NYC Department of Environmental Protection

1429-ENGSVC-S-NC-008

BNR Feasibility Study for the Newtown Creek Wastewater Resource Recovery Facility

March 31, 2022

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Contents

Tables

Figures

Appendices

Acronyms and Abbreviations

AA	average annual
AEMLSS	aerator effluent mixed liquor suspended solids
cBOD5	5-day carbonaceous biochemical oxygen demand
cfm	cubic feet per minute
BAF	biologically active filter
CO2eq	carbon dioxide equivalent
GHG	greenhouse gas
gpm	gallons per minute
IFAS	integrated film activated sludge
lbd	pounds per day
LGOP	Local Government Operations Protocol
MABR	membrane aerated biofilm reactor
MBR	membrane bio reactor
MGD	millions of gallons per day
mg/L	milligrams per liter
MOP	Design of Water Resource Recovery Facilities Manual of Practice
MOPO	maintenance of plant operations
NH3-N	ammonia
NO2-N	nitrite
NO3-N	nitrate
NYCDEP	New York City Department of Environmental Protection
OACE	Office of the Agency Chief Engineer
O&M	operations and maintenance
RAS	return activated sludge
SRT	solids retention time
TKN	Total Kjeldahl Nitrogen
TN	total nitrogen
TSS	total suspended solids
VSR	volatile solids reduction
WAS	waste activated sludge
WRRF	wastewater resource recovery facility

Executive Summary

Pursuant to Appendix A.3.d, of the Long Island Sound Dissolved Oxygen TMDL Order on Consent Case # CO 2-20190107-303 (LIS TMDL Order) between the New York State Department of Environmental Conservation (DEC) and the New York City Department of Environmental Protection (DEP), this Biological Nitrogen Removal (BNR) Feasibility Study was prepared on behalf of DEP for the Newtown Creek Wastewater Resource Recovery Facility (NC WRRF). This BNR study was developed to determine the feasibility of reducing total nitrogen from the NC WRRF effluent.

Nitrogen discharges from point sources can contribute to hypoxic (low dissolved oxygen) conditions in waterbodies such as the Long Island Sound. Pursuant to the Long Island Sound Total Maximum Daily Load (LIS TMDL) for Dissolved Oxygen approved by the United States Environmental Protection Agency (EPA) wasteload allocations for total nitrogen were established for identified nitrogen point sources based on their proximity to Long Island Sound in numbered zones. For the East River this meant that the four WRRFs that discharge to the Upper East River (UER), Hunts Point, Wards Island, Tallman Island and Bowery Bay were assigned to Zone 8. The two WRRFs that discharge to the Lower East River (LER), Red Hook and Newtown Creek were assigned to Zone 9. In accordance with the LIS TMDL the ratio between the WRRFs that discharge to Zone 8 and Zone 9 was established as 4:1.

The NC WRRF discharges treated effluent to the East River in accordance with a State Pollutant Discharge Elimination System (SPDES) permit (permit number: NY0026204). Pursuant to that SPDES permit, the NC WRRF is rated to treat up to 310 million gallons of wastewater per day (MGD) on a 12-month rolling average basis and is physically capable of receiving and treating a minimum of 700 MGD during wet weather operations. The focus of the study was to identify potential WRRF enhancements that may achieve BNR and help DEP further reduce nitrogen loading to the East River. It is important to note that pursuant to DEP's associated SPDES permits, nitrogen discharges from the Zone 8 WRRFs, Wards Island, Hunts Point, Bowery Bay, and Tallman Island WRRFs and the Zone 9 WRRFs, Newtown Creek and Red Hook WRRFs, are aggregated and have a total nitrogen (TN) 12-month rolling average Total Maximum Daily Limit (TMDL) of 44,325 lbs/day, with an additional allowance for 2,143 lbs/day from CSOs and a total mass of 46,468 lbs/day. Accordingly, as established pursuant to the TMDL and the ratio for Total Nitrogen reduction between Zone 8 and Zone 9 the nitrogen loading discharged from the Newtown Creek and Red Hook WRRFs are assessed at 25% of their mass against the 12-month rolling average. Thus, 1 lb/day of total nitrogen discharged from these two WRRFs counts as 0.25 lb/day nitrogen to the East River based on their Zone 9 location established pursuant to the LIS TMDL. The LIS Zone 8 + 9 aggregate is defined as the sum of the Zone 8 Aggregate and one-fourth of the Zone 9 Aggregate, described in this report as the Combined East River (CER) Aggregate.

Previous studies determined that it was not effective to reduce total nitrogen discharge from the NC WRRF compared to reducing the total nitrogen discharge from the UER WRRFs. Given the advancement of nitrogen removal systems/technologies, this BNR study takes a fresh look at the potential options to further reduce the total nitrogen discharge from the NC WRRF.

Unique Aspects of the NC WRRF

It is crucial to note that the NC WRRF is a high rate activated sludge facility and is distinctly different from the WRRFs operating in BNR mode that discharge to the UER as follows:

- *Absence of Primary Clarification*

The NC WRRF does not utilize primary clarification, with screened and degritted raw influent being sent directly to the aeration basins for treatment. This treatment configuration results in higher than typical loadings rates for both 5-day carbonaceous biochemical oxygen demand ($cBOD_5$) and total suspended solids (TSS).

- *High-Rate Treatment Configuration*

The NC WRRF operates with a target solids retention time (SRT) of 1.5 days. This is well below those WRRFs operating in BNR mode, which operate with SRTs above 5 days to ensure nitrification performance is maintained on a year-round basis. Because of low SRT design, the NC WRRF cannot facilitate year-round nitrification and total nitrogen removal without overloading the secondary clarifiers and risking poor effluent quality.

- *Wet Weather Operation*

The NC WRRF is required to accept and treat a minimum of 700 MGD during wet weather, which is 2.25 times the design average flow of 310 MGD, without the benefit of secondary system flow bypass to reduce solids loadings on the secondary clarifiers. All other DEP WRRFs are required to accept and treat a minimum 2 times their design average flow through the WRRF, with only 1.5 times the design average flow being treated through the biological treatment process (aeration basins and secondary clarifiers) through use of secondary bypass (primary effluent flow directly to disinfection).

BNR Alternatives Comparison

This study evaluated five (5) treatment configuration alternatives, that may be suitable for evaluation of BNR at the NC WRRF, listed below.

- Alternative 1 – Step-Feed BNR
- Alternative 2 – Conventional + Biological Active Filters (BAFs)
- Alternative 3 – Conversion to Membrane Bioreactors (MBR)
- Alternative 4 – Conversion to Membrane Aerated Biofilm Reactors (MABR)
- Alternative 5 – Conversion to Integrated Fixed Film Activated Sludge (IFAS)

Based upon preliminary process modeling and analysis, two of the treatment configuration alternatives listed were determined to be unfeasible at the NC WRRF:

- **Alternative 1 – Step-Feed BNR** was the most obvious treatment alternative for evaluation given this approach has been implemented at the UER WRRFs. However, the NC WRRF is a high-rate facility without primary clarification and a hydraulic detention time well below that of the UER BNR WRRFs and lacking the benefits of biological treatment system wet weather bypass. The implementation of Step-Feed BNR would require a significant increase in operating SRT which would bring operating MLSS concentrations well above what the secondary clarifiers can accommodate. Accordingly, this alternative was considered unfeasible, and the corresponding cost estimate was not developed.

- **Alternative 5– Conversion to MABR** would convert the activated sludge process to an MABR system. Due to limitations in aeration basin volume leading to constructability issues and the need for fine screening of raw influent, the vendor of this technology did not believe their technology was appropriate for the NC WRRF. Accordingly, this alternative was considered unfeasible, and the corresponding cost estimate was not developed.

The other three potentially feasible treatment configuration alternatives for implementation of increased TN removal at the NC WRRF: **Alternative 2 – Step-Feed Conventional + BAFs**, **Alternative 3 – Conversion to MBR**, and **Alternative 4 – Conversion to IFAS** were further evaluated. Even though all three treatment alternatives offer an increase in TN removal at the NC WRRF and therefore within the East River, with regards to the cost-benefit analysis and implementation complexity, and other factors considered, these three alternatives were also found to be unfeasible.

Table ES-2 compares all treatment configuration alternatives in terms of pre-treatment requirements, energy consumption, implementation considerations, total nitrogen removal, and estimates of construction costs and operations and maintenance costs.

Total Nitrogen Removal

Table ES-1 below summarizes effluent total nitrogen loads leaving the NC WRRF under all three treatment alternatives and then compares those values to the baseline condition where NC WRRF remains a high-rate secondary treatment facility. As shown, **Alternative 3 - Conversion to MBR** provides the greatest level of TN removal, followed by **Alternative 4 – Conversion to IFAS**, and finally **Alternative 2 – Conventional + Nite/Denite BAF**.

It is important to note that both the conversion to MBR and IFAS alternatives would require demonstration/pilot testing to confirm the ability of the fine screens to operate properly as well as the BNR treatment performance.

Table ES 1 - Total Nitrogen Removal Comparison – NC WRRF and the CER/LIS

Parameter/Criteria	Baseline	Alt 2 - Conventional + Nite/Denite BAF	Alt 3 - Conversion to MBR	Alt 4 - Conversion to IFAS
Eff TN, lbd	36,100	32,727	15,150	30,274
Reduction in TN at NC WRRF, lbd		3,373	20,950	5,826
Reduction in TN, %		9%	58%	16%
CER Contribution, lbd	9,025	8,182	3,788	7,569
CER TN Mass Reduction, lbd	---	843	5,238	1,457

Estimate of Net O&M Costs and Capital Construction Costs

Probable construction costs and net increase in O&M costs to implement the three alternatives noted above, are shown in **Table ES-2**. A 30-year annualized costs were also developed for all potential alternatives, assuming financing of the plant upgrade over a 30-year period at a 3% bond rate and yearly O&M costs in terms of 2021 dollars. As noted earlier, a reduction of nitrogen at NC WRRF only reduces the discharge of nitrogen to the East River by 25%. Thus, the cost per pound nitrogen removal would need to be multiplied by a factor of 4 to compare these costs versus additional treatment options performed in any of the four UER WRRFs.

Considering their potential for TN removal and their associated risks and costs, none of the three alternatives studied are feasible for NC WRRF.

Table ES 2 – Treatment Configuration Alternatives Comparison – NC WRRF

Treatment Configuration Alternative	Baseline – Conventional (Non-BNR)	Alt 1 – Step-feed BNR	Alt 2 – Conventional + Nite/Denite BAF	Alt 3 – Conversion to MBR	Alt 4 – Conversion to IFAS	Alt 5 – Conversion to MABR
Implementation	---	*Not Feasible*	Moderate	Very Complex	Moderate	*Not Feasible*
Pre-Treatment Requirements	---	---	No	Yes – 2mm screening	Yes – 3 mm screening	---
Increase in Energy Consumption	---	---	Moderate	Highest	High	---
Chemical Addition	---	---	Methanol/Glycerol	Sodium hypochlorite and Citric Acid for cleaning	None	---
O&M Considerations	---	---	Moderate	High	Moderate	---
Effluent TN, lbd	36,100	---	32,727 (9 % Reduction)	15,150 (58% Reduction)	30,274 (16% Reduction)	---
CER Contribution, lbd	9,025	---	8,182	3,788	7,569	---
CER Contribution, %	20	---	18	9	17	---
Total Capital Cost, $MM	---	---	$129	$990	$245	---
Annualized Capital Cost, $MM/year	---	---	$6.6	$52	$13	---
O&M Cost, $MM/year	---	---	$3.3	$9.2	$5.0	---
Total Annualized Cost, $MM/year	---	---	$9.8	$61	$18	---
$/lb TN Removed	---	---	$8.00	$8.04	$8.25	---
$/lb TN Removed CER	---	---	$32.00	$32.15	$32.99	---

1 Introduction

Pursuant to Appendix A.3.d, of the LIS TMDL Order, this BNR Feasibility Study was prepared on behalf of DEP for the NC WRRF. The focus of the study is to identify potential WRRF enhancements that may achieve BNR and help DEP further reduce nitrogen loading to the East River. It is important to note that pursuant to DEP's associated SPDES permits, nitrogen discharges from the Wards Island, Hunts Point, Bowery Bay, and Tallman Island WRRFs, as well as the Newtown Creek and Red Hook WRRF, are aggregated and have a TN 12-month rolling average TMDL of 44,325 lbs/day, with an additional allowance for 2,143 lbs/day from CSOs and a total mass of 46,468 lbs/day. However, in accordance with the LIS TMDL and the zoned wasteload allocations based on a point source's proximity to the Long Island Sound the nitrogen loading discharged from the Newtown Creek and Red Hook WRRF are assessed at 25% of their mass against the 12-month rolling average. Accordingly, 1 lbs/day of total nitrogen discharged from these two WRRFs count as 0.25 lbs/day nitrogen to the East River based on their Zone 9 location established pursuant to the LIS TMDL. Thus, the LISS Zone 9 aggregate is defined as the sum of effluent discharges from Newtown Creek and Red Hook WRRFs, described in this report as the LER WRRFs. The LISS Zone 8 aggregate is defined as the sum of effluent discharges from Bowery Bay, Hunts Point, Tallman Island and Wards Island WRRFs, described in this report as the UER WRRFs. The LIS Zone 8 + 9 aggregate is defined as the sum of the Zone 8 Aggregate and one-fourth of the Zone 9 Aggregate, described in this report as the CER Aggregate.

This report is divided into the following seven (7) sections:

- **Section 2 – WRRF Background and Objectives**

Section 2 of the report focuses on a background summary of the existing NC WRRF, detailing the existing treatment systems, operational philosophies, and effluent quality goals. In addition, this section will speak to regulatory drivers and programmatic considerations that influenced this study.

- **Section 3 – Asset Conditions Assessment**

Section 3 details an on-site asset conditions assessment performed at the outset of this study, which focused on the activated sludge process and associated tanks/ structures/ systems. The results were compared to previous condition assessments recently performed at NC WRRF.

- **Section 4 – Historical Operation and Performance Evaluation**

Section 4 of this report summarizes the findings of a detailed historical operations and performance evaluation that was performed on the last six (6) years' worth of plant data. The purpose of this evaluation was to document historical performance, assist in the development of the full-plant process model, and inform the development of influent flow and loading projections to be used in this study.

- **Section 5 – Process Model Calibration and Hydraulic Capacity Evaluation**

Section 5 summarizes the calibration of a full-plant process model (developed in BioWin) and the evaluation of the hydraulic capacity of the existing WRRF. Both analyses were utilized when developing potential feasible treatment alternatives for BNR operation.

- **Section 6 – Influent Flow and Loading Projections**

Section 6 summarizes the development of future influent flow and mass loading projections to the NCWRRF. The focus of this study is to evaluate BNR treatment potential at the 2050 condition, which incorporates a 14% increase in plant loading from the current condition (2015 to 2019).

- **Section 7 – BNR Alternatives Evaluations**

Section 7 contains a detailed evaluation of five (5) treatment configuration alternatives at the NC WRRF, each with a goal of achieving meaningful increases in total nitrogen removal at the facility through BNR operation. Each treatment alternative is presented with an overview of the biological treatment technology, as discussion of the upgrade requirements for implementation at NC WRRF, anticipated effluent quality in terms of nitrogen in the East River, as well as anticipated energy consumption, GHG emission, and estimates of capital construction and operations and maintenance costs of applicable alternatives.

- **Section 8 – Evaluation Conclusions**

The final section of the report summarizes the findings of the study, focusing on the impacts on nitrogen discharges at the NC WRRF as well as in the East River, and important considerations with regard to implementing these upgrades at the NC WRRF. This section also includes estimates of operations and maintenance costs, 20-year life cycle costs, and capital construction costs estimates both in terms of 2021 dollars and in relation to the mass of nitrogen removed both at the NC WRRF and in the East River.

2 WRRF Background and Objectives

This section of the report presents background information for the study, including a description of the WRRF and the regulatory and programmatic drivers that were considered as part of the evaluation.

2.1 Process Description and Unique Design and Operational Characteristics

The NC WRRF is rated to treat up to 310 MGD of wastewater on a 12-month rolling average basis and be physically capable of receiving and treating a minimum of up to 700 MGD during wet weather operations. The WRRF discharges treated effluent to the East River pursuant to a SPDES permit (permit number: NY0026204). **Table 1** summarizes the current permit requirements for flow, 5-day carbonaceous biochemical oxygen demand ($cBOD_5$), total suspended solids (TSS), ammonia (NH_3-N), fecal coliform, and total residual chlorine.

Table 1 - NC WRRF SPDES Permit Requirements

Parameter	Limit Basis	Value	
Flow	12-Month Rolling Average	310 MGD	
$cBOD_5$	Monthly Average	25 mg/L	65,000 lbd
	Weekly Average	40 mg/L	100,000 lbd
TSS	Monthly Average	30 mg/L	78,000 lbd
	Weekly Average	45 mg/L	120,000 lbd
	Daily Maximum	50 mg/L	---
NH_3-N	Monthly Average	41 mg/L	---
Fecal Coliform	30-Day Geometric Mean	200/100 mL	
	7-Day Geometric Mean	400/100 mL	
Total Residual Chlorine	Daily Maximum	0.23 mg/L	

The current liquid treatment train of the WRRF consists of the following unit processes:

- Raw influent pumping from Manhattan Pump Station and Brooklyn/Queens Pump Station
- Primary influent bar screens (1 inch)
- Secondary screening (3/8 inches) of raw influent
- Grit Removal
- Aeration Basins (Step-Feed Configuration)
- Secondary Clarification
- Effluent Chlorination
- Effluent Dechlorination

The solids treatment train consists of the following unit processes:

- Wasting from the Return Activate Sludge (RAS) system
- Mechanical thickening of WAS via thickening centrifuges

- Co-digestion of WAS and outside food waste via mesophilic anaerobic digestion
- Marine hauling of digested sludge to outside facilities for dewatering and ultimate disposal

A simplified process flow diagram is shown in **Figure 1.**

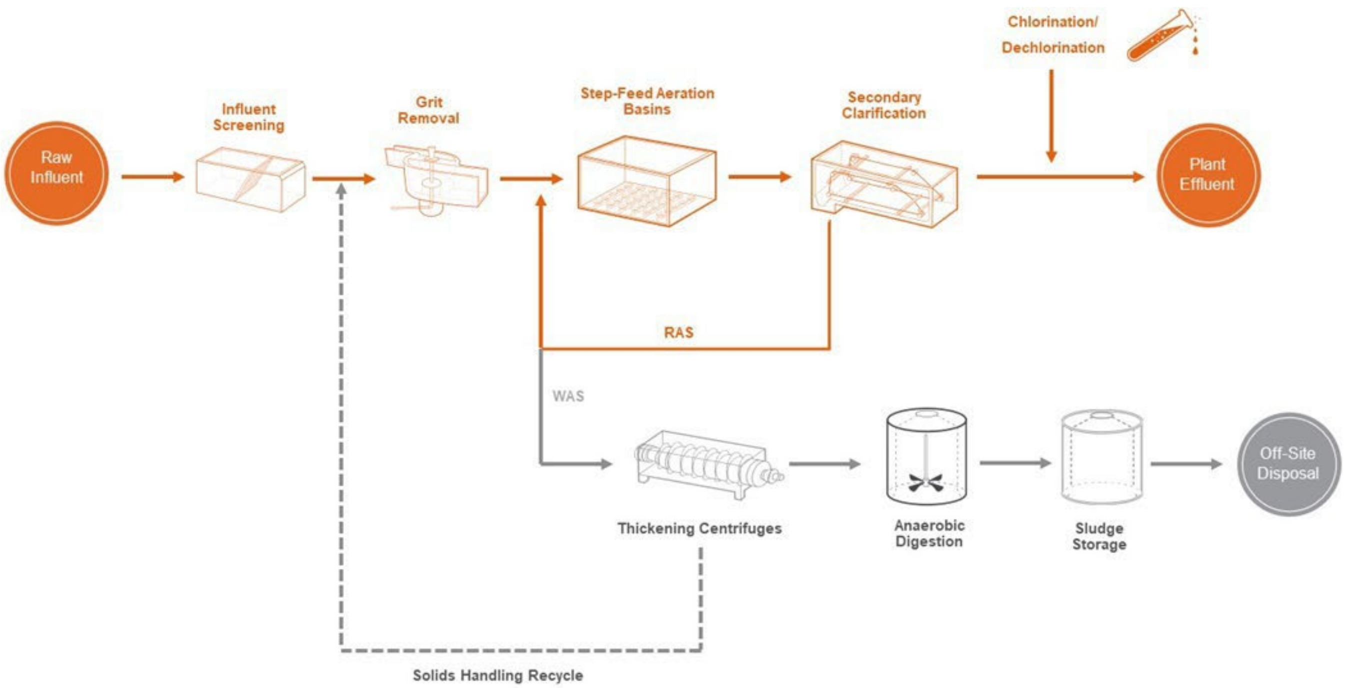

Figure 1 - NC WRRF Simplified Process Flow Diagram

It is important to note that the NC WRRF has several design and operational characteristics that are unique amongst DEP WRRFs, especially to those operating in BNR mode and discharging to the UER. The key design criteria and treatment configuration aspects that make this facility distinct from other NYC DEP WRRF's include:

Absence of Primary Clarification

The NC WRRF does not utilize primary clarification, with screened and degritted raw influent being sent directly to the aeration basins for treatment. This treatment configuration results in higher than typical loadings rates for both 5-day carbonaceous biochemical oxygen demand ($cBOD_5$) and total suspended solids (TSS). As noted in *Technical Memorandum 3 – Flow and Loading Projections* (**Appendix C**), the aeration basins were designed to operate with $cBOD_5$ loading rates which are well above those outlined in the *Recommended Standards for Wastewater Facilities,* also known as the "Ten States Standards" (10 SS).

