

2025 Technical Survey of Nitrogen Removal Alternatives for the Deer Island Treatment Plant

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2025 Technical Survey of Nitrogen Removal Alternatives for the Deer Island Treatment Plant

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Environmental Quality Department Report 2026-04

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Executive Summary

Section 8.e.i of the Massachusetts Water Resources Authority's (MWRA's) wastewater NPDES discharge permit (No. MA0103284) requires MWRA to "maintain a comprehensive technical survey of effective treatment technologies for nitrogen removal which are applicable to the Deer Island treatment facility." The survey is supported by the monitoring program designed to characterize the quality of wastewater streams within the treatment plant required by Section I.8.e.ii of the permit.

The requirement for the survey grows out of concern about the possible impacts of nitrogen, a nutrient, on the Massachusetts Bay ecosystem. Concerns that nitrogen in effluent might lead to low dissolved oxygen or undesirable algal blooms in the Bay prompted the inclusion of the above clauses in the permit. Should MWRA need to reduce nitrogen discharges, the survey will allow MWRA to make an informed decision on available nitrogen removal options. However, over 20 years of monitoring data shows no adverse effects in the Bay. Eutrophication has not been observed, nor have there been any nitrogen-related cyanobacteria or nuisance algae blooms. Dissolved oxygen concentrations in the past 20 years have remained well above levels that would endanger aquatic life. In addition, the permit-required and calibrated Bays Eutrophication Model computes that over an annual cycle only 5% to 9% of the total nitrogen entering the Massachusetts Bay system is derived from the MWRA effluent (e.g., Deltares, 2022a, 2022b, 2023, 2024, and 2025). The model also indicates that most of the nitrogen entering the Massachusetts Bay system is associated with inflowing waters from the Gulf of Maine (approximately 88% to 93%; Deltares, 2022a, 2022b, 2023, 2024, and 2025). Current nitrogen levels in the effluent appear to have no negative effect on Massachusetts Bay water quality. Hypothetical scenarios run with increases of effluent nitrogen concentrations of 10% (Zhao et al., 2015), 20% (Zhao et al., 2017), and 50% (Deltares, 2022b) predict increased nitrogen at depth near the outfall, much smaller chlorophyll increases, and imperceptible effects on dissolved oxygen. Although effluent nitrogen was predicted to increase nitrogen close to the outfall by about 50%, a hypothetical doubling of the effluent nitrogen (Zhao et al. 2015) led to only modest increases (~7%) in chlorophyll and less than a 0.5% increase in dissolved oxygen. The results suggest that the Bay's ecology would be unharmed even for nitrogen loads above the 14,000 metric tons per year Contingency Plan warning threshold, which was set at the projected 2020 load for anticipated population increases (Zhao et al., 2017).

This report was first submitted in November 2001 (Camp Dresser and McKee, 2001) and has been updated annually since then, as required by the permit. The design criteria for the selection of alternative treatment are updated annually and are based on their suitability at Deer Island, process reliability, and land and space requirements.

Approximately 11.2 acres of usable area exist on Deer Island for siting potentially needed nitrogen removal facilities. This area was dedicated to future needed nitrogen facilities as part of long-term Deer Island planning and would allow for the construction of nitrogen removal facilities without significantly encroaching on the landforms that were constructed to mitigate noise and visual impacts on the Town of Winthrop. The usable area was reduced in this 2025 report to account for the space required for a proposed new Combined Heat and Power (CHP) Facility and its associated battery energy storage system (BESS). Both would increase energy

efficiency at Deer Island and reduce MWRA's fuel oil usage and greenhouse gas emissions.

At present, combined biological aerated filters and moving-bed biofilm reactors, biological aerated filters with fluidized-bed reactors, and moving-bed biofilm reactors alternatives continue to be the most viable options for nitrogen removal at Deer Island.

This report includes sections addressing sidestream treatment. Although sidestream flows account for less than 1% of the total plant flow, they contribute up to 12% of the total nitrogen (TN) load. The Residuals Processing Plant has a sidestream flow from the residual dewater, and the Deer Island sludge processing side stream flows include overflow from the gravity thickeners and centrate from the waste activated sludge centrifuges. Benefits of sidestream treatment systems include a relatively small footprint at a low cost, lowering waste activated sludge production, and reducing methanol requirements for other methods of nitrogen removal.

Biological nitrogen removal technologies currently appear to be the most feasible method of nitrogen removal. A research project entitled *Sustainable Technology for Achieving Very Low Nitrogen and Phosphorus Effluent Levels* (WERF, 2003), funded by the Water Environment Research Foundation (WERF), assessed a variety of technologies to determine the feasibility and cost benefits of nutrient reduction at treatment plants around the nation. The final report was released in 2009. In addition, the US Environmental Protection Agency (EPA) released a reference document (USEPA, 2008) that presented information on advances in nutrient removal technology and practices. The technologies identified in these documents are included in this report. MWRA will continue to monitor progress and advances in nitrogen removal technologies for applicability to Deer Island.

Section 1. Introduction

1.1 Purpose of Report

MWRA's National Pollutant Discharge Elimination System (NPDES) permit requires maintenance of a comprehensive technical survey of nitrogen removal technologies that are applicable to the Deer Island Treatment Plant (DITP). This report updates the previous report, *Technical Survey of Nitrogen Removal Technologies for the Deer Island Treatment Plant*, published in 2024. This update will help to facilitate selection and implementation of a nitrogen removal technology if such technology is required at Deer Island. If nitrogen removal were deemed necessary, the most promising feasible technologies identified in this report (or future versions of this report) will require full system evaluations, assessment, and design to ensure compatibility with the full DITP system.

1.2 Content of Report

This report describes existing conditions at the Deer Island site and identifies and evaluates various treatment alternatives capable of providing nitrogen removal at the Deer Island facility.

Section 2 begins with a description of existing facilities and of the remaining space available at Deer Island for siting nitrogen removal facilities. Section 2 also presents the most current nitrogen monitoring data available, and updates estimates of flows and nitrogen loads used in the previously submitted reports.

Section 3 discusses processes available for nitrogen removal. This section summarizes physical/chemical nitrogen removal and biological nitrification and denitrification technologies. Processes are evaluated for applicability to the Deer Island site, and viable alternatives are selected for a more in-depth review. Sidestream processes are also described in Section 3, including those that could be implemented on Deer Island and those that could be used at the Residuals Processing Plant in Quincy, MA.

Section 4 further investigates the alternatives selected in Section 3. Each alternative is sized to determine feasibility of implementation. Elements common to all feasible options, such as oxygen and chemical needs and sludge production, are evaluated in Section 4.5.

Section 5 evaluates one sidestream treatment method in detail and examines how sidestream treatment could modify the estimated requirements for mainstream treatment alternatives.

Section 2. Basic Planning Criteria

This section reviews existing facilities and identifies available space that could be used for nitrogen removal facilities. In addition, this section summarizes July 2020 – June 2025 nitrogen monitoring data, updates flows and nitrogen loads from the previous year's report, and presents basic information used for selecting facilities.

2.1 Existing Facilities

The Deer Island Treatment Plant (DITP) is a pure oxygen activated sludge process treatment plant with an average design flow of 361 MGD and hydraulic capacity of 1,270 MGD. During wet weather, the secondary treatment process can treat up to a maximum of 700 MGD. Figure 1 depicts the DITP site layout and Table 1 lists major facilities and pertinent information regarding those facilities.

2.2 Available Space

Nitrogen removal would require additional facilities for wastewater treatment and solids processing. The goal of this analysis is to estimate whether these facilities could be sited in areas previously allocated for treatment processes or support facilities that were not built, and to avoid construction on the landforms developed to lessen the impact of wastewater treatment facilities on Winthrop.

Areas available for nitrogen removal facilities are highlighted on Figure 2 and include:

- Area A: 4.9 acres, the area west of the existing secondary batteries
- Area B: 0.4 acres, the area to the north of secondary Battery A
- Area C: 1.4 acres, the area north of secondary Batteries B
- Area D: 3.5 acres, the area located north of the maintenance warehouse

While the total available gross area is 10.2 acres, piping and operational considerations limit the use of available space. Additionally, each option's particular design requirements need more in-depth evaluation for its feasibility. While a solar canopy is planned for installation in Area D, which is an existing employee parking area, this could be removed and parking could be relocated if this space was required. Sections 4 and 5 present these conceptual design evaluations. Portions of the available space west of the existing secondary batteries (in both Area A, and Area C) are likely to be used for the construction of the new Combined Heat and Power (CHP) Facility and its associated battery energy storage system (BESS). The new CHP Facility is expected to take up approximately 2.6 acres of the available gross area, reducing the available gross area from 12.8 acres to 10.2 acres. This project is in its preliminary design stages, and the exact acreage and size of the proposed CHP Facility is not known currently. The proposed area for the CHP Facility has been removed from Figures 2, 12, 13, and 14.

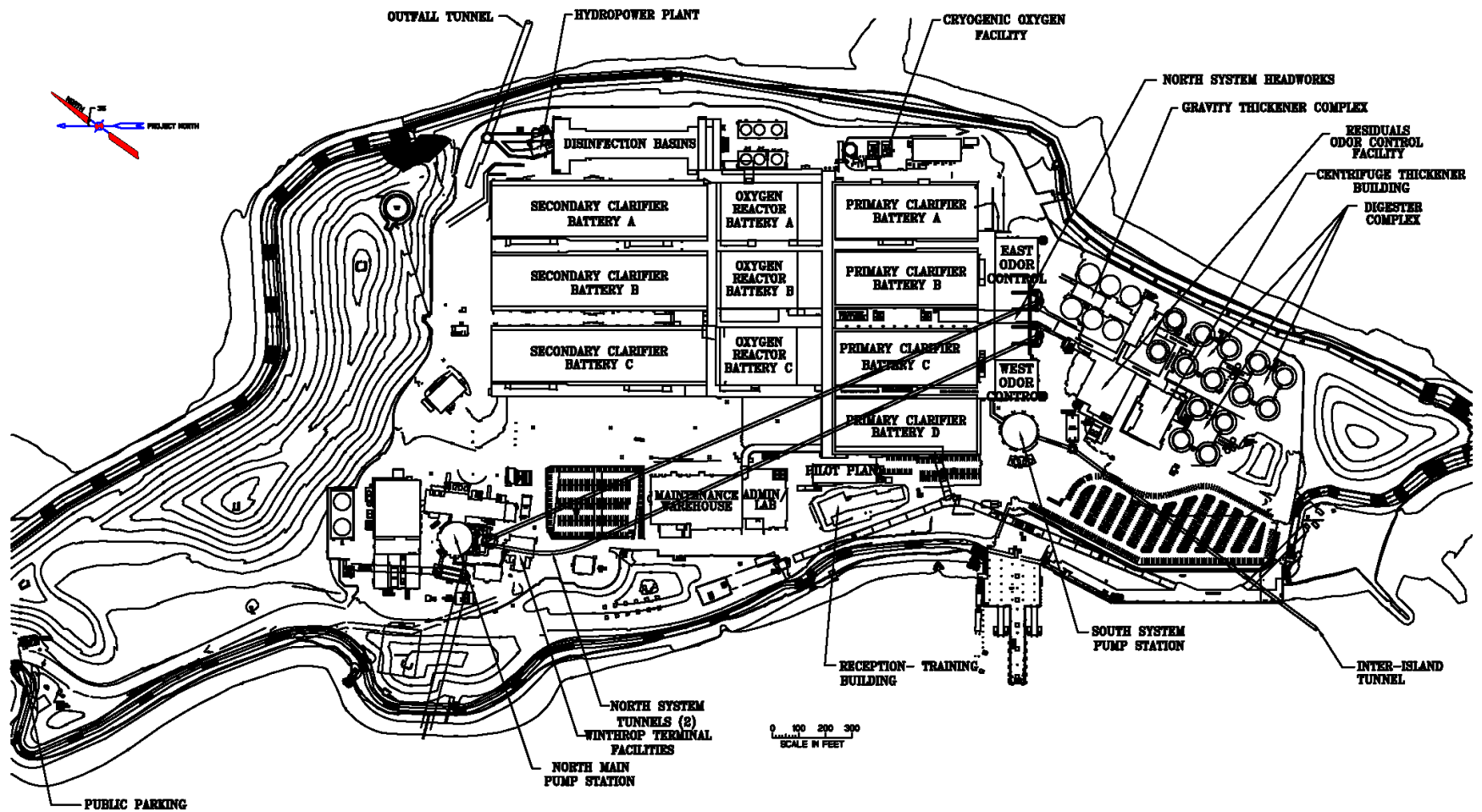


Figure 1. Deer Island Site Plan.

Table 1. Facilities at Deer Island Treatment Plant

Stacked Rectangular Primary Clarifiers	
Number of batteries	4
Clarifiers per battery (stacked sets)	12
Effective surface area per clarifier (ft ²)	15,252
Aeration Tanks	
Number of batteries	3
Number of trains per battery	3
Total number of trains	9
Number of stages for selectors	3/train
Volume of selectors per train (MG)	1.07
Number of aeration stages per train	4
Aeration volume per train (MG)	3.55
Stacked Rectangular Secondary Clarifiers	
Number of batteries	3
Clarifiers per battery (stacked sets)	18
Effective surface area per clarifier (ft ²)	13,940
Gravity Thickeners (for Primary Sludge)	
Number of units	6
Diameter (ft)	70
Sidewater depth (ft)	12
Centrifuges for Thickening Waste Activated Sludge	
Number	12
Allowable range of flow/centrifuge (gpm)	300 to 900
Anaerobic Digesters/Thickened Sludge Storage	
Number of digesters	12
Volume of each digester (MG)	3.0
Number of storage tanks	2
Diameter (ft)	90
Total depth (ft)	130
Volume each (MG)	3.0

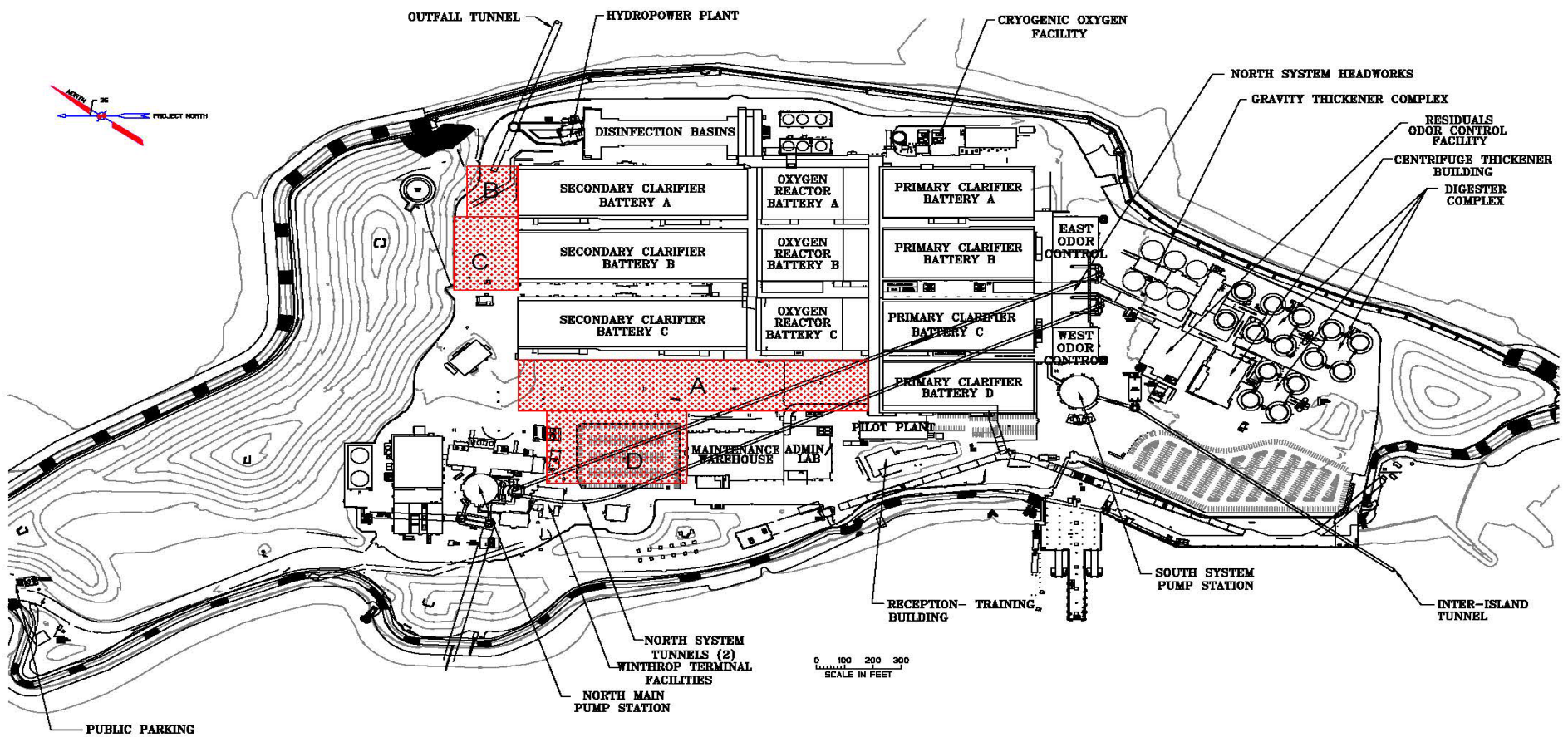


Figure 2. Areas Available for Nutrient Removal

2.3 Flows and Loads

This section provides a summary of monitoring results conducted during the period July 2020 to June 2025 and quantifies nitrogen loads from various wastewater streams. Due to operational changes in 2005, these load calculations supersede the estimates that were used in developing and sizing the conceptual designs of the selected nitrogen removal alternatives in the July 2001 report (CDM, 2001). In this report, we are using the most recent 5 years since that is more representative of the current characteristics of the plant for design.

