitor sludges. The 26th Ward WRRF, which operates as a centralized Dewatering Facility with SCT, is equipped with a supplemental alkalinity system. The supplemental alkalinity system is typically not required for SCT deammonification processes, and even in conventional SCT processes (such as 26th Ward's AT-3 Process) has been shown to only be required if a supplemental carbon is not being applied to the SCT.

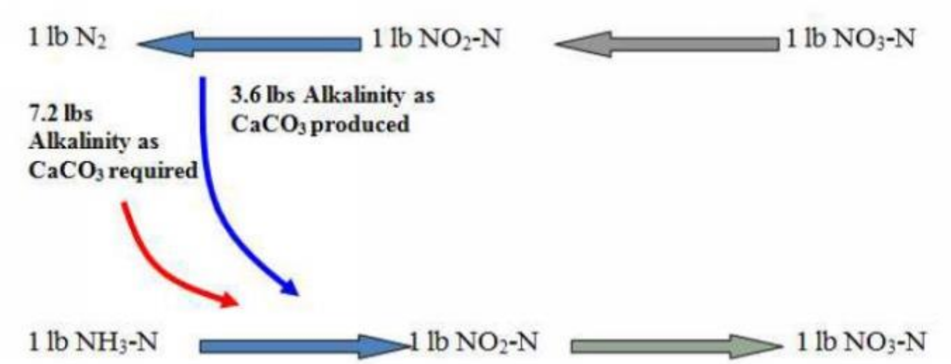


Figure 4-4: Alkalinity in Nitrification and Denitrification

4.2.2 Denitrification Control

Once nitrification performance has been maximized, plant process staff can focus on optimizing denitrification, aided by supplemental carbon addition. To maximize denitrification performance, the following additional operational parameters must be monitored and adjusted:

- Anoxic Zone DO Concentrations
- Supplemental Carbon Addition

4.2.2.1 Anoxic Zone DO Concentrations

Heterotrophic microorganisms responsible for denitrification will utilize available DO as an electron accepter during oxidation of readily biodegradable substrate before they utilize NO_3 or NO_2. Thus, it is important to minimize DO concentrations within the anoxic zones, which can be accomplished by minimizing DO bleed through from the aerobic zone of the previous pass. The best way to accomplish this is to ensure that the pre-anoxic zones are in operation, allowing for a significant reduction in DO leaving the aerobic zones. Tapering the aerobic zones and ensuring that oxygenated flow from the aerobic zones does not backflow into the upstream anoxic zone is critical. When anoxic zones are not being aerated, **DO measurement within the anoxic zones are not meaningful; however the process engineer should measure the DO in the upstream deoxygenation zone and estimate the amount of organic carbon being scavenged by the carryover oxygen, with the goal of minimizing it.**

4.2.2.2 Supplemental Carbon Addition

New York City wastewater has a relatively low readily biodegradable carbon content and the carbon available in the wastewater may be insufficient to promote complete denitrification. Therefore, carbon addition is utilized in conjunction with conventional BNR processes to allow for higher TN removal. The 26th Ward and Jamaica WRRFs are equipped with supplemental carbon addition systems to maximize denitrification and increase overall TN removal.

Judicious use of supplemental carbon needs is required in NYC step feed BNR WRRFs. Adding too little supplemental carbon does not allow for maximum denitrification performance. Adding too much supplemental carbon, particularly during the winter and spring, when wastewater temperatures are at their lowest, reduces nitrification capacity, actually reducing overall nitrogen removal. Proper optimization of the operation of the facility requires regular assessment and weighing of the flow split, the anoxic volume implemented, the operating SRT and the supplemental carbon dose being applied.

4.2.3 Additional BNR Control Elements

Other operating guidelines address common issues associated with BNR operation:

- Wet Weather Operations
- AT Foam Control
- Effluent disinfection under low/no ammonia conditions

4.2.3.1 Wet Weather Operations

Wet weather flows can negatively impact BNR performance by overloading the final clarifiers and potentially washing solids inventory out into the plant effluent.

The main operational goal during a wet weather event is to maintain solids inventory and minimize effluent TSS concentrations. This can be accomplished through a contact stabilization strategy in which a large percentage of the PE flow is directed to Pass D of the AT during wet weather conditions to reduce solids loading to the clarifiers and preserve solids inventory in the earlier passes.

A PE flow distribution of 0:25:25:50 percent to Passes A, B, C, and D, respectively, is recommended to allow the plant to successfully return to optimal nitrification/denitrification performance after the wet weather event. A more severe flow redistribution may be required during instances of reduced secondary clarification capacity or when sludge bulking is being experienced by the reactors.

4.2.3.2 Aeration Tank Foam Control

As stated earlier, a sufficient solids inventory and aerobic SRT must be maintained for optimal nitrification performance. This is especially true under colder temperature conditions. However, an elevated solids inventory and SRT can result in *Nocardioforms* and other foam producing filaments accumulating on the surface of the aeration basin. This foam can result in the majority of biomass floating the surface and poor BNR performance. Severe foaming can result in hazardous field conditions and foaming in downstream process such as the digesters, which can cause damage to the digester covers and the gas collection system.

Foam can be managed through a combination of operational protocols aimed at:

- Selective wasting of filamentous biomass to prevent accumulation and reseeding of filaments in the aeration tanks (SWAS)
- Inactivating of filamentous biomass via chlorine addition (**1 to 3 lbs hypochlorite per 1,000 lbs MLVSS for continuous usage or 3 to 4 lbs hypochlorite per 1,000 MLVSS for a short period of time**). Care needs to be exercised as hypochlorite addition can result in nitrification loss particularly in the winter and spring, when wastewater temperatures are below 18C.

- Reincorporating the surface foam biomass back into the bulk activated sludge physically using spray water or chemically using polymer (**2 mg of active product per L of secondary influent flow).** Polymer can only be dosed for short periods of time, as it will accumulate in the activated sludge, resulting in floating of the sludge in the secondary clarifiers and in severe cases, in the aeration tanks as well.

4.2.3.3 Managing Hypochlorite Consumption with Low Effluent Ammonia

In conventional wastewater chlorination, ammonia reacts with chlorine to produce monochloramines, which function as the primary disinfectant. However, when BNR plants are operating well, complete nitrification can be achieved during all or part of the day. When there is very little ammonia present in the final effluent, the hypochlorite added can exceed the chlorine to ammonia-nitrogen ratio required for effective monochloramine formation and can result in the formation of ineffective dichloramines and can further proceed to unwanted and ineffective breakpoint chlorination. If the chlorine dose results in a breakpoint reaction, the chlorine dosing system will feed additional hypochlorite to meet the residual target, even when ammonia levels increase. Hypochlorite will thus be required to meet not just the disinfection residual, but also for breakpoint chlorination of the effluent ammonia peaks, resulting in a significant increase in hypochlorite consumption. In addition, under certain BNR conditions significant nitrite can be present in the effluent. When neither ammonia nor chloramine is present, the reaction between nitrite and free chlorine becomes significant, resulting in the formation of nitrate. This reaction also has a significant chlorine demand.

Analysis of other NYC WRRF’s hypochlorite consumption has shown that breakpoint chlorination starts to occur as the 24-hour composite effluent NH_3-N level drops below 1.0 mgN/L, indicating that very low levels of effluent ammonia are discharged at some period during the day. The Jamaica Bay WRRFs may encounter daily periods of low/no effluent ammonia, especially in warmer temperatures. To maintain adequate chloramines disinfection during these periods plants may alter operations in one of two ways:

1. The DO set points in Passes C and D can be reduced during warm temperatures and good nitrification performance. The decreased air flow should result in a small bleed through of ammonia resulting in chloramination without reaching breakpoint. However this approach can also result in bulking and is not preferred.
2. Flow to Pass D could be increased to achieve the same result as Option 1.
3. Anoxic Volume in Pass D can be maximized. Anoxic volumes of 50% or greater reduce the likelihood of effluent ammonia discharges of less than 0.5 mgN/L.

These operational changes are likely only needed during warm weather operations and it is likely that breakpoint chlorination will still occur at times, even with prevention measures in place. If breakpoint chlorination does occur, the chlorine dose will have to be manually reset to get out of the breakpoint cycle and reduce hypochlorite consumption. For facilities with future ammonia discharge permit requirements, on-line ammonia analyzers should be investigated to assess their ability to control aeration rates in Pass D.

4.2.4 SCT Control (26th Ward WRRF Only)

The SCT process can impact Main Plant BNR performance in a number of ways:

1. SCT effluent is a source of significant nitrogen load to the main plant
2. SCT performance can alter the concentration and speciation of nitrogen entering the main plant
3. SCT process can serve a source of nitrifying biomass to augment the main plant nitrification process during periods of decreased nitrification performance. Since the SCT process directly impacts main plant BNR performance, there are operational parameters that need to be monitored and adjusted in order to maximize the benefit of operating the SCT Process.
4. SCT process effluent can be a significant source of inert solids and biomass for the main plant's bioreactors. Elevated solids loadings from the SCT process can reduce the operating SRT of the facility for a given aeration tank effluent MLSS target.

The following operational parameters must be monitored and adjusted in order to maximize nitrification in the SCT process:

- Zone configuration
- Internal Recycle (IR) rate
- RAS flow rate
- DO concentrations
- pH/alkalinity

Typical targets for the operational parameters listed above will be discussed in more detail in the following subsections. Note, these parameters only pertain to the 26th Ward WRRF which is the only Jamaica Bay WRRF to operate a Dewatering Facility.

4.2.4.1 Zone Configuration

Generally, **operation with maximum anoxic volume online is recommended** to prevent pH limiting conditions via alkalinity recovery using endogenous and/or supplemental carbon sources.

4.2.4.2 Internal Recycle (IR) Rate

SCT internal recycle directs treated flow from then end of Pass D to the head of Pass A, providing a dilution of the high strength ammonia stream entering the SCT. This dilution acts to reduce the inhibition of AOBs and NOBs from free ammonia, which is present in small amounts at pH conditions between 6 and 8. Typically, an **IR-to-Centrate ratio of 1.0 is advised to allow for full nitrification of centrate, however the IR rate may need to adjusted depending on operating conditions in the SCT reactor and centrate strength**.

4.2.4.3 RAS Flow

Integrating main plant RAS into the SCT process provides a source of nitrifiers that will grow and flourish under the ideal conditions (high ammonia concentrations and high temperatures) provided in the SCT aeration tank and will ultimately optimize nitrification while producing a seeding effect on the main plant. Ideally, the **ratio of RAS to the centrate flow in the SCT process should be targeted at 1.0 or greater** to ensure optimized performance and adequate main plant seeding effect. The RAS rate needs to be seasonally adjusted to maximize the bioaugmentation potential. Note that RAS flow will not be utilized if a deammonification reactor is deployed at 26th Ward in the future.

4.2.4.4 Dissolved Oxygen (DO)

Adequate DO is required to support the nitrification process, with targets of 2 to 4 mg/L typically for full nitrification.

4.2.4.5 pH and Alkalinity

Supplemental alkalinity is recommended in the SCT process at the 26th Ward WRRF if the process effluent pH drops to below 6.5 and/or effluent NH_3-N concentrations exceed the nitrification capacity of Pass A in the mainstream reactors. Optimal caustic dose is dependent on influent centrate characteristics, including ammonia and alkalinity load. These characteristics can vary depending on the properties of the visitor sludges. Based on historical centrate properties, a supplemental caustic dose (50% NaOH solution) of ~0 to 300 gpd is recommended. Plant process staff are also provided with a spreadsheet caustic dosing tool for a more precise caustic dose based on influent centrate characteristics.

4.3 Comprehensive Supplemental Sampling Programs

NYCDEP implemented multiple comprehensive supplemental sampling programs to facilitate a smooth transition into BNR operation and operation with Supplemental Carbon Addition at the 26th Ward and Jamaica WRRFs. The sampling programs were intended to supplement routine sampling already conducted by plant staff to optimize the BNR process and more specifically define optimized operations.

Supplemental sampling was typically performed on a weekly basis and consisted of inorganic nitrogen profiles through the anoxic and aerobic zones of each AT, DO/pH/TSS profiles, operational settings (liquid flows, air flows, and gate settings), and installed probe readings. A typical schematic of the sampling locations within the aeration tanks is provided in **Figure 4-6**.

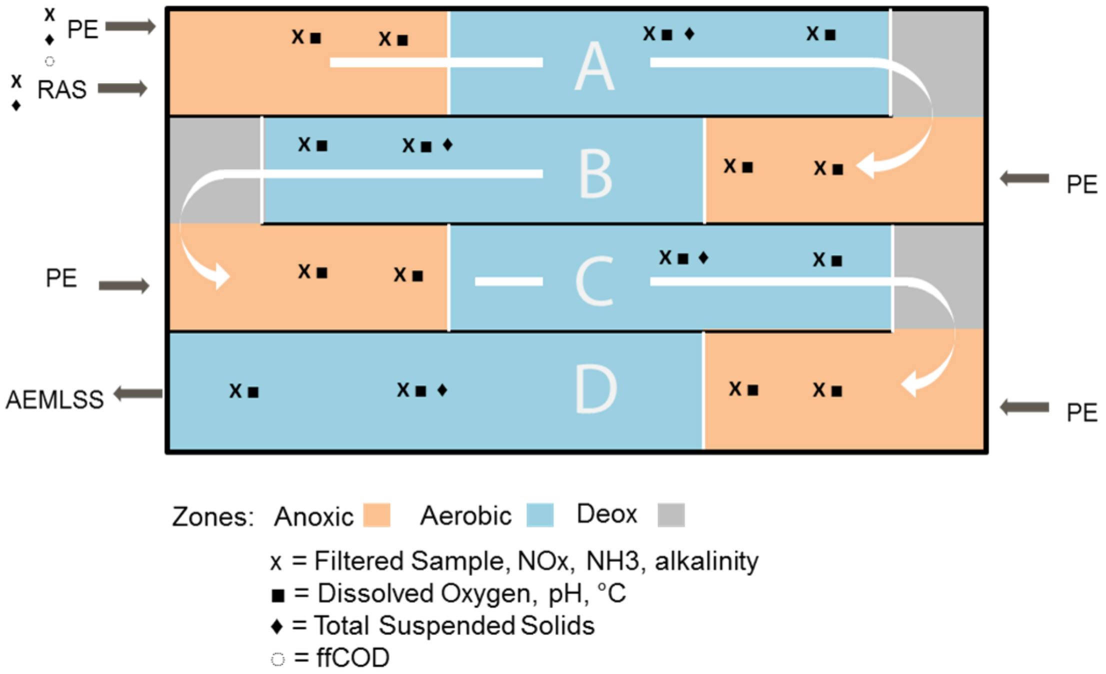


Figure 4-5: Example of Typical AT Sampling Locations

Comprehensive sampling allowed for the implementation of the initial BNR settings, provided plant staff with sufficient data to confirm the new BNR settings, and allowed for the development of plant specific BNR operational parameters.

The specific sampling programs included:

- 26th Ward BNR Optimization, June 2010 through February 2011
- 26th Ward BNR SCT Glycerol Demonstration, December 2011 through October 2012
- JA BNR Optimization, January 2015 through July 2015
- 26W BNR Glycerol Optimization, December 2015 through July 2016
- JA BNR Glycerol Optimization, June 2016 through March 2017

A summary of the outcomes of each sampling program are provided in **Appendix B**.

4.4 Contingency Sampling

Given the complexity and operational sensitivity of the BNR process, there is the potential for periods of reduced nitrification performance. A nitrification upset, if caught early enough, can be treated with changes to operational settings (increased air, alkalinity, decreased wasting, conversion of swing zones to aerobic operation) to avoid failure. An effluent ammonia concentration higher than 5 mgN/L is typically an indication that operational changes should be implemented (note, this concentration trigger is plant-specific).

The 26th Ward and Jamaica WRRFs proactively monitor nitrification performance by following a daily guided checklist. During periods of reduced nitrification performance, the checklist provides plant staff with a set of immediate actions that can be taken to recover the nitrification process. An example of this checklist is provided in **Appendix B**.

4.5 Instrumentation Control

For optimized biological processes, a stricter degree of control is needed for several parameters within the aeration tanks. Although instrumentation is not an essential component of the BNR process, NYCDEP has incorporated instrumentation at both the 26th Ward and Jamaica WRRFs to provide plant operators with real-time information and allow the plant to take corrective action to keep the plant operating at optimal nitrogen removal rates and/or prevent process upsets.

Brief descriptions of the various types of instrumentation available for BNR process control are provided below:

- **In-situ Total Suspended Solids (TSS) Probes**
    - Real-time TSS concentration measurements at various points in the ATs allows the process engineer to estimate the plant's SRT and ensure that nitrifier washout is not imminent.
- **In-situ Dissolved Oxygen Probes**
    - Plant operators will wish to deliver process air at a rate sufficient to maximize the rate of nitrification (approximately 2 to 4 mg/L), but not so much air that energy is wasted. A DO concentration greater than 0.2 mg/L has been shown to inhibit denitrification; hence information on the DO concentrations in the anoxic zones is important to reduce the effects of back mixing from upstream aerobic zones.
    - DO probes can allow for automated aeration control via DO concentration readings.
- **In-situ pH Probes**
    - The nitrification process consumes alkalinity, and thus alkalinity addition may be needed to ensure optimal nitrification. pH meters allow for monitoring the pH of the mixed liquor to ensure that sufficient alkalinity is added (if necessary) to maintain the optimal pH range.
- **Various Flow Measurement Devices** (e.g., PE, RAS, WAS, SWAS, air flows)
- **In-situ Nitrogen Speciation Probes (Ammonia and/or Nitrate)**
    - Knowledge of the relative concentrations of ammonia and oxidized nitrate will assist operations staff in optimizing zone configurations to aid in nitrogen removal efforts. Knowledge of real-time ammonia and nitrate concentrations also provides plant staff with an early warning of nitrification losses and can provide an opportunity to take corrective action prior to total nitrification loss.

- Nitrate analyzer control is NYCDEP's preferred strategy for glycerol addition as it ensures that glycerol is being adequately dosed while avoiding over-dosing. A more detailed description of this strategy is provided in **Section 1.6.6**.

A schematic of typical installation locations of the instruments described within the step-feed BNR process is provided in **Figure 4-6**.

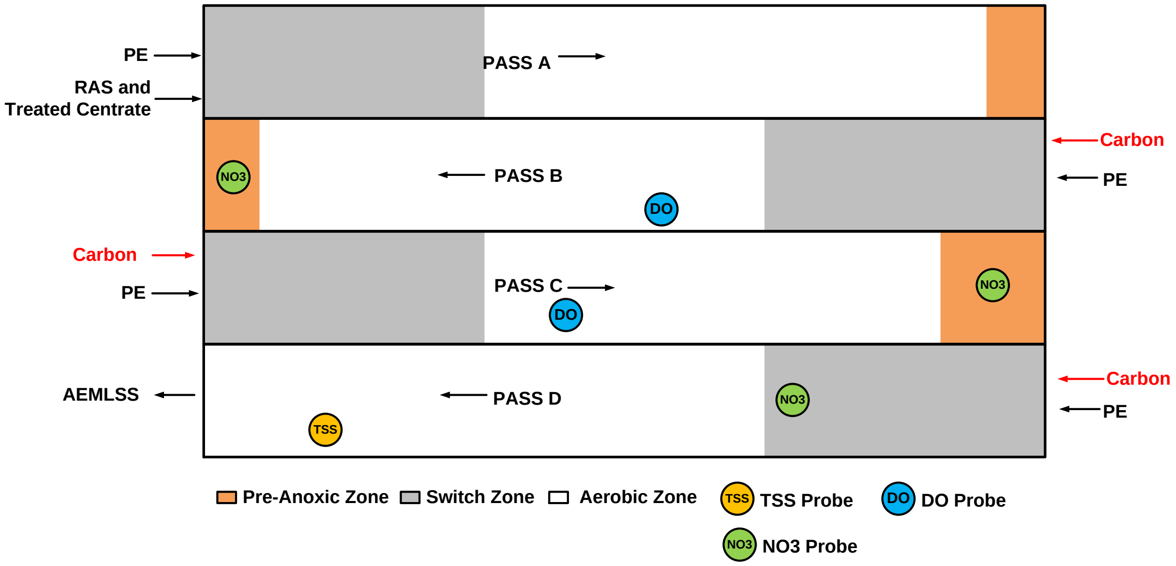


Figure 4-6: Main Plant AT Probe Locations

4.6 Equipment Optimization

NYCDEP implemented a standardized approach for retrofitting existing step-feed aeration tanks to BNR operation at each facility by developing design guidance and initial BNR process control strategies (described in **Section 4.2)**. This approach allowed NYCDEP to continuously optimize the BNR process over the past decade as both Upper East River facilities (Bowery Bay, Hunts Point, Tallman Island, and Wards Island) and Jamaica Bay facilities (26th Ward and Jamaica) came online with BNR operation.

This Section provides an overview of the procedures NYCDEP implements for optimal operation of BNR related equipment.

4.6.1 Flow Control Equipment

AT flow distribution and control is an important process parameter that has a direct impact on the nitrogen removal performance of the BNR process. As such, determining the optimal PE flow distribution during dry weather and wet weather events is essential for step-feed BNR systems. Step-feed aeration tanks are configured to make use of the readily biodegradable carbon present in the PE for denitrification. Additionally, one of the main advantages of step-feed systems is the ability to divert excess flow to the later passes of the AT during wet weather events to prevent washout of biomass.

As part of the supplemental sampling programs at the 26th Ward and Jamaica WRRFs, PE flow splits were determined through AT TSS profiling during each sampling event. PE flow splits were tested throughout the supplemental sampling programs to determine ideal flow splits for varying operational conditions, including: normal dry weather operation, wet weather operation, and operation at reduced nitrification performance. This allowed for refinement of optimal PE flow splits and determination of PE sluice gate positions needed to achieve the desired flow split condition.

4.6.2 Mixers

As part of the BNR upgrade, within each switch zone and pre-anoxic zone, mixers were installed to keep the mixed liquor solids in suspension. For optimal operation of anoxic zone mixers, NYCDEP performs regular preventive maintenance.

4.6.3 Process Aeration Equipment

Aeration Tanks running in BNR mode have both oxic and anoxic zones. In oxic zones, the presence of oxygen is required to oxidize ammonia into nitrite and nitrate via the nitrification process. Both the presence and the amount of DO in the mixed liquor stream are of vital importance to ensure optimal nitrification. Plant operators will wish to deliver process air at a rate sufficient to maximize the rate of nitrification (approximately 2-3 mg/L) and ensure MLSS is properly mixed, but not so much air that energy is wasted. In anoxic zones, nitrate and nitrite are reduced to nitrogen gas through the denitrification process. A DO concentration greater than 0.2 mg/L has been shown to inhibit denitrification; hence information on the DO concentrations in the anoxic zones is important to reduce the effects of carryover from upstream aerobic zones. Diffusers need to be cleaned regularly to prevent fouling. Instrumentation is used to optimize operation.

4.6.4 Foam Control Equipment

Operating at the elevated solids inventory and SRT needed for nitrification also allows for foam producing filaments such as Nocardioforms to accumulate on the surface of the aeration basin. This foam can result in the majority of biomass floating the surface and poor BNR performance.

BNR plants have equipment that provides multiple lines of defense against foam accumulation, including:

- Selective wasting of filamentous biomass to prevent accumulation and reseeding of filaments in the aeration tanks (SWAS) – operated to waste 30 to 100 percent of the plant’s total wasting
- Inactivating of filamentous biomass via chlorine addition
- Reincorporating the surface foam biomass back into the bulk activated sludge physically using spray water or chemically using polymer

4.6.5 RAS and WAS Equipment

As mentioned previously, the RAS flow rate is a key process control element in the step-feed BNR process. Based on typical BNR practice and experience from operation of all NYCDEP WRRFs that operate in BNR mode, RAS rates should be at least approximately 50 percent of the raw influent flow rate. In general, RAS rates will be increased and WAS rates will be decreased to elevate solids inventory in response to an event when significant solids are lost from the system and to increase inventory as the plant moves into colder operating temperatures and operating AEMLSS targets increase. Care should be taken to make sure the balance of SWAS and WAS does not exceed daily wasting rates needed to attain target solids inventory and SRT. Finally, RAS rates may be altered during wet weather and bulking events (see **Table 4-1**).

Sufficient redundancy on RAS and WAS pumping equipment is provided at all of the Jamaica Bay WRRFs to allow for routine preventive maintenance.

4.6.6 Chemical Storage and Delivery Systems (Glycerol and Caustic)

Caustic addition is provided at the 26th Ward WRRF to support the SCT process, which is susceptible to low pH conditions due to the high strength ammonia load in dewatering centrate and longer hydraulic residence time (HRT). As mentioned earlier, the nitrification process consumes significant alkalinity (see **Figure 4-4**). In main plant BNR, the alkalinity inherent in influent wastewater and the alkalinity recovered via denitrification is sufficient in ensuring pH limiting conditions are not present. The SCT process at 26th Ward has been continually optimized since it went online in June 2010 through NYCDEP's multiple supplemental sampling programs. Through these programs, caustic dosing guidelines were refined for optimal nitrification conditions within the SCT process.

Glycerol addition is provided at the 26th Ward and Jamaica WRRFs to drive the denitrification process. The glycerol facilities at 26th Ward and Jamaica were designed similarly with multiple control strategies for glycerol addition, including:

- **Manual Control**: The dosing control valve is set to one position by the operator.
- **Semi-Auto Flow Control**: A flow set point is input by the operator and the flow control valve adjusts to maintain the flow.
- **Auto Flow Control**: The flow controller set point for each flow control valve is set by the PLC based on each AT plant flow.
- **Nitrate Analyzer Control**: A nitrate set point is input by the operator and the flow control valve adjusts to maintain the nitrate level.

Nitrate analyzer control is a NYCDEP's preferred strategy for glycerol addition as it ensures that glycerol is being adequately dosed while avoiding over-dosing. Additionally, the NYCDEP developed manual set-points for glycerol addition as part of the 'BNR with Glycerol Addition' supplemental sampling programs at 26th Ward and Jamaica.

4.6.7 Instrumentation

Regular maintenance and calibration of in-situ analyzers (i.e., nitrate probes and DO probes) is performed to ensure optimal operation of automation-based strategies (i.e., glycerol addition via nitrate probe readings and process air via DO probe readings). NYCDEP is also equipped with multiple back-up strategies in the event the probes need to be taken out of service for maintenance and/or repair to ensure that the BNR process is maintained. Through the extensive sampling programs that NYCDEP has implemented over the years and the resulting plant specific O&M plans, plant staff are equipped with guidelines to ensure optimal BNR performance.

5. Bench Scale Testing

5.1 Introduction

The NYCDEP is committed to conducting testing of new and emerging technologies that are focused on, or allow optimization of, nitrogen removal, to meet the City's overall goals of reducing nitrogen discharges (Total Nitrogen and ammonia) from their Wastewater Resource Recovery Facilities (WRRFs) and improving water quality in the receiving waterbodies.

The NYCDEP has partnered with various entities, including universities, consultants, and national and state funding agencies and organizations to support several research projects. These projects include completed, ongoing and planned studies as summarized in **Table 5-1**, below. Each project is described in detail in the following sections.

Table 5-1: Summary of NYCDEP Testing for Nitrogen Removal

Project Name	Description	Partner/Supporting Agency	Status
Supplemental Carbon (Methanol, Glycerol) Testing	Optimization of methanol addition, and pilot testing of glycerol as a supplemental carbon source to support denitrification	Hazen and Sawyer, CH2M Hill	Completed 2011
Deammonification pilot studies at the 26th Ward WRRF	MBBR pilot study to examine operational conditions for optimal nitrogen removal while considering typical NYC centrate characteristics	CCNY	Completed 2014
Struvite Control Alternative	Bench-scale study to assess the two struvite control methods and examine the dewaterability of treated sludge	CCNY	Completed 2014
Stabilization of 26th Ward Main Plant Nitritation/Denitritation Performance (WERF U4R12)	Full scale nitritation/denitritation demonstration study targeting reliable nitritation at low operating nitrogen concentrations and temperatures using the concurrent application of multiple NOB suppression mechanisms	WERF, Columbia University, Greeley and Hanson	Completed 2015
26th Ward Separate Centrate Deammonification process	A separate centrate deammonification process was tested in the lab and later piloted to exploit the natural predisposition of the mixed culture community to produce a mixture of nitrite and nitrate when oxygen is provided, and denitrify to nitrite in the presence of glycerol, to facilitate anaerobic ammonia oxidation.	NYSERDA, Hazen and Sawyer, Manhattan College, Columbia University	Completed 2016
Testing of Nitritation Induction using SBRs at Hunts Point Wastewater Resource Recovery Facility	Study to assess selective pressures to induce nitritation/denitritation in integrated mainstream/sidestream process including free nitrous acid exposure, reducing sludge retention time and dissolved oxygen control strategy.	CCNY	Completed, 2017

Granular Sludge Testing	Ongoing project to optimize the simultaneous removal of carbon, nitrogen and phosphorus using aerobic granules	CCNY	Completed, 2018
Centrate Fine Screen Pilot Study at Wards Island WRRF	Pilot of a rotary drum perforated plate screen to remove solids from centrate as one step in a multi-step strategy to pretreat the centrate prior to deammonification.	Arcadis	Completed, 2018
Dispersant Polymer Testing	Use of dispersant polymer in lieu of ferric chloride to prevent nuisance struvite precipitation	NYCDEP	Completed, 2018
Sludge Screening Piloting at Wards Island WRRF	Piloting of sludge screening to remove floatables/plastics, rags to allow for equalization of centrate characteristics to reduce the risks of process failure in the future MBBR deammonification facility.	Arcadis	Ongoing

5.2 Supplemental Carbon (Methanol, Glycerol) Testing

Carbon addition is a major component of NYC biological nitrogen removal (BNR) compliance strategy. Both methanol and glycerol testing has been conducted to determine optimization strategies for increased nitrogen removal.

5.2.1 Methanol Testing

Battery E at the Wards Island WRRF is the NYCDEP’s 25 mgd high-rate, 4-pass step-feed BNR demonstration facility. DEP’s Applied Research and Demonstration Project led a monitoring and optimization program of Battery E performance and operation, including developing a methanol addition strategy for the startup of carbon addition operations and seasonal optimization of methanol addition once supplemental carbon addition began.

As a starting point, a spreadsheet calculation was developed to determine the initial methanol dose per pass. This calculation included Battery E operating conditions (tank size, anoxic zones, step-feed setup), feed sources (Primary Effluent and Centrate), endogenous denitrification, and kinetic limitations using methanol-specific denitrification rates.

Carbon addition began with methanol addition at the head of all four passes. After methanol addition began, several full-tank profiles were conducted to determine the methanol utilization in each Pass and identify opportunities to optimize methanol addition. **Figure 5-1** shows the initial operational setup of Battery E, with the sampling zones used in the profiles.

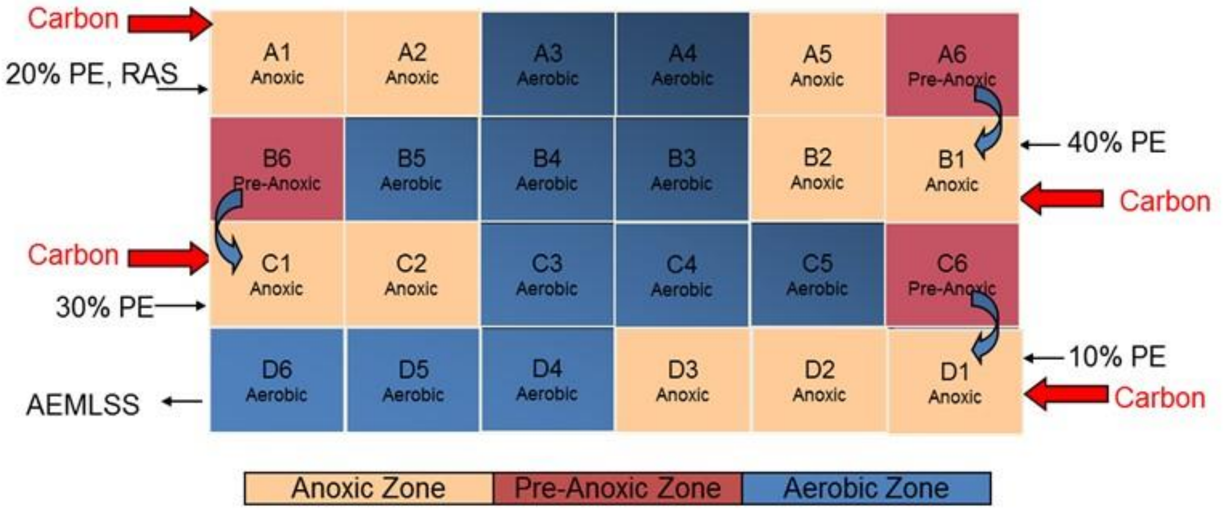


Figure 5-1: Battery E Layout with Carbon Addition Points

Results from the four-point methanol addition profiles are shown in **Figure 5-2**. With four-point methanol addition, full nitrification was noted in each pass and essentially full denitrification was seen in each anoxic zone, with effluent NO_x less than 1 mgN/L. The four-point addition profile indicated that anoxic zones in Passes A and B did not need supplemental carbon addition, and the Battery was converted to two-point carbon addition (Passes C and D only).

