South Coast Embayments and West Falmouth Harbor

CWMP/TWMP Notice of Project Change Update

December 2019

Falmouth Water Quality Management Committee

GHD Inc.

Science Wares, Inc.

Town of Falmouth, MA

South Coast Embayments and West Falmouth Harbor CWMP/TWMP Notice of Project Change Update

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Appendices are numbered according to the Chapter and Section in which they are discussed.

TOWN OF FALMOUTH

Office of the Town Manager & Selectmen

59 Town Hall Square, Falmouth, Massachusetts 02540
Telephone (508) 495-7320
Fax (508) 457-2573

November 22, 2019

Ms. Kathleen A. Theoharides, Secretary
Executive Office of Energy & Environmental Affairs
MEPA Office
100 Cambridge Street – Suite 900
Boston, MA 02114

Subject: Notice of Project Change Update Report
South Coast Embayments CWMP/TWMP
Town of Falmouth, MA EEA# 14154

Dear Ms. Theoharides,

Attached for your review is the South Coast Embayments CWMP/TWMP Notice of Project Change Update Report for Little Pond, Great Pond, Green Pond, Bournes Pond, Eel Pond and Waquoit Bay Watersheds and the West Falmouth Harbor Watershed.

The Town of Falmouth has worked diligently during the last five years, from the time that the initial Secretary's Certificate was issued, to develop and evaluate various demonstration/pilot projects as discussed in the approved CWMP/TWMP. This document provides an update of the findings of that work and next steps in the development of the next Targeted Watershed Management Plan for Great Pond as requested in the Secretary's Certificate. This is a continuation of the implementation of the approved plan and its adaptive management approach that is fundamental to our environmental and economic sustainability of Falmouth. This document also addresses the various issues raised in the Secretary's Certificate regarding the filing of subsequent NPC's related to the CWMP/TWMP process. We have consulted with the MEPA Office, the Massachusetts Department of Environmental Protection, the Cape Cod Commission and many other stakeholders on this document and on our overall planning process, and have responded to their input.

The important next step in this ongoing process has been affirmed by vote of the Falmouth Board of Selectmen in approving this Wastewater Management Plan at their regular business meeting of Monday, November 18. We look forward to the MEPA review of this document so that we can proceed to the next step of planning and implementation. If you have any questions, please contact Amy Lowell, Falmouth Wastewater Superintendent at (508) 457-2543 (amy.lowell@falmouthma.gov) or J. Jefferson Gregg, P.E., GHD Senior Project Manager at (774) 470-1640 (jeff.gregg@ghd.com). Thank you.

Sincerely,

Julian M. Suso

Julian M. Suso
Falmouth Town Manager

Cc Falmouth Board of Selectmen
Ray Jack
Amy Lowell
Eric Turkington
Virginia Valiela
Frank Duffy
J. Jefferson Gregg

Commonwealth of Massachusetts

Executive Office of Energy and Environmental Affairs ■ MEPA Office

For Office Use Only Executive Office of Environmental Affairs
MEPA Analyst:
Phone: 617-626-

Notice of Project Change

The information requested on this form must be completed to begin MEPA Review of a NPC in accordance with the provisions of the Massachusetts Environmental Policy Act and its implementing regulations (see 301 CMR 11.10(1)).

EEA # 14154			
Project Name: Falmouth Comprehensive Wastewater Management Plan			
Street Address: 59 Town Hall Square			
Municipality: Falmouth, MA	Watershed: Cape Cod		
Universal Transverse Mercator Coordinates:	Latitude: 41.55137 Longitude: -70.618299		
Estimated commencement date: 2009	Estimated completion date: 2040		
Project Type: CWMP/TWMP	Status of project design: 10 %complete		
Proponent: Town of Falmouth, MA			
Street Address: 59 Town Hall Square			
Municipality: Falmouth	State: MA	Zip Code: 02540	
Name of Contact Person: J. Jefferson Gregg, P.E., BCEE			
Firm/Agency: GHD Inc.	Street Address: 1545 Iyannough Road		
Municipality: Hyannis	State: MA	Zip Code: 02601	
Phone: 774-470-1640	Fax: 774-470-1631	E-mail: jeff.gregg@ghd.com	

With this Notice of Project Change, are you requesting:

a Single EIR? (see 301 CMR 11.06(8)) ☐Yes ☑No

a Special Review Procedure? (see 301CMR 11.09) ☐Yes ☑No

a Waiver of mandatory EIR? (see 301 CMR 11.11) ☐Yes ☑No

a Phase I Waiver? (see 301 CMR 11.11) ☐Yes ☑No

Which MEPA review threshold(s) does the project meet or exceed (see 301 CMR 11.03)?

Implementation may exceed the following: Land alteration, wastewater facilities/collection systems, new discharge, ACEC, wetlands, waterways and tidelands.

Which State Agency Permits will the project require?

As applicable to various implementation of projects the following may be required: MassDEP GWDP, 401 Water Quality, Chapter 91 License, Mass Historical Review, NHESP Review, CZM Fed. Consistency review, MassDOT road opening.

Identify any financial assistance or land transfer from an Agency of the Commonwealth, including the Agency name and the amount of funding or land area in acres: N/A

PROJECT INFORMATION

In 25 words or less, what is the project change? The project change involves . . .
an update to the approved CWMP/TWMP as called for in the January 10, 2014 Secretary's Certificate, EEA NO. 14154.
See full project change description beginning on page 3.

Date of publication of availability of the ENF in the Environmental Monitor: (Date:)

Was an EIR required? ☑Yes ☐No; if yes,
was a Draft EIR filed? ☑Yes (Date: 6/30/19) ☐No
was a Final EIR filed? ☑Yes (Date: 9/16/13) ☐No
was a Single EIR filed? ☐Yes (Date:) ☑No

Have other NPCs been filed? ☑Yes (Date(s): 3/11/16) ☐No

If this is a NPC solely for lapse of time (see 301 CMR 11.10(2)) proceed directly to **ATTACHMENTS & SIGNATURES**.

PERMITS / FINANCIAL ASSISTANCE / LAND TRANSFER

List or describe all new or modified state permits, financial assistance, or land transfers not previously reviewed: **dd w/ list of State Agency Actions (e.g., Agency Project, Financial Assistance, Land Transfer, List of Permits)**

Several new permits were issued as part of the Bournes Pond NPC, including: MassDEP 401WQ and Chapter 91; MassDEP NOI, US Coast Guard US ACE 404

Are you requesting a finding that this project change is insignificant? A change in a Project is ordinarily insignificant if it results solely in an increase in square footage, linear footage, height, depth or other relevant measures of the physical dimensions of the Project of less than 10% over estimates previously reviewed, provided the increase does not meet or exceed any review thresholds. A change in a Project is also ordinarily insignificant if it results solely in an increase in impacts of less than 25% of the level specified in any review threshold, provided that cumulative impacts of the Project do not meet or exceed any review thresholds that were not previously met or exceeded. (see 301 CMR 11.10(6)) ☐**Yes** ☑**No; if yes, provide an explanation of this request in the Project Change Description below.**

FOR PROJECTS SUBJECT TO AN EIR

If the project requires the submission of an EIR, are you requesting that a Scope in a previously issued Certificate be rescinded?
☐**Yes** ☑**No; if yes, provide an explanation of this request______________.**

If the project requires the submission of an EIR, are you requesting a change to a Scope in a previously issued Certificate?
☐**Yes** ☑**No; if yes, provide an explanation of this request______________.**

SUMMARY OF PROJECT CHANGE PARAMETERS AND IMPACTS (NOTE: comprehensive planning, all values are estimates.)

Summary of Project Size & Environmental Impacts	Previously reviewed	Net Change	Currently Proposed
LAND			
Total site acreage	27,251 (in planning area)	no change	same
Acres of land altered	>30	no change	same
Acres of impervious area	>0.5	no change	same
Square feet of bordering vegetated wetlands alteration	>100	no change	same
Square feet of other wetland alteration	>100	no change	same
Acres of non-water dependent use of tidelands or waterways	>0.5	no change	same
STRUCTURES			
Gross square footage	>20,000	no change	same
Number of housing units	0	no change	same
Maximum height (in feet)	>20	no change	same
TRANSPORTATION			
Vehicle trips per day	>20	no change	same
Parking spaces	>10	no change	same
WATER/WASTEWATER			
Gallons/day (GPD) of water use	>500	no change	same
GPD water withdrawal	0	no change	same
GPD wastewater generation/ treatment	3,200,000	no change	same
Length of water/sewer mains (in miles)	>50	no change	same

Does the project change involve any new or modified:

1. conversion of public parkland or other Article 97 public natural resources to any purpose not in accordance with Article 97? ☐**Yes** ☑**No**

2. release of any conservation restriction, preservation restriction, agricultural preservation restriction, or watershed preservation restriction? ☐**Yes** ☑**No**

3. impacts on Rare Species? ☐**Yes** ☑**No**

4. demolition of all or part of any structure, site or district listed in the State Register of Historic Place or the inventory of Historic and Archaeological Assets of the Commonwealth? ☐**Yes** ☑**No**

5. impact upon an Area of Critical Environmental Concern? ☐**Yes** ☑**No**

If you answered 'Yes' to any of these 5 questions, explain below:

PROJECT CHANGE DESCRIPTION (attach additional pages as necessary). The project change description should include:

(a) a brief description of the project as most recently reviewed

(b) a description of material changes to the project as previously reviewed,

(c) if applicable, the significance of the proposed changes, with specific reference to the factors listed 301 CMR 11.10(6), and

(d) measures that the project is taking to avoid damage to the environment or to minimize and mitigate unavoidable environmental impacts. If the change will involve modification of any previously issued Section 61 Finding, include a draft of the modified Section 61 Finding (or it will be required in a Supplemental EIR).

Please refer to the attached "South Coast Embayments: CWMP/TWMP Notice of Project Change Update" Report Dated: December 2019; prepared for the Town of Falmouth, MA. This document is being prepared per the requirements stated in the EEA Secretary's Certificate Dated January 10, 2014.

- Chapter 11 Titled "CWMP/TWMP Notice of Project Change Summary and Next Steps" summarizes those items covered in Chapters 1 through 10 regarding the requirements as requested in the above referenced Certificate.

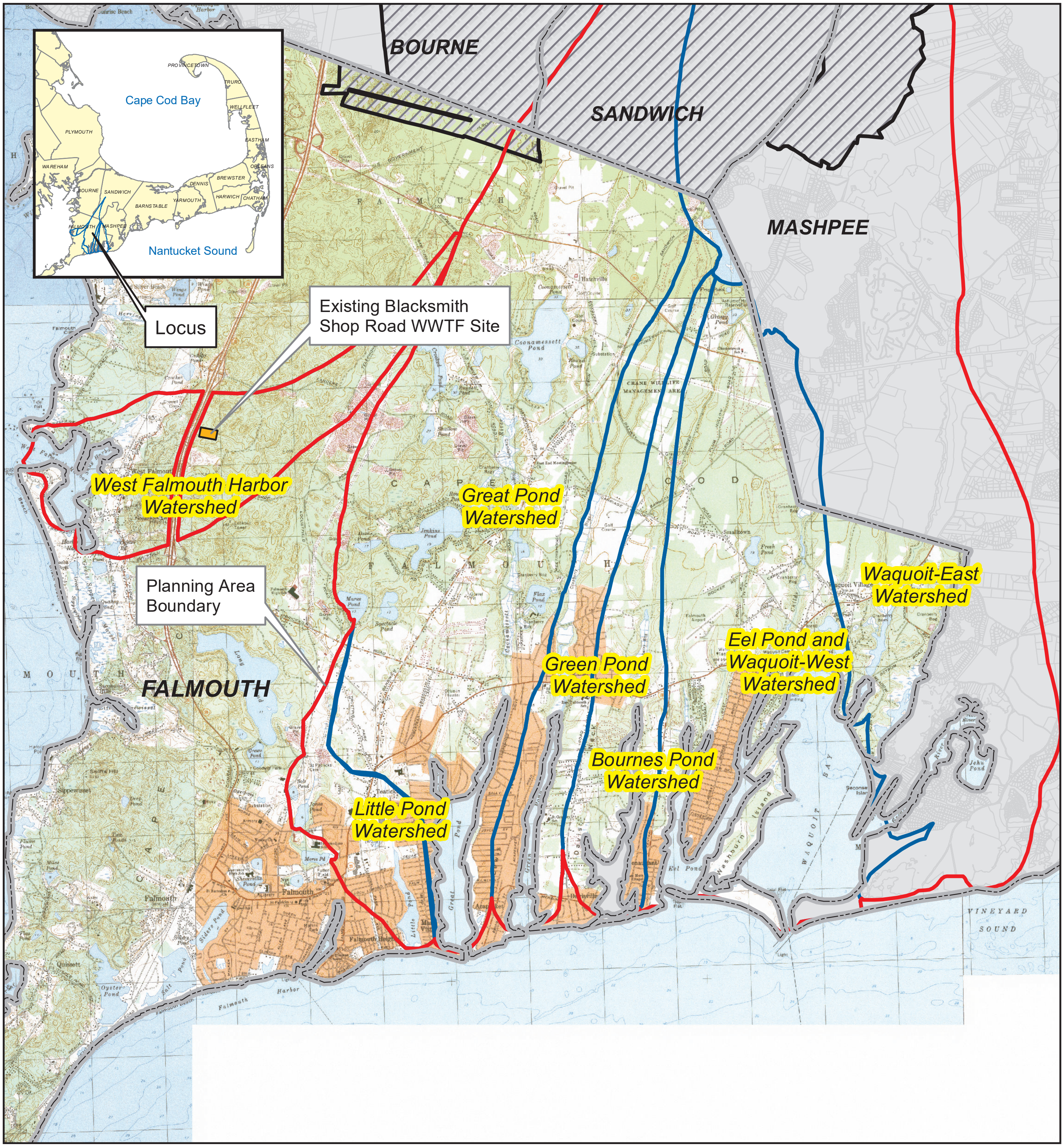
ATTACHMENTS & SIGNATURES

Attachments:

1. Secretary's most recent Certificate on this project (Refer to Appendix 1.1)
2. Plan showing most recent previously-reviewed proposed build condition (Refer to Chapter 1, Figure 1.1.)
3. Plan showing currently proposed build condition (Refer to Chapter 1, Figure 1.1)
4. Original U.S.G.S. map or good quality color copy (8-1/2 x 11 inches or larger) indicating the project location and boundaries (See Attached Figure NPC-1)
5. List of all agencies and persons to whom the proponent circulated the NPC, in accordance with 301 CMR 11.10(7) (See Report "Distribution List")

Signatures:

11/22/19 Julian M Suso	11/22/19 J. Jefferson Gregg
Date Signature of Responsible Officer or Proponent	Date Signature of person preparing NPC (if different from above)
Julian M. Suso, Town Manager	J. Jefferson Gregg, P.E., BCEE
Name (print or type)	Name (print or type)
Town of Falmouth, MA	GHD Inc.
Firm/Agency	Firm/Agency
59 Town Hall Square	1545 Iyannough Road
Street	Street
Falmouth, MA 02540	Hyannis, MA, 02601
Municipality/State/Zip	Municipality/State/Zip
(508) 495-7320	(774)470-1640
Phone	Phone



LEGEND

Planning Area/MEP Watershed Boundary

MEP Watershed Boundary

Town Boundary

Paper Size ANSI A

0 0.5 1 2 Miles

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1927
Grid: NAD 1927 StatePlane Massachusetts Mainland FIPS 2001

N

TOWN OF FALMOUTH, MA
CWMP UPDATE

Job Number 86-12163
Revision -
Date 25 Jul 2019

NOTICE OF PROJECT CHANGE
LOCATION MAP

Figure NPC-1

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

G:\86\12163\GIS\71045 Falmouth\Figures\June 2012 Final Report Figures\JULY 2019 REV\Figure NPC-1.mxd

Distribution List

Notice of Project Change (NPC) Document
to
Final Comprehensive Wastewater Management Plan (CWMP) and
Final Environmental Impact Report (FEIR) and
Targeted Watershed Management Plan (TWMP)
EEA #14154

A copy of the NPC Document will be sent to the following:

Secretary of Energy and Environmental Affairs
Executive Office of Energy and Environmental Affairs (EEA)
Attn: MEPA Office
100 Cambridge Street, Suite 900
Boston, MA 02114
(1 Hard Copy and 1 CD)

Cape Cod Commission
3225 Main Street
Barnstable, MA 02630
(CD)

Massachusetts Department of Environmental Protection
One Winter Street
Boston, MA 02108
(Hard Copy)

Gary Moran, Deputy Commissioner
MassDEP
One Winter Street
Boston, MA 02108
(Hard Copy)

DEP/Southeastern Regional Office
20 Riverside Drive
Lakeville, MA 02347
Attn: MEPA Unit
(Hard Copy)

Brian Dudley
MassDEP
20 Riverside Drive
Lakeville, MA 02347
(Hard Copy)

Department of Energy Resources
100 Cambridge Street, Suite 1020
Boston, MA 02114
Attn: John Ballam, MEPA Liaison
(CD)

Massachusetts Historical Commission
Archives Building
220 Morrissey Boulevard
Boston, MA 02125
(Hard Copy)

Buzzards Bay Coalition
114 Front Street
New Bedford, MA 02740
(CD)

Commonwealth of Massachusetts
Military Division Joint Base Cape Cod (JBCC)
Office of the JBCC Executive Director,
Building 1204
West Inner Road
Camp Edwards, MA 02542
(Hard Copy)

Massachusetts Division of Fisheries & Wildlife
Natural Heritage & Endangered Species Program
One Rabbit Hill Road
Westborough, MA 01581
Attn: Thomas W. French, Ph.D.
(Hard Copy)

Massachusetts Department of Transportation, Highway Division
District #5
1000 County Street
Taunton, MA 02780
Attn: MEPA Coordinator
(Hard Copy)

US Army Corps of Engineers
N.E. District
696 Virginia Road
Concord, MA 01742-2751
(Hard Copy)

Coastal Zone Management
251 Causeway Street, Suite 800
Boston, MA 02202
Attn: MEPA Coordinator
(Hard Copy)

Coastal Zone Management
3195 Main Street, Route 6A
PO Box 220
Barnstable, MA 02630
Attn: Steve McKenna
(Hard Copy)

Division of Marine Fisheries
1213 Purchase Street
New Bedford, MA 02740
Attn: MEPA Coordinator
(Hard Copy)

Town of Mashpee Public Library
64 Steeple Street
PO Box 657
Mashpee, MA 02649
Attn: Library Director
(Hard Copy)

Town of Mashpee
16 Great Neck Road North
Mashpee, MA 02649
Attn: Rodney C. Collins, Town Manager and Board of Selectmen
(Hard Copy)

Jonathan Bourne Public Library
19 Sandwich Road
Bourne, MA 02532
Attn: Library Director
(Hard Copy)

Town of Bourne
24 Perry Avenue
Buzzards Bay, MA 02532
Attn: Anthony Schiavi, Town Administrator and Board of Selectmen
(Hard Copy)

Town of Sandwich
130 Main Street
Sandwich, MA 02563
Attn: George H. Dunham, Town Manager and Board of Selectmen
(Hard Copy)

Sandwich Public Library
142 Main Street
Sandwich, MA 02563
Attn: Library Director
(Hard Copy)

Town of Falmouth DPW
59 Town Hall Square
Falmouth, MA 02540
Attn: Amy Lowell, Wastewater Superintendent
29 hard copies with distribution to:

- Town Manager/BOS Office (6)
- Health Agent/BOH Office (2)
- Conservation Agent/Cons. Comm. Office (2)
- DPW 9 hard copies and 1 CD
- Falmouth Libraries (2)
- Planning Board (1)
- Waterways Committee 1CD
- Coastal Resiliency Action Committee 1 CD
- WQMC 7 hard copies and 1 CD
- Beach Committee 1 CD
- Marine and Environmental Services 1 CD

Applied Coastal Research and Engineering
766 Falmouth Road, Suite A-1
Mashpee, MA 02649
(Hard Copy)

School for Marine Science & Technology
UMass Dartmouth
706 S. Rodney French Blvd.
New Bedford, MA 02744-1221
Attn: Brian Howes
(CD)

Sen. Viriato M. DeMacedo
10 Cordage Park Circle, Room 229
Plymouth MA 02360 (CD)

Rep. Dylan Fernandes
354 Gifford St., Unit 4
Falmouth MA 02540 (CD)

Rep. David T. Vieira
354 Gifford St., Unit 3
Falmouth MA 02540 (CD)

Commenters list: (All Receive CDs)

The Association for Crocker Pond
Andrew Bunker
11 Westmoreland Drive
Falmouth, MA 02540

Hilde Maingay and Earl Barnhart
28 Common Way
East Falmouth, MA 02536

Cape Cod & Islands Group – Sierra Club
David Dow
18 Treetop Lane
Falmouth, MA 02540

Preface

P.1 Introduction

Ten years ago, Stearns & Wheler, the engineering firm hired by the Town of Falmouth to study the deteriorating water quality in West Falmouth Harbor, Little Pond, Great Pond, Bournes Pond, Green Pond, Eel River, and Waquoit Bay (Figure P.1) made an expected finding: yes, these estuaries were impaired, and yes, nitrogen from residential septic systems was the main cause. But it was their recommendation for addressing the problem that got everyone's attention.

Sewering, they said, was the only answer. Sewer Falmouth Heights, Maravista, Teaticket, Acapesket, Davisville, Menauhant, and Seacoast Shores, everything south of Route 28 in East Falmouth, and then north of Route 28. The price tag: $600 million dollars.

Once Falmouth got over the shock of that number, the Town quickly decided there had to be a better way. A review committee was appointed, and two years later the Water Quality Management Committee was created by Town Meeting and appointed by the Selectmen.

The committee's assigned mission: to explore every practical alternative means of improving the water quality in the Town's estuaries, and to come up with an implementation plan that used cost-effective alternatives where practical, and sewers only where they were the most cost-effective solution.

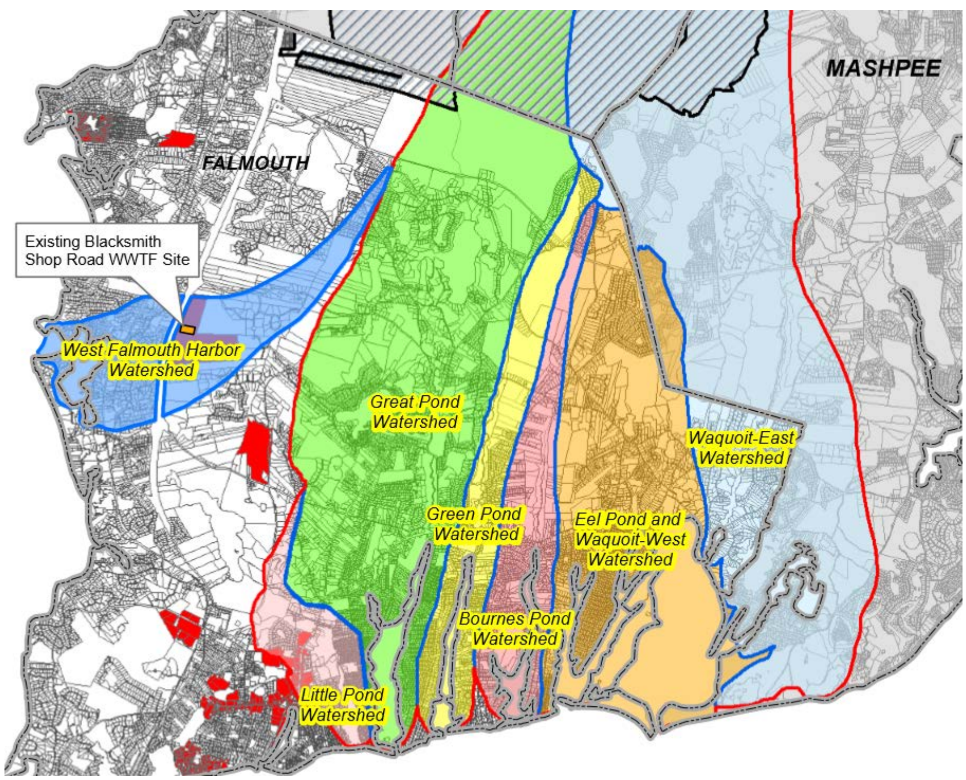


Figure P.1 Impaired Estuaries in the 2019 CWMP Update

This is that plan. This document, titled “South Coastal Embayments CWMP/TWMP Notice of Project Change (NPC) Update Report,” is a report to the Massachusetts Department of Environmental Protection (DEP) and the Massachusetts Environmental Policy Act office (MEPA).

But more importantly, it is a report to the people of Falmouth, telling them what has been done, with their support, over the past 10 years; and what we are recommending the Town should do in the next five years and beyond.

We have had many partners in these 10 years: The Board of Selectmen, the Department of Public Works, the Shellfish Advisory Committee, the Department of Marine and Environmental Services (MES), the Town GIS coordinator, the Planning Board, Buzzards Bay Coalition, Cape Cod Commission, George Heufelder and Barnstable County Alternative Septic System Test Center, UMASS Dartmouth School of Marine Science and Technology (SMAST), Woods Hole Oceanographic Institution (WHOI), Marine Biological Laboratory (MBL), Woods Hole Research Center, US Geological Survey (USGS), US Environmental Protection Agency (EPA), MassDEP, US Department of Agriculture, Cape Cod Water Protection Collaborative, Cape Cod Economic Development Commission, the Town of Mashpee, Citizens for the Protection of Waquoit Bay, and the Mashpee Environmental Coalition, consultants GHD and Wright-Pierce, the Woods Hole Group, Applied Coastal Research & Engineering Inc (ACRE), BETA, CDM Smith, MT Environmental Restoration, the Commonwealth of Massachusetts, and Science Wares.

With their help, the Town has accomplished a great deal. A brief summary:

P.2 Progress Summary Since 2014

Fertilizer Reduction: Too much lawn fertilizer, a significant source of nitrogen, ends up in our estuaries. So Falmouth passed the toughest fertilizer control bylaw in the Commonwealth—among other things, it bans all fertilizer application within 100 feet of an estuary. The Town DMES follows it up every year with a letter to affected property owners and also posts the letter at stores selling fertilizer.

Shellfish Aquaculture: Shellfish consume the microalgae that thrive on nitrogen. Falmouth demonstrated that we could grow millions of oysters from seed in an impaired estuary, overwinter them, and successfully transplant them for harvest. The Town is now identifying the best growing areas in each estuary and partnering with local aquaculture growers to reduce the nitrogen via aquaculture.

Inlet Widening in Bournes Pond: SMAST estimated that widening the inlet 40 feet would increase flushing enough to achieve approximately one-half of the nitrogen removal needed to restore Bournes Pond to a healthy state. Falmouth voters provided funding to widen the inlet and also replace the current 35-year-old bridge with a newer one. All environmental permits are now in place for this project to proceed.

Innovative/Alternative Septic Systems (I/As): For neighborhoods where sewering is not the most practical alternative and expected to be more costly, the Town is testing I/As that can be added onto existing home septic systems in order to remove nitrogen. Falmouth, with its partner the Buzzards Bay Coalition, worked with willing homeowners in the West Falmouth Harbor area to install 25 such systems. We are now measuring how well they work, and their short and long-term capital and operating costs.

This concept is being studied on a larger scale in the Oyster Pond watershed, where the Town has developed a plan for 187 homes to reduce their nitrogen effluent using I/As, along with a parallel alternative plan using sewers. Economic costs, environmental gains, and impact on homeowners of the two options will all be analyzed and compared.

West Falmouth Harbor: This is the first estuary on Cape Cod projected to meet the reduction target for nitrogen set by the Massachusetts Estuaries Project (MEP). The largest source of nitrogen to West Falmouth Harbor is the Town's wastewater treatment plant. This estuary is projected to meet its nitrogen reduction goal without sewering, thus saving the Town an estimated $24 million by:

- reducing the permitted volume of tertiary treated effluent discharged into the harbor watershed;
- reducing the nitrogen concentration in the treated effluent to the limit of technology for nitrogen removal; and
- taking into account further reductions due to the 25 I/As installed, fertilizer reduction, and stormwater improvement credits.

In addition, other projects include a shellfish reef and the transplantation of thousands of oysters to improve habitat quality.

Sewering Little Pond: To deal with the Town's most impacted estuary whose watershed has a high density of development, Falmouth voted to sewer approximately 1,350 parcels in the Little Pond lower watershed. Special legislation approved by the Town enabled the annual betterment charge to the affected homeowners to be reduced from $1,220 per year to $435, and the Town also provided low pressure pumps, at no cost, to homeowners who needed them to connect to the sewer. Our partners at USGS and MBL are measuring the nitrogen in groundwater entering the pond before and after sewering to provide a true test case of the environmental benefits of sewers.

Those are the highlights of Falmouth's progress in the past 10 years. We hope, in this document, to provide a road map for continued progress that addresses the Town's goal of restoring its coastal estuaries in a way that the Town can afford.

P.3 Vision for Next Five Years

Here is what we are recommending for the next five years and beyond (Table ES.1).

Upgrading the Wastewater Treatment Plant: To accommodate any additional sewering, or even to accommodate expected growth in the existing sewered areas, the Town's treatment plant will need some new and updated infrastructure in the next five years.

Connecting to the Plant: The existing force mains connecting currently sewered areas' collection systems to the plant do not have enough capacity to accommodate wastewater flow from any large new areas. A new force main from Teaticket along Brick Kiln Road to the plant will be needed to carry the additional wastewater flows being proposed from Teaticket and Acapesket in the next five years.

A New Discharge Site: The existing sites for discharge of the tertiary treated wastewater from the Town's treatment plant are at or approaching permitted capacity. Over the next five years the Town will need to identify and construct a new discharge site outside the West Falmouth Harbor watershed for the additional flow that any new sewered areas would bring to the plant.

Three potential sites are currently being studied: an ocean outfall into Buzzards Bay; recharge beds at the Town-owned “Allen Parcel” on Carriage Shop Road in East Falmouth; and expanded recharge beds at the Town-owned “swap parcel” (existing recharge beds 14 and 15) near Thomas Landers Road in West Falmouth. In addition, there is a regional evaluation being conducted on wastewater discharge options on Joint Base Cape Cod.

Sewering Great Pond Watershed: The next estuary where the high levels of nitrogen and the density of development indicate sewering is going to be required as part of the solution is Great Pond. To keep within the financial guidelines set by the Town, this would need to be done in two phases, with phase one being done in the next five years.

Phase One would encompass northern Maravista, Perch Pond, Teaticket Path, Falmouthport, and northern Shorewood Drive, and would be presented to voters in 2024 and constructed in 2025. Phase Two would include most of the rest of the Acapesket peninsula down to Emerson Road and would be presented to voters when the next Town debt drop-off occurs that would allow the project to be funded without raising the property tax rate.

Not Sewering Davisville and Menauhant Peninsulas: Because a substantial part of the recommended sewered area on the Acapesket peninsula is in the Green Pond watershed, and because inlet widening will produce major nitrogen reduction for Bournes Pond, and because expanded aquaculture is an option for both estuaries, we have concluded that these measures combined with the fertilizer and stormwater credits will be sufficient to improve the health of these estuaries and are therefore projecting that these areas will not need to be sewered, except possibly some small portions near Route 28.

Waquoit Bay Intermunicipal Agreement: With 48 sub-watersheds and shared by Falmouth, Mashpee, and Sandwich, the Waquoit Bay watershed is far and away the most complicated system to address.

The first question to answer is – for what amount of nitrogen reduction is each town responsible? Falmouth, Mashpee, and Sandwich have collaborated to fund and move forward with a study to answer that question and are awaiting the other towns’ responses. But given what we already know about this watershed, we feel confident in projecting that sewering is likely to be recommended in the future for the Seacoast Shores peninsula, as well as possibly Antler Shores and the Seapit peninsula.

Mashpee has also approved a plan to manage their nitrogen load to this watershed and the Town of Sandwich has also developed their Comprehensive Water Resources Management Plan regarding management of nitrogen within this watershed as well.

Executive Summary

ES.1 Introduction

This Notice of Project Change to the Comprehensive Wastewater Management Plan and Final Environmental Impact Report and Targeted Watershed Management Plan (CWMP/FEIR/TWMP) Document provides an update to several of the Town's CWMP implementation efforts and pilot projects as called for in the January 10, 2014 Executive Office of Energy and Environmental Affairs (EOEEA) Secretary Certificate.

These pilot projects and other initiatives have been primarily funded by Article 17 of Spring 2011 Town Meeting and a ballot vote in May 2011 and are underway. Their progress to date is summarized in this document.

This update has been prepared by GHD, the Falmouth Water Quality Management Committee (WQMC), and its contractor Science Wares, and has been approved by the Falmouth Board of Selectmen. It is a summary of the efforts and studies to date that support the Compliance Plan Approaches developed for each watershed.

ES.2 Water Quality Monitoring and Data Summary

The University of Massachusetts Dartmouth School of Marine Science and Technology (SMAST) facilitates two water quality monitoring programs in Falmouth's south-facing estuaries. The Pond Watch Monitoring Program has been collecting water quality data every two weeks during the critical impairment months (July and August) in Little, Great, Green, and Bournes Ponds since 1989. In Waquoit Bay, which is shared with the Town of Mashpee, there has been bi-weekly monitoring of the 19 established stations since 2001 during the critical impairment months. Measured parameters for each sampling event include total nitrogen, salinity, and chlorophyll as well as total depth, temperature, Secchi depth, nitrate + nitrite, ammonium, dissolved organic nitrogen, particulate organic nitrogen, phosphate, and dissolved oxygen.

All five of these estuaries remain nitrogen-impaired, as demonstrated by SMAST data. Historical trends from each of the estuaries do not indicate any significant change in the level of impairment in each of the estuaries. These results indicate that the conditions have remained relatively constant in the four Pond Watch estuaries (Little, Great, Green, and Bournes Pond) since 2004 and in Waquoit Bay since 2010.

Overall, the SMAST data show that the total nitrogen levels remain highest in the upper reaches of the estuaries [Station 1] and are lowest near the mouth of the estuary [Station 5]. The total nitrogen concentrations at the sentinel stations are still in excess of their target thresholds (see red line in Figures ES.1 and ES.2). For example, G4 is the sentinel station for Green Pond. Chlorophyll measurements also indicate nutrient enrichment in these estuaries.

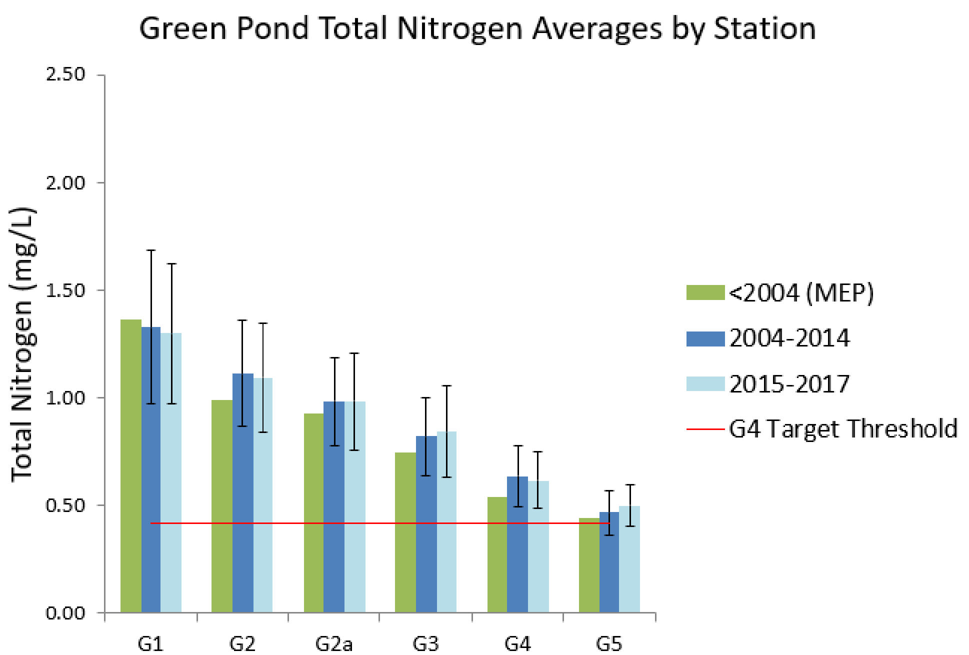


Figure ES.1 Example of the General Trend of Average Annual Total Nitrogen Concentration by Monitoring Period in the South-Facing Estuaries

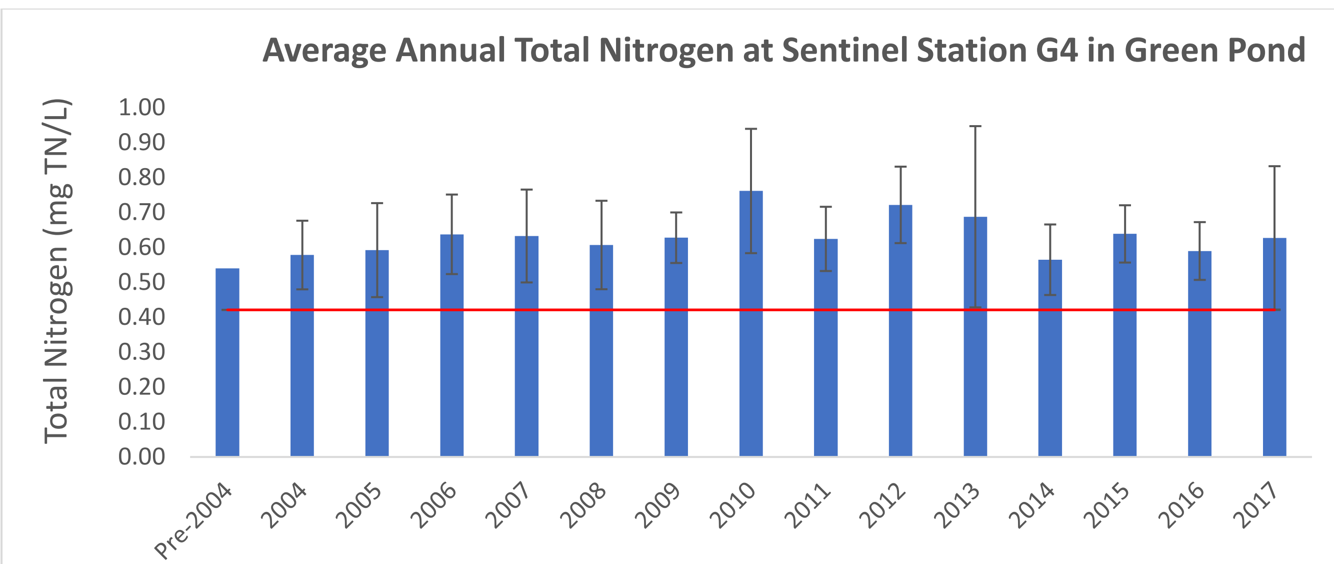


Figure ES.2 Example of the General Trend of Average Annual Total Nitrogen Concentration for the Sentinel Stations in the South-Facing Estuaries

The SMAST data for total nitrogen for Green Pond between 2004 and 2017 present a fairly constant level of impairment. Data from the other south-coast estuaries including Waquoit Bay show a similar pattern. Falmouth and Mashpee will continue to contract with SMAST to monitor these estuaries during July and August each year.

ES.3 Summary of Pilot Projects

At the 2011 Falmouth Spring Town Meeting, Town Meeting Members voiced their strong support for finding ways, in addition to sewering, to control nitrogen and improve the health of the estuaries. To fund the effort, a $2.77 million bond issue was voted and subsequently approved by the voters in a town-wide ballot. Since then, the WQMC and various Town departments have initiated a wide range of pilot/demonstration projects to provide a comprehensive analysis of non-traditional options for nutrient management in the impaired watersheds. Completed projects include a demonstration project on eco-toilets and a nitrogen control bylaw for fertilizer. The Town continues to actively conduct project initiatives on shellfish aquaculture, innovative and alternative septic systems (I/As), permeable reactive barriers (PRBs), stormwater management, and inlet widening.

ES.3.1 Eco-Toilets

The first of the Town's demonstration projects to have been completed focused on eco-toilets. The Town initiated an Eco-Toilet Incentive Program to encourage homeowners to install either composting or urine-diverting fixtures in their homes to gauge the effectiveness of the eco-toilets and general public response. To encourage participation, the Town offered three different financial incentives. Numerous outreach efforts were made to increase public awareness of the program, including a mailing to every household in town; about 170 homeowners responded.

Of the 170 homeowners, only 50 had site visits conducted. At the final stage of the program, only nine fixtures were installed. The performance of these systems was monitored by the Barnstable County Department of Health and Environment. Of those homeowners who initially showed interest in the program and chose not to participate, the reasons given were concerns over resale value of their home and the commitment to the ongoing operation and maintenance required for the systems.

The monitoring data results from the installed fixtures indicated a 48% to 86% nitrogen removal depending on the system. However, while the performance of the fixtures was effective in nitrogen reduction, the general findings from the program indicated that a large-scale initiative in Falmouth would likely not be embraced by the community. At present, the Town has no plans to pursue any further eco-toilet initiatives.

ES.3.2 Town Bylaw for Fertilizer

The second of the Town's demonstration projects to be completed was an effort to regulate fertilizer use in the immediate vicinity of the coastal estuaries and within the entire Town. The Town adopted a Nitrogen Control Bylaw that restricts fertilizer application timing, location, and application rate, and bans its application entirely within 100 feet of coastal estuaries. In efforts to regularly educate the public and encourage adherence to the bylaw, there is an annual mailing to all homeowners of properties within 100-feet of coastal estuaries. The bylaw and outreach efforts are expected to result in a 25% reduction in the attenuated fertilizer load to the estuaries.

ES.3.3 Shellfish Aquaculture

The Town initiated a significant oyster aquaculture project in Little Pond beginning in 2013. This demonstration project was funded by the Town, the Cape Cod Economic Development Council, and the Cape Cod Water Protection Collaborative. It was a three-year project to verify nitrogen uptake by oysters and to culture enough oysters to yield a detectable change in water quality at the site. SMAST was contracted for the three-year monitoring effort for the project. Results from SMAST show that the deployment of oysters in Little Pond produced small-scale, localized water quality improvements including total nitrogen concentration. The primary mechanism for these water quality improvements appears to be the uptake of phytoplankton.

During the course of the three-year program in Little Pond several overwintering techniques were evaluated. The project saw the highest survival when first-year oysters were removed from the water and placed in insulated cold-storage containers, resulting in < 1% mortality.

Based on the success of the pilot project, municipal aquaculture efforts are still ongoing in Little Pond. In 2017 the municipal propagation program assessed the comparative growth rates of different oyster seed stock and began exploring methods for optimizing propagation in impaired estuaries for shellfish other than oysters, such as quahogs and scallops (Figure ES.3).

Figure ES.3 2017 Little Pond Farm <2 Acre Deployment

Additional shellfish aquaculture pilot programs have occurred in West Falmouth Harbor, Waquoit Bay, and Bournes Pond. In West Falmouth Harbor, the project established an oyster reef and studied its ability to self-sustain. In Bournes Pond and Waquoit Bay, the projects examined the effects of various culture techniques on oyster growth rates, nitrogen sequestration by these oysters, and the potential for denitrification rates of oysters grown in the high-density floating bag system similar to those used in Little Pond (Figure ES.3).

Using the findings from the shellfish aquaculture demonstration projects in Little Pond, Waquoit Bay, and Bournes Pond, the Town has been able to progressively optimize its oyster growing strategies for nitrogen removal. The Town now has the experience and ability to grow large numbers of oysters in a high-density floating bag system and successfully overwinter the animals with minimal mortality. In addition, the Town used quantitative analyses to estimate the amount of nitrogen sequestered by oysters in the high-density floating gear using initial season weights and harvest weights for the total area occupied by gear and analyzing a subset of about 25 oysters for the percent nitrogen content in the shell and the tissue. Using these measures, the Town is able to accurately determine the total nitrogen removal on a kilogram per acre basis and produce measurable improvements in the surrounding water quality.

In 2017 the Town developed a plan that would promote increased aquaculture activities as a nitrogen removal strategy in impaired estuaries. The plan identified areas suitable for shellfish aquaculture activities based on a number of parameters (e.g. presence of eelgrass and/or harvestable shellfish, navigation channels, mooring fields, anadromous fish runs, etc.). The plan recommended involving commercial growers in the municipal efforts. As such, the Town is currently pursuing a pilot program in Eel River to contract with commercial growers to grow on Town-owned aquaculture sites following Town growing protocols including a target nitrogen removal condition (Figure ES.4). A request for proposals for the Eel River sites has been distributed and applicants have been evaluated.

