# 2023 Technical Survey of Nitrogen Removal Alternatives for the Deer Island Treatment Plant

Massachusetts Water Resources Authority
Environmental Quality Department
Report 2024-04

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# 2023 Technical Survey of Nitrogen Removal Alternatives for the Deer Island Treatment Plant

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Environmental Quality Department Report 2024-04

## Acknowledgements:

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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 removal options. However, over 20 years of monitoring data show no adverse effects. Eutrophication has not been observed, nor have there been any nitrogen-related cyanobacteria or nuisance algae blooms. Oxygen concentrations in the past 20 years have remained well above levels that would endanger aquatic life. In addition, the calibrated Bays Eutrophication Model computes that over an annual cycle only 3% to 9% of the total nitrogen entering the Massachusetts Bay system is derived from the MWRA effluent (e.g., Zhao et al. 2017, Deltares, 2022a, Deltares, 2022b). 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 89%-93%; Hydroqual, 2000, Deltares, 2022a, 2022b, 2023). Current nitrogen levels in 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), 50% (Deltares 2022b) predict increased nitrogen at depth near the outfall, much smaller chlorophyll increases, and imperceptible effects on oxygen. Even doubling the effluent nitrogen (Zhao et al. 2015), although it was predicted to increase nitrogen close to the outfall by about 50%, led to only modest increases (~7%) in chlorophyll, and changes of less than 0.5% in oxygen. The results suggest bays ecology would be unharmed even for nitrogen load above the 14,000 MT/yr warning threshold (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. The design criteria for the selection of alternative treatment remain unchanged and are based on their suitability at Deer Island, process reliability, and land and space requirements.

Approximately 13 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.

This report carries forward new technologies added in the last report. A new addition this year is the

Modified High-Purity oxygen Ludzack-Ettinger (HPOLE) Process, which has been piloted at the Joint Water Pollution Control Plant (JWPCP) in Los Angeles County, CA. This technology is not feasible to reach design nitrogen limits in this report. However, the plant where the technology was piloted is very similar in operation to Deer Island, and the technology could potentially be used in conjunction with a tertiary nitrogen removal process. Mainstream deammonification and nitritation-denitritation processes, which have already been evaluated for implementation in the sidestream processes, continue to be piloted for mainstream treatment at other wastewater treatment facilities in the US. Mainstream deammonification may be suitable for implementation at Deer Island in the future. At present, the 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 at Deer Island.

This report includes sections considering sidestream treatment. Sidestream flows account for less than 1% of total plant flow, but up to 10% of the of the total nitrogen (TN) load. Benefits of sidestream treatment systems include a relatively small footprint at a low cost. Other benefits of sidestream treatment would be to help lower waste activated sludge production and reduce methanol requirements for other methods of nitrogen removal.

Biological nitrogen removal technologies appear to be the most feasible method of nitrogen removal at this time. 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*, released in 2023. 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.

## 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 done on Deer Island and those that could be used at the Residuals Processing Plant in Quincy.

Section 4 investigates the alternatives selected in Section 3 for further review. 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 2018 – June 2023 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: 5.7 acres, the space west of the existing secondary batteries
- Area B: 0.4 acres, the area to the north of secondary Battery A
- Area C: 3.2 acres, the area north of secondary Batteries B and C
- Area D: 3.5 acres, the area located north of the maintenance warehouse

While the total available gross area is 12.8 acres, piping and operational considerations limit the use of available space and each option with its particular design requirements needs more in-depth evaluation for its feasibility. While a solar canopy is planned for installation in Area D, this could be removed if this space was required. Sections 4 and 5 present these conceptual design evaluations. A portion of the available space west of the existing secondary batteries (Area A) is likely to be used for the construction of the new CHP (Combined Heat and Power) Facility. This project is in its infant stages and the exact acreage and size of the proposed CHP Facility is not known at this time.

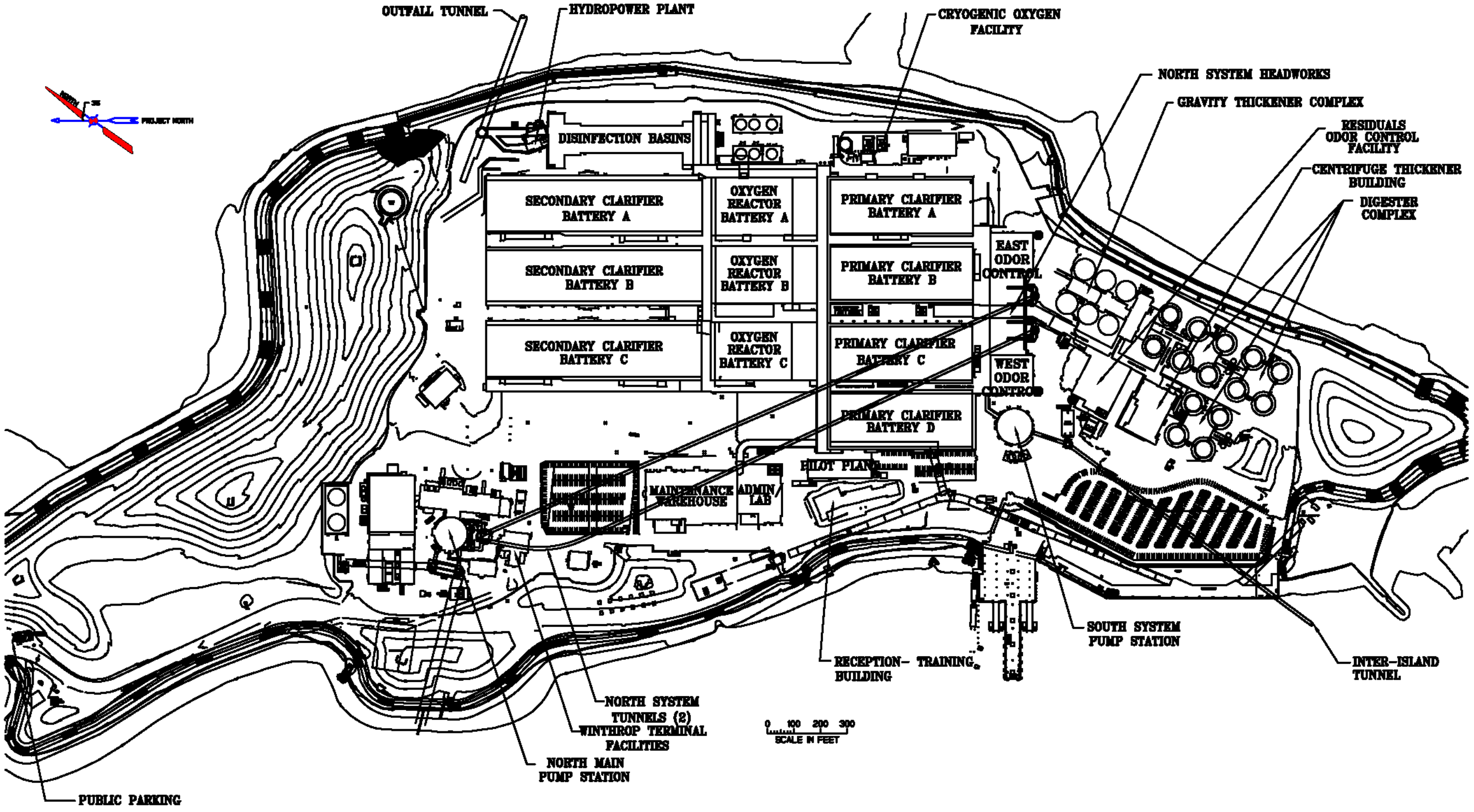


Figure 1. Deer Island Site Plan.