High-Rate Treatment Configuration

Unlike all other WRRFs operated by BWT, the NC WRRF is a high rate activated sludge facility, operating with a target solids retention time (SRT) of 1.5 days. This is well below operating SRTs (minimum of 5-day aerobic SRT) for the WRRFs operating in BNR mode to ensure nitrification performance is maintained on a year-round basis. Because of low SRT design, the NC WRRF is not capable of operating at higher mixed liquor suspended solids (MLSS) concentration required to achieve nitrification and total nitrogen removal without overloading the secondary clarifiers and exceeding effluent discharge limits. Similarly, the NC WRRF operates at low aeration basin hydraulic retention times HRT, with a design value of 2 hours, whereas the DEP BNR facilities have a minimum design detention time of 4 hours (following primary clarification). The WRRFs operating in BNR mode and discharging to the UER are able to operate with HRTs well above those at NC WRRF, which allows for improved denitrification and total nitrogen removal.

Wet Weather Operation

The NC WRRF is required to treat up to 700 MGD during wet weather, which is 2.25 times the design average flow of 310 MGD, without the benefit of secondary system flow bypass to reduce solids loadings on the secondary clarifiers. All other WRRFs operated by BWT are required to treat up to 2 times their design average flows with all flow passing through primary treatment but only 1.5 times the design average flow goes through the activated sludge process and the remaining primary effluent is blended with the final clarifier effluent prior to disinfection. This allows the WRRFs operating in BNR mode to maintain higher SRTs and nitrification performance.

2.2 Regulatory Drivers

The NC WRRF is one of six WRRFs that discharge to the East River, which is connected with the Long Island Sound, along with the Red Hook, Wards Island, Bowery Bay, Hunts Point, and Tallman Island WRRFs. The DEC issues and maintains individual SPDES permits for each of the facilities. However, nitrogen discharges to the East River are governed under a single aggregate 12-month rolling average in terms of total mass loading.

For the purposes of meeting the LIS TMDL established wasteload allocations for nitrogen discharge levels for the East River and the Long Island Sound, discharges from the Wards Island, Hunts Point, Bowery Bay, and Tallman Island WRRFs, as well as the Newtown Creek and Red Hook WRRFs, are aggregated and have a TN 12-month rolling average TMDL of 44,325 lbs/day, with an additional allowance for 2,143 lbs/day from CSOs and a total mass of 46,468 lbs/day. In in accordance with the LIS TMDL and the zoned wasteload allocations based on a point source's proximity to the Long Island Sound, the nitrogen loading discharged from the Newtown Creek and Red Hook WRRFs are assessed at 25% of their mass against the 12-month rolling average. Accordingly, 1 lb/day of total nitrogen discharged from these two WRRFs counts as 0.25 lb/day nitrogen to the East River based on their Zone 9 location established pursuant to the LIS TMDL.

2.3 Programmatic Considerations

As part of OneNYC, the City vision is to make the 14 in-City WRRFs have "net-zero" energy consumption and reduce greenhouse gas (GHG) emissions by 80%, by 2050. While the goal of the BNR Study is to identify potential plant enhancements that will achieve BNR, the impacts to electrical consumption and GHG emissions will be assessed. Each design alternative considered will show impacts to both electrical consumption and GHG emissions from the existing systems baseline performance.

2.3.1 Energy Consumption

NC WRRF is the City's largest WRRF and its largest energy consumer. NC WRRF uses 124,412,700 kWh annually according to the NC WRRF Facility Energy Audit report (FY 2011-2012), leading to annual electrical operating expense of $12.60 M/year (excluding labor and maintenance) and 36,000 MT of CO_2eq per year. The process air blowers account for 30,782,862 kWh annually (25% of plant consumption, 33% of process consumption), making it the single greatest consumer at the plant.

As part of the BNR alternatives analysis, the electrical consumption impacts for each alternative were estimated. Additional aeration, beyond the capacity of the existing blowers, was required for all alternatives resulting in higher energy consumption.

2.3.2 GHG Emissions

Reducing GHG emissions by 80% from fiscal year (FY) 2005 baseline by 2050 is a key programmatic driver for the New York City government, according to the OneNYC Plan released in 2015. The water and wastewater treatment systems are responsible for nearly 20% of the city government emissions.

Considering the methodology adopted by the DEP, with reporting of Scopes 1 and 2 emissions, NC WRRF GHG emissions are measured in ton CO_2eq and come from the following sources:

- Electricity
- Natural Gas
- Fuel Oil
- Biogas flared/fugitive emissions
- Process (N_2O)

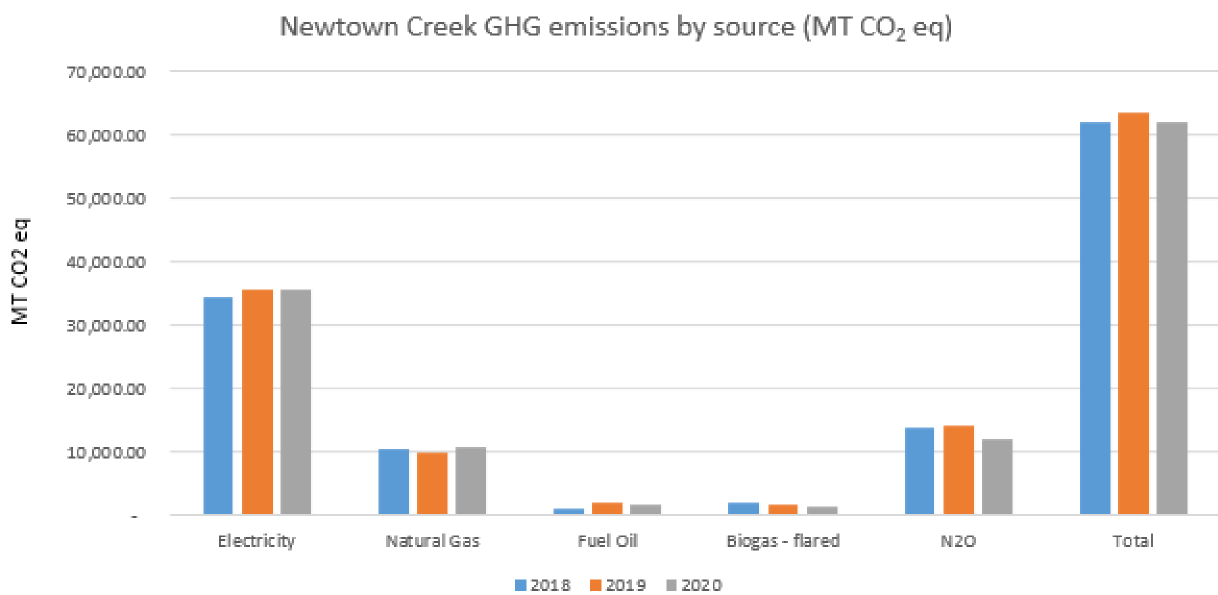

Figure 2 - NC WRRF GHG Emissions by Source – 2017 to 2020

Figure 2 illustrates the GHG emissions in CO_2 equivalence by source according to the 2021 DICE data provided by DEP. Electricity currently represents 56% of the total GHG emissions for NC WRRF. As part of the BNR alternatives analysis, the study estimated the change in GHG emission relative to the plant's performance for the baseline scenario.

3 Asset Condition Assessment

As part of the BNR feasibility analysis, Arcadis has conducted an Asset Condition Assessment focused on the Aeration Tanks and associated tanks/ structures/ systems. The results were compared to previous condition assessments recently performed at NC WRRF.

3.1 Recent Asset Condition Assessments (2020/ 2021)

In 2020, a comprehensive condition assessment was developed under the Office of the Agency Chief Engineer (OACE) at NC WRRF. During that assessment, physical scores for all assets at the facility were assigned according to DEP's Asset Condition Assessment and Risk Scoring Framework.

Arcadis has conducted another assessment on July 14, 2021, in order to confirm the previous scores and rating given and identify changes in condition. The team did not open any electrical panels or interrupt plant operations to inspect the interior mechanisms of tanks, wet wells, and other assets. The goal was to perform an evaluation without requiring any maintenance of plant operations (MOPO).

Table 2 shows a comparison summary of the average rating for all assets across the North, Central, and South batteries between assessments. Results were similar, as expected given the short interval between both evaluations. Discrepancies in ratings are explained in the notes:

Table 2 - Summary of NC WRRF 2020/2021 Condition Assessment Scores

System	Discipline	Primary Asset	2020 Rating	2021 Rating
Grit Removal	Process Mechanical	Pumps	Good	Fair to Good [1]
Grit Removal	Process Structural	Tanks	Good	Good
Aeration	Process Structural	Tanks	Good	Good
Aeration	Process Mechanical	Process Air	Good	Fair to Good [2]
RAS/WAS	Process Mechanical	RAS Pumps	Good	Fair to Good [3]
RAS/WAS	Process Mechanical	WAS Pumps	Good	Good
Skimmings Removal	Process Mechanical	Scum Collection	Good	Fair to Good [2]
Sediment Tanks	Process Mechanical	Collectors and Drives	Good	Good
Sediment Tanks	Process Structural	Tanks	Good	Good
North Control Building	Structural	Building	Good	Good
North Control Building	Electrical	Electrical Distribution	Fair to Good	Good[4,5,6]
South Control Building	Structural	Building	Good	Good
South Control Building	Electrical	Electrical Distribution	Good	Good
Blowers	Process Mechanical	Blowers	Good	Good

Notes:

1. North Battery Grit Pumps were considered in good condition in 2020. During the 2021 assessment, our team downgraded the North Battery grit pumps to fair condition due to observed leakage and continued deterioration.
2. The actuators on the sluice gates associated with the Aeration and Settling Tanks are presenting significant issues for plant operations. The Rotork actuators seem to be having issues with water infiltration, which is causing failures within the unit. We noted several failed actuators with several others displaying clear signs of water infiltration inside.
3. RAS Pump #3 has significant leakage during our assessment. That individual pump has been downgraded to fair condition.
4. Motor Control Center MCC-18-01-03 was rated in fair condition in 2020. During our 2021 inspection, we upgraded the score of this asset to good condition due to proper maintenance.
5. Automatic Transfer Switch ATS-18-02 was rated in fair condition in 2020. During our 2021 inspection, we upgraded the score of this asset to good condition due to proper maintenance.
6. UPS in North Control Building were scored in fair condition in 2020 and 2021.

3.2 Recommendations

Based on the results presented, the existing aeration tanks and associated systems at NC WRRF do not require any major capital improvements at this time. The only capital improvements to be considered under the BNR Study will be process-driven, where the existing systems do not have the excess capacity required to facilitate BNR.

More information including photo documentation and recommendations by discipline can be found in **Appendix B** *(Technical Memorandum 2 – Existing Condition Assessment of Aeration Tanks and Associated Systems).*

4 Historical Operations and Performance Evaluation

As an initial step in this study, Arcadis reviewed and analyzed the previous six years of plant operations and performance operations (January 2015 to March 2021) and documented influent flow and mass loadings, activated sludge operation and performance, final effluent quality, and solids handling operations and performance. A summary of this evaluation is shown below for both the liquid treatment train and the solids handling treatment train. The complete evaluation of historical operations and performance data is available in **Appendix A** (*Technical Memorandum 1 – Historical Operations and Performance Data Evaluation*).

4.1 Liquid Treatment Train

Historically observed WRRF influent data represents a low to medium strength wastewater. Influent flow and mass loading peaking factors for all parameters are also consistent and fall within expected ranges for maximum month, (MM), maximum week (MW), and maximum day (MD) conditions for a WRRF of this size.

A review of the liquid treatment data indicates that the WRRF is performing very well, with consistent process control and excellent effluent quality:

Activated Sludge Process:

- Aerator effluent mixed liquor suspended solids (AEMLSS) concentrations have been very consistent through the data set, with an average value of 1,400 mg/L.
- Solids Retention Time (SRT) has also been consistent, with an average value of approximately 1.5 days.
- The average historical sludge volume index (SVI) is 105 mL/g with a 95th percentile value of 173 mL/g.

Effluent Quality – cBOD$_5$ and TSS:

- Effluent quality in terms of cBOD$_5$ and TSS has been excellent and well below permit limits, with average values of 15 mg/L or below for both parameters. The removal rates for cBOD$_5$ and TSS are approximately 93% for both parameters and appear to be well below the monthly and weekly limits.

Effluent Quality – Total Nitrogen:

- The WRRF is not fully nitrifying, with effluent NO_3-N and NO_2-N concentrations below 2 mg/L year-round. This is expected given low SRT operation.
- Historical effluent TN concentrations and loadings average to approximately 17 mg/L-N and 30,500 lbd, respectively. This equates to an average yearly TN removal rate of approximately 43%.

The historical operations and performance related to the liquid treatment train is summarized in additional detail in **Section 3.1** of *Technical Memorandum 1 – Historical Operations and Performance Data Evaluation* **(Appendix A).**

4.2 Solids Handling Treatment Train

Available data for the solids handling train suggests fair performance, with no major process upsets or periods of suboptimal performance:

Sludge Thickening:

- A mass balance around sludge thickening units indicates solids capture rates of approximately 80%.

Anaerobic Digestion:

- Anaerobic digestion is operating with more than sufficient HRTs for mesophilic anaerobic digestion, and a mass balance around the unit process suggests that volatile destruction is routinely as high as 60%.
- The amount of biogas produced per pound of volatile sludge destroyed ranges from 10.5 to almost 20 CF/lb of volatile destroyed, with an average long-term value of approximately 15 CF/d.

The historical operations and performance related to the solids treatment train is summarized in additional detail in **Section 3.2** of *Technical Memorandum 1 – Historical Operations and Performance Data Evaluation* (**Appendix A).**

5 Process Model Calibration and Hydraulic Capacity Evaluation

5.1 Process Model Development and Calibration

Arcadis developed a full-plant process model utilizing BioWin 6.2 by EnviroSim to assess the feasibility of future biological nutrient removal operation at the facility to reduce effluent nitrogen discharges.

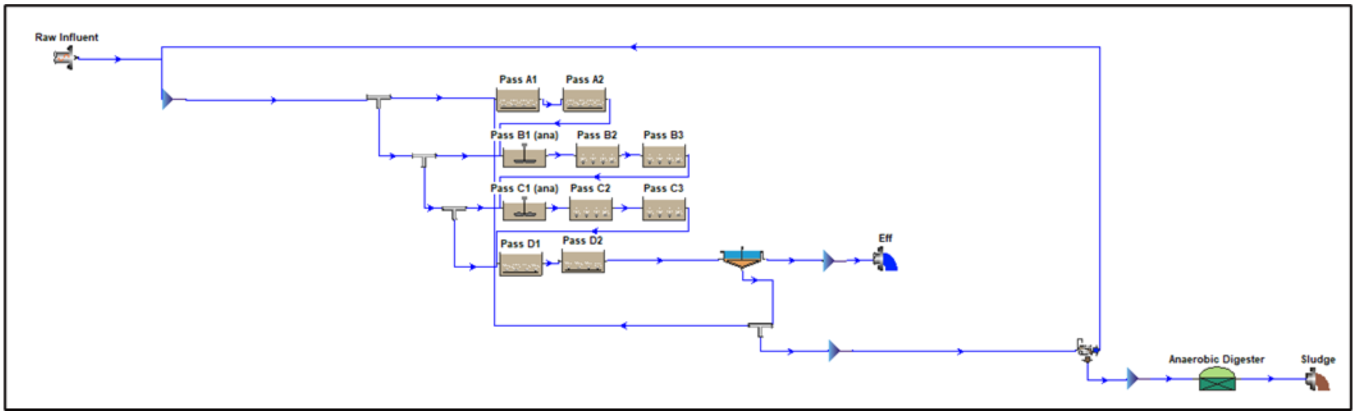

Figure 3 - Full Plant Biowin Process Model: NC WRRF

The output from a 3-year daily dynamic process model simulation was compared with the historical data to determine current AA concentrations for use in the flow and loading projections and BNR alternative evaluation. There was a close match between the observed historical raw influent concentrations and model predictions for all influent parameters, along with good to excellent matches on all key operating parameters and performance indicators (see **Table 3**). Therefore, it is proposed to utilize the historical annual average influent concentrations (pre-COVID 19 Pandemic) verified during the calibration effort when developing current and future flow and loadings projections for use in the BNR alternatives evaluation for NC WRRF.

Table 3 - Historical Average and Proposed Raw Influent Concentrations: Annual Average Conditions

Parameter	Plant Data (2015 – 2019)	Model (2015 – 2017)	Proposed AA Values
Flow, MGD	212.5	211.9	212.5
COD, mg/L	326	367	367
$cBOD_5$, mg/L	166	166	166
$cBOD_5$ (uninhibited), mg/L	175	174	175
TSS, mg/L	162	157	162
VSS, mg/L	145	138	145
TKN, mg/L	31	30	31
NH_3-N, mg/L	20	21	20
TP, mg/L	4.1	4.7	4.1
PO_4-P, mg/L	2.5	2.3	2.5

In addition to the close match in influent quality the model calibration effort resulted in the following conclusions on plant operations:

- **Biological Treatment**: Model predictions for average mixed liquor suspended solids (MLSS), aerator effluent MLSS (AEMLSS), waste activated sludge (WAS) loadings, and return activated sludge (RAS) TSS concentrations were within 2% of the historical plant data, with model predicted solids retention times (SRT) within 0.1 days of reported SRTs. These parameters show the process model accurately reflects typical plant operations at the WRRF.

- **Effluent Quality**: Effluent quality matched well for $cBOD_5$, TSS, TP, PO_4-P, NH_3-N, NO_3-N, NO_2-N, and TN. The model predicted effluent nitrogen speciation were all within 5% of the plant data, which provides confidence in the full-plant process model as an accurate tool for modeling BNR alternatives as part of this feasibility study.

- **Solids Handling**: Solids handling data for thickened and digested sludge loading was tracked during the model calibration. The model predictions for thickened and digested sludge are within approximately 10% of plant data, which is a good match to observed data is acceptable for the purposes of this evaluation.
  - *Note: A sensitivity analysis on anaerobic digester performance was not performed as part of this effort since anaerobic digestion does not impact the liquid treatment stream. All thickened sludge sent to the anaerobic digesters discharge to sludge holding tanks and are shipped to one of the DEP's sludge dewatering facilities.*

The details of the model calibration are discussed in *Technical Memorandum 4 – Full-Plant Process Model Development and Calibration* (**Appendix D**).

5.2 Hydraulic Model Development and Results

A hydraulic model was developed in Microsoft Excel to assess the hydraulic losses through each of the treatment processes within NC WRRF. The goal of the hydraulic model was two-fold: (1) to assess the hydraulic conditions in the various treatment units for the rated wet weather capacity of 700 MGD and (2) to assess the maximum throughput for each of the treatment processes and determine the maximum flow that can potentially be handled by the plant hydraulically.