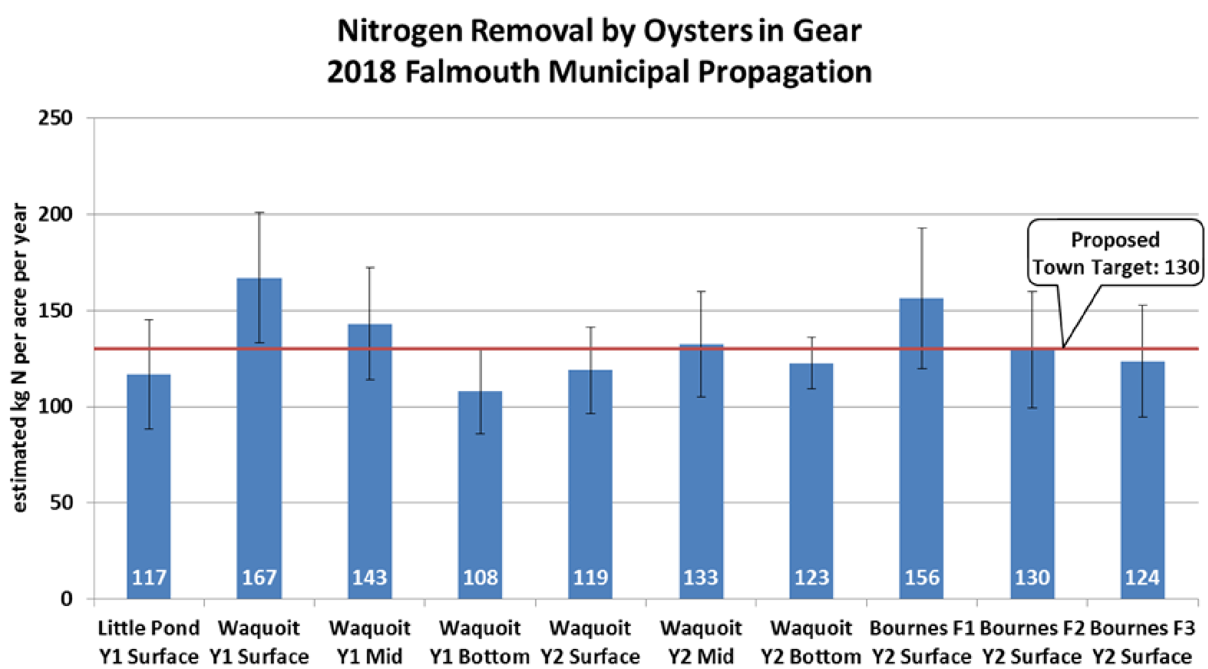


Figure ES.4 Summary of Nitrogen Removal Measurements in 2018

ES.3.4 Innovative and Alternative Septic Systems

In partnership with the Buzzards Bay Coalition, the Town received all equipment for and has completed the first phase of the West Falmouth Harbor Shoreline Septic System Remediation Project (WHFSSSRP) using advanced I/A septic systems. For the first phase of the project, 20 systems were installed and monitored. The range of installation costs for each system varied and were primarily driven by site constraints for installment and the costs to restore the landscaping.

The Town considers the MassDEP standard of 19 mg N/L to be too high to effectively improve the health of the estuary and therefore set a performance goal of 12 mg N/L for each system in this project. The monitoring results showed a wide range of performance from the various installed systems. Through the course of the project it was determined that to be the most effective for achieving Falmouth's Total Maximum Daily Loads (TMDL) goals, there needs to be options for I/A systems that achieve 10 mg N/L, or 75% total nitrogen reduction approved by MassDEP. The installation and monitoring costs are among the primary concerns in using I/A systems. The conclusion from the pilot project is that for the cost of I/As to be similar to sewers, loans for I/A systems would ideally be available that provide financing comparable to Falmouth's previous betterments.

Phase II of the WFHSSSRP is currently in progress with an additional five systems installed to date and another five systems planned. The groundwater monitoring for all of the systems installed is performed by the Barnstable County Department of Health and Environment. The Coalition for Buzzards Bay published an initial report of the project in 2018 and expects to make a final report at the end of the project.

ES.3.5 Permeable Reactive Barriers

The Town has actively explored and evaluated several potential sites in Great, Green, and Bournes Pond watersheds suitable for the installation of a permeable reactive barrier (PRB). Several potential sites suitable for a PRB were initially identified by a mapping exercise and funds were obtained through the Cape Cod Water Protection Collaborative and the EPA to install monitoring wells to characterize the groundwater hydrology, the soils, and the chemistry of dissolved substances.

Two candidate sites have been identified as a result of these efforts: 0 Shorewood Drive in the Great Pond watershed and Sailfish Drive in the Bournes Pond watershed. Both have a high groundwater velocity rate, high groundwater nitrate concentrations, and shallow depth to the water table. The Town has pursued various funding opportunities to aid in the installation costs to initiate a PRB demonstration project and expects to hear soon from the latest grant application to the Southeastern New England Program for a PRB installation at 0 Shorewood Drive. The US Geological Survey has also assisted in this project by installing a multi-port sampler at an upstream location on Shorewood Drive and sharing the data.

ES.3.6 Stormwater Management

The Town has worked to identify several candidate locations to implement stormwater Best Management Practices (BMP) for nitrogen removal. An initial review of the storm drain system in Great Pond was conducted to determine the nitrogen load from the two most prominent catchment areas in the watershed. Based on subsequent field investigations of the two catchment areas and the necessary steps to implement the BMP, the Town has decided to further review the effectiveness of emerging technologies such as media boxes prior to carrying out any specific stormwater management projects. The Falmouth Department of Public Works continues to employ Best Management Practices in all of its road improvement projects.

ES.3.7 Inlet Widening

In 2016, the Town filed a Notice of Project Change to advance the Bournes Pond Inlet Widening program. The objective of the project is to widen the existing inlet to increase water exchange within Bournes Pond. Historic information indicates the inlet width has naturally varied from 88-feet wide up to 400-feet wide from 1844 to 1984. Its current restrained opening of 50-feet wide occurred in 1985 with the construction of the bridge. The planned widening will open the inlet to approximately 90-feet which is on the lower end of the historical stable inlet widths observed at the Bournes Pond entrance. Modeling scenarios done by SMAST and ACRE indicate that inlet widening to 90-feet should achieve approximately 50% of the total nitrogen removal requirement in Bournes Pond. To date all of the required permits for the construction phase have been obtained and construction could begin as early as 2020.

ES.4 Little Pond Targeted Watershed Management Plan Update

As part of the approach for meeting the TMDL in Little Pond, the Little Pond Sewer Service Area (LPSSA) was designed to connect approximately 1,350 developed properties to the Town sewer system. Approximately 19% of these properties are within the boundaries of the Great Pond watershed.

The Town has partnered with the USGS and EPA on a project to monitor the groundwater beneath the Maravista Peninsula through a series of 18 monitoring wells. The objectives of the study are to assess groundwater levels and water quality beneath a densely developed coastal neighborhood undergoing a conversion from septic systems and cesspools to municipal sewers, and develop an understanding of water-quality conditions before and after installation of the sewers. It is estimated that it will take approximately seven years for the existing nitrogen load from the traditional septic systems to move through the groundwater and soils before the full benefit of sewering the LPSSA can be evaluated.

Construction of the new collection system for the LPSSA began in 2015. Groundwater sampling by the USGS began in June of 2016 and has continued to date. Data from the USGS efforts will show the timing of the impacts of sewering on the groundwater in Maravista while the continued monitoring data from the Pond Watch Monitoring Program (see Section ES.2) will indicate when the effects of sewering have reached Little Pond. The USGS groundwater monitoring data are publicly available through the USGS data repository.

To date, over 95% of the properties in the LPSSA have connected to the sewer system, and it is anticipated that the remaining properties will be connected by the fall of 2019. It is estimated that the sewering of the LPSSA will accomplish a minimum of an 83% reduction of the total nitrogen removal required to meet the TMDL goal.

The Town anticipates that the fertilizer bylaw and stormwater management practices will receive the State-approved nitrogen reduction credit of 25% reduction of the total attenuated load from these sources. Additionally, there are municipal aquaculture efforts in Little Pond that will further aid in meeting the TMDL goal.

Falmouth has taken significant steps to reduce the nitrogen load into Little Pond. As part of the adaptive management approach adopted by the Town, monitoring of the LPSSA will continue to assess the impacts from sewering. If the current efforts have not fully met the nitrogen removal requirements, use of I/A systems in the upper watershed or the expansion of the LPSSA northward would be the “back-up plan” to achieve TMDL compliance in the Little Pond watershed.

ES.5 West Falmouth Harbor Targeted Management Plan Update

The largest source of controllable nitrogen in the West Falmouth Harbor watershed is the effluent plume from the original lagoon wastewater treatment facility (WWTF) constructed in the 1980s. Since the plant came on line in 1986, significant upgrades to the plant have reduced nutrient concentrations in the effluent discharged into the West Falmouth Harbor watershed. In 2005, the WWTF was upgraded to a tertiary treatment facility. As a result of an evaluation on nitrogen removal optimization done as part of the design process for the LPSSA (see Section ES.4), several recommendations for additional upgrades to the WWTF were made and completed by 2016. In 2019, a new evaluation was conducted to assess additional requirements for the WWTF to process additional load from the proposed Teaticket/Acapesket Study Area (see Section ES.6). This evaluation recommended adding a third sequencing batch reactor (SBR) to the plant and constructing additional effluent discharge capacity outside of the West Falmouth Harbor watershed. The Town has requested capital funds to complete the recommended upgrades to accommodate additional flow and load from future sewer extensions.

Currently the plant is operating under the most recent Modified Groundwater Discharge Permit (December 2015); this permit limits discharge to 450,000 gpd within the West Falmouth Harbor watershed and to 260,000 gpd outside the watershed.

One of the requirements of the current discharge permit is quarterly groundwater monitoring for nitrogen and phosphorus. There is an existing network of monitoring wells upgradient and downgradient of the various recharge beds within and outside of the West Falmouth Harbor watershed. Monitoring wells downgradient from Recharge Beds 1 – 13 in the West Falmouth Harbor watershed have shown a significant decrease in groundwater total nitrogen concentration since the WWTF upgrade to a tertiary treatment plant was completed in 2005. All the monitoring wells except one, the furthest downgradient from the WWTF, have contained total nitrogen concentrations less than 2 mg/L for more than a year. The monitoring well most distant from the plant still contains a total nitrogen concentration greater than 4 mg/L, though that is expected to drop over time as well as the plume from the original lagoon WWTF washes out. Data from wells downgradient of Recharge Beds 1 - 13 also indicate that there has been no increase in phosphorus concentration in groundwater over the background levels, despite over 30 years of WWTF discharge.

In 2016, SMAST conducted additional modeling scenarios for West Falmouth Harbor to meet TMDL compliance. Using build-out scenarios and the current discharge permit restrictions, the modeling results indicated that if the plant effluent averages an annual concentration at or below 3 mg TN/L the system should meet the West Falmouth Harbor TMDL once the plume from the original lagoon WWTF has flushed out. As shown in Figure ES.5, effluent total nitrogen concentration from the original lagoon WWTF averaged 23.3 mg/L from 1994 to 2005; upgrades completed in 2005 resulted in effluent total nitrogen concentrations averaging 4.7 mg/L from 2006 to May 2016, and additional upgrades completed in 2016 resulted in effluent total nitrogen concentrations averaging 2.7 mg/L from June 2016 to December 2018. The WWTF did have a mechanical problem resulting in reduced performance in 2019. However, the performance from 2016 through 2018 demonstrates the capacity of the WWTF to average 3 mg/L over extended periods. Additional WWTF upgrades including the third SBR and upgrades to the WWTFs sludge processing system are envisioned as part of the next phase of wastewater system expansion to accommodate additional flow from additional service areas and to further improve the consistency of WWTF performance.

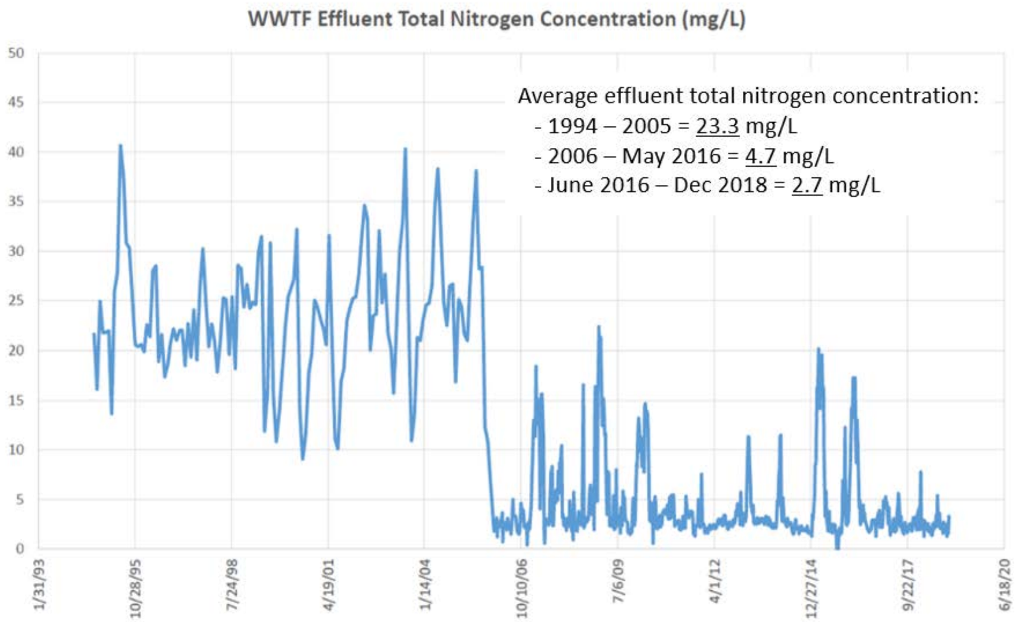


Figure ES.5 Historical Wastewater Treatment Facility Effluent Total Nitrogen Concentrations

To provide a suitable discharge site for treated effluent from the LPSSA, the Town built Recharge Beds 14 and 15 north of the WWTF and outside of the West Falmouth Harbor watershed. Data from the monitoring network for these beds show that total nitrogen has increased slightly in some downgradient wells since discharge began in 2016. It is noted that the upgradient background monitoring well contains slightly elevated total nitrogen concentrations, as well, indicating the potential influence of upgradient sources. Total phosphorus concentrations in the monitoring wells have not increased in any monitoring wells except for the two wells located only 20 feet horizontally from the recharge beds. These two adjacent wells, one screened at the top of the groundwater table and the other screened just below the first, were installed in this manner within 20 feet of the recharge beds in order to confirm phosphorus attenuation in aquifer soils over a short distance, as indeed demonstrated to date.

Crocker Pond lies generally downstream from Recharge Beds 14 and 15 and has been monitored in July, August, and September since 2016. The current data is considered baseline data and will be compared to future data to assess potential nutrient impacts to the pond from discharge to Beds 14 and 15.

The Town has made several additional efforts to augment the nitrogen removal in the West Falmouth Harbor watershed. The Town expects that the fertilizer bylaw and stormwater management practices will receive the State-approved nitrogen reduction credit of 25% reduction of the total attenuated load from these sources. Additionally, the West Falmouth Harbor Shoreline Septic System Remediation Project with the Buzzards Bay Coalition (See Section ES.3) has removed a small portion of the nitrogen load through the installation of approximately 25 I/A systems to date; five more I/A systems are in the planning stage.

Based on the SMAST modeling, the Town expects to be able to meet the nitrogen TMDL goal for West Falmouth Harbor with the WWTF improvements alone. However, the Town will also continue with the other nutrient mitigation strategies (fertilizer management, I/A system demonstrations, etc.) in order to provide the greatest flexibility to manage nitrogen within the watershed.

ES.6 Great Pond Watershed Planning Scenario

The largest source of controllable nitrogen in Great Pond is wastewater from on-site septic systems. Due to the large nitrogen reduction requirements (about 12,000 kg/yr) and density of development adjacent to the pond, sewering is being considered in order to meet the nitrogen TMDL goal for Great Pond.

The Town contracted GHD to develop a conceptual sewer plan and to provide an evaluation of the nitrogen load per parcel in the Great Pond watershed. GHD's conceptual design is for a phased sewering project in the Teaticket/Acapesket Study Area. In total this project proposes to sewer approximately 1,791 developed properties, 1,289 of which are located in the Great Pond watershed and 502 in the Green Pond watershed (Figure ES.6). The first phase of the project would be on the Teaticket Peninsula and contains approximately 811 dwelling units including 210 condominiums in Falmouthport. The mid-point of construction for the first phase of the sewering project is anticipated to be in 2026. It is estimated that the sewering of the Teaticket/Acapesket Study Area combined with the sewered parcels from the LPSSA (see Section ES.4) in Great Pond will remove a minimum of 59% of the nitrogen needed to meet the TMDL goal for Great Pond.

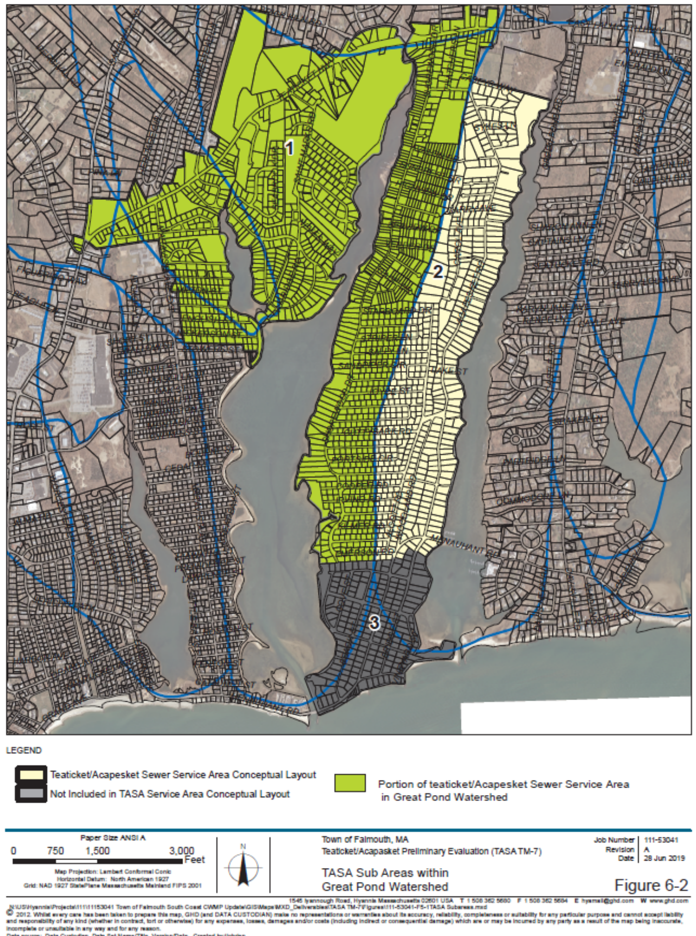


Figure ES.6 Teaticket/Acapesket Study Area Collection System Conceptual Layout of Parcels within the Great and Green Pond Watersheds

Part of GHD's evaluation of the Teaticket/Acapesket Study Area includes an assessment of effluent recharge technologies and disposal sites available to Falmouth. The flow from future development in existing sewered areas in Falmouth is also a consideration. The discharge options considered include: several sites for open sand beds or sub-surface leaching facilities in Falmouth or at Joint Base Cape Cod; and an ocean outfall into Buzzards Bay or Vineyard Sound and evaluations for capacity, community support, and cost.

Another main source of controllable nitrogen comes from the Coonamessett River which discharges into the head of Great Pond. It is estimated that 50% of the unattenuated nitrogen load entering Great Pond enters via the Coonamessett River. In 2014, the Falmouth Conservation Commission along with nearly two dozen project partners began to plan the conversion of 45 acres of retired cranberry bogs along the river into wetlands. To monitor the effects of the restoration efforts, the Town contracted the Woods Hole Research Center to quantify the nitrogen dynamics and physical characteristics of the river for a period of three years (2018 – 2020). Physical restoration of Lower Bog was completed only recently in 2018, and so the monitoring data has yet to show the anticipated nitrogen reduction impacts. Physical restoration of Middle and Reservoir Bogs is in design and permitting stages and will likely take place in 2020.

To meet the remaining nitrogen removal requirements to achieve the TMDL, the Town's plan expects that the fertilizer bylaw and stormwater management practices will receive the State-approved nitrogen reduction credit of 25% reduction of the total attenuated load from these sources. Additionally, the Town is currently evaluating potential acreage for significant shellfish aquaculture activities in Great Pond. At the head of the estuary, the Town is actively pursuing funding opportunities to install a 300-foot PRB at the Shorewood Drive parcel. It is estimated that the nitrogen reduction from the sewering, State-approved credits, shellfish aquaculture, and PRB will meet the TMDL. However, if these efforts do not fully meet the nitrogen removal requirements, the Town can consider I/A systems, sewer extensions north of Route 28, and exploring sites for an additional PRB north of Route 28 to achieve TMDL compliance in the Great Pond watershed.

ES.7 Green Pond Watershed Planning Scenario

The largest source of controllable nitrogen in Green Pond is from wastewater from on-site septic systems. In order to meet the nitrogen removal TMDL goal for Green Pond, the Town is considering various alternative options directly in the estuary and upstream in Mill Pond in addition to sewer extensions (Figure ES.7).

Figure ES.7 Green Pond Watershed

As part of the compliance approach for Great Pond (see Section ES.6) the Town's engineers have prepared a conceptual design for the Teaticket/Acapesket Study Area which proposes to sewer approximately 1,791 developed properties, 502 of which are located in the Green Pond watershed (Figure ES.7). It is estimated that the sewering of these properties on the Acapesket Peninsula will remove approximately half of the total requirement for nitrogen removal to meet the TMDL goal in Green Pond.

Another main source of controllable nitrogen comes from Mill Pond which discharges directly into the head of Green Pond. From 2015 to 2017 SMAST conducted an assessment on nutrient cycling in Mill Pond and determined that Mill Pond attenuates approximately 60% of the upstream nitrogen load and that the pond itself is phosphorus(P)-limited, not nitrogen-limited. The final report from SMAST made several recommendations for nutrient management in the pond which the Town has begun to pursue. Among the recommendations, a few were direct modifications to the cranberry agricultural practices upstream including: alternating the type of fertilizers used between 'low P' and 'no P', more strategic release of the dam boards to minimize water velocities into Mill Pond, and reducing the board height when damming during harvest and flood to increase flushing in the pond. According to the SMAST report, the bog owner is agreeable to putting these recommendations into practice.

Two additional recommendations made in the SMAST report are being pursued by the Town: installation of a detention pond and harvesting the macrophytes in Mill Pond. The Town is currently discussing with MassDEP the possibility of an agricultural exemption to install a tailwater recovery system rather than a detention pond. A tailwater recovery system would allow plant matter and fine sediments to settle out prior to discharge into Mill Pond and also allow for some recycling of nutrient runoff from irrigation practices back into the cranberry bog operations. Harvesting the macrophytes below the surface of Mill Pond will remove a significant nitrogen source from the pond that is generated when the plants die off and begin to decay. The macrophyte removal will also facilitate wind-driven vertical mixing in the pond to allow for the increased dissolved oxygen levels necessary for the natural denitrification cycle to occur in the sediments.

To meet the remaining nitrogen removal requirements to achieve the TMDL, the Town's plan expects that the fertilizer bylaw and stormwater management practices will receive the State-approved nitrogen reduction credit of 25% reduction of the total attenuated load from these sources. Additionally, the Town is currently evaluating potential acreage for some shellfish aquaculture activities in Green Pond. It is estimated that the nitrogen reduction from the sewering, State-approved credits, shellfish aquaculture, and nutrient management efforts in Mill Pond will meet the TMDL. However, if these efforts do not fully meet the nitrogen removal requirements, the Town can consider I/A systems or sewer extensions on the Davisville Peninsula, and explore sites for PRBs within the watershed to achieve TMDL compliance in the Green Pond watershed.

ES.8 Bournes Pond Watershed Planning Scenario

The largest source of controllable nitrogen in Bournes Pond is from wastewater from on-site septic systems. The Town believes that it can achieve TMDL compliance in Bournes Pond by using alternative options for nitrogen removal rather than by sewering.

As a result of the additional modeling done for the inlet widening demonstration project (see Section ES.3), the Town opted to pursue inlet widening for Bournes Pond. This project will expand the current inlet width from approximately 50-feet to 90-feet (Figure ES.8). This expansion will require the construction of a new two-span bridge and modifications to the surrounding coastal areas and structures including extending the western jetty by 25-feet, reconstructing an existing groin, and dredging the inner and outer channel of the inlet. Modeling results done by SMAST indicate that this project will achieve almost half of the required nitrogen removal to meet the TMDL goal. The Notice of Project Change (NPC) for the inlet widening project was filed in 2016. Several ecological assessment studies were conducted between 2015 and 2018 by Stantec, AECOM, and Applied Coastal to evaluate flood impacts, eelgrass beds, and shellfish locations in relation to the widened inlet. The project is now in its final design and permitting phase, and to date, all pre-construction permits have been obtained. It is anticipated that construction could begin as early as Fall 2020 with completion anticipated by December of 2022.

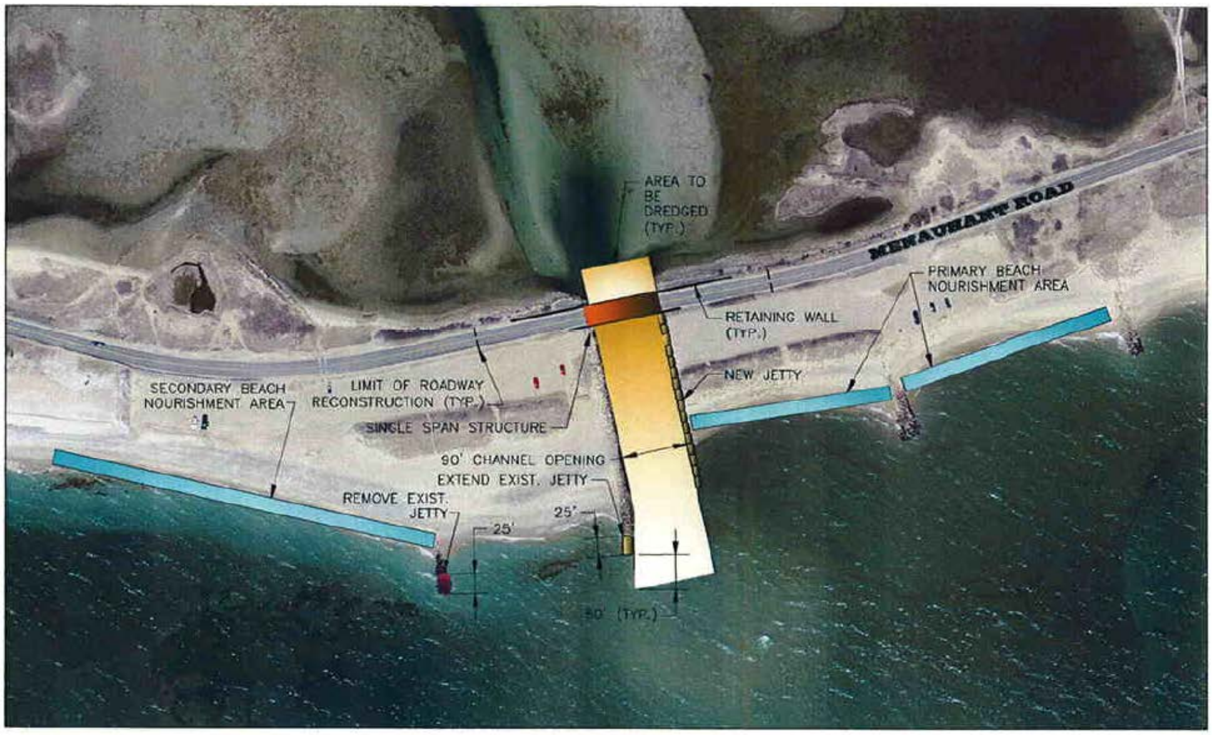


Figure ES.8 Proposed Plan for Widening the Bournes Pond Inlet

In addition to the inlet widening, the Town is currently evaluating suitable potential acreage for significant shellfish aquaculture activities in Bournes Pond which could remove about one-third of the total nitrogen needed to meet the TMDL goal. Additional nitrogen reductions are anticipated from shellfish bio-deposit denitrification.

To meet the remaining nitrogen removal requirements to achieve the TMDL, the Town's plan expects the fertilizer bylaw and stormwater management practices will receive the State-approved nitrogen reduction credit of 25% reduction of the total attenuated load from these sources. It is estimated that the nitrogen reduction from the inlet widening, State-approved credits, and shellfish aquaculture will be close to meeting the TMDL. Since Falmouth has adopted an adaptive management approach, if these efforts do not fully meet the nitrogen removal requirements, the Town can consider sewer extensions along Route 28, the use of I/A systems, exploring sites for a PRB in the upper watershed, and exploring nitrogen reduction options entering from Bournes Brook to achieve TMDL compliance in the Bournes Pond watershed.

ES.9 Eel Pond/Waquoit Bay Watershed Planning Scenario

The Waquoit Bay watershed is shared by the towns of Falmouth, Mashpee, and Sandwich (Figure ES.9). The entire Eel Pond sub-embayment and the majority of the Childs River sub-embayment fall entirely within Falmouth. The largest source of controllable nitrogen in the Waquoit Bay system is from wastewater from on-site septic systems. The three towns have begun the process of creating an Inter-municipal Agreement (IMA) to determine the allocation of nitrogen that each town is responsible for in order to plan their respective nitrogen reduction efforts. However, prior to determining this allocation, Falmouth has begun to explore options in the Eel Pond and Childs River sub-embayments because the majority of the nutrient reduction efforts for these areas lies within Falmouth. According to the MEP report, the main basin of Waquoit Bay does not require any formal reduction of nitrogen loads and therefore no specific plan has been prepared. SMAST conducted a study examining two potential nitrogen reduction approaches in the Quashnet / Moonakis River sub-embayment, dredging, and aquaculture. The study indicated tidal inlet dredging and shellfish aquaculture could address a portion of the nitrogen load reduction. No further investigation has been done in this region because the watershed is shared, and the IMA process is just beginning.

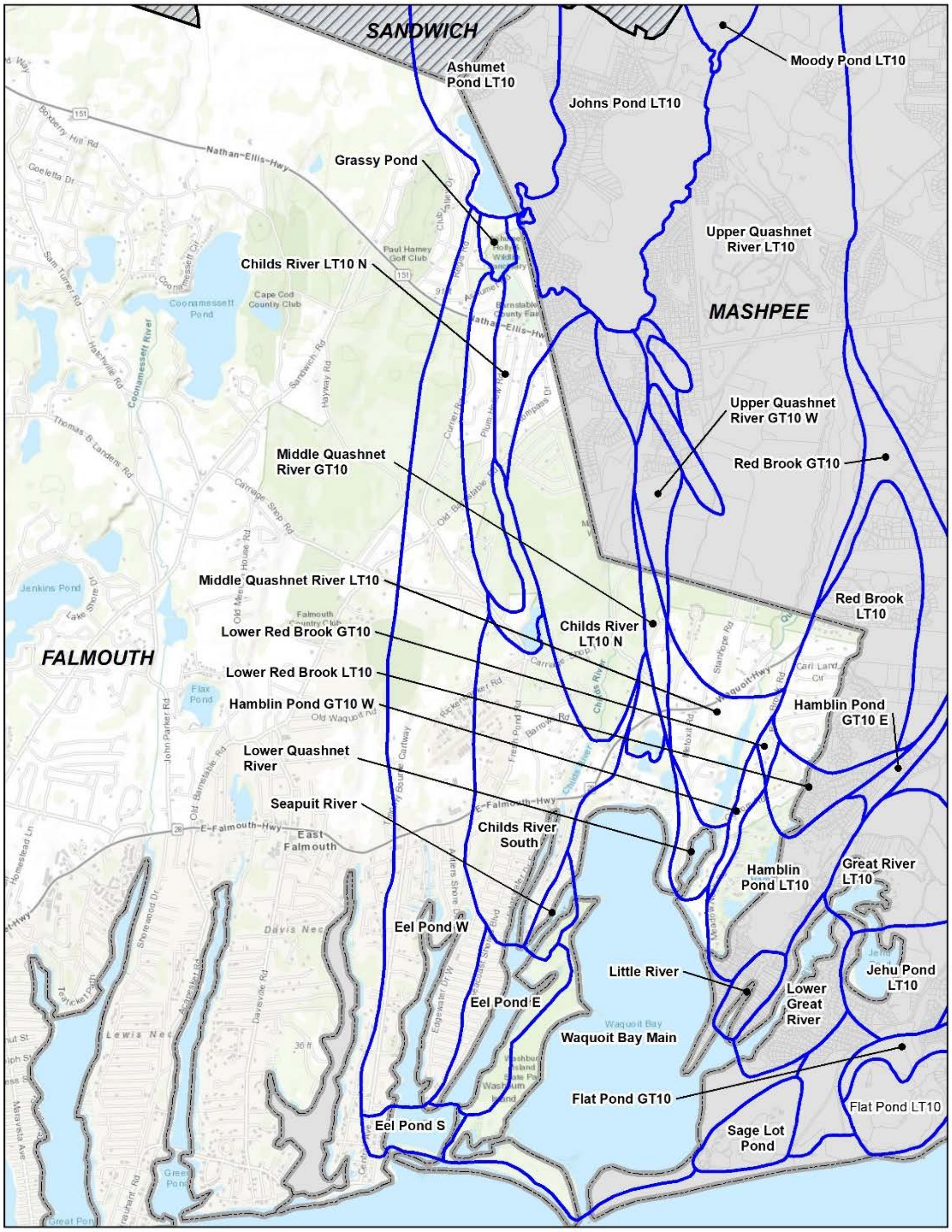


Figure ES.9 Waquoit Bay Sub-Watersheds with Town Lines

As part of the compliance effort for both Eel Pond and Childs River, the Town could consider sewer extensions for the Antler Shores, Seacoast Shores, and Seapit peninsulas. Sewering these three areas would connect an additional 1,300 properties to the sewer system. Due to the complex flow dynamics and exchange of water between the Waquoit Bay sub-watersheds, it is likely that improvements—such as sewering—made within a specific area like Eel Pond will also have some net benefit to other areas (e.g. Childs River). To accurately predict the secondary benefits to additional watersheds is a challenging task given the present level of information. Therefore, the secondary benefits have not been included in the final projections.

Prior to determining the nitrogen removal allocation, the Town has become involved in two projects with the goal of nutrient load reduction. The Town has begun efforts to develop a municipal aquaculture program that contracts commercial growers to remove a targeted amount of nitrogen per acre (see Section ES.3). Three initial sites for this project have been identified in Eel River. The project applicants have been evaluated, and it is anticipated that full-scale growing will begin in 2020. Another project in the Waquoit Bay watershed is a restoration effort that began in 2019 involving collaboration between the local Rod and Gun Club, Falmouth, and the Town of Mashpee to convert 12.4 acres of retired cranberry bogs into wetlands along the Childs River. It is too early in the implementation of this restoration project to determine the full extent of nitrogen removal potential from this effort.

After considering the potential nitrogen reduction from sewering the Antler Shores, Seacoast Shores, and Seapit Peninsulas to meet the remaining nitrogen removal requirements to achieve the TMDL, the Town is exploring several alterative options for nitrogen reduction. The Town's plan expects that the fertilizer bylaw and stormwater management practices in each sub-embayment will receive the State-approved nitrogen reduction credit of 25% reduction of the total attenuated load from these sources. Additionally, the Town is currently evaluating potentially suitable acreage for some shellfish aquaculture activities in Eel Pond and Childs River. It is estimated that the nitrogen reduction from the State-approved credits, shellfish aquaculture, and proposed sewering (including Mashpee's sewer contribution in the Childs River watershed) will meet the TMDL for Eel Pond and Childs River. However, if these efforts do not fully achieve TMDL compliance in the Waquoit Bay system, the Town can consider I/A systems or sewer extensions, and exploring sites for PRBs within the watersheds to achieve Falmouth's yet-to-be-designated allocation of the nitrogen removal load.

ES.10 Public Outreach Efforts

The Town continues to engage in public awareness and outreach efforts on Falmouth's water quality issues. Over the past five and a half years almost 80% of the Falmouth Water Quality Management Committee's regular meetings have been recorded and made available on the Falmouth Community Television local cable station and on its website. A journalist from the local newspaper, The Falmouth Enterprise, regularly attends the WQMC meetings. Approximately 129 articles have appeared in this local newspaper on water quality updates or issues raised during the WQMC meetings. On the Upper Cape, approximately 13,000 households have full access subscriptions to The Enterprise in print or online.

In addition to the regular committee meetings, the WQMC has made special outreach efforts for high-impact or localized community issues such as the Little Pond Sewer Service Area project, the initiation of the fertilizer bylaw, hosting a vendor workshop in West Falmouth for interested homeowners to speak with I/A system representatives, and frequent reports at the Falmouth Town Meetings. The Water Quality Management Committee plans to continue to work with the Board of Selectmen and relevant Town departments to inform the public and to provide a forum for open dialogue on water quality issues.

ES.11 CWMP/TWMP Notice of Project Change Summary and Next Steps

The compliance approach for each of the watersheds in this CWMP has been laid out in detail within this report; a synopsis is presented in the Notice of Project Change summary. The Town decided to implement the Comprehensive Watershed Management Plan by moving from west to east along the southern coastline. With the completion of the Little Pond TWMP, the TWMP for Great Pond has been identified as the next watershed to be evaluated. The TWMP for the Great Pond watershed will provide information on several key elements including: the background on the watershed, update and recommended effluent discharge site selection, development of a recommended plan, an update to the environmental impact analysis, and an update to the section 61 findings and mitigation measures.

The Town has prepared Table ES-1, Estimated Costs and Financing Plans, that lists in detail 15 steps that need to be taken and decisions that need to be made at both the local and state levels to achieve a funded plan for the Great Pond watershed. In the process of developing the Great Pond TWMP, Falmouth must make an important decision in choosing a site for discharge of the treated effluent. The financing plan in Table ES-1 is consistent with Falmouth's originally stated policy of funding sewer projects in those years when new debt can replace retiring debt. The next funding window is Fiscal Year 2025, and expectations are that Town Meeting and the voters would approve a bond issue of $60 million in April/May 2024 to be effective at the start of Fiscal Year 2025 starting on July 1, 2024.

ES.12 Section 61 Findings and Mitigation Measures Update

An update to the Section 61 findings and mitigations measures is a regulatory requirement. The changes to these findings have built upon those in the original CWMP. Mitigation measures are described for general construction sites, sewer construction, wastewater treatment facility, and infiltration sites. The update also includes additional mitigation measures involving adaptive management and climate change.

Table ES.1 Estimated Costs and Financing Plans

Item	Action Item	2019	2020	2021	2022	2023	2024	2025
1	Little Pond Sewer Service Area Completed	X						
2	(A) CWMP Update/NPC; (B) Oyster Pond Draft CWMP Submitted to MEPA/DEP	X						
3	Capital Plan within debt limit: add third Sequencing Batch Reactor; plant upgrade		X	X	X			
4	Receive MEPA Secretary's Certificate for CWMP Update		X					
5	Evaluate Results of Remediation to date; Engineering Contract for Great Pond TWMP		X					
6	Draft TWMP for Great Pond Sewer Service Area; Decision on Discharge Site; Submit to MEPA/DEP		X	X				
7	Sec. Certificate for Draft TWMP; Final TWMP; Sec. Certificate for Final TWMP				X			
8	Town Meeting Sets Betterment Percentage					X		
9	Construction Design Funding; Ballot Vote					X		
10	SRF PEF Application Submittal					X		
11	Obtain Listing on the SRF Intended Use Plan						X	
12	$60M Town Vote Bond for Construction Contingent on 0% SRF Loan; Ballot Vote						X	
13	SRF Full Application Submitted - all required items must be in place						X	
14	State SRF Commitment; Bid Approval							X
15	SRF-Funded Construction Projects; On-going Adaptive Management							X

Program Funding and Timetable 2025-2040	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Town Construction of $60M																
Plan Next Construction Projects																
$40M Town Vote - Spring 2030						X										
Town Construction of $40M																
$XX Town Vote - Spring 2035 [1]											X					
Town Construction																

Notes:

CWMP = Comprehensive Wastewater Management Plan

NPC = Notice of Project Change

TWMP = Targeted Watershed Management Plan

PEF = Project Evaluation Form

SRF = State Revolving Fund

1. Due to the unknowns and uncertainties related to funding in the future, the Town has not identified the appropriation goal for 2035.

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Glossary of Common Acronyms

ACRE	Applied Coastal Research and Engineering, Inc.
ASAR	Alternatives Screening Analysis Report
BBC	Buzzards Bay Coalition
BCDHE	Barnstable County Department of Health and Environment
BMP	Best Management Practices
BOD	Biochemical Oxygen Demand
CCC	Cape Cod Commission
CCWPC	Cape Cod Water Protection Collaborative
CFR	Code of Federal Regulations
CMR	Code of Massachusetts Regulations
CRWG	Coastal Resources Working Group
CWMP	Comprehensive Wastewater Management Plan
CWMP/FEIR/TWMP	Comprehensive Wastewater Management Plan and Final Environmental Impact Report, and Targeted Watershed Management Plan
CWSRF	Clean Water State Revolving Fund
CZM	Coastal Zone Management
DCWMP/DEIR	Draft CWMP and Draft Environmental Impact Report
DEP	Department of Environmental Protection
DIN	Dissolved Inorganic Nitrogen
DMF	Division of Marine Fisheries
DO	Dissolved Oxygen
DON	Dissolved Organic Nitrogen
DPW	Department of Public Works
EEA	Energy and Environmental Affairs
EIR	Environmental Impact Report
ENF	Environmental Notification Form
EOEEA	Executive Office of Energy and Environmental Affairs
EPA	Environmental Protection Agency
FCTV	Falmouth Community Television
GHD	GHD Inc.
GHG	Greenhouse Gas

GIS	Geographic information System
gpd	Gallons per day
gpd/sf	Gallons per day per square foot
GWDP	Groundwater Discharge Permit Program
IMA	Inter-Municipal Agreement
I/A	Innovative and Alternative
JBCC	Joint Base Cape Cod
kg/d	Kilograms per Day
kg/yr	Kilograms per Year
kW	Kilowatt
lbs/yr	Pounds per Year
LPSSA (or LPSA)	Little Pond Sewer Service Area
MassDEP	Massachusetts Department of Environmental Protection
MassDOT	Massachusetts Department of Transportation
MBL	Marine Biological Laboratory
MEP	Massachusetts Estuaries Project
MEPA	Massachusetts Environmental Policy Act
MES	Marine and Environmental Services
MESA	Massachusetts Endangered Species Act
mgd	million gallons per day
mg/L	milligrams per liter
M.G.L.	Massachusetts General Law
MHC	Massachusetts Historical Commission
MSL	Mean Sea Level
NAR	Needs Assessment Report
NHESP	Natural Heritage and Endangered Species Program
NOAA	National Oceanic and Atmospheric Administration
NOI	Notice of Intent
NO_3	Nitrate
NPC	Notice of Project Change
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resource Conservation Services
N/L	Nitrogen per Liter
N/yr	Nitrogen per Year

ORP	Oxidation/Reduction Potential
OSHA	Occupational Safety and Health Administration
PEF	Project Evaluation Form
PGP	Programmatic General Permit
PON	Particulate Organic Nitrogen
ppm	parts per million
PRB	Permeable Reactive Barrier
psi	pounds per square inch
PSU	Practical Salinity Units
QAPP	Quality Assurance Project Plan
RMME	Responsible Municipal Management Entity
SAS	Soil Absorption System
SBR	Sequencing Batch Reactor
sf	Square Foot
SMAST	School for Marine Science and Technology
SNEP	Southeast New England Program
SRF	State Revolving Fund
STA	Soil Treatment Area
SWPPP	Stormwater Pollution Prevention Plan
TASSA	Teaticket Acapesket Sewer Service Area
TM	Technical Memorandum
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TN/L	Total Nitrogen per Liter
TWMP	Targeted Watershed Management Plan
UCWSC	Upper Cape Water Supply Cooperative
UMass	University of Massachusetts
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WFH	West Falmouth Harbor

WFHSSSR	West Falmouth Harbor Shoreline Septic System Remediation
WHOI	Woods Hole Oceanographic Institute
WHRC	Woods Hole Research Center
WNMP	Watershed Nitrogen Management Plan
WPA	Wetlands Protection Act
WQMC	Water Quality Management Committee
WWTF	Wastewater Treatment Facility

1. Introduction

1.1 Background and Purpose

This Notice of Project Change to the Comprehensive Wastewater Management Plan and Final Environmental Impact Report and Targeted Watershed Management Plan (CWMP/FEIR/TWMP) Document provides an update to several of the Town's CWMP implementation efforts and pilot projects as identified in the January 10, 2014 Executive Office of Energy and Environmental Affairs (EOEEA) Secretary Certificate [EEA#14154] as included in Appendix 1.1. This document will be the next Notice of Project Change issued for this project. The first was specifically related to the Bournes Pond Inlet Widening Project EEA # 14154 issued March 11, 2016, as included in Appendix 1.1.

The Town of Falmouth (Town) has produced six reports related to the Comprehensive Wastewater Management Planning (CWMP) Project.

The first of these reports was the Needs Assessment Report (NAR) dated October 2007, which documented the wastewater and nitrogen-management needs for the Planning Area and related areas of Falmouth. The second report was the Alternatives Screening Analysis Report (ASAR) dated November 2007, which identified possible solutions to address the wastewater and nitrogen-management needs and then "screened" these alternative solutions to retain the most feasible ones for cost development and detailed evaluation. The third was the Environmental Notification Form (ENF) document dated December 17, 2007 that summarized the findings of the Needs Assessment Report to initiate environmental review of the project (as part of the Massachusetts Environmental Policy Act or MEPA review process). The fourth was the Draft Comprehensive Wastewater Management Plan and Draft Environmental Impact Report (DEIR) and Draft Notice of Project Change (Draft Report) dated July 30, 2012 which presented the draft plan, and further advanced MEPA review of the project. A Secretary's Certificate was issued on November 14, 2012 stating that the DEIR was adequate, and provided a scope of work for the FEIR.