In addition to the required NPDES permit influent and effluent monitoring, MWRA implemented a comprehensive nitrogen monitoring program (Coughlin, 2000), to characterize wastewater streams within the treatment plant. If necessary, these data will facilitate the selection and design of nitrogen removal facilities at Deer Island.

Figure 3 shows the Deer Island process flow and the various sampling locations along the process. South system flow arrives at Deer Island's south system pump station via the inter-island tunnel and combines with the north system flow after the grit removal facility. This combined raw wastewater is characterized by taking the flow-weighted average of the individual north and south system measurements.

2.3.1 Flows

The average daily flow for the period July 2020 to June 2025 was 315 million gallons per day (MGD). This flow and the maximum sustainable flow to secondary treatment of 700 MGD (based on experiments conducted from March 2006 to June 2007), will be used to size nitrogen removal facilities at Deer Island. Figure 4 shows the daily effluent flow while Figure 5 graphs the monthly averages.

Return streams from sludge processing at Deer Island include overflow from the gravity thickeners and waste activated sludge centrifuge centrate from secondary treatment. Gravity thickener overflow can be pumped directly to the primary tanks or flow by gravity via the south system pump station depending on pump availability. During the period between July 2020 and June 2025, an average of 6.2 MGD of gravity thickener overflow and 5.2 MGD of waste sludge centrifuge centrate were returned to the plant via the south system pump station or to the influent of the primary tanks. While these return flows can be considered negligible compared to the raw influent flow (315 MGD), their nitrogen loads are high (4.8% and 8.1% of the influent total nitrogen load, respectively).

As of April 1, 2005, digested sludge is sent to the Residuals Processing Plant in Quincy via the inter-island tunnel. In addition to the internal recycle flows described in the previous paragraph, which are shown on Figure 6 and summarized in Table 2, there is also a high-nitrogen side stream derived from the residuals dewatering process at the Processing Plant (see section 5.1). This side stream returns to Deer Island via the Intermediate Pump Station in Quincy and is included in the South System influent flow.

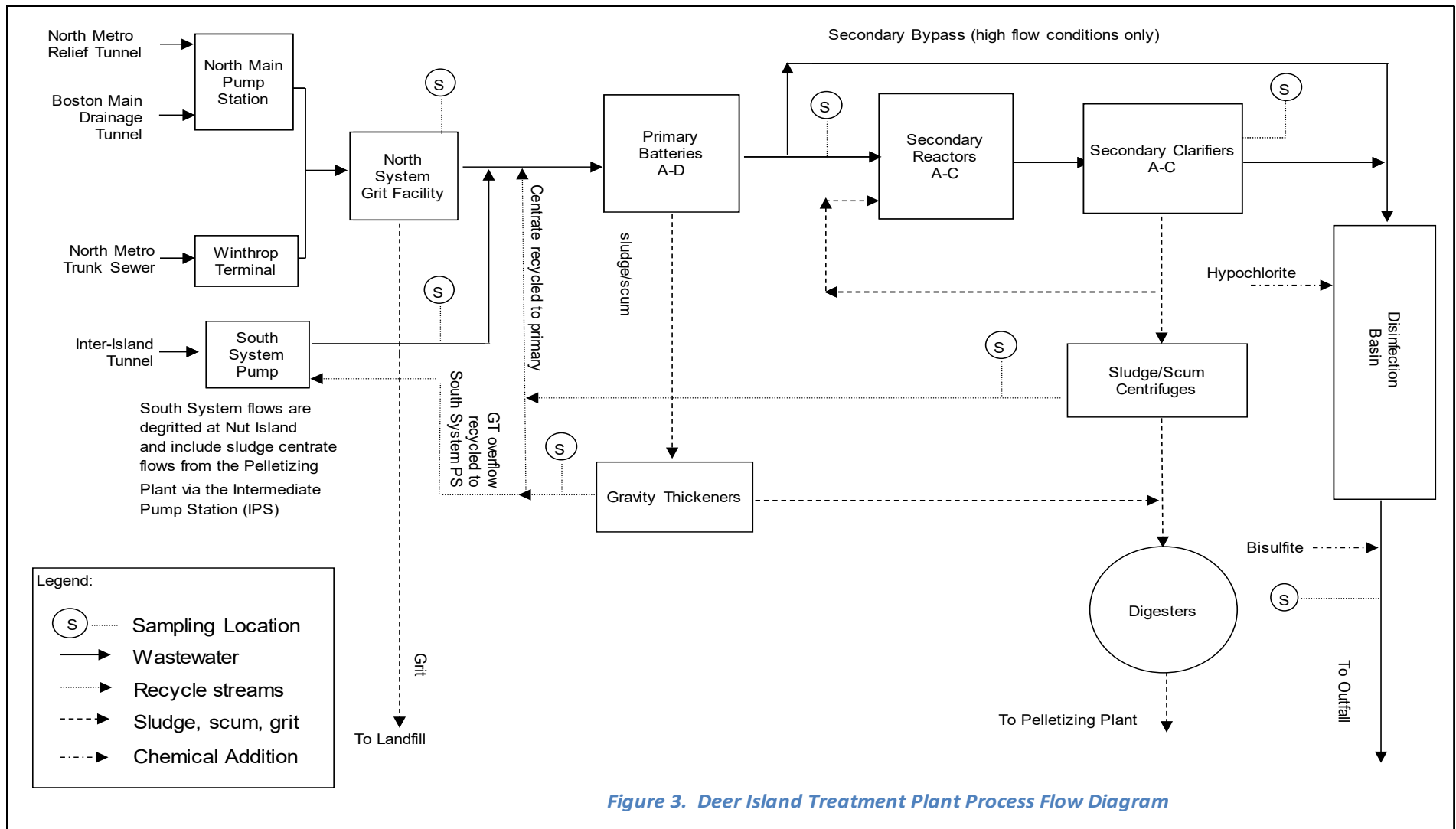


Figure 3. Deer Island Treatment Plant Process Flow Diagram

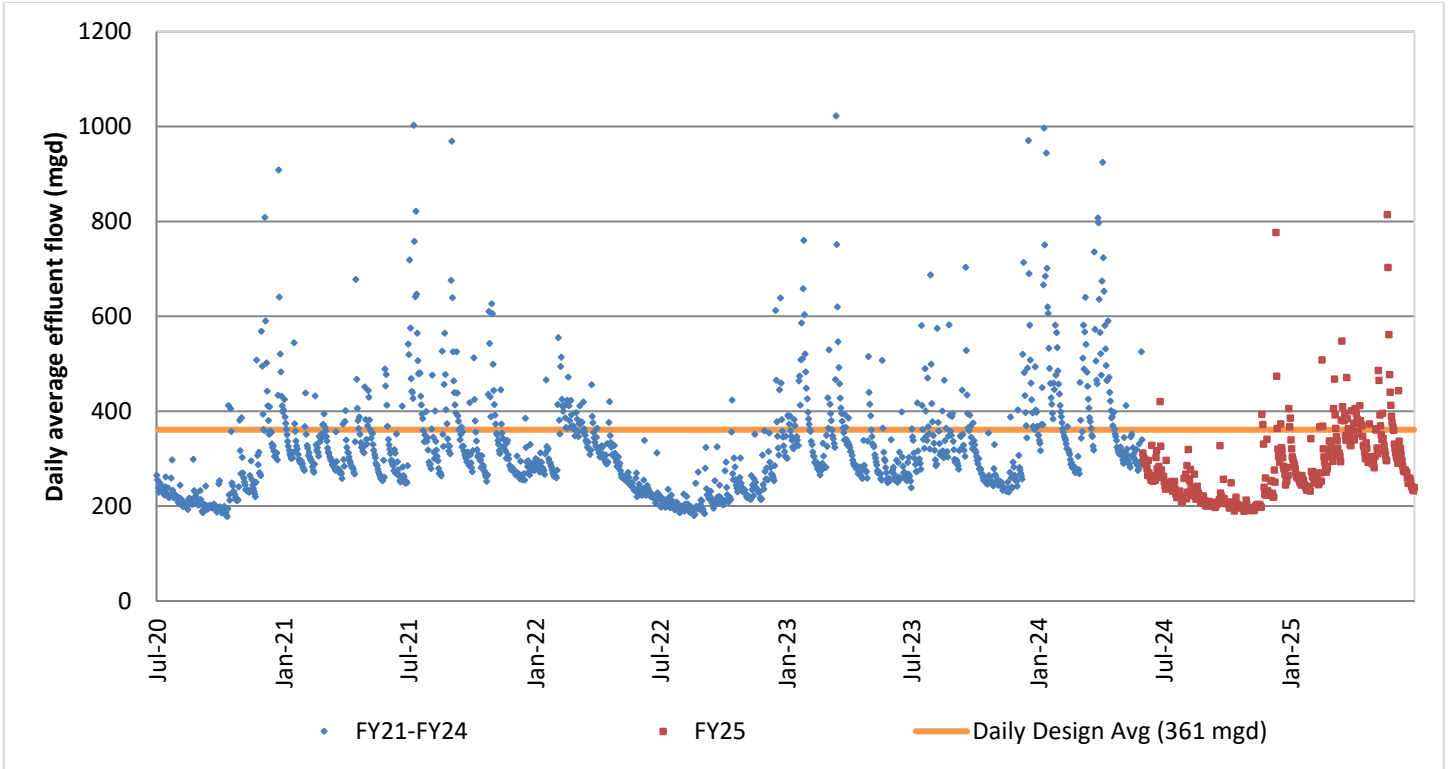


Figure 4. Average Daily Flow

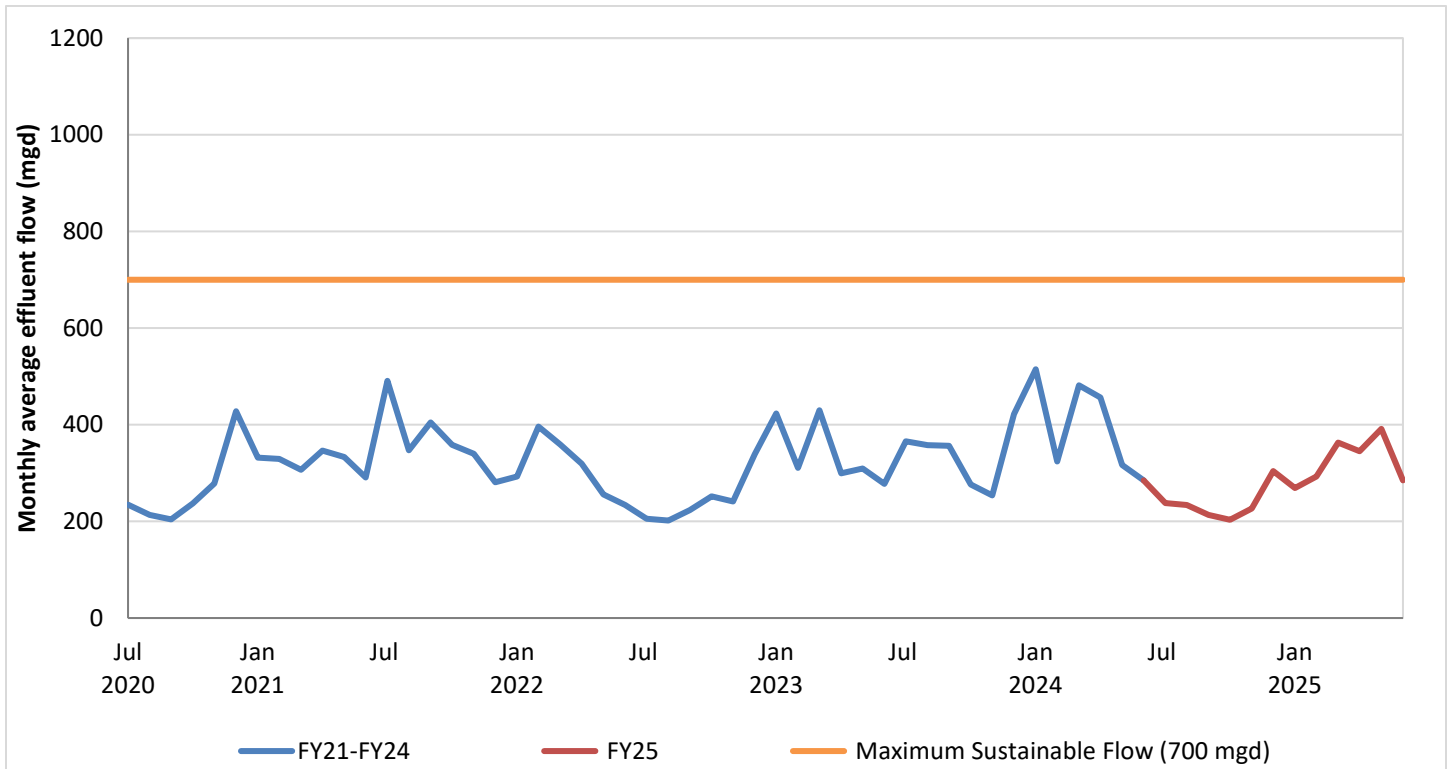


Figure 5. Average Monthly Flow

2.3.2 Nitrogen Loads

Extensive nitrogen data have been gathered from the nitrogen monitoring program. While the first report in 2001 used estimated nitrogen loads, actual data are now available to quantify nitrogen in the major waste streams at Deer Island. These data are presented in Table 2.

Monitored nitrogen species include ammonia (NH_3^-), nitrite (NO_2^-), nitrate (NO_3^-), and total Kjeldahl nitrogen (TKN), all expressed as nitrogen. TKN consists of ammonia and organic nitrogen. Total nitrogen (TN) is the sum of TKN, NO_3^- , and NO_2^- . For each monitoring event, the actual flow for each waste stream is used to derive the daily loads of each nitrogen species. The TN load is determined from these calculated loads.

From July 2020 – June 2025, the average flow-weighted Deer Island influent concentration of ammonia was 30.0 mg/L and TN was 40.3 mg/L. These concentrations are typical of medium-strength wastewater (Metcalf & Eddy, 1991). The average TN load from raw influent during the same period was about 99,321 lb/d.

Figure 6 shows the TN mass balance across the unit processes at Deer Island. Figure 7 shows the monthly average total nitrogen loads to the primary clarifiers, while Figure 8 shows the total nitrogen monthly average effluent loads out of the primary clarifiers, secondary clarifiers, and final effluent.