The results from the hydraulic evaluation through the existing NC WRRF show that all the process treatment units can hydraulically handle the rated wet weather capacity of 700 MGD. Following the model validation, it was used to perform the throughput analysis and determine the maximum flows that could be sent through each treatment unit hydraulically. The results of this analysis are summarized below in **Table 4**, showing the hydraulic capacity for each unit process with all units in service and with one unit out of service (OOS) in each treatment battery.

Table 4 - Unit Process Hydraulic Capacities

Treatment Process System	Max Throughput Flow (MGD)	Max Throughput Flow (MGD)
	All Units in Service	One Unit OOS per Battery
Grit Influent Channels	1,000	750
Grit Tanks	1,100	850
Aeration Influent Channels	2,950	2,500
Aeration Tanks	2,450	2,150
Sedimentation Influent Channels	2,700	2,400
Sedimentation Tanks	2,300	1,800
Chlorine Contact Influent Channel	1,900	1,300
Chlorine Contact Tanks (215 MGD to Whale Creek Outfall + Remaining to East River Outfall)	2,900	2,000

Based upon this evaluation the WRRF can meet the 700 MGD peak sustained flow per the SPDES permit requirement with up to one unit out of service in all unit processes. A full explanation of the hydraulic model development and results is included in *Technical Memorandum 3 – Flow and Loading Projections* (**Appendix C**).

6 Influent Flow and Loading Projections

The establishment of future influent flow and mass loadings for use in this study was based on observed historical operations and performance data (as confirmed by the full-plant process model) and population growth projections from the New York Metropolitan Transportation Council (NYMTC) based on 2010 US Census Data for 2030, 2040 and 2050 conditions at the Newtown Creek Sewershed. The growth projections were developed in 2019 by DEP and the basis for the projections is historical average influent flows and concentrations for the 2015 to 2019 operating period. The provided growth projections showed an increase in loading to the facility of 8, 12, and 14% for 2030, 2040, and 2050 conditions, respectively. For the purposes of this evaluation, it was assumed that influent flow would increase at the same rate and that the influent strength would remain consistent over time.

The three future flow and loading scenarios are shown in **Table 5** to **Table 7**. A detailed summary of the development of these flows and loadings are available in **Appendix C**.

Table 5 - Future Influent Flow and Mass Loadings – 2030 Condition

Parameter	AA	MM	MW	MD
Flow	230	262	320	563
Flow PF	---	1.14	1.40	2.45
Load PF	---	1.15	1.35	2.00
COD, lbd	701,676	806,928	947,263	1,403,353
$cBOD_5$, lbd	317,659	365,308	428,840	635,318
$cBOD_5$ (uninhibited), lbd	334,378	384,535	451,410	668,756
TSS, lbd	310,228	356,762	418,807	620,455
VSS, lbd	277,359	318,963	374,435	554,718
TKN, lbd	59,130	67,999	79,825	118,260
NH_3-N, lbd	38,358	44,111	51,783	76,715
TP, lbd	7,764	8,929	10,482	15,529
PO_4-P, lbd	4,705	5,410	6,351	9,409

Notes:
AA – average annual, MM – maximum monthly, MW – maximum weekly, MD – maximum daily.

Table 6 - Future Influent Flows and Mass Loadings – 2040 Condition

Parameter	AA	MM	MW	MD
Flow	238	272	332	583
Flow PF	---	1.14	1.40	2.45
Load PF	---	1.15	1.35	2.00
COD, lbd	727,664	836,814	982,347	1,455,329
$cBOD_5$, lbd	329,424	378,838	444,723	658,849
$cBOD_5$ (uninhibited), lbd	346,762	398,777	468,129	693,525
TSS, lbd	321,717	369,975	434,319	643,435
VSS, lbd	287,632	330,776	388,303	575,263
TKN, lbd	61,320	70,518	82,782	122,640

Parameter	AA	MM	MW	MD
NH_3-N, lbd	39,778	45,745	53,701	79,557
TP, lbd	8,052	9,260	10,870	16,104
PO_4-P, lbd	4,879	5,611	6,587	9,758

Notes:
AA – average annual, MM – maximum monthly, MW – maximum weekly, MD – maximum daily.

Table 7 - Future Influent Flows and Mass Loadings – 2050 Condition

Parameter	AA	MM	MW	MD
Flow	242	277	338	594
Flow PF	---	1.14	1.40	2.45
Load PF	---	1.15	1.35	2.00
COD, lbd	740,658	851,757	999,889	1,481,317
$cBOD_5$, lbd	335,307	385,603	452,664	670,614
$cBOD_5$ (uninhibited), lbd	352,955	405,898	476,489	705,909
TSS, lbd	327,462	376,582	442,074	654,925
VSS, lbd	292,768	336,683	395,237	585,536
TKN, lbd	62,415	71,777	84,260	124,830
NH_3-N, lbd	40,489	46,562	54,660	80,977
TP, lbd	8,196	9,425	11,064	16,392
PO_4-P, lbd	4,966	5,711	6,704	9,932

Notes:
AA – average annual, MM – maximum monthly, MW – maximum weekly, MD – maximum daily.

7 BNR Alternatives Evaluation

Several alternative treatment configurations for BNR at the NC WRRF were initially considered at the outset of this study, with five (5) being shortlisted for evaluation in further detail. The 2050 flow and mass loading condition were adopted as the basis for evaluation of treatment technologies. This section of the report starts with a brief overview of each technology for each treatment alternative and its applicability to the NC WRRF for the purposes of TN removal.

Preliminary treatment footprint requirements, proposed layout and anticipated effluent quality, operations and maintenance costs, conceptual capital cost estimates, etc. are presented along with practical considerations for implementation. Conceptual layouts and cost estimates (capital and operational expenditures) were developed for the alternatives considered potentially feasible at the NC WRRF. It is important to note that changes and/or upgrades to the solids handling treatment train were not considered as part of this evaluation based on discussions with DEP and that the focus was the liquid treatment train and improvements to TN removal.

The following alternative treatment configurations were evaluated as part of this study:

- **Alternative 1 – Step-Feed BNR**

  In this treatment alternative the activated sludge process would be upgraded to operate similarly to the WRRFs in the UER, with step-feed of wastewater to four-pass aeration tanks operating in nitrification/denitrification model. The existing basins would be retrofitted to operate with upfront anoxic/swing zones to facilitate denitrification and the WRRF would operate at higher SRTs to facilitate year-round nitrification. As such, the process air blower and diffuser systems would be upgraded to deliver the increased volume of process air required for nitrification.

- **Alternative 2 – Conventional + Biological Active Filters (BAFs)**

  Alternative 2 was based on maintaining the existing liquid treatment train as it is today and directing a portion of the secondary effluent to a nitrifying and denitrifying BAF system before returning the process flow immediately upstream of effluent disinfection. This approach would allow for nitrification to occur in an aerated BAF unit, followed by denitrification through an anoxic BAF dosed with supplemental carbon (i.e., glycerol or methanol).

- **Alternative 3 – Conversion to Membrane Bioreactors (MBR)**

  In this treatment alternative the activated sludge process would be converted to an MBR configuration. The existing aeration basins would be converted to operate in plug flow mode with upfront anoxic/swing zones to facilitate denitrification. The existing secondary clarifiers would be retrofitted to house fine screens and a membrane filtration system. This conversion would allow the WRRF to operate at the much higher MLSS concentrations/SRTs required for BNR within the existing site treatment footprint.

- **Alternative 4 – Conversion to Membrane Aerated Biofilm Reactors (MABR)**

  Alternative 4 includes the installation of an attached growth process within the existing aeration tanks. MABR technology is like MBR but in this application the membrane cassette units placed within portions of the aeration tanks and are aerated in order to grow biofilm. The growth of this supplemental biomass can help improve the ability to nitrify while at the same time minimizing MLSS concentration in the bulk solution, keeping solids loading rates on the secondary clarifiers low and maintaining effluent quality.

- **Alternative 5 – Conversion to Integrated Fixed Film Activated Sludge (IFAS)**

  Alternative 5 is similar to Alternative 4 in that it also includes an attached growth process to intensify treatment within the existing aeration tanks. In this configuration portions of the existing aeration basins would have to be retrofitted to house floating biomass media carriers. This media promotes the growth of a nitrifying biomass, which helps improve nitrogen removal while at the same time minimizing MLSS concentration in the bulk solution, keeping solids loading rates on the secondary clarifiers low and maintaining effluent quality.

7.1 Site Constraints and Limitations

7.1.1 Available Treatment Footprint

The NC WRRF is footprint-limited and additional land acquisition is not considered feasible given the location and occupation levels of the surrounding areas. Accordingly, this evaluation required limiting treatment alternatives that would fit within the existing facilities.

The largest currently unused portion of the site is occupied by abandoned gravity thickeners (GTs). From the original set of eight GTs, four are planned to be used by the food waste co-digestion program and one is reserved for future use as a sludge storage tank, according to DEP. The remaining three west GTs could potentially be demolished in order to provide footprint for new systems proposed in this study. Another area currently occupied by unused equipment is the second floor of the grit handling building, situated at the eastern end of the plant. According to DEP, the existing WAS degritters located in that area are offline and could be removed if needed. Areas available for development are highlighted in **Figure B**.

7.1.2 Secondary Clarifier Capacity

Alternatives 1, 3, 4, and 5 have their TN removal performance restricted by the existing secondary clarifiers due to the limitations in maximum allowable AEMLSS and therefore achievable SRT. A desk top state-point analysis (SPA) was prepared for the existing secondary clarifiers for the following parameters:

- **Flow conditions:** Peak Hydraulic (700 MGD) and Maximum Day (594 MGD) projected for 2050.

- **Sludge Volume Index**: 95th percentile (173 mg/L) and 90th percentile (147mg/L). Average SVI for the data collected is 105 mg/L.

- **Units in service:** all units in service (24 units online) and one unit offline per battery (21 units online).

The analysis resulted in eight different scenarios as shown in **Table 8.** A constant RAS rate of 234 MGD was adopted in all scenarios, which corresponds to the maximum capacity of the existing RAS pumping system with one unit offline per RAS well. Maximum RAS concentration allowed was 9,000 mg/L for any scenario.

Table 8 - State-Point Analysis for Existing Secondary Clarifiers

Flow Condition, MGD	SVI Percentile	SVI, mL/g	Units in Service (TOTAL: 24)	SOR, gpd/ft^2	SLR, lbd/ft^2	Allowable MLSS, mg/L
MD - 594	95th	173	24	1,118	31.2	2,400
	95th	***173***	***21***	***1,277***	***31.2***	***2,100***
	90th	147	24	1,118	35.2	2,700
	90th	147	21	1,277	35.5	2,600
Peak - 700	***95th***	***173***	***24***	***1,317***	***30.8***	***2,100***
	95th	173	21	1,506	30.2	1,800
	90th	147	24	1,317	32.3	2,200
	90th	147	21	1,506	33.5	2,000

A maximum allowable AEMLSS of 2,100mg/L, corresponding to Peak Flow Condition with all clarifiers in service or Maximum Daily Flow Condition with three clarifiers offline was adopted for the subsequent alternative evaluation.

7.1.3 Raw Influent Screening

Alternative 3 (MBR), 4 (MABR), and 5 (IFAS) all require finer influent or MLSS screening (1 to 3 mm compared to the current 10 mm secondary screens) due to the lack of primary clarification and the need to protect sensitive treatment equipment from debris that may enter the WRRF. Due to the footprint limitations and the large flowrates involved, diversion of raw influent for screening at a different location is not feasible. The most promising approach for fine screening implementation at the NC WRRF was assumed to be the swapping of existing secondary screens with finer ones.

The NC WRRF receives influent from the Manhattan pump station (PS) and the Brooklyn-Queens PS. Influent is pre-screened at those stations, with 1" screens installed in the Brooklyn-Queens PS and in the Manhattan PS. Both influent streams are then combined at the forebay of the Secondary Screens located in the Residuals Building at NC WRRF. Downstream to the Secondary screens afterbay, the influent flows into a junction chamber followed by a splitter box.

There are twelve secondary screens staggered at twelve channels. Each 3/8" (~ 10mm) screen has a maximum capacity of 80 MGD. In peak hydraulic flow condition, it is expected that ten screens would be put in operation, with two units in standby mode. There is an overflow that allows for secondary screening bypass when upstream water levels achieve a certain elevation (25.25 ft versus 23.4 ft at peak hour operation conditions). The overflow has a maximum capacity of 80 MGD and was designed to prevent influent back up in case one screen gets blinded.

Figure 4 presents a Process Flow Diagram for the raw influent up to the head of the aeration basins. **Figure 5** shows the hydraulic profile with expected water levels at various operation conditions (peak hour, peak day, design average and existing average).

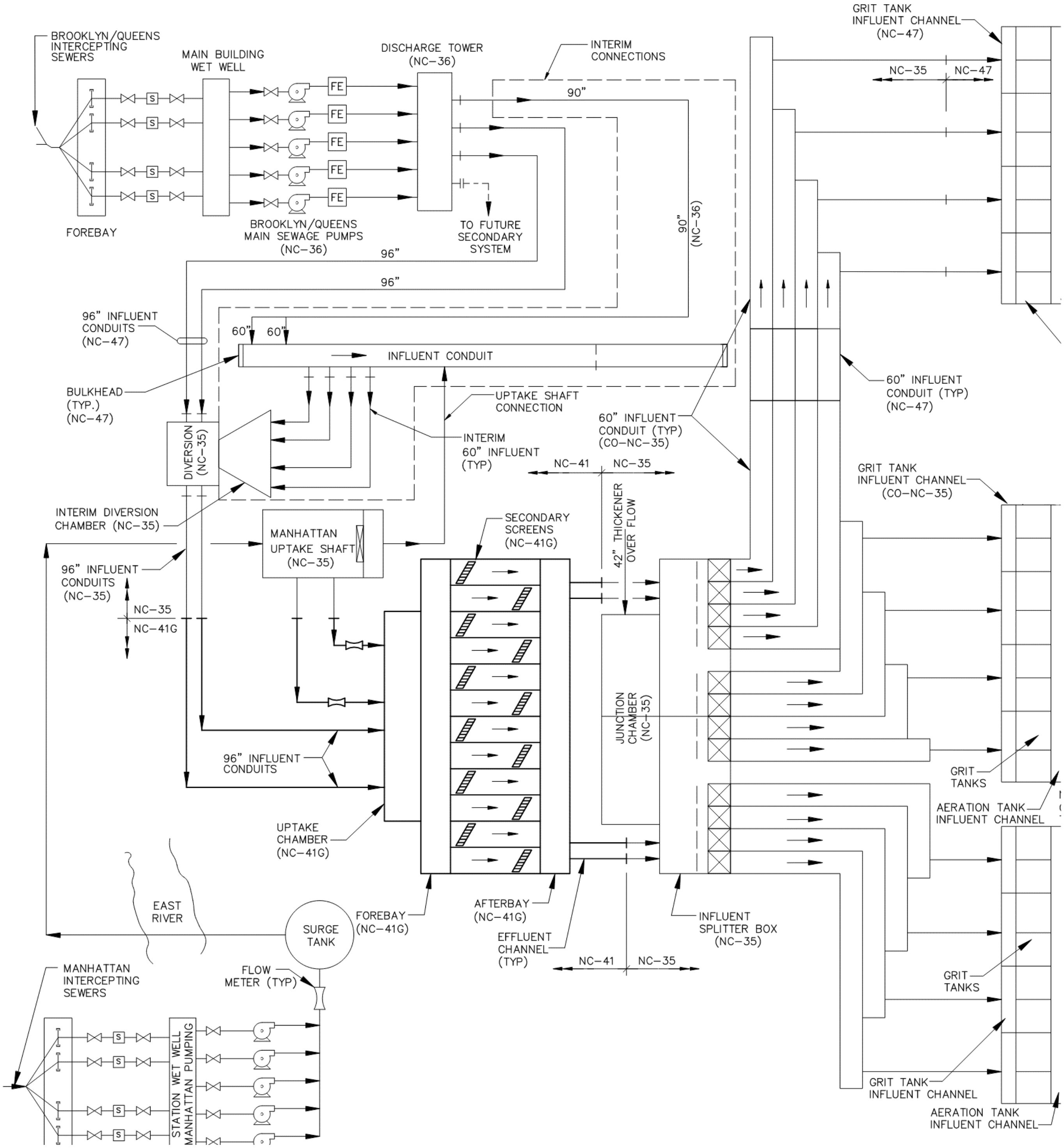

Figure 4 - Partial process flow diagram (from AB-41G-00G-04)

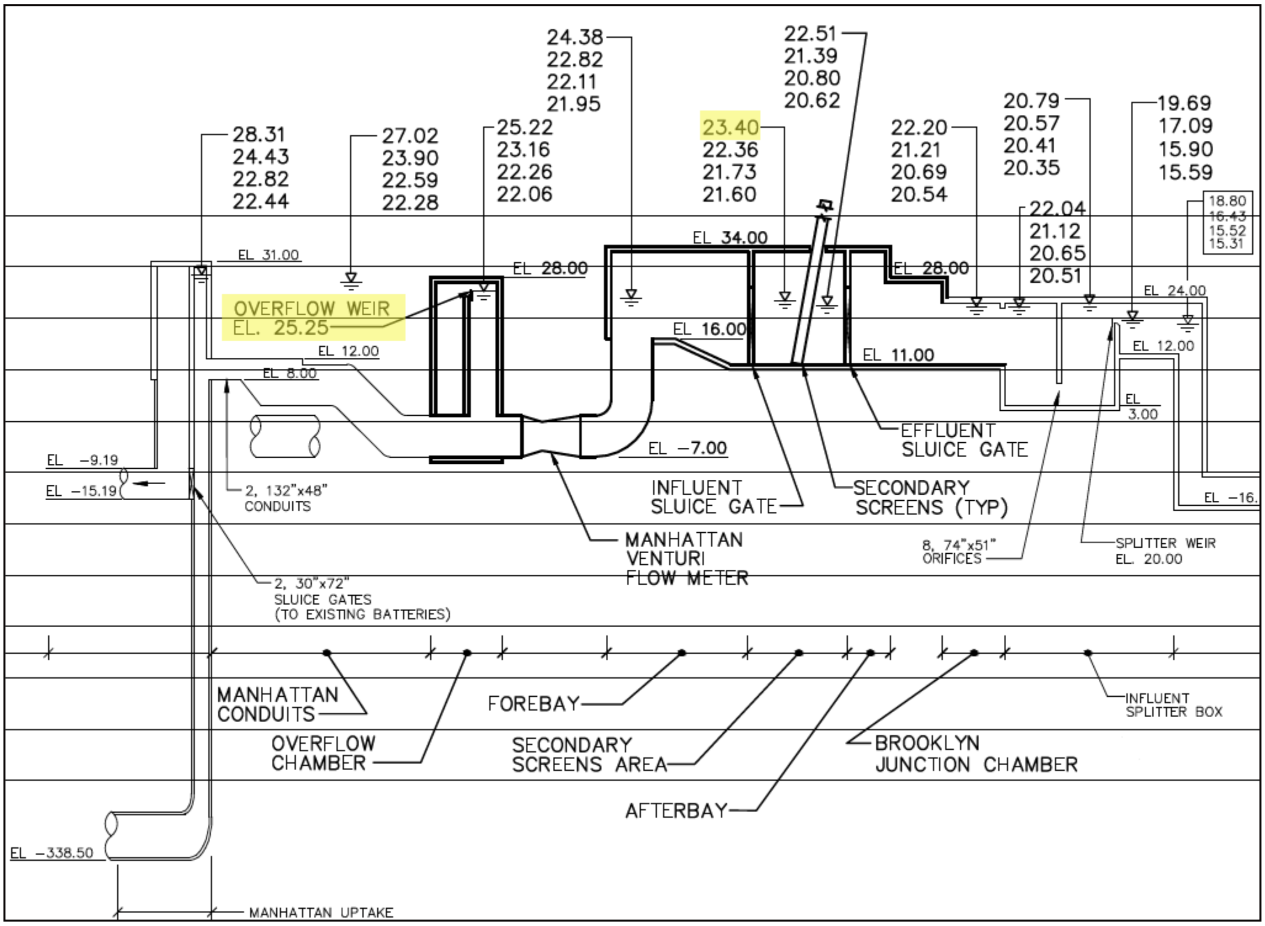

Figure 5 - Hydraulic profile of raw influent conveyance and screening (from AB-41G-00G-05)

A screenings equipment manufacturer (Headworks International) was consulted and concluded that the existing channels could accommodate finer screens (see attached proposal in Appendix F). However, there are several risks associated with implementation of fine secondary screens of raw influent that should be considered:

- 2 mm spacing will capture virtually all solids in the influent flow and even particles smaller than 2 mm due to the potential for matting on the screens. Because of this the headloss associated with the fine screens may be higher than theoretical headloss values.