The CWMP/FEIR/TWMP, the fifth report dated September 16, 2013, summarized the detailed evaluations and the changes made since the review of the Draft Report, and presented the Recommended Plan to address the wastewater and nitrogen management needs of the Little Pond watershed. It also presented the estimated environmental impact (and benefits) of the Recommended Plan as compared to the consequences of not acting on the wastewater needs (also called the No-Action Alternative).

The sixth report is the Amended TWMP dated October 6, 2014. This document was issued to address a Massachusetts Department of Environmental Protection (MassDEP) request to clarify the Town's approach for addressing the Nitrogen Total Maximum Daily Load (TMDL) for Little Pond using the traditional and non-traditional management approaches identified in the 2013 CWMP Report.

Several components of the CWMP/TWMP needed further coordination and agreement, and therefore, the associated Adaptive Management Plan identified a number of pilot projects and other initiatives necessary to determine the feasibility of various non-traditional wastewater and nitrogen management technologies and approaches.

These pilot projects and other initiatives have been primarily funded by Article 17 of Spring 2011 Town Meeting and a ballot vote in May 2011 (see Appendix 1.1) and are underway. Their progress to date is summarized in this document.

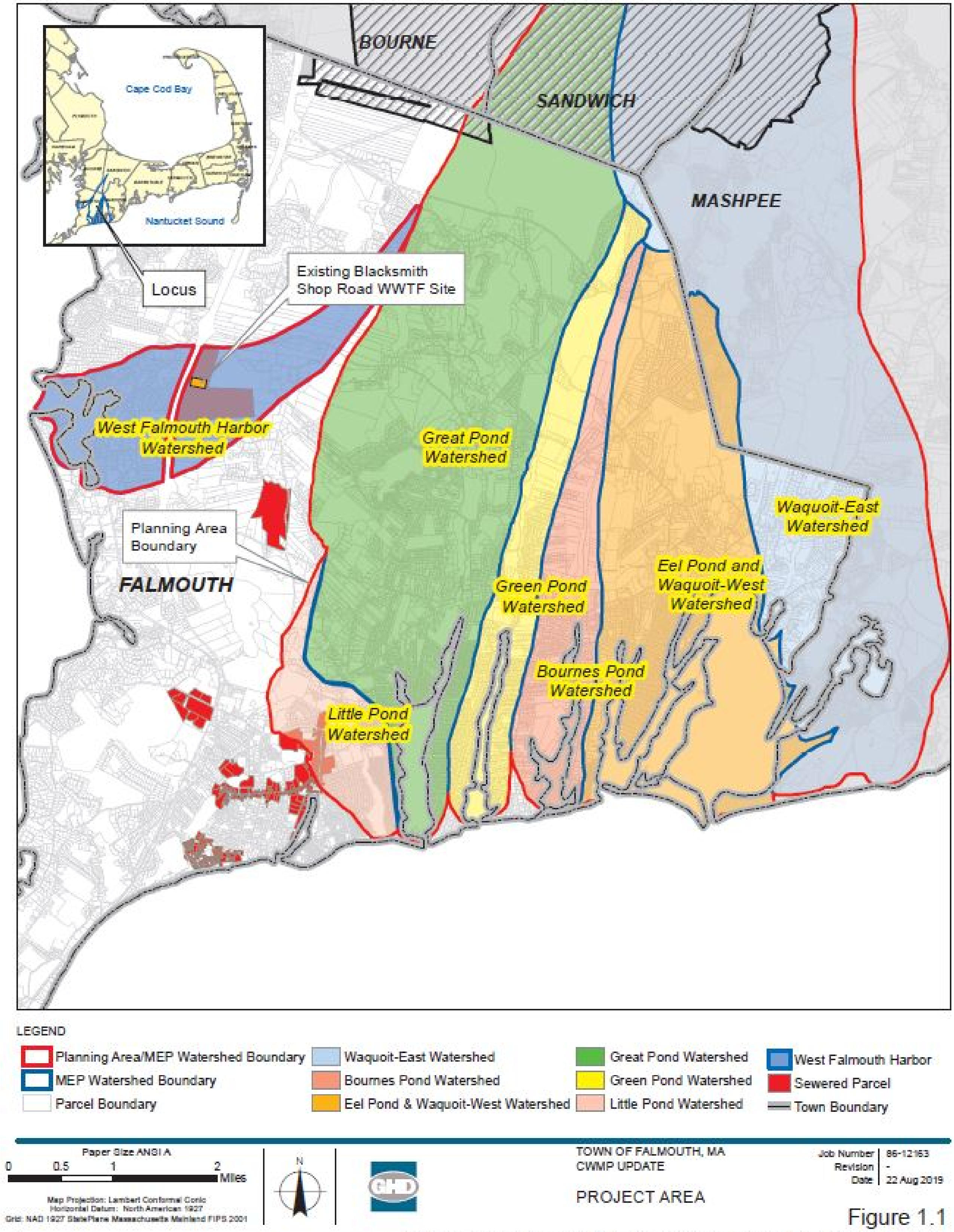
This update has been prepared by GHD, the Falmouth Water Quality Management Committee, and its contractor Science Wares, and has been approved by the Falmouth Board of Selectmen. It is a summary of the efforts and studies to date that support the Compliance Plan Approaches developed for each watershed.

1.2 Planning Area

The Town of Falmouth is located in the southwestern portion of Cape Cod as shown in the following Figure 1.1. This figure also identifies the Planning Area as the watersheds to Little, Great, Green, Bournes, and Eel Ponds, and Waquoit Bay as well as the West Falmouth Harbor watershed. All of the estuarine waters in the Planning Area are impacted by excessive nitrogen loadings in the respective watersheds.

Demonstration/pilot projects were initiated for the following non-traditional nitrogen management approaches:

- Shellfish, a Town-wide program with a focus on the West Falmouth Harbor and Little Pond watersheds.
- Eco-Toilets, a Town-wide initiative.
- Innovative and alternative (I/A) septic systems with a focus in West Falmouth Harbor watershed.
- Permeable Reactive Barrier (PRB) feasibility studies in Great Pond and Bournes Pond watersheds.
- Inlet widening in the Bournes Pond watershed.
- Fertilizer bylaw is a Town-wide initiative.


BOURNE
SANDWICH
MASHPEE
FALMOUTH
Cape Cod Bay
Nantucket Sound
Locus
Existing Blacksmith Shop Road WWTF Site
West Falmouth Harbor Watershed
Great Pond Watershed
Waquoit-East Watershed
Planning Area Boundary
Eel Pond and Waquoit-West Watershed
Green Pond Watershed
Bournes Pond Watershed
Little Pond Watershed
LEGEND
Planning Area/MEP Watershed Boundary
MEP Watershed Boundary
Parcel Boundary
Waquoit-East Watershed
Bournes Pond Watershed
Eel Pond & Waquoit-West Watershed
Great Pond Watershed
Green Pond Watershed
Little Pond Watershed
West Falmouth Harbor
Sewered Parcel
Town Boundary
Paper Size ANSI A
0 0.5 1 2 Miles
Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1927
Grid: NAD 1927 StatePlane Massachusetts Mainland FIPS 2001
N
TOWN OF FALMOUTH, MA
CWMP UPDATE
PROJECT AREA
Job Number 86-12163
Revision -
Date 22 Aug 2019
Figure 1.1
1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com
G:\86\12163\GIS\71045 Falmouth\Figures\June 2012 Final Report Figures\JULY 2019 REV\Figure 1.1.mxd

1.3 Update Outline

This Notice of Project Change (NPC) Report provides an update of the numerous efforts that the Town has been undertaking to develop a TMDL compliance approach for each of its impaired South Coast Embayments.

The document includes the following chapters:

Chapter 1: Introduction and background on the project.

Chapter 2: A summary of water quality monitoring data for Little, Great, Green, and Bournes Pond and Eel Pond/Waquoit Bay.

Chapter 3: A summary of pilot projects including: shellfish aquaculture, eco-toilets, I/A septic systems, PRBs, nitrogen control fertilizer bylaw, stormwater management, and inlet widening.

Chapter 4: Little Pond TWMP update.

Chapter 5: West Falmouth Harbor TWMP update.

Chapter 6: Great Pond watershed planning scenario.

Chapter 7: Green Pond watershed planning scenario.

Chapter 8: Bournes Pond watershed planning scenario.

Chapter 9: Eel Pond/Waquoit Bay watershed planning scenario.

Chapter 10: A summary of public outreach efforts.

Chapter 11: A summary of the NPC and next steps.

2. Water Quality Monitoring and Data Summary

2.1 Little, Great, Green, and Bournes Pond Water Quality Monitoring Data

2.1.1 Introduction

Water quality monitoring of Little Pond, Great Pond, Green Pond, and Bournes Pond was conducted by the Falmouth Pond Watch Monitoring Program through collaboration with the Town of Falmouth in conjunction with the University of Massachusetts – Dartmouth School for Marine Science and Technology (SMAST). Monitoring in these four estuaries by Pond Watch has occurred annually since 1997, with additional monitoring data prior to the establishment of the Pond Watch Monitoring Program dating back to 1989. All four ponds are post-glacial stream valleys that have been flooded by rising sea levels. Their average depth is about six feet, slightly deeper at the mouth and very shallow at the head.

In the Massachusetts Estuary Project (MEP) Report for each water body, a target threshold nitrogen concentration (with units of milligrams per liter) was established for a "sentinel location" in the water body, representing restored/desired habitat quality for the water body (Table 2.1). The MEP report then identifies a Total Maximum Daily Load (TMDL) of nitrogen (with units of kilograms per day) from the watershed expected to achieve the target nitrogen concentration at the sentinel location.

Table 2.1 Sentinel Station ID and Target Threshold Nitrogen Concentration Values Established in the MEP Reports

Estuary	Sentinel Station ID	Target Threshold Nitrogen Concentration (mg/L)
Little Pond	LP2	0.449
Great Pond	GT5	0.404
Green Pond	G4	0.421
Bournes Pond	B3	0.454

Analyses of data trends for Little Pond, Great Pond, Green Pond, and Bournes Pond are made based on the pre-MEP baseline water quality data compared to the water quality data collected through Pond Watch for each estuary. **Data presented in this chapter are for the sentinel station of each estuary.** Water quality monitoring data for all sampling sites included in the Pond Watch Monitoring Program are found in the report entitled *Pond Watch Nutrient Related Water Quality Bournes Pond, Great Pond, Green Pond, Little Pond, Oyster Pond, West Falmouth Harbor: SMAST POST-MEP Sampling Assessment (2004 -2007)* by Howes et al. 2019 (Appendix 2.1). The following are the main components of the Falmouth Pond Watch Monitoring Program:

- Primary water quality parameters measured for historical monitoring include total nitrogen, salinity, and chlorophyll *a* concentrations.
  - Additional measurements obtained include: total depth, temperature, Secchi depth, nitrate + nitrite, ammonium, dissolved organic nitrogen, particulate organic nitrogen, phosphate, and dissolved oxygen.

- Monitoring of four or more stations in each estuary.
- Monitoring of each station four times annually during July and August with annual average measurements of all data presented.
  - For each sampling date and parameter at surface and at depth, two sets of samples measured and averaged.

2.1.2 Little Pond Monitoring Data

There are four monitoring stations in the Pond Watch Monitoring Program for the Little Pond estuary. Station 'LP2' is the sentinel station and is located in the mid-reach of the pond (Figure 2.1).

Figure 2.1 Monitoring Stations for Little Pond (Howes et al. 2019)

The MEP study for Little Pond (January 2006) determined the nitrogen threshold of the Little Pond Sentinel Station to be 0.449 mg TN/L. Comparison of the monitoring data in Howes et al. 2019 is divided into three analysis periods: pre-MEP monitoring, post-MEP monitoring, and recent monitoring. The average total nitrogen concentration (± standard deviation) by Pond Watch monitoring period and an additional point generated to encompass all available post-MEP data are presented in Table 2.2. Annual average total nitrogen (± standard deviation) for the sentinel station is presented in Figure 2.2. The average annual total nitrogen (± standard deviation) by station for each of the Pond Watch analysis periods is presented in Figure 2.3.

Table 2.2 Summary of Historical Total Nitrogen Concentration at the Little Pond Sentinel Station (LP2)

	Target Threshold Nitrogen Concentration	Pre-MEP Baseline (prior to 2005)	Post-MEP Monitoring (2005 – 2014)	Recent Monitoring (2015- 2017)	Post-MEP Continuous Average (2005 – 2017)
Total Nitrogen (mg TN/L)	0.449	0.898	1.048 (± 0.465)	0.974 (± 0.392)	1.030 (± 0.447)

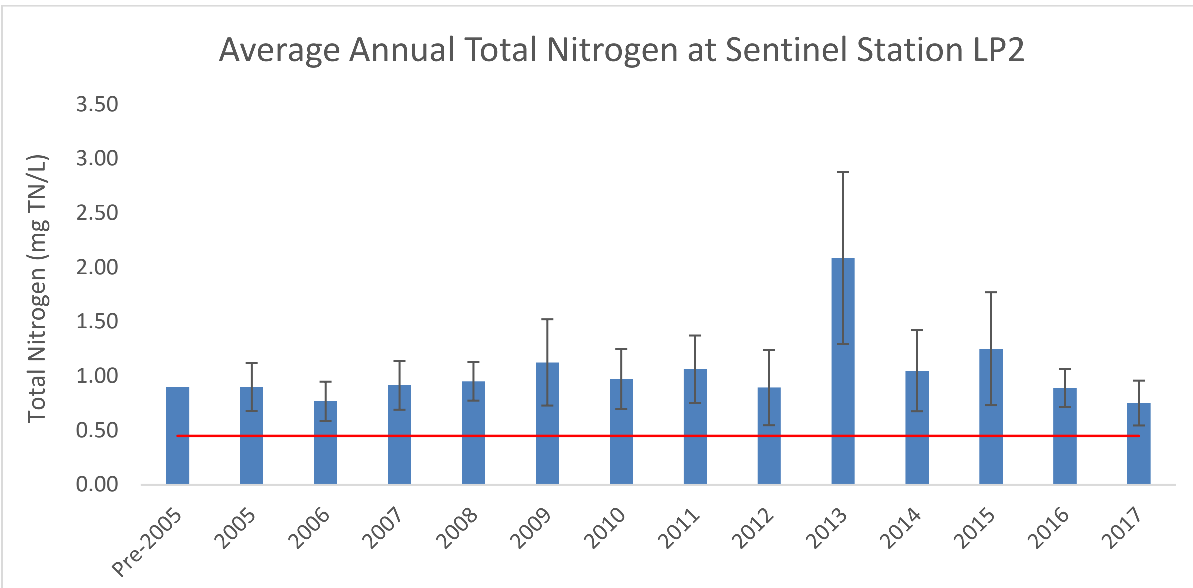


Figure 2.2 Average Annual Total Nitrogen Concentration for Little Pond Sentinel Station (LP2) (The target threshold concentration is represented by the red line.)

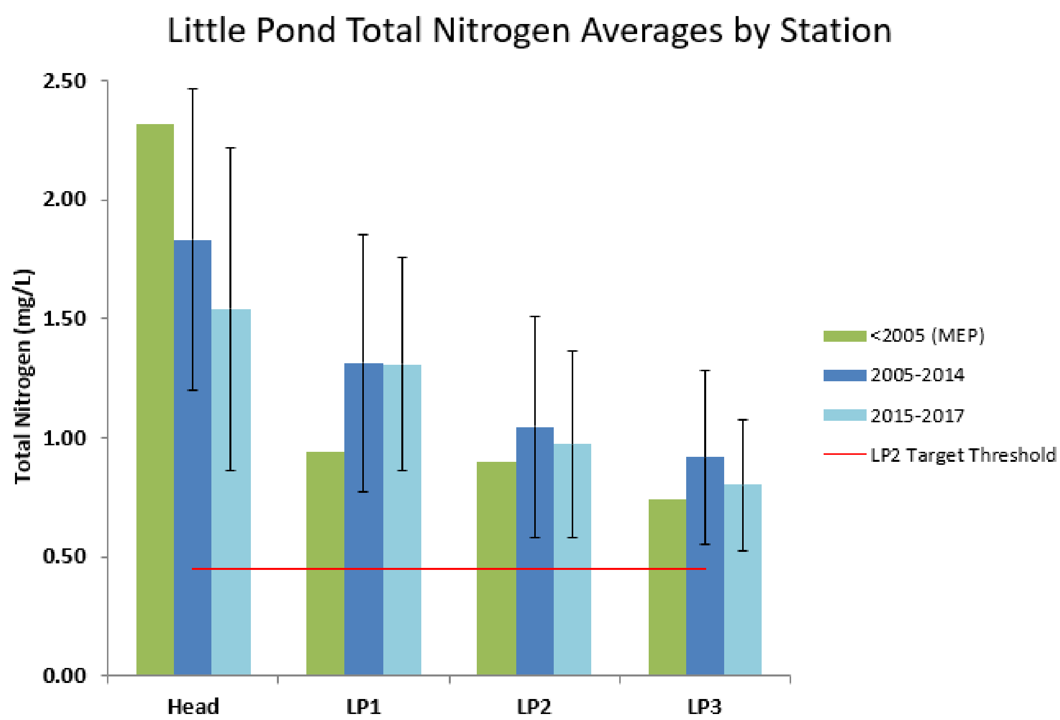


Figure 2.3 Average Annual Total Nitrogen Concentration by Monitoring Period for all Monitoring Stations in Little Pond

According to the Pond Watch data, there was slight interannual variability in the salinity measurements for the Little Pond Sentinel Station from 2005 to 2017. The average annual salinity at the sentinel station ranged from 24.5 to 29.5 PSU (Practical Salinity Unit) from 2005 to 2017 with an overall average of 27.0 PSU.

Chlorophyll *a* pigment concentration measurements are a highly variable metric. In the Little Pond estuary in 2013, an annual average of 24.1 µg/L was measured by Pond Watch, while in 2014 an annual average of 2.3 µg/L of chlorophyll *a* was measured. The range of annual average chlorophyll *a* measurements from 2005 to 2017 was from 2.3 to 24.1 µg/L. The overall average was 16.5 µg/L.

Beginning in 2016, as a baseline study, the US Geological Survey (USGS) and US Environmental Protection Agency conducted additional monitoring to examine the effects of sewer installation on groundwater quality in the Maravista Peninsula portion of the Little Pond watershed. In 2016, approximately one year prior to the start of sewer connections in the Little Pond Sewer Service Area, the USGS installed numerous wells to monitor the groundwater. The parameters monitored included nutrients, major ions, boron, and chloride. Information and data from the USGS monitoring efforts can be found at:

https://www.usgs.gov/centers/new-england-water/science/assessment-hydrologic-and-water-quality-changes-shallow?qt-science_center_objects=0%23qt-science_center_objects

Nutrient sampling by the USGS from 2016 through 2018 showed variable nitrate (NO_3) concentrations over time. No significant decrease in nutrient concentration in the groundwater has been seen to date, probably because many homes have yet to be connected to the sewer system.

The deadline for residences to connect to the sewer is April 2019. The USGS plans to continue groundwater monitoring efforts through at least 2020.

The water quality data from both the Pond Watch and USGS monitoring efforts indicate that there has been no significant reduction in the annual average total nitrogen in Little Pond at the sentinel station (LP2) to date. Little Pond remains above the threshold established by the MEP report to restore critical marine habitat and thus remains nitrogen impaired. However, it is anticipated that improvements from the Little Pond Sewer (see Chapter 4) will be seen in the water quality monitoring data within the next few years.

Key Findings from the Pond Watch Monitoring Program for Little Pond:

- As of 2017, Little Pond shows no sign of nitrogen reduction and remains impaired.
- There is no significant trend in total nitrogen concentration from 2005 to 2017.

2.1.3 Great Pond Monitoring Data

In addition to the sentinel station (GT5), five additional stations in the upper and lower reaches of the Great Pond estuary have been monitored annually by the Falmouth Pond Watch Monitoring Program (Figure 2.4). The sentinel station is located in the mid-reach of Great Pond.

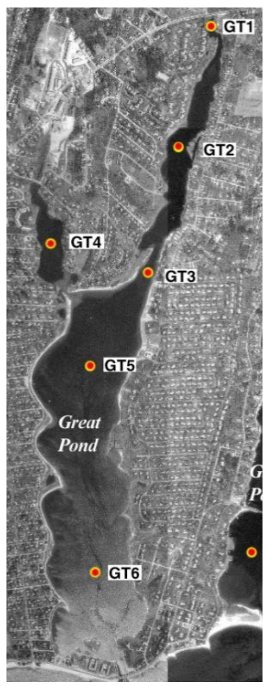


Figure 2.4 Monitoring Stations for Great Pond (Howes et al. 2019)

The MEP study for Great Pond (April 2005) established a target nitrogen threshold for the sentinel station of 0.404 mg TN/L (Table 2.3). The average total nitrogen concentration (± standard deviation) by Pond Watch monitoring period and an additional point generated to encompass all available post-MEP data are also presented in Table 2.3. The average annual total nitrogen measurements (± standard deviation) for the sentinel station are presented in Figure 2.5. The average annual total nitrogen concentration (± standard deviation) by station for each Pond Watch monitoring period is presented in Figure 2.6.

Table 2.3 Summary of Historical Total Nitrogen Concentration at the Great Pond Sentinel Station (GT5)

	Target Threshold Nitrogen Concentration	Pre-MEP Baseline (prior to 2004)	Post-MEP Monitoring (2004 – 2014)	Recent Monitoring (2015- 2017)	Post-MEP Continuous Average (2004 – 2017)
Total Nitrogen (mg TN/L)	0.404	0.644	0.788 (± 0.186)	0.748 (± 0.161)	0.779 (± 0.181)

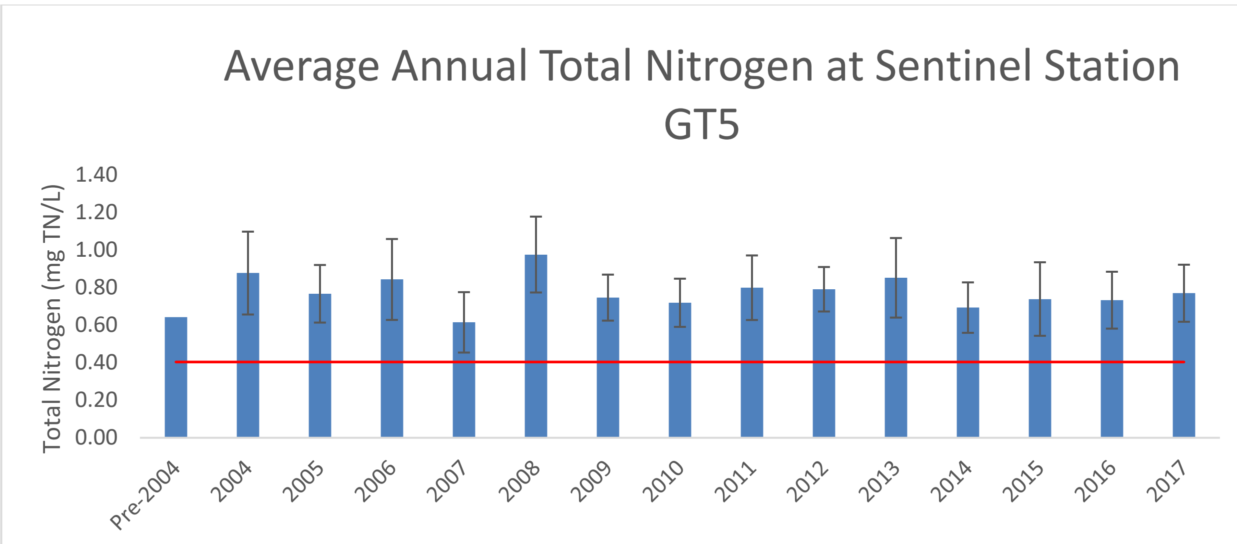


Figure 2.5 Average Annual Total Nitrogen Concentration for Great Pond Sentinel Station (GT5)

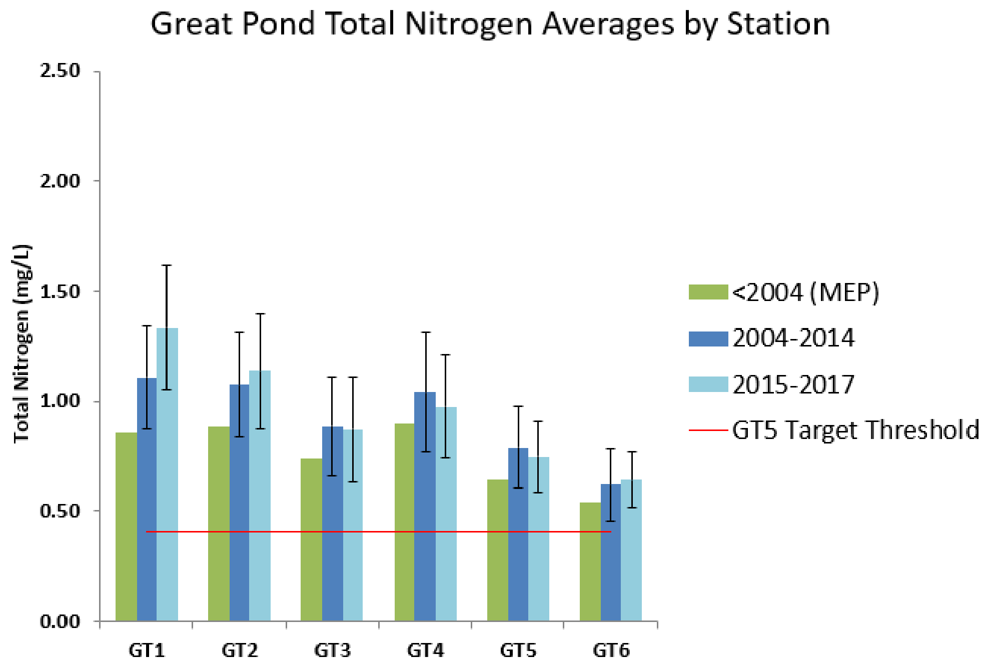


Figure 2.6 Average Annual Total Nitrogen Concentration by Monitoring Period for all Monitoring Stations in Great Pond

There was interannual variability observed in salinity measurements for the sentinel station for Great Pond from 2004 to 2017. Average annual salinity at the sentinel station ranged from 19.4 to 28.8 ppt (parts per thousand) from 2004 to 2017 with an overall average of 26.1 ppt.

Average chlorophyll *a* pigment measurements varied on an annual basis. In 2007, an average of 12.5 µg/L was measured, while in 2008 an average of 34.3 µg/L of chlorophyll *a* was measured. The range of average chlorophyll *a* concentrations from 2004 to 2017 was from 7.0 to 34.3 µg/L. The overall average chlorophyll *a* concentration for 2004 to 2017 was 17.3 µg/L.

The water quality data indicates that there has been no significant change in the average annual total nitrogen in Great Pond as indicated by the sentinel station (GT5). Great Pond remains above the threshold indicated by the MEP report to restore critical marine habitat and thus remains nitrogen impaired.

Key Findings from the Pond Watch Monitoring Program for Great Pond:

- As of 2017, Great Pond shows no sign of nitrogen change and remains impaired.
- There is no significant trend in total nitrogen concentration from 2004 to 2017.

2.1.4 Green Pond Monitoring Data

There are six monitoring stations in the Pond Watch Monitoring Program for the Green Pond estuary. Station G4 is the sentinel station and is located toward the lower reach of the pond (Figure 2.7).

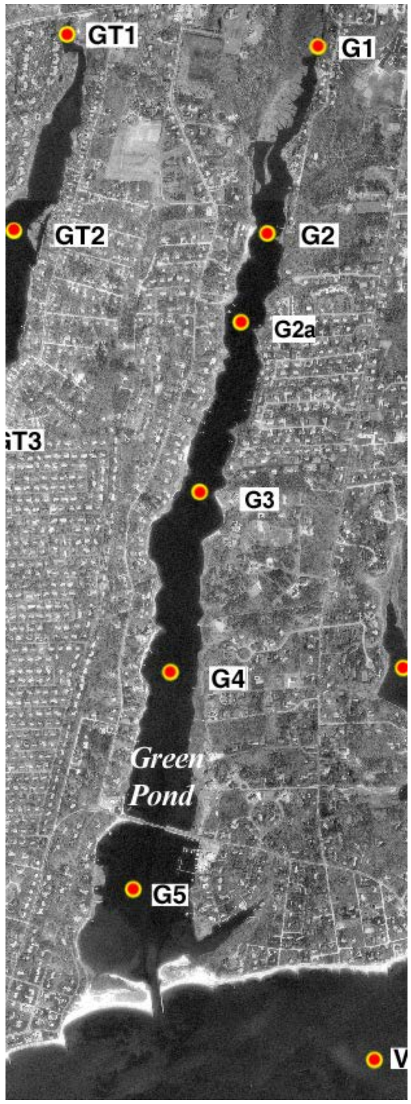


Figure 2.7 Monitoring Stations for Green Pond (Howes et al. 2019)

The MEP study for Green Pond (April 2005) determined the average annual nitrogen threshold at the sentinel station to be 0.421 mg TN/L (Table 2.4). The average total nitrogen concentration (± standard deviation) by Pond Watch monitoring period and an additional point including all available post-MEP data are presented in Table 2.4. The average annual total nitrogen measurements (± standard deviation) for the sentinel station from 2004 to 2017 are presented in Figure 2.8. The average annual total nitrogen (± standard deviation) by monitoring period for each monitoring station is presented in Figure 2.9.

Table 2.4 Summary of Historical Total Nitrogen Concentration at the Green Pond Sentinel Station (G4)

	Target Threshold Nitrogen Concentration	Pre-MEP Baseline (prior to 2004)	Post-MEP Monitoring (2004 – 2014)	Recent Monitoring (2015- 2017)	Post-MEP Continuous Average (2004 – 2017)
Total Nitrogen (mg TN/L)	0.421	0.540	0.638 (± 0.142)	0.618 (± 0.132)	0.634 (± 0.139)

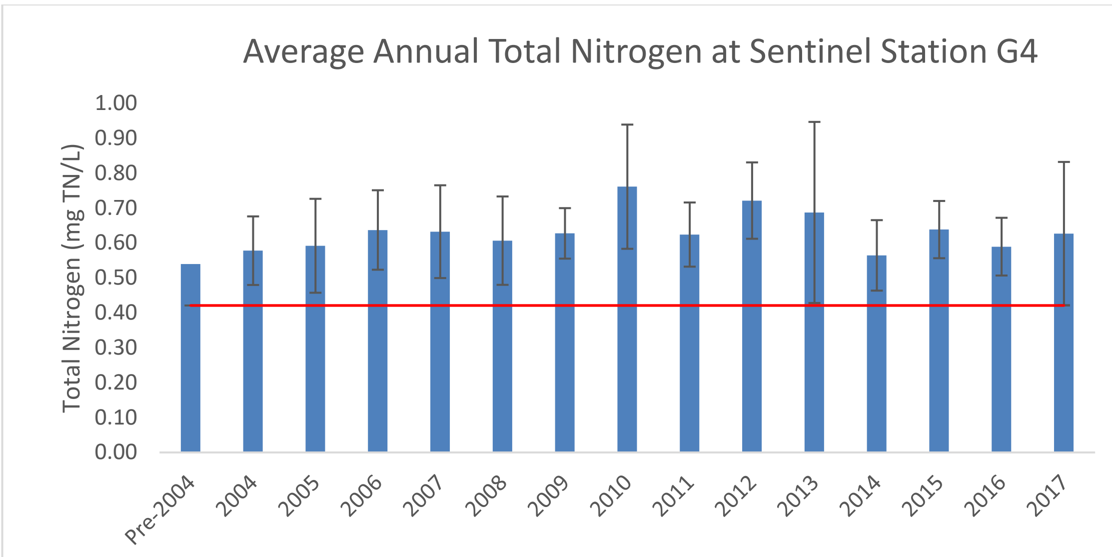


Figure 2.8 Average Annual Total Nitrogen Concentration for Green Pond Sentinel Station (G4)

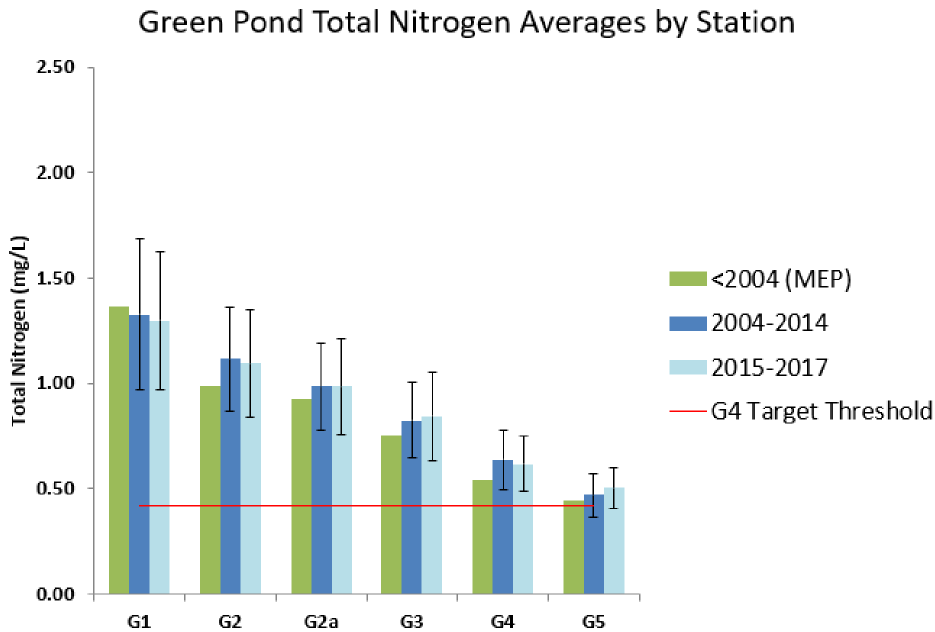


Figure 2.9 Average Annual Total Nitrogen Concentration by Monitoring Period for all Monitoring Stations in Green Pond

There was low inter-annual variability in salinity measurements for the sentinel station for Green Pond from 2004 to 2017. Average annual salinity at the sentinel station ranged from 24.0 to 28.5 ppt from 2004 to 2017 with an overall average of 27.4 ppt.

Average chlorophyll *a* pigment measurements indicated inter-annual variability. The range of annual average chlorophyll *a* measurements from 2004 to 2017 was from 4.2 to 19.4 µg/L. The overall average annual chlorophyll *a* concentrations for 2004 to 2017 was 13.3 µg/L.

The water quality data indicate that there has been no significant change in the total nitrogen in Green Pond as indicated by the sentinel station (G4). Green Pond remains above the threshold indicated to restore critical marine habitat and thus remains significantly nitrogen impaired.

Key Findings from the Pond Watch Monitoring Program for Green Pond:

- As of 2017, Green Pond shows no sign of nitrogen change and remains impaired.
- There is no significant trend in total nitrogen concentration from 2004 to 2017.

2.1.5 Bournes Pond Monitoring Data

There are six monitoring stations for Bournes Pond, two in the lower reach of the pond, one in the western lesser branch of the pond, and three stations in the upper reaches of the main branch of the pond. The sentinel station, B3, is located in the mid-reach of the main branch of the pond (Figure 2.10).

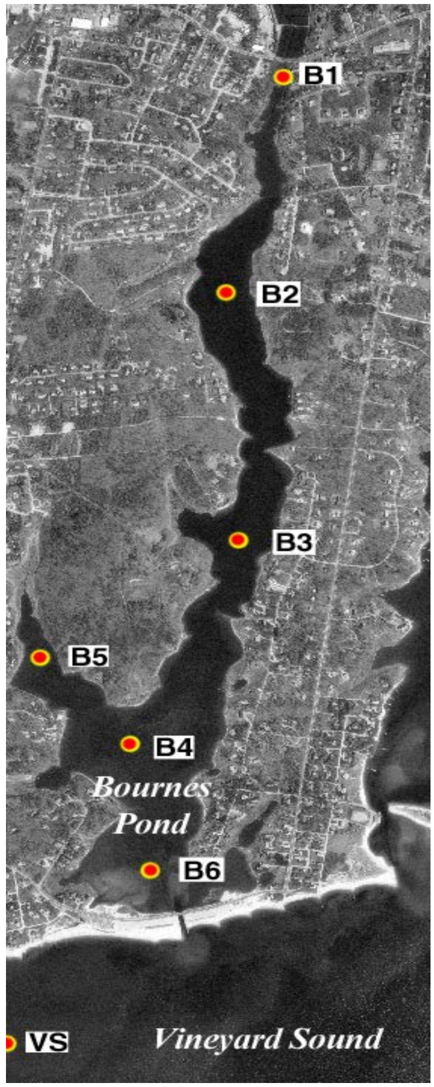


Figure 2.10 Monitoring Stations for Bournes Pond (Howes et al. 2019)

The nitrogen threshold established by the MEP study for Bournes Pond (April 2005) at the sentinel station was determined to be 0.454 mg TN/L (Table 2.5). The average total nitrogen concentration (± standard deviation) by Pond Watch monitoring period and the average of all available post-MEP data are presented in Table 2.5. The Pond Watch average annual total nitrogen measurements (± standard deviation) for the sentinel station at all sampling depths from 2004 to 2017 are presented in Figure 2.11. The average annual total nitrogen (± standard deviation) by period for each monitoring station is presented in Figure 2.12.

Table 2.5 Summary of Historical Total Nitrogen Concentration at the Bournes Pond Sentinel Station (B3)

	Target Threshold Nitrogen Concentration	Pre-MEP Baseline (prior to 2004)	Post-MEP Monitoring (2004 – 2014)	Recent Monitoring (2015- 2017)	Post-MEP Continuous Average (2004 – 2017)
Total Nitrogen (mg TN/L)	0.404	0.644	0.788 (± 0.186)	0.748 (± 0.161)	0.779 (± 0.181)

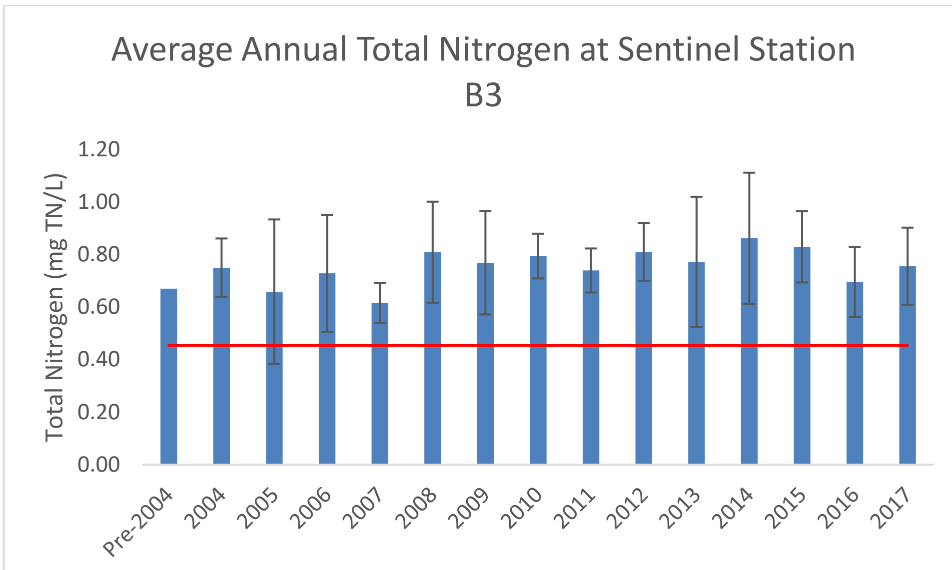


Figure 2.11 Average Annual Total Nitrogen Concentration for Bournes Pond Sentinel Station (B3)

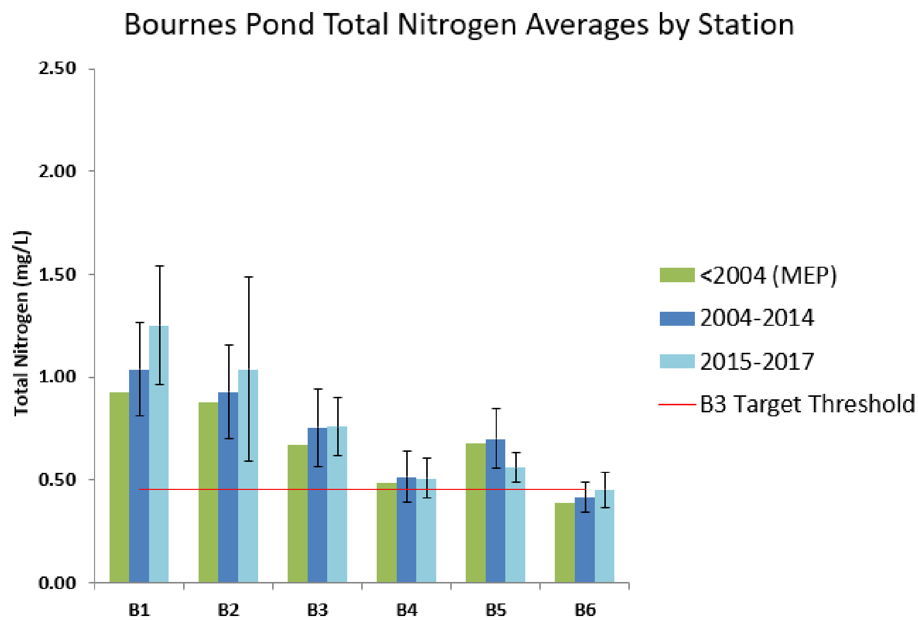


Figure 2.12 Average Annual Total Nitrogen Concentration by Monitoring Period for all Monitoring Stations in Bournes Pond

According to the Pond Watch data, there was low interannual variability in the salinity measurements for the sentinel station for Bournes Pond from 2004 to 2017. The average annual salinity at the sentinel station ranged from 26.5 to 29.0 PSU from 2004 to 2017 with an overall average of 27.9 PSU.

Chlorophyll *a* pigment concentration measurements indicated high interannual variability. The range of average chlorophyll *a* concentrations from 2004 to 2017 was from 3.3 to 23.3 µg/L. The overall average for 2004 to 2017 was 10.9 µg/L.

The water quality data indicate that there has been no significant change in the total nitrogen in Bournes Pond as indicated by the sentinel station (B3). Bournes Pond remains above the threshold indicated in the MEP to restore critical marine habitat and thus remains nitrogen impaired.

Key Findings from the Pond Watch Monitoring Program for Bournes Pond:

- As of 2017, Bournes Pond shows no sign of nitrogen change and remains impaired.
- There is no significant trend in total nitrogen concentration from 2004 to 2017.

<u>All four ponds show no sign of nitrogen change and remain impaired, and there is no significant trend in TN in any of the ponds over their study periods.</u>

2.2 Waquoit Bay/Eel River Water Quality Monitoring Data

2.2.1 Introduction

The watershed of the Waquoit Bay estuary is shared among the towns of Falmouth, Mashpee, and Sandwich. Water quality monitoring efforts for the entirety of the Waquoit Bay estuarine system were conducted by the SMAST under contract with the Mashpee Water Quality Monitoring Consortium.

The primary focus of water quality monitoring efforts in Falmouth's estuaries is to monitor the concentration of nitrogen at the sentinel location compared to the target threshold nitrogen concentration established in the estuary-specific MEP report (Table 2.6). The MEP report for Waquoit Bay (2013) established a target threshold nitrogen concentration for Waquoit Bay as a whole system as well as individual thresholds for the Childs River and Eel Pond sub-embayments. The monitored areas of the Waquoit Bay system that are in Falmouth include the main basin (including the Seapit River), Eel Pond, Childs River, Quashnet River, and a portion of Hamblin Pond. The water quality monitoring results for these relevant areas are summarized in this section.

Analyses of data trends for Waquoit Bay including the main basin, Eel Pond, Childs River, Quashnet River and Hamblin Pond are made based on the long-term baseline water quality data (2001 – 2009) and data from the periods of 2010 – 2012, 2013 – 2015, 2016 and 2017 as presented in the SMAST report entitled *Water Quality Monitoring Program for the Popponesset Bay and Waquoit Bay Estuaries* by Howes et al. 2018 (Appendix 2.1). A summary of the water quality monitoring data is found in this report.

The key features of the Waquoit Bay water quality monitoring program consisted of:

- Primary water quality measurements of parameters including dissolved nutrients, particulate nutrients, chlorophyll/pheophytin and additional field parameters
- Monitoring of the sentinel station(s) and additional established stations throughout the estuary
- Monitoring of each station four times annually during July and August

Table 2.6 Sentinel Station ID and Target Threshold Nitrogen Concentration Values Established in the MEP Reports

Sub-embayment	Sentinel Station ID	Target Threshold Nitrogen Concentration (mg/L)
Waquoit Bay – Whole System	WB12	0.38
Eel Pond – Western Branch	ER01	0.50
Childs River – Upper	CR02	0.38

2.2.2 Waquoit Bay

There are 19 sampling stations distributed throughout the Waquoit Bay system (Figure 2.13). With the exception of stations WB01 through WB05, all stations are in the Town of Falmouth. The sentinel station for the main basin of Waquoit Bay is WB12 in the upper portion of the main basin. Eel Pond is the western sub-embayment of Waquoit Bay and is further divided into the Eel River and Childs River sub-embayments. Eel River is the western-most branch of Eel Pond, and its sentinel station is ER01 in the upper portion of its main branch. The sentinel station for the Childs River sub-embayment area of Waquoit Bay is CR02, in its upper reach.