Table 2. Summary of Nitrogen Monitoring Results

Sampling Location	Flow* (mgd)	TKN		NH3-N		NO3-N		NO2-N		NO3+NO2		Total Nitrogen	
		(mg/L)	(lb/d)	(mg/L)	(lb/d)	(mg/L)	(lb/d)	(mg/L)	(lb/d)	(mg/L)	(lb/d)	(mg/L)	(lb/d)
North System Influent (7/1/20 - 6/30/25)													
Minimum	121	13.5	31,356	7.2	22,086	0	0	0	0	0	0	15.4	31,836
Maximum	704	120	214,291	55.5	81,404	2.3	8616.6	1.0	1,898	2.5	9,179	120	214,534
Average	204	30.0	47,856	20.9	32,839	0.5	844	0.2	419	0.7	1,263	30.7	49,118
Standard Deviation	70.4	9.0	12,763	5.5	4,898	0.4	802	0.2	294	0.5	974	9.0	12,751
South System Influent (7/1/20 - 6/30/25)													
Minimum	55.8	26.1	21,766	17.2	14,289	0	0	0	0	0	0	26.8	21,800
Maximum	363	107	70,951	91.6	58,993	4.1	4884	2.10	2,813	4.14	7,553	108	73,266
Average	111	58.0	49,785	47.0	39,958	0.2	197	0.22	222	0.38	418	58.4	50,203
Standard Deviation	41	16.5	6,785	14.3	5,607	0.4	438	0.28	340	0.55	672	16.6	6,913
Calculated Raw Influent													
Minimum	178	18.5	61,444	11.2	39,717	0	0	0	0	0	5.3	19.7	62,788
Maximum	1,022	93.2	272,548	54.6	121,590	2.2	13,501	0.9	3,234	2.7	16,735	93.4	273,032
Average	315	39.7	97,641	30.0	72,798	0.4	1,041	0.2	641	0.6	1,681	40.3	99,321
Standard Deviation	108	9.6	15,048	7.6	7,947	0.3	1,075	0.1	430	0.3	1,358	9.5	15,149
Waste Activated Sludge Centrate (7/1/20- 6/30/25)													
Minimum	1.8	10.0	493	10.3	196	~	~	~	~	0	0	10.0	495
Maximum	8.4	437	19,804	65.3	2,959	~	~	~	~	0.072	3.9	437	19,804
Average	5.2	189	8,020	31.6	1,372	~	~	~	~	0.007	0.3	189	8,021
Standard Deviation	1.0	51.8	2,683	6.7	466	~	~	~	~	0.007	0.4	51.8	2,683
Calculated Primary Influent													
Minimum	184	18.7	68,863	11.2	40,625	~	~	~	~	0	5.6	20.2	70,207
Maximum	1,024	93.1	275,806	54.5	123,287	~	~	~	~	2.7	16,735	93.3	276,290
Average	320	42.3	105,477	30.0	74,065	~	~	~	~	0.6	1,681	42.9	107,157
Standard Deviation	107	10.3	15,304	7.5	8,116	~	~	~	~	0.3	1,360	10.2	15,325
Primary Effluent (7/1/20 - 6/30/25)													
Minimum	180	17.6	37,344	11.6	36,343	~	~	~	~	0	0	18.0	37,851
Maximum	1,037	69.4	164,312	59.1	135,718	~	~	~	~	2.0	12,458	69.4	169,883
Average	323	39.8	99,698	31.3	77,831	~	~	~	~	0.3	1,050	40.1	100,758
Standard Deviation	110	9.6	13,831	7.9	9,691	~	~	~	~	0.3	1,171	9.5	13,971
Secondary Effluent (7/1/20 - 6/30/25)													
Minimum	178	13.6	44,148	9.5	36,586	~	~	~	~	0.1	200	16.9	45,983
Maximum	707	52.7	140,280	51.9	110,968	~	~	~	~	5.7	20,042	53.8	149,911
Average	312	30.4	74,556	27.8	67,454	~	~	~	~	1.8	4,548	32.1	79,115
Standard Deviation	96	6.7	10,813	6.7	8,661	~	~	~	~	0.8	2,551	6.6	11,267
Gravity Thickener Overflow (7/1/20 - 6/30/25)													
Minimum	2.3	28.6	981	12.8	587	~	~	~	~	0	0	28.6	981
Maximum	13.6	395	18,609	59.9	2,861	~	~	~	~	0.47	42.2	395	18,609
Average	6.2	95.8	4,780	32.8	1,625	~	~	~	~	0.01	0.7	95.8	4,781
Standard Deviation	1.5	50.7	2,665	7.4	367	~	~	~	~	0.03	2.5	50.7	2,665
Final Effluent (7/1/20 - 6/30/25)													
Minimum	178	6.9	32,646	5.8	28,206	0	0	0	0	0	15.8	9.8	39,282
Maximum	1,022	50.3	150,900	53.0	119,813	4.0	12,716	2.4	10,109	4.6	20,546	51.2	162,817
Average	315	28.2	68,816	26.4	63,999	0.4	1,232	0.6	1,586	1.1	3,065	29.1	71,191
Standard Deviation	108	7.8	13,946	7.7	12,062	0.5	1,445	0.5	1,419	0.8	2,450	7.7	14,088

Notes: *: * Flows reported are averages of the whole sampling period. The flow-weighted concentrations were calculated using flows during sampling events. ~ No samples collected.

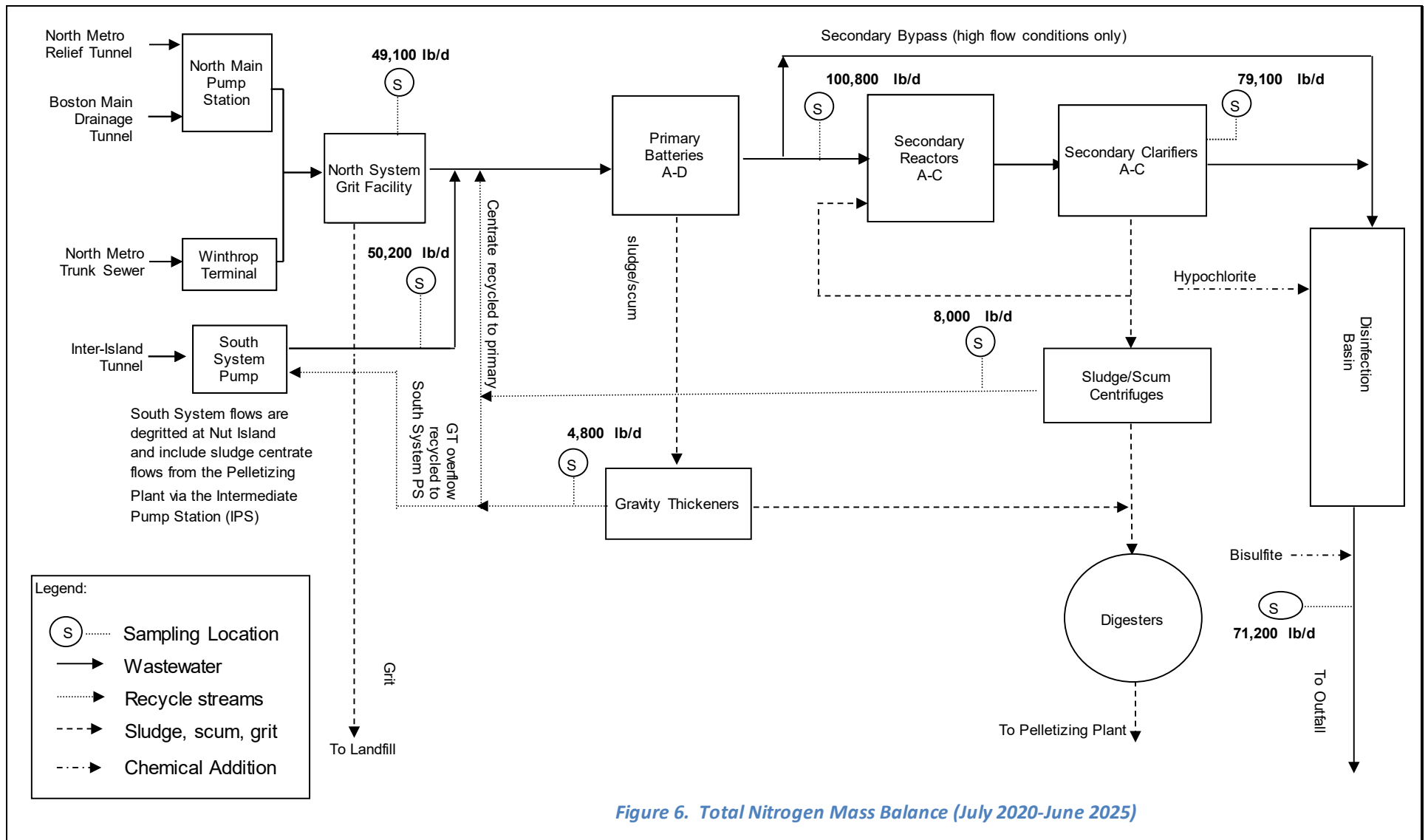


Figure 6. Total Nitrogen Mass Balance (July 2020-June 2025)

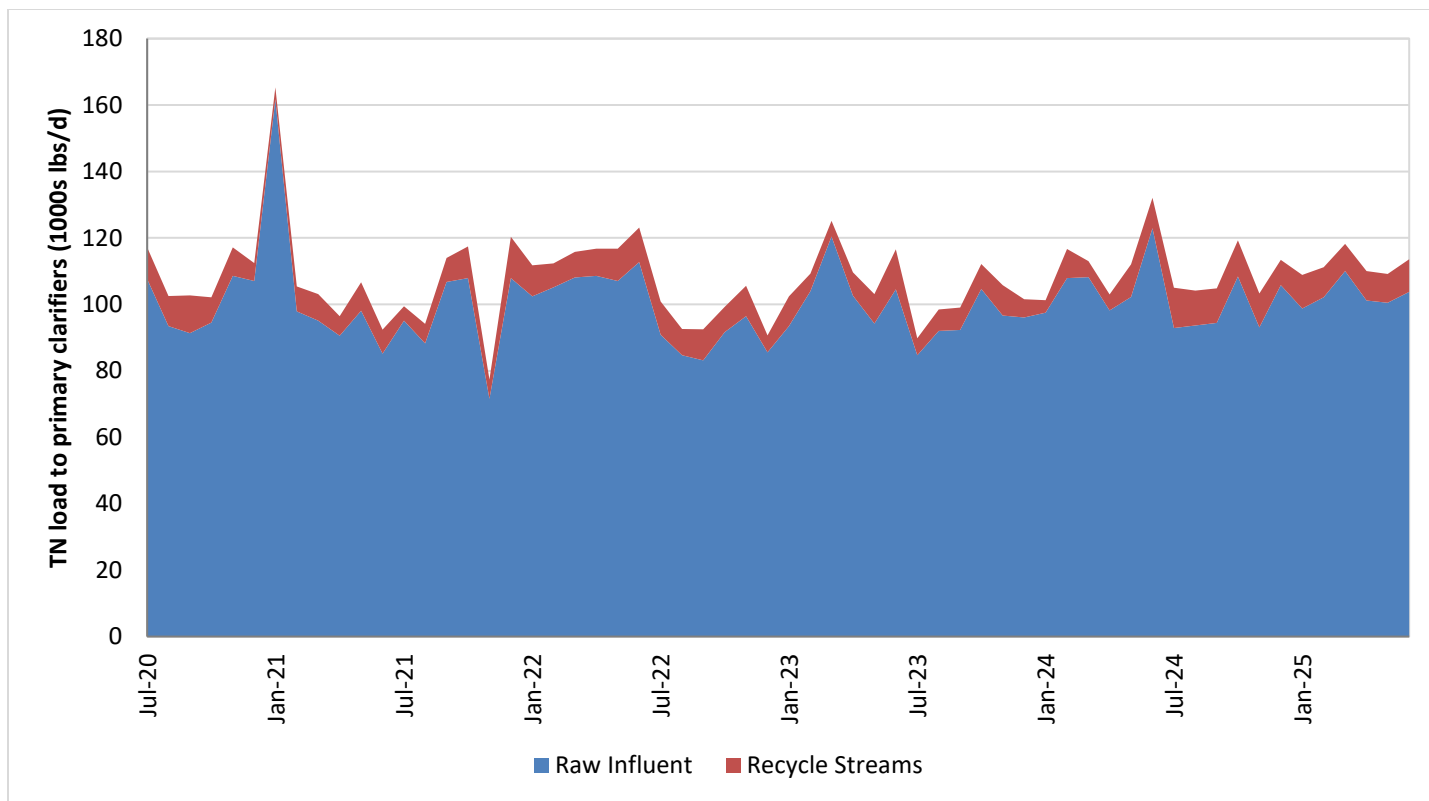


Figure 7. Total Nitrogen Load to Primary Clarifiers (Monthly Average)

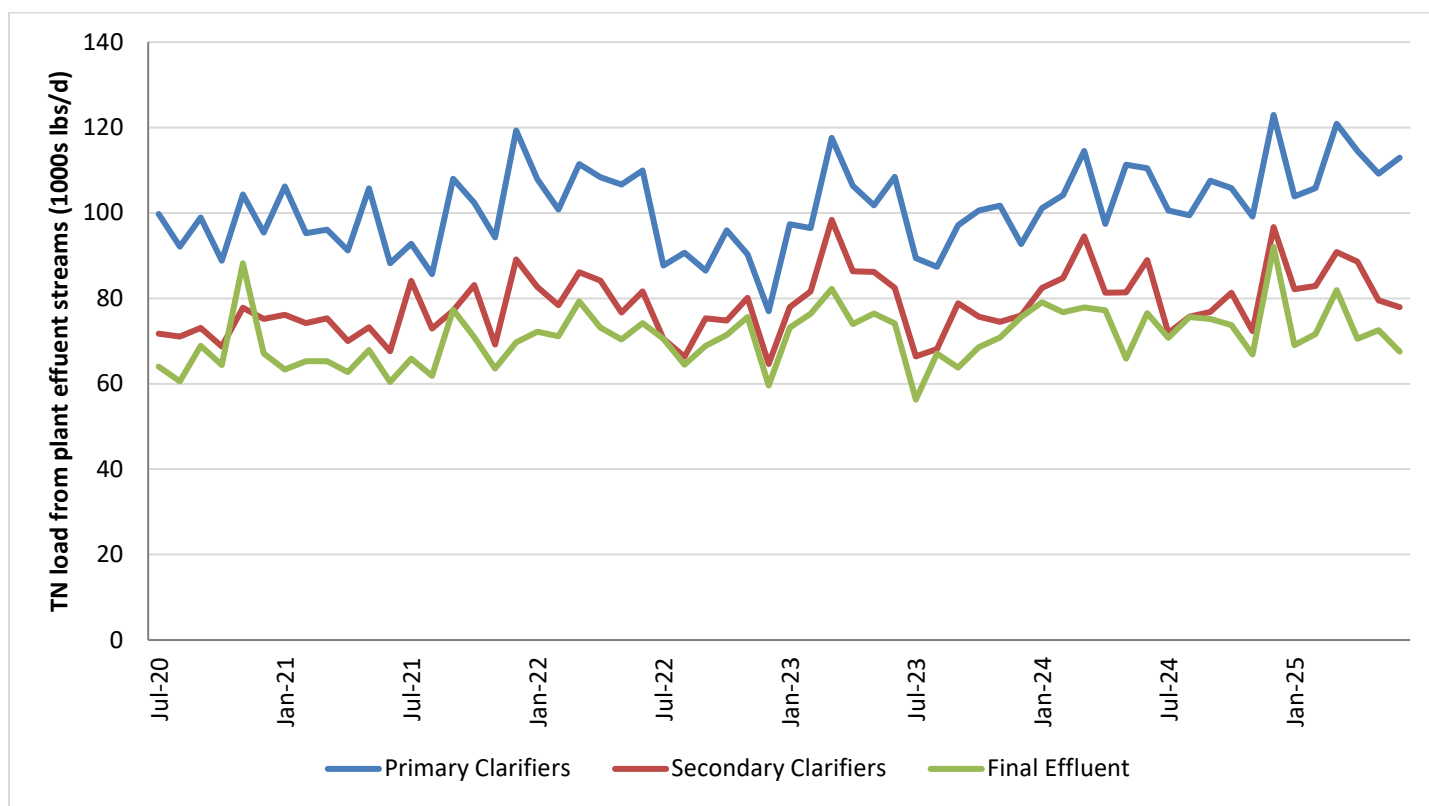


Figure 8. Total Nitrogen Load from Plant Effluent Streams

2.4 Basic Design Information

To develop a conceptual design for a nitrogen removal system, some basic information is required. This includes ambient temperature, design flows and loads, and the target effluent quality.

