



preserve our community



protect our environment



manage our resources



explore innovative solutions

City of Portsmouth
Wastewater Master Plan

Phase 2 Initial Piloting Technical Memorandum

Volume One • September, 2012



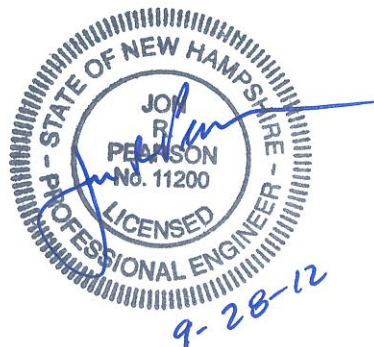
AECOM

**City of Portsmouth, New Hampshire
Wastewater Master Plan**

**Phase 2 Initial Piloting
Technical Memorandum**

Volume One of Two

September, 2012



Prepared by

AECOM



AECOM
701 Edgewater Drive
Wakefield, MA 01880
www.aecom.com

781 246 5200 tel
781 245 6293 fax

J-60223731

September 28, 2012

Mr. Terry Desmarais, P.E.
City Engineer
Department of Public Works
680 Peverly Hill Road
Portsmouth, NH 03801

Subject: Wastewater Master Plan (WWMP) Phase 2 Initial Piloting
Piloting Technical Memorandum

Dear Mr. Desmarais:

In accordance with our Agreement, we are pleased to submit this Technical Memorandum on the Phase 2 Initial Piloting of potential technologies to upgrade the Peirce Island Wastewater Treatment Facility (WWTF). The recommendations in this Technical Memorandum were prepared to fulfill the requirements of the modified Consent Decree that requires that "The City shall submit a Piloting Technical Memorandum that includes data from piloting and a recommendation on the design and capacity of secondary treatment facilities".

This Technical Memorandum presents the approach, equipment, methods, and results of the pilot study of the three treatment technologies selected in the Phase 1 Engineering Evaluation for piloting:

- Biological Aerated Filter (BAF)
- Conventional Activated Sludge with BioMag (CASB)
- Moving Bed Bioreactor (MBBR) & DAF

The piloting data showed that all three technologies were capable of achieving the effluent goals of the pilot study for secondary treatment (30 mg/l Biochemical oxygen demand (BOD) and 30 mg/l total suspended solids (TSS)) as well as for the effluent total nitrogen goal of 8 mg/l. All three technologies were able to intermittently, but not consistently, achieve the effluent total nitrogen goal of 3 mg/l.

The Technical Memorandum also includes updated data on wastewater characteristics and revised flows and loads for the WWTF upgrade. Updated process sizing, layouts, and estimated costs for upgrading the WWTF to provide secondary treatment with the ability to meet an effluent total nitrogen limit of 8 mg/l for each of the three technologies are presented. Based on the estimated capital and operation and maintenance costs, as well as consideration of non-monetary factors, the three technologies were compared.

Based on the evaluation and comparison of the three piloted technologies, it is recommended that the City pursue preliminary design of a BAF for secondary treatment sized to treat an average daily flow of 6.13 mgd, and the preliminary design include the ability to meet an effluent total nitrogen of 8 mg/l on a seasonal rolling average basis.



Mr. Terry Desmarais, P.E.
September 28, 2012
Page 2

For the purposes of the pilot performance analysis and preliminary design, effluent is considered to be at the downstream end of the proposed secondary (nitrogen removal) treatment system. This is not inclusive of the wet weather treatment effluent, which will be considered as a separate flow from secondary effluent and measured independently. The recommended treatment technology was based on meeting treatment levels summarized below:

- Secondary Treatment: In accordance with the secondary treatment permit limits as summarized in the 2007 NPDES permit. The permit limits require meeting an effluent TSS and BOD of 30 mg/l or less on a monthly average basis, 45 mg/l on a maximum weekly basis and 50 mg/l on a maximum day basis and TSS and BOD percent removals of 85 percent. Achieving 85 percent removal for BOD and TSS will only be required on dry weather days.
- Total Nitrogen to 8 mg/l: Meeting a TN effluent limit of 8 mg/l on a seasonal rolling average basis from April to October. TSS and BOD limits for will be the same as stipulated above for Secondary Treatment.

We would be pleased to meet with you or other City staff to review and discuss the report findings and recommendations. If you should have any questions, please feel free to contact us.

Very truly yours,

A handwritten signature in blue ink, appearing to read "Jon R. Pearson".

Jon R. Pearson, P.E.
Vice President
AECOM

JRP/mtf

**CITY OF PORTSMOUTH, NH
PHASE 2 INITIAL PILOTING TECHNICAL MEMORANDUM**

TABLE OF CONTENTS

	<u>Page</u>
Letter of Transmittal	i
Table of Contents	ii
List of Attachments	iii
List of Figures	iv
List of Tables	vi
List of Abbreviations	viii
Acknowledgements	x

Volume One of Two

EXECUTIVE SUMMARY

Section1- Introduction and Purpose.....	ES-1
Introduction	ES-1
Purpose.....	ES-2
Consent Decree Requirements	ES-2
Section 2 - Pilot Process, Equipment, and Approach	ES-2
Section 3 - Pilot Data Analysis.....	ES-2
Ability to Meet Study Effluent Goals	ES-3
Effluent Performance Comparison	ES-3
Vendor Constituent Loading Rate Validation and Potential to Reduce Technology Size.....	ES-4
Hydraulic Stress Test Summary.....	ES-5
Section 4 - Wastewater Data and Revised Full scale Design Criteria	ES-6
Wastewater Characterization Program.....	ES-6
Revised Flows and Loads.....	ES-6
Section 5 - Secondary Process Resizing and Comparison.....	ES-7
Approach.....	ES-8
Capital Cost Comparison	ES-8
Operations and Maintenance Comparison	ES-9
Life Cycle Cost Comparison.....	ES-9
Section 6 - Non-Monetary Evaluation Factors Update.....	ES-9
Technology Comparison and Ranking	ES-10
Section 7 – Pilot technical Memorandum Recommendations.....	ES-10
Secondary Treatment Facilities Design Capacity	ES-10
Design Recommendations.....	ES-10

SECTION ONE – INTRODUCTION AND PURPOSE

Background.....	1-1
WWMP Piloting – Phase 1 Evaluation	1-1
Purpose.....	1-2
Consent Decree Requirements	1-3

SECTION TWO - PILOT PROCESSES, EQUIPMENT, AND APPROACH

Introduction	2-1
Overview of Piloted Technologies.....	2-1
BAF.....	2-1

	<u>Page</u>
CAS with BioMag.....	2-1
MBBR with DAF	2-2
Pilot Equipment.....	2-2
Primary Clarifier.....	2-3
BAF.....	2-6
CAS with BioMag.....	2-7
MBBR with DAF	2-8
Piloting Approach.....	2-10

SECTION THREE – PILOT DATA ANALYSIS

Introduction.....	3-1
Review of Pilot Testing.....	3-1
Sample Pilot Loading vs. Constituent Removal Graph.....	3-1
Biological Aerated Filter	3-3
Experimental Plan Summary.....	3-4
Data Presentation.....	3-4
Ability to Meet Pilot Study Effluent Concentration Goals.....	3-6
Load Rate Validation	3-6
Hydraulic Stress Testing Performance	3-17
Concerns with Fats, Oils, and Grease.....	3-23
Piloting Observations and Considerations for Full Scale Implementation	3-23
Conventional Activated Sludge with BioMag.....	3-25
Experimental Plan Summary.....	3-26
Data Presentation.....	3-26
Ability to Meet Pilot Study Effluent Concentration Goals.....	3-26
Load Rate Validation	3-28
Hydraulic Stress Testing Performance	3-43
Piloting Observations and Considerations for Full Scale Implementation.....	3-47
Moving Bed Bioreactor with Dissolved Air Floatation	3-50
Experimental Plan Summary.....	3-50
Data Presentation.....	3-50
Ability to Meet Pilot Study Effluent Concentration Goals.....	3-52
Load Rate Validation	3-53
Hydraulic Stress Testing Performance	3-62
Piloting Observations and Considerations for Full Scale Implementation.....	3-66
Pilot Data Analysis Summary	3-68
Experimental Plan Results and Ability to Meet the Treatment Goals.....	3-68
Comparison of Effluent Concentrations.....	3-68
Vendor Constituent Loading Rate Validation and Potential to Reduce Technology Size.....	3-73
Hydraulic Stress Test Summary.....	3-74

SECTION FOUR- WASTEWATER DATA AND REVISED FULL SCALE DESIGN CRITERIA

Introduction.....	4-1
Wastewater Characterization Program	4-1
Recalcitrant Dissolved Organic Nitrogen (rDON)	4-2
Revised Flows and Loads	4-3
Secondary Treatment Revised Flows Analysis.....	4-4
Secondary Treatment Revised Loads Analysis	4-5
Upgraded WWTF Effluent Treatment Requirements.....	4-6

	<u>Page</u>
SECTION FIVE - SECONDARY PROCESS RESIZING AND COMPARISON	
Introduction	5-1
Approach	5-1
Common Elements	5-2
BAF Process	5-3
Conventional Activated Sludge with BioMag Process	5-5
MBBR with DAF Process	5-12
Cost Comparison	5-13
Capital Cost Comparison	5-13
Operation and Maintenance Cost Comparison	5-16
Life Cycle Cost Comparison	5-16
SECTION SIX - NON-MONETARY EVALUATION FACTORS UPDATE	
Introduction	6-1
Peirce Island WWTF Operators Questionnaire	6-1
Revised Criteria Evaluation Matrix	6-2
Eliminated Phase 1 Evaluation Criteria	6-2
Added Phase 2 Evaluation Criteria	6-6
Unchanged Evaluation Criteria	6-7
Phase 2 Evaluation Criteria	6-7
Technology Comparison and Ranking	6-7
SECTION SEVEN - DESIGN RECOMMENDATIONS	
Secondary Treatment Facilities Design Capacity	7-1
Design Recommendations	7-1
Recommended next Steps	7-1

LIST OF ATTACHMENTS

ATTACHMENT A	PHASE 1 TECHNOLOGY EVALUATION AND FINAL TECHNICAL MEMORANDUM
<u>Volume Two of Two</u>	
ATTACHMENT B	BLUELEAF INCORPORATED PILOT REPORT
ATTACHMENT C	REVISED FLOW AND LOADING TECHNICAL MEMORANDUM
ATTACHMENT D	FINAL WASTEWATER CHARACTERIZATION DATA
ATTACHMENT E	2007 NPDES PERMIT
ATTACHMENT F	UPDATED EQUIPMENT/TECHNOLOGY SIZING COST PROPOSALS
ATTACHMENT G	OPINION OF COSTS
ATTACHMENT H	BLANK OPERATOR EVALUATION QUESTIONNAIRE
ATTACHMENT I	EPA JULY 31, 2012 LETTER

LIST OF FIGURES

	<u>Page</u>
Figure ES-1. Box Plot of Effluent TSS for All Processes, All Experimental Plans.....	ES-4
Figure ES-2. Box Plot of Effluent BOD for All Processes, All Experimental Plans.....	ES-5
Figure ES-3. Box Plot of Effluent TN for All Processes, Experimental Plans-05/06.....	ES-6
Figure 2-1. Pilot Process Flow Schematic.....	2-4
Figure 2-2. Pilot Floor Plan	2-5
Figure 2-3. Pilot Primary Clarifier	2-3
Figure 2-4. BAF Pilot Units	2-6
Figure 2-5. CAS with BioMag Aeration Tank.....	2-7
Figure 2-6. CAS with BioMag Clarifier.....	2-8
Figure 2-7. MBBR Aeration Tank.....	2-9
Figure 2-8. MBBR DAF.....	2-10
Figure 3-1. Sample Pilot Loading vs. Constituent Removal Graph	3-2
Figure 3-2A. BOD Loading Rate and Removal through Stage 1 BAF.....	3-7
Figure 3-2B. Ammonia Loading Rate and Removal through Stage 1 BAF	3-10
Figure 3-2C. Average Daily Effluent Ammonia Through BAF Process	3-11
Figure 3-2D. Nitrate Loading Rate and Removal through Stage 2 BAF	3-13
Figure 3-2E. Estimated Average Daily Effluent Total Nitrogen Through Stage 2 BAF	3-15
Figure 3-2F. Stage 1 BAF and Stage 2 BAF Average Daily Effluent TSS	3-16
Figure 3-3A. BOD Volumetric Loading Rate and Removal through CAS-BioMag.....	3-29
Figure 3-3B. BOD Mass Loading Rate and Removal through CAS-BioMag	3-30
Figure 3-3C. Ammonia Volumetric Loading Rate and Removal through CAS-BioMag.....	3-33
Figure 3-3D. Ammonia Mass Loading Rate and Removal through CAS-BioMag	3-34
Figure 3-3E. CAS-BioMag Average Daily Effluent Nitrogen Species.....	3-36
Figure 3-3F. Solids Loading vs. CAS-BioMag Average Daily Clarifier Effluent TSS	3-39
Figure 3-3G. Surface Overflow Loading vs. CAS-BioMag Average Daily Clarifier Effluent TSS	3-40
Figure 3-3H. CAS-BioMag Mixed Liquor Magnetite:VSS Ratio vs. SVI	3-42
Figure 3-3I. CAS-BioMag Effect of Polymer on Settling Times of Mixed Liquor.....	3-44

	<u>Page</u>
Figure 3-4A. BOD Loading Rate and Removal through MBBR BOD Reactor.....	3-54
Figure 3-4B. Ammonia Loading Rate and Removal through MBBR N1 & N2 Reactors	3-56
Figure 3-4C. Average Daily Effluent Ammonia Through MBBR-DAF Processes	3-58
Figure 3-4D. Nitrate Loading Rate and Removal through MBBR DN1 & DN2 Reactors.....	3-59
Figure 3-4E. MBBR-DAF Average Daily Effluent TSS	3-61
Figure 3-5A. Sample Box Plot.....	3-70
Figure 3-5B. Box Plot of Effluent TSS for All Processes, All Experimental Plans.....	3-72
Figure 3-5C. Box Plot of Effluent BOD for All Processes, All Experimental Plans.....	3-73
Figure 3-5D. Box Plot of Effluent TN for All Processes, Experimental Plans-05/06.....	3-74
Figure 5-1. BAF Total Nitrogen < 8 mg/l Process Flow Schematic.....	5-6
Figure 5-2. BAF Total Nitrogen < 8 mg/l Site Layout	5-7
Figure 5-3. CAS with BioMag Total Nitrogen < 8 mg/l Process Flow Schematic	5-9
Figure 5-4. CAS with BioMag Total Nitrogen < 8 mg/l Site Layout	5-10
Figure 5-5. MBBR with DAF Total Nitrogen < 8 mg/l Process Flow Schematic	5-13
Figure 5-6. MBBR with DAF Total Nitrogen < 8 mg/l Site Layout.....	5-14

LIST OF TABLES

	<u>Page</u>
Table ES-1. Projected Year 2032 Design Flows and Loads to Secondary.....	ES-7
Table ES-2. Opinion of Capital Cost Summary	ES-8
Table ES-3. Estimated Annual Operation and Maintenance Costs Summary	ES-9
Table ES-4. Estimated Life Cycle Costs Summary (\$MM)	ES-9
Table ES-5. Criteria Evaluation Matrix.....	ES-11
Table ES-6. Option Evaluation Matrix.....	ES-12
Table ES-7. Secondary Treatment Facilities Design Capacity	ES-13
Table 1-1. Consent Decree Modification Peirce Island WWTF Milestones and Dates.....	1-3
Table 3-1. BAF Experimental Plan Summary	3-4
Table 3-2. BAF Experimental Plan Data Result.....	3-5
Table 3-3. Maximum BOD Concentrations with Primary and Single Stage BAF Treatment To Meet WWTF Permit Conditions.....	3-8
Table 3-4. BAF Hydraulic Stress Test Summary	3-18
Table 3-5. CAS-Biomag Experimental Plan Summary.....	3-26
Table 3-6. CAS-BioMag Experimental Plan Data Results	3-27
Table 3-7. Maximum BOD Concentrations with Primary and CAS-BioMag Treatment To Meet WWTF Permit Conditions	3-32
Table 3-8. CAS-BioMaAg Hydraulic Stress Test Summary	3-46
Table 3-9. MBBR-DAF Experimental Plan Summary	3-50
Table 3-10. MBBR-DAF Experimental Plan Data Results	3-51
Table 3-11. Maximum BOD Concentrations with Primary and MBBR-DAF Treatment To Meet WWTF Permit Conditions	3-55
Table 3-12. MBBR-DAF Hydraulic Stress Test Summary.....	3-63
Table 3-13. Experimental Plan Summary.....	3-69
Table 3-14. Ability to meet Pilot Study Effluent Concentration Goals.....	3-68
Table 3-15. Pilot Technology Effluent TSS Concentration ANOVA Analysis.....	3-71
Table 3-16. Pilot Technology Effluent BOD Concentration ANOVA Analysis	3-71

	<u>Page</u>
Table 3-17. Pilot Technology Effluent TN Concentration ANOVA Analysis.....	3-72
Table 3-18. Vendor Constituent Loading Rate Validation Summary	3-75
Table 4-1. Sampling and Analysis Summary.....	4-1
Table 4-2. Final Average Wastewater Characterization Results	4-2
Table 4-3. Peirce Island Raw Wastewater rDON Test Data	4-3
Table 4-4. Secondary Treatment Process Design Flow Rates.....	4-5
Table 4-5. Projected Year 2032 Design Flows and Loads to Secondary.....	4-6
Table 4-6. 2007 Peirce Island WWTF NPDES Permit Limits	4-7
Table 5-1. CAS-BioMag Bioreactor and Clarifier Dimensions.....	5-5
Table 5.2. MBBR Bioreactor Dimensions.....	5-11
Table 5-3. Total Nitrogen < 8 mg/L Opinion of Capital Cost Summary	5-15
Table 5-4. Estimated Annual Operation and Maintenance Costs Summary.....	5-15
Table 5-5. Estimated Life Cycle Costs Summary (\$MM)	5-16
Table 6-1. Portsmouth WWTF Operator Pilot Evaluation.....	6-3
Table 6-2. Portsmouth WWTF Operator Pilot Evaluation by Category	6-4
Table 6-3. Criteria Evaluation Matrix.....	6-9
Table 6-4. Option Evaluation Matrix.....	6-10
Table 7-1. Secondary Treatment Facilities Design Capacity.....	7-1

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BAF	Biologically Aerated Filter
BDL	Below Detection Limit
BOD	Biochemical Oxygen Demand
C	Celsius
Cf	Cubic Foot
CaCO ₃	Calcium Carbonate
CAS	Conventional Activated Sludge
CAS-BioMag	Conventional Activated Sludge with BioMag
CASB	Conventional Activated Sludge with BioMag
CEPT	Chemically Enhanced Primary Treatment
CSO	Combine Sewer Overflow
COD	Chemical Oxygen Demand
C/N	Carbon and Nitrification Removal
CWT	Cambridge Water Technologies
DAF	Dissolved Air Floatation
DN	Denitrification
DN1	Denitrification Reactor Tank 1
DN2	Denitrification Reactor Tank 2
DO	Dissolved Oxygen
DPE	Diluted Strength, Peak Flow, Extended Duration Trial
EP	Experimental Plan
EPA	Environmental Protection Agency
F/M	Food to Microorganism Ratio
FMS	Full Strength, Mid Flow, Short Duration Trial
FOG	Fats, Oils, and Grease
FPS	Full Strength, Peak Flow, Short Duration Trial
FPM	Full Strength, Peak Flow, Medium Duration Trial
Ft	Feet
FXM	Full Strength, High-Peak Flow, Medium Duration Trial
FXE	Full Strength, High-Peak Flow, Extended Duration Trial
gpm	Gallons per Minute
gpm/sf	Gallons per Minute per Square Foot (of surface area)
gpd	Gallons per Day
g	Gram
I&C	Instrumentation and Control
IR	Internal Recycle Rate
Hr	Hour
L	Liter
Lab	Laboratory
Lb	Pound
LTCP	Long Term Control Plan
MBBR	Moving Bed Bioreactor
mg	Milligram
MG	Million Gallons
MGD	Million Gallons per Day

mg/l	Milligrams per liter (equivalent to ppm)
min	Minutes
ML	Mixed Liquor
MLE	Modified Ludzack-Ettinger
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids
MBR	Membrane Bioreactor
MOR	Monthly Operating Report
mV	Millivolt
N	Nitrogen
N1	Nitrification Reactor Tank 1
N2	Nitrification Reactor Tank 2
NA	Not Applicable
NO _x	Nitrogen Oxides
NO ₃	Nitrate
NR1	Nitrification Reactor Tank 1
NR2	Nitrification Reactor Tank 1
NH ₃	Ammonia
NHDES	New Hampshire Department of Environmental Services
µg/L	Micrograms per liter (equivalent to ppb)
N/A	Not Available / Not Applicable
ND	Not Detected
O&M	Operation and Maintenance
ORP	Oxidation Reduction Potential
PID	Proportional Integral Derivative
ppb	Parts per Billion
ppm	Parts per Million
R ²	Coefficient of Determination
RAS	Return Activated Sludge
rDOM	Recalcitrant Dissolved Organic Nitrogen
SALR	Surface Area Loading Rate
SARR	Surface Area Removal Rate
SBR	Sequencing Batch Reactor
Sf	Square Foot
SLR	Solids Loading Rate
SOR	Surface Overflow Rate
SRT	Solids Retention Time
SVI	Sludge Volume Index
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
PO ₄ -P	Phosphate
TSS	Total Suspended Solids
µM	Micrometer
VSS	Volatile Suspended Solids
WAS	Waste Activated Sludge
WWMP	Wastewater Master Plan
WWTF	Wastewater Treatment Facility

ACKNOWLEDGMENTS

We would like to acknowledge the invaluable assistance and cooperation of the staff of the Portsmouth Department of Public Works and the Peirce Island WWTF. In particular, we extend our thanks to Mr. David Allen, Assistant City Manager; Mr. Peter Rice, Deputy Director of Public Works; Mr. Terry Desmarais, City Engineer; Ms. Paula Anania, WWTF Chief Plant Operator; Mr. Michael Baker, WWTF Assistant Chief Plant Operator; Mr. David Lovely, Assistant Chief Plant Operator; and Ms. Roxanna Chomas, Plant Operator.

This Technical Memorandum was prepared by Mr. Matthew Formica, Project Manager, and Mr. Jon Pearson Project Manager and Vice President, under the direction of Donald Chelton, Vice President. Technical review and guidance was Provided by Mr. Mark Laquidara, Vice President.

The Cover Photos are used under Creative Commons Public License from Doug Kerr; and the project consulting team.

EXECUTIVE SUMMARY

The City of Portsmouth has been issued a Consent Decree by the US Environmental Protection Agency (EPA) to upgrade the existing Peirce Island Wastewater Treatment Facility (WWTF) to provide secondary treatment. In response to the requirements of the Consent Decree, the City has completed this Phase 2 Initial Piloting Technical Memorandum which includes data from piloting and a recommendation on the design and capacity of secondary treatment facilities. This data and the recommendations are presented in seven sections comprising the Initial Piloting Technical Memorandum and each section is described in more detail below.

SECTION 1 - INTRODUCTION AND PURPOSE

This section presents background information related to the Phase 2 Initial Piloting Technical Memorandum.

Introduction

This section describes the prior planning efforts conducted by the City to address the initial Consent Decree requirements and subsequent modifications to the Consent Decree including the following:

- The Draft WWMP/LTCP Update which recommended a preferred alternative of phased expansion of the Pease WWTF for treatment of sanitary (dry weather) wastewater, and conversion of the Peirce Island WWTF to a CSO treatment facility for wet weather flows.
- Following submittal of the Draft WWMP/LTCP the EPA indicated that the proposed schedule for implementation of the preferred alternative recommended in the Draft WWMP/LTCP Update was unacceptable. EPA encouraged the City to pursue a revised compliance strategy that focused on achieving secondary treatment of the Peirce Island sanitary flows as expeditiously as possible.
- The City promptly pursued a revised compliance strategy which was focused on upgrading the existing WWTF to secondary treatment using high rate, small footprint treatment technologies. The Final Wastewater Master Plan Submission (November 2010) identified a number of potential high rate secondary treatment technologies that could be implemented, identified the preliminary hydraulic sizing basis, and provided concept level estimated capital costs for construction of the identified treatment technologies. The Final Wastewater Master Plan Submission recommended that the technologies be piloted to determine the most applicable technology for use in upgrading the Peirce Island WWTF in the revised compliance strategy.
- The City conducted a Phase 1 Engineering Evaluation of potential high rate secondary treatment technologies to select the technologies to be piloted. As part of this evaluation existing flow and loading data for the Peirce Island WWTF were reviewed to identify projected dry weather flows and loadings for the proposed secondary treatment processes. The projected flows and loadings were used in developing conceptual planning level unit process sizes and estimated capital, operating, and maintenance costs for eight technologies. These technologies were evaluated on both a monetary and non monetary basis. Based on this evaluation the following technologies were selected for piloting:
 - o Biological Aerated Filter (BAF)
 - o Conventional Activated Sludge with BioMag (CAS-BioMg)
 - o Moving Bed Bioreactor (MBBR) & DAF

Purpose

The focus of the Phase 2 Initial Piloting was to evaluate the ability of the three technologies to meet the secondary treatment effluent limits. With the recent indications from EPA that nitrogen removal will now be required as part of the upgrade of the Peirce Island WWTF, an additional focus of the pilot evaluation was to evaluate the ability of the three processes to meet effluent nitrogen levels of 8 mg/l and 3 mg/l. Other goals of the piloting effort included:

1. Complete a wastewater characterization program to define the loadings that the upgraded WWTF will be required to treat.
2. Establish the design flows for the upgraded WWTF.
3. Confirm Manufacturer/Vendor sizing criteria and space requirements to provide secondary treatment/nitrogen removal using each technology.
4. Define technology performance under varying flow conditions.
5. Identify operational and maintenance factors specific to each technology.

The results of the piloting effort have been used to prepare an updated evaluation and comparison of the three technologies to allow the City to select the technology for upgrading the Peirce Island WWTF.

Consent Decree Requirements

The Consent Decree between the City and EPA was executed in August 2009 and contained milestones and dates for the completion of the Draft and Final WWMP/LTCP Updates. During the course of the piloting evaluation, EPA and the City negotiated a modification to the Consent Decree which contains further milestones and dates for the upgrade of the Peirce Island WWTF to secondary treatment. This report has been prepared for submittal to the EPA to fulfill the October 1, 2012 Consent Decree milestone which states "The City shall submit a Piloting Technical Memorandum that includes data from piloting and a recommendation on the design and capacity of secondary treatment facilities".

SECTION 2 – PILOT PROCESS, EQUIPMENT, AND APPROACH

This section provides an overview of the three technologies and the piloting equipment and approach. A brief overview of the three technologies that were piloted is presented in this section followed by a description of the three piloted technologies. This section describes the layouts and components of the three piloted technologies as well as the common piloting systems utilized by the technologies. This section also describes the piloting approach of evaluating the three technologies including configuring and testing of the technologies for secondary treatment as well as nitrogen removal and the implementation of different influent flows and loading to assess the technologies.

SECTION 3 – PILOT DATA ANALYSIS

This section presents the analysis of the pilot data collected for three technologies. Items that are addressed for each technology include:

1. Summary of the Pilot Testing Experimental Plan
2. Summary of Experimental Plan Data
3. Summary of Technology's Ability to Meet Permit Goals
4. Vendor Provided Loading Rate Validation
5. Hydraulic Stress Tests Performance
6. Pilot Observations and Considerations for Full Scale Implementation

For each technology the items above are presented separately. At the end of the section the pilot data collected for the technologies are compared to each other. The general findings of the comparisons are as follows:

Ability to Meet Study Effluent Goals

All three technologies were deemed capable of achieving the effluent goals of the pilot study for secondary treatment (30 mg/l Biochemical oxygen demand (BOD) and 30 mg/l total suspended solids (TSS)) as well as for the effluent total nitrogen goal of 8 mg/l. All three technologies were able to intermittently, but not consistently, achieve the effluent total nitrogen goal of 3 mg/l.

Effluent Performance Comparison

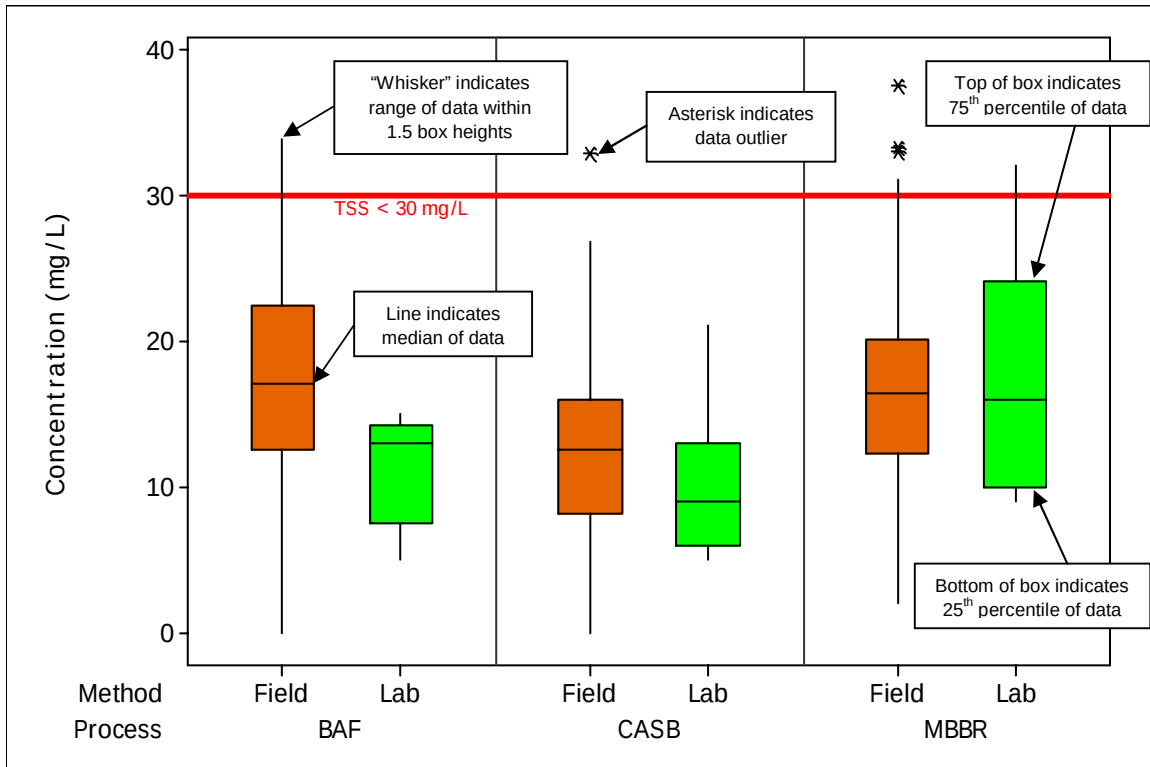
A statistical comparison was conducted on the effluent concentration for TSS, BOD and Total Nitrogen for the three technologies based on the laboratory data collected. This statistical analysis was conducted to identify if one or more technologies produced a better or worse effluent quality than the others. The results for the constituents were as follows:

TSS. The effluent TSS from the MBBR-DAF process was statistically different and greater than the effluent TSS from either the CASB (CAS-BioMag) or the BAF while the CAS-BioMag and BAF effluent TSS concentrations were not statistically different. Both the laboratory and field generated TSS data from the pilot testing are shown in a Box Plot form in Figure ES-1. The average effluent TSS concentration of the BAF differed from the average effluent TSS concentration of the CAS-BioMag system by only 2.7 mg/L, which is less than the standard deviation of TSS of either of the two processes. Note that the variability of effluent TSS from the MBBR-DAF is much higher than the other two processes.

BOD. The results showed that there was not a statistically significant difference in the laboratory effluent BOD concentrations between technologies. The BAF process had higher median effluent BOD than the other two processes, but the statistical test could not detect a difference because there were only three lab samples collected for BOD. Both the laboratory and field generated BOD data from the pilot testing are shown in a Box Plot form in Figure ES-2. Similar to the results for the effluent TSS, the effluent BOD from the MBBR process had a high amount of variability relative to the other processes.

Total Nitrogen. In this analysis there are five processes being compared, with CASB4 representing the four-stage conventional activated sludge process (for CAS-BioMag), and MBBR5 representing the 5-stage MBBR process (MBBR-DAF), both used for TN removal below 3 mg/L. There was only one configuration of the BAF process tested. The data is from the experimental plans conducted with high influent ammonia loading. The results showed that there was not a statistically significant difference between effluent TN concentrations for the five processes evaluated. The four-stage CASB process had the lowest effluent average TN of 3.1 mg/L, while the “normal” 2-stage MLE CASB had the highest effluent TN concentration of 5.8 mg/L. Figure ES-3 shows the box plot for both the field and laboratory analyses of TN for all processes. Both the laboratory and field generated TN data from the pilot testing are shown in a Box Plot form in Figure ES-3.

Figure ES-1. Box Plot of Effluent TSS for All Processes, All Experimental Plans

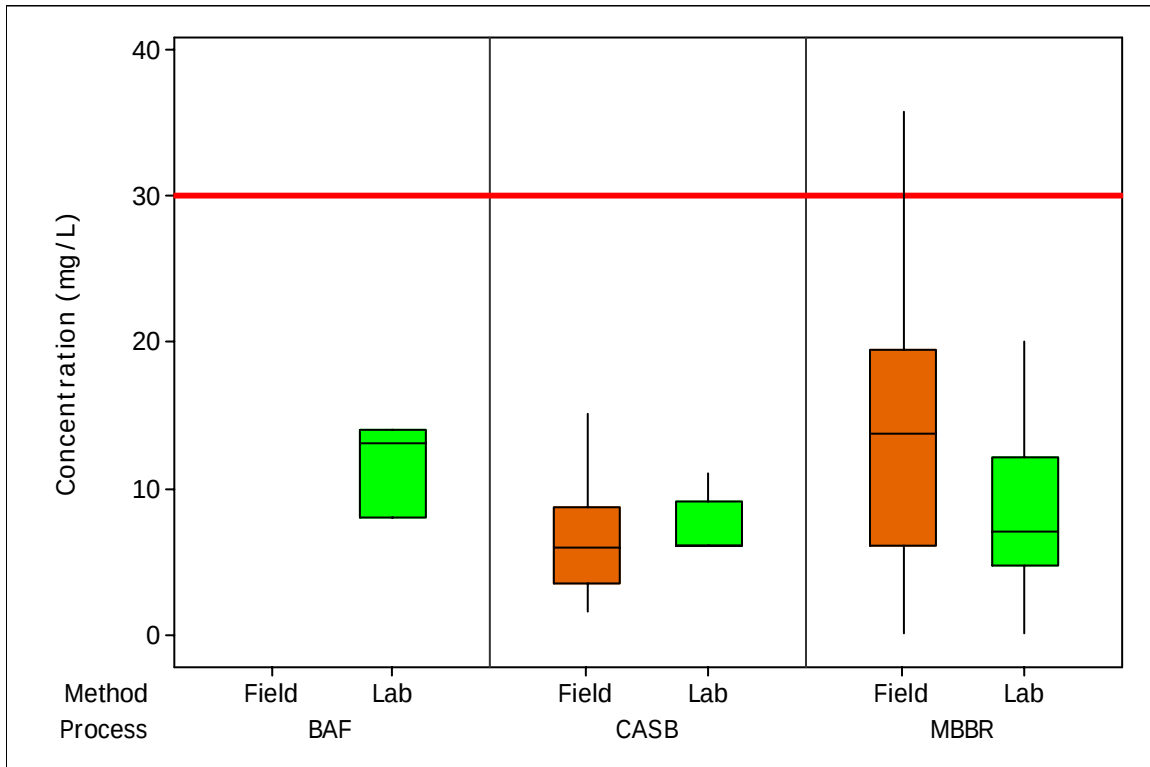


Vendor Constituent Loading Rate Validation and Potential to Reduce Technology Size

As part of the piloting effort, the technology vendors provided design loading rates for the various elements of their processes (BOD, nitrification, and denitrification). The data collected during the experimental plans were evaluated to validate vendor provided loading rates and confirm if their proposed process/equipment sizing were adequate for meeting the treatment goals of the Peirce Island WWTF. The vendor loading rates and collected data were also examined to assess if there was the potential for optimizing the process (i.e. potential to reduce the process equipment size) in a full scale installation. The results are as follows:

- All design loading rates and process equipment sizes provided by the vendor were validated.
- All technologies had the potential to increase their loading rates for BOD removal. However the ability to provide this modification is dependent upon if dedicated carbon removal or combined carbon removal/nitrification zones/stages are used.
- Only the MBBR-DAF showed the potential to increase their nitrification loading rate.
- Only the MBBR-DAF showed the potential to increase their denitrification loading rate.

**Figure ES-2. Box Plot of Effluent BOD
for All Processes, All Experimental Plans**

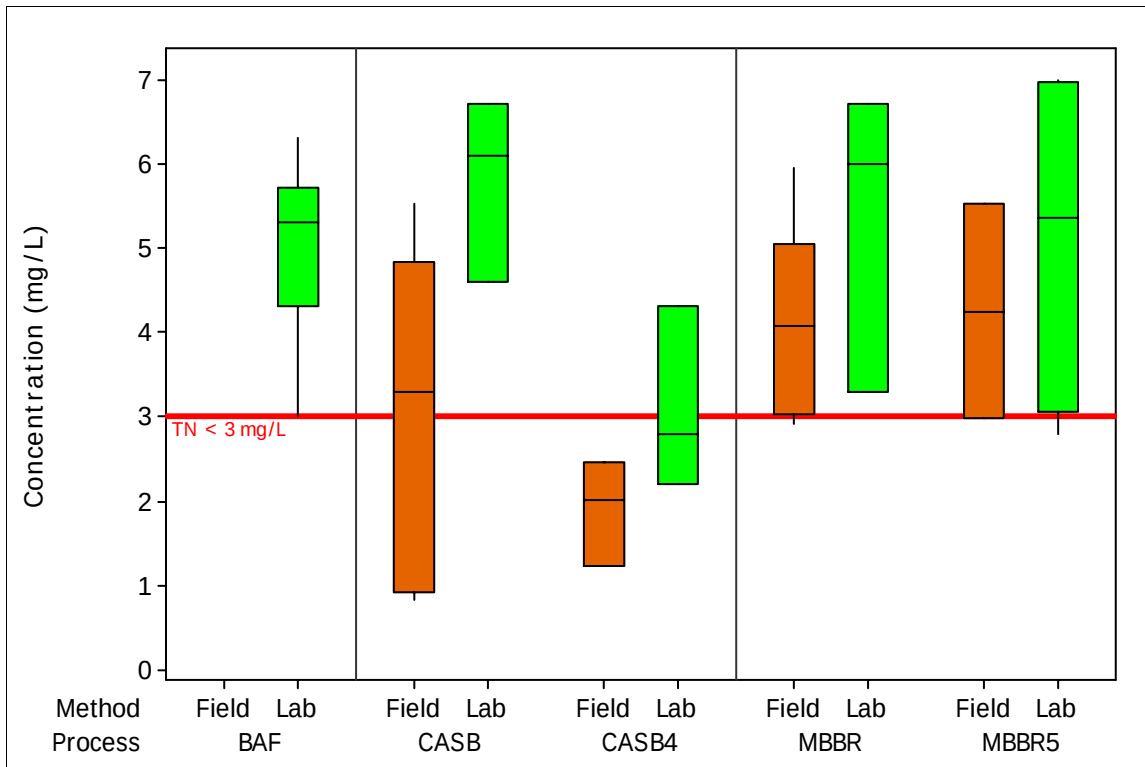


Hydraulic Stress Test Summary

As part of the piloting effort, each technology was run under different hydraulic stress conditions to assess its ability to perform and recover from the stress condition as well as determine if there was any biomass washout. This was done to simulate the effects of wet weather flows in the combined sewer system. None of the processes were observed to lose biomass as a result of the increased flow rates. It should also be noted that the only process changes that were made to both the BAF and MBBR-DAF systems during the tests was the increase in the influent flow. However, process changes to the CAS-BioMag system were made (DO increase and RAS flow rate increase) during its stress tests.

Both the BAF and MBBR-DAF effluents exceeded total nitrogen limit of 8 mg/l during a portion of the high stress conditions (as the result of dissolved oxygen suppression and incomplete nitrification) , but generally recovered within four to six hours after the flow condition was returned to pre-stress conditions. None of the hydraulic stress tests caused the CAS-BioMag process effluent to exceed total nitrogen limit of 8 mg/L. However again it should be noted that process adjustments were made to the BioMag system during the stress tests that were not made to the other technologies.

**Figure ES3. Box Plot of Effluent TN
for All Processes, Experimental Plans-05/06**



SECTION 4 – WASTEWATER DATA AND REVISED FULL SCALE DESIGN CRITERIA

This section presents updated data on wastewater characteristics and revised information regarding the sizing and design criteria for the proposed upgrade of the Peirce Island WWTF.

Wastewater Characterization Program

A wastewater characterization program was conducted to provide data on the different constituents within Portsmouth's wastewater. The program included sampling and analysis of both the Peirce Island WWTF influent wastewater and the CEPT effluent and was performed over an extended period of time to quantify seasonal changes in wastewater characteristics. Section 4 presents the data collected which shows the WWTF influent is characteristic of a medium strength wastewater with a high degree of variability.

Revised Flows and Loads

As part of the first phase of the Wastewater Master Plan Piloting work, an analysis of data on influent wastewater flows and loads was conducted. Since that submittal was prepared, several conditions warrant revision of the projected flows and loadings. The conditions included the following:

- EPA's indication that the projected flows for the Peirce Island WWTF upgrade were not acceptable.
- During the course of the piloting effort it was noted that the influent wastewater strength

was higher than originally projected.

- The City is now planning to upgrade the Peirce Island WWTF to provide secondary treatment with the ability to achieve total nitrogen removal to a level of 8 mg/l (the previous projected loadings did not include nitrogen).
- Previous projections did not contain any allowance for future wastewater flow and load increases due to growth.

The projected flows and loads have been revised to address these changed conditions. Table ES-1 presents a summary of the revised projected future condition flows and loads. In addition to the average daily and maximum monthly flows noted in Table ES-2, the secondary process would be sized to treat a maximum daily flow of 9.06 mgd. The instantaneous hydraulic maximum flow through secondary will be established during preliminary design. Wet weather flows in excess of the secondary treatment system capacity would be treated through chemically enhanced primary treatment and disinfection.

Table ES-1. Projected Year 2032 Design Flows and Loads to Secondary

Parameter	Annual Average Day	Max Month
Flow (mgd)	6.13	8.86
Influent TSS (mg/L)	199	187
Influent TSS (lb/d)	10,176	13,853
Influent BOD ₅ (mg/L)	195	161
Influent BOD ₅ (lb/d)	9,959	11,881
Influent TKN (mg/L)	29.5	27.6
Influent TKN (lb/d)	1,511	2,039
Primary Effluent TSS (mg/L)	99 - 147	94 - 138
Primary Effluent TSS (lb/d)	5,088 - 7,510	6,927 - 10,224
Primary Effluent BOD ₅ (mg/L)	136 - 165	113 - 136
Primary Effluent BOD ₅ (lb/d)	6,971 - 8,435	8,317 - 10,063
Primary Effluent TKN (mg/l)	26.9 - 28.6	25.1 - 26.8
Primary Effluent TKN (lb/d)*	1,375 - 1,465	1,856 - 1,978
CEPT Effluent TSS (mg/L)	51	48
CEPT Effluent TSS (lb/d)	2,618	3,564
CEPT Effluent BOD ₅ (mg/L)	121	100
CEPT Effluent BOD ₅ (lb/d)	6,166	7,356
CEPT Effluent TKN (mg/L)	24.2	22.6
CEPT Effluent TKN (lb/d)	1,239	1,672

Primary effluent loads and concentrations are presented as ranges based on constituent percent removals observed from the WWTF characterization data, observed pilot data, text book values, and CEPT removal.

The revised flow and loading projections have been used as the basis for the updated sizing of each technology as described in Section 5.

SECTION 5 – SECONDARY PROCESS RESIZING AND COMPARISON

This section presents updated process sizing, layouts, and estimated costs for each of the three piloted technologies. Each process has been sized for the revised flows and loads presented in Section 4 and configured to achieve secondary treatment with the ability to meet an effluent total nitrogen concentration of 8 mg/l.

Approach

In addition to pilot performance data, tank sizing, process requirements/limitations, capital costs, and operation and maintenance costs were developed for each technology. After completion of the pilot testing, revised full-scale proposals were requested from the technology vendors. The vendors were requested to provide a process design to meet secondary treatment with the ability to meet effluent total nitrogen of 8 mg/l. Using the information provided by the vendors, AECOM advanced the concept for each technology to a conceptual level design and were used as the basis of developing the capital and operation and maintenance cost estimates for the evaluation.

Capital Cost Comparison

Conceptual opinions of cost for the implementation of the three technologies to achieve secondary treatment with the ability to meet a total nitrogen limit of 8 mg/L were developed. The estimates combine components of the Wastewater Master Plan opinions of cost and new opinions of cost developed for the three technologies for secondary treatment.

The Wastewater Master Plan recommended a number of upgrades at the Peirce Island WWTF that would need to be implemented if the facility were upgraded to achieve secondary treatment with the ability to meet a total nitrogen limit of 8 mg/L using one of the three technologies considered. Accordingly, the Wastewater Master Plan opinion of cost for Headworks, Sanitary Disinfection, Biosolids Processing, and parts of Additional Structures and Modifications from "Compliance Strategy Cost Estimate Biomag Secondary Treatment" were added to the piloted technologies opinions of cost developed in this technical memorandum. It is recommended that costs taken from the Wastewater Master Plan be reevaluated to determine their suitability for the purposes of presenting a total upgrade cost.

The total estimated capital costs are conceptual planning level costs and have been developed based on a number of assumptions and may not represent the final project capital costs for the facilities once designed. The final costs could be higher or lower depending on what decisions are made during the design phase, how the final facilities are constructed, and when the final facilities are constructed. The preliminary opinions of capital cost for the three technologies presented in 2016 costs (based on the scheduled midpoint of construction) and are presented in Table ES-2.

Table ES-2. Opinion of Capital Cost Summary

Technology	Estimated Cost (\$MM)
Biological Aerated Filter (BAF)	\$60.5
Conventional Activated Sludge (CAS) with BioMag	\$54.0
Moving Bed Bioreactor (MBBR) & DAF	\$56.5

Operations and Maintenance Cost Comparison

Conceptual level estimated annual operation and maintenance costs for each candidate technology were developed. These estimates reflect only the operation and maintenance costs to support the proposed technology and are not inclusive of other processes at the Peirce Island WWTF. The estimates consist of annual costs for electricity, chemicals, labor and equipment replacement as shown in Table ES-3.

Table ES-3. Estimated Annual Operation and Maintenance Costs Summary

Item	BAF	CAS w/ BioMag	MBBR & DAF
Electricity	\$390,000	\$802,000	\$540,000
Labor & Maintenance	\$307,000	\$354,000	\$291,000
Chemicals	\$219,000	\$105,000	\$383,000
Parts & Replacement	\$192,000	\$207,000	\$176,000
Total	\$1,108,000	\$1,468,000	\$1,390,000

Life Cycle Cost Comparison

20 year life cycle costs for each technology were evaluated. The present worth value of the operation and maintenance costs was developed using a period of 20 years and a present worth annual interest rate of 4.375 percent based on the United States Department of Agriculture's Natural Resources Conservation Service's discount rate for federal water projects. Table ES-4 summarizes the calculated life cycle costs.

Table ES-4. Estimated Life Cycle Costs Summary (\$MM)

Cost Item	BAF	CAS w/ BioMag	MBBR & DAF
Capital	\$60.50	\$54.00	\$56.50
20 Year Present Worth O&M	\$14.60	\$19.30	\$18.30
20 Year Life Cycle	\$75.10	\$73.30	\$74.80

With the limited definition of project elements and the number of unknown variables at this level of conceptual development, all three technologies can be considered essentially equal on a capital and life cycle cost basis.

SECTION 6 – NON-MONETARY EVALUATION FACTORS UPDATE

In the Phase 1 Evaluation, in addition to evaluating the capital and O&M costs for potential treatment technologies, a Criteria Evaluation Matrix was developed as a tool to quantify the subjective non-monetary aspects of the technologies. The evaluation criteria and the matrix have been updated. These updates were based on information and insight gained during the piloting effort of the three technologies. Some of the criteria used in the updated matrix were obtained from input from the WWTF operations staff through a questionnaire as well as day-to-day interaction, while others were developed by the project team and the City based on considerations resulting from the change in effluent treatment goals from secondary to total nitrogen removal to 8 mg/l.

The evaluation criteria used were as follows:

1. Operations Factors
2. Maintenance Factors
3. Health and Safety Factors
4. Operational Track Record/Established Process
5. Ability to Retrofit TN of 8 mg/l to Future TN of 3 mg/l
6. Response to Sustained Wet Weather Flows
7. Response to Process Disruption
8. Potential for Technology Optimization
9. Ability to Exceed Treatment Performance Goals

Technology Comparison and Ranking

For the criteria evaluation, a two step process was used to compare and rank the technologies. In the first step, the paired comparison technique was used to weigh the revised evaluation criteria. The weighted evaluation criteria are shown in Table ES-5.

In the second steps these criteria were placed in the Option Evaluation Matrix, shown in Table ES-6, where the three technologies are listed. In this table each technology was assessed to on how well the technology met each criterion. The points assigned to each technology for each criterion were then multiplied by the weighting factor, and the results summed to identify the non-monetary value points for each technology. The estimated capital cost and life cycle cost of each technology were added to the matrix and scores were divided by the costs (in millions) to obtain value ratios.

As indicated, the BAF had the highest life cycle cost value ratio of the three piloted processess and was tied having the highest capital cost value ratio.

SECTION 7 – PILOT TECHNICAL MEMORANDUM RECOMMENDATIONS

This section presents recommendations regarding the secondary treatment facilities upgrade of the Peirce Island WWTF resulting from the Phase 2 Initial Piloting program. The recommendations address the design and capacity of the secondary treatment facilities upgrade.

Secondary Treatment Facilities Design Capacity

Table ES-7 presents the recommended design flows and loads to secondary based on the use of conventional primary treatment. In addition to an average daily flow of 6.13 mgd, and a maximum month flow of 8.86 mgd, the secondary treatment facility will be designed to treat a maximum day flow of 9.06 mgd. The instantaneous maximum hydraulic capacity will be established during preliminary design. Wet weather flows in excess of 9.06 mgd will receive chemically enhanced primary treatment and disinfection.

Design Recommendations

The Phase 2 Piloting Evaluation was completed to identify the proposed size and design of facilities required to meet secondary treatment limits with the ability to meet a TN of 8 mg/l; to estimate the costs for those facilities; to compare the technologies to provide nitrogen removal to a TN of 8 mg/l based on cost and non-monetary factors; and to identify a recommended approach. It is recommended that the City proceed with the design and construction of a secondary treatment facility with the ability to meet a TN of 8 mg/l. As part of the design effort, consideration should be given to what further modifications to the recommended facilities would be necessary to meet a lower effluent TN limit should one be imposed.

Table ES-5. Criteria Evaluation Matrix

	B	C	D	E	F	G	H	I	Evaluation Criteria	Score	Weighting Factor
A	A 1	C 3	D 2	A 1	F 2	G 2	A 3	A 1	Operations Factors	6	10
	B	C 3	D 2	E 1	F 2	G 2	B 2	I 1	Maintenance Factors	2	3
		C	C 1	C 2	C 2	C 2	C 2	C 2	Health & Safety Factors	17	27
			D	D 2	D 1	D 1	D 2	D 2	Operational Track Record/Established Process	12	19
				E	F 2	G 2	E 1	I 1	Ability to Retrofit TN of 8 mg/l to Meet TN of 3 mg/l	2	3
					F	G 1	F 1	F 1	Response to Sustained Wet Weather Flows	8	13
						G	G 2	G 2	Response to Process Disruption	11	18
							H	I 2	Potential for Technology Optimization	0	0
								I	Ability to Exceed Treatment Performance Goals	4	6
										Total	100

Key

Evaluation criteria are used to compare the alternatives

Score is the total number of points accumulated for each criterion

Weighting Factor is the relative values of each criterion

Ranking

1 – Slightly more important than the other criterion it is being compared with

2 – Somewhere between extremes of importance

3 – Much more important than the other criterion it is being compared with

Table ES-6. Option Evaluation Matrix

Evaluation Criteria	Weight	BAF		CAS-BioMag		MBBR-DAF	
		Rating	Score	Rating	Score	Rating	Score
Operations Factors	10	3.0	30	2.1	21	3.2	32
Maintenance Factors	3	3.2	9.6	1.6	4.8	3.5	10.5
Health & Safety Factors	27	3.2	86.4	2.0	54	3.3	89.1
Operational Track Record/Established Process	19	4.0	76	2.0	38	3.0	57
Ability to Retrofit TN of 8 mg/l to Meet Future TN of 3 mg/l	3	5.0	15	2.5	7.5	3.0	9
Response to Sustained Wet Weather Flows	13	3.5	45.5	4.0	52	3.5	45.5
Response to Process Disruption	18	4.0	72	3.0	54	4.0	72
Potential for Technology Optimization	0	2.5		2.5		4.0	
Ability to Exceed Treatment Performance Goals	6	3.0	18	4.0	24	3.0	18
Total Weighted Criteria		353		255		333	
Capital Cost (estimated - in millions)		\$60.5		\$54.0		\$56.5	
Value Ratio (criteria/capital cost)		5.8		4.7		5.9	
Life Cycle Cost (in millions)		\$75.1		\$73.3		\$74.8	
Value Ratio (criteria/ life cycle cost)		4.7		3.5		4.5	

Rating 1-5. 5 is the most advantageous. 1 is the least advantageous.