- The high potential for fouling due to the elevated concentration of grease and colloidal material in raw influent of a combined sewer system, which could result in increased maintenance efforts and washwater consumption for both screens and compactors.

- Screens expected to run more frequently than typical raw influent screens, increasing wear and tear. Reinforced frames are needed due to high headlosses expected.

- High potential for blinding in fine screening for combined sewer overflow (CSO) systems which often see high instantaneous screening loads – particularly non-flushable material which can overwhelm the screens and/or the screening handling system. Additionally, the existing emergency by-pass could not be used anymore since the conveyance of non-screened influent to delicate systems such as MBR, MABR, or IFAS is unacceptable.

- Very large volume of screenings expected to be generated and managed with considerable footprint restrictions. Headworks International declined to provide an estimate of the quantity of screenings to be generated due to the lack of literature data available. Manual of Practice (MOP) no.8 indicates that the amount of screenings will increase by a minimum of 2 to 3 times the existing on average. This would require a significant change in the screening management units. It is worth noting that a number of operations in the screenings management system is manual and labor intensive.

- General concerns with odor generation and possibility of solids "extrusion".

Based upon these considerations it is recommended that fine screening of raw influent would require extensive pilot testing, whereby a 2 mm screening unit is installed into an influent screenings channel to demonstrate the ability of the screen to operate as well as define the quantity and characteristics of the screening material.

7.1.4 Existing Electrical Distribution Systems

Every treatment alternative presented in this report involves higher energy consumption than what is currently seen at the WRRF. The estimated capital construction costs associated with upgrading existing electrical distribution systems are usually estimated as a percentage of the additional equipment cost for conceptual level evaluations. However, if additional power consumption is very significant compared to the original design of the WRRF power supply system, upgrades beyond local level (outside the WRRF) distribution may be required. In that case, the estimated of costs for electrical distribution system upgrades become higher and harder to accurately estimate without a more detailed engineering analysis.

The existing NC WRRF electrical distributions system consists of both medium and low voltage distributions that serve the connected equipment loads. Four 26,400-volt Con Eddison feeders serve the Main Substation which supplies 15,000 Volt for distribution throughout the plant. The design capacity of the main substation is 54 million volt-amps (MVA).

Four turbine generators supply a backup power source to the plant in the event of a Con Edison outage. The total capacity of the existing turbine generators is 20 MVA assuming all four generators in operation and not intended as an N+1 system. The backup power source capacity is 37 % of the main substation capacity which usually indicates that the backup power source supplies only critical plant equipment, normally pumping, secondary clarification, and effluent disinfection.

480 Volt double-ended unit substations are positioned at various location across the site. There are two double ended unit substations located at the south battery control building with a total design capacity of 4 MVA. There are four double ended unit substations located at the north battery control building serving both the north and central batteries. The total design capacity of the four substations is 12 MVA.

7.2 Baseline Treatment - 2050

A set of process model simulations were performed at steady state to represent the 2050 scenario without changes to the liquid treatment processes or operational strategies. The model was performed at a total SRT of 1.5 days for all scenarios and with a wastewater temperature of 21°C for the summer and 16°C for the winter runs. The baseline modelling effort resulted in effluent quality as follows:

- Similar to historical operations there is no nitrification under for the same treatment configuration under the 2050 loading scenario. For this scenario the AA effluent NH_3 concentration is 15 mg/L-N and AA effluent TN concentration is 18 mg/L-N.

- For the 2050 loading scenario the AA effluent TN is 36,100 lbd, equal to 9,025 lbd of nitrogen equivalents or 20% of the aggregate TN limit for the CER.

Table 9 - Modelling Results: Baseline (2050 Condition)

Loading Condition	Temp, °C	AEMLSS, mg/L	Total SRT, days	Aer SRT, days	Eff NH_3, mg/L	Eff NO_3, mg/L	Eff NO_2, mg/L	Eff TN, mg/L	Eff TN, lbd
AA	21	1,800	1.5	1.3	13	< 1	< 1	16	32,400
MM	21	2,000	1.5	1.3	13	< 1	< 1	16	37,100
AA	16	1,800	1.5	1.3	18	< 1	< 1	20	39,800
MM	16	2,000	1.5	1.3	18	< 1	< 1	20	45,400
Yearly AA		1,900	1.5	1.3	15	< 1	< 1	18	36,100
CER Contribution									9,025 (20% of TMDL)

7.2.1 Baseline Process Air Demand - 2050

The WRRF has nine process air blowers located in the Main Building designed for $cBOD_5$ oxidation. Each of the centrifugal blowers has a 39,000 scfm capacity and the system was intended to have seven operational units with two units available as standby. There is space available in the blower room for one additional unit to be installed in the future. These blowers feed diffuser grids in the twelve aeration tanks. The aerobic zones are fitted with ceramic diffusers while the selector zones have membrane diffusers.

Table 10 - Existing Blower Design Parameters

Parameter	Value
Quantity	9
Operational	7
Standby	2
Max. scfm per Blower	39,000
Total SCFM (7 Units)	273,000
Total SCFM (9 Units)	351,000

Table 11 - Existing Diffuser Design Parameters

Parameter	Ceramic	Membrane
Location	Aerobic Zones	Selector Zones
Zones	A1, A2, B2, B3 C2, C3, D1, D2	B1, C1
Total Grids	132	24
scfm/diffuser	0.5-2.25	0.5-2.25
Total per Tank	7,728	1,756
Total Diffusers	92,736	21,072

Arcadis calculated the baseline aeration demand for the 2050 loading condition under the following assumptions:

- Influent $cBOD_5$ and NH_3 loadings are from the 2050 flow and loading projections **(Appendix C)**.
- System is designed for complete oxidation of $cBOD_5$ and no nitrification.
- The current configuration of aerobic and selector zones (see **Table 11**) is used.

Based on these assumptions the 2050 baseline air demand is 147,981 scfm, as summarized in **Table 12** below:

Table 12 - 2050 Process Air Demand for Baseline

Loading Condition	Daily Average, scfm
Min. Day	53,944
AA	147,981
MM	172,605
Max Day	317,494

7.3 Alternative 1 – Conventional Step-Feed BNR

7.3.1 Treatment Technology Overview

This treatment alternative includes conventional step-feed BNR in the existing aeration tanks. The treatment configuration would be altered to include an anoxic/swing zone at the beginning of each pass (A through D). In this arrangement nitrification would occur in the aerated zones converting NH_3 to NO_3, and denitrification would occur in the anoxic zones converting NO_3 to nitrogen gas. A flow split of 10% to Pass A, 40% to Pass B, 30% to Pass C, and 20% to Pass D was assumed for this evaluation. To facilitate nitrification as part of this alternative, process air blowers would be replaced with larger units and the existing diffuser system would need to be upgraded. A simplified process flow diagram of this alternative is shown in **Figure 6.**

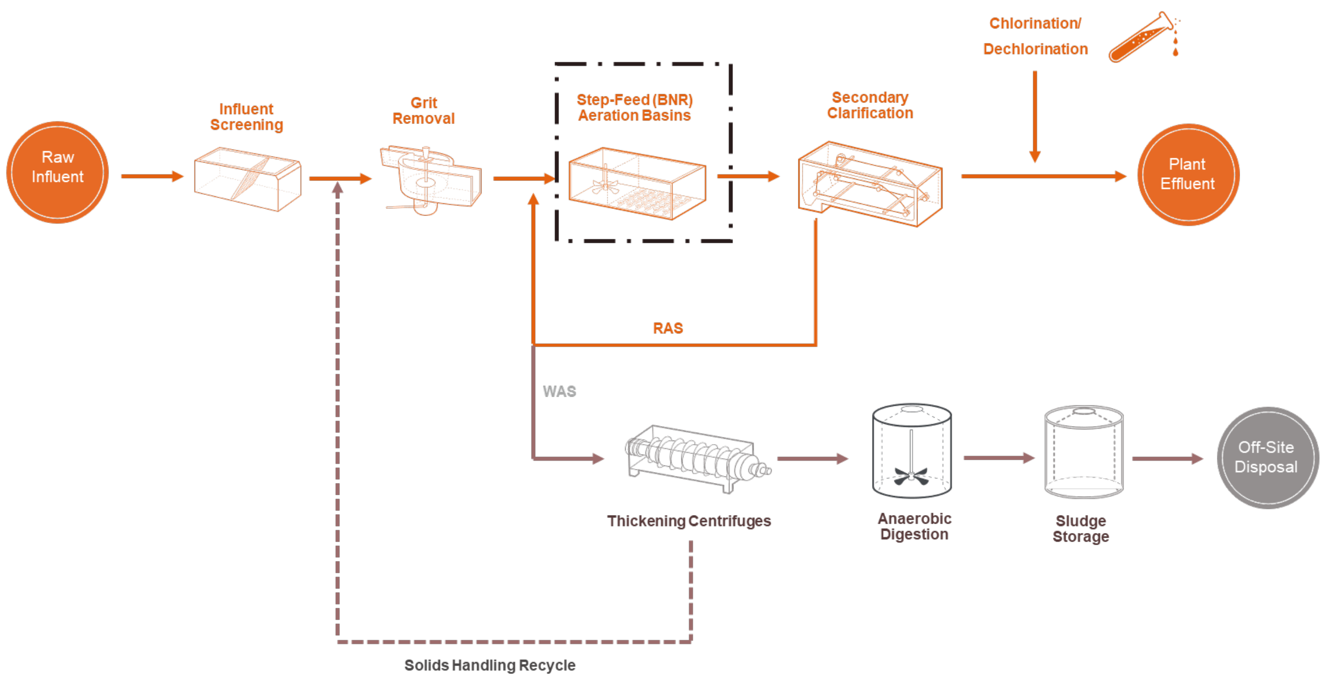

Figure 6 - PFD for the implementation of Alternative 1 - Conventional Step-Feed BNR at NC WRRF

7.3.2 Unit Process/Equipment Sizing and Footprint

As this scenario utilizes all existing infrastructure no footprint is required for the installation of new equipment.

7.3.3 Anticipated Effluent Quality

The full-plant process model was used to evaluate the potential for nitrogen removal with this treatment method. As with the baseline configuration model simulations, Arcadis used steady state models for summer and winter scenarios at AA and MM loadings. The wastewater temperature was 21°C for the summer scenario and 16°C for the winter scenario.

To achieve meaningful nitrification and denitrification in the existing aeration tanks the WRRF needs to operate at an aerobic SRT of approximately 6 days during the summer months or 8 days during winter months. With these SRTs, however, the AEMLSS exceeds 6,000 mg/L in the summer and is greater than 7,000 mg/L in the winter, which greatly surpasses the allowable mixed liquor of 2,100 mg/L as determined in the state point evaluation of the existing secondary clarifiers (**Section 7.1.2**). Model simulations were also performed limiting AEMLSS concentrations to 2,100 mg/L for all scenarios per the state point analysis limitation. This results in an associated aerobic SRT of approximately 1.4 days, which is far too low to provide BNR level performance at the WRRF.

While the modeling predicts an effluent TN reduction of 54% for this alternative compared to the baseline, it is not feasible due to the higher SRT requirement and associated AEMLSS concentrations.

Table 13 - Modelling Results: Conventional Step-feed BNR (2050 Condition)

Loading Condition	Temp, °C	AEMLSS, mg/L	Total SRT, days	Aer SRT, days	Eff NH_3, mg/L	Eff NO_3, mg/L	Eff NO_2, mg/L	Eff TN, mg/L	Eff TN, lbd
AA	21	6,000	8.7	6.0	0.9	5.1	0.3	8.2	16,600
MM	21	6,600	8.7	6.0	1.0	5.3	0.3	8.6	19,700
AA	16	7,700	12	8.0	1.6	4.2	0.5	8.4	16,900
MM	16	8,500	12	8.0	1.8	4.3	0.6	8.7	19,900
Yearly AA		6,850	10	7.0	1.3	4.7	0.4	8.3	16,750
% Reduction Eff TN									54%
CER Contribution									4,188 (9% of TMDL)

7.4 Alternative 2 – Step-Feed Conventional + Biological Active Filters (BAFs)

7.4.1 Treatment Technology Overview

Alternative 2 includes a nitrifying and denitrifying BAF system that would treat a small portion of secondary effluent flow before returning the process flow immediately upstream of effluent disinfection. This approach would allow for nitrification to occur in an aerated BAF unit, followed by denitrification through an anoxic BAF dosed with supplemental carbon (i.e., glycerol or methanol). BAFs promote wastewater treatment and solids removal simultaneously through media that acts both as biofilm carrier and filtration medium. Accumulated solids are removed from the filter by backwashing (water and/ or air). Media can be mineral (such as sand) or plastic (random or structured). BAFs can be used for secondary or tertiary treatment, for $cBOD_5$ removal, nitrification, or denitrification.

Figure 7 - Example of BAF installation (De Nora's website)

BAFs can be classified into different categories depending on the type (density) of media used and their flow regimes. Sunken media filters can be upflow (such as Suez's Biofor) or downflow, with downflow configurations performing better for tertiary treatment (such as De Nora's Denite filter). Floating media filters are strictly upflow (such as Veolia's Biostyr). While sunken media filters required media support at the bottom, floating media filters require nozzle decks or metal grids for media retention at the top of the bed.

Process and scour air (when required) are usually supplied at the bottom of the filter with the use of coarse bubble diffusers. Air supply is sometimes located closer to the mid-section when the filter is upflow with an anoxic zone at the bottom. For tertiary denitrification systems, such as filters, BAFs, and MBBRs with a postanoxic fixed-film zone, the supplemental carbon source is vital to system operation.

For the NC WRRF, the configuration evaluated is the use of BAF units for tertiary treatment. The existing treatment units would continue to operate as in the baseline (step-feed aeration followed by sedimentation tanks). A portion of the flow would be diverted to BAF units for nitrogen removal and the treated effluent would be blended with secondary effluent prior to disinfection. There is little footprint available at the site for the installation of tertiary filters, as mentioned in **Section 7.1.1**. The approach for this alternative is to treat only a portion of the secondary effluent, as much as possible within the given footprint. It is assumed that the abandoned gravity thickeners currently occupying the area would have to be demolished for the installation of the BAF system. The available footprint is estimated in ~30,000 sqft.

The proposed configuration is shown in **Figure 8.**

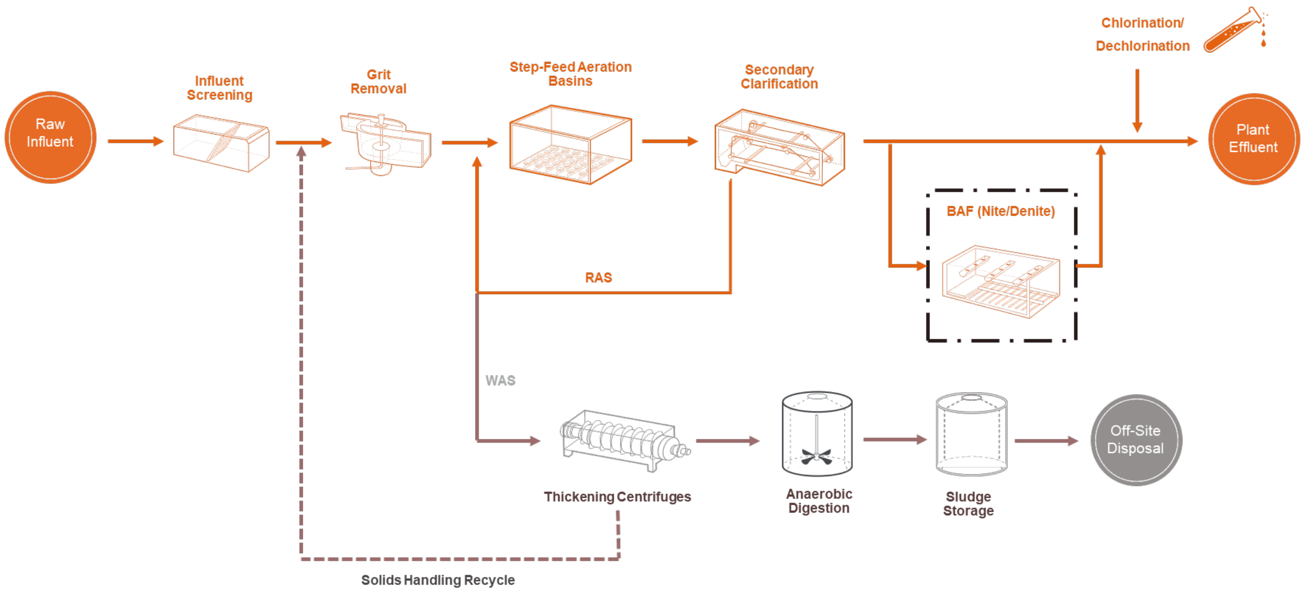

Figure 8 - PFD for implementation of Alternative 2 – Conventional Step-Feed and BAF at NC WRRF

7.4.2 Unit Process/Equipment Sizing and Footprint

Input was requested from De Nora and Veolia for the installation of a nitrifying/denitrifying BAF system. De Nora's proposed solution is a two-stage system consisting of Tetra ColOX reactors (nitrification) and Denite filters (denitrification), both filled with mineral media, able to treat up to 24 MGD. Veolia's proposed solution is a two-stage system with plastic floating media, composed by Biostyr Duo cells (for nitrification) and Biostyr cells (for denitrification), able to treat up to 30 MGD. Veolia's proposal was used for the development of conceptual design and costs. Both proposals are attached to this report in **Appendix F**.

Table 14 shows design parameters and configuration proposed by Veolia for the system. Application rates and loadings are within the range provided by MOP 8, with hydraulic loading being the limiting factor for this application.

Table 14 - Design Criteria and Proposed Configuration for Alternative 2 – Conventional Step-Feed and BAF (Veolia)

Parameter	Nitrification Step	Denitrification Step
Number of cells	6	10
Size of cells (ft^2)	940	468
Total media volume (ft^3)	79,000	38,400
Application loads - NH_3-N or NO_3-N (lbs/day/ft^3)	0.05	0.1
Filtration velocity (AA) (gpm/ft^2)	3.7	4.2
Filtration air/ cell (scfm)	650	N/A
Backwash air/ cell (scfm)	990	400
Backwash wastewater production (MGD)	1.2	0.72

Secondary effluent would be pumped to the BAF units elevated inlet channel by submersible pumps. Three units (1 spare) would be installed in the secondary effluent channel in the Central battery. Daily flows in the channel are above the 30MGD that will be pumped out.

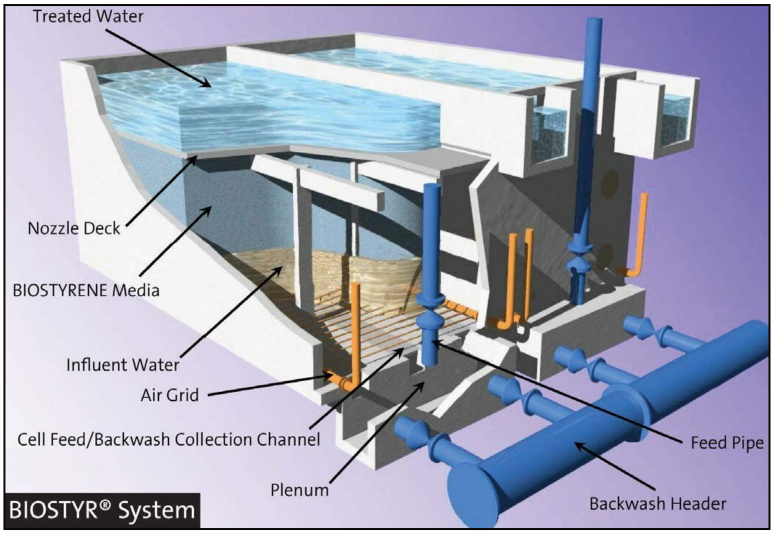

Figure 9 - Biostyr System (Veolia) schematics

No preliminary treatment is necessary for tertiary filtration – Veolia recommends 10 mm screening at the headworks, which corresponds to the existing equipment installed at NC WRRF. Therefore, no changes in the current screening and screenings management operations at the plant would be required.