2.4.1 Wastewater Temperature

Wastewater temperature plays a critical role in the design and performance of biological treatment systems, especially for nitrification. Like most biochemical processes, nitrification rates are highly dependent on temperature. Specifically, the rate of ammonium oxidation is influenced by the growth rate of *Nitrosomonas* bacteria, which increases with temperature. Given the potential need for year-round nitrification, a conservative minimum wastewater temperature must be used for design purposes. Based on monitoring data and the possible requirement for year-round nitrification, this report uses the consultant's recommendation of a minimum wastewater temperature of 51.8°F (11°C) (CDM, 2001).

Final effluent temperature is often the most reliable indicator for establishing the design temperature of a biological nitrogen removal system, as it reflects the conditions under which the biological process must perform. Analysis of FY20-FY25 data shows that the effluent temperature dropped below the selected design criterion of 51.8°F (11°C) zero days of the five-year period. While colder temperatures may reduce nitrification efficiency, the plant is not expected to exceed a hypothetical permit limit even under these conditions. This supports the selection of 51.8°F as an appropriate and conservative minimum design temperature. Figure 9 shows the effluent temperature trends over the monitoring period.

Influent wastewater temperature data were also reviewed to provide additional context regarding seasonal temperature variability entering the facility and to better understand the relationship between incoming wastewater temperatures and resulting effluent conditions. Figures 10 and 11 show the influent temperature trends over the monitoring period.

2.4.2 Design Flows and Nitrogen Loads

As a result of operational experiments conducted from March 2006 to June 2007, Deer Island established that it has a maximum-day capacity of 700 MGD for secondary treatment. Because of the experiments, Deer Island set its secondary process limit at 700 MGD. The design average plant flow of 361 MGD and the maximum sustainable flow to secondary treatment of 700 MGD were used in the conceptual design of the nitrogen removal facility. The corresponding loads in primary and in secondary effluent are presented in Table 3. Table 3 also compares previous load estimates from 2001 with more current data.

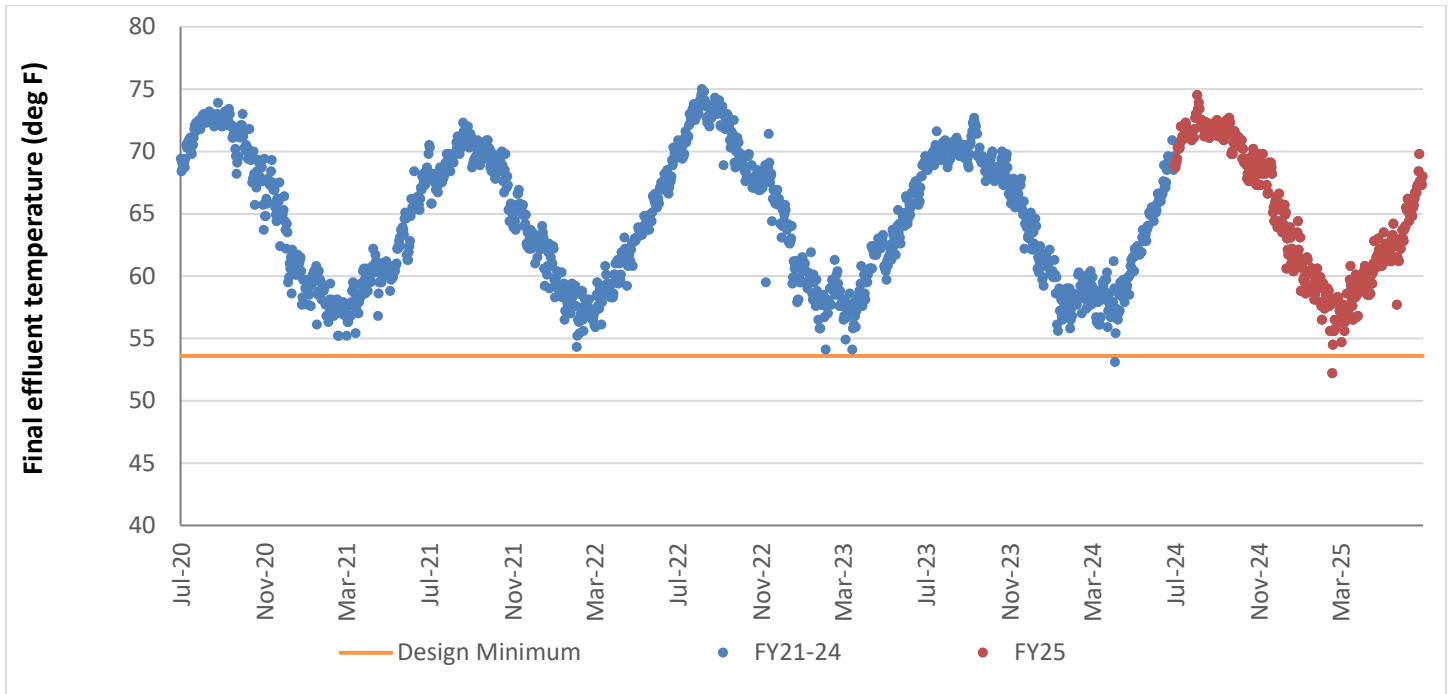


Figure 9. Final Effluent Temperatures

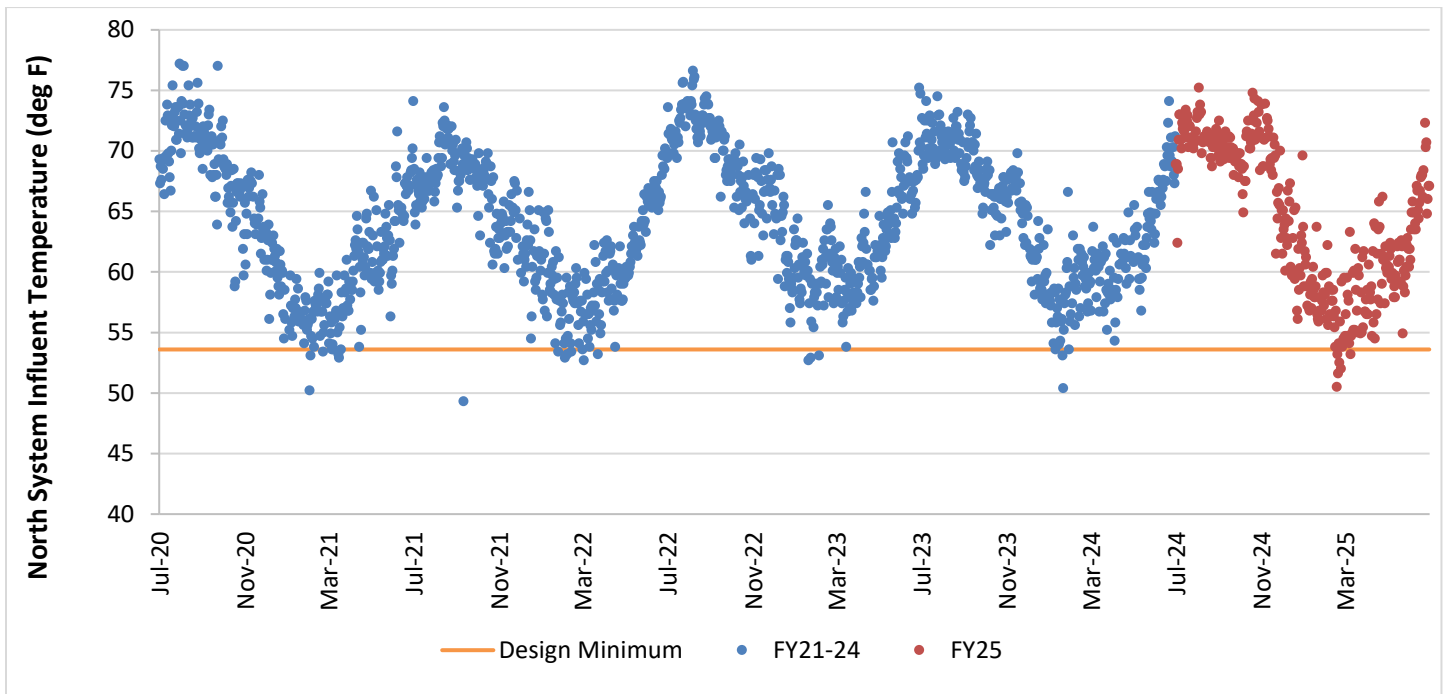


Figure 10. North System Influent Temperatures

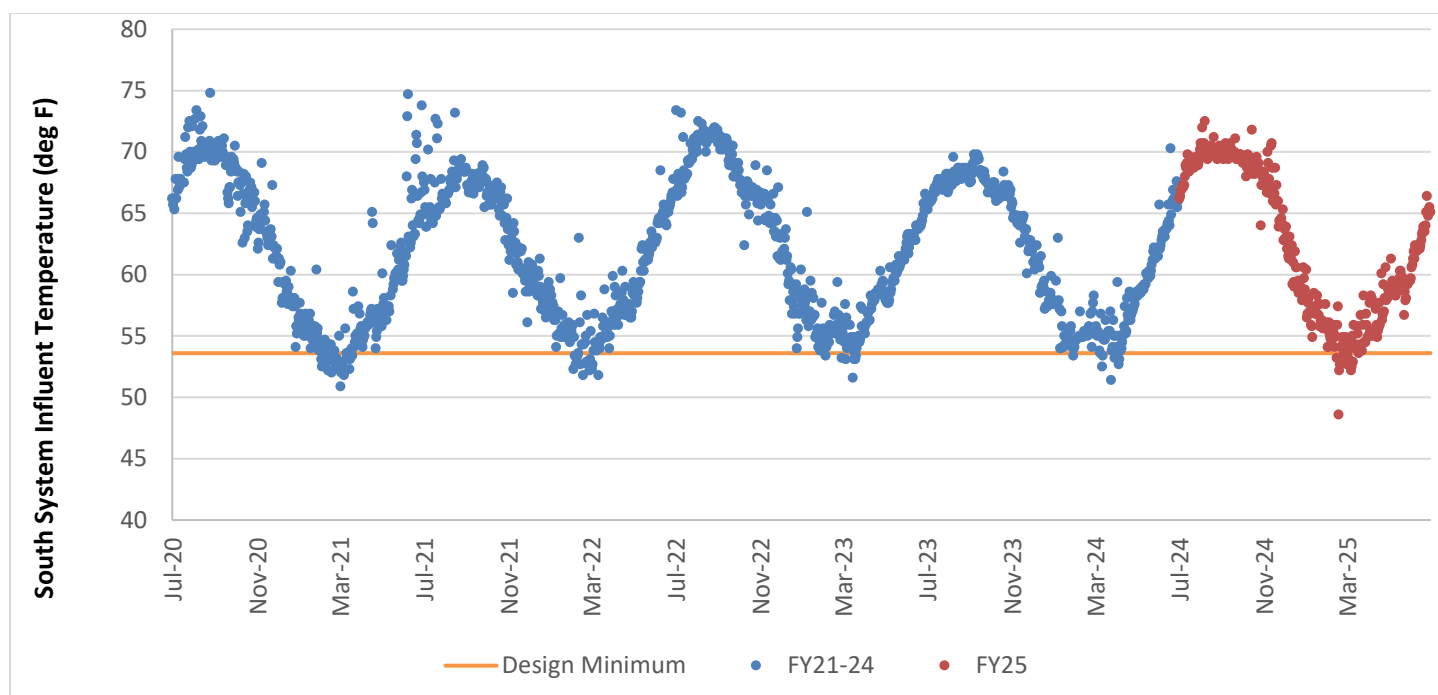


Figure 11. South System Influent Temperatures

Table 3. Flows and Nitrogen Loads

	Design Flow (MGD)	Primary Effluent Nitrogen Load (lb/d)		Secondary Effluent Nitrogen Load (lb/d)	
		2001*	FY20-FY25	2001*	FY20-FY25
Average – Day	361	80,600	100,758	66,200	79,115
Max – Month	700	104,700†	122,942	86,000†	98,380

* In the first edition of this report, published in 2001, nitrogen load was based on limited monitoring data (July-December 1999) and estimated total nitrogen loads from residuals processing recycle flows

† Estimated.

2.4.3 Required Effluent Quality

Effluent limits for nitrogen in effluent from Deer Island have not been set. This evaluation considers two levels of effluent quality: 4 mg/L and 8 mg/L of total nitrogen, both year-round. These concentrations reflect typical NPDES permit effluent limits for total nitrogen, though some permits have given effluent limits as low as 2 or 3 mg/L total nitrogen in order to address water quality impairments or a total maximum daily load. Other permits have given seasonal effluent limits, with limits in place during the warm months, and reporting only during colder months. To allow for making assessments and comparisons in alignment with this report’s purpose, conceptual land requirements and site layouts are conservatively based on a year-round effluent limit of 4 mg/L because a year-round limit requires more space for nitrogen removal.

Section 3. Screening of Alternatives

This section identifies processes available to remove nitrogen from wastewater and screens them to generate a list of alternatives appropriate for further evaluation. Table 4 below lists all the technologies evaluated, the current state of the technology, and whether it is currently suitable for use at Deer Island. Section 4 then examines the potentially suitable systems retained for further evaluation in detail.

Table 4. Alternatives for Controlling Nitrogen at the Deer Island Treatment Plant

Technology	Type of Process	Nitrogen Removal	Current Stage of Technology	Largest Installation is Comparable to DITP	Current Suitability for Use at DITP
Mainstream Treatment					
Reverse Osmosis	Physical/Chemical	Total N Removal	Full-Scale		
Ammonia Stripping	Physical/Chemical	Total N Removal	Full-Scale		
Ion Exchange	Physical/Chemical	Total N Removal	Full-Scale		
Breakpoint Chlorination	Physical/Chemical	Total N Removal	Full-Scale		
Suspended Growth					
Sequencing Batch Reactors	Biological	Total N Removal	Full-Scale		
Membrane Bioreactors	Biological	Total N Removal	Full-Scale	X	
Single Stage and Two Stage	Biological	Total N Removal	Full-Scale	X	
Fixed Film					
Rotating Biological Contactor	Biological	Total N Removal	Full-Scale		
Nitrifying Trickling Filter	Biological	Nitrification	Full-Scale		
Biological Aerated Filters	Biological	Total N Removal	Full-Scale	X	X
Combined BAF-MBBR Reactors	Biological	Total N Removal	Full-Scale	X	X
Fluidized-Bed Reactors	Biological	Denitrification	Full-Scale	X	X
Moving-Bed Biological Reactor	Biological	Total N Removal	Full-Scale	X	X

Technology	Type of Process	Nitrogen Removal	Current Stage of Technology	Largest Installation is Comparable to DITP	Current Suitability for Use at DITP
Treatment Innovations					
MFC	Biological and Physical/Chemical	Total N Removal	Pilot-Scale		
Microvi MNE	Biological	Total N Removal	Pilot-Scale		
CLEARAS	Biological	Total N Removal	Full-Scale		
Mainstream Deammonification	Biological	Total N Removal	Pilot-Scale		
Mainstream Nitritation-Denitritation	Biological	Total N Removal	Pilot-Scale		
MABR	Biological	Total N Removal	Full-Scale		
Simultaneous Nitrification-Denitrification (sNdN)	Biological	Total N Removal	Full-Scale		
CANDO	Biological	Total N Removal	Pilot-Scale		
HPOLE	Biological	Total N Removal	Full-Scale		
Sidestream Treatment*					
SHARON	Biological	Total N Removal	Full-Scale	X	X
Anammox/DEMON	Biological	Total N Removal	Full-Scale	X	X
PANDA	Biological	Total N Removal	Pilot-Scale		
SHARON-Anammox	Biological	Total N Removal	Full-Scale	X	X
CANON	Biological	Total N Removal	Full-Scale	X	X
PAD	Biological	Total N Removal	Full-Scale		
Struvite Recovery Processes	Physical/Chemical	Total N Removal	Full-Scale	X	X

*Note technologies in the sidestream treatment section are evaluated as they relate to installation in the sidestream only.