Figure 2.13 Waquoit Bay Water Quality Monitoring Stations
(image from Howes et al. 2018)

Total Nitrogen Monitoring Results

The MEP report for Waquoit Bay (March 2013) determined the nitrogen thresholds for both the Waquoit Bay sentinel station WB12 and the Childs River sentinel station CR02 to be 0.38 mg TN/L, and for the western branch of the Eel Pond sub-embayment (ER01) to be 0.50 mg TN/L. Neither the Seapit River, the Quashnet River, nor Hamblin Pond were assigned specific nitrogen thresholds in the MEP report. The Seapit River is a channel connecting Eel Pond to Waquoit Bay. The Quashnet River discharges directly into the main basin of Waquoit Bay, and Hamblin Pond discharges into the main basin of the bay by way of the Little River. Monitoring results for total nitrogen for the Waquoit Bay system including each of Falmouth's sub-embayments are presented in Figure 2.14.

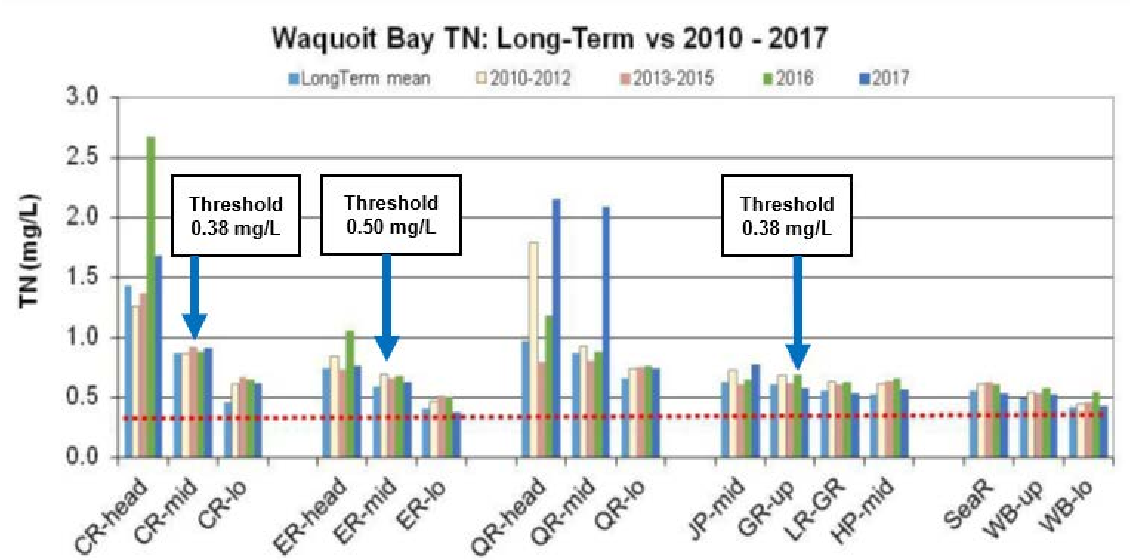


Figure 2.14 Average Total Nitrogen Concentration in the Waquoit Bay Estuary for Long-Term Data (2001 – 2009) and During 2010 – 2017

In the above figure, the target threshold nitrogen concentration for the Waquoit Bay sentinel station is indicated by the red line (0.38 mg TN/L). WB = Waquoit Bay main basin; SeaR = Seapit River; ER = Eel River; CR = Childs River; QR = Quashnet River; HP = Hamblin Pond; JP = Jehu Pond; GR = Great River; LR-GR = Little River Great River confluence; LR = Little River. Head = uppermost reach; mid = middle reach; lo = lower basin (Howes et al. 2018).

The main basin of Waquoit Bay including the Seapit River shows a potential slight increase in average total nitrogen concentrations compared to the previous long-term monitoring period (2001 – 2009). Overall there are minor fluctuations in the average total nitrogen concentrations between the long-term and recent monitoring periods. The lower basin of the bay shows some nitrogen impairment with declining water quality conditions moving towards the upper reaches of the bay into the Seapit River. No standard deviation values were provided in the Howes (2018) report.

The lower and mid-reaches for both Eel River and Childs River show a similar total nitrogen concentration trend as in the main basin. There has generally been a small increase in the average total nitrogen concentrations in these regions since the long-term monitoring data period. Both sub-embayments show the highest TN values in their upper reaches (Figure 2.14). The highest average total nitrogen values occurred in the upper reaches of both sub-embayments in 2016. These high average total nitrogen values in 2016 are associated with large rust tide blooms (Howes et al. 2018), and this is supported by a similar trend in the results of the chlorophyll *a* monitoring. The MEP report established a separate, higher threshold concentration for Eel River of 0.50 mg TN/L. Monitoring data at the Eel River sentinel station indicate that this sub-embayment still exceeds its target threshold for nitrogen and is considered impaired. The nitrogen concentration at the Childs River sentinel station exceeds its target threshold as well and Childs River water quality remains impaired.

The lower reaches of the Quashnet River follow a similar trend to the main basin of Waquoit Bay of a potential slight increase in the average total nitrogen concentration compared to the previous long-term monitoring period. There is fluctuation in the average total nitrogen in the mid and upper reaches between all monitoring periods. The 2017 monitoring of the Quashnet River shows a large increase in the average total nitrogen measured in the mid-reach and head of the river. Howes et al. (2018) states that this increase caused a large phytoplankton bloom, and this was supported by the corresponding increased chlorophyll *a* measurements (Figure 2.16). The average total nitrogen concentration at the sentinel location in the Quashnet River remains above the threshold concentration of 0.38 mg TN/L, and this region remains impaired.

The single monitoring station in Hamblin Pond shows an increase in the average total nitrogen concentration compared to the previous long-term monitoring period. The results from the recent monitoring periods indicate that the average total nitrogen concentrations in Hamblin Pond have remained relatively stable.

Salinity Monitoring Results

Water quality monitoring results for the average salinity for the Waquoit Bay system including each of Falmouth's sub-embayments are presented in Figure 2.15. Average salinity measurements for the main basin show the most fluctuations in the upper basin. Overall there appears to be low variability in the salinity of the lower Waquoit Bay basin between the monitoring periods, and minor variability in the Seapit River. The average salinity measurements in Eel River show very little variation between monitoring periods. The Childs River shows high variation in salinity at the head of the river, moderate fluctuations in the lower reach, and general consistency in the mid-reach. The variability in average salinity measurements seen at the head of Childs River is thought to be primarily driven by annual precipitation (Howes et al. 2018). The Quashnet River shows some fluctuation in salinity throughout the system. In general, the respective annual trend is reflected throughout all reaches of the river for a given monitoring period. Hamblin Pond shows some minor salinity fluctuations between the monitoring periods.

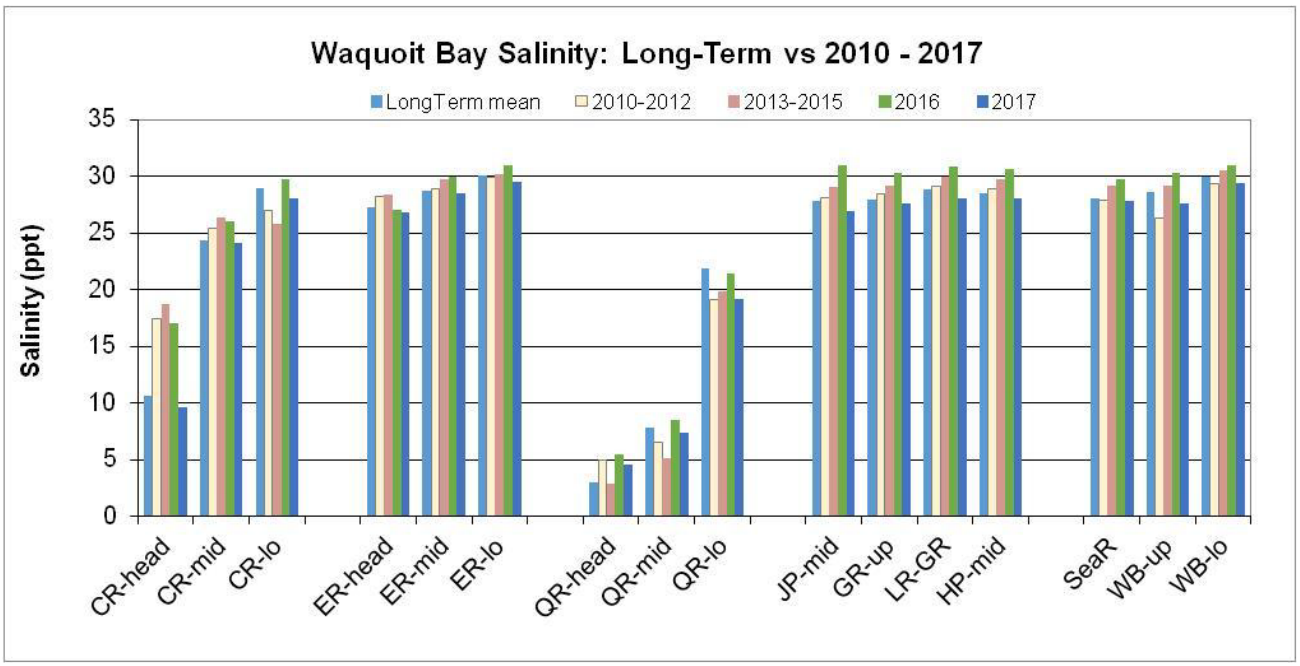


Figure 2.15 Average Salinity Measurements in the Waquoit Bay Estuary for Long-Term Data (2001 – 2009) and During 2010 – 2017

In the Figure 2.15, WB = Waquoit Bay main basin; SeaR = Seapit River; ER = Eel River; CR = Childs River; QR = Quashnet River; HP = Hamblin Pond; JP = Jehu Pond; GR = Great River; LR-GR = Little River Great River confluence; LR = Little River. Head = uppermost reach; mid = middle reach; lo = lower basin (Howes et al. 2018).

Pigment Monitoring Results

Water quality monitoring results for average chlorophyll *a* concentrations for the Waquoit Bay system including each of Falmouth's sub-embayments are presented in Figure 2.16. Chlorophyll *a* values < 3 µg/L suggest low phytoplankton biomass indicating waters that have low nitrogen enrichment. Chlorophyll *a* levels in excess of 10 µg/L indicate there is some impairment in the system (Howes et al. 2018).

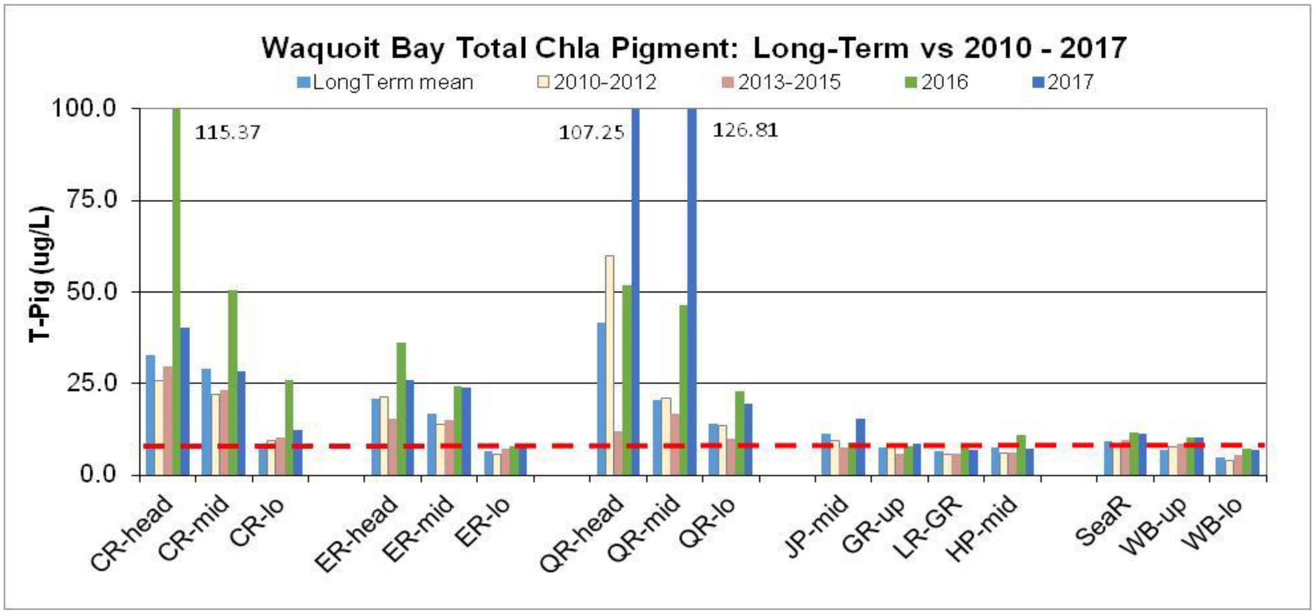


Figure 2.16 Average Total Chlorophyll *a* Concentrations in the Waquoit Bay Estuary for Long-Term Data (2001 – 2009) and During 2010 – 2017

In the above figure, the red line indicates a value of 3 µg/L. WB = Waquoit Bay main basin; SeaR = Seapit River; ER = Eel River; CR = Childs River; QR = Quashnet River; HP = Hamblin Pond; JP = Jehu Pond; GR = Great River; LR-GR = Little River Great River confluence; LR = Little River. Head = uppermost reach; mid = middle reach; lo = lower basin (Howes et al. 2018).

The main basin of Waquoit Bay including the Seapit River, the lower reach of Eel River, and Hamblin Pond generally have measures of chlorophyll *a* concentrations ≤ 3µg/L indicating low nitrogen enrichment in these regions. The mid and upper reaches of Eel River, Childs River, and the Quashnet River all show high variability in chlorophyll *a* concentrations between the monitoring periods. Large phytoplankton blooms were reported in the Childs River in 2017 and in the Quashnet River in 2016. The chlorophyll *a* monitoring indicates that Eel River, Childs River, and the Quashnet River all show some impairment.

Key Findings from the Waquoit Bay water quality monitoring efforts:

- As of 2017, Waquoit Bay and all of its sub-embayments in Falmouth remain impaired.
  - There is no significant change in the recent total nitrogen concentrations compared to the previous long-term data period.
- The main basin and Eel River show little variation in salinity among the reaches. Childs River and the Quashnet River show a strong salinity gradient with significantly lower salinity waters observed in the upper reaches of both sub-embayments.
- With the exception of the main basin and Hamblin Pond, chlorophyll *a* concentration levels generally follow the average total nitrogen concentrations and indicate that the sub-embayments remain impaired.

<u>The main basin of Waquoit Bay and all sub-embayments show no sign of nitrogen change and remain impaired, and there is no significant trend in TN in any of the sub-embayments over their study periods.</u>

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3. Summary of Pilot Projects

3.1 Introduction – Requirements of Secretary's Certificate, January 10, 2014

The Secretary's Certificate of January 2014 recognized the commitments Falmouth has made to improving water quality in its coastal pond watersheds. The Town intends to "evaluate, design, and construct both traditional and innovative technologies to reduce nitrogen loading to the watersheds."

Chapter 3 is an update on efforts made over the last five years to investigate and document alternative ways of removing nitrogen discharged to the groundwater. The Secretary's Certificate required the Town to report back by December 2019 on the effectiveness of various pilot projects.

The funding for these investigations came from Article 17, a bond issue for $2.77 million passed by Town Meeting and the voters in 2011. The intent of this article was to gather information that was missing for a comprehensive analysis of options and alternatives to conventional sewers. The article was purposely broad in scope as to on-site demonstrations and pilot projects. The sections listed below summarize the information that has been gathered on various projects and nitrogen-reduction strategies during the last five years:

- 3.2 Shellfish Aquaculture
- 3.3 Eco-toilets (composting, packaged, and urine diverting toilets)
- 3.4 Innovative and Alternative (I/A) Septic Systems
- 3.5 Permeable Reactive Barriers (PRBs)
- 3.6 Nitrogen Control Bylaw for Fertilizer
- 3.7 Stormwater Management
- 3.8 Inlet Widening – Bournes Pond

The technical reports and supporting documents are located in the associated Appendices (3.2 through 3.8).

3.2 Shellfish Aquaculture

3.2.1 Introduction

Using shellfish to reduce nitrogen concentrations is a non-traditional approach for improving estuarine water quality. Oysters (*Crassostrea virginica*) are often used because they grow rapidly, typically growing from seed to a harvestable (and marketable) size in less than two years. In the past six years the Town of Falmouth has utilized the Water Quality Management Committee (WQMC), the Town of Falmouth Department of Marine and Environmental Services (MES), and other resources to develop and engage in two significant oyster culture pilot projects: a three-year demonstration in Little Pond that began in 2013, and the development of an oyster reef in West Falmouth Harbor that began in 2014. In addition, projects in Little Pond, Waquoit Bay, and Bournes

Pond have examined the effects of various culture techniques on oyster growth rates, nitrogen sequestration by these oysters, and denitrification rates in nearby sediments.

These projects demonstrate that large numbers of oysters can be successfully grown in floating gear in Falmouth's estuaries, while producing measurable improvements in water quality. Additionally, a sustainable, naturally reproducing oyster reef has been established by planting oysters on hard bottom. In both situations, these oysters increase water clarity and convert nitrogen into soft tissue and shell by removing phytoplankton from the water. When combined with elemental analyses of soft tissues and shells, weighing oysters before and after their culture quantifies the actual removal of nitrogen specific to each site and time period. There is also evidence that the accumulation of oyster waste products on nearby sediments can lead to substantially increased rates of denitrification in these sediments, except in areas subject to episodic low oxygen events. At the same time, MES states that an extensive outreach program has been very successful in securing broad public participation in and support for these projects, from both recreational and commercial shellfishing interests.

3.2.2 Little Pond Shellfish Pilot Project – 2012 to Present

The Little Pond Shellfish Pilot project was partially funded by an allocation of $200,000 in Article 17 of the Spring 2011 Town Meeting, covering the cost of viability testing, equipment, and seed purchase for the first two years, staff support of the project for two years, and the cost of the monitoring for the first year. Grants from the Cape Cod Economic Development Council and the Cape Cod Water Protection Collaborative (CCWPC) paid for the third year of implementing the Little Pond Shellfish Pilot Project and the second and third years of monitoring, respectively. Chapter 3 of the Town's 2013 Comprehensive Wastewater Management Plan (CWMP) update provides details of the feasibility and planning studies as well as the permitting for this project. The pilot project area is shown in Figure 3.1

The goals of this project were to:

- Culture enough oysters to yield a detectable change in water quality.
- Verify nitrogen uptake by oysters to establish Total Maximum Daily Load (TMDL)-credit for these shellfish.
- Monitor and measure water quality over the three-year project period.
- Evaluate implementation logistics including winter storage.
- Determine levels of public acceptance.

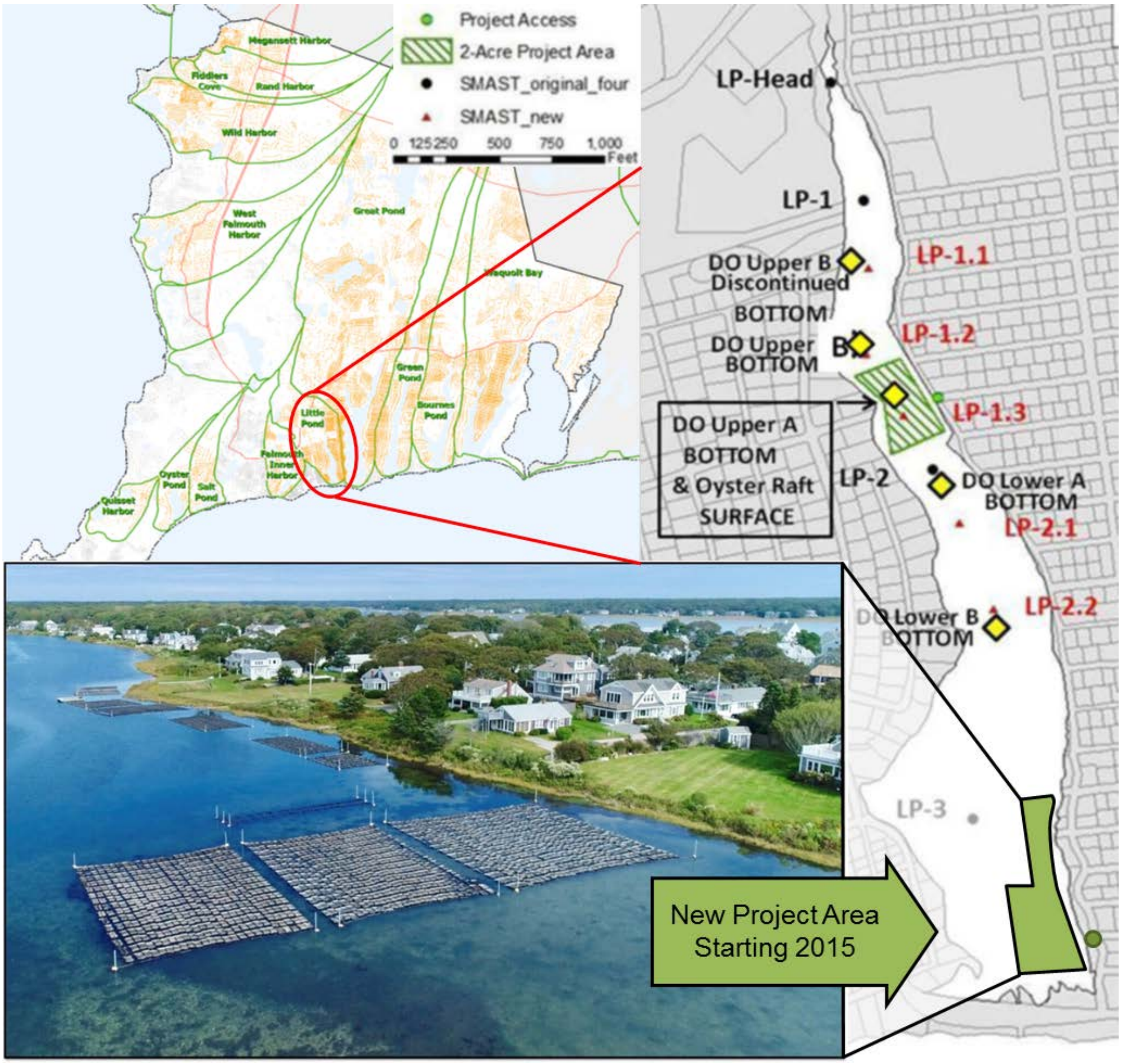


Figure 3.1 Pilot Project Location

In 2013 and 2014, 1.25 and 1.5 million oysters respectively were deployed in the project area between LP-1.2 and LP-1.3 shown in Figure 3.1. In 2015, about two million oysters were deployed in floating bags at the same location. Several weeks into the project, extended anoxic water conditions were suspected in the immediate area due to fish kills and a change in water color and were confirmed by grab sample measurements. Approximately two-thirds of the floating bags were moved to a southerly area that had been included in permitting as a backup location in case of anoxic events. The remaining one-third of the bags stayed in the original location and were able to withstand the conditions, and growth was comparable to the other two-thirds. Both oyster growth and neighborhood acceptance were immediately identified as favorable in the southerly location, so the project has continued to operate here in subsequent years; and there has been no further aquaculture activity at the northerly site.

The municipal propagation efforts undertaken by MES at the Little Pond site are partially funded by an allocation in the Town budget. Additional funds come from a variety of research projects. Starting in 2017 the program began exploring methods for optimizing propagation in impaired estuaries for shellfish other than oysters, such as quahogs and scallops. This is a direct response to concerns raised by individuals connected with regional planning about ensuring biological diversity as well as economic and ecosystem resilience in anticipation of increased aquaculture becoming a substantial contributor to nitrogen remediation strategies for many impaired estuaries on Cape Cod.

3.2.3 Little Pond Shellfish Pilot Project Monitoring

To establish and quantify the causal relationship between shellfish cultivation and improved water quality, the University of Massachusetts Dartmouth School for Marine Science and Technology (SMAST) performed three years of monitoring for this shellfish project and prepared a final report entitled *Shellfish Aquaculture Demonstration Project Little Pond Year 3 Monitoring Summer/Fall 2015 Oyster Deployment*, included as Appendix 3.2.

To meet the needs of MassDEP for TMDL compliance and potential nitrogen credit, both “grab-sampling” and continuous monitoring were done in a manner consistent with MEP Reports and in accord with the MEP Quality Assurance Project Plan (QAPP). Sampling parameters at both water surface and bottom locations (where depth is greater than 5 feet) at the sampling stations included: total nitrogen (TN), nitrate + nitrite, ammonia, dissolved organic nitrogen (DON), dissolved inorganic nitrogen (DIN), particulate organic nitrogen (PON), temperature, chlorophyll *a*, pheophytin *a*, orthophosphate, salinity, dissolved oxygen (DO), and transparency (Secchi depth). The spatial distribution of grab sampling as well as continuous monitoring of DO is shown in Figure 3.1. Continuous monitoring of salinity, chlorophyll *a*, DO, and turbidity occurred at several locations within and surrounding the pilot project site.

Key Findings of SMASTs Three-Year Monitoring Effort:

- 2013 and 2014 data demonstrate a localized reduction in TN via the removal of phytoplankton, but 2015 TN data is inconclusive because oysters had to be relocated during the growing season.
- Turbidity data demonstrate that the oysters increased water clarity.
- Absolute TN levels overall in Little Pond did not change significantly from 2006 MEP findings.
- Hypoxic conditions (low DO) in 2012 to 2015 are consistent with conditions from 2006 MEP findings.
- Deployment of oysters in Little Pond produced small-scale, localized water quality improvements, and the primary mechanism of these water quality improvements appears to be the uptake of phytoplankton.
- Removal of oysters was correlated with decreased water clarity and increased pigments.

3.2.4 Additional Findings from Little Pond Projects

Trials to evaluate the most effective overwintering techniques were conducted from 2016 to 2018. In 2016, 1st-year oysters were removed from culture bags in October and November and simply scattered in hard bottom areas that would be open to harvesting the following fall. This approach resulted in high mortality rates (>50%) due to a wide variety of negative impacts on the animals. In the second trial (2017), about 300 bags were overwintered at 12- to 15-foot depths in Little Harbor, Woods Hole, where there were significant conflicts with other users of the harbor, moderate hazards in using SCUBA to access the bags, and moderate mortality of oysters. In the third trial (2018), about 200 bags were suspended vertically among boat slips in Falmouth Inner Harbor to minimize space requirements and to reduce the bags' exposure to surface ice. Survival rates were high, but this technique required the use of circulators to reduce ice formation and involved considerable physical effort in placing and recovering the bags. The fourth technique, (2018) the late-December placement of 1st-year oysters in insulated cold-storage containers and maintaining these at about 32 degrees, required a moderate initial capital investment in equipment with low long-term costs and resulted in mortality rates less than 1%. Given this high rate of survival, MES anticipates utilizing cold storage to overwinter oysters for municipal propagation in the future and can currently store approximately one million oysters.

Denitrification rates in sediment cores from Little Pond were measured in 2014 and 2015, and these rates were significantly higher (~2X) underneath the oyster bags than at control sites.

MES has continued to grow oysters in Little Pond as part of its municipal propagation program. The comparative growth rates of different oyster seed stock were assessed in 2017, and in 2018 quahogs (*Mercenaria mercenaria*) and bay scallops (*Aequipecten irradians*) were both grown in Little Pond. In both years, oysters were grown in Little Pond and relayed to West Falmouth Harbor, Green Pond, and Great Pond for recreational and commercial harvest. MES expects to continue growing oysters and to expand the culture of quahogs and bay scallops in Little Pond, while also using it as an aquaculture training site.

3.2.5 West Falmouth Harbor Oyster Reef Pilot Project – 2014 to Present

Over a three-year period beginning in 2014, the Town planned and installed an oyster reef where Mashapaquit Creek enters Snug Harbor, in the upper reaches of West Falmouth Harbor (Figure 3.2). The goals of this project were to determine the feasibility of developing an oyster reef in this estuary, assess its potential maximum population size and self-sustainability, and develop a generic plan for using remote oyster set to establish reefs. The Town began this effort in 2014 with a viability study and continued in 2015 at a pilot-scale when 500 bags of oyster remote set were grown for one season and then planted on the sandy bottoms of the opposing shorelines. The same procedure, but with 1,500 bags of remote set, was followed in 2016, resulting in the bottom-planting of an estimated 308,000 oysters on cultch in an area of ~3,000 square feet. This area is closed to shellfish harvest and has developed into a successful spawning sanctuary as evidenced by several years of natural spat strike on hard surfaces in the vicinity. The 2015 and 2016 implementation phases were funded by a grant from the U.S. Environmental Protection Agency (EPA) through the Southeast New England Program (SNEP) Water Quality Management Grants, administered by the Buzzards Bay National Estuary Program. The West Falmouth Harbor Oyster Bed (Reef) Development Project Final Report (April 24, 2017) describes this project and its findings in detail and is included as Appendix 3.2.

Figure 3.2 West Falmouth Oyster Reef Location and 2018 Inspection

Key Findings of the Oyster Reef Project:

- Survival and growth rates of remote set are both high in bags. Of the oysters grown on cultch to a size where shell was visible, mortality was less than 5% over the growing season. Oysters grew from spat to over 30mm from early August to late October in both 2015 and 2016. This growth rate over these warm-weather periods is similar to the growth of oyster singles cultured by MES for municipal propagation.
- The oyster reef has continued to grow and mature and is thriving in spring 2019. The persistence of this reef demonstrates the potential utility of similar self-sustaining structures in reducing shoreline erosion.
- Due to the visibility of the Snug Harbor location, many people have stopped to ask questions when staff is working on site. This has provided excellent opportunities to discuss environmental issues and the role of shellfish in water quality improvements.

As shown in Figure 3.2, a visual inspection of the oyster reef area in January 2018 confirmed that the reef is growing and the oyster population is thriving. A new oyster reef has successfully been established at this location.

3.2.6 Waquoit Bay Project – 2017 to Present

MES, Woods Hole Oceanographic Institution, Stonehill College, the Waquoit Bay National Estuarine Research Reserve, and Science Wares, Inc. received a $500,000 grant from the National Estuarine Research Reserve System Science Collaborative for a project entitled, *Evaluating effectiveness of different oyster aquaculture strategies for nitrogen loading remediation to inform end user decisions to restore water quality.* This project consists of a two-year program, which uses three typical oyster culture techniques—surface, midwater, and bottom cultures—to investigate the relationship between impacts on the community beneath and near the growing gear and the surrounding water quality (Figure 3.3). Overall weight gain of 1st-year oysters was highest in mid-water bags and lowest in trays on the bottom, while the gains in 2nd-year oysters were lowest in mid-water bags and nearly identical to each other in the floating and bottom bags. In addition to the nitrogen removal represented by sequestration in both year-classes of oysters, substantially higher rates of denitrification occurred in the sediments under all three cultural techniques, when compared to rates measured in nearby control sediments, and the highest denitrification rates were measured in sediments underneath the bottom cages.

This project also has educational and end-user components. In the final year of this project (2019), participating organizations will be completing training for end-users. The Waquoit Bay study area has been used as training site for aquaculture students, high school students, children's science camps, and community tours. This work dovetails well with the oyster nitrogen reduction work conducted by Falmouth and nearby communities.

3.2.7 Bournes Pond Project – 2017 to Present

The Town funded a study to assess the denitrification enhancement associated with bottom-planted oysters in Bournes Pond in 2017. MES deployed oysters at the end of 2016 to support this project, but the research group was not able to identify the location of the oysters in time to conduct their study during the 2017 growing season. The Town confirmed the placement of the oysters, but in subsequent discussions with the research group recommended a different strategy of studying the effects on denitrification rates of oyster deployments that could be permitted for operation by commercial growers inside impaired estuaries. The result was a project in 2018 to study the effects on water quality and denitrification rates of second year oysters grown in a high-density floating bag system (Figure 3.3).

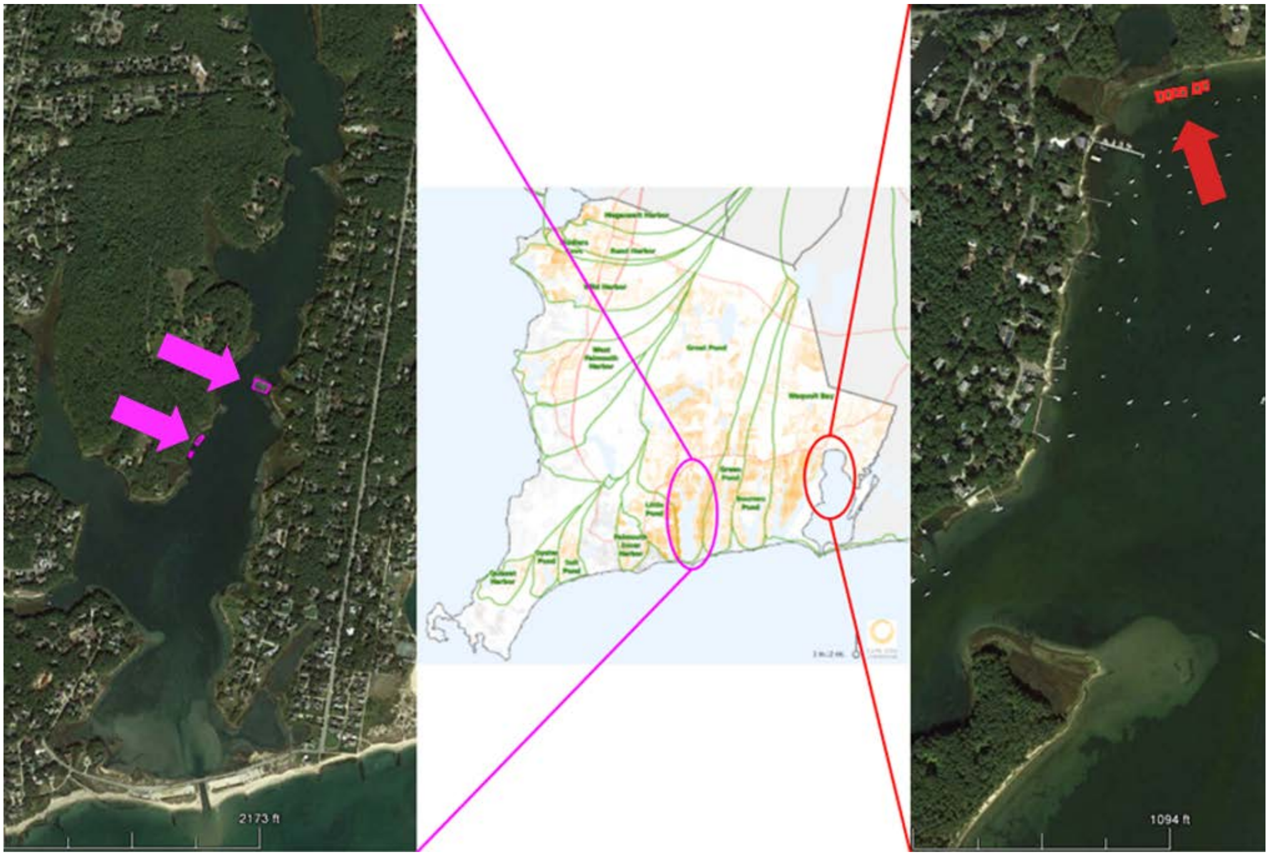


Figure 3.3 Oyster Deployments in Bournes Pond and Waquoit Bay in 2018

To quantify some of the local water quality impacts of suspended oyster culture, SMAST and MES initiated a detailed assessment of nutrient cycling in the sediments of Bournes Pond in 2018 that also utilized water quality datasets dating from 2012. Similar to other studies conducted in Falmouth estuaries, the cultured oysters significantly reduced total nitrogen and chlorophyll *a* concentrations in water passing through their vicinity, while organically enriching the nearby sediments and increasing nitrogen regeneration from these sediments. However, denitrification rates here were so variable that it was difficult to detect the substantial rate increases in the sediments near the cultured oyster bags that have been seen in other studies. It appears that sediment oxygen levels were depleted enough to suppress the coupled nitrification-denitrification process. Also, the combination of episodic low background dissolved oxygen events and the oxygen demand created by the high rate of organic deposition underneath the cages were responsible for this local oxygen depletion.

At the April 2019 Town Meeting, $40,860 was approved to fund the second year of research in Bournes Pond.

3.2.8 Quantitative Analyses of Nitrogen Sequestration by Oysters

MES has adopted quantitative analytical techniques to estimate the nitrogen sequestered by the growth of shellfish in impaired estuaries using the following equation:

$$\text{kg Nitrogen removed per Acre} = \frac{(\text{Outgoing Weight} - \text{Incoming Weight}) * (\text{N \% of Weight})}{\text{Acres Occupied by Gear}} \quad (3.1)$$

The ‘N % of Weight’ (Eq. 3.1) can be directly measured by selecting adequately sized samples of oysters, typically 25 animals, and processing as follows:

- Obtain harvest weights for each individual oyster after handling in the same way a commercial operation would handle them before weighing: drain in air, without scrubbing;
- Place a numbered identifier on each oyster so lab results can be individually linked with field-measured harvest weights; and
- Send the oysters to a capable analysis facility where they will be separated into shell and tissue that is dried, weighed, and evaluated by mass analysis for percent nitrogen content of each component.

The remaining quantities in Equation 3.1 can be directly measured in the field. A summary of measurements made during the 2018 growing season as well as the target nitrogen removal for the next phase of the commercial-scale aquaculture plan (see 3.2.9) is presented in Figure 3.4. The Town anticipates requiring, as a condition of granting a license to a commercial grower to operate in an impaired estuary, that the grower provide a representative sample of oysters which the Town will pay to have analyzed for nitrogen content. Also, the grower must self-record incoming and outgoing weights, and provide this information and the Standard Atlantic Fisheries Information System data for the grower’s harvest to the Town.

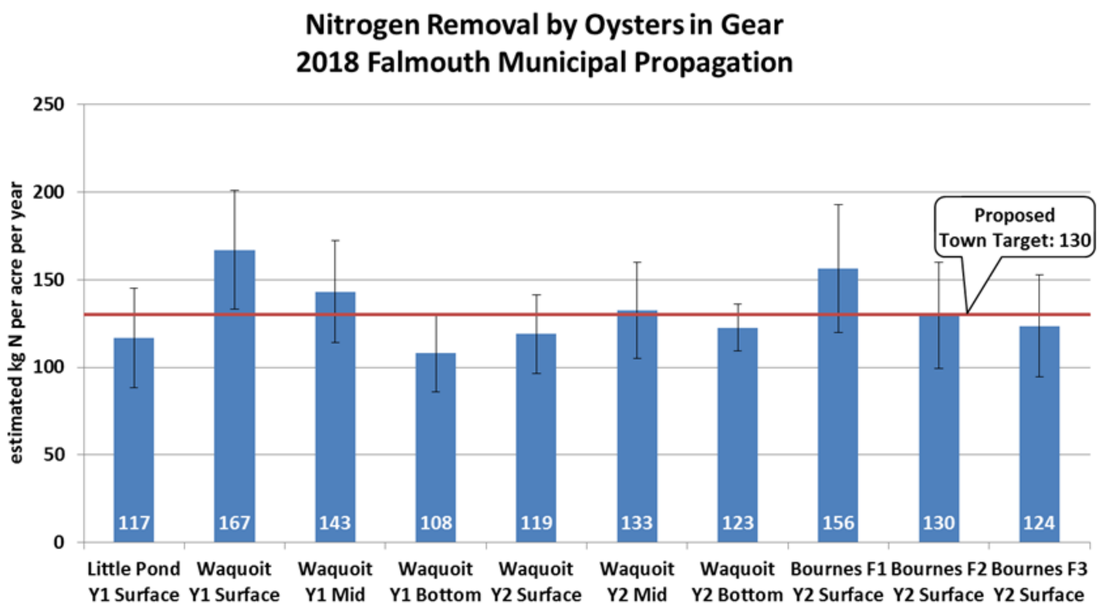


Figure 3.4 Summary of Nitrogen Removal Measurements Made by MES During 2018

3.2.9 Commercial-Scale Aquaculture Plans – 2019

In 2016 the Town contracted for the development of an aquaculture plan that would incorporate increased aquaculture as an alternative technology for removing nitrogen from its impaired estuaries (See Appendix 3.2). The plan includes an assessment suggesting that increased aquaculture may be able to account for up to 7% of the total nitrogen removal that the Town anticipates will be necessary to restore some of its impaired estuaries. The plan recommends involving growers who would be able to sell shellfish commercially, with the idea that this revenue can potentially more than cover the cost of seed and labor required in using the shellfish to remove nitrogen from these impaired estuaries. The plan further recommended pursuing a pilot program to work through siting, permitting, abutter, and contractual issues. Three sites that will support 20,000 sq. ft. of floating gear have been identified in Eel River adjacent to Washburn Island, and the process of permitting and contracting began in January of 2019. Based on a conservative average of nitrogen removal by oysters in several Falmouth estuaries as demonstrated in the 2018 municipal propagation efforts (see 3.2.8), the target is to remove 60kg of nitrogen each year at each of three sites in floating gear (Figure 3.4). Based on the data, the target nitrogen removal per site is expected to be attainable by any commercial grower when following the draft policy on aquaculture within the estuaries. By running a pilot project with three sites, the Town will be able to produce aggregate data for the pilot program for consideration by other stakeholders.

The Town had issued a Request for Proposals to commercial growers to operate the three sites identified in Eel River. Proposals are currently under review.

3.3 Eco-Toilets

3.3.1 Introduction

In 2010, as part of the public discussion process on the Draft Comprehensive Wastewater Management Plan, an organized group of citizens urged the Town to evaluate what role Eco-toilets could play in reducing the need for conventional sewering with all of its attendant monetary and energy costs. Town Meeting and the voters passed Article 17 in 2011 that included an allocation of up to $500,000 for studying composting, packaging, and urine-diverting toilets, and denitrifying septic components. The purpose was to provide in situ information on the use and function of these systems in homes and businesses and to determine their acceptability and effectiveness.

Eco-toilets separate human feces and urine from the wastewater system of a house or business. Once this source separation occurs, the human waste can be composted on-site or treated in a centralized facility. The human-derived residue is then useable as a soil amendment that is rich in nutrients. Compared to traditional sewerage systems, eco-toilet capital, operating, and maintenance expenses are all vastly lower.

3.3.2 Eco-Toilet Pilot Projects

Falmouth completed a pilot project to evaluate the nitrogen-removal, costs, and public acceptance aspects of eco-toilets, which can be either composting or urine-diverting fixtures or combinations thereof. The Eco-Toilet Incentive Program (Program) was designed to provide information on the following:

- Nitrogen-removal efficacy of eco-toilets, for TMDL-compliance.
- Total installed costs, including labor and materials.
- Critical factors involved in installation as well as operation and maintenance.
- Public acceptance.

To encourage participation in this voluntary project, three different incentive programs over a three-year period were provided:

- Up to $5,000 incentive and a septic system pump-out valued at approximately $300 for any home or business in Falmouth that would install eco-toilets in all its bathrooms;
- An exemption from an estimated $17,000 betterment assessment for over 1200 homes in the Little Pond Sewer Service Area; and
- Up to $10,000 incentive for any home within 300 feet of West Falmouth Harbor as part of the West Falmouth Harbor Shoreline Septic Remediation Program

These financial incentives were well-publicized to encourage participation in the Program. First, every Falmouth residence received a colorful notice in its water bill advertising a $5,000 incentive for installing eco-toilets. In addition to this mailing, marketing efforts included regular articles in the local newspaper, attendance at community events such as a concert in 2012 and the weekly Falmouth Farmer's Market, and workshops held by a local non-profit, The Green Center. These outreach and promotional efforts generated a list of 170 interested people. Each of these homeowners was contacted by phone about the Program. Ultimately nine [9] homeowners participated by installing eco-toilets in their bathrooms through these public information initiatives and two [2] more homeowners with prior installations joined the monitoring program conducted by the Barnstable County Department of Health and Environment.

To encourage additional participation, over 1,200 homeowners in the Little Pond Sewer Service Area (LPSSA) were mailed a letter from the Town alerting them to the option of installing eco-toilets instead of paying an estimated $17,000 betterment. Two homeowners initially enrolled from the LPSSA, but subsequently dropped out of the Program and instead hooked up to the sewer system. A third initiative offered homeowners within 300 feet of West Falmouth Harbor a $10,000 incentive to install eco-toilets or Innovative/Alternative septic systems. None of the 30 participants in this project selected eco-toilets.

In order to ease the burden on the homeowner of permitting the installation of an eco-toilet, the Technical Consultant to the WQMC assisted all homeowners in the permitting process. The Technical Consultant first obtained a Test Site permit from the State Board of Plumbers and Gas Fitters in March 2013 that allowed up to 40 test sites. Subsequently, all installations were permitted through the local Board of Health.

Public participation in the Eco-Toilet Pilot Project was low in Falmouth, despite significant financial incentives and ongoing promotion to encourage participation. Of the 170 people who showed initial interest in eco-toilets, 55% indicated they ultimately chose not to participate due to factors such as the effort involved in ongoing operation and maintenance of the eco-toilet and a concern over resale value of the home. Cost was only a factor for 10% of respondents who did not choose to participate.