Table ES-7. Secondary Treatment Facilities Design Capacity

Parameter	Annual Average Day	Max Month
Flow (mgd)	6.13	8.86
Influent TSS (mg/L)	199	187
Influent TSS (lb/d)	10,176	13,853
Influent BOD ₅ (mg/L)	195	161
Influent BOD ₅ (lb/d)	9,959	11,881
Influent TKN (mg/L)	29.5	27.6
Influent TKN (lb/d)	1,511	2,039
Primary Effluent TSS (mg/L)	99 - 147	94 - 138
Primary Effluent TSS (lb/d)	5,088 – 7,510	6,927 – 10,224
Primary Effluent BOD ₅ (mg/L)	136 - 165	113 - 136
Primary Effluent BOD ₅ (lb/d)	6,971 – 8,4357	8,317 – 10,063
Primary Effluent TKN (mg/l)	26.9 - 28.6	25.1 - 26.8
Primary Effluent TKN (lb/d)	1,375 – 1,465	1,856 – 1,978

Primary effluent loads and concentrations are presented as ranges based on constituent percent removals observed from the WWTF characterization data, observed pilot data, text book values, and CEPT removal.

Based on the data and evaluation presented in the report, the BAF technology was judged to provide the City with the highest value. Accordingly, this technology is the recommended technology for upgrading the Peirce Island WWTF to secondary treatment. This recommendation is based on the following

1. Secondary treatment facilities sized to treat the flow and loads presented in Section 4 and Attachment C.
2. Secondary treatment effluent limits apply to the effluent from the secondary treatment process prior to combining the secondary effluent with wet weather flows for discharge.
3. The ability to achieve an effluent total nitrogen of 8 mg/l through the secondary treatment facilities based on a seasonal rolling average for April through October.
4. Achieving 85 percent removal of BOD and TSS through the secondary treatment facilities is only required during dry weather days as defined in Attachment C.

Once an NPDES permit is issued which defines the requirements that the upgraded facility will be required to meet, the recommendation for a secondary treatment facility using the BAF technology can be reviewed and revised as needed.

SECTION 1- INTRODUCTION AND PURPOSE

1.0 BACKGROUND

The City of Portsmouth has been issued a Consent Decree by the US Environmental Protection Agency (EPA) to upgrade the existing Peirce Island Wastewater Treatment Facility (WWTF) to provide secondary treatment. In response to the requirements of the Consent Decree, the City completed a Draft Wastewater Master Plan and Long Term Control Plan Update (WWMP/LTCP Update). The Draft WWMP/LTCP Update was developed to address the requirements of the Consent Decree while also taking into consideration the long term needs of the City's wastewater collection and treatment system. The Draft WWMP/LTCP Update recommended a preferred alternative of phased expansion of the Pease WWTF for treatment of sanitary (dry weather) wastewater, and conversion of the Peirce Island WWTF to a CSO treatment facility.

Following submittal of the Draft WWMP/LTCP to EPA and the New Hampshire Department of Environmental Services (NHDES) in June 2010, EPA indicated that the proposed schedule for implementation of the preferred alternative recommended in the Draft WWMP/LTCP Update was unacceptable. The schedule for the preferred alternative was deemed unacceptable as secondary treatment of the current sanitary discharges from the Peirce Island WWTF would not be achieved until the year 2028. EPA encouraged the City to pursue a revised compliance strategy that focused on achieving secondary treatment of the Peirce Island sanitary flows as expeditiously as possible.

The City promptly pursued a revised compliance strategy that was presented in the Final Wastewater Master Plan Submission in November, 2010. The revised strategy was focused on upgrading the existing WWTF to secondary treatment by staying within the fence line. This was planned to be accomplished by reusing the existing Filter Building at the Peirce Island WWTF to achieve secondary treatment in accordance with the National Pollutant Discharge Elimination System (NPDES) permit issued in 2007. The revised compliance strategy was based on using high rate, small footprint treatment technologies to provide secondary treatment. The Final Wastewater Master Plan Submission identified a number of potential high rate secondary treatment technologies that could be implemented, identified the preliminary hydraulic sizing basis, and provided concept level estimated capital costs for construction of the identified treatment technologies. Recognizing that these high rate technologies are considered emerging technologies as there are limited full scale installations, the Final Wastewater Master Plan Submission recommended that the technologies be piloted to determine the most applicable technology for use in upgrading the Peirce Island WWTF in the revised compliance strategy. It was also recommended that due to a lack of data on existing wastewater characteristics, a wastewater characterization program be completed during the piloting effort. The piloting program was then undertaken in phases.

1.0.1 WWMP Piloting – Phase 1 Evaluation

In the Phase 1 Engineering Evaluation, potential high rate technologies were identified, developed, and compared to select the most promising technologies for piloting in Phase 2, the Initial Piloting Phase. As part of the Phase 1 Engineering Evaluation, existing flow and loading data for the Peirce Island WWTF were reviewed to identify projected dry weather flows and loadings for the proposed secondary treatment processes. The projected flows and loadings were used in developing conceptual planning level unit process sizes and estimated capital, operating, and maintenance costs for each technology for comparison.

The eight technologies considered included:

1. Biological Aerated Filter (BAF)

2. Sequencing Batch Reactor (SBR) with BioMag
3. Conventional Activated Sludge (CAS) with BioMag
4. Moving Bed Bioreactor (MBBR) & ActiFlo
5. Moving Bed Bioreactor (MBBR) & CoMag
6. Moving Bed Bioreactor (MBBR) & DAF
7. Membrane Bioreactor (MBR)
8. Conventional Activated Sludge (CAS)

Each technology was evaluated to review its ability to achieve different treatment levels including conventional secondary treatment (monthly average BOD₅ and TSS of less than 30 mg/L) and nitrogen removal to monthly average concentrations of 8, 5 and 3 mg/L. The approximate site layout and process configurations for each technology for each treatment level were determined. Concept level opinions of probable construction costs, operation and maintenance costs and life cycle costs were developed for the secondary treatment level. Each technology was objectively compared to one another using a weighted evaluation matrix to rank the technologies. This information was initially submitted to the City as a preliminary draft Technical Memorandum. The draft memorandum was followed by a workshop with City staff to review the results of the evaluation, obtain input on the evaluation criteria and ranking, and select the technologies for piloting in Phase 2. The project team collectively reviewed the non-monetary factors and weighting basis and finalized the ranking of the technologies to identify the technologies to be piloted as part of Phase 2 of this project. Based on this review, it was agreed that piloting would be conducted for BAF (Option 1), CAS with BioMag (Option 3), and MBBR and DAF (Option 6) in the Phase 2 Initial Piloting effort. The results of this evaluation were summarized in the Task 1.7 Technology Evaluation Final Technical Memorandum dated September 26, 2011, hereinafter referred to as the Phase 1 Evaluation. This Phase 1 Evaluation is included as Attachment A.

1.1 PURPOSE

The primary focus of the Phase 2 Initial Piloting was to evaluate the ability of the three technologies to meet the secondary treatment effluent limits as defined in the NPDES permit issued to the City by EPA in 2007. With the recent indications from EPA that nitrogen removal will now be required as part of the upgrade of the Peirce Island WWTF, an additional focus of the pilot evaluation was to evaluate the ability of the three processes to meet effluent nitrogen levels of 8 mg/l and 3 mg/l. Other goals of the piloting effort included:

1. Complete a wastewater characterization program to define the loadings that the upgraded WWTF will be required to treat.
2. Establish the design flows for the upgraded WWTF.
3. Confirm Manufacturer/Vendor sizing criteria and space requirements to provide secondary treatment/nitrogen removal using each technology.
4. Define technology performance under varying flow conditions.
5. Identify operational and maintenance factors specific to each technology.

The results of the piloting effort are presented in this report and have been used to prepare an updated evaluation and comparison of the three technologies to allow the City to select the technology for upgrading the Peirce Island WWTF.

This report is a working document prepared to meet the requirements of the Consent Decree. It has not yet been fully reviewed by the City and is subject to revisions and modifications as the review process proceeds. Since a revised NPDES permit for the Peirce Island WWTF has not yet been issued, the City is continuing to consider options regarding the upgrade of the WWTF which may further modify the findings of this report.

1.2 CONSENT DECREE REQUIREMENTS

The Consent Decree between the City and EPA was executed in August 2009 and contained milestones and dates for the completion of the Draft and Final WWMP/LTCP Updates. The City has met the required milestone dates contained in the original Consent Decree. During the course of the piloting evaluation, EPA and the City negotiated a modification to the Consent Decree which contains further milestones and dates for implementation of both the CSO Long Term Control Plan projects and the upgrade of the Peirce Island WWTF to secondary treatment. The Consent Decree modification has not yet been executed, but the relevant milestones and dates for the Peirce Island WWTF upgrade are presented in Table 1-1.

Table 1-1. Consent Decree Modification Peirce Island WWTF Milestones and Dates

Milestone Action	Date
The City shall complete pilot testing of potential treatment technologies for achieving secondary treatment, including, but not necessarily limited to: Biologically Aerated Filters (BAF), BioMag, Moving Bed Biofilm Reactors (MBBR) w/ Dissolved Air Flotation (DAF), and Conventional Activated Sludge with BioMag.	June 30, 2012
The City shall complete a data summary relative to the pilot testing.	July 30, 2012
The City shall submit a Piloting Technical Memorandum that includes data from piloting and a recommendation on the design and capacity of secondary treatment facilities	October 1, 2012
The City shall commence final design of secondary treatment facilities.	July 1, 2013
The City shall complete design of secondary treatment facilities.	August 31, 2014
The City shall commence construction of secondary treatment facilities.	March 1, 2015
The City shall complete construction of secondary treatment facilities.	March 1, 2017
The City shall achieve compliance with secondary treatment limits in the Permit.	May 1, 2017

This report has been prepared for submittal to the EPA to fulfill the October 1, 2012 Consent Decree milestone.

SECTION 2 – PILOT PROCESSES, EQUIPMENT, AND APPROACH

2.0 INTRODUCTION

This section provides an overview of the three technologies and the piloting equipment and approach. A more detailed description of the pilot treatment units and the piloting process is provided in Section 2 of the Blueleaf Pilot Report which is included in Attachment B.

2.1 OVERVIEW OF PILOTED TECHNOLOGIES

A brief overview of the three technologies that were piloted is presented in this section.

2.1.1 BAF

Upflow biological filters are attached growth processes, which act in a similar manner to packed filter beds. In these systems the media provides a surface for the biological organisms to attach which provide treatment. The wastewater flows upward through the media. The media is retained in the filter while the treated effluent is discharged. The upward flow passing through the packed media provides a level of solids removal, eliminating the need for separate clarifiers. Periodically a filter cell is removed from service and backwashed to remove accumulated excess biomass solids. For BOD removal and nitrification, air is added at the bottom of the media to keep the process aerobic, and for denitrification air is not added, but a supplemental carbon source is required.

Multiple filter cells are typically provided in order to provide redundancy as well as accommodate flow and loading variation and backwash cycles. The media type and media retention systems vary between manufacturers. The system has flow nozzles to distribute the flow evenly across the filter area, and an aeration grid at the bottom of each cell to maintain aerobic conditions.

Secondary treatment can be provided in a single stage BAF. To achieve nitrogen removal, multiple BAF stages arranged in series are required. Depending on the vendor and effluent limits, there may be one, two, or three BAF stages required to provide secondary treatment (carbon removal), nitrification, and denitrification.

2.1.2 CAS with BioMag

CAS with BioMag uses inert iron ore (magnetite) ballast in the aeration tank and clarifiers to increase secondary settling rates. The magnetite has a specific gravity of 5.2 and when combined with biological floc increases settling rates. This allows for higher mixed liquor suspended solids (biomass) concentrations in the aeration tanks than possible with conventional active sludge. The ballasted floc is settled in the clarifiers and the majority of the magnetite ballasted floc is returned to the aeration tank in the return activated sludge (RAS) flow. Waste activated sludge (WAS) is sent through a magnetite recovery process prior to thickening or dewatering. Virgin magnetite is added to the recovered magnetite to replace the amount lost in the WAS and effluent. The recovered along with some virgin magnetite are returned to the process via direct feed to the aeration tank. The magnetite recovery process includes a shear device to release the ballast from the floc, and a magnetic recovery drum to recover the magnetite from the WAS.

The CAS with BioMag process uses conventional rectangular or circular secondary sedimentation tanks (clarifiers) for clarification. Surface overflow rates and solid loading rates are significantly higher than conventional secondary clarifiers.

Secondary treatment is provided with an aerobic aeration tank. To achieve nitrogen removal, the aeration tank is partitioned into different zones, some aerobic and some anoxic, and internal

recycle of nitrified mixed liquor from the aerobic zone to the anoxic zone is required. The sizing and tank configuration is a function of the effluent treatment goals.

2.1.3 MBBR and DAF

MBBRs incorporate neutral buoyant media with a high specific surface area to increase treatment surface area in the reactors. Since the media has a large surface area to volume ratio treatment can occur in relatively small tankage thereby reducing the footprint of new tanks or increasing the capacity of existing tanks. The biomass that treats the wastewater is attached to the media and is retained in the reactor and thus there is no need for return sludge from the solids separation process. The media is continuously agitated by the medium bubble aeration systems used to support biomass growth if the treatment goals are carbon or ammonia removal. Mechanical mixers are provided if denitrification is the treatment objective. The neutral buoyant media is retained in the reactors by retention screens located at the outlets of the tanks. The level of treatment provided in an MBBR can be modified by the percentage of media in the reactor, referred to as fill, which typically does not exceed 60 percent by volume. The media does not require changing, cleaning or backwashing. Similar to the CAS with BioMag process, secondary treatment is provided with an aerobic aeration tank. To achieve nitrogen removal, the aeration tank is partitioned into different zones, some aerobic and some anoxic. To provide denitrification, either internal recycle of nitrified effluent from the aerobic zone to the anoxic zone, or addition of a supplemental carbon source, is required.

Clarification is still needed following the MBBR to remove solids that pass through the system and biomass associated with growth that sloughs off the media. In lieu of conventional clarifiers, a MBBR system can use a number of different solids separation devices, and for this effort a dissolved air flotation device to provide solids separation in a small footprint was evaluated. DAF systems use microbubbles to float floc formations to the water surface (termed float) for solids removal. A typical system includes two stages of floc formation and in-line mixing upstream of the dissolved air section. Microbubbles are produced when the pressurized stream is allowed to depressurize in the float tank where the clarified water remains at the bottom and air and solids rise to the top. Clarified water passes under the surface float weir as DAF effluent, and the surface float is removed on a periodic basis by a surface skimmer system.

2.2 PILOT EQUIPMENT

As noted in the Phase 1 Task 1.7 Technology Evaluation Final Technical Memorandum dated September 26, 2011 (included as Attachment A), the piloting effort was focused on evaluating each of the three selected technologies to meet secondary treatment limits. The intent of the piloting effort was not to select a particular vendor for a technology, but to evaluate the ability of each technology to meet the required effluent limits. For two of the three technologies selected for piloting, MBBR with DAF and BAF, there are multiple vendors for the equipment. There is only a single vendor for the BioMag process.

During the Phase 1 Evaluation, proposals were solicited and received from vendors of the different technologies that outlined process configurations to achieve both secondary treatment as well as total nitrogen treatment levels. These vendors were contacted to determine availability of pilot units for the different elements of each technology, and based on pilot unit availability and on a review of the proposals a vendor's equipment and process were selected for piloting. The selected vendors were:

BAF – Kruger

CAS with BioMag – Siemens (formerly Cambridge Water Technology)

MBBR and DAF – World Water Works

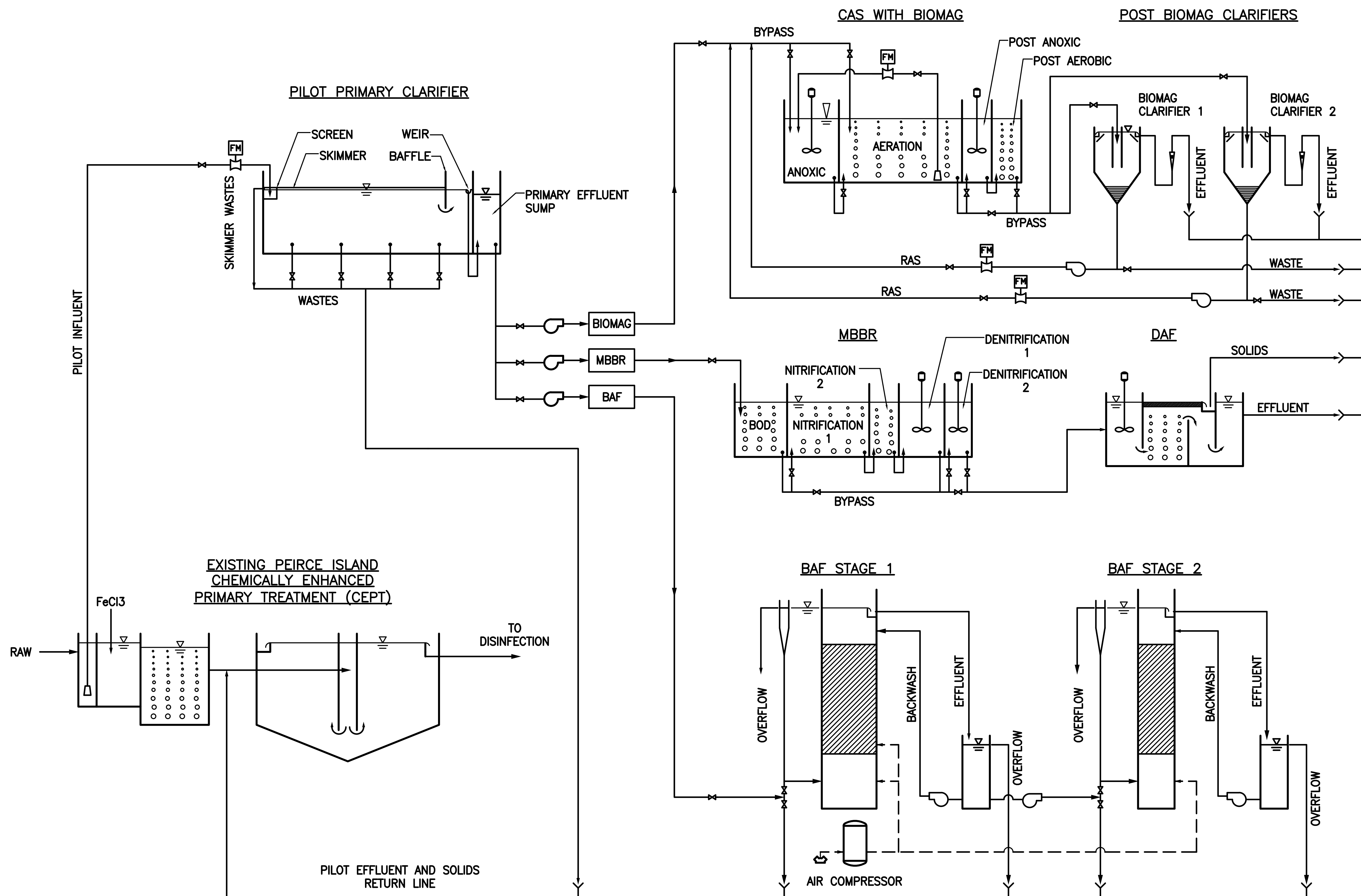
The treatment technology proposed by each selected vendor was scaled down to the pilot scale based on the projected design flows developed in the Phase 1 Evaluation and on the capacity of available pilot equipment. Refer to Attachment A for more detailed information on the projected design flows developed in the Phase 1 Evaluation that were used to scale down each technology for piloting. The pilot units were configured to allow testing of each technology in meeting three different effluent goals: secondary treatment; secondary treatment and total nitrogen removal to 8 mg/l; and secondary treatment and total nitrogen removal to 3 mg/l. In many cases, prefabricated pilot scale reactors and tanks were not available and this required that these items be fabricated onsite as part of the pilot effort. Figure 2-1 presents a flow schematic for each of the pilot units, Figure 2-2 shows the layout of the pilot systems and the major components of the pilot systems are described below. For more detailed information on the pilot systems, refer to the Blueleaf Pilot Report in Attachment B.

2.2.1 Primary Clarifier

The concept for the upgrade of the Peirce Island WWTF involves discontinuing the use of the CEPT process during dry weather so that the influent to the secondary treatment process would be conventional primary effluent, or non-chemically enhanced primary effluent. Non-chemically enhanced primary effluent was therefore used as the influent to the pilot secondary treatment technologies. Since the existing Peirce Island WWTF must operate the CEPT process to meet the existing permitted effluent limits, the pilot system included a pilot scale primary clarifier. The rectangular pilot primary clarifier was sized to mimic the hydraulic overflow rate of the existing primary settling tanks at the dry day average flow and was fabricated onsite. Raw wastewater flow to the pilot primary clarifier was provided by a submersible pump located in the influent channel of the WWTF prior to the existing grit chambers. Effluent from the pilot primary clarifier was then pumped to each of the three secondary pilot units. Figure 2-3 shows a photograph of the pilot primary clarifier

Figure 2-3. Pilot Primary Clarifier

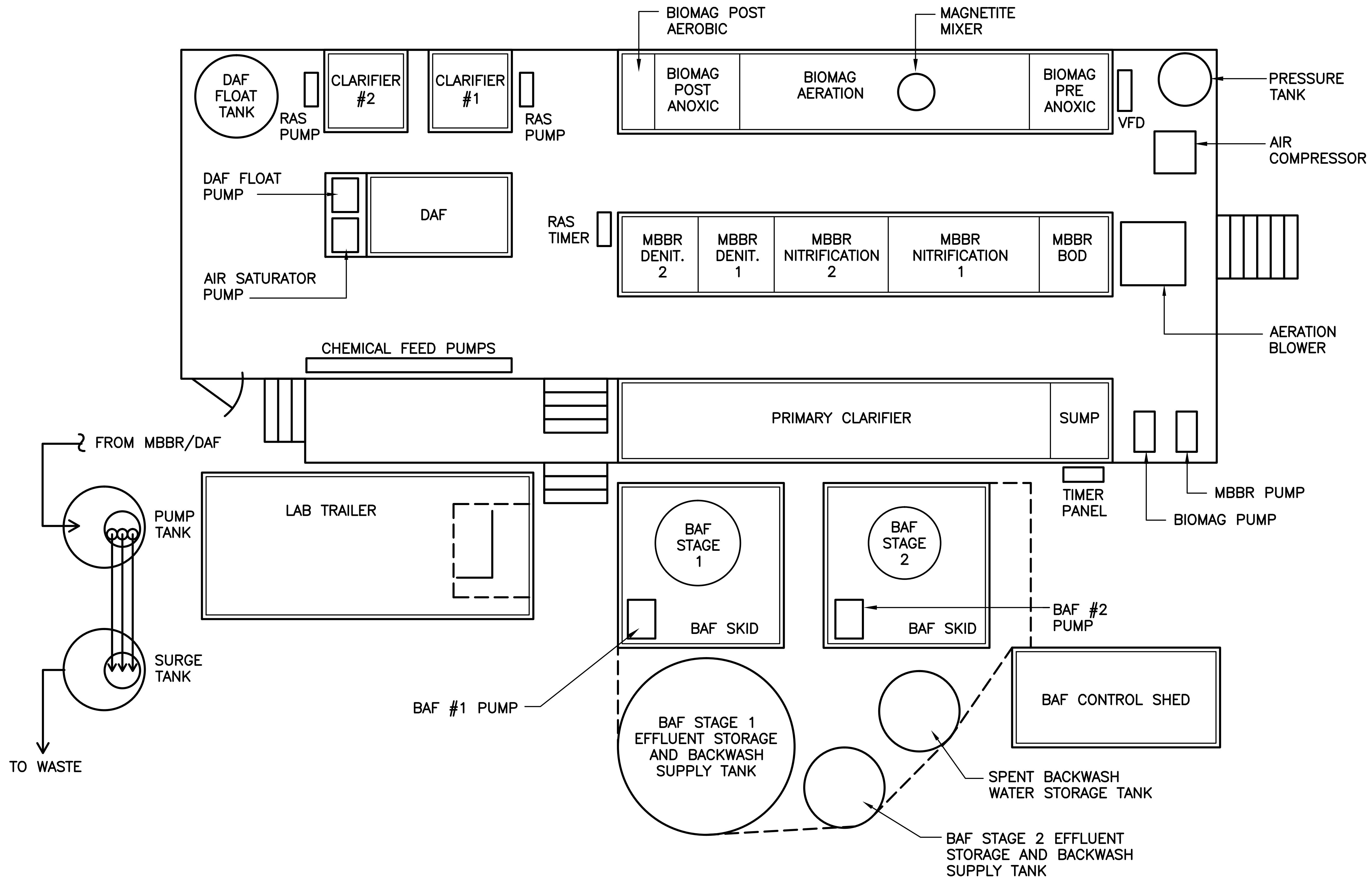




Blueleaf, Inc.

WWMP PILOTING - PHASE 2 INITIAL PILOTING
PEIRCE ISLAND WWTF - PORTSMOUTH, NH





2.2.2 BAF

The BAF pilot system consisted of pilot scale filter cells provided with air and backwash systems. The pilot filter cells were provided by Kruger, and consisted of round vertical columns that contained the polystyrene bead media and air feed grids. The BAF pilot unit was provided complete by Kruger including feed pumps, backwash pumps, pneumatic valves, compressor, and a programmable logic controller and associated instrumentation for automated operation. Two pilot filters were provided, one capable of providing BOD removal and nitrification in a single combined filter, and a second filter to provide denitrification. The first stage filter also could be operated in an MLE mode by changing the location of air addition and using an internal recirculation pump and thus provide a level of nitrogen removal (carbon, nitrification, and denitrification).

Primary effluent was pumped to the inlet of the first stage BAF where it traveled upwards through the media, and discharged from the top of the unit. Air was added in the unit in the first stage to provide oxygen for the aerobic biomass. For the secondary treatment trials, only the first stage of the BAF was used. During the nitrogen removal trials, the effluent from the first stage was pumped to the inlet of the second stage, together with a supplemental carbon source, for denitrification.

The effluent from each stage of the BAF pilot was directed into a storage tank to provide sufficient water to backwash each stage. During backwash of the BAF, the forward flow was stopped and backwash pumps provided flow to the top of the cell and downwards through the cell to flush out accumulated solids and excess biomass. The storage tanks also provided a degree of protection against unintended media loss as the Kruger media are buoyant and the tank effluent was pumped from the bottom of the tanks. Figure 2-4 presents a photograph of the pilot BAF units.

Figure 2-4. BAF Pilot Units



2.2.3 CAS with BioMag

The pilot CAS with BioMag process consisted of a pilot scale aeration tank, clarifiers, magnetite, air supply, and supporting pumps and chemical feed systems. The rectangular pilot conventional activated sludge aeration tank was fabricated onsite, and was constructed with internal baffle walls and piping to provide the different zones needed to achieve only BOD removal or BOD and nitrogen removal. Air was supplied from a blower that served both the CAS with BioMag and MBBR reactors. Mixers were provided in the anoxic zones to keep the magnetite and mixed liquor in suspension. Unlike the full scale CAS with BioMag system where magnetite feed and recovery are automated, in the pilot operation magnetite addition was done manually, and magnetite lost in the waste sludge from the system was not recovered. Magnetite was provided by Siemens.

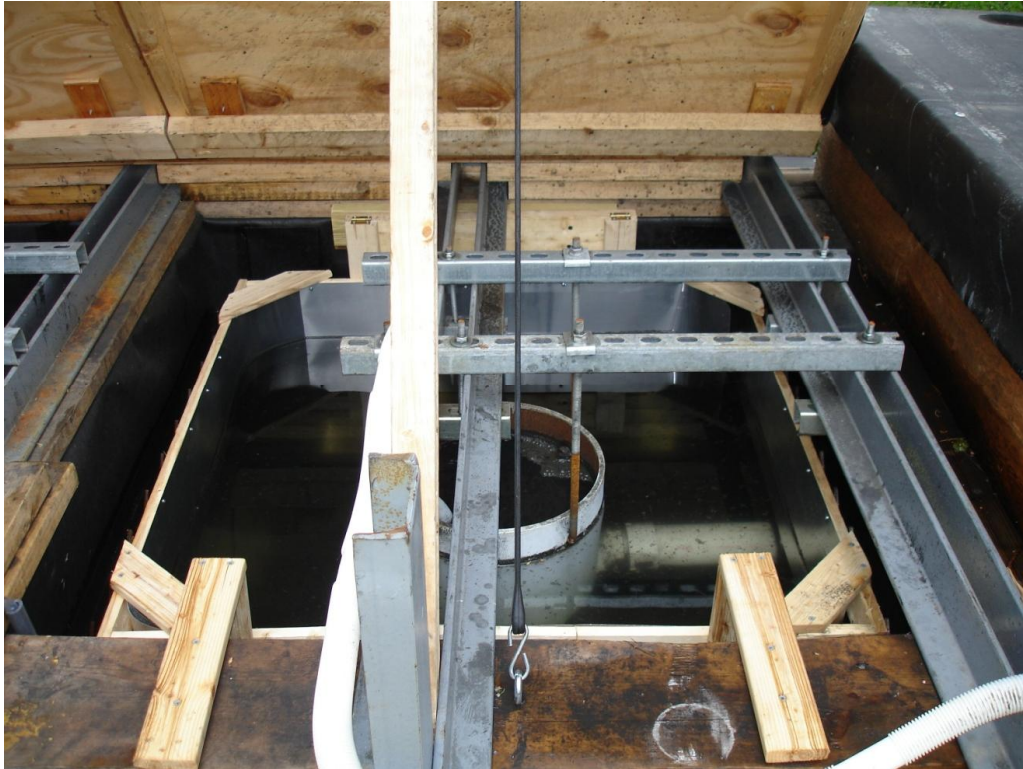
As shown on Figure 2-1, the CAS with BioMag aeration tank was partitioned into different zones that would be operated depending on the treatment level being tested. During the secondary treatment trials, the tank was operated as an aerobic reactor. For the TN of 8 mg/l trials, the aeration tank was operated in an MLE configuration using the pre-anoxic zone and an internal recirculation system from the aerobic zone. For the TN of 3 mg/l trials the post anoxic and post aerobic zones were used.

Mixed liquor from the CAS with BioMag aeration tank was conveyed to two clarifiers. These square clarifiers were fabricated on site, and each clarifier was provided with a return sludge pump to return the magnetite ballasted floc to the aeration tank. Figure 2-5 shows the CAS with BioMag aeration tank with the magnetite make up tank in the foreground, and Figure 2-6 shows a view of a clarifier.

Figure 2-5. CAS with BioMag Aeration Tank



Figure 2-6. CAS with BioMag Clarifier



2.2.3 MBBR and DAF

The pilot MBBR and DAF process consisted of a pilot scale aeration tank, air supply, chemical feed systems, and a pilot scale DAF clarifier. The rectangular pilot aeration tank was fabricated onsite, and was constructed with internal baffle walls and piping to provide the different zones needed to achieve only BOD removal or BOD removal and nitrogen removal. Air was supplied from a blower that served both the CAS with BioMag and MBBR reactors. Mixers were provided in the anoxic zones and one of the nitrification zones to keep the MBBR media in suspension. The MBBR media was provided by World Water Works.

As shown on Figure 2-1, the MBBR aeration tank was partitioned into different zones that would be operated depending on the treatment level being tested. During the secondary treatment trials, the tank was operated as an aerobic reactor using only the first zone of the tank. For the TN of 8 mg/l trials, the aeration tank was operated using the first aerobic zone as well as the nitrification 1 and 2 zones and the denitrification 1 zone along with supplemental carbon addition. For the TN of 3 mg/l trial the denitrification 2 zone was also used.

Flow from the MBBR aeration tank was conveyed by gravity to the pilot DAF unit. This prefabricated unit was provided complete by World Water Works including the air saturator pump and float pump. Figure 2-7 presents a view of the MBBR aeration tank, and Figure 2-8 shows the DAF unit. Effluent from the MBBR and DAF process was conveyed to a storage tank to provide a protection against unintended media loss as the MBBR media are neutral buoyant and the tank effluent was pumped from the bottom of the tanks.

Figure 2-7 MBBR Aeration Tank



Figure 2-8. MBBR DAF



2.3 PILOTING APPROACH

The focus of the piloting effort was the evaluation of the ability of the pilot technologies to achieve secondary treatment levels. As a result, the piloting approach initially configured the pilot units for secondary treatment, and experimental trials were conducted at different flows and loadings. Once the secondary treatment trials were completed for a technology, the pilot configuration was modified to examine the ability of a technology to achieve nitrogen removal. Section 3 and the Blueleaf Pilot Report included as Attachment B review the results of the pilot testing.

SECTION 3 - PILOT DATA ANALYSIS

3.0 INTRODUCTION

This section presents the analysis of the pilot data collected. A more detailed presentation of the data under the various operating conditions is included in Attachment B in the Blueleaf Pilot Report. This Section will focus on the evaluation of the data as it relates to the three piloted technologies. Items that will be addressed for each technology include:

- Summary of the Pilot Testing Experimental Plan
- Summary of Experimental Plan Data
- Summary of Technology's Ability to Meet Permit Goals
- Vendor Provided Loading Rate Validation
- Hydraulic Stress Tests Performance
- Pilot Observations and Considerations for Full Scale Implementation

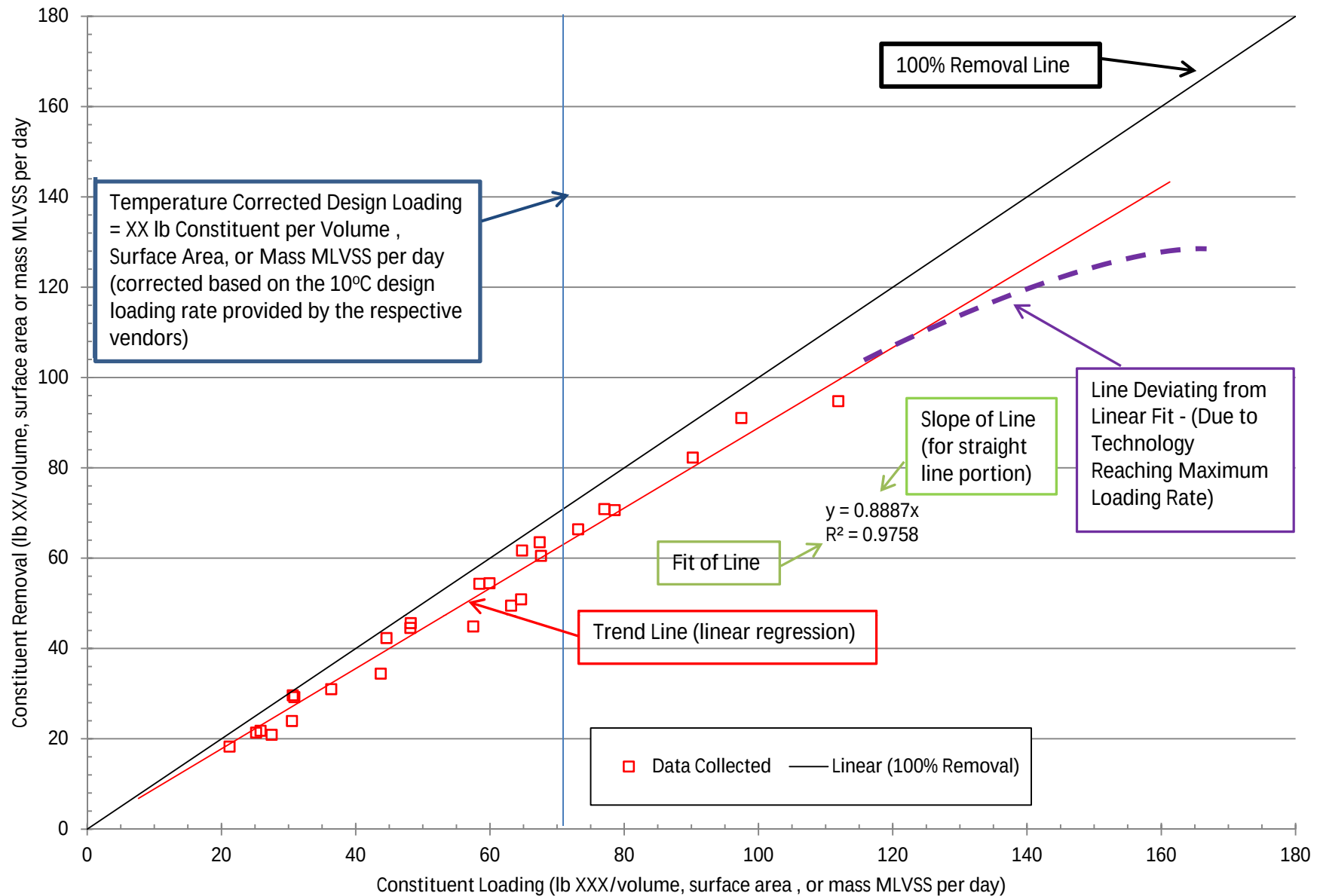
3.1 REVIEW OF PILOT TESTING

3.1.1 Sample Pilot Loading vs. Constituent Removal Graph

Prior to presenting specific data and evaluations of the three piloted technologies, Figure 3-1 presents a sample graph for pilot loading vs. constituent removal to illustrate the analysis approach that is subsequently presented for the three piloted technologies. These graphs are presented to determine the constituent removal rate specific to Portsmouth's wastewater and to assess and validate the vendor provided design loading rates as appropriate for BOD, ammonia, or nitrate and the specific process stages (BOD removal, nitrification or denitrification) of the piloted technologies. In Figure 3-1 it should be noted that the following items are common to the subsequent loading vs. removal graphs described in each technology section below:

- The X-axis presents the specific constituent loading rate per day on a unit volume, surface area basis, or mass basis while the Y-axis presents the constituent removal across the specific technology stage (BOD removal, nitrification, and denitrification) on the same basis.
- The red squares present the data (loading applied per day (per volume, surface area, or mass) vs. loading removed).
- The red line represents a linear regression best fit line of the data which has been forced through the graph's origin. It should be noted that this line will curve and the slope will decrease (flatten) as load is increased. If observed the horizontal portion of the best fit line represents the maximum or rate limiting loading rate for the technology. It is prudent design to ensure that the technology's design loading rate is not at the maximum loading rate, rather in the lower straight line portion of the data. When in this straight line data range, the technology should have the ability to be loaded at higher loading rates (commonly the case during normal diurnal load variations) but still achieve adequate performance.

Figure 3-1. Sample Pilot Loading vs. Constituent Removal Graph



- The linear regression line equation and R^2 value (coefficient of determination) are presented on the graph and are noted in green text boxes. The slope of the linear portion of the line represents the best fit percent removal of the presented wastewater constituent for the specific technology and stage. The R^2 value is used to evaluate how good the data presented is predicted by the regression equation. The closer the R^2 value is to 1.0 the better the prediction.
- The 45 degree black line represents the 100% removal rate of a constituent at a specific loading. This line should be used as a reference to determine the actual removal data presented in the graph
- The blue vertical line presents the design loading of the specific technology and stage provided by the vendors. All of the design loading rates provided by the vendors were at the low temperature (10 deg. C) design conditions. The loading rate provided on the graphs has been temperature corrected to the average wastewater temperature during the period of time at which the data presented on the figure was taken. Data to the left of the line represents pilot loadings that were lower than the temperature adjusted vendor provided design loading. Data to the right of the line represents loadings that were higher than the temperature adjusted vendor provided design loading. It is important to note that under real world conditions, all technologies will be loaded below and above the design loading rate.
- Temperature corrected vendor provided design loading rates that are in a linear portion of a data set indicate that the system is capable of achieving consistent performance. The position of the design loading rate, meaning at a point below the maximum loading rate “the knee of the curve”, indicates the system is robust and that the system can potentially handle additional loading without a decrease in loading performance.
- The purple line shows when the technology's performance deviates from a linear fit removal rate. This deviation shows that the removal performance of the technology stage is decreasing as the loading becomes greater. Simply put the technology cannot remove any more pollutant. If the design loading rate provided by the vendors is located in this area of a data set, this would indicate that the vendor sizing was inadequate to provide a robust system and it cannot handle additional loading without reduced removal performance or modifications to the stage (increased size, increased chemical use, etc).

3.2 BIOLOGICAL AERATED FILTER (BAF)

The pilot BAF system was examined to assess its ability to remove carbon (BOD) and total suspended solids (TSS) to meet secondary treatment effluent limits as well as to meet total nitrogen (TN) effluent limits (8 mg/l and 3 mg/l) under different constituent loading and hydraulic loading conditions. The pilot system was a two stage system employing carbon oxidation and nitrification in the first stage and denitrification in the second stage. The layout of the BAF system is presented in Section 2. The BAF system was operated from 1/29/12 to 8/3/12. Initially only the first stage was operated with the goal of providing BOD removal. During subsequent testing when the goal was total nitrogen removal, the first stage operation was changed to provide both BOD removal and nitrification and a second stage was put on line to provide denitrification. The Blueleaf Incorporated Pilot Report included in Attachment B, presents a detailed physical description of the BAF pilot system, the BAF pilot phases and associated testing conditions, and the data collected during the various phases to assess the performance of this technology.

3.2.1 Experimental Plan Summary

Table 3-1 presents a brief summary of the experimental plans that were used to evaluate the BAF technology. The results of these experiments are subsequently discussed

Table 3-1. BAF Experimental Plan Summary

Experimental Plan (EP) Number	Test Conditions	Testing Objective
EP-01	Experimental plan number not used*	
EP-02	Maximum Month BOD Loading	BOD and TSS Removal
EP-03	Experimental plan number not used*	
EP-04	Hydraulic Stress Tests	BOD removal, TSS Removal and TN Removal
EP-05	Maximum Month BOD Loading Elevated Ammonia Loading	BOD removal, TSS Removal and TN < 8 mg/l
EP-06	Maximum Month BOD Loading Elevated Ammonia Loading	BOD removal, TSS Removal and TN < 3 mg/l

* see Attachment B for experimental plan details

3.2.2 Data Presentation

Table 3-2 presents a summary of the data collected for the different experimental plans carried out on the BAF system with the exception of EP-04. For EP-04, a transient hydraulic load was imposed on the technology. The purposes of applying a transient load were to evaluate the removal performance of the system under different flow and loading conditions as well as to evaluate the ability of the technology to recover after applying these short term loads. For all of the experimental plans with the exception of EP-04 the goal was to examine the performance based on a target loading basis and not a hydraulic basis. The hydraulic stress testing conducted in EP-04 will be discussed later in this section.

The water quality data (concentration values) presented in Table 3-2 are presented in one of the two following formats:

- For larger data sets (typically field data)- Median value (minimum value – maximum value) [number of samples] is provided
- For small data sets (typically laboratory data) – sample value, sample value, sample value, is provided

It should be further noted the data for all of the experimental trials is presented graphically as time plots. These data along with the time plots are part of the Blueleaf Incorporated Pilot Report which is included as Attachment B.

Table 3-2. BAF Experimental Plan Data Results

	Experimental Plan Summaries					
Parameter	EP-02 Target	EP-02 Results	EP-05/06 Stage 1 Target	EP-05/06 Stage 1 Results	EP-05/06 Stage 2 Target	EP-05/06 Stage 2 Results
Test Condition	Maximum Month BOD Loading		Maximum Month BOD Loading Elevated Ammonia Loading			
Test Objective	BOD and TSS Removal		BOD, TSS, and TN<8 mg/l and TN<3 mg/l			
Influent Flow Rate (gpm)	NA	6.2	NA	3	NA	2
Influent Loading Rate (gpm/sf)	NA	0.88	NA	0.43	NA	1.13
Influent BOD Field (mg/l)	NA	173 (109) – 238) [19]	NA	NA	NA	NA
Influent BOD Calculated from COD (mg/l)	NA	175 (134 – 269) [20]	NA	279 (127 – 490) [67]	NA	NA
Influent TSS (mg/l)	NA	98.4 (58-134) [30]	NA	120 (85-145) [22]	NA	NA
Influent Ammonia (mg/l)	NA	NA	NA	41.2 (19 – 77) [56]	NA	NA
BOD Loading Rate (lbs BOD/1000cf*day)	153	166 (124 – 215) [9]	153	124 (46 - 218) [67]	NA	NA
NH ₃ Loading Rate (lbs NH ₃ /1000 cf * day)	NA	NA	20.6	18.3 (8.4 – 32.2) [56]	NA	NA
Effluent BOD Field (mg/l)	30	19.2 (14.3 – 27.7) [17]	NA	NA	30	NA*
Effluent BOD Lab (mg/l)	30	13, 8, 14	NA	NA	30	NA*
Effluent BOD calculated from COD (mg/l)	30	18.7 (12 – 23.4) [18]	NA	NA	30	NA*
Effluent TSS Field (mg/l)	30	12.9 (0 – 23.4) [26]	NA	17.6 (5 – 48.3) [28]	30	19.2 (4 – 29.2) [23]
Effluent TSS Lab (mg/l)	30	25, 5, 13	NA	16 (12 – 23) [6]	30	11.1 (<5 – 15) [7]
Effluent TN Field (mg/l)	NA	NA	NA	NA	3 - 8	NA
Effluent TN Lab (mg/l)	NA	NA	NA	NA	3 - 8	4.9 (3 – 6.3) [7]

Data presentation format - For large data sets - Median value (minimum value – maximum value) [number of samples]

- For small data sets – sample value, sample value, sample value

* Not analyzed due to intentional excess supplemental carbon addition to ensure carbon addition was not limiting denitrification performance

3.2.3 Ability to Meet Pilot Study Effluent Concentration Goals

The following is a brief summary describing the ability of the BAF to meet the BOD, TSS and TN effluent concentration goals under the varying conditions of the experimental plans not including EP-04 (stress testing).

3.2.3.1 BOD. The BAF met the effluent BOD goal of 30 mg/l for all samples collected and analyzed during EP-02 (as shown in Table 3-2). It should be noted that due to a time limitation when the BAF was being operated in a TN removal mode (EP-05/06), excess supplemental carbon was added to the second stage to insure adequate carbon for denitrification and to insure that carbon addition was not the limiting factor for total nitrogen removal performance. As a result of this overdosing, BOD was not analyzed for the samples collected during EP-05/06.

3.2.3.2 TSS. For all of the experimental plans the BAF met the effluent TSS goal of 30 mg/l for all effluent samples. Under the BOD removal scenario (EP-02) the BAF was able to meet the 30 mg/l TSS goal for all field and laboratory samples collected. For the total nitrogen removal scenarios (EP-05/06) the BAF was run as a two stage system. The first stage met the 30 mg/l TSS goal on an average basis with all of the laboratory data below the 30 mg/l goal. On a few occasions when the system was operated in a TN mode the field analyzed samples were above the 30 mg/l limit for the effluent exiting the first stage. However, all of the second stage effluent samples were below the 30 mg/l goal.

3.2.3.3 Total Nitrogen of 8 mg/l and 3 mg/l. For EP-05/06 the BAF met the TN goal of 8 mg/l for all samples collected under elevated ammonia loading conditions. Based on the laboratory results collected only one sample was able to meet the TN goal of 3 mg/l. See the ammonia and nitrate removal performance and loading rate validation sections below for further discussion on the ability of the pilot BAF system to meet the effluent TN concentration goals.

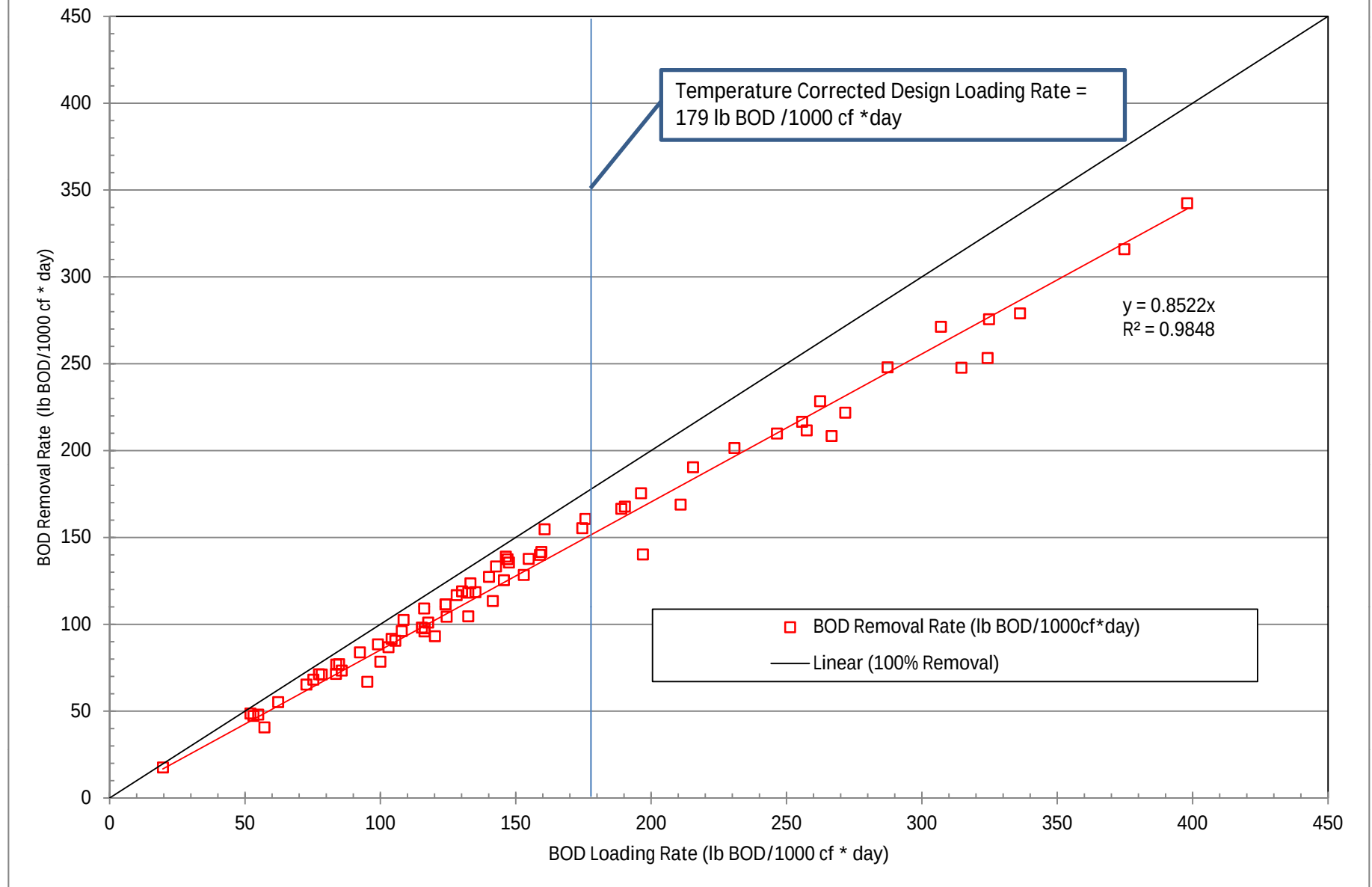
3.2.4 Loading Rate Validation

The data collected during the BAF pilot testing was evaluated to validate the vendor provided loading rates of the various process stages. This was done to assess if the system's reactors were sized properly to meet the effluent concentration goals while treating Portsmouth's wastewater. If the process reactors were unable to meet the target effluent goals this might be an indication that the vendor sizing might have been too aggressive (the result being recommending a system that is too small) and that lower loading rates should be used. If this was the case, the result would be the need for larger full scale process tankage/equipment. Conversely, if the process reactors were able to meet the effluent goals easily when operated at a high loading rate, this in turn might indicate the vendor sizing might be too conservative and there may be the opportunity to increase the loading rate and decrease the size of the process tankage/equipment. The Blueleaf Incorporated Pilot Report in Attachment B presents portions of the pilot loading data. This data and other data presented in Attachment B has been further manipulated and refined for presentation and discussion in the sections below.