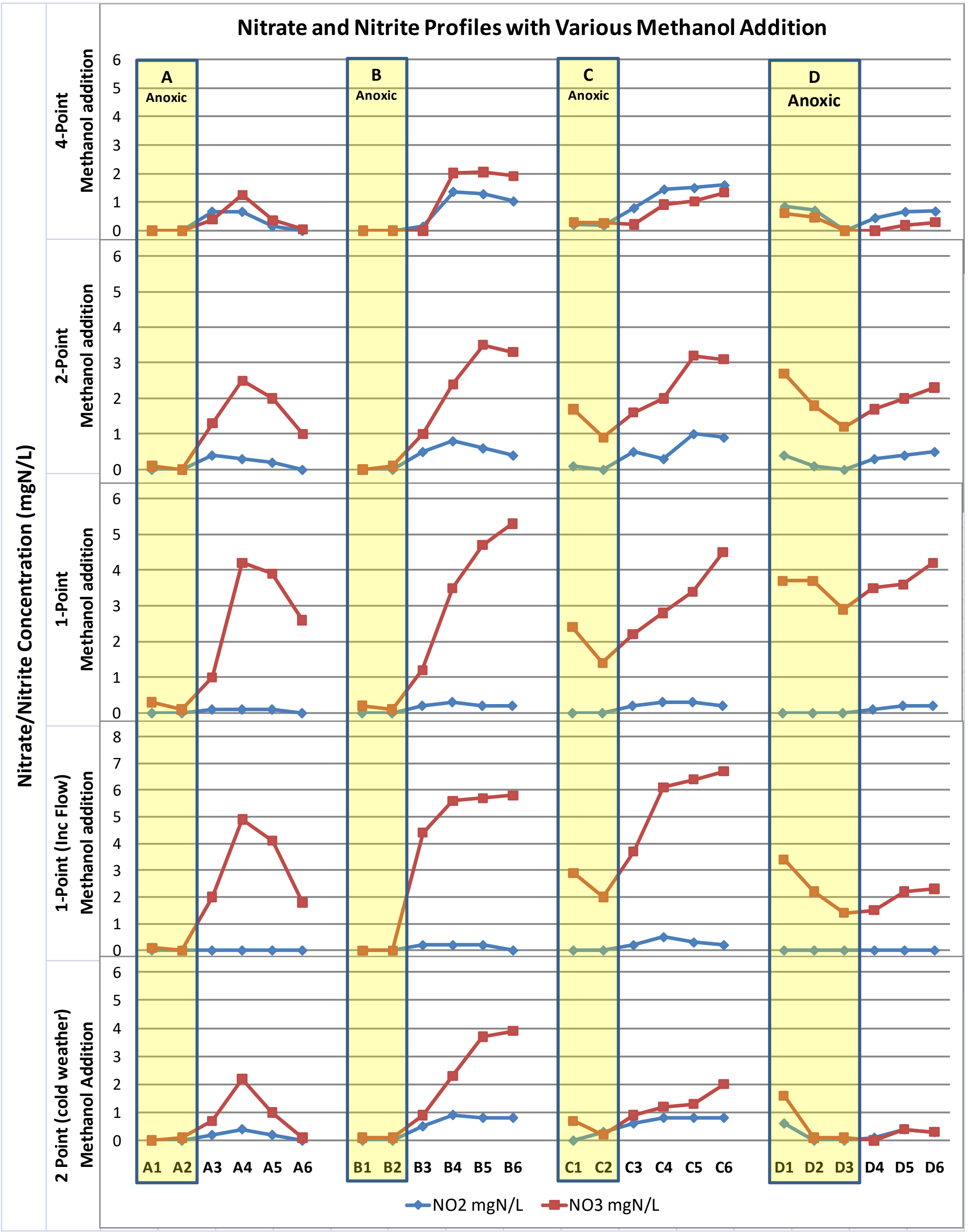


Figure 5-2: Profile Results for Various Methanol Addition Strategies

Additional full-tank profiles were conducted to determine the impact of two-point carbon addition on Battery E performance. Results are shown in **Figure 5-2**. The anoxic zones in Passes C and D showed effluent NO_x concentrations of 1 mg/L, indicating that a two-point carbon addition strategy provided sufficient denitrification.

To further test the limit of methanol addition, the Battery was converted to one-point carbon addition operation with methanol addition to Pass D only. The carbon addition to Pass D was not increased, and was left at the original spreadsheet-calculated theoretical settings.

Profile results from the one-point addition operation are shown in **Figure 5-2**. The anoxic zone in Pass C showed an effluent of 1.5 mgNO_x-N/L, which was similar to that seen with two-point methanol addition, however Pass D showed an elevated anoxic zone effluent of 3 mgNO_x-N/L. Methanol profiles indicated that methanol was not being fully used in Pass D (methanol concentrations leaving Pass D were 5 mgCOD/L), and yet full-denitrification was not achieved. Given that the influent loadings were stable for the operating periods studied, a review of the composite sampling data showed that the increase in effluent nitrate in Pass D was significantly higher than would be theoretically expected by the reduction in the total mass of methanol added (stoichiometry indicated that the reduction in methanol should have equated to a 1 mgN/L increase in effluent nitrate).

Further investigation into the profiles showed that although sufficient methanol was being added to denitrify 1,300 lb NO_3-N/d (theoretically), only 400 lb NO_3-N/d were actually being denitrified, with approximately 170 lb NO_3-N/d being attributed to endogeny. Calculations confirmed that the methylotrophic anoxic growth rate in Pass D should have been sufficient to achieve complete denitrification in the well-defined anoxic zone in Pass D, and there was no indication that there were nitrate or methanol limitations that would have interfered with the methylotrophic anoxic growth rate; nitrate concentrations were consistently greater than 1 mgN/L and methanol concentrations ranged between 2 and 10 mgCOD/L.

The higher nitrate concentrations leaving the anoxic zone in Pass D were hypothesized to be due to a reduced methylotrophic population. The growth rate and denitrification rate checks indicated that methylotrophic washout should not be occurring theoretically, however the shift in the stoichiometry indicated that the methanol-degrader population was significantly reduced and approaching washout. To determine if methanol limitation was truly the cause for reduced Pass D anoxic zone performance, the methanol dose to Pass D was doubled.

The Battery profiles conducted to test the impact of the increased methanol flow to Pass D (see Figure 2) showed effluent NO_x from the anoxic zones in Pass C at 2 mgN/L and from Pass D at 1.5 mgN/L, an improvement over the effluent observed with a lower methanol flow to Pass D. Furthermore, under the increased methanol dose 5 mgNO_3-N/L were removed, compared to only 1.5 mgNO_3-N/L when half the dose was applied.

Investigation into the profiles showed that sufficient methanol was being added to denitrify 2,400 lb NO_3-N/d (theoretically), and 1,500 lb NO_3-N/d were actually being denitrified, with approximately 170 lb NO_3-N/d being attributed to endogeny. Doubling the methanol addition resulted in an almost 400% increase in nitrate removal. The improvement in performance was attributed to an increased methylotrophic growth rate, resulting from higher substrate levels from the increased methanol flow to Pass D. The additional methanol can be completely accounted for in the increased removal of nitrate (an extra 1,100 lbNO_3-N/d were removed with the addition of 3,100 lbCOD/d). Additionally, under both one-point methanol dosing strategies, the traditional methanol denitrification theory overestimated nitrate removal by 900 lbN/d and the same levels of methanol (5-6 mgCOD/L) were observed leaving the anoxic zone in Pass D, providing further anecdotal evidence that methanol was becoming limiting within the process at higher than expected concentrations. These results were contrary to traditional methanol-driven denitrification theory, which indicated that full denitrification should have been achieved at a lower methanol dose. The complete optimization results are summarized in **Figure 5-3**, showing the impact of each subsequent change in methanol dosing on nitrate concentration.

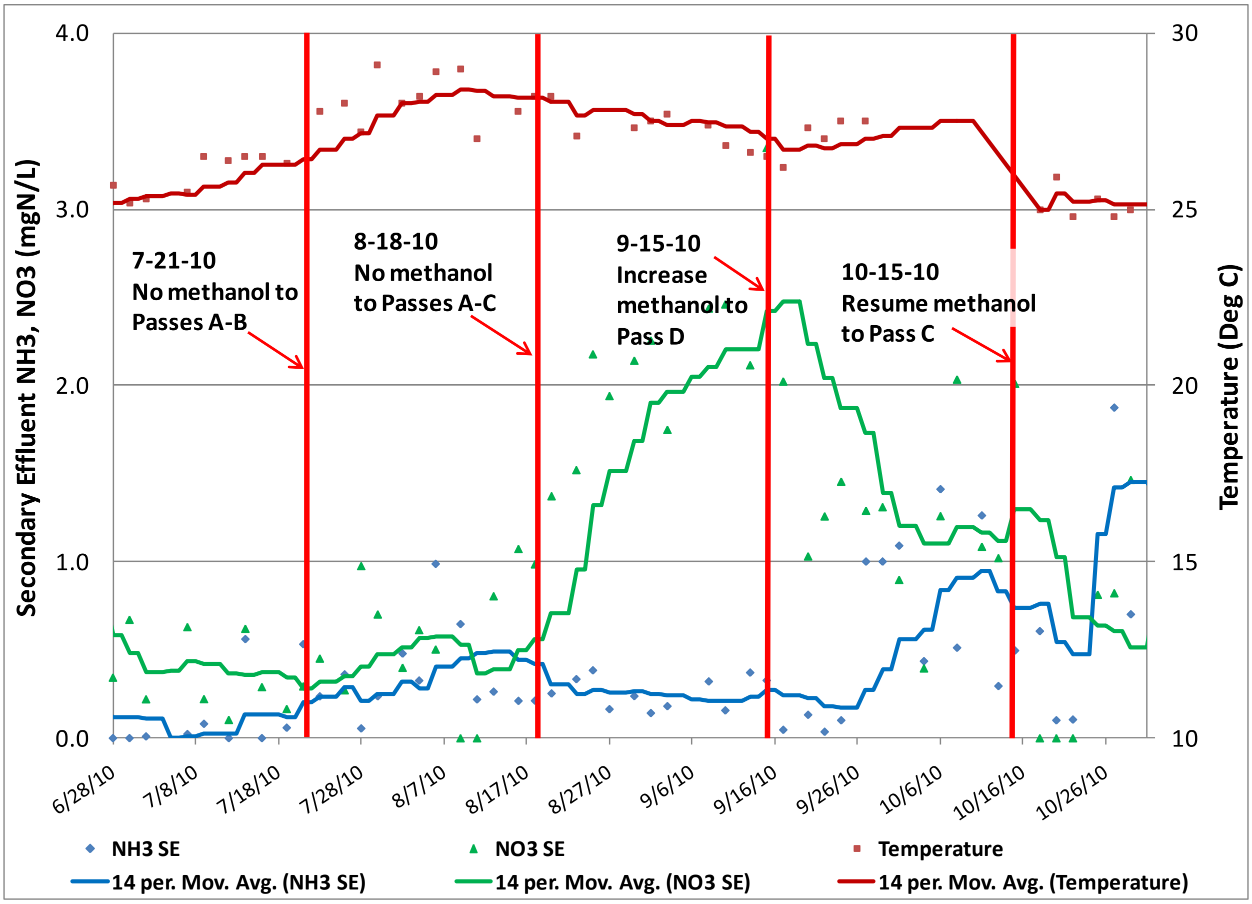


Figure 5-3: Summary of Impact of Methanol Optimization on BNR Performance

The methanol optimization research conducted at Battery E indicated that:

- Full denitrification could be achieved with approximately 30% less methanol than was originally anticipated with early modeling of the BNR program.
- The optimization of methanol addition at the Battery E facility showed that sufficient denitrification can be achieved with only one-point carbon addition, greatly reducing operational complexity as well as capital costs. Note, one-point methanol addition is a warm-weather seasonal operation.
- Results from this study indicated that the relationship between methanol substrate concentration and methylotrophic growth rates may differ from traditional theory in this high-rate, step feed system. The data suggests that the methanol half saturation constant may

effectively be underestimated under these testing conditions, resulting in the need for additional methanol to meet performance goals. If this relationship can be verified, it must be accounted for when optimizing methanol doses using computer models and traditional methanol theory.

Additional information for this study can be found in *Full Scale Methanol Optimization at a Step-Feed BNR Demonstration Facility*, Dailey, S., Sharp, R., Deur, A., Beckmann, K., Katehis, D., 2011.

5.2.2 Glycerol Testing

Two pilot plants at the 26th Ward WRRF (Figure 5-4) were retrofitted and used to understand the impact and effectiveness of glycerol as a carbon source to support denitrification. One pilot served as the control, with no supplemental carbon addition, the second pilot plant received glycerol at a constant dose to the anoxic zone in the fourth pass (Pass D) (**Figure 5-5**).

Figure 5-4: Pilot for Glycerol Addition Research

Glycerol proved to be a viable supplemental carbon source for a high rate step feed BNR process such as those deployed in NYC's WRRFs. The pilot receiving glycerol exhibited an effluent soluble nitrogen of approximately 1.5 mgN/L less than the control during periods of stable operation. A greater differential would likely have likely been realized (up to a practical level of approximately 3 mgN/L) if complete nitrification had been retained in the pilot plant during winter operations. Glycerol continued to provide denitrification even when the overall operating SRT was as low as 2-3 days (~0.4 days SRT for the anoxic zone fed glycerol), however, a significant amount of nitrite was observed, flagging this as the lower bound of operations. Recognizing that the typical anoxic SRT in NYC's WRRFs would be on the order of 2 days, denitrification with glycerol can be successfully deployed in NYC WRRFs.

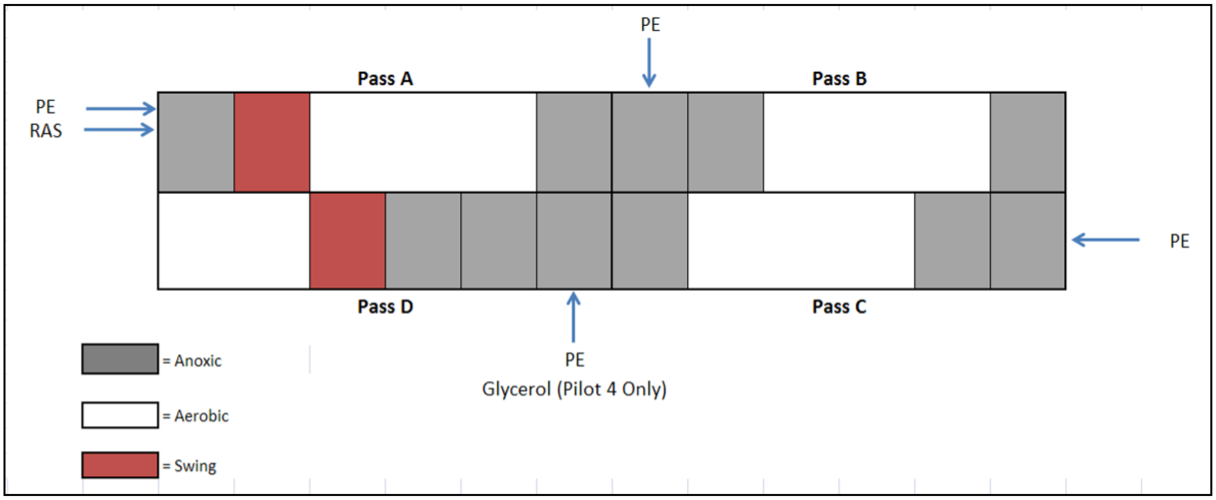


Figure 5-5: Re-Configured Step Feed BNR Pilot Plants

The pilot's ability to maintain nitrification was limited by the high SVI observed, and as a result the need to operate at reduced SRT levels (as low as 3 days overall; approximately 2 days aerobic) at sustained temperatures of 15-16°C with values as low as 14°C. The higher than anticipated SVI was likely a result of the pilot plant's half depth geometry, which resulted in a high level of surface froth and Enhanced Biological Phosphorus Removal in both pilot systems. Profiles showed that complete denitrification was achieved in Pass A of both pilots, and in Pass D for the pilot receiving supplemental carbon in the form of glycerin.

The presence of *Nostocoida limicola*, which was identified as the primary filament causing bulking in both pilot systems was likely selected for in the activated sludge population due to the diurnal loadings and subsequent periodic anaerobic activity experienced by this plant. In the pilot plant receiving glycerol, anaerobic conditions in the anoxic zones were more pronounced as complete denitrification occurred in the Pass D anoxic zone at all times. This resulted in a greater proliferation of the *N.limicola* and more severe bulking conditions.

Extending the Pass D anoxic zone in both the control and the pilot receiving supplemental carbon resulted in a significant enhancement in denitrification performance without compromising nitrification performance of the reactors. Extension of the anoxic zone in Pass D to 66% of the total volume in that pass, resulted in enhanced denitrification performance in both pilots; removing an estimated additional 1.5 mgN/L of nitrate versus an anoxic zone in Pass D that constituted 33% of the pass volume. The enhanced performance of the control pilot minimized the nitrate differential between the control and the pilot operating with supplemental carbon to approximately 1.5-2 mgN/L when both reactors were operating in a stable manner.

Minimizing the supplemental carbon dosage to reflect diurnal variations in demand, thereby reducing or shutting down supplemental carbon addition in the late afternoon through the early morning hours represents one mechanism that would minimize the potential for the formation of anaerobic conditions and thereby reduce the high level of enhanced biological phosphorus removal (EBPR). With a reduced potential for anaerobic conditions, the likelihood of a reduction in filaments that are capable of EBPR would also be reduced. A full-scale demonstration of glycerol application would allow the plants to develop Standard Operating Procedures to manage supplemental carbon addition in a manner specific to NYC's high rate step feed BNR process. This may be considered as part of the planned full scale demonstration of glycerin at 26th Wards separate centrate treatment reactor.

The piloting process provided an opportunity to assess BNR performance with an optimized activated sludge configuration (although it was limited by pilot scale issues such as clarifier geometry). The ability to retain nitrification performance at aerobic SRTs of less than 3 days was a significant finding of this piloting effort. In addition, it was determined that supplemental alkalinity addition was not needed in the optimized configuration, where the dewatering centrate ammonia load was removed. At full scale operation, caustic addition may be needed if a dewatering centrate load is present. Finally, the results showed that glycerol addition could improve nitrogen removal at temperatures as low as 14°C, which is significantly lower than methanol driven denitrification temperature limits.

Furthermore, this piloting effort highlighted the potential of using active operational modifications to enhance the plant's ability to retain nitrification. Maintaining a constant DO level of 2 mg/L, during periods of stable nitrification performance, and being able to reliably increase the DO levels to up to 4 mg/L during periods of ammonia bleedthrough, were key to maintaining nitrification performance. The ability to convert the Pass A swing zone to aerobic operation, thereby increasing the aerobic SRT when needed, contributed to the pilots' nitrification stability, even when excessive solids losses occurred.

Surface wasting of froth, in concert with conventional sludge wasting was able to control surface froth in the pilots, although the reactor geometry resulted in approximately twice the aeration per unit surface area versus a conventional high rate BNR reactor. This created significant operational challenges; however the proliferation of bulking filaments, rather than frothing filaments were the principal concern during this piloting effort.

In summary:

- Usage of glycerol will allow optimization of denitrification in the winter months, as denitrification performance is retained at the minimum operating temperatures observed in the piloting effort.

- The presence of nitrite in the effluent, when glycerin is being added, is an indicator that the denitrification process is stressed. Addition of glycerin to Pass C, along with Pass D would serve to mitigate this effect.

- Successful operation with glycerol addition was attained at the minimum winter temperatures with anoxic SRT levels of as low as 0.4 days. Based on overall performance, and to prevent nitrite accumulation, the minimum anoxic SRT should be retained at greater than 0.8 days, well within the operating envelope of NYC's WRRFs. Multi-point glycerin addition would likely be necessary to achieve this target SRT in NYC WRRFs. Pass C and Pass D would be the preferred addition locations. Extension of Pass D to 66% of the pass volume, as was done in the pilots, would allow the glycerin to be used most effectively while minimizing feed points.

- Elevated SVI levels due to bulking EBPR filaments were observed at the minimum temperature condition. A full scale demonstration of glycerol addition should be undertaken to develop operating procedures in a controlled environment, such as AT-13, allowing the full scale deployment of glycerol at NYC's WRRFs to proceed more smoothly.
- Minimizing supplemental carbon addition by using a control strategy that reflects the changes in diurnal nitrogen and carbon loadings will reduce the likelihood of transient anaerobic conditions in the plants, while also increasing the utilization efficiency of the supplemental carbon source.
- Extension of the anoxic zone in Pass D, to represent 66% of the total volume in Pass D, resulted in significantly enhanced performance in both pilots; extension of the anoxic zone resulted in the stable removal of approximately 1 mgN/L of additional nitrate. The enhanced performance of the control pilot limited the nitrate differential between the control and the pilot operating with supplemental carbon to approximately 1.5-2 mgN/L when both reactors were operating in a stable manner.
- Supplemental alkalinity addition is not required to bioreactors when the centrate load has been otherwise removed. Operation without caustic addition to the main plant flow can represent a significant cost savings for BWT.

Additional information for this study can be found in *Pilot Scale Demonstration of Glycerol as a Supplemental Carbon Source*, Hazen and Sawyer/CH2MHILL, A Joint Venture, December 2011.

5.3 Deammonification Pilot Studies at the 26th Ward WRRF

BNR is the most cost-effective method to remove nitrogen from either the municipal wastewater or the centrate. Typically, ammonia is oxidized in a two-step process to nitrate, and then nitrate is reduced to nitrogen gas via denitrification. This nitrogen removal method entails significant use of energy for aeration, chemicals to supplement alkalinity, and carbon which accounts for most of the operating costs. Significant savings can be realized by introducing a biological shunt where ammonia is oxidized to nitrite and then reduced to nitrogen gas as done in the SHARON process facility at the Wards Island WRRF. A more promising method is the anammox process, which further reduces the energy cost, the alkalinity required, eliminates the need for a carbon source, reduces the production of sludge solids, and diminishes the carbon footprint.

To test the anammox process and the specific challenges it would face at a NYCDEP dewatering WRRF, an MBBR pilot at the 26th Ward facility was operated continuously. The main challenges addressed were: 1) abrupt changes in the concentrations of ammonia and soluble COD, 2) the occasional high concentrations of polymers in the centrate that coagulated the suspended solids which were then washed out of the reactor, and 3) controlling the NOB activity. Note, testing was conducted at the optimum temperature of approximately 33°C.

The process variables that could be controlled in the pilot MBBR were nitrogen loading rates, DO concentration, degree of turbulence, and ratio of the aerated and non-aerated periods. Different combinations of these variables were assessed until a maximum nitrogen removal efficiency of 70% was reached without external alkalinity addition. This removal efficiency occurred when the average DO concentration was 2.5 mg/L in a continuous mode, a nitrogen load of 3.9 gN/m^2-day was applied, and a thick biofilm was present with surface concentrations ranging from 30 to 55 gTS/m^2. The thickness of the biofilm was found to be an important factor in achieving maximum removal efficiency.

Addition of alkalinity was evaluated to assess if higher nitrogen removals were possible. Periods of operation with and without alkalinity were compared at a loading rate of 3.9 gN/m^2-day. Without alkalinity addition achieved an average nitrogen removal efficiency of 60 percent, with highs in the 70 percent removal range. With alkalinity, nitrogen removals were increased to an average 80 percent, with highs in the 90 percent range.

Figure 5-6 below shows the flow schematic of the process, and **Figure 5-7** shows the Nitrogen removal efficiency as a function of the loading rate to the MBBR reactor. Having accumulated a substantial amount of performance data and realizing that, in order to proceed to a full-scale design, an important relationship needed is between nitrogen removal and nitrogen loading rate, the total database was reduced as shown in **Figure 5-7** The performance data was first plotted with nitrogen surface loading rate in grams of N/m^2-d on the X-axis versus the nitrogen removal rate, also in grams of N/m^2-d on the Y-axis. Subsequently, straight lines of specific percent removals were drawn ranging from a low of 40% to a high of 90%. The data shows that 90% removals are possible, especially when alkalinity is added. At loadings greater than 3 gN/m^2-d, significant scatter is evident, which is a sign of process instability. Surface loading rates at the lower end of the range assessed tend to produce a tight cluster of performance data with a higher degree of reliability. Therefore, the loading rate for design of a full-scale MBBR process should be within the range of 2 to 3 g N/m^2-d for a stable operation to achieve consistent nitrogen removal.

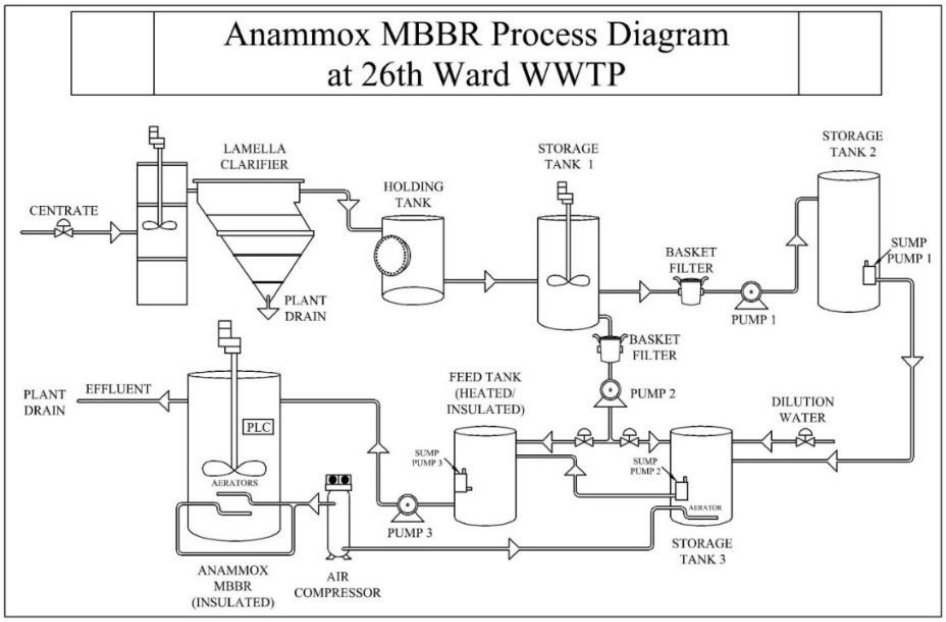


Figure 5-6: Flow schematic of the Anammox MBBR Process at the 26th Ward WRRF

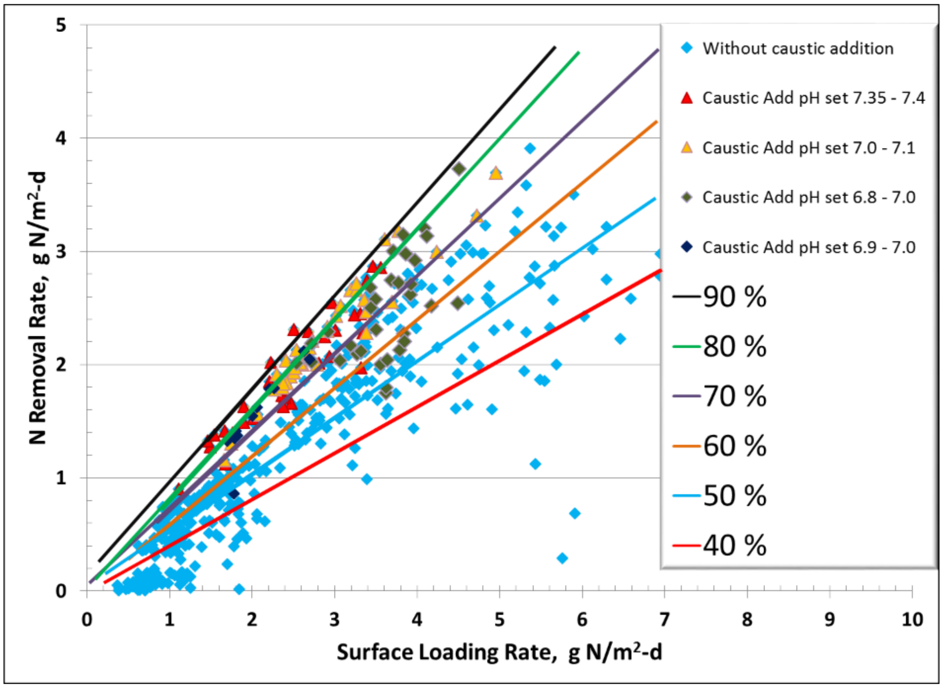


Figure 5-7: Nitrogen (N) Removal Rate versus Surface Loading Rate

For a full-scale design, the following recommendations were developed for consideration:

- The minimum startup period for a full scale single stage nitritation/anammox MBBR would be five months with virgin media. Seeding from an existing operating facility would considerably reduce this time and should be considered.
- Flow equalization storage is advisable to overcome the variability of flow and abrupt changes in the concentrations of ammonia nitrogen and COD.
- Continuous aeration with DO concentration set at approximately 2 mg/L would support the MBBR nitritation/anammox process. However, flexibility should be provided to enable the operators to achieve different DO concentration levels, address periodic high COD Concentrations, or establish anoxic periods as needed.
- The MBBR process should be able to reach 70% nitrogen removal efficiency without supplemental alkalinity. However, for higher removals, alkalinity addition would be needed.
- Nitrogen removal performance stability depends significantly on the nitrogen loading rate and should be limited to 3gN/m^2-d for process stability to be able to absorb abrupt changes in the quality of the centrate being treated.

These recommendations were considered and incorporated into the NYCDEP's ongoing deammonification design for centrate treatment at the Wards Island WRRF.

Further details can be obtained from the report *Bench scale Granular and MBBR, Pilot MBBR at the 26th Ward Waste Water Treatment Plant and Instruments Evaluated at the Pilot MBBR, 26th Ward Waste Water Treatment Plant*, prepared for New York City Environmental Protection under PW 70, Contract# CTC 826 20100016552 by The City College of New York, Department of Civil Engineering, 160 Convent Ave., NY, NY 10031, January 2014.

5.4 Struvite Control Alternative

The overall objective of the solids handling process is stabilization of the combined primary and secondary sludge in mesophilic anaerobic digesters followed by dewatering to achieve the highest percent solids cake using sludge conditioning and centrifuges and thus minimize the disposal costs. NYCDEP owns and operates fourteen WRRFs treating a combined flow of approximately 1.3 billion gallons per day. Eight of the fourteen plants have centralized dewatering facilities where anaerobically digested sludge from other plants is either barged or piped. The sludge is dewatered using centrifuges and the resulting "cake" is either applied to land or shipped to landfills. The nitrogen rich "reject water" emanating from the centrifugation process is typically referred to as "centrate" and treated separately in a "side stream" biological nitrogen removal process.

Much of the solids handling infrastructure, from the gravity thickeners through the digesters at most of the 14 WRRFs, has been in operation for several decades and is in need for an upgrade. The City is assessing several technologies to upgrade such facilities under its Comprehensive Biosolids Management Plan (CBMP). Several recommendations that will improve gas production, reduce the net solids production rate, and also reduce the carbon footprint by minimizing energy usage are being considered. The emphasis is on a dual prong approach; one to target the demand side to minimize input requirements – pumping/aeration, heat, and chemicals – and the second to maximize the supply side benefits by using renewable energy, recovery of nutrients, and other high value byproducts. A collateral issue that has been recognized in New York City is struvite formation, including its present practice of using ferric chloride in attempting to prevent and reduce its formation rate. An alternate struvite control method could address the synergies presented above that are part of the CBMP. In response, the City College of New York (CCNY) in conjunction with NYCDEP, conducted a bench-scale study to assess the two struvite control methods: addition of ferric chloride and sludge aeration.