Eco-Toilet Demonstration Program Final Statistics:

- Number of people contacted: 170
- Number of people with site visits: 50
- Number of people who installed eco-toilets: 9
- Types of installations/eco-toilets chosen covered the full range:
  - central composters,
  - self-contained units, and
  - urine-diverting fixtures.

3.3.3 Eco-Toilet Performance Monitoring, Installation Costs, and Operation and Maintenance

The Barnstable County Department of Health and Environment (BCDHE) monitored all nine eco-toilet systems that were installed as part of this Program plus two more systems that joined the Program for monitoring only. BCDHE found that composting toilets removed 86% of nitrogen that would otherwise enter a septic system; urine-diverting toilets that only divert urine from the septic system removed 48% of the nitrogen. At locations that used a combination of urine diversion and composting technologies, the reduction in the nitrogen load was 80%. This report, entitled Final Report to the Town of Falmouth-Performance of Eco-Toilets, dated April 2018, is included in Appendix 3.3, and provides technical details for the different eco-toilet systems that were installed.

In addition to their nitrogen-removal effectiveness, the cost and practicality of retrofitting existing structures with eco-toilets is critical to an evaluation of whether these toilets are a viable alternative to more traditional wastewater management techniques. The Water Quality Management Committee's technical consultant tracked the costs of installation (including labor and materials) as well as findings related to public acceptance. In summary, costs (including labor and materials) to install eco-toilet system in one, first-floor bathroom ranged from $2,600 for a small, self-contained unit where the bin holding excrement and urine is directly below the toilet bowl, to $9,500 for a central composting unit with a remote bin. Additional bathrooms cost approximately $2,500 each to retrofit.

Operation and maintenance of eco-toilets includes weekly maintenance of composting bins as well as residuals management. Residuals include compost (feces and urine mixed with wood shavings) and leachate, which is the excess liquid that is not taken up during the process of composting. Leachate accumulates at approximately 2 gallons/person/month. Urine-diverting toilets require periodic pumping of urine from a holding tank. Regular turning and ultimate burial of compost is usually done by the homeowner but hauling of residuals and urine must be performed by a licensed septic hauler. All eco- toilets require some form of residuals management. All eco-toilets also required some sort of odor control, usually an exhaust fan with back-up battery. Periodic occurrences of flies and gnats were reported as well.

3.3.4 Key Findings of Eco-Toilet Pilot Project

- Measured nitrogen removal for composting systems is 86% and for urine-diverting fixtures is 48%. Hybrid systems removed 80% of the nitrogen load.
- Installation costs of most systems are significant for existing homes with more than one bathroom, ranging from $2,600 to $9,500 per unit.
- Homeowners must make a commitment to maintain their eco-toilets. Operation and maintenance includes removing compost and disposing of liquids such as urine and leachate.
- **Homeowner acceptability of installing eco-toilets is low.**
- **Homeowner concern with re-sale value of dwelling is high.**

Based on these conclusions, eco-toilets are not included as a separate non-traditional technology for watershed planning purposes in Falmouth. They continue to be listed as an I/A septic system option. In watersheds where I/A septic systems are the recommended solution for TMDL compliance, property owners will also be able to select eco-toilets that achieve the same level of nitrogen-removal as is required for I/A septic systems.

3.4 Innovative and Alternative (I/A) Septic Systems

3.4.1 Introduction

Beginning in 2010, Town officials and the general public became increasingly aware of a wide variety of alternative septic systems available either 'off the shelf' or under development as prototypes. As part of the investigation into technologies that could reduce nitrogen discharged to the groundwater at or near the source, the Water Quality Management Committee decided to pursue in situ testing of multiple concepts. The Town was fortunate to have the interest and expertise of the

Director of the Massachusetts Alternative Septic System Test Center, located at Joint Base Cape Cod. This Test Center has been in operation for over 20 years, and the monitoring data it collects and analyzes has a high level of credibility with the public and the regulators. Article 17 provided funding for this pilot project as needed along with various grants.

The DEP currently requires that advanced I/A septic systems must meet a standard of 19 mg TN/L. Based on the TMDL targets, the Town of Falmouth considered the DEP standard to be too high to effectively improve the health of an impaired estuary. Therefore, at the various locations where advanced I/A systems were installed as part of the pilot project, the goal was 12 mg TN/L for each I/A septic system or 70% removal.

3.4.2 West Falmouth Harbor Shoreline Septic System Remediation Project

The Town completed a pilot project entitled West Falmouth Harbor Shoreline Septic System Remediation Project (WFHSSSR Project) to evaluate nitrogen-removal, costs, and ongoing operational issues of I/A Septic Systems and eco-toilets in partnership with the Buzzards Bay Coalition (BBC). The main purposes of the WFHSSSR Project were to:

- Measure the nitrogen removal of off-the-shelf I/A septic systems or eco-toilets installed at single-family homes.
- Determine the real-world costs and logistics of installing these systems.
- Evaluate the ongoing operation and maintenance requirements.

With the help of the West Falmouth Village Association, more than 30 homeowners within 300 feet of West Falmouth Harbor (WFH) were identified as willing to voluntarily upgrade or replace their existing Title 5 septic systems or cesspools with I/A septic systems. The installed I/A septic systems were expected to reduce nitrogen concentrations in the septic tank effluent to at least 12 mg/L nitrogen (N) or approximately 68% (12 mg N/L versus 38 mg N/L for septic effluent from a standard Title V system per MassDEP). Homeowners were given a choice of an array of systems for their property. None of the participants installed eco-toilets although this option was presented alongside the I/A septic system choices. Phase I of this Project, involving 20 homeowners, was funded by a $250,000 grant from the United States EPA through the Buzzards Bay National Estuary Program. The West Falmouth Harbor Shoreline Septic System Remediation Project Final Report (October 12, 2016) presents the details of Phase I [Appendix 3.4]. Phase II, involving 10 additional homeowners, was funded by a $75,000 grant from the Cape Cod Water Protection Collaborative and $50,000 from the BBC to cover monitoring expenses. The BBC plans to summarize the installation and monitoring information in late 2019.

Four different I/A septic system technologies were installed in Phase I:

- Blackwater Holding Tanks
- Eliminite™
- HOOT™
- Layered Soil Treatment Area (STA) “Layer Cake”

Three additional technologies were installed in Phase II:

- Drip Dispersal System
- NitROE™
- FujiCLEAN™

The West Falmouth Nitrogen-Reducing Septic Systems Demonstration Project Status Report (May 2017) describes the monitoring results of the first four technologies that were installed [Appendix 3.4]. In terms of overall nitrogen-removal, project partners set out to reduce nitrogen from on-site septic systems at these 30 homes by at least 68%.Data collected as of August 31, 2017 indicates that overall effluent nitrogen entering a soil absorption system, also known as a drainfield, from the first 20 systems has been reduced by at least 69%. For the nine Blackwater Holding Tanks that were installed, the average nitrogen concentration of pre-installation effluent was 95 mg N/L and the average nitrogen concentration post-installation was 8 mg N/L. The reduction in nitrogen from these homes is 92%. The Falmouth Board of Health only permits Blackwater Holding Tanks as part of this pilot project and only for seasonal homes.

For the three Eliminite™ systems that were installed, the average nitrogen concentration of pre-installation effluent was 78 mg N/L and the average nitrogen concentration post-installation was 30 mg N/L. The reduction in nitrogen from these homes is 62%. One of these systems was installed during an extensive house remodel and did not perform well, likely due to solvents that were used and then disposed of improperly. The average nitrogen concentration after the upgrade of the two other Eliminite™ systems was 13.66 mg N/L or 82% removal.

For the three HOOT™ systems that were installed, the average nitrogen concentration of pre-installation effluent was 63 mg N/L and the average nitrogen concentration post-installation was 17 mg N/L. The reduction in nitrogen from these homes is 72%.

For the one Layered STA that was installed, the average nitrogen concentration of pre-installation effluent was 56 mg N/L and the average nitrogen concentration post-installation was 29 mg N/L. The reduction in nitrogen from this home is 48%.

The Layered STA is under detailed investigation by the BCDHE through a grant from the EPA. Twelve Layered STA systems are being installed across southeastern Massachusetts and performance data for this larger number of installations will be reported as part of that initiative at a later date.

Table 3.1 presents the wide range of total project costs for different I/A septic systems installed in Phase I and Phase II. Total project costs include engineering, equipment, installation and restoring landscaping. The average cost to add on to an existing, conventional Title 5 system was $20,417, while full upgrades from old cesspools cost an average of $33,225. While the cost range for the Eliminite™ and HOOT™ systems are modest, approximately $1000 and $6000 respectively, the range for the Blackwater Storage Tank option is significant (approximately $15,000). This large range for costs can be explained by the difference in installation requirements. In some cases, existing Title 5 systems were in place and the addition of a blackwater tank and plumbing modifications were all that was required. In other cases, full Title 5 upgrades, including a new soil absorption system, were needed. The cost range for the HOOT™ system illustrates the significance of site conditions on installation costs. The low end of the installed costs was a case where there were minimal site constraints. The high end case had significant landscaping constraints, adding to the time required for installation and the extent of landscaping to return the property to existing conditions. For the Layered STA system, the costs associated with a deep excavation and fill were the cost drivers. A standard drainfield would have similar costs.

Table 3.1 Installation Costs by System Type – Phase I

System Type	Average Total Installed Cost by System Type ($)	High Total Installed Cost by System Type ($)	Low Total Installed Cost by System Type ($)
Blackwater Holding Tank	$18,274	$32,327	$13,353
Eliminite™	$20,760	$21,458	$19,523
HOOT™	$34,581	$40,425	$28,158
Layered STA [1]	$42,530	Only one installation	Only one installation

Notes:

1. The cost of this installation was dominated by the required 15-foot strip-out of the STA area. The cost for a standard STA (drainfield) would have been comparable.

Using I/A septic systems as part of TMDL-compliance will likely require that these systems be installed on existing properties where there are numerous constraints that limit the area available for locating the tanks and soil absorption system (SAS), including:

- Lot size.
- Location of existing structures and driveways on the property.
- Mature landscaping, including trees.
- Proximity to wetlands.
- Soil types.
- Depth to groundwater.
- Property setbacks.

Installation costs will be significantly affected by these site-specific constraints.

To enable a comparison of capital costs for I/A systems with other traditional septic systems as well as alternative wastewater management technologies like sewering, a benchmark installed cost of $26,000 was calculated. This cost was determined by obtaining estimates from three local septic system installers for a three-bedroom, Title 5 system on a hypothetical lot. Key parameters for these cost estimates include:

- The system including a tank and a soil absorption system.
- Direct and easy access to install the Title 5 system on the hypothetical lot (for example in the front of the house).
- The hypothetical lot did not have any existing landscaping.

Based on these parameters, the cost to install a Title 5 system for a three-bedroom home, including equipment, was $12,800. The average vendor-provided cost for the equipment that is specific to the

I/A functionality for HOOT™, Eliminite™, Layer Cakes, and Nitrex™ systems was $9,900. This average cost was added to the baseline cost for a Title 5 system. An allowance of $3,300 for preparing engineering plans and Board of Health permitting was also included in the benchmark cost for a total of $26,000.

3.4.3 Key Findings of the I/A Septic System Pilot Project

- To be useful for wastewater planning in Falmouth, I/A systems that achieve an effluent standard of 10 mg N/L or 75% TN removal must be approved by MassDEP.
- Ongoing, regular maintenance and monitoring of I/A systems is needed to ensure that expected performance is realized.
- A Town entity should be identified and given explicit responsibility for oversight of I/A systems installed as part of plans for shared watersheds as well as Targeted Watershed Management Plans.
- Installed costs of I/A systems vary considerably, depending on site constraints.
- The required frequency of monitoring significantly impacts operating costs. If the required monitoring can be reduced from the currently required frequency to annual then the costs may be acceptable.
- For the cost to homeowners of I/A systems to be comparable to the cost of sewers, loans for I/A systems must be available that provide financing comparable to Falmouth's betterments (0%/30-year term/level payments).
- Barnstable County Community Septic Management Loan Program currently provides loans at 5% for 20 years.

3.4.4 Watershed Management and Monitoring Plan for Advanced I/A Septic Systems

An important lesson learned as part of the WFHSSSR Project is that I/A septic systems must be properly maintained and monitored to achieve their expected nitrogen removal. A management approach that is acceptable to both property owners as well as state and local officials is needed to ensure that I/A septic systems that are installed as part of the Town's CWMP or a watershed's Targeted Watershed Management Plan (TWMP) are appropriately maintained and monitored over the long term. The WQMC has drafted a Watershed Management and Monitoring Plan for Advanced Innovative/Alternative Nitrogen Reducing Septic Systems (Monitoring Plan) and circulated it to DEP, BCDHE and others [Appendix 3.4]. A key feature of this Monitoring Plan is that the advanced I/A septic systems must meet a standard of 10 mg TN/L or 75% removal of TN. The current DEP standard is 19 mg TN/L, which the WQMC felt was insufficient to effectively improve the health of an impaired estuary. Qualifying vendors of I/A systems will be required to achieve 10 mg TN/L or 75% TN removal.

The Monitoring Plan addresses a number of important issues:

- Requirements for owners of designated properties within a watershed who must install I/A septic systems.
- Designation and role of a Responsible Municipal Management Entity (RMME).

- Selection of vendors of advanced I/A systems and performance monitoring during the probation period.
- Frequency of monitoring after the probation period to ensure that the performance standards for installed I/A septic systems are being met.
- Operation and maintenance of the advanced I/A system including annual inspections.
- Reporting, recordkeeping, and other tasks performed by the RMME.
- Semi-annual fee paid to the Town to cover the costs of the RMME.

This Monitoring Plan will be included in the implementation strategy for advanced I/A septic systems installed as part of watershed-level planning for a given estuary.

3.5 Permeable Reactive Barriers (PRBs)

3.5.1 Introduction

A PRB is a technology that has been used for contaminated groundwater remediation for several decades. It is a recognized engineering approach in many hazardous waste sites nationwide. However, the application of the technology to nitrogen contamination in groundwater from non-point sources is relatively new. A PRB for nitrogen remediation involves the installation of a carbon substrate perpendicular to the lateral flow of groundwater. As the groundwater moves through this carbon source, the nitrate contained in the groundwater is converted by naturally occurring bacteria to nitrogen gas through the biologically mediated process of denitrification. Historically, the permeable barrier was composed of solid fragments such as wood chips installed in a trench dug into the aquifer. More recently methods involving injection of various liquid carbon sources have been used.

Falmouth committed $175,000 of Article 17 funding to hire CDM Smith in 2013 to do a desktop evaluation of all of the south coast estuaries plus the West Falmouth Harbor watershed for possible locations for PRBs. As part of this planning analysis, groundwater-profiling data from Seacoast Shores collected by the Cape Cod Commission and the US Geological Survey were used. These data indicated that a trench of over 50-feet deep would be required, which was physically impossible due to site constraints and financially prohibitive. CDM Smith suggested that injection wells might be a viable alternative. Chapter 3 of the Town’s CWMP/TWMP/EIR (September 2013) provides details on the feasibility and planning studies that were accomplished for this project.

Before an injected PRB can be installed, the groundwater hydrology of the site must first be established. The speed and direction of groundwater flow must be characterized by installing a number of monitoring wells and water table wells. Key parameters must be measured at different elevations in the groundwater, such as nitrate and dissolved oxygen concentrations, oxidation/reduction potential (ORP), pH and the presence of certain metals. Analysis of permeability of the specific soils at the site is also necessary. These investigations require several rounds of sampling and analysis to characterize seasonal and inter-annual variability in flow and chemical distributions. Only then can a determination be made as to whether a given site is a potential candidate for an injected PRB.

Using a mapping exercise to determine depth to the water table, distance from wetlands, and accessibility for monitoring wells both upstream and downstream of the potential PRB, Falmouth identified about 10 areas within the CWMP planning area where a pilot PRB project might be installed. Two sites ranked very high, one in the Great Pond Watershed (Shorewood Drive) and the other in the Bournes Pond Watershed (Sailfish Drive). Two grants from the CCWPC made it possible for Falmouth to hire MT Environmental Restoration to investigate the hydrogeology of the Shorewood Drive site. As part of its regional groundwater studies, the US Geological Survey installed a multi-port monitoring well near the intersection of Route 28 and Shorewood Drive. A grant from the EPA, Region 1, using the subcontractor WaterVision LLC, funded an investigation of the hydrogeology of the Bournes Pond site called Sailfish Drive. Some additional work was also done at the Shorewood site as part of the EPA study.

3.5.2 Groundwater Evaluations in the Great Pond Watershed

Two grants from CCWPC, totaling $75,000, funded an in-depth groundwater and soils investigation of the central and northern sections of the Acapesket peninsula in the Great Pond watershed. Figure 3.5 shows the locations of the monitoring wells within the northern section of the Acapesket peninsula, with the Town-owned 0 Shorewood Drive site outlined.

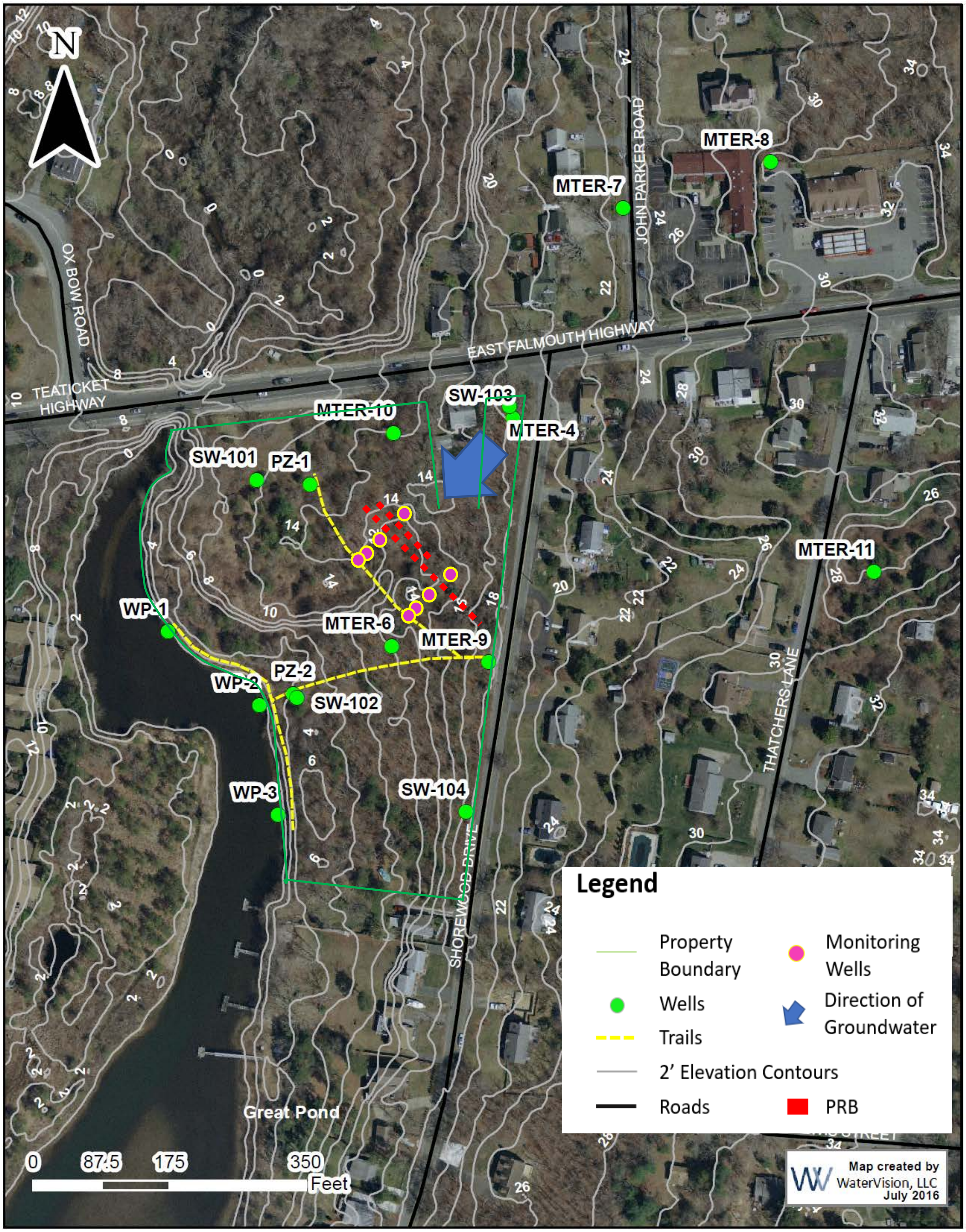


Figure 3.5 Map of Investigational Well Locations and Groundwater Flow Paths

These investigations are documented in the following list of reports (see Appendix 3.5):

- Falmouth Acapesket Peninsula Groundwater Investigation Report (MT Environmental Restoration March 23, 2015)
- Falmouth Acapesket Peninsula Groundwater Investigation Phase II Report (MT Environmental Restoration December 21, 2015)
- WaterVision LLC Technical Memorandum: Project Summary Memorandum: Site Characterization for Design of Pilot-Scale Permeable Reactive Barrier for Nitrogen Reduction in Groundwater on Cape Cod – Supplemental Field Work at Shorewood Drive, Falmouth, MA dated September 26, 2016
- WaterVision LLC Technical Memorandum: Supplemental Sampling Summary Memorandum: Site Characterization for Design of Pilot-Scale Permeable Reactive Barriers for Nitrogen Reduction in Groundwater on Cape Cod – Supplemental Fieldwork at Shorewood Drive, Falmouth, MA dated April 18, 2017)

As reported in the March 2015 report, a relatively low nitrogen mass flux was observed within monitoring wells in the central portion of the Acapesket peninsula, approximately 3,500 feet south of Route 28. In the December 2015 report, results from additional sampling of the wells in the central Acapesket peninsula confirmed the results of the first round of sampling. This low nitrogen flux is due to low nitrate concentrations in the groundwater and slow horizontal groundwater velocities. This low flux means that this would be a poor location for a PRB.

As part of Phase II, MT Environmental Restoration installed groundwater monitoring wells in the northern section of the Acapesket peninsula in the vicinity of Route 28 and 0 Shorewood Drive, a 5-acre parcel owned by the Town. Additional investigations at 0 Shorewood Drive were completed in 2016 by WaterVision, a contractor for EPA Region 1, and by the US Geological Survey which installed a multiport sampling well as part of their regional network. Two rounds of water quality samples were collected and analyzed for the northern section of the Acapesket peninsula and a third round at selected locations for an analysis of stable isotopes of nitrogen. These data showed that this Town-owned site is an advantageous location for a PRB.

Key Findings for 0 Shorewood Drive include:

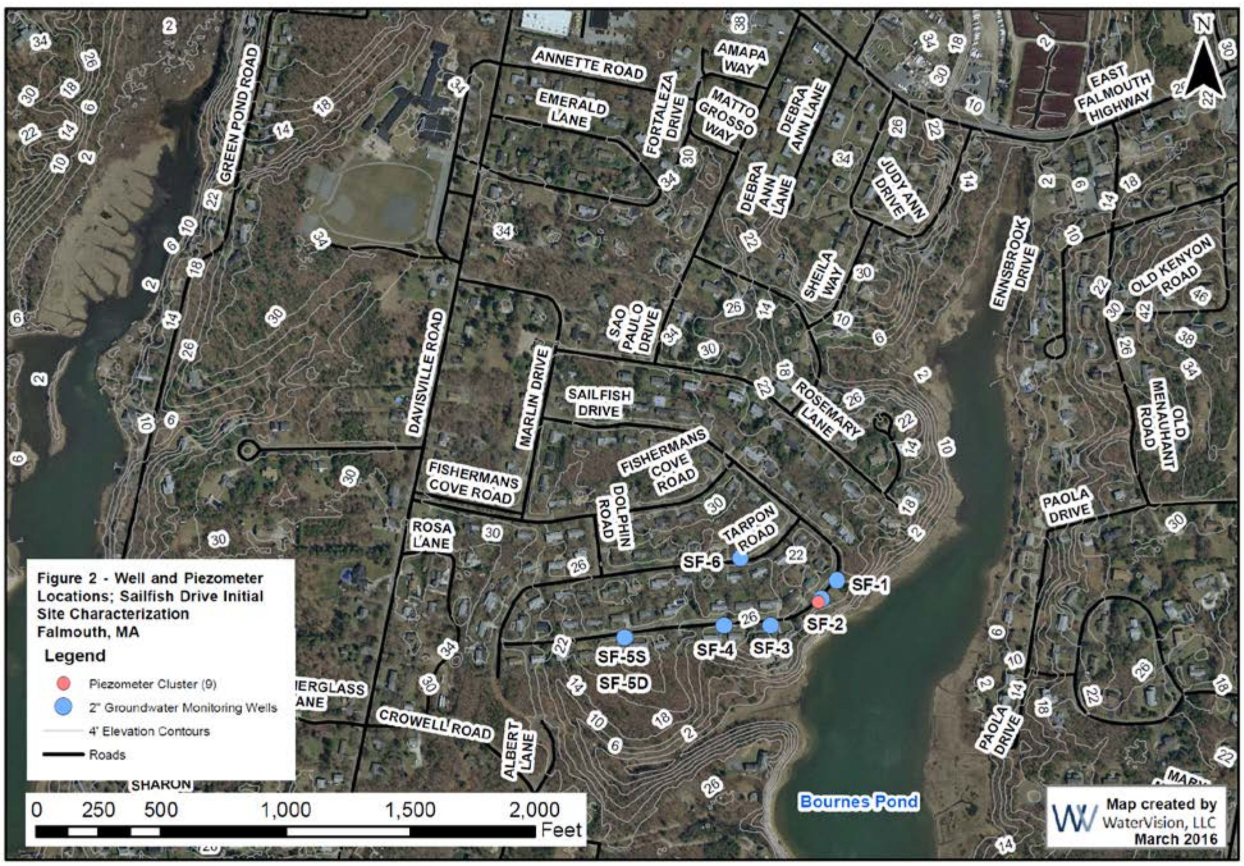
- The predominant species of nitrogen detected was nitrate.
- Nitrate concentrations are high (up to 14 mg N/L at elevations between -10msl to -20msl).
- Nitrate contaminated groundwater is present at a shallow depth that can be easily reached by injection of a liquid carbon source.
- Soil types on site are predominantly well-graded sand; shallow backfill of wood and asphalt was encountered at two locations.
- Horizontal groundwater velocity is estimated to range from 2.1 ft./day to 4.0 ft./day, which is considerably higher than the regional average rate of 1 ft./day.
- Groundwater chemistry and nitrate distribution are generally conducive to groundwater nitrate treatment.

- Compounds that compete for treatment substrate and increase costs (e.g. sulfate) are at relatively low concentrations.

There is significant flux of nitrate through the area due to two conditions: high concentrations of nitrate present in groundwater and a significant groundwater velocity. From this flux, it is estimated that 330 kg N/year flowing toward Great Pond will be removed by a 200-linear foot pilot-scale PRB using injection. Based on these reports, a Section 319 grant proposal was submitted to MassDEP in 2017 to help cover the costs of the installation of a pilot-scale PRB but was not funded. A similar proposal submitted to the EPA SNEP program in 2018 also was not funded.

3.5.3 Groundwater Evaluations in the Bournes Pond Watershed

There are several dense residential developments along the upper reaches of the Bournes Pond estuary. One of them, Fisherman's Cove, contained a road layout and a recreational area that appeared promising as a potential PRB site. Sailfish Drive (Figure 3.6) was evaluated as part of an EPA Region 1 initiative.



Sources: Aerial photography 2013-2014 and Roads from Mass GIS, Parcel Boundaries from Cape Cod Commission, Surveyed Groundwater Monitoring Well and Piezometer locations from WaterVision LLC. Elevation contours from the Cape Cod Commission.

Figure 3.6 Map of Investigational Well Locations at Sailfish Drive

The project report prepared by WaterVision, Cape Cod Permeable Reactive Barrier Initial Hydrogeologic Site Characterization Results and Evaluation of Site Suitability for Permeable Reactive Barrier Installation – Sailfish Drive, Falmouth MA (July 29, 2016), is included in Appendix

3.5. Six water-table wells were installed in this area. Sampling results from these wells were used to establish groundwater surface elevation, flow direction, and velocity as well as groundwater chemistry. Three rounds of water level measurement and two water quality sampling rounds were completed. The data indicated that the specific conditions at Sailfish Drive are favorable to installing a PRB.

Key Findings for Sailfish Drive include:

- The predominant species of nitrogen detected was nitrate.
- Nitrate concentrations are moderate (up to 8.9 mg N/L at elevations between -22 feet below ground surface (bgs) to -29 ft bgs).
- Soil types on site are predominantly well-graded sand.
- Horizontal groundwater velocity is estimated at 1.4 ft./day, which is higher than the regional average rate of 1 ft./day.
- Groundwater chemistry and nitrate distribution are generally conducive to groundwater nitrate treatment.
- Compounds that compete for treatment substrate and increase costs (e.g. sulfate) are at relatively low concentrations.
- Nitrate contaminated groundwater is present at a shallow depth that can be reached for treatment.

EPA calculated the nitrate mass flux at Sailfish Drive to be 1.13 g/day between -22 ft bgs and -26 ft bgs, and 0.55 g/day between -29 ft bgs and -36 ft bgs. With this mass flux, a 300-linear foot, pilot-scale PRB with a vertical thickness of 14 feet at this location would remove almost 400 kg N/year. Hydraulic conductivity for this flux is assumed to be 150 ft/day based on a soil type of silty fine to medium sand.

3.5.4 Next Steps

Permeable reactive barrier technology for the purpose of groundwater nitrogen remediation is still under development. On Cape Cod, there have only been three such installations: two shallow, wood chip-based PRBs beneath the shoreline of Waquoit Bay and Childs River, and a liquid carbon PRB in Orleans. Neither is deployed in a setting similar to what would be installed in the Town of Falmouth. As such, additional pilot projects are required to determine the cost and effectiveness of the technology, which will determine whether or not PRBs are a viable alternative approach for nitrogen remediation for the Town. In June 2019, the Woods Hole Oceanographic Institution in partnership with the Water Quality Management Committee/Town of Falmouth submitted a request for a $298,598 grant from the EPA-Southeast New England Program to fund a 120-foot PRB to be installed at 0 Shorewood Drive. The Town will provide $36,222 of in-kind services. The proposed project will last 30 months if funded.

3.6 Nitrogen Control Bylaw for Fertilizer

3.6.1 Introduction

Fertilizer contributes 5- to 10-percent of the controllable nitrogen sources entering Falmouth's watersheds. A summary of the nitrogen loads to the watersheds from various sources including fertilizer is included in Appendix 3.8 of the Town's CWMP (September 13, 2014). To address this controllable load, the WQMC authored a Nitrogen Control Bylaw for Fertilizer that was adopted at Fall 2012 Town Meeting and approved by the Attorney General of Massachusetts. This bylaw prohibits the application of nitrogen within 100 feet of resource areas as defined in Falmouth's Wetlands Regulations, FWR 10.02 (1)(a - d), as well as on impervious surfaces. The bylaw also prohibits the application of fertilizer anywhere in Town from October 16th to April 14th. During the growing season of April 15th to October 15th, fertilizer application is banned during heavy rain. There are exceptions for agriculture and horticulture. On golf courses, fertilizer may be applied over the entire growing season; but on greens and fairways within defined wetland resource areas, no more than 1.0 pound of nitrogen can be applied per 1,000 square feet per year and 85% or more of this fertilizer must be in an organic or inorganic, slow-release, water-insoluble form. There are also allowances for the application of organic constituents applied to improve the physical condition of the soil and the establishment of turf. Enforcement is through the Department of Marine and Environmental Services (a merging of the Harbormaster's Office and the Department of Natural Resources). A copy of this Nitrogen Control Bylaw is included in Appendix 3.6.

This Nitrogen Control Bylaw coupled with local educational efforts is expected to reduce the controllable watershed load of nitrogen attributed to fertilizer by 25%. This nitrogen-removal credit is consistent with the methodology used in the Cape Cod Commission's 208 Area-wide Plan Update.

3.6.2 Ongoing Public Education and Enforcement

Since the adoption of this Bylaw, two main efforts have been used to build public understanding of and compliance with this regulation. These include:

- Annual mailings to approximately 2,700 properties that are within 100-feet of coastal estuaries throughout the Town regardless of their level of impairment of these estuaries;
- A requirement in the Conservation Commission's Standard Order of Conditions that applicants must obey the Nitrogen Control Bylaw.

A copy of the letter that is mailed out and a copy of the Standard Condition adopted by the Conservation Commission are included in Appendix 3.6. The mailing list is updated each year through Falmouth's GIS and assessor's records. The Standard Condition is included in all Orders of Conditions issued.

3.7 Stormwater Management

3.7.1 Introduction

Stormwater runoff contributes 5- to 10-percent of the controllable nitrogen sources entering Falmouth's watersheds. A summary of the nitrogen loads to these watersheds from various sources including stormwater is included in Appendix 3.8 of the Town's CWMP (September 13, 2014). To date, little has been done to directly address this controllable load, so the WQMC has coordinated with the Department of Public Works (DPW) to review the Town's stormwater systems and identify opportunities to implement stormwater Best Management Practices (BMPs) that remove nitrogen. Actions taken to date include:

- Submission of a Statement of Interest to the EPA Region 1 Southeast New England Coastal Watershed Restoration Program in response to a grant request issued in 2014. Falmouth's proposal was not selected to participate in this program.
- Detailed review of stormwater inputs to Great Pond in collaboration with the Town's engineering department.
- Review of a promising technology based on modified catch basins (called media boxes) designed and installed by the Town of Dover, New Hampshire as part of the Berry Brook river restoration project.

Implementing stormwater BMPs is expected to reduce the controllable watershed load of nitrogen attributed to stormwater by 25%. This nitrogen-removal credit is consistent with the methodology used in the Cape Cod Commission's 208 Area-wide Plan Update.

3.7.2 Inventory of Stormwater Systems for EPA Region 1 Statement of Interest

In order to submit a Statement of Interest to the EPA Region 1, approximately 12 potential stormwater systems were reviewed by WQMC and DPW engineering staff. Through this review, three promising locations were identified where stormwater BMPs could be implemented.

Candidate sites included:

- Green Pond watershed: storm drain #10 - end of Captain's Lane that discharges directly into Green Pond (Davisville peninsula, East Falmouth).
- Falmouth Inner Harbor watershed: storm drain #50 – 180 Scranton Ave at the Harbormaster's Office that discharges directly into Falmouth Harbor.
- Waquoit Bay watershed: White's Landing – off White's Landing Road that discharges directly into Eel River via Childs River.

All locations are Town-owned and publicly accessible. A copy of this Statement of Interest is included in Appendix 3.7.

3.7.3 Great Pond Watershed

The following storm drain locations around Great Pond were reviewed with the DPW engineering staff to identify whether stormwater BMPs implementations would be feasible and advantageous:

- Route 28 at Coonamessett River crossing (under Mass. Dept. of Transportation control).
- Teaticket Path.
- Perch Pond Circle.
- Six (6) streets on the Maravista peninsula: Reynolds, Randolph, Mattapan, Milton, Morris, and Great Bay Road.

Perch Pond, a small sub-embayment of Great Pond, is of particular interest because it receives, directly or indirectly, the flow of most of the above storm drains resulting in the highest nitrogen concentrations measured in all of Great Pond. Therefore, its setting presents a good location to determine if BMPs implementations result in observable reductions in nitrogen concentrations in the receiving waters.

Because the drains discharge to the head of Perch Pond in the Great Pond watershed, calculations for the potential nitrogen input from Route 28 storm drains and the Teaticket Path stormwater system were completed. Approximately 16 kg N/year and 60 kg N/year, respectively, flow into Perch Pond from these two catchment areas. In order to implement BMPs that could remediate these sources, land would need to be acquired and wetlands permitting completed, including filing with MassDEP. Coordination with the state is also required to address the Route 28 storm drains. Initial field review of the other discharge locations immediately after a heavy rain event in early December 2017 did not show significant discharge into Great Pond. The leaf debris on the slope at the discharge end of the pipe was not disturbed. Given the existing space limitations, the decision was made to review the effectiveness of media boxes and other space-efficient solutions before implementing any specific measure.

3.8 Inlet Widening – Bournes Pond

3.8.1 Bournes Pond Inlet Widening Notice of Project Change

In January 2016, the Town of Falmouth filed their first Notice of Project Change (NPC) for the Bournes Pond Inlet Widening piloting program as part of their adaptive management approach. The NPC identified the inlet widening's potential contribution towards attaining water quality standards within the watershed and reviewed the alternatives analysis and mitigation measures needed to mitigate adverse impacts during construction and following implementation. The Town received the Certificate of the Secretary of Energy and Environmental Affairs on the Notice of Project Change on March 11, 2016 (EEA Number 14154).

3.8.2 Background

The Bournes Pond Inlet Widening Project (Project) is a water quality improvement and tidal restoration project being advanced by the Town of Falmouth and the Town's WQMC. The widened inlet will provide long-term, immediate improvements to water quality due to increased tidal flushing with an increase in water exchange of over 9 million gallons per tide. Widening will remove approximately 50% of the target nitrogen load and enhance eelgrass and shellfish habitats. This will be accomplished by increasing the width of the inlet from 50 feet to the optimal size of 90 feet.

Bournes Pond Inlet (Figure 3.7) currently has a single span bridge and two jetties. There is no change in bridge height planned, so the intentional restriction of large boats from entering this pond remains intact. The new bridge design specifies a 25-foot extension of the western jetty, complemented by the removal of 25-feet of groin currently located to the west of that jetty. This results in no net increase in the footprint of coastal structures.

Figure 3.7 Bournes Pond Inlet Location

Bournes Pond Inlet separates East and West Menauhant Beaches. Parking areas run along the south side of the road and manmade dunes serve as a seaward barrier to the parking areas, road, and bridge (Figure 3.7).

The project is within a barrier beach-coastal beach system, velocity zone, Natural Heritage and Endangered Species Program (NHESP) Priority Habitat, and Chapter 91 Jurisdiction. Required permits and authorizations are further detailed in Section 3.8.3.

Historically, the inlet was generally wider than the existing 50-foot inlet that was constructed in 1985. Based on the available historical information since 1844, the inlet width varied between 88 feet and 400 feet, where the widest inlet may be a result of storm breaching. More recently, it appears that the inlet width in 1969 was 209 feet wide. Overall, the historical inlet information for Bournes Pond demonstrates that the proposed 90-foot wide inlet is well within the range of previously mapped inlet widths and is generally at the lower end of the historical stable inlet widths observed at the Bournes Pond entrance.

Appendix 3.8 includes the “Narrative” of the January 2016 NPC which outlines the evaluations, nitrogen loads, modeling, potential environmental impacts, and permitting. In 2016 the projected costs for the proposed inlet widening totaled $5.52 million. The inlet widening is projected to have an effective nitrogen removal of approximately 2,000 kg N/year. Factoring in operating and maintenance costs over a 45-year period, it is estimated that the widening of the Bournes Pond inlet will cost approximately $84 per kilogram of nitrogen removed.

3.8.3 Permitting

The following permits have either been filed or received:

- US Army Corps of Engineers (USACE): 404 Permit – Approved July 12, 2019.
- Cape Cod Commission (CCC): Development of Regional Impact (DRI) Certificate of Compliance – Approved April 7, 2016.
- Massachusetts Historical Commission (MHC) – Project Notification Form – Approved April 26, 2017.
- Massachusetts Office of Coastal Zone Management (CZM) – Federal Consistency Review – Approved September 14, 2018.
- Massachusetts Department of Environmental Protection (MassDEP).
  - 401 Water Quality Certification and Chapter 91 Permit – Approved July 30, 2018.
  - Chapter 91 License – Approved November 19, 2018.
  - Notice of Intent /Superseding Order of Conditions – Approved January 31, 2018.
- Massachusetts Department of Transportation (MassDOT) – Chapter 85 Submission – In Development.
- Natural Heritage Endangered Species Program (NHESP) – MESA Project Review Form – Approved June 21, 2017.
- Town of Falmouth Conservation Commission – NOI – Approved June 28, 2017 (see MassDEP).
- US Coast Guard – Coast Guard Permit – Approved December 19, 2017.
- United States Environmental Protection Agency (USEPA) – NPDES General Permit – Required during construction.

A full description of the status of the Bournes Pond inlet project is outlined in Chapter 8.

4. Little Pond Targeted Watershed Management Plan Update

4.1 Current Status of Meeting the TMDL

4.1.1 Little Pond Sewer Service Area Update

The construction of the collection system serving the Little Pond Sewer Service Area (LPSSA) was initiated April 15, 2015 and included sewering 1,350 developed properties within both the Little and Great Pond watersheds, as well as properties within the lower portion of the watershed in the neighborhoods of Falmouth Heights and Maravista. The Falmouth Heights portion of the area was completed and ready for properties to connect to the sewer system in June of 2016. The remainder of the sewer system (Maravista and Teaticket Highway areas) was completed and ready for sewer connection in April of 2017. As of May 2019, 95% of those 1,350 parcels have been connected to the sewer system. It is expected that nearly 100% of the LPSSA parcels will be connected to the sewer system by the fall of 2019.

The LPSSA sewer system was constructed to improve Little Pond water quality by reducing the nitrogen load to the pond from septic systems. It increasingly serves this purpose as more properties in the service area are connected to the sewer system. Water quality in Little Pond is expected to improve over time. Water quality improvement is anticipated to be gradual, as it will take an estimated seven years for the entire nitrogen load from previous years' septic discharge to move through the groundwater and soils and seep into the pond. As this proceeds, the Town will continue to monitor water quality in Little Pond. The Town and the United States Geological Survey (USGS) have commissioned a sampling effort described in the following section.

The following Table provides an estimated breakdown of the parcels within the entire sewer service area described above. The subsequent analysis will focus on those properties of the sewer service area specifically within the Little Pond Watershed (approximately 1,010).

Table 4.1 Breakdown of Little Pond Sewer Service Area Sewered Parcels

Watershed	Parcel Count
Little Pond Watershed	1010
Great Pond Watershed	253
Outside Watershed (1)	87
Total (2)	1350

(1) Outside watershed – recharges directly to Vineyard Sound.

(2) The total number of parcels in the LPSSA required to connect to the sewer system is approximately 1,350 (that number is lower than the number of properties bettered because some of the bettered parcels are undeveloped and some parcels include multiple property units).

4.1.2 Analysis of Little Pond Water Quality Data and Groundwater Data

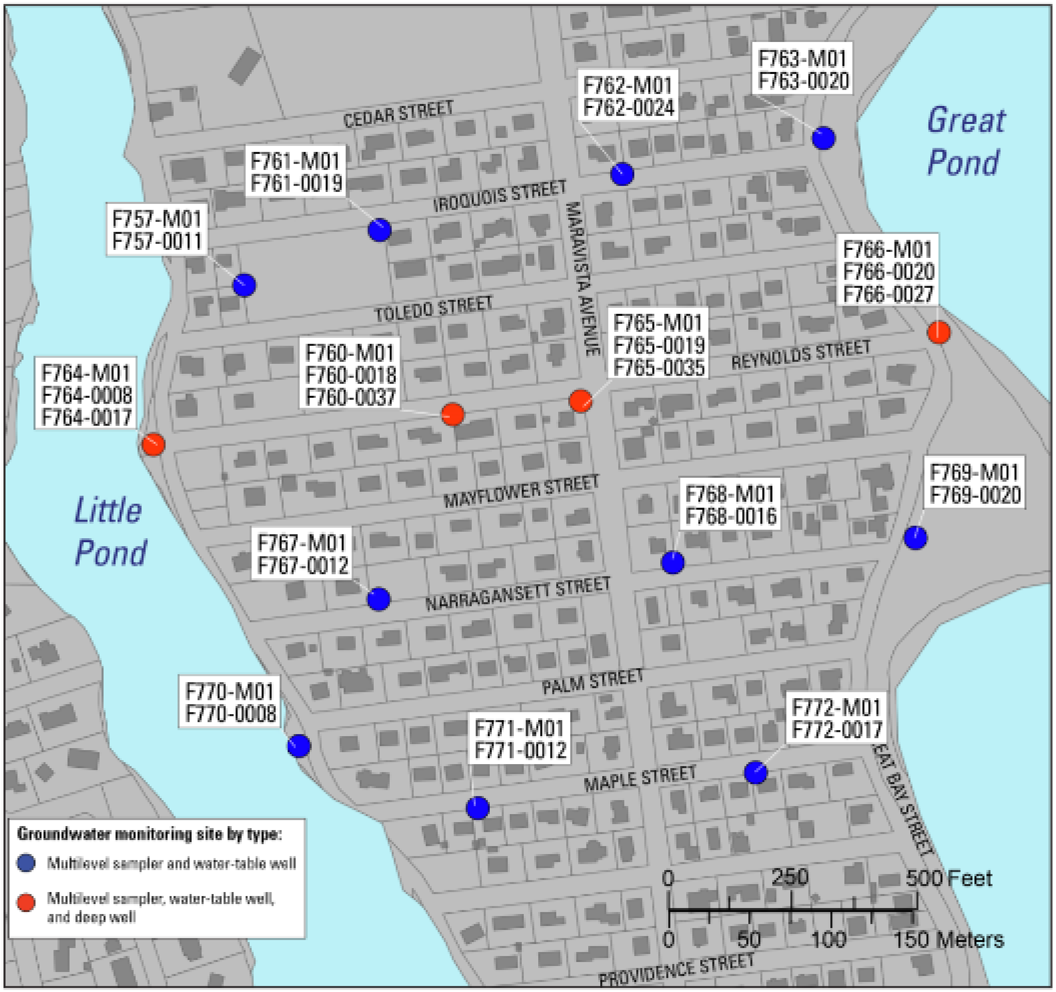
As discussed in Chapter 2, the USGS, the Town of Falmouth, and the United States Environmental Protection Agency (USEPA) have been cooperating in a groundwater sampling and modeling study of the Little Pond watershed. To date, this project has collected data since 2016 through April 2018 to establish baseline groundwater-quality data for the area as the Town moved forward with its sewer implementation.