3.2.4.1 Secondary/BOD Removal and Loading Rate Validation. Figure 3-2A presents the BOD applied vs. removed loading through the BAF stage 1 reactor from the period of 3/12/12 to 7/21/12. The vendor provided a design loading rate of 153 lb BOD/1000 cf*day at 10°C. Because the BOD data presented in the figure was collected at an average wastewater temperature of 14.5°C the vendor design loading rate has been temperature corrected. The temperature corrected loading rate is 179 lb BOD/1000 cf*day, which is equivalent to 153 lb BOD/1000 cf*day at 10°C, and is shown as a vertical line on the graph. The pilot data in Figure 3-2A show the following:

- The data shows 85% removal of BOD across the BAF stage 1 filter (see the slope of the linear regression line) while treating Peirce Island's primary effluent.

Figure 3-2A. BOD Loading Rates and Removal through Stage 1 BAF



- The data shows a linear relationship between load applied and load removed both above and below the temperature corrected design loading rate. There was no tail-off of the data at higher loading rates. This indicates that for the range of loads tested, the performance of the stage 1 BAF reactor was not impacted by increased loads, and the maximum loading rate for the technology was not approached.

The figure shows many data points both above and below the vendor's temperature corrected loading rate. All of the data collected in the area of the vendor's temperature corrected loading rate are on the linear part of the regression line. Some of the data collected were at loading rates that were more than two times the vendor's temperature corrected loading rate with limited or no impact on the BOD removal performance. This indicates that the system is robust and potentially could be run at increased loadings (smaller reactors) for BOD removal. Note that if a single BAF stage is going to provide both BOD and ammonia removal then the potential to reduce the sizing would need to be evaluated while considering the loading rates and performance of the stage 1 reactor for both BOD and ammonia.

BOD Removal Performance Implications

Based on the results from the pilot testing, the ability of the stage 1 BAF to meet the anticipated future WWTF BOD permit limits was assessed. This includes the anticipated permit limits for average month, maximum week, and maximum day. Table 3-3 presents the anticipated WWTF BOD permit limits as well as the calculated maximum primary effluent concentration to meet the permit limits (based on 85% removal in the stage 1 BAF). Table 3-3 also shows the calculated maximum WWTF influent BOD concentrations to meet permit limits based on the 85% stage 1 BAF BOD removal and the anticipated primary clarifier BOD removal range. The calculated maximum influent BOD concentrations for each permit condition are presented as two values. These values are based on the anticipated range of primary clarifier BOD removals (15% - 30%) identified in the Revised Flow and Loading Memorandum included in Attachment C.

Table 3-3. Maximum BOD Concentrations with Primary and Single Stage BAF Treatment To Meet WWTF Permit Conditions.

WWTF BOD Permit Condition	WWTF BOD Effluent Limit, mg/l	Maximum Primary Effluent Concentration with 85% BOD Removal in Stage 1 BAF, mg/l	Maximum WWTF Influent BOD Concentration, mg/l	
			15% BOD Removal in Primary Treatment	30% BOD Removal in Primary Treatment
Maximum Month	30	200	235	286
Maximum Week	45	300	353	429
Maximum Day	50	333	392	476

In order for the stage 1 BAF to be able to meet the anticipated BOD permit limits the maximum WWTF influent BOD concentration cannot exceed the range of influent BOD values shown in Table 3-3 or exceed the maximum primary effluent concentrations noted above both for maximum month, maximum week and maximum day conditions, respectively.

With only one BAF stage, it would be recommended that the BOD concentration in the WWTF influent and primary effluent be monitored to assess the primary clarifier removal and to ensure that the primary effluent does not exceed the values noted in Table 3-3 for the different WWTF conditions (max month, week, and day).

If it is anticipated or determined that the primary effluent is, or is going to, exceed the maximum values noted in Table 3-3 when running a single BAF stage, there are a few options to maintain BOD permit compliance. One option is for the WWTF to run CEPT to improve the removal in the primary clarifiers. Another, likely less cost effective option would be to provide second BAF reactor stage.

It should be noted that under a total nitrogen of 8 mg/l operating condition, it is anticipated that the BAF system will not have difficulty meeting the monthly BOD limits since required second stage denitrification process required will consume any residual BOD from the stage 1 BAF to the point that supplemental carbon will be required.

3.2.4.2 Ammonia Removal and Loading Rate Validation. Figure 3-2B presents the ammonia removal observed through the stage 1 BAF reactor from 6/13/12 to 7/21/12. Refer to the Blueleaf Incorporated Pilot Report in Attachment B for more details on the data.

The vendor provided a design loading rate of 20.6 lb NH₃/1000 cf*day at 10°C. Because the NH₃ data presented in the figure was collected at an average wastewater temperature of 20.8°C the vendor design loading rate has been temperature corrected. The temperature corrected loading rate is 29 lb NH₃/1000cf*day which is equivalent to 20.6 lb NH₃/1000 cf*day at 10°C and is shown as a vertical line on the graph. The data and this figure show the following:

The data in this figure show the following:

- This figure shows a good linear correlation between the applied surface area loading rate and the surface area removal rate for the loading rates applied during piloting.
- There are only data points below the design loading rate.
- Although the loading rates evaluated never reached or exceeded the temperature corrected design loading rate, the pilot loading rates approached the temperature corrected loading rate without any decrease in ammonia removal. This suggests that the reactors are sized appropriately for ammonia removal. Application of this loading rate at full scale should be discussed with the vendor to confirm that they will guarantee its performance. Based on the pilot data and the fact that the pilot loading never exceeded the temperature corrected loading rate it is not recommended that the size of this BAF stage for ammonia removal in the future be reduced.
- Based on a linear regression of the data the ammonia removal data through the BAF showed on average of 94% removal of the influent ammonia with a coefficient of determination (R^2) value of 0.97 indicating the linear regression line was a very good fit for the data. Note this removal is misleading as it does not account for the TKN which was also applied to the system and is often used as another metric for evaluating nitrogen removal. In addition to ammonia the TKN also includes organic nitrogen which will either be taken up in cell growth in the filters, hydrolyze into ammonia, or is not removed through biological processes (this portion of the TKN is often called recalcitrant dissolved organic nitrogen rDON)).

Another way of looking at the performance of the piloted BAF system is to examine the effluent ammonia concentrations from the stage 1 BAF and the stage 2 BAF. Since the primary goal is to consistently have complete nitrification, ammonia concentrations below 1 mg/L should be consistently achieved. This data was plotted for the time periods within EP-05/EP-06 (See Figure 3-2C). It should be noted that the ammonia feed to the BAF system was spiked during the EP-05/06 trials. This figure shows that:

- A significant number of data points from both the stage 1 BAF and the stage 2 BAF effluent routinely showed complete nitrification (NH₃ < 1.0 mg/l).

Figure 3-2B. Ammonia Loading and Removal through Stage 1 BAF

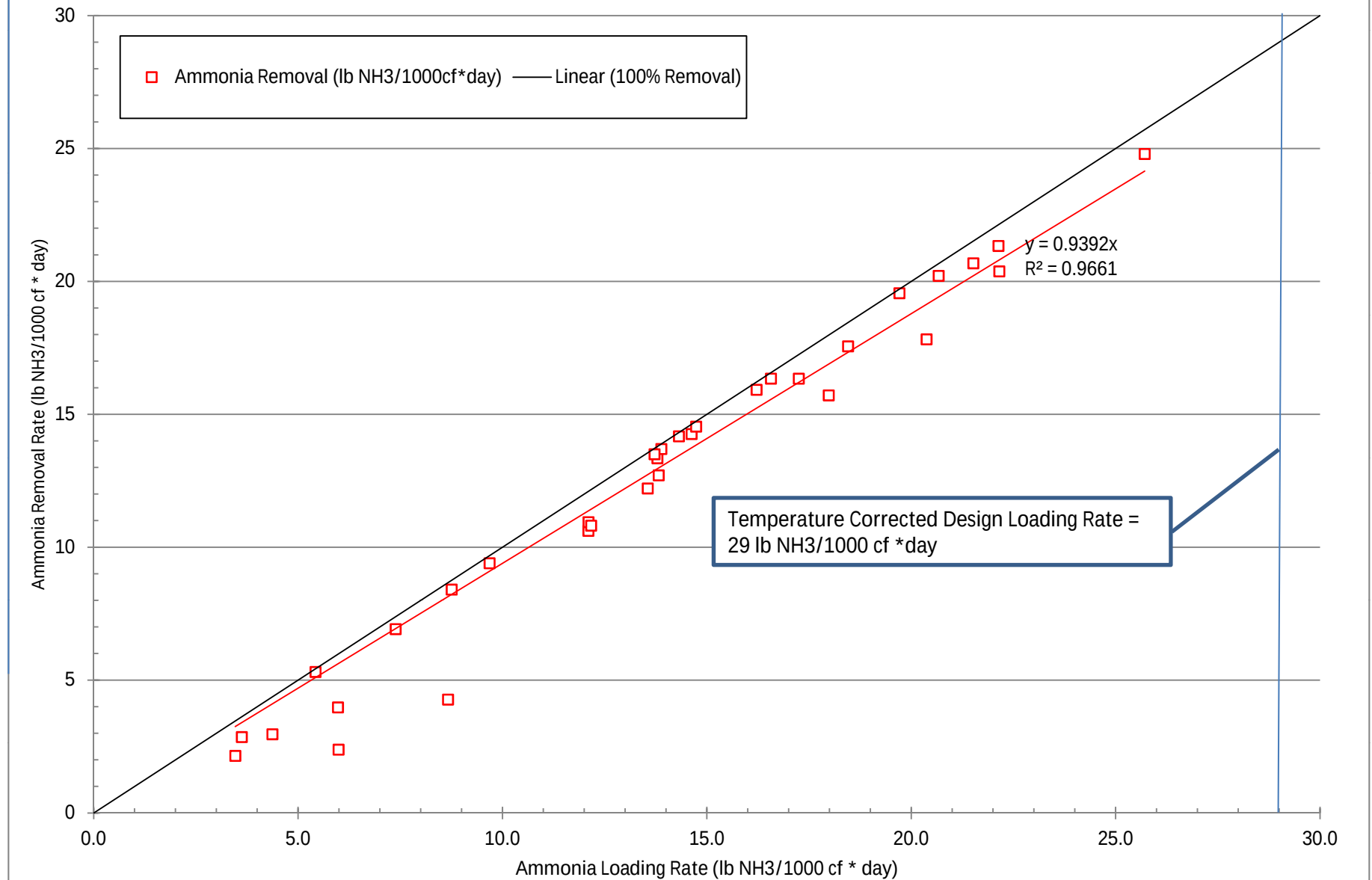
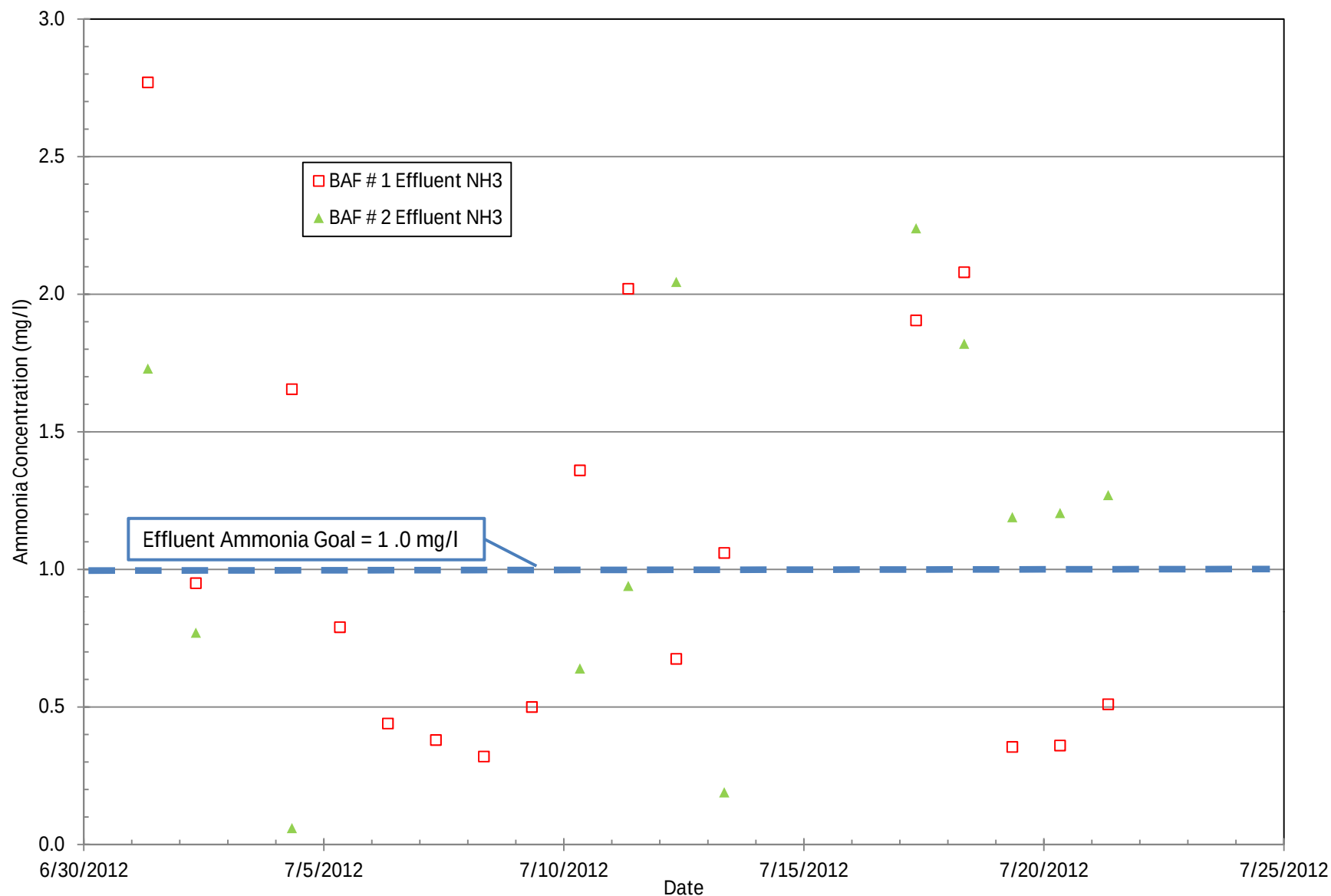


Figure 3-2C. Average Daily Effluent Ammonia Through BAF Process



- There are a number of days which show that the stage 2 BAF effluent ammonia concentrations are greater than the stage 1 BAF effluent concentrations. It is believed that this increase is the result of reactions (hydrolysis) in the stage 1 BAF effluent storage tank that would increase the NH_3 feed to the stage 2 BAF. The detention time in this 2,000 gallon storage tank is estimated at approximately 11 hours at 3 gpm. An effluent storage tank of this relative magnitude would not be part of a full scale design, but was provided in the pilot to prevent accidental media release.
- There were a few data points during EP-05/06 where the effluent ammonia was slightly greater than 2.0 mg/l indicating incomplete nitrification.
- Overall the NH_3 data collected from the stage 1 BAF indicates that the system was able to fully nitrify for the majority of the samples collected.

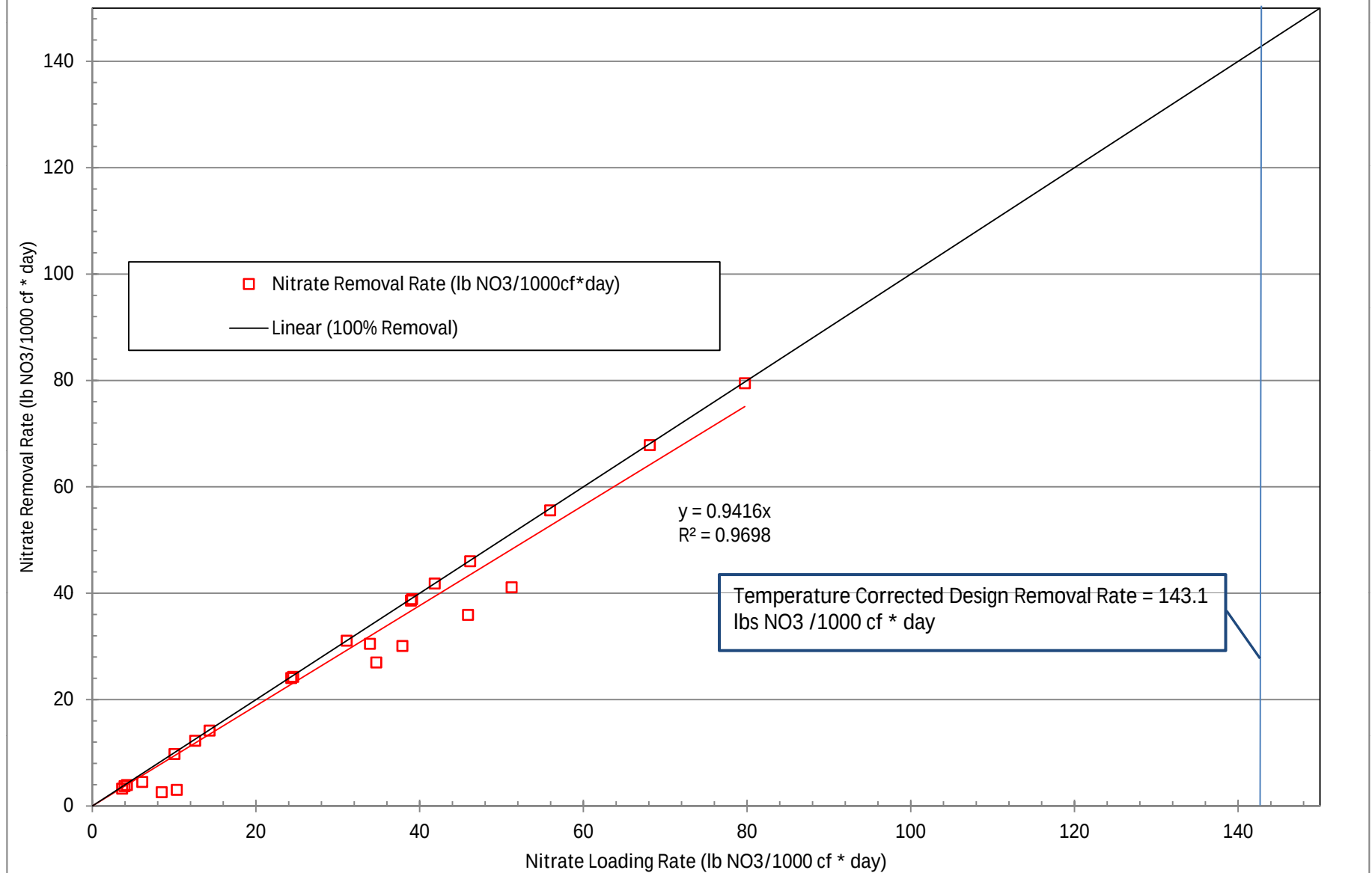
3.2.4.3 Denitrification Performance and Nitrate Loading Rate Validation

Figure 3-2D presents the nitrate (NO_3) loading vs. removal from the second stage BAF (denitrification stage) collected from 7/1/12 to 7/23/12. Refer to the Blueleaf Incorporated Pilot Report in Attachment B for more details on the data. The vendor provided a design loading rate of 98.7 lb NO_3 /1000 cf*day at 10°C. Because the NO_3 data presented in the figure was collected at an average wastewater temperature of 20.8°C and thus the vendor design loading rate has been temperature corrected to the temperature observed during piloting. The temperature corrected loading rate is 143 lb NO_3 /1000 cf*day, which is equivalent to a design loading rate of 98.7 lb NO_3 /1000 cf*day at 10°C, is shown as a vertical line on the graph. The data and this figure show the following:

- The data show a linear relationship between load applied and load removed. This indicates that in the range of loads tested that the performance of the BAF was not impacted by increased loads.
- The figure only shows data points below the temperature corrected vendor provided loading rate.
- Based on a linear regression of the data the nitrate removal through the stage 2 BAF showed on average over 94% removal of the influent nitrate with a coefficient of determination (R^2) value of 0.97 indicating the linear regression line was a very good fit for the data.
- The maximum loading tested during the pilot study was approximately 55% of the vendor's temperature corrected design loading rate. The pilot study was unable to run the stage 2 BAF at the design loading due to the different sizes of the two BAF stages. The stage 1 BAF was smaller than the stage 2 BAF stage limiting the amount of stage 1 BAF effluent that could be fed to the stage 2 BAF.

Although the pilot was unable to run at the temperature corrected vendor loading rate of 143 lb NO_3 /1000 CF * day, the temperature corrected and non temperature corrected vendor provided NO_3 loading rate appears to be reasonable when comparing it to other full scale BAF denitrification loading rates. The Cheshire, CT WPCP operates a Kruger denitrification BAF and the Southington CT WPCP operates an Infilco Degremont denitrification BAF. Both of these facilities have seasonal average TN limits and target effluent TN concentrations of between 3.0 mg/l TN to 3.5 mg/l TN. Both WWTFs have successfully met their TN effluent goals since the systems began operation in 2007 and 2010 respectfully. As a point of reference to the Portsmouth pilot vendor supplied nitrate loading rates, the Cheshire BAF design loading rate is 175 lbs NO_3 / 1000 cf *day at 10°C and the Southington BAF design loading rate is 152 lbs NO_3 / 1000 cf * day at 10°C.

Figure 3-2D. Nitrate Loading and Removal through Stage 2 BAF



As noted in the Blueleaf Incorporated Pilot Report and as shown in Table 3-2, the laboratory analyzed TN data collected for the EP-05/06 testing (7 samples) indicated that the BAF was unable to produce a TN of less than 3 mg/l reliably. The field data collected during this time was not specifically analyzed for effluent TN however an estimate of the effluent TN from the field data can be made by looking at the total of the measured ammonia, nitrate and the average recalcitrant dissolved organic nitrogen (rDON). Section 4 of this report describes the rDON samples collected at Peirce Island from July 2011 to July 2012 as part of this study. The average rDON concentration observed during this period was 0.66 mg/l. The estimated TN concentration during the EP-05/06 time period is shown in Figure 3-2E. This figure shows the field measured stage 2 BAF NH_3 , NO_3 , as well as a sum of these constituents and the average rDON concentration noted above.

This figure shows that for the majority of the EP-05/06 operating period the BAF fully denitrified the NO_3 fed to the stage. This figure also shows that for the majority of the EP-05/06 operating period the BAF might produce a TN concentration of less than 3 mg/l but potentially not reliably.

Based on the denitrification BAFs employed at other WWTFs and the estimated TN concentrations shown in Figure 3-2E it is believed that a BAF system can meet an effluent TN concentration of 3 mg/l at the Peirce Island WWTF but potentially inconstantly. Evaluation of the ability to consistently meet a TN of 3 mg/l should be investigated further.

3.2.4.4 TSS Removal. The effluent TSS concentrations in the stage 1 BAF and stage 2 BAFs were evaluated. Figure 3-2F presents the average daily effluent TSS concentration for the pilot BAFs.

The data in this figure shows:

- The pilot stage 1 BAF and stage 2 BAF produced a TSS lower than 30 mg/l the majority of the time with only a few excursions which were above 30 mg/l for the stage 1 BAF.
- The few excursions above 30 mg/l were observed during Experimental Plan 05/06 for the stage 1 BAF but it should be noted that the Stage 2 BAF effluent was always below 30 mg/l.
- There is a significant period of time between EP-02 and EP-05/06 where no BAF TSS data is shown. During this time, the filter was being converted from a carbon oxidation only mode (BOD) to a single stage carbon oxidation and nitrification mode. This acclimation took a significant amount of time. More details on this conversion are included in Blueleaf Incorporated's Pilot Report included as Attachment B.
- Typically a BAF will operate with relatively consistent effluent TSS. If there was to be an increase in TSS concentration in the effluent it is typically significant and would indicate a solids break through and/or the need to backwash the BAF. Typically BAFs are backwashed on time basis or when headloss in the filters will build up to a point where a backwash cycle is initiated. Backwash frequency is typically determined on experience at a specific WWTF and occurs well in advance of a solids break through.

The feed storage tank between BAF stage 1 and stage 2 caused the feed to the second stage BAF to be not representative of a full scale system. The feed to second stage BAF was found at times to contain long term effects of any stage 1 BAF pilot process upsets. In addition, at times the feed to the stage 2 BAF was found to have lower water quality than the effluent from the stage 2 BAF. Also, during the time when the stage 2 BAF was operated, it was intentionally overfed with supplemental carbon. This overfeeding was to ensure the denitrification process was not carbon limited during these experimental plans. It is believed that this carbon resulted in additional

Figure 3-2E. Estimated Average Daily Total Nitrogen Through Stage 2 BAF Process

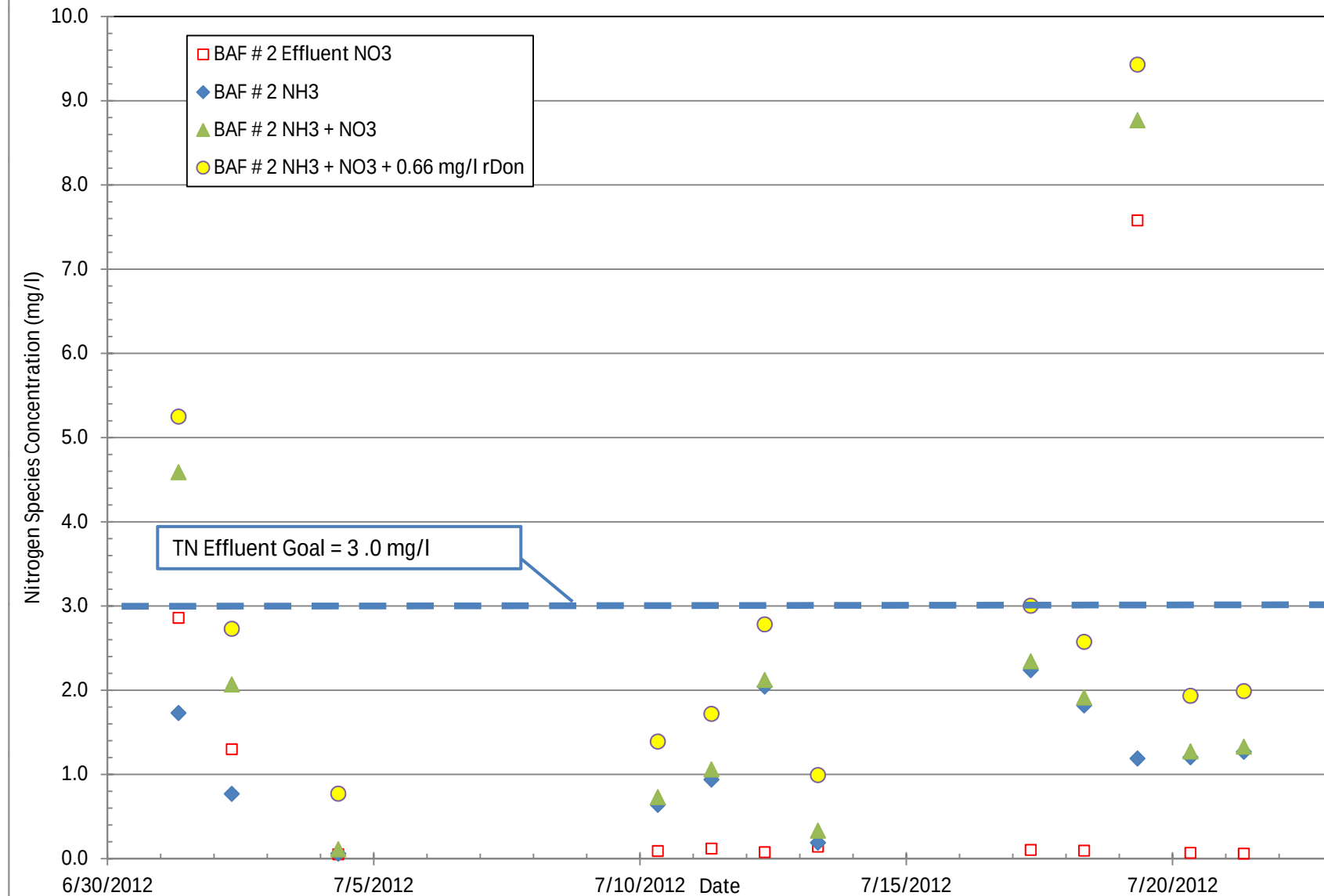
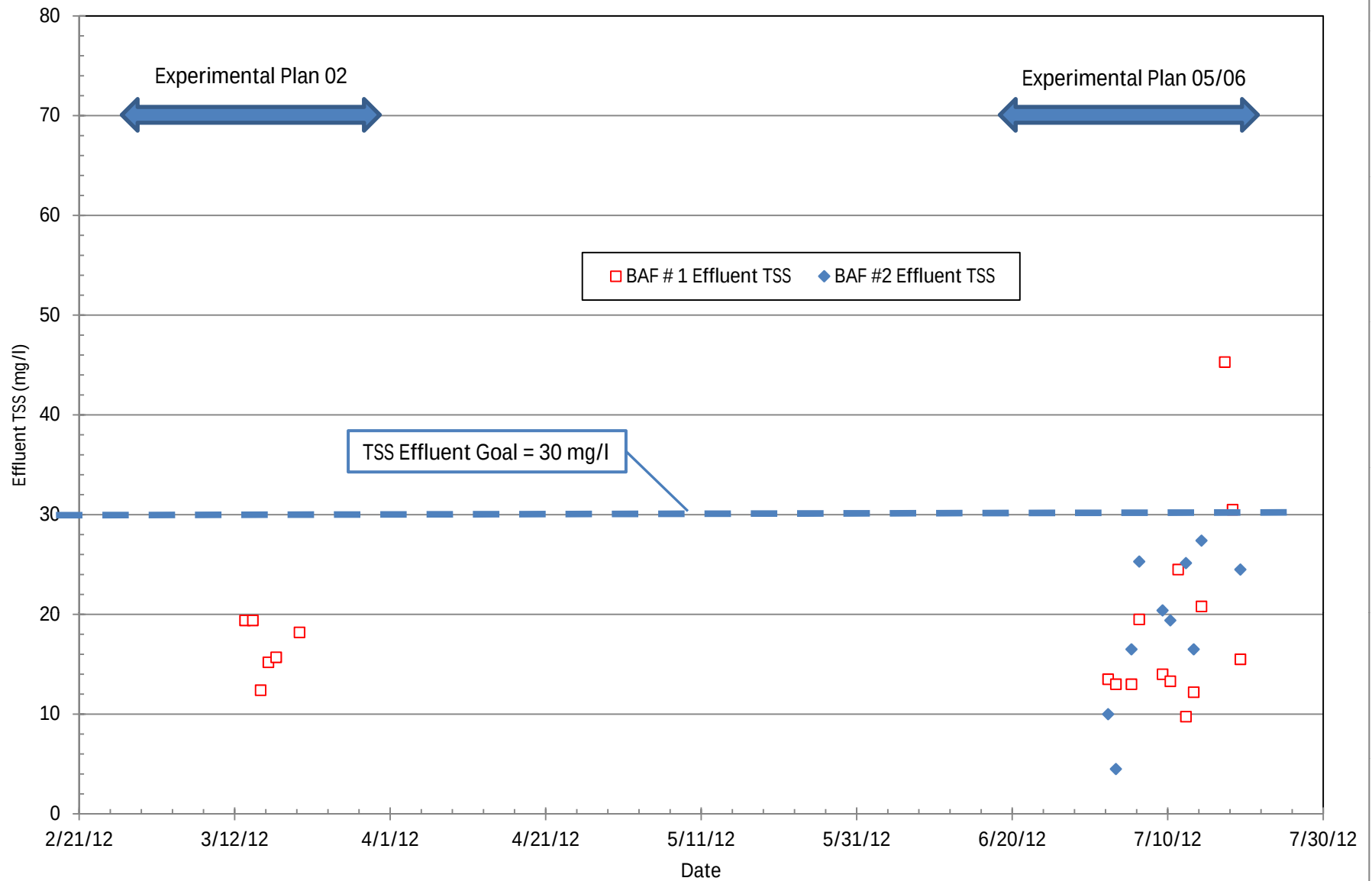


Figure 3-2F. Stage 1 BAF and Stage 2 BAF Average Daily Effluent TSS



biological growth that is also not representative of a denitrification BAF under normal operating conditions.

It is believed that the TSS concentration from a second stage denitrification BAF (require for a TN of 8 mg/l) will meet a 30 mg/l limit in a full scale application. It should be noted that the Cheshire, CT WPCP and Southington, CT WPCP as well as other operating denitrification BAFs all show very efficient TSS removal (low TSS effluent).

3.2.5 Hydraulic Stress Tests Performance

During Experimental Plan 04, the BAF was subjected to increased influent flows and loading conditions to mimic different types of storm events. During these trials, the system was subjected to an increased flow condition and the system performance was monitored during and after the event to assess how long the system would take to recover to base line conditions. A number of wastewater constituent treatment goal conditions were used to evaluate the system. The recovery evaluation involved sampling a number of wastewater constituents (TSS, COD, TN, NOx, NH₃) and reactor dissolved oxygen (DO) concentrations. The wastewater constituent effluent concentrations for the stage 1 BAF and stage 2 BAF were examined statistically with a one way ANOVA analysis to assess if any of the data sets from the three testing phases (pre-stress, stress, and recovery) for each stress test were different than the other phases. For a discussion on the details of the one way ANOVA analyses see the Blueleaf Incorporated Pilot Study included as Attachment B. The wastewater constituents and DO concentrations were also visually examined to identify if there appear to be changes due to the different phase of each stress test that might not have been identified as statistically significant. For example an increase in TSS that was observed but not statistically significant might indicate a washout of biomass.

3.2.5.1 Test Conditions. The hydraulic stress testing conducted included:

- A full strength, medium flow increase short duration (2 hours at elevated condition) test.
- A full strength, peak flow increase short duration (2 hours at elevated condition) test.
- A full strength, peak flow increase medium duration (6 hours at elevated condition) test.
- A diluted strength, peak flow increase extended duration (28 hours at elevated condition) test.
- A full strength, high-peak flow increase medium duration (6 hours at elevated condition) test.
- A full strength, high-peak flow increase extended duration (28 hours at elevated condition) test.

The flow rates for the hydraulic stress tests were selected to mimic the full scale flow rates. All tests started at the pilot equivalent of the maximum month flow rate of 5.99 mgd. The medium flow increase target flow was selected to be between the maximum month flow and the hydraulic maximum flow of 10.5 mgd. The peak flow rate was selected to mimic the hydraulic maximum flow of 10.5 mgd in the piloted two stage BAF configuration. As consideration is being given to using a three stage BAF system, the high peak flow was selected to mimic the hydraulic maximum flow of 10.5 mgd at the higher hydraulic loading rates provided by Kruger for a three stage BAF configuration.

3.2.5.2 Performance. A number of samples were collected before, during and after the flow increase to establish a baseline condition, as well as to evaluate the performance through the event, and the system's recovery. Within Blueleaf Incorporated's Pilot Test Report, included as Attachment B, are the experiment details and graphical presentation of the data. Table 3-4 presents a summary of the hydraulic stress testing conditions and recovery results.

Table 3-4. BAF Hydraulic Stress Test Summary

Test	Full Strength, Medium Flow Increase, Short Duration	Full Strength, Peak Flow Increase, Short Duration	Full Strength, Peak Flow Increase, Medium Duration	Diluted Strength Peak Flow Increase, Extended Duration	Full Strength, High-Peak Flow Increase, Medium Duration	Full Strength, High-Peak Flow Increase, Extended Duration
Actual Flow/Load Increase Condition Duration	2 hours	2 hours	6 hours	28 hours	6 hours	28 hours
Flow - Start (gpm) to Increase conditions (gpm)	Stage 1 from 3 to 8.2 Stage 1 from 2 to 6.2	Stage 1 from 3 to 9.2 Stage 1 from 2 to 7.2	Stage 1 from 3 to 9.2 Stage 1 from 2 to 7.2	Stage 1 from 3 to 9.2 Stage 1 from 2 to 7.2	Stage 1 from 3 to 18.6 Stage 1 from 2 to 15.1	Stage 1 from 3 to 18.6 Stage 1 from 2 to 15.1
Statistical Impact	Stage 1 - NH ₃ Stage 2 - NH ₃ ³	Stage 1 - NH ₃ , TN, NOx, TSS Stage 2 – TSS, COD ¹	Stage 1 - NH ₃ , TN, NOx, TKN Stage 2 – NH ₃ ³ , COD ¹	Stage 1 - NH ₃ , TN, NOx, TKN ³ Stage 2 – NH ₃ , TN, TKN ³	Stage 1 - NH ₃ Stage 2 – TSS	Stage 1 – TSS, COD, NH ₃ Stage 2 – TSS
Observed Impact	Stage 1 - TSS increase, Slight DO depression Stage 2 – NH ₃ , TN (increase 6 hour delay) ³ Stage 2 – COD ¹	Stage 1 – Slight DO depression Stage 2 – NH ₃ , TN (increase 6 hour delay) ³	Stage 1 - TSS increase (did not exceed 30 mg/l), Slight DO depression Stage 2 – TSS (decreased during event)	Stage 1 - Slight DO depression Stage 1 – NH ₃ increase recovered during event. Stage 2 COD increase in effluent (COD overdosing)	Stage 1 - Slight DO depression Stage 1 significant TSS increase (up to 130 mg/l)	Stage 1 significant decrease in DO concentration Stage 2 TSS decrease then increase (might be impact of break tank)
Stage 1 TSS Recovery (to 30 mg/l goal)	1 hour	Below 30 mg/l goal at all times	NA	NA	3 hours	Meet goal at event end. Full recovery 1 hour after event
Stage 2 TSS Recovery (to 30 mg/l goal)	NA	NA	NA	NA	Didn't recover to goal within 12 hours	During middle of event and 7 hours after event
Stage 1 NH ₃ Recovery (to 1 mg/l goal)	6 hours	4 hours	2 hours	Recovered during stress test	6 hours	10 hours
TN Recovery (to 8 mg/l goal)	Increase 6 hours after event ³	Increase 6 hours after event ³	Not until the next day ~ 20 hrs ³	NA	TN not measured.	TN not measured. However complete denitrification in Stage 2 observed
Stage 1 DO Recovery	Immediate	4 hours corresponds with NH ₃ spike recovery	2 hours corresponds with NH ₃ spike recovery	Depressed for ~ 12 hrs	6 hours corresponds with NH ₃ spike recovery	10 hours corresponds to NH ₃ spike recovery
Notes	Stage 2 BAF showed complete denitrification	Stage 2 BAF showed complete denitrification	Stage 2 BAF showed complete denitrification	Stage 2 BAF showed complete denitrification	Only TSS, NH ₃ and NOx measured for stage 2 Stage 2 BAF showed complete denitrification	Stage 1 BAF – Only TSS, COD, NH ₃ measured Stage 2 BAF – Only TSS and NOx measured

1 – Stage 2 BAF COD depression attributed to supplemental carbon dilution

2 - All stage 2 BAF tests showed complete denitrification

3 - Increases in NH₃ and TN in stage 2 BAF effluent observed after stress test and are attributed to increase in stage 1 effluent NH₃ concentrations discharging to the 2,000 gal stage 2 BAF feed tank.

For the full strength medium flow short duration event (2 hr duration) the following was observed:

- The DO concentration in the stage 1 BAF was slightly suppressed during the event. Note the air flow to this stage was not adjusted during this stress test. An expected result was the partial loss of nitrification. The DO in the stage 1 BAF recovered immediately once the flow was returned to pre-stress rates.
- Statistically the event had a significant effect on both BAF stages for NH_3 . It should be noted that during the event the NH_3 loading to the stage 1 BAF was approximately 20% greater than the design loading rate.
- The increase in NH_3 and TN observed in the stage 2 BAF was attributed to the 2,000 gallon storage tank used to collect the stage 1 BAF effluent and feed the stage 2 BAF. Any significant changes in wastewater constituent concentrations in the stage 1 BAF effluent will be observed in the stage 2 BAF feed. Therefore until the stage 1 BAF system recovers and begins to dilute the concentration in the 2,000 gallon tank feed to stage 2, the stage 2 BAF will show an impact. This impact was observed during the various hydraulic stress testing experimental runs.
- A TSS increase was observed for stage 1 (up to 55 mg/l) with recovery to below the 30 mg/l effluent goal within 1 hour after the flow was back to pre-stress rates.
- Stage 2 showed a decrease in the effluent COD. However during the stress testing the supplemental carbon feed was dosed to stage 2 at a high rate to not impede denitrification. The impact on the effluent COD is attributed to dilution of the supplemental carbon (i.e. the carbon feed rate did not change but the stage 2 flow increased). In a full scale design care should be taken to match the supplemental carbon feed to the demand as to prevent overdosing of the carbon resulting increased BOD in the effluent and the additional costs associated with overdosing the carbon.
- The stage 2 BAF showed complete denitrification during and after the stress event indicating a robust and well attached biomass.

For the full strength peak flow short duration event (2 hr duration) the following was observed:

- The DO concentration in the stage 1 BAF was slightly depressed during the event. Note the air flow to this stage was not adjusted during this stress test. An expected result would be the partial loss of nitrification which was observed. Statistically the event had a significant impact on the stage 1 NH_3 , TN, NO_x and TSS. Based on the extended DO depression and increased loading in stage 1 this is expected. It should be noted that during the event the NH_3 loading to the stage 1 BAF was approximately 15% greater than the design loading rate.
- The DO in the stage 1 BAF recovered in 4 hours after the flow returned to pre-stress levels which corresponded to the NH_3 recovery.
- Statistically the event had a significant impact on the Stage 2 TSS and COD and an observed impact on the stage 2 NH_3 and TN.
- The increase in NH_3 and TN observed in the stage BAF effluent was attributed to the 2,000 gallon storage tank used to collect the stage 1 BAF effluent and feed the stage 2 BAF.
- The TSS increase was observed for stage 1 and stage 2 were below the 30 mg/l effluent goal at all times. The generally low TSS concentrations and the fact that the performance of the removal of the other wastewater constituents recovered quickly indicates that there was not significant biomass washout.

- Stage 2 showed a decrease in the effluent COD. The impact on the effluent COD is attributed to dilution of the supplemental carbon (i.e. the carbon feed rate did not change but the stage 2 flow increased).
- The stage 2 BAF showed complete denitrification during and after the stress event indicating a robust and well attached biomass.

For the full strength, peak flow, 6 hour duration test the following was observed:

- The DO concentration in the stage 1 BAF was slightly depressed during the event. Note the air flow to this stage was not adjusted during this stress test. An expected result would be the partial loss of nitrification which was observed. Statistically the event had a significant impact on the stage 1 NH_3 , TN, NO_x and TKN. Based on the extended DO depression and increased loading in Stage 1 this is expected. The event also had a slight impact on TSS for stage 1. It should be noted that during the event the NH_3 loading to the stage 1 BAF was approximately 90% of design loading rate.
- The DO in the stage 1 BAF recovered in 2 hours after the flow returned to the pre-stress rates which corresponded to the NH_3 recovery.
- Statistically the event had a significant impact on the stage 2 NH_3 and COD and an observed impact on the stage 2 TSS.
- The increase in NH_3 and TN observed in the stage 2 BAF effluent was attributed to the 2,000 gallon storage tank used to collect the stage 1 BAF effluent and feed the stage 2 BAF. The impact on the stage 2 TN lasted approximately 20 hours after the flow returned to pre-stress rates.
- The TSS increase was observed for stage 1 and stage 2 but were below the 30 mg/l effluent goal at all times suggesting no substantial loss of biomass.
- Stage 2 showed a decrease in the effluent COD. The impact on the effluent COD is attributed to dilution of the supplemental carbon (i.e. the carbon feed rate did not change but the stage 2 flow increased).
- The stage 2 BAF showed complete denitrification during and after the stress event indicating a robust and well attached biomass.

For the diluted strength, peak flow, 28 hour duration test the following was observed:

- The DO concentration in the stage 1 BAF was slightly depressed during the event. Note the air flow to this stage was not adjusted during this stress test. An expected result of depressed DO would be the partial loss of nitrification which was observed. Statistically the event had a significant impact on the stage 1 NH_3 , TN, NO_x and TKN. Based on the extended DO depression and increased loading in stage 2 the increase in the nitrogen species with the exception of the NO_x is expected due to decreased nitrification is expected.
- The increase in NH_3 observed during the beginning of the event actually recovered to a value of less than 1 mg/l during the event. In addition a backwash occurred during the event which also raised the NH_3 in the stage 1 BAF effluent. However the NH_3 recovered again to a concentration of less than 1 mg/l prior to the end of the event. It should be noted that during the event the NH_3 loading to the stage 1 BAF was approximately 80% of the design loading rate.

- This NH_3 recovery in stage 1 coupled with no substantial loss of TSS during the event indicates that the initial NH_3 increases were most likely not due to biomass washout but rather due to the acclimation of the filter biomass (heterotrophs and autotrophs) to the new loading. The quick acclimation of the biomass to the changed conditions is an indication that the system is robust and will be able to handle long duration wet weather events that will dilute the incoming wastewater and only briefly impact effluent performance.
- The DO in the stage 1 BAF fully recovered in approximately 12 hours after the flow returned to pre-stress rates.
- Statistically the event had a significant impact on the stage 2 NH_3 , TN and TKN. This was attributed to the 2,000 gallon storage tank used to collect the stage 1 BAF effluent and feed the stage 2 BAF.
- Stage 2 showed an increase in the effluent COD. This was attributed to a timer malfunction and resulting over feeding of supplemental carbon.
- The stage 2 BAF showed complete denitrification during and after the stress event indicating a robust and well attached biomass.

For the full strength, high-peak flow increase medium duration (6 hours at elevated condition) test the following was observed:

- The DO concentration in the stage 1 BAF was depressed during the event. Note the air flow to this stage was not adjusted during this stress test. An expected result of depressed DO would be the partial loss of nitrification which was observed. The DO returned to pre-stress condition in approximately 6 hours of returning to pre-stress flow conditions.
- Statistically the event had a significant impact on the stage 1 NH_3 (COD and TSS were the other constituents measured). It should be noted that during the event the NH_3 loading to the stage 1 BAF was approximately 2.7 times greater than the design loading rate.
- The stage 1 BAF NH_3 recovery to less than 1 mg/l in 6 hours or returning to pre-stress flow conditions.
- Although TSS changes were not statistically significant there was a significant impact on the stage 1 BAF effluent with concentrations as high as 130 mg/l. The TSS from stage 1 did recover to less than 30 mg/l within 3 hours of the system returning to pre-stress conditions. The change in the stage 1 BAF TSS before during and after the event were not considered statistically significant likely due to the high background TSS concentration observed for the stage 1 BAF due to a pre test backwash that was performed.
- The stage 1 BAF effluent COD concentrations did not return to background levels during the analysis period (6 hours) after the stage 1 BAF was returned to pre-stress flow conditions. It should be noted that the BOD loading to the BAF during the event was 535 lb BOD / 1000 cf* day vs the temperature corrected design loading rate of 179 lb BOD/1000 cf *day. This may have also impacted the nitrification in the reactor during the event (incomplete carbon oxidation inhibiting nitrification).
- The high TSS concentration from the stage 1 BAF and the slower recovery of the NH_3 removal (relative to the full strength, peak flow medium duration event (see above)) and the elevated COD concentrations in the effluent may indicate a partial washout of the biomass the biomass in the stage 1 BAF at these very high flows.

- Statistically the event had a significant impact on the stage 2 TSS. The stage 2 BAF effluent ammonia was not measured during or after this event. The increase in the TSS observed in the stage 2 BAF effluent was attributed to the 2,000 gallon storage tank used to collect the stage 1 BAF effluent (high in TSS during the event) and feed the stage 2 BAF.
- The stage 2 BAF showed complete denitrification during and after the stress event. Even though the TSS increased in the stage 2 BAF effluent, the lack of impact on the denitrification indicates a robust and well attached biomass in the stage 2 BAF.

For the full strength, high-peak flow increase extended duration (28 hours at elevated condition) test, the following was observed:

- The DO concentration in the stage 1 BAF was significantly depressed during the event. Note the air flow to this stage was not adjusted during this stress test. An expected result of depressed DO would be the partial loss of nitrification which was observed. The DO returned to pre-stress condition in approximately 10 hours of returning to pre-stress flow conditions.
- Statistically the event had a significant impact on the stage 1 NH₃, TSS, and COD (no other constituents were measured).
- It should be noted that during the event the NH₃ loading to the stage 1 BAF was approximately 2.4 times greater than the design loading rate. The stage 1 BAF NH₃ recovered to less than 1 mg/l in 10 hours of returning to pre-stress flow conditions.
- The stage 1 BAF TSS was above the 30 mg/l limit (with data as high as 80 mg/l for the majority of the event with it falling below the 30 mg/l goal at the very end of the high flow event). Subsequent to returning to pre-stress flow rates the TSS recovered to the 30 mg/l goal in 1 hour.
- The stage 1 BAF 1 COD increased during the high flow event and decreased significantly (below pre-stress conditions) after the flow was returned to the pre-stress conditions. It should be noted that the BOD loading to the BAF during the event was 563 lb BOD / 1000 cf* day vs the temperature corrected design loading rate of 179 lb BOD/1000 cf *day. This may have also impacted the nitrification in the reactor during the event (incomplete carbon oxidation inhibiting nitrification).
- The high TSS concentration from the stage 1 BAF and the slower recovery of the NH₃ removal (relative to the full strength, peak flow medium duration event (see above)) may indicate a partial washout of the biomass the biomass in the stage 1 BAF at these very high flows. It is also possible the any biomass that may have washed out during the previous stress test may not have fully recovered prior to the being of this stress test and may have slowed the stage 1 NH₃ recovery.
- Statistically the event had a significant impact on the stage 2 TSS. The stage 2 BAF effluent ammonia was not measured during or after this event. The increase in the TSS observed in the stage 2 BAF effluent was attributed to the 2,000 gallon storage tank used to collect the stage 1 BAF effluent (high in TSS during the event) and feed the stage 2 BAF.
- The stage 2 BAF showed complete denitrification during and after the stress event. Even though the TSS increased in the stage 2 BAF effluent, the lack of impact on the denitrification indicates a robust and well attached biomass in the stage 2 BAF.

3.2.5 3 Conclusions. Based on the hydraulic stress testing the following conclusions can be made based on the simulated storm events:

- Denitrification was the least sensitive to hydraulic stress applied as full denitrification of the influent nitrate to the stage 2 BAF continued throughout the stress tests.
- Nitrification was the most sensitive parameter to the increase in flow, and associated decrease in detention time, during the stress tests. Recovery was typically rapid, indicating that a sufficient number of nitrifying bacteria were retained in the system and were not washed out during the tests.
- During the hydraulic stress testing there was an increase in the stage 1 effluent TSS and thus stage 2 saw an increase TSS load during the event. Piloting did not show an adverse impact in stage 2, however in final design this increased load should be accounted for.
- Consideration should be given to the volume and/or control of the clear wells between the different filter stages to minimize the impact of a upstream filter upset impacting the downstream filters for an extended period of time (as was seen with the long during increase in NH_3 in the stage 2 BAF feed due to the 2,000 gallon storage tank volume.) Possible means to control this impact would be to minimize the clear well volumes or provide control that would backwash a cell immediately after a process upset and recovery (in the upstream filters) to remove the upset process water stored in the clear well and begin to feed the downstream filters recovered upstream filter effluent.
- In a full scale design care should be taken to match the supplemental carbon feed to the demand to prevent overdosing of the carbon resulting increased BOD in the effluent and the additional costs associated with overdosing the carbon.
- The high peak flow rates were selected based on the hydraulic loading rates for the 3 stage BAF (C, N, DN) configuration. However, the pilot 2 stage BAF had both the C and N in a single media bed with reduced biomass populations and detention times when compared to the 3 stage BAF configuration. While the test at the high peak flow rates provided some insight into the potential for washout of the biomass, it may not be representative of how the 3 stage configuration would have responded to the increased flow rates.

3.2.6 Concerns with Fats Oils and Grease.

It was identified in the November 15, 2010 Wastewater Master Plan Final Submission that there were potential concerns with the BAF system being able to treat the primary effluent at the Peirce Island WWTF since the raw wastewater is known to have a significant grease concentrations on occasion. This concern was based on other earlier BAF piloting efforts in other locations. Based on samples collected during the Portsmouth BAF pilot operation and as part of the WWTF wastewater characterization data, the WWTF influent FOG concentrations averaged 26 mg/l with a maximum observed concentration of 44 mg/l. Based on observations during the BAF pilot operation there did not appear to be any issues associated with FOG build up in the BAF reactors or an excessive amount of floating grease on the primary clarifiers.