The effluent would feed the nitrification units flowing upwards, with air being supplied from the bottom through bubble diffusers. From the top of those units, effluent would be gravity-fed to the nitrification units (also upwards filtration). Supplemental carbon is provided by methanol or glycerol. Treated effluent is stored at the top of the nitrification unit and sent back to disinfection by gravity.

Figure 10 shows the proposed hydraulic profile the system. Grade level for this study is at ~ 95ft, with a buried mudwell and a partially buried denitrification unit.

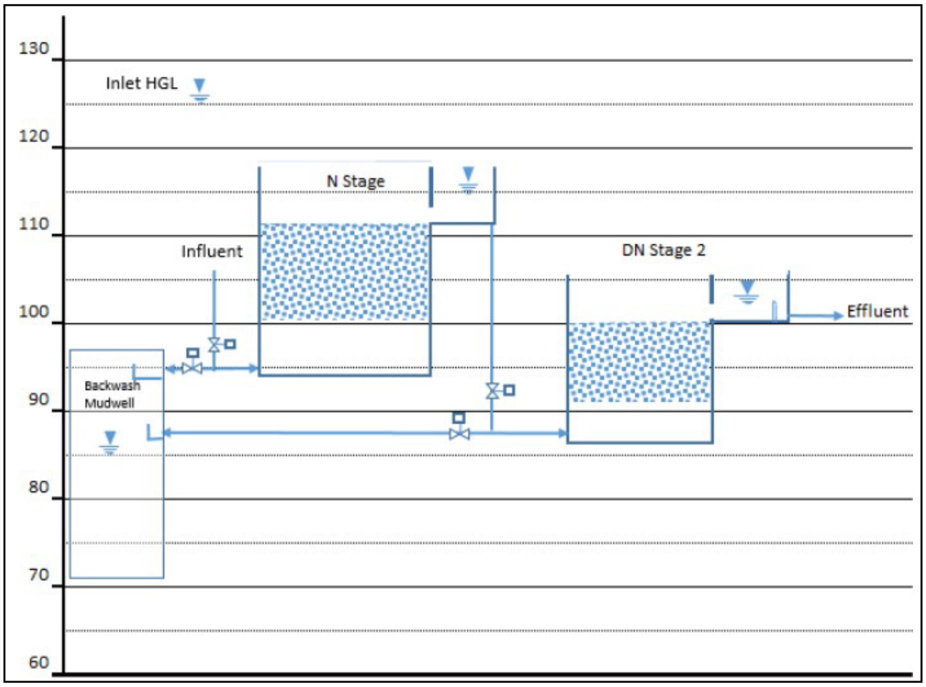

Figure 10 - Preliminary hydraulic profile for BAF area (from Veolia). Grade level – 95ft.

The filtered effluent stored at the top of the filters (shown in **Figure 10**) and is used for downflow backwashing when required. Air is also used for backwashing in the nitrification units. Backwash water is stored in a common mudwell and slowly pumped back to the headworks by submersible pumps. The total volume of water consumed in backwashing (recycled) is ~1.9 MGD. General operation, including backwashing, is completely automated.

The areas shown in the layout for nitrification and denitrification units include all associated piping and equipment. A small supplemental carbon storage area would be located in a building above the mudwell.

7.4.3 Anticipated Effluent Quality

Treatment with the implementation of BAFs was modelled using the existing configuration for the liquid treatment train operating at a total SRT of 1.5 days and aerobic SRT of 1.3 days. Based on manufacturer input, the BAF system would be able to treat approximately 30 MGD of secondary effluent to a total inorganic nitrogen (TIN) concentration of less than 3 mg/L-N. Using the information provided by the BAF manufacturer, a nitrogen balance was completed for each of the model scenarios under the assumption that the BAF will reduce TIN to 3 mg/L-N in a treated volume of 33 MGD during winter months or 30 MGD during the summer months.

As summarized in **Table 15**, this treatment alternative provides a 3,400 lbs TN/d reduction (**9% reduction**) in effluent total nitrogen discharges compared to the baseline treatment configuration. This equates to an increase in the removal of nitrogen from the by approximately **840 lbd.**

Table 15 - Modelling Results: Alternative 2 - Conventional Step-feed + BAF (2050 Condition)

Loading Condition	T, °C	AEMLSS, mg/L	Secondary Eff.				BAF				Final Eff. TN, lbd
			NH_3, mg/L	TIN, mg/L	Org. N, mg/L	TN, mg/L	Flow, MGD	Inf TIN, mg/L	Eff TIN, mg/L	N Removed, lbd	
AA	21	1,813	13.2	13.9	2.1	16.0	30	13.9	3.0	2,727	29,626
MM	21	2,005	13.4	14.0	2.1	16.1	30	14.0	3.0	2,752	34,360
AA	16	1,845	17.6	17.6	2.2	19.7	33	17.6	3.0	4,013	35,828
MM	16	2,041	17.6	17.6	2.1	19.7	33	17.6	3.0	4,013	41,416
Yearly Average		1,829	15.4	15.7	2.1	17.9	32	15.7	3.0	3,370	32,727
Reduction Eff TN, %											9% (36,100 lbd Baseline)
CER Contribution, lbd											8,182 (18% of TMDL)

7.4.3.1 Energy Consumption

Additional energy consumption for the implementation of this treatment alternative is in the order of 4,500,000 kWh/year, according to the breakdown provided by **Table 16:**

Table 16 - Energy consumption for Alternative 2 - Conventional Step-feed and BAF

Equipment	Energy consumption (kWh/year)
BAF Blowers	1,677,000
Effluent Pump Station	2,434,000
Mudwell mixing	261,000
Backwash pumps	156,000
TOTAL:	**4,528,000**

7.4.3.2 GHG Emissions

GHG emissions from Scopes 1 and 2 shall consider the following sources:

- Scope 1:
  - N_2O emissions from process (aeration)
  - N_2O emissions from effluent discharge
- Scope 2:
  - Power consumption (electricity use)

It was considered that no significant changes would occur in the solids treatment train, with no expected variation in GHG emissions for Scope 1 sources such as biogas or fuel oil combustion.

The Local Government Operations Protocol (LGOP) is based on the GHG Protocol, which require a two-part calculation to quantify N_2O emissions. The first part quantifies N_2O emission occurring during the treatment of wastewater and is based on the population served by the WRRF and whether the facility is using a conventional activated sludge treatment process or a nitrification/denitrification process. The second source of N_2O emissions is from nitrogen contained in the WRRF effluent. Emissions from electricity use for all alternatives were based on the emission factor from E-grid 2019, for NPCC NYC/Westchester subregion (251.8 kg CO_2eq /MWh).

Additional (net) GHG emissions for Alternative 2 are presented in **Table 17:**

Table 17 - GHG emissions for Alternative 2 - Conventional Step-Feed + BAF

Source	Scope	Emissions ($MTCO_2$eq/ year)
N_2O (treatment)	1	92
N_2O (discharge)	1	(1,360)
Electricity	2	1,140
TOTAL	1 and 2	(128)

Although N_2O emissions from the treatment system are expected to increase due to the implementation of BNR (per LGOP calculations), the nitrogen content in the effluent at the BNR Plants will decrease resulting in a reduction of discharge N_2O emissions. Considering Scope 1 and 2 emissions, a modest net decrease of 128 MT CO_2eq is expected for this alternative.

7.4.4 Operational and Construction Phase Considerations

The following operational considerations should be taken into account with this treatment alternative:

- The construction of BAFs for nitrogen removal at NC WRRF appears to be the simplest of all alternatives in this study. Most of the demolition and new construction effort will be confined to the footprint shown in **Figure C**. Installation of secondary effluent pumping and rerouting of filtered effluent for disinfection would require coordination with plant operations staff to ensure treatment performance is maintained but no major shutdowns are expected with implementation of this alternative.

- Operation of the BAF system is automated and requires minimal attention. Maintenance of air diffusers requires effort due to accessibility issues, but those events are expected to be minimal or non-existent according to Veolia. Media replacements are not required during the lifespan of the equipment.

- The use of methanol as source of supplemental carbon introduces a new hazardous chemical to the plant. If this alternative is to be implemented in the future, safer alternatives such as glycerol can be considered.

7.4.5 Estimate of Conceptual Construction Costs

AACE Class 4 construction cost estimates (accuracy range from -15 to -30% on the low side and 20 to 50% on the high side) were developed for each feasible treatment alternative and are presented in detail in **Appendix E**.

Major equipment costs were based on budgetary quotes from consulted vendors (presented in **Appendix F**). Installation costs were estimated to correspond to 10% or 15% of total equipment cost. General process piping was estimated at 20% of equipment cost, and electrical costs were estimated as 15% of total cost.

Cost Estimates developed do not include the following:

- Professional or permitting fees.
- Escalation.
- Construction contingency (a general design contingency of 35% is included)
- Hazardous materials abatement and handling.
- Rock removal.

Table 18 presents the summary of Construction Costs for Alternative 2, including markups adopted:

Table 18 - Construction Costs for Alternative 2 - Conventional Step-Feed and BAF

Cost Component			Cost ($)
Maintenance of Plant Operations (1)			$500,000
Secondary Effluent Pump Station			$6,919,000
New BAF Area			$40,028,375
Site Piping			$12,220,000
		Subtotal	**$59,667,375**
Phasing	5%		$2,983,325
General Conditions	20%		$12,530,100
General Contractor OH&P	21%		$15,788,000
Design Contingency	35%		$31,839,100
Bonds and Insurance	5%		$6,140,400

Cost Component	Cost ($)
Total Construction Cost	**$128,948,300**
Notes: (1) Allowance	

Total Construction Costs for Alternative 2 are in the order of $130 MM.

7.4.6 Estimate of Operations and Maintenance Costs

Operations and maintenance costs were estimated for each alternative as addition to the baseline costs. **Table 19** presents the breakdown per cost component for Alternative 2 – Conventional Step-Feed and BAF in terms of additional yearly cost to operate the biological treatment system,

Table 19 - O&M Costs for Alternative 2 - Conventional Step-Feed and BAF

O&M Component	Quantity	Unit Cost	Cost ($ / year)
Energy	4,528,000 kWh/year	0.1 $/kWh	$453,000
Glycerol	438,000 gal/ year	3.18 $/gal	$1,393,000
Labor	8 FTE (1)	140,000 $/year	$1,120,000
Maintenance (2.5% equipment cost)			$305,000
TOTAL:			**$3,271,000**
Notes: (1) FTE = full time employee			

The number of required full time employees (FTEs) considers one full time position for operation of the BAF system. Each full-time position created at any DEP plant corresponds to the hiring of five new FTEs when accounting for benefits. Another 3 FTEs are expected to be needed for additional maintenance to the blowers, pumps, and instruments.

7.4.7 30-Year Annualized Cost Estimates

A 30-year annualized cost was developed for this alternative, assuming financing over a 30-year period at a 3% bond rate and yearly OM costs in terms of 2021 dollars. With this approach, the annualized capital cost for this alternative is $6,578,847 per year over 30-years. The total annualized cost, including O&M (in 2021 dollars), is approximately $9,900,000 per year over 30 years.

In terms of nitrogen removal, the annualized investment to implement this alternative will cost approximately $8.00 per pound of nitrogen removed at the WRRF over a 30-year period of operation or $32.00 per pound of nitrogen removed in the East River.

Table 20 – 30-Year Annualized Costs for Alternative 2 - Conventional Step-Feed and BAF

Parameter	Value
N Removed, lbd	3,373
N Removed, lb/year	1,231,145
CER Equivalents Removed, lbd	843
Total Capital Cost, $	$128,948,300
Annualized Capital Cost, $/year*	$6,578,847
Annual O&M Cost, $/year**	$3,271,000
Total Annualized Cost, $/year	$9,849,847
$/lb N Removed	$8.00
$/lb N Removed in CER	$32.00

**Annualized cost of construction based on 3% Bond rate and 30-year financing period.*
***OM costs based on 2021 dollars.*

7.5 Alternative 3 – Membrane Bioreactor

7.5.1 Treatment Technology Overview

Membrane bioreactors (MBR) systems combine activated sludge treatment with membrane filtration. In the most common configuration for municipal WRRFs, membranes are immersed in the suspended growth activated sludge and replace secondary clarifiers in the function of separating solids and liquid. The liquid permeates the membranes driven by low vacuum created by permeate pumps. The effluent, called permeate, is of tertiary quality (TSS < 1mg/L). Although it is possible to install the membranes directly in the bioreactor, the most common option for large facilities is to install the membranes in a separate tank to simplify cleaning operations.

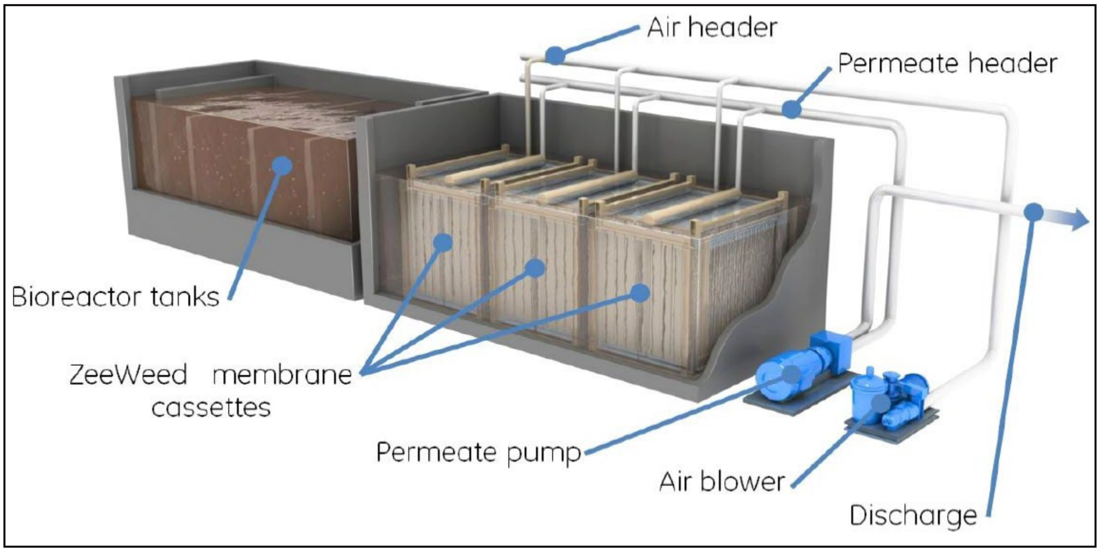

Figure 11 - Schematics for MBR system (source: Suez Zeeweed brochure)

MBR systems can operate at mixed liquor concentrations as high as 8,000 mg/L-10,000 mg/L, allowing for a higher biomass inventory for a given aeration basin volume. The higher mixed liquor concentrations in the reactor and the elimination of the need for secondary clarifiers provide for significant footprint reduction when comparing MBRs to conventional activated sludge processes.

MBR systems are more energy intensive than conventional processes due to higher RAS pumping rates (RAS flows four times the influent flow) and the need for constant membrane air scouring. The scouring is executed by dedicated air scour blowers with the goal of preventing biofilm growth at the surface of the membrane. Fine screening in the order of 2-3 mm is an absolute requirement upstream to the membrane tanks to prevent membrane clogging.

There are two types of membrane cleanings required for MBR systems. Maintenance cleanings are short and automated with daily frequency, usually accomplished with the injection of sodium hypochlorite at low concentration in the permeate piping. Recovery cleanings are recommended when a certain level of fouling is observed in the membranes through an increase in transmembrane pressure. They are normally needed every 4 to 6 months and require the corresponding membrane train tank to be put offline, drained, and filled with the recommended cleaning chemicals (usually citric acid). The membranes then soak in the chemicals for a few hours. Apart from these planned recovery cleanings, the operation of MBR systems is fully automated and operator attention required is reduced.

Figure 12 shows the process flow diagram for implementation of a MBR system at NC WRRF with the implementation of fine screening downstream to the aeration basins followed by membrane filtration.

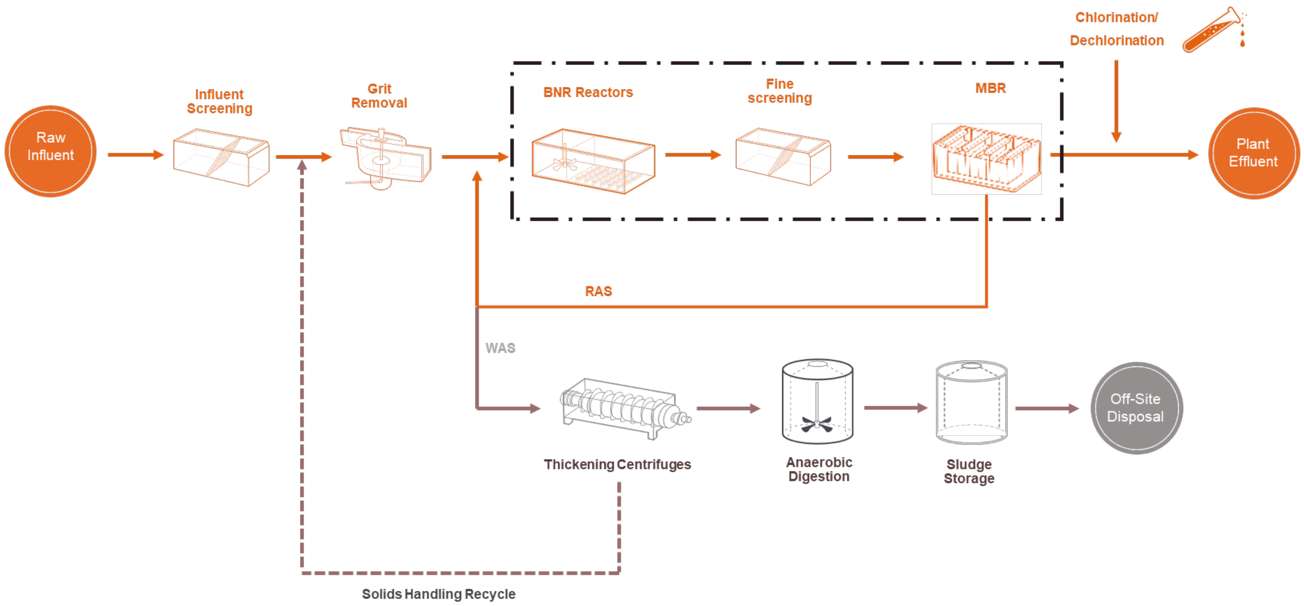

Figure 12 - PFD for implementation of Alternative 3 - MBR at NC WRRF

7.5.2 Unit Process/Equipment Sizing and Footprint

The three treatment batteries at the NC WRRF operate independently, meaning there is no way of diverting flow from one battery to another downstream of the influent splitting box. The implementation of MBR would follow the same philosophy, with a membrane filtration facility and associated systems being installed at the west end of each battery, and each battery assumed to continue to treat 1/3 of the influent flow. In this treatment alternative each aeration basin would also need to be reconfigured to operate in plug-flow mode, with an initial upfront anoxic swing zone to facilitate denitrification.

For this study Arcadis received input from Suez, the main supplier of hollow fiber type membranes filtration systems. For the design flows and loads adopted, the solution proposed would be the retrofit of the second half of the secondary clarifiers to accommodate 24 membrane trains per battery (each existing clarifier would be divided into 3 narrower tanks). The back end of the clarifiers would be converted to an equipment room to accommodate pumps and blowers associated with the system. It would also include a storage tank for citric acid (used for periodic recovery cleanings) and a day tank of sodium hypochlorite. The day tank would be fed from the existing sodium hypochlorite storage tanks (currently used for disinfection).