Nitrogen removal technologies fall into three basic categories: physical/chemical processes, biological processes, and hybrids of the two.

3.1 Physical/Chemical Processes

Physical/chemical processes rely on basic chemical reactions to remove nitrogen species. Physical/chemical processes employed for nitrogen removal include:

- Reverse osmosis
- Ammonia stripping
- Ion exchange
- Breakpoint chlorination.

Reverse Osmosis

Reverse osmosis (RO) is expensive and requires a high degree of pretreatment. Additionally, the permeability of ammonium through RO filters has not been extensively studied. Its use is not necessary to achieve potential nitrogen standards at Deer Island.

Ammonia stripping

Ammonia stripping requires addition of lime or another softening chemical to raise the pH of wastewater to about 11. At this pH, ammonia is present as a gas, rather than as the ammonium ion. The limed wastewater is sprayed over a packing material, with air added counter-current to the liquid flow to strip the ammonia gas. A problem with this alternative is that power requirements and ammonia emissions are high, and the calcium carbonate scale that forms on the packing requires a high level of maintenance. Very few wastewater treatments plants (WWTPs) use ammonia stripping today.

Ion exchange

In ion exchange, wastewater is passed through a bed of material that exchanges sodium or potassium in the exchange material for the ammonium ion in wastewater. When the ion-exchange material becomes exhausted, passing a caustic solution through the bed regenerates it. Regeneration releases the adsorbed ammonium ions, which are collected in the exhaust solution. This concentrated regeneration solution must then be hauled and treated offsite. Ammonia in the exhaust can be recovered for use as a fertilizer, if the offsite treatment facility has a recovery system. Problems with ion exchange include high operation and maintenance costs and head loss resulting from suspended solids build-up on the resin. There are few large-scale applications of ion exchange for nitrogen removal.

Breakpoint chlorination

With breakpoint chlorination, chlorine at high doses oxidizes ammonia nitrogen to nitrogen gas. Dechlorination is needed after breakpoint chlorination, and volatile organic compounds such as chloroform and other trihalomethanes are formed. Breakpoint chlorination is most effective on polished effluent, meaning it must be preceded by treatment steps like coagulation, settling, and filtration. However, this alternative is economically unfeasible for the Deer Island Treatment Plant. The facility currently lacks secondary effluent filtration, and the high chemical demand requires an estimated 10 pounds of chlorine to remove just one pound of ammonia.

Physical/chemical processes remove nitrogen only in the ammonia form. Although ammonia contributes the most to the total nitrogen load of the plant, these methods do not remove organic nitrogen or nitrite and nitrate. They have never been used extensively, and their use is declining, so there are few plants now using physical/chemical processes for nitrogen removal. These older physical/chemical processes are judged to be inappropriate for use at Deer Island.

Other Physiochemical Processes

Several other physical/chemical processes are being studied for nitrogen removal. These include electrodialysis, membrane distillation, and oxidation and reduction processes. These processes are currently in benchtop and pilot stages and would be difficult to scale up to the required size to treat the flow at Deer Island. For this reason, these technologies are currently not suitable for use at Deer Island.

3.2 Biological Processes

Biological nitrogen removal generally involves two processes in sequence: nitrification in an aerobic environment and denitrification in the absence of oxygen. In nitrification, ammonia is oxidized to nitrite by *Nitrosomonas* bacteria and then to nitrate by *Nitrobacter* bacteria. Nitrification can typically be achieved in one step. In denitrification, nitrate is reduced to nitrogen gas by various groups of bacteria. For denitrification to occur at an appreciable rate, suitable concentrations of organic material must be present. In some configurations, the organic matter present in the wastewater is sufficient for denitrification to occur. For other configurations, a supplementary carbon source, such as methanol, must be provided.

Nitrification and denitrification eliminates the required conversion of nitrite to nitrate, which reduces the amount of supplemental carbon and alkalinity required for nitrogen removal. Deammonification, which is the direct conversion of ammonia to nitrogen gas using anammox bacteria, is also possible. This is typically done by combining the anammox process with a partial nitrification (nitrification) or partial denitrification (denitrification) process.

The use of anammox bacteria for sidestream treatment is described in section 3.2.4.

Processes available for biological nitrogen removal include suspended-growth systems, fixed-film systems, and hybrid systems. In hybrid systems, fixed-film material is added to the aeration tank of suspended-growth systems.

3.2.1 Suspended Growth Systems

Deer Island uses a high purity oxygen activated-sludge process to provide secondary treatment. The activated sludge units at Deer Island include aeration tanks and secondary clarifiers. Options for use of the activated sludge process for nitrogen removal at Deer Island include:

- Sequencing batch reactors
- Membrane Bioreactors (MBR)
- Two-stage activated sludge
- Single-stage activated sludge

Sequencing Batch Reactors

Sequencing batch reactors combine biological activity and settling in a single tank by cycling between two phases, rather than separating these functions in an aeration tank and a clarifier. They do not save space, however, and control and piping become complicated for large facilities. They are not evaluated further in this report.

Membrane Bioreactors (MBR)

Membrane bioreactors combine a membrane process (like ultrafiltration) with a suspended growth bioreactor. Membrane activated sludge systems (MBRs) use membranes instead of clarifiers, to separate effluent from biomass. Their advantage is that the concentration of mixed liquor in aeration tanks can be much higher than with conventional activated sludge. With higher concentrations, the volume of aeration tanks can be decreased to maintain the required solids residence time (SRT).

MBRs in an aerobic zone have proven to be effective ammonia and nitrite oxidizers, though they most successfully remove organic nitrogen. When followed by an anoxic post-denitrification process, MBRs can be very effective for total nitrogen removal. The membrane can be either submerged in the existing reactor, or external, where the membranes are a separate process and require additional pumping. Aerobic and anoxic zones are required upstream of the membranes for the nitrogen removal. A significant amount of membranes would be required for nitrogen removal at DITP. Membrane backwashing and cleaning systems, as well as a foam control system, would be required. Upstream fine filtration is also needed to remove large particles that could damage the membranes.

MBRs are currently being constructed at larger municipal facilities. Their use for sidestream treatment may be evaluated for implementation at Deer Island in the future, but MBRs will not be reviewed further in this report.

Two-Stage Activated Sludge

When activated sludge systems were first used for nitrification, they were designed and built as two-stage systems, with the first stage designed to remove biochemical oxygen demand and the second stage designed to oxidize ammonia. It is now recognized that single-stage nitrification is feasible, and, except for special cases, today's treatment plants feature single-stage nitrification.

At Deer Island, two-stage nitrification would require construction of aeration tanks and clarifiers after the existing units. There is not enough space remaining to build these units, and two-stage nitrification is thus

impractical.

Single-Stage Activated Sludge

As mentioned above, nitrification and denitrification can be obtained in a single-stage system, such as the Modified Ludzack-Ettinger (MLE) process and step feed variations of the activated-sludge process. The MLE process modifies an aeration tank of an activated sludge system by incorporating an anoxic zone ahead of an aeration section designed to provide nitrification. Mixed liquor, which contains nitrate, is recycled to the anoxic zone, and nitrate is reduced to nitrogen gas. The step-feed process can achieve denitrification by providing alternating anoxic and aerobic zones with no separate internal recycle. Primary effluent is typically introduced at different points in the tank, typically at the head of each anoxic zone to provide carbon for the denitrification reaction. Both processes have been used successfully in many WWTPs in the United States. A MLE process in a high purity oxygen system has not been installed until recently. This is discussed further in Section 3.2.5.

Temperature is the controlling factor in single-stage activated sludge nitrification/denitrification. To provide nitrification in cold weather (when the wastewater temperature can be 53.6°F [12°C] or colder), the minimum solids retention time (SRT) would have to be increased to 10 to 11 days. Current design provides for an SRT of less than 3 days. However, the wastewater temperature rarely drops below 53.6°F. If nitrification in cold weather were required, more aeration tanks would be needed. The area required for just the aerobic zone (about ten acres) exceeds the space available with reasonable geometry and this option is dropped from further evaluation. Therefore, a single-stage activated-sludge process will not be reviewed further.

3.2.2 Fixed Growth Systems

In fixed-film systems, biological organisms grow on a supporting surface, in contrast to suspended- growth systems, where the organisms grow in a liquid phase and then must be separated from effluent in clarifiers. Fixed-film systems provide a greater surface area for biological growth than suspended growth systems and thus can operate more efficiently at the same volume. Fixed-film systems include rotating biological contactors, nitrifying trickling filters, biological aerated filters and submerged packed-bed reactors, fluidized bed reactors, and moving bed biofilm reactors.

Rotating Biological Contactors

Rotating biological contactors (RBCs) consist of disks rotating on shafts arranged so that all or part of the disks are submerged. Excessive growth sloughs from the disks and is captured in clarifiers. For aerobic treatment, the disks are submerged to about 40% of their diameter. For denitrification, the disks are completely submerged. The rotation of the disk allows for bulk mixing, and thus no aeration is required. Mechanical reliability of RBCs due to microbiologically introduced corrosion and excess stress due to biomass growth can be a problem. Additionally, RBCs are not often used at large treatment plants. Therefore, RBCs will not be reviewed further in this report.

Nitrifying Trickling Filters

Trickling filters can be used for nitrification after biochemical oxygen demand (BOD) removal, sometimes without the need for settling tanks. Additional odor control may be required for trickling filters. Some plants

operating trickling filters have had problems with flies and other organisms consuming the biofilm, leading to reduced performance. A preliminary comparison of the area required for trickling filters and of space available at Deer Island showed that space is insufficient. Nitrifying trickling filters will not be reviewed further.

Biological Aerated Filters

Biological aerated filters (BAFs) consist of fully submerged, stationary beds of media about 3 to 4 mm in diameter. Flow through the system is usually upward (although there are some downflow systems), and air diffusers are placed at the bottom of the filter. Periodically, the filters are backwashed to remove accumulated solids. The backwash water requires treatment and is usually returned to the main wastewater flow after settling. BAFs are used primarily for nitrification, though they can also be used anaerobically for denitrification. They are retained in this report for further evaluation.

Submerged Packed-Bed Reactors

Submerged packed-bed reactors are similar in configuration to BAFs. However, they are not aerated and supplemental carbon, such as methanol, is usually added to the feed stream to provide a carbon source for denitrification. Like BAFs, submerged packed-bed reactors require backwashing to remove trapped solids and excess biological growth. In both cases, this backwash stream must be treated and pumped to the head of the plant to be treated as primary influent.

Nitrification and denitrification can also be achieved in a single packed-bed that combines the features of a biological aerated filter and of a submerged packed-bed reactor. In this type of reactor, the packed-bed is about three meters deep. The air diffusers are set at about two meters beneath the surface, so that the lower section is not aerated, allowing denitrification to take place. This combined nitrification/denitrification process has not been attempted at large plants and is not retained for further evaluation.

Simultaneous nitrification and denitrification in submerged packed bed reactors is also an emerging technology. This process requires additional instrumentation for close control over the process DO. This would be difficult to achieve at Deer Island's scale. Both processes are worth considering in the future if feasibility at large scale is demonstrated.

Fluidized-Bed Reactors

Fluidized-bed reactors are tanks filled with 4 to 10 feet of sand or other granular medium to support the growth of biomass. Wastewater is fed from the bottom of the reactor at a velocity high enough to fluidize the bed. (This contrasts with biological aerated filters, where the bed is not fluidized during normal operation.) Excessive growth shears from the media and is separated from the treated effluent in an upper zone of the reactor. The system supplier believes that other options such as Biological Aerated Filters are preferred for nitrification, and fluidized-bed reactors are not retained for further study for nitrification. Fluidized-bed reactors are retained, however, for denitrification.

Moving-Bed Biofilm Reactors

The moving-bed biofilm reactor (MBBR) process consists of a tank filled with small plastic elements. The hollow cylindrical elements are about 1 cm in all dimensions and have ridges on the exterior and a crosspiece on the

inside. These carriers are specially designed to maximize surface area to allow for the most biofilm growth. A clarifier is required to separate excess growth. With air addition, MBBR can be used for nitrification. With supplemental carbon addition, the process can be used for denitrification. MBBRs are further evaluated in this report.

The Veolia BIOSTYR system now combines BAF with MBBR. The BIOSTYR system, with its submerged media, has the ability to provide for both biological treatment and filtration in a single step. The system's upflow submerged fixed-film process biologically treats cBOD, ammonia, and nitrate, and removes TSS through the filtering mechanism of the process. This new BAF system uses less equipment in a smaller footprint than a traditional BAF. The combined BAF/MBBR technology is further evaluated in this report.

3.2.3 Hybrid Systems

Hybrid systems are sometimes called integrated fixed-film activated sludge systems (IFAS). The fixed-film material placed in the suspended-growth tanks includes ropes, sponges, trickling filter media, RBCs, and the media used for MBBR. These materials could be placed in the existing aeration tanks at Deer Island to increase the surface area, and therefore their capacity for nitrogen removal. An IFAS system is further evaluated in this report, but pilot testing is recommended to determine appropriate design criteria.

3.2.4 Sidestream Treatment

Several other processes for nitrogen removal have been developed based on the partial nitrification of ammonium to nitrite combined with anaerobic ammonium oxidation. However, these processes target the removal of nitrogen from wastewater containing significant quantities of ammonium, such as sludge.

Although none of the processes described in this section are currently feasible for mainstream treatment, some have been retained as possible sidestream treatment alternatives. Sidestream total nitrogen is typically composed almost entirely of nitrogen as ammonia and some organic nitrogen. Possible applications include use on primary sludge gravity thickener overflow, the waste activated sludge centrifuge centrate from secondary treatment, or the centrate from residuals dewatering. All these streams are highly concentrated in ammonia and contribute significantly to the overall nitrogen load of Deer Island, while accounting for a small fraction of the overall flow. Sidestream treatment would not be sufficient to achieve a target effluent concentration of 4 mg/L but would aid in reducing the total nitrogen load to the plant. This would lower the construction footprint of mainstream treatment processes, reduce the supplemental carbon requirements, and reduce the overall sludge production.

The previous fixed-film nitrogen removal technologies are better suited for mainstream treatment at Deer Island, while those discussed below are better suited for sidestream treatment. However, nitrogen removal technology is advancing rapidly and some of these technologies are in the pilot stages for mainstream treatment. They may be suitable for mainstream nitrogen removal at Deer Island in the future.

Nitrite Shunt

In a nitrite shunt process, ammonium is oxidized in a one reactor system under aerobic conditions to nitrite (nitrification), which in turn is reduced to nitrogen gas (denitrification) under anoxic conditions using an external

carbon source. By stopping the reaction from nitrite to nitrate, oxygen, alkalinity, and supplemental carbon requirements are reduced. Several technologies utilize nitrite shunt for nitrogen removal.

The Single Reactor System for High Ammonia Removal Over Nitrite (SHARON) process creates reactor conditions, which encourage faster growth of the Ammonia Oxidizing Bacteria (AOB) and increase the likelihood of the Nitrite Oxidizing Bacteria (NOB) washing out. The system operates at a low SRT and a high temperature.