*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 |

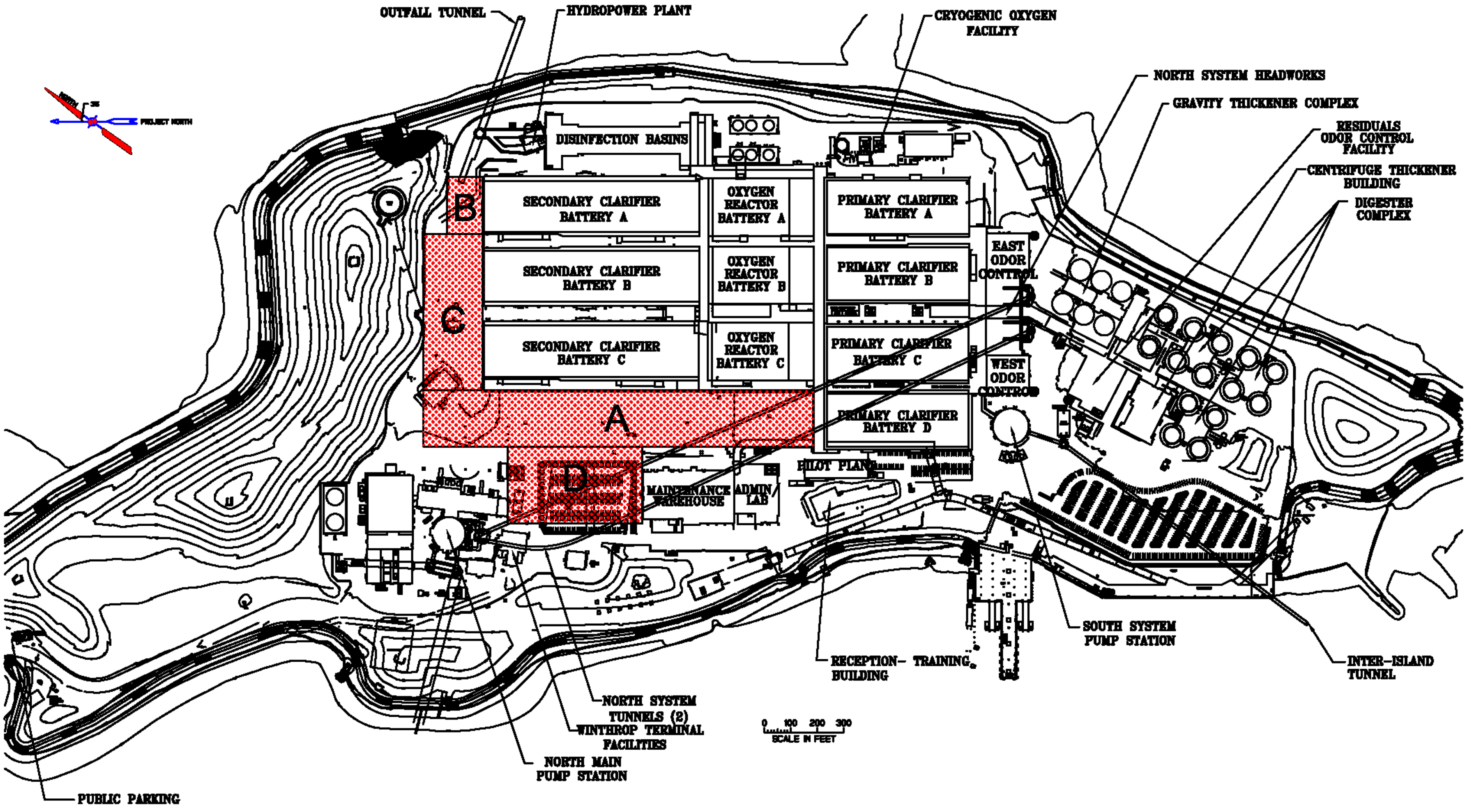


*Figure 2. Areas Available for Nutrient Removal*

## 2.3 Flows and Loads

This section provides a summary of monitoring results conducted during the period July 2018 to June 2023 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.

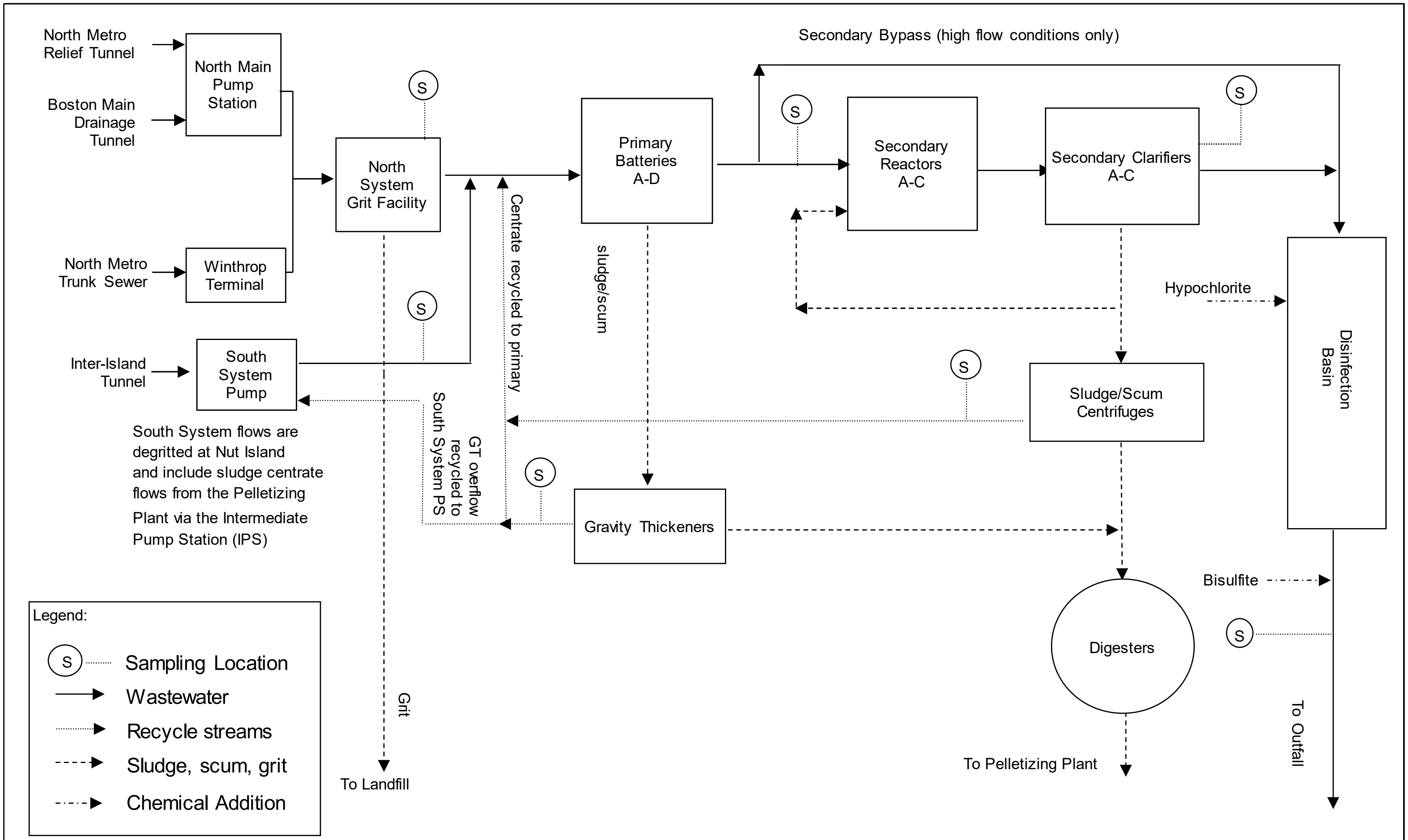
Figure 3 shows the Deer Island process flow and the various sampling locations along the process. South system flow arrives at Deer Island's south system pump station via the inter-island tunnel and combines with the north system flow after the grit removal facility. This combined raw wastewater is characterized 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 2018 to June 2023 was 320 million gallons per day (MGD). This flow and the maximum sustainable flow to secondary treatment of 700 MGD (based on experiments conducted from October 2005 to June 2006), 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 2018 and June 2023, averages of 6.2 MGD of gravity thickener overflow and 5.3 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 (320 MGD), their nitrogen loads are high (4.7% and 7.6% of the influent total nitrogen load respectively).

As of April 1, 2005, digested sludge is sent to the Residuals Pelletizing 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.



South System flows are degritted at Nut Island and include sludge centrate flows from the Pelletizing Plant via the Intermediate Pump Station (IPS)