3.2.7 Pilot Observations and Considerations for Full Scale Implementation

- The BAF pilot system was simple to operate, partly due to the automation built into the pilot system, the pilot being a complete vendor package and to the nature of the process. Mechanical issues that interrupted the BAF operation were commonly issues such as stuck level-indicating floats that prevented the system from restarting after a backwash cycle.

- The existence of the large backwash water supply tank caused delays with the acclimation of the C/N BAF system, as high solids were re-introduced into the stage 1 BAF during each backwash cycles. When the solids were flushed from the storage tank, the C/N system began to completely nitrify the influent TKN within 24 hours. It is believed that this issue was more a nature of the pilot unit's pilot set-up and not commonly associated with full-scale systems
- The use of the stage 1 BAF effluent tank as the stage 2 BAF feed tank made it difficult to assess the stage 2 BAF performance on some occasions, especially during short duration stress tests when the stage 1 BAF effluent water quality was rapidly changing. The tank itself might have affected the stage 2 BAF influent water quality by retaining settled solids as well as attenuating the concentration. Additionally, the stage 2 BAF feed water was observed on occasion to be poorer quality than the stage 1 BAF effluent, suggesting the possibility of biological activity in the stage 1 BAF effluent/stage 2 BAF feed tank. This should not be an issue in a full-scale facility since these systems are not commonly designed with a large intermediate feed tank. Some BAF manufacturers do however have intermediate clear wells for the purposes of backwash storage water. The operation of these clear wells to avoid the issues above should be addressed during detailed design.
- The pilot operators suspected that there was potential to improve the effluent water quality by adjusting the air feed to reduce or better control turbulence in the bed. Two sets of samples showed effluent TSS that was less than 5 mg/L. Subsequent attempts to recreate the air feed conditions were abandoned because the air control valve had insufficient fine-tuning capabilities (in effect the air regulators allowed two settings: off and high, separated by perhaps a 20° turn of the regulator control knob). The vendor should be consulted to determine if there are significant improvements that could be achieved with better air flow control, and care should be expressed that the full-scale design should include the ability to control the air flow control.
- The flow rate into the BAF pilot system was controlled by a PID loop, and remained very constant during the pilot study. The pilot system did not duplicate varying flow conditions that the full scale system would be subjected to. Kruger states that their full scale systems operate multiple cells within a limited range of flows, and that large variations in flow are accommodated by bringing cells online or offline however there is a limit to how many cells can be on and off-line in this fashion. The control of flow variations should be addressed during detailed design.
- The hydraulic stress tests did test the capacity of the BAF to accommodate large and sudden changes in flow and loading. The results of the 24 hour stress tests suggested that the BAF filters did in fact perform well in response to significant increases in nitrogen loads. Over the course of each 24 hour stress test, the stage 1 BAF effluent ammonia concentrations initially increased in concentration, but then decreased, suggesting that the nitrifying bacteria in the filter had the capacity to treat a wide range of influent ammonia loads if given sufficient time to acclimate and react. The change in hydraulic load had much less effect upon performance than the change in mass load.
- One observed disadvantage of the BAF pilot system was the inability to access the media zones inside the filter to troubleshoot performance. There were a series of taps on the outside of the pilot filter, but the media retention screens were not functioning and samples could not be obtained. This feature should be considered as part of a full-scale design.
- Piloting showed that the BOD design loading rate may be able to be increase and thus a reduction in the size and capital cost of the installation be realized.

- The stage 1 BAF operational change from a carbon only removal mode to a carbon-ammonia removal mode was difficult and consumed a lot of time. Troubles were encountered in getting the system to nitrify. It was theorized that the established carbon only attached biomass were inhibiting the establishment of nitrifying bacteria. This issue should be addressed if seasonal nitrogen limits are imposed.
- It is recommended that during preliminary design consideration be given to evaluating a three stage system (carbon oxidation, nitrification, and denitrification) for the purpose of improving operational flexibility and/or performance. It should be noted that a three stage system will increase the overall system footprint.
- It is recommended that during preliminary design consideration be given to evaluating a MLE configuration for the BAF system. The result would be potentially a one stage system when achieving high TN effluent limits and a polishing second denitrification stage. It should be noted that a MLE configuration may reduce operating costs, but will necessitate a sole source procurement for the BAF technology.
- The BAF technology uses its effluent for backwash which will mean that treatment sizing capacity and flow through capacity are not equal to each other. The volume of backwash needed and ultimately retreated by the BAF is substantial especially since there are two stages. The backwash volume and characteristics need to be considered in system sizing as well as solids processing.
- The BAF is considered an easy system to operate since it is highly automated. On the other hand the system is very difficult if not impossible to operate in a manual mode making I&C maintenance that much more critical for the BAF technology.
- The technical support provided by the BAF vendor was very knowledgeable which suggested the BAF can be considered as a mature technology.

3.3 CONVENTIONAL ACTIVATED SLUDGE WITH BIOMAG (CAS-BIOMAG)

The conventional activated sludge system with BioMag (CAS-BioMag) pilot was examined to assess its ability to remove carbon (BOD) and total suspended solids to meet secondary treatment effluent limits as well as to meet total nitrogen (TN) effluent limits (8 mg/l and 3 mg/l) under different constituent loading and hydraulic loading conditions.

For the BOD removal testing, the CAS-BioMag system was operated as a conventional activated sludge system with only aeration zones (one zone with a total aerobic volume of 2,700 gallons) for average day BOD loading testing and two zones (with a total aerobic volume of 3,900 gallons) for maximum month BOD loading testing. For the TN goal of 8 mg/l testing the system was converted to a MLE system to also include a pre-anoxic zone and an internal recycle from the downstream end of the second aeration zone (total volume under aeration 2,900 gallons). For the TN of 3 mg/l testing, the system was converted to a 4 stage Bardenpho configuration (pre-anoxic zone, aeration zone, denitrification zone with supplemental carbon addition, and a post aerobic zone). The total volume under aeration was 2,900 gallons for this testing. Under all testing phases, the process reactors were followed by clarifiers (the pilot had two clarifiers that could operate in parallel but typically only one was operated) for solids removal. Settled solids were returned to the reactors via return sludge pumping. It should be noted that polymer was added to the CAS-BioMag system intermittently throughout the testing (specifically during the 24 hour stress test in EP-04 and the beginning of EP-05). The CAS-BioMag testing was conducted from 1/29/12 to 7/14/12. The Blueleaf Incorporated Pilot Report included in Attachment B, presents a detailed physical description of the CAS-BioMag pilot system, the CAS-BioMag pilot phases and associated test conditions, as well as the data collected during the various phases to assess the performance of this technology.

3.3.1 Experimental Plan Summary

Table 3-5 presents a brief summary of the experimental plans that were used to evaluate the CAS-BioMag technology. The results of these experiments are discussed below.

3.3.2 Data Presentation

Table 3-6 presents a summary of the data collected for the different experimental plans carried out on the CAS-BioMag system with the exception of EP-04. For EP-04, a transient hydraulic and organic load was imposed on the technology. The purpose of applying a transient load was

Table 3-5. CAS-BioMag Experimental Plan Summary

Experimental Plan (EP) Number	Test Conditions	Testing Objective
EP-01	Average Daily BOD Loading	BOD and TSS Removal
EP-02	Maximum Month BOD Loading	BOD and TSS Removal
EP-03	Maximum Month BOD Loading	BOD removal, TSS Removal and TN < 8 mg/l
EP-04	Hydraulic Stress Tests	BOD removal, TSS Removal and TN < 8 mg/l
EP-05	Maximum Month BOD Loading Elevated Ammonia Loading	BOD removal, TSS Removal and TN < 8 mg/l
EP-06	Maximum Month BOD Loading Elevated Ammonia Loading	BOD removal, TSS Removal and TN < 3 mg/l

to evaluate the removal performance of the system under different flow and loading conditions as well as evaluate the ability of the technology to recover after applying these short term loads. For all of the experimental plans with the exception of EP-04, the goal was to examine the performance based on a target loading basis, not a hydraulic basis. The hydraulic stress testing conducted in EP-04 will be discussed separately at the end of this section.

The water quality data (concentration values) presented in Table 3-6 are presented in one of the two following formats:

- For large data sets- Median value (minimum value – maximum value) [number of samples] is provided
- For small data sets - value, value, value, is provided

It should be further noted the data for all of the experiment trials are also presented graphically as time plots. These data along with the time plots are part of the Blueleaf Incorporated Pilot Report which is included as Attachment B of this report.

3.3.3 Ability to Meet Pilot Study Effluent Concentration Goals

The following is a brief summary describing the ability of the CAS-BioMag to meet the BOD, TSS and TN effluent concentration goals under the conditions described within the experimental plans.

3.3.3.1 BOD. For all of the non hydraulic stress experimental plans and all of the data collected the CAS-BioMag was able to meet the BOD goal of 30 mg/l. The average effluent BOD concentration was less than 10 mg/l and the effluent concentration often less than 5 mg/l.-

Table 3-6. CAS-BioMag Experimental Plan Data Results

	Experimental Plan Summaries									
Parameter	EP-01 Target	EP-01 Results	EP-02 Target	EP-02 Results	EP-03 Target	EP-03 Results	EP-05 Target	EP-05 Results	EP-06 Target	EP-06 Results
Test Condition	Average Daily BOD Loading		Maximum Month BOD Loading		Maximum Month Daily BOD Loading		Maximum Month BOD Loading Elevated Ammonia Loading		Maximum Month BOD Loading Elevated Ammonia Loading	
Test Objective	BOD and TSS Removal		BOD and TSS Removal		BOD, TSS, and TN < 8 mg/l		BOD, TSS, and TN<8 mg/l		BOD, TSS, and TN< 3 mg/l	
Influent Flow Rate (gpm)	8.2	7.0 (4.8 – 10.9)	8.2	5.9 (+ 11 to clarifier)	11.4	10.9 (+ 4 to clarifier)	13.5	9.8	13.5	8.5
Reactor MLVSS, mg/l	NA	1,680 (1,404 – 2,108) [21]	NA	1,870 (1,620 – 2,080) [12]	NA	2,550 (1,715 – 8,635) [20]	NA	3,190 (2,870 – 3,570) [12]	NA	3,040 (2,835 – 3,200) [12]
Clarifier Surface Overflow Rate (gpd/sf)	1,038	630	1,445	1,521	1,445	1,340	1444	792	704	792
Clarifier Solids Loading Rate (lbs/sf*day)	46	37	60	28	71	55.1	60	56	70	24.0
Influent BOD (mg/l)	NA	210 (89-273) [3]	NA	186 (161 - 227) [10]	NA	225 (151-355) [18]	NA	210 (127-490) [18]	NA	280 (157-395) [30]
Influent TSS (mg/l)	NA	105 (62-151) [36]	NA	113 (99-130) [12]	NA	133 (78-182) [19]	NA	100 (70-146) [12]	NA	123 (98-145) [10]
Influent Ammonia (mg/l)	NA	NA	NA	NA	NA	18.7 (13.2 – 26.9) [10]	NA	30 (18-56) [17]	NA	41 (22-58) [19]
BOD Loading Rate (lbs BOD/1000 cf * day)	35	39	60	28	60	62	60	56	60	73
BOD Loading Rate (lbs BOD/lbs MLVSS*day (F:M))	NA	0.37	NA	0.24	NA	0.39	NA	0.28	NA	0.39
NH ₃ Loading Rate (lbs NH ₃ /1000 cf * day)	NA	NA	NA	NA	NA	0.040	NA	0.041	NA	0.057
Effluent BOD Field (mg/l)	30	9.2 (6 – 13) [4]	30	4.7 (2 – 7.3) [6]	30	3.5 (1.6 – 5.9) [17]	30	NA	30	N/A
Effluent BOD Lab (mg/l)	30	<6, 11, 9	30	<6, <6, <6	30	<6, <6, <6	30	NA	30	NA
Effluent BOD –calculated from COD (mg/l)	30	7.7 (5 – 11) [19]	30	6.9 (3.6 – 14.8) [12]	30	5.3 (3.8 – 7.7) [20]	30	8.2 (5.2 – 15.1) [14]	30	11.2 (8.6 – 15.4) [8]
Effluent TSS Field (mg/l)	30	14.2 (7 - 26) [30]	30	14.2 (7.2 – 26.8) [12]	30	12.5 (4.8 – 32.8) [20]	30	10.7 (0 - 26) [14]	30	5.9 (1 – 12.8) [8]
Effluent TSS Lab (mg/l)	30	<5, 10, 9	30	10, 9, 13	30	<5, <5, 7	30	8, 13, 21	30	10, <5, 16, 6, 7
Effluent TN Field (mg/l)	NA	NA	NA	NA	8	3.8 (0.6 – 8.8) [10]	8	2.95 (0.83 – 5.51)	3	2.45 (1.2 – 4.1) [4]
Effluent TN Lab (mg/l)	NA	NA	NA	NA	8	3.6, 3.6, 11, 3.7, 2.8, 3.4	8	4.6, 6.1, 6.7	3	4.3, 2.2, 2.8
Effluent NH ₃ Lab (mg/l)	NA	NA	NA	NA	NA	NA	NA	0.72, 0.18, 0.20	NA	0.26, 0.11, 1.5, 0.44, 0.88
Effluent NO _x Lab (mg/l)	NA	NA	NA	NA	NA	NA	NA	2.4, 3.8, 4.8	NA	5.9, 2.8, <0.5, <0.5, <0.5

Data presentation format - For large data sets - Median value (minimum value – maximum value) [number of samples]
- For small data sets – sample value, sample value, sample value

3.3.3.2 TSS. For all of the non hydraulic stress experimental plans and all of the data collected (with the exception on one data point; 32.8 mg/l) the CAS-BioMag was able to meet the TSS goal of 30 mg/l. The average effluent TSS concentration was less than 15 mg/l. and the effluent concentration often less than 10 mg/l.

3.3.3.3 Total Nitrogen of 8 mg/l. For EP-03 the CAS-BioMag was able to meet the TN goal of 8 mg/l on an average basis. There was one excursion when the effluent was above a TN of 8 mg/l when the field data reported 8.8 mg/l and the laboratory tested data reported 11 mg/l. These high TN concentration samples had correspondingly high nitrate concentrations, suggesting that the amount of denitrification temporarily decreased. For EP-05 (elevated influent ammonia) the CAS-BioMag was able to meet the TN goal of 8 mg/l for all samples collected with some of the field samples collected during EP-05 below a TN of 3 mg/l. It should be noted that polymer was added to the CAS-BioMag system for the first 10 days of EP-05.

3.3.3.4 Total Nitrogen of 3 mg/l. EP-06 assessed the ability of the CAS-BioMag to meet an effluent TN of 3 mg/l at elevated ammonia loadings. During this experiment only a portion of the field samples and some of the laboratory samples showed the ability of this technology to produce a TN of 3 mg/l but not consistently. However, it is believed that with sufficient time to optimize the system the CAS-BioMag might be able to produce an effluent TN of 3 mg/l or less on a more consistent basis.

3.3.4 Loading Rate Validation

The experimental plans along with the data collected and evaluated during the CAS-BioMag pilot testing were designed to validate the vendor provided conceptual sizing. While the vendor did not provide specific design loading rates, design loading rates were back calculated from the conceptual design provided by the vendor. A comparison of the pilot data and the calculated vendor loading rates was performed to validate the vendor provided sizing. This exercise was done to assess if the system's reactors were sized correctly to meet the effluent concentration goals while treating Portsmouth's wastewater. If the process reactors were unable to meet the target effluent goals this would indicate that the vendor sizing was too aggressive (the result being recommending a system that is too small) and that a less aggressive design should be considered. If this was the case the result would be the need for larger process tankage/equipment. Conversely, if the process reactors were able to easily meet the effluent goals when they were operated at a high loading rate relative to the calculated vendor loading rate, this might indicate the vendor sizing might be too conservative and there may be the opportunity to increase the loading rate by decreasing the size of the process tankage/equipment. The Blueleaf Incorporated Pilot Report in Attachment B presents portions of the pilot loading data. This data and other data presented in Attachment B has been further manipulated and refined for presentation and discussion in the sections below.

3.3.4.1 Secondary/BOD Removal and Loading Rate Validation. Figure 3-3A and Figure 3-3B present the BOD load applied vs. the load removed on a volumetric and mass basis respectively through the CAS-BioMag system from the period of 1/29/12 to 7/17/12 when the experimental plans were being conducted (with the exception of EP-04 since this was a hydraulic test).

Volumetric Loading. Based on the vendor provided process configuration/design at 10°C, a BOD process loading rate of 57.6 lb BOD/1000cf*day was calculated. This calculation was based on the design loading to aerobic portion of the CAS-BioMag reactors. It should be noted that the calculated vendor loading rate is within the range of a typical complete mix or plug flow activated sludge systems (20-40 lb BOD/1000cf*day for plug flow systems and 20-100 lb BOD/1000cf*day for complete mix systems). The pilot CAS-BioMag was operated between these two conditions which is expected since the advantageous reduction in volume typically observed in CAS-BioMag systems is in the clarifier sizing. The BOD data presented in the figure was collected at an average wastewater temperature of 14.9°C and thus the calculated vendor design loading rate has been temperature corrected to 10°C. The temperature corrected vendor calculated design loading rate is 67.2 lb BOD/1000cf*day

Figure 3-3A. BOD Volumetric Loading and Removal through CAS-BioMag

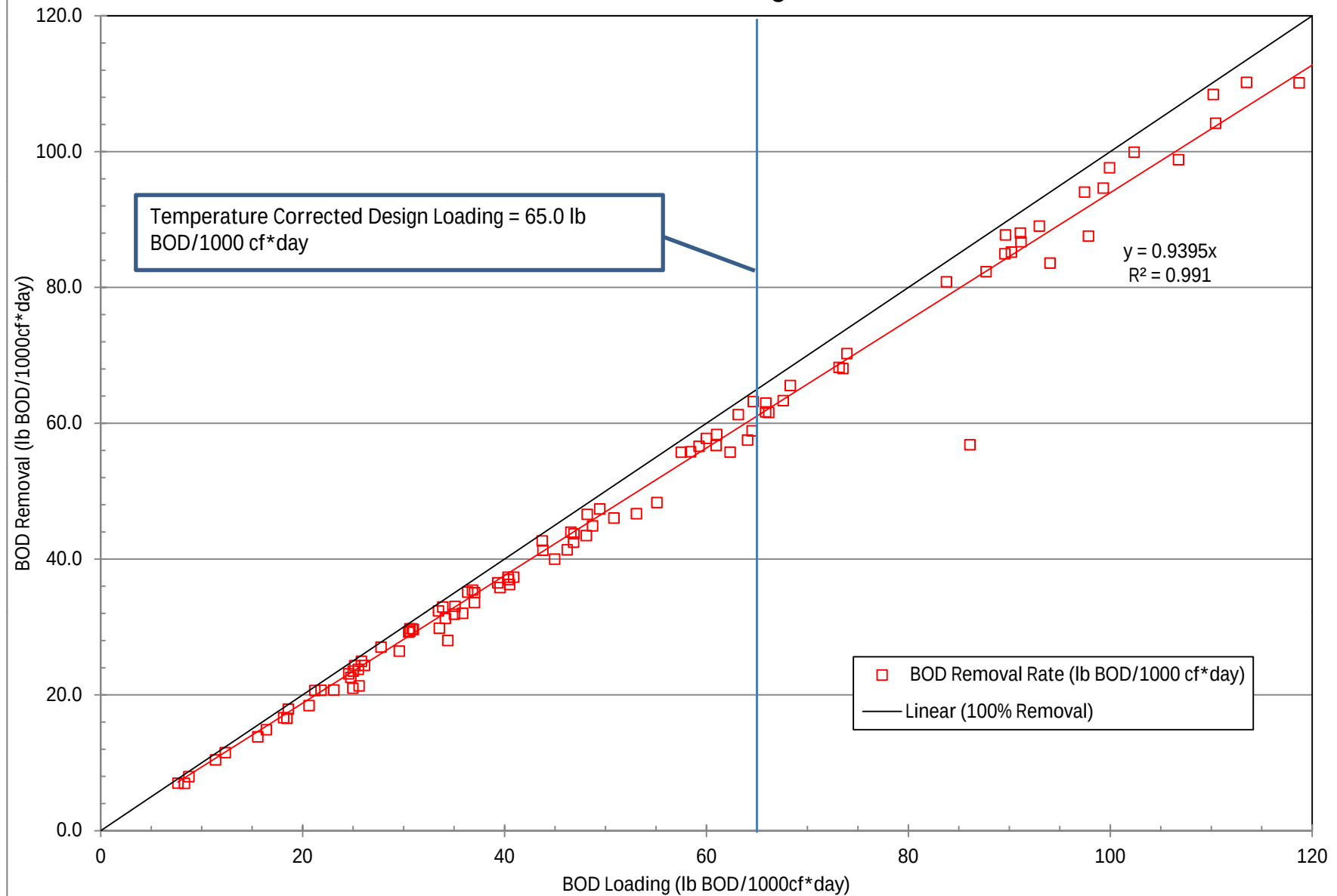
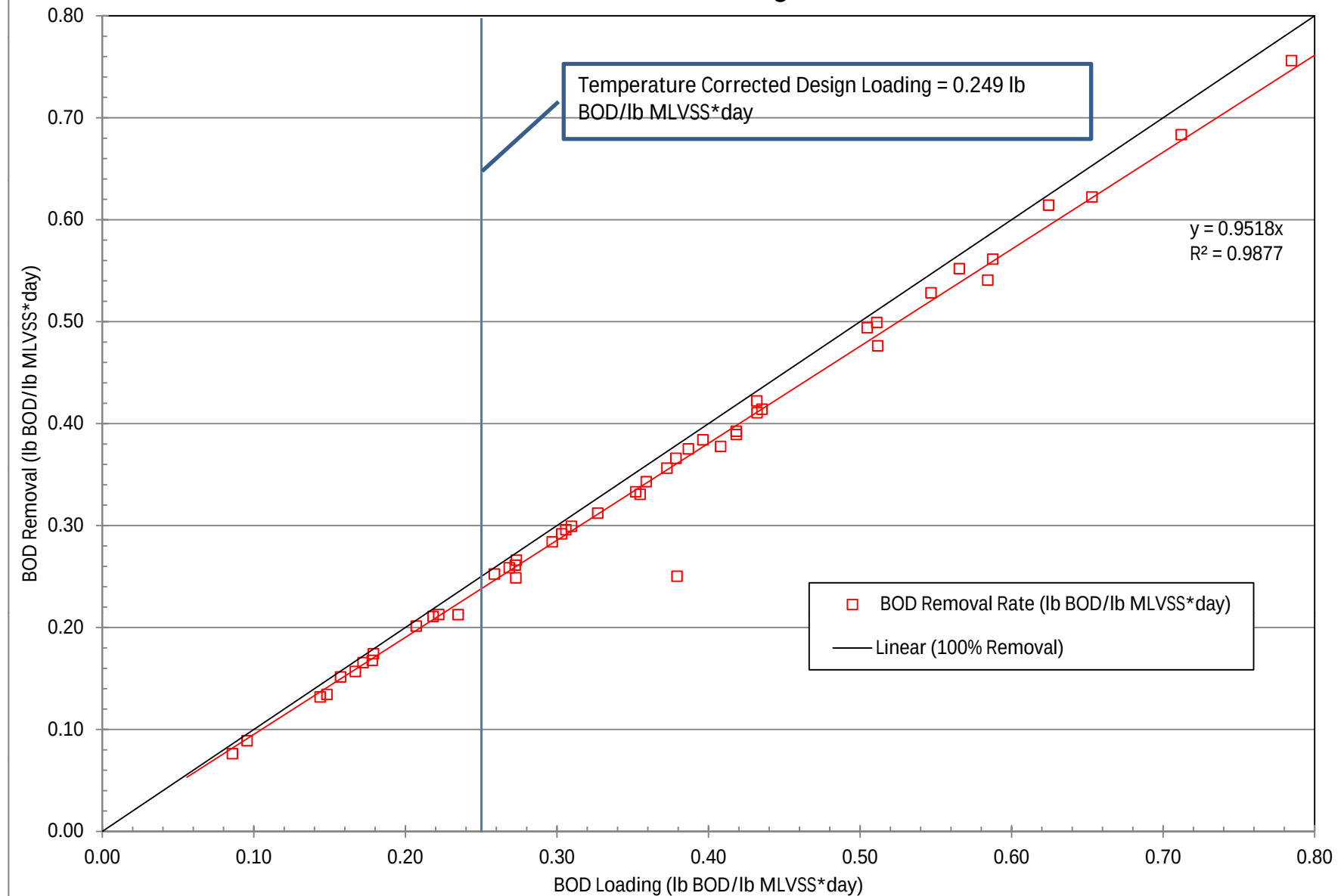


Figure 3-3B. BOD Mass Loading and Removal through
CAS-BioMag



which is equivalent to 57.6 lb BOD/1000cf*day at 10°C. The pilot data in Figure 3-3A show the following:

- The data shows a 94% removal of BOD rate across the CAS-BioMag (see the slope of the linear regression line) with respect to volumetric loading while treating Portsmouth primary effluent.
- The data shows a linear relationship between load applied and load removed. There was no tail-off of the data at higher loading rates. This indicates that in the range of loads tested that the performance of the CAS-BioMag was not adversely impacted by increased loads, and thus did not approach the maximum loading rate for the technology.
-
- The figure shows many data points both above and below the temperature corrected calculated vendor loading rate. All of the data collected are in the area of the temperature corrected loading rate and are on the linear part of the regression line. Some of the data collected was at loading that was approximately two times the temperature corrected calculated vendor volumetric loading rate and showed limited if any impact on the BOD removal performance. This indicates that the system is very robust and potentially could be run at increased loadings (smaller reactors).

Mass Loading. Based on the vendor provided process configuration/design at 10°C a BOD process loading rate of 0.208 lb BOD/lb MLVSS*day was calculated. This calculation was based on the design loading to the aerobic portion of the CAS-BioMag reactors along with the vendor's assumed MLVSS concentration. The BOD data presented in the figure was collected at an average wastewater temperature of 14.9°C, so the calculated vendor design loading rate has been temperature corrected. The temperature corrected vendor calculated loading rate is 0.249 lb BOD/lb MLVSS*day which is equivalent to 0.208 lb BOD/lb MLVSS*day at 10°C. It should be noted that the calculated vendor loading rate are within the range of a typical complete mix or plug flow activated sludge systems (0.2-0.5 lb BOD/MLVSS*day for plug flow systems and 0.2-1.0 lb BOD/MLVSS*day for complete mix systems). The pilot CAS-BioMag was operated between these two conditions which is expected since the advantageous reduction in volume typically observed in CAS-BioMag systems is in the clarifier sizing. The pilot data in Figure 3-3B show the following:

- The data shows a 95% removal of BOD rate across the CAS-BioMag (see the slope of the linear regression line) with respect to mass loading while treating Portsmouth primary effluent.
- The data shows a linear relationship between load applied and load removed. There was no tail-off of the data at higher loading rates. This indicates that in the range of loads tested that the performance of the CAS-BioMag was not impacted by increased loads, and thus did not approach the maximum loading rate for the technology at the observed MLVSS concentrations of 1,680 mg/l to 3,190 mg/L (which were also below the vendor's design MLVSS concentrations).
- The figure shows many data points both above and below the temperature corrected calculated vendor loading rate. All of the data collected are in the area of the temperature corrected loading rate and are on the linear part of the regression line. The data collected that was higher than the temperature corrected calculated vendor loading rate values some being approximately three times the this rate showed no adverse impact on the BOD removal performance. This indicates that the system is robust and potentially could be run at increased loadings at lower mixed liquor concentrations or with smaller reactors.

BOD Removal Performance Implications

Based on the results from the pilot testing, the ability of the CAS-BioMag to meet the anticipated future WWTF BOD permit limits was assessed. This includes the anticipated permit limits for average month, maximum week, and maximum day. Table 3-7 presents the anticipated WWTF BOD permit limits as well as the calculated maximum primary effluent concentration to meet the permit limits (based on 95% removal in the CAS-BioMag). Table 3-7 also shows the calculated maximum WWTF influent BOD concentrations to meet permit limits based on the 95% CAS-BioMag BOD removal and the anticipated primary clarifier BOD removal range. The calculated maximum influent BOD concentrations for each permit condition are presented as two values. These values are based on the anticipated range of primary clarifier BOD removals (15% - 30%) identified in the Revised Flow and Loading memorandum included in Attachment C.

In order for the CAS-BioMag to be able to meet the anticipated BOD permit limits, the maximum WWTF influent BOD concentration cannot exceed the range of influent BOD values shown in Table 3-7 or exceed the maximum primary effluent concentrations noted above both for maximum month, maximum week and maximum day conditions, respectively. It is not anticipated that the WWTF influent and primary effluent BOD concentrations will exceed the values in the Table 3-7 for the different WWTF conditions (max month, week, and day).

Table 3-7. Maximum BOD Concentrations with Primary and CAS-BioMag Treatment To Meet WWTF Permit Conditions.

WWTF BOD Permit Condition	WWTF BOD Effluent Limit, mg/l	Maximum Primary Effluent Concentration with 95% BOD Removal in CAS-BioMag, mg/l	Maximum WWTF Influent BOD Concentration, mg/l	
			15% BOD Removal in Primary Treatment	30% BOD Removal in Primary Treatment
Maximum Month	30	600	706	857
Maximum Week	45	900	1,059	1,285
Maximum Day	50	1,000	1,176	1,429

3.3.4.2 Ammonia Removal and Loading Rate Validation. Figure 3-3C and Figure 3-3D present the ammonia load applied vs. the load removed on a volumetric and mass basis, respectively, through the CAS-BioMag system from the period of 5/15/12 to 7/17/12 (with the exception of the testing performed in experimental plan EP-04).

Volumetric Loading Rate. Figure 3-3C presents the NH_3 load applied ($\text{lb NH}_3/1000\text{cf}\cdot\text{day}$) vs. the load removed ($\text{lb NH}_3/1000\text{cf}\cdot\text{day}$) on a volumetric basis. Based on the vendor provided process configuration/design at 10°C , a NH_3 process loading rate of $15.3 \text{ lb NH}_3/1000\text{cf}\cdot\text{day}$ was calculated. This calculation was based on the assumed ammonia loading to the aerobic portion of the CAS-BioMag reactor. The assumed ammonia loading rate to the aerobic portion of the reactor was based on the CAS-BioMag influent TKN concentration minus some TKN uptake for removal BOD cell growth (assumed to be 3.5% of the BOD removed in the CAS-BioMag system). As the NH_3 data presented in the figure was collected at an average wastewater temperature of 19.1°C the calculated vendor design loading rate has been temperature corrected. The temperature corrected vendor calculated loading rate is $20.9 \text{ lb NH}_3/1000\text{cf}\cdot\text{day}$ which is equivalent to $15.3 \text{ lb NH}_3/1000\text{cf}\cdot\text{day}$ at 10°C .

Figure 3-3C. Ammonia Volumetric Loading Rate vs. Removal through CAS- BioMag

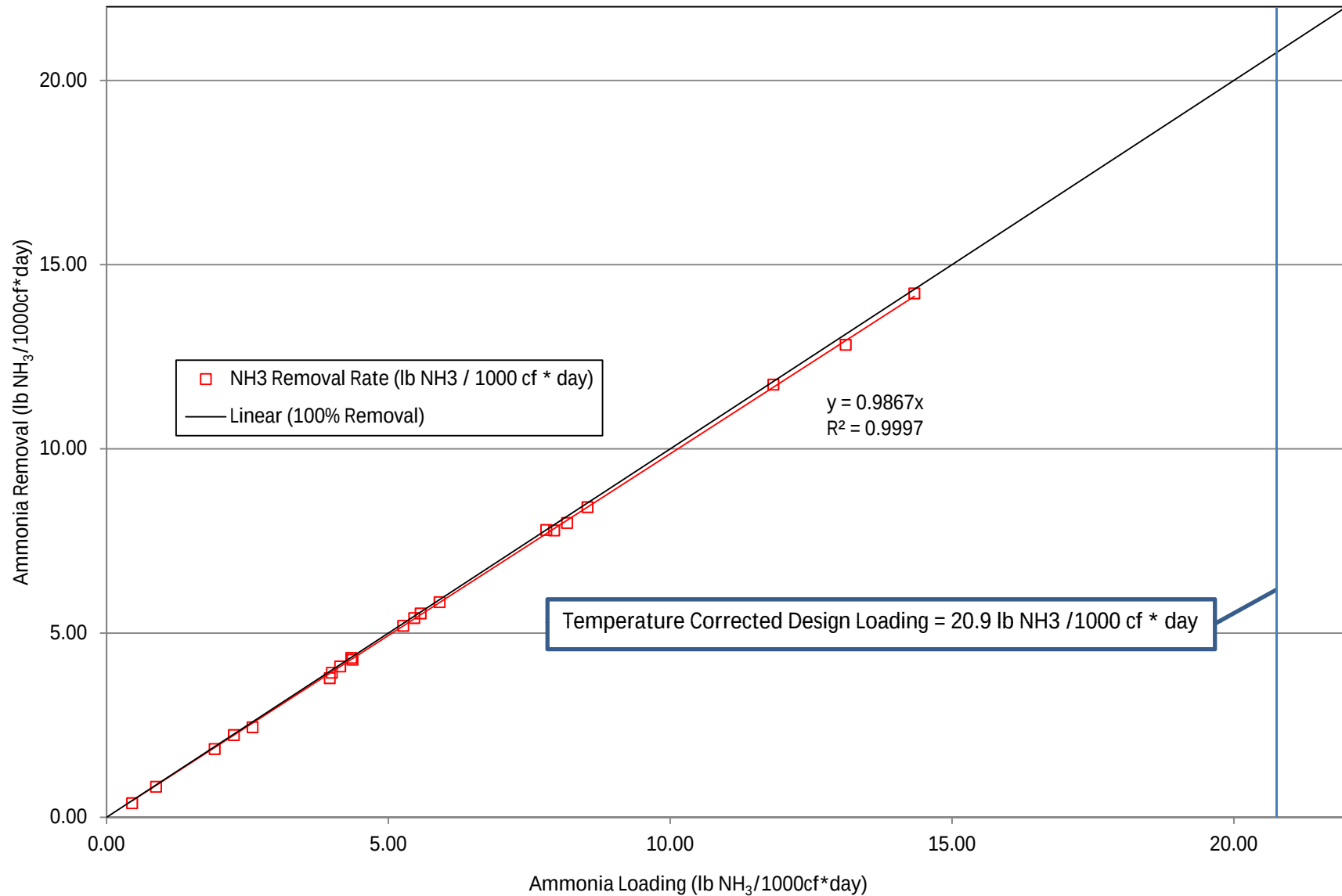
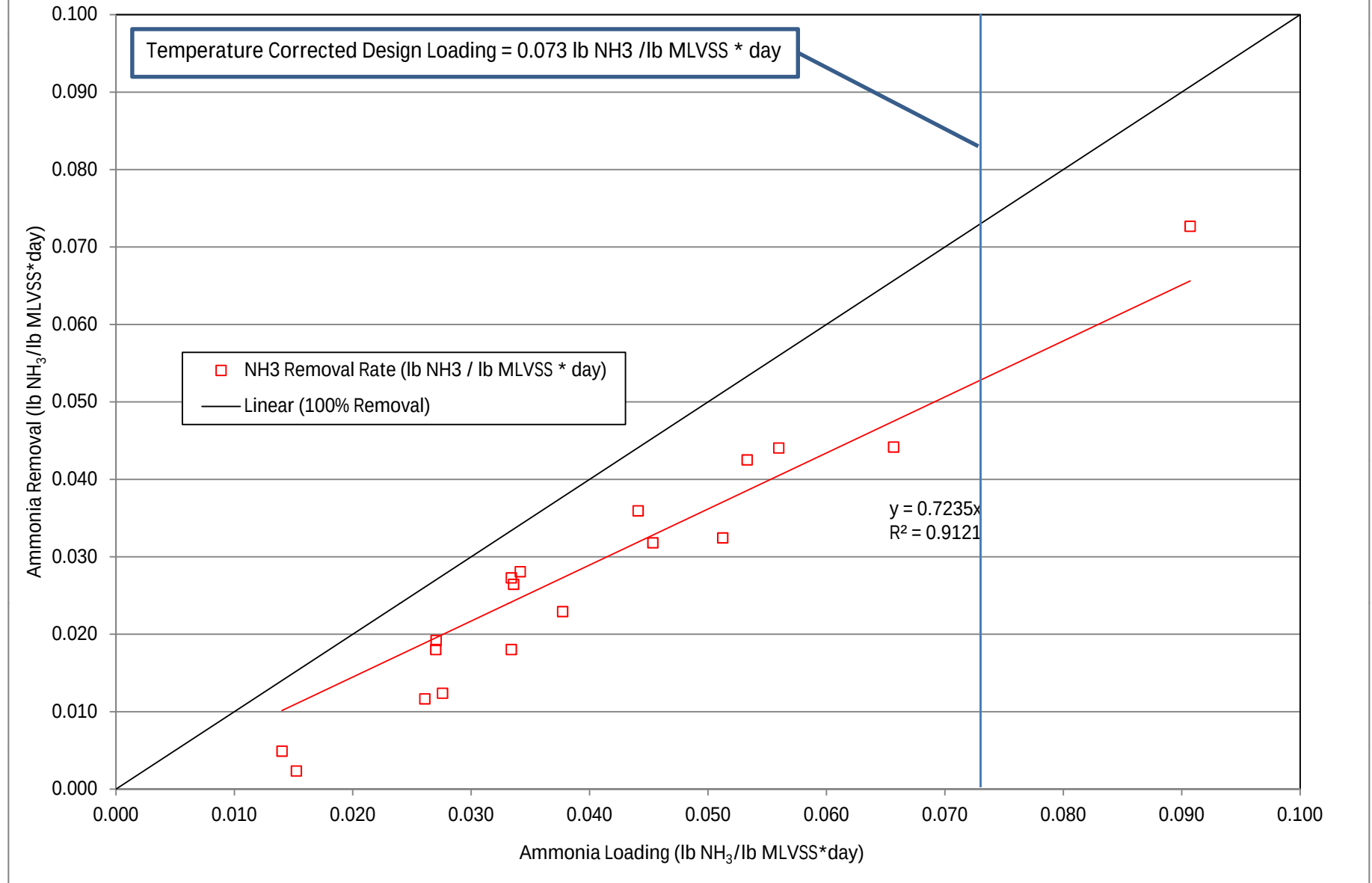


Figure 3-3D. Ammonia Mass Loading Rate vs. Removal through CAS-BioMag



The pilot data and this figure show the following:

- There is a good linear correlation between the applied surface area loading rate and the surface area removal rate for the loading rates applied during piloting.
- The figure only shows data points below the calculated vendors loading rate.
- The maximum loading rate tested during the pilot study was approximately 66% of the temperature corrected calculated vendor design loading rate.
- Although the loading rates evaluated never reached or exceeded the temperature corrected calculated vendor design loading rate, the pilot loading rates observed showed no decrease in ammonia removal. Due to the fact that the pilot testing loading rates did not reach the vendor calculated loading rates it does not appear that consideration should be given to reducing the size of this system on a volumetric ammonia loading basis. Other loading rate metrics as well as removal performance should be examined to make further support this determination.

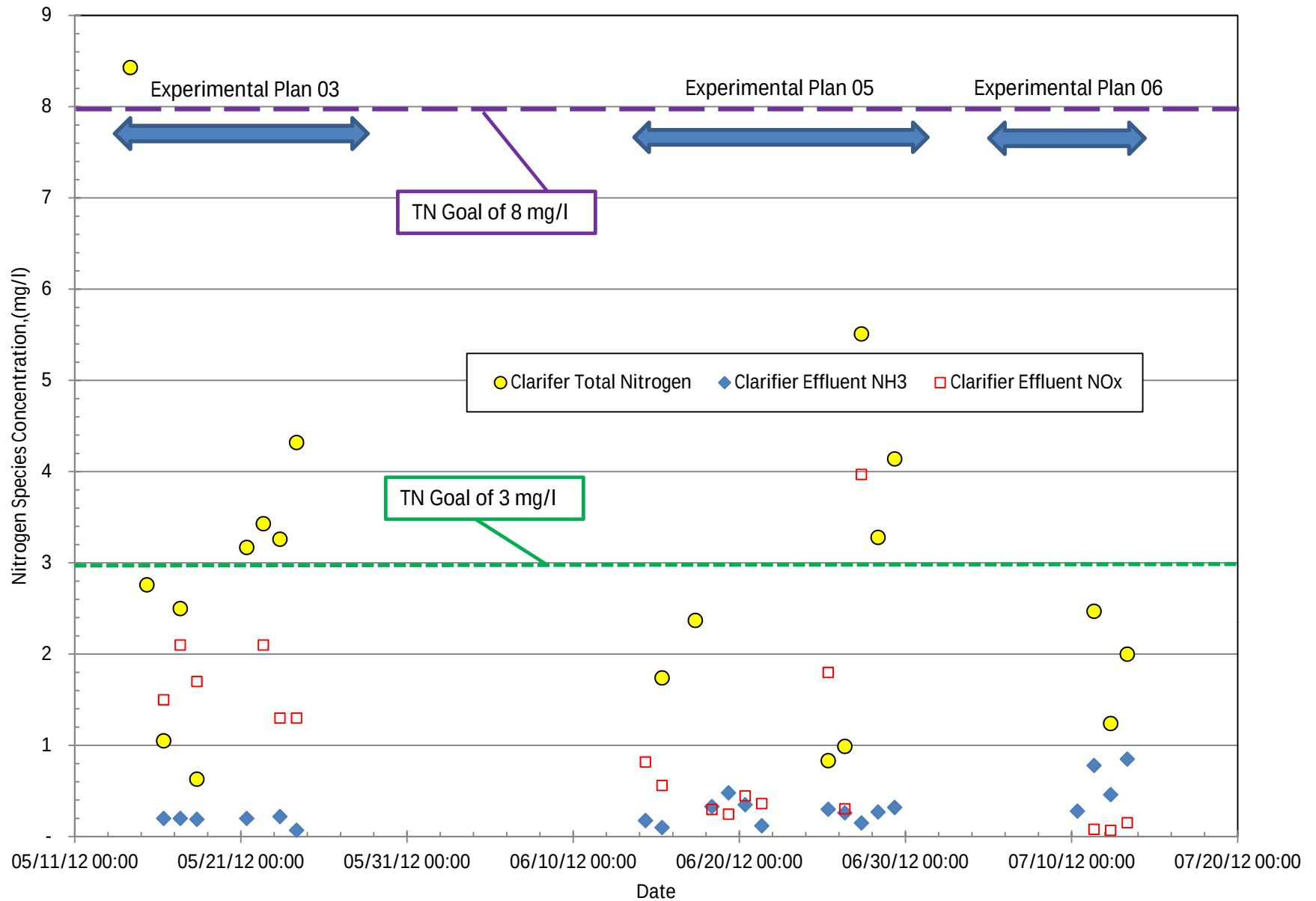
Mass Loading Rate. Figure 3-3D presents the ammonia removal observed through the CAS-BioMag from 5/15/12 to 7/14/12 on a mass loading basis during the periods when the experimental plans were being conducted (with the exception of EP-04). The data is presented as the loading rate (lb NH₃/lb MLVSS*day) vs. the removal rate (lb NH₃/MLVSS cf*day) on a mass basis. Based on the vendor provided process configuration design at 10°C, a NH₃ process loading rate of 0.053 lb NH₃/lb MLVSS*day was calculated. This calculation was based on the assumed ammonia loading to the aerobic portion of the CAS-BioMag reactor. The assumed ammonia loading rate to the aerobic portion of the reactor was based on the CAS-BioMag influent TKN concentration minus some TKN uptake for removal BOD cell growth (assumed to be 3.5% of the BOD removed in the CAS-BioMag system) and the provided vendor assumed MLVSS concentration. Since the NH₃ data presented in the figure was collected at an average wastewater temperature of 19.3°C, the calculated vendor design loading rate has been temperature corrected to the cold weather design rate of 10C. The temperature corrected vendor calculated loading rate is 0.073 lb NH₃/LB MLVSS*day which is equivalent to 0.053 lb NH₃/lb MLVSS*day at 10°C.

The pilot data and this figure show the following:

- There is a good linear correlation between the applied mass loading rate and the mass removal rate for the loading rates applied during piloting.
- The figure shows most data points below the calculated temperature corrected vendor loading rate and one data point slightly above the temperature corrected loading rate without a decrease in removal performance. All of the data appears to have a linear relationship without the performance decreasing at the higher loading rates. This indicates that the assumed MLVSS concentration with reactors of this size were adequate to achieve necessary performance. Based on this data it does not appear that consideration should be given to reducing the size of this system from an ammonia removal stand point in the future.

Effluent Ammonia. Another way of evaluating the performance of the nitrification step in the CAS-BioMag process is to examine the actual effluent ammonia concentration during the test period. Since the overarching goal is consistent complete nitrification, expected ammonia concentrations should be below 1 mg/L routinely. The CAS-BioMag effluent nitrogen speciation data, including effluent NH₃ data collected during experimental plans EP-03, EP-05, and EP-06 are shown in Figure 3-3E.

Figure 3-3E. CAS-BioMag Aveage Daily Effluent Nitrogen Species



With respect to NH₃ data, this figure shows that:

- All of the effluent NH₃ data is below 1 mg/l indicating complete nitrification (NH₃ < 1.0 mg/l) during the entire period.
- The NH₃ data from EP-05 and EP-06 (CAS-BioMag feed spiked with NH₃) only showed a slight increase in effluent ammonia.

Based on the fact that the system showed no deterioration in performance when loaded at ammonia loading rates above calculated design loading rate and the fact that the system was able to provide complete nitrification throughout the entire test period, it is believed that this system is robust and will be able to provide consistent good ammonia removal which will provide a solid basis for achieving low effluent total nitrogen concentrations.

3.3.4.3 Denitrification (Nitrate Removal). Due to the fact that the CAS-BioMag system was run in two different nitrogen configurations (MLE and 4-stage Bardenpho) and the difficulty in collecting samples between the CAS zones, no evaluation of the nitrate removal rates for this technology were performed. The overarching goal is to have consistent desired denitrification rates for each of the respective nitrogen limits. To achieve low effluent total nitrogen effluent concentrations, essentially complete denitrification is required. When the goal is higher total nitrogen, say 8 mg/L, the denitrification does not have to be as efficient. So, another way of looking at the performance of the denitrification (nitrate removal) in the CAS-BioMag is to examine the effluent nitrate and total nitrogen concentrations for the condition. As noted in the section above, the CAS-BioMag effluent nitrogen speciation data collected during experimental plans EP-03, EP-05, and EP-06 are shown in Figure 3-3E.

With respect to NO_x and total nitrogen this figure shows that:

- For EP-03 the effluent NO_x concentration was typically between 2.1 mg/l and 1.3 mg/l
- For EP-05 the effluent NO_x concentration was typically between 1.8 mg/l and 0.2 mg/l which the exception of one excursion that was as high as 4.0 mg/l NO_x. The improved effluent NO_x concentrations between EP-03 and EP-05 was believed to be due to a longer acclimation period as well as the familiarity of running the pilot system in a TN of 8 mg/l mode.
- For EP-06 the effluent NO_x concentration was between 0.2 mg/l and 0.1 mg/l. This improvement over EP-05 was attributed to the addition of a second denitrification zone and the addition of supplemental carbon.
- For EP-03 and EP-05 both with a TN goal of 8 mg/l the total nitrogen, values were less than the 8 mg/l goal with the exception of one data point during EP-06. In addition during these trials the CAS-BioMag was able to produce a TN of less than 3 mg/l on a number of occasions (although not reliably) without the second denitrification zone or supplemental carbon addition as was used in EP-06.
- EP-06 showed the ability of the CAS-BioMag to meet the TN limit of 3 mg/l however not reliably.

Based on the CAS-BioMag performance it is believed that a CAS-BioMag system can meet a desired effluent TN concentration of 8 mg/l (reliably) and probably meet 3 mg/l (intermittently) at the Peirce Island WWTF.

3.3.4.4 CAS-BioMag Clarifier Solids Removal. To assess the performance of the BioMag clarifier, data was collected and evaluated from the pilot BioMag clarifier as well as bench top settling tests. This data is presented below.

Solids Loading Rate (SLR). Figure 3-3.F presents the CAS-BioMag clarifier solids loading rate vs. the clarifier effluent TSS during all of the experimental plans with the exception of the hydraulic stress tests performed in EP-04. It should be noted that the data presented is based on the mixed liquor suspended solids concentration without the magnetite. Solids loading rates provide an indication of how well the mass of applied solids to the clarifiers match-up with the mass of solids removed via the return sludge. Typical solids loading rates for clarifiers being used in a nutrient removal treatment scheme are typically 24 to 36 lb/ft²*day for average conditions and 43 lb/ft²*day for peak flow conditions.

This figure shows the following:

- The data showed no significant increase or decrease of clarifier effluent solids with changes in the solids loading rate.
- For the range of the loading rates tested, the effluent TSS was always below the TSS effluent goal of 30 mg/l.
- The vendor provided average day, maximum month and maximum day design solids loading rates (excluding the magnetite) were 45 lb/ft²*day, 71 lb/ft²*day, and 115 lb/ft²*day, respectively.
- The loading rates tested did not exceed the maximum month or maximum day design loading rates but did approach the maximum month design loading rate.
- The data from the hydraulic stress tests (EP-04) were examined separately. Note that the data from these tests were not included on Figure 3-3F due to the fact that the majority of the tests were short duration (2 or 6 hours) and the 24 hour stress test was carried-out with a diluted influent that was not believed to be representative for actual TSS growth. However, the TSS results from the hydraulic testing period did not exceed to exceed the 30 mg/l effluent TSS goal. It should also be noted that both 2 hour stress tests had short term solids loading rates of 86 lbs TSS/ft²*day and 77 lbs TSS/ft²*day, respectively, while the 6 hour test had a short term solids loading rate of 93 lbs TSS/ft²*day, and the 24 hour diluted influent test had a short term solids loading rate of 76 lbs TSS/ft²*day. All of these loading rates were well in excess of the maximum month SLR. The results of the hydraulic stress tests (EP-04) are discussed in more detail later in this section.
- Based on the data in Figure 3-3F it appears that that clarifier was appropriately sized from a solids loading stand point.
- The solids loading rates for the BioMag process which proved acceptable are 25%-90% higher than conventional clarifier solids loading rates for average conditions, and over 200% for peak conditions.

Surface Overflow Rate (SOR). Figure 3-3.G presents the CAS-BioMag clarifier surface overflow rates vs the clarifier effluent TSS during all of the experimental plans with the exception of the hydraulic stress tests performed in EP-04. The surface overflow rate, is essentially the cross-sectional velocity in the clarifier, or a hydraulic loading rate for the clarifier. For solids that have a high settling velocity, higher SORs are acceptable. Typical SORs for conventional activated sludge systems treating nutrients are typically capped at 700 gpd/ft²*day for average conditions and 1,600 gpd/ft²*day for peak conditions.

This figure shows the following:

- The data showed no significant increase or decrease of clarifier effluent solids with changes in the clarifier surface overflow rates tested.