Anaerobic Ammonium Oxidation (Anammox)/Deammonification

In the Anaerobic Ammonium Oxidation (Anammox) process, nitrite and ammonium are converted into nitrogen gas under anoxic conditions by unique anammox bacteria without the need for an external carbon source. Sludge production is significantly reduced compared to other sidestream treatment processes. One disadvantage is the significant acclimation period for the bacteria; it has taken up to two years for the process to operate at full capacity in some installations.

Processes typically combine the anammox bacteria with partial nitrification (PN/A) or partial denitrification (PdN/A) to convert half of the ammonia to nitrite for the Anammox reaction. Anammox bacteria convert ammonia to nitrogen gas using nitrite as an electron acceptor. Partial nitrification and partial denitrification increase the concentration of nitrite in the reactor for the anammox bacteria. These processes reduce the aerobic SRT compared to conventional biological nitrogen removal. PN/A is currently the more common anammox process but requires tight control of the SRT and dissolved oxygen (DO) concentration to suppress the Nitrite Oxidizing Bacteria (NOB). Processes that utilize PN/A include the CANON and SHARON-Anammox processes as discussed below. PdN/A processes, such as the PANDA process discussed below, do not require suppression of the NOB and are currently being researched for implementation at larger facilities in the mainstream process.

There are several companies with commercially available systems using the anammox bacteria. These include Veolia's ANITA™ Mox Process, World Water Work's DEMON® process, and Ovivo's ANAMMOPAQ® process. The DEMON process is a continuous or sequencing batch reactor granular deammonification system. Ovivo's ANAMMOPAQ™ PROCESS is a continuous flow granular anammox system. Specifically evaluated in this report is Veolia's ANITA™ Mox Process, which is an attached growth anammox system.

In the ANITA™ Mox Process, a single reactor is filled with polyethylene carriers with a density slightly less than water for biogrowth. In an anammox system, nitrification and denitrification take place in the same reactor. This simultaneous nitrification and denitrification is the result of unique anammox bacteria. The two steps take place in different layers of the biofilm. The aerobic nitrification reaction occurs in the outer layer, where approximately 55% of the influent ammonia is oxidized to nitrite. In the inner layer, anoxic ammonia oxidation (anammox) takes place, producing nitrite and converting the remaining ammonia directly to nitrogen gas and a negligible amount of nitrate. No supplemental carbon is required for this process. Since the anammox bacteria growth rate is very slow compared to conventional wastewater bacteria growth rates, biomass retention is

crucial. Media screens and sufficient aeration to keep the carriers in suspension aids in biomass retention. ANITA™ Mox has been retained for sidestream treatment evaluation as the representative for this type of treatment, and is discussed further in Section 5.1.1. The specifics of a DEMON system could be further explored in the future, if a more detailed design is warranted.

PANDA

In the partial nitrification, denitrification and anaerobic ammonia oxidation (PANDA) process, approximately 50% of the ammonia is converted to nitrate. The nitrate is then converted to nitrite. The ammonia and nitrite are converted to nitrogen gas by the denitrifying bacteria and anammox bacteria. This process uses less supplemental carbon, oxygen, and alkalinity as compared to conventional biological nitrogen removal. PdN/A processes are not evaluated further in this report as it is still in the pilot-stage of commercial availability but may be suitable for nitrogen removal at Deer Island in the future.

SHARON-Anammox Process

The Anammox process provides an alternative to nitrification and denitrification with no requirement for an external carbon source. When combined with the SHARON process, the total aeration costs are greatly reduced when compared to the conventional nitrogen removal by nitrification-denitrification. The two-step ANAMMOX® process from Paques utilizes this process.

Completely Autotrophic Nitrogen Removal Over Nitrite (CANON)

The Completely Autotrophic Nitrogen Removal Over Nitrite (CANON) is a two-step, one reactor PNA process that involves the removal of nitrogen under oxygen limited conditions. An alternative to the two-reactor SHARON-Anammox process, the ammonium oxidizing organisms coexist with the organisms performing the Anammox process. Nitrite oxidizers, performing the unwanted reaction to nitrate, are outcompeted on two fronts: competing for ammonium with Anammox, and competing with oxygen with the aerobic ammonium oxidizers.

Post Aerobic Digestion (PAD)

Post Aerobic Digestion is used to treat activated sludge and involves implementing aerobic digestion after anaerobic digestion. Although sludge itself is not a sidestream, the centrate from sludge dewatering is, and by reducing the nitrogen load in sludge, the influent nitrogen load to the plant can ultimately be reduced as well. Sludge holding tanks can be retrofitted to PADs in order to see a reduction of TN, as well as volatile suspended solids, and phosphorus. PADs can be fitted with intermittent aerators in order to achieve nitrification and denitrification in the same reactor, or sludge can be recycled from aerobic to anaerobic digester as in an MLE process. No supplemental carbon or alkalinity is required. A cooling system is necessary in order to regulate temperature and foaming. This alternative also reduces the amount of ammonia available for struvite formation.

Struvite Recovery Processes

Struvite recovery processes, such as Ostara's Pearl® process, can be used to purposefully precipitate struvite from the digested sludge centrate using an up flow fluidized bed crystallizer. Struvite, or magnesium ammonium phosphate, is made up of equimolar concentrations of ammonium, phosphate, and magnesium.

Since magnesium is the limiting component of the three, it is typically added to supplement the existing magnesium in the wastewater in a controlled pH setting. The crystalized struvite can then be sold as a fertilizer for beneficial reuse. Although this process is typically sold as a phosphorus removal process, for every pound of phosphorus removed, 0.45 pounds of ammonia-N are also removed. Struvite recovery would reduce the ammonia concentration in the dewatering centrate but would likely need to be combined with another sidestream nitrogen removal technology to meet the 4.0 mg/L or 8.0 mg/L effluent concentration targeted in this report.

3.2.5 Treatment Innovations

Microbial Fuel Cells (MFCs)

Microbial fuel cells (MFCs) operate essentially as large galvanic cells, using an anode and cathode to convert organic matter to electricity. MFCs take advantage of the electrons released during ammonia and nitrate oxidation and harvest them on carbon-based electrodes. The use of algae or bacteria-based biocathodes can aid in nitrogen removal. MFCs require no aeration, no supplemental carbon, and produce low volumes of sludge. However, they are very pH-sensitive and difficult to maintain. Presently, MFCs are used primarily for agricultural and food wastewater with no applications larger than 100,000 gallons per day.

Microvi MicroNiche Engineering (MNE™)

The Microvi MNE combined nitrification-denitrification process utilizes single-pass reactors filled with biocatalyst composites, pre-populated with process-specific cultures of naturally occurring microorganisms at high densities. The microorganisms remain within the biocatalyst at a steady population without adding suspended solids to the treated wastewater. This eliminates the need for replacement, recycling, or re-seeding of active microorganisms. Microvi has recently commissioned their first sidestream wastewater treatment plant. However, the technology has not been used at larger plants like DITP.

Algal Process - CLEARAS Water Recovery Advanced Biological Nutrient Recovery (ABNR™)

The CLEARAS Water Recovery ABNR mixes wastewater with algae. This mixture then enters a photobioreactor, which promotes photosynthesis and nutrient consumption. The nutrient reduced wastewater is then returned for discharge or reuse. A portion of the biomass stream is returned to the mix-stage as Returned Activated Algae (RAA) to sustain the biological balance. Dewatering then results in an algal biomass coproduct with various potential uses. This ABNR system has been piloted in over 45 studies in the United States and is nearing completion of its first full-scale installation, but it has not been used at larger plants like DITP.

Mainstream Anaerobic Ammonium Oxidation (Anammox)/Deammonification

Deammonification is the conversion of ammonia nitrogen to nitrogen gas with the anammox bacteria as discussed in Section 3.2.4. This process is a proven technology for warmer concentrated ammonia waste sidestreams such as the dewatering centrate. It is currently in the research and pilot stages for implementation in mainstream wastewater treatment. The development of this technology for mainstream treatment is of particular interest at Deer Island as deammonification requires less supplemental carbon and it is more energy and cost efficient than traditional nitrification-denitrification processes. There are several concerns with the technology though, which must be resolved prior to consideration for use at Deer Island. These include

operation at low wastewater temperatures, low ammonia concentrations, and wet weather operational strategies.

Mainstream Deammonification with Biological Phosphorus Removal

Mainstream deammonification as discussed above can be combined with enhanced biological phosphorus removal (EBPR) to efficiently remove both nitrogen and phosphorous. This novel process is currently being researched.

Mainstream Nitritation-Denitritation

Nitritation-denitritation or nitrite shunt is the conversion of ammonia nitrogen to nitrite and then to nitrogen gas. It is done by stopping the nitrite to nitrate reaction as discussed in Section 3.2.4. It is typically used in warmer high-strength ammonia streams, but there is research and smaller pilot studies on modifying this process for nitrogen removal in the mainstream wastewater process to reduce energy, supplemental carbon, and alkalinity requirements. Since the application of this technology to mainstream processes is still emerging, it is not yet considered for use at Deer Island.

Membrane Aerated Biofilm Reactor

A membrane aerated biofilm reactor is an attached growth biofilm reactor system that is designed for simultaneous nitrification and denitrification. The biofilm reactors can be retrofit into the existing aeration tanks. The gas permeable membrane delivers oxygen to the wastewater for nitrification, while denitrification occurs in the anoxic layer of the biofilm. Recirculation of nitrates is not required, and the aeration requirements are lower than traditional biological nitrogen removal systems. Additional upstream screening is required to prevent damage to the membranes. Replacement of the membranes would be an additional operating expense. There are several companies that make these systems including Fluence's SUBRE, Oxymem's MABR, and Suez Water's ZeeLung. However, the largest planned installation of this technology is less than 10 MGD, and it has not been used at larger plants such as Deer Island. The technology is currently limited to smaller plants and installation in shallower secondary reactors. Furthermore, denitrification filters may be required to reach a TN less than 4mg/L.

Simultaneous Nitrification-Denitrification (sNdN)

Simultaneous Nitrification-Denitrification is a process in which nitrification and denitrification occur in a single bioreactor. It is typically done as a process control optimization in several different process configurations but is most common in MABRs and aerobic granular sludge processes. The process requires tight DO control to allow for layered growth of nitrifying and denitrifying bacteria. There is ongoing research on implementing low dissolved oxygen biological nutrient removal in existing activated sludge systems. This technology could be implemented using a digital twin application to further assist with the highly precise process control requirements. This technology would be implemented in conjunction with another nitrogen removal technology. This level of precision is currently impractical for a large plant like Deer Island and is not further evaluated in this report.

CANDO

CANDO or Coupled Aerobic-Anoxic Decomposition Operation is a process that converts ammonia to nitrite

then from nitrite to nitrous oxide. Nitrous oxide can then be used as a fuel additive for more efficient methane combustion. This process has the advantage of energy recovery through methane combustion. The technology is currently in the pilot stage and is not further evaluated in this report.

Modified High-Purity Oxygen Ludzack-Ettinger (HPOLE) Process

The HPOLE process is a variation of the Ludzack-Ettinger (MLE) method. Section 3.2.1 elaborates on the MLE process. The HPOLE process underwent a full-scale retrofit demonstration at the Joint Water Pollution Control Plant (JWPCP) in Los Angeles County, CA. The JWPCP is a high purity oxygen activated sludge facility (HPOAS). The concept was to utilize a HPOAS facility for nitrogen removal with no changes to infrastructure. The HPOLE demonstration was achieved by operating a reactor train in a Ludzack-Ettinger configuration for a 120% - 170% increase in return sludge rate. Total inorganic nitrogen removal of approximately 70% was achieved in the study, with an average effluent nitrate concentration of 14.6 mg/L. The HPOLE process, as demonstrated in this study, would not be adequate for DITP, as it would not meet the levels of effluent quality of 4 mg/L and 8 mg/L of total nitrogen considered in this report. DITP also does not have the space needed to accommodate the process as described in this study.

3.3 Systems Retained for Further Evaluation

Table 5 shows systems retained for further evaluation. These systems were chosen based on ability to handle the flows and nitrogen loads at Deer Island, as well as the consideration of cost, reliability, and ability to fit into the available land at the treatment plant. Since the sidestream treatment processes utilize similar technologies and have similar levels of nitrogen removal, only the ANITA Mox system was retained for further evaluation in this report.

Table 5. Systems Retained for Further Evaluation

	Nitrification	Denitrification	Treatment Type
Combined BAF-MBBR Reactors	X	X	Mainstream
Biological Aerated Filters and Fluidized-Bed Reactors	X	X	Mainstream
Moving Bed Biofilm Reactor	X	X	Mainstream
Integrated Fixed Film Activated Sludge	X	X	Mainstream
Anammox (ANITA Mox)	X	X	Sidestream

Section 4. Evaluation of Alternatives

This section investigates the alternatives proposed in Section 3 for further evaluation. They are grouped into these process alternatives:

- Combined biological aerated filters with moving-bed biological reactors for nitrification and denitrification
- Biological aerated filters for nitrification with fluidized-bed reactors for denitrification
- Moving-bed biofilm reactors for nitrification and denitrification
- Integrated Fixed Film Activated Sludge MLE for nitrification and denitrification

The ANITA™ Mox process will be addressed separately in Section 5, as it is being retained as a potential sidestream treatment alternative only.

Development of the alternatives includes selection of criteria for sizing units and preliminary sizing of components. Alternatives are developed to meet hypothetical permit limits of 4 mg/L and 8 mg/L of effluent total nitrogen.

MWRA was able to obtain information about proprietary equipment and processes from system suppliers. Recommendations from the suppliers were reviewed, and professional judgment and experience were applied to select and update the design criteria as required (CDM 2001). The units provided allow for standby, such as for backwashing or other maintenance and repair.

Oxygen requirements, chemical requirements, and sludge production for each alternative would be about equal. Those needs are covered in Section 4.4.

4.1 Combined Biological Aerated Filters and Moving-Bed Biofilm Reactors (MBBR)

Design criteria for nitrification and denitrification in biological aerated filters (BAFs) and moving-bed biofilm reactors (MBBRs) such as the Biostyr Duo technology are shown in Table 6. VEOLIA provided the design criteria.

The table shows that 48 BAF-MBBR nitrification cells and 36 BAF-MBBR denitrification cells would be required. The nitrification (N) process is arranged in 3 batteries of 2 trains, containing 8 cells each (2x8). The denitrification (DN) process is arranged in 3 batteries of 2 trains, containing 6 cells each (2x6).

The secondary effluent currently flows to an effluent channel south of the secondary clarifiers. To reach the new facilities, the secondary effluent would be diverted to a new effluent channel north of the clarifiers and then to a new pumping station to lift flow to the new facilities. The secondary effluent would need to be prescreened prior to entering the BAF-MBBR units. Blowers would inject air at the base of each biological aerated filter and flow upward, concurrent with the wastewater flow. Effluent from the new facilities would enter a new tunnel discharging to the chlorine contact tanks.

The tanks need to be backwashed approximately every 24 hours or at a pre-determined set head loss across the filter. The airflow rate required for backwashing is approximately 2,500 standard cubic feet per minute per cell (scfm/cell). Water for backwashing is supplied from a common reservoir above the filter cells at a rate of 9,300 gpm per battery. Backwash waste would be returned to the head of primary or to the head of the plant.

The gross area required for siting the BAF and MBBR system, including blowers, a pump station, and galleries would be about 8.1 acres. Figure 12 shows a preliminary BAF and MBBR layout. Figure 12 has been updated due to the proposed location for the new DITP Combined Heat and Power (CHP) Facility, and its associated battery energy storage system (BESS).