Between the membrane trains and the equipment room, a new RAS channel would be constructed, with sufficient volume to provide for deoxygenation prior to recirculation back to aeration. Permeate would be pumped to the existing effluent channels and sent to effluent disinfection and dechlorination.

Table 21 presents the design criteria and configuration adopted for the MBR system.

Table 21 - Design criteria and proposed configuration for Alternative 3 - MBR

Parameter	Value
Number of membrane trains per battery	24
Redundancy Criteria for membrane trains	4 trains offline per battery for less than 24h
Redundancy criteria for shared equipment (scour blowers, backpulse pumps, air compressor)	(N + 1) per battery
Number of cassettes installed per battery	432
Membrane module spare space	10.8%
Maximum allowed MLSS	10,000 mg/L 12,000 mg/L (peak events only)
Effluent quality guarantee	TSS < 5mg/L Turbidity < 5 NTU

RAS flows expected for the whole plant are in the order of 970 MGD (average conditions) to 1400 MGD (for peak hydraulic conditions). The existing RAS split boxes on top of the aeration basins would need to be replaced or adapted to accommodate larger flows. Existing wasting systems (WAS pumps and WAS handling systems) will not be modified.

Given the difficulty involved in headworks fine screening, the approach adopted is the fine screening of mixed liquor prior to the membrane tanks. Mixed liquor flows including recycled RAS can reach up to 700 MGD per battery at peak hydraulic conditions. A set of 8 (7 + 1) drum screens was selected for installation in the first half of the secondary clarifiers. Each screen is rated for 100 MGD, with 2 mm aperture as required by Suez.

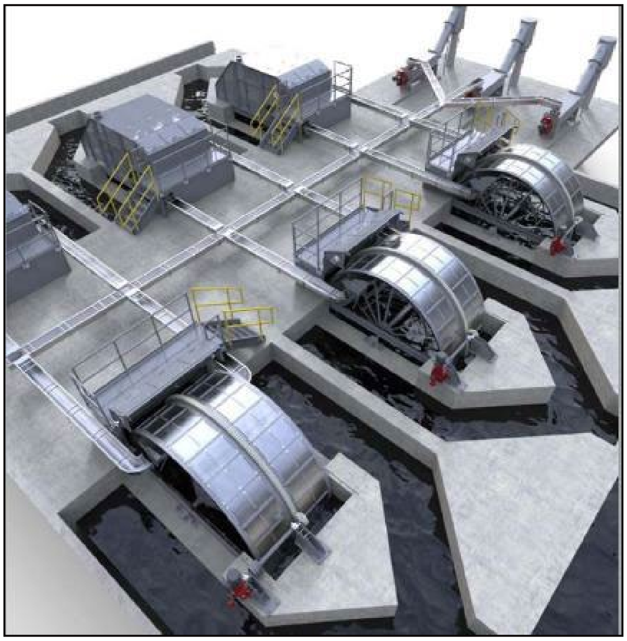

Figure 13 - Drum screens proposed by Ovivo to fine screen mixed liquor in channel

Ovivo estimates a high and constant consumption of water (in the order of ~ 170 gpm per screen) for washing down of the screens given the characteristics of the mixed liquor. Similar to the observations made by Headworks International regarding fine screening of raw influent, Ovivo also indicated that it would be hard to accurately estimate the volume of screenings to be generated and their concentration.

Traditional compactors are not recommended for this application given the type of material expected to be retained by the screens and the dilution of the screenings. The solution adopted was to send the material captured by the drums to static screens followed by spiral presses for dewatering. A covered concrete deck above the screening channels would accommodate the screenings management equipment as well as odor control and other ancillary systems. **Figure D**, at the end of this document, shows the proposed conceptual layout for the MBR implementation at NC WRRF.

The operation at higher MLSS/SRT would provide for nitrification, which will increase process air requirements. Currently the WRRF has nine (seven duty, two standby) multi-stage centrifugal blowers each with a maximum air flow rate of 39,000 scfm, for a total capacity of 351,000 scfm with all nine units in operation. The air requirements for the 2050 design condition are summarized in **Table 22** below. To meet the future air demand four existing air blowers would need to be replaced with higher capacity models. The final configuration would include six existing blowers (39,000 scfm capacity) combined with four new blowers (78,000 scfm capacity).

Table 22 - 2050 Conditions – Estimate of Process Air Demand for BNR

Loading Condition	Daily Average, scfm
Min. Day	73,963
AA	189,600
MM	220,971
Max Day	415,328

The fine bubble diffusers would also need to be upgraded to accommodate the increase in oxygen delivered to the aeration tanks. There are 92,736 ceramic disc diffusers currently installed in the aerobic zones. One concern with increasing the diffuser quantity is the density in terms of ft^2 diffuser per ft^2 tank area, which can create challenges for installation and maintenance of the diffusers. This alternative would require a full replacement of the ceramic disc diffusers with 55,000 membrane disc diffusers. While the existing ceramic diffusers are limited to 2.25 scfm per diffuser, the membrane diffusers can deliver over 8 scfm per diffuser, which allows adequate oxygen to the aeration tanks while limiting the overall diffuser density.

7.5.3 Anticipated Effluent Quality

This scenario was modelled with the existing aeration tanks in a plug flow configuration and the MBR replacing the existing secondary clarifiers. Additionally, a 2.3 MG RAS de-oxygenation zone was added to reduce the DO concentration to approximately 2 mg/L before being recycled to the head of the aeration tanks to prevent excess oxygen in the RAS from inhibiting nitrification. For all four model runs the AEMLSS was limited to 8,000 mg/L per industry standard recommendations for MBR influent.

Shown in **Table 23** below, this resulted in aerobic SRTs from 5 to 6 days and a TN reduction of 58% compared to the baseline scenario (**Table 9**). This alternative provides the largest potential reduction of effluent total nitrogen discharged from the NC WRRF**.** As shown in **Table 23**, implementation of MBR would provide an almost 20,800 lbs TN/d reduction from NC WRRF which equates to approximately **5,200 lbs/d** removed from the East River.

Table 23 - Modelling Results: Membrane Bioreactor

Loading Condition	Temp, °C	AEMLSS, mg/L	Total SRT, days	Aer SRT, days	Eff NH_3, mg/L	Eff NO_3, mg/L	Eff NO_2, mg/L	Eff TN, mg/L	Eff TN, lbd
AA	21	7,800	8.9	6.0	< 1	6.3	< 1	7.6	15,200
MM	21	7,800	7.5	5.0	< 1	6.3	< 1	7.5	17,400
AA	16	7,900	8.7	5.8	< 1	6.1	< 1	7.5	15,100
MM	16	7,900	7.3	4.9	< 1	6.0	< 1	7.4	17,100
Yearly Average		7,850	8.8	5.9	< 1	6.2	< 1	7.5	15,150
Reduction Eff TN,%									58% (36,100 lbd Baseline)
CER Contribution, lbd									3,788 (9% of TMDL)

7.5.3.1 Energy Consumption

Energy consumption is usually high for MBR systems compared to conventional activated sludge systems. The additional installed power at the plant is estimated at 47,500 HP or 35 MW, including major load additions such as:

- New process blowers to be installed in the blower room, net addition of 4,000 HP.
- MBR equipment room: approximately 5,900 HP per battery.
- Replacement of RAS pumps: net addition of 2,400 HP.
- New screens and screenings management systems: 40 HP per battery.

The additional electricity consumption for implementing MBR at NC WRRF is estimated at ~ 36,000,000 kWh/year, according to the breakdown provided by **Table 24**.

Table 24 - Additional energy consumption for Alternative 3 - MBR

New or retiring	Equipment	Energy consumption (kWh/year)	Comment
New	Permeate pumps	2,756,000	Provided by Vendor
	Air scour blowers	14,333,000	Provided by Vendor
	Instrument air compressors	495,000	Provided by Vendor
	Process Blowers (net addition)	11,565,000	Estimated based on 28% additional air demand
	Aeration mixers	245,000	Assumed all units online
	RAS pumps (net addition)	10,182,000	Estimated based on average flows
	Drum Screens	196,000	Assumed 15 channels online
	Ancillary screens/ press	294,000	Assumed 15 channels online
Retiring	Cross Sludge Collectors	- 784,000	Assumed all units online
	Longitudinal collectors	- 1,568,000	Assumed all units online
	Double longitudinal collectors	- 1,568,000	Assumed all units online
	TOTAL (net addition)	**36,147,000**	

7.5.3.2 GHG Emissions

Additional GHG emissions for Alternative 3 are presented in **Table 25:**

Table 25 - GHG emissions for Alternative 3 - MBR

Source	Scope	Emissions ($MTCO_2eq$/ year)
N_2O (treatment)	1	1,283
N_2O (discharge)	1	(8,428)
Electricity	2	9,102
TOTAL	1 and 2	**1,957**

The implementation of MBR at NC WRRF results in a net increase of 1,957 MT CO_2eq emissions per year due to the very high energy consumption expected.

7.5.4 Operational and Construction Phase Considerations

The implementation of MBR at the NC WRRF would require taking a full battery offline at a time during construction. As informed by DEP, historically the facility has been able to operate with only two batteries online and meet its dry weather permit requirements. However, a wet weather exception with more lenient limits would be needed during construction phase.

An SPA analysis for the clarifiers similar to the one presented in subsection 7.1.2 – Site Constraints – Secondary Clarifier Capacity is summarized in **Table 26,** considering only 16 units online (1 full battery offline). The Maximum Daily flow condition shown corresponds to the current conditions, and not to the projected 2050 flows (521 MGD instead of 594 MGD).

Table 26 - State-Point Analysis of existing secondary clarifiers considering 1 battery offline

Flow Condition, MGD	SVI Percentile	SVI, mL/g	Units in Service (TOTAL: 24)	SOR, gpd/ft2	SLR, lbd/ft2	Allowable MLSS, mg/L
MD - 521	95th	173	16	1,470	32.9	1,850
	90th	147	16	1,470	35.5	2,000
Peak - 700	95th	173	16	1,976	26.4	1,200
	90th	147	16	1,976	35.2	1,600

As shown in the SPA (**Table 26**) maintaining the AEMLSS at the AA historical value of 1,450 mg/L meets the peak 90th percentile allowable MLSS of 1,600 mg/L. By maintaining the AEMLSS to 1,450 mg/L, the aerobic SRT would decrease from the average operating value of 1.3 days to approximately 0.9 days. While this SRT is lower than typical operations it's not expected to significantly impact treatment efficacy.

Arcadis used Ten State Standard recommendations for aeration basins (**Table 27**) and sedimentation tanks (**Table 28**) to assess the treatment efficacy while the first battery is converted to an MBR system. Maintaining the same influent and recycle flow and load assumptions that were used in *Technical Memorandum 3 – Flow and Loading Projections* design parameters for the aerations tanks (BOD loading rate, F:M ratio, HRT) and sedimentation tanks (SOR, SLR, WLR) were calculated with one battery out of service.

The aeration tanks were designed with a BOD loading rate and F:M ratio higher than the recommendations given in 10 SS. With one battery out of service the BOD loading rate increases from 89 lbd BOD/1,000 ft^3 at current conditions to 134 lbd BOD/1,000 ft^3 at current conditions while the *Enhanced Track 3* design BOD loading rate is 106 lbd BOD/1,000 ft^3. Similarly, the F:M ratio increases from 1.2 to 1.8 lbd BOD/lb MLVSS with one battery out of service, while the design value is 0.8 lbd BOD/lb MLVSS. The current HRT is 3 hours at AA conditions and would decrease to 2 hours at AA conditions with one battery out of service, which is the same HRT outlined in the *Enhanced Track 3* design.

Table 27 - Ten States Standards Design Considerations for Aeration Tanks

Parameter	Current		Current (1 Battery OOS)		Design (Enhanced Track 3)	
	AA	**Pk Hr**	**AA**	**Pk Hr**	**AA**	**Pk Hr**
Influent Flow, MGD	213	700	213	700	310	700
RAS Flow, MGD	90	90	90	90	155	154
Recycle, MGD	8.0	13.2	8.0	13.2	11.7	13.2
Recycle BOD, mg/L	313	-	313	-	313	-
Aerator Influent BOD, lbd	315,040	-	315,040	-	372,900	-
AEMLVSS, mg/L	1,210	-	1,210	-	2,003	-
# Units	12		8		12	
Volume, MG/unit			2.2			
10 SS MLSS, mg/L			1,000 – 3,000			
AEMLSS, mg/L	1,450	-	1,450	-	2,400	-
10 SS BOD Loading, lbd BOD/1,000 ft^3			40			
BOD Loading, lbd BOD/1,000 ft^3	89	-	134	-	106	-
10 SS F:M, lbd BOD/lb MLVSS			0.2 – 0.5			
F:M, lbd BOD/lb MLVSS	1.2	-	1.8	-	0.8	-
HRT, hours	3.0	0.9	2.0	0.6	2.0	0.9

A similar assessment was completed for the sedimentation tanks with one battery out of service. The SOR, SLR, and WLR would all increase with one battery out of service. However, under AA conditions these three parameters remain in the range provided in the *Enhanced Track 3* design for each of these parameters. The SOR and WLR would exceed 10 SS recommendations during peak hourly flows, which may need to be considered if this alternative is considered for construction.

Table 28 - Ten States Standards Design Considerations for Sedimentation Tanks

Parameter	Current		Current (1 Battery OOS)		Design (Enhanced Track 3)	
	AA	Pk Hr	AA	Pk Hr	AA	Pk Hr
Influent Flow, MGD	213	700	213	700	310	700
RAS Flow, MGD	90	90	90	90	155	154
AEMLSS, mg/L	1,450		1,450		2,400	
# Units	24		16		24	
Weir Length, LF/unit	1,188					
Length, ft/unit	396					
Width, ft/unit	56					
Volume, MG/unit	2.0					
10 SS SOR, gpd/ft^2	1,200					
Surface Overflow Rate, gpd/ft^2	399	1,314	599	1,971	582	1,314
10 SS SLR, lbd/ft^2	40					
Solids Loading Rates, lbd/ft^2	6.9	18	10	27	17	32
10 SS WLR, gpd/LF	30,000					
Weir Loading Rates, gpd/ft	7,454	24,551	11,181	36,827	10,873	24,551

In addition to significant considerations with regard to phasing in an MBR conversion during construction, the following operational considerations should be taken into account with this treatment alternative:

- Although no structural improvements appear to be necessary at the aeration basins, air supply infrastructure at the basins would be expanded to include additional diffusers and larger air piping diameters. Secondary clarifiers mechanical systems would be removed, and new channels would be constructed within the existing footprint. New buildings would be constructed to shelter MBR and screening equipment. 5ton bridge cranes would be positioned above the membrane tanks to allow for the removal of membrane cassettes (for routine inspection purposes).

- The modifications to the existing clarifiers, the high volumes of RAS being recirculated and the conversion of the biological reactors to plug-flow configuration would impact the hydraulic profile of the facility. Although hydraulic modeling prepared for the existing conditions indicated considerable extra capacity available in the existing channels in the current configuration, a more detailed analysis should be developed at a later stage.

- Daily operation of the MBR system is fully automated. However, the large number of motors in the system require significant preventive maintenance effort. Membrane recovery cleanings, expected to occur twice a year for each membrane train, can be labor intensive. In addition, there would be significant extra effort related to the new screens and screenings management.

- Screening of MLSS at WRRFs without primary clarification is expected to be an operational challenge. High fouling levels are expected in the drum screens, with a significant amount of pressurized backwash water being required. The screenings are expected to be very diluted and would be conveyed to static screens for further dewatering prior to disposal. MOP 8 estimates an increase in screenings volume in the order of 300% when changing 3/8" screens for 2mm screens. That is a very large volume of residuals to be managed inside the plant and offsite as well since screenings are trucked out of the plant (instead of barged out like sludge).

- As expected for any MBR system, energy consumption would increase considerably. The additional installed loads described in the previous subsection are estimated in 47,500 HP, with additional energy consumption in the order of 36,000,000 kWh/year. As discussed previously in subsection 7.1.4 – Site Constraints – Existing Electrical Infrastructure, this is a very large energy demand addition that may require upgrades at all electrical distribution levels, including possibly the facility's main substation.

- If MBR loads are to operate on the generator supply a load evaluation would be necessary to determine if upgrades would be necessary in the emergency power system. A detailed analysis, including evaluating the plant's current power demand, peak expected consumption for the MBR system as well as emergency power needs should be developed to accurately determine electrical upgrades needs.

- Finally, a new hazardous chemical would be introduced to the plant with the storage and use of citric acid at 50% concentration for recovery cleanings on the membrane filters. The facility's overall consumption of sodium hypochlorite is expected to increase 5% compared to baseline levels due to membrane maintenance and recovery cleanings.

7.5.5 Estimate of Conceptual Construction Costs

Table 29 presents the summary of Construction Costs for Alternative 3, including markups adopted:

Table 29 - Construction Costs for Alternative 3 - MBR

Cost Component	Cost ($)
Maintenance of Plant Operations (1)	$25,000,000
Aeration Basins	$13,727,500
Sedimentation Basins Conversion to MBR Facility	$363,614,900
Blower Room	$7,565,000
Site Piping	$46,935,000
Subtotal	**$456,842,400**

Cost Component		Cost ($)
Phasing	5%	$22,842,100
General Conditions	20%	$95,936,900
General Contractor OH&P	21%	$120,880,500
Design Contingency	35%	$243,775,700
Bonds and Insurance	5%	$47,013,900
	Total Construction Cost	**$987,291,500**

Notes:
(1) Allowance

Total Construction Costs for Alternative 3 are in the order of $990 MM.

7.5.6 Estimate of Operations and Maintenance Costs

Table 30 presents the breakdown per cost component for Alternative 3 – MBR in terms of additional yearly cost to operate the biological treatment system:

Table 30 – Additional O&M Costs for Alternative 3 - MBR

O&M Component	Quantity	Unit Cost	Cost ($ / year)
Energy	36,147,000 kWh/ year	0.1 $/ kWh	$3,615,000
Sodium Hypochlorite	170,400 gal/ year	0.75 $/ gal	$128,000
Citric Acid	134,400 gal/ year	3.0 $/ gal	$403,000
Screenings	16,176 wet ton/ year	100 $/ wet ton	$1,618,000
Labor	15 FTE (1)	140,000 $/ year	$2,100,000
Maintenance (2.5% equipment cost)(2)			$1,376,000
TOTAL:			**$9,240,000**

Notes:
(1) FTE = full-time employee
(2) Mechanical equipment cost, excluding membranes.

Labor efforts were estimated at a total of 3 new full-time positions (corresponding to 15 new FTEs) considering the following needs:

- One new full-time position for the operation of the new fine screens.
- One new full-time position for the operation of the membrane system.
- One new full-time position for the calibration/maintenance of the new instruments, given the high automation level of the system.

Maintenance labor for the screens and membrane system was assumed to correspond to the existing staff that currently operates and maintain the clarifiers.

7.5.7 30-Year Annualized Costs

A 30-year annualized cost was developed for this alternative, assuming financing over a 30-year period under at a 3% bond rate and yearly OM costs in terms of 2021 dollars. The initial capital investment to implement an MBR treatment configuration of approximately $988,000,000 was financed for the 30-years under a 3% bond rate for an annualized capital cost of $50,370,881. To account for membrane filter unit replacement after 15 years of operation, at a cost of $1,320 per module, an additional $88,200,000 was financed for 15 years at a 3% bond rate and added to the annualized cost of the initial investment. This results in an average annualized capital cost over 30-years of $52,217,874. The total annualized cost, including O&M in 2021 dollars, is approximately $61,457,874 per year.

In terms of nitrogen removal, the annualized investment to implement this alternative would cost approximately $8.00 per pound of nitrogen removed at the WRRF over a 30-year period of operation or $32.00 per pound of nitrogen removed in the East River.