Additionally, the study preliminarily looked into the dewaterability of the aerated sludge. A series of tests were carried out using the anaerobically digested sludge samples exposed to a series of conditioning alternatives with the following variations:

- The sludge as is without any treatment as a baseline
- Sludge preconditioned with cationic polymer at various dosages
- Sludge conditioned with $MgCl_2$ to various Mg: P ratios followed by aeration
- Sludge conditioned with MgCl2 and polymer addition and aeration.

The variations listed above were tested to determine the alternative that provided the highest percent solids in the cake produced

Control of struvite formation using ferric chloride is based on the removal of soluble phosphate in the form of ferric phosphate, ($FePO_4$). Control of struvite formation with sludge aeration is based on aeration stripping of carbon dioxide, causing the pH of the sludge to rise. As pH rises, the solubility of struvite decreases and upon exceeding saturated conditions, precipitation of struvite is initiated. Several air flow rates were tested with and without supplementing the magnesium available in the sludge by adding magnesium chloride. The comparison of the two struvite control methods was conducted in the environmental engineering laboratory at The City College of New York using a series of bench/pilot scale experiments in parallel with the sludge dewatering studies. In each case the source of digested sludge was the anaerobic mesophilic digesters at the Wards Island WRRF. **Table 5-2** and **Table 5-3**show results from the struvite control tests.

Table 5-2: Summary of $FeCl_3$ dosing experiments

	Untreated Sludge	**Average $FeCl_3$ Dosage -σ**	**Average $FeCl_3$ Dosage**	**Average $FeCl_3$ Dosage +σ**
pH	7.19	7.00	6.86	6.75
Residual ortho-P	146	60	41	27
pKs	13.26			
Saturation Index (1)	0.564	0.019	-0.127	-0.293

(1) Saturation Index
Positive: Over Saturated
Negative: Under saturated

Table 5-3: Summary of Aeration Experiments at a Mg2+:Ortho-P dose of 0.99

	Untreated Sludge	Approximately 10 min of Aeration	Approximately 25 min of Aeration	Approximately 45 min of Aeration
Residual ortho-P	206	60	41	27
pH	6.87	7.4	7.65	8
pKs	13.26			
Saturation Index (1)	0.590	0.826	0.898	0.982

(1) Saturation Index
Positive: Over Saturated
Negative: Under saturated

Based on the experimental results, air stripping appeared to be equally effective in controlling subsequent struvite formation compared to the commonly used method of dosing with ferric chloride. This method has additional potential advantages that include removal of both ammonia and phosphate, incorporation of struvite within the cake produced, less sludge and cake produced, and elimination of corrosive conditions caused by the low pH values experienced with ferric chloride dosing. In addition, the method is primarily a physical process where the design of air stripping processes is well understood, easier to control by adjusting air flow rates and/or aeration time and when necessary struvite formation can be further enhanced by supplementing the availability of magnesium in the sludge. The sludge dewatering experiments conducted on the bench-top centrifuge were batch type unlike the actual centrifuges used in the field, which work in the continuous mode of sludge feed and withdrawal of the centrate and “cake”. Nevertheless, the results could be used as a guide to develop either large scale pilot or full-scale demonstration experiments. Preliminary findings indicate that there is significant improvement in percent solids removal when an appropriate dosage of polymer and magnesium is added to the digested sludge. Experimental data reveal that at a polymer dosage of 45.3 kg/ton (100 lbs./ton), the percent solids in the cake was the highest value, at 15.6%.

Further details can be obtained from: *A Struvite Control Alternative that Complements the Comprehensive Biosolids Management to Traditional Struvite Control Practices in NYC Water Resource Recovery Plants*, 86th Annual WEFTEC Proceedings, 2013.

5.5 Stabilization of 26th Ward Main Plant Nitritation/Denitritation Performance (WERF U4R12)

Control of nitrogen discharges in an economical manner has become a critical mission for an increasing swath of utilities. Deammonification has proven to be an effective and economical biological process to remove total nitrogen from high strength streams such as centrate (digester reject water) with low carbon to nitrogen (C/N) ratio, high ammonia concentration (>500-1,000 mg-N/L) and high temperature (>25 °C). The next step in the biological nitrogen removal evolution is to develop strategies to promote deammonification in the mainstream (or main plant) where ammonia concentrations are dilute (~40 mg-N/L) and temperatures dip down to 10-15 °C in the winter months, especially in the northern half of the United States. A major challenge of deammonification is nitritation stabilization; promoting ammonia oxidizing bacteria (AOB) growth while selectively suppressing nitrite oxidizing bacteria (NOB) growth.

In sidestream processes, deammonification has been accomplished with high temperatures, low solids retention time (SRT), low dissolved oxygen (DO) and free ammonia toxicity. Alternative NOB suppression tools coupled with known strategies are needed. Stabilized nitritation and denitritation in the mainstream is critical to set the stage to integrate mainstream deammonification.

Full scale nitritation/denitritation has occurred at the 26th Ward WRRF between 2000 and 2004, initially with a nitritation sidestream treatment reactor providing bioaugmentation. However, in 2004 the sidestream was partially or fully compromised and resulted in a spike in plant effluent nitrate levels. From 2004 to 2012 the SCT at 26th Ward operated strictly as a standard nitrification/dentrification process with limited bioaugmentation. In early 2012 operations switched to a glycerin based supplemental carbon source for the sidestream reactor. Thereafter, the NOB suppression ceased in the sidestream reactor and the whole plant, including the sidestream bioaugmentation system, reverted to conventional nitrification and denitrification. The need for better operational controls was evident, however without a strong understanding of the underlying causes, the plant’s primary optimization response was a targeted reduction in operating SRT.

Summary of the testing conducted

Full scale nitritation/denitritation demonstration study took place at 26th Ward WRRF from August 2013 through December 2015. The plant has a design capacity of 85 MGD with a centralized dewatering facility which accepts additional anaerobic digested sludge from several other WRRFs. **Figure 5-8** illustrates the process flow diagram of the 26th Ward facility, which consists of primary treatment, centralized dewatering facility, sidestream centrate treatment reactor (AT-3), parallel mainstream BNR step-feed reactors (AT-1 and AT-2), anaerobic digestion, and secondary clarification. It is important to note that the sidestream and the mainstream work in conjunction, with the effluent from the sidestream discharging into the mainstream aeration tanks.

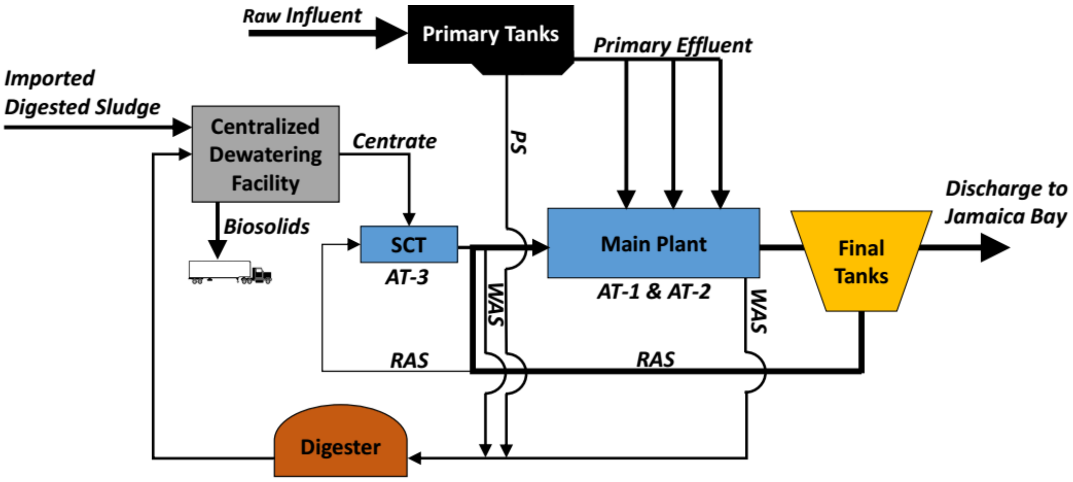


Figure 5-8: Schematic flow diagram of 26th Ward WRRF.

Achieving and maintaining reliable nitritation at low operating nitrogen concentrations and temperatures required a concurrent application of multiple NOB suppression mechanisms. A combination of several operating parameters (listed below), coupled with nitritation of the sidestreams and bioaugmentation of the produced AOB biomass into the main plant reactor was utilized to achieve NOB suppression at low temperatures (<18°C). Additionally, the sidestream reactor was “detuned” to allow for higher ammonia (100 mg-N/L) and nitrite (100 mg-N/L) concentrations to bleed over to the mainstream reactors to potentially take advantage of free ammonia and/or free nitrous acid inhibition on NOBs.

- Growth kinetics - Temperature & SRT
- Competition for DO
- Free ammonia
- Free nitrous acid
- Anoxic volume vs aerobic volume
- Chemical dosage

As a result of the process modifications, consistent nitritation was observed in the sidestream reactor with nitrite concentration of 20-40 mg-N/L in the sidestream effluent, yet below the target of (100 mg-N/L). Furthermore, NOBs remained present as indicated by significant nitrate concentration (50-100 mg-N/L) in the sidestream effluent. A potential reason was high DO concentrations (>2 mg/L) in the sidestream reactor due to inadequate aeration controls. Yet, anammox granules were observed in the sidestream and confirmed by quantitative polymerase chain reaction (qPCR). It is not known to what extent the anammox bacteria contributed to nitrogen removal in the sidestream due to insufficient data.

As for the mainstream reactors, little or no nitrite accumulation was observed in the mainstream effluent. However, a reduction in the plant effluent ammonia and nitrate was observed which resulted in an approximately 25% reduction in average effluent total nitrogen (12 to 9 mg-N/L) and a 10-15% increase in the overall plant nitrogen removal efficiency (70 to 80%), as shown in

Figure 5-9 and **Figure 5-10.**

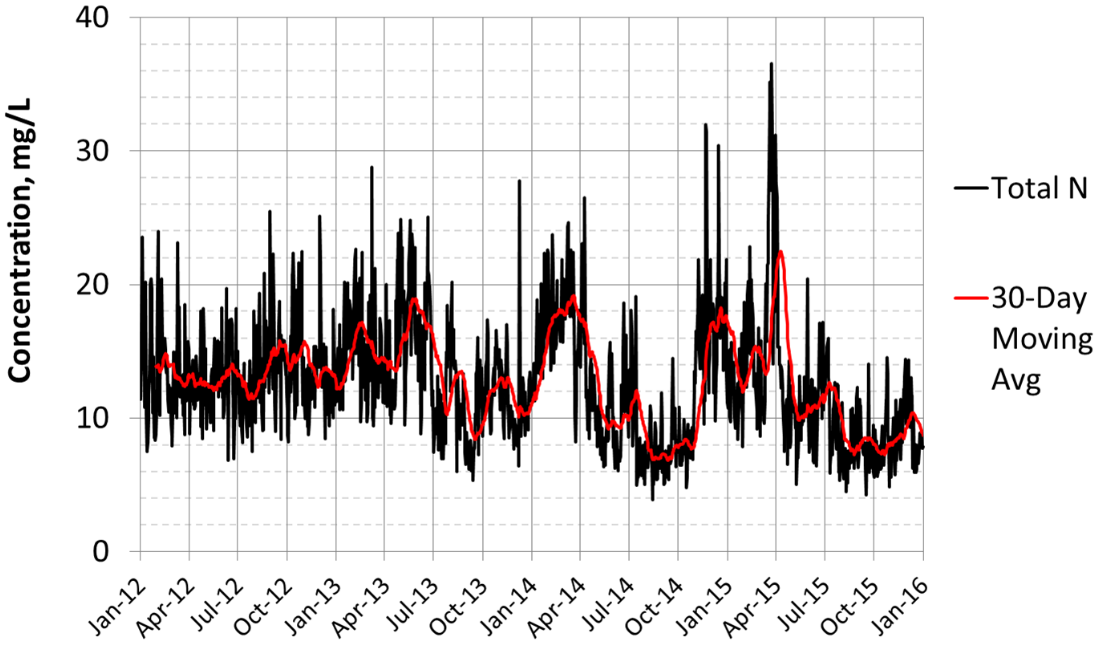


Figure 5-9: Mainstream effluent total nitrogen concentrations

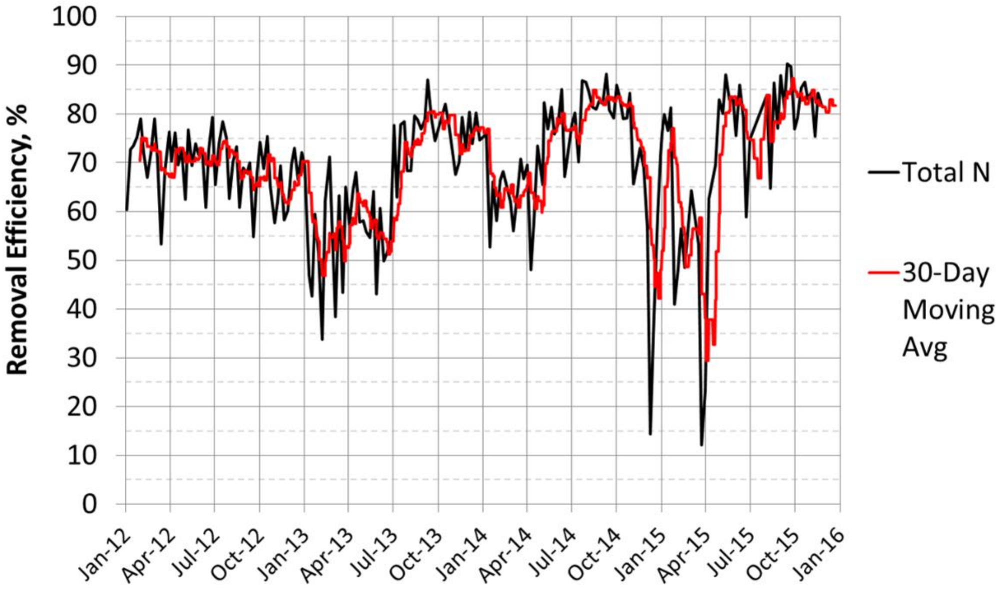


Figure 5-10: Whole plant nitrogen removal efficiency

Further details can be obtained from the WERF Report: *Stabilization of the Main Plant Nitritation/Denitritation Performance* (2017).

5.6 26th Ward Separate Centrate Deammonification process

Increasingly stringent nutrient discharge limits require utilities to employ energetically and cost intensive biological nutrient removal (BNR) processes. For many facilities that practice anaerobic digestion, separate treatment of sidestream process flows generated from anaerobic stabilization processes represents an economical approach for nutrient removal.

The 26th Ward Wastewater Resource Recovery Facility (26th Ward WRRF) is an 85 million gallon per day (MGD) facility that employs BNR for nutrient removal. The sidestream that is generated from the solids handling process at the 26th Ward WRRF can consist of up to 50% of the total nitrogen load that is treated in the main plant. Currently, the 26th Ward WRRF employs separate centrate treatment (SCT) in one of its three aeration tanks. In this SCT process, nitrogen removal is accomplished via nitrification and denitrification. Since operating costs associated with operating the SCT process are significant (ie. carbon addition, aeration, etc.), implementation of anaerobic ammonia oxidation-based technologies that can reduce energy and chemical demand are desired.

In this project, a novel partial denitratation anammox (PDNA) deammonification process was piloted at the 26th Ward WRRF. This PDNA process is different from commercially available deammonification processes since the PDNA process does not require use of complex controls to achieve nitrite oxidizing bacteria (NOB) repression. Instead, the process is designed to exploit the natural predisposition of the mixed culture community to produce a mixture of nitrite and nitrate when oxygen is provided, and denitrify to nitrite in the presence of glycerol, to facilitate anaerobic ammonia oxidation, as shown in **Figure 5-11**.

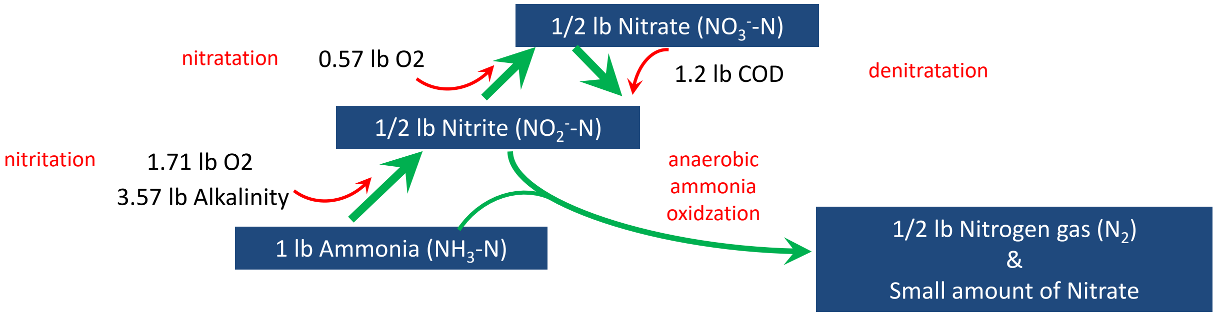


Figure 5-11: Overview of PDNA pathway

The proof-of-principle research and early laboratory research demonstrating the effectiveness of this novel SCT process was carried out under DEP's Applied Nitrogen Research Program (PO-88). Bench scale reactors were seeded with biomass from the 26th Ward SCT tank, and later combined with BNR sludge collected from 26th Ward and Hunts Point WRRF. BNR sludge was acclimated in a separate nitrification/denitrification lab reactor prior to being combined with the 26th Ward anammox sludge. Using this combined biomass, SBR lab tests were conducted to optimize nitrification, determine effective carbon dosage, and discover any biomass inhibition present at high nitrate or ammonia concentrations. The results are summarized below and detailed in a report submitted to DEP in 2015 and in the paper by Sharp, et. al. (2017).

- The new partial denitratation/deammonification process using 26th Ward WRRF anammox sludge can be very effective and can achieve TN removals of up to 80% with proper carbon dosing and effective pH and DO control.
- Findings show the process to be robust and completely independent of NOB suppression.
- The process requires approximately 40-50% of the air required for traditional nite/denite nitrogen removal. The air requirement is about 30% higher than that required for the traditional nitritation/deammonification process.
- The carbon requirements are approximately 20-25% of the dose required for traditional BNR processes.
- The only added equipment needed for this full-scale implementation at 26th Ward WRRF is a plate settler with underflow internal recycle used to retain the anammox biomass within the SCT system, or equivalent solids retention equipment.
- The bench scale studies have demonstrated that the novel partial denitratation deammonification process can achieve a high degree of TN removal with significant saving on aeration and chemicals (glycerol).

The PDNA pilot was constructed onsite at the 26th Ward WRRF to allow for direct use of centrate generated onsite by the full-scale dewatering process (**Figure 5-12**). An existing flocculation tank and plate settler were re-purposed as the reactor (Vol = 1,700 gal) and solids separation device respectively. Centrate from the full-scale facility was equalized for up to 48 hours in existing storage tanks to allow for settling of solids. Effluent from the reactor was clarified using the inclined plate settler. Settled solids were recycled to the main reactor daily.

The system was configured to be operated as a sequential batch reactor with alternating aerobic and anoxic cycles. Total hydraulic retention/cycle time was 48 hours with the aerobic/anoxic phases lasting up to 24 hours each. These retention/cycle times were selected to mimic hydraulic retention times that would be experienced in the full-scale PDNA system. Aeration was provided via a single stage reciprocating air compressor and delivered via a membrane disc diffuser installed at the base of the reactor. Airflow to the system was monitored using a rotameter. Total suspended solids (TSS) and dissolved oxygen (DO) were monitored using an Insite Model 2000 Process Analyzer. pH was also monitored using a Hach sc100 meter.

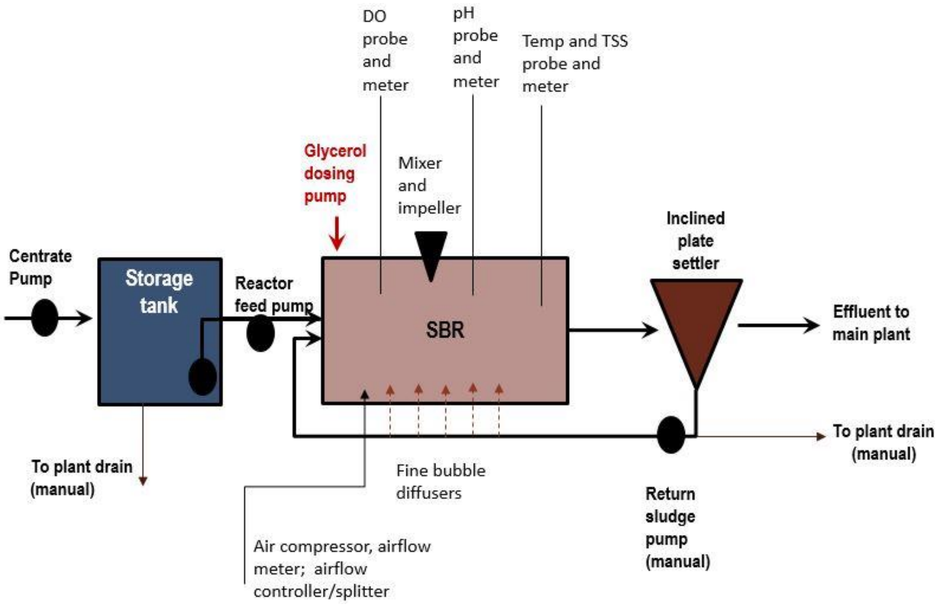


Figure 5-12: Process Flow of the PDNA SCT Pilot.

The objectives of the pilot were to:

- Demonstrate the use of PDNA for performing nitrogen removal using low energy and carbon.
- Validate the reduction in energy and supplemental carbon requirements associated with the PDNA process.
- Determine the applicability and logistics of implementing the PDNA process for full-scale operation

Key Findings

Demonstration of the PDNA process yielded the following insights into applying advanced nutrient removal technologies at the 26th Ward WRRF:

- Implementation of a deammonification based technology for sidestream nitrogen treatment at the 26th Ward WRRF would result in significant operational and energy savings as compared to the conventional SCT operation.
- The PDNA process achieved 64 ± 13 % removal of total inorganic nitrogen (TIN) at a total nitrogen loading rate of 0.20 kg N/m^3-day, as shown in **Figure 5-13**. This level of nitrogen removal is equivalent to the performance of the conventional SCT system.

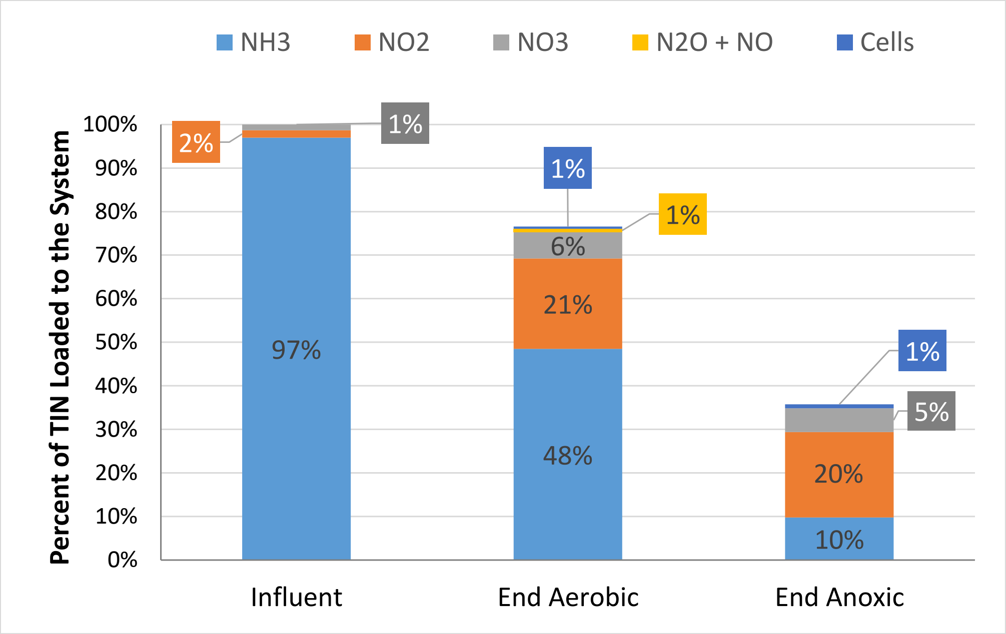


Figure 5-13: Fate of Nitrogen in PDNA Process.

- The PDNA process was able to recover rapidly from multiple periods of unstable operation resulting from centrate supply and quality issues. The resiliency of the PDNA process indicates that it is robust enough for application in real world settings where highly variable flow and centrate quality can be expected.

- The PDNA process allowed for significant reduction in aeration (57%), glycerol (90%) and alkalinity (50%) requirements versus conventional SCT operation.

- Nitric Oxide (NO) emissions accounted for 0.034 ± 0.034 % of the NH_3-N fed to the PDNA system (corresponding to 0.066 ± 0.065% of the NH_3-removed in the PDNA process). Nitrous Oxide (N_2O) emissions accounted for 1.6 ± 2.1 % of the NH_3-N fed to the system (corresponding to 3.1 ± 4.0 % of the NH_3-N removed in the PDNA process).

- The strategy utilized for operating the PDNA pilot allowed for successful enrichment of a culture that facilitated TIN removal through a combination of nitrification, denitrification, denitratation, and anaerobic ammonia oxidation.

- Full-scale implementation of PDNA at the 26th Ward WRRF would require infrastructure and operational modifications that require capital investment. Savings associated with the reduction in energy and chemical addition would allow for a simple payback of capital investment within four to six years.\

Further details can be obtained from the NYSERDA Report: Demonstration of a Separate Centrate Deammonification Process at the 26th Ward Wastewater Treatment Plant (October 2016). In addition, the concept of the PDNA process and results from the early laboratory research funded by NYDEP can be found R. Sharp, A. Neimiec , W. Khunjar , S. Galst & A. Deur. “*Development Of A Novel Deammonification Process For Cost Effective Separate Centrate And Main Plant Nitrogen Removal.”*

International Journal. Of Sustainable Development and Planning. Vol. 12, No. 1 (2017) 11–21 and the report submitted to DEP titled “Bench-scale Testing of Novel Denitratation/Anammox SCT Process” submitted in May, 2015.

5.7 Testing of Nitritation Induction using SBRs at Hunts Point Wastewater Resource Recovery Facility

The Hunts Point (HP) WRRF is in the Bronx, NY treating an average flow of 125 MGD. It has five aeration tanks (ATs) treating the main flow in a step feed BNR mode and a sixth AT which now operates as a separate centrate tank (SCT) for nitrogen removal handling an average centrate flow of 1.3 MGD. The nitrogen removal in mainstream is through nitrification/denitrification process with glycerol addition to Pass C and D of all aeration tanks. The objective of this project is to assess selective pressures to induce nitritation/denitritation in integrated mainstream/sidestream process of the HP WRRF.

The selective pressures that have been identified and assessed in this study were free nitrous acid (FNA) exposure, reducing sludge retention time (SRT) and dissolved oxygen (DO) control strategy. An FNA concentration range of 0.42-1.72 mg N/L has been reported to result in a 50% reduction in ammonia oxidizing bacteria (AOB) activity, whereas 0.026-0.22 mg N/L of FNA has been found to result in complete inhibition of nitrite oxidizing bacteria (NOB) (Zhou et al., 2011). FNA exposure was considered as a selective pressure to suppress NOB activity because at the HP facility SCT biomass is exposed to high levels of FNA. Additionally, it has been reported that out selection of NOB has been achieved in the mainstream reactor as a result of aggressive operations such as reducing the SRT (Regmi et al., 2014). The use of transient anoxia is also a known mechanism to achieve NOB out-selection in the main stream (Regmi et al. 2014, Wett et al. 2013, Miller et al. 2012). It is believed that transient anoxia introduces mini-anoxic periods within the process that creates a lag-time which impacts NOB activity as it transits from the anoxic to aerobic environment. Both low SRT and transient anoxia were tested to induce nitritation using waste water and sludge from the HP WRRF in a series of laboratory Sequencing Batch Reactor Studies.

Bench Scale Sequencing Batch Reactor (SBR) Setup

The bench scale system consisted of two SBRs; one serving as a physical process model for mainstream reactors’ four pass step feed system treating primary effluent and the second for the sidestream reactor receiving centrate from the dewatering facility along with return activated sludge (RAS) from the mainstream.

The feed of main SBR in each cycle was added in four steps with a split of 10%/40%/30%/20%. Each step in a cycle of both main and centrate reactors included 33% of anoxic zone followed by 60% of aerobic zone and approximately 5-10 % of unaerated zone at the end. Glycerin was added to steps 1 and 2 of sidestream reactor and step 3 of main reactor to provide additional carbon source for denitritation. A portion of the main reactor’s biomass was directed to the sidestream SBR reactor daily, simulating the effect of mainstream RAS addition to the sidestream reactor. The mixed effluent from the sidestream SBR (the sidestream SBR did not have a settling/decant period) was added to the mainstream reactor daily, simulating the return of the RAS after exposure to the sidestream conditions back to the mainstream reactor.

Sidestream SBR Process Performance

Phase I of the sidestream reactor’s operation started in April 2016 which was to mimic actual operational conditions at the Hunts Point facility to provide a baseline for further performance comparison. In Phase II, operational conditions were changed to control FNA concentrations in a range of 0.1-0.2 mg N/L. For this purpose, internal recirculation (IR) volume was increased from 0.65L to 1.9L and the low pH set point was adjusted in the sidestream SBR. Two low pH set points of 6.5 and 6.7 were tested to control FNA concentrations over a range in which NOB activity was suppressed while AOB remained active. The sidestream SBR process performance is shown in **Figure 5-14** and **Figure 5-15**. During baseline operations, the reactor cycle was 24-30% anoxic/60% oxic. Dissolved Oxygen (DO) concentration was controlled between 1-2 mg O2/L in the oxic zones and there was no pH control. Average ammonia oxidation efficiency during baseline operations was 47% and the average nitrite accumulation at the end of cycle was 82 mg N/L. In phase II of the operations, as a result of increasing IR volume, the reactor cycle was reduced from 24 to 8 hours. **Figure 5-14** and **Figure 5-15** show that with the lower pH set point at 6.7, average ammonia oxidation and nitrite accumulation increased to 65% and 188 mg N/L, respectively. Thus, the strategy of controlling FNA in a range of 0.1-0.2 mg N/L at this pH was effective to suppress NOB activity relative to AOB activity.

In the next step, the reactor operation was switched to 100% aeration to enhance ammonia oxidation with no DO control. Although ammonia oxidation reached a high of 82%, a slow increase in nitrate was observed reaching up to 130 mg N/L by mid-December 2016. Therefore, DO control was instituted again with a lower range of 1-1.7 mg O2/L to decrease NOB activity as shown in **Figure 5-15**. And by February 16,2017 the reactor operating mode was switched back to 30% anoxic/60% oxic which resulted in 65% ammonia oxidation and 90% nitrite accumulation with nitrite concentration of 160 mg N/L at the end of cycle.

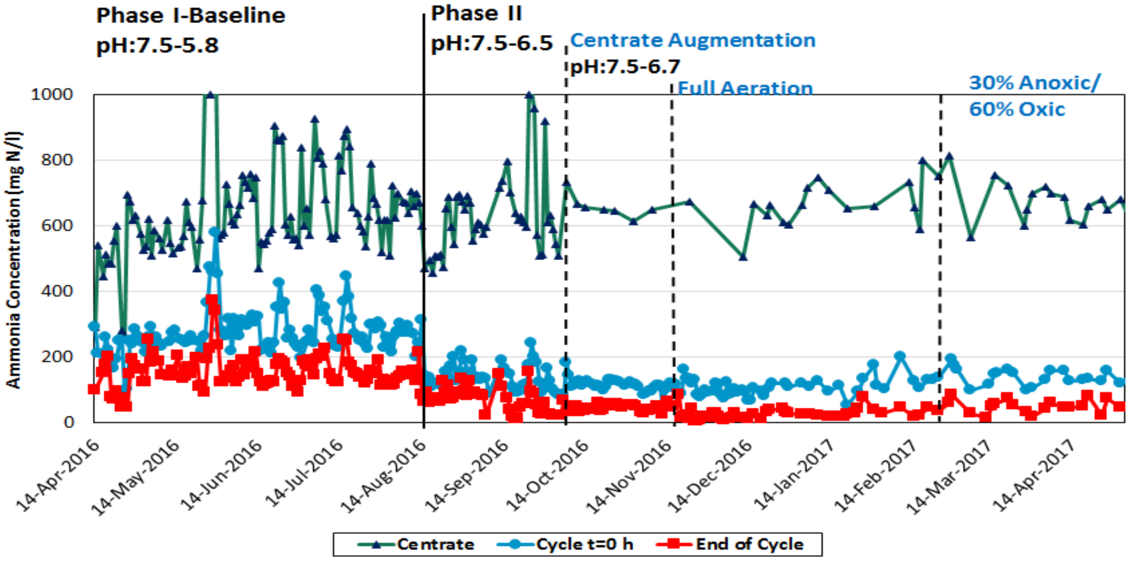


Figure 5-14: Ammonia concentration in sidestream SBR; Centrate, ammonia concentration at the beginning of cycle t=0 h and ammonia concentration at the end of cycle.