The following information is from the USGS webpage and the work of Timothy McCobb and Jeffrey Barbaro, et. al. related to the "Assessment of Hydrologic and Water-Quality Changes in Shallow Groundwater Beneath a Coastal Neighborhood Being Converted from Septic Systems to Municipal Sewers (USGS 2019)." https://www.usgs.gov/centers/new-england-water/science/assessment-hydrologic-and-water-quality-changes-shallow?qt-science_center_objects=0#qt-science_center_objects

The study's objectives are as follows:

- "Establish a monitoring network to assess groundwater levels and water quality beneath a densely developed coastal neighborhood undergoing a conversion from septic systems and cesspools to municipal sewers; and
- Develop an understanding of water-quality conditions before and after installation of the sewers."

The effort has included the installation of 18 monitoring wells and 14 multilevel samplers at 14 locations to monitor water levels and groundwater quality beneath the Maravista Peninsula (USGS 2019). Sampling was performed in June 2016, April 2017, and April 2018, with field parameters measured including: specific conductance, dissolved oxygen, pH, alkalinity, and temperature, in addition to lab sampling for nitrate, nitrite, ammonium, and phosphorus, boron, and chloride, amongst others (USGS 2019). The sampling team completed its next round of sampling in June 2019. Figure 4.1 shows the location of the groundwater monitoring well network (USGS 2019).



"F" in site name shorthand for MA-FSW; "M01" in site name indicates 15-port multilevel sampler; For monitoring wells, four digit number after site name reflects depth of well below land surface, in feet (e.g. MA-FSW 764-0017)

Figure 4.1 USGS Groundwater Monitoring Well Locations (USGS 2019)

Once the data are collected, USGS will complete a report documenting their findings and establishing a baseline groundwater condition to be compared against future monitoring.

The Town of Falmouth is also continuing to monitor water quality in the pond itself using the Pond Watchers Program directed by University of Massachusetts School for Marine Science and Technology (SMAST). As reported in Chapter 2, during the last two decades there has been basically no change in water quality in Little Pond.

4.2 Updated Little Pond Total Maximum Daily Load Compliance Plan Approach

4.2.1 Background

On October 6, 2014, the Town of Falmouth submitted the "Amended Targeted Watershed Management Plan for Little Pond." This document outlined the TWMP components for the entire

Little Pond watershed using traditional and non-traditional nitrogen management approaches identified in the 2013 Comprehensive Wastewater Management Plan (CWMP) Report.

The compliance plan approach established in 2014 included the following potential components:

1. Sewer extension to the Little Pond Sewer Service Area.
2. Continued use of conventional septic systems for the non-sewered properties in the Little Pond Watershed.
3. Fertilizer management in compliance with the Town's approved Bylaw.
4. Stormwater management.
5. Shellfish aquaculture.
6. Little Pond inlet opening.
7. Use of enhanced innovative and alternative (enhanced I/A) systems as defined in the Cape Cod Commission (CCC) 208 Plan (CCC, 2014) for the non-sewered properties in the watershed and eco-toilets (composting and urine-diverting).

The above components were then integrated into several options to achieve the nitrogen Total Maximum Daily Load (TMDL). These options for achieving compliance are summarized below:

- First option using sewering, fertilizer and stormwater management, aquaculture, and inlet widening;
- A second option with no inlet opening but increased use of I/A systems.
- A third option with no inlet opening or shellfish and increased use of I/A systems.
- And lastly an option of expanded sewering.

As part of this current Update Report, the various components identified in 2014 are discussed and their relevance for use as part of an Updated TMDL Compliance Approach are identified.

4.2.2 Sewer Extension to the Little Pond Sewer Service Area

As identified in Section 4.1, sewer service to this area was provided in 2016 to 2017 and 95% of the developed properties have connected to the sewer system as of May 2019. It is expected that 100% of the developed properties will be connected to the sewer system by the fall of 2019. The sewer service area remains the same as presented in 2014.

4.2.3 Continued Use of Conventional Septic Systems for Non-Sewered Properties in the Watershed

As part of the 2014 TWMP, two build-out analyses were performed to estimate nitrogen load from properties not proposed to be connected to the LPSSA collection system. For the purposes of the development of the 2014 TWMP, an average of the two buildout methods was used in order to estimate the potential load from these systems. The report estimated the annual load to Little Pond from unsewered properties in the future (buildout) condition to be 4.00 kg/d.

It is anticipated that in the future some improvement to existing septic systems may be required in order to achieve TMDL compliance. At this time it is anticipated that TMDL compliance will be met through the use of the LPSSA sewers, credit for fertilizer and stormwater nitrogen reduction, shellfish aquaculture, and some form of enhanced nitrogen removal through the use of I/A systems at these unsewered properties. The number of properties required to convert to enhanced I/A systems will depend on the measured success of the other strategies (sewers, aquaculture, etc.) in achieving TMDL compliance over time.

It is important to note, however, that two significant parcels of land that could have been developed have been put into conservation and park uses in perpetuity and will therefore never be developed: a former golf driving range [10.7 acres] at the headwaters of Little Pond Stream, and a former golf course [16.69 acres]. Both parcels, instead of contributing nitrogen to the watershed, will now be attenuating nitrogen from the watershed.

4.2.4 Use of Enhanced I/A Systems for the Non-Sewered Properties in the Watershed

As outlined in the 2014 Amended TWMP, the wastewater nitrogen loadings from the non-sewered properties using enhanced I/A systems were estimated using the following steps:

1. Nitrogen load to the groundwater system for the properties in each watershed (not proposed to be sewered) was calculated by multiplying the estimated wastewater flow values for each property with a nitrogen concentration of 13 mg/L (along with several conversion factors) to obtain nitrogen loading values.[1]
2. The wastewater nitrogen load estimate to Little Pond is adjusted utilizing the nitrogen attenuation and pass-through factors identified as part of the MEP analysis.

This resultant wastewater nitrogen loading value was calculated in the 2014 Report to be 1.98 kg/d for all remaining non-sewered, wastewater generating parcels at a projected build-out level with attenuation.

For the purpose of this update, a reduction from 26.25 mg/L to 10 mg/L is assumed as the concentration reduction for these types of systems and then a factor for attenuation (depending on its subwatershed of origin) was applied. The Town has adopted 10 mg/L performance for I/A systems based on the Town's Board of Health regulations (see Appendix 4.2). This was done for a total count of existing non-sewered parcels (166) and equates to a potential removal of 340 kg/yr. This calculation does not take into account the reduction in parcels and nitrogen loading from conversion to parkland described in 4.2.3. The Town is only proposing the installation of I/A systems in this watershed if necessary based on the performance of other alternatives and sewering within the watershed.

[1] This value is identified in the Draft CCC 208 Plan as the expected nitrogen performance of enhanced I/A systems.

4.2.5 Fertilizer Management in Compliance with the Town's Approved Bylaw

As discussed in the 2013 CWMP Report and the 2014 Amended TWMP and this document, the Town passed a Nitrogen Control Bylaw for Fertilizer Management that includes the following main components:

1. Prohibits fertilizer application within 100 feet of resource areas as defined in Falmouth's Wetland Regulations, as well as on impervious surfaces.
2. Prohibits the application of fertilizer from October 16 to April 14.
3. Prohibits fertilizer application during heavy rain in the growing season (April 15 to October 15).
4. The fertilizer application rate to golf courses is limited to 1 lb of nitrogen per 1,000 square feet for the entire growing season, and 85 percent or more of this fertilizer must be in organic, slow release, and water-insoluble form.

Enforcement is through the Town's Department of Marine and Environmental Services. A copy of the bylaw and related information is included in Appendix 3.6, as discussed in Chapter 3.

With this bylaw in place and enforced, a nitrogen fertilizer removal of 25 percent was estimated, as allowed in the CCC 208 Plan (CCC, 2014). Per the Amended 2014 TWMP, the build-out fertilizer load to Little Pond was estimated as 476 kg/yr (653 kg/yr minus 18 kg/yr, with the remainder multiplied by 0.75 to accommodate the 25 percent removal allowed for the bylaw). This resulted in a load of 1.30 kg/d.

It is anticipated as part of this update that this same 25 percent reduction would be applied as part of the approach. For the purposes of this update the non-buildout attenuated load of 631 kg/y was used, equating to a removal of 158 kg/yr, which still leaves approximately 1.30 kg/d of contribution. The summary of these estimates are included in Appendix G of the 2014 Amended TWMP.

4.2.6 Stormwater Management

As part of the National Pollutant Discharge Elimination System (NPDES/MS-4) permitting efforts, the Falmouth Department of Public Works (DPW) provides the following items with respect to stormwater management:

1. Education and outreach.
2. Mapping of all catchment areas (Falmouth Heights and Maravista have been completed).
3. Adding new infiltration basins (leaching catch basins) for roads with inadequate or no stormwater management infrastructure.
4. Eliminating direct outfalls where possible.
5. Installing bioretention where feasible.
6. Incorporating general stormwater improvements as needed at the time of road paving operations.

Future stormwater nitrogen loadings to Little Pond were estimated from information compiled as part of the technical evaluation for Little Pond (MEP, 2006). Appendix G of the 2014 Amended TWMP contains a worksheet summarizing this evaluation. A total attenuated build-out stormwater nitrogen load of 485 kg/yr was estimated as part of the 2014 TWMP, which equates to a load of 1.33 kg/d. As part of the 2014 Amended TWMP, the Town did not elect to take the 25 percent credit allowed by the CCC 208 Plan at that time, but stated it would consider it in the future.

The Town has elected to take advantage of the 25 percent credit as part of this update. The estimated load reduction of the non-buildout load is 115.5 kg/yr, or 25 percent of the attenuated “present” load (462 kg/yr) as identified in that same Appendix G of the TWMP. In addition, as part of the LPSSA sewering project the Town has initiated improvements to its existing stormwater infrastructure in accordance with stormwater management practices outlined above.

4.2.7 Permeable Reactive Barriers (PRBs)

As described in Chapter 3, PRBs have been considered in several of the Town’s watersheds. However, this technology was not identified as part of the 2014 TWMP and a credit for nitrogen removal from PRBs is not being estimated at this time. The Town may consider utilizing a credit in the future following further evaluation.

4.2.8 Shellfish Aquaculture

As discussed in Chapter 3, Section 3.2, the Town has actively investigated the use of shellfish aquaculture in order to achieve TMDL compliance in several watersheds, including Little Pond.

The Town currently has a minimum estimated effective nitrogen removal (nitrogen sink) of 29 kg/yr from Little Pond by applying oyster aquaculture on 0.25 acres of Little Pond. The municipal aquaculture program currently has the capacity to expand to approximately 1.0 acre in Little Pond. The expansion of the program is dependent on the outcome of several pilot projects and funding availability.

Removal of 33 to 53 kg/yr by applying oyster aquaculture on 0.25 acres of Little Pond will be applied as part of the proposed compliance approach.

4.2.9 Little Pond Inlet Widening

The MEP Technical Report for Little Pond (MEP, 2006) investigated possible benefits of increasing the inlet opening (summarized in Tables VIII-2 and IX-3). The effective nitrogen removal for the enlarged inlet is estimated by subtracting the threshold septic load of the Non-Widened Inlet Scenario (summarized in Table VIII-2 at 2.198 kg/d) from the threshold load of the Widened Inlet Scenario (summarized in Table IX-3 at 3.847 kg/d). The difference of 1.65 kg/d is the effective nitrogen removal (nitrogen sink) of the inlet opening and represents the amount of attenuated nitrogen to the pond that would not need to be removed through other methods if the inlet were enlarged.

At this time, the Town is not actively considering inlet widening at this waterbody and is planning to address nitrogen TMDL compliance through other means.

4.2.10 Summary of Updated Compliance Approach

The nitrogen budget, based on Table 7 of the 2014 TWMP for Little Pond (compliance approach without using inlet opening), is summarized in Table 4.2 and is the same as the original second option or "preferred scenario" identified in the 2014 Amended TWMP.

Table 4.2 TWMP Table 7 Nitrogen Budget for Little Pond (Option 2)

Watershed Nitrogen Sources and Sinks(1)	Nitrogen Loading (kg/d)
Wastewater from Sewered Properties	0.00
Wastewater from Unsewered properties (I/A)	1.98
Fertilizer(2)	1.30
Stormwater(2)	1.33
Shellfish Aquaculture(1)	-0.25
Total(1)	**4.36**
Target Threshold Watershed Load (controllable)	**5.36**

(1) Nitrogen sinks are nitrogen removals that occur in the water body.
(2) Loadings for these sources are all attenuated loadings and incorporate the nitrogen removals that occur as the groundwater flows through ponds and streams.

The applicable TMDL number for the nitrogen loading to Little Pond is 5.36 kg/d. This is the Target Watershed Load as summarized in Table 5 of the Little Pond TMDL Document (MassDEP, 2008). Because this Target Watershed Load number is greater than the total nitrogen budget loading of the above table, the Updated Compliance Approach using enhanced I/A systems and no modifications to the inlet meets the TMDL. As was identified in the 2014 TWMP, the TMDL components of Table 5 of the TMDL for Little Pond do not sum properly, and it is believed that this table has a typo or the sum was incorrectly rounded. Reviewers at MassDEP are requested to verify this belief.

As an alternative means of summary, consistent with the approach used by the Water Quality Management Committee for each of the watersheds discussed as part of this update, Table 4.3 has been created to represent the nitrogen loading removals based on "existing" conditions (no buildout) and from the perspective of load reduction vs. load remaining. The following table summarizes the estimated nitrogen removals anticipated for each "system" component as compared to the overall nitrogen removal goal for Little Pond based on the Massachusetts Estuaries Project (MEP) Table VIII-3 total attenuated load threshold of controllable sources. That goal is 5,006 kilograms of total nitrogen per year.

Table 4.3 Nitrogen Budget for Little Pond Updated Compliance Approach

Compliance Component	Nitrogen Loading Reduction (kg/yr)
Sewering	4,141 - 5,252
I/A Systems	340
Fertilizer (25% of fertilizer load)	158
Stormwater (25% of impervious load)	116
Shellfish Aquaculture (uptake)	33 - 53
Shellfish Aquaculture (denitrification)	17 - 27
Total Estimated Reduction	**4,858 – 5,946**
Nitrogen Removal TMDL Goal	**5,006**

In summary, the Town of Falmouth believes that it has taken significant steps to meet the TMDL for Little Pond and remove nitrogen from the watershed. Monitoring of water quality in Maravista over the next five years will show to what degree sewering reduces nitrogen in the groundwater prior to discharge to Little Pond. Monitoring of water quality in Little Pond itself will provide evidence of how long it takes for a shallow estuary to recover.

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5. West Falmouth Harbor Targeted Watershed Management Plan Update

5.1 Current Status of Meeting the Total Maximum Daily Load (TMDL)

5.1.1 Blacksmith Shop Road WWTF Background

The Falmouth Wastewater Treatment Facility (WWTF) was originally constructed in 1986. This original facility was a lagoon secondary treatment system with effluent recharge in the West Falmouth Harbor watershed. In 2001, the Town completed a facilities plan which proposed upgrades to the facility to improve wastewater treatment. In 2005, the treatment process at the WWTF was upgraded to a tertiary treatment process involving sequencing batch reactors (SBR) followed by denitrification filters in order to provide enhanced nitrogen removal.

The location of treated wastewater recharge from the WWTF has varied substantially over the years. Figure 5.1 shows all recharge locations used since the original WWTF began operating, relative to watershed boundaries, monitoring well locations, and other features.

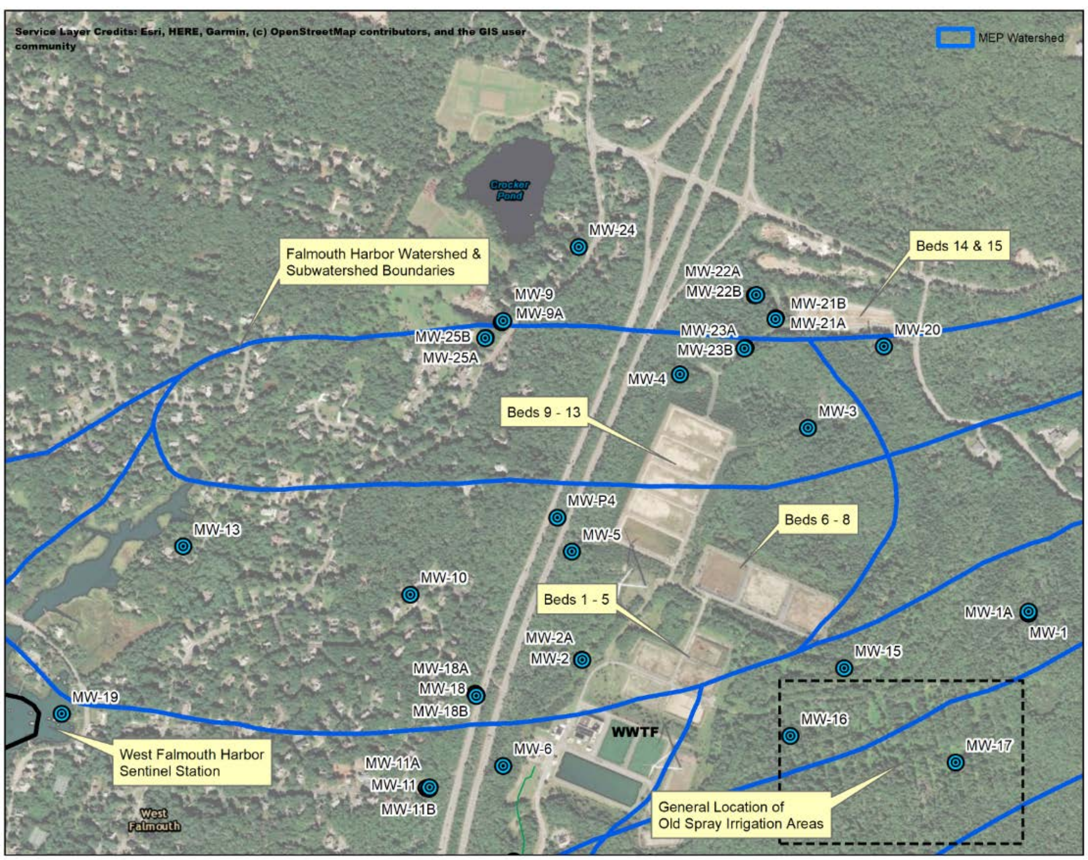

Figure 5.1 Falmouth Main WWTF – Recharge Locations, Monitoring Wells, West Falmouth Harbor Sentinel Location, and Watershed Boundaries

From start-up of the original WWTF in 1986 through 2005, a significant fraction of the recharge was distributed across five spray irrigation beds in the spring through fall. The Town ceased use of spray irrigation for recharge in 2005. In addition, the WWTF has 15 open sand recharge beds which were constructed for effluent recharge in four phases. Effluent recharge to Recharge Beds 1 through 5 was initiated in 1986. Recharge to Beds 6 through 8 began in the 1990s, to Beds 9 through 13 in 2006, and to Beds 14 and 15 in 2017. Beds 14 and 15 were constructed to accommodate effluent flow from the Little Pond Sewer Service Area. Recharge Beds 1 through 13 are located within the West Falmouth Harbor watershed, and Recharge Beds 14 and 15 are located north of the West Falmouth Harbor watershed.

The WWTF currently operates under Modified Groundwater Discharge Permit No. 168-5, effective date December 22, 2015 (2015 Permit). The 2015 Permit allocates effluent flow limits by watershed. The 2015 Permit limits average annual effluent recharge within the West Falmouth Harbor watershed (to beds 1 to 13) to 450,000 gpd, and outside of the West Falmouth Harbor watershed (to beds 14 and 15) to 260,000 gpd.

As part of the preliminary design process for the Little Pond Sewer Service Area Project (LPSSA), an evaluation of the existing facilities at the Blacksmith Shop Road WWTF was conducted to assess the facility's treatment capacity and identify operational limitations. In particular, the evaluation was intended to identify any improvements required to accommodate additional flow and nitrogen load from the LPSSA. The evaluation was summarized in the memorandum titled "Technical Memorandum WW-1, Existing WWTF and Vent Evaluation," prepared by GHD and dated March 2013.

A second evaluation titled "Nitrogen Removal Optimization Planning – Falmouth Flow and Nitrogen Planning," prepared by GHD and completed in September 2013 focused on means of improving the WWTF's ability to meet the low effluent nitrogen best effort level of 3 mg/L. Main process-related recommendations from these evaluations included:

- Installation of additional diffusers in each SBR to increase treatment capacity.
- Addition of a flow-paced sodium hydroxide feed system to provide more reliable alkalinity and pH to the SBRs.
- Installation of standard analyzer assemblies for the denitrification filters to provide continuous analysis of filter influent and effluent nitrate-nitrogen.
- Optimization of the methanol (carbon) injection location.
- Installation of a second blended sludge tank to provide operational flexibility.
- Modifications to the effluent distribution system to improve WWTF effluent flow measurement.

Construction of the recommended modifications was completed in 2015-2016 as part of the LPSSA project.

In 2019, a preliminary evaluation was conducted to assess required upgrades to accommodate proposed flow from the Teaticket/Acapesket Sewer Service Area (TASSA) as well as additional flow from the Existing Sewer Service Area. The evaluation is summarized in the "Teaticket/Acapesket Study Area Technical Memorandum No. 4 – WWTF Evaluation," prepared by GHD and dated April 2019 (Appendix 5.1). The evaluation recommended construction of a third SBR and construction of additional effluent recharge capacity outside of the West Falmouth Harbor watershed. The Wastewater Division has requested funds in the FY 2020 Capital Plan to better delineate the next phase of WWTF upgrades required, including SBR sizing and design requirements, sludge processing technology replacement options, and operations building rehabilitation needs.

5.1.2 WWTF Flow and Nitrogen Removal Performance

The effluent total nitrogen concentration from the original lagoon wastewater treatment facility averaged greater than 23 mg/L from 1994 to 2005.

Since the tertiary treatment facility replaced the original lagoon wastewater treatment facility, i.e., from January 2006 through June 2019, the WWTF's effluent total nitrogen concentration has averaged less than 4.5 mg/L.

Table 5.1 lists WWTF effluent flow and nutrient data for the first two full years after the most recent WWTF improvements were completed in 2016, compared to 2015 Permit limitations.

Table 5.1 Falmouth WWTF Effluent Flow and Nutrient Data for 2017 and 2018, Compared to 2015 Permit Limitations

Effluent Parameter	2017	2018	2015 Permit[1] Discharge Limitations
Average Flow to Recharge Beds 1 through 13 (gpd)	310,526	349,782	450,000
Average Flow to Recharge Beds 14 and 15 (gpd)	78,864	101,066	260,000
Average Total Nitrogen (mg/L)	2.81	2.49	Best efforts to meet an annual average concentration of 3 mg/L (or less)
Average Nitrate – Nitrogen (mg/L)	0.45	0.34	Best efforts to meet an annual average concentration of 3 mg/L (or less)
Cumulative Nitrogen Annual Load within the West Falmouth Harbor Watershed (lb/yr)[2]	2,733 (1,242 kg/yr)	2,733 (1,242 kg/yr)	Best efforts to discharge 4,109 lbs (or less) of nitrogen per year within the West Falmouth Harbor watershed[2]
Average Total Phosphorus (mg/L)	2.7	4.3	NA[3]
Average Ortho-phosphate (mg/L)	2.6	4.3	NA[3]

Notes:

1. Modified Individual Groundwater Discharge Permit No. 168-5', effective date December 22, 2015. (2015 Permit).
2. Not an average; total annual load. The goal is to discharge less than the Cumulative Nitrogen Annual Load. 4,109 lbs/yr = 450,000 gpd x 3 mg/L. It is a coincidence that the cumulative total nitrogen load was the same in 2017 and 2018.
3. The 2015 WWTF Permit does not have an effluent limit for phosphorus but requires monthly phosphorus monitoring.

In this period (2017-2018), effluent flow was lower than the permitted average annual flow limits, in part because LPSSA properties were still connecting to the sewer in this period, and in part because of the build-out allocation in the Permit. All LPSSA properties are expected to be connected by the fall of 2019.

The Wastewater Division reviews new development and redevelopment within the sewer service areas with regard to sewer system capacity. Based on existing flows and projected flows from development and redevelopment planned to-date, the Wastewater Division projects that total average annual flow will reach 80% of the permitted total average annual flow in year 2021 or 2022. The 2015 permit requires that when this point is reached "the permittee shall submit a report to the Department describing what steps the permittee will take in order to remain in compliance with the permit limitations…" Because the Town projects that this point will be reached in year 2021 or 2022, this CWMP/TWMP NPC Update includes plans for accommodating additional flow from TASSA and from existing sewer service areas by: implementing an additional phase of WWTF upgrades, developing additional recharge capacity, and addressing capacity-limited points in the existing collection and transmission system, all in parallel with the proposed design and construction of the TASSA collection system.

In 2017 and 2018, effluent total nitrogen and nitrogen as nitrate concentrations both averaged below the discharge permit's average annual effluent best effort level of 3 mg/L. In February 2019, a mechanical failure in one of the two SBRs necessitated the removal of one SBR from operation while maintenance was completed. During that maintenance event, the SBR manufacturer's representative recommended additional service to the SBR diffusers. This service/repair period impacted WWTF performance from February through May of 2019. After the SBR was returned to service and the WWTF returned to dual tank mode of operation, WWTF performance returned to the normal range of 2.5 – 4.0 mg/L in June 2019.

Based on the effluent flow recharged to beds 1 to 13 and the effluent total nitrogen concentration, the total nitrogen load contributed to the West Falmouth Harbor watershed was 2,733 lbs/yr in both 2017 and 2018 (it is a coincidence that the load was the same both years). That load of 2,733 lbs/yr is 33% lower than the best efforts cumulative annual load level of 4,109 lbs/yr in the 2015 Permit. Due to the issues explained above, the total nitrogen load discharged to the West Falmouth Harbor watershed in 2019 is expected to be greater than the best efforts load level.

This data demonstrates that the upgraded WWTF is capable of reducing effluent total nitrogen concentration to the best effort level of 3 mg/L for extended periods of time (in this case, for more than two years). However, like any WWTF, this WWTF is potentially subject to unforeseen conditions that can impact performance. Capital funds are being requested in FY 2020, 2021, and 2022 to evaluate, design, and construct a third SBR (and complete other WWTF upgrades) to provide greater operational flexibility and to accommodate additional flow and load from future sewer service areas.

5.1.3 Monitoring Wells

Groundwater monitoring requirements for the WWTF in the 2015 WWTF Permit include quarterly sampling for nitrogen and phosphorus through a groundwater monitoring network comprised of 17 monitoring wells (well locations shown on Figure 5.1). The groundwater monitoring network is summarized in Table 5.2.

As indicated in Table 5.2, six of the wells are intended to monitor up and downgradient of recharge beds 1 through 13, within the West Falmouth Harbor watershed, and 11 of the wells are intended to monitor up and downgradient of the newest Recharge Beds 14 and 15, outside the West Falmouth Harbor watershed.

Table 5.2 Falmouth WWTF Groundwater Monitoring Network

Effluent Recharge Location	Up-Gradient Wells	Down-Gradient Wells	Well Locations – By Watershed
Recharge Beds 1 - 13	MW-1a	MW-2A MW-P4 MW-10 MW-13 MW-19	• West Falmouth Harbor
Recharge Beds 14 - 15	MW-20 (GHD-1)	MW-21A (GHD-4A) MW-21B (GHD-4B) MW-22A (GHD-5A) MW-22B (GHD-5B) MW-23A (GHD-6A) MW-23B (GHD-6B) MW-25A (GHD-3A) MW-25B (GHD-3B) MW-24 (GHD-2) MW-4	• West Falmouth Harbor[1] • Crocker Pond • Buzzards Bay

Notes:

1. Groundwater modeling for Open Beds 14 and 15 indicates that all of the effluent recharged at Recharge Beds 14 and 15 will ultimately surface in Buzzards Bay and none of the flow will go to West Falmouth Harbor. Several groundwater monitoring wells are included in the West Falmouth Harbor watershed to validate this modeling conclusion.

Total nitrogen and total phosphorus concentration data collected from the Recharge Beds 1 through 13 monitoring network is summarized in the following Figures 5.2 and 5.3.

Figure 5.2 shows that total nitrogen concentration in the downgradient wells increased after the original lagoon WWTF began discharging and then decreased in recent years after the tertiary WWTF began operating. The timing, consistency, and scale of that trend varies from well to well based on location of the well relative to historic and current discharges. (Figure 5.1 shows locations of monitoring wells relative to recharge locations and other features.)

For example, in MW-2A which is located closest to (immediately downgradient of) the original Recharge Beds 1 through 5 (and downgradient of the old spray irrigation areas), the total nitrogen concentration was greater than 7 mg/L during many of the monitoring events from 1987 to 2005, but has declined to less than 2 mg/L in recent years. Total nitrogen concentration in MW-19, which is furthest downgradient from the recharge (immediately adjacent to West Falmouth Harbor), began to increase in 2001, about 15 years after the discharge began from the original lagoon WWTF, peaked at > 9 mg/L in 2006, and currently remains > 4 mg/L. Total nitrogen concentrations in all wells downgradient from beds 1 through 13—other than MW-19—have been below 2 mg/L for more than one year.

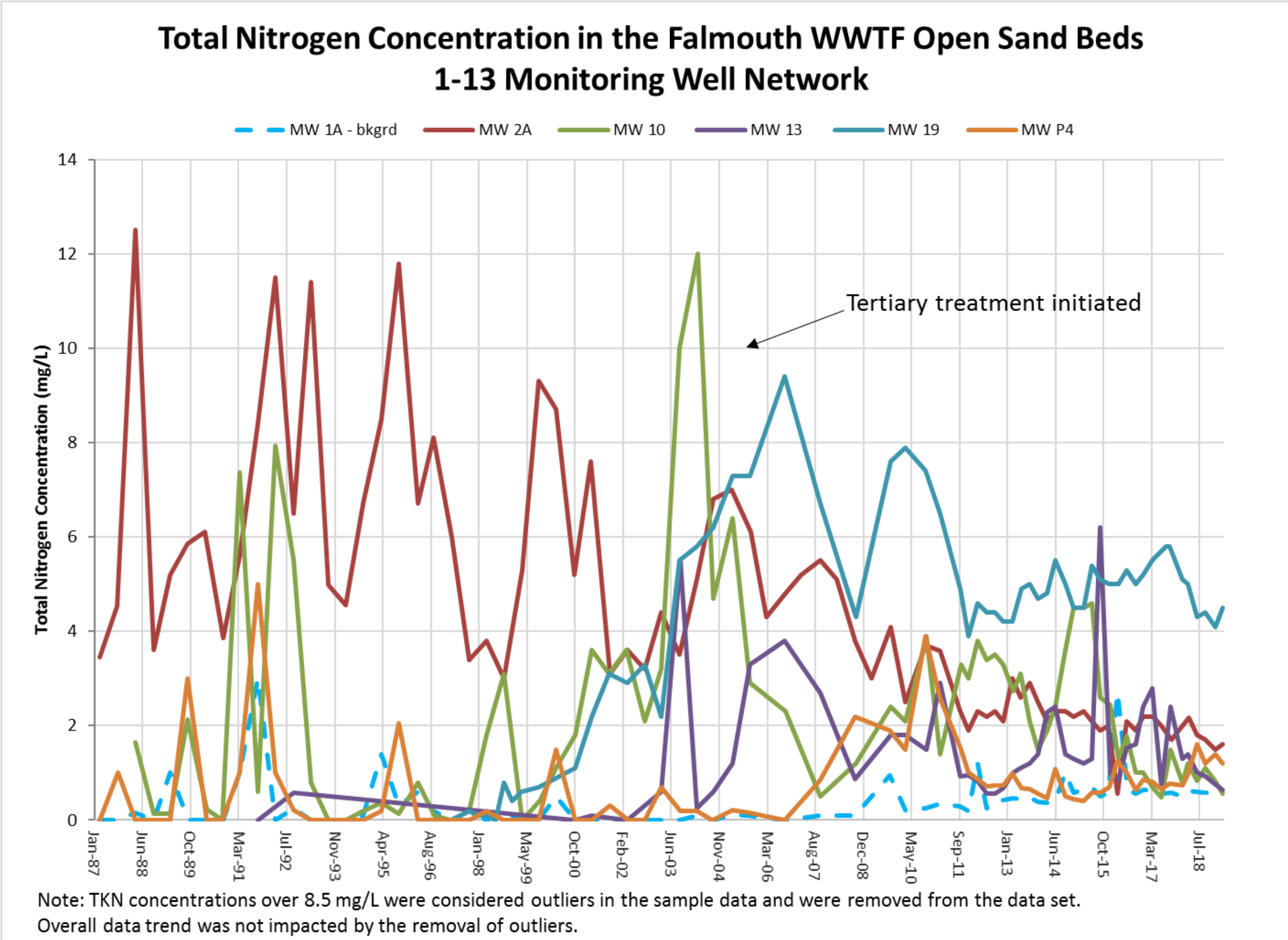

Figure 5.2 Total Nitrogen Concentration in the Falmouth WWTF Recharge Beds 1 through 13 Monitoring Well Network

In Figure 5.2, MW-1A, the background or upgradient monitoring well is shown with a dashed line. It can be seen that background nitrogen concentration appears to have increased slightly over time, likely due to upgradient septic systems and other watershed impacts. The total nitrogen concentration in the background well has averaged >0.5 mg/L over the past five years and has in some samples exceeded 1 mg/L.

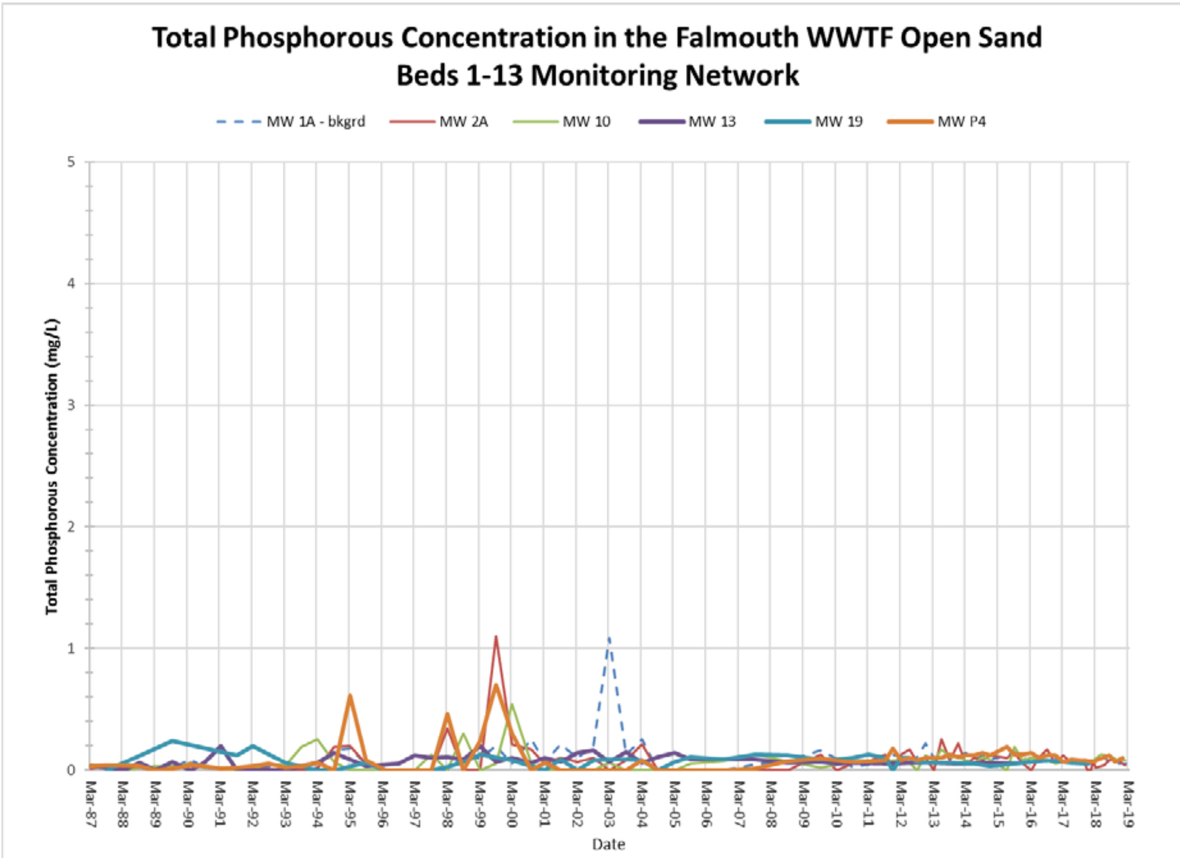

Figure 5.3 Total Phosphorus Concentration in the Falmouth WWTF Recharge Beds 1 through 13 Monitoring Well Network

Figure 5.3 demonstrates that though total phosphorus is present in low concentrations in the WWTF effluent (2.7-4.3 mg/L, see Table 5.1), phosphorus has not regularly been detected in concentrations above background levels in the monitoring well network downgradient of Recharge Beds 1 through 13.

Total nitrogen and total phosphorus concentration data collected from the Recharge Beds 14 and 15 monitoring network is summarized in Figures 5.4 and 5.5. Because Beds 14 and 15 have only received effluent from the tertiary WWTF (after upgrades were completed in 2016), their monitoring well network has not been influenced by discharge from the original lagoon WWTF, only by background conditions in the groundwater and by discharge from the upgraded WWTF.

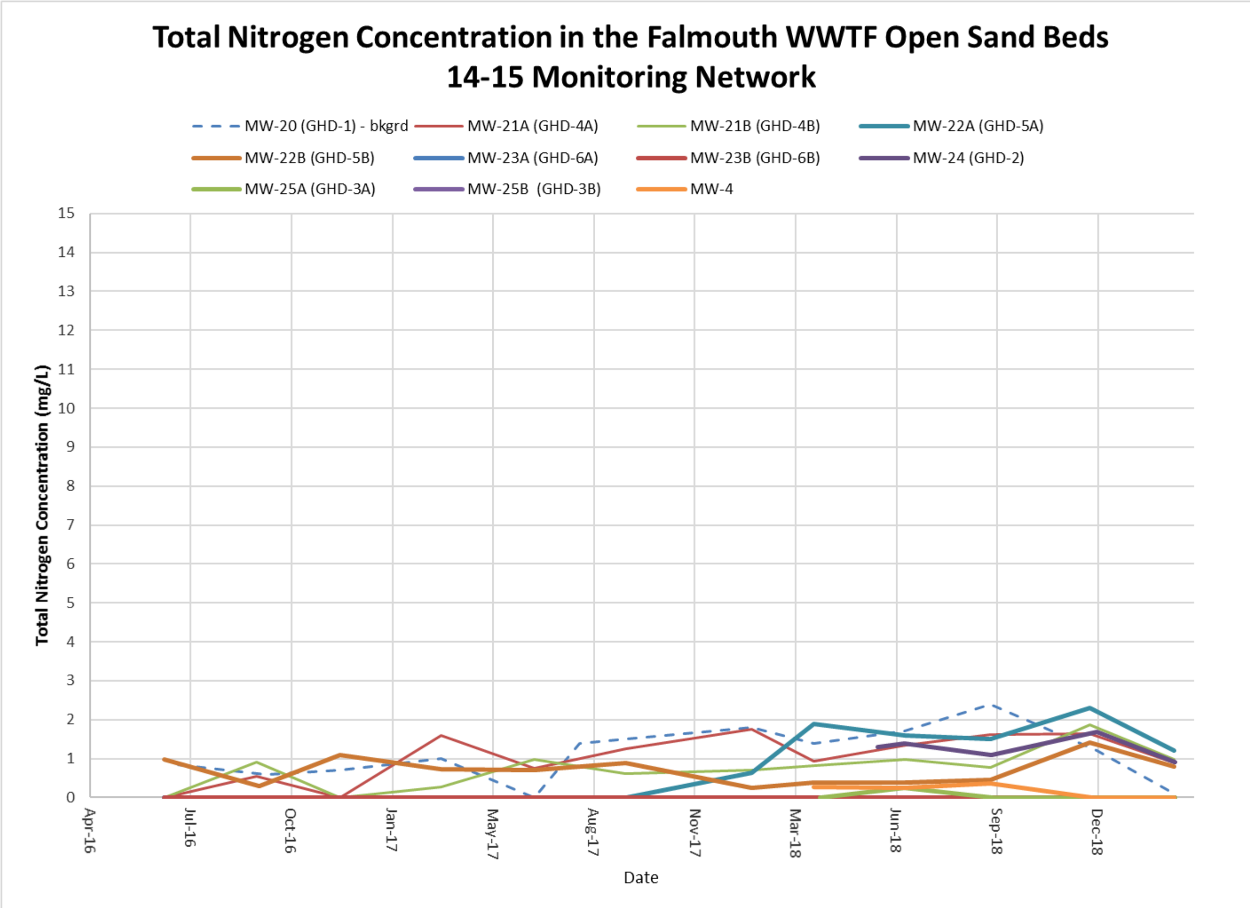

Figure 5.4 Total Nitrogen Concentration in the Falmouth WWTF Recharge Beds 14 and 15 Monitoring Well Network

In Figure 5.4, one can see that concentrations of total nitrogen have increased slightly in some of the downgradient wells (including MW-21A, MW-21B, MW-22A, and MW-22B, the downgradient wells closest to Beds 14 and 15) since discharge to Beds 14 and 15 began in 2017.

MW-20, the upgradient (background) monitoring well, is shown with a dashed line in Figure 5.4. It can be seen that total nitrogen concentration in this well has been above detection in most samples and has frequently been >1 mg/L (one sample >2 mg/L). This indicates that this well, and therefore probably other wells in this area, is impacted by other nitrogen sources upgradient of the WWTF discharge, for example, upgradient septic systems.

Total nitrogen concentration has remained below detection in wells MW-23A and MW-23B to date, which indicates that these wells have not been impacted by either the effluent discharge to Beds 14 and 15 or by other upgradient nitrogen sources. Total nitrogen concentration in MW-4, an older well north of Beds 1 through 13 and southwest of Beds 14 and 15 has been below or near the detection limit in all samples collected since Beds 14 and 15 began operating. The lack of nitrogen impact on MW-23A, MW-23B, and MW-4 helps to confirm the assumption that, as shown by the watershed lines on Figure 5.1, Recharge Beds 14 and 15 are located outside of the West Falmouth Harbor watershed.

MW-24 has contained total nitrogen concentrations ranging from 0.82 to 1.4 mg/L since sampling of this well began in May 2018 (initial sampling of this well was delayed because of difficulty locating the well because the gas company covered it after working in the area and the well had a non-ferrous cover).

Since groundwater in this region travels 1 to 2 feet per day horizontally and MW-24 is >1,400 feet from the nearest edge of recharge beds, the soonest the impact from Beds 14 and 15 could be seen at this location would be about 1.9 years (conservatively assuming 2 feet per day horizontally and not accounting for additional time to move vertically) from start of recharge. Recharge to Beds 14 and 15 first began in January of 2017 (and was intermittent, as recharge is rotated among beds), so the soonest that MW-24 could be expected to see a potential effect of recharge to Beds 14 and 15 would have been approximately December 2018. For these reasons, it is believed that the nitrogen concentrations observed to date in MW-24—like those in upgradient background well MW-20—are due to other watershed nitrogen sources, most likely septic systems. Nitrogen concentrations in MW-25A and MW-25B, south of MW-24 have been near or below detection to date (similar to MW-23A and MW-23B to the east).