*Figure 3. Deer Island Treatment Plant Process Flow Diagram*

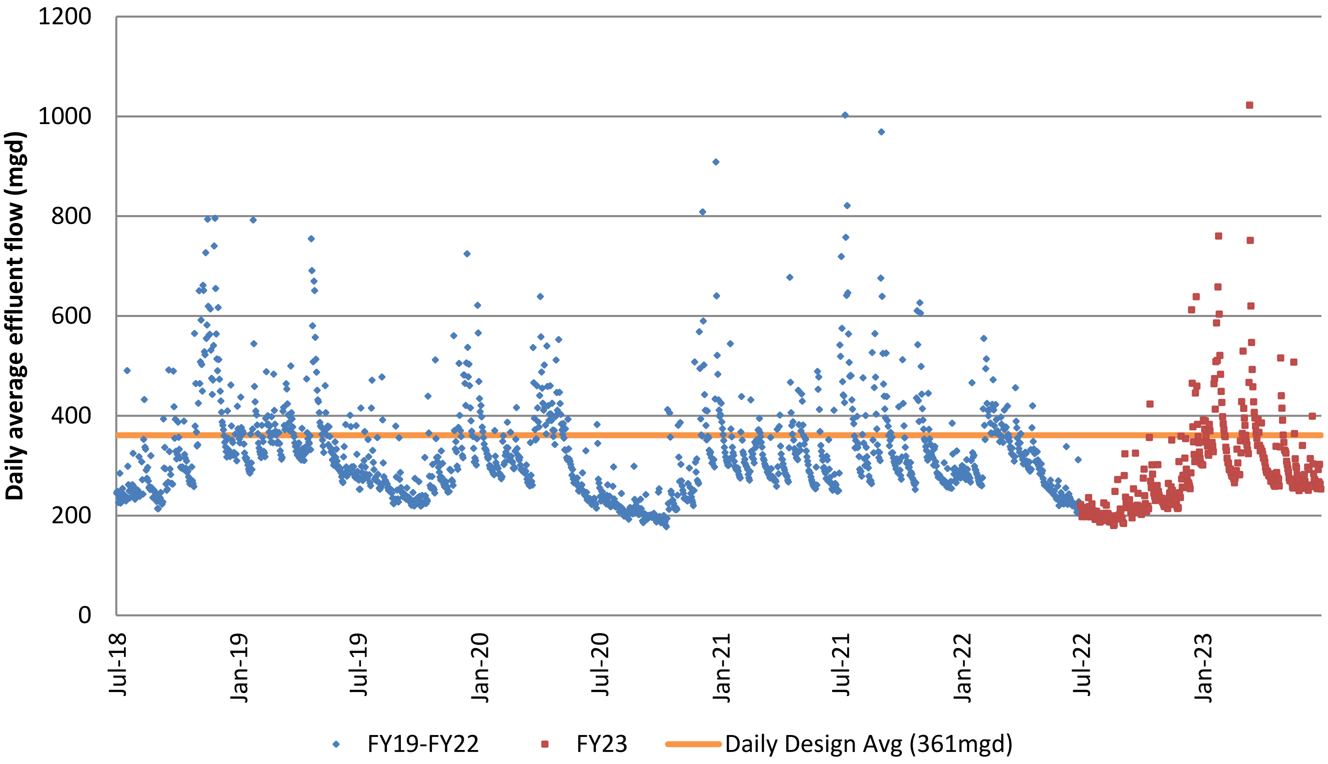


*Figure 4. Average Daily Flow*

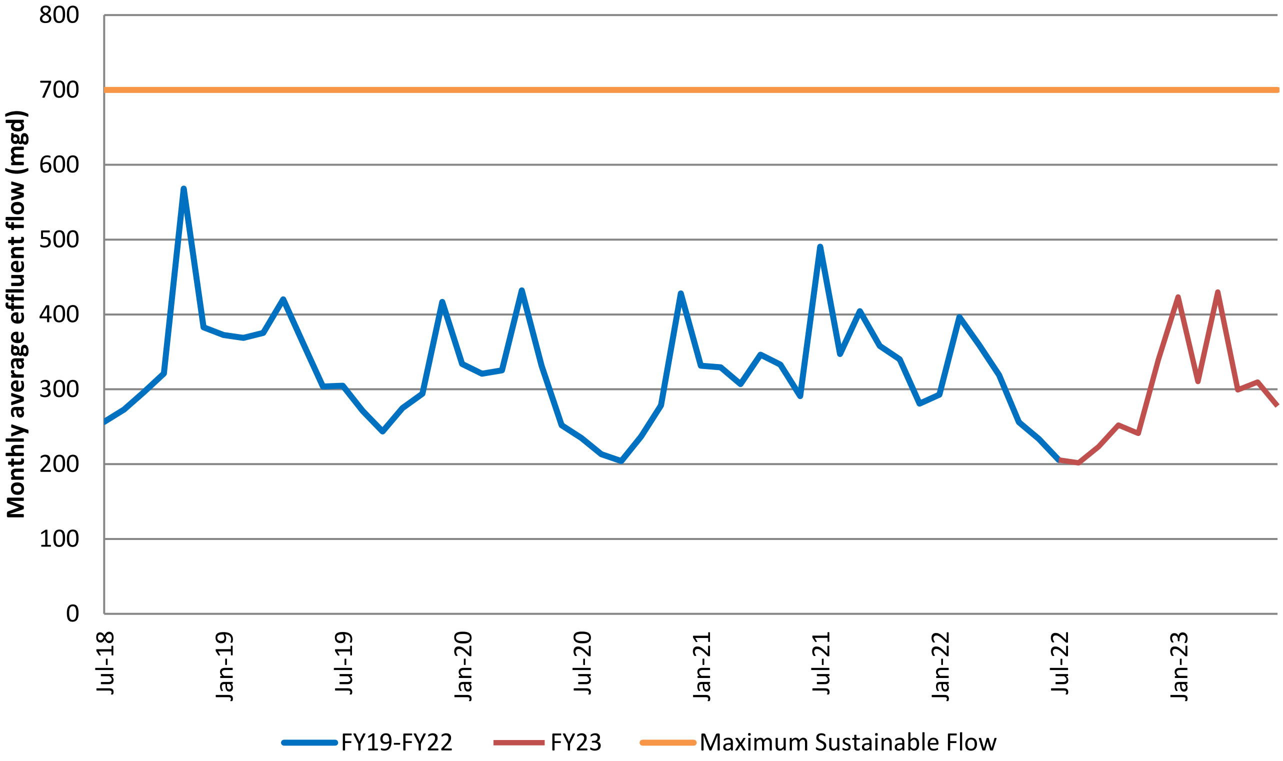


*Figure 5. Average Monthly Flow*

### 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 2018 – June 2023, the average flow-weighted Deer Island influent concentration of ammonia was 29.5 mg/L and TN was 41.3 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 104,798 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* | TKN | | NH3-N | | NO3-N | | NO2-N | | NO3+NO2 | | Total Nitrogen | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (mgd) | (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 (7/1/18 - 6/30/23)** | | | | | | | | | | | | | |
| Minimum | 120.7 | 13.5 | 31356 | 7.2 | 16235 | 0.0 | 0 | 0.0 | 0 | 0.00 | 0 | 15.4 | 31836 |
| Maximum | 331.8 | 120.0 | 214291 | 55.5 | 81404 | 2.3 | 8617 | 0.5 | 1191 | 2.45 | 9179 | 120.1 | 214534 |
| Average | 113.7 | 31.3 | 51633 | 20.7 | 33628 | 0.2 | 333 | 0.1 | 193 | 0.29 | 526 | 31.6 | 52155 |
| Standard Deviation | 39.8 | 10.2 | 16502 | 5.8 | 6482 | 0.3 | 717 | 0.1 | 222 | 0.36 | 848 | 10.1 | 16464 |
| **South System Influent (7/1/18 - 6/30/23)** | | | | | | | | | | | | | |
| Minimum | 55.8 | 22.9 | 21766 | 16.7 | 13508 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 25 | 21800 |
| Maximum | 703.8 | 107.0 | 84565 | 88.7 | 57717 | 4.13 | 4884 | 2.10 | 2813 | 4.14 | 7553 | 108 | 84660 |
| Average | 206.7 | 60.0 | 52519 | 46.7 | 40424 | 0.24 | 253 | 0.29 | 292 | 0.53 | 544 | 61 | 53065 |
| Standard Deviation | 65.3 | 18.1 | 8371 | 15.5 | 6389 | 0.47 | 579 | 0.37 | 431 | 0.67 | 882 | 18 | 8517 |
| ***Calculated Raw Influent*** | | | | | | | | | | | | | |
| Minimum | 177.7 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.00 | 5 | 0 | 0 |
| Maximum | 1022.3 | 93.2 | 272548 | 54.6 | 126755 | 2.2 | 13501 | 0.9 | 3234 | 2.67 | 16735 | 93 | 273032 |
| Average | 320.4 | 41.0 | 103320 | 29.5 | 73754 | 0.2 | 585 | 0.2 | 485 | 0.37 | 1070 | 41 | 104798 |
| Standard Deviation | 100.5 | 10.4 | 21602 | 8.2 | 10656 | 0.3 | 1113 | 0.1 | 508 | 0.34 | 1465 | 10 | 20741 |
| **Waste Activated Sludge Centrate (7/1/18- 6/30/23)** | | | | | | | | | | | | | |
| Minimum | 1.8 | 10.0 | 493 | 10.3 | 196 | ~ | ~ | ~ | ~ | 0.00 | 0.00 | 10.0 | 495 |
| Maximum | 8.4 | 437.0 | 19804 | 65.3 | 2959 | ~ | ~ | ~ | ~ | 0.08 | 3.90 | 437.0 | 19804 |
| Average | 5.3 | 179.0 | 7958 | 30.6 | 1382 | ~ | ~ | ~ | ~ | 0.01 | 0.49 | 179.1 | 7958 |
| Standard Deviation | 1.1 | 58.4 | 3111 | 7.6 | 517 | ~ | ~ | ~ | ~ | 0.01 | 0.50 | 58.4 | 3111 |
| ***Calculated Primary Influent*** | | | | | | | | | | | | | |
| Minimum | 184.1 | 1.8 | 5141 | 0.3 | 904 | ~ | ~ | ~ | ~ | 0.00244 | 6 | 1.8 | 5141 |
| Maximum | 1024.2 | 93.1 | 275806 | 54.2 | 128690 | ~ | ~ | ~ | ~ | 2.66356 | 16735 | 93.3 | 276290 |
| Average | 325.7 | 43.4 | 111682 | 29.5 | 75116 | ~ | ~ | ~ | ~ | 0.36617 | 1071 | 43.8 | 112745 |
| Standard Deviation | 99.8 | 11.1 | 20807 | 8.1 | 10846 | ~ | ~ | ~ | ~ | 0.3394 | 1468 | 11.1 | 20854 |
| **Primary Effluent (7/1/18 - 6/30/23)** | | | | | | | | | | | | | |
| Minimum | 180.0 | 17.6 | 37344 | 11.6 | 36343 | ~ | ~ | ~ | ~ | 0.00 | 0 | 18 | 37851 |
| Maximum | 1037.3 | 69.4 | 181302 | 51.0 | 144217 | ~ | ~ | ~ | ~ | 1.95 | 12458 | 69 | 181470 |
| Average | 328.3 | 39.3 | 100943 | 30.6 | 78003 | ~ | ~ | ~ | ~ | 0.22 | 668 | 39 | 101617 |
| Standard Deviation | 103.4 | 10.0 | 15858 | 8.2 | 11085 | ~ | ~ | ~ | ~ | 0.30 | 1198 | 10 | 15878 |
| **Secondary Effluent (7/1/18 - 6/30/23)** | | | | | | | | | | | | | |
| Minimum | 177.7 | 13.6 | 44665 | 9.5 | 42295 | ~ | ~ | ~ | ~ | 0.10 | 200 | 16.5 | 48225 |
| Maximum | 699.2 | 52.7 | 148592 | 51.3 | 116507 | ~ | ~ | ~ | ~ | 7.76 | 29063 | 53.8 | 152306 |
| Average | 318.0 | 29.7 | 74683 | 27.3 | 68191 | ~ | ~ | ~ | ~ | 1.52 | 4057 | 31.2 | 78747 |
| Standard Deviation | 91.9 | 7.2 | 12690 | 7.2 | 10644 | ~ | ~ | ~ | ~ | 1.06 | 3446 | 7.2 | 12922 |
| **Gravity Thickener Overflow (7/1/18 - 6/30/23)** | | | | | | | | | | | | | |
| Minimum | 3.4 | 27.6 | 981 | 12.4 | 587 | ~ | ~ | ~ | ~ | 0.00 | 0 | 27.6 | 981 |
| Maximum | 12.2 | 395.0 | 21127 | 59.9 | 3656 | ~ | ~ | ~ | ~ | 0.47 | 42 | 395.0 | 21127 |
| Average | 6.2 | 95.2 | 4893 | 32.0 | 1628 | ~ | ~ | ~ | ~ | 0.01 | 1 | 95.3 | 4893 |
| Standard Deviation | 1.5 | 64.9 | 3489 | 8.8 | 446 | ~ | ~ | ~ | ~ | 0.03 | 3 | 64.9 | 3489 |
| **Final Effluent (7/1/18 - 6/30/23)** | | | | | | | | | | | | | |
| Minimum | 177.7 | 6.9 | 30151 | 5.8 | 28406 | 0.0 | 0.0 | 0.0 | 0.0 | 0.01 | 16 | 9.8 | 30912 |
| Maximum | 1022.2 | 49.8 | 143187 | 46.2 | 122313 | 2.4 | 12716.2 | 3.1 | 10109.4 | 3.46 | 20546 | 49.8 | 144323 |
| Average | 320.4 | 27.5 | 68866 | 25.6 | 64363 | 0.3 | 774.9 | 0.6 | 1738.9 | 0.91 | 2631 | 28.4 | 71441 |
| Standard Deviation | 100.5 | 8.5 | 16636 | 7.8 | 13883 | 0.4 | 1351.6 | 0.6 | 2039.4 | 0.83 | 2792 | 8.2 | 16600 |