Figure 3-3F. Solids Loading vs. CAS-BioMag Average Daily Clarifier Effluent TSS

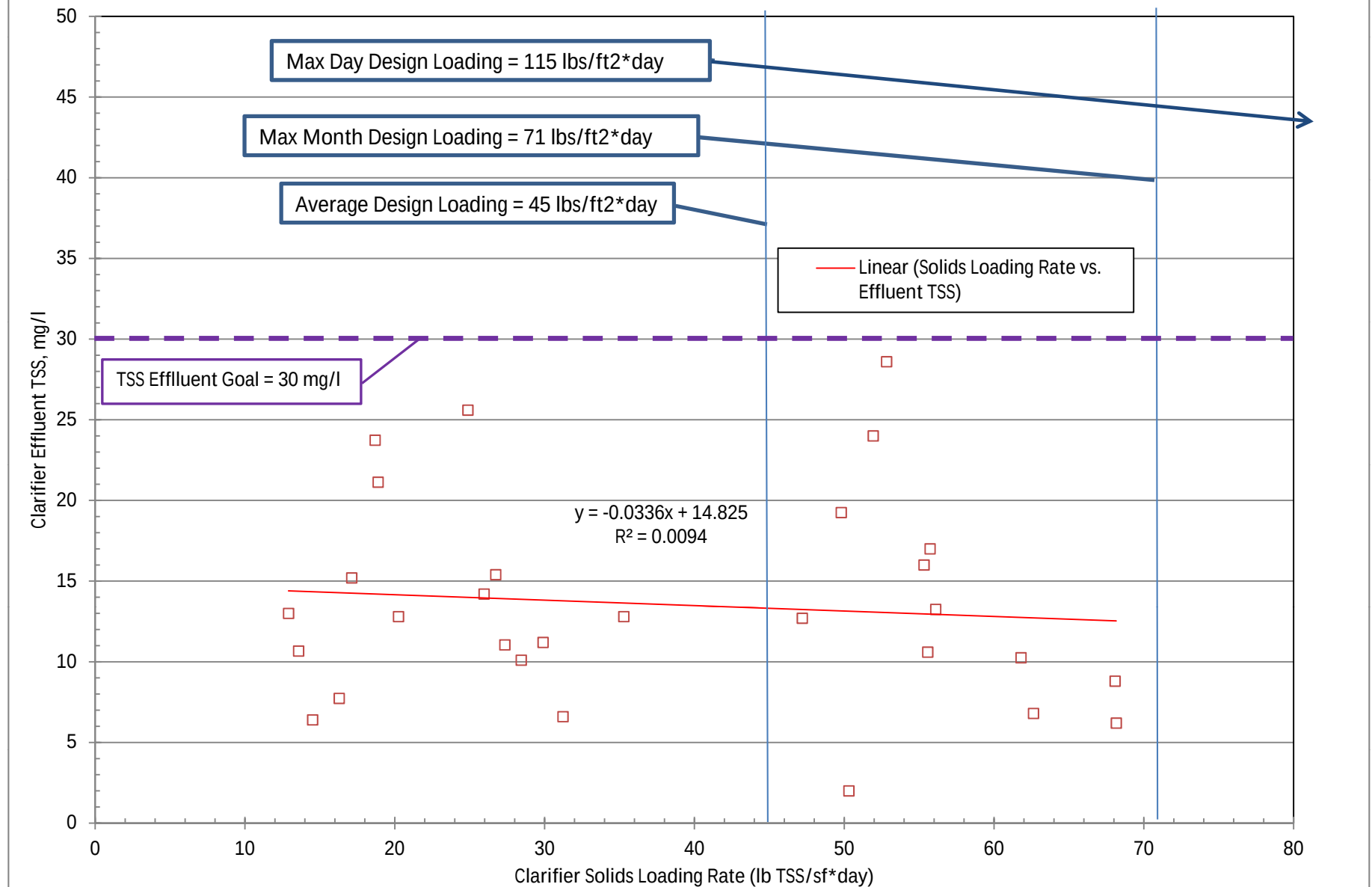
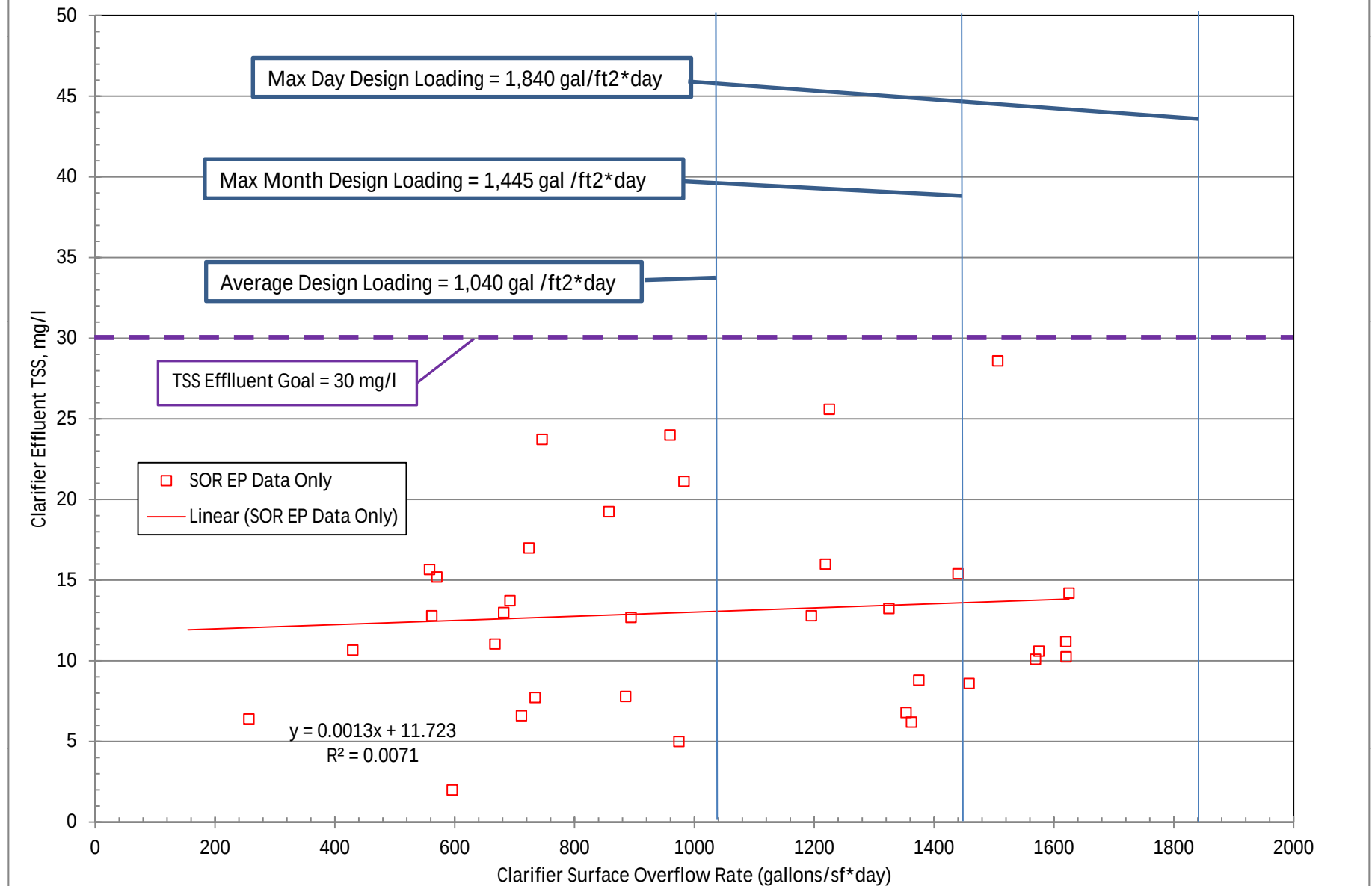


Figure 3-3G. Surface Overflow Loading vs CAS-BioMag Average Daily Clarifier Effluent TSS



- For the range of the loading rates test the effluent TSS was always below the TSS effluent goal of 30 mg/l.
- The vendor provided average day, maximum month and maximum day design surface overflow rates were 1,040 gal/ft²*day, 1,445 gal/ft²*day, and 1,840 gal/ft²*day, respectively. The loading rates tested did not reach the maximum design loading rates.
- The data from the hydraulic stress tests (EP-04) were examined. Note that the data from these tests were not included on the Figure 3-3G due to the fact that the majority of the tests were short term (2 or 6 hours) and the 24 hour stress test was with a diluted influent that was not believed to be representative. However, the TSS from these tests did not exceed the effluent TSS goal of 30 mg/l. Both 2 hour stress tests had short term surface overflow rate rates of 1,980 gal/ft²*day and 2,520 gal/ft²*day, respectively, while the 6 hour test had a short term solids loading rate of 2,520 gal/ft²*day, and the 24 hour diluted influent test had a short term surface overflow rate of 1,260 gal/ft²*day. The results of the hydraulic stress tests (EP-04) are discussed in more detail later in this section.
- Based on the data in Figure 3-3G it appears that that clarifier was sized appropriately from a hydraulic or surface overflow rate stand point and that there may be the opportunity to operate at higher loading rates and decrease the size of the clarifiers.
- The hydraulic loading rates (SOR) for the BioMag process which proved acceptable are generally 50% higher than conventional clarifier surface overflow rates for average conditions, and 20% higher for peak conditions.

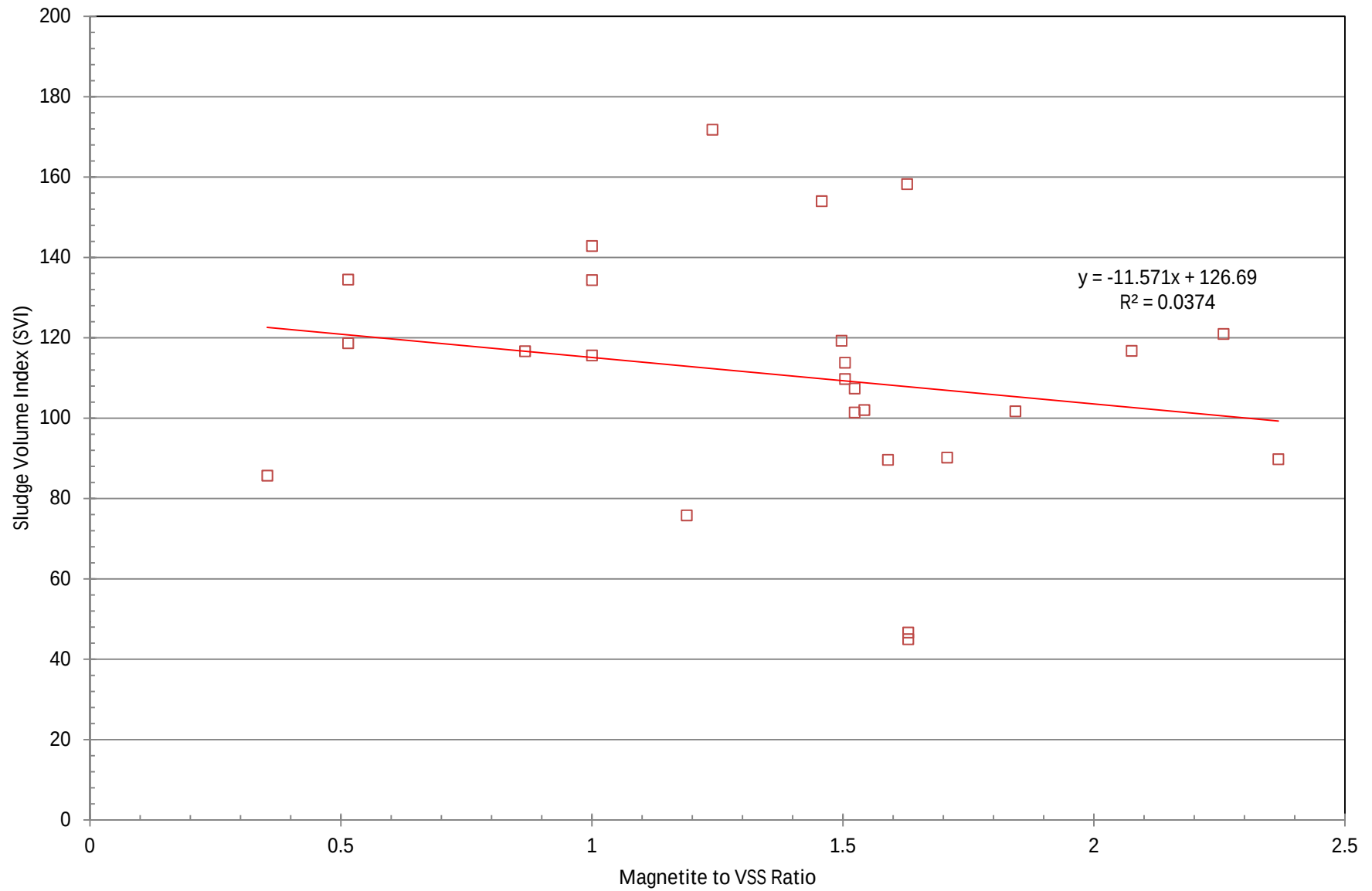
It should be noted that for the pilot testing (for the non-hydraulic stress testing experimental plans) that the CAS-BioMag clarifier produced an average TSS effluent concentration of 14 mg/l which is below the target goal of 30 mg/l.

Magnetite:VSS Ratio versus Solids Volume Index (SVI). SVI is a calculated value which uses both settling velocity and TSS concentration. This parameter is used to assess how well activated sludge will settle in a clarifier. Typically an SVI in the range of 77 to 150 mg/ml would indicate a good settling sludge. When you have lower SVI readings this usually means the sludge is settling too fast and the result is a turbid effluent. When readings are in excess of 150 mg/ml, this reflects poor settling and is typical of a sludge bulking condition. Figure 3-3.H presents the results from a number of bench tests performed to assess the CAS-BioMag mixed liquor magnetite to VSS ratio versus SVI.

The data in this figure shows the following:

- As expected, there is a trend of improved SVI (less than 150 mg/ml) with increasing magnetite:VSS ratios. The increased magnetite concentration has more of an opportunity to contact and flocculate with the particles (suspended solids) in the mixed liquor. As the number of particles that are attached to the magnetite increase the overall settling and compaction characteristics of the sludge will improve.
- At controllable SVI values it may be possible to reduce the size of the clarifiers or to run mixed liquor at higher concentrations. This second possibility would potentially allow the required aeration tank sizes to be reduced.
- Most of the data was collected in the 1 to 2 range of magnetite to VSS ratio which is considered the typical operating range for the BioMag process

Figure 3-3H. CAS-BioMag Mixed Liquor Magnetite:VSS Ratio vs. SVI



- Based on the impact of the increased magnetite lowering the SVI, this may allow the operation of a CAS-BioMag system at lower magnetite concentrations during the early years of operation. As the design flows and loads increase, additional magnetite could be added (up to the 20 year design concentration) to improve settling performance in lieu of adding additional equipment
- It was observed during the pilot testing that the BioMag technology produced a very clear effluent even at very low SVIs which suggest that there may not be a lower limit to BioMag SVI readings.

Effect of Polymer on Mixed Liquor Settling. Figure 3-3.1 presents the CAS-BioMag data from a number of settling tests performed on the mixed liquor with and without the addition of polymer. The data is presented as both discrete data points as well as averages. The range of polymer dose added to the mixed liquor for these tests ranged from 1.3 to 1.8 mg/l.

This figure shows the following:

- The figure shows that the settling times of the mixed liquor is reduced with the addition of polymer. Generally speaking polymer addition approximately doubled the settling velocity.
- The settleable solids volume (ml) as measured by the 30 minute settling time was approximately 40% less with addition of polymer. This data indicates that the addition of polymer improved sludge compaction.

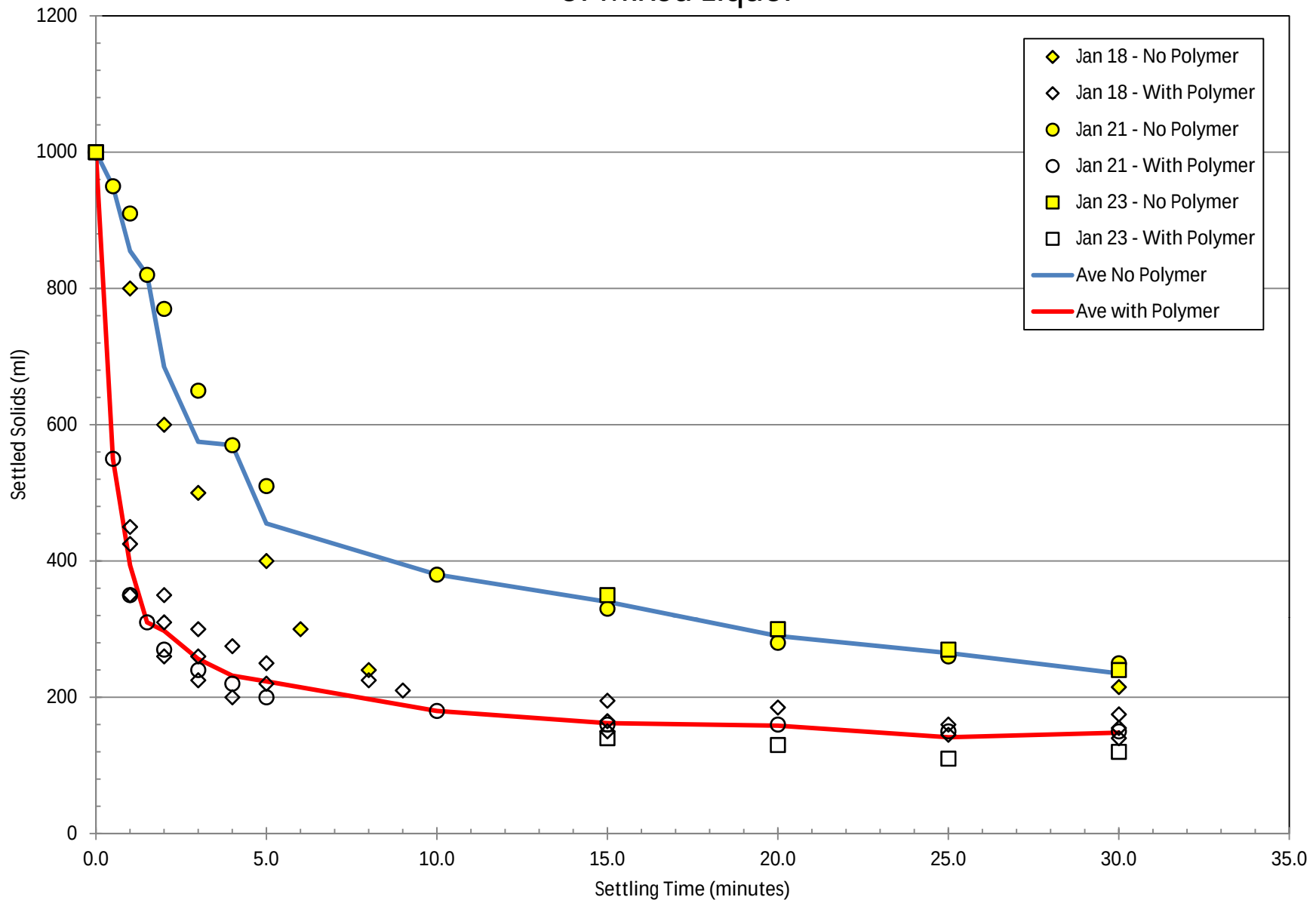
The improved settling times with polymer would allow operation at higher SOR and potentially use smaller clarifiers

- The figure shows that the compaction point (at the end of 30 minutes) is lower with the addition of polymer. More compact solids results in more concentrated RAS and WAS. The more concentrated RAS has the advantage of reducing RAS pumping cost due to less volume needing to be returned to the process tanks to maintain the mixed liquor concentrations. More concentrated WAS has the advantage of producing a thicker solids handling product (thickening and dewatering as appropriate) and potential reducing solids handling costs. The cost reductions due to the more concentrated RAS and WAS would need to be compared to the polymer addition costs.
- With improved solids settling with the use of polymer, the WWTF could use smaller clarifiers or run at lower mixed liquor concentrations in the early years after an upgrade and then increase the mixed liquor concentrations and begin to add polymer in the future when the plant loadings increase to the 20 year design loading rates
- It should be noted that the use of polymer for day to day operation may impact the acute toxicity of the effluent, and therefore further testing of the effluent for toxicity should be carried-out if this path is taken.

3.3.5 Hydraulic Stress Tests Performance

During Experimental Plan 04, the CAS-BioMag was subjected to increased influent flow conditions to mimic different storm events. During these trials, the system was subjected to flow spikes (hydraulic loading condition) and was assessed to see how the system performed during and after the event. The recovery phase was also examined to determine how long the system would take to recover to base line or wastewater treatment goal conditions subsequent to the

Figure 3-3I: CAS-BioMag Effect of Polymer on Settling Times of Mixed Liquor



events. The recovery evaluation was based on effluent TSS, COD, TN, NO_x, NH₃, and reactor dissolved oxygen (DO) concentrations. These wastewater constituent effluent concentrations as measured by the CAS-BioMag aeration tank and the clarifier were examined statistically with a one way ANOVA analysis. These analyses were used to assess if any of the data sets collected during the three test phases (pre-stress, stress and recovery) for each stress test were different as compared to the other phases. The wastewater constituents and DO concentrations data was also further examined to identify if there appear to be changes due to the different phases of each stress test that might not have been identified as statistically significant.

3.3.5.1 Test Conditions. The hydraulic stress testing conducted included:

- A full strength, medium flow increase short duration (2 hours at elevated condition) test.
- A full strength, peak flow increase short duration (2 hours at elevated condition) test.
- A full strength, peak flow increase medium duration (6 hours at elevated condition) test.
- A diluted strength, peak flow increase extended duration (24 hours at elevated condition) test.

3.3.5.2 Performance. A number of samples were collected before, during and after the flow spike to establish a baseline condition, performance through the event, and the system's recovery. Within Blueleaf Incorporated's Pilot Test Report, included as Attachment B, are the experimental details and graphical presentation of the data. Table 3-8 presents a summary of the hydraulic stress testing conditions as well as recovery results.

For the full strength medium flow short duration event (2 hr duration), the following was observed:

- The DO concentration in the aeration tanks was slightly suppressed during the event. The air flow to the aerobic reactors was increased during this stress test although apparently not sufficiently to prevent a depression in the DO concentration. As expected the result was the partial loss of nitrification. The DO in the nitrification reactors recovered in 1 hour.
- Statistically the event had a significant impact on the aeration tank NH₃, TN and TKN (increase during the event).
- Statistically the event had a significant impact on the clarifier TN, NO_x, and TKN although the TN never exceeded the 8 mg/l goal.
- The impact of the DO suppression is believed to be responsible for the impact on the nitrogen species in the aeration tank and clarifier effluent.
- Although not statistically significant, the event appeared to have an impact on the clarifier effluent TSS with recovery to concentrations less than 10 mg/l immediately after the event. This quick recovery after the event suggests that there was not a loss of biomass but rather environmental conditions in the reactor that were not optimal.

For the full strength peak flow short duration event (2 hr duration), the following was observed:

- The DO concentration in the aeration tanks was slightly suppressed during the event despite increased air flow to the aerobic reactors during this stress test. An expected result would be the partial loss of nitrification. The DO in the nitrification reactors recovered in 1 hour.
- Statistically the event had a significant impact on the aeration tank TN and NO_x (decrease after the event).

Table 3-8. CAS-BioMag Hydraulic Stress Test Summary

Test	Full Strength, Medium Flow Increase, 2 hour Duration	Full Strength, Peak Flow Increase, 2 hour Duration	Full Strength, Peak Flow Increase, 6 hour Duration	Diluted Strength Peak Medium Flow Increase, 24 hr Duration
Actual Flow/Load Increase Condition Duration	2 hours	2 hours	6 hours	24 hours
Flow - Start (gpm) to Increase conditions (gpm)	11 - 22	13.5 - 28	13.5 -28	13.5 - 28
Statistical Impact	Aeration Tank – NH ₃ , TN, TKN Clarifier – TN, NOx, TKN	Aeration Tank – TN, NOx Clarifier – NA	Aeration Tank – NA Clarifier – TSS, NOx	Aeration Tank - NA Clarifier – TSS, COD, TKN (all decreased) during event.
Observed Impact	Small DO depression in Aeration Tanks Small TSS increase in clarifier effluent	Small DO depression in Aeration Tanks Small TSS increase in clarifier effluent	Small Do depression in Aeration Tanks	The DO in the aeration tanks fluctuated during event (all Do lower then background DO)
TSS Recovery (to 30 mg/l goal)	NA- no sampes above 30 mg/l	NA- no samples above 30 mg/l	NA- TSS decreased during event and recovered to background levels (all less than 30 mg/l) after event	NA- TSS decreased during event and all samples were below 30 mg/l
TN Recovery (to 8 mg/l goal)	NA – no samples above 8 mg/l	NA – no samples above 8 mg/l	NA – no samples above 8 mg/l	All TN samples were below 8 mg/l and some below 3 mg/l
DO Recovery	1 hour	2 hours	Immediate	DO fluctuated during and after event. Full recovery not observed during observation period.
Notes			NOx increase to 0.9 mg/l during event	

- Statistically the event had no impact on the clarifier performance
- Although not statistically significant, the event appeared to have an impact on the clarifier effluent TSS with recovery to background concentrations 2 hours after the event. At no point was any TSS sample greater than the 30 mg/l goal. This quick recovery after the event suggests that only a minor loss of biomass occurred most likely the result of not having optimal environmental conditions in the reactor.

For the full strength, peak flow, 6 hour duration test the following was observed:

- The DO concentration in the aeration tanks was slightly suppressed during the event. The air flow to the aerobic reactors was increased during this stress test which resulted in the DO depression being less than the previous event. The DO in the aeration tank recovered immediately after the event
- Statistically the event only had an impact on TSS and NOx in the clarifier effluent with the TSS decreasing during the event from 20 mg/l to 9 mg/l and the NOx increased from 1.7 mg/l to a maximum concentration of 2.8 mg/l.

For the diluted strength, peak flow, 24 hour duration test the following was observed:

- The DO concentration in the aeration tanks was slightly suppressed during the event. The air flow to the aerobic reactors was increased during this stress test. The DO in the aeration tank fluctuated somewhat after the event but may not have been related to the event.
- Statistically the event only had an impact on TSS, COD and TKN in the clarifier effluent with of these parameters all decreasing during the event. It appears that the dilution water used to reduce the influent wastewater strength may have reduced the pollutant loading and thus decreased these parameters in the effluent.

3.3.5 3 Conclusions. Based on the hydraulic testing the following conclusions can be made based on the simulated storm events

- Unlike the stress testing with the other technologies air flow to the aeration tanks was increased during the events as was the RAS flow rates. In addition, polymer was added during a portion of the 24 hr stress test. These changes make it more difficult to detect the impact of the high flows conditions or the impact of under aeration on the CAS-BioMag system.
- No significant biomass loss was observed as determined by effluent TSS.
- By increasing the RAS rates during the event, the increased the solids loading rate to the clarifiers did not adversely impact the process. Increasing the RAS flow rates is an effective means of controlling sludge blanket levels during such an event.
- Although there was a depression in reactor DO concentration during these trials, it is felt that in a full-scale application where automated DO control will be practiced there will not be DO suppression.

3.3.6 Pilot Observations and Considerations for Full Scale Implementation

- The CAS-BioMag system was started and acclimated very quickly; however it should be noted that seed mixed liquor was provided from an external plant. It produced a high-quality effluent within a few days of startup. The process was also very responsive to process changes, producing poor water nearly immediately if the conditions were outside

of the optimal range and good effluent water quality when the conditions were returned to an appropriate range.

- The responsiveness of the system allowed the system to perform well during the pilot study experimental plans. It should also be noted that the vendor representative was onsite while most of the experimental plans were being completed, and either proactively maintained the optimal ranges for the system, or notified Blueleaf personnel that changes were required. A high degree of operator attention was required for a number of reasons, the most important were the air feed had to be manually controlled, which would not be the case in a full-scale application since it would be automated.
- The Blueleaf operators found the pilot process fairly complicated to operate requiring a higher degree of operator knowledge and expertise. It should be noted that this is often the case in a suspended cell system where hydraulic retention time and solids retention time can be controlled independently. Normal process control maintenance entailed a few hours to measure mixed liquor TSS and VSS concentration, determine the mass of magnetite required to be added, waste solids, and perform field testing on the various reaction tanks. Many of these functions can most likely be automated or be more routine for a full scale system. Determination of the appropriate level of automation with input from the vendor should be considered during design.
- Filaments were a major problem during the pilot study. The initial problem with filaments was likely caused by conditions in the pilot system which promoted their growth after the inadvertent loss of biomass. It was theorized that the F/M was drastically reduced causing rapid filament growth. The second occurrence with filaments was caused by obtaining a seed from a plant with a pre-existing growth of filaments. In both cases, much effort was expended to understand the factors that promoted the growth of filamentous organisms, how to identify and enumerate the organisms, and control their growth. It should be noted that filaments is very common with all suspended active sludge wastewater treatment schemes. Specific to the CAS-BioMag it should also be noted that increasing the magnetite concentration had little effect on the settleability of the filamentous organisms. However, the addition of chlorine into the RAS line, the addition of a defoaming agent to the aeration tank inlet, and daily surface wasting eventually reduced the filamentous organism population to a controllable level; all of which are common practices to control and remedy sludge bulking in all suspended cell systems.
- The time and expertise provided by the vendor representatives were important for maintaining a well performing CAS-BioMag system, and especially for addressing issues such as filaments, proper VSS/magnetite ratios, modifications to the physical installations, etc. Proper operator training or support would be extremely important for a full-scale system.
- Magnetite handling was manual at the pilot scale. It is not recommended that a manual operation be used for full scale application. The pilot scale equipment that was installed to mix and discharge the magnetite slurry plugged and failed regularly, and the lines that transferred mixed liquor with magnetite were often plugged with magnetite. A full-scale design should rely on proven past use and the design should incorporate the vendor's past success experiences with at other sites to ensure these types of issues are not experienced in the full-scale facility.
- Maintaining appropriate velocities and mixing energy in any pipes or channels containing a mixed liquor-magnetite floc is a critical design parameter. Improper pipe sizing might result in settling in the pipes, which occurred constantly with the pilot plant and required frequent maintenance. During preliminary design minimum velocity criteria must be adhered to for all piping transporting floc-magnetite. In addition, it is recommended that flushing connections be provided to all processing piping carrying magnetite.

- During the pilot trials it was observed that accumulation of floc-magnetite occurred in corners of the reactors. During preliminary design, care should be applied to ensure adequate mixing be provided in channels and reactors. Proper mixing and aeration was critical at the pilot scale, and additional mixers were added to keep the magnetite suspended in solution. The vendor should be consulted to determine the mixing energy required for the full scale system. Accumulation of magnetite under aeration grids must also be addressed.
- Polymer addition was needed at times to control the effluent TSS. The frequency of polymer addition was not carefully documented during the pilot study. Only one polymer stock was used for both the MBBR-DAF system and the CAS-BioMag system, and it is surmised that this is an area where further optimization should be carried-out for this technology. When the polymer was used, a typical dose for controlling the CAS-BioMag effluent TSS was 1 ppm of Aries 26614. Aries 26614 is a high charge, high molecular weight, polyacrylamide flocculent. Proper polymer dispersion and mixing into the clarifier influent was also important and full-scale optimization should be carried-out.
- Since this technology requires the intermittent use of polymer in the day to day operation, further testing of the effluent for toxicity should be carried-out.
- During the course of the pilot study the method of sludge wasting was changed. Initially wasting via the return sludge was practiced. However, due to the pilot size the TSS concentration fluctuated greatly and the amount of waste solids could not be controlled adequately. The method of wasting was revised, and wasting of mixed liquor was practiced for process control purposes. Since the method of sludge wasting for a full-scale system would likely be via the return sludge, it is essentially that a full-scale system should have the capability to surface skim the reactors and clarifiers to control unwanted foam.
- Dissolved oxygen over at high internal recycle rates was an issue during piloting and special provisions such as automated DO control and/or the inclusion of a de-oxygenation zone should be considered during the preliminary design phase.
- During the piloting period the magnetite material was relatively messy and required continuous housekeeping. The final design should include provisions to adequately address housekeeping for this material.
- Magnetite recovery was not practiced during this piloting effort. If selected it is recommended that a performance test be incorporated to ensure efficient magnetite recovery is proven and the make-up quantities are better identified for operation and maintenance purposes.
- There was no observed abrasion of the magnetite in high velocity areas, however it is recommended that this issue should be further evaluated as part of the design process.
- The improved setting of the floc-magnetite showed a doubling of the settling velocity, and thus should greatly improve solids capture even during high hydraulic stress.
- All testing and observations showed the magnetite material to be non-reactive maintaining same properties and appearance during its use.
- The methodology to distinguish between MLVSS and TSS within the reactor mixed liquor proved accurate and should be considered as a tool for operating the process.
- During the piloting effort vendor support was essentially continuous however it was felt that system optimization was constantly going on suggesting the technology was not as mature as other technologies

3.4 MOVING BED BIOREACTOR WITH DISSOLVED AIR FLOATATION (MBBR-DAF)

The pilot MBBR-DAF system was examined to assess its ability to remove carbon (BOD) and total suspended solids (TSS) to meet secondary treatment effluent limits as well as to meet total nitrogen (TN) effluent limits (8 mg/l and 3 mg/l) under different constituent loading and hydraulic loading conditions. The pilot system consisted of a multi-stage MBBR reactor followed by a dissolved air floatation (DAF) solid separation process. For the BOD removal testing, the MBBR had a carbon oxidation (BOD) reactor (stage) followed by a DAF. For the TN goal of 8 mg/l, testing the MBBR had a carbon removal (BOD) stage followed by nitrification stage 1, nitrification stage 2, and single denitrification stage followed by a DAF. And finally for the TN goal of 3 mg/l, the MBBR had a carbon oxidation (BOD) stage followed by nitrification stage 1, nitrification stage 2, denitrification stage 1, and denitrification stage 2. The layout of the MBBR-DAF system is presented in Section 2. The MBBR was operated from 12/28/11 to 7/17/12. The Blueleaf Incorporated Pilot Report included in Attachment B, presents a detailed physical description of the MBBR-DAF pilot system, the MBBR-DAF pilot phases and associated testing conditions, and the data collected during the various phases to assess the performance of this technology.

3.4.1 Experimental Plan Summary

Table 3-9 presents a brief summary of the experimental plans that were used to evaluate the MBBR -DAF technology. The results of these experiments are subsequently discussed.

Table 3-9. MBBR-DAF Experimental Plan Summary

Experimental Plan (EP) Number	Test Conditions	Testing Objective
EP-01	Average Daily BOD Loading	BOD and TSS Removal
EP-02	Maximum Month BOD Loading	BOD and TSS Removal
EP-03	Average Daily BOD Loading	BOD removal, TSS Removal and TN < 8 mg/l
EP-04	Hydraulic Stress Tests	BOD removal, TSS Removal and TN < 8 mg/l
EP-05	Average Daily BOD Loading Elevated Ammonia Loading	BOD removal, TSS Removal and TN < 8 mg/l
EP-06	Average Daily BOD Loading Elevated Ammonia Loading	BOD removal, TSS Removal and TN < 3 mg/l

3.4.2 Data Presentation

Table 3-12 presents a summary of the data collected for the different experimental plans carried out on the MBBR-DAF system with the exception of EP-04. For EP-04, transient hydraulic and organic loads were imposed on the technology. The purpose of applying these transient loads was to evaluate the removal performance of the system under different flow and loading conditions and the ability of the technology to recover after applying short term loads. For all of the experimental plans with the exception of EP-04 the goal was to examine the performance based on a target loading basis and not a hydraulic basis. The hydraulic stress testing conducted in EP-04 will be discussed later in this section.

The water quality data (concentration values) presented in Table 3-10 are presented in one of the two following formats:

- For large data sets- Median value (minimum value – maximum value) [number of samples] is provided

Table 3-10. MBBR-DAF Experimental Plan Data Results

	Experimental Plan Summaries									
Parameter	EP-01 Target	EP-01 Results	EP-02 Target	EP-02 Results	EP-03 Target	EP-03 Results	EP-05 Target	EP-05 Results	EP-06 Target	EP-06 Results
Test Condition	Average Daily BOD Loading		Maximum Month BOD Loading		Average Daily BOD Loading		Average Daily BOD Loading Elevated Ammonia Loading		Average Daily BOD Loading Elevated Ammonia Loading	
Test Objective	BOD and TSS Removal		BOD and TSS Removal		BOD, TSS, and TN < 8 mg/l		BOD, TSS, and TN<8 mg/l		BOD, TSS, and TN< 3 mg/l	
Influent Flow Rate (gpm)	12.4	8.4 (5.8 – 13.7)	17.2	11.4 (9.3 – 13.3)	13.6	8.7 (3.3 – 12.8)	13.6	7.03	13.6	8.56 (4.88 – 10.87)
Influent BOD (mg/l)	NA	174 (109 – 238) [19]	NA	197 (164 – 229) [6]	NA	190 (175 – 202) [3]	NA	238 (127 – 490) [12]	NA	274 (157 – 395) [32]
Influent TSS (mg/l)	NA	92 (49 – 134) [36]	NA	145 (91 – 194) [36]	NA	166 (108 - 205) [8]	NA	103 (82 - 142) [6]	NA	122 (98 - 1145) [12]
Influent Ammonia (mg/l)	NA	NA	NA	NA	NA	20.7 (15.3 – 31.4) [5]	NA	29 (18 – 36) [8]	NA	38 (22 – 58) [25]
BOD Loading Rate (g BOD/1000 cf * day)	7.6	5.2 (3.2 – 8.6)	10.77	9.6 (5.5 – 15.1)	7.6	6.1 (5.6 – 6.4) [3]	7.6	6.1 (3.3 – 12.6) [12]	7.6	8.6 (4.9 – 12.4) [32]
NH ₃ Loading Rate (g NH ₃ /1000 cf * day)	NA	NA	NA	NA	NA	0.31 (0.23 – 0.47) [5]	NA	0.35 (0.23-0.43) [8]	NA	0.56 (0.32 – 0.85) [25]
Effluent BOD Field (mg/l)	30	21.3 (8.9 – 35.6) [16]	30	22 (20 – 24) [6]	30	11.7 (5.3 – 23.5) [18]	30	NA	30	N/A
Effluent BOD Lab (mg/l)	30	8, 20, 17	30	17.8 (11.7 – 24.5) [14] *	30	7.5 (2.6 – 11.3) [20]*	30	17.4 (13.3 – 22.4) [6] *	30	17.5 (11.2 – 31.5) [11] *
Effluent TSS Field (mg/l)	30	14.5 (2.0-22.0) [30]	30	26.9 (17.2 – 40.4) [21]	30	19.7 (11.6 – 37.5) [20]	30	23.8 (17 – 31) [6]	30	15.3 (8.4 – 33.2) [10]
Effluent TSS Lab (mg/l)	30	16, 13, 19	30	NA	30	13.3 (9 – 21) [3]	30	21, 27, 32	30	27, 9, 10, 12
Effluent TN Field (mg/l)	NA	NA	NA	NA	8	5.3 (0.2 – 19.6) [8]	8	4.0 (2.9 – 5.9) [5]	3	2.98, 5.5
Effluent TN Lab (mg/l)	NA	NA	NA	NA	8	7.5 (1.3 – 13) [7]	8	6.7, 3.3, 6	3	6.9, 7, 2.8, 3.8

* Effluent BOD (Calculated from COD)
Data presentation format - For large data sets - Median value (minimum value – maximum value) [number of samples]
 - For small data sets – sample value, sample value, sample value

- For small data sets - value, value, value, is provided

It should be further noted the data for all of the experiment trials are further presented graphically as time plots. These data along with the time plots are part of the Blueleaf Incorporated Pilot Report which is included as Attachment B.

3.4.3 Ability to Meet Pilot Study Effluent Concentration Goals

The following is a brief summary describing the ability of the MBBR-DAF to meet the BOD, TSS and TN effluent concentration goals under the varying conditions of the experimental plans.

3.4.3.1 BOD. For all of the experimental plans, the MBBR-DAF was able to meet the BOD goal of 30 mg/l on an average basis. There were a few BOD excursions above the 30 mg/l limit for both EP-01 and EP-06, which were related to equipment upsets or laboratory sampling/testing. For EP-01 the excursions were attributed to a polymer dosing problem and a potential field lab error as the corresponding EPA certified contract laboratory data met the 30 mg/l BOD effluent limit and did not match the corresponding field data with the excursion. For EP-06 there was one excursion above the 30 mg/l limit.

3.4.3.2 TSS. For all of the experimental plans, the MBBR-DAF was able to meet the TSS goal of 30 mg/l on an average basis. There were however TSS excursions above the 30 mg/l limit in each of the experimental plans with the exception of EP-01. It should be recognized that the pilot performance of the DAF may not be a true indicator of full scale DAF system performance. See section 3.4.4.4 below for additional information on the DAF pilot system. It should also be noted that the MBBR effluent has relatively low solids which are floatable making a DAF system a good fit for the MBBR technology.

3.4.3.3 Total Nitrogen of 8 mg/l. For EP-03 the MBBR-DAF was able to meet the TN goal of 8 mg/l on an average basis. There were a number of excursions of TN greater than 8 mg/l during EP-03 however on average the TN concentration in the DAF effluent was less than 8 mg/l TN (5.3 mg/l for the field tested samples and 7.5 mg/l for the laboratory tested samples). The total nitrogen data showed increasing TN concentrations as EP-03 testing progressed. It is believed that insufficient supplemental carbon addition and poor mixing in the denitrification reactors contributed to the TN excursions during EP-03.

For EP-05 the MBBR-DAF was able to meet the TN goal of 8 mg/l for all samples collected. This performance improvement between EP-05 and EP-03 was likely due to mixing improvements made to the reactors and improved supplemental carbon dose control. For EP-05 an ORP probe was added for supplemental carbon addition control in the denitrification reactors. Based on these observations (and if this technology is selected as the preferred technology) care should be taken during design to ensure adequate mixing and the sufficient instrumentation and controls for tightly controlled supplemental carbon addition are provided.

3.4.3.4 Total Nitrogen of 3 mg/l. EP-06 assessed the ability of the MBBR-DAF to meet an effluent TN of 3 mg/l at elevated ammonia loadings. During this experimental plan none of the lab data showed the ability of this technology to produce a TN of 3 mg/l and only one sample measured in the field was able to meet the TN of 3 mg/l. The elevated ammonia concentrations likely resulted from the inability to maintain DO concentrations in the N2 reactor during this time and contributed to the higher than desired effluent TN concentrations. It should also be noted that at times the MBBR was able to produce a TN concentrations of less than 3 mg/l (under the EP-03 and EP-05 testing conditions) prior to the second denitrification reactor being included in the MBBR process for EP-06. It should be noted that EP-06 was the last experimental plan conducted, and it is suspected that the short acclimation period (one week) was not sufficient to develop the biomass needed to treat the elevated influent ammonia. Based on these observations it is believed that the EP-06 process configuration (BOD/N1/N2/DN1/DN2/DAF) should be able to produce an effluent TN of 3 mg/l with proper acclimation (although may not reliably). However, if the MBBR-DAF process is ultimately selected to meet a TN of 8 mg/l, and is

later required to be modified to achieve and TN of 3 mg/l, further evaluation of process modifications at that time would be recommended to assess the ability to meet a TN of 3 mg/l reliably.

3.4.4 Loading Rate Validation

The data collected during the MBBR pilot testing was evaluated to validate the vendor provided loading rates of the various process stages (as applicable). This was done to assess if the system reactors were sized correctly to meet the effluent concentration goals. If the process reactors were unable to meet the target effluent goals this might be an indication that the vendor sizing might have been too aggressive (the result being recommending a system that is too small system) and that lower loading rates should be used, which would result in the need for larger process tankage/equipment. Conversely, if the process reactors were easily able to meet the effluent goals when operated at high loading rates this might indicate the vendor sizing might be too conservative and there may be the opportunity to increase the loading rate by decreasing the size of the process tankage/equipment. The Blueleaf Incorporated Pilot Report in Attachment B presents portions of the pilot loading data. This data and other data present in Attachment B has been further manipulated and refined for presentation and discussion in the sections below.

3.4.4.1 Secondary/BOD Removal and Loading Rate Validation. Figure 3-4A presents the BOD load applied vs. the load removed through the MBBR BOD reactor from the period of 3/10/12 to 7/17/12. The vendor provided a design loading rate of 7.55 g BOD/m²*day at 10°C. As the BOD data presented in the figure was collected at an average wastewater temperature of 12.3°C, the vendor design loading rate has been temperature corrected. The temperature corrected loading rate is 8.17 g BOD/m²*day which is equivalent to 7.55 g BOD/m²*day at 10°C and is shown as a vertical line on the graph. The pilot data and this figure show the following:

- The data shows an 87% removal of BOD rate across the MBBR BOD reactor (see the slope of the linear regression line).
- The data shows a linear relationship between load applied and load removed. There was no tail-off of the data at higher loading rates. This indicates that in the range of loads tested that the performance of the MBBR BOD reactor was not impacted by increased loads, and thus did not approach the maximum loading rate for the technology.

The figure shows many data points both above and below the vendor's temperature corrected loading rate. All of the data collected are in the area of the vendor's temperature corrected loading rate and are on the linear part of the regression line. Some of the data collected had loading rates that were more than two times the vendor's temperature corrected loading rate with limited or no impact on the BOD removal performance. This indicates that the system is robust and potentially could be run at increased loadings (smaller reactors).

BOD Removal Performance Implications

Based on the results from the pilot testing, the ability of the MBBR-DAF to meet the anticipated future WWTF BOD permit limits was assessed. This includes the anticipated permit limits for average month, maximum week, and maximum day. Table 3-11 presents the anticipated WWTF BOD permit limits as well as the calculated maximum primary effluent concentration to meet the permit limits (based on 87% removal in the MBBR-DAF). Table 3-11 also shows the calculated maximum WWTF influent BOD concentrations to meet permit limits based on the 87% MBBR-DAF BOD removal and the anticipated primary clarifier BOD removal range. The calculated maximum influent BOD concentrations for each permit condition are presented as two values. These values are based on the anticipated range of primary clarifier BOD removals (15% - 30%) identified in the Revised Flow and Loading memorandum included in Attachment C.

In order for the MBBR-DAF to be able to meet the anticipated BOD permit limits the maximum WWTF influent BOD concentration cannot exceed the range of influent BOD values shown in.

Figure 3-4A. BOD Loading Rate vs. Removal through MBBR BOD Reactor

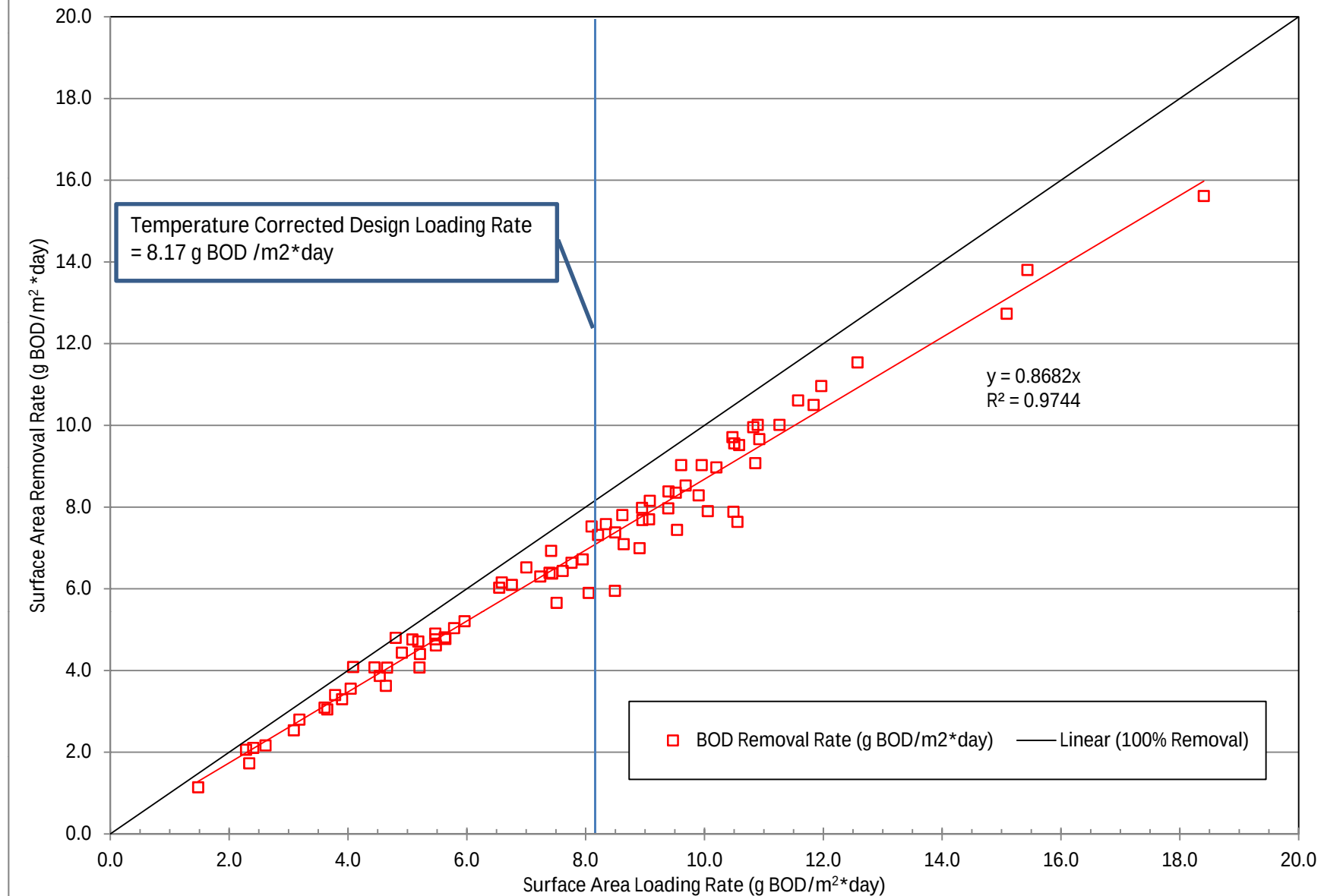


Table 3-11. Maximum BOD Concentrations with Primary and MBBR-DAF Treatment To Meet WWTF Permit Conditions.

WWTF BOD Permit Condition	WWTF BOD Effluent Limit, mg/l	Maximum Primary Effluent Concentration with 87% BOD Removal in MBBR-DAF, mg/l	Maximum WWTF Influent BOD Concentration, mg/l	
			15% BOD Removal in Primary Treatment	30% BOD Removal in Primary Treatment
Maximum Month	30	231	271	330
Maximum Week	45	346	407	495
Maximum Day	50	385	452	549

Table 3-11 or exceed the maximum primary effluent concentrations noted above both for maximum month, maximum week and maximum day conditions, respectively.

With only one MBBR BOD removal reactor, it would be recommended that the BOD concentration in the WWTF influent and primary effluent be monitored to assess the primary clarifier removal and to ensure that the primary effluent does not exceed the values noted in Table 3-11 for the different WWTF conditions (max month, week, and day).

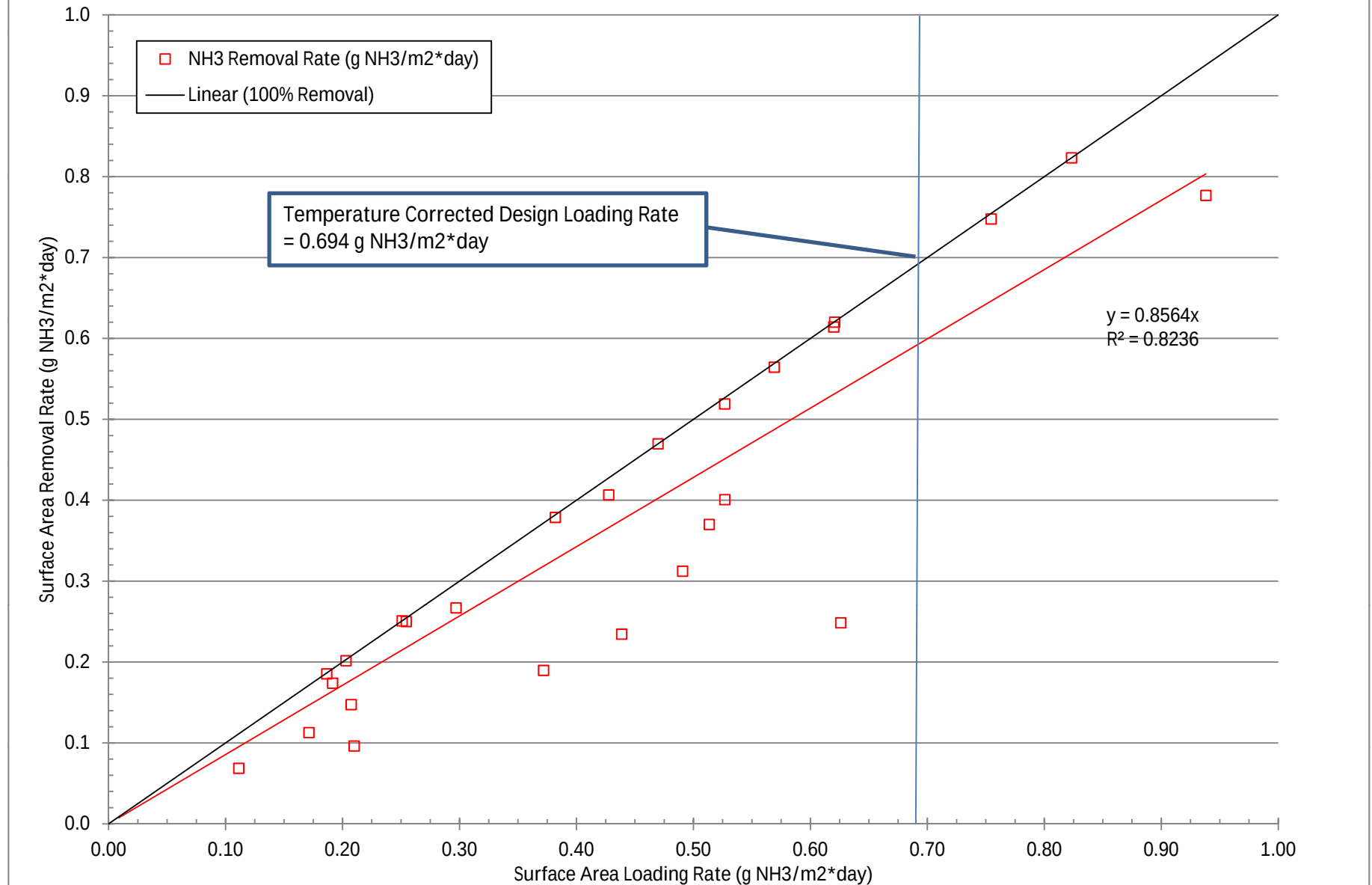
If it is anticipated or determined that the primary effluent is, or is going to, exceed the maximum values noted in Table 3-11 when running a single MBBR BOD removal reactor, there are a few options to maintain BOD permit compliance which include:

- Run CEPT to improve the removal in the primary clarifiers.
- Split the MBBR BOD reactor into two stages to provide 87% removal in the 1st BOD stage and some additional removal in the 2nd BOD stage. Based on Figure 3-4A the system was able to operate at a loading rate much greater than the design loading rate which would allow these two stages to have the same volume as the single stage.
- Increase the media fill in the BOD reactors (depending on the starting fill rate).