Table 6. Biological Aerated Filter and Moving-Bed Biological Reactors for Nitrification and Denitrification

	BAF-MBBR Nitrification (N)	BAF-MBBR Denitrification (DN)
Influent TKN		
Maximum Month TKN (lb/d)	98,400	98,400
Maximum Month Flow (MGD)	700	700
Unit Dimensions		
Height of BIOSTYR Media (ft)	11.48	8.2
Height of AnoxKaldnes MBBR media (ft)	2.3	1.6
Surface Area (ft ²)	2,582	2,582
Size of Media (mm)	4.0	4.5
Active Units	48	36
Units Provided	48	36
Acres Needed	4.6	3.5

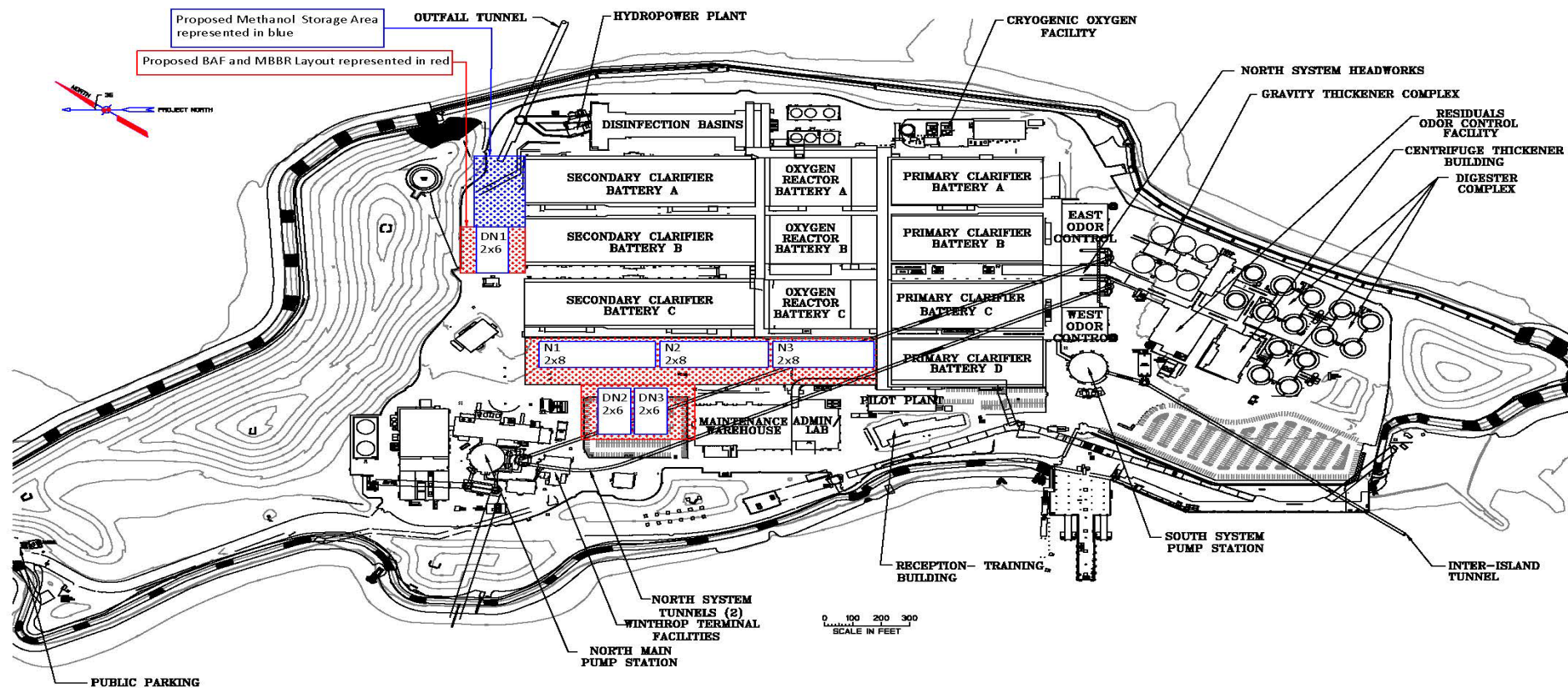


Figure 12. Proposed BAF and MBBR Layout

4.2 Biological Aerated Filters and Fluidized-Bed Reactors

The BAF design for this treatment combination would be similar to that described in Section 4.1. The secondary effluent, which flows to an effluent channel south of the secondary clarifiers, would be diverted to a new effluent channel north of the clarifiers and to a new pumping station to lift flow to the new facilities. The secondary effluent would need to be prescreened prior to entering the BAFs. Table 7 summarizes sizing information for the fluidized bed reactors (FBRs) for denitrification. The FBR design is based on information provided by US Filter. The effluent from the fluidized beds would flow to the chlorine disinfection basin and then be discharged from the facility. Table 7 shows that 92 BAFs and 49 FBRs would be required; these include standby units.

The total area requirements for the BAF/FBR system would be approximately 6.3 acres including the tanks and additional area for support equipment. This area exceeds the space available in Area A, the space west of the existing secondary batteries, but the proposed layout can be incorporated as shown in Figure 13. Figure 13 has been updated due to the proposed possible location for the new DITP CHP Facility and its associated battery energy storage system (BESS).

Table 7. Biological Aerated Filter for Nitrification and Fluidized Bed Reactors for Denitrification

	BAF	FBR
	Nitrification	Denitrification
TKN Load (lb/d)		
Maximum Month	98,400	98,400
Nitrogen Loading Rate Allowed (lb/d/1,000ft ³)	49.6	250*
Hydraulic Loading Rate Allowed (gpm/ft ²)	4	18
Unit Dimensions		
Depth (ft)	12	10
Surface Area (ft ²)	1,940	800
Volume (ft ³)	23,500	8,000
Active Units	83	44
Units Provided	92	49
Acres Needed	4.1	0.9

* The FBR loading rate is based on information provided by US Filter

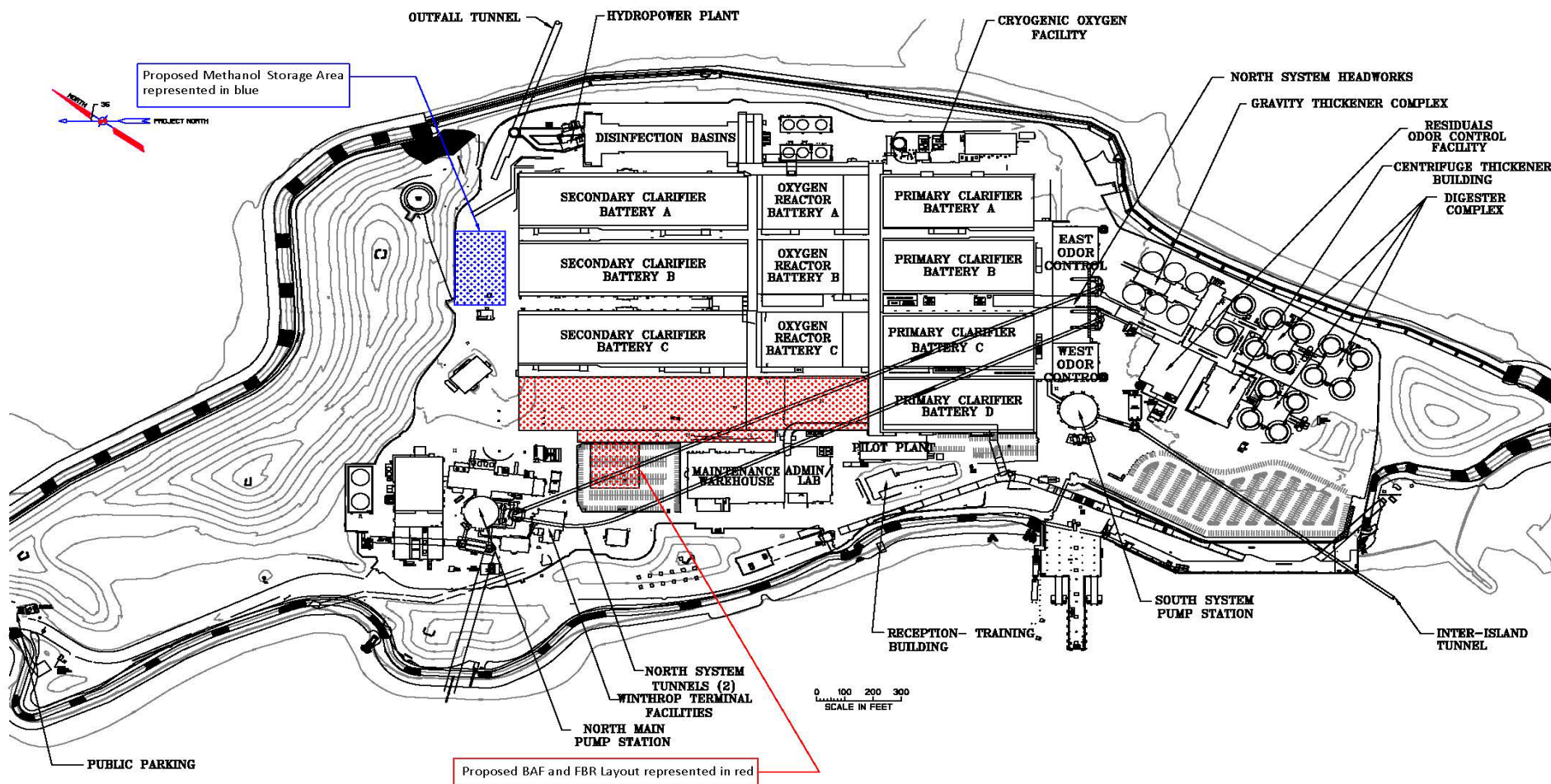


Figure 13. Proposed BAF and FBR Layout

4.3 Moving-Bed Biofilm Reactors

For this option, Kaldnes provided the design concept criteria. Media would be added to the existing aeration tanks, where nitrification would occur. There are several configurations for removing BOD and nitrogen using an MBBR process. This evaluation assumes that a separate post-anoxic denitrification MBBR will be constructed after the MBBRs for BOD removal and nitrification.

Table 8 summarizes design criteria for the MBBR BOD removal and nitrification systems and Table 9 summarizes the MBBR denitrification system. Because the MBBRs would be treating primary effluent, the analysis for MBBRs accounted for nitrogen removed via assimilation into the biomass produced during BOD removal. In the proposed MBBR systems, polyethylene media would be added to the existing aeration tanks. The biomass for biological treatment would grow on the media, thus eliminating the need for recycling solids from the secondary clarifiers. Stainless steel sieves would be installed at the outlets of the aeration basins to retain the media.

The existing on-site pure oxygen aeration system would provide oxygen and mixing. Because the aeration basins would now provide nitrification as well as oxidation of BOD, additional tankage, as described in Table 8, would be required to handle the design flows. Additional facilities for producing and distributing oxygen would also be required. New effluent channels would be required to divert flow from the aeration basins to the denitrification MBBRs and then to the existing secondary settling basins for clarification.

Effluent from the aeration basins would be deaerated before flowing to additional MBBRs for denitrification. Deaeration can be accomplished by nitrogen stripping, which drives dissolved oxygen from the wastewater. Nitrogen gas is a by-product of the cryogenic pure-oxygen generation system. This excess nitrogen can possibly be used as the nitrogen stripping source.

For aeration (nitrification and BOD removal), approximately 7,650,000 ft³ of total volume would be required. The existing aeration basins provide 5,637,000 ft³. However, with the need to construct two new channels, 485,100 ft³ of aeration volume would be lost from the existing basins. The total new volume required (2,500,000 ft³) could be located in Area A, the space west of the existing secondary batteries.

Denitrification would require between 2,873,000 to 3,221,000 ft³ of new construction depending on the level of effluent nitrogen concentration to be met. Prior to denitrification, 152,000 ft³ of deaeration tankage is required to remove dissolved oxygen from the wastewater. Deaeration/denitrification facilities can also be sited in Area A, the space west of the existing secondary batteries. Methanol facilities for denitrification would be located in Area C, north of the secondary clarifiers.

The proposed MBBR nitrification/denitrification system would require about 7.03 acres. Figure 14 shows the conceptual layout of the MBBR nitrification/ denitrification system. Figure 14 has been updated due to the proposed possible location for the new DITP CHP Facility, and its associated battery energy storage system (BESS).

Table 8. Moving Bed Biofilm Reactor for BOD Removal and Nitrification

	MBBR for Nitrification
Nitrogen Load in Primary Effluent (lb/d)	
Maximum Month	122,000
Nitrogen Assimilated Plus Ammonia Nitrogen in Effluent (lb/d)	15,500
Ammonia to be Treated (lb/d)	106,500
Nitrification Rate (g/m ² ·d)	0.931
Specific Surface Area (m ² /m ³)	500
Total Media Required (ft ³)	3,700,000
% Fill of Carrier Elements	65%
Volume Required for Nitrification (ft ³)	5,700,000
Volume Required for BOD Removal (ft ³)	1,950,000
Total Existing Aerobic Tank Volume (ft ³)	5,637,000
Volume Lost to New Channel (ft ³)	485,100
New Volume Provided (ft ³)	2,500,000
Unit Dimensions of New Basins	
Depth (ft)	24.5
Surface Area (ft ²)	4,900
Number of Basins	21
Acres Needed	2.36

Table 9. Moving Bed Biofilm Reactor for Denitrification

	MBBR for Denitrification	
	4 mg/L Total Nitrogen	8 mg/L Total Nitrogen
Total Nitrate Nitrogen Reduced (lb/d)	98,600	87,900
Loading Rate (g/m ² ·d)	2.45	2.45
Specific Surface Area (m ² /m ³)	500	500
Media Required (ft ³)	1,289,900	1,150,000
% Fill of Carrier Elements	40%	40%
Total Tank Volume (ft ³)	3,221,000	2,873,000
Deaeration Volume	152,000	152,000
Tank Dimensions		
Surface Area (ft ²)	4,900	4,900
Depth (ft)	24.5	24.5
Number of Reactors	29	26
Acres Needed	3.26	2.92

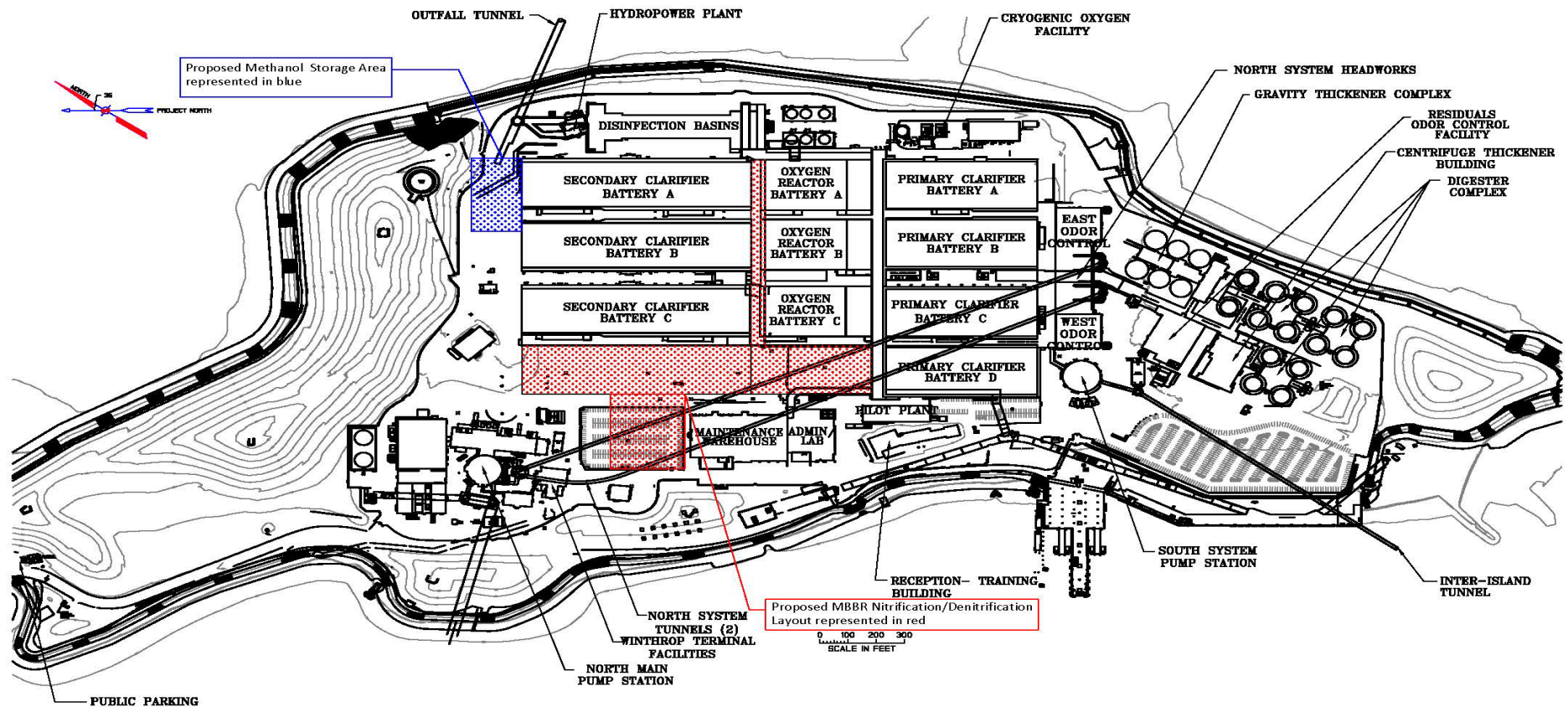


Figure 14. Proposed MBBR Nitrification/Denitrification Layout

4.4 Integrated Fixed Film Activated Sludge MLE for nitrification and denitrification

Section 3.2.1 described the MLE process, which is a modification of the activated sludge process. In that section, it was stated that the MLE process and other modifications of the activated sludge process require more space than is available at Deer Island. The volume (and hence, space) required can be decreased by adding carrier material to the system, to serve as medium on which dense biological growth could be supported.