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

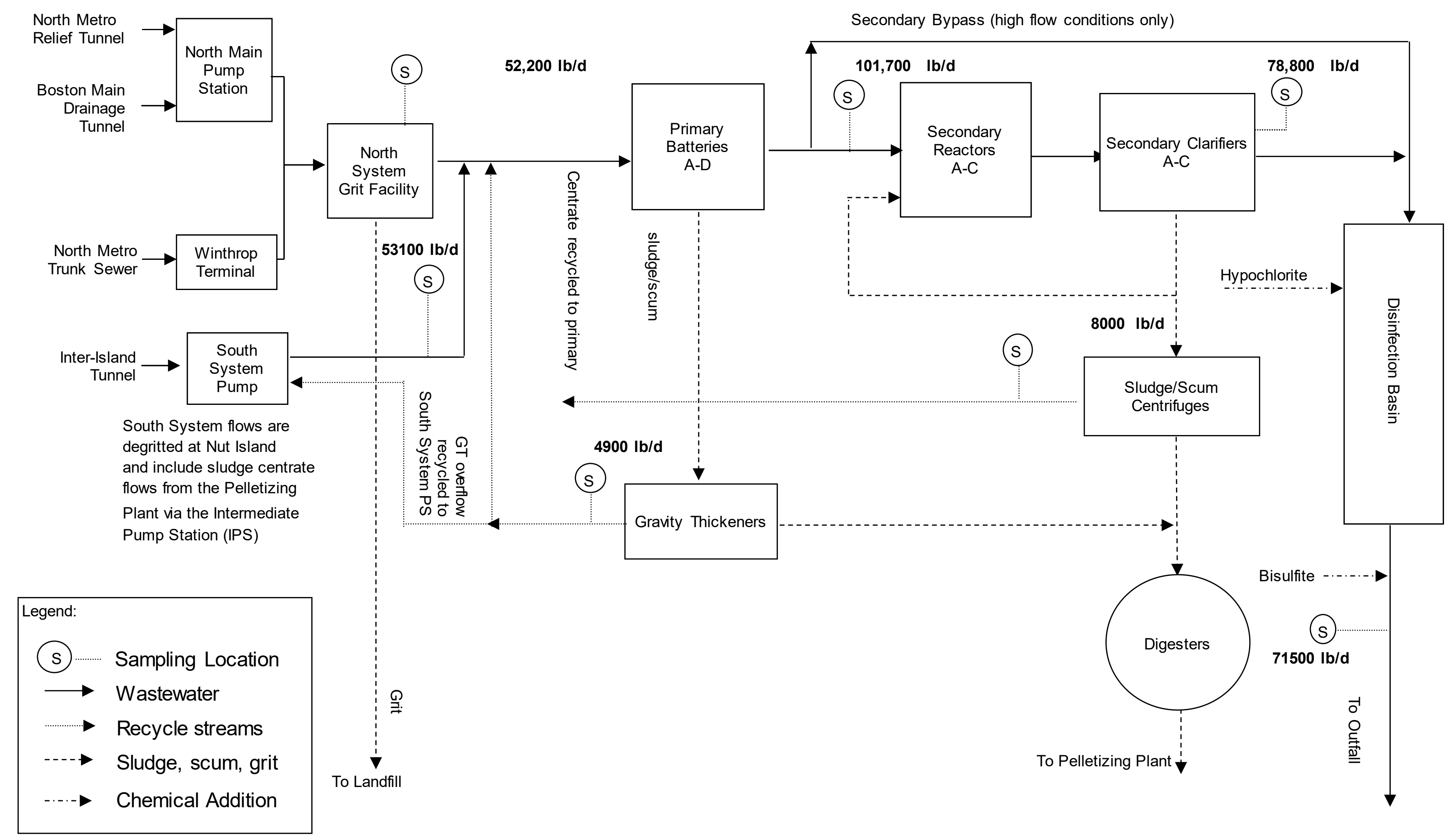


*Figure 6. Total Nitrogen Mass Balance (July 2018-June 2023)*

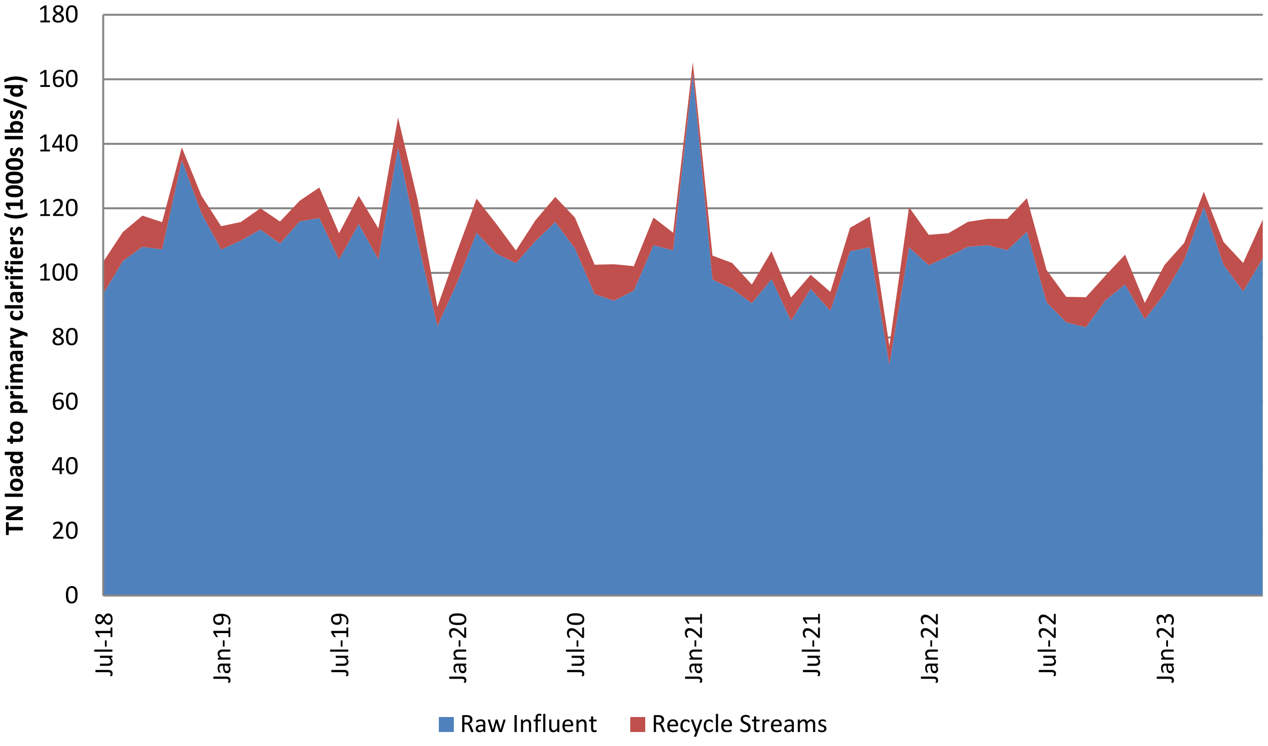


*Figure 7. Total Nitrogen Load to Primary Clarifiers (Monthly Average)*

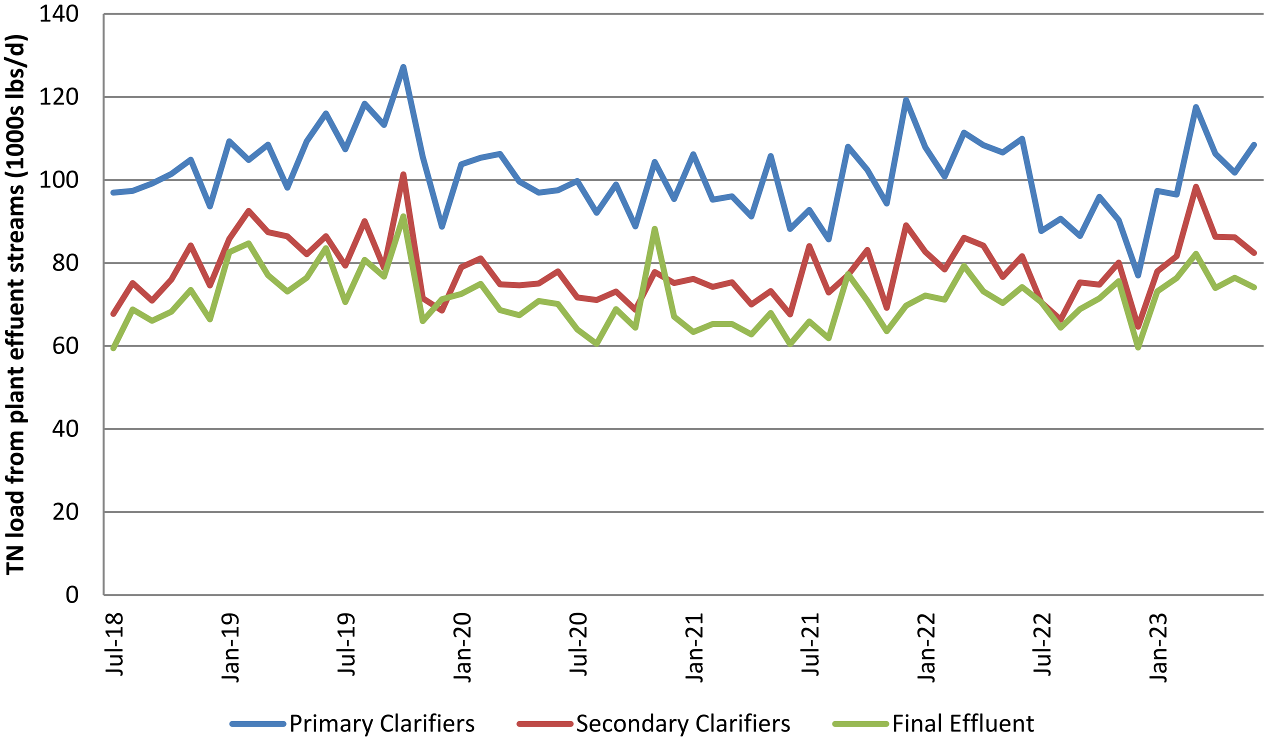


*Figure 8. Total Nitrogen Load from Plant Effluent Streams*

## 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 is important for sizing biological systems for nitrification. As in most biochemical reactions, temperature greatly influences nitrification rates. The rate of ammonium oxidation depends on the growth rate of the bacteria *Nitrosomonas*, which in turn depends on temperature. Based on monitoring data and the possible requirement for year-round nitrification, this report uses a minimum wastewater temperature of 53.6°F (12°C). This design temperature was updated from 11°C that was used in previous versions of this report, based on the most recent five years of data. Between FY18 and FY23, the wastewater temperature measurements of the south system influent averaged about 2.7°F colder than the north system influent. Figures 9 and 10 graph the north and south system influent temperatures, respectively.

Final effluent is probably the best source for determining the temperature in designing a biological nitrogen removal system. There were no days during FY23 when the temperature dipped below the 53.6°F design criterion. Plant performance would deteriorate during very cold weather but the reduced performance should not cause the plant to exceed a hypothetical permit limit. Figure 11 depicts effluent temperatures during 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.  Also because of the experiments, Deer Island set its 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 with more current data.