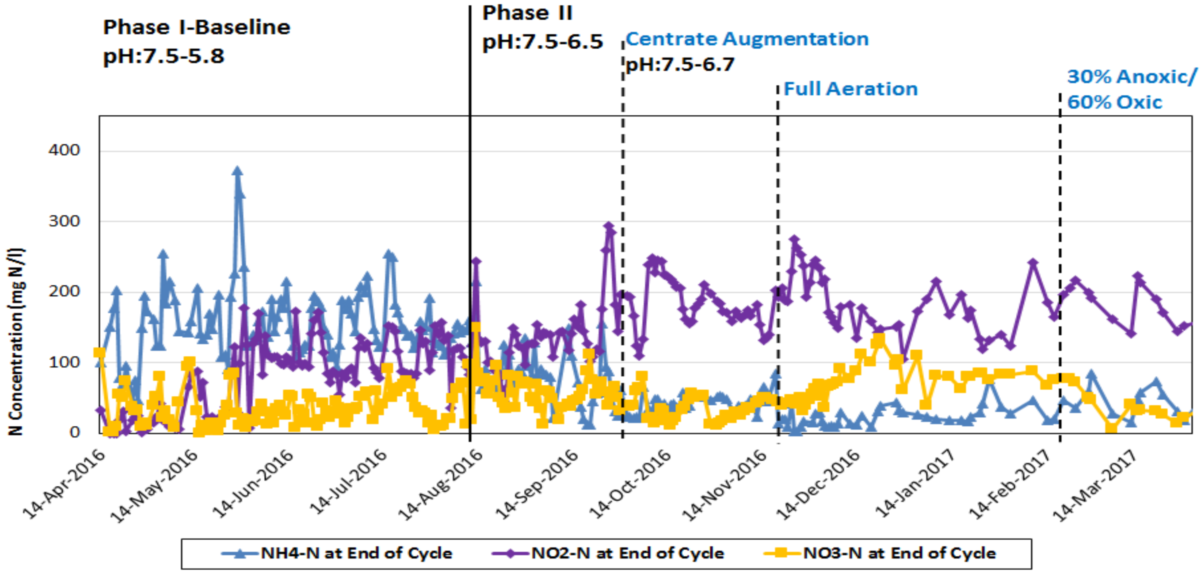


Figure 5-15: Nitrogen species at the end of cycle in sidestream SBR.

Main SBR Process Performance

Primary settling tank effluent (PSTE) of HP WRRF was used as the feed for the main SBR and had an average ammonia concentration of 15.5 mg N/L. For Phase I, the main SBR operating conditions simulated the actual HP operations to provide a baseline and hence was operated with 30% anoxic/60% oxic mode, DO controlled between 1-2 mg O_2/L with a SRT of 7 days and no external carbon addition.

Figure 5-16 and **Figure 5-17** show the main SBR performance. During the baseline period, high loads of NOx was transferred from sidestream SBR to main SBR and because there was no organic carbon addition, high NOx-N concentration was observed in the effluent of the main SBR. By September 2016, glycerol was added to the anoxic zone of Pass A as an external carbon source to remove the transferred load of nitrite and nitrate. From the initiation of baseline operations till October 2016, nitrate was accumulating in the reactor as a result of nitrification. From October 16, 2016 to February 17, 2017 a series of strategies including decreasing SRT to 5 days and switching the aeration mode to transient anoxia were assessed to suppress NOB activity in the reactor. However, none of these strategies resulted in an increase in nitrite concentration in the effluent and nitrate remained as the dominant species.

Several batch experiments were conducted in parallel to the operation of the SBRs to identify selective pressures to induce nitritation. The results from the batch experiments indicated a 30% nitritation activity at low DO concentrations of 0.5-0.8 mg O_2/L (data not shown). Hence, by mid-March 2017, aeration was switched to low a DO mode with DO set points of 0.5-0.6 mg O_2/L. Anoxic zones of Pass B, C and D were eliminated to increase the aeration time.

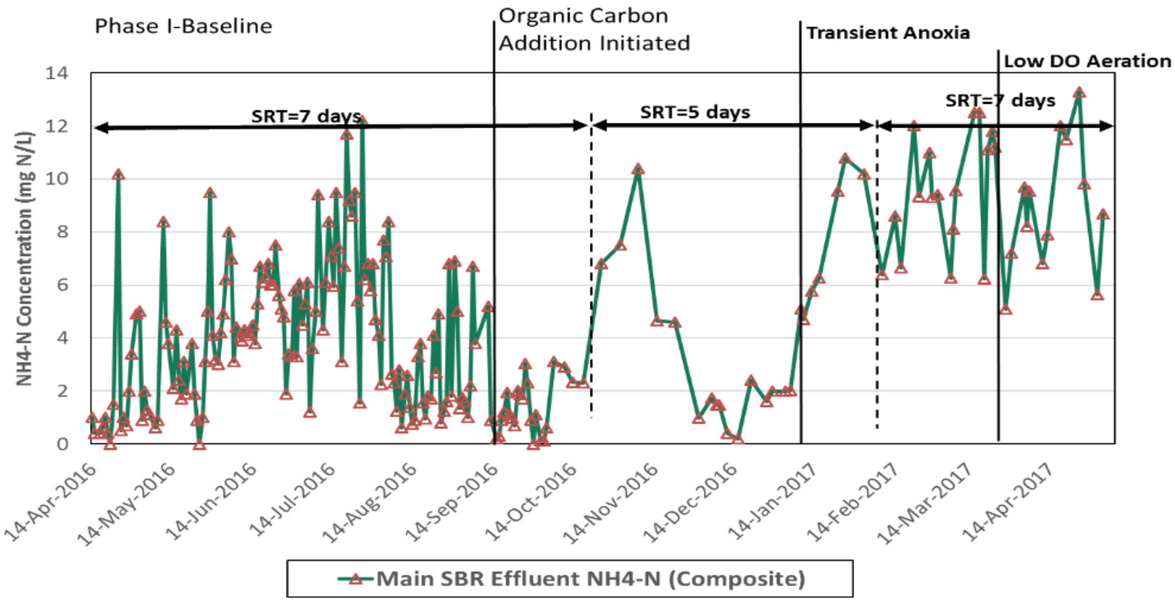


Figure 5-16: Ammonia concentration in effluent composite of Main SBR

As operations changed to low DO aeration, nitrate concentration decreased over the course of the next several weeks and nitrite increased to 2-3 mg N/L and up to 70-80% nitritation was achieved during this period. Ex *situ* activity tests conducted simultaneously indicated the improvement of nitritation and NOB suppression in mainstream biomass over time.

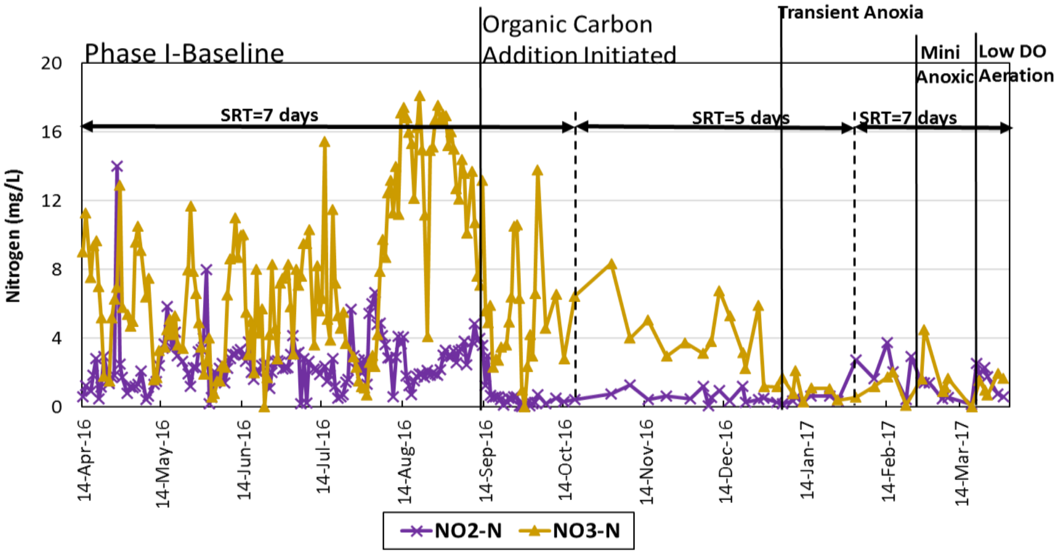


Figure 5-17: Nitrite and nitrate concentration in effluent composite of main SBR.

Additional details are provided in *Nitritation Induction at Hunts Point WRRF* presented at the Water Environment Federation Nutrient Symposium, Fort Lauderdale, Florida, June 2017.

5.8 Granular Sludge Testing

Aerobic Granulation is an opportunity to integrate the next generation of technologies to achieve long term compliance while reducing chemical usage and carbon footprint/GHG emissions.

Aerobic granulation has achieved significant progress primarily with high strength wastewater since its early development and is very attractive with its capability to remove carbon, nitrogen and phosphorus simultaneously in a smaller foot print. This study, being conducted by the CCNY in conjunction with the NYCDEP, was to develop aerobic granulation using the primary settling tank effluent (PSTE) from the Wards Island WRRF. The study consisted of different stages when granulation was attempted initially with PSTE only and subsequently by external addition of carbon sources such as acetate and volatile fatty acids (VFAs) very similar to what would be available in fermented primary sludge. The weak wastewater in New York City with respect to both COD and nitrogen concentrations partly due to the combined sewer collection system and the high per capita water usage was a challenge. An up-flow sequencing batch reactor (SBR) with an anoxic feeding phase was used in the study. Sustainable granule formation could not be achieved in the earlier phases of the study when only PSTE was used but subsequently with the addition of acetate and VFAs such as those found when primary sludge is fermented, a very stable aerobic granulation environment was achieved with high removals of carbon, nitrogen and phosphorus. The system was restarted after a major failure and granulation was established within 30 days of operation further reinforcing the robustness of the process. The size of aerobic granules was measured to be around 1 to 1.2 mm.

Aerobic granulation experiments were initiated in July 2014 using a sequencing batch reactor (SBR) which was made from acrylic and had a working volume of approximately 4 liters. The reactor height was 91 cm with an internal diameter of 7.6 cm which resulted in a height to diameter (H:D) ratio of 12.

Period J, K, and L in **Table 5-4** are the optimization periods to maximize the nitrogen and phosphorus removal after granules successfully developed in Period I.

Table 5-4: History of operation of the aerobic granulation reactor (AGR)

Periods of Operation	Duration of each operating period		Duration	Cycle time	Volumetric sCOD loading rate[1]	Settling time (min. settling velocity)	Superficial air flow rate	DO Set-point
			Days	Hrs.	kg sCOD/m^3-day	Min. (m/h)	cm/s (L/min)	mg/L
	Start	End						
A	07/31/2014	10/08/2014	69	4, 3, and 2	0.2 to 0.6	30 (1.9) to 10 (5.7)	2.7 to 2.3 (7.3 to 6.3)	No DO control
B	10/09/2014	11/30/2014	53	2	0.6	18 (3.1)	1.8 (5)	No DO control
C	12/01/2014	04/05/2015	125	2	0.6	18 (3.1) to 7 (7.9)	1.5 (4)	No DO control
D	04/06/2015	05/03/2015	27	2	0.6	18 (3.1)	1.1 (3)	No DO control
E	05/04/2015	07/27/2015	84	2 and 3	0.9 and 0.6 (primary sludge addition)	18 (3.1) to 10 (5.5)	1.1 (3)	No DO control
F	07/28/2015	08/30/2015	33	3	0.5 (acetic acid addition)	10 (5.5) to 7 (7.9)	1.1 (3)	No DO control
G	08/31/2015	09/27/2015	27	3	0.6 (mixed VFA addition)	7 (7.9)	1.1 (3)	No DO control
H	09/28/2015	01/12/2016	106	3	1.0 (mixed VFA addition)	7(7.9) to 5 (11)	1.1 (3)	No DO control
I	01/13/2016	07/10/2016	118	3	1.0 (mixed VFA addition)	10 (5.5) to 5 (11)	1.1 (3)	No DO control
J	07/11/2016	10/02/2016		3	1.3 (mixed VFA addition)	7 (7.9)	1.1 (3)	1.5 to 2
K	10/03/2016	05/25/2017		3, 4, and 5.5	1.3, 1.0, and 0.7 (mixed VFA addition)	7 (7.9)	1.1 (3)	1.5 to 2
L	05/05/2017	08/01/2017		5.5	0.7 (mixed VFA addition)	7 (7.9)	1.1 (3)	1.0 to 1.5

[1] Average sCOD concentration during Periods A, B, C, and D was 68 mg/L, average sCOD during period E (with primary sludge addition) = 100 mg/L, average sCOD during period F (with acetic acid addition) = 80 mg/L, period G (with mixed VFA addition) = 106 mg/L, period H and I (with mixed VFA addition) = 168 mg/L, period J, K, and L = 213 mg/L

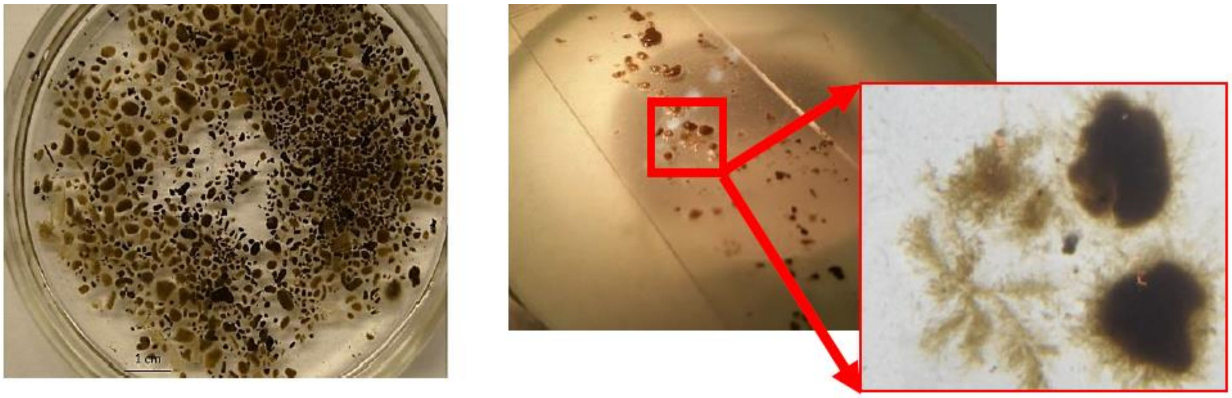


Figure 5-18: Granules Size and Development

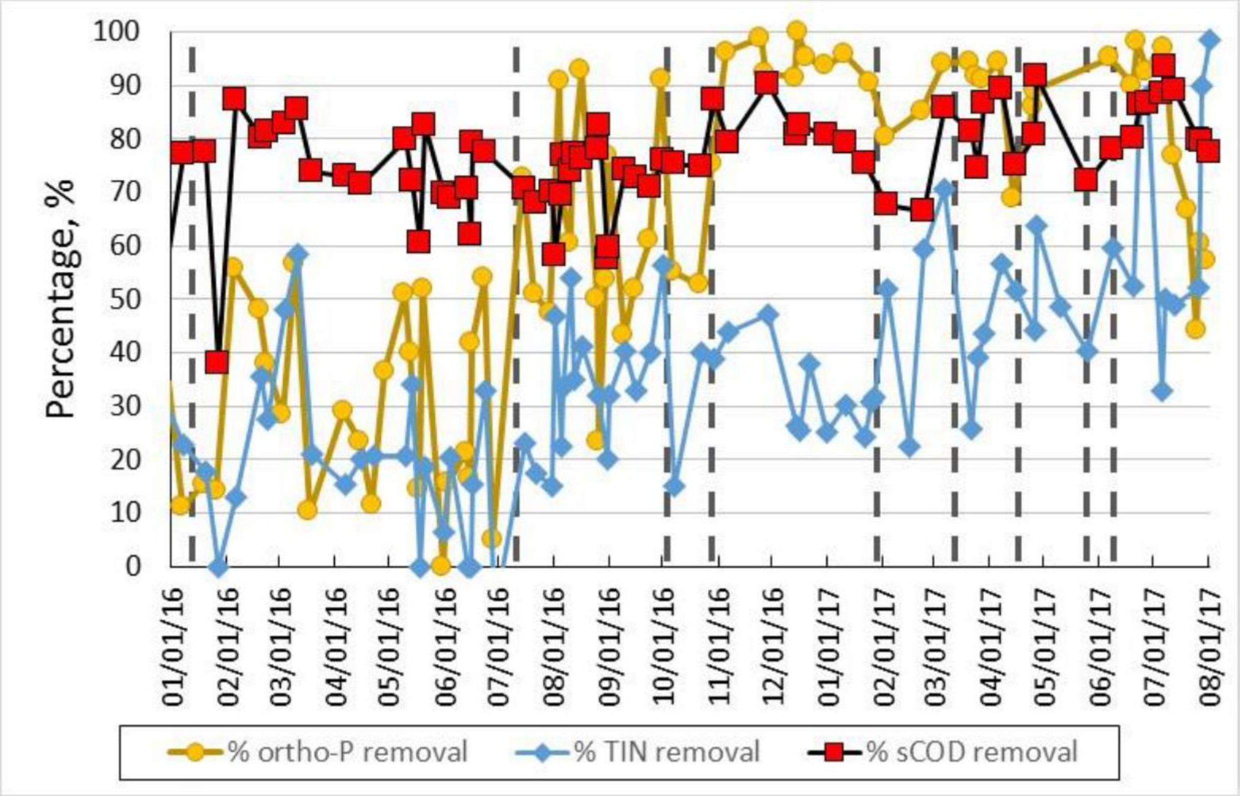


Figure 5-19: Process Performance –COD, P & N removal

Figure 5-18 shows the granule development and size while **Figure 5-19** illustrates the process performance of the system for COD, N & P removal which are typically in the 70- 90% removal range.

NYC DEP is continuing to monitor the maturation of aerated granulation technologies as a continuous flow reactor configuration is required to be able to implement aerobic granulation in large WRRFs facilities.

5.9 Centrate Fine Screen Pilot Study at Wards Island WRRF

The Wards Island (WI) WRRF operates the largest sludge dewatering facility (SDF) in New York City. In addition to dewatering WI sludge, visitor sludge is barged in from other plants for dewatering. The WI and visitor digested sludge is then mixed to better equalize the solids loading to the SDF. Wards Island does not currently screen biosolids to or the centrate from the SDF. After dewatering, the centrate is currently routed to either the SHARON® Facility (primary route) or Aeration Tank No. 9 for separate centrate treatment (SCT). The digested sludge contains rags and large objects that were not captured in the plants' headworks, which accumulate in the WI SCT facilities resulting in the loss of SCT process efficiency. The plant staff has reported significant issues with ragging and fouling within the current SCT SHARON® system.

A Deammonification Moving Bed Biological Reactor (MBBR) will replace the SHARON® Facility for SCT in the coming years. Excessive solids, such as hair or small plastics, can cause issues with the blinding of the MBBR media which can lead to lower performance and process upsets. To prevent process upsets, all flow entering the MBBR facility will be routed through fine screens to minimize the accumulation of these materials.

As part of the WI-298 Deammonification MBBR design project, DEP piloted a rotary drum perforated plate screen at the WI WRRF to remove solids from the WI dewatering facility's centrate as one step in a multi-step strategy to pretreat the centrate.

Demonstration Details:

Several centrate screening technologies were reviewed, including rotary drum, step, and strainpress-type screens. The MBBR screening aperture was set at 2 mm using perforated plates, the aperture minimum at which the screen type must be switched to wire mesh. A wire mesh system is not compatible with this application, due to the lack of upstream fine screens, which will likely result in overloading of the mesh with hair and other debris. To achieve high efficiencies in the removal of fine plastics and hair, a rotary drum perforated plate technology was selected. Perforated plate rotary screens allow for consistent operation with a mat, allowing for high removal efficiencies to be achieved.

DEP ran a Huber ROTATMAT RPPS Pro (**Figure 5-20**) pilot scale unit at WI from 2017 to 2018. The perforated plate screen consisted of a rotating cylindrical screen with an integral screw conveyor and screenings press. The screening equipment produced dewatered screenings. The fine screen used a single drive for screening, conveying, dewatering, and compressing the screening material.

This pilot aided the DEP in determining the amount of solids that will be collected per unit per day at full-scale, quantifying the amount of solids that will pass through the screen, the number of units needed to maintain peak flow rates, and gave plant personnel a chance to become familiar with equipment.

The Pilot was located on the north-western corner of E Battery (**Figure 5-21**, **Figure 5-22**), where there is an accessible centrate line to connect the pilot (**Figure 5-23**). The effluent from the pilot, which accounts for a small portion of the centrate generated by the dewatering facility, was discharged into E Battery for nitrogen removal. The pilot was operated for two weeks, 24 hours a day.

Figure 5-20: Huber ROTATMAT RPPS Pro- Rotary Drum Screen and Control Panel

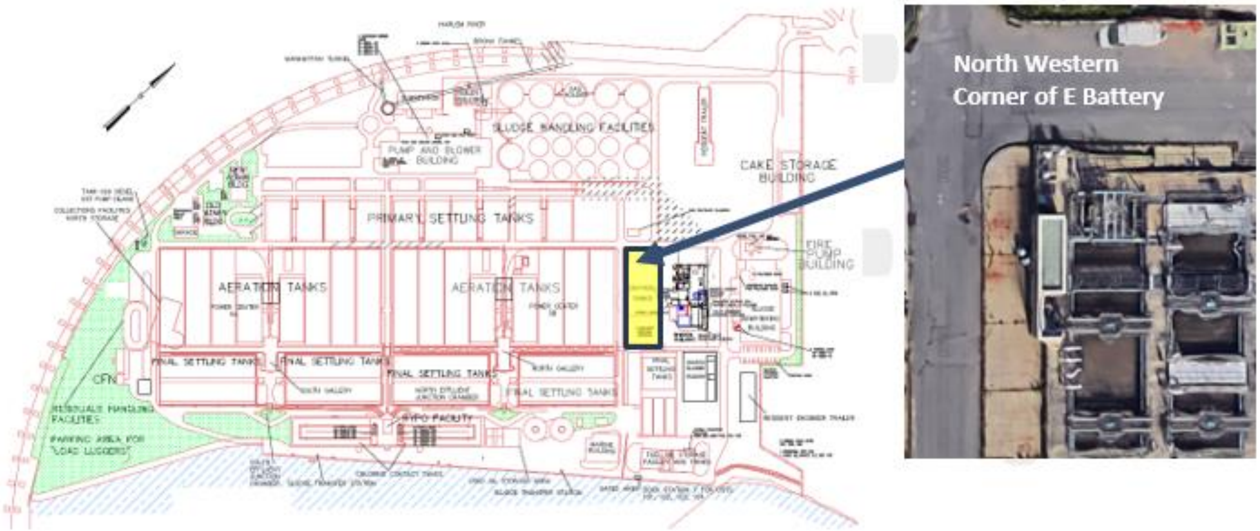


Figure 5-21: Wards Island Layout with E Battery Close-Up

Figure 5-22: Proposed Pilot Location by E Battery

Figure 5-23: E Battery Centrate Tie In

Key Findings:

The maximum capacity of the ROTATMAT pilot was 0.5 MGD. It was operated at 0.1 MGD during testing with a short term (about 1 hour) maximum flow rate of 0.3 MGD to assess hydraulic capacity with centrate solids present. The pilot demonstrated that the ROTATMAT has the ability to capture 95% of all particles larger than 2mm (as marketed).

5.10 Sludge Screening Piloting at Wards Island WRRF

Additional screening piloting is part of the WI-298 deammonification MBBR design project, with a focus on the Sludge Storage Facility (**Figure 5-24**). WI does not currently screen liquid biosolids and solids and rags accumulate in the WI Sludge Storage Tanks (SST) resulting in the loss of storage capacity and requiring more frequent cleanings of the tanks. Plant staff has reported that there is a significant accumulation of rags and other floating debris on the surface of the sludge storage tanks, effectively decreasing the available storage volume in the SSTs. The cumulative theoretical working volume of the tanks is 3.8 MG, due to the observed accumulation of screenings, it is reported by plant personnel that the actual working volume is roughly 70% of the total, approximately 2.7 MG.

As part of the WI-298 deammonification MBBR design, sludge screening will be provided to remove floatables/plastics, rags, and allow the facility to recapture full use of the volume of the SSTs and reduce maintenance of SST grinders and pumps. Indirect consequences of deployment of sludge screening will be the removal of plastics and debris from both the dewatering centrate and the dewatering cake, which is a necessary step in producing a biosolids product for beneficial reuse.

A sludge screening facility will be deployed to screen all sludges from the barges and WI, prior to introduction into the SSTs. Then the screened sludge will be directed to a sludge wet well from where it will be pumped into the SSTs. The sizing of the sludge screening facility will be driven by the offloading rate of the barged liquid biosolids, as it is significantly more cost and operationally effective to screen at high rates rather than store unscreened material for subsequent screening. The peak flow from the sludge barges is approximately 12 MGD. During this time, the native sludge flow will continue to be screened. Thus, the total flow to the screens would be on the order of 13.5 MGD, with up to 1.5 MGD of flow from WI. Flow from the barges to the screening facility would be constricted by a flow control system, to prevent the barges from offloading at flows in excess of the design flow.

Multiple technologies are being evaluated, including strain presses, rotary drum screens and step screens.

NYCDEP is currently deploying the pilot unit for a demonstration at the Wards Island WRRF.

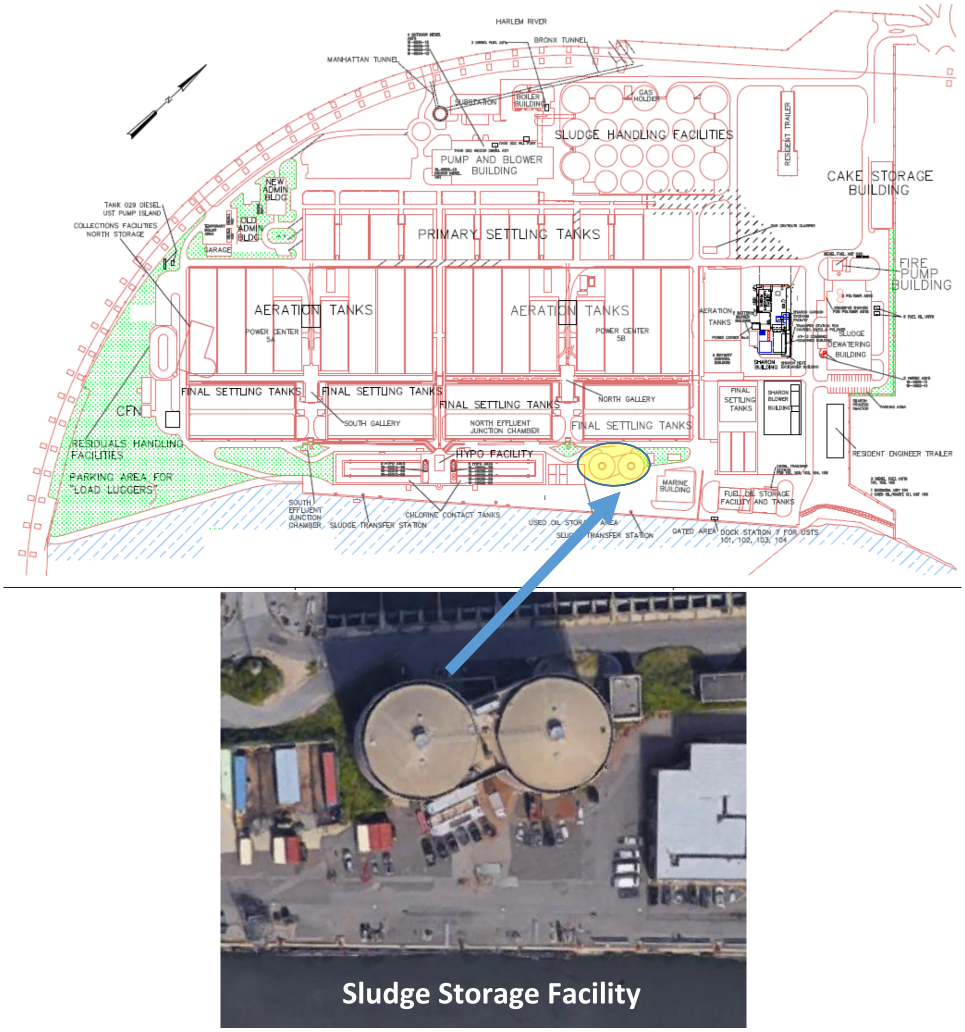


Figure 5-24: Wards Island Layout with Sludge Storage Tanks Close-up.

5.11 Suggested Future Projects

Additional projects that could be beneficial from both an energy and nutrient reduction perspective include the following:

Simultaneous Nitrification/Denitrification (SND) allows both nitrification and denitrification to occur in the same tank at low DO levels. SND may occur within floc of organic material in WRRFs, as suggested by the DO gradient that forms within. The anoxic floc interior fosters anaerobic denitrification, while the oxic exterior layer provides nitrification conditions. SND does not require the construction of baffles like BNR systems, as the creation of oxic and anoxic zones is not required. However, the chemical mechanisms of nitrogen removal are complex and not completely understood, rendering operational control over an SND system difficult. Testing to better understand this control mechanism would be beneficial, with control strategies such as Ammonia Based Aeration Control (ABAC).

Ammonia Based Aeration Control (ABAC) is a feedback control based on oxygen and/or ammonia as the controlled variable. In ABAC, partial/incomplete nitrification is encouraged by operating the aerobic zones at lower concentrations of dissolved oxygen (DO) in order to maintain a desired ammonia concentration leaving the aeration basin. The main incentive for implementing ABAC at a full-scale nutrient removing facility was to decrease the usage of supplemental carbon for denitrification while maintaining consistent removal of total nitrogen, partially due to simultaneous nitrification-denitrification (SND) as well as some possible suppression of nitrite oxidizing bacteria (NOB) for nitrite shunt, while simultaneously decreasing aeration energy usage, with the potential for decreased chlorine demand downstream (through chloramination) as well as decreased alkalinity demand. Ammonia based control can also serve to rapidly respond to increased ammonia breakthrough during low temperature operations. Conversely during high temperatures, ammonia based control can help prevent breakpoint chlorination.

Membrane Aerated Bioreactors (MABR) is a treatment technology consisting of a gas transfer membrane to deliver oxygen to a biofilm that is attached to the surface of the membrane. The MABR process leverages the synergy between a gas transfer membrane and an attached growth biofilm. The biolfilm develops on the water side of the sleeve containing nitrifying bacteria against the membrane (nearest to the aeration source), and deeper into the water side an anoxic biofilm develops. This process provides simultaneous nitrification and denitrification and requires less aeration energy than conventional BNR processes while reducing sludge production. Like most advanced processes, MABR require that fine screening be provided upstream of the reactors to avoid litter damaging the membranes.

Mainstream Deammonification at low temperatures and more dilute wastewater characteristics is an emerging operational application of sidestream deammonification, which is currently successfully conducted at high temperatures and concentrations. With the design and eventual application of sidestream deammonification at the WI WRRF under WI-298 Deammonification MBBR design project, the NYCDEP would benefit from testing a seeding process, whereby biomass from the sidestream reactor(s) could be directed to the mainstream process to encourage mainstream deammonification.

6. Nitrogen Reduction Efforts in Jamaica Bay

6.1 Introduction

Over the last 15 years, substantial investments have been made by New York City in addition to the wastewater treatment upgrades that have resulted in measurable water quality improvements in Jamaica Bay. This section of the Jamaica Bay Feasibility Study provides a description of specific efforts that have been undertaken by DEP to reduce nitrogen discharges and improve dissolved oxygen (DO) water quality in Jamaica Bay.