However it should be noted that under a total nitrogen of 8 mg/l operating condition it is not anticipated that the MBBR system will have difficulty meeting the monthly BOD limits as the denitrification process will consume any residual BOD from the carbon removal and nitrification stages to the point that supplemental carbon will be required for denitrification

3.4.4.2 Ammonia Removal and Loading Rate Validation. Figure 3-4B presents the ammonia removal observed through the two MBBR nitrification reactors (NR1 and NR2) from 5/15/12 to 7/17/12. The data is presented as the surface area loading rate ($\text{g NH}_3/\text{m}^2\cdot\text{day}$) vs. the surface area removal rate ($\text{g NH}_3/\text{m}^2\cdot\text{day}$). The vendor provided a design loading rate of $0.56 \text{ g NH}_3/\text{m}^2\cdot\text{day}$ at 10°C . As the NH_3 data presented in the figure was collected at an average wastewater temperature of 16.2°C , the vendor design loading rate has been temperature corrected. The temperature corrected loading rate is $0.69 \text{ g NH}_3/\text{m}^2\cdot\text{day}$ which is equivalent to $0.56 \text{ g NH}_3/\text{m}^2\cdot\text{day}$ at 10°C and is shown as a vertical line on the graph. Due to the difficulty associated with measuring the influent ammonia to the nitrification reactors, the influent ammonia to the nitrification reactors (effluent of the BOD reactor) was based on the spiked or un-spiked primary effluent TKN concentration. It is realized that a portion of the primary effluent TKN would be removed from the nitrification reactor influent due to cell growth in the BOD reactor and some partial nitrification in the BOD reactor. However the use of the primary effluent TKN to assess the ammonia removal rate is not anticipated to change the conclusions that can be drawn from the loading figure.

Figure 3-4B. Ammonia Loading Rate vs. Removal through
MBBR NR1 & NR2 Reactors



The data and Figure 3-4B show the following:

- This figure shows a good linear correlation between the applied surface area loading rate and the surface area removal rate for the loading rates applied during piloting.
- There are data points both above and below the temperature corrected design loading rate with little or no impact on the removal performance.
- A few data points showed that at loading rates that were approximately 20%-35% greater than the temperature corrected design loading, there was not a significant decrease in ammonia removal. This indicates that the reactors are sized as a robust system for ammonia removal. Based on this data, it might be advantageous to evaluate the possibility of reducing the size of the nitrification reactors or providing less media fill in the future.
- Based on a linear regression of the data the ammonia removal data through the MBBR reactors showed on average of 86% removal of the influent ammonia with a coefficient of determination (R^2) value of 0.82 indicating the linear regression line was a good fit for the data. Note this removal is misleading as it does not account for the TKN removal which is often used as another metric for evaluating nitrogen removal. In addition to ammonia, the TKN data will also include organic nitrogen, which will be taken up in cell growth in the BOD reactors, hydrolyzed into ammonia or a portion of the organic nitrogen is consider recalcitrant and will not be removed through biological processes.

Another way of looking at the performance of the MBBR-DAF nitrification reactors is to examine the effluent ammonia concentrations from the N2 reactor and the DAF. Since the overarching goal is to consistently have complete nitrification, expected ammonia concentrations below 1 mg/L should be routine. The N2 reactor and DAF effluent NH_3 data was plotted for the time periods within EP-03, EP-05 and EP-06 (See Figure 3-4C). This figure shows that:

- All of the data from experimental plan 03 (EP-03) in which the feed to the MBBR was not spiked with ammonia showed complete nitrification ($\text{NH}_3 < 1.0 \text{ mg/l}$).
- EP-05 and EP-06 (MBBR feed spiked with ammonia) showed that for the majority of the data that there was complete nitrification ($\text{NH}_3 < 1.0 \text{ mg/l}$).
- There were a few data points during EP-05 and EP-06 where the effluent ammonia was slightly greater than 1.0 mg/l and two significant excursions where there was incomplete nitrification with values greater than 4.0 mg/l.
- For the days where the effluent NH_3 was greater than 1 mg/l, there were corresponding lower dissolved oxygen concentrations in nitrification reactor 2. As a result it is believed that insufficient aeration was responsible for the ammonia increases on these days and not overloading of the media nitrification capacity.

3.4.4.3 Denitrification Removal and Loading Rate Validation. Figure 3-4D presents the nitrate (NO_3) removal observed through the MBBR denitrification reactors from 5/15/12 to 7/17/12. Again, this data is presented as the surface area loading rate ($\text{g NO}_3/\text{m}^2\cdot\text{day}$) vs. the surface area removal rate ($\text{g NO}_3/\text{m}^2\cdot\text{day}$). The vendor provided a design loading rate of $1.5 \text{ g NO}_3/\text{m}^2\cdot\text{day}$ at 10°C . As the NO_3 data presented in the figure was collected at an average wastewater temperature of 18.7°C , the vendor design loading rate has been temperature corrected. The temperature corrected loading rate is $2.02 \text{ g NO}_3/\text{m}^2\cdot\text{day}$, which is equivalent to $1.5 \text{ g NO}_3/\text{m}^2\cdot\text{day}$ at 10°C , is shown as a vertical line on the figure. The data and this figure show the following:

Figure 3-4C. Average Daily Effluent Ammonia Through MBBR-DAF Processes

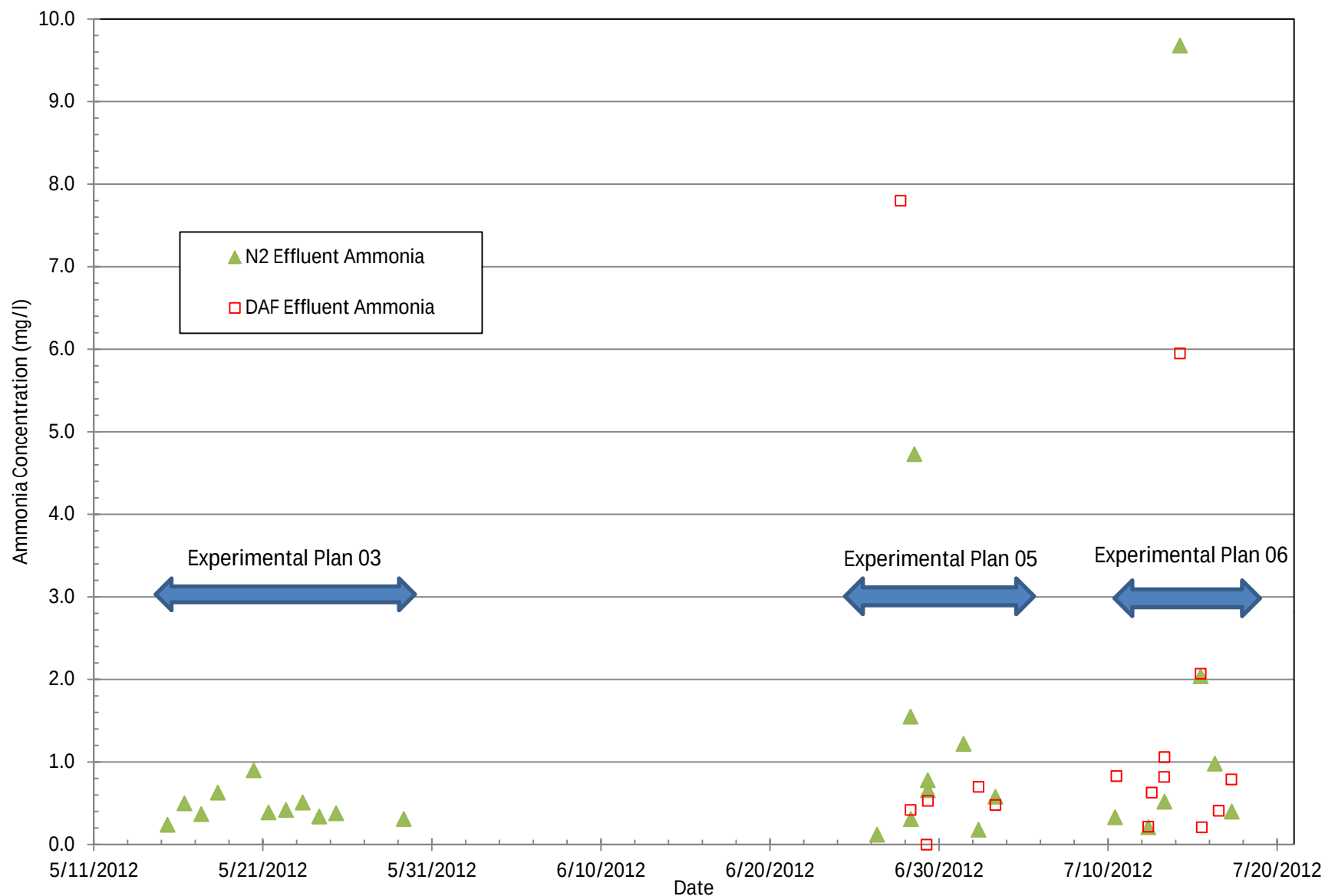
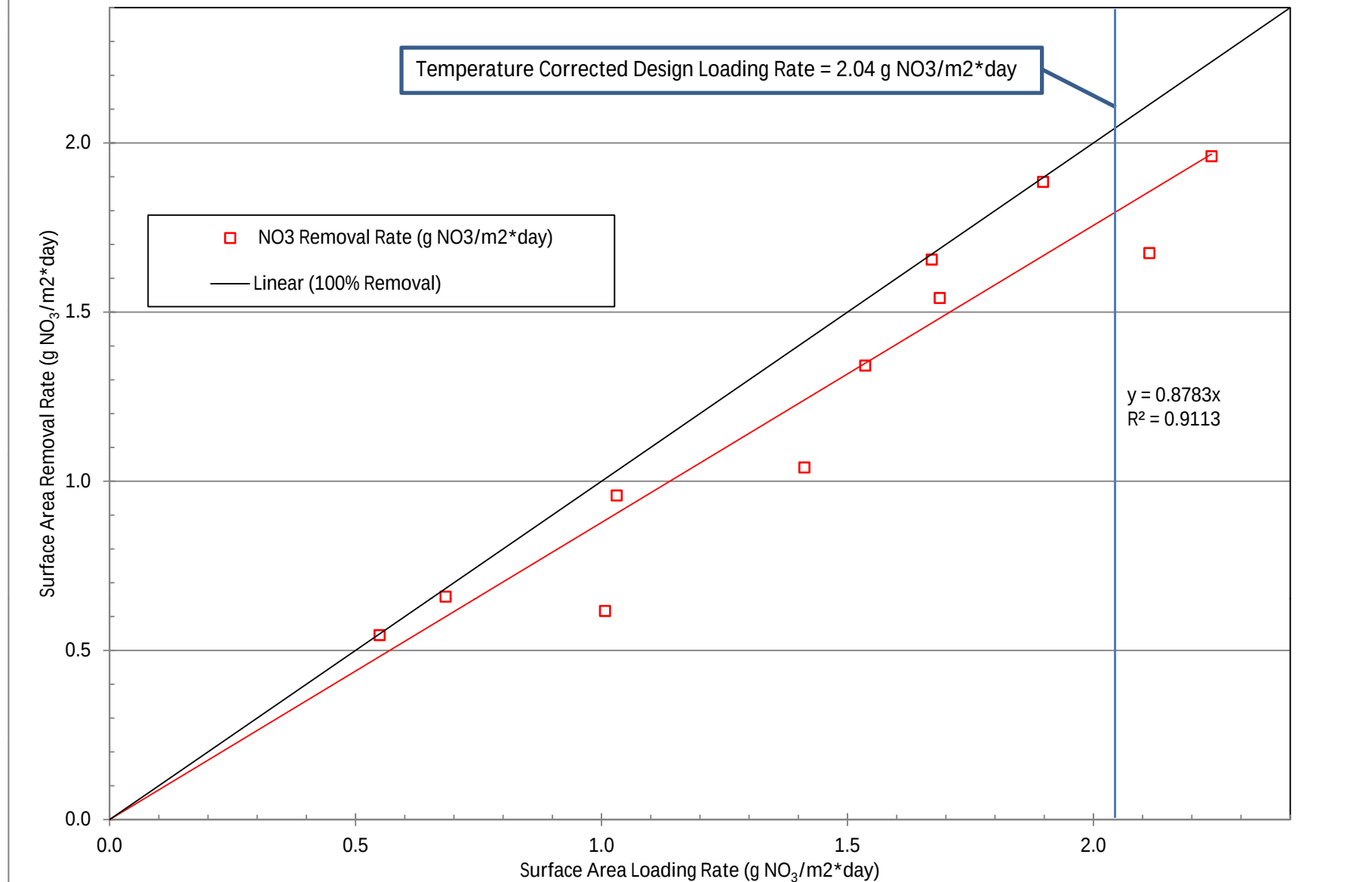


Figure 3-4D. Nitrate Loading Rate vs. Removal through
MBBR DN1 & DN2 Reactors



- Based on a linear regression of the data the nitrate removal through the MBBR denitrification reactors showed on average of 88% removal of the influent nitrate with a coefficient of determination (R^2) value of 0.96 indicating the linear regression line was a very good fit for the data.
- There are data points both above and below the design loading rate with little or no impact on the removal performance.
- A few data points showed that even at loading rates what were approximately 10% higher than the temperature corrected design loading without a significant decrease in removal.
- The data appear to indicate that the data point at the highest loading rate did not deviate from a straight line indicating that the performance of the DN reactor(s) is consistent with increased loading rate at the loadings tested. However, as noted previously, the tested loading rates were not significantly greater than the temperature corrected design loading rates. As a result it might be possible for the MBBR denitrification reactors be designed more aggressively since pilot data suggests the design loading rates could be exceeded. This should be examined in more detail if the technology is ultimately selected.
- It should be noted that the pilot testing experimental plan 06 (EP-06) was unable to achieve its target effluent total nitrogen concentration of 3 mg/l. However the systems limited acclimation time prior to the start of EP-06 and insufficient aeration are suspected to be the main causes of not being able to meet a TN of 3 mg/l. Under a full scale installation there would be sufficient acclimation time and aeration capacity. It was also noted that at times during EP-03 and EP-05 the MBBR-DAF was able to produce a TN of less than 3 mg/l. If in the future a MBBR-DAF system is employed for a TN of 8 mg/l and is subsequently required to meet at TN of 3 mg/l it is recommended that the full scale be optimized to see if it can consistently meet a TN of 3 mg/l and, if not, to determine the necessary modifications to consistently meet a TN of 3 mg/l.

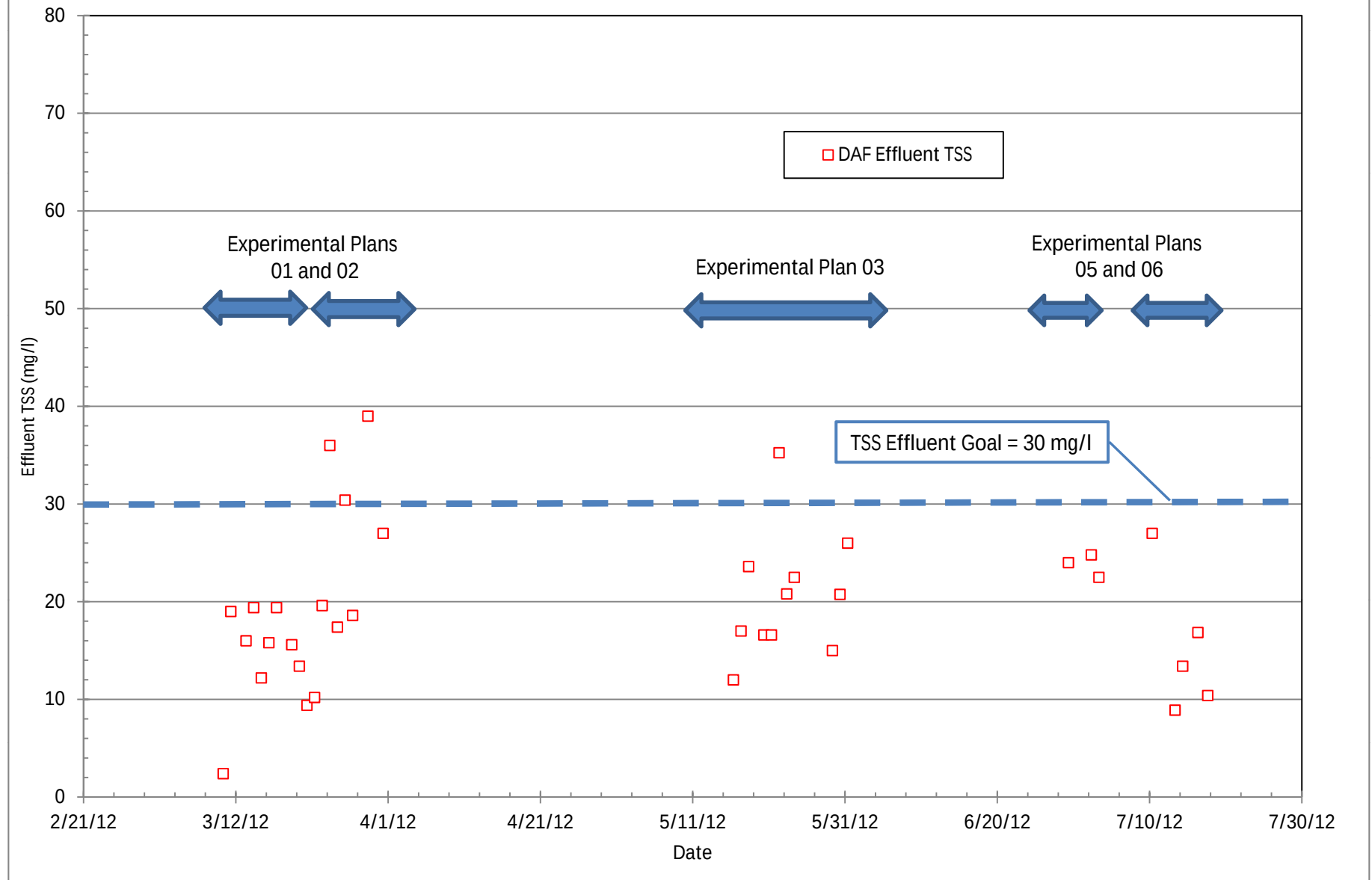
3.4.4.4 DAF Solids Removal. A pilot scale DAF system was used to provide solids separation for the MBBR process reactor effluent. Figure 3-2E presents the average daily effluent TSS concentration for the pilot DAF. This data in this figure shows:

- The pilot DAF produced a TSS lower than the TSS goal of 30 mg/l the majority of the time with only a few excursions above 30 mg/l.
- The excursions above 30 mg/l during Experimental Plan 02 are believed to be the result of a pipe blockage in the DAF that resulted in an increase in the water surface elevation.
- The excursion above 30 mg/l during Experimental Plan 03 is believed to be the result of mechanical issues that required the shutting off of the flow to the MBBR process for a period of time.

It should be noted that for the pilot testing for the non-hydraulic stress testing experimental plans that the DAF produced an average TSS effluent concentration of 20 mg/l which is below the target goal of 30 mg/l. During the pilot testing, there were no indications that a full-scale DAF solids separation unit process would not function and would not produce an effluent quality at or below the observed 20 mg/L TSS.

Due to the small size of the pilot scale DAF and other concerns with its operations, the pilot scale DAF was not used to evaluate the performance of a full scale DAF system. Some of the pilot scale DAF concerns identified which are described in more detail in the Blueleaf Incorporated Pilot Report included as Attachment B of this report include:

Figure 3-2E. MBBR-DAF Average Daily Effluent TSS



- The pilot scale DAF did not use an air saturator and injector process that is commonly used in full scale operations.
- Pilot DAF systems are very sensitive to hydraulic parameters, do not handle changes in flow well, and therefore do not scale up well. As a result the flow to the DAF system was not adjusted during the pilot study.
- The pilot DAF system was susceptible to the accumulation of solids in a number of the system components which is believed to have adversely impacted the effluent TSS concentrations during the pilot testing.

Based on these concerns and the fact that the pilot solids separation DAF was run at a consistent flow rate, it is not recommended that the pilot data be used to establish a loading rate, air to solids ratios or sludge production for a full scale DAF system. In addition, the design loading criteria does differ on types of DAFs being provided. The more common method used to ensure proper DAF sizing by various vendors is to include detailed performance criteria within the design specification. This will allow individual vendors the opportunity to tailor their particular product for the exact application.

3.4.5 Hydraulic Stress Tests Performance

During Experimental Plan 04 (EP-04), the MBBR-DAF was subjected to increased influent flows and loading conditions to mimic different storm events. During these trials, the system was subjected to an increased flow and or loading condition and was assessed as to how long the system would take to recover to base line or wastewater constituent treatment goal conditions subsequent to the events. The recovery of a number of wastewater constituents (TSS, COD, TN, NO_x, NH₃) and reactor dissolved oxygen (DO) concentrations were specifically examined. The wastewater constituent effluent concentrations for the denitrification reactor 1 (DN1) or the DAF were examined statistically with a one way ANOVA analysis to assess if any of the data sets from the three testing phases (pre-stress, stress and recovery) for each stress test were different than the other phases. The wastewater constituents and DO concentrations were also visually examined to identify if there appear to be changes due to the different phase of each stress test that might not have been identified as statistically significant.

3.4.5.1 Test Conditions. The hydraulic stress testing conducted included:

- A full strength, medium flow increase short duration (2 hours at elevated condition) test.
- A full strength, peak flow increase short duration (2 hours at elevated condition) test.
- A full strength, peak flow increase medium duration (6 hours at elevated condition) test.
- A diluted strength, peak flow increase extended duration (24 hours at elevated condition) test.

3.4.5.2 Performance. A number of samples were collected before, during and after the flow increase to establish a baseline condition, performance through the event, and the system's recovery. Within Blueleaf Incorporated's Pilot Test Report, included as Attachment B, are the experiment details and graphical presentation of the data. Table 3-12 presents a summary of the hydraulic stress testing conditions and recovery results.

For the full strength medium flow short duration event (2 hr duration) the following was observed:

Table 3-12. MBBR-DAF Hydraulic Stress Test Summary

Test	Full Strength, Medium Flow Increase, 2 hour Duration	Full Strength, Peak Flow Increase, 2 hour Duration	Full Strength, Peak Flow Increase, 6 hour Duration	Diluted Strength Peak Medium Flow Increase, 24 hr Duration (Blueleaf figure missing)
Actual Flow/Load Increase Condition Duration	2 hours	2 hours	8.3 hours	24 hours
Flow - Start (gpm) to Increase conditions (gpm)	From 8 to 19	From 13.5 to 23	From 15 to 22	Primary Eff. from 10 to 11 Potable water from 0 to 11
Statistical Impact	DN1 – NO _x lower during spike – back up during recovery. DAF – COD increased during spike – back down during recovery.	DN1 COD - COD increased during spike – back down during recovery. DN1 TN - TN increased during spike – and slight increase during recovery.	DN1 and DAF NH ₃ – NH ₃ increased during spike – back down during recovery. DN1 and DAF TN – TN increased during spike – back down during recovery.	DN1 NH ₃ and TN – Both decreased during spike – back up during recovery. DAF NO _x – NO _x decreased during spike – back up during recovery.
Observed Impact	Depressed DO in N1 and N2 reactors. Impact on TSS, COD and TN performance.	Immediate DO depression in N1 reactor. Immediate impact on TSS, COD and TN performance.	Slight depression of DO in N1 reactor.	Small impact on TN (>8 mg/l) after 3 hours.
TSS Recovery (to 30 mg/l goal)	2 hours	2 hours. Slight increase. Never exceeded 15 mg/l	NA - DAF effluent decreased with increased flow	NA- didn't exceed 30 mg/l goal
TN Recovery (to 8 mg/l goal)	2 hours	18 hours. Limited samples collected.	6 hours	6 Hours
DO Recovery	3 hours	3 hours	Rapid DO Recovery	NA – No DO suppression
Notes		Increase in NH ₃ observed in DAF effluent during the event. Recovered in 3 hours.		High COD in DN1 and DAF effluent

- The DO concentration in the nitrification reactors was depressed during the event. Note the air flow to the aerobic reactors was not adjusted during this stress test. An expected result would be the partial loss of nitrification. The DO in the nitrification reactors recovered in 3 hours of the flow returning to the pre-stress levels.
- Statistically the event had a significant impact on the DN1 reactor effluent NO_x and the DAF effluent COD (ammonia analysis could not be performed due to data limitations).
- The DN1 reactor NO_x concentration decreased during the event and came back up during the recovery period. It is believed that this is the result of reduced nitrification in the upstream reactors during the event which would have decreased the NO_x to the DN1 reactor based on the decrease in DO concentration observed in these reactors.
- The DAF effluent COD increased during the event and subsequently recovered to the treatment goal (equivalently calculated BOD concentration of 30 mg/l).
- Although not statistically significant, the event appeared to have an impact on the effluent TSS and TN with recovery to the effluent concentration goal levels within 2 hours of returning to the pre-stress levels. This quick recovery after the event suggests that there was not a loss of biomass but rather environmental conditions in the reactor that were not optimal.

For the full strength peak flow short duration event (2 hr duration) the following was observed:

- The DO concentration in the nitrification reactors was depressed during the event. Note the air flow to the aerobic reactors was not adjusted during this stress test. An expected result would be the partial loss of nitrification. The DO in the nitrification reactors recovered in 3 hours of returning to the pre-stress levels.
- Statistically the event only had a significant impact on the DN1 reactor COD and TN.
- For COD there was an increase in the DN1 effluent concentration during the stress event followed by a decrease in the effluent COD after flows were returned to the pre-stress flow rates.
- For TN, the DN1 there was an increase in the effluent TN during the event followed by a subsequent increase in the DN1 effluent after flows were returned to the pre-stress flow rates.
- The event appeared to have an impact on the DAF effluent TSS, COD, NH₃ and TN concentrations. It is likely that the ANOVA test did not detect a difference in the ammonia response due to low ammonia recovery data.
- The TSS did not exceed the 30 mg/l target at any time during the event or recovery period
- An increase in ammonia was observed in the DAF effluent during the event indicating incomplete nitrification in the nitrification reactors. This is likely due to the increased load to the reactors and the DO suppression in the nitrification reactors. The ammonia concentrations recovered to the pre-stress condition within 3 hours of the flow returning to the pre-stress flow conditions. In a full scale operation care should be taken to ensure sufficient aeration is available under peak loading conditions. It should be noted that the BOD (calculated based on COD) and TKN loadings to the reactors were within the vendor specified loading rates which indicates that environmental conditions in the reactors resulted in the effluent concentration variations and not exceeding the treatment capacity of the reactors.

For the full strength, peak flow, 6 hour duration test the following was observed:

- The event was longer (8.3 hrs) than planned due to problems with other systems.

- There was a slight depression in DO in the nitrification reactors during the event with a rapid recovery subsequent to the event.
- Statistically the event only had an impact on NH₃ and TN in both the DN1 and DAF effluents with the NH₃ and TN concentrations recovering (TN to effluent concentration goal of 8 mg/l) in approximately 6 hours. In both cases the NH₃ and TN increased during the event and decreased during the recovery. This quick recovery after the event suggests that there was not a loss of biomass but rather environmental conditions in the reactor that were not optimal.
- It is believed there was incomplete nitrification in the N1 and N2 reactors that resulted in the increases in effluent NH₃ and TN. Although there was only a slight suppression of DO in the nitrification reactors it is believed that this resulted in the incomplete nitrification.

For the diluted strength, peak flow, 24 hour duration test the following was observed:

- There was no depression in DO in the nitrification reactors during the event. This was expected as there was no increase in the organic loading under diluted strength loading condition.
- Statistically the event had an impact on the DN1 reactor effluent NH₃ and TN and the DAF TSS and NO_x.
- For all of these statistically significant constituents their effluent concentrations were found to decrease during the event and increased during the recovery. This is believed to be the result of the 50% dilution of the wastewater feed during the event.
- The impact on the denitrification reactor and DAF TN effluent concentrations during the event after 3 hours of high flow with the TN recovering to the TN effluent concentration goal of 8 mg/l in approximately 6 hours.
- There was a small increase in the TSS effluent concentration during the event however the TSS concentration did not exceed the 30 mg/l TSS effluent concentration goal during the event.
- An increase in the COD in the denitrification reactor effluent and DAF effluent was observed during the event. This high COD was attributed to overdosing of supplemental carbon to the denitrification reactor.

3.4.5.3 Conclusions. Based on the hydraulic testing the following conclusions can be made based on the simulated storm events:

- Under medium and peak flow full strength wastewater conditions of 2 hr or 6 hr duration (which could be considered similar to first flush conditions) there was an impact on the TN effluent concentration, TSS effluent concentrations, and DO suppression in the reactors.
- The DO suppression observed is likely due to the insufficient aeration capacity as the aeration airflow rate was not increased during the events. Care should be taken to include sufficient blower capacity in a full scale design to minimize the DO suppression in the aerated reactors. This DO suppression likely had an impact on the effluent TN due to incomplete nitrification while the DO was suppressed. It is possible that with sufficient blower capacity that there would be a reduced or no impact on the effluent TN concentrations.
- Under medium and peak flow full strength wastewater conditions with 2 hr or 6 hr durations the recovery of the affected wastewater parameters was approximately as long as the event. This indicates that for short duration events of high concentrations (first flush type events) that the systems recover quickly and should not have a significant impact on monthly or weekly average effluent concentrations. It also appears that the TSS and TN excursions during the events would

not impact the WWTF on a daily effluent basis because effluent quality recovered within hours of the events ending and it is unlikely that the high influent concentrations would continue for extended period of time.

- Under the diluted strength peak flow 24 hour event (similar to a sustained wet weather event) there was little detrimental impact on effluent wastewater constituents with the exception of TN. This indicates that the MBBR system with DAF should be able to operate within the anticipated permit limit for TSS and BOD for average monthly, maximum week and maximum day conditions at the diluted wastewater concentrations which are typical of the high flows at the WWTF observed in the Monthly Operating Report (MOR) data for the last 4.5 years.
- It appears that the high flow conditions did not have a detrimental impact on the MBBR biomass (not washed out)

3.4.6 Pilot Observations and Considerations for Full Scale Implementation

- The MBBR-DAF system was fairly simple to operate and troubleshoot. The growth of organisms on the media appeared to be easy to establish and maintain. Evaluating the mass of biogrowth on the media was straightforward. There was also easy access to different sections of the reaction tanks, so the operator could directly separately assess BOD removal, nitrification, and denitrification.
- During the piloting effort vendor support was essentially not needed for the MBBR-DAF system suggesting a relatively easy system to operate.
- It was felt that the MBBR-DAF system was easiest to operate as compared to other technologies. It should be noted that this technology has the least amount of complexity.
- At the pilot scale, media retention was fairly simple, but screens and pumps required constant cleaning, as the sloughed organic matter blocked screens constantly.
- During the piloting start-up effort, the media was difficult to wet when potable water was used, but this issue was resolved when wastewater was applied. This point should be brought forward in the design process to reduce potential issues with initial startup.
- There was poor mixing in the smaller reaction tanks, especially NR2 and DN1, and keeping the media from stagnating in the corners was difficult. Stagnant media was likely not effective in providing treatment, and reduced the surface area available for bio-growth and substrate utilization. It is believed that most of the stagnant media issues were due to the small pilot tank size, and the fact that corners trapped a larger fraction of media in a small tank than they would in a large full scale tank. The design engineer should consider the design at other sites, and consult with the media vendor for proper mixing recommendations.
- The media itself was of some concern at the pilot scale. A fraction of the media beads were not manufactured to the proper size and shape, being flattened along the axis. These beads often passed through, or lodged in, screen structures. Many actually passed through small submersible pumps, and they were a regular cause of clogging pumps, valves, and small diameter pipes such as the DAF feed line. Media quality control is of paramount importance for full-scale application.
- The pilot MBBR aeration system (like the CAS-BioMag system) was a manual system. Dissolved oxygen carry-over from the nitrification zone to the denitrification was often suspected. It is necessary that care be given in designing an efficient automated system for full-scale application and well as other means to minimize DO carry-over to the denitrification stages (small de-oxygenation zone) be considered.

- Adequate mixing of the media appeared to be an issue during the testing. Consideration should be given to improve mixing in a full scale application or a reduction in the media fill from the maximum fill of approximately 60% to a lower fill percentage.
- Selected design BOD design loadings may be too conservative (See Figure 3-4A) and thus there is the potential to increase the loading and therefore decrease the reactor size.
- Consideration should be given to include a small storage tank for the DAF solids so can be adequately and reliably transferred to sludge thickening.
- Piloting showed that on many occasions there were issues associated with the DAF efficiently removing TSS. It was felt that the performance issues were more centered around the scale and nature of the DAF pilot unit and would not be repeated in a full-scale DAF operation. However, as part of the design process it is recommended that special attention be taken when developing the performance requirements for the DAF units.
- During the MBBR-DAF piloting effort a number of performance issues were cited such as TSS excursions above 30 mg/l. However upon further evaluation it is believed that the causes for this poor performance may have been associated with the piloting equipment and not the actual technology.
- It is recommended that as part of the design process adequate performance testing requirements be included to ensure both increased hydraulic and/or varying hydraulic loads to DAF units be included to ensure adequate performance.
- As part of the design it is essential to ensure sufficient aeration capacity be included to handle short term high flow events with undiluted wastewater strength.
- The loss of media is always a concern in moving bed media reactors and care during the design process should be taken to assure no loss of media occurs during normal and abnormal operation. Adequate fail safe media retention systems should be incorporated in the design.
- It is recommended that during the design phase that MBBR operation as a MLE process be evaluated. Both capital and operational savings should be included within this evaluation.
- The pilot DAF system used did not have the capabilities to vary polymer addition on a real time basis. For the most part during the pilot program, polymer and DAF feed rates were kept constant. It is recommended that as part of design consideration be given on how best to control and adjust DAF polymer addition.
- Since this technology requires the intermittent use of polymer in the day to day operation, further testing of the effluent for toxicity should be carried-out.
- The pilot MBBR system like the BAF and for that matter the four stage CAS-BioMag system all require the addition of supplemental carbon to achieve low TN effluent concentrations. The under dosing of supplemental carbon will adversely impact TN removal and the overdosing of supplemental carbon will adversely impact the effluent BOD concentration. It is necessary that all full-scale systems which employ the addition of supplemental carbon at the later stages of the treatment reactors include adequate I&C and addition equipment for tight control.
- The pilot scale DAF system was used to provide water quality information for MBBR bioreactor effluent. Due to the small size of the pilot-scale DAF, the need to clean the DAF and other concerns with the operation, it is unlikely that the pilot data can be directly used to evaluate the performance of full-scale DAF processes. Problems with the DAF operation likely contributed to high effluent concentrations of TSS, DAF, and TN which may not be representative of a full-scale application.

3.5 PILOT DATA ANALYSIS SUMMARY

This section presents a summary of the analysis of the pilot data analysis of the three technologies. This summary is presented as an overview of the pilot data, but in addition to the data there are other factors that should be considered in the selection of a technology for the WWTF upgrade including the subjective criteria which is found in Section 6 of this report. This summary does not reflect all of the specific details of the entire pilot program. Additional detail can be found in previous sections and in the Blueleaf Incorporated Pilot Testing Report which is included at the end of the report as Attachment B.

3.5.1 Experimental Plan Results and Ability to Meet the Treatment Goals

The effluent field and laboratory data collected from all of the experimental plans for all the technologies are presented in Table 3-13. This table presents a summary of the field and laboratory BOD, TSS and TN effluent data collected for each experimental plan for each technology. This presentation shows how the technologies performed under different flow and loading conditions while trying to achieve secondary or secondary and total nitrogen removal treatment goals.

Based on the data presented in Table 3-13, the ability of each technology to meet the established treatment goals is summarized in Table 3-14. As noted in the Table 3-14, all technologies were deemed capable of achieving the effluent goals the pilot study.

Table 3-14. Ability to Meet Pilot Study Effluent Concentration Goals

	BAF	CAS-BioMag	MBBR-DAF
BOD – 30 mg/l	Yes	Yes	Yes
TSS – 30 mg/l	Yes	Yes	Yes
Total Nitrogen - 8 mg/l	Yes	Yes	Yes
Total Nitrogen - 3 mg/l	Yes*	Yes*	Yes*

*may not be able to meet the goal consistently

Further discussion of the comparison of the performance of the different technologies is presented below.

3.5.2 Comparison of Effluent Concentrations

Presented below are statistical comparisons of the effluent wastewater constituents of the three technologies as measured by treatment performance. The evaluation used an one way analysis of variance (ANOVA) of the laboratory data. This data was collected to determine if the performance of the each technology is statistically different from the others. The Blueleaf Incorporated Pilot Testing Report included as Attachment B describes this analysis in more detail. Also, all of the laboratory and field data is visually presented below as box plots. A sample box plot and the important aspects of the box plots are described below.

Table 3-13. Experimental Plan Summary

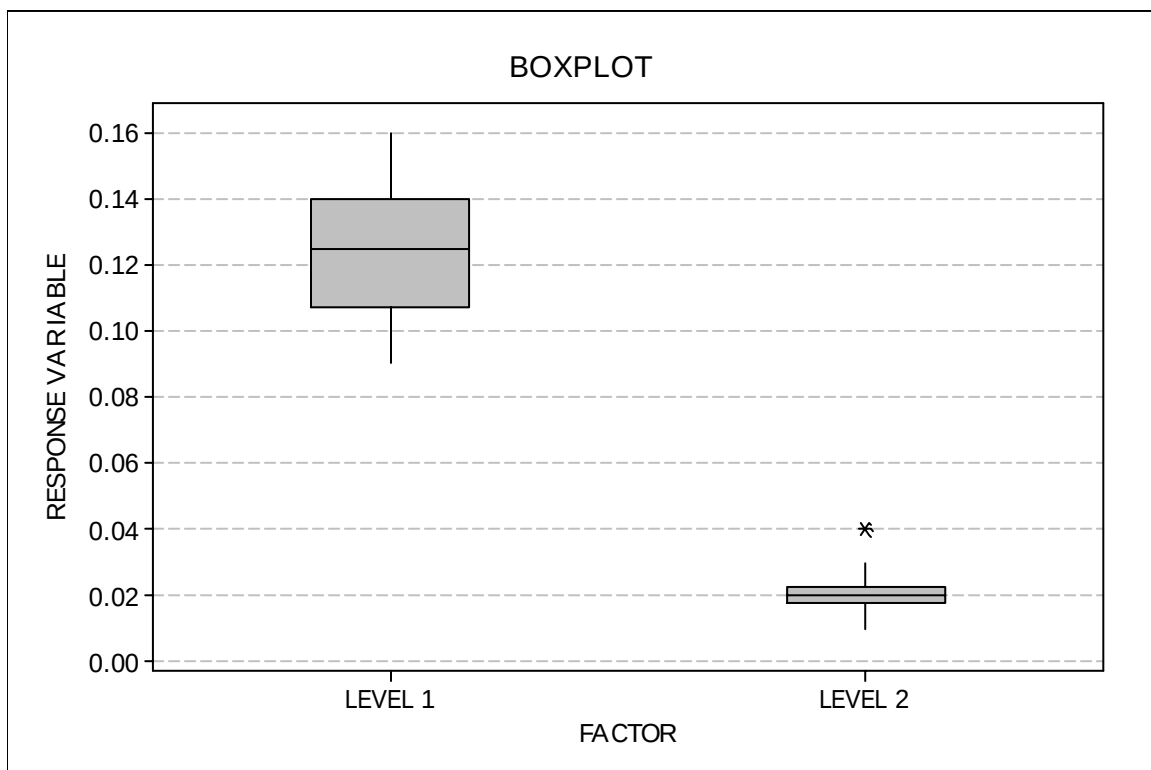
Parameter	Experimental Plan	EP-01 Results	EP-02 Results	EP-03 Results	EP-05 Results	EP-06 Results
	Test Condition	Average Daily BOD Loading	Maximum Month BOD Loading	Maximum Month Daily BOD Loading	Maximum Month BOD Loading Elevated Ammonia	Maximum Month BOD Loading Elevated Ammonia
	Test Objective	BOD and TSS Removal	BOD and TSS Removal	BOD, TSS, and TN < 8 mg/l	BOD, TSS, and TN<8 mg/l	BOD, TSS, and TN< 3 mg/l
BOD Field Results, mg/l	BAF	NA	19.2 (14.3 – 27.7) [17]	NA	NA**	
	CAS-BioMag	9.2 (6 – 13) [4]	4.7 (2 – 7.3) [6]	3.5 (1.6 – 5.9) [17]	8.2 (5.2 – 15.1) [14]*	11.2 (8.6 – 15.4) [8]*
	MBBR-DAF	21.3 (8.9 – 35.6) [16]	22 (20 – 24) [6]	11.7 (5.3 – 23.5) [18]	NA	N/A
BOD Lab Results, mg/l	BAF	NA	13, 8, 14	NA	NA**	
	CAS-BioMag	<6, 11, 9	<6, <6, <6	<6, <6, <6	NA	NA
	MBBR-DAF	8, 20, 17	17.8 (11.7 – 24.5) [14] *	7.5 (2.6 – 11.3) [20]*	17.4 (13.3 – 22.4) [6] *	17.5 (11.2 – 31.5) [11] *
TSS Field Results, mg/l	BAF	NA	12.9 (0 – 23.4) [26]	NA	Stage 1- 17.6 (5 – 48.3) [28] Stage 2 - 19.2 (4 – 29.2) [23]	
	CAS-BioMag	14.2 (7 - 26) [30]	14.2 (7.2 – 26.8) [12]	12.5 (4.8 – 32.8) [20]	10.7 (0 - 26) [14]	5.9 (1 – 12.8) [8]
	MBBR-DAF	14.5 (2.0-22.0) [30]	26.9 (17.2 – 40.4) [21]	19.7 (11.6 – 37.5) [20]	23.8 (17 – 31) [6]	15.3 (8.4 – 33.2) [10]
TSS Lab Results, mg/l	BAF	NA	25, 5, 13	NA	Stage 1- 16 (12 – 23) [6] Stage 2 - 11.1 (<5 – 15) [7]	
	CAS-BioMag	<5, 10, 9	10, 9, 13	<5, <5, 7	8, 13, 21	10, <5, 16, 6, 7
	MBBR-DAF	16, 13, 19		13.3 (9 – 21) [3]	21, 27, 32	27, 9, 10, 12
TN Field Results, mg/l	BAF	NA	NA	NA	NA	
	CAS-BioMag	NA	NA	3.8 (0.6 – 8.8) [10]	2.95 (0.83 – 5.51)	2.45 (1.2 – 4.1) [4]
	MBBR-DAF	NA	NA	5.3 (0.2 – 19.6) [8]	4.0 (2.9 – 5.9) [5]	2.98, 5.5
TN Lab Results, mg/l	BAF	NA	NA	NA	4.9 (3 - 6.3) [7]	
	CAS-BioMag	NA	NA	3.6, 3.6, 11, 3.7, 2.8, 3.4	4.6, 6.1, 6.7	4.3, 2.2, 2.8
	MBBR-DAF	NA	NA	7.5 (1.3 – 13) [7]	6.7, 3.3, 6	6.9, 7, 2.8, 3.8

* Effluent BOD Calculated from COD. ** BOD not tested due to intentional supplemental carbon overdosing of the stage 2 BAF.
Data presentation format - For large data sets - Median value (minimum value – maximum value) [number of samples]
 - For small data sets – sample value, sample value, sample value

3.5.2.1 Box Plots. Box plots are used to provide a graphical summary of the distribution of a sample set. A box plot shows the shape, central tendency, and variability of the samples. A sample box plot is shown below as Figure 3-5A. One factor (such as effluent concentration) was tested at two levels (ex. laboratory and field data or two different technologies). The box plot in Figure 3-5.A suggests that Level 2 resulted in a lower median response (concentration) than Level 1, and also had a narrower range of variation than level 1. The important aspects of the box plot include:

- The range box contains the middle 50% of the data.
- The top of the box indicates the third quartile (Q3). 75% of the data are less than or equal to this value.
- The line inside the box indicates the median (Q2). 50% of the data are less than or equal to this value, and 50% of the data are greater than this value.
- The bottom of the box indicates the first quartile (Q1). 25% of the data are less than or equal to this value.
- The upper whisker (vertical line) extends to the maximum data point within 1.5 box heights from the top of the box.
- The lower whisker extends to the minimum data point within 1.5 box heights from the bottom of the box.
- An asterisk (*) denotes an outlier, an observation that is beyond the upper or lower whisker.

Figure 3-5A. Sample Box Plot



3.5.2.2 Effluent TSS Comparison. A one-way ANOVA was used to compare the effluent TSS collected for all processes during all experimental plans, using laboratory results only. The results of this analysis are presented in Table 3-15.

Table 3-15. Pilot Technology Effluent TSS Concentration ANOVA Analysis

	BAF	CAS-BioMag	MBBR-DAF
Number of Samples	10	15	13
Mean Effluent TSS, mg/l	11.3	9.6	17.4
Standard Deviation	3.7	4.5	7.8

The results showed that there was a statistically significant difference in the laboratory TSS concentrations between processes. The analysis indicated that the effluent TSS from the MBBR-DAF process was statistically different and greater than the effluent TSS from either the CASB (CAS-BioMag) or the BAF while the CAS-BioMag and BAF effluent TSS concentrations were not statistically different.

The average effluent TSS concentration of the BAF differed from the average effluent TSS concentration of the CAS-BioMag system by only 2.7 mg/L, which is less than the standard deviation of TSS of either of the two processes. Note that the standard deviation of effluent TSS from the MBBR-DAF is much higher than the other two processes. The high standard deviation is believed to be the result of the frequent occurrence of high TSS escaping the DAF, likely from poor cleaning, or poor hydraulics.

Figure 3-5B shows a box plot for both the laboratory and field effluent TSS data from each process. Note that the tail from the MBBR (MBBR-DAF) included a data point with a very low effluent TSS concentration, indicating that the MBBR-DAF produced a low effluent TSS concentration, but not consistently. It is unclear if the poor performance of the DAF is an indicator of technology, or of the specific DAF unit used during this pilot study.

3.5.2.3 Effluent BOD Comparison. A one-way ANOVA was used to compare the effluent BOD for all processes during all experimental plans, but using laboratory results only. The results of this analysis are presented in Table 3-16.

Table 3-16. Pilot Technology Effluent BOD Concentration ANOVA Analysis

	BAF	CAS-BioMag	MBBR-DAF
Number of Samples	3	11	13
Mean Effluent BOD, mg/l	11.7	7.0	8.4
Standard Deviation	3.2	1.8	6.0

The results showed that there was not a statistically significant difference in the laboratory BOD concentrations between technologies. The BAF process had higher median effluent BOD than the other two processes, but the statistical test could not detect a difference because there were only three lab samples collected for BOD.

Figure 3-5B. Box Plot of Effluent TSS for All Processes, All Experimental Plans

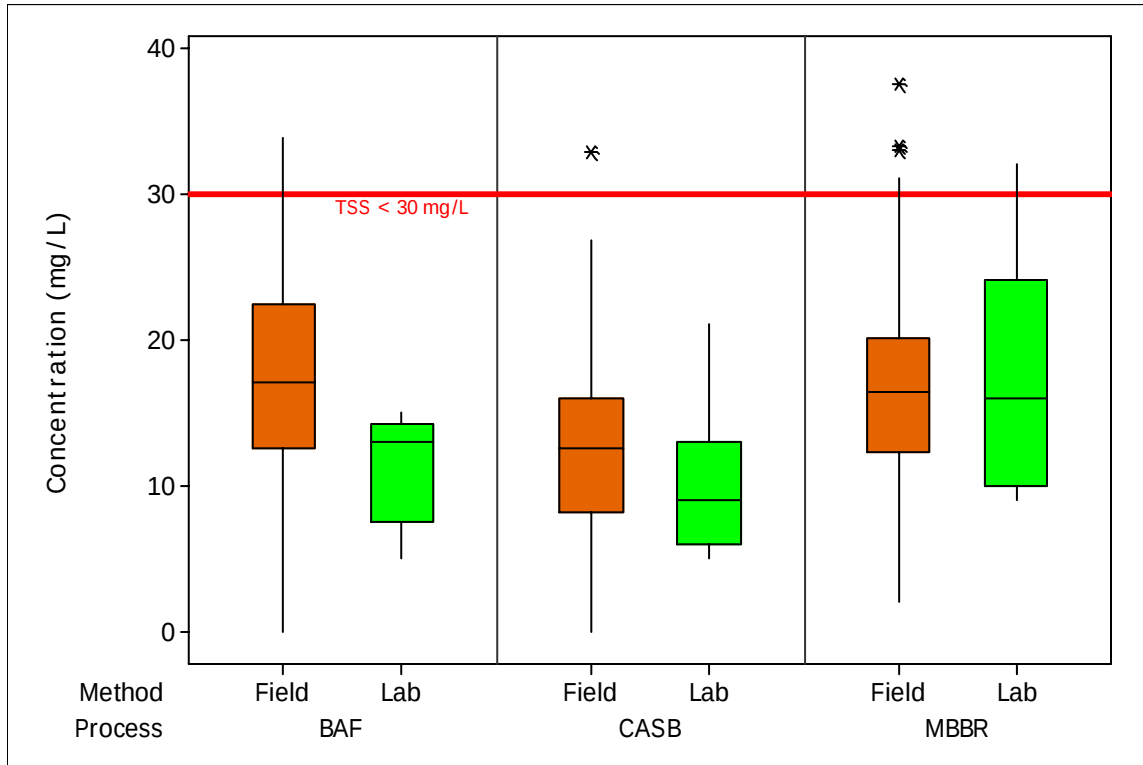


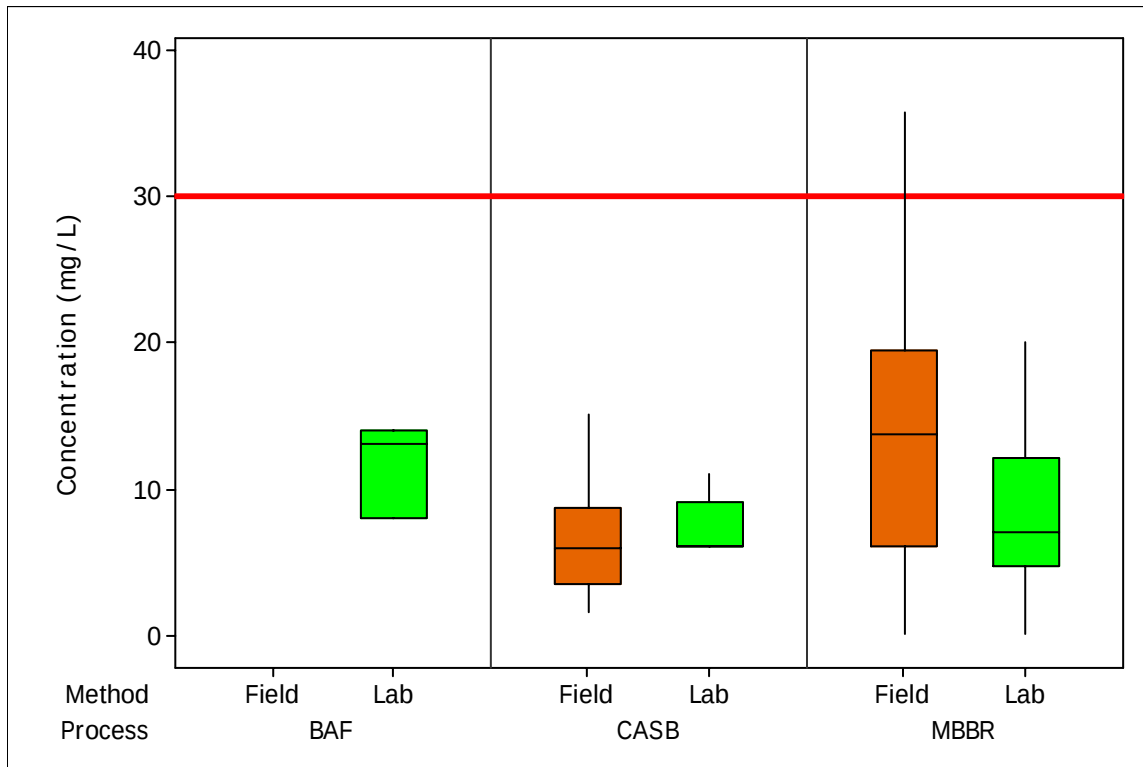
Figure 3-5C shows the box plot for both the field and laboratory analyses of BOD for all processes. Similar to the results for the effluent TSS, the effluent BOD from the MBBR process had a high amount of variability relative to the other processes.