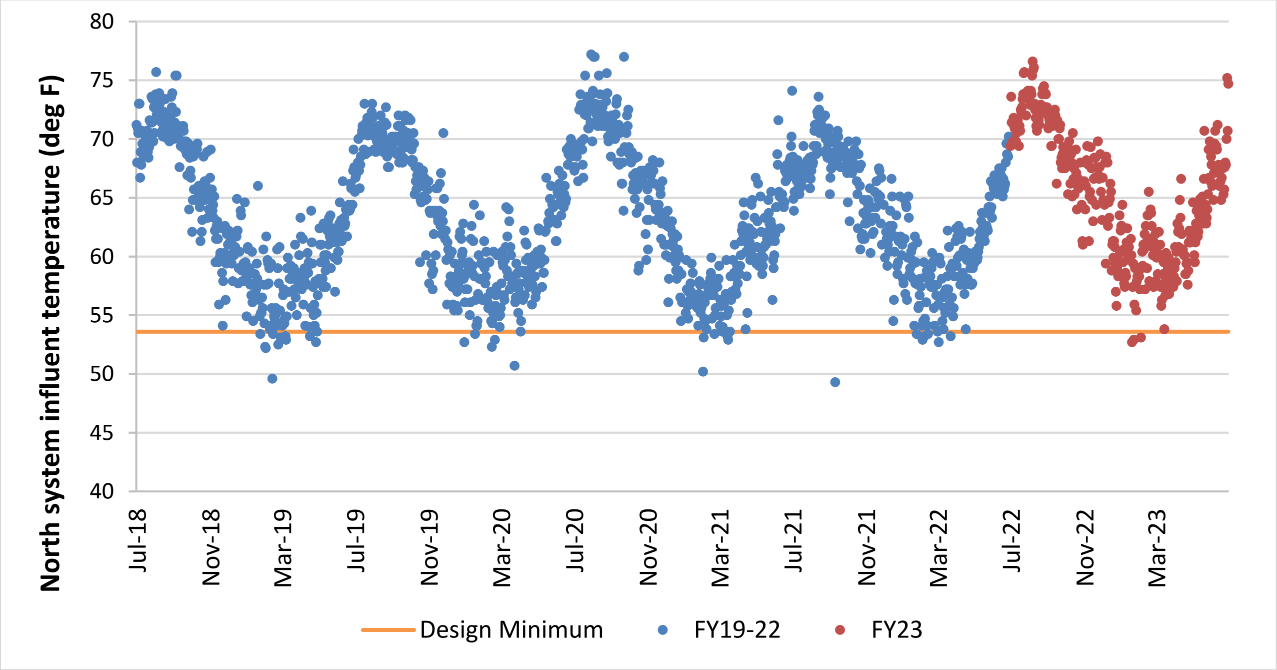


*Figure 9. North System Influent Temperatures*

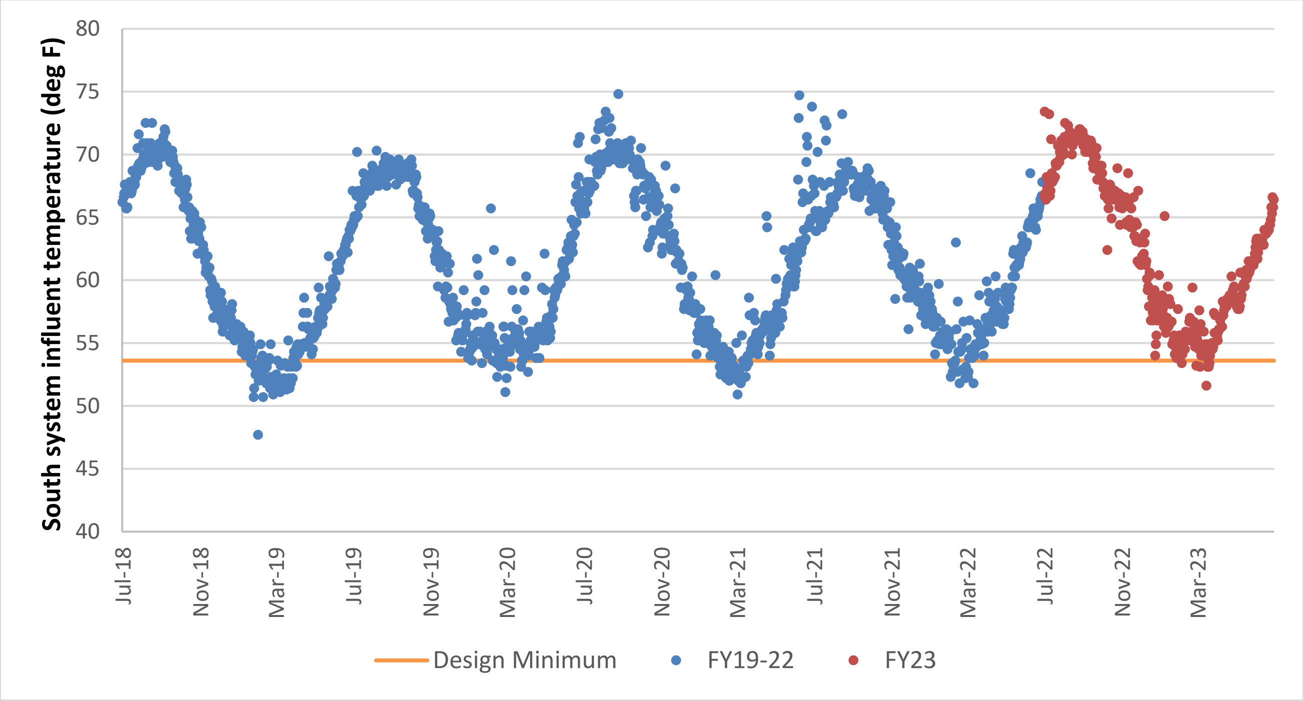


*Figure 10. South System Influent Temperatures*

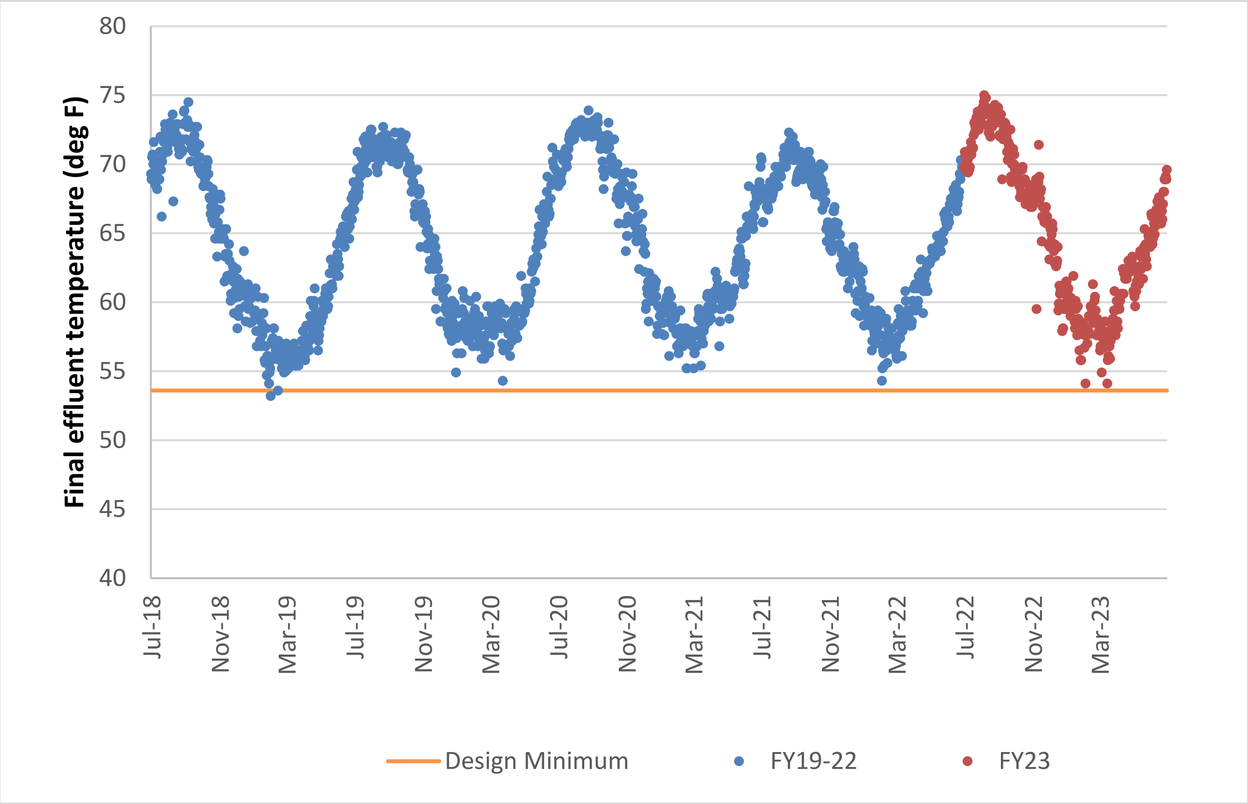


*Figure 11. Final Effluent Temperatures*

*Table 3 Flows and Nitrogen Loads*

| | | **Primary Effluent Nitrogen Load (lb/d)** | | **Secondary Effluent Nitrogen Load (lb/d)** | |
|---|---|---|---|---|---|
| | **Design Flow (MGD)** | ***2001**** | **FY18-FY23** | **2001*** | **FY18-FY23** |
| Average – Day | 361 | 80,600 | 101,617 | 66,200 | 78,747 |
| Max – Month | 700 | 104,700† | 127,222 | 86,000† | 101,351 |

* 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

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 effluent standards for 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 recent permits have given seasonal effluent limits, with limits in place during the warm months, and reporting only during colder months. For purposes of this report, to allow for making assessments and comparisons, 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 summarizes the alternatives, and Section 4 examines them in detail.

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 regeneration solution must then be treated as well. Ammonia in the exhaust can be recovered for use as a fertilizer. 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 must be preceded by treatment beyond secondary treatment, typically coagulation, settling, and filtration, thus making it most effective on polished effluents. A problem with this alternative is that the chlorine demand will be too great to allow for cost- effective implementation. It is estimated that 10 pounds of chlorine are required to remove 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.

Nitritation and denitritation 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 (nitritation) or partial denitrification (denitratation) 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 will be required for nitrogen removal at DITP. Membrane backwashing and cleaning systems as well as a foam control system will be required. Upstream fine filtration is also needed to remove large particles that could damage the membranes.

Membrane activated sludge systems are currently being constructed at larger municipal facilities, and may be evaluated for implementation at Deer Island in the future. MBRs could also be used for sidestream treatment. Membrane activated sludge systems 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 variation 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 returned 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. This process has 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 (about ten acres) exceeds the space available with reasonable geometry and this option is dropped from further evaluation. Addition of an anoxic zone would require even more area. Additional clarifiers may also be required.

### 3.2.2 Fixed Growth Systems

In fixed-film systems, the biological organisms grow on a supporting surface, in contrast to suspended-growth systems, where the organisms grow in a liquid phase and then have to 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 or 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 is 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 of these 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 medium and is separated from treated effluent in an upper zone of the reactor. The system supplier believes that other options 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, 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 to increase their capacity. 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 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 of 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 footprint of mainstream treatment processes to be installed, and reduce the supplemental carbon requirements and 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 (nitritation), which in turn is reduced to nitrogen gas (denitritation) 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 is operated 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 as 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. This process requires less supplemental carbon and oxygen.