Low DO conditions can result from a variety of factors, including:

- Excessive nutrients from point and non-point sources
- Organic pollution for point, non-point and mobile sources
- Water stagnation and poor mixing/flushing of inlets and bay
- Loss of native plant species that assist in the removal of excess nutrients and carbon from the ambient water.

DEP focused on a variety of methods to improve water quality in Jamaica Bay, including:

- Restoration of wetlands in Jamaica Bay
- Improvements in infrastructure to reduce nitrogen discharges into Jamaica Bay
- Removal of problematic plant growth/suspend plant growth
- Introduction of organisms that promote a healthy wetland ecosystem
- Protection of wetlands in Jamaica Bay

Seagrasses in Jamaica Bay are an additional concern. Seagrasses have long been recognized as vital habitat and nursery grounds for commercially, recreationally and ecologically important fish and shellfish species. They also function as a food source for fish and waterfowl, important nutrient and carbon cyclers, sediment stabilizers, contributors to the marine and estuarine food web, and indicator species of estuarine health and quality. Acres of seagrass have been reduced to about one–tenth their historic level primarily due to anthropogenic causes, primarily decreased water quality and clarity due to increased nutrient loading, as well as large phytoplankton blooms, habitat degradation, fishing gear and boating impacts, and climate change impacts. Natural events such as disease also contribute to seagrass loss.

Municipal discharges, combined sewer overflows (CSOs), urban storm runoff and other nonpoint sources are the primary sources of pollutants to the Bay. Failing and/or inadequate on-site system discharges (Broad Channel Island) have also been cited as persistent issues in and around Jamaica Bay. These sources discharge pathogens, nutrients and oxygen–demanding substances which result in algal blooms and low dissolved oxygen. The bathymetry and poor flushing in the Grassy Bay portion of the Bay cause low dissolved oxygen. Habitat modification, particularly the loss of seagrass beds in the bay, are also a major concern.

CSOs represent a source of organics and nutrients to New York Harbor waters and tributaries. In 2005, NYSDEC issued a Consent Order requiring New York City to address the CSOs of the NYCDEP municipal wastewater system. In 2012, the CSO Order was modified to include the integration of green infrastructure, the substitution of more cost-effective grey infrastructure, and fixed dates for submittal of the Long-Term Control Plans. Under the 2005/2012 Orders, NYCDEP was required to develop Long Term Control Plans (LTCPs) to bring CSO-impacted waters into compliance with water quality standards, including Jamaica Bay and its tributaries. The LTCP will be submitted on June 30, 2018.

The CSO Consent Order requires post-construction monitoring to verify modeling projections and actual water quality compliance, inform decisions regarding SPDES permit renewal at five–year intervals, and evaluate future management actions, including additional CSOs controls if necessary (DEC/DOW, BWC/NYCC and NYCDEP, January 2017). These waters are included within the core area of the New York/New Jersey Harbor Estuary Program (HEP). The HEP is a National Estuary Program authorized in 1987 by the U.S. Environmental Protection Agency. The program is a continuing multi–agency and multi-state effort to develop and implement a plan to protect, conserve, and restore the estuary. Participants in the program include representatives from local, state, and federal environmental agencies, scientists, citizens, business interests, environmentalists, and others (DEC/DOW, BWAM, December 2015).

With the many policy and regulatory drivers aimed at improving Jamaica Bay water quality, the NYC DEP has undertaken several efforts to improve Jamaica Bay and its tributaries. The main objectives to these efforts are to:

- Improve water quality in Jamaica Bay and its tributaries
- Protect, restore and enhance fish and wildlife ecosystems and habitats
- Preserve and enhance public use of and recreation in the Jamaica Bay and its tributaries
- Provide public education and outreach related to its efforts
- Ensure sound land use practices on the bay perimeter and surrounding watershed
- Foster watershed stewardship

A summary of the efforts undertaken by NYCDEP is provided in **Table 6-1**.

Table 6-1: Summary of Measures Taken by NYCDEP to Improve DO Water Quality Conditions in Jamaica Bay

Project/Study	Category	Objective	Impact on DO Water Quality	Description	Status
Algal Turf Scrubber Pilot	Ecological Technology	Reduce nitrogen discharges from wastewater facilities via an Algal Turf Scrubber (ATS) and identify potential beneficial uses of algae collected.	Nitrogen discharges impact DO water quality by acting as a nutrient to problematic vegetation, such as sea lettuce, allowing them to thrive.	ATS is designed to mimic a stream ecosystem in a constructed environment that promotes algal growth. Nutrients in effluent wastewater are removed via algal photosynthesis.	Construction completed in September 2010. The ATS system ran until damage from Superstorm Sandy required that the system be discontinued in late 2012.
Sea Lettuce Harvesting Pilot	Ecosystem Restoration	Determine feasibility/potential benefits of restoring habitat that is currently degraded by accumulation of sea lettuce, as well as evaluate various uses for the sea lettuce if collected at a larger scale.	When sea lettuce dies, the decomposition process consumes a large amount of oxygen which results in low DO conditions in the water body. By harvesting sea lettuce, the decomposition process would be bypassed, allowing for improved DO quality conditions.	DEP trash skimmer boats used to harvest sea lettuce where it amasses in the waters of Jamaica Bay to determine if this approach is feasible and to chemically analyze sea lettuce for its use as a source of biofuel.	Harvests completed in August and September 2010. Testing of sea lettuce for its use as biofuel was completed successfully in late 2010.
Eel Grass Study	Ecosystem Restoration	Determining the potential of restoring Submerged Aquatic Vegetation (SAV) in Jamaica Bay.	The eel grass habitat produces food and oxygen, improves water quality by filtering polluted runoff, absorbs excess nutrients, stores greenhouse gases like carbon dioxide, and protects the shoreline from erosion.	The Cornell Cooperative Extension (CCE), in cooperation with NYCDEP, conducted a series of test plantings of eelgrass in multiple locations in Jamaica Bay.	Initial planting occurred spring 2009 with additional larger scale plantings in multiple locations in Spring 2010, Fall 2010, and Fall 2011.
Oyster Bed Pilot	Ecosystem Restoration	Oyster pilot projects were conducted to evaluate whether climatic and environmental conditions within the bay were suitable for oyster growth, survival, and reproduction. The study also measured how effective these bivalves were at filtering and removing nutrients from the water column.	As filter feeders, oysters indirectly remove nitrogen from a water body by consuming algae and using it to build their tissues and cells. Bio-deposits (or waste) from oysters contain nitrogen but are known to settle to the bottom of a water body and get buried in the sediment. Additionally, oyster reefs promote a bacterial population that convert nitrogen into nitrogen gas.	DEP conducted two oyster reintroduction pilot studies within Jamaica Bay – the design and construction of an oyster bed off Dubos Point, Queens, and the placement of oyster reef balls in Gerritsen Creek, Brooklyn. Monitoring activities included discrete and continuous water quality sampling, photo/video documentation, site maintenance, and investigation of sediment and current patterns.	Although continuous monitoring has ceased, a twice-a-year assessment of the site is continuing through 2018.
Head of Bay Oyster Project	Ecosystem Restoration	Evaluating survival of large scale Oyster Beds in terms of oyster growth and health, water quality improvements due to oyster filter feeding, and oyster reefs as functional habitat for other coastal wildlife.	See description for 'Oyster Bed Pilot'.	A floating "nursery reef" containing 50,000 adult oysters will serve primarily as the supply of oyster larvae. 30 sampling locations were established throughout eastern Jamaica Bay to monitor for the settlement of oyster larvae. Monitoring activities include water quality sampling, adult oyster health, growth, reproduction and recruitment.	Construction for the project began in September 2016 and monitoring will continue through late 2018.
Ribbed Mussel Pilot	Ecosystem Restoration	Determine whether the filtering capacity of mussels can be adapted to	Like oysters, as filter feeders, mussels indirectly remove nitrogen from a water body by consuming algae and using it to	Artificial structures were constructed in Fresh Creek, a tributary to Jamaica Bay, to encourage the growth of	Initial monitoring period was completed. Additional monitoring will be conducted through Fall 2018. A

Project/Study	Category	Objective	Impact on DO Water Quality	Description	Status
		the practical application of filtering discharges to improve water quality.	build their tissues and cells. Bio-deposits (or waste) from mussels contain nitrogen but are known to settle to the bottom of a water body and get buried in the sediment.	ribbed mussels. The study monitored mussel growth and qualitative water quality improvements to measure the effectiveness of ribbed mussels in removing nutrients and particulate organic matter from the water.	detailed experimental program has been developed to allow extension of the benefits of ribbed mussel system to include pathogen reduction.
Paerdegat Basin Restoration	Wetland Restoration	To improve water quality, reestablish native habitat, and create recreational and educational opportunities for the public.	Wetlands remove nitrogen, BOD, and other pollutants through various physical, chemical, and biological processes.	DEP established 52 acres of restored wetlands, including a public Ecology Park, along the shores of Paerdegat Basin.	Construction completed January 2013.
Marsh Island Wave Attenuator Study	Wetland Restoration	To reduce the rate of loss of existing wetlands and provide protection of other wetland restoration efforts against wind and wave erosion in Jamaica Bay. Additionally, a temporary wave attenuator system may also provide important research data and inform future design modifications that can be effectively used to protect the vulnerable wetlands.	Through preservation of wetland shoreline, wave attenuators indirectly contribute to improvements in DO water quality conditions. Wetlands are a vital part of the wetland ecosystem and provide removal of nitrogen, BOD, and other pollutants through various physical, chemical, and biological processes.	A floating wave attenuator was installed at Brant Point, along the southern shoreline of Jamaica Bay near a severely degraded and actively eroding wetland edge. The wave attenuator deflects and reduces the energy of incoming waves, allowing for the accumulation of important wetland building sediments. These temporary structures are a proxy for future oyster beds around wetlands to evaluate the wave energy reduction and sediment capture potential.	Construction was completed in August 2015. Monitoring is projected to occur through 2018.
Historical CSO Abatement Projects	CSO Reduction	Maximize utilization of the existing collection system infrastructure and treatment of combined sewage at the 26th Ward, Jamaica, and Rockaway WRRFs.	A CSO is a permitted discharge composed of a mixture of stormwater and sanitary sewage into a receiving water body. CSO discharges occur when a combined sewer system is overwhelmed by stormwater during wet weather conditions. Depending on the intensity and duration of the storm event, CSOs can contribute highly variable levels of biological matter and nutrients and impact DO conditions in a receiving water body.	• Spring Creek AWPCP Upgrades • Meadowmere and Warnerville DWO Abatement • Shellbank Basin Destratification System • Laurelton and Springfield Blvd Storm Sewer Buildout Regulator Automation	Completed
Paerdegat CSO Retention Facility	CSO Reduction	To reduce CSO discharges to Paerdegat Basin and improve water quality conditions within the receiving waters.	See description for ‘Historical CSO Abatement Projects.	The Paerdegat Basin CSO Retention Facility provides 50 million gallons of CSO storage capacity for capture of CSO discharges tributary to Paerdegat Basin. Captured CSO is pumped back to the collection system following a wet weather event for conveyance to the WRRF for treatment.	Construction was completed in May 2011. Post construction monitoring (PCM) is being performed. The February 2016 Post Construction Compliance Monitoring Analysis

Project/Study	Category	Objective	Impact on DO Water Quality	Description	Status
					Report concluded that Paerdegat Basin attains current DO WQS.
Bergen Basin Bending Weirs and Parallel Sewer to Jamaica WRRF	CSO Reduction	Improve the conveyance of wet weather flow to the Jamaica WRRF for treatment, thereby reducing CSOs.	See description for 'Historical CSO Abatement Projects.	Bending weirs were installed and regulator discharge orifices were enlarged for Regulators JA-03, JA-06 and JA-14. A new 48-inch sewer was also constructed parallel to the West Interceptor. These projects improve wet weather conveyance to the Jamaica WRRF.	Bending weir construction was completed in mid-2016. The parallel sewer was activated in February 2017.
Environmental Benefit Projects (EBPs)	CSO Reduction	Environmental Benefit Projects (EBPs) are funded by DEP and are designed to abate CSOs and/or address wet weather water quality impacts from CSOs and to benefit the waters in and around New York City.	See description for 'Historical CSO Abatement Projects.	• Jamaica Bay Watershed Stormwater Pilot Project • CSO EBP Work Plan Stormwater BMP Implementation	Completed
Jamaica Bay and Tributaries Long Term Control Plan (LTCP)	CSO Reduction	The goal of each LTCP is to identify appropriate CSO controls necessary to achieve waterbody-specific water quality standards that are consistent with the federal CSO Policy and the water quality goals of the Clean Water Act (CWA).	See description for 'Historical CSO Abatement Projects.	As part of the LTCP program, extensive water quality sampling and modeling was performed for the six waterbodies tributary to Jamaica Bay. The gap between a baseline condition without CSO control and a baseline condition with 100 percent CSO control was compared to assess whether the appropriate water quality standards can be attained through CSO controls. The results of this gap analysis will inform the development alternatives for reducing the amount and frequency of CSO discharges to improve water quality and provide DEP with the basis for development of an implementation plan and strategy.	The Jamaica Bay and Tributaries CSO LTCP will be submitted June 30, 2018.
Green Infrastructure	CSO Reduction	Reduce CSOs by intercepting as much stormwater as possible before it gets to the storm sewer system using hybrid green and gray infrastructure.	See description for 'Historical CSO Abatement Projects.	Green Infrastructure (GI) practices are designed to manage storm water runoff from impervious services such as streets and sidewalks. Examples include raingardens, pond restoration, Right of Way runoff capture.	Ongoing

6.2 Algal Turf Scrubber Pilot

An Algal Turf Scrubber (ATS)™ pilot was constructed at the Rockaway WRRF. The purpose of this pilot study was to evaluate the effectiveness of the system at removing nutrients, carbon, and other pollutants and to identify potential beneficial uses of the algae collected.

Figure 6-1: Algal Turf Scrubber at the Rockaway WRRF

The ATS is designed to mimic a stream ecosystem in a constructed environment that promotes algal growth. The ATS consists of an inclined flow way, a long slightly sloped shallow trough made of waterproof materials that is raised on a support frame, and a screen liner. Wastewater effluent is pumped into the flow way in regular pulses to allow the algae to take up nutrients, carbon, and other materials via photosynthesis. Effluent from the ATS is enriched with oxygen as a byproduct of this process. Algae is periodically harvested to promote continued algal growth.

In September 2010, DEP completed construction of the ATS pilot at the Rockaway WRRF. The pilot treated a small portion of the effluent flow (2,400 gallons per hour maximum). Algae collected throughout the life of the project was sent to the University of Arkansas for processing into butanol. Reuse of the algae as a beneficial by-product could possibly make the treatment of wastewater with ATS more cost-efficient. If future efforts to utilize algae for biofuel production prove effective, large volumes of algae produced from a reconstructed ATS could potentially fuel vehicles used within the Rockaway WRRF.

Monitoring results indicated that approximately 2.13 kg/m^2 of nitrogen, 0.32 kg/m^2 of phosphorus, and 13.7 kg/m^2 of carbon were removed from the water and captured in the algae in 2012, with daily algae productivity averaging approximately 13 g/m^2/day. Of this, approximately 70 kg of dry algae were harvested and sent to the University of Arkansas for conversion to biofuel. It was also found that increases in solar radiation and ambient temperature resulted in increased productivity. Future research can be conducted to investigate methods for increasing solar radiation and ambient temperatures through the year.

The study found that land availability is one of the primary factors limiting the future use of ATS at WRRFs with large discharges, although preliminary evaluations did identify a few opportunities near WRRFs on Jamaica Bay.

6.3 Sea Lettuce Harvesting Pilot

DEP conducted a pilot study to demonstrate the effectiveness of sea lettuce harvesting on improving water quality and environmental conditions in selected areas of Jamaica Bay. The objective of the pilot was to gain information regarding the feasibility and potential benefits of restoring habitat that is currently degraded by accumulation of sea lettuce, as well as evaluate various uses for the sea lettuce if collected at a larger scale.

Currently, Jamaica Bay experiences seasonal recurring blooms of sea lettuce from late winter through spring and again in late summer through fall. However, the timing and extent of these blooms can vary considerably from year to year and are influenced not only by nutrients but local climate conditions as well. Where it accumulates, detrimental effects may include suffocation of benthic invertebrate communities, suppression of spawning/nesting activity by horseshoe crabs and diamondback terrapins, and interference with recreational boating and fishing activity. Decomposition of dense mats of sea lettuce along intertidal shores and beaches produces noxious odors and discourages beachgoers and nature watchers.

Figure 6-2: Sea Lettuce Accumulation on Jamaica Bay Shoreline

The goals of the Sea Lettuce Harvesting Pilot Study were to:

- Demonstrate the effectiveness of sea lettuce harvesting in benefiting water quality in selected areas of Jamaica Bay.
- Provide an important initial step toward restoring shallow, subtidal habitat in Jamaica Bay that is currently subjected to smothering by dense mats of detached sea lettuce.

- Form the foundation for future, larger scale macroalgae removal projects that could ultimately benefit a variety of associated marine species and habitats.

DEP characterized potential pilot study sites during the summers of 2009 and 2010 based on site location, recent history of algae accumulation, hydrology, sediments, and bathymetry. DEP tested their existing fleet of trash skimmer boats and found them to be effective at collecting floating trash mats of sea lettuce. Sea lettuce was also manually harvested from several locations throughout Jamaica Bay from May 2010 through September 2010.

Figure 6-3: NYCDEP Boat Collecting Sea Lettuce

Throughout the pilot harvesting program, nearly 300 gallons of sea lettuce were collected and sent to the University of Arkansas for processing into biofuel. A sample volume of one liter of butanol was produced and delivered to DEP in December 2010. A variety of potential beneficial use options have been identified as alternatives to disposal of harvested sea lettuce in landfills. Some of these are relatively straightforward to implement (e.g., use as compost/fertilizer) while others (waste-to-energy generation, high-volume biofuel distillation) will require additional research and development to determine feasibility and cost of implementation. A preliminary cost-benefit evaluation indicates that a range of potential ecosystem and societal benefits may be attributed to large-scale harvesting of sea lettuce in Jamaica Bay. Further analyses and data gathering will be necessary to quantify these benefits.

Figure 6-4: Biofuel Produced from Macro-Algae

6.4 Eel Grass Pilot Study

Submerged aquatic vegetation (SAV) beds are important for several fish and shellfish species. SAV also absorbs wave energy, nutrients, produces oxygen, and improves water quality. For this reason, the Jamaica Bay Watershed Protection Plan (JBWPP) included a call for determining the potential of restoring SAV in the region.

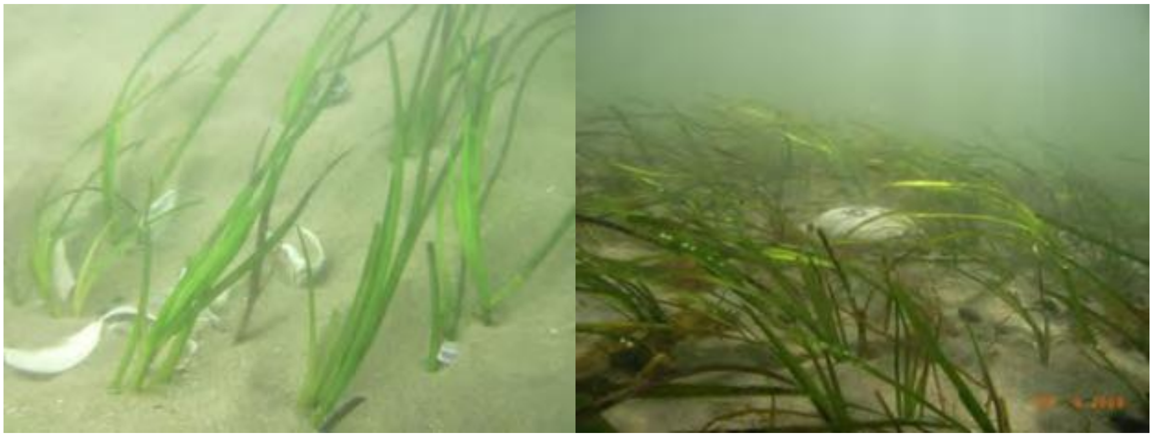


Figure 6-5: Eel Grass

Eelgrass, a common SAV native to this region, was explored through this study to better understand the logistics and implications of restoring eelgrass in Jamaica Bay. The Cornell Cooperative Extension (CCE), in cooperation with DEP, conducted a series of test plantings of eelgrass in multiple locations in Jamaica Bay. Objectives of the study included refining site selection parameters, planting methodology, appropriate planting depths, timing of plantings, and propagule (seed vs. adult shoot) selection. Although not all plantings resulted in a long-term establishment of eelgrass, they did provide valuable scientific insight into the issues affecting planting in the area.

These investigations were also necessary to compare current eelgrass growth potentials with the growth after anticipated water quality improvements given nitrogen reduction upgrades at the bay's four WRRFs.

Data from the pilot study indicated that eelgrass meadows in Jamaica Bay under existing conditions face significant environmental and physical stressors.

It is likely that the mortality experienced among the various planting populations throughout the Bay were due to several site-specific conditions. For example, monitoring results suggested that water quality at the Breezy Point location appeared to be suitable for growth and that plant mortality was attributable to blue mussel colonization and strong sediment movement (sand waves) that buried many of the tender shoots. During Fall 2011, there was an unusually large population of blue mussel larvae all along the east coast. This was a major contributor to the demise of the planting due to the larvae attaching to the eelgrass blades and reducing the ability of the plant to photosynthesize.

Identification of potential causes of the low eelgrass survival rates at the pilot sites will allow DEP to determine the efficacy of this particular restoration method as conditions in the bay evolve. DEP is aware of major impacts such as seasonal fluctuations in various environmental disturbances and observed predation.

The pilot project has provided DEP with a continuous learning opportunity regarding both eelgrass and the overall conditions within the bay.

6.5 Oyster Bed Pilot Study

The restoration of oysters could potentially help regenerate the natural environment of the bay, once teaming with oysters, while providing additional water quality benefits. DEP conducted two oyster reintroduction pilot studies within Jamaica Bay – the design and construction of an oyster bed off of Dubos Point, Queens, and the placement of oyster reef balls in Gerritsen Creek, Brooklyn. These oyster pilot projects were conducted to evaluate whether climatic and environmental conditions within the bay are suitable for oyster growth, survival, and reproduction. The study also measured how effective these bivalves are at filtering various pollutants that affect the bay, such as nitrogen, other nutrients, and particulate organic matter.

Using information and recommendations generated by several pre-construction workshops, DEP worked with the Suffolk County Cornell Cooperative Extension (CCE) Service to implant oyster larvae (spat) on New York State Department of Environmental Conservation (DEC) approved shell and reef balls. The spat-on-shell and spat-covered reef balls were then placed in Jamaica Bay in October 2010. The sites were monitored on a bi-weekly basis through 2013 to determine if the oysters could survive, grow, reproduce and provide water quality and ecological benefits. Monitoring activities included discrete and continuous water quality sampling, photo/video documentation, site maintenance, and investigation of sediment and current patterns.

Monitoring efforts revealed that many oysters have populated the structures, and in their fourth year of growth, are still alive, have reproduced, and appeared healthy. The monitoring results from 2013 indicated adequate environmental conditions for oyster growth and survival within Jamaica Bay.

Figure 6-6: Images of Oysters in Jamaica Bay

Throughout the project, DEP gained information necessary for future oyster habitat restoration efforts. In addition, DEP coordinated with other organizations and researchers undertaking similar efforts in the NY/NJ Harbor Estuary to help form a foundation for future oyster habitat development projects that will ultimately benefit a variety of associated marine species.

While continuous monitoring has ceased, a twice-a-year assessment of the site is continuing through 2018. The latest assessments in the fall of 2015 revealed that many oysters, in their fifth year of growth, were still alive and appear healthy. Overall, the monitoring results indicate adequate environmental conditions for oyster growth and survival within Jamaica Bay and water quality data demonstrated ranges within normal tolerances for the Eastern oyster.

If deemed feasible and sustainable, future steps could include developing a program to create a self-sustaining oyster population in Jamaica Bay to improve water quality and increase oyster larvae recruitment.

6.6 Head of Bay Oyster Project

The Head of Bay Oyster Project builds upon Oyster Bed pilot studies conducted at Dubos Point, Queens and Gerritsen Creek, Brooklyn that demonstrated that oysters could not only survive in Jamaica Bay, but also thrive and reproduce. In contrast to earlier efforts, this project is much larger in scale and focuses mainly on adult oyster reproduction and juvenile survival. A floating “nursery” of 50,000 adult oysters was installed in Head of Bay to evaluate natural recruitment, as this has been one of the more challenging aspects to fully understand. The project includes donor and receiver beds to study recruitment within Jamaica Bay. In addition to the monitoring of the donor and receiver beds, we will also evaluate the spatial and temporal patterns of oyster reproduction and juvenile settlement using spat collectors in the eastern sections of Jamaica Bay. It is anticipated that oysters will colonize four constructed beds suitable for oyster larvae attachment adjacent to the floating nursery. Additional monitoring will examine adult oyster growth and health, water quality improvements due to oyster filter feeding, and oyster reefs as functional habitat for other coastal wildlife.

Dense beds of eastern oyster (Crassostrea virginica) historically covered much of Jamaica Bay, New York Harbor and the lower Hudson River until the early 20th century. These natural oyster beds were a crucial component of the coastal ecosystem by constructing habitat and feeding grounds for diverse assemblages of fishes, birds, and other aquatic organisms. Oyster beds also provided important ecosystem services to adjacent human communities such as improving water quality and attenuating wave action. Overharvesting, dredging and water pollution led to the decline and closure of oyster fisheries in Jamaica Bay by 1921 (National Park Service, Jamaica Bay: A History, p. 47. 1981.)

This research project includes the initial construction of five artificial oyster bed structures in Head of Bay followed by two years of biological and environmental monitoring. Previous modeling efforts suggest that this area of the bay has the highest potential for retaining oyster larvae as they spend much of the time within the Idlewild salt marsh complex. A floating "nursery reef" containing 50,000 adult oysters will serve primarily as the supply of oyster larvae. These larvae or juvenile oysters float freely in the water with limited mobility for a period of approximately 2 to 3-weeks. Four submerged beds were constructed nearby to serve as suitable settlement locations for the developing juvenile oysters. These four "receiver reefs" are composed of porcelain fragments, clamshells, and oyster shells. The porcelain was salvaged from nearly 5,000 recycled toilets removed as part of DEP's water conservation plan in local public schools. Additionally, 30 sampling locations were established throughout eastern Jamaica Bay to monitor for the settlement of oyster larvae. For the duration of the project, the team will monitor water quality within Head of Bay to examine its effect on juvenile oyster settlement and survival as well as adult oyster health, growth, reproduction and recruitment.

Figure 6-7: Oyster Nursery in Jamaica Bay

Figure 6-8: Crushed Porcelain used in Receiver Reefs

Wild oyster beds offer an important ecosystem service to humans by improving water quality. A single adult oyster is capable of filtering dozens of gallons of water per day through its natural feeding process. To examine the potential benefits of a restored oyster reef in urbanized Jamaica Bay, the team will measure the amount of phytoplankton and particulate matter removed from water flowing through the project site.

Lastly, the team will document the role of restored oyster beds as functional habitat for other coastal organisms. This work will include sampling seafloor sediments and oyster bed materials within the project site.

6.7 Ribbed Mussel Pilot Study

The objective of this pilot was to study whether the filtering capacity of mussels can be adapted to the practical application of filtering the water column to improve water quality. Several artificial structures were constructed in Fresh Creek, a tributary to Jamaica Bay, to encourage the growth of ribbed mussels. The study monitored mussel growth and qualitative water quality improvements to measure the effectiveness of ribbed mussels in removing nutrients and particulate organic matter from the water.

Figure 6-9: Ribbed Mussels Grown in Fresh Creek

Ribbed mussels were chosen because they naturally occur in Jamaica Bay, are very abundant in some locations, and are a local species that can tolerate the existing, lower water quality conditions that seasonally occur in some locations. Ribbed mussels are also desirable for biofiltration purposes in that they are not used for human consumption, so there is minimal risk of poaching in closed waters.

Based on discussions held at pre-construction workshops and field reconnaissance, DEP selected Fresh Creek as the pilot site. Fresh Creek has several suitable characteristics for this study including combined sewer overflow discharge and several stormwater outfalls. The Creek currently supports ribbed mussels and there is a tidal wetland edge over most of its length. A section near the middle of Fresh Creek was selected due to its narrow channel which concentrates tidal flows in the pilot project area. This location enhances the chances of detecting water quality differences across the array of mussels.

While the filtering capacity of mussels is well known, it is unclear whether that capacity can be adapted to the practical application of filtering within the water column to improve the water quality. DEP has undertaken this pilot study to evaluate if a “wall” of ribbed mussels can be built to support a sufficient mussel population to carry out effective filtration and improve water quality.

Full monitoring of the arrays was conducted monthly through late fall of 2014 and will continue bi-annually from through 2018. Naturally recruited mussel spat, i.e. mussel larvae, was observed on all five arrays beginning in June 2012. The site continues to be monitored, and more mussel spat and other organisms, like barnacles, have continued to attach to the structures. The spat was generally observed to occur in the nooks and crannies of the cargo netting and metal pilings. In the summer of 2014, over 150 mussels were observed to have set on the structures. While this is below the expected colonization density, the structure may need to reach a biological threshold before full colonization can occur. If ribbed mussel populations increase to significant densities in the future, DEP plans to qualitatively analyze correlations between mussel growth and changes to water quality.

6.8 Paerdegat Basin Restoration

To improve water quality, reestablish native habitat, and create recreational and educational opportunities for the public, DEP established 52 acres of restored wetlands, including a public Ecology Park, along the shores of Paerdegat Basin. This educational park includes restored New York City coastal and adjacent upland habitat.

In January 2010, DEP initiated a contract funded by the American Resource and Recovery Act (ARRA) to restore 52 acres of wetlands and coastal grasslands adjacent to the Paerdegat Basin Combined Sewer Overflow (CSO) Facility located in Brooklyn. Paerdegat Basin is a tributary of Jamaica Bay and this investment is meant to greatly improve the ecology of the area surrounding both the Basin and the Bay. Design objectives of the project also include sustainable stormwater management to promote infiltration and the creation of tidal wetland habitat.

Figure 6-10: Paerdegat Basin Wetland Restoration

A major element of the restoration project is a five-acre ‘Ecology Park’ composed of sixteen native coastal plant communities that attract and support a wide variety of wildlife. The habitats include salt marshes; intertidal mudflats; and coastal grasslands, shrublands and forests. Once open to the public, the Ecology Park will serve as an educational resource to promote awareness of the varied coastal environments found throughout the New York City region. Walking trails, viewing platforms, and educational exhibits are provided to enhance public enjoyment of the coastal habitats.

Construction began in spring 2010 and was completed in January 2013. The Paerdegat restoration complements the $357 million capital investment DEP has made to build the Paerdegat Basin CSO Retention Facility. When too much stormwater enters the sewer system, it can trigger CSOs when sewers and treatment plants reach capacity. While this overflow mechanism protects the sewer system and treatment plants by design, the overflows are a contributing factor to the degradation of water quality. The Paerdegat CSO Retention Facility coupled with the Paerdegat Basin Restoration has significantly contributed to the improvement of water quality in Paerdegat Basin and the surrounding environment.

6.9 Marsh Island Wave Attenuator Study

It is estimated that the Jamaica Bay estuary is only about half of its pre-colonial extent and salt marsh wetlands, a defining ecological feature of the bay, are decreasing. Jamaica Bay’s wetlands have been compromised over the years resulting from a variety of factors, including: rising sea levels, bathymetric changes, mean tidal range changes, warmer temperatures, and increased nitrogen loadings.

Over the last 150 years:

- Interior wetland islands and perimeter wetlands have been permanently removed because of extensive filling operations, with shorelines hardened and bulk headed to stabilize and protect existing communities and infrastructure
- Deep channels and borrow areas have been dredged, altering bottom contours and affecting natural flows
- Natural tributaries, along with their important benefits of balance fresh water and coarse wetland building sediment exchanges, have almost disappeared leaving behind deposits of silts and particulates from urban runoff

Numerous efforts have been made by federal, state, and local agencies to restore Jamaica Bay's wetlands. However, newly restored wetlands are vulnerable to the damaging effects of wind and wave energies due to their limited vegetative cover and limit benefits of sediment anchoring from an under-developed root system.