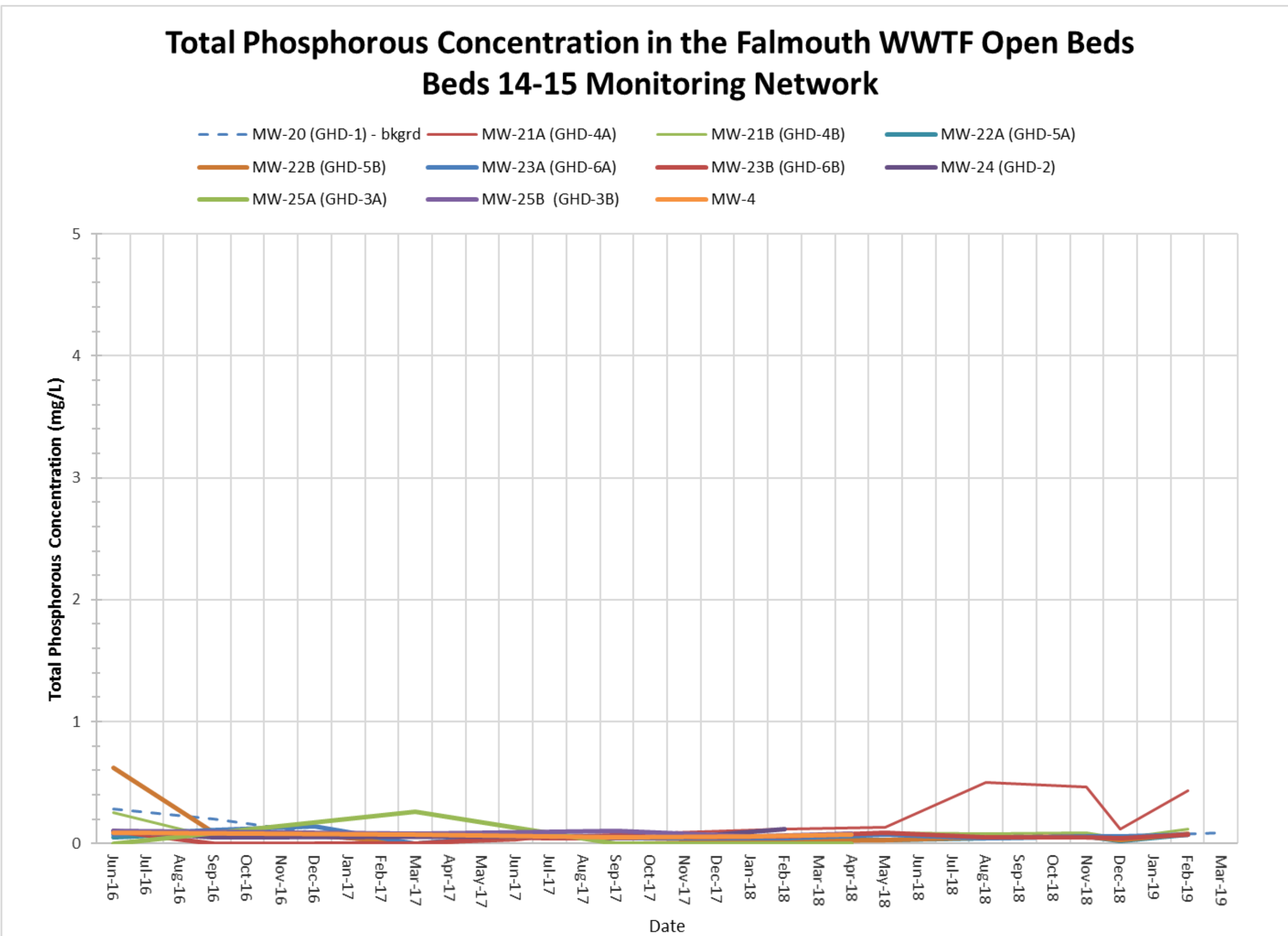

Figure 5.5 Total Phosphorus Concentration in the Falmouth WWTF Recharge Beds 14 and 15 Monitoring Well Network

As with Figure 5.3, Figure 5.5 demonstrates that though total phosphorus is present in low concentrations in the WWTF effluent (2.7-4.3 mg/L, see Table 5.1), phosphorus is not detected in concentrations above background levels in any downgradient monitoring well other than MW-21A and MW-21B. MW-21A and MW-21B are located on the berm on the west (downgradient) side of recharge Bed 14, approximately 20 feet from the edge of Bed 14. MW-21A is screened at the top of the groundwater table and MW-21B is screened 30 feet below MW-21A.

MW-21A and MW-21B were located and screened in this way to detect the effect of the discharge to Beds 14 and 15 as it initially contacts groundwater, and to observe the change in that effect over a short vertical distance (30 feet) in the water table. Since discharge to Beds 14 and 15 began, the concentration of total phosphorus in the groundwater at MW-21A (at the top of the water table) has increased from approximately 0.06 mg/L to approximately 0.5 mg/L. In MW-21B, screened 30 feet below MW-21A at the same location, the highest total phosphorus concentration to date was approximately 0.16 mg/L. In MW-22A and MW-22B, screened at the same elevations as MW-21A and MW-21B, but just 200 feet downgradient, total phosphorus concentrations remain near the detection limit (0.05 mg/L). These results are consistent with the expectation that phosphorus would take a long time (hundreds of years) to migrate with the groundwater due to the tendency of phosphorus to adsorb to soil particles.

Key Findings of Groundwater Monitoring Well Data

- Recharge Beds 1 through 13 Groundwater Monitoring Network
  - Total nitrogen concentrations in these wells increased after recharge from the original lagoon WWTF began in 1986 and have decreased to less than 2 mg/L in recent years since the tertiary WWTF began operating at the end of 2005. The partial exception to this trend is MW-19, which is the monitoring well furthest from the WWTF recharge and still contains a total nitrogen concentration >4 mg/L. It is expected that total nitrogen concentrations in MW-19 will decline over time as the plume from the original lagoon WWTF (some of which began as far away as the far edge of the spray irrigation areas, about 6,500 feet east of MW-19). Since it took approximately 15 years for the effects of discharge from the lagoon WWTF to appear at MW-19, it may take 15 years or more for that effect to dissipate.
  - Total phosphorus concentrations do not appear to have increased in the monitoring well system over background levels, even after 20 years of discharge from the original lagoon WWTF and an additional more than 13 years now from the tertiary WWTF.
- Recharge Beds 14 and 15 Groundwater Monitoring Network
  - Measured total nitrogen concentrations in some of the monitoring wells downgradient of Recharge Beds 14 and 15 have increased slightly since initiation of effluent recharge to Recharge Beds 14 and 15. A similar increase is seen in the upgradient (background) monitoring well, indicating the potential influence of non-WWTF-related nitrogen sources, such as upgradient septic systems and fertilizer use on some wells.
  - Since initiation of effluent recharge at Recharge Beds 14 and 15, total phosphorus concentrations in the monitoring well systems do not appear to have increased in any of the monitoring wells except for the two wells located only 20 feet horizontally from the recharge beds. The phosphorus concentration reduction between the shallow and the deeper well at

this location and between this location and all other downgradient wells confirms the significant attenuation of phosphorus (via adsorption to soil particles) over a short distance in the water table.

5.1.4 West Falmouth Harbor Water Quality Data

Water quality field data has been collected in West Falmouth Harbor since the early 1990's. As part of the Massachusetts Estuaries Project, a network of eight surface water monitoring stations were established by the University of Massachusetts Dartmouth SMAST. Data collected at the stations was used to develop SMAST's Linked Watershed-Embayment Model, which was used to set the Total Maximum Daily Load (TMDL) for West Falmouth Harbor. The Snug Harbor station (WFH-5) was selected as the "sentinel station" for West Falmouth Harbor. The TMDL Report identified a target total nitrogen concentration for the sentinel station of 0.35 mg/L, which if achieved would be expected to permit the entire West Falmouth Harbor system to meet water quality goals. Subsequent to the MEP project, water quality data has been collected in West Falmouth Harbor by the Buzzards Bay Coalition. In addition, since 2015, the Town of Falmouth has been contracting for water quality data collection at the sentinel station as required by the 2015 Permit. The 2015 WWTF Permit requires monitoring at the "sentinel station" twice monthly in July, August, and September for nitrogen and other parameters. Figure 5.6 shows the total nitrogen data collected at the sentinel station from 2014 to 2018 in accordance with the 2015 Permit.

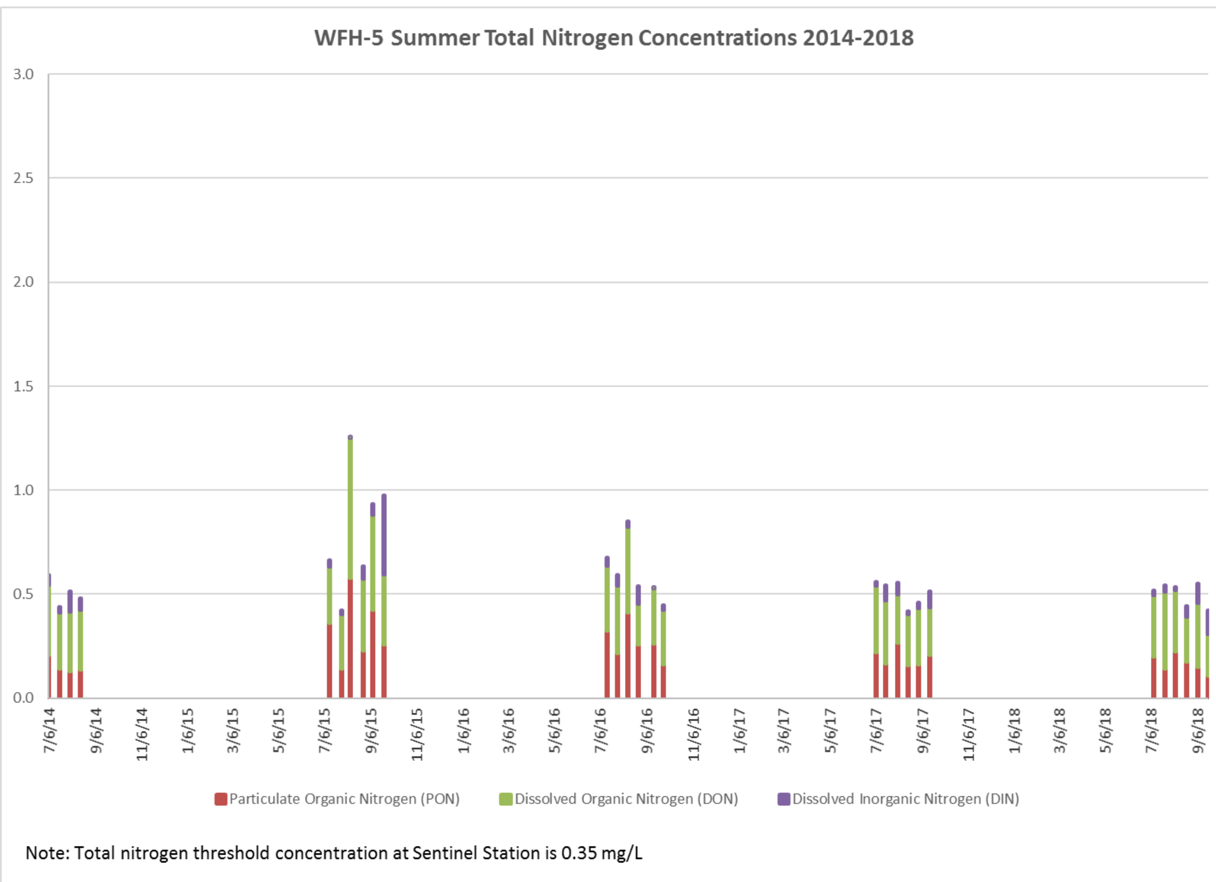

Figure 5.6 Sentinel Station WFH-5 Nitrogen Concentration 2014-2018

Key Findings of West Falmouth Harbor Water Quality Data

- West Falmouth Harbor water quality field data has indicated a general decrease in total nitrogen concentration at the sentinel station since approximately 2010. However, total nitrogen concentrations at the sentinel station are still above the target concentration of 0.35 mg/L.
- Initially it was estimated that the nitrogen plume from the original lagoon WWTF would take approximately seven to 10 years to flush out of the West Falmouth watershed. However, this projection was based simply on estimated groundwater time of travel from the recharge beds to the harbor. The closest edge of the closest open sand bed is about 3,800 feet and the far edge of the furthest open sand bed is about 5,200 feet from the closest shoreline of West Falmouth Harbor. The average horizontal groundwater migration rate in this area is generally 1 to 2 feet per day. So, at a rate of 1.5 feet per day, groundwater would reach the Harbor from the closest point in seven years and from that furthest point in 10 years. However, this projection did not take into account vertical migration distance/time, the location of the spray irrigation areas (furthest point in spray irrigation is about 6,500 feet from the harbor, which would take 12 years to traverse at 1.5 feet per day horizontally), or dispersion/retardation of the movement of some wastewater constituents in the subsurface. As discussed in Section 5.1.3, it took approximately 15 years for the effect of the original lagoon WWTF recharge to reach MW-19, the well located furthest from the WWTF and right on the nearest shore of West Falmouth Harbor. Therefore, it may take 15 years or more for the remnants of the plume from the original WWTF to reach West Falmouth Harbor, and even longer for the reduction in groundwater nitrogen input to manifest itself in reduction in West Falmouth Harbor nitrogen concentrations, because of nitrogen stored in sediments. The Town will continue to monitor nitrogen concentrations in groundwater wells and West Falmouth Harbor.

5.1.5 Crocker Pond Data and Herring Brook Consideration

Groundwater modeling and particle tracking of treated water recharge at the Recharge Beds 14 and 15 site, conducted in 2011, indicated that a portion of the recharged water could pass through Crocker Pond, a small freshwater kettle pond west of Recharge Beds 14 and 15, which is phosphorus-limited. An evaluation conducted by EcoLogic in 2013 indicated that the aquifer soils downstream of Recharge Beds 14 and 15 have a large capacity to sequester phosphorus from the groundwater and significantly retard migration of phosphorus downstream to the kettle pond. The absorptive capacity of the soil was estimated to be 100 to 1,400 years of phosphorus discharge, depending on the level of effluent treatment.

The 2015 WWTF Permit requires surface water sampling in Crocker Pond at two depths in July, August, and September of each year. Analytical parameters include total phosphorus, total nitrogen, total inorganic nitrogen, and total organic nitrogen.

Baseline data has been collected at two depths in Crocker Pond since the summer of 2016. Future data will be compared to the baseline to assess potential nutrient impacts to Crocker Pond from recharge to Recharge Beds 14 and 15. Crocker Pond baseline data collected from 2016 to 2018 for total nitrogen and total phosphorus is summarized in Table 5.3. Due to variability of summer conditions (temperature, rainfall, etc.) for the limited amount of data that has been collected so far, the data is presented as a baseline range for the pond as opposed to a trend. As more data is collected in future years a trend line for both nutrients can be established.

Table 5.3 2016 – 2018 Crocker Pond Total Nitrogen and Total Phosphorus Baseline Data Summary

Parameter	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
0.5 Meter Depth – Concentration Range	0.30 – 0.90	0.01 – 0.03
7 Meter Depth – Concentration Range	0.38 – 1.88	0.03 – 0.20

Additional modeling and evaluations conducted in 2013 summarized in GHD Technical Memorandum 12 dated July 30, 2013 indicated that a small fraction of the discharge to Beds 14 and 15 could, after passing through Crocker Pond, flow towards Herring Brook to the north. The 2015 WWTF Permit states that three additional monitoring wells would be installed northwest of Crocker Pond if "the quarterly monitoring of the groundwater monitoring wells GHD-3A and B [MW-25A and MW-25B] and GHD-2 [MW-24] show a Boron concentration of >6uM or a nitrate concentration >0.75 mg/L." The intent of these future wells would be to monitor groundwater downgradient of Crocker Pond flowing in the direction of Herring Brook to identify any potential impact to Herring Brook. As discussed in Section 5.1.3, concentration of nitrate has been >0.75 mg/L in MW-24 since it was initially sampled, and nitrate concentrations in MW-25A and MW-25B have been near or below the nitrate detection limit (0.25 mg/L) to date, (similar to MW-23A and MW-23B to the east). As stated above, due to the distance from Recharge Beds 14 and 15 to MW-24, the estimated time of travel and the timing of commencement of discharge to Beds 14 and 15, it is believed that the nitrogen concentrations observed to date in MW-24—like those in upgradient background well MW-20—are due to other watershed nitrogen sources, namely septic systems. Nutrient concentrations in all three wells will continue to be monitored quarterly.

The University of Massachusetts Dartmouth SMAST conducted an evaluation in 2013 of the potential effect of recharge to Beds 14 and 15 on downgradient wetlands and on Buzzards Bay. The study concluded that it was unlikely that downgradient wetlands would be impacted or that the anticipated maximum nitrogen load from Recharge Beds 14 and 15 would be detectable in Buzzards Bay.

Key Findings of Crocker Pond Data and Consideration of Herring Brook

- Baseline data has been collected at two depths in Crocker Pond since the summer of 2016. Future data will be compared to the baseline to assess potential nutrient impacts to Crocker Pond from discharge to Recharge Beds 14 and 15.
- Data from MW-25A, MW-25B, MW-24, and Crocker Pond will be evaluated over time to determine the need for additional wells or monitoring for potential impact to Herring Brook.

5.2 Updated West Falmouth Harbor TMDL Compliance Plan Approach

5.2.1 Background

In 2001, the Town of Falmouth completed its Comprehensive Plan for Wastewater Management in West Falmouth Harbor, and a primary component of that work was the upgrade of the Blacksmith Shop Wastewater Treatment Facility to a tertiary treatment facility for nitrogen removal. The tertiary treatment facility began operating in 2006. Process upgrades to that tertiary treatment facility were completed in 2016. The Groundwater Discharge Permit (GWDP) issued for the WWTF in 2015 includes recharge flow and nitrogen loading restrictions intended to provide the basis for achieving Nitrogen TMDL compliance in West Falmouth Harbor.

Based on the Massachusetts Estuaries Report's Table VIII-3 for West Falmouth Harbor, approximately 8,472 kg/yr needs to be removed from the system in order to meet the West Falmouth Harbor TMDL.

Within the West Falmouth Harbor watershed, the Town has been evaluating all of and is implementing some of the following nitrogen management approaches in order to achieve TMDL compliance:

- Implementation of improvements to the WWTF;
- Innovative and alternative septic systems;
- Aquaculture;
- Fertilizer reduction;
- Stormwater management improvements; and
- Use of Permeable Reactive Barriers (PRBs).

5.2.2 Blacksmith Shop Road WWTF

As discussed in Section 5.1.2, WWTF effluent data have demonstrated that the upgraded WWTF is capable of reducing effluent total nitrogen concentration to the best effort level of 3 mg/L for extended periods of time (years). However, like any WWTF, this WWTF is potentially subject to unforeseen conditions that can impact performance. Capital funds are being requested in FY 2020, 2021, and 2022 to evaluate, design, and construct a third SBR (and complete other WWTF upgrades) to provide greater operational flexibility and to accommodate additional flow and load from future sewer service areas. Based on WWTF performance in 2017 and 2018 and with the planned additional WWTF improvements, it is expected that the annual nitrogen load from the Blacksmith Shop Road WWTF will, with the other nitrogen management approaches listed, meet the West Falmouth Harbor TMDL.

In the 2001 MEP report, it was estimated that 10,013 kg of nitrogen was being discharged per year from the original WWTF to the West Falmouth watershed. At the permitted best effort average annual effluent total nitrogen concentration of 3 mg/L and the permitted average annual flow of 450,000 gallons per day to the West Falmouth Harbor watershed, the annual load from the upgraded tertiary WWTF to the West Falmouth Harbor watershed is reduced to 1,868 kg/yr (4,109 lbs/yr). This is a reduction in load from the WWTF to the watershed of 8,145 kg/yr.

5.2.3 Use of Enhanced Innovative and Alternative (I/A) Systems

As discussed in Chapter 3, the Town has collaborated with the Buzzards Bay Coalition and others to implement a pilot program to install innovative and alternative septic systems on 25 properties in close proximity to West Falmouth Harbor. This is estimated to account for a 92 kg/yr reduction in nitrogen.

5.2.4 Aquaculture

The Town re-established an oyster reef within West Falmouth Harbor, as described in Chapter 3. At this time there is no plan to harvest the oysters in order to achieve a level of nitrogen removal, so the reef is simply a demonstration of habitat restoration.

5.2.5 Fertilizer Management in Compliance with the Town's Approved Bylaw

As discussed in Chapters 3 and 4, Falmouth enacted a fertilizer bylaw, based on the Cape Cod Commission 208 Plan update. As a result of this, communities are afforded a 25% credit for nitrogen removal. Based on Table IV-4 of the MEP report, the West Falmouth Harbor System receives approximately 365 kg/yr of nitrogen from fertilizer, which after applying a 25% credit would be reduced by 91 kg/yr.

5.2.6 Stormwater Management

The Town will continue best management practices to address stormwater impacts and consider the implementation of nitrogen-reducing options where feasible as discussed in Chapter 3. The implementation of these practices in Falmouth allows the Town to receive another 25% reduction of nitrogen credit per the CCC 208 Plan. This 25% reduces the impervious surface loads from approximately 1,139 kg/yr of nitrogen to 854 kg/yr (285 kg/yr less).

5.2.7 Permeable Reactive Barriers

The Town conducted some preliminary evaluations for the use of the PRBs within the West Falmouth Harbor watershed. However, a suitable location was not identified in this watershed and at this time the Town is not considering further use of this nitrogen removal approach in West Falmouth Harbor.

5.2.8 Updated Compliance Plan Approach Summary for West Falmouth Harbor

The following table outlines the current compliance plan approach established for West Falmouth Harbor to achieve Nitrogen TMDL compliance within the estuary.

Table 5.4 Nitrogen Budget for West Falmouth Harbor Updated Compliance Approach

Compliance Component - Nitrogen Removal Approach	Estimated Nitrogen Loading Reduction (kg N/yr)
Wastewater Treatment Improvement	8,145
I/A Systems	92
Fertilizer (25% of fertilizer load)	91
Stormwater (25% of impervious load)	285
Aquaculture	0
Total Estimated Reduction	**8,613**
Nitrogen Removal TMDL Goal	**8,472**

As demonstrated in Table 5.4, based on this approach, the Town is expected to be able to meet the requirement for Nitrogen TMDL compliance for West Falmouth Harbor with the WWTF improvements alone. However, the Town continues to move forward with other nutrient mitigation strategies as well, in order to provide the greatest flexibility to manage nitrogen and possible population growth within the watershed.

6. Great Pond Watershed Planning Scenario

6.1 Current Status of Meeting the TMDL

6.1.1 Great Pond TMDL

The Great Pond System watershed is sub-divided into 24 sub-watersheds, one of which is the Coonamessett River (see section6.3). The Total Maximum Daily Load (TMDL) Report presents a target threshold watershed load for two waterbodies in the Great Pond System—Great Pond and Perch Pond. The TMDL allocation outlines the maximum nitrogen loading that the waterbody may receive while maintaining its water quality standards and designated uses. Table 6.1 outlines the TMDL for the two waterbodies.

Table 6.1 Great Pond and Perch Pond Total Maximum Daily Loads (TMDL)

Major Watershed	Waterbody Segment[1]	Description[1]	TMDL (kg/d)[2]	Estimated Equivalent Annual Load Target (kg/y)
Great Pond System	Great Pond	From the inlet of Coonamessett River to Vineyard Sound (excluding Perch Pond), Falmouth	22.50	8,213
	Perch Pond	Connects to northwest end of Great Pond, west of Keechipam Way, Falmouth	0.59	215

Sources:

1. Massachusetts Year 2016 Integrated List of Waters.
2. 'Table 5 – The Total Maximum Daily Loads (TMDL) for the Great, Green, and Bournes Pond Embayment Systems, represented as the sum of the calculated target threshold loads (from controllable watershed sources), atmospheric deposition, and sediment sources (benthic flux)' of the 'Final Great, Green and Bournes Pond Embayment Systems Total Maximum Daily Loads for Total Nitrogen' (report #96-TMDL-6 Control #181.0), dated April 6, 2006.

The largest source of controllable nitrogen in the Great Pond watershed comes from on-site septic systems. Water usage data provided by the Falmouth Water Department, for the years 2014 through 2016, was used to develop estimated per-parcel nitrogen loads for properties within the Great Pond watershed. The nitrogen load evaluation methodology is outlined in "TASA TM-1 – Teaticket / Acapesket Study Area, Flow, and N Load Evaluation," prepared by GHD and dated April 2019 (Appendix 6.1). To account for the variability in effluent nitrogen concentrations and future water usage, a per parcel septic nitrogen load range was developed for estimating removals to achieve TMDL compliance. The nitrogen load for each watershed calculated using parcel specific water usage data falls within the nitrogen load range presented in this document.

6.1.2 Little Pond Sewer Service Area

A portion of the Great Pond watershed has been sewered as part of the Little Pond Sewer Service Area (LPSSA) project. As discussed in Chapter 4, construction of the collection system serving the LPSSA was completed in April 2017. LPSSA includes 253 parcels in the Great Pond watershed. As of May 2019, 95% of the parcels in LPSSA have been connected to the sewer system.

The nitrogen load removal through the sewering of these parcels is estimated at 1,037 to 1,316 kg/yr.

6.2 Conceptual Sewer Plans for Great Pond Watershed

6.2.1 Service Area, Wastewater Flow, and Nitrogen Removal

The Town has undertaken the conceptual design of the Teaticket Acapesket Sewer Service Area (TASSA) collection system in order to reduce the septic nitrogen load to the Great Pond watershed. The system would collect wastewater from 1,791 parcels and convey the flow to the Falmouth WWTF through a combination of gravity and low-pressure sewers, and includes nine new wastewater lift stations and one booster lift station. In the conceptual layout, 1,289 of the parcels are located in the Great Pond watershed. The nitrogen load removal in Great Pond through sewering of TASSA is estimated at 6,142 to 7,789 kg/yr.

This sewer extension would significantly reduce the nitrogen loading to Great Pond. It will be augmented by additional removals provided by the non-traditional nitrogen removal technologies, as discussed later in this chapter.

6.2.2 Collection and Transmission System Layouts

The conceptual TASSA is illustrated in Figure 6.1. The conceptual collection system is divided into eleven sewersheds and configured to maximize the number of properties served by gravity sewer. In the conceptual layout nine sewersheds are serviced by a new lift station, and two sewersheds connect into existing lift stations (Alphonse Street Lift Station and Spring Bars Road Lift Station). Ten of the sewersheds are located partially or completely in the Great Pond watershed, as shown in Figure 6.2.

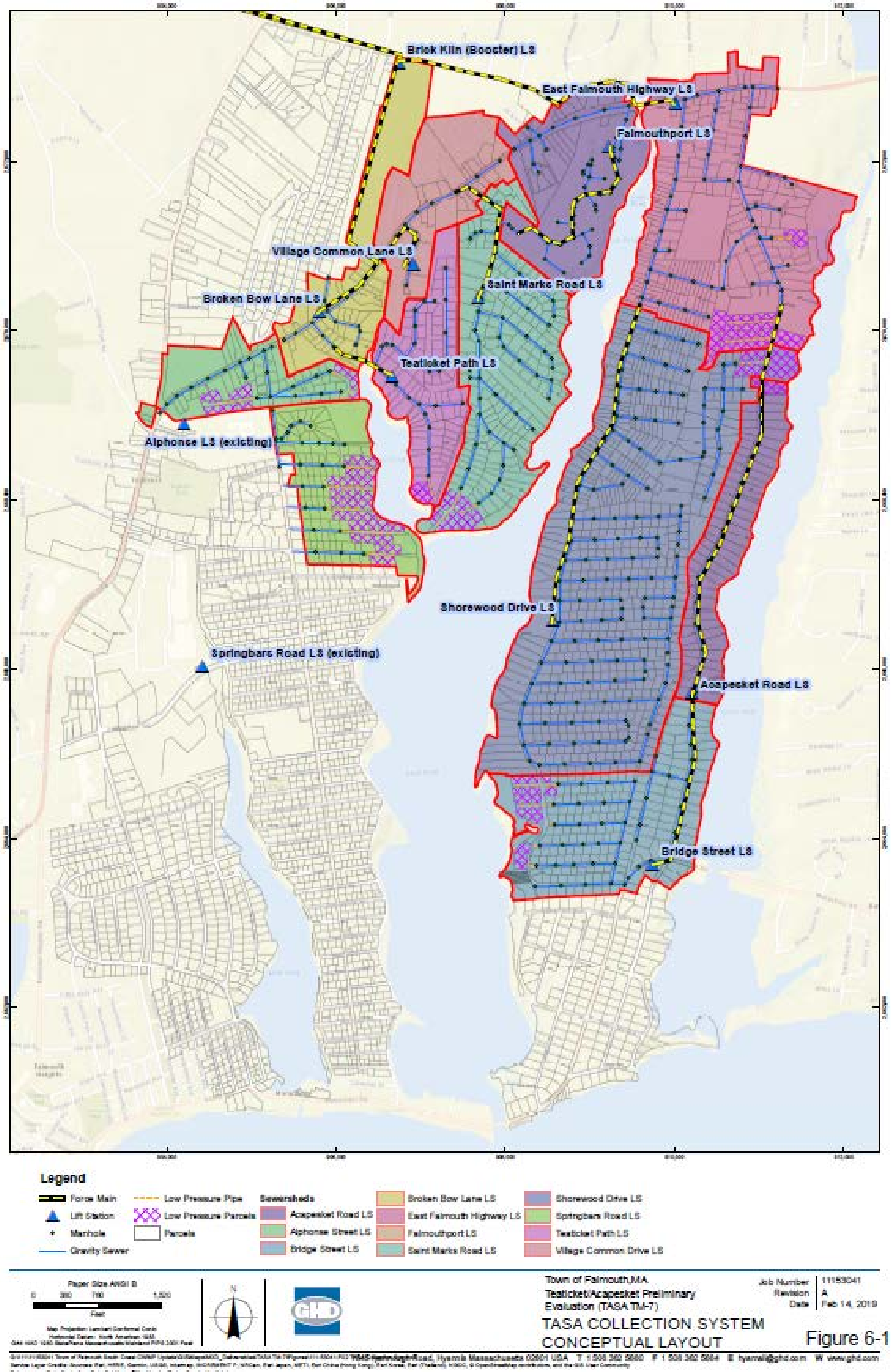

Figure 6.1 TASSA Collection System Conceptual Layout

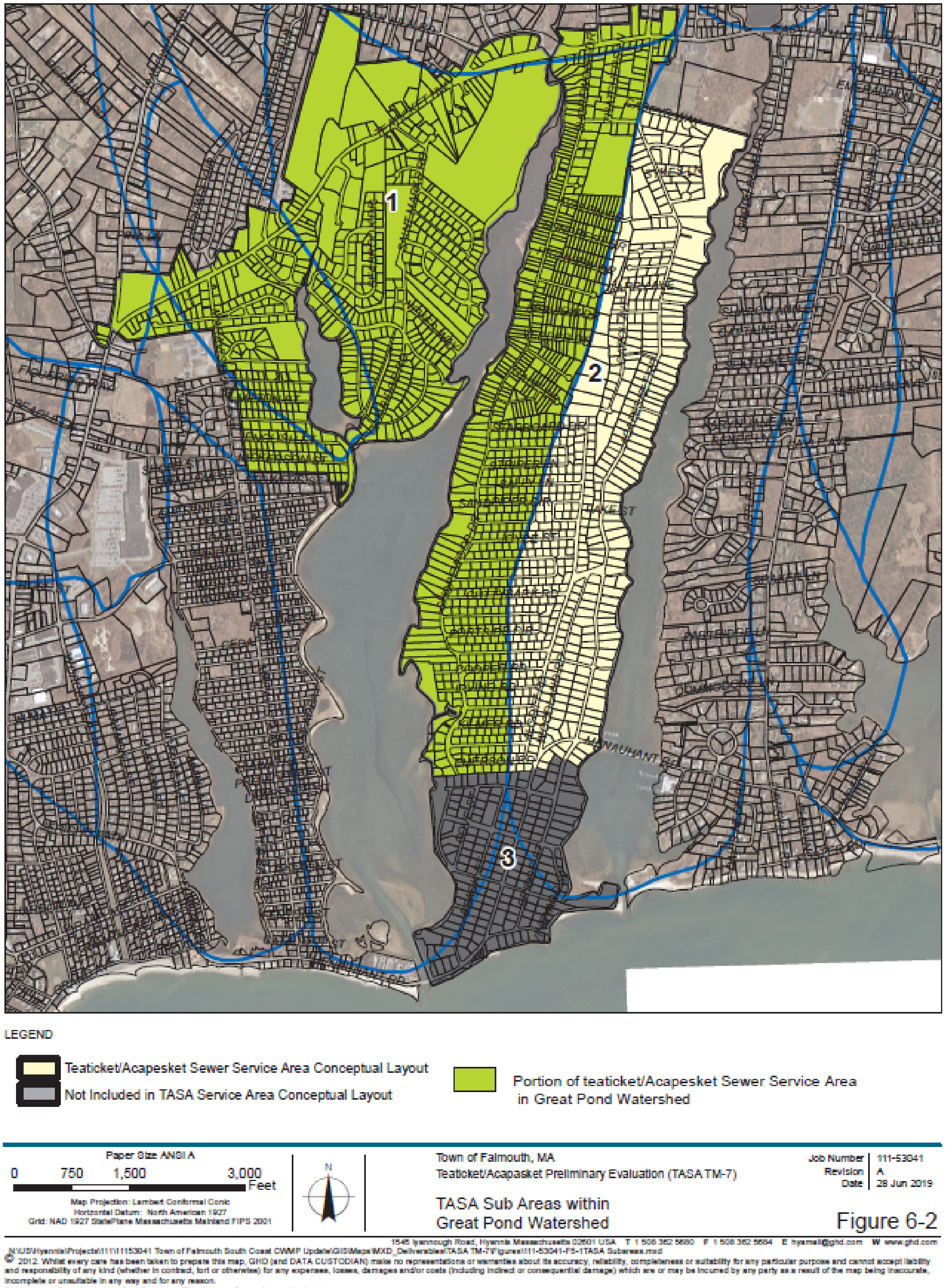

Figure 6.2 TASSA Collection System Conceptual Layout Parcels Within the Great Pond Watershed

Flow from the nine sewersheds with new lift stations is conveyed to a single booster lift station, for treatment at the Falmouth Wastewater Treatment Facility (WWTF) via a new force main system along Brick Kiln Road. The Brick Kiln Road force main system would then connect to Gifford Street Extension, to Locustfield Road, and finally to Blacksmith Shop Road for treatment at the WWTF. In areas where gravity sewers are not feasible due to topography, low-pressure sewers are proposed. The development of the conceptual TASSA layout is outlined in the TASA Technical Memorandums (Appendix 5.1).

6.2.3 Wastewater Treatment (Falmouth WWTF)

Flow collected through the TASSA collection system will be conveyed to the Falmouth WWTF. An evaluation of the existing Falmouth WWTF to treat the proposed flow from TASSA on a capacity and treatment level basis was conducted and is summarized in “TASA TM-4 – Teaticket / Acapesket Study Area Technical Memorandum No. 4,” prepared by GHD and dated April 2019 (Appendix 5.1). The analysis indicated that an additional (third) Sequencing Batch Reactor tank will need to be constructed to treat the anticipated nitrogen load from TASSA and provide operational flexibility. No other major capacity or treatment level process improvements are anticipated to treat the project flow from TASSA.

6.2.4 Disposal Site Options, Including Ocean Outfall and Joint Base Cape Cod

An evaluation of effluent recharge technologies and disposal sites was performed and is summarized in “TASA TM-3 – Teaticket / Acapesket Study Area Discharge Technologies Evaluation – Technical Memorandum No. 3,” prepared by GHD and dated April 2019 (Appendix 5.1). The evaluation recommended the following discharge technologies for incorporation into conceptual layouts:

1. Open sand beds are recommended for conceptual layout development due to their relatively high hydraulic loading capacity, which required less land area than other land-based options. Additionally, The Town of Falmouth currently uses this technology at the Falmouth WWTF and is familiar with the technology.

2. Leaching facilities are recommended for conceptual layout development in areas with a potential secondary use (for example under fairways in a golf course or under public parks/ballfields) due to their minimal visual impact. Additionally, the Town of Falmouth currently uses this technology at the New Silver Beach WWTF and is familiar with the technology.

3. Ocean outfalls are recommended for conceptual layout development due to the relatively small land area required for this technology, relatively high disposal capacity, and the ability to discharge outside a nutrient impacted watershed thereby reducing the nitrogen loading impacts to coastal embayments.

Four different potential discharge sites and two potential ocean outfall locations were evaluated, along with the development of discharge capacities for all six options. As part of that evaluation, the following four effluent disposal options were selected for conceptual layout development:

1. Open Sand Beds at the Allen Parcel.

2. Subsurface Effluent Disposal (Leaching Trenches) at the Falmouth Country Club.

3. Expanded Open Sand Beds 14 & 15 within the existing Town-owned parcel.
4. Buzzards Bay Ocean Outfall.

The basis of design for each conceptual layout is outlined in “TASA TM-7 – Teaticket / Acapesket Study Area Conceptual Layouts and Preliminary Cost Estimates Evaluation – Technical Memorandum No. 7,” prepared by GHD and dated April 2019 (Appendix 5.1). A decision to select the effluent disposal option for TASSA is anticipated in 2021.

6.2.5 Estimated Cost and Implementation Schedule

Preliminary capital cost estimates for the TASSA collection system, WWTF improvements and effluent disposal options are outlined in “TASA TM-7 – Teaticket / Acapesket Study Area Conceptual Layouts and Preliminary Cost Estimates Evaluation – Technical Memorandum No. 7,” prepared by GHD and dated April 2019 (Appendix 5.1).

The TASSA collection system is anticipated to be implemented through a two-phase approach. The anticipated mid-point of construction for Phase 1 is 2026.

6.3 Coonamessett River Restoration Project Summary

6.3.1 Introduction

The Coonamessett River flows from Coonamessett Pond to Great Pond, a total length of about 4,750 meters. It flows through multiple wetland areas and incorporates additional outflow from the Broad River, Pond 14, and Flax Pond. The Massachusetts Estuaries Project (MEP) report for the Great Pond watershed (Howes, 2005) estimates that over 50% of the unattenuated nitrogen load to Great Pond enters via the Coonamessett River. As a large source of groundwater to Great Pond, data on the dynamics of nitrogen species in the river water is useful in planning strategies to improve water quality in Great Pond.

In 1971, Falmouth acquired approximately 45 acres of cranberry bogs along the lower reach of the Coonamessett River south of Sandwich Road. The bogs are divided into three main areas: Lower Bog, Middle Bog, and Reservoir Bog. Cultivation of Lower Bog ceased in 2010, and Middle and Reservoir Bogs were retired in 2013. Lower Bog was restored to wetlands in 2018. As part of the restoration process, the river channel was physically lengthened by making it more sinuous in order to increase the water’s residence time within the wetland and increase the potential for greater nitrogen attenuation prior to discharging into Great Pond. Wetland restoration for Middle Bog and Reservoir Bog are scheduled for 2019-2020. The Coonamessett River Restoration Project is being led by the Town of Falmouth (Conservation Commission) with the support of nearly two dozen partners. Major funding sources include National Oceanic and Atmospheric Administration (NOAA), Massachusetts Environmental Trust, Massachusetts Fish & Game/Division of Ecological Restoration, US Fish and Wildlife Service, and the Town of Falmouth.

To monitor the potential nitrogen attenuation due to the bog restoration efforts, the Woods Hole Research Center (WHRC) was contracted in 2018 to install several sampling wells and monitor eleven stations along the entire length of the Coonamessett River (Figure 6.3). This research project is quantifying the physical and nitrogen dynamics of the river over a three-year period (2018-2020) utilizing the following procedures:

- Monitor river height and discharge on an hourly basis
- Monitor nitrate and dissolved and particulate nitrogen concentrations every two weeks.
- Use a mass balance approach to calculate total input and output of nitrate along certain sections of the river channel south of Pond 14.
- Evaluate the performance of restored wetlands for nitrogen attenuation to infer potential nitrogen removal benefits from additional planned restoration areas along the Coonamessett River.

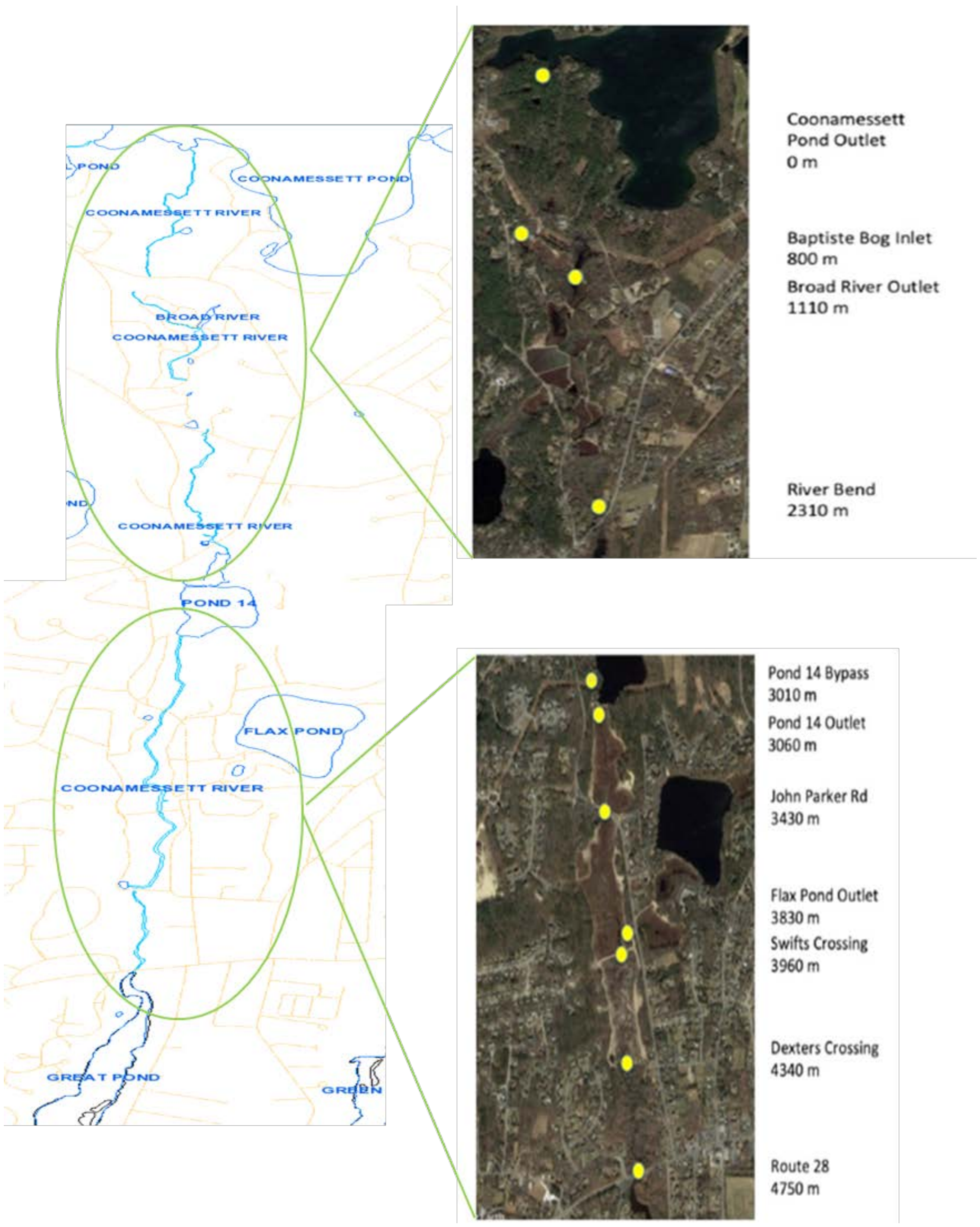

Figure 6.3 Approximate Sampling Site Distances (in meters) From the Coonamessett Pond Outlet (adapted from Neill et al. 2019)

6.3.2 Monitoring Results Summary

All results can be found in the "Data Report on Nitrogen Monitoring and Dynamics of the Coonamessett River May 2018 to April 2019" (Neill et al., 2019) (Appendix 6.2).

River Stage Results

In 2018, a staff gauge was installed in Lower Bog to measure the hourly river height in the lower reach of the Coonamessett River. The results of the 2018 river stage monitoring show that the removal of the Lower Bog dam at Dexters Crossing occasionally allows exceptionally high tidal and storm water levels from Great Pond to flow up into the restored wetland areas. Overall, monitoring data showed an expected seasonal trend of high stage heights in the spring and lower stage heights in the summer, and increased stage heights in fall and winter.

Dissolved and Particulate Nitrogen Results

Nitrate concentrations generally increase with distance from Coonamessett Pond. This downstream increase is particularly pronounced below the Pond 14 sampling location (arrow in Figure 6.4). This pronounced increase in nitrate concentrations appears to be directly related to the greater density of residential development and septic systems south of Pond 14.

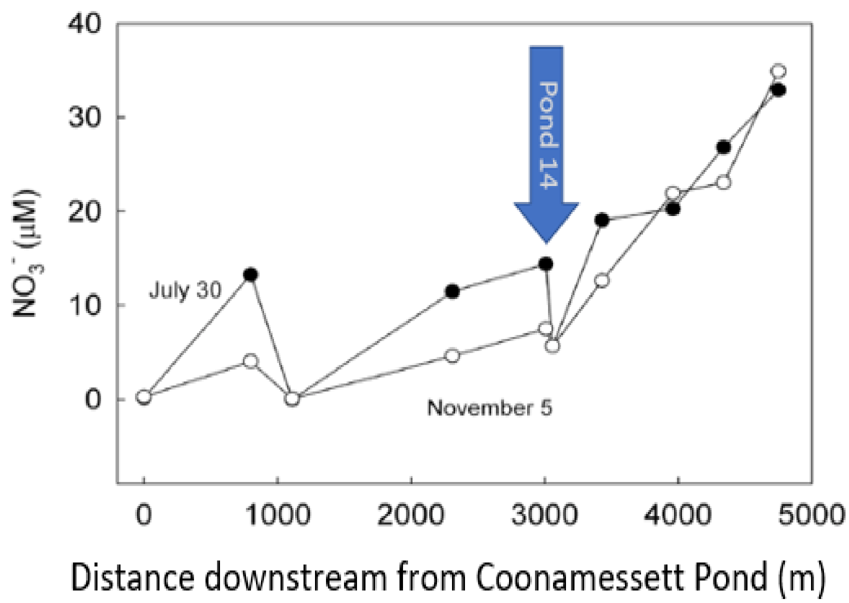

Figure 6.4 Nitrate Concentrations Measured Along the Coonamessett River on July 30th and November 5, 2018 (Neill et al. 2019)

Concentrations of nitrate varied seasonally with higher concentrations of nitrate in the lower reaches during winter (Figure 6.5). This result suggests there are temperature and light-dependent biological processes (e.g. plant uptake) removing dissolved nitrogen that are elevated during the warmer growing season. The seasonal variability in nitrate concentration was not as pronounced in the upper reaches of the river north of Pond 14. Additional nitrogen monitoring results indicate that there is little variability during summer versus winter in the concentrations of ammonium or dissolved or particulate organic nitrogen [DON or PON] along the length of the river.