3.5.2.4 Effluent TN Comparison. A one-way ANOVA was also used to compare the effluent TN for all processes during experimental plans 05 and 06, again using only laboratory results. The results of this analysis are presented in Table 3-17. However in this analysis there are five processes being compared, with CASB4 representing the four-stage Bardenpho conventional activated sludge process (for CAS-BioMag), and MBBR5 representing the 5-stage MBBR process (MBBR-DAF), both used for a target effluent TN of 3 mg/L. There was only one configuration of the BAF process tested. The data from the Experimental Plans 05 and 06 were used, so all data represents periods with high influent ammonia loading.

Table 3-17. Pilot Technology Effluent TN Concentration ANOVA Analysis

	BAF	CAS-BioMag (MLE)	CAS-BioMag (4 Stage)	MBBR-DAF (4 Stage)	MBBR-DAF (5 Stage)
Number of Samples	7	3	3	3	4
Mean Effluent TN, mg/l	5.0	5.8	3.1	5.3	5.1
Standard Deviation	1.1	1.1	1.1	1.8	2.2

Figure 3-5C. Box Plot of Effluent BOD for All Processes, All Experimental Plans



The results showed that there was not a statistically significant difference between effluent TN concentrations for the five processes evaluated. The four-stage CASB (CAS-BioMag) process had the lowest effluent average TN of 3.1 mg/L, while the “normal” 2-stage MLE CASB (CAS-BioMag) had the highest effluent TN concentration of 5.8 mg/L.

Figure 3-5D shows the box plot for both the field and laboratory analyses of TN for all processes.

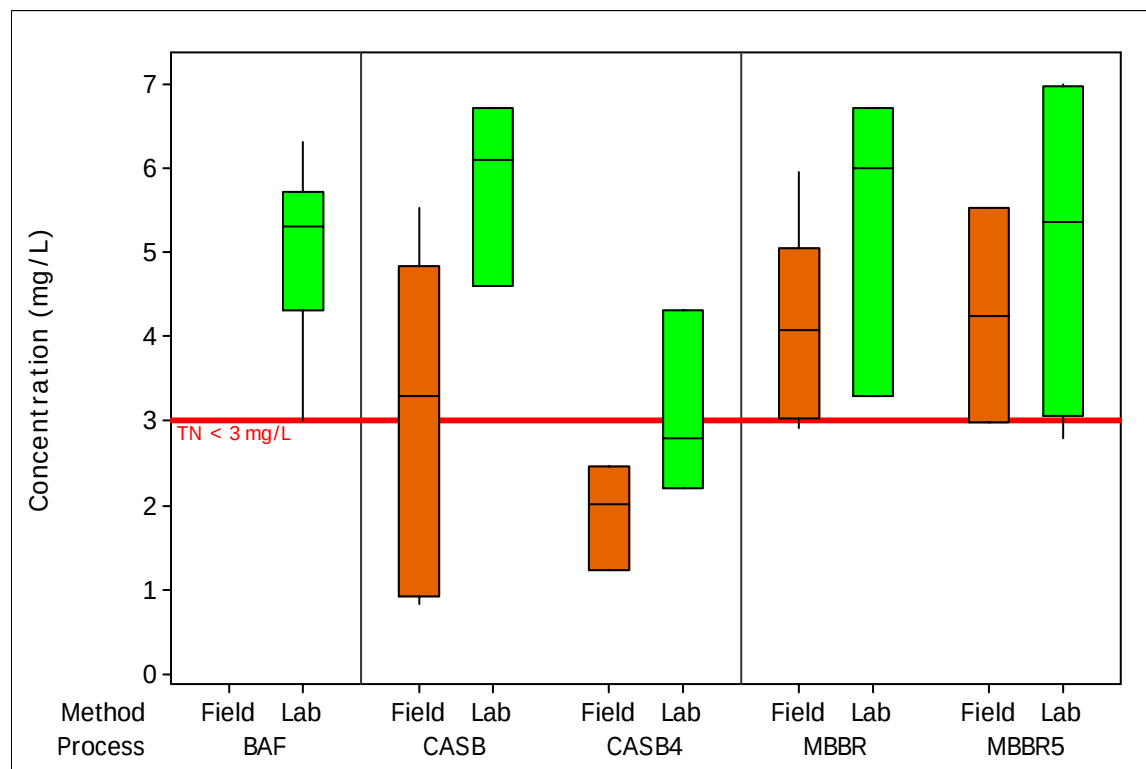
3.5.3 Vendor Constituent Loading Rate Validation and Potential to Reduce Technology Size

As part of the piloting effort, the technology vendors provided design loading rates for the various portions of their processes (BOD, nitrification, and denitrification). The data collected during the experimental plans were evaluated to validate vendor provided loading rates and confirm if their proposed process/equipment sizing were adequate for meeting the treatment goals of the Peirce Island WWTF.

The vendor loading rates and collected data were also examined to assess if there was the potential for optimizing the process. It should be noted that all load criteria (e.g., carbon, nitrification, and denitrification) were examined for adequacy and/or conservatism. If not adequate the system maybe to small and would need to be increased whereas if too conservative there is the potential to reduce the process/equipment size in a full scale installation.

A summary of the vendor constituent loading rate validation and potential to reduce the technologies process/equipment size for each technology for BOD, nitrification and denitrification are included in Table 3-18. Any potential increases in loading rate and potential reduction in process/equipment size should be considered in more detail during design. Potential loading rate changes should be discussed with the technology vendors. Their input and buy-in to any loading rate changes is needed since it

**Figure 3-5D. Box Plot of Effluent TN
for All Processes, Experimental Plans-05/06**



will likely be recommended in the design that the vendors be required to provide a performance guarantee for their processes and at specified loading rates.

3.5.4 Hydraulic Stress Test Summary

As part of the piloting effort, each technology was run under different hydraulic stress conditions to assess its ability to perform and recover from the stress condition as well as determine if there was any biomass washout.

It is difficult to directly compare the results of the hydraulic stress tests for each of the technologies to each other since each technology experienced a different flow condition. For instance, the flow rate through the CAS-BioMag process was doubled to achieve the peak flow rates, while the flow rate through the BAF was increased by a factor of 3, and then 6 during its tests.

None of the processes appeared to lose biomass as a result of the increased flow rates. It should also be noted that the only process changes that were made to both the BAF and MBBR-DAF systems during the tests was the increase in the influent flow. Conversely, process changes to the CAS-BioMag system were made (DO increases and RAS flow rate increases for all tests and polymer dosing for the 24 hr stress test) during its stress tests.

Both the BAF and MBBR-DAF effluents exceeded total nitrogen limit of 8 mg/l during a portion of the high stress conditions (as the result of dissolved oxygen suppression and incomplete nitrification), but generally recovered within four to six hours after the flow condition was returned to pre-stress conditions. None of the hydraulic stress test caused the CAS-BioMag process effluent to exceed total nitrogen of 8 mg/l. However again it should be noted that process adjustments were made to the BioMag system during the stress tests that were not made to the other technologies.

Table 3-18. Vendor Constituent Loading Rate Validation Summary

Constituent	Technology	Vendor Loading Rate Validated	Potential to Modify Loading Vendor Loading Rate	Notes/Comments
BOD Removal	BAF	Yes	Potential to increase	Pilot loading rate 2x vendor loading rates without performance impacts. Ability to modify dependent if a single or two stage carbon/nitrification process is used
	CAS-BioMag	Volumetric Loading - Yes Mass Loading - Yes	Volumetric Loading Rate - Potential to increase Mass Loading Rate - Potential to increase	Pilot volumetric loading rate 2x vendor loading rates without performance impacts. Pilot mass loading rate 3x vendor loading rates without performance impacts. Ability to modify dependent if a single zone or combined with nitrification
	MBBR-DAF	Yes	Potential to increase	Pilot loading rate 2x vendor loading rates without performance impacts. Ability to modify dependent if dedicated carbon removal or combined carbon removal/nitrification zones are used
Nitrification	BAF	Yes	No	Pilot loading rates approached vendor loading rates with good nitrification performance
	CAS-BioMag	Volumetric Loading – No - pilot not run at high enough rates Mass Loading - Yes	No	Pilot loading rates appear to be adequate
	MBBR-DAF	Yes	Potential to increase	Pilot loading rates 20-30% greater than vendor loading rates without performance impacts.
Denitrification	BAF	No – Pilot not run at high enough rates	No	Rates are acceptable based on denitrification performance and comparing to rates at other full scale DN BAFs
	CAS-BioMag	NA – Was not evaluated*	NA – Was not evaluated	Vendor sizing was adequate Technology should be able to meet TN of 8 mg/l reliably and 3 mg/l intermittently
	MBBR-DAF	Yes	Potential to increase	Limited pilot data above the vendor loading rate

* Loading rate not provided by vendor.

The hydraulic stress test experiments was designed to test the capacity of the BAF to accommodate large (larger than the other technologies) and sudden changes in flow and loading. The results of the 24 hour BAF stress tests suggested that the BAF filters did perform well to significantly increased nitrogen loads. Over the course of each 24 hour stress test, Stage 1 BAF effluent ammonia concentrations initially spiked, but then decreased quickly, suggesting that the nitrifying filter had the capacity to treat a wide range of influent ammonia loads when given sufficient time to acclimate to the loading change. The change in hydraulics had much less effect upon BAF performance than the change in mass loading.

SECTION 4 – WASTEWATER DATA AND REVISED FULL SCALE DESIGN CRITERIA

4.0 INTRODUCTION

This section presents updated data on wastewater characteristics and revised information regarding the sizing and design criteria for the proposed upgrade of the Peirce Island WWTF. This information is an update of the information contained in the Phase 1 Task 1.7 Technology Evaluation Final Technical Memorandum dated September 26, 2011 (included as Attachment A).

4.1 WASTEWATER CHARACTERIZATION PROGRAM

A wastewater characterization program was developed to provide data on the different constituents within Portsmouth's wastewater. The program included sampling and analysis of both the Peirce Island WWTF influent wastewater and the CEPT effluent and was performed over an extended period of time to quantify seasonal changes in wastewater characteristics. Analysis parameters included temperature, dissolved oxygen (DO), pH, alkalinity, fats, oils and grease (FOG), total suspended solids (TSS), volatile suspended solids (VSS), chemical oxygen demand (COD), five day biochemical oxygen demand (BOD₅), total Kjeldahl nitrogen (TKN), ammonia (NH₃-N), nitrate and nitrite (NO_x-N), total phosphorous (TP) and phosphate (PO₄-P). COD and BOD₅ were further analyzed to determine their soluble and particulate fractions.

For the majority of the analysis parameters, a 24 hour flow proportional composite sample was used for analysis after lab blending and lab filtering as required for different types of analyses. A grab sample was taken and used for FOG and DO analysis. All samples were analyzed by Eastern Analytical in Concord, NH. Additional data collected included the average daily flow and precipitation for the sampling day. Sampling and analysis began on May 13, 2011 and continued on a weekly basis through March 2, 2012. The sampling and analysis parameters are summarized in Table 4-1.

Table 4-1. Sampling and Analysis Summary

Sample Type	Temp	DO	pH	Alk	FOG	TSS	VSS	COD	BOD	TKN	NH ₃ -N	NO _x -N	TP	PO ₄ -P
Raw Influent														
Not Filtered	X		X	X	X	X	X	X	X	X			X	
1.2 µm Filtered								X	X		X	X		X
0.45 µm Filtered								X						
Flocculated and 0.45 µm Filtered								X						
CEPT Effluent														
Not Filtered	X	X	X	X	X	X	X	X	X	X			X	
1.2 µm Filtered								X	X		X	X		X
0.45 µm Filtered								X						
Flocculated and 0.45 µm Filtered								X						

A summary of the averaged data for the Wastewater Characterization Program is provided in Table 4-2. The full set of data is provided in Attachment D. The data indicated that the WWTF influent is characteristic of a medium strength wastewater with a high degree of variability. It should be noted that raw and CEPT $\text{NO}_x\text{-N}$, TP and $\text{PO}_4\text{-P}$ sampling and analysis provided the same results through the month of June 2011 and analysis for these parameters was discontinued at that time.

Table 4-2. Final Average Wastewater Characterization Results

Sample Type	Temp (deg C)	DO (mg/l)	pH	Alk(mg/l as CaCO_3)	FOG (mg/l)	TSS (mg/l)	VSS (mg/l)	COD (mg/l)	BOD (mg/l)	TKN (mg/l-N)	$\text{NH}_3\text{-N}$ (mg/l)	$\text{NO}_x\text{-N}$ (mg/l)	TP (mg/l)	$\text{PO}_4\text{-P}$ (mg/l)
Raw Influent														
Not Filtered	16.5	-	6.7	147	28	202	175	401	167	27			9.7	
1.2 μm Filtered								169	95		14	<0.5		4.0
0.45 μm Filtered								136						
Flocculated and 0.45 μm Filtered								106						
CEPT Effluent														
Not Filtered	16.3	2.6	6.7	138	8.8	59	49	200	108	22			9.0	
1.2 μm Filtered								158	89		14	<0.5		3.5
0.45 μm Filtered								124						
Flocculated and 0.45 μm Filtered								108						

The collected wastewater characterization data was used in the development of the revised flows and loads.

4.2 RECALCITRANT DISSOLVED ORGANIC NITROGEN (rDON)

Nitrogen is present in wastewater in a number of different forms including dissolved and particulate organic nitrogen, as well as dissolved ammonia, nitrate, and nitrite. In raw wastewater, nitrogen is primarily present as ammonia and organic nitrogen, which is found both in a particulate and a dissolved fraction. Of particular concern when considering a biological nitrogen removal process is amount of dissolved organic nitrogen that is not readily removable by conventional biological means, which is referred to as the recalcitrant dissolved organic nitrogen (rDON). With the potential for future total nitrogen permit limits lower than 8 mg/l, the recalcitrant component of nitrogen should be carefully considered.

As part of the Phase 2 Initial Piloting effort, samples of the raw influent wastewater were collected and analyzed to determine the rDON concentration present. The methods used to perform the rDON testing were provided to the City in a memorandum from AECOM titled "Task 1.2 Wastewater Characterization Program" and dated May 6, 2011. The test generally included mixing a combined volume of five gallons of Peirce Island WWTF raw (non-CEPT) wastewater with a seed mixed liquor suspended solids (MLSS) and aerating for an extended period of time. Filtered samples (0.45 μm) are taken at specific times and total kjeldahl nitrogen (TKN) and ammonia concentrations are measured. All samples were sent to an outside laboratory for analysis of nitrogen species. Based on the results of the first two tests, minor modifications were recommended to the program to improve efficiency as well as increase the frequency of testing

as described in a memorandum from AECOM to the City titled "rDON Intermediate Results and Testing Modifications" dated January 4, 2012. Additional tests were completed using the modified procedure and to date a total of 11 tests have been performed. Table 4-3 presents a summary of the rDON batch tests that have been completed to date.

Table 4-3. Peirce Island Raw Wastewater rDON Test Data

Date Begin	Temp. (deg. C)	DO (mg/L)	pH	TSS (mg/L)	Soluble TKN (mg/L)	Soluble NH3- N (mg/L)	rDON (mg/L)
7/5/2011	24.7	6.6	6.9	911	0.9	0.6	0.3
10/25/2011	22.4	7.0	7.2	765	1.5	<0.5	1.0
1/18/2012	18.8	8.3	7.4	922	1.8	<0.5	1.3
1/31/2012	20.2	7.9	7.3	788	<0.5	0.07	0.4
2/15/2012	21.9	5.5	6.70	884	1.1	0.05	1.1
2/27/2012	20.6	8.2	7.04	756	<0.5	0.07	0.4
3/12/2012	23.8	8.1	7.14	720	<0.5	0.11	0.4
5/8/2012	22.1	7.1	7.29	1,013	0.8	0.26	0.5
5/15/2012	24.7	5.9	7.07	998	0.5	< 0.05	0.5
5/29/2012	25.9	6.4	7.17	1,047	< 0.5	0.07	0.4
7/24/2012	24.2	7.0	7.02	1,082	1.3	0.33	1.0
Average							0.66
Std Dev							0.35
Maximum							1.3
Minimum							0.3

Note: Where minimum detection limit was provided, the absolute value was used for computations

As indicated, the average rDON value is 0.66 mg/l and the data range from a low of 0.3 mg/L to 1.3 mg/l. Typical wastewater rDON values vary between 0.5 mg/L and 1.5 mg/L.

With the standard deviation of the data at a value greater than 50 percent of the average, this shows that the data are widely variable. The rDON value along with the variability in the data should be considered as it can have an impact on the ability of the proposed secondary treatment facility to meet a low effluent nitrogen limit. The rDON concentration variability should also be considered for different regulatory time period nitrogen compliance requirements and/or basis (concentration vs. mass) requirement to be established. For example, excessive variability may make compliance for a monthly average permit limit versus a rolling average or seasonal limit more difficult to achieve.

4.3 REVISED FLOWS AND LOADS

As part of the first phase of the Wastewater Master Plan Piloting work, AECOM completed an analysis of data on influent wastewater flows at the Peirce Island WWTF to quantify design dry weather flow rates. This was completed to identify the design flows for the secondary treatment upgrade as secondary treatment would be provided for dry weather flows, and wet weather flows exceeding the secondary treatment capacity would receive CEPT treatment and disinfection. Similarly, influent pollutant concentration data were evaluated to project influent dry weather loadings for the proposed Peirce Island WWTF secondary treatment upgrade. The values determined in this analysis were used as the sizing basis for the proposed secondary treatment

system technologies evaluated as part of the Phase 1 Engineering Evaluation.

Since that submittal was prepared, several conditions warrant revision of the projected flows and loadings. First, the City has had several discussions with representatives of the EPA and the NH DES regarding the projected flows for the Peirce Island WWTF upgrade where it was indicated that the projected flows were not acceptable. Second, during the course of the piloting effort it was noted that the influent wastewater strength was higher than originally projected. Third, while it is not yet required, the City is now planning to upgrade the Peirce Island WWTF to provide secondary treatment with the ability to meet a total nitrogen limit of 8 mg/l, and the projected loadings did not include nitrogen. Lastly, the previous projections were an analysis of current wastewater flows and did not contain any allowance for future wastewater flow and load increases due to growth. The projected flows and loads have been revised to address these changed conditions.

4.3.1 Secondary Treatment Revised Flow Analysis

In the Phase 1 evaluation, AECOM used monthly operating report (MOR) data provided by the City and precipitation data from other sources to complete the evaluation. To classify days as “wet” or “dry”, AECOM developed a set of definitions which identified a finite number of days to be classified as “wet” following a specific precipitation event total depth, as well as consideration of snowmelt. The definitions were based on a system response curve developed from the available data defining the number of days for WWTF flow rates to recede to the approximate pre-event flow rate. These definitions were applied to parse the flow data into a wet classification or dry classification. Since the secondary treatment system will treat only dry weather flows, with wet weather flows in excess of the secondary treatment capacity receiving chemically enhanced primary treatment and disinfection, the dry weather flows were used as the basis for sizing of the secondary treatment system.

EPA raised a concern with this approach that since wet days were excluded from the analysis, that the average dry day flow was not representative of the annual average daily flow. To determine the annual average daily flow, which considers both wet and dry days, the flow that will be treated in the secondary treatment facilities on days classified as wet needs to be accounted for. A memorandum describing the revised approach to the flow analysis that accounts for the wet days is presented in Attachment C.

As noted previously, the Phase 1 Evaluation flow projections were based on an analysis of current wastewater flows and did not contain any allowance for future wastewater flow increases due to growth. Recognizing that growth within the Peirce Island WWTF service area is projected to occur during the 20 year service life of the upgraded plant, the City requested that the revised flows include an allowance for growth. Data from the June 2010 Draft WWMP/LTCP Update was used to account for flows resulting from projected future growth as described in the memorandum in Attachment C. Table 4-4 presents a summary of the revised existing and future condition flow rates. The instantaneous hydraulic maximum secondary treatment capacity will be established during preliminary design of the WWTF upgrade. Wet weather flows in excess of the secondary treatment capacity will receive chemically enhance primary treatment and disinfection.

Table 4-4. Secondary Treatment Process Design Flow Rates

Criteria	2012 Flow (MGD)	Peaking Factor (to average day)	Projected 20 Year Flow Increase (MGD)	2032 Flow (MGD)
Secondary Treatment Average Annual Flow	5.23		0.9	6.13
Secondary Treatment Maximum Month	7.56	1.44	1.30	8.86
Secondary Treatment Maximum Day	7.73	1.48	1.33	9.06

1. Note values shown in bold were calculated values for this table.

4.2.2 Secondary Treatment Revised Loading Analysis

In the Phase 1 Loading Evaluation, influent concentration data for total suspended solids (TSS) and 5-day biochemical oxygen demand (BOD₅) for 2008-2010 were reviewed and analyzed to project the loadings for the secondary treatment process. During the course of the Phase 2 piloting effort, it was noted that data on the plant influent BOD₅ concentrations from both the WWTF's influent sampling as well as the pilot influent sampling were generally higher than the Phase 1 loading projections. There is a clear trend in increasing influent BOD₅ concentrations from the MOR data for 2008-2012. Following review of the different data sets, the loading analysis has been revised to use the most recent MOR data for January 2011- June 2012 as the basis for the loading projection as described in the memorandum in Appendix C. It was also noted that the location of the plant recycle flows may be influencing the influent sample data. In light of this, it is recommended that during preliminary design of the WWTF upgrade additional sampling be performed on the influent wastewater in a location that is not impacted by the recycle loads. These data should be used during preliminary design to revise sizing (if necessary) and to complete a mass balance for the WWTF. In addition, the Phase 1 Loading Evaluation did not include a projection of the total nitrogen loading to the secondary treatment system, as the treatment level required at that time did not include nitrogen removal.

Similar to the flow projections, the Phase 1 Evaluation loading projections were based on analysis of existing data and did not include any allowance for loading increase due to future growth. With the inclusion of a future flow increase due to growth, the future loading projections need to include an increase in loading due to growth. To account for anticipated growth in the Peirce Island WWTF service area, data from the June 2010 Draft Wastewater Master Plan and Long Term Control Plan Update and the Wastewater Characterization program were used as described in the memorandum in Appendix C. Table 4-5 presents a summary of the revised flow and loading projections for both primary effluent and CEPT effluent.

Table 4-5. Projected Year 2032 Design Flows and Loads to Secondary

Parameter	Annual Average Day	Max Month PF	Removal Efficiency, %	Max Month
Flow (mgd)	6.13	1.44		8.86
Influent TSS (mg/L)	199			187
Influent TSS (lb/d)	10,176	1.36		13,853
Influent BOD ₅ (mg/L)	195			161
Influent BOD ₅ (lb/d)	9,959	1.19		11,881
Influent TKN (mg/L)	29.5			27.6
Influent TKN (lb/d)	1,511	1.35		2,039
Primary Effluent TSS (mg/L)	99 - 147		26% - 50% ³	94 - 138
Primary Effluent TSS (lb/d)	5,088 – 7,510			6,927 – 10,224
Primary Effluent BOD ₅ (mg/L)	136 - 165		15% - 30% ³	113 - 136
Primary Effluent BOD ₅ (lb/d)	6,971 – 8,4357			8,317 – 10,063
Primary Effluent TKN (mg/l)	26.9 - 28.6		3% - 9% ⁴	25.1 - 26.8
Primary Effluent TKN (lb/d)	1,375 – 1,465			1,856 – 1,978
CEPT Effluent TSS (mg/L)	51		74% ¹	48
CEPT Effluent TSS (lb/d)	2,618			3,564
CEPT Effluent BOD ₅ (mg/L)	121		38% ¹	100
CEPT Effluent BOD ₅ (lb/d)	6,166			7,356
CEPT Effluent TKN (mg/L)	24.2		18% ²	22.6
CEPT Effluent TKN (lb/d)	1,239			1,672

1. Percent removals based on WWTF MOR loading data capped at the maximum parsed dry flow day of 7.73 mgd.
2. Percent removal based on WWTF characterization data (May 13, 2011 to March 2, 2012).
3. Percent removal range of observed pilot data, text book values, and approximately 1/2 of the CEPT removal.
4. Percent removal range of observed wastewater characterization data, text book values and approximately 1/2 of the CEPT removal.
5. Note values shown in bold were calculated values for this table.

The revised flow and loading projections have been used as the basis for the updated sizing of each technology as described in Section 5.

4.3 UPGRADED WWTF EFFLUENT TREATMENT REQUIREMENTS

In 2007 the City received an NPDES permit (Permit No. NH0100234) from the EPA for the Peirce Island WWTF that required secondary treatment. A copy of this permit is included in Appendix E. The effluent limitations included in the permit are typical for secondary treatment with disinfection and are summarized in Table 4-6.

Table 4-6. 2007 Peirce Island WWTF NPDES Permit Limits

Effluent Parameter	Discharge Limitation		
	Average Monthly	Average Weekly	Maximum Daily
Flow, MGD	Report	-	Report
BOD ₅ Effluent, mg/L (pounds/day)	30 (1201)	45 (1801)	50 (2002)
BOD ₅ Influent, mg/L	Report	-	Report
TSS Effluent, mg/L (pounds/day)	30 (1201)	45 (1801)	50 (2002)
TSS Influent, mg/L	Report	-	Report
pH Range, Standard Units	6.0 – 8.0		
Total Residual Chlorine, mg/L	0.33	-	0.57
Fecal Coliform, %	-	-	Report
Fecal Coliform, MPN/100 ml	14	-	-
Enterococci Bacteria, Colonies/100 ml	Report	-	Report
Whole Effluent Toxicity, LC ₅₀ , % Effluent	-	-	100
Ammonia Nitrogen as Nitrogen, mg/l	-	-	Report
Total Recoverable Aluminum, mg/l	-	-	Report
Total Recoverable Cadmium, mg/l	-	-	Report
Total Recoverable Chromium, mg/l	-	-	Report

The 2007 permit expired in March 2012. The City filed a timely application for renewal of the permit in accordance with the requirements of the NPDES program. No new permit has yet been issued by EPA to the City.

In accordance with the Consent Decree and the 2007 permit, the City proceeded to undertake the piloting evaluation of potential technologies to achieve secondary treatment at the Peirce Island WWTF. The Phase 1 Evaluation reviewed eight potential technologies and selected the three of the most promising technologies for secondary treatment for piloting. During the course of the Phase 2 initial piloting effort, discussions between the City and EPA regarding the pending permit have continued, with recent verbal indications from EPA that a limit on total nitrogen in the Peirce Island WWTF effluent of 8 mg/l will be included in the new permit.

Given the likelihood that the revised NPDES permit will include an effluent limit on total nitrogen of 8 mg/l, the focus of the pilot evaluation was revised from secondary treatment only to secondary treatment with the ability to meet a total nitrogen limit of 8 mg/l. Section 5 describes the facilities necessary to implement each of the three technologies to meet the revised effluent limits at the revised flows and loadings. This change in focus from secondary treatment to secondary treatment with the ability to meet a total nitrogen limit of 8 mg/l is consistent with the commitment made by the City as part of the Great Bay Municipal Coalition to implement the Great Bay Municipal Coalition Adaptive Management Plan.

SECTION 5 – SECONDARY PROCESS RESIZING AND COMPARISON

5.0 INTRODUCTION

This section presents updated process sizing, layouts, and estimated costs for each of the three piloted technologies. The data and process insights gained during the pilot testing were used to develop the updated information. Additionally, each process has been sized for the revised flows and loads presented in Section 4 and configured to achieve secondary treatment with the ability to meet an effluent total nitrogen concentration of 8 mg/L. This information is an update of the information contained in the Phase 1 Task 1.7 Technology Evaluation Final Technical Memorandum dated September 26, 2011 included as Attachment A.

5.1 APPROACH

In addition to pilot performance data, tank sizing, process requirements/limitations, capital costs, and operation and maintenance costs were developed for each technology. After completion of the initial pilot testing, AECOM requested revised full-scale proposals from the vendors. Modifying the existing filter building to accommodate the upgrade was the preferred approach to the upgrade, but with the recognition that due to the need to achieve secondary treatment with the ability to meet an effluent total nitrogen concentration of 8 mg/L and the increase in flows and loads this would be challenging. Similarly, construction of all new facilities within the existing fence line was also preferred but it was recognized that this may not be possible due to the change in effluent limitations and the increase in flows and loads.

It was requested that the vendors provide recommendations, process sizing and layouts, and equipment costs for the concept that, in the vendor's judgment, best met the City's goals. Additional details were provided for each concept. These details are provided in the proposals which are included in Attachment F. The vendors were requested to provide a process design to provide secondary treatment and to meet the effluent total nitrogen of 8 mg/l.

Using the information provided by the vendors, AECOM advanced the concept for each technology to a conceptual level design by developing a process flow schematic and site layout. These items were used as the basis of developing the capital and operation and maintenance cost estimates for the evaluation. Lastly, a comparison matrix to evaluate non-monetary factors to rank the technologies was prepared. The evaluation matrix was used to rank the technologies to assist in the decision-making. This comparison is presented in Section 6.

Similar to the Phase I Evaluation, it was decided that the basis of process sizing, layout, and costs would be the sizing necessary for treating primary effluent rather than CEPT effluent. This approach provides a more conservative layout because these loadings are higher than CEPT loadings, which results in a larger process footprint, and thus higher costs. This option would also allow the City to limit the use of CEPT to only wet weather events, reducing the annual operating cost for chemicals and sludge disposal. This evaluation is based on the upgraded plant treating non-CEPT primary effluent to secondary treatment standards with the ability to meet an effluent total nitrogen of 8 mg/l for only dry weather flow. The existing CEPT system will be maintained for wet weather treatment.

The evaluation of the three technologies has been completed using the process configurations that were piloted. Process variations have been suggested by the vendors for several of the technologies, such as the MBBR reactor in an MLE configuration. However, the piloted configuration was used since performance data were obtained for this configuration. Further process modifications to optimize the selected technology and the configuration to minimize the extent of the upgrade outside the fence line should be considered in the future during preliminary design.

5.1.1 Common Elements

There were a number of required support unit processes common to multiple, if not all, of the proposed technologies. AECOM focused on each of the common elements and separated the costs for these facilities so that a direct comparison of the technology costs could be made. This section describes some of the common components.

5.1.1.1 Alkalinity Feed. With the requirement to provide nitrogen removal, supplemental alkalinity is needed in all of the processes in order to maintain effluent pH within permit limitations and to maintain the maximum nitrification rate. Alkalinity is typically added in the form of sodium hydroxide (caustic soda) or lime. For this evaluation, a caustic soda system was used since it is currently in use at the WWTF for effluent pH adjustment. The alkalinity storage and feed facility would house two chemical storage tanks as well as chemical feed pumps indoors to prevent freezing. This facility would be near or attached to the new headworks described in the WWMP.

5.1.1.2 Fine Screening and Pumping. Common to all the technologies was the need for influent pumping into the secondary treatment process. Common to the BAF and MBBR processes was the need for fine screening. The Conventional Activated Sludge with BioMag process did not require fine screening of the secondary influent wastewater. The concept for a combined pump station and fine screening building was carried over from the Phase I evaluation. Fine screening requirements generally ranged from 2 mm for BAFs to 6 mm for MBBRs.

The proposed building to house both fine screens and the pump station would be located between the primary clarifier (PC) distribution box and the Filter Building (southeast of the Control Building). Overall dimensions are expected to be on the order of 45 feet by 35 feet and will include the following major components:

- Screen Room
 - o Fine screens with integral washer-compactor and screening container (2)
- Pump Room
 - o Wet well
 - o Submersible pumps (3)
- Odor control unit (1)
 - o External pad mounted fan and carbon canister
- Electrical Room

5.1.1.3 Sludge and TWAS Storage. A biological treatment process will require sludge processing improvements and additional sludge storage. Previous work done as part of the WWMP identified the need for a sludge storage tank. The WWMP, however, did not provide a proposed location or other specifics of the sludge type to be stored or its operations. For the purposes of this evaluation, a sludge storage tank and a thickened waste sludge (TWAS) storage tank would be provided for the Conventional Activated Sludge with BioMag and MBBR alternatives. In this scenario, the waste sludge storage tank will provide a short amount of holding time between the sludge separation process and thickening process to allow for additional process flexibility and emergency shutdowns. The TWAS sludge storage tank will store thickened sludge prior to dewatering. It is envisioned that these tanks will be co-located to the west of the existing Control Building with an attached building. The building will house blowers, pumps and electrical equipment necessary for keeping the sludge mixed and transferring it to the thickening and dewatering processes as well as odor control equipment.

Because the WWMP proposes locating the new thickening process in the existing Sludge Processing Building, equipment to transfer thickened sludge from the sludge thickener to the TWAS storage tank is necessary in this arrangement. A new wet well as well as two new thickened sludge pumps on the lower level of the Sludge Processing Building are necessary.

5.1.1.4 Supplemental Carbon. Supplemental carbon storage and feed facilities are necessary for the BAF and MBBR alternatives. Because these alternatives consume all or most of the primary effluent BOD prior to denitrification, supplemental carbon is necessary to reduce nitrate sufficiently to achieve an effluent total nitrogen concentration of 8 mg/L. Supplemental carbon is often supplied as methanol or as a synthetic carbon source such as Micro-C. The storage and feed facilities are similar for both materials, with additional requirements for methanol due to the flammable nature of the material. To be conservative, a methanol storage and feed facility has been included as it will have a higher cost than a Micro-C storage and feed facility. The BAF alternative includes a facility with two, above grade 6,000 gallon double-walled storage tanks whereas the MBBR alternative includes two, above grade 10,000 gallon double-walled storage tanks. Each facility is equipped with feed pumps and is designed to store approximately one month of methanol based on projected use at design average flow. The location of a methanol facility relative to the other buildings and the fire suppression requirements should be considered in the future.

5.1.1.5 Main Electrical Building and Standby Generator. The main electrical feed to the WWTF and the standby generator are located in the existing Filter Building. Because the increased flows and loads and additional permit limitations have increased the footprint of all three technologies, the main electrical feed and standby generator will need to be replaced and put in a new location. Because of available site space limitations, these functions are currently envisioned to be separated. The proposed Main Electrical Building would be located to the east of the Filter Building if the parshall flume would be reused while the proposed Standby Generator would be constructed in the area of the effluent metering structure. For the purposes of the evaluation, it was assumed a new Main Electrical Building would be constructed and a new pad mounted generator with belly fuel tank and prefabricated enclosure would be provided.

5.1.1.6 Other Common Elements. The Wastewater Master Plan recommended a number of upgrades at the Peirce Island plant that would need to be implemented if the Filter Building were retrofitted to provide secondary treatment. Accordingly, AECOM carried the Wastewater Master Plan opinion of costs, but did not further develop the conceptual level concepts for Headworks (coarse screens and grit), Sanitary Disinfection (pumping and UV), Biosolids Processing (rotary drum thickeners and inclined screw presses), and Additional Structures and Modifications (splitter box improvements). These upgrade items should be further developed during preliminary design.

5.2 BAF PROCESS

The BAF option is based on the BIOSTYR® system manufactured by Kruger. In order to provide removal of carbon and nitrogen, two BAF stages would be provided in series. These include aerated BAFs for carbon removal and nitrification followed by anoxic BAFs for denitrification. The organic loading rates proposed by Kruger in this phase are similar to the prior proposal and closely match those observed during the pilot testing. Supplemental carbon addition to the anoxic BAFs would be necessary. The specific filter surface area needed is summarized below:

- Stage 1 (Carbon Removal and Nitrification) BAF – 7 filter cells at 1,268 square feet per filter
- Stage 2 (Denitrification) BAF – 4 filter cells at 304 square feet per filter

The media depth in the Stage 1 BAF is approximately 10 feet while in the Stage 2 BAF media depth is 6.5 feet. The overall building height is roughly 30 feet due to the upflow nature of the filters and the position of the clearwell on top of the filters.

When positioned together, the footprint of the two proposed BAF stages are larger than the footprint of the existing Filter Building and extends well past the limits of the existing access road. Therefore, the Stage 1 and Stage 2 BAFs have been separated. It has been assumed that the Filter Building would be demolished and the Stage 1 BAFs built in its place. The Stage 2 BAFs, mudwells, and control building would be built in a separate location west of the Control Building. To maintain gravity flow through the disinfection process and avoid a second set of intermediate pumps, the filter elevations will be positioned so that the water surface exiting the second stage filter flows by gravity to either the Parshall flume or

disinfection process. There is the possibility that the filters could re-use the foundation of the Filter Building however a new base slab was incorporated into the cost estimate to be conservative.

Backwash from the filters will flow to separate mudwells for temporary storage. The vendor prefers separate mudwells although the potential for combining them could be examined during preliminary design. Returning the backwash, which includes sludge generated by the BAF, to the primary clarifiers will potentially result in high TSS loading to the BAFs because of the decreased primary clarifier removals expected with non-chemically enhanced operation during normal, dry weather. To maintain acceptable TSS loading to the BAFs, polymer will be mixed with only the BAF backwash prior to its return to the primary clarifiers. It is believed that a dose of approximately 1 mg/L of polymer will result in sufficient additional settling to eliminate concerns of high TSS loading. A new gravity thickener will be necessary to process the additional primary sludge generated by the return of the backwash to the primary clarifiers.

The major components of the BAF process include:

- Aerobic upflow biological filters (7 cells) including nozzle decks, process air distribution system, media
- Anoxic upflow biological filters (4 cells) including nozzle decks, backwash air distribution system, media
- Influent distribution channels (2)
- Combined effluent channel and clearwell (2) between the filter cells
- Process piping to/from the process tanks
- Mudwell for backwash storage (2), polymer system for dosing backwash
- Mudwell pumps (4)
- Process air blowers (5)
- Air scour blower (2)
- Manual and automated valves
- Instrument air compressors for system pneumatic valves (2)
- Controls and instrumentation

Additional work to support this treatment alternative includes the following:

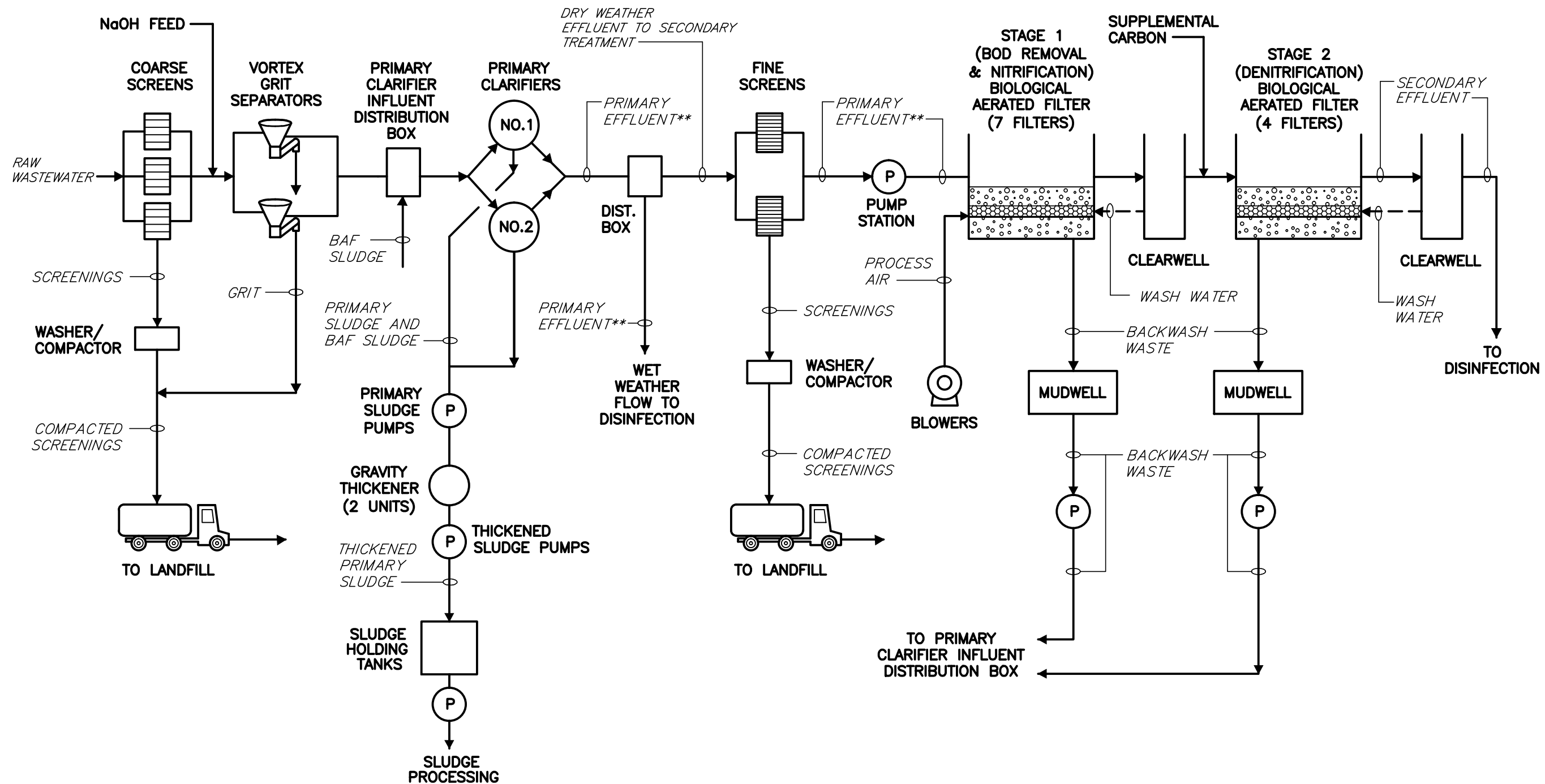
- Secondary influent pumping station and screen building southeast of the existing Control Building
- Main Electrical Building and Standby generator to replace the electrical systems in the existing Filter Building.
- Supplemental carbon addition facility.
- BAF Control Building to house the process blowers, pumps, electrical and other equipment
- Piping galleries
- Gravity thickener and sludge storage tank

A process flow schematic is presented in Figure 5-1 and a site layout is shown in Figure 5-2.

5.3 CONVENTIONAL ACTIVATED SLUDGE WITH BIOMAG PROCESS

The second technology under consideration is the BioMag system manufactured by Siemens (formerly Cambridge Water Technologies). Similar to the other processes considered, a secondary influent pump station will be required. However, fine screens are not necessary for the BioMag process. The space used by the fine screens in the other two processes will instead be used to house the process aeration blowers.

The BioMag process is separated into three parallel trains arranged as a traditional MLE process with an aerobic zone following an anoxic zone. Internal nitrate recycle pumps, piping and appurtenances would



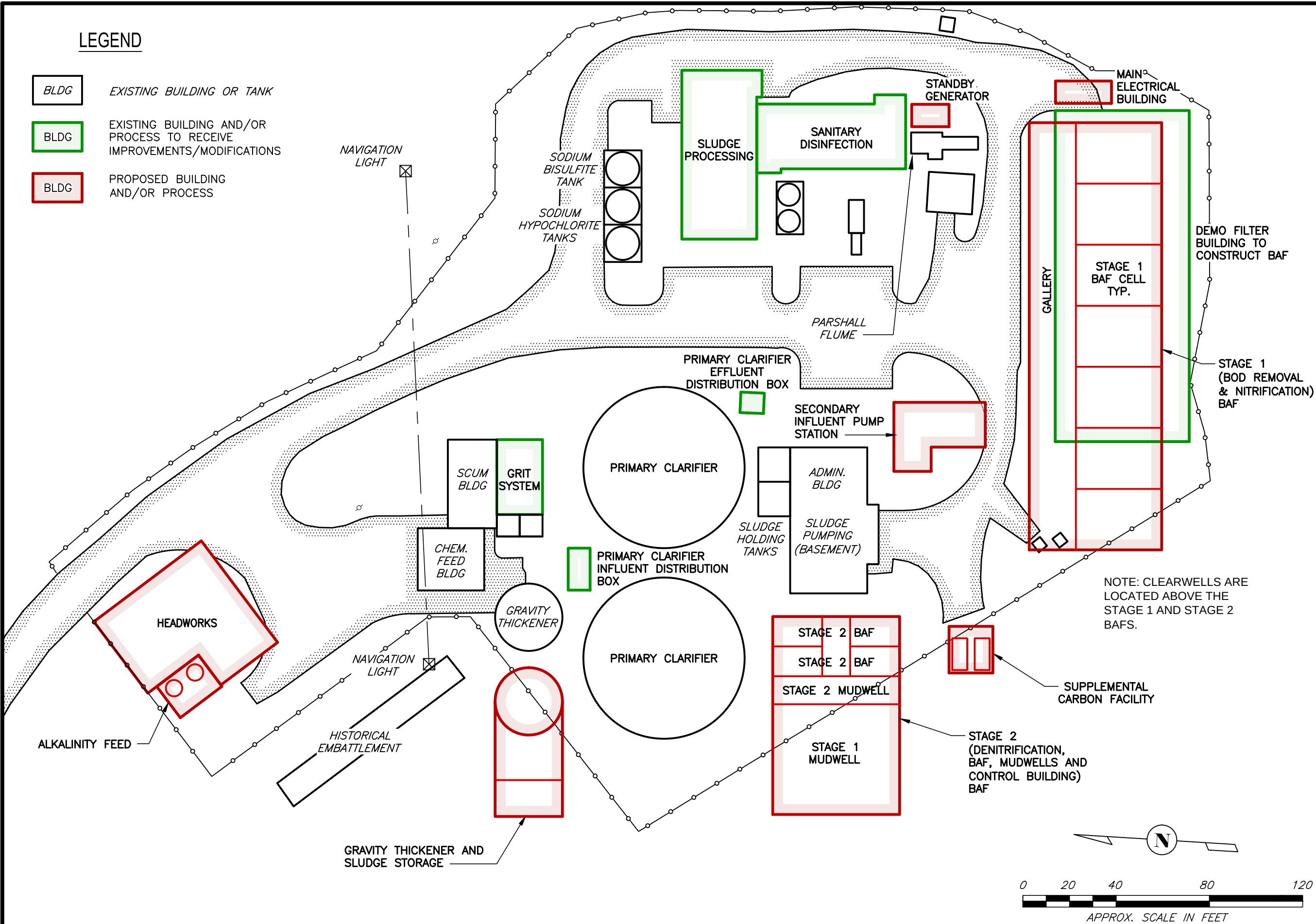
** DURING WET WEATHER EVENTS, CLARIFIERS MAY BE OPERATED IN CHEMICALLY ENHANCED MODE.

WWMP PILOTING - PHASE 2 INITIAL PILOTING
PEIRCE ISLAND WWTF - PORTSMOUTH, NH
BAF
TOTAL NITROGEN < 8 mg/L

FIGURE 5-1
PROCESS FLOW
SCHEMATIC

LEGEND

- BLDG EXISTING BUILDING OR TANK
- BLDG EXISTING BUILDING AND/OR PROCESS TO RECEIVE IMPROVEMENTS/MODIFICATIONS
- BLDG PROPOSED BUILDING AND/OR PROCESS



AECOM
701 Edgewater Drive
Wakefield, MA 01880
Ph. (781) 246-5200

WWMP PILOTING - PHASE 2 INITIAL PILOTING
PIERCE ISLAND WWTF - PORTSMOUTH, NH

BAF

TOTAL NITROGEN < 8 mg/L

FIGURE 5-2

SITE
LAYOUT

recycle large volumes of mixed liquor from the aerobic zones to the anoxic zones for total nitrogen removal. A small deoxygenation zone would be added upstream of the anoxic zone for this internal recycle to ensure that the anoxic zone remains fully devoid of oxygen. A method for surface wasting from the aeration basins would also be provided for purposes of scum removal from the reactors.

As proposed by Siemens, the biological MLSS concentration in the basins will be approximately 3,700 mg/L, not including the weight of the magnetite. There will be influent and effluent channels on each end of the aeration basins. The bioreactor dimensions are larger than the footprint of the filter building. Based on the pilot results, the aeration tank depth was limited to 23 feet due to concerns with mixing of the magnetite impregnated MLSS. The filter building would be demolished and the excavation used for the new reactors.

In addition to the reactors, three new rectangular secondary clarifiers would be required, also with influent and effluent channels. The secondary clarifiers would be equipped with chain and flight mechanisms to transport settled sludge into a sump near the influent end. Scum removal will also be provided at the effluent end. Three clarifiers are required to satisfy NHDES regulations requiring a minimum of three clarifiers for treatment plants with an average daily flow of 5 mgd or greater. To minimize space and interconnecting piping and use common wall construction, the RAS/WAS building would be attached to the influent end of the clarifiers. Table 5-1 summarizes the sizes of the process zones and clarifiers:

Table 5-1. CAS-BioMag Bioreactor and Clarifier Dimensions

Zone	Number of Trains	Length (ft)	Width (ft)	Side Water Depth (ft)
Deoxygenation	3	10	21	23
Anoxic	3	49	21	23
Aerobic	3	115	21	23
Clarifiers	3	100	20	15

The proposed secondary clarifiers have a surface area of 6,000 square feet and the proposed RAS rate is 75% of forward flow at average flow conditions. This results in an average day surface overflow rate of approximately 1,000 gallons per day per square foot and an average day solids loading rate of 55 pounds per day per square foot. At maximum month flows and loads, the solids loading rate would increase to nearly 70 pounds per day per square foot. Typical guidelines for an MLE process are for a RAS rate between 50 and 100%. RAS rates during the pilot were approximately 100%. The vendor provided solids loading rates are greater than those provided during the Phase 1 Technology Evaluation and are at the high end of the range of the rates tested during piloting. Further analysis during preliminary design may result in an increase in clarifier size.

Waste sludge from the return sludge from the clarifiers would be sent to a separate magnetite recovery building. Recovered magnetite would be returned the bioreactors along with virgin "make-up" magnetite on an as necessary basis. Siemens projects that approximately 400 pounds of virgin magnetite would be necessary per day. Waste sludge that has had the magnetite stripped out will be sent to the sludge storage tank prior to further processing.