While not an ideal scenario from an ecological perspective, the use of a temporary wave attenuator system may provide important research data and inform future design modifications that can be effectively used to armor the vulnerable windward fringes of these marshes, allowing sufficient protection while *Spartina Alterniflora* (smooth cordgrass) becomes fully established. The floating breakwater systems reduce energy in the wave thereby creating an environment for protection and accretion of the shoreline to occur. Used in combination with other restoration protection measures, these treatments may help to reduce the rate of loss of existing wetlands and increase the protective benefits of previous restoration efforts. These systems also have the potential to increase the capture of marsh building sediments and may allow the outward expansion and stabilization of these wetland systems.

DEP implemented a floating island attenuator at Brant Point along the southern shoreline of Jamaica Bay. A floating island wave attenuator is an anchored series of floating mats planted with salt tolerant wetland plants located offshore of a shoreline, set into place to deflect and reduce the energy of waves.

This pilot study evaluated the potential for using floating island technology as a wave attenuator for a section of an eroding wetland shoreline, with the objective of investigating the potential accretion of beneficial wetland building sediments and decreased rate of shoreline loss due to erosion. The temporary floating islands are being tested as a "proxy" for potential oyster reefs, which are planned to be restored within the Bay in the future.

Figure 6-11: Floating Wetland Wave Attenuator

Several key parameters determined the final design of the floating island wave attenuators. These site-specific considerations included: water depth, storm data, wave action, and sediment conditions. DEP determined the placement, sizing and anchoring of the attenuators using modeling, field characterization and research on historical weather patterns.

Pilot construction occurred in August 2015 and is being monitored through 2018.

6.10 Miscellaneous/Historical CSO Abatement Measures

NYCDEP has a long history of implementing extensive CSO control measures, dating back to the early 1970s. As documented in the *Jamaica Bay Waterbody/Watershed Facility Plan Report (WB/WS Facility Plan)*, submitted in November 2012, NYCDEP has already built or is planning to build over $2.9 billion (2010 dollars) in targeted grey infrastructure to reduce CSO volumes. This does not include millions spent annually on the Nine Minimum Controls2 (NMC) that have been in place since 1994 to control CSOs. The purpose of the WB/WS Facility Plan was to take the first step toward development of an LTCP for Jamaica Bay and its tributaries affected by CSO including: Fresh Creek, Hendrix Creek, Spring Creek, Bergen Basin, and Thurston Basin.

As part of the WB/WS Facility Plan, descriptions and updates of historical CSO abatement measures taken by NYCDEP (listed below) were provided and are summarized in this Section of the Jamaica Bay Feasibility Study.

- Spring Creek Auxiliary Water Pollution Control Plant
- Meadowmere and Warnerville DWO Abatement
- Shellbank Basin Destratification System
- Laurelton and Springfield Blvd. Drainage Plan
- Regulator Automation

6.10.1 Spring Creek Auxiliary Water Pollution Control Plant

The Spring Creek Auxiliary Water Pollution Control Plant (AWPCP) retention facility is located on Spring Creek at the confluence with Old Mill Creek along the Brooklyn-Queens border and is approximately 1 mile east of the 26th Ward WRRF (see **Figure 6-12**). Placed into service in the early 1970s and originally named an “Auxiliary Water Pollution Control Plant” (AWPCP), the current primary function of the Spring Creek AWPCP is to capture CSO from tributary drainage areas in Brooklyn and Queens and convey them to the 26th Ward WPCP for treatment. The Spring Creek AWPCP is permitted as a regional CSO storage facility under the 26th Ward SPDES permit; however, it also receives wet weather overflow from the Jamaica WRRF service area via Regulator J-2 in Queens.

2The NMC are as follows (EPA Guidance for NMC, 1995):

1. Proper operation and regular maintenance programs for the sewer system and CSO outfalls
2. Maximum use of the collection system for storage
3. Review and modification of pretreatment requirements to ensure that CSO impacts are minimized
4. Maximization of flow to the POTW for treatment
5. Elimination of CSOs during dry weather
6. Control of solid and floatable materials in CSOs
7. Pollution prevention programs to reduce containments in CSOs
8. Public notification to ensure that the public receives adequate notification of CSO occurrences and CSO impacts
9. Monitoring to effectively characterize CSO impacts and the efficacy of CSO controls.

The Spring Creek AWPCP underwent a major upgrade in 2007, in compliance with the 2005 CSO Consent Order milestone. The upgrades and improvements included the following:

- A new tide gate control system consisting of effluent sluice gates that are controlled by the differential in the basin elevation and the tide elevation
- New dewatering pumps consisting of three 5.8 MGD variable speed horizontal centrifugal pumps, new pump controls, and new piping
- Pump building upgrades, including a new computer-based process instrumentation and control system; New high volume, low head basin cleaning system consisting of spray water pumps, distribution piping and spray headers that clean the walls and floor of the basins
- New odor control system and building with three odor control units rated at 517 MGD
- Extensive structural improvements, including new weir wall, floating booms for floatables retention, the elimination of spray water channels, and the lowering of the existing concrete roof approximately 9 feet to reduce ventilation volumes.

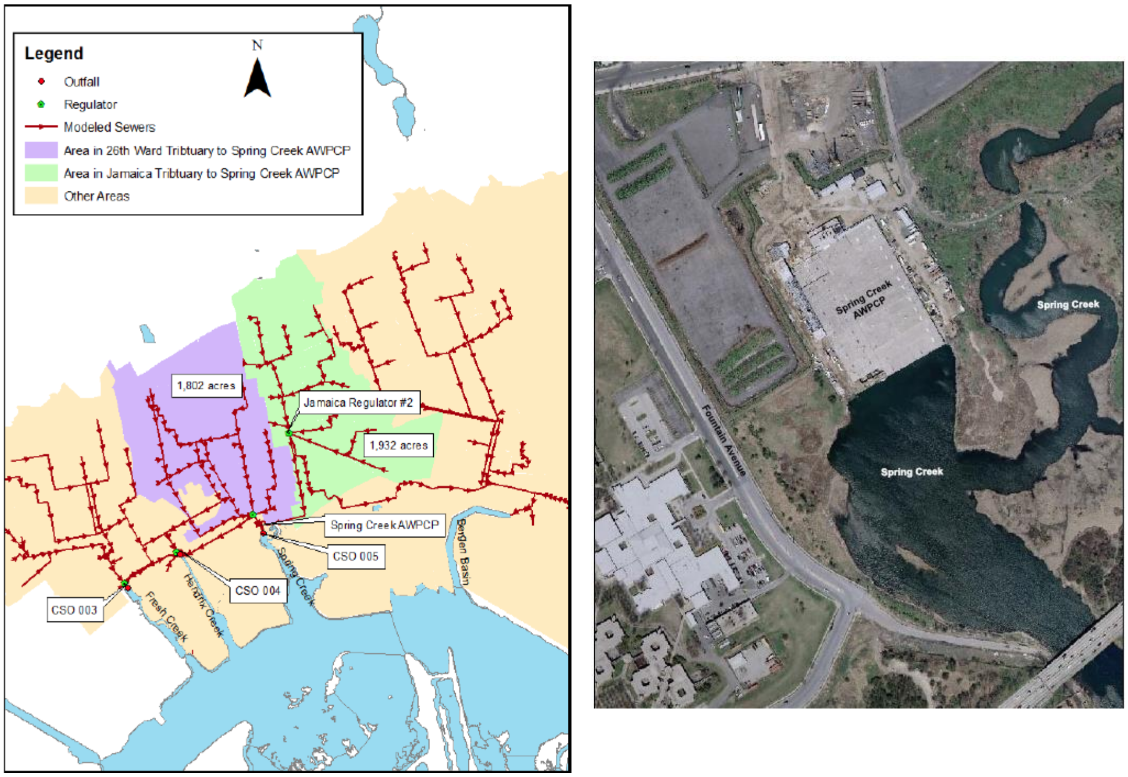


Figure 6-12: Spring Creek AWPCP Service Area and Collection System (left) and Layout (Right)

6.10.2 Meadowmere & Warnerville DWO Abatement

Two small neighborhoods, Meadowmere and Warnerville, located at the base of Thurston Basin, previously utilized septic systems to provide sanitary sewer service. These septic systems were

identified as discharging into Jamaica Bay during both dry and wet weather flow periods, impacting water quality in the Bay. The project included the design and construction of a wastewater pumping station and force main system, a new separate wastewater conveyance system, and a storm water collection system for the Meadowmere and Warnerville neighborhoods. A separate gravity sewer system collects the flow from each neighborhood and then discharges it to the Warnerville Wastewater Pumping Station. From the pump station, the flow is conveyed to the nearest existing NYCDEP sanitary sewer system (near the intersection of Brookville Boulevard and 149th Avenue) for ultimate treatment at the Jamaica WRRF. Construction was completed in 2010.

6.10.3 Shellbank Basin Destratification System

Shellbank Basin is a long, narrow tributary waterbody of Jamaica Bay. Shellbank Basin is bound by 157th Avenue to the north, Cross Bay Boulevard to the west and 85th Street to the east. The mouth of the basin is flanked by Frank Charles Park to the east and a portion of the Spring Creek Park to the west. The basin is approximately 5,200 feet long and is approximately 250 feet in width, on average. The basin is wider at its head with a width of approximately 550 feet. Depths in the basin range from 10 to 52 feet at mean low water. As it is separately serviced by sanitary and storm sewer systems, Shellbank Basin is not considered a CSO tributary to Jamaica Bay. Without natural mixing, the layer of water at the surface becomes much warmer due to heating by the sun (especially during the summer), while the deeper water layers are trapped on the bottom and remain cooler. This separation into warm and cool layers is known as stratification, and eventually the bottom waters become devoid of oxygen (anoxic). Summer weather conditions then cause the basin to turn over, bringing anoxic water to the surface and causing ecological and odor problems. A DEP pilot destratification system operated successfully in Shellbank Basin during the summer season since 2000 (see **Figure 6-13**). The pilot system consisted of a small air compressor system which introduces oxygen to the bottom of Shellbank Basin.

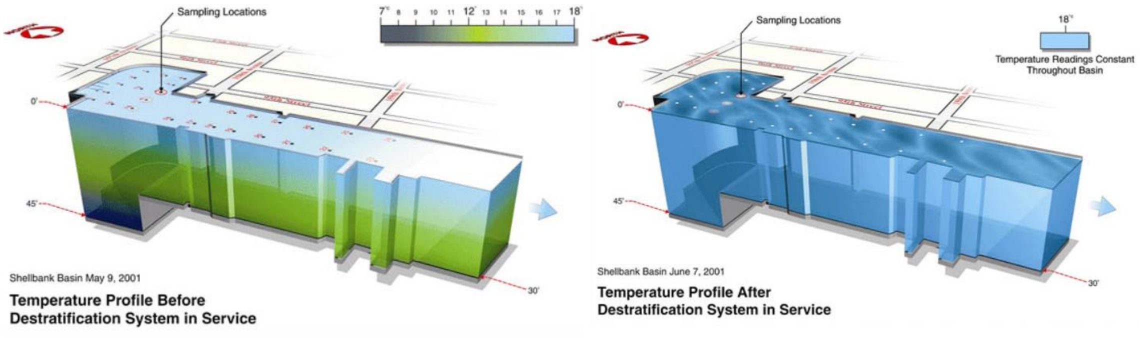


Figure 6-13: Temperature Before (left) and after (Right) Destratification System in Service

Following a successful pilot demonstration, permanent Destratification System was placed into service in 2012 based on the Pilot System, as shown in **Figure 6-14**.

Figure 6-14: Shellbank Basin Destratification Facility

6.10.4 Laurelton and Springfield Blvd. Drainage Plan

A drainage plan for 7,000 acres in southeast Queens was developed to address flooding and construct high-level storm sewers in a 1,450-acre CSO drainage area tributary to Thurston Basin. The drainage plan identified the necessary capital sewer projects to alleviate flooding and convert the CSO area to a high-level storm sewer (HLSS) system. Some sections of southeast Queens were developed faster than NYCDEP was able to fully construct the storm and sanitary sewer system. As such, the area has a mixture of combined sewers, separate sewers, areas where storm sewers interconnect with combined sewers, and areas with inadequate sewers. NYC DEP has constructed hundreds of seepage basins in the area to provide some level of relief to the communities until storm sewers could be properly constructed. DEP had always intended to fully build-out the storm sewers in the area to prevent both street and basement flooding in the area. HLSS conversion involved the construction of a storm drainage system that conveys wet weather flow from drainage inlets directly to Thurston Basin. While the existing combined sewer system would primarily convey sanitary flow after the construction of the HLSS, some storm water flow (roof drains, sump pumps, etc.) would continue to be conveyed for treatment at the Jamaica WRRF.

6.10.5 Regulator Automation

Automation of key regulators was recommended in response to the 1988 State Pollution Discharge Elimination System (SPDES) permit requirements that called for telemetry in the regulators to detect dry weather overflows. It was recommended at those regulators contributing the largest flows to the treatment plants, specifically Regulators 2, 3, and 14 in the Jamaica WPCP drainage area. The Citywide Collection Facilities Supervisory Control and Data Acquisition (SCADA) System Project will automate key regulators in the City by installing electro-hydraulic actuators capable of controlling flows to the sewer interceptor.

The automation of Regulator J2 includes the installation of an electro-hydraulic actuator that is capable of controlling flows at the regulator. Under dry weather conditions, Regulator J2 conveys flow to the Jamaica WRRF via the Howard Beach Pumping Station. During wet weather periods, the Regulator J2 diverts wet weather flow to the Spring Creek AWPCP.

6.11 Paerdegat CSO Retention Facility

Combined sewer overflow (CSO) discharges have traditionally been the major source of pollution entering Paerdegat Basin, a 1.25-mile tributary of Jamaica Bay located in the Borough of Brooklyn in the southern portion of New York City. These discharges are one of several pollutant sources contributing to non-attainment of New York State water quality standards for dissolved oxygen, coliforms, floatables, and settleable solids.

In 1992, NYCDEP entered into an Order on Consent with the New York State Department of Environmental Conservation (NYSDEC) to reduce CSOs throughout New York City's combined sewer system. The Paerdegat Basin CSO Retention Facility was one of several projects to be constructed under the consent order, and a result of recommended measures for reducing CSOs and improving water quality in the basin. The consent order stipulated construction of the CSO Facility in accordance with the approved Facility Plan and required construction completion by May 31, 2011. The facility was certified complete as of May 31, 2011. Prior to this facility's construction and 2011 commissioning, CSO discharges flowed directly into Paerdegat Basin, leading to water quality issues, particularly during wet weather. Approximately 30 million gallons of offline CSO storage capacity is provided in the CSO retention tanks and tank influent channels. An additional 20 million gallons of CSO can be retained in the influent sewers. In a typical year, the Paerdegat CSO facility results in up to 70 percent reduction in biochemical oxygen demand (BOD) and total suspended solids (TSS), preserving and protecting the Jamaica Bay estuary.

An analysis of post-construction monitoring data and modeling results from the Jamaica Bay Eutrophication Model (JEM) show that the Retention Facility has led to the attainment of the dissolved oxygen (DO) existing water quality standards (DO never less than 4 mg/L based on Class I water quality standards).

Figure 6-15: Paerdegat Basin CSO Retention Facility

6.12 Bergen Basin Bending Weirs and Parallel to Jamaica WRRF

NYCDEP's combined sewer system includes various CSO structures, referred to as regulators, designed to provide hydraulic relief during large storm events and discharge combined flows to surface waters. Of the 10 regulators within the Jamaica WRRF service area, Regulators JA-3 and JA-14 discharging to the West Interceptor and Regulator JA-6 discharging to the East Interceptor, were selected for modifications to improve wet weather conveyance capacity and reduce CSO discharges. The regulator modifications consist of retrofitting the existing structures with bending weirs and enlarging the orifices which control flow to the respective interceptor sewers.

The Jamaica WRRF service area is highly urbanized and contains a large percentage of impervious surfaces. Runoff from roof drains, street gutters, and catch basins are connected to the combined sewer system, generating rapid and intense flow peaks in excess of the Jamaica WRRF capacity, even though New York City WRRFs were generally designed to process higher flows during wet weather. Flow regulators in the combined sewer system limit the amount of flow to the interceptor sewer and divert excess flow to nearby water bodies via outfall lines when the hydraulic capacity of the interceptor system is exceeded.

The West Interceptor has limited conveyance capacity and the upstream regulators (JA-03 and JA-14) have relatively low weir crest elevations that result in CSO discharges occurring before significant surcharging in the downstream interceptor can occur.

Bending weirs are mechanical devices that are designed to maximize upstream in-system storage and capacity for smaller and medium-sized storms, while allowing flows generated during larger storm events to discharge in a similar manner as they do with the existing fixed weirs. In addition to the regulator modifications, a 48-inch diameter sewer was constructed along a hydraulically restricted section of the West Interceptor to improve conveyance capacity to the WRRF. The bending weir project was completed in mid-2016, while the parallel sewer was completed and activated in February 2017.

Figure 6-16: 3D CAD Rendering of Regulator JA-3

6.13 Environmental Benefit Projects (EBPs)

Environmental Benefit Projects (EBPs) are funded by DEP and are designed to abate CSOs and/or address wet weather water quality impacts from CSOs and to benefit the waters in and around New York City.

In connection with the settlement of an enforcement action taken by New York State and DEC for violations of New York State law and DEC regulations, NYCDEP submitted a Nitrogen

Consent Judgment Environmental Benefit Project (EBP) Plan to DEC in January 2007 that proposed a stormwater pilot study in the Jamaica Bay drainage area. NYCDEP used Nitrogen Consent Judgment EBP funds to conduct a three-year pilot study program to implement and monitor several stormwater treatment technologies and volume reduction stormwater BMPs for potential application within the Jamaica Bay watershed. The goals of Jamaica Bay Watershed Stormwater Pilot Project included documenting the quality of New York City stormwater and refining the specific capture rates and treatment efficiencies that may be expected locally.

In connection with the settlement of an enforcement action taken by New York State and DEC for violations of New York State law and DEC regulations, DEP also submitted a CSO EBP Work Plan in March 2008 (approved by the DEC in April 2008) to partially mitigate the impacts of stormwater and CSO discharges in the New York Harbor Estuary through stormwater BMP implementation. Practices such as bio-infiltration swales, enlarged street tree pits with underground water storage, constructed wetlands, and others would be evaluated. The CSO EBP Work Plan proposes pilots in the Bronx River, Flushing Bay and Creek, and Gowanus Canal watersheds using the $4 million which has been placed in an EBP Fund.

6.14 Long Term Control Plan (LTCP)

On March 8, 2012, DEC and DEP signed an agreement to reduce CSOs using a hybrid green and gray infrastructure approach. As part of this agreement, DEP was tasked with developing ten waterbody-specific LTCPs plus one citywide LTCP to reduce CSOs and improve water quality in NYC’s waterbodies and waterways. The goal of each LTCP is to identify appropriate CSO controls necessary to achieve waterbody-specific water quality standards that are consistent with the Federal CSO Policy and the water quality goals of the Clean Water Act (CWA).

Each LTCP:

- Assesses the feasibility of attaining current water quality standards, the next highest standards, and fishable/swimmable standards
- Builds from Waterbody/Watershed Facility Plans (the first phase of the planning process)
- Requires robust, targeted public participation and feedback processes
- Identifies a grey-green balance of CSO management solutions for different watersheds

As part of the LTCP program, extensive water quality sampling and modeling was performed for the six waterbodies tributary to Jamaica Bay. The gap between a baseline condition without CSO control and a condition with 100 percent CSO control was compared to assess whether the appropriate water quality standards can be attained through CSO controls. The results of this gap analysis will inform the development alternatives for reducing the amount and frequency of CSO discharges to improve water quality and will provide DEP with the basis for development of an implementation plan and strategy.

The LTCP for Jamaica Bay and Tributaries was submitted to DEC on June 30, 2018. The recommended projects are shown on Figure 1-17.

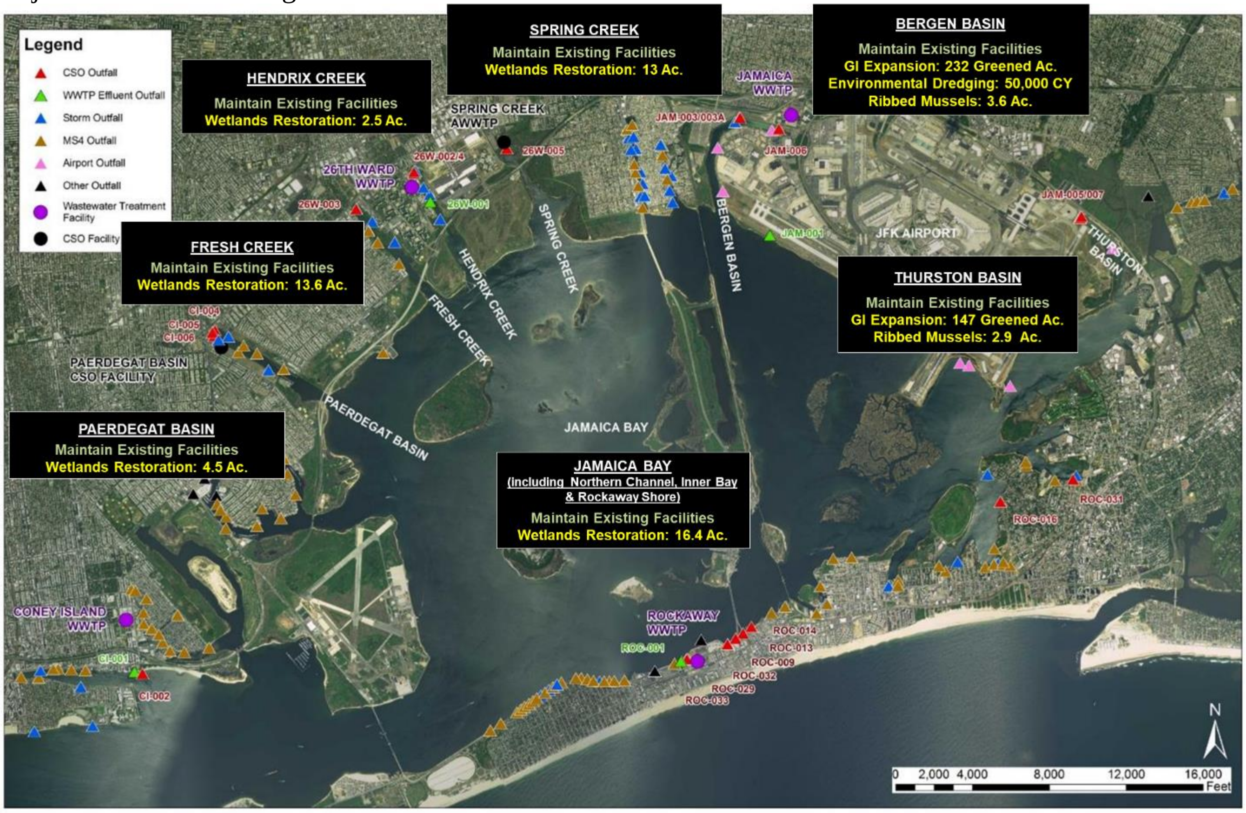


Figure 6- 17: JB CSO LTCP Recommended Plan

6.15 Green Infrastructure

Green infrastructure (GI) practices are designed and constructed to manage stormwater runoff from impervious surfaces such as streets, sidewalks, and rooftops. City-wide, NYCDEP has invested $410 million of capital on GI projects as of March 2017, with another $1 billion budgeted over the next 10 years. A key goal of the NYC Green Infrastructure Plan is to manage the first inch of runoff from 10 percent of the impervious surfaces in combined sewer watersheds through detention and infiltration source controls over the next 20 years. Green infrastructure technologies currently in use and being piloted throughout the City include green roofs, blue roofs, enhanced tree pits, bioinfiltration, vegetated swales, pocket wetlands, and porous and permeable pavements.

NYCDEP identified 11 Priority CSO Tributary Areas for green infrastructure implementation within the Jamaica Bay watershed. Through NYCDEP’s area-wide strategy, four of these areas have completed design and/or construction contracts for green infrastructure on City-owned streets and sidewalks. The design process for the other seven Priority CSO Tributary Areas was completed in 2017 and construction will commence in 2018. **Figure 6-18** shows the extent and status of Areawide GI contracts. An example of a right-of-way (ROW) raingarden, also referred to as a bioswale, is pictured in **Figure 6-19**.

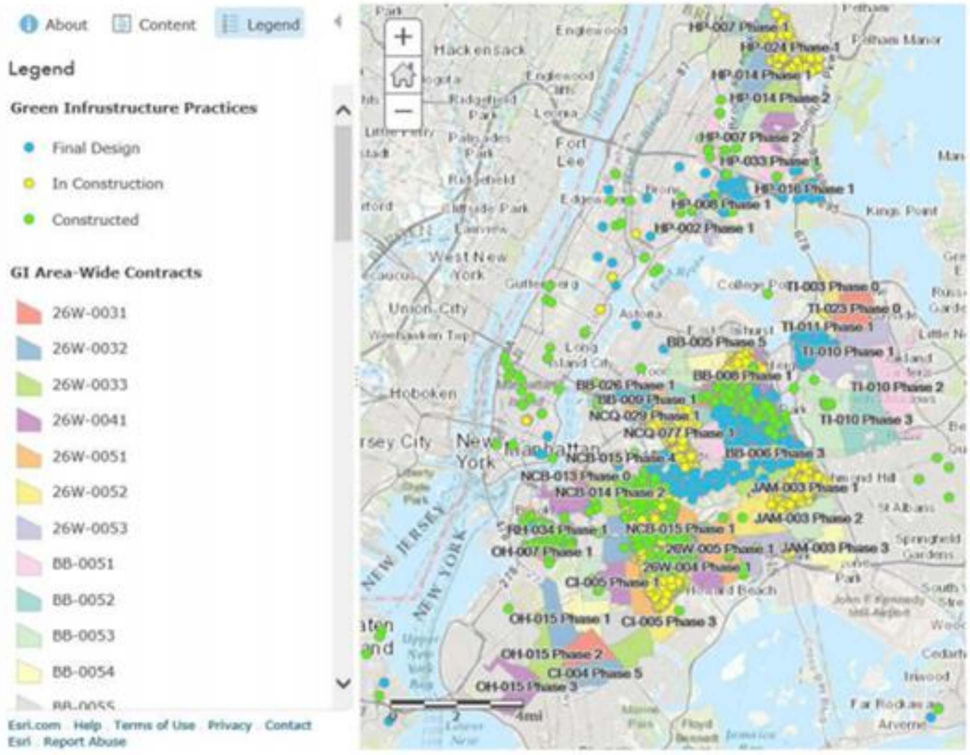


Figure 6-18: Program Map indicating Green Infrastructure Practice Locations and Contract Areas

Figure 6-19: Example of a NYCDEP Rain Garden

Area	Category	Description	SCORES			
			0	1	2	3
Technology Fundamentals	Transparency	Is a third party review of the design calculations possible?	Black-box (No check possible)	Basic operation qualitatively explained	Basis of design provided, but information inadequate to execute calculations specific to DEP application	Basis of design calculations specific to DEP application provided for review
	Proof of Principles	Are the scientific principles on which this technology works well known and accepted by the scientific/engineering community	Scientific basis largely unproven/untested	Limited data provided, claims cannot be corroborated via conventional scientific/engineering principles	Significant data to corroborate technology claims available but lacks consensus of scientific community	Uses well known and accepted scientific principals
	Applicability	Will this process meet a specific existing or emerging need within NYC WRRFs	Not applicable for stated DEP purpose/objective	Potentially applicable to future or emerging DEP need	In concert with other technologies can mitigate specific, previously identified challenge to DEP	Primary purpose of technology is to mitigate specific DEP objective
	Patents/Intellectual Property Rights	Will DEP be protected from future patent infringement claims?	Patent status unknown	Copy of Patent Applications provided	Copy of Patent(s) provided and Patent ascribed to vendor and verified by vendor that no patent contested	No patent issues/Needed
	Documentation	Is information on this technology published in the literature?	No external publications	Copies of press releases provided/trade magazines	Few publications	Multiple Publications in peer reviewed research journals
	Level of Understanding	Is the basic underpinning of this technology well understood by engineering professionals in the field	Not understood by engineering community	Requires highly specialized academic and technical training to understand technology	Requires limited training to understand technology	Universally understood by mainstream professionals
Technology Maturity	Technology trials published in respected peer review literature		None	Publications in a single journal	Publications in two journals	Published in multiple journals
	Technology received federal or state funding for demonstration		No			Yes
	Independent Verification of Technology	Technology undergone third-party verification with a detailed report available	No			Yes
	Full Scale Facility Available in North America		No			Yes
	Would you characterize this technology as:	What stage of development is this technology at?	Embryonic/Bench	Pilot	Demonstration Scale	Full Scale/Established
	Strength of company championing technology	Is a financially strong, well reputed firm representing this technology	Company privately held, previously unknown	Privately Held Firm with Revenue over $10M/yr	Public Firm or, Private Firm with Revenue over $100M/yr	Public or Well know Privately Held firm with Annual Revenues in excess of $1Billion
	Technical Representative Network	Are spare parts and technical know-how to trouble shoot this technology available?	No	Support will be provided through overseas network	Defined network available in North America	Defined Network Available in Greater Metro Area
	Presence of Competing, Similar Technologies	Are there other vendors providing technologies using similar processes	First of its kind	Similar technologies under development by other teams/vendors	At least one other vendor has commercial scale similar technology successfully deployed	Multiple vendors with documented track record
Implementation in DEP	Chemicals Required	Will this technology introduce new chemicals that DEP will need to handle	Multiple new chemicals or hazardous chemical required	New chemical that is non-hazardous and readily procured is required	DEP is familiar with and utilizes required chemicals	No chemicals required
	Quantity of Chemicals	Is a significant expansion of the quantities of chemicals consumed required for this technology	Large quantities of chemical consumed in the process (more than 1 tanker per week)	Significant chemical consumption (up to 1 tanker per week)	Small quantities of chemicals required (no more than 1 tanker per month)	No chemicals required
	Skilled Labor	Level and availability of skilled labor required to operate the technology at full scale	Skilled labor available in only private sector required for operation	Skilled labor, not currently utilized in DEP, but likely available required	Plant staff able to support functions after training	An STW's dream
	Operational complexity	Does operation require mechanical or computer-based controls, simultaneous operator coordination or coordination with other processes or personnel?	Very complex	Moderately complex	Low complexity	No complexity
	Special Training	Training different from typical WRRF Operations training? Provided by specialized contractors?	Regular specialized training required for operation	Moderate amounts of special training required; external trainers necessary	Some special training required; can be handled in-house	No special training required
	Hazardous Emissions	Does this process produce emissions that are hazardous to the operators, public or environment?	High amounts of hazardous emissions generated	Moderate amounts of hazardous emissions generated	Low amounts of hazardous emissions generated	No hazardous emissions generated
	Hazardous Waste	Will this technology generate a solid or liquid waste and will it be difficult to dispose of?	Potential for hazardous waste generation	Potential for hazardous waste generation, or waste that will not be accepted by commercial haulers	Waste generated, but disposed as non-hazardous	No waste generated
	Electrical Energy Requirements	Will this technology negatively impact the plant's electrical energy balance?	Significant energy consumption; will require modifications to electrical feed and distribution system	Will increase electrical consumption but not enough to affect other mission critical components (pumps, blowers, H&S)	Minimal or no changes in energy consumption	Will result in energy saving versus baseline condition
	Infrastructure	Does technology use existing infrastructure/equipment	All new infrastructure needed requiring new foot print	new infrastructure on existing plant foot print	utilizes some existing infrastructure	utilizes all existing infrastructure
	Maintenance	Will frequent, specialized maintenance be required?	Regular specialized maintenance required via vendor	Regular maintenance required utilizing plant staff	Routine annual maintenance required by plant staff	No maintenance required
	Level of Automation	Is the technology fully automated?	Operation manually controlled	Some functions automated, operator assist required	Functions automated, operator oversight required	Operation Fully Automated
	Pretreatment Requirements	Type of pretreatment required	High - Membrane filtration/chemical coagulation	Moderate - chemical and/or other	Low - settling only	None
Institutional compatibility	Sustainability - 35/25 and 80/50; energy neutrality	Is this process aligned with NYC and DEP Sustainability Goals	Makes meeting Energy and GHG goals more challenging for DEP	No significant impact anticipated on Energy and GHG goals	Potential to help DEP meet goals; quantification of impact difficult	Will result in measurable increase in the sustainability of DEP operations
	Worker Health & Safety	Will this technology introduce new Health & Safety concerns in DEP WRRFs?	Likely H&S issue flagged by DEP or vendor. Significant institutional and operational changes must be made to mitigate identified concerns.	Review indicated that concerns not easily mitigated	Review indicated that concerns can be readily mitigated	Detailed documentation provided by vendor; no H&S issues anticipated after DEP EHS review. Currently operating at DEP facilities
	Long Term Permit Compliance (TN, NH3, other) All side stream processes will have no negative impact on future permit compliance	Is the process aligned with anticipated future regulatory requirements?	Will create challenges in meeting future potential permit limitations	Potential for creating challenges with future permit requirements will create small challenges	No impact on potential future requirements some impact or none	Will prepare DEP for meeting potential future permit requirements beneficial
	Public Acceptance	Would implementation of this technology require an extensive PR effort; Previously encountered significant public resistance on?	Public concerns expected	Moderate public concerns anticipated	Minor public concerns anticipated	No public response anticipated
	DEP plant operator acceptance	Will operations staff be willing to operate technology	Concerns expected	Moderate concerns anticipated	Minor concerns anticipated	No response anticipated
	Benefits	Does technology offer additional benefits other than those evaluated	No benefits	Few benefits	Moderate benefits	Many benefits