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) bacteria. Processes that utilize PN/A include the CANON and SHARON-Anammox processes as discussed below. PdN/A processes do not require suppression of the NOB bacteria, and are currently being researched for implementation at larger facilities in the mainstream process. The PANDA process discussed below is a PdN/A process. PdN/A processes are not evaluated further in this report, but may be suitable for nitrogen removal at Deer Island in the future.

There are several companies with commercially available systems using the anammox bacteria. These include Veolia's ANITA$^{TM}$ 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$^{TM}$ Mox Process, which is an attached growth anammox system.

In the ANITA$^{TM}$ 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 as 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$^{TM}$ Mox has been retained for sidestream treatment evaluation, and is discussed further in Section 5.1.1.

**PANDA**

In the partial nitrification, denitratation 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 is 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.

**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. Struvite, or magnesium ammonium phosphate, is made up of equimolar concentrations of ammonium, phosphate, and magnesium. The Ostara Pearl® process is an upflow fluidized bed crystallizer. Magnesium is typically added to supplement the 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.

### 3.2.5 Treatment Innovations

**Microbial Fuel Cells (MFC)**

Microbial fuel cells operate essentially as large galvanic cells, using an anode and a 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 biodes. 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 wastewaters 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, eliminating 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 back 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, 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 as a way 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. The largest planned installation of this technology is less than 10 MGD, however, 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 can be done in a number of 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 in process control. SNdN would need to be implemented as part of the process controls for a new system, 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 methane combustion. This process has the advantage of energy recovery through nitrous oxide. 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, 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.

Table 4 below lists all of the technologies evaluated, the current state of the technology, and whether it is currently suitable for use at Deer Island.

*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

## 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** |
|---|---|---|
| Biological Aerated Filters | X | |
| Combined BAF-MBBR Reactors | X | X |
| Fluidized-Bed Reactors | | X |
| Moving Bed Biofilm Reactor | X | X |
| Integrated Fixed Film Activated Sludge | X | X |
| Anammox (ANITA Mox) for Sidestream Treatment | X | X |

# 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

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 for 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.

To reach the new facilities, 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 units. Effluent from the new facilities would enter a new tunnel discharging to the chlorine contact tanks.

Blowers would provide aeration. The air would be injected at the base of each biological aerated filter and flow upward, concurrent with the wastewater flow.

The tanks need to be backwashed every 24 hours, approximately, or at a pre-determined set head loss across the filter. Water for backwashing is supplied from a common reservoir above the filter cells. Backwash waste would be returned to the head of primary or to the head of the plant; the backwash rate is about 9300 gpm/battery. The airflow rate required for backwashing is approximately 2,500 standard cubic feet per minute per cell (scfm/cell).

The gross area required for siting the BAF and MBBR system, including blowers, a pump station and galleries would be about 7.95 acres. Figure 12 shows a preliminary BAF and MBBR layout.