The major components of the process include:

- Aeration tanks and fine bubble diffuser system
- Bioreactor supplemental tank mixers (21)
- Internal Recycle Pumps (6)
- Coarse bubble mixing for influent and effluent channels
- Rectangular sedimentation tanks, chain and flight mechanism, scum skimmers/baffles (3)
- Process piping to/from the process tanks
- Ballasted RAS Pumps (4)
- Ballasted WAS Pumps (2)

- Scum Pumps (2)
- Process air blowers (3)
- Shear mills (2)
- Magnetic recovery drums (3)
- Magnetite make-up tank (1)
- Magnetite tank mixer (1)
- Virgin magnetite silo (1)
- Polymer Feed System (1)
- Compressor and dryer (1)
- Manual and automated valves
- Controls and instrumentation

Additional work to support this treatment level would include the following:

- Influent pumping station and blower building to the east of the existing Filter Building.
- Magnetite recovery building southeast of the existing Control Building.
- Main Electrical Building and Standby generator to replace the electrical systems in the existing Filter Building.
- Sludge and TWAS Storage

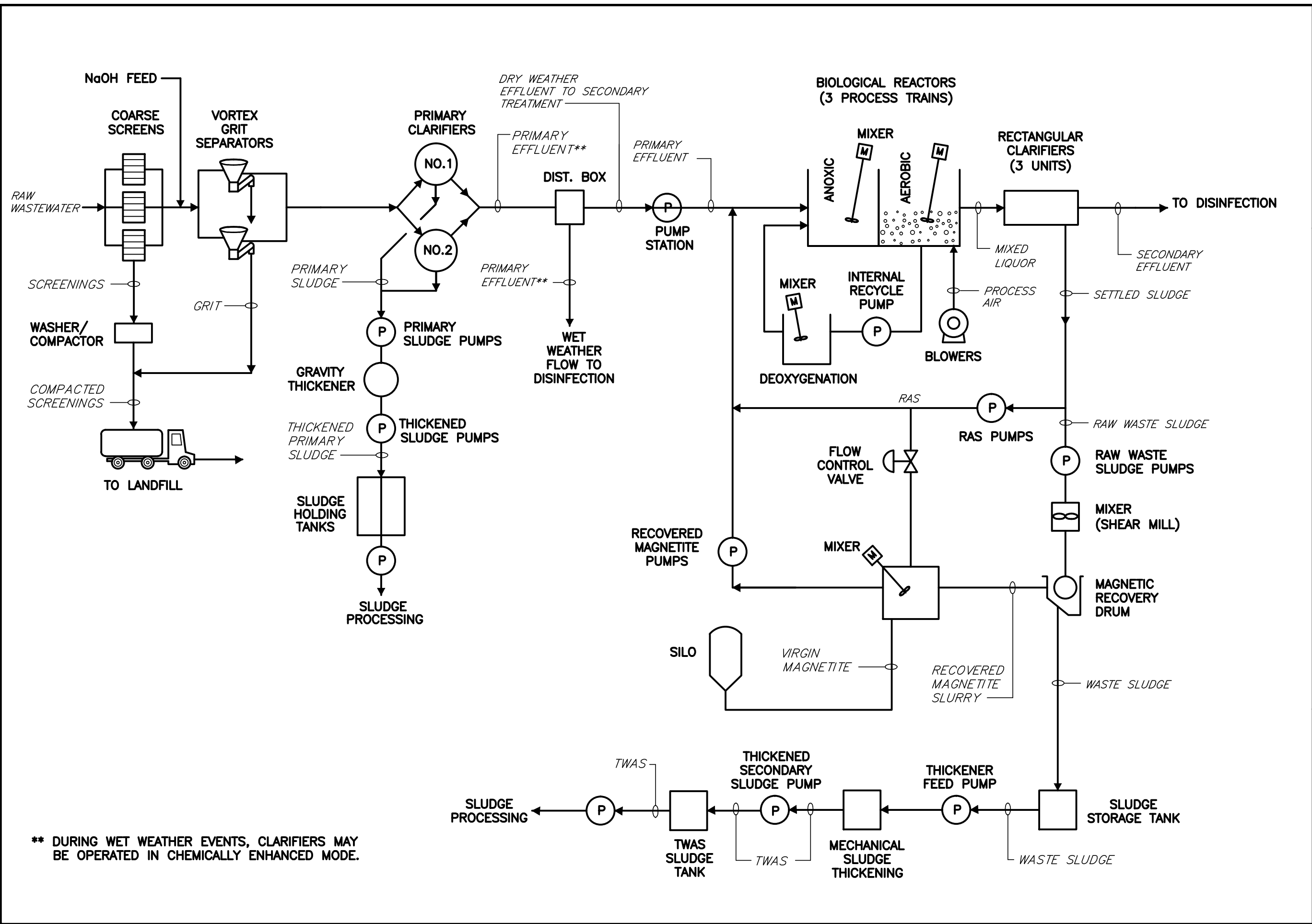
A process flow schematic is presented in Figure 5-3 and a site layout is shown in Figure 5-4.

5.4 MBBR WITH DAF PROCESS

The MBBR and DAF vendor used for this layout was World Water Works. The World Water Works MBBR system will require the use of 7 reactors per train and is designed with three parallel process trains. The first two reactors are designed for BOD removal and will be aerated. The following three reactors are designed for nitrification. Some of these nitrification reactors will be equipped with mixers and all of them will be aerated. The third nitrification reactor is proposed to have reduced aeration and supplemental mixing to keep the media in suspension while minimizing dissolved oxygen carryover to the subsequent reactor. The next reactor is designed for denitrification. It will be equipped with mixers and will not be aerated since it will be anoxic. Supplemental carbon will need to be added to this cell to provide the carbon for the denitrification reaction. Lastly, the final cell is designed for post-aeration and will be aerated. This tank's purpose is to consume any BOD associated with overdosing carbon in the denitrification stage. The total tank volume proposed is 281,800 ft³. The proposed side water depth is 21 feet. Somewhat less than half of the tank volume (119,383 ft³) will be filled with the MBBR media. Based on the pilot results, AECOM limited the percent fill to 45% due to concerns with mixing and rafting of media. The following table summarizes the sizes of the process zones and clarifiers:

Table 5.2. MBBR Bioreactor Dimensions

Zone	Number of Trains	Length (ft)	Width (ft)	Side Water Depth (ft)
BOD Reactor #1	3	31	21	21
BOD Reactor #2	3	31	21	21
Nitrification Reactor #1	3	41	21	21
Nitrification Reactor # 2	3	41	21	21
Nitrification Reactor #3	3	38	21	21
Post Denitrification Reactor	3	38	21	21
Post Aeration Reactor	3	10	21	21



WWMP PILOTING - PHASE 2 INITIAL PILOTING
 PEIRCE ISLAND WWTF - PORTSMOUTH, NH

CAS WITH BIOMAG
TOTAL NITROGEN < 8 mg/L

FIGURE 5-3

PROCESS FLOW
 SCHEMATIC

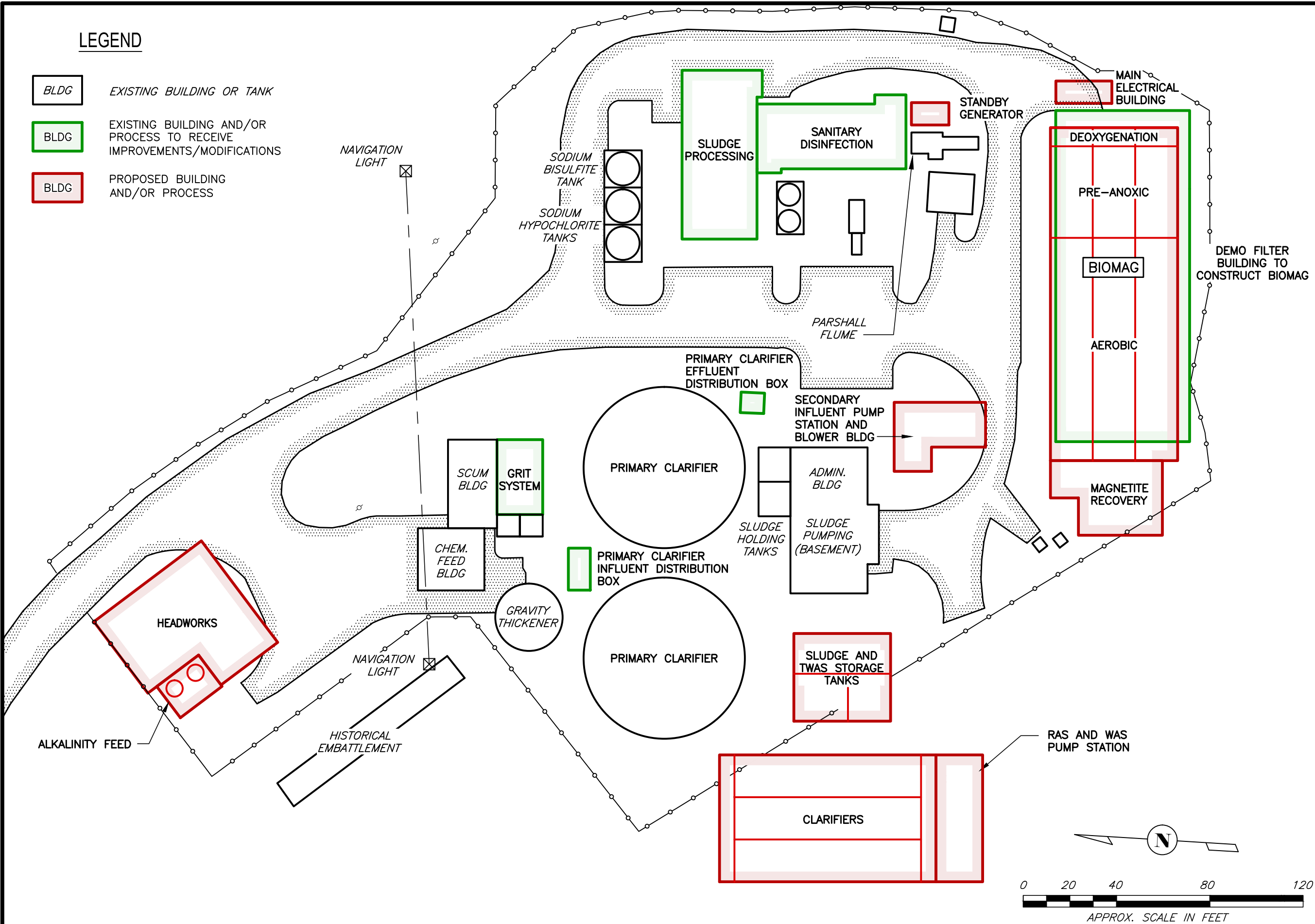
LEGEND

- BLDG

EXISTING BUILDING OR TANK
- BLDG

EXISTING BUILDING AND/OR
PROCESS TO RECEIVE
IMPROVEMENTS/MODIFICATIONS
- BLDG

PROPOSED BUILDING
AND/OR PROCESS



AECOM
701 Edgewater Drive
Wakefield, MA 01880
Ph. (781) 246-5200

WWMP PILOTING - PHASE 2 INITIAL PILOTING
PEIRCE ISLAND WWTf - PORTSMOUTH, NH
CAS WITH BIOMAG
TOTAL NITROGEN < 8 mg/L

FIGURE 5-4

SITE
LAYOUT

The proposed total tank volume is significantly larger than the footprint of the existing filter building. Similar to the BAF alternative, it is envisioned that the filter building would be demolished and the excavation re-used for the MBBR basins. The basins would be positioned so that gravity flow is maintained through the downstream solids separation and disinfection processes. Once again, there is the possibility that the foundation of the filter building could be re-used however a new base slab was incorporated into the cost estimate to be conservative.

WWW's DAF unit processes are pre-manufactured steel tanks with internal components and an in-line mixing system for polymer addition. The air pumps are provided loose and are typically located adjacent to the units. The proposed system consists of three DAFs where each unit can treat half of the peak flow. The proposed process flow path includes piping directly from the MBBR effluent channel to the DAF influent connection. Each pre-manufactured DAF tank is approximately 20 feet by 12 feet and 15 feet high. As currently envisioned, the three DAF tanks would be housed in a new building with space for process pumps, access to the tanks, polymer systems and an electrical room. The overall footprint of the system including the three tanks and associated equipment is approximately 86 feet by 40 feet. Effluent from the DAF system will discharge to the disinfection process by gravity. Sludge from the DAF units will be transferred to the new sludge storage tank prior to thickening and dewatering.

The major components of the process include:

Bioreactor

- Medium bubble aeration system
- MBBR media and media retention screens
- Blowers for process air (4 – 3 duty and 1 standby)
- Mixers for denitrification and nitrification cells (9)

Solids Separation

- DAF Building housing DAF units with clarifier internals, air distribution piping and in-line mixer (3)
- Process piping
- Polymer make-up systems (3)
- Air pumps (2)
- Waste sludge pumps (3)
- Controls and instrumentation

Additional work to support this treatment level would include the following:

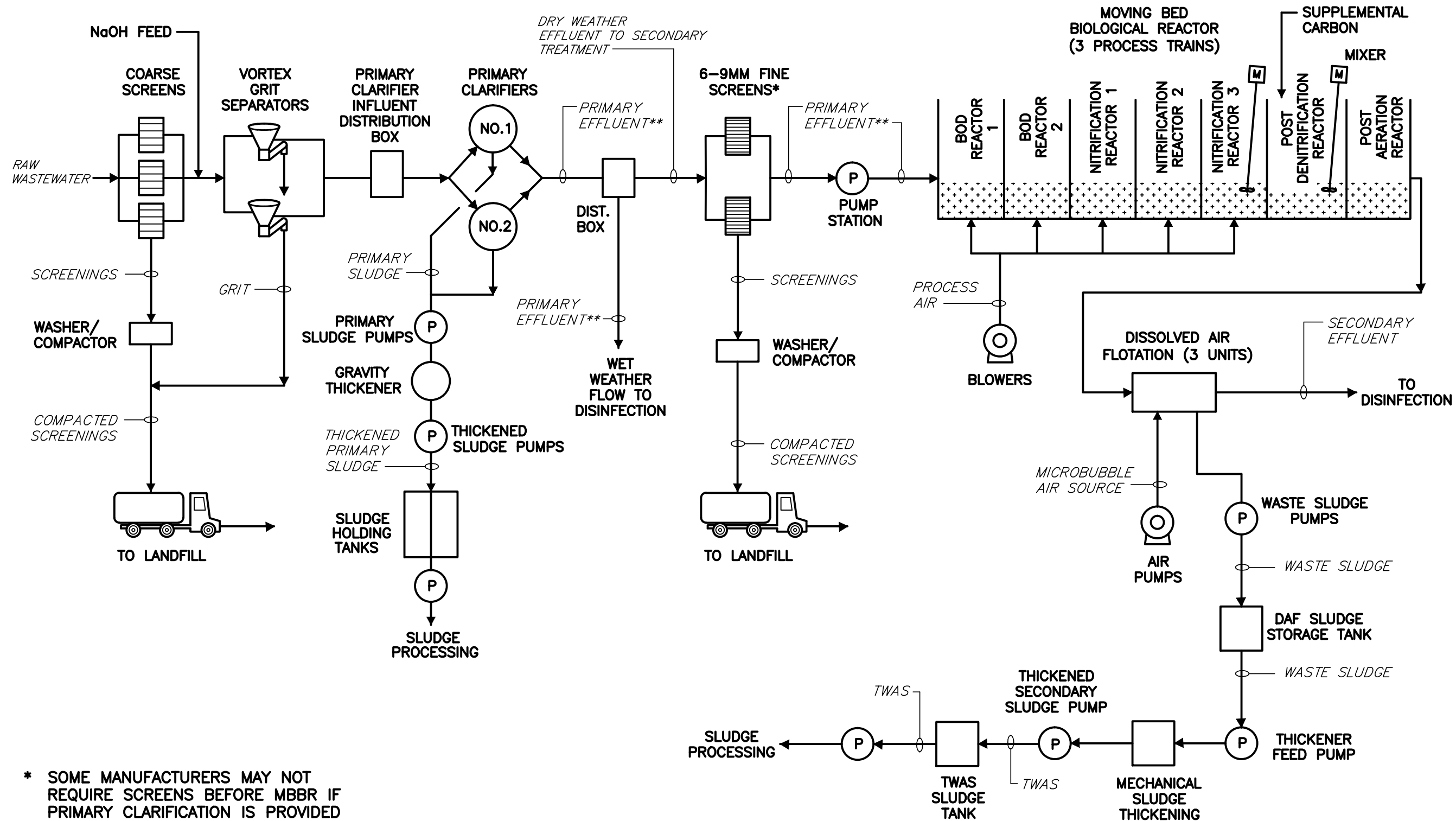
- Secondary influent pump station and screening building to the southeast of the existing Control Building.
- Supplemental carbon source facility
- Main Electrical Building and Standby generator to replace the electrical systems in the existing Filter Building.
- Sludge and TWAS Storage

A process flow schematic is presented in Figure 5-5 and a site layout is shown in Figure 5-6.

5.5 COST COMPARISON

5.5.1 Capital Cost Comparison

Conceptual opinions of cost for the implementation of the three technologies to achieve secondary treatment with the ability to meet a total nitrogen limit of 8 mg/L were developed. The opinion of cost developed for each technology is provided in Attachment G and are summarized below. The estimates



* SOME MANUFACTURERS MAY NOT REQUIRE SCREENS BEFORE MBBR IF PRIMARY CLARIFICATION IS PROVIDED

** DURING WET WEATHER EVENTS, CLARIFIERS MAY BE OPERATED IN CHEMICALLY ENHANCED MODE.

WWMP PILOTING - PHASE 2 INITIAL PILOTING
PEIRCE ISLAND WWTF - PORTSMOUTH, NH
MBBR WITH DAF
TOTAL NITROGEN < 8 mg/L

FIGURE 5-5
PROCESS FLOW
SCHEMATIC

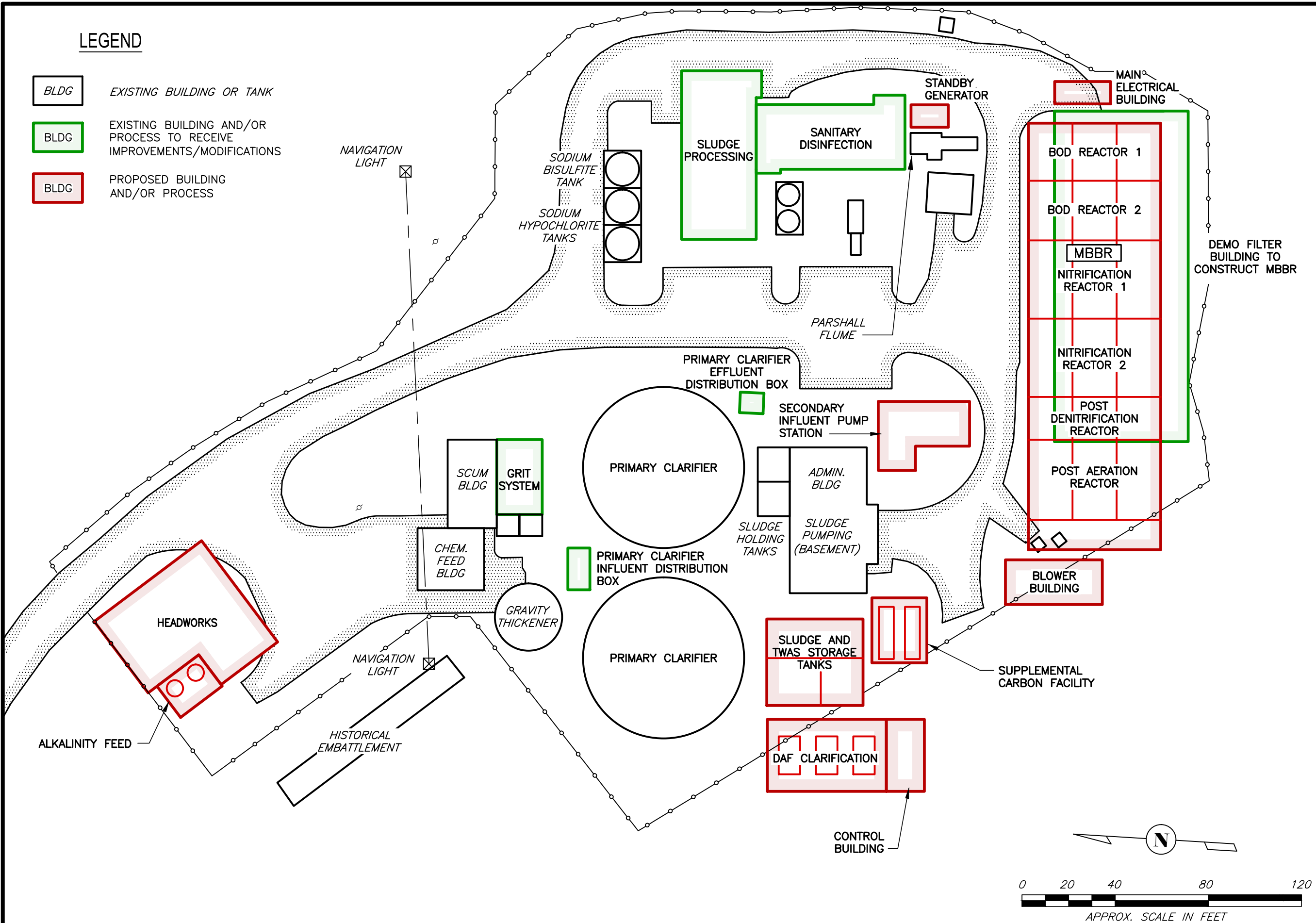
LEGEND

- BLDG

EXISTING BUILDING OR TANK
- BLDG

EXISTING BUILDING AND/OR
PROCESS TO RECEIVE
IMPROVEMENTS/MODIFICATIONS
- BLDG

PROPOSED BUILDING
AND/OR PROCESS



AECOM
701 Edgewater Drive
Wakefield, MA 01880
Ph. (781) 246-5200

WWMP PIOTING - PHASE 2 INITIAL PIOTING
PEIRCE ISLAND WWTF - PORTSMOUTH, NH
MBBR WITH DAF
TOTAL NITROGEN < 8 mg/L

FIGURE 5-6

SITE
LAYOUT

combine components of the Wastewater Master Plan opinions of cost and new opinions of cost developed for the treatment alternatives presented in this report. The Wastewater Master Plan recommended a number of upgrades at the Peirce Island plant that would need to be implemented if the facility were upgraded to achieve secondary treatment with the ability to meet a total nitrogen limit of 8 mg/L using one of the three technologies considered. Accordingly, AECOM carried the Wastewater Master Plan opinion of cost for Headworks, Sanitary Disinfection, Biosolids Processing, and parts of Additional Structures and Modifications from “Compliance Strategy Cost Estimate Biomag Secondary Treatment” contained in Appendix D of the Final Submission WWMP dated November 15, 2010. For the Wastewater Master Plan upgrade elements, the Wastewater Master Plan allowance percentages were used for yard piping, electrical, instrumentation and controls, and site work and landscaping. The Wastewater Master Plan allowances for engineering and contingency, which total 50 percent, were also used for the Wastewater Master Plan upgrade elements.

The Wastewater Master Plan cost estimates for work on Peirce Island also included an Island Construction Premium of 15 percent. In developing the updated opinions of cost for the secondary treatment options, AECOM had previously discussed the applicability of this factor with two construction contractors that specialize in water and wastewater facilities, and who were familiar with the Peirce Island constraints. Based on their feedback, the 15 percent Island Construction Premium in the Wastewater Master Plan estimates was reduced to 3 percent.

The total estimated capital costs are conceptual planning level costs and have been developed based on a number of assumptions and may not represent the final project capital costs for the facilities once designed. The final costs could be higher or lower depending on what decisions are made during the design phase, how the final facilities are constructed, and when the final facilities are constructed. The preliminary opinions of capital cost for the three technologies are based on 2012 costs and have been escalated to the estimated mid-point of construction of April 2016.

Based on the capital cost estimates shown below, Conventional Activated Sludge with BioMag is the technology with the lowest capital cost for achieving secondary treatment with the ability to meet a total nitrogen limit of 8 mg/L on Peirce Island.

Table 5-3. Total Nitrogen < 8 mg/L Opinion of Capital Cost Summary

Technology	Estimated Cost (\$MM)
Biological Aerated Filter (BAF)	\$60.5
Conventional Activated Sludge (CAS) with BioMag	\$54.0
Moving Bed Bioreactor (MBBR) & DAF	\$56.5

5.5.2 Operations & Maintenance Cost Comparison

AECOM developed conceptual level estimated annual operation and maintenance costs for each candidate technology. The estimated annual operation and maintenance costs developed for each option are summarized below. These estimates reflect only the operation and maintenance costs to support the proposed technology and are not inclusive of other processes at the Peirce Island WWTF. The estimates consist of annual costs for electricity, chemicals, labor and equipment replacement. Annual electricity costs were based on motor horsepower and an estimated annual runtime at an electricity cost of \$0.13 per Kilowatt hour. Chemical costs were developed based on vendor provided and/or estimated chemical dosages and chemical costs. Required chemicals included polymers, alkalinity addition, and supplemental carbon. Estimated labor costs were developed based on the *The Northeast Guide for Estimating Staffing at Publicly and Privately Owned Wastewater Treatment Plants prepared in November 2008 by the New England Interstate Water Pollution Control Commission (NEIWPCC)*. Equipment replacement costs were based on a percentage of raw equipment costs and were adjusted as needed based on vendor specifics.

Table 5-4. Estimated Annual Operation and Maintenance Costs Summary

Item	BAF	CAS w/ BioMag	MBBR & DAF
Electricity	\$390,000	\$802,000	\$540,000
Labor & Maintenance	\$307,000	\$354,000	\$291,000
Chemicals	\$219,000	\$105,000	\$383,000
Parts & Replacement	\$192,000	\$207,000	\$176,000
Total	\$1,108,000	\$1,468,000	\$1,390,000

5.5.3 Life Cycle Cost Comparison

AECOM estimated life cycle costs for each technology evaluated. The life cycle cost was estimated by summing the total capital cost and the present worth of the annual operation and maintenance costs. The present worth value of the operation and maintenance costs was developed using a period of 20 years and a present worth interest rate of 4.375 percent based on the United States Department of Agriculture's Natural Resources Conservation Service's discount rate for federal water projects. Table 5-5 summarizes the calculated life cycle costs.

Table 5-5. Estimated Life Cycle Costs Summary (\$MM)

Cost Item	BAF	CAS w/ BioMag	MBBR & DAF
Capital	\$60.50	\$54.00	\$56.50
20 Year Present Worth O&M	\$14.60	\$19.30	\$18.30
20 Year Life Cycle	\$75.10	\$73.30	\$74.80

As indicated in Table 5-5, the technology with the lowest estimated life cycle cost for providing a total nitrogen of 8 mg/L is CAS with BioMag. The difference from the highest estimated cost (BAF) to the lowest estimated cost (CAS with BioMag) alternative is \$1.8 MM, or approximately 2% of the total life cycle cost. With the limited definition of project elements and the number of unknown variables at this level of conceptual development, all three technologies can be considered equal on a life cycle cost basis.

SECTION 6 – NON-MONETARY EVALUATION FACTORS UPDATE

6.0 INTRODUCTION

In the Phase 1 Evaluation, in addition to evaluating the capital and O&M costs for potential treatment technologies, a Criteria Evaluation Matrix was developed as a tool to quantify the subjective non-monetary aspects of the technologies. As part of the Phase 2 evaluation, the evaluation criteria and the matrix have been updated. These updates were based on information and insight gained during the piloting effort of the three technologies. Some of the criteria used in the updated matrix were obtained from input from the WWTF operations staff through a questionnaire as well as day-to-day interaction, while others were developed by the project team based on considerations resulting from the change in effluent treatment goals from secondary to secondary with the ability to meet a total nitrogen effluent of 8 mg/l. The development of the updated evaluation criteria, the final criteria used and the evaluation process and results are provided in this section.

6.1 PEIRCE ISLAND WWTF OPERATORS QUESTIONNAIRE

One of the goals of the pilot effort was to allow the City's WWTF operations staff to become familiar with the three pilot technologies. During the course of the seven months of pilot operations, operators from the Peirce Island WWTF assisted the AECOM/Blueleaf project team with a variety of pilot operations. Assistance with construction issues, responding to pilot process alarms, learning and understanding start-up and performance issues, and laboratory analysis of samples were just a few of the areas where efforts by the WWTF staff were invaluable to the piloting effort. These experiences allowed the WWTF operations staff the opportunity to gain insight into the routine operation and maintenance of each of the processes, as well as to understand some of the challenges encountered during the piloting period.

Since the Peirce Island WWTF operators will ultimately be responsible for the operation and maintenance of the upgraded treatment facility, their views are of paramount importance. The views of the WWTF operators on a variety of aspects of the piloted processes were solicited throughout the piloting program as well as through completion of an operator's questionnaire. The questionnaire was distributed towards the end of the piloting period and posed questions covering the following 10 areas of interest:

1. Sampling & Analysis Requirements
2. Number & Complexity of Sub-Systems
3. Access for Troubleshooting Process
4. Appearance & Cleanliness
5. Maintenance Requirements
6. Ability To Automate System
7. Requirement for Online Analyzers
8. Health & Safety Issues
9. Requirement for Proprietary or Special Order Equipment, Materials, or Chemicals
10. Anticipated Level (Both Man-hours and Training) of Labor for Operation

A blank questionnaire is contained in Attachment H. Each of the 10 areas of interest addressed by the questionnaire had several factors to consider allowing operators to assess and rank each area for the three pilot processes. The areas of interest were ranked on a scale of 1 to 5 as follows:

- 5 - Highly Advantageous
- 4 – Advantageous
- 3 - Neutral, Not Advantageous

- 2 - Not Advantageous
- 1 - Not Desirable

Seven of the eleven Peirce Island WWTF operators reviewed the pilot processes and completed the questionnaire. Table 6-1 presents a summary of the questionnaire results. As indicated, in reviewing the average rankings for each question, on a number of questions the operators scored all three processes very similar. However, on several questions there were significant differences between the scores for the three processes.

On Questions 4 – Appearance & Cleanliness, 8-Health & Safety Issues, and 10- Anticipated Level of Labor for Operation, BioMag was scored well below the other two processes which were scored similarly.

There was also a difference in the scores on Question 9 – Requirement for Proprietary or Special Order Equipment, Materials or Chemicals. On this question, the MBBR/DAF process was scored higher than the other two processes likely in recognition that it is the only process of the three which uses the least amount of propriety processes or materials.

As indicated in Table 6-1, using the ranking criteria on a score of 1 to 5, with 1 being the least desirable and 5 being the most advantageous, the Portsmouth operator's average rankings for the three processes were:

MBBR/DAF	3.3
BAF	3.1
BioMag	1.9

It should be noted that this average ranking did not try to distinguish a weighted average, rather all categories were assumed to be equally important.

To bring the results of the questionnaire into the Criteria Evaluation Matrix, the 10 questions on the questionnaire were aggregated into three categories by subject. Table 6-2 lists the three categories of Operations questions, Maintenance questions, and Health & Safety questions. In this table the distribution of the questions into these categories is also identified. This average ranking for each technology in each category is shown on Table 6-2 and was used in the evaluation of the three processes in the Criteria Evaluation Matrix. Further discussion on each of these three question categories is provided below in the Added Phase 2 Evaluation Criteria section below.

6.2 REVISED CRITERIA EVALUATION MATRIX

Based on the piloting effort, and the revision in treatment goal from secondary treatment to secondary treatment with the ability to meet a TN of 8 mg/l, the Criteria Evaluation Matrix developed in the Phase 1 Evaluation was revised and updated. The Criteria Evaluation Matrix provides a means to compare the non-monetary factors that are important for meeting the City's needs and project goals. In addition to adding the results of the operators' questionnaire as evaluation criteria, some of the criteria in the Phase 1 Evaluation were eliminated as they were no longer applicable in light of the revision in the treatment goal and the three technologies that were piloted. Additional evaluation criteria were identified based on experience gained during the piloting. A summary of the eliminated Phase 1 evaluation criteria and added Phase 2 evaluation criteria are described below.

Eliminated Phase 1 Evaluation Criteria

The eliminated Phase 1 evaluation criteria and an explanation of the why these criteria were eliminated are as follows:

Table 6-1. Portsmouth WWTF Operator Pilot Evaluation

Evaluation Criteria	Operator Questionnaire Number							Total	Average
	1	2	3	4	5	6	7		
1. Sampling & Analysis Requirements									
BioMag	2	2	2	3	2	2	2	15	2.1
MBBR/DAF	3	3	3	3	3	3	3	21	3.0
BAF	3	3	3	3	3	3	3	21	3.0
2. Number & Complexity of Sub-Systems									
BioMag	2	2	2	2	2	2	2	14	2.0
MBBR/DAF	4	4	4	3	3	3	3	24	3.4
BAF	3	3	3	3	2	2	2	18	2.6
3. Access for Troubleshooting Process									
BioMag	2	2	2	2	3	2	2	15	2.1
MBBR/DAF	3	3	3	3	3	3	3	21	3.0
BAF	2	4	2.5	3	3	3	3	20.5	2.9
4. Appearance & Cleanliness									
BioMag	1	1	1	1	2	2	1	9	1.3
MBBR/DAF	3	3	3	3	3	3	5	23	3.3
BAF	4	4	4	3	3	3	4	25	3.6
5. Maintenance Requirements									
BioMag	2	2	2.5	3	2	2	2	15.5	2.2
MBBR/DAF	4	4	3	3	3	4	4	25	3.6
BAF	3	3	3	3	2	3	4	21	3.0
6. Ability To Automate System									
BioMag	2	2	2	3	2	2	2	15	2.1
MBBR/DAF	3	3	4	3	2	3	3	21	3.0
BAF	4	4	4	3	3	4	4	26	3.7
7. Requirement for Online Analyzers									
BioMag	3	2	3	3	2	2	3	18	2.6
MBBR/DAF	3	3	3	3	2	3	4	21	3.0
BAF	3	3	3	3	2	3	2	19	2.7
8. Health & Safety Issues									
BioMag	2	2	2.5	2	1	2	1	12.5	1.8
MBBR/DAF	3	4	4	3	3	3	5	25	3.6
BAF	3	4	3	4	3	3	4	24	3.4
9. Requirement for Proprietary or Special Order Equipment, Materials, or Chemicals									
BioMag	1	2	2	1	1	1	1	9	1.3
MBBR/DAF	4	4	3.5	4	3	4	4	26.5	3.8
BAF	3	3	3	4	2	3	3	21	3.0
10. Anticipated Level (Both Man-hours and Training) of Labor for Operation									
BioMag	2	1	2	1	3	2	1	12	1.7
MBBR/DAF	4	3	4	3	3	3	4	24	3.4
BAF	3	3	3	3	3	3	4	22	3.1

Total Score by Process:

BioMag 135.0
MBBR/DAF 231.5
BAF 217.5

Average Score by Process:

BioMag 1.9
MBBR/DAF 3.3
BAF 3.1

Rating Criteria:

5 - Highly Advantageous
 4 - Advantageous
 3 - Neutral, Not Advantageous
 2 - Not Advantageous
 1 - Not Desirable

Table 6-2. Portsmouth WWTF Operator Pilot Evaluation by Category

Evaluation Criteria	Scoring Summary		Question Category	Operations Questions		Maintenance Questions		Health & Safety Questions	
	Total	Average		Total	Average	Total	Average	Total	Average
1. Sampling & Analysis Requirements			Operations						
BioMag	15	2.1		15	2.1				
MBBR/DAF	21	3.0		21	3.0				
BAF	21	3.0		21	3.0				
2. Number & Complexity of Sub-Systems			Operations						
BioMag	14	2.0		14	2.0				
MBBR/DAF	24	3.4		24	3.4				
BAF	18	2.6		18	2.6				
3. Access for Troubleshooting Process			Health/Safety						
BioMag	15	2.1						15	2.1
MBBR/DAF	21	3.0						21	3.0
BAF	20.5	2.9						21	2.9
4. Appearance & Cleanliness			Maintenance						
BioMag	9	1.3				9	1.3		
MBBR/DAF	23	3.3				23	3.3		
BAF	25	3.6				25	3.6		
5. Maintenance Requirements			Maintenance						
BioMag	15.5	2.2				16	2.2		
MBBR/DAF	25	3.6				25	3.6		
BAF	21	3.0				21	3.0		
6. Ability To Automate System			Operations						
BioMag	15	2.1		15	2.1				
MBBR/DAF	21	3.0		21	3.0				
BAF	26	3.7		26	3.7				
7. Requirement for Online Analyzers			Operations						
BioMag	18	2.6		18	2.6				
MBBR/DAF	21	3.0		21	3.0				
BAF	19	2.7		19	2.7				
8. Health & Safety Issues			Health/Safety						
BioMag	12.5	1.8						13	1.8
MBBR/DAF	25	3.6						25	3.6
BAF	24	3.4						24	3.4
9. Requirement for Proprietary or Special Order Equipment, Materials, or Chemicals			Maintenance						
BioMag	9	1.3				9	1.3		
MBBR/DAF	26.5	3.8				27	3.8		
BAF	21	3.0				21	3.0		
10. Anticipated Level (Both Man-hours and Training) of Labor for Operation			Operations						
BioMag	12	1.7		12	1.7				
MBBR/DAF	24	3.4		24	3.4				
BAF	22	3.1		22	3.1				

Operations Maintenance Health and Safety

Rating Criteria:

- 5 - Highly Advantageous
- 4 - Advantageous
- 3 - Neutral, Not Advantageous
- 2 - Not Advantageous
- 1 - Not Desirable

Total Score by Category by Process:

BioMag	74	34	28
MBBR/DAF	111	75	46
BAF	106	67	45

Average Score by Category by Process:

BioMag	2.1	1.6	2.0
MBBR/DAF	3.2	3.5	3.3
BAF	3.0	3.2	3.2

Operability. As noted previously, the operators' questionnaire consisted of 10 questions that were subdivided into three categories. All of these categories were used as evaluation criteria to expand on the Phase 1 "operability" criteria.

Ability to Convert the Secondary Treatment Processes to Meet Future Nitrogen Limits of 8 mg/l. In Phase 1, this criterion was used to help distinguish between the complexities of converting the secondary treatment processes to meet a total nitrogen effluent concentration of 8 mg/l. With the desire to of the City to provide a process upgrade that can achieve an effluent TN of 8 mg/l this criterion was no longer applicable and was eliminated.

Constructability. In Phase 1, this criterion was used to help distinguish between the different technologies with the understanding that some of the technologies would have easier construction and have less impact on the WWTF while some technologies would require more difficult construction and would have more impact existing WWTF processes. For the Phase 2 technologies it is believed that three technologies will have similar construction complexity and impacts on the WWTF. As a result of this similarity, this criterion was eliminated.

Site Hydraulic Layout. In Phase 1, this criteria was used to help distinguish between the different technologies with the understanding that some of the technologies would more difficult flow routing and sometimes require pumping within the WWTF fence line (for the purposes of hydraulic lift) more than once. For the Phase 2 technologies, all three technologies will only require pumping within the WWTF fence line (for the purposes of hydraulic lift) once. As a result of this similarity, this criterion was eliminated.

Ability to Stay within the Fence Line for Secondary Treatment. In Phase 1, this criterion was used to help distinguish between the different technologies with the understanding that some of the technologies (sized for carbon and solids removal only) would be able to stay within the fence line and some technologies would not. With the increase in projected future flows and loads to the WWTF and the desire to of the City to provide a process upgrade that can achieve an effluent TN of 8 mg/l, the three Phase 2 technologies are unable to stay within the fence line (see Section 5). As a result of this similarity, this criterion was eliminated.

It should be noted that minimizing the extent of the upgrades going outside of the existing fence line is still important. Efforts to minimize the extent of the upgrades outside of the fence line should be given significant attention during preliminary design.

Ability to Stay Within the Fence Line for Future TN Treatment. In Phase 1, this criterion was used to help distinguish between the different technologies with the understanding that some of the carbon and solids removal processes that may be subsequently upgraded to provide TN removal might be able to stay within the existing fence line. With the increase in projected future flows and loads to the WWTF and the desire to of the City to provide a process upgrade that can achieve an effluent TN of 8 mg/l the three Phase 2 technologies are unable to stay within the fence line (see Section 5). As a result of this similarity, this criterion was eliminated.

Ability to Treat High FOG levels. In Phase 1, this criterion was used to help distinguish between the different technologies with the understanding that some might have more difficulty in treating a waste with a high concentration of fats, oils, and grease (FOG). Based on the data collected during the wastewater characterization study (see Section 4) and the observations during the pilot study that the concentration of FOG measured and observed were lower than had been anecdotally described. Given the data collected and the pilot observations, it is not believed that FOG will be an issue for the piloted technologies provided that proper pretreatment is provided. As a result this criterion was eliminated. It should be noted that proper pretreatment consists of coarse screening, grit removal and primary or enhanced primary treatment for all three technologies. The BAF and the MBBR-DAF have the additional pretreatment requirement of fine screening.

Added Phase 2 Evaluation Criteria

As noted above, the “operability” criteria used in Phase 1 was eliminated and had been replaced by the three subcategories (factors) that were developed from the 10 questions in the operators’ questionnaire. These factors are Operation Factors, Maintenance Factors, and Health and Safety Factors and are described below and are noted as “From Operators’ Questionnaire”. Subsequent to the descriptions of these criteria, the other evaluation criteria added for the Phase 2 evaluation are described.

Operations Factors (From Operators’ Questionnaire). Generally, treatment systems that are less complex are preferable to those that require specialized skills and equipment for routine operation. Technologies that do not require extensive sampling and complex analysis to monitor, have fewer and less complex support subsystems, do not require extensive online analyzers, and can be automated to reduce routine operation attention would receive a more favorable score for this criterion.

Maintenance Factors (From Operators’ Questionnaire). Treatment systems that do not have extensive equipment and support subsystems requiring routine maintenance are preferable. Technologies where tanks are enclosed and the process is neat and clean, and do not require propriety or special order equipment, materials or chemicals would receive a more favorable score for this criterion.

Health & Safety Factors (From Operators’ Questionnaire). Treatment systems with process components that are easily accessible for routine operation and maintenance are preferred. Treatment systems that do not require hazardous chemicals and are readily accessible for troubleshooting without the need for specialized assistance would receive a more favorable score for this criterion.

Response to Sustained Wet Weather Flows. The Peirce Island WWTF experiences periods of sustained wet weather flows from the combined sewer system during and after significant storm and/or snow melt events. Technologies that did not experience significant loss of performance and/or exhibited a rapid recovery following a high flow period test during the piloting received a more favorable score for this criterion.

Response to Process Disruption. The ability of a technology to quickly recover from a disruption is a significant consideration in maintaining treatment performance. Technologies that were able to quickly recover from a process disruption during the piloting received a more favorable score for this criterion. For example, the MBBR pilot reactor experienced a leak during the piloting, and this required a temporary shutdown of the process and relocation of the media to repair the tank liner. The MBBR process recovered from this disruption within a short period of time and showed it was a resilient process. Conversely, the CAS-BioMag process was affected by filamentous growth which affected performance over the extended period of time required for the process to recover.

Potential for Technology Optimization. The revised evaluation of the technologies has been based on the piloted configurations for each technology. There is the potential to further optimize the use of a specific technology, for example configuring the MBBR-DAF process as an MLE, may reduce cost and footprint. Those technologies that have a potential for further optimization were given a more favorable score for this criterion.

Ability to Exceed Treatment Performance Goals. During the piloting effort, all three of the technologies achieved the effluent goals for secondary treatment as well as a TN of 8 mg/l. However, effluent quality varied between the processes with some achieving lower effluent concentrations than others. Those technologies that were able achieve lower effluent concentrations on a consistent basis when compared to the treatment goals were given a more favorable score for this criterion.

Unchanged Evaluation Criteria

Two of the Phase 1 evaluation criteria were used for as evaluation criteria for the Phase 2 evaluation. They are as follows:

Operational Track Record/Established Process. High rate treatment technologies are becoming increasingly popular because of the smaller footprint and the capability to increase treatment capacity within existing infrastructure. The three piloted technologies do not all have similar numbers of full scale installations and in some cases those facilities have not been operating for an extended period of time. The processes with fewer full-scale installations received less favorable scores for this criterion.

Ability to Retrofit TN of 8 mg/l to Meet Future TN of 3 mg/l. The City is currently only required to implement secondary treatment at the Peirce Island WWTF. However, as noted in Section 4, the City has committed to upgrading the WWTF to provide the ability to provide nitrogen removal to 8 mg/l. The EPA subsequently indicated that a requirement to achieve total nitrogen removal to 8 mg/l will likely be included in the permit renewal that is currently pending. There has also been extensive discussion that at some point in the future, it is possible that the City will receive a lower effluent TN limit of 3 mg/l, but the timing is not known at this time.

Those technologies that can readily add to, or modify, the existing process layout for achieving a TN limit of 8 mg/l to a layout that can achieve 3 mg/l received a more favorable score than technologies that required a significantly different process layout for the lower TN removal limits compared to the 8 mg/l TN level.

Phase 2 Evaluation Criteria

Based on the description above the Revised Phase 2 Criteria are:

1. Operations Factors
2. Maintenance Factors
3. Health and Safety Factors
4. Operational Track Record/Established Process
5. Ability to Retrofit TN of 8 mg/l to Future TN of 3 mg/l
6. Response to Sustained Wet Weather Flows
7. Response to Process Disruption
8. Potential for Technology Optimization
9. Ability to Exceed Treatment Performance Goals

The technology ranking and comparison of these factors is described below.

6.3 TECHNOLOGY COMPARISON & RANKING

For the criteria evaluation, a two step process was used to compare and rank the technologies. In the first step, the paired comparison technique was used to weigh the evaluation criteria noted above. In this technique, each pair of criteria were evaluated by the project team by deciding first which criterion is the more important criterion to consider, and then its relative importance to the other criterion using a scale of 1 - 3 where:

- 1 - Indicates it is only slightly more important;
- 2 - Indicates its importance is somewhere between the extremes; and
- 3 - Indicates its importance is very much greater.

For example, when comparing Criterion A to Criterion B, the team felt that Criterion A was slightly more important than Criterion B. As a result, in the box (cell) where Row A and Column B intersect, a score of A1 was given. The points accumulated by each criterion when compared to the other criteria were then summed to obtain a score. The scores were then normalized to 100 to create the weighting factors as shown in Table 6-3. The total score for each criterion is the sum of the points where each criterion was judged to be the more important of the two criteria compared. The Criterion H, Potential for Future Technology Optimization received a score of zero, indicating that it was judged to be not more important than any of the other criteria and it was not considered further for the purposes of this evaluation.

In the second step, these criteria were placed in the Option Evaluation Matrix, shown in Table 6-4, where the three technologies are listed. AECOM initially assessed how well each technology met each criterion using a scale of 1 -5 where 5 indicates almost perfect conformance to the criterion and 1 indicates almost no compliance with the criterion. The points assigned to each for each criterion were then multiplied by the weighting factor, and the results summed to identify the non-monetary value points for each technology. The estimated capital cost and life cycle cost of each technology were added to the matrix and scores were divided by the costs (in millions) to obtain value ratios. The estimated costs are described in Section 5 and in Attachment G.

AECOM and the City participated in a workshop on September 19, 2012 to review the information presented in this report. The project team collectively reviewed and revised the non-monetary factors and weighting basis and finalized the ranking of the technologies. As indicated, the BAF had the highest life cycle cost value ratio of the three piloted processes and has the second highest capital cost value ratio.

Table 6-3. Criteria Evaluation Matrix

	B	C	D	E	F	G	H	I	Evaluation Criteria	Score	Weighting Factor
A	A 1	C 3	D 2	A 1	F 2	G 2	A 3	A 1	Operations Factors	6	10
	B	C 3	D 2	E 1	F 2	G 2	B 2	I 1	Maintenance Factors	2	3
		C	C 1	C 2	C 2	C 2	C 2	C 2	Health & Safety Factors	17	27
			D	D 2	D 1	D 1	D 2	D 2	Operational Track Record/Established Process	12	19
				E	F 2	G 2	E 1	I 1	Ability to Retrofit TN of 8 mg/l to Meet TN of 3 mg/l	2	3
					F	G 1	F 1	F 1	Response to Sustained Wet Weather Flows	8	13
						G	G 2	G 2	Response to Process Disruption	11	18
							H	I 2	Potential for Technology Optimization	0	0
								I	Ability to Exceed Treatment Performance Goals	4	6
										Total	100

KEY

Evaluation Criteria are used to compare the alternatives

Score is the total number of points accumulated for each criterion

Weighting Factor is the relative numerical value of each criterion

Ranking

- 1 = Slightly more important than the other criterion it is being compared with
- 2 = Somewhere between the extremes of importance
- 3 = Much more important than the other criterion it is being compared with

Table 6-4. Option Evaluation Matrix

Evaluation Criteria	Weight	BAF		CAS-BioMag		MBBR-DAF	
		Rating	Score	Rating	Score	Rating	Score
Operations Factors	10	3.0	30	2.1	21	3.2	32
Maintenance Factors	3	3.2	9.6	1.6	4.8	3.5	10.5
Health & Safety Factors	27	3.2	86.4	2.0	54	3.3	89.1
Operational Track Record/Established Process	19	4.0	76	2.0	38	3.0	57
Ability to Retrofit TN of 8 mg/l to Meet Future TN of 3 mg/l	3	5.0	15	2.5	7.5	3.0	9
Response to Sustained Wet Weather Flows	13	3.5	45.5	4.0	52	3.5	45.5
Response to Process Disruption	18	4.0	72	3.0	54	4.0	72
Potential for Technology Optimization	0	2.5		2.5		4.0	
Ability to Exceed Treatment Performance Goals	6	3.0	18	4.0	24	3.0	18
Total Weighted Criteria		353		255		333	
Capital Cost (estimated - in millions)		\$60.5		\$54.0		\$56.5	
Value Ratio (criteria/capital cost)		5.8		4.7		5.9	
Life Cycle Cost (in millions)		\$75.1		\$73.3		\$74.8	
Value Ratio (criteria/ life cycle cost)		4.7		3.5		4.5	

Rating 1-5. 5 is the most advantageous. 1 is the least advantageous.

SECTION 7 – PILOT TECHNICAL MEMORANDUM RECOMMENDATIONS

7.0 INTRODUCTION

This section presents recommendations regarding the secondary treatment facilities upgrade of the Peirce Island WWTF resulting from the Phase 2 Initial Piloting program. The recommendations address the design and capacity of the secondary treatment facilities upgrade.

7.1 SECONDARY TREATMENT FACILITIES DESIGN CAPACITY

As noted in Section 4, updated projected influent flows and loads together with projected primary effluent (secondary influent) flows and loads were developed to define the design capacity of the upgrade. Table 7-1 presents the recommended design flows and loads to secondary based on the use of conventional primary treatment. In addition to an average daily flow of 6.13 mgd, and a maximum month flow of 8.86 mgd, the secondary treatment facility will be designed to hydraulically pass a maximum day flow of 9.06 mgd. The instantaneous maximum hydraulic capacity will be established during preliminary design. Wet weather flows in excess of 9.06 mgd will receive chemically enhanced primary treatment and disinfection.

Table 7-1. Secondary Treatment Facilities Design Capacity

Parameter	Annual Average Day	Max Month
Flow (mgd)	6.13	8.86
Influent TSS (mg/L)	199	187
Influent TSS (lb/d)	10,176	13,853
Influent BOD ₅ (mg/L)	195	161
Influent BOD ₅ (lb/d)	9,959	11,881
Influent TKN (mg/L)	29.5	27.6
Influent TKN (lb/d)	1,511	2,039
Primary Effluent TSS (mg/L)	99 - 147	94 - 138
Primary Effluent TSS (lb/d)	5,088 – 7,510	6,927 – 10,224
Primary Effluent BOD ₅ (mg/L)	136 - 165	113 - 136
Primary Effluent BOD ₅ (lb/d)	6,971 – 8,435	8,317 – 10,063
Primary Effluent TKN (mg/l)	26.9 - 28.6	25.1 - 26.8
Primary Effluent TKN (lb/d)	1,375 – 1,465	1,856 – 1,978

Primary effluent loads and concentrations are presented as ranges based on constituent percent removals observed from the WWTF characterization data, observed pilot data, text book values, and CEPT removal.

7.2 DESIGN RECOMMENDATIONS

The current NPDES permit issued by EPA in 2007 requires that the Peirce Island WWTF be upgraded to secondary treatment. The modified Consent Decree requires a piloting evaluation technical memorandum on the piloting data and a recommendation on the design and capacity of secondary treatment facilities be prepared and submitted by October 1, 2012. The City completed the Phase 1 Evaluation based on consideration of potential treatment technologies to provide secondary treatment at the Peirce Island WWTF. The City proceeded with the Phase 2

Initial Piloting of the three most promising technologies for upgrading the Peirce Island WWTF identified in the Phase 1 Evaluation.

During the course of the Phase 2 Piloting evaluation, EPA verbally indicated that a limit on total nitrogen was likely to be included in the next NPDES permit. On July 31, 2012 the City received a letter from EPA stating that the pending draft permit would contain a Total Nitrogen effluent limit of 8 mg/l (TN of 8 mg/l). A copy of this letter is presented in Attachment I.

The Phase 2 Piloting Evaluation was completed to identify the proposed size and design of facilities required to meet secondary treatment limits with the ability to meet a TN of 8 mg/l; to estimate the costs for those facilities; to compare the technologies to provide nitrogen removal to a TN of 8 mg/l based on cost and non-monetary factors; and to identify a recommended approach. It is recommended that the City proceed with the design and construction of a secondary treatment facility with the ability to meet a TN of 8 mg/l. As part of the design effort, consideration should be given to what further modifications to the recommended facilities would be necessary to meet a lower effluent TN limit should one be imposed.

Based on the piloting data, the data comparison presented in Section 3, the updated capital and O&M cost comparison presented in Section 5, and the non-monetary factor comparison and ranking in Section 6, the BAF technology was judged to provide the City with the highest value. Accordingly, this technology is the recommended technology for upgrading the Peirce Island WWTF to secondary treatment. This recommendation is based on the following:

1. Secondary treatment facilities sized to treat the flow and loads presented in Section 4 and Attachment C.
2. Secondary treatment effluent limits apply to the effluent from the secondary treatment process prior to combining the secondary effluent with wet weather flows for discharge.
3. The ability to achieve an effluent total nitrogen of 8 mg/l through the secondary treatment facilities based on a seasonal rolling average for April through October.
4. Achieving 85 percent removal of BOD and TSS through the secondary treatment facilities is only required during dry weather days as defined in Attachment C.

Once an NPDES permit is issued which defines the requirements that the upgraded facility will be required to meet, the recommendation for a secondary treatment facility using the BAF technology can be reviewed and revised as needed.