Mainstream Technologies for Consideration for 26th Ward and Jamaica WWTP only - ability to meet or exceed current TN performance and Proposed Permit Ammonia Limits

		Technology Fundamentals					
		Transparency	Proof of Principles	Applicability for both TN and NH3 removal	Patents/ Intellectual Property Rights	Documentation	Level of Understanding
1	Simultaneous Nitrification/ Denitrificaiton w ABAC Control	3	3	2	3	3	2
2	Battery Level BNR	3	3	3	3	3	3
3	Nitritation/ Denitritation	2	3	2	3	3	2
4	BNR with add-on Denitrification Process (filters, MBBR)	3	3	3	3	3	3
5	IFAS + Denite Filters	2	3	3	2	3	3
6	Integrated Fixed Film Activated Sludge (IFAS)	2	3	2	2	3	3
7	PDNA	2	2	2	3	2	2
8	Moving Bed Biofilm Reactor (MBBR)	2	3	2	2	3	2
9	Membrane Aerobic Biofilm Reactor (SABRE/MABR/Z-lung)	2	2	2	2	2	2
10	Chemically Enhanced Primary Treatment (CEPT) with full step feed BNR (with Carbon)	3	3	2	3	3	3
11	tertiary algae process	2	2	2	2	3	2
12	A/B	3	3	3	3	3	2
13	Mainstream ANAMMOX	1	3	2	1	3	1
14	NEREDA	2	3	2	2	3	2
15	Membrane Aerobic Biofilm Reactor + Denite Filters	2	2	3	2	2	2
16	Indense	2	2	2	2	2	2
17	Membrane Bioreactor (MBR)	2	3	3	2	3	3
18	Nitrification/ Denitrification BAF	2	3	2	2	3	2
19	Ballasted Floculations	2	2	2	2	3	3
20	Reverse Osmosis (RO)	2	3	3	2	3	3
21	HYBACs	2	2	2	2	2	1
22	Ion Exchange	2	3	3	2	3	2
23	n-DAMO	1	1	2	2	1	1
24	mainstream anaerobic mbr + n-DAMO	1	1	3	2	1	1

Mainstream Technologies for Consideration for 26th Ward and Jamaica WWTP only - ability to meet or exceed current TN performance and Proposed Permit Ammonia Limits

	Technology Maturity							
	Technology trials published in respected peer review literature	Technology received federal or state funding for demonstration	Independent Verification of Technology	Full Scale Facility Available for Site Visit in North America	Would you characterize this technology as:	Strength of company championing technology	Technical Representative Network	Presence of Competing, Similar Technologies
Simultaneous Nitrification/ Denitrificaiton w ABAC Control	3	3	3	3	2	3	3	3
Battery Level BNR	3	3	3	3	3	3	3	3
Nitritation/ Denitritation	3	3	3	0	2	3	3	3
BNR with add-on Denitrification Process (filters, MBBR)	3	3	3	3	3	3	3	3
IFAS + Denite Filters	3	3	3	3	3	3	3	3
Integrated Fixed Film Activated Sludge (IFAS)	3	3	3	3	3	3	3	3
PDNA	1	3	3	0	2	2	3	3
Moving Bed Biofilm Reactor (MBBR)	3	3	3	3	3	3	3	3
Membrane Aerobic Biofilm Reactor (SABRE/MABR/Z-lung)	3	3	3	0	2	3	3	3
Chemically Enhanced Primary Treatment (CEPT) with full step feed BNR (with Carbon)	3	3	3	3	3	3	3	3
tertiary algae process	3	3	0	0	2	1	2	1
A/B	3	3	3	3	3	3	3	3
Mainstream ANAMMOX	3	3	3	0	2	3	3	3
NEREDA	3	3	3	0	3	3	3	1
Membrane Aerobic Biofilm Reactor + Denite Filters	3	3	3	0	2	3	3	3
Indense	3	3	3	3	3	2	2	2
Membrane Bioreactor (MBR)	3	3	3	3	3	3	3	3
Nitrification/ Denitrification BAF	3	3	3	3	3	3	3	3
Ballasted Floculations	3	3	3	3	3	3	3	2
Reverse Osmosis (RO)	3	3	3	3	3	3	3	3
HYBACs	2	0	0	0	3	3	3	1
Ion Exchange	3	3	3	3	3	3	3	3
n-DAMO	1	3	0	0	1	3	1	1
mainstream anaerobic mbr + n-DAMO	1	3	0	0	1	3	1	1

Mainstream Technologies for Consideration for 26th Ward and Jamaica WWTP only - ability to meet or exceed current TN performance and Proposed Permit Ammonia Limits

	Implementation in NYCEP										
	Chemicals Required	Quantity of Chemicals	Skilled Labor	Operational complexity	Special Training	Hazardous Emissions	Hazardous Waste	Electrical Energy Requirements	Maintenance	Infrastructure	Level of Automation
Simultaneous Nitrification/ Denitrificaiton w ABAC Control	2	1	1	1	1	3	2	3	0	2	2
Battery Level BNR	2	0	2	1	1	3	2	1	1	0	2
Nitritation/ Denitritation	2	1	1	1	0	3	2	3	0	2	2
BNR with add-on Denitrification Process (filters, MBBR)	2	0	2	1	1	3	2	0	1	0	1
IFAS + Denite Filters	2	0	2	1	1	3	2	0	1	0	1
Integrated Fixed Film Activated Sludge (IFAS)	2	0	2	1	1	3	2	0	1	3	1
PDNA	2	2	1	1	1	3	2	2	1	2	1
Moving Bed Biofilm Reactor (MBBR)	2	0	2	1	1	3	2	0	0	3	1
Membrane Aerobic Biofilm Reactor (SABRE/MABR/Z-lung)	2	1	1	1	1	3	2	2	0	3	2
Chemically Enhanced Primary Treatment (CEPT) with full step feed BNR (with Carbon)	1	0	2	1	1	3	2	1	1	3	1
tertiary algae process	3	3	2	2	1	3	2	1	1	0	1
A/B	2	0	2	0	1	3	2	2	0	0	1
Mainstream ANAMMOX	2	2	0	0	0	3	2	3	0	2	2
NEREDA	2	1	1	1	0	3	2	2	0	0	2
Membrane Aerobic Biofilm Reactor + Denite Filters	2	0	1	1	1	3	2	2	0	0	2
Indense	2	0	1	1	1	3	2	2	0	1	2
Membrane Bioreactor (MBR)	0	0	1	1	1	2	2	0	0	3	2
Nitrification/ Denitrification BAF	2	1	1	1	0	3	2	1	1	0	1
Ballasted Floculations	1	0	1	1	1	3	2	2	0	0	1
Reverse Osmosis (RO)	0	1	1	1	0	3	0	0	0	0	2
HYBACs	2	1	1	1	1	3	2	2	1	0	2
Ion Exchange	0	1	1	1	1	3	1	0	0	0	2
n-DAMO	2	2	1	0	0	3	2	3	0	0	2
mainstream anaerobic mbr + n-DAMO	0	1	1	1	0	2	2	1	0	3	2

Mainstream Technologies for Consideration for 26th Ward and Jamaica WWTP only - ability to meet or exceed current TN performance and Proposed Permit Ammonia Limits

	Institutional compatibility					
	Sustainability - PlaNYC	Worker Health & Safety	Long Term Permit Compliance	Public Acceptance	NYCEP plant operator acceptance	Benefits
Simultaneous Nitrification/ Denitrificaiton w ABAC Control	2	2	1	3	1	0
Battery Level BNR	0	3	2	2	2	0
Nitritation/ Denitritation	2	2	1	2	1	0
BNR with add-on Denitrification Process (filters, MBBR)	0	2	2	2	1	1
IFAS + Denite Filters	0	2	3	2	1	1
Integrated Fixed Film Activated Sludge (IFAS)	0	2	1	2	1	1
PDNA	3	2	1	2	1	0
Moving Bed Biofilm Reactor (MBBR)	0	2	2	2	1	1
Membrane Aerobic Biofilm Reactor (SABRE/MABR/Z-lung)	0	2	2	2	1	1
Chemically Enhanced Primary Treatment (CEPT) with full step feed BNR (with Carbon)	0	2	1	2	0	0
tertiary algae process	2	2	2	2	1	0
A/B	1	2	2	2	0	0
Mainstream ANAMMOX	3	2	1	3	0	0
NEREDA	1	2	2	2	1	1
Membrane Aerobic Biofilm Reactor + Denite Filters	0	2	3	2	1	1
Indense	1	2	2	2	1	0
Membrane Bioreactor (MBR)	0	1	2	2	0	2
Nitrification/ Denitrification BAF	0	2	1	3	1	0
Ballasted Floculations	1	2	2	2	1	0
Reverse Osmosis (RO)	0	1	3	2	0	2
HYBACs	0	2	1	3	1	1
Ion Exchange	0	0	2	2	0	1
n-DAMO	2	1	1	2	0	1
mainstream anaerobic mbr + n-DAMO	1	1	2	2	0	2

Mainstream Technologies for Consideration for 26th Ward and Jamaica WWTP only - ability to meet or exceed current TN performance and Proposed Permit Ammonia Limits

Mainstream Technologies for Consideration for 26th Ward and Jamaica WWTP only - ability to meet or exceed current TN performance and Proposed Permit Ammonia Limits

						15%	15%	40%	30%	
	Unweighted scores					Weighted scores				
	(18 max) Technology Fundamentals sum	(24 max) Technology Maturity sum	(30 max) Implentation at DEP sum	(18 max) Institutional Compatibility sum	(90 total) Total score (not weighted)	Technology Fundamentals sum	Technology Maturity sum	Implentation at DEP sum	Institutional Compatibility sum	Total score (weighted)
Simultaneous Nitrification/ Denitrificaiton w ABAC Control	16	23	18	9	66	13	14	24	15	67
Battery Level BNR	18	24	15	9	66	15	15	20	15	65
Nitritation/ Denitritation	15	20	17	8	60	13	13	23	13	61
BNR with add-on Denitrification Process (filters, MBBR)	18	24	13	8	63	15	15	17	13	61
IFAS + Denite Filters	16	24	13	9	62	13	15	17	15	61
Integrated Fixed Film Activated Sludge (IFAS)	15	24	16	7	62	13	15	21	12	61
PDNA	13	17	18	9	57	11	11	24	15	60
Moving Bed Biofilm Reactor (MBBR)	14	24	15	8	61	12	15	20	13	60
Membrane Aerobic Biofilm Reactor (SABRE/MABR/Z-lung)	12	20	18	8	58	10	13	24	13	60
Chemically Enhanced Primary Treatment (CEPT) with full step feed BNR (with Carbon)	17	24	16	5	62	14	15	21	8	59
tertiary algae process	13	12	19	9	53	11	8	25	15	59
A/B	17	24	13	7	61	14	15	17	12	58
Mainstream ANAMMOX	11	20	16	9	56	9	13	21	15	58
NEREDA	14	19	14	9	56	12	12	19	15	57
Membrane Aerobic Biofilm Reactor + Denite Filters	13	20	14	9	56	11	13	19	15	57
Indense	12	21	15	8	56	10	13	20	13	56
Membrane Bioreactor (MBR)	16	24	12	7	59	13	15	16	12	56
Nitrification/ Denitrification BAF	14	24	13	7	58	12	15	17	12	56
Ballasted Floculations	14	23	12	8	57	12	14	16	13	55
Reverse Osmosis (RO)	16	24	8	8	56	13	15	11	13	52
HYBACs	11	12	16	8	47	9	8	21	13	51
Ion Exchange	15	24	10	5	54	13	15	13	8	49
n-DAMO	8	10	15	7	40	7	6	20	12	45
mainstream anaerobic mbr + n-DAMO	9	10	13	8	40	8	6	17	13	44

Mainstream
Rockaway and Coney Island Only

		Technology Fundamentals					
		Transparency	Proof of Principles	Applicability to TN Limit	Patents/ Intellectual Property Rights	Documentation	Level of Understanding
1	Advanced Basic Step-feed BNR	3	3	3	3	3	3
2	SND with Dynamic Aeration Control ABAC and AvN	3	3	2	3	3	2
3	Battery Level BNR	3	3	3	3	3	3
4	Full Step-feed BNR with Carbon Addition	3	3	3	3	3	3
5	Integrated Fixed Film Activated Sludge (IFAS)	2	3	2	2	3	3
6	Moving Bed Biofilm Reactor (MBBR)	2	3	3	2	3	2
7	Chemically Enhanced Primary Treatment (CEPT) with full step feed BNR (with Carbon)	3	3	2	3	3	3
8	SCAD	2	2	2	3	2	2
9	Nitritation/ Denitritation	2	3	3	3	3	2
10	Membrane Aerobic Biofilm Reactor (SABRE/MABR/Z-lung)	2	2	2	2	2	2
11	Tertiary algae process	2	2	3	2	3	2
12	A/B Process	3	3	2	3	3	2
13	IFAS + Denite Filters	2	3	3	2	3	3
14	BNR with add-on Denitrification Process (filters, MBBR)	3	3	3	3	3	3
15	Mainstream ANAMMOX	1	3	3	1	3	1
16	NEREDA	2	3	3	2	3	2
17	Membrane Bioreactor (MBR)	2	3	3	2	3	3
18	Ballasted Flocculation	2	2	2	2	3	3
19	Membrane Aerobic Biofilm Reactor + Denite Filters	2	2	3	2	2	2
20	Nitrification/ Denitrification BAF	2	3	3	2	3	2
21	Indense	2	2	2	2	2	2
22	Reverse Osmosis (RO)	2	3	3	2	3	3
23	HYBACs	2	2	3	2	2	1
24	Ion Exchange	2	3	3	2	3	2
25	n-DAMO	1	1	3	2	1	1
26	Mainstream anaerobic mbr + n-DAMO	1	1	3	2	1	1

Mainstream
Rockaway and Coney Island Only

	Technology Maturity							
	Technology trials published in respected peer review literature	Technology received federal or state funding for demonstration	Independent Verification of Technology	Full Scale Facility Available for Site Visit in North America	Would you characterize this technology as:	Strength of company championing technology	Technical Representative Network	Presence of Competing, Similar Technologies
Advanced Basic Step-feed BNR	3	3	3	3	3	3	3	3
SND with Dynamic Aeration Control ABAC and AvN	3	3	3	3	3	3	3	3
Battery Level BNR	3	3	3	3	3	3	3	3
Full Step-feed BNR with Carbon Addition	3	3	3	3	3	3	3	3
Integrated Fixed Film Activated Sludge (IFAS)	3	3	3	3	3	3	3	3
Moving Bed Biofilm Reactor (MBBR)	3	3	3	3	3	3	3	3
Chemically Enhanced Primary Treatment (CEPT) with full step feed BNR (with Carbon)	3	3	3	3	3	3	3	3
SCAD	1	3	3	0	2	2	3	3
Nitritation/ Denitritation	3	3	3	0	2	3	3	3
Membrane Aerobic Biofilm Reactor (SABRE/MABR/Z-lung)	3	3	3	0	2	3	3	3
Tertiary algae process	3	3	0	0	2	1	2	1
A/B Process	3	3	3	3	3	3	3	3
IFAS + Denite Filters	3	3	3	3	3	3	3	3
BNR with add-on Denitrification Process (filters, MBBR)	3	3	3	3	3	3	3	3
Mainstream ANAMMOX	3	3	3	0	2	3	3	3
NEREDA	3	3	3	0	3	3	3	1
Membrane Bioreactor (MBR)	3	3	3	3	3	3	3	3
Ballasted Flocculation	3	3	3	3	3	3	3	2
Membrane Aerobic Biofilm Reactor + Denite Filters	3	3	3	0	2	3	3	3
Nitrification/ Denitrification BAF	3	3	3	3	3	3	3	3
Indense	3	3	3	3	3	2	2	2
Reverse Osmosis (RO)	3	3	3	3	3	3	3	3
HYBACs	2	0	0	0	3	3	3	1
Ion Exchange	3	3	3	3	3	3	3	3
n-DAMO	1	3	0	0	1	3	1	1
Mainstream anaerobic mbr + n-DAMO	1	3	0	0	1	3	1	1

Mainstream
Rockaway and Coney Island Only

	Implementation in NYCEP										
	Chemicals Required	Quantity of Chemicals	Skilled Labor	Operational complexity	Special Training	Hazardous Emissions	Hazardous Waste	Electrical Energy Requirements	Maintenance	Infrastructure	Level of Automation
Advanced Basic Step-feed BNR	2	1	2	2	1	3	2	1	1	3	1
SND with Dynamic Aeration Control ABAC and AvN	2	1	1	1	1	3	2	3	1	2	2
Battery Level BNR	2	0	2	1	1	3	2	1	1	2	1
Full Step-feed BNR with Carbon Addition	2	0	2	1	1	3	2	1	1	2	1
Integrated Fixed Film Activated Sludge (IFAS)	2	0	2	1	1	3	2	0	1	3	1
Moving Bed Biofilm Reactor (MBBR)	2	0	2	1	1	3	2	0	0	3	1
Chemically Enhanced Primary Treatment (CEPT) with full step feed BNR (with Carbon)	1	0	2	1	1	3	2	1	1	3	1
SCAD	2	2	1	1	1	3	2	2	1	2	1
Nitritation/ Denitritation	2	1	1	1	0	3	2	3	0	2	2
Membrane Aerobic Biofilm Reactor (SABRE/MABR/Z-lung)	2	1	1	1	1	3	2	2	0	3	2
Tertiary algae process	3	3	2	2	1	3	2	1	1	0	1
A/B Process	2	0	2	0	1	3	2	2	0	0	1
IFAS + Denite Filters	2	0	2	1	1	3	2	0	1	0	1
BNR with add-on Denitrification Process (filters, MBBR)	2	0	2	2	1	3	2	0	1	0	1
Mainstream ANAMMOX	2	2	0	0	0	3	2	3	0	2	2
NEREDA	2	1	1	1	0	3	2	2	0	0	2
Membrane Bioreactor (MBR)	0	0	1	1	1	2	2	0	0	3	2
Ballasted Flocculation	1	0	1	1	1	3	2	2	0	0	1
Membrane Aerobic Biofilm Reactor + Denite Filters	2	0	1	1	1	3	2	2	0	0	2
Nitrification/ Denitrification BAF	2	1	1	1	0	3	2	1	1	0	1
Indense	2	0	1	1	1	3	2	2	0	1	2
Reverse Osmosis (RO)	0	1	1	1	0	3	0	0	0	0	2
HYBACs	2	1	1	1	1	3	2	2	1	0	2
Ion Exchange	0	1	1	1	1	3	1	0	0	0	2
n-DAMO	2	2	1	0	0	3	2	3	0	0	2
Mainstream anaerobic mbr + n-DAMO	0	1	1	1	0	2	2	1	0	3	2

Mainstream
Rockaway and Coney Island Only

	Institutional compatibility					
	Sustainability - PlaNYC	Worker Health & Safety	Long Term Permit Compliance	Public Acceptance	NYCEP plant operator acceptance	Benefits
Advanced Basic Step-feed BNR	0	3	1	2	2	0
SND with Dynamic Aeration Control ABAC and AvN	2	2	1	3	1	0
Battery Level BNR	0	3	2	2	2	0
Full Step-feed BNR with Carbon Addition	0	3	1	2	2	0
Integrated Fixed Film Activated Sludge (IFAS)	0	2	3	2	1	1
Moving Bed Biofilm Reactor (MBBR)	0	2	3	2	1	1
Chemically Enhanced Primary Treatment (CEPT) with full step feed BNR (with Carbon)	0	2	3	2	0	0
SCAD	3	2	2	2	1	0
Nitritation/ Denitritation	2	2	1	2	1	0
Membrane Aerobic Biofilm Reactor (SABRE/MABR/Z-lung)	0	2	3	2	1	1
Tertiary algae process	2	2	3	2	1	0
A/B Process	2	2	2	2	0	1
IFAS + Denite Filters	0	2	3	2	1	1
BNR with add-on Denitrification Process (filters, MBBR)	0	2	1	2	1	1
Mainstream ANAMMOX	3	2	1	3	0	0
NEREDA	1	2	2	2	1	1
Membrane Bioreactor (MBR)	0	1	3	2	0	2
Ballasted Flocculation	1	2	3	2	1	0
Membrane Aerobic Biofilm Reactor + Denite Filters	0	2	3	2	1	1
Nitrification/ Denitrification BAF	0	2	1	3	1	0
Indense	1	2	2	2	1	0
Reverse Osmosis (RO)	0	1	3	2	0	2
HYBACs	0	2	1	3	1	1
Ion Exchange	0	0	2	2	0	1
n-DAMO	2	1	1	2	0	1
Mainstream anaerobic mbr + n-DAMO	1	1	2	2	0	2

Mainstream
Rockaway and Coney Island Only

Weighting

						15%	15%	40%	30%	
	Unweighted scores					Weighted scores				
	(18 max) Technology Fundamentals sum	(24 max) Technology Maturity sum	(30 max) Implentation at DEP sum	(18 max) Institutional Compatibility sum	(90 total) Total score (not weighted)	Technology Fundamentals	Technology Maturity	Implentation at DEP	Institutional Compatibility	Total score (weighted)
Advanced Basic Step-feed BNR	18	24	19	8	69	15	15	25	13	69
SND with Dynamic Aeration Control ABAC and AvN	16	24	19	9	68	13	15	25	15	69
Battery Level BNR	18	24	16	9	67	15	15	21	15	66
Full Step-feed BNR with Carbon Addition	18	24	16	8	66	15	15	21	13	65
Integrated Fixed Film Activated Sludge (IFAS)	15	24	16	9	64	13	15	21	15	64
Moving Bed Biofilm Reactor (MBBR)	15	24	15	9	63	13	15	20	15	63
Chemically Enhanced Primary Treatment (CEPT) with full step feed BNR (with Carbon)	17	24	16	7	64	14	15	21	12	62
SCAD	13	17	18	10	58	11	11	24	17	62
Nitritation/ Denitritation	16	20	17	8	61	13	13	23	13	62
Membrane Aerobic Biofilm Reactor (SABRE/MABR/Z-lung)	12	20	18	9	59	10	13	24	15	62
Tertiary algae process	14	12	19	10	55	12	8	25	17	61
A/B Process	16	24	13	9	62	13	15	17	15	61
IFAS + Denite Filters	16	24	13	9	62	13	15	17	15	61
BNR with add-on Denitrification Process (filters, MBBR)	18	24	14	7	63	15	15	19	12	60
Mainstream ANAMMOX	12	20	16	9	57	10	13	21	15	59
NEREDA	15	19	14	9	57	13	12	19	15	58
Membrane Bioreactor (MBR)	16	24	12	8	60	13	15	16	13	58
Ballasted Flocculation	14	23	12	9	58	12	14	16	15	57
Membrane Aerobic Biofilm Reactor + Denite Filters	13	20	14	9	56	11	13	19	15	57
Nitrification/ Denitrification BAF	15	24	13	7	59	13	15	17	12	57
Indense	12	21	15	8	56	10	13	20	13	56
Reverse Osmosis (RO)	16	24	8	8	56	13	15	11	13	52
HYBACs	12	12	16	8	48	10	8	21	13	52
Ion Exchange	15	24	10	5	54	13	15	13	8	49
n-DAMO	9	10	15	7	41	8	6	20	12	45
Mainstream anaerobic mbr + n-DAMO	9	10	13	8	40	8	6	17	13	44

Sidestream 26th Ward

		Technology Fundamentals					
		Transparency	Proof of Principles	Applicability	Patents/Intellectual Property Rights	Documentation	Level of Understanding
1	Deammonification/Nitritation	3	3	3	3	3	2
2	Deammonification - ANITA^{TM} Mox	3	3	3	2	3	2
3	Deammonification - CONDEA	3	3	3	2	3	2
4	SHARON	3	3	3	2	3	2
5	Deammonification - ANAMMOX	3	3	3	2	3	2
6	Simultaneous Nitrification/ Denitrificaiton	3	3	3	3	3	2
7	P-Recovery and Anammox	2	3	3	2	3	2
8	SABRE/MABR/Z-lung	2	2	3	2	2	2
9	SCAD (PANDA)	2	2	2	3	2	2
10	Ion-exchange	2	3	3	1	3	3
11	CANDO (Coupled Aerobic-anoxic Nitrous	0	2	3	1	2	1
12	High Rate Pure Oxygen Nitrification Reactor	3	3	2	1	3	3
13	Generic stream stripping	3	3	3	3	3	3
14	Bion	0	1	3	1	2	1
15	Electrodialysis	0	2	3	0	2	2
16	Magneto (Bioelectrochemical NH3 recovery)	0	1	3	0	1	1

Sidestream 26th Ward

		Technology Maturity							
		Technology trials published in respected peer review literature	Technology received federal or state funding for demonstration	Independent Verification of Technology	Full Scale Facility Available for Site Visit in North America	Would you characterize this technology as:	Strength of company championing technology	Technical Representative Network	Presence of Competing, Similar Technologies
1	Deammonification/Nitritation	3	3	3	3	3	3	3	3
2	Deammonification - ANITA™ Mox	3	3	3	3	3	3	3	3
3	Deammonification - CONDEA	3	3	3	3	3	2	3	3
4	SHARON	3	3	3	3	3	3	3	3
5	Deammonification - ANAMMOX	3	3	3	0	3	3	3	3
6	Simultaneous Nitrification/ Denitrificaiton	3	3	3	3	3	3	3	3
7	P-Recovery and Anammox	3	3	3	0	3	3	3	2
8	SABRE/MABR/Z-lung	3	3	3	0	2	3	3	3
9	SCAD (PANDA)	1	3	3	0	2	2	3	3
10	Ion-exchange	3	3	3	0	2	3	3	3
11	CANDO (Coupled Aerobic-anoxic Nitrous	1	3	0	0	1	0	0	0
12	High Rate Pure Oxygen Nitrification Reactor	3	3	0	2	3	3	3	3
13	Generic stream stripping	3	3	3	3	3	3	2	2
14	Bion	1	3		0	0	1	2	0
15	Electrodialysis	2	0	3	0	0	0	0	0
16	Magneto (Bioelectrochemical NH3 recovery)	2	0	3	0	0	0	0	0

Sidestream 26th Ward

		Implementation in NYCEP										
		Chemicals Required	Quantity of Chemicals	Skilled Labor	Operational complexity	Special Training	Hazardous Emissions	Hazardous Waste	Electrical Energy Requirements	Maintenance	Level of Automation	Pretreatment
1	Deammonification/Nitritation	2	2	2	1	1	3	3	2	1	2	2
2	Deammonification - ANITA$^{\text{TM}}$ Mox	2	2	2	1	1	3	3	2	1	2	2
3	Deammonification - CONDEA	2	2	2	1	1	3	3	2	1	2	2
4	SHARON	2	0	2	1	1	3	3	3	1	2	2
5	Deammonification - ANAMMOX	2	2	2	1	1	3	3	2	1	2	2
6	Simultaneous Nitrification/ Denitrificaiton	2	1	1	1	1	3	2	3	1	2	3
7	P-Recovery and Anammox	0	1	2	1	1	3	3	1	1	2	2
8	SABRE/MABR/Z-lung	2	1	1	1	1	3	2	2	0	2	2
9	SCAD (PANDA)	2	2	1	1	1	3	2	2	1	1	3
10	Ion-exchange	0	1	1	1	1	3	1	1	1	3	1
11	CANDO (Coupled Aerobic-anoxic Nitrous	2	2	1	1	1	1	3	3	0	2	2
12	High Rate Pure Oxygen Nitrification Reactor	0	0	1	2	1	3	3	0	0	2	3
13	Generic stream stripping	0	0	1	0	0	3	0	0	0	2	1
14	Bion	0	0	1	0	0	3	0	0	1	3	1
15	Electrodialysis	0	0	1	1	0	3	2	0	0	2	0
16	Magneto (Bioelectrochemical NH3 recovery)	0	0	1	1	0	3	2	0	0	2	0

Sidestream 26th Ward

		Institutional compatibility					
		Sustainability - PlaNYC	Worker Health & Safety	Long Term Permit Compliance	Public Acceptance	NYCEP plant operator acceptance	Benefits
1	Deammonification/Nitritation	3	2	2	2	1	1
2	Deammonification - ANITA^{TM} Mox	3	2	2	2	1	1
3	Deammonification - CONDEA	3	2	2	2	1	1
4	SHARON	2	3	2	3	1	0
5	Deammonification - ANAMMOX	3	2	2	2	1	1
6	Simultaneous Nitrification/ Denitrificaiton	2	2	1	3	1	0
7	P-Recovery and Anammox	3	2	3	1	1	2
8	SABRE/MABR/Z-lung	0	2	3	2	1	1
9	SCAD (PANDA)	3	2	1	2	1	0
10	Ion-exchange	2	1	3	1	0	2
11	CANDO (Coupled Aerobic-anoxic Nitrous	3	2	2	2	1	0
12	High Rate Pure Oxygen Nitrification Reactor	0	0	2	0	0	0
13	Generic stream stripping	0	0	2	0	0	2
14	Bion	1	1	3	1	0	2
15	Electrodialysis	0	1	2	1	0	2
16	Magneto (Bioelectrochemical NH3 recovery)	0	1	3	1	0	2

Sidestream 26th Ward

15% 15% 40% 30%

		Unweighted scores					Weighted scores				
		(18 max) Technology Fundamentals sum	(24 max) Technology Maturity sum	(33 max) Implentation at DEP sum	(18 max) Institutional Compatibility sum	(90 total) Total score (not weighted)	Technology Fundamentals sum	Technology Maturity sum	Implentation at DEP sum	Institutional Compatibility sum	(100 max)Total score (weighted)
1	Deammonification/Nitritation	17	24	19	11	71	14	15	23	18	71
2	Deammonification - ANITA^{TM} Mox	16	24	19	11	70	13	15	23	18	70
3	Deammonification - CONDEA	16	23	19	11	69	13	14	23	18	69
4	SHARON	16	24	18	11	69	13	15	22	18	68
5	Deammonification - ANAMMOX	16	21	19	11	67	13	13	23	18	68
6	Simultaneous Nitrification/ Denitrificaiton	17	24	17	9	67	14	15	21	15	65
7	P-Recovery and Anammox	15	20	15	12	62	13	13	18	20	63
8	SABRE/MABR/Z-lung	13	20	15	9	57	11	13	18	15	57
9	SCAD (PANDA)	13	17	16	9	55	11	11	19	15	56
10	Ion-exchange	15	20	13	9	57	13	13	16	15	56
11	CANDO (Coupled Aerobic-anoxic Nitrous	9	5	16	10	40	8	3	19	17	47
12	High Rate Pure Oxygen Nitrification Reactor	15	20	12	2	49	13	13	15	3	43
13	Generic stream stripping	18	22	6	4	50	15	14	7	7	43
14	Bion	8	7	8	8	31	7	4	10	13	34
15	Electrodialysis	9	5	9	6	29	8	3	11	10	32
16	Magneto (Bioelectrochemical NH3 recovery)	6	5	9	7	27	5	3	11	12	31

1. Appendix B

1.1 26th Ward WRRF BNR Supplemental Sampling

BNR Supplemental Sampling at the 26th Ward WRRF was initiated in June 2010, shortly after BNR operation officially commenced on June 1, 2010 and concluded in February 2011. A schematic of the sampling locations in the Main Plant (AT-1 and AT-2) and SCT (AT-3) are provided in **Figure 1-1** and **Figure 1-2**, respectively.