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

| | **BAF-MBBR Nitrification** | **BAF-MBBR Denitrification** |
|---|---|---|
| Influent TKN | | |
| Maximum Month TKN (mg/L) | 40 | 40 |
| 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 | 4.62 | 3.13 |
| | | |

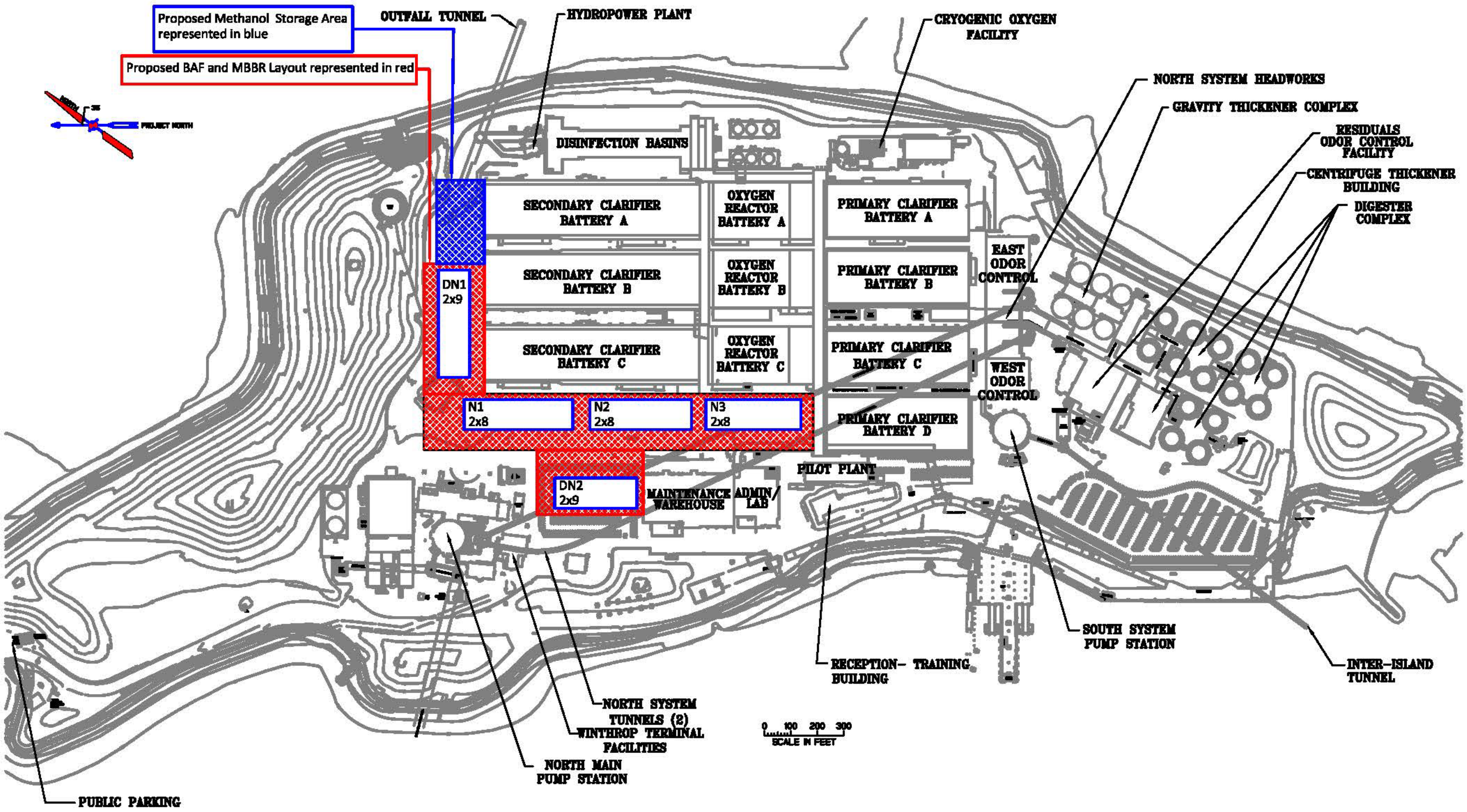


*Figure 12. Proposed BAF and MBBR Layout*

## 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 94 BAFs and 51 FBRs would be required; these include standby units.

The area requirements for the BAF/FBR system would be approximately 6.4 acres. 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.

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

| | BAF Nitrification | FBR Denitrification |
|---|---|---|
| TKN Load (lb/d) | | |
| Maximum Month | 101,400 | 101,400 |
| 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) | 12.1 | 10 |
| Surface Area (ft$^2$) | 1,940 | 800 |
| Volume (ft$^3$) | 23,500 | 8,000 |
| Active Units | 85 | 46 |
| Units Provided | 94 | 51 |
| | | |
| Acres Needed | 4.2 | 0.9 |

* There is little information available on FBRs and nitrogen loading rates.

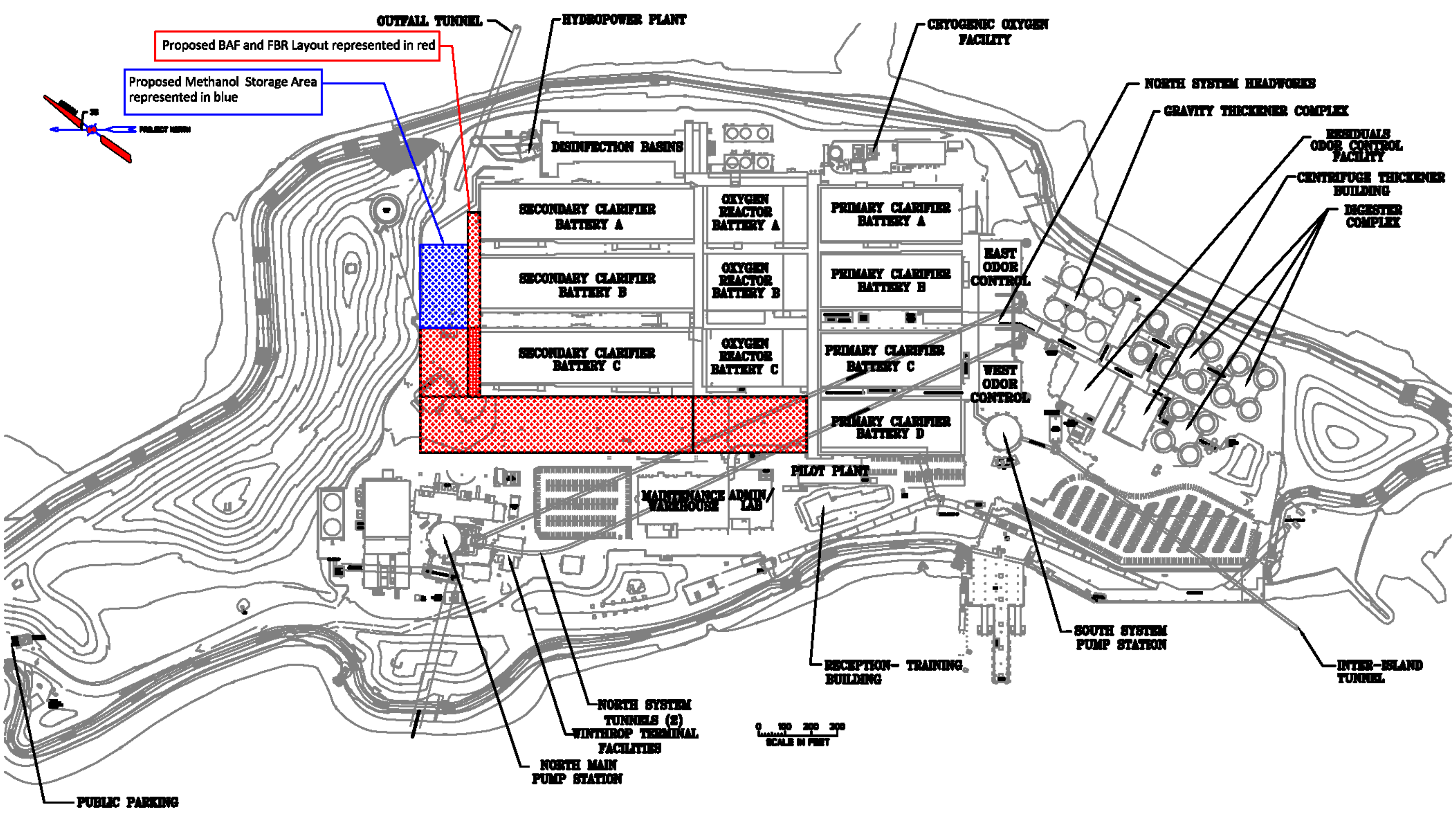


*Figure 13. Proposed BAF and FBR Layout*

## 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 postanoxic 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.

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.

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.

For aeration, approximately 7,800,000 ft$^3$ of total volume would be required. The existing aeration basins provide 5,637,000 ft$^3$. However, with the need to construct two new channels, 485,100 ft$^3$ of aeration volume would be lost from the existing basins. The total new volume required (2,650,000 ft$^3$) could be located in Area A, the space west of the existing secondary batteries.

Denitrification would require between 2,997,000to 3,345,000 ft$^3$ of new construction depending on the level of effluent nitrogen concentration to be met. Prior to denitrification, 152,000 ft$^3$ 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 7.45 acres. Figure 14 shows the conceptual layout of the MBBR nitrification/ denitrification system.