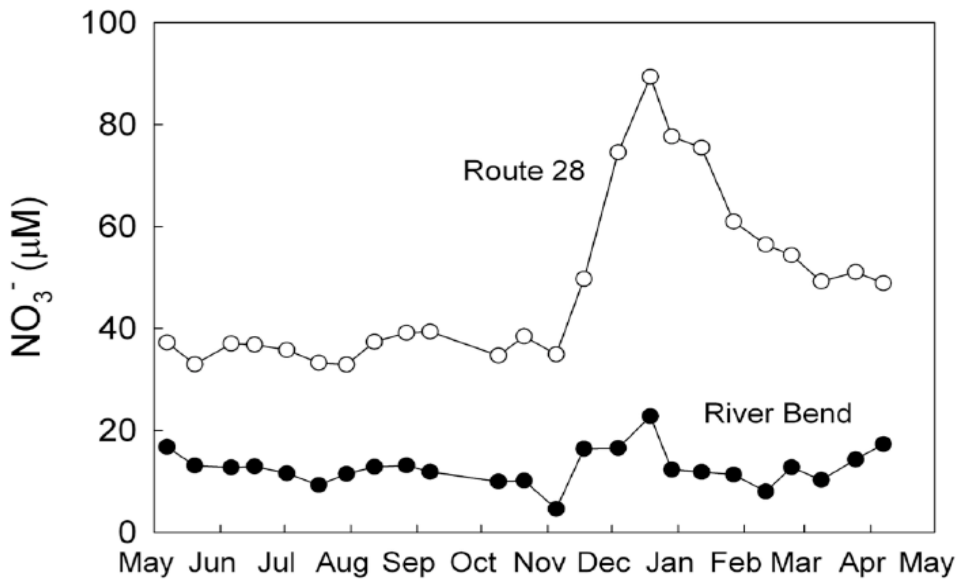

Figure 6.5 Seasonal Variation in Nitrate Concentrations Measured at the Route 28 and River Bend Stations (Neill et al. 2019)

Nitrogen Mass Balance

The mass balance analysis indicated that a net flux of 12.3 kg-N/day entered the river south of Pond 14. Of this amount, 10.1 kg-N/day (82%) entered as groundwater seepage, and the balance of 2.2-kg N/day entered from the surface waters of Pond 14 and Flax Pond. The results also showed a high amount of nitrate entering the system along the borders of the retired cranberry bogs. Specifically, the mass of nitrate seeping into the lower reaches of the river was five times greater than the mass of nitrogen from the entire upper reaches or from Flax Pond.

Based on the monitoring results and the determination that the majority of the nitrate entering the Coonamessett River enters as groundwater seepage south of Pond 14, restoration efforts of the bogs in the lower reaches have the potential to reduce the total nitrogen load entering Great Pond. Over the next two years, continued monitoring during and after restoration efforts of Middle and Reservoir Bogs will provide more information for developing the Targeted Watershed Management Plan for meeting the TMDL for Great Pond.

6.4 Great Pond TMDL Compliance Plan Approach

6.4.1 Background

The MEP report for the Great Pond watershed indicates that approximately 100% of the current septic system nitrogen load in the Great Pond and Perch Pond sub-watersheds and 50% of the current septic system nitrogen load in the Coonamessett River sub-watershed needs to be removed if the Great Pond Nitrogen TMDL was met through sewering alone ("TMDL sewering only scenario").

This percentage represents only one of many possible nitrogen removal scenarios that could be used to meet the nitrogen concentration threshold. The MEP-estimated attenuated nitrogen loading reduction is approximately 62% of the total attenuated watershed load. Based on the Massachusetts Estuaries Reports Table VIII-3 and Nitrogen TMDL Table 4 for Great Pond Watershed, including Perch Pond and the Coonamessett River, approximately 17,637 kg/yr of the attenuated nitrogen load needs to be removed.

As the Town of Falmouth is developing and summarizing the findings of several demonstration projects and pilot efforts, the Town has considered several options of addressing nitrogen for this watershed including: centralized sewering, a satellite wastewater treatment facility, innovative and alternative septic systems (I/A systems), shellfish aquaculture, stormwater improvements, permeable reactive barriers (PRBs), and fertilizer reductions.

Specifically within the Great Pond watershed, the Town is evaluating several approaches in order to achieve TMDL compliance:

- Fertilizer reduction
- Stormwater improvements
- Shellfish aquaculture
- Installation of a PRB
- Sewer extensions

6.4.2 Fertilizer Management in Compliance with the Town's Approved Bylaw

As discussed in Chapters 3 and 4, Falmouth has enacted a fertilizer bylaw, based on the Cape Cod Commission 208 Plan update. As a result of this, Falmouth is afforded a 25 percent removal credit for nitrogen attributed to fertilizer. Based on the MEP Report Table IV-4, the Great Pond System receives approximately 1,700 kg/yr of lawn fertilizer load, which after applying a 25 percent credit would be reduced by 425 kg-N/year.

6.4.3 Stormwater Management

The Town will continue best management practices to address stormwater impacts and consider the implementation of nitrogen reducing options where feasible as discussed in Chapter 3. The implementation of these practices in Falmouth allows the Town to receive another 25 percent reduction credit of nitrogen attributed to stormwater runoff per the CCC 208 Plan. Applying this credit to the estimated impervious surfaces load of 2,319 kg/yr (as called out on MEP Report Table IV-4) would equate to approximately 580 kg-N/year reduction.

6.4.4 Shellfish Aquaculture

The Town is evaluating whether to pursue the use of shellfish aquaculture within Great Pond based on the findings at the other locations currently being evaluated throughout Town. The Town is actively exploring the establishment of a shellfish program over approximately 10 acres of potential suitable shellfish habitat within the pond. The next step in the Town’s approach is to perform additional surveys to refine the available acreage number for suitable shellfish aquaculture.

Presuming that 10 acres are available within the pond, the Town is anticipating nitrogen uptake between 1,300 and 2,100 kg/yr and an additional removal of approximately 50% of the uptake through denitrification. This would be accomplished through a combination of gear types to support the shellfish growth.

6.4.5 Permeable Reactive Barriers

As discussed in Chapter 3, the Town is actively seeking funding to pursue the installation of a PRB within one or more of their impacted watersheds. One location under consideration, a site located off of Shorewood Drive, is within the Great Pond Watershed. It was identified that a 300 feet PRB at this location has the potential to remove up to 1,325 kg-N/year based on the US Environmental Protection Agency (USEPA) estimated nitrate mass flux. A pilot scale PRB of approximately 120 feet long and a vertical thickness of 20 feet is being proposed for this location. The ultimate length of the PRB for nitrogen TMDL compliance will depend on piloting performance and the performance of the other alternative nitrogen removal options.

6.4.6 Teaticket Acapesket Sewer Service Area

Completion of the LPSSA has provided an initial nitrogen reduction by sewering approximately 250 properties within the Great Pond Watershed along the Maravista Peninsula. This sewering is anticipated to provide approximately 1,037 to 1,316 kg-N/yr reduction within the watershed.

Construction of a portion of the Teaticket Acapesket Sewer Service Area (TASSA) within the Great Pond watershed is anticipated to achieve approximately 43 – 55% of the septic system nitrogen removal. Although this reduction is not enough to meet the nitrogen TMDL threshold concentration, it is a significant reduction from existing conditions. The sewering will be augmented by additional removals provided by the non-traditional nitrogen methods that are currently being evaluated by ongoing demonstration projects.

6.4.7 Summary of Compliance Approach for Great Pond

The following table outlines the overall nitrogen budget proposed for Great Pond in order to achieve Nitrogen TMDL Compliance.

Table 6.2 Nitrogen Budget for Great Pond to Achieve Nitrogen TMDL Compliance

Compliance Component – Nitrogen Removal Approach	Estimated Nitrogen Loading Reduction (kg-N/year)
Fertilizer Bylaw (25% of fertilizer load)	425
Stormwater BMPs (25% of impervious load)	580
Shellfish Aquaculture (uptake)	1,300-2,100
Shellfish (denitrification)	650-1,050
PRB at Shorewood Drive (300 feet)	1,325
Sewer Extensions (Total)	7,179-9,105
LPSSA (Great Pond)	*1,037-1,316*
TASSA Subarea 1	*3,325-4,217*
TASSA Subarea 2	*2,817-3,572*
Total Estimated Reduction	11,459-14,585
Nitrogen Removal TMDL Goal	12,154

As shown above, the nitrogen removal goal may be achieved through the use of these approaches. However, a shortfall may result due to the variability of some of the removal options and the potential phasing of any sewering within this watershed. Therefore active monitoring of the water quality within the system will be necessary and will allow the Town to apply adaptive management approaches to best target sewer infrastructure implementation, and gauge the performance of some of the other alternative approaches, namely shellfish.

The Town has also identified several options in the event that strategies from the proposed compliance plan approach are not sufficient including:

- Use of I/A Septic Systems in the upper watershed.
- Potential sewer extensions north of Route 28.
- Additional Permeable Reactive Barriers within the watershed, north of Route 28.

7. Green Pond Watershed Planning Scenario

7.1 Expected Impact of Great Pond Sewer Plan on Green Pond Nitrogen Removal

7.1.1 Green Pond TMDL

The Green Pond System watershed is divided into four subwatersheds, one of which is Mill Pond (see section 7.2). The Total Maximum Daily Load (TMDL) Report presents target threshold watershed loads for one waterbody in the Green Pond System—Green Pond. The TMDL allocation outlines the maximum nitrogen loading that the waterbody may receive while maintaining its water quality standards and designated uses. Table 7.1 outlines the TMDL for the waterbody. The largest source of controllable nitrogen in the Green Pond watershed comes from on-site septic systems.

Table 7.1 Green Pond Total Maximum Daily Loads

Waterbody Segment[1]	Description[1]	TMDL (kg/d)[2]	Estimated Equivalent Annual Load Target (kg/yr)
Green Pond	East of Acapesket Road, outlet to Vineyard Sound, Falmouth	46.26	16,885

Sources:
1. Massachusetts Year 2016 Integrated List of Waters.
2. ‘Table 5 – The Total Maximum Daily Loads (TMDL) for the Great, Green, and Bournes Pond Embayment Systems, represented as the sum of the calculated target threshold loads (from controllable watershed sources), atmospheric deposition, and sediment sources (benthic flux)’ of the ‘Final Great, Green and Bournes Pond Embayment Systems Total Maximum Daily Loads for Total Nitrogen’ (report #96-TMDL-6 Control #181.0), dated April 6, 2006.

7.1.2 Conceptual Sewer Plans for Green Pond Watershed

The Teaticket / Acapesket Sewer Service Area (TASSA) conceptual collection system, which is described in further detail in Chapter 6, would collect wastewater from approximately 1,791 parcels and convey the flow to the Falmouth Wastewater Treatment Facility (WWTF) for treatment. There are 502 TASSA parcels located within the Green Pond watershed (see Appendix 5-1). The nitrogen load removal in Green Pond through the sewering of TASSA is estimated at 2,058 to 2,610 kg/yr. A nitrogen removal range was developed for calculating TMDL compliance due to the variability of parameters required to estimate a value, such as effluent nitrogen concentration and future water usage trends.

This sewer extension would significantly reduce the nitrogen loading to Green Pond and will be augmented by additional removals provided by the non-traditional nitrogen removal technologies, as discussed later in this chapter.

7.1.3 Collection, Transmission System Layouts, and Discharge

The conceptual TASSA is illustrated in Figure 6.1. The conceptual collection system is divided into 11 sewersheds and configured to maximize the number of properties served by gravity sewer. In the conceptual layout each of nine sewersheds is serviced by a new lift station, and two sewersheds connect into existing lift stations (Alphonse Street Lift Station and Spring Bars Road Lift Station). Four of the sewersheds are located partially in the Green Pond watershed, as shown in Figure 7.1.

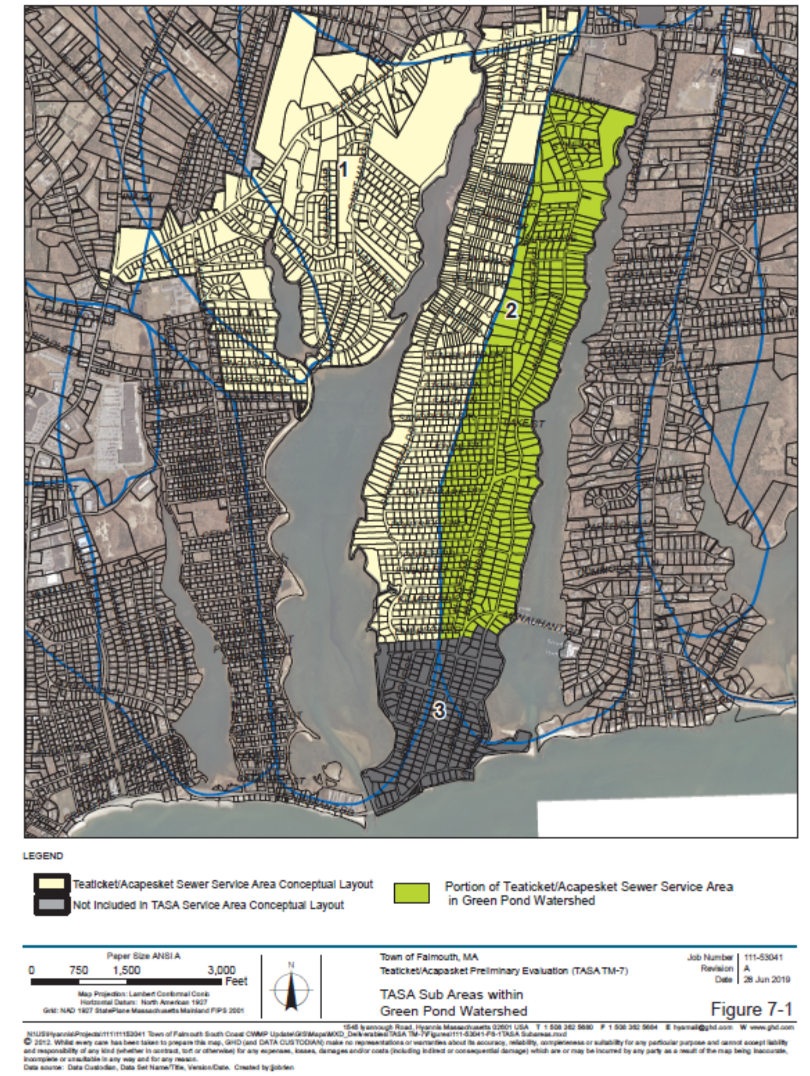

Figure 7.1 Teaticket/Acapesket Study Area Collection System Conceptual Layout Parcels Within the Green Pond Watershed

Flow from the nine sewersheds with new lift stations is conveyed to a single booster lift station, for treatment at the Falmouth WWTF via a new force main system along Brick Kiln Road. The Brick Kiln Road force main system would then connect to Gifford Street Extension, to Locustfield Road, and finally to Blacksmith Shop Road for treatment at the WWTF. In areas where gravity sewers are not feasible due to topography, low-pressure sewers are proposed. The development of the conceptual TASSA layout is outlined in the TASA Technical Memorandums (Appendix 5.1). As outlined in Chapter 6 flow collected through the TASSA collection system will be conveyed to the Falmouth WWTF and will be discharged at a new effluent disposal site. A decision to select the effluent disposal site for TASSA is anticipated to be made in 2021.

7.2 Mill Pond Investigation and Remedial Approach

7.2.1 Background

As part of Falmouth's approach for examining strategies to meet the TMDL in Green Pond, the Town partnered with the University of Massachusetts Dartmouth School of Marine Science and Technology (SMAST) to conduct a study on nutrient cycling in Mill Pond. Mill Pond is a shallow (≤ 5.25 ft (1.6 m) deep), manmade, 15.6-acre pond that intercepts groundwater and surface water runoff from upstream agricultural operations and discharges directly into Green Pond. Ninety percent of the water volume received by Mill Pond arrives via Backus Brook through 52 acres of active cranberry bogs (Figure 7.2). Nearby residents have expressed concern over the water quality of Mill Pond, particularly during the summer months. Residents report a heavy vegetation load and a foul odor (e.g. rotten-egg smell) being emitted from the pond. Both observations indicate a pond that is in a eutrophic and impaired state during a large portion of the year.

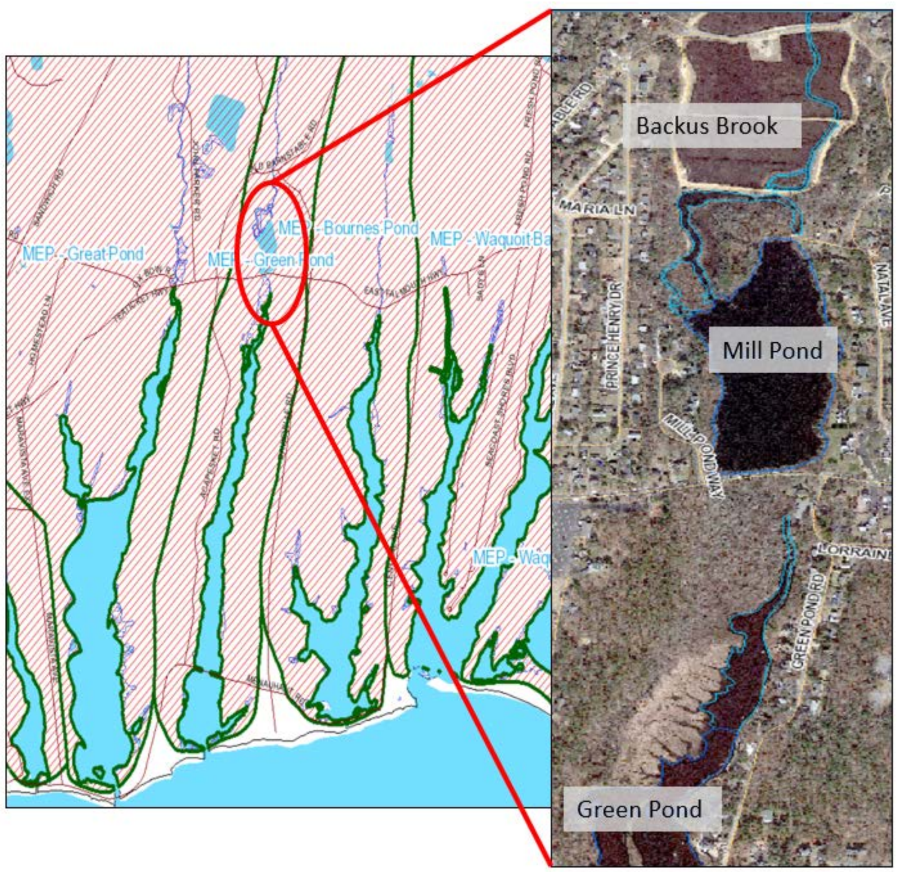

Figure 7.2 Area Map of the Mill Pond System

Efforts to restore Mill Pond are a key component of the nitrogen-reduction strategies for Green Pond. Mill Pond serves a critical role in reducing the overall nutrient load to Green Pond due to its attenuation of a significant fraction of the upstream nitrogen load prior to discharge into the head of Green Pond. During the critical impairment period (summer months) when the pond is eutrophic and the dissolved oxygen levels decline, the coupled nitrification-denitrification cycle cannot occur resulting in an efflux of nitrogen into Green Pond. It is for this reason that nutrient mitigation strategies for Mill Pond are being studied.

The University of Massachusetts Dartmouth conducted a study from September 2015 to December 2017, "Diagnostic Assessment of Nutrient Cycling in Mill Pond" (Unruh et al. 2018) (see Appendix 7.1). Data collected included nitrogen and phosphorous loads flowing into and leaving Mill Pond; in-pond measurements of sediment nitrogen and phosphorous fluxes; a vegetative profile of the pond and measurements of water level; stream flow; dissolved oxygen; chlorophyll *a*; and temperature. Select water quality parameters were measured weekly from May to October at 12 sites. Sampling efforts decreased to at least biweekly in order to establish baseline measurements during November through April when inflow to and outflow from Mill Pond are less influenced by upstream agricultural activities.

7.2.2 Results

Monitoring results from the 2015 – 2017 study indicate that Mill Pond is in a eutrophic state from June through October. Dissolved oxygen concentrations remain below 5.0 mg/L in June and July, and experience shorter periods of low levels later in the season (Figure 7.3). There is an observed correlation between periods of low dissolved oxygen and presence of phytoplankton blooms (as measured by chlorophyll *a*).

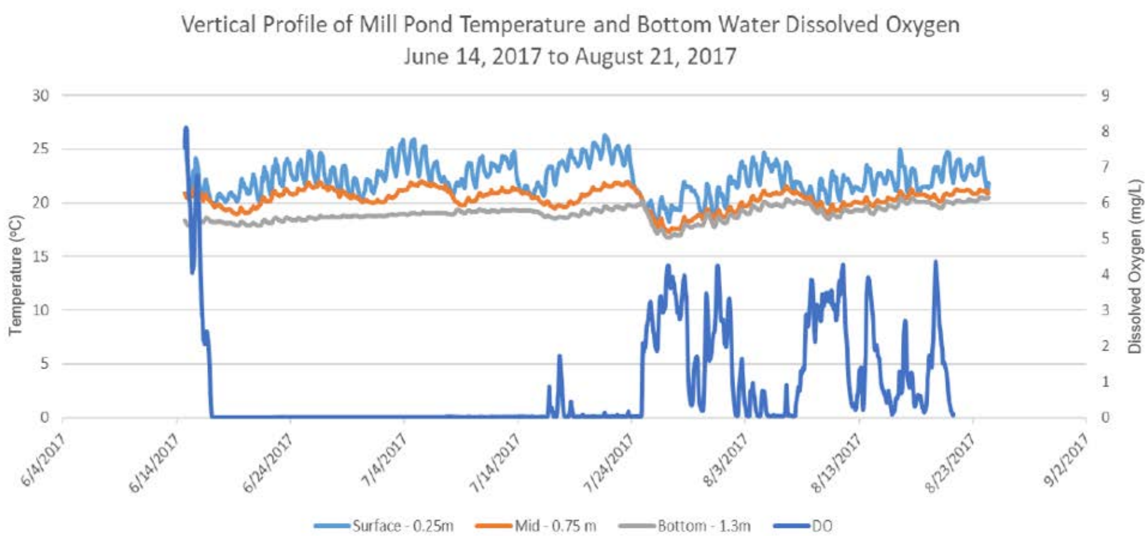

Figure 7.3 Vertical Temperature and Bottom Water Dissolved Oxygen Concentrations During the Critical Impairment Period in Mill Pond (Unruh et al. 2018)

A vegetation survey was conducted in 2017 to identify the dominant species and the associated coverage in Mill Pond. Aquatic vegetation covers approximately 90% of Mill Pond and is dominated by 11 macrophyte species. The plant growth from spring into the fall takes up approximately 453 kg of nitrogen and 10 kg of phosphorus (Unruh et al. 2018). When the plant biomass dies off, the associated nutrients accumulate in the sediments. When the pond experiences periods of low oxygen, the vegetation-associated nutrients are released back into the water column.

Nutrient monitoring of Mill Pond showed that the most significant sources of external nitrogen load come from stream inflow (58%) and groundwater (38%), and input is highest in the spring and summer months (Figure 7.4). A mass balance approach incorporating nitrogen sources and sinks was used to determine the net movement of nitrogen through Mill Pond. Nutrient monitoring results combined with the nitrogen mass balance model indicated that 59% (2016) and 64% (2017) of nitrogen entering Mill Pond was attenuated within Mill Pond and did not enter Green Pond. The rate of attenuation reported in the MEP Report (2005) was 67%, indicating the mass balance model used during this study was a comparable predictor of attenuation rates in Mill Pond.

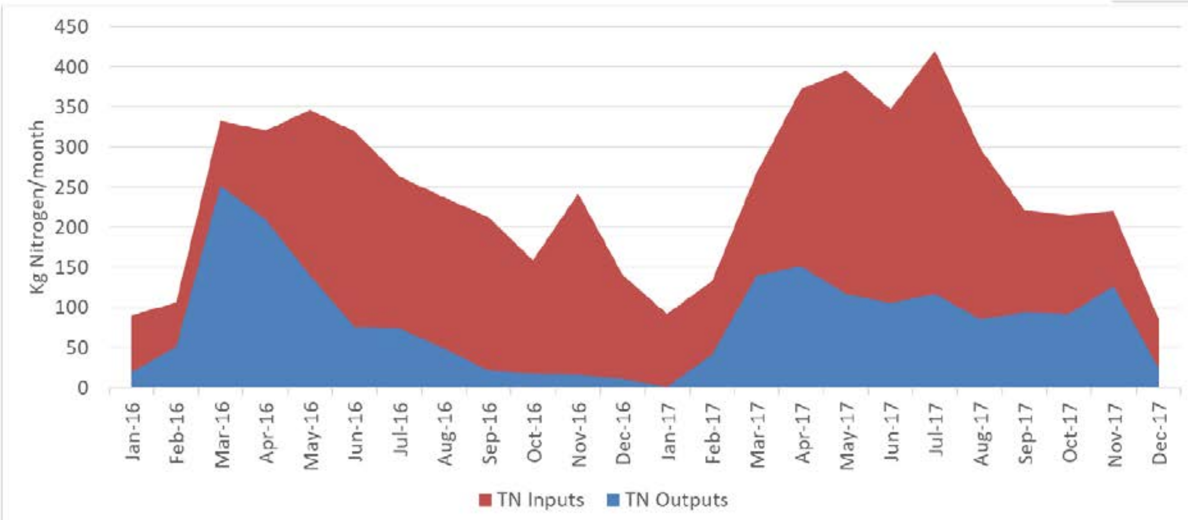

Figure 7.4 Monthly Nitrogen Dynamics of Mill Pond (Unruh et al., 2018)

Nutrient limitation determination experiments indicated that phosphorus is the limiting nutrient in Mill Pond. This suggests that management efforts for Mill Pond should be focused on phosphorus. However, due to the unique nature of Mill Pond directly discharging into a nitrogen-impaired estuary, both nitrogen and phosphorous management options need to be considered.

Key Findings from the 2015 – 2017 University of Massachusetts Dartmouth Mill Pond study:

- 58% of the nitrogen input to Mill Pond is from Backus Brook.
- Mill Pond attenuates an average 62% of the nitrogen that enters the pond.
- Mill Pond is generally eutrophic from June through October with aquatic vegetation covering 90% of the sediment and water surface.
- Phosphorus is the limiting nutrient in Mill Pond.

7.2.3 Recommendations for Nutrient Management of Mill Pond

The main objective in the management of Mill Pond is the control of the nitrogen and phosphorus loads entering Green Pond. Several of the recommendations made by Unruh et al. (2018) and efforts that the Town has made in pursuing these recommended strategies are detailed below.

Alternating Bog Fertilizers

It was recommended that the bog operations alternate between 'low P' and 'no P' fertilizers as a strategy to reduce phosphorus export from the bog. The bog owner is reported as being agreeable to altering his operating procedures and practices. There are no further efforts for this implementation needed from the Town.

Slow Release of Bog Flood Water

A strategy to remove the dam boards one at a time over a period of several days was proposed to minimize water velocities and fine sediments from being washed into the pond. The bog owner is reported as being agreeable to altering his operating procedures and practices. There are no further efforts for this implementation needed from the Town.

Increase Flow During Harvest and Winter Floods

Careful consideration of the board height placement when damming for the harvest and winter floods was recommend in order to increase flushing in the pond during these periods. The bog owner has indicated that this is a practice that can be implemented but is dependent on annual water flows. There are no further efforts for this implementation needed from the Town.

Grate Between Bog and Mill Pond

Placing a metal grate at the bog discharge point would catch debris and prevent large plant matter from being washed downstream into Mill Pond. The installation of a grate would require periodic cleaning to ensure adequate water flow. While the bog owner has indicated he is willing to alter some practices, he seems less in favor of assuming the periodic maintenance to ensure the grate is clean. The Town is pursing grate options that meet regulatory requirements and is continuing discussions with the bog owner about the feasibility of this management strategy.

Construct a Detention Pond

This is a preferred management option. Constructing a 0.25-acre detention pond at the bog discharge point would allow plant matter and fine sediments to settle prior to being washed downstream into Mill Pond. Unruh et al. (2018) estimates this strategy could reduce the nitrogen and phosphorus loads to Mill Pond by 192 and 40 kg/yr respectively.

The bog owner has agreed to work with the Town and is agreeable to the idea of installing a detention pond. The bog owner has also verbally indicated that he would be willing to accept the periodic maintenance of a detention pond. The Town is currently having discussions with the MassDEP on investigating an option of obtaining an agriculture exemption to 310 CMR 10.00 to install a tailwater recovery system rather than a detention pond. A tailwater recovery system would allow for some recycling of nutrient runoff from irrigation practices back into the cranberry bog operations. The Falmouth Conservation Commission has indicated that a hearing will be necessary.

Macrophyte Harvesting

Reducing the macrophyte biomass in the pond will reduce the nutrient load to the sediments and water column of Mill Pond when the plants begin to decay in the fall. Under hypoxic conditions denitrification in the sediments cannot occur and the nutrients from the decaying macrophytes are released back into the water column. In addition, a reduction in the surface-level plants will allow for more wind-driven surface layer mixing which may aid in odor control.

Harvesting is a process of trimming macrophytes to a depth below the surface of the water and is the primary approach to macrophyte management being explored by the Town.

Harvesting would have multiple benefits including the removal of the harvested macrophyte material and its associated nutrient load; visual and odor reduction to reduce the neighborhood concerns; and allowance for the ecosystem service of plant growth that continually removes phosphorus from the sediments. This form of macrophyte management is considered an adaptive management approach and may need to be monitored and adjusted in the future to meet the desired management outcomes for the pond.

Recommendations and informal cost estimates for macrophyte management have been obtained from an outside contractor. Discussions with the Town of Brewster on an intermunicipal agreement for utilizing the Brewster-owned macrophyte harvester have also been initiated. The Town has received verbal approval for the use of an abutting property as an access point for the equipment necessary for macrophyte management. Regulatory pathways for macrophyte harvesting have also been discussed with the Falmouth Conservation Commission, and a hearing will be required for that option to move forward.

As of July1, 2019: The initial work for filing a Notice of Intent (NOI) with MassDEP and the Falmouth Conservation Commission to harvest macrophytes from the pond has begun. The NOI will include options for macrophyte removal by mechanical and non-mechanical means. Additional options such as pond aeration are being included in the NOI filing to seek approval for alternate adaptive management approaches to improve the overall health of Mill Pond. The Town anticipates that with regulatory approval the initial macrophyte removal by harvesting could occur in the Fall of 2019.

7.3 Green Pond TMDL Compliance Plan Approach

7.3.1 Background

The Green Pond nitrogen TMDL indicates that approximately 73% of the current septic system nitrogen load needs to be removed if the Green Pond TMDL were met through sewering alone ("TMDL sewering only scenario"). This percentage represents only one of many possible nitrogen removal scenarios that could be used to meet the nitrogen concentration threshold. The MEP estimated attenuated nitrogen loading reduction is approximately 55% of the total attenuated watershed load. Based on the Massachusetts Estuaries Reports Table VIII-3 and Nitrogen TMDL Table 4 for Green Pond Watershed, including Backus Brook, approximately 4,453 kg/yr of the attenuated nitrogen load needs to be removed.

As the Town of Falmouth is developing and summarizing the findings of several demonstration projects and pilot efforts, the Town has considered several options of addressing nitrogen for this watershed including: centralized sewering, a satellite wastewater treatment facility, innovative and alternative septic systems (I/A systems), shellfish, stormwater improvements, permeable reactive barriers, and fertilizer reductions.

Specifically within the Green Pond watershed, the Town is evaluating several approaches in order to achieve TMDL compliance:

- Fertilizer reduction
- Stormwater improvements
- Shellfish propagation
- Mill Pond Improvements

- Installation of a Permeable Reactive Barrier (PRB)
- Sewer extensions
- I/A systems

7.3.2 Fertilizer Management in Compliance with the Town's Approved Bylaw

As the Town has enacted a fertilizer bylaw, based on the Cape Cod Commission 208 Plan update, it should receive a 25 percent removal credit for nitrogen attributed to fertilizer. Based on the MEP Report Table IV-4, the Green Pond System receives approximately 908 kg/yr, which after applying a 25 percent credit would be reduced by 227 kg/yr.

7.3.3 Stormwater Management

The Town will continue best management practices to address stormwater impacts and consider the implementation of nitrogen reducing options where feasible as discussed in Chapter 3. The implementation of these practices in Falmouth allows the Town to receive another 25 percent reduction of nitrogen attributed to stormwater runoff credit per the CCC 208 Plan. This would equate to approximately 172 kg N/yr. Falmouth has identified the “Captain’s Lane” catchment area as having the potential to manage an additional 120 kg-N/yr.

7.3.4 Shellfish Aquaculture

The Town is evaluating whether to pursue the use of shellfish aquaculture within Green Pond based on the findings at the other locations currently being evaluated throughout Town. Initially, three different locations were being considered to evaluate nitrogen reduction potential within the waterbody. A preliminary approach identified the relay of 1 million first year oysters and 1 million quahogs, and would require demonstration of denitrification in the sediments. This relay has the potential to remove up to a total of 945 kg N/yr when considering both the uptake by the shellfish and the potential increased denitrification in the sediments due to the presence of the shellfish.

7.3.5 Mill Pond Improvements

The Town is also evaluating management options around Mill Pond in order to take advantage of natural nitrogen uptake and attenuation. This would be through modifications to the upstream cranberry bog system, tailwater recovery pond, and natural pond attenuation.

In addition, the Town is considering macrophyte harvesting in order to remove an additional 15% of the total nitrogen passing through that system.

7.3.6 Teaticket Acapesket Sewer Service Area

Construction of the Teaticket Acapesket Sewer Service Area (TASSA) within the Green Pond watershed is anticipated to reduce the nitrogen load by 2,058 to 2,610 kg/yr. This represents 46 – 59% of the overall septic load that needs to be removed from the watershed, according to the MEP report. Although this reduction is not enough to meet the TMDL threshold concentration, it is a major reduction from existing conditions. The sewering will be augmented by additional removals provided by the non-traditional nitrogen methods that are currently being evaluated by ongoing demonstration projects.

7.3.7 Permeable Reactive Barriers

As described in Chapter 3, PRBs have been considered in several watersheds. However, this technology was not identified for use at this time in the watershed and therefore a credit for nitrogen removal from PRBs is not being estimated. The Town may consider utilizing a credit in the future following further evaluation.

7.3.8 Summary of Compliance Approach for Green Pond

The following table outlines the overall nitrogen budget proposed for Green Pond in order to achieve Nitrogen TMDL compliance.

Table 7.2 Nitrogen Budget for Green Pond Nitrogen TMDL Compliance

Compliance Component - Nitrogen Removal Approach	Estimated Nitrogen Loading Reduction (kg N/yr)
Fertilizer Bylaw (25% of fertilizer load)	227
Stormwater BMPs (25% of impervious load)	172
Stormwater – Captain's Lane Catchment Area	120
Shellfish Aquaculture (uptake)	390-630
Shellfish (denitrification)	195-315
Mill Pond	491-961
Sewer Extensions (total)	2,058-2,610
Total Estimated Reduction	**3,653-5,035**
Nitrogen Removal TMDL Goal	4,453

As demonstrated above, the nitrogen removal goal can be achieved through the use of these approaches. However, a shortfall may result due to the variability of some of the removal options and the potential phasing of any sewering within this watershed. Therefore, active monitoring of the water quality within the system will be necessary and will allow the Town to apply adaptive management approaches to best target sewer infrastructure implementation and gauge the performance of some of the other alternative approaches, namely shellfish.

The Town has also identified several options in the event that strategies from the proposed compliance plan approach are not sufficient including:

- Use of I/A septic systems on the Davisville Peninsula.
- Potential sewer extensions on the Davisville Peninsula and north of Route 28.
- PRBs within the watershed, locations to be determined.

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8. Bournes Pond Watershed Planning Scenario

8.1 Status of Inlet Widening Project

As identified in Chapter 3, a Notice of Project Change for this project was filed in 2016 and the Town received the Certificate of the Secretary of Energy and Environmental Affairs on the Notice of Project Change on March 11, 2016 (EEA Number 14154).

The inlet widening will increase the bridge inlet width from approximately 50 feet to the optimal width of 90 feet with no change in bridge height. The project also calls for the extension of the western jetty by 25 feet, and reconstruction of an existing groin. In addition, the project includes dredging of both the inner and outer areas of the pond with reuse of compatible material for dune and beach restoration.

Several studies were also performed as part of this project including evaluation of flood impacts, eelgrass studies within the proposed dredge areas, and shellfish evaluations:

- Bournes Pond Shellfish and Eelgrass Assessment Summary Report, Bournes Pond, Falmouth, MA, March 2017, Stantec
- Town of Falmouth Bournes Pond Inlet Opening Project – Eelgrass Survey, September 2018, AECOM
- Bournes Pond Inlet Opening Flooding and Coastal Erosion Analysis, January 2015, Applied Coastal

The project is currently in the final design and permitting stage. Permits received to date are listed in Chapter 3, Section 3.8.3 Permitting. As of July 2019, all permits have been received. The final design drawings are being completed and the project will be put out to bid. The Town of Falmouth is currently considering this project with other coastal resiliency projects and is in the process of implementing additional mitigation measures to protect the Town's other infrastructure (unrelated to this project) but including its existing roadways and water mains. Therefore, the current tentative schedule anticipates bidding in the summer of 2020 with completion anticipated by December of 2022.

8.2 Bournes Pond TMDL Compliance Plan Approach

As the Town of Falmouth is summarizing the findings of several demonstration projects and pilot efforts, the Town has considered several options of addressing nitrogen removal for this watershed including: centralized sewering, a satellite wastewater treatment facility, inlet widening, shellfish aquaculture, permeable reactive barriers, and fertilizer reductions.

Based on the Massachusetts Estuaries Reports Table VIII-3 and Nitrogen Total Maximum Daily Load (TMDL) Table 4 for Bournes Pond Watershed, including Bournes Pond, Israel's Cove, and Bournes Brook, approximately 4,161 kg/yr of nitrogen needs to be removed.

Specifically within the Bournes Pond watershed, the Town is evaluating several approaches in order to achieve TMDL compliance:

- Fertilizer reduction

- Stormwater improvements
- Shellfish aquaculture
- Inlet widening
- Installation of a Permeable Reactive Barrier (PRB)

8.2.1 Fertilizer Management in Compliance with the Town's Approved Bylaw

As the Town has enacted a fertilizer bylaw, based on the Cape Cod Commission 208 Plan update, it should receive a 25 percent removal credit for nitrogen attributed to fertilizer. Based on the Massachusetts Estuaries Project (MEP) Report Table IV-4, the Bournes Pond System receives approximately 485 kg/yr, which after applying a 25 percent credit would be reduced by 121 kg/yr.

8.2.2 Stormwater Management

The Town will continue best management practices to address stormwater impacts and consider the implementation of nitrogen reducing options where feasible as discussed in Chapter 3. The implementation of these practices in Falmouth allows the Town to receive another 25 percent reduction of nitrogen attributed to stormwater runoff credit per the Cape Cod Commission (CCC) 208 Plan. This is estimated to reduce the impervious surface loads from approximately 502 kg/yr of nitrogen to 377 kg/yr (126 kg/yr less).

8.2.3 Shellfish Aquaculture

The Town is also actively pursuing the evaluation of shellfish aquaculture within Bournes Pond at three different locations to evaluate nitrogen reduction potential within the waterbody. University of Massachusetts School for Marine Science and Technology (SMAST) is currently under contract to study nitrogen uptake at the three “farm” sites within the pond, tracking oyster productivity.

Falmouth Marine and Environmental Services has preliminarily indicated eight suitable areas for shellfish aquaculture. Additional survey work is required to determine actual available acreage.

8.2.4 Inlet Widening

As discussed in Chapter 3 and Section 8.1, the Town is nearing the end of the permitting process for the Bournes Pond inlet widening project that will include the construction of a new bridge and modifications to coastal structures in the vicinity of the widened inlet. The proposed inlet opening project is projected (based on modeling) to reduce the nitrogen load within the pond by 50 percent, thereby removing nearly 1,995 kg/yr of nitrogen.

8.2.5 Permeable Reactive Barriers

As discussed in Chapter 3, the Town is actively seeking funding to pursue the installation of a PRB within one or more of its impacted watersheds. One location under consideration, a site located off of Sailfish Drive, is within the Bournes Pond Watershed. It was determined that a PRB at this location has the potential to remove between 400 and 800 kg-N/year based on the United States Environmental Protection Agency (USEPA) estimated nitrate mass flux. A pilot scale PRB approximately 300 feet long with a vertical thickness of 14 feet is estimated to remove approximately 400 kg N/year. The ultimate length of the PRB for nitrogen TMDL compliance will depend on piloting performance and the performance of the other alternative nitrogen removal options.

However, at this time, the Town is not including this as part of its primary approach to achieving Nitrogen TMDL compliance.

8.2.6 Summary of Compliance Approach for Bournes Pond

The following table outlines the overall Nitrogen budget proposed for Bournes Pond in order to achieve Nitrogen TMDL compliance.

Table 8.1 Nitrogen Budget for Bournes Pond Nitrogen TMDL Compliance

Compliance Component - Nitrogen Removal Approach	Estimated Nitrogen Loading Reduction (kg N/yr)
Fertilizer Bylaw (25% of fertilizer load)	121
Stormwater BMPs (25% of impervious load)	126
Shellfish Aquaculture (uptake)	1,352-1,680
Shellfish (denitrification)	676-840
Inlet Widening (50% of controllable load)	1,995
Total Estimated Reduction	**4,270-4,762**
Nitrogen Removal TMDL Goal	4,162

As demonstrated in Table 8.1, the outlined compliance approach should achieve the nitrogen TMDL compliance goal. However, if following implementation of this approach they are unable to meet the nitrogen reduction requirements, the Town would consider several options as part of its adaptive management. These strategies include:

- Sewer extensions along Route 28 and Fisherman's Cove.
- Use of Innovative and Alternative (I/A) septic systems.
- Exploring additional sites for PRB installation in the upper watershed.
- Exploring and evaluating nitrogen reduction options associated with nitrogen loads entering the system from Bournes Brook.

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9. Eel Pond/Waquoit Bay Watershed Planning Scenario

9.1 Collaboration Under 208 Plan with Neighboring Communities

9.1.1 Moonakis River Evaluation Update

In 2017, University of Massachusetts Dartmouth School of Marine Science and Technology (SMAST) completed their “Detailed Assessment of Water and Nutrient Exchange within the Quashnet River/Moonakis River Sub-embayment to Waquoit Bay” report. In that report they evaluated the nutrient related health of this system and examined two approaches to improve water quality and habitat including improved flushing and the use of aquaculture to remove excess nitrogen.

The overall findings of the study were:

- System health is highly impaired by nitrogen, and the nitrogen load has increased since 2003.
- Although the lower and middle portions of the Quashnet Estuary could support shellfish, their performance will depend on how the shellfish are deployed (surface bags vs. bottom trays) due to variations in salinity and biofouling.
- Dredging would only be recommended in the region of the shoal at the tidal inlet.

The report stated that although the approaches outlined above could remove some nitrogen, they would be insufficient to address the entire load.

9.1.2 Mashpee Watershed Nitrogen Management Plan/Comprehensive Wastewater Management Plan Summary

The Town of Mashpee completed its Watershed Nitrogen Management Plan/Comprehensive Wastewater Management Plan (WNMP/CWMP) in 2015 and received its Massachusetts Environmental Policy Act (MEPA) Certificate in July of that same year. They also received their 208 Compliance letter from the Cape Cod Commission for the implementation of Phase 1 in 2015 and Phase 2 in 2017.

Initially, the Town of Mashpee’s primary focus has been on the Popponesset Bay watershed, but they are actively advancing its shellfish program and are in joint discussions with Joint Base Cape Cod and its neighboring communities, including Falmouth, regarding the potential use of the wastewater treatment and recharge facilities at the Base.

9.1.3 Waquoit Bay Inter-Municipal Agreement Development with Mashpee and Sandwich

Currently the Towns of Falmouth, Mashpee, and Sandwich have begun discussions about establishing nitrogen loading allocations by Town for the entire system such that the towns could create an Inter-municipal Agreement (IMA) for managing nitrogen within this system in the future.

9.2 Waquoit Bay TMDL Compliance Plan Approach

9.2.1 Background

This section will consider five of the six major watersheds/subwatersheds of the Waquoit Bay system. Those are:

- Eel Pond
- Childs River
- Hamblin Pond/Little River
- Quashnet/Moonakis River
- Waquoit Bay

The remaining subwatershed, Jehu Pond/Great River is completely within the bounds of Mashpee and is therefore not part of this update analysis.

As the Town of Falmouth is developing and summarizing the findings of several demonstration projects and