Table 31 – 30-Year Annualized Costs for Alternative 3 - MBR

Parameter	Value		
Years in Operation	1 to 30	15 to 30	Overall
N Removed, lbd	20,950	20,950	20,950
N Removed, lb/ year	7,646,750	7,646,750	7,646,750
CER Equivalents Removed, lbd	5,238	5,238	5,238
Total Capital Cost, $	$987,291,500	$88,197,120	$1,075,488,620
Annualized Capital Cost, $/year	$50,370,881	$57,758,852	$52,217,874
Annual O&M Cost, $/year	$9,240,000	$9,240,000	$9,240,000
Total Annual Cost, $/year	$59,610,881	$66,998,852	$61,457,874
$/lb N Removed	$7.80	$8.76	$8.04
$/lb N Removed in CER	$31.18	$35.05	$32.15

**Annualized cost of construction based on 3% Bond rate and 30-year financing period.*
***OM costs based on 2021 dollars.*

7.6 Alternative 4 – Conversion to IFAS

7.6.1 Treatment Technology Overview

Integrated Fixed-film Activated Sludge (IFAS) processes combine the attached- and suspended-growth environments into one bioreactor system with the addition of biofilm support media to activated sludge basins. The process provides for the ability to upgrade existing tanks on site to meet new effluent standards and higher loads within the same footprint. In this configuration, the limitation for AEMLSS is the secondary clarifiers capacity as summarized in the state point analysis.

IFAS plants can use three categories of media: fixed bed, plastic carrier moving bed biofilm bioreactor (MBBR) media, and sponge-type MBBR media. Frames are used to keep fixed-bed media in place while retention screens are deployed in random media systems. The addition of media and screens to existing aeration basins increases headlosses and requires hydraulics evaluations to be performed. It can also lead to foaming issues.

Figure 14 - Retention screens installed in activated sludge aeration basins (Veolia)

Aeration for IFAS zones (portions of the reactor filled with media) is performed by medium or coarse bubble diffusers which provide oxygen supply and adequate mixing levels. Energy for aeration is higher than for conventional systems due to the inefficiency of coarse-bubble diffusers and the additional media mixing needs. Fine-bubble diffusers are to be avoided due to their more frequent maintenance requirements which can become taxing due to the need to remove the media from the reactor for access.

Fine screening is required upstream of IFAS reactors typically at 6 mm. For plants without primary clarifiers such as Newtown Creek, however, upstream screening at 3 mm levels is required. **Figure 15** shows the Process Flow Diagram for the implementation of IFAS at NC WRRF.

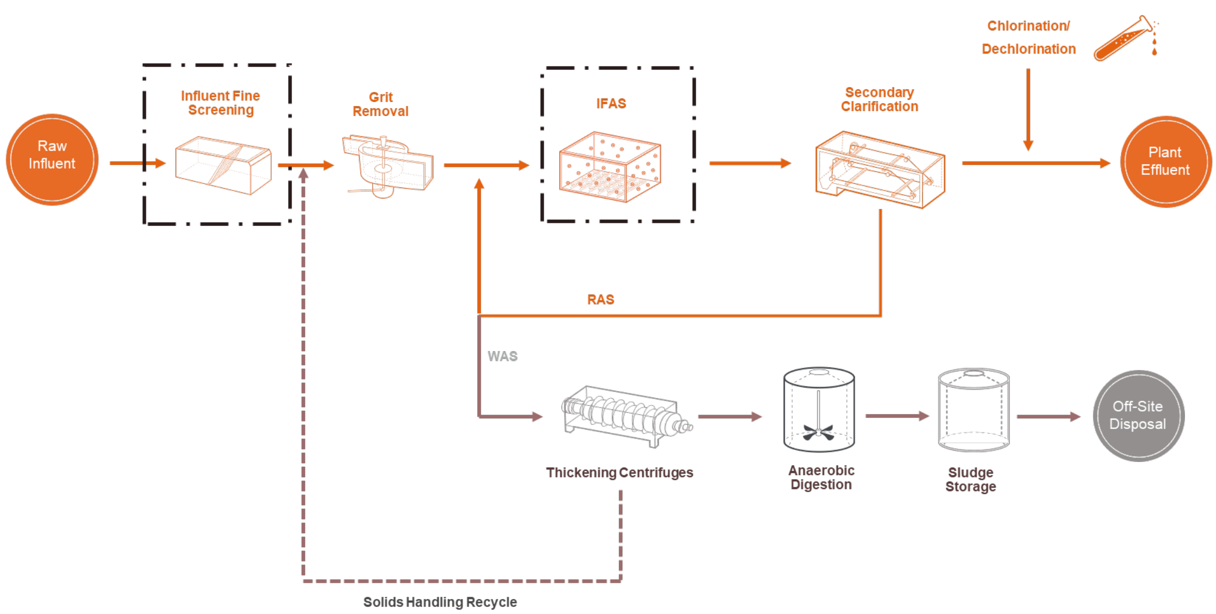

Figure 15 - PFD for Alternative 4 - IFAS implementation at NC WRRF

7.6.2 Unit Process/Equipment Sizing and Footprint

Arcadis requested input from Veolia and World Water Works for the sizing of an IFAS system at the WRRF. Veolia informed that their preliminary evaluation indicated non-favorable conditions for a conversion to IFAS, given the low SRTs and low hydraulic retention times of the existing activated sludge process. Accordingly, they did not provide any information for implementing IFAS process at NC WRRF.

World Water Works however prepared a proposal with their suggested solution (attached to this report in **Appendix F**) showing the ability to fully nitrify year-round, which will be adopted for the purposes of this evaluation. The design considered a step-feed configuration for the basins, with 30% anoxic volume and two IFAS zones (aerobic). Media fill fraction is 65% for Zone 1 and 40% for Zone 2. The media volume to be provided is high at almost 41,000m^3 (1,440,000 ft^3).

To implement IFAS would result in increased design process air demand as summarized in **Table 32** with a new capacity of 383,000 scfm required to meet 2050 MW loading conditions. Additionally, this treatment configuration requires a full replacement of the existing fine bubble ceramic diffusers with a medium or coarse bubble model. Since the aeration tanks would be filled with IFAS media, each time the diffusers are serviced the IFAS media would need to be removed from the given tank or zone using a recessed impeller pump. The medium or coarse bubble diffusers would provide the benefit of reducing maintenance frequency compared to the existing fine bubble diffusers.

Table 32 - IFAS Process Air Requirements (provided by World Water Works)

Loading Condition	Total Air Requirement, scfm
Min Day	93,624
AA	240,000
MM	298,000
MW	383,000

7.6.2.1 MOP 8 IFAS Design Considerations

The standard design criteria for an IFAS system as provided by the *Design of Water Resource Recovery Facilities Manual of Practice No. 8* (MOP 8) are the hydraulic retention time (HRT) in hours and the nitrification rate in terms of kg/day NH_3 nitrified per 1,000 m^2 of IFAS media.

Based on the design parameters provided by World Water Works, the HRT and nitrification rate for the design was calculated for the 2050 AA and 2050 MM scenarios. The design HRT is lower than the MOP 8 recommendation of 4 hours while the nitrification rate exceeds the range of 0.05 to 0.5 kg/1,000 m^2*day as recommended by MOP 8.

This comparison suggests that the IFAS rector volume is too small to meet the MOP 8 recommendations for HRT and nitrification rate, however the volume is constrained by the existing aeration tank infrastructure making it unfeasible to achieve the values provided by MOP 8.

Table 33 - Comparison of IFAS Design Parameters and MOP 8 Recommendations

Parameter	AA		MM
IFAS Reactor Volume, MG		18.8	
Zone 1 Media Fill, %		65%	
Zone 2 Media Fill, %		40%	
Zone 1 Media SA, m^2		15,020,959	
Zone 2 Media SA, m^2		9,243,667	
Media Specific Surface Area, m^2/m^3		650	
Flow to IFAS, MGD	242		277
Ammonia to Nitrify, kg/day	17,424		20,042
Design HRT, hours	1.9		1.6
MOP 8 Minimum HRT (Plastic Carrier), hours		4	
Design Nitrification Rate, kg/1,000 m^2*day	0.7		0.8
MOP 8 Nitrification Rate, kg/1,000 m^2*day		0.05 - 0.5	

7.6.3 Anticipated Effluent Quality

The treatment results anticipated for IFAS implementation are based on the proposal from World Water Works. For the AA and MM loading scenarios the average MLSS and AEMLSS concentrations will be 3,000 mg/L and 2,000 mg/L respectively. Based upon a proposal from the IFAS system manufacturer, this alternative provides the second total nitrogen reduction of all the potentially feasible alternatives, with a **5,600 lbs/d TN reduction** in effluent nitrogen discharges at the NC WRRF, which equates to approximately **1,400 lbd** removed from the CER.

Table 34 - Treatment Results: Alternative 4 – IFAS (World Water Works)

Loading Condition	Avg MLSS, mg/L	Total SRT, days	Aer SRT, days	Eff NH_3, mg/L	Eff NO_3, mg/L	Eff NO_2, mg/L	Eff TN, mg/L	Eff TN, lbd
AA	3,000	2.01	1.34	1.0	11	< 1	15	30,274
MM	2,000	1.14	0.76	1.0	11	< 1	15	34,555
Yearly Average	3,000	2.01	1.34	1.0	11	< 1	15	30,274
% Reduction Eff TN								16% (36,100 lbd Baseline)
CER Contribution, lbd								7,569 (17% of TMDL)

7.6.3.1 Energy Consumption

Energy consumption increase for the implementation of IFAS at NC WRRF is due to higher process air demand. The process requires considerably more air due to the use of medium-bubble diffusers and the use of air for mixing purposes. Mixing in anoxic zones is executed by new aeration mixers.

Table 35 presents the breakdown of additional energy consumption required for Alternative 4 – IFAS.

Table 35 - Energy Consumption for Alternative 4 - IFAS

Equipment	Energy consumption (kWh/year)
Process Blowers	25,571,000
Aeration mixers	245,000
TOTAL:	**25,816,000**

7.6.3.2 GHG Emissions

Additional GHG emissions for Alternative 4 are presented in **Table 36**.

Table 36 - GHG emissions for Alternative 4 - IFAS

Source	Scope	Emissions ($MTCO_2eq$/ year)
N_2O (treatment)	1	1,283
N_2O (discharge)	1	(2,349)
Electricity	2	6,500
TOTAL	1 and 2	**5,433**

The implementation of IFAS at NC WRRF would yield a net increase of 5,433 MT CO_2eq/ year due to the high additional energy consumption expected. The modest reduction in effluent discharge N_2O emissions does not compensate for the significant electricity emissions increase.

7.6.4 Operational and Construction Phase Considerations

The conversion of the activated sludge process to an IFAS system should consider the following:

- Based upon the proposal from World Water Works, input from Veolia, and a review of MOP 8 IFAS design guidelines against the proposed system, the implementation of IFAS at the NC WRRF may require extensive piloting to ensure that the system can achieve full nitrification with the low SRT and low HRT limitations of the existing aeration basins.

- Conversion to an IFAS system would require fine screening of the raw influent. As discussed in **Section 7.1.3**, the replacement of existing influent screens with smaller opening units appears to be technically feasible but would require extensive piloting prior to consideration for implementation.

- The biofilm carrier media occupy large volumes within the aeration basin. If access to an aeration tank is required in the future for maintenance, then some method of storage of the media or transfer to and from an adjacent tank is required.

- The addition of media, media retention walls and screens to the existing basins would impact the hydraulic profile of the WRRF. Although hydraulic modeling prepared for the existing conditions indicated considerable extra capacity available in the aeration channels, a more detailed analysis should be developed at a later stage to determine the potential impacts of implementing this alternative.

- Foam entrapment at basin screens is a concern for IFAS systems. World Water Works included a defoaming system in their scope of supply, but other foam control methods may also be evaluated and included such as surface chlorine sprays, surface wasting and RAS chlorination. In any case, considerable operator attention is likely to be required.

7.6.5 Estimate of Conceptual Construction Costs

Table 37 presents the summary of Construction Costs for Alternative 4, including markups adopted.

Table 37 - Construction Costs for Alternative 4 - IFAS

Cost Component		Cost ($)
Maintenance of Plant Operations [(1)]		$5,000,000
Influent Secondary Screens		$7,735,988
Aeration Basins		$88,770,000
Blower Room		$12,082,500
Subtotal		**$113,588,488**
Phasing	5%	$5,679,412
General Conditions	20%	$23,853,600
General Contractor OH&P	21%	$30,055,500
Design Contingency	35%	$60,612,000
Bonds and Insurance	5%	$11,689,500
Total Construction Cost		**$245,478,500**

Notes:
[(1)] Allowance

Total Construction Costs for Alternative 4 are in the order of $245 MM.

7.6.6 Estimate of Operations and Maintenance Costs

Table 38 presents the breakdown per cost component for Alternative 4 – IFAS in terms of additional yearly cost to operate the biological treatment system:

Table 38 – Net O&M Costs for Alternative 4 – IFAS

O&M Component	Quantity	Unit Cost	Cost ($ / year)
Energy	25,816,000 kWh/ year	0.1 $/ kWh	$2,582,000
Screenings	16,176 wet ton/ year	100 $/ wet ton	$1,618,000
Labor	1 FTE [1]	140,000 $/ year	$700,000
Maintenance (2.5% equipment cost)[2]			$115,000
TOTAL:			**$5,015,000**

Notes:
[1] FTE = full time employee
[2] Mechanical equipment cost, excluding media and retention screens.

Labor effort estimates assumed that new screens would be operated and maintained by the current staff operating the existing screens. One full-time position was added (corresponding to five full-time employees) due to the implementation of a more complex process which NC WRRF staff is unfamiliar with.

7.6.7 30-Year Annualized Costs

A 30-year annualized cost was developed for this alternative, assuming financing over a 30-year period under at a 3% bond rate and yearly OM costs in terms of 2021 dollars. The initial capital investment of approximately $245,500,000 was financed for the 30-years under a 3% bond rate for an annualized capital cost of $12,524,131. The total annualized cost, including O&M in 2021 dollars, is approximately $17,539,131 per year.

In terms of nitrogen removal, the annualized investment to implement this alternative would cost approximately $8.00 per pound of nitrogen removed at the WRRF over a 30-year period of operation or $32.00 per pound of nitrogen removed in the CER.

Table 39 – 30-Year Annualized Costs for Alternative 4 – IFAS

Parameter	Value
N Removed, lbd	5,826
N Removed, lb /year	2,126,490
CER Equivalents Removed, lbd	1,457
Total Capital Cost, $	$245,478,500
Annualized Capital Cost, $/year*	$12,524,131
Annual O&M Cost, $/year**	$5,015,000
Total Annualized Cost, $/year	$17,539,131
$/lb N Removed	$8.25
$/lb N Removed in CER	$32.99

**Annualized cost of construction based on 3% Bond rate and 30-year financing period.*
***OM costs based on 2021 dollars.*

7.7 Alternative 5 – MABR

7.7.1 Treatment Technology Overview

Membrane Aerated Biofilm Reactor (MABR) is a relatively new technology that can intensify nitrogen removal through the use of an immersed gas transfer membrane, which delivers oxygen to a biofilm naturally forming at its outer surface.

Similar to other membrane systems, MABRs require upstream fine screen to 2-3 mm levels to avoid membrane damage. However, unlike membranes from MBR systems (which act as water filters) the pores of MABR membranes are filled with gas and, therefore, are unlikely to foul with solids or bacteria. There are no dedicated scouring air blowers or cleaning requirements for MABR membranes (maintenance cleanings are not expected to be needed during the whole life spam of the membranes). Periodic aeration below the membranes is used to control the biofilm thickness. "Off-gas", which is the portion of the blown air that didn't diffuse through the membrane, can be used biofilm control aeration.

The most common configuration for MABRs locates the membrane cassettes in anoxic zones in the bioreactor. Nitrification typically occurs in the inner portions of the biofilm, close to the air-filled membrane, and denitrification and BOD removal occur in the outer portions, where the bulk-liquid dissolved oxygen concentrations are low.

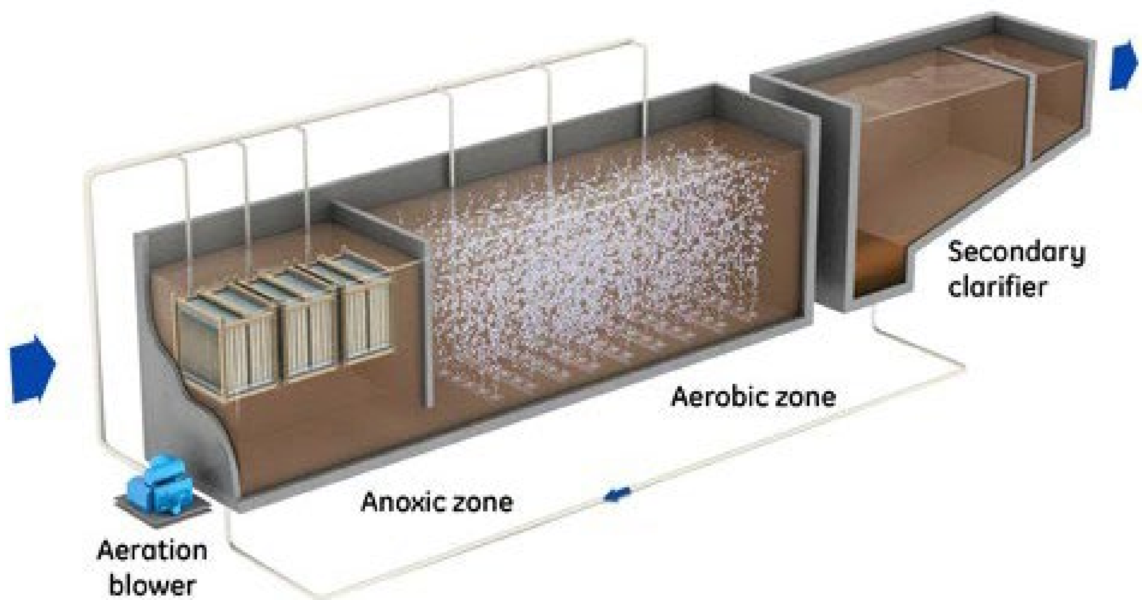

Figure 16 - Traditional MABR system layout (Zeelung - Suez brochure)

MABR membranes can be sheet type or hollow-fiber type (more common). The system has high energy efficiency since nitrification is accomplished with passive diffusion, which is more efficient than traditional bubble aeration. BOD removal continues to happen at the bulk mixed liquor at the aerobic zones.

Figure 17 shows the process flow diagram for implementation of a MBR system at NC WRRF.

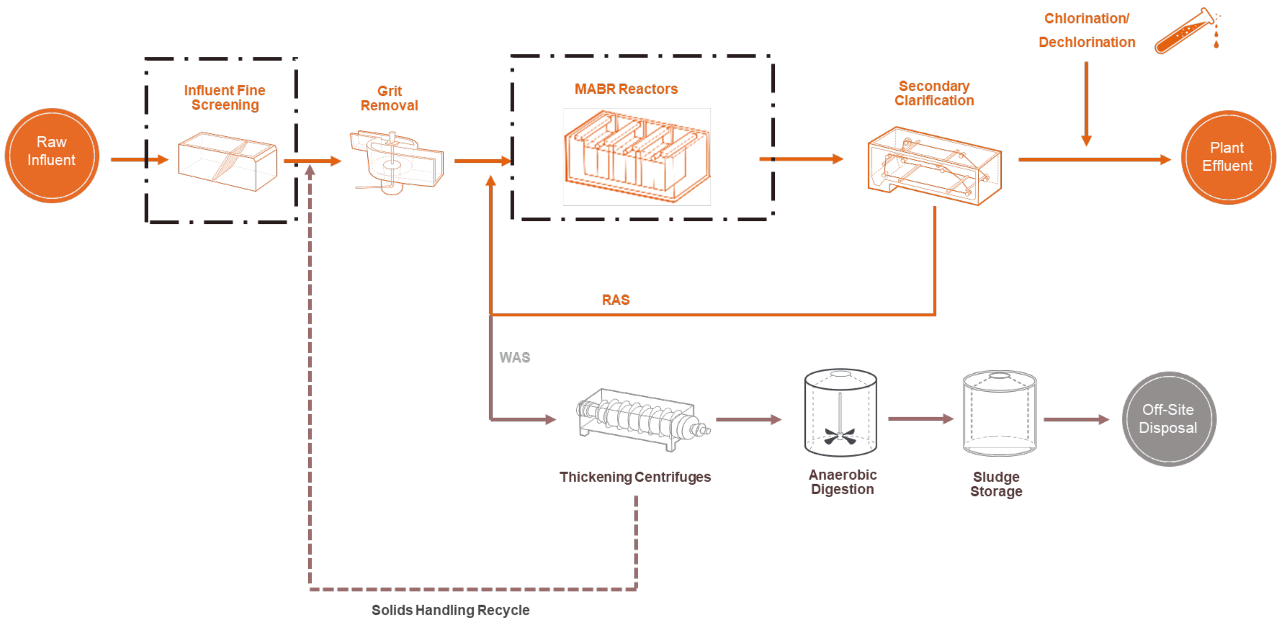

Figure 17 - Process Flow Diagram for MABR implementation at NC WRRF

7.7.2 Unit Process/Equipment Sizing and Footprint

MABR systems are normally designed to provide from 20% to 80% of nitrification requirements in the biofilm. However, due to the extremely low retention times observed at the NC WRRF, no nitrification occurs at the bulk mixed liquor. As a result, all nitrification required needs to be reached in the MABR biofilm alone.