Veolia provided a proposal for installing their Hybrid Biofilm Activated Sludge (Hybas) system at Deer Island. The design uses the volume of existing aeration basins and reconfigures them into different zones for BOD and nitrogen removal. This design incorporates 6 different zones with different dissolved oxygen requirements to facilitate nitrification and denitrification and includes traditional activated sludge zones as well as MBBR zones. This configuration may use less supplemental carbon than traditional nitrification-denitrification designs. However, the design requires more tank volume than a typical MBBR design.

Additional work would be required to assess the kinetics of these systems and to determine how to configure tanks and piping at Deer Island.

4.5 Common Elements

Elements common to the four alternatives include oxygen required for nitrification, chemical required for denitrification and additional capacity for processing sludge produced from both nitrification and denitrification systems.

4.5.1 Oxygen Requirement

Nitrification will increase the requirement for oxygen. This section examines two alternatives for providing oxygen.

The first case is for the BAF system, which would process secondary effluent from the existing activated-sludge system and for which air from the atmosphere would be used to provide oxygen. In that case, blowers provided by the system supplier would provide diffused air. The blowers would be housed in the BAF building. During a day of maximum TN loading, about 250 tons/day of oxygen would be needed in the BAF. Air use would be about 135,000 cfm at the maximum rate, and connected power for the blowers would be about 6,800 horsepower. Additional blowers would be required for backwashing the media as discussed in Section 4.1.

The second case is for the MBBR system, which would process primary effluent. With the MBBR system, high-purity oxygen would be used. During the peak month, approximately 400 tons/day oxygen would be required. Two new 150-ton units would have to be added, to supplement the two 150-ton/day units existing at Deer Island's cryogenic plant.

4.5.2 Chemical Requirements

Denitrification would require the addition of supplemental carbon, such as methanol or glycerol. Assuming that methanol will be used, the methanol requirement for all the denitrification systems is 3 pounds of methanol per pound of nitrate-nitrogen reduced. At peak month loadings, methanol consumption for denitrification would average about 248,000 lb/d for less than 8 mg/L effluent TN concentration and 280,000 lb/d for an effluent TN concentration of less than 4 mg/L. This would require bringing in five 30-ton trucks of methanol every day. Alternatively, six 243,000-gallon methanol storage tanks could be constructed. Each tank would provide about 5.8 days of storage during the peak month. The chemical usage requirements could be reduced by utilizing the primary effluent carbon for denitrification.

The transportation and safety issues surrounding methanol addition would present substantial challenges to implementing any of the denitrification methods considered for mainstream nitrogen removal. Alternatives to methanol may mitigate some of the safety concerns. Alternatives could include ethanol, glycerol, acetate, or a proprietary chemical such as MicroC™. The feasibility of sourcing and transporting the external carbon source to Deer Island would still need to be investigated.

4.5.3 Sludge Production

Methanol addition would increase sludge production at the rate of about 0.6 lb/lb of nitrate nitrogen reduced. For example, using MBBR, about 98,600 lbs/d of nitrogen would be reduced to achieve 4 mg/L of total nitrogen during the maximum month, and about 60,000 lb/d of additional sludge would thus be produced.

The additional sludge produced would impact thickening of biological sludge and sludge digestion. At a concentration of about 0.6%, additional sludge to be thickened would amount to about 840 gallons per minute. The design concentration of thickened biological sludge is 5% and the digesters are sized to provide 15 days of storage at the maximum month. Under these conditions, about 2.16 million gallons of additional digestion capacity would be needed. Based on current operating practices, the digesters have enough capacity to handle the additional sludge flow. However, if necessary, the volume of additional sludge produced could be lowered with sidestream treatment, which is further examined in Section 5.4.

Section 5 Sidestream Treatment and Additional Considerations

Biological nitrogen removal technologies appear to be the most cost-effective method of nitrogen removal currently. In the spring of 2003, the Water Environment Research Foundation (WERF) embarked on a research project, Sustainable Technology for Achieving Very Low Nitrogen and Phosphorus Effluent Levels (WERF, 2003). This 2-year project assessed a variety of technologies to develop information about the feasibility and cost benefits of nutrient reduction. WERF determined that among advanced treatment processes, membrane separation technology in the form of membrane bioreactors and SHARON/Anammox applications have emerged as promising alternatives to conventional nutrient removal processes. Additional considerations in the selection of alternative options include separate treatment of residual processing return flows at the Residuals Processing Plant in Quincy, decreasing methanol requirements, and decreasing sludge production.

5.1 Separate Treatment at the Residuals Processing Plant

Since April 2005, all digested sludge has been sent to the Residuals Processing Plant in Quincy via the inter-island tunnel. Sidestreams from dewatering the digested sludge contain high concentrations of ammonia, so it may be most economical to treat the sidestreams at the Processing Plant. An unused land area of approximately 54,800 ft² could potentially be utilized for additional reactor construction. Treatment at the Residuals Processing Plant therefore may decrease the size of facilities needed at Deer Island.

The centrate from the residuals dewatering process at the Processing Plant flows to the Intermediate Pump Station in Quincy at an average rate of 1.21 MGD over seven days. The centrate contains an average concentration of 775 mg/L ammonia nitrogen. This amounts to an average of 7,820 lb/day of ammonia over seven days. Since the Residuals Processing Plant is typically only operated on weekdays, the centrate flow accounts for 13.9% of the total influent ammonia to Deer Island over the design period and only 0.54% of the total flow on an average weekday. Centrate equalization tanks and an 85% reduction of ammonia in the residuals dewatering centrate would account for an 8.0% reduction of the TN load to the entire plant during the peak month loading. This TN load reduction would in turn reduce the number of mainstream reactors required to meet effluent limits (see Table 13 below). Either a DEMON or ANITA Mox anammox installation would be able to achieve this desired reduction (see preliminary design criteria below).

5.1.1 Anammox ANITA™ Mox

Veolia provided the design criteria for their ANITA Mox anammox system. A total suspended solids (TSS) concentration of 800 mg/L was assumed. However, the centrate from the dewatering process has an average concentration of total suspended solids over 1,600 mg/L and a peak concentration over 6,000 mg/L, which could pose operational issues. Although most anammox systems are not affected by TSS, it could lead to reduced dissolved oxygen (DO) if the TSS is biologically active. Larger blowers could help to increase DO and disc filters upstream of the reactors could help to reduce TSS concentration. Screening and/or pretreatment to remove larger sized particles would also be required. These solutions would require additional space beyond what is already proposed.

The proposed ANITA Mox system predicts up to 90% ammonia nitrogen removal, and up to 80% total inorganic nitrogen removal. The total footprint of the reactors required for this system is approximately 21,100 ft², which fits within the available space at the Residuals Processing Plant. However, aerators would be required to provide the necessary aeration. Veolia recommended the installation of approximately one blower per tank, each rated at 3,500 standard cubic feet per minute (scfm), and one for standby. The operating temperature for optimal performance ranges between 77°F and 95°F, with a maximum operating temperature of 98.6°F. This wide range accommodates the fluctuations in the digester sludge effluent temperature while still maintaining optimal performance. The remaining design criteria for this system are summarized in Table 10.

Table 10. Anammox ANITA™ Mox Design Criteria

Residuals Centrifuge Centrate Flow (MGD)	1.21
Number of Process Trains	5
Number of ANITA Mox Reactors per Train	1
Dimensions, each (ft – L x W x D)	65 x 65 x 16
Volume, each (ft ³)	67,600
Total Volume (ft ³)	338,000
Media Type	K5
Effective Surface Area (m ² /m ³)	800
Volumetric Loading Rate (kg-N/day/m ³)	0.0582
Surface Area Loading Rate (g-N/day/m ²)	1.25*
Fill of Biofilm Carriers in each Reactor (%)	46.2
Media Volume, total (ft ³)	156,000
Total Effective Surface area (ft ²)	82,500,000
Aeration Rate (scfm)	17,500
Design Temperature (°F)	95
*Higher Surface Area Loading rates have been successful at similar plants in the US. Additional testing would be required to determine the best design loading rate for sidestream operation.	

5.2 Sidestream Treatment at Deer Island Treatment Plant

The average combined gravity thickener overflow and the waste activated sludge recycle streams are about 11.4 MGD and contain about 12,800 pounds of total nitrogen, about 12.9% of the total load to the plant. However, most sidestream treatment processes are able to treat only ammonia nitrogen and small amounts of nitrate at a smaller scale (the largest sidestream treatment installations are up to 8 MGD). The total ammonia load in both streams is roughly 3,000 pounds per day, or about 4% of the total load to the plant. Pretreatment of these streams would reduce the load to the activated sludge process, but it is unlikely that the resulting nitrogen concentrations could meet the effluent quality levels of 4 mg/L and 8 mg/L evaluated in this report. Sidestream treatment at Deer Island would serve as a supplement to mainstream nitrogen removal processes to help reduce the footprint and number of reactors required (see Table 11 below).

The gravity thickener overflow rate varies more day to day than the waste activated sludge centrate stream flow rate (standard deviation of 1.53 MGD vs. 1.03 MGD), making it difficult to accurately design a reactor. Historically, the waste activated sludge centrate has had a higher ammonia nitrogen concentration than the gravity thickener overflow and would be more economical to treat. Recently, both streams have had similar ammonia concentrations. Using a design ammonia load from the waste activated sludge centrate of approximately 1,800 pounds and assuming 85% reduction of ammonia in this stream, results in only a 1.5% reduction of the total nitrogen load to the plant. Therefore, separate treatment of the waste activated sludge centrate or gravity thickener overflow would not be as economical as treating the centrate from the residuals processing facility.

Table 11. Reactors Required for Nitrogen Removal with and without Sidestream Treatment

	No Sidestream Treatment	Residuals Processing Plant Centrate Treatment	Waste Activated Sludge Centrate Treatment
Required BAF Reactors	92	85	90
Required SPBR Reactors	29	26	28
Required FBR Reactors	49	49	49
Additional Tankage Required for MBBR BOD Removal and Nitrification (ft³)	2,500,000	2,190,000	2,500,000
Required MBBR Denitrification Reactors	29	27	28

5.3 Decreasing Requirement for Methanol

All the mainstream treatment alternatives considered in Section 4 would require the addition of methanol as a carbon source for denitrification. With these options, the purchase of methanol would be a major expense. Based upon estimates from the Methanex Corporation, it is estimated that methanol costs would be approximately \$0.34/lb. It would be costly at over \$33 million/year to purchase over 280,000 lb/day to achieve an effluent concentration of less than 4 mg/L. Therefore, it is imperative to find ways to reduce the methanol demand of these treatment processes. Applying treatment processes that use wastewater as the carbon source would decrease use of methanol. Additionally, the use of sidestream treatment systems would help reduce the methanol demand by reducing the overall nitrogen load to the plant. See Table 12 below for methanol requirements for FBR and MBBR. Anammox processes require little to no supplemental methanol.

Table 12. Estimated Methanol Demand for Effluent of 4 mg/L TN with and Without Sidestream Treatment

	No Sidestream Treatment	Residuals Processing Plant Centrate Treatment	Waste Activated Sludge Centrate Treatment
FBR			
Methanol Required (lb/day)	264,000	244,000	259,000
Cost per year (\$)	\$33,017,000	\$30,516,000	\$32,412,000
MBBR			
Methanol Required (lb/day)	296,000	276,000	291,000
Cost per year (\$)	\$37,074,000	\$34,553,000	\$36,472,000

5.4 Decreasing Activated Sludge Production

With any of the mainstream treatment options would come an increase in activated sludge production due to the supplemental methanol. As was discussed in Section 5.3, the existing facilities would be able to handle and process this increase. However, treating this additional sludge would be costly and energy intensive. Sidestream treatment would reduce the amount of additional sludge produced by reducing the methanol demand. See Table 13 below for a summary of additional sludge production with various sidestream treatments.

Table 13. Additional Sludge Production with and Without Sidestream Treatment

	No Sidestream Treatment	Residuals Processing Plant Centrate Treatment	Waste Activated Sludge Centrate Treatment
BAF-MBBR/FBR Additional Sludge Produced (lb/day)	53,000	49,000	52,000
MBBR Additional Sludge Produced (lb/day)	60,000	56,000	59,000

Section 6. Conclusions

Although MWRA's current NPDES Permit (No. MA0103284) does not have a limit for effluent nitrogen, it does require that a comprehensive survey of nitrogen removal technologies be maintained and submitted every year. The outfall monitoring data shows that the nitrogen in Massachusetts Bay has had no adverse effects on algal blooms, cyanobacteria populations, or dissolved oxygen concentrations. This is not unexpected since only about 5-9% (e.g., Deltares, 2022a, 2022b, 2023, 2024, and 2025) of the total nitrogen entering Massachusetts Bay is the result of DITP effluent. However, an increasing number of wastewater treatment plants across the United States are being issued permits with nitrogen effluent limits. This survey will allow MWRA to select appropriate treatment processes that can be more intensely evaluated for nitrogen removal should an effluent limit be introduced.

Approximately 10.2 acres of usable space for nitrogen removal facilities currently exist on Deer Island. Combined biologically aerated filters and moving-bed biofilm reactors, biologically aerated filters with fluidized bed reactors, and moving-bed biofilm reactors were determined to be the most feasible options for implementation at Deer Island. BAFs, BAF/MBBRs, and FBRs would all require entirely new tankage and would require a large amount of land area. MBBRs could be partially retrofitted into the existing aeration basins in secondary treatment but would require additional tankage for denitrification. All these options would also require a supplemental carbon source for complete denitrification which would lead to increased sludge production.

Sidestream treatment could be beneficial in reducing the demand of some of these treatment processes. Anammox and DEMON processes were considered to be the most feasible sidestream treatment processes. It would be most economical to treat the centrate from the residuals processing plant instead of the gravity thickener overflow or the secondary treatment sludge centrifuge centrate. While none of these sidestream treatment processes would be able to achieve an effluent standard as low as 4 mg/L, they would significantly reduce the overall nitrogen load to the plant. Treating the centrate from the residuals processing plant (1.21 MGD, accounting for <1% of the total Deer Island flow) would reduce the total nitrogen load to the plant by 8% at peak month loadings. Sidestream treatment processes have a smaller footprint, are relatively inexpensive, and could aid in reducing the overall footprint, methanol requirement, and additional sludge production of the mainstream treatment processes.

Preliminary evaluation shows that the selected processes would fit within the limited footprint on Deer Island. A full engineering design would be required to confirm the space requirements of each process. Regardless of which mainstream treatment process is chosen, a sidestream treatment process should be considered. The technologies presented in this report include the most up to date and advanced processes for nitrogen removal used around the world at large treatment plants. MWRA will continue to research novel nitrogen removal technologies and their possible applications at Deer Island as they emerge.

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