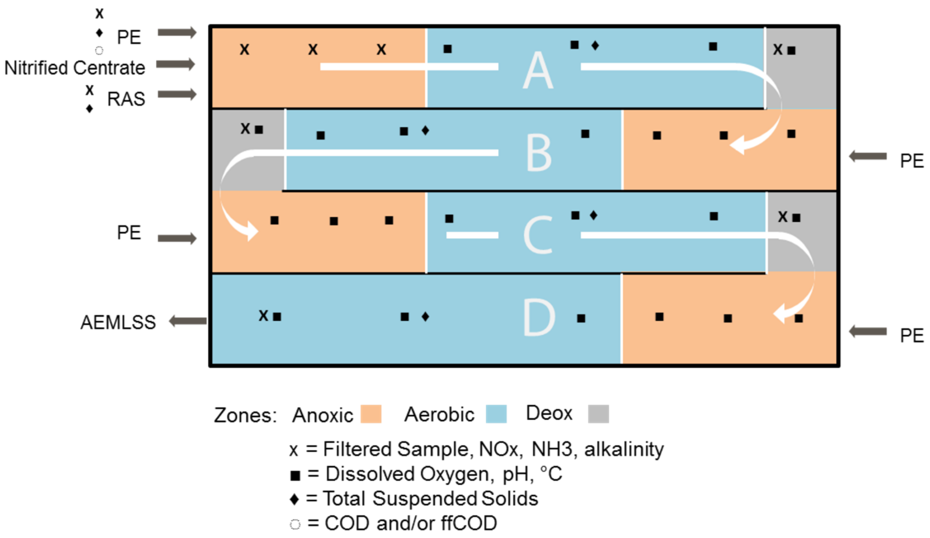


Figure 1-1: 26th Ward Schematic of AT-1 and AT-2 Sampling Locations and Analyses

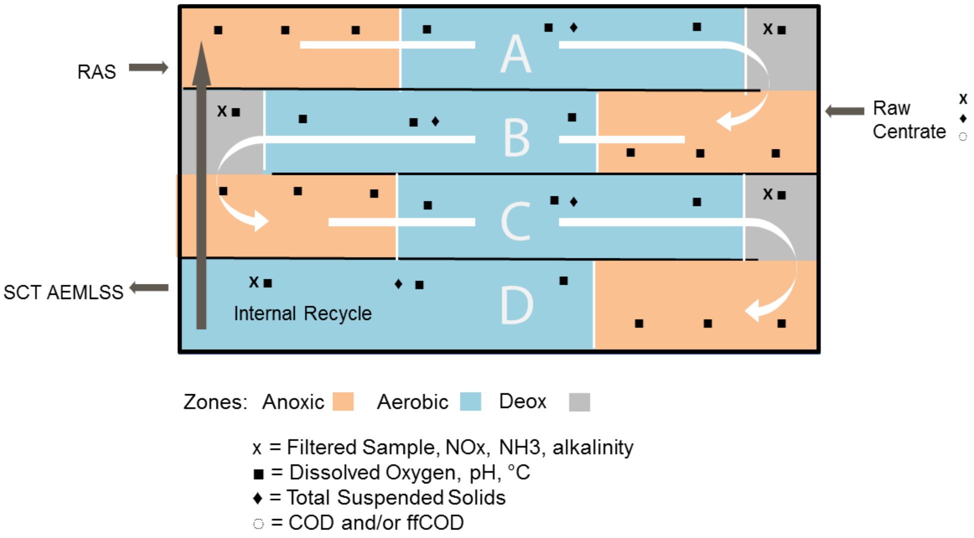


Figure 1-2: 26th Ward Schematic of AT-3 Sampling Locations and Analyses

The Target Operating Parameters based on this Comprehensive Sampling Program are summarized below:

Aeration Tanks 1 and 2

- **Target AEMLSS**: 1,800 mg/L to 2,000 mg/L
- **Target DO Concentrations**:
    - Aerobic Zones: 2 to 4 mg/L
    - Anoxic Zones: Less than 0.1 mg/L
- **Target RAS Rate**: 50% of Plant Influent Flow
- **Target PE Flow Distribution**: 0:33:33:33 % to Passes A/B/C/D
- **Target Anoxic/Aerobic Zone Configuration**: 33 percent anoxic and 67 percent aerobic volume
- **SWAS:** 100% of wasting

Aeration Tank 3 (SCT)

- **IR pumps** should be operated to return between 1 and 1.5 MGD from the D-Pass to the A-Pass of AT-3
- **RAS flows** should be between 300 and 500 gpm
- **Target Anoxic/Aerobic Zone Configuration**: Same as AT-1 and AT-2
- **Target DO Concentrations**: (Same as AT-1 and AT-2)
- **Supplemental Alkalinity Addition**:
    - Alkalinity addition of 900 gpd total to the aerobic zones of Passes B, C, and D to maintain effluent pH of 6.8 and 7.2

1.2 26th Ward WRRF BNR Supplemental Sampling with Glycerol SCT Demonstration

26th Ward Glycerol SCT Demonstration officially commenced on December 31, 2011. The comprehensive sampling effort associated with this upgraded initiated in December 2011, prior to the upgrade coming online, and concluded in October 2012. The purpose of this sampling effort was to examine and optimize the glycerol-driven SCT process, including glycerol kinetics, glycerol dosing optimization, and overall TN

A schematic of the sampling locations in the Main Plant (AT-1 and AT-2) and SCT (AT-3) process are provided in **Figure 1-3** and **Figure 1-4**, respectively. Although the Main Plant tanks were sampled routinely throughout the sampling program, the recommendations resulting from the sampling program are mainly related to operation of SCT.

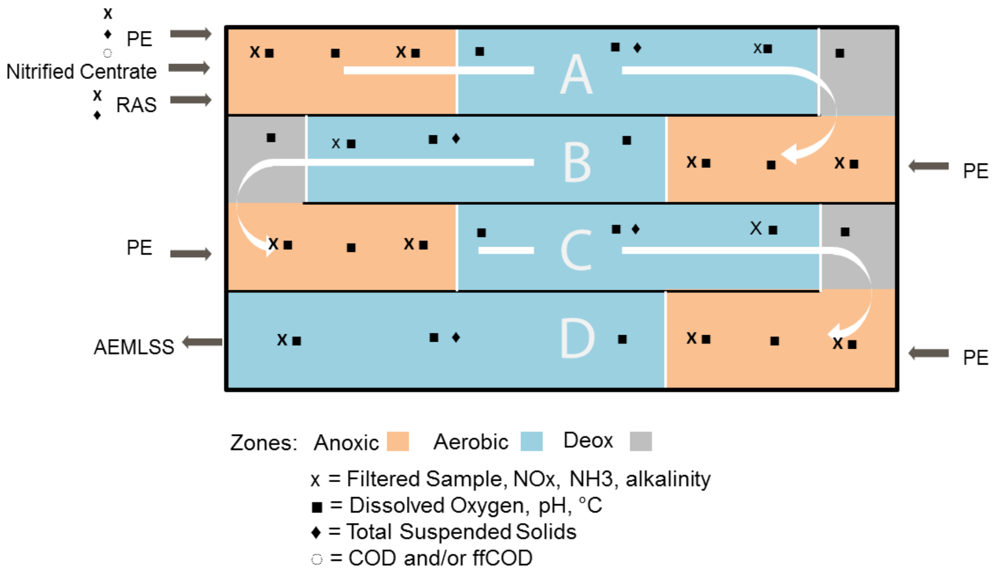


Figure 1-3: 26th Ward AT-1 and AT-2 Sampling Locations

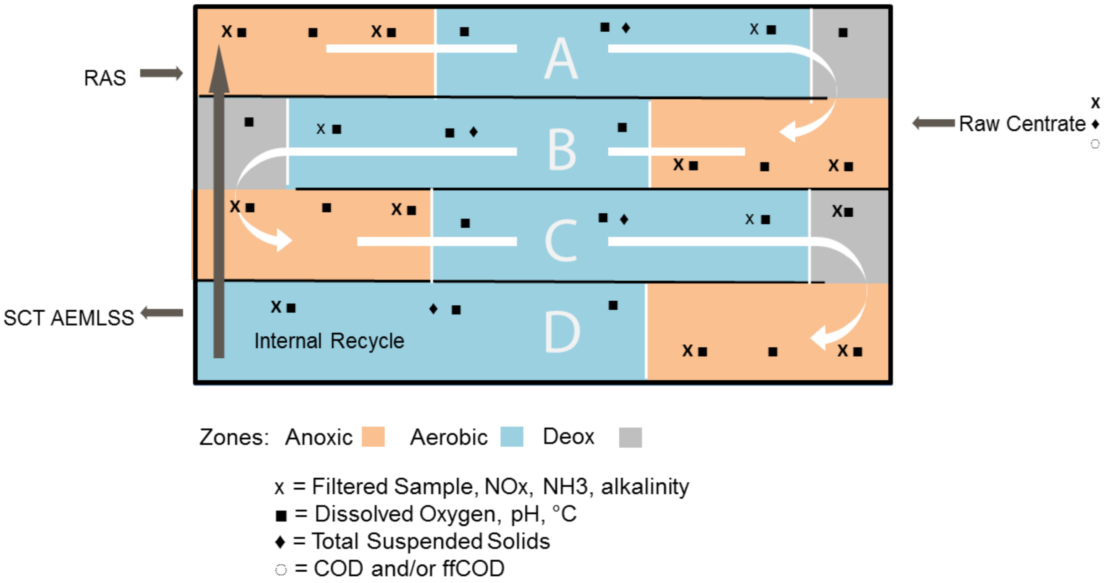


Figure 1-4: 26th Ward AT-3 (SCT) Sampling Locations

The Target Operating Parameters based on this Comprehensive Sampling Program are summarized below:

Aeration Tanks 1 and 2

No changes in previous targets based on this comprehensive sampling program.

Aeration Tank 3 (SCT)

- **IR pumps** should be operated to return between 1 MGD from the D-Pass to the A-Pass of AT-3
- **RAS flows** should target 1:1 RAS to Centrate flow ratio
- **Target Anoxic/Aerobic Zone Configuration**: No change from previously developed targets
- **Target DO Concentrations**: (Same as AT-1 and AT-2)
- **Supplemental Carbon Addition:**
  - Glycerol doses of 0, 1, 2, and 2 gpm of dilute (20%) product to Passes A, B, C, and D
- **Supplemental Alkalinity Addition**:
  - Alkalinity addition of 800 gpd total to the aerobic zones of Passes B, C, and D to maintain effluent pH of 6.8 and 7.2

1.3 Jamaica WRRF BNR Supplemental Sampling

BNR Supplemental Sampling at the Jamaica WRRF was initiated in January 2015, shortly after BNR operation officially commenced on December 1, 2014, and concluded in July 2015. A schematic of the sampling locations is provided in **Figure 1-5**.

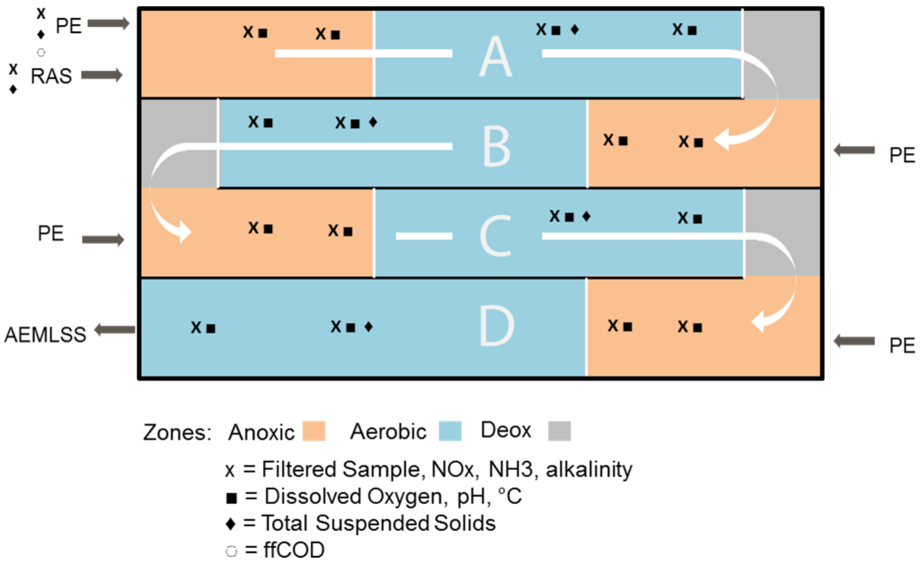


Figure 1-5: Jamaica WRRF AT Sampling Locations

The Target Operating Parameters based on this Comprehensive Sampling Program are summarized below:

- **Target AEMLSS**: 1,800 mg/L to 2,000 mg/L
- **Target DO Concentrations**:

  - Aerobic Zones: 2 to 4 mg/L
  - Anoxic Zones: Less than 0.1 mg/L
- **Target RAS Rate**: 50% of Plant Influent Flow
- **Target PE Flow Distribution**:

Operational Condition	PE Flow Distribution (%)			
	Pass A	Pass B	Pass C	Pass D
Preventative	0	33	33	33
Winter	20	40	30	10
Summer				
Wet Weather	0	25	25	50

- **Target Anoxic/Aerobic Zone Configuration**:

Operational Condition	Anoxic Volume at Head of Pass (%)			
	Pass A	Pass B	Pass C	Pass D
Preventative	0	17	17	50
Winter	17	17	33	50
Summer	33	33	33	50

- **SWAS:** 100% of wasting

1.4 BNR with Glycerol Addition Sampling Program

To effectively optimize BNR treatment with glycerol addition, an experimental approach was utilized which included designated one AT as a ‘Control’ reactor, with no carbon addition, and one AT as a ‘Test’ reactor receiving supplemental carbon. Sampling and monitoring was conducted over a six-month period, including diurnal nitrogen profiles of the control and test aeration tanks, specific denitrification rate batch tests, and operational monitoring at both the 26th Ward and Jamaica WRRFs. The specific sampling programs undertaken at the 26th Ward and Jamaica WRRFs are discussed in more detail in the following sub-sections.

1.4.1 26th Ward WRRF BNR Supplemental Sampling with Glycerol Addition

The monitoring activities at 26th Ward were conducted twice per day (morning and afternoon) between December 3, 2015 and July 12, 2016. AT-2 was designated as the “No Carbon” control aeration tank to allow for a direct comparison to the “Test” aeration tank (AT-1) that received supplemental carbon in the form of glycerol. AT-3, the SCT reactor, was also monitored and optimized. AT-3 received glycerol throughout the entire monitoring period. **Figure 1-6** and **Figure 1-7** are schematics of the sampling locations for main plant process (AT-1 and AT-2) and SCT (AT-3).

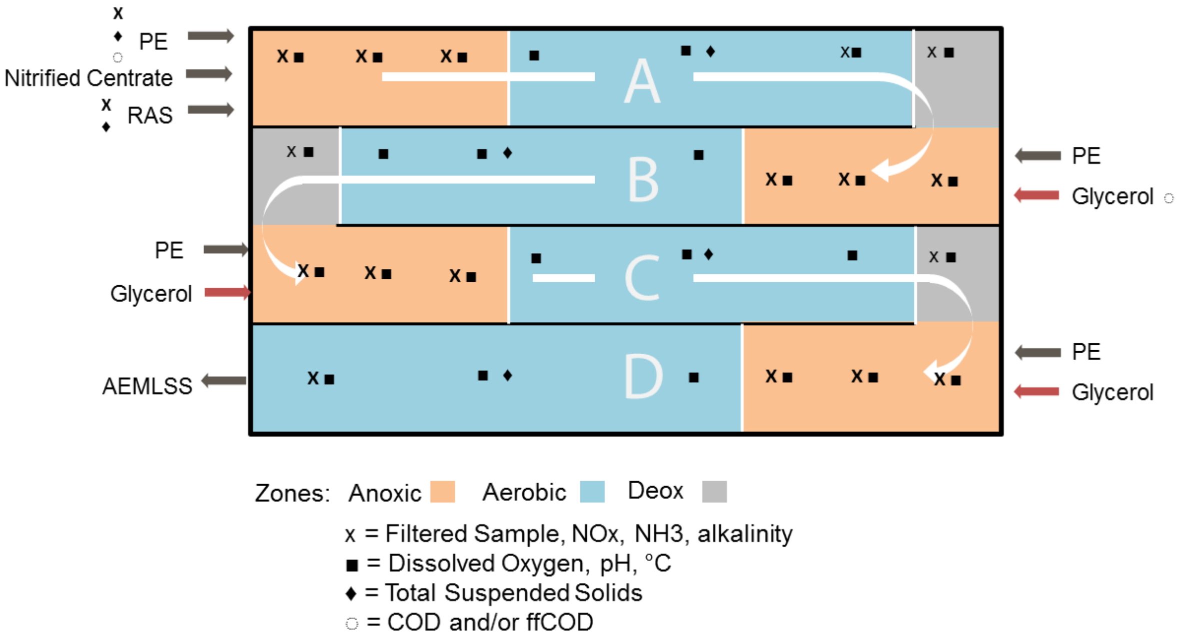


Figure 1-6: Sampling Plan Schematic of 26th Ward Main Plant Aeration Tanks

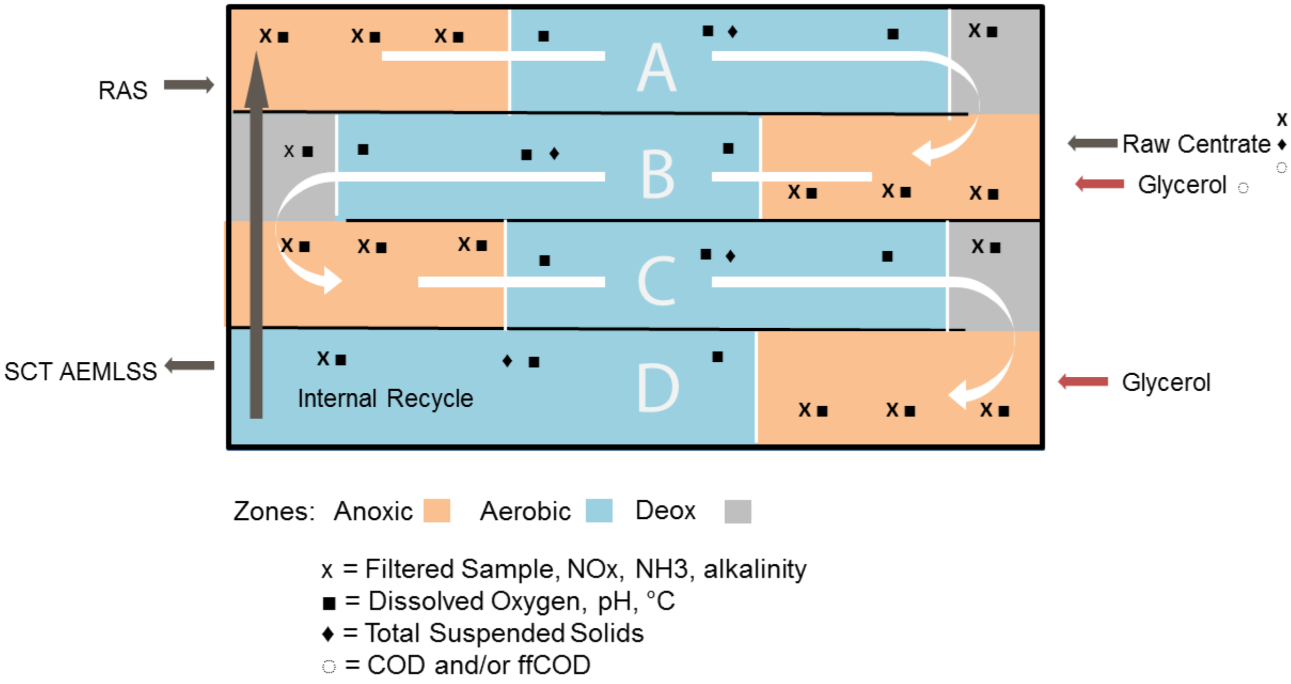


Figure 1-7: Sampling Plan Schematic of 26th Ward SCT Tank

The Target Operating Parameters based on this Comprehensive Sampling Program are summarized below:

Aeration Tanks 1 and 2

- **Target AEMLSS**: 2,500 mg/L to 3,000 mg/L
- **Target DO Concentrations**:
    - Aerobic Zones: 2 to 4 mg/L
    - Anoxic Zones: Less than 0.1 mg/L
- **Target RAS Rate**: 50% of Plant Influent Flow
- **Target PE Flow Distribution**:

Operational Condition	PE Flow Distribution (%)			
	Pass A	Pass B	Pass C	Pass D
Dry Weather	10	40	30	20
Wet Weather	0	25	25	50

- **Target Anoxic/Aerobic Zone Configuration**:

Operational Condition	Anoxic Volume at Head of Pass (%)			
	Pass A	Pass B	Pass C	Pass D
Summer/Spring	33	33	33	33
Fall/Winter	17	33	33	33

- **SWAS:** 100% of wasting
- **Supplemental Carbon Addition:**
    - Total flow of ~800 to 1,100 gpd of 65-70% glycerol solution per main plant aeration tank
    - Halt glycerol addition during wet weather and snowmelt events

Aeration Tank 3 (SCT)

- **IR pumps** should be operated to return between 1 MGD from the D-Pass to the A-Pass of AT-3
- **RAS flows** should target 1:1 RAS to Centrate flow ratio
- **Target Anoxic/Aerobic Zone Configuration**: All anoxic volume should be online to maximize alkalinity recovery
- **Target DO Concentrations**: (Same as AT-1 and AT-2)
- **Supplemental Carbon Addition:**
    - Main plant BNR process has the capacity to achieve optimal nitrogen removal performance when the SCT tank is not receiving supplemental carbon addition for denitrification
- **Supplemental Alkalinity Addition**:

  - Recommended if process effluent pH drops to below 6.5 or SCT effluent ammonia is greater than 100 mgN/L
  - If above condition is met, caustic dose of 550 gpd of 50% NaOH solution should be added (based on historical centrate loading conditions)

1.4.2 Jamaica WRRF BNR Supplemental Sampling with Glycerol Addition

The monitoring activities at Jamaica were conducted twice per day (morning and afternoon) between June 21, 2016 and March 21, 2017. AT-1 was designated as the “No Carbon” control aeration tank to allow for a direct comparison to the “Test” aeration tank (AT-2) that received supplemental carbon in the form of glycerol. AT-3, the SCT reactor, was also monitored and optimized. **Figure 1-8** is a schematic of the sampling locations for AT-1 and AT-2.

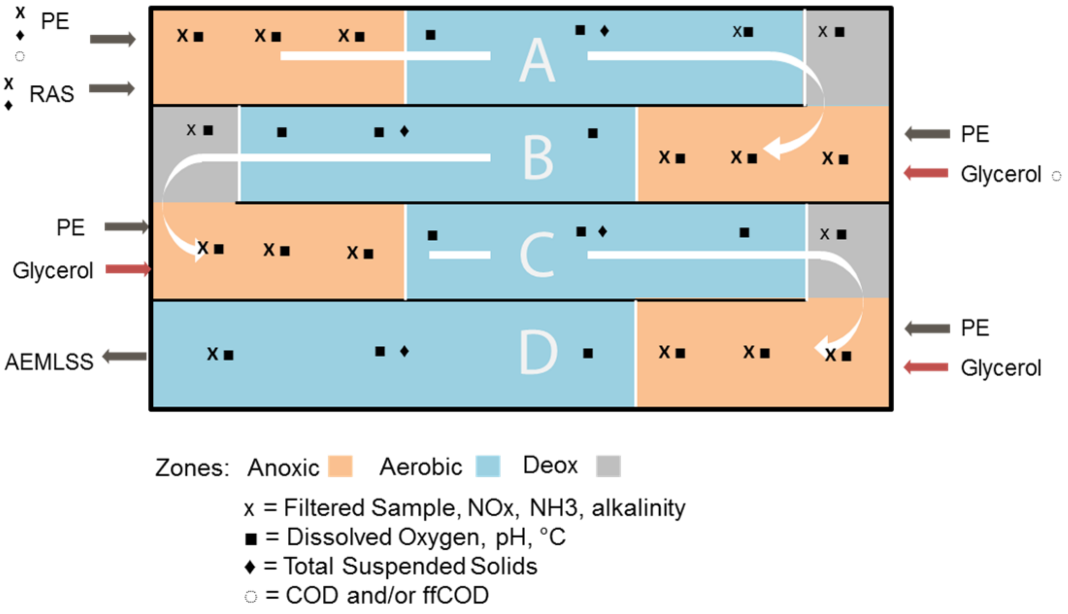


Figure 1-8: Sampling Plan Schematic of Jamaica Aeration Tanks

The Target Operating Parameters based on this Comprehensive Sampling Program are summarized below:

- **Target AEMLSS**: 2,400 mg/L
- **Target DO Concentrations**:
  - Aerobic Zones: 2 to 4 mg/L
  - Anoxic Zones: Less than 0.1 mg/L
- **Target RAS Rate**: 50% of Plant Influent Flow
- **Target PE Flow Distribution**:

Operational Condition	**PE Flow Distribution (%)**			
	Pass A	**Pass B**	**Pass C**	**Pass D**
Dry Weather	20	40	30	10
Wet Weather	0	25	25	50

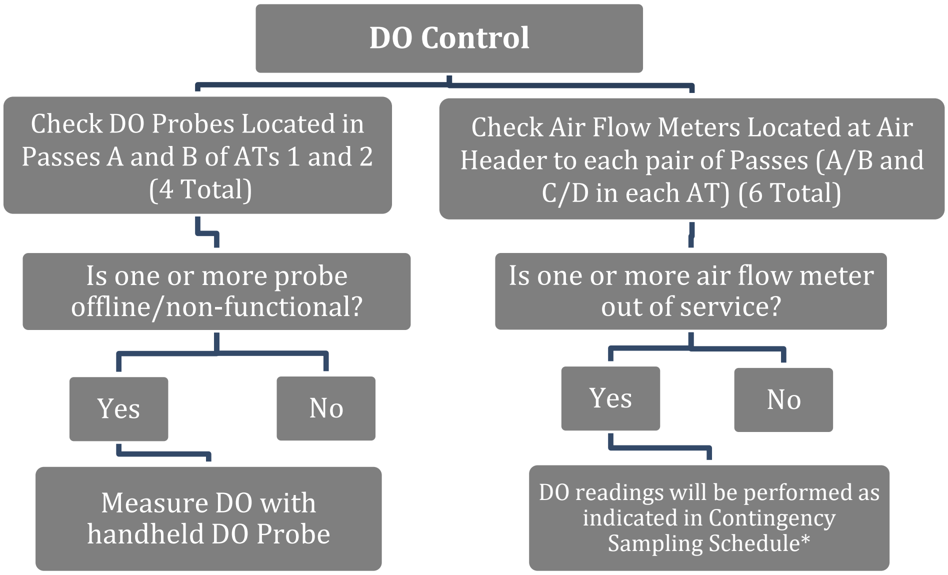
- **Target Anoxic/Aerobic Zone Configuration**:

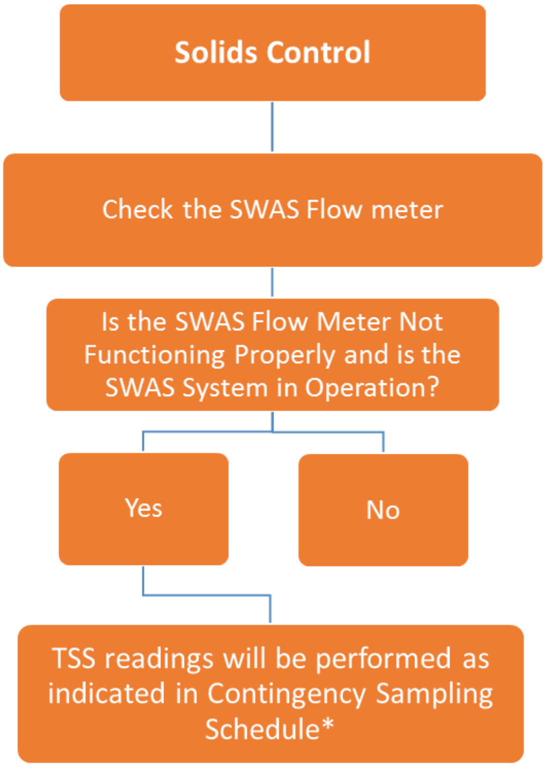
Operational Condition	**Anoxic Volume at Head of Pass (%)**			
	Pass A	**Pass B**	**Pass C**	**Pass D**
Summer	33	33	33	50
Spring	17	17	33	50
Fall	0	17	33	50
Summer	0	0	33	50

- **SWAS:** 100% of wasting
- **Supplemental Carbon Addition:**
    - Total flow of ~300 to 600 gpd of 65-70% glycerol solution per main plant aeration tank
    - Halt glycerol addition during wet weather and snowmelt events

1.5 Example Contingency Sampling for 26th Ward WRRF

1.5.1 26th Ward Weekly Contingency Sampling Walkthrough (To Be Performed Every Monday)



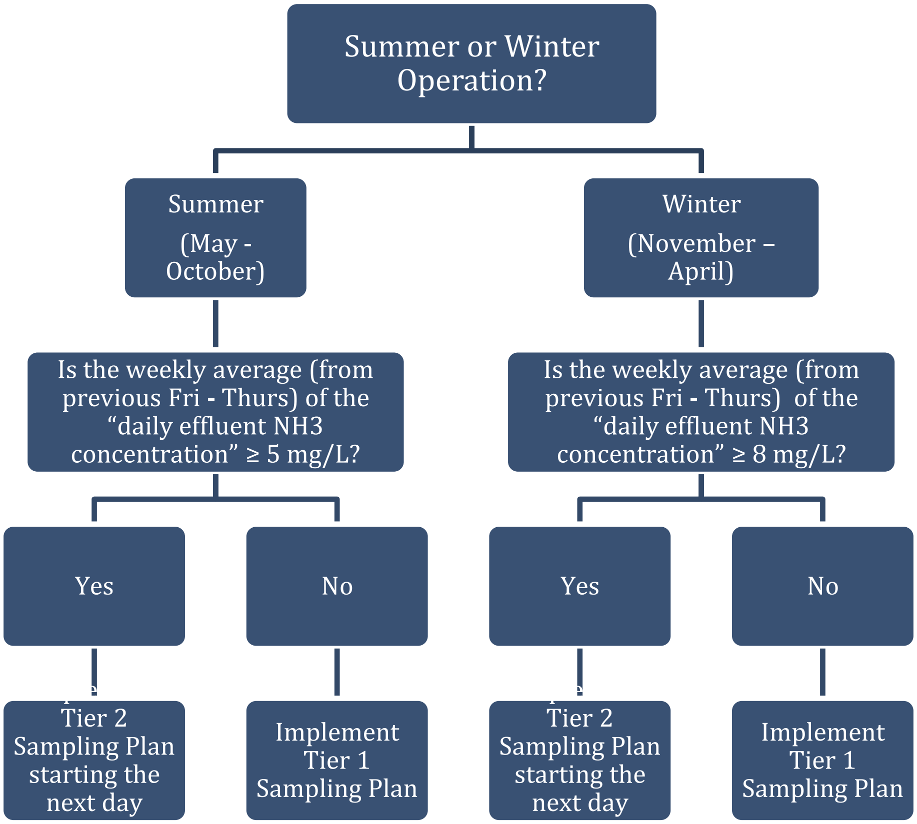


26th Ward Contingency Sampling Schedule for DO and TSS Instrumentation

Parameter	Plant Effluent	RAS	AT Effluent	SCT Effluent
DO	4/month		5/week	
TSS		5/week	5/week	5/week

Contingency Sampling will be re-evaluated every Monday to determine status of Specified Instrumentation. Once the Specified Instrumentation is put back into service, the contingency sampling plan will cease.

1.5.2 26th Ward Weekly Performance Related Sampling Evaluation (To Be Performed Every Monday)



*Tier 2 Sampling involves the following increase in sampling/monitoring from the Tier 1 (regular) Sampling Plan:

- Primary Effluent samples will be analyzed NO_2, NO_3, NH_3, and Alkalinity 2/week
- Centrate samples analyzed for NH_3 and Alkalinity will be collected 2/week
- AT effluent DO will be measured 5/week
- SCT effluent pH will be measured 5/week

Tier 2 will continue until the effluent NH_3 weekly average is re-evaluated on the following Monday.