Arcadis required input from Suez (supplier of Zeelung MABR membranes, formerly a GE product) to evaluate how much nitrogen removal could be achieved with the installation of MABR cassettes in the existing aeration basins. In order to reach meaningful removal, the aeration basins would have to be fully populated with cassettes, as shown in **Figure 18.**

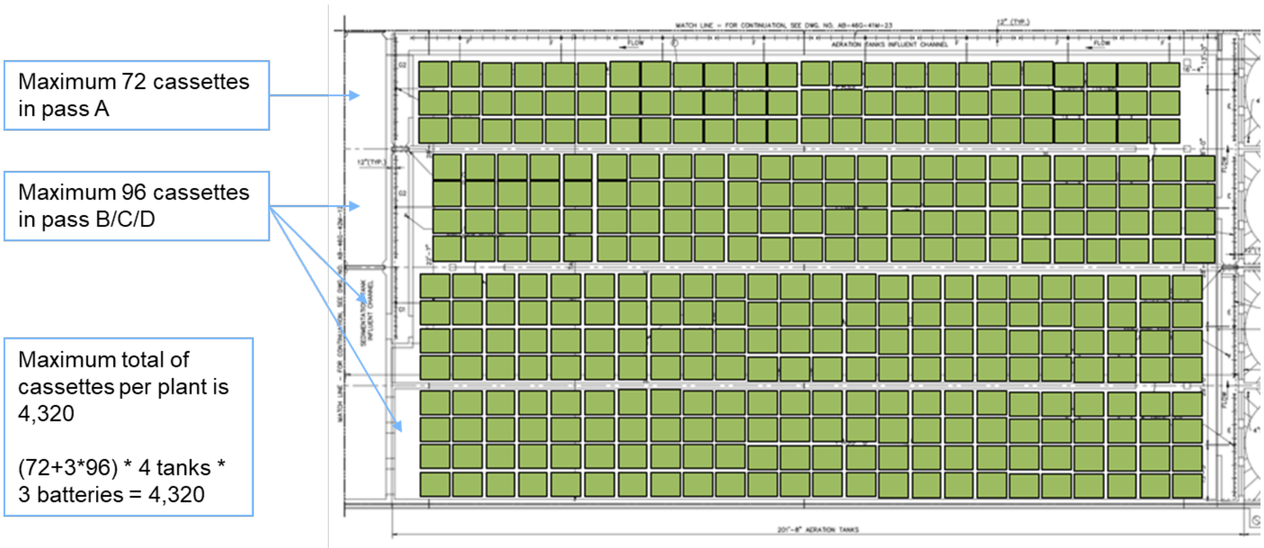

Figure 18 - Aeration basins layout for MABR. The green blocs represent MABR cassettes. (Suez analysis).

In the configuration proposed operation would still occur in step-feed mode, with passes 1 and 3 being anoxic MABR zones (50%). No changes would be required in the existing secondary clarifiers or RAS pumping systems. New blowers would be required for air supply to the membranes.

7.7.3 Anticipated Effluent Quality

Based upon a proposal from Suez, this alternative would result in an average effluent TN concentration of 9.7 mg/L. However, the system would not be able to fully nitrify in both summer and winter conditions.

While this is the theoretical treatment performance and effluent quality, it should be noted that the implementation of the membrane cassettes was ultimately not recommended by the manufacturer due to several concerns as summarized in this report.

7.7.4 Operational Considerations

The implementation of MABR at NC WRRF was considered non-feasible due to the following concerns:

- The manufacturer of this technology does not recommend this technology for NC WRRF. The proposed MABR system would not be able to fully nitrify due to aeration tank volume limitations and would require a significant number of cassettes in order to reduce effluent TN.

- Fine screening of raw influent, as mentioned previously, is likely to cause significant operational concerns and have potential impacts to the hydraulic capacity of the WRRF. Though technically feasible, fine screening of raw influent not often pursued and would require extensive piloting on-site prior to consideration for implementation.

- Although geometrically feasible based upon manufacturer input, the installation of such a large number of cassettes (4,320 units) would present a unique set of challenges for installation and access, in particular with regard to modifying the exiting aeration tank concrete covers and associated odor control systems.

- Aerobic MABR zones would be especially problematic since the cassettes would be installed above the existing diffusers, rendering those pieces of equipment difficult to access and maintain.

8 Evaluation Conclusions

This study evaluated five (5) treatment configuration alternatives, that may be suitable for evaluation of BNR at the NC WRRF, listed below.

- Alternative 1 – Step-Feed BNR
- Alternative 2 – Conventional + Biological Active Filters (BAFs)
- Alternative 3 – Conversion to Membrane Bioreactors (MBR)
- Alternative 4 – Conversion to Membrane Aerated Biofilm Reactors (MABR)
- Alternative 5 – Conversion to Integrated Fixed Film Activated Sludge (IFAS)

Based upon preliminary modeling and analysis, two of the treatment configuration alternatives listed were readily determined to be unfeasible at NC WRRF:

- **Alternative 1 – Step-Feed BNR** is the most obvious treatment alternative for evaluation given this approach has been implemented at the UER WRRFs. As stated in **Section 7.3** however, the NC WRRF is a high-rate facility without primary clarification, an activated sludge design average detention time of ½ the UER BNR facility nor the ability bypass high wet weather flow around the biological treatment system. This alternative would also require a significant increase in operating SRT which would bring operating MLSS concentrations well above what the secondary clarifiers can accommodate. Accordingly, this alternative was considered unfeasible, and the corresponding cost estimate was not developed.

- **Alternative 5– Conversion to MABR** would convert the activated sludge process to an MABR system. Due to limitations in aeration basin volume leading to constructability issues and the need for fine screening of raw influent, the vendor of this technology did not believe their technology was appropriate for the NC WRRF. Accordingly, this alternative was considered unfeasible, and the corresponding cost estimate was not developed.

The other three potentially feasible treatment configuration alternatives for implementation of increased TN removal at the NC WRRF: **Alternative 2 – Step-Feed Conventional + BAFs**, **Alternative 3 – Conversion to MBR**, and **Alternative 4 – Conversion to IFAS** were further evaluated. Even though all three treatment alternatives offer an increase in TN removal at the NC WRRF and therefore within the CER, with regards to the cost-benefit analysis and implementation complexity, and other factors considered, these three alternatives were also found to be unfeasible.

All three alternatives are discussed below in the context of effluent quality, capital and O&M costs, and important considerations regarding implementation at the NC WRRF. It is important to note that both the conversion to MBR and IFAS alternatives would require demonstration/pilot testing to confirm the ability of the fine screens to operate properly as well as the BNR treatment performance.

Effluent Quality, Total Nitrogen Removal

- All three treatment alternatives offer a potential to increase in TN removal at the NC WRRF and therefore within the East River. **Figure 19** and **Table 40** below summarizes effluent total nitrogen loads leaving the NC WRRF under all three treatment alternatives and then compares those values to the baseline condition where NC WRRF remains a high-rate secondary treatment facility.

- **Alternative 2 - Conventional + Nite/Denite BAF** provides a 3,400 lbs TN/d reduction (**9% reduction)** in effluent total nitrogen discharges. This equates to an increase in the removal of nitrogen from the CER of approximately **840 lbd** (out of a total allowable mass loading of 44,323 lbd for all six WRRFs discharging to the CER).

- **Alternative 3 – Conversion to MBR** provides the largest potential reduction of effluent total nitrogen at the NC WRRF**.** As shown in **Figure 19**, implementation of MBR would provide an almost 20,800 lbs TN/d reduction (58% reduction) discharged from NC WRRF which equates to approximately **5,200 lbs/d** removed from the CER.

- **Alternative 4 – Conversion to IFAS** provides the second total nitrogen reduction of all the feasible alternative, with a **5,600 lbs/d TN reduction** (16% reduction) in effluent nitrogen discharges. This equates to approximately **1,400 lbs/d** removed from the CER.

It is important to note that as discussed earlier in this document, the conversion of the existing activated sludge system to an IFAS system was not recommended by Veolia due to SRT and HRT limitations in the aeration basins and that extensive on-site performance piloting would be recommended to determine the applicability of this treatment technology to the NC WWRF for meaningful total nitrogen removal.

Table 40 - Total Nitrogen Removal Comparison – NC WRRF and the CER/LIS

Parameter/Criteria	Baseline	Alt 2 - Conventional + Nite/Denite BAF	Alt 3 - Conversion to MBR	Alt 4 - Conversion to IFAS
Eff TN, lbd	36,100	32,727	15,150	30,274
Net Reduction	---	3,373	20,950	5,826
CER Contribution, lbd	9,025	8,182	3,788	7,569
CER TN Mass Reduction, lbd	---	843	5,238	1,457
Annualized Capital Cost, $/year	---	$6,578,847	$52,217,874	$12,524,131
O&M Cost, $/year	---	$3,271,000	$9,240,000	$5,015,000
Total Annualized Cost, $/year	---	$9,849,847	$61,457,874	$17,539,131
$/TN Removed	---	$8.00	$8.04	$8.25
$/TN Removed CER	---	$32.00	$32.15	$32.99

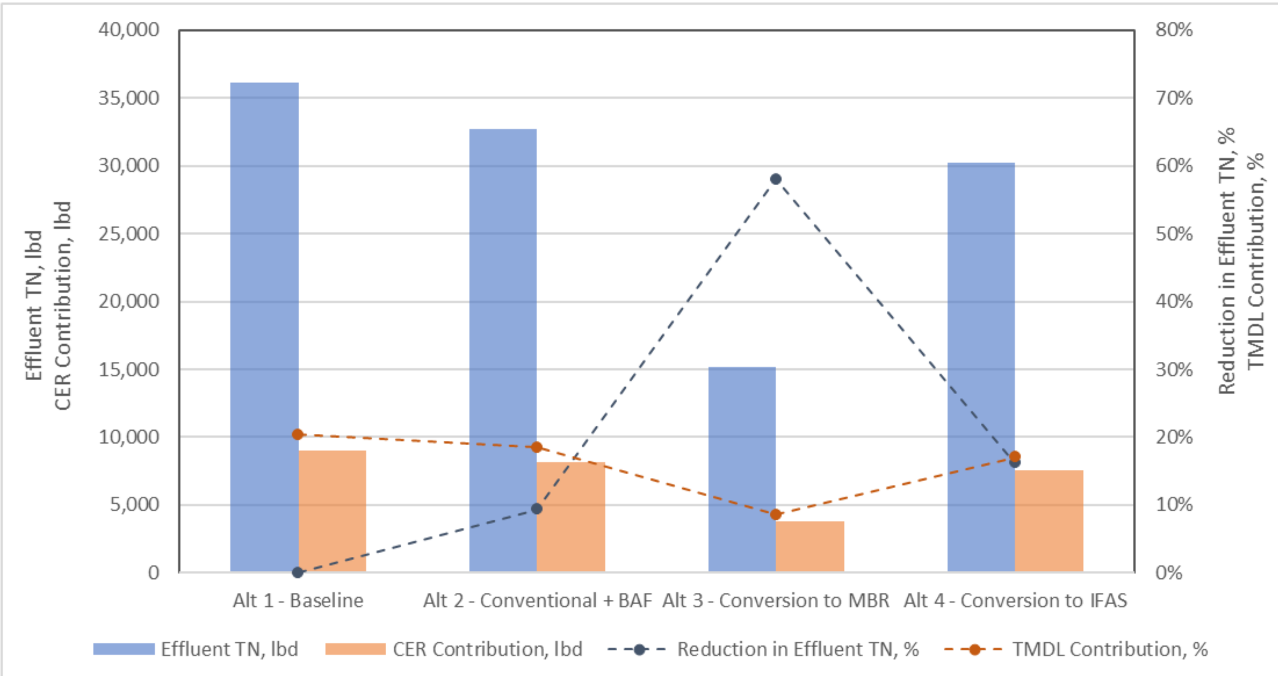

Figure 19 - Total Nitrogen Removal Comparison – NC WRRF and the CER/LIS

- **Yearly Operations and Maintenance Cost Estimates and 30-Year Annualized Costs**

Alternative 3 - Conversion to MBR has the highest additional yearly operations and maintenance cost at approximately $9.2 M, which is driven primarily by additional energy consumption for membrane air scouring, return activated sludge pumping, permeate pumping, additional process aeration needs, and additional cost of screenings disposal. **Alternative 4 – Conversion to IFAS** has the second highest operations and maintenance cost at $5.0 M, which is driven by increased process aeration and media mixing requirements and the additional cost of screenings disposal. **Alternative 2 – Conventional + Nite/Denite BAF** has an additional yearly operations and maintenance cost at approximately $3.3 M, which is primarily driven by BAF unit feed pumping, carbon addition, and process aeration of the nitrifying BAF.

Alternative 3 - Conversion to MBR has the highest total annualized cost, accounting for the annualized capital cost and O&M, at $61.5 M, which equates to $8.04 per lb N removed, or $32.15 per lb N removed in the CER.

Alternative 4 – Conversion to IFAS has the second highest total annualized cost at $17.5 M, which equates to $8.25 per lb N removed, or $32.99 per lb N removed in the CER. **Alternative 2 – Conventional + Nite/Denite BAF** has a total annualized cost at $9.8 M, which equates to $8.00 per lb N removed, or $32.00 per lb N removed in the CER.

- **Programmatic Drivers**

All alternatives evaluated require additional energy input for Nitrogen removal and result in the increase of GHG emissions from electricity consumption and N_2O (treatment). There is a decrease of emissions from N_2O (discharge) for all alternatives due to the reduction in Nitrogen load discharged with the effluent. The only alternative presenting a modest overall emissions decrease is **Alternative 2 – Conventional + Nite/Denite BAF.**

Alternative 3 – Conversion to MBR has the highest absolute increase in energy consumption and overall GHG increase of 1,957 MTCO2eq/year. **Alternative 4 – Conversion to IFAS** has the highest GHG emissions increase and energy intensity amongst all alternatives. **Table 41** presents the comparison between feasible alternatives.

Table 41 – Energy and GHG emissions comparison

Parameter/Criteria	Alt 2 - Conventional + Nite/Denite BAF	Alt 3 - Conversion to MBR	Alt 4 - Conversion to IFAS
Effluent TN, lbd	32,727	15,150	30,274
Net Reduction, TN lbd	3,373	20,950	5,826
Additional energy use, kWh/year	4,528,000	36,147,000	25,816,000
Additional kWh/ lb TN removed	3.7	4.7	12.1
Additional GHG emissions, $MTCO_2eq$/year	(128)	1,957	5,433
Additional $MTCO_2eq$ / lb TN removed	-0.0001	0.0003	0.0026

The analysis indicates that implementing MBR or IFAS at NC WRRF would have significant negative impact on NYC DEP's goal of reaching energy neutrality and reducing GHG emissions by 80% by 2050 (as stated in OneNYC Plan).

- **Implementation Considerations**

Of the three technically viable treatment configuration alternatives, **Alternative 2 – Conventional + Nite/Denite BAF** is the most straight forward to implement and involves the least amount of disruption to maintaining current treatment goals and performance during construction. The new unit processes would be constructed in an area of the existing site that is not currently utilized for treatment, simplifying construction effort, and minimizing impacts to daily operations. However, its benefits from a TN removal perspective are reduced and its cost per pound of Nitrogen removed is as high as the costs for **Alternatives 3 and 4**.

Due to the current configuration of the biological treatment system at the NC WRRF, the implementation of **Alternative 3 - Conversion to MBR** would require major modifications, including structural and new building to provide the necessary new flow patterns and fine screens. This would require an entire battery of grit removal units, aeration basins, and secondary clarifiers to be removed from service at a time. This would increase flow and mass loadings to the remaining two treatment batteries during construction, which would complicate operations significantly, increase loading rates on the biological system, and likely require the WRRF to operate lower SRTs than the WRRF design intent and historical operation. While feasible, implementation would leave very little room for error when it comes to meeting treatment goals and maintaining effluent quality. Also, this alternative requires on-site piloting of fine screening would be also recommended on both the raw influent and MLSS to understand the implications of implementing this technology on residuals management at the WRRF, as well as the MBR operating criteria.

Alternative 3 would also significantly increase the connected electrical loads to the existing electrical distribution system at the WRRF and a detailed analysis would be required to determine what modifications would be required to accommodate this upgrade and at what cost for construction.

Similar to **Alternative 3**, the implementation of **Alternative 4 – Conversion to IFAS** would require fine screening upstream of the new treatment technology, in this instance of the raw influent. As discussed previously this would require extensive on-site piloting to determine feasibility as fine screening on raw influent is not a typical approach. The implementation of this technology would require the existing aeration basins to be reconfigured, with the construction of dedicated aerobic zones segregated from the remaining tank volume with concrete baffles. These zones would then be filled with floating biofilm media carriers. The baffles would be fitted with media retention screens that ensure the media stays within the zones and does not shift into other portions of the reactors. In addition, the existing diffusers would need to be replaced with media bubble units and the existing process air blower system would have to be upgraded, with a few existing units being replaced with larger capacity units. Also, only one vendor thought IFAS could work at NC WRRF, but an extensive demonstration study would be required to confirm process design criteria and costs.

Considering their potential for TN removal and their associated risks and costs (summarized in **Table 42**), none of the three alternatives studied are feasible for NC WRRF.

Table 42 - Treatment Configuration Alternatives Comparison – NC WRRF

Treatment Configuration Alternative	Baseline – Conventional (Non-BNR)	Alt 1 – Step-feed BNR	Alt 2 – Conventional + Nite/Denite BAF	Alt 3 – Conversion to MBR	Alt 4 – Conversion to IFAS	Alt 5 – Conversion to MABR
Implementation	---	*Not Feasible*	Simple	Very Complex	Moderate	*Not Feasible*
Pre-Treatment Requirements	---	---	No	Yes - 2mm screening	Yes - 3 mm screening	---
Increase in Energy Consumption	---	---	Moderate	Highest	High	---
Chemical Addition	---	---	Methanol/Glycerol	Sodium hypochlorite and Citric Acid for cleaning	None	---
O&M Considerations	---	---	Moderate	High	Moderate	---
Effluent TN, lbd	36,100	---	32,727 (9 % Reduction)	15,150 (58% Reduction)	30,274 (16% Reduction)	---
CER Contribution, lbd	9,025	---	8,182	3,788	7,569	---
CER Contribution, %	20	---	18	9	17	---
Total Capital Cost, $MM/year	---	---	$129	$990	$245	---
Annualized Capital Cost, $MM/year	---	---	$6.6	$52	$13	---
O&M Cost, $MM/year	---	---	$3.3	$9.2	$5.0	---
Total Annualized Cost, $MM/year	---	---	$9.8	$61	$18	---
$/TN Removed	---	---	$8.00	$8.04	$8.25	---
$/TN Removed CER	---	---	$32.00	$32.15	$32.99	---

Figures

Figures

Figure A - NC WRRF Site Plan

Figures

Figure B - NC WRRF Site Plan: Available Footprint for New Systems

Figures

Figures

Figure D - NC WRRF Conceptual Layout: Implementation of MBR

Figures

Appendix A

Technical Memorandum 1 – Historical Operations and Performance Data Evaluation

Appendix B

Technical Memorandum 2 – Existing Condition Assessment of Aeration Tanks and Associated Systems

Appendix C

Technical Memorandum 3 – Flow and Loading Projections

Appendix D

Technical Memorandum 4 – Full-Plant Process Model Development and Calibration

Appendix E

Opinion of Probable Construction Cost

Appendix F

Vendor Quotes

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