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

| | **MBBR for Nitrification** |
|---|---|
| Nitrogen Load in Primary Effluent (lb/d) | |
| Maximum Month | 128,000 |
| Nitrogen Assimilated Plus Ammonia Nitrogen in Effluent (lb/d) | 17,700 |
| Ammonia to be Treated (lb/d) | 110,300 |
| Nitrification Rate ($g/m^2 \cdot d$) | 0.931 |
| Specific Surface Area ($m^2/m^3$) | 500 |
| Total Media Required ($ft^3$) | 3,800,000 |
| % Fill of Carrier Elements | 65% |
| Volume Required for Nitrification ($ft^3$) | 5,850,000 |
| 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 ($ft^3$) | 2,650,000 |
| Unit Dimensions of New Basins | |
| Depth (ft) | 24.5 |
| Surface Area ($ft^2$) | 4,900 |
| Number of Basins | 23 |
| Acres Needed | 2.59 |

*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) | 102,400 | 91,700 |
| Loading Rate (g/$m^2$·d) | 2.45 | 2.45 |
| Specific Surface Area ($m^2/m^3$) | 500 | 500 |
| Media Required ($ft^3$) | 1,338,000 | 1,199,000 |
| % Fill of Carrier Elements | 40% | 40% |
| Total Tank Volume ($ft^3$) | 3,345,000 | 2,997,000 |
| 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 | 30 | 27 |
| Acres Needed | 3.37 | 3.04 |

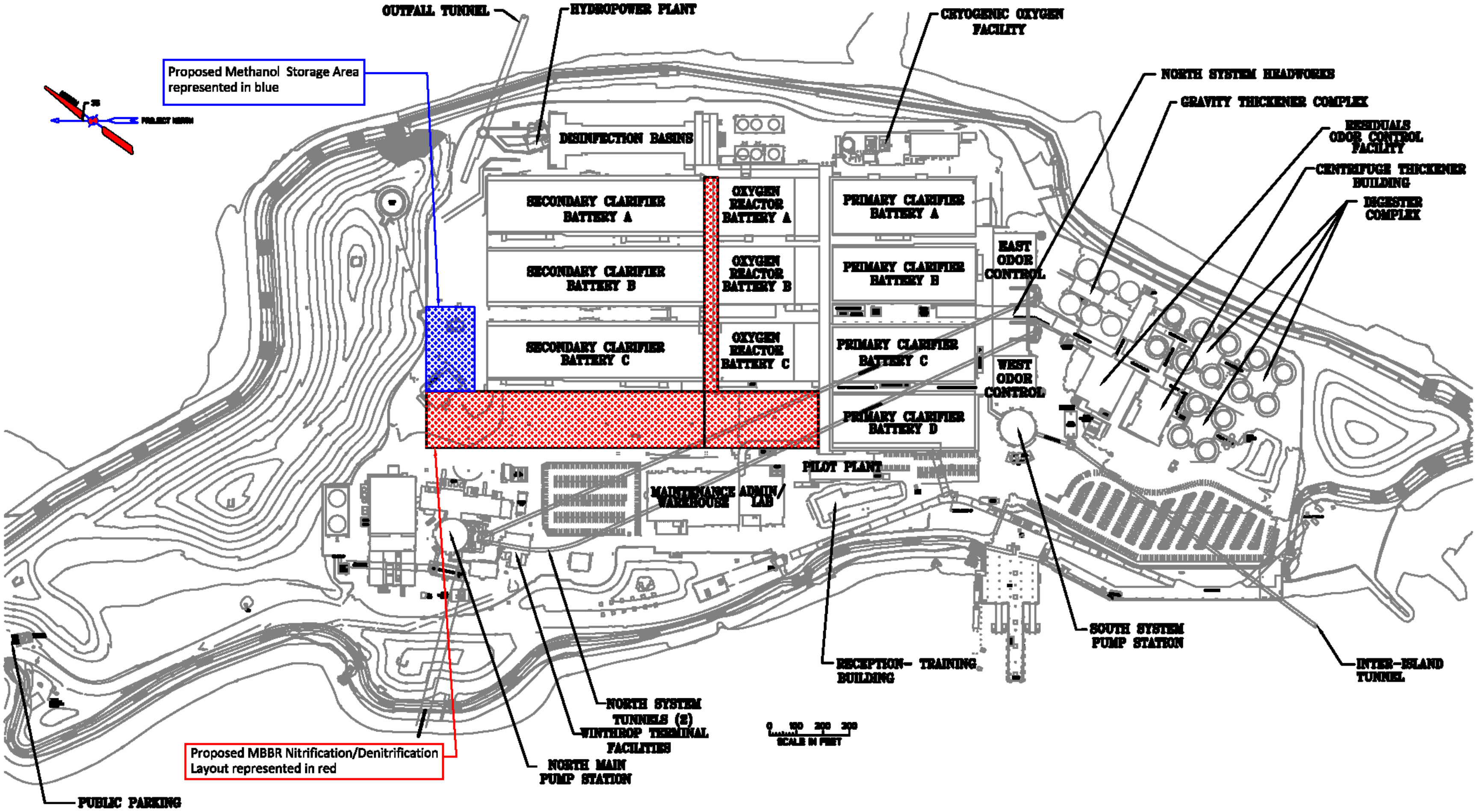


*Figure 14. Proposed MBBR Nitrification/Denitrification Layout*

## 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 three 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 the maximum day, 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 4.2.

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 of 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 258,000 lb/d for less than 8 mg/L effluent TN concentration and 290,000 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 5.9 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 102,400 lbs/d of nitrogen would be reduced to achieve 4 mg/L of total nitrogen during the maximum month, and about 62,000 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 870 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 2.23 million gallons of 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 at this time. 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, digested sludge has been sent to the Residuals Processing Plant in Quincy via the inter-island tunnel. With all processing of digested sludge taking place at the Processing Plant, sidestreams from dewatering the digested sludge contain high concentrations of ammonia, and it might be economical to treat the sidestreams for nitrogen removal at the Processing Plant. An unused land area of approximately 54,800 $ft^2$ 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 of 1.29 MGD over seven days and contains an average concentration of 1,100 mg/L ammonia nitrogen. This amounts to an average of 11,800 lb/day of ammonia over seven days. Since the Residuals Processing Plant is typically only operated on weekdays, the centrate flow accounts for 21% of the total influent ammonia to Deer Island over the design period and only 0.6% 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 10.5% reduction of the TN load to the entire plant. 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 4,000 mg/L and a peak concentration over 18,000 mg/L, which could pose operational issues. Although most anammox systems are not affected by TSS since flow in is equal to flow out, it could lead to reduced dissolved oxygen (DO). 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 29,600 ft$^2$, 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 3500 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 temperatures while still maintaining optimal performance. The remaining design criteria for this system is summarized on the following page in Table 10.

*Table 10. ANITA Mox Design Criteria*

| | |
|---|---|
| Residuals Centrifuge Centrate Flow (MGD) | 1.29 |
| Number of Process Trains | 7 |
| 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$^3$) | 473,200 |
| Media Type<br>Effective Surface Area (m$^2$/m$^3$) | K5<br>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$^3$) | 218,400 |
| Total Effective Surface area (ft$^2$) | 115,400,000 |
| Aeration Rate (scfm) | 24,500 |
| 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 11.6 MGD and contain about 12,800 pounds of total nitrogen, about 12% of the total load to the plant. However, most sidestream treatment processes are able to treat only ammonia nitrogen and small amounts of nitrate, and at a smaller scale, (the largest sidestream treatment installations are up to 8 MGD). The total ammonia load in both of these streams is roughly 3,000 pounds per day, or less than 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 flow rate varies more day to day than the waste activated sludge centrate stream flow rate (standard deviation of 1.53 MGD vs. 1.08 MGD), making it difficult to accurately design a reactor. The waste activated sludge centrate also has a higher ammonia nitrogen concentration than the gravity thickener overflow and would be more economical to treat. The design ammonia load from the waste activated sludge centrate is approximately 1,800 pounds. An 85% reduction of ammonia in this stream would account for a 2% reduction of the total nitrogen load to the plant. Therefore, it would be most economical to provide separate treatment of the waste activated sludge centrate.

*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** | 94 | 85 | 93 |
| **Required SPBR Reactors** | 29 | 26 | 29 |
| **Required FBR Reactors** | 51 | 50 | 50 |
| **Additional Tankage Required for MBBR BOD Removal and Nitrification ($ft^3$)** | 2,650,000 | 2,190,000 | 2,650,000 |
| **Required MBBR Denitrification Reactors** | 30 | 27 | 29 |

## 5.4 Decreasing Requirement for Methanol

All of the mainstream treatment alternatives considered in Section 4 would require addition of methanol as a carbon source for denitrification. With these options, purchase of methanol would be a major expense. Based upon estimates from the Methanex Corporation, it is estimated that methanol costs would be approximately $0.26/lb. It would be costly (over $25 million/year) to purchase over 270,000 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 to provide the carbon source would decrease use of methanol. 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. 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) | 273,000 | 243,000 | 268,000 |
| Cost per year ($) | $26,166,000 | $23,283,000 | $25,720,000 |
| **MBBR** | | | |
| Methanol Required (lb/day) | 307,000 | 277,000 | 303,000 |
| Cost per year ($) | $29,514,000 | $26,630,000 | $29,053,000 |

## 5.5 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) | 55,000 | 49,000 | 54,000 |
| MBBR Additional Sludge Produced (lb/day) | 62,000 | 56,000 | 61,000 |

# 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 6-7% 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.

Currently, there exist approximately 13 acres of usable space for nitrogen removal facilities 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 of these options would require a supplemental carbon source for complete denitrification, and would also lead to increased sludge production from denitrification.

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 (1.29 MGD, accounting for <1% of the total flow) would reduce the total nitrogen load to the plant by over 10%. Sidestream treatment processes have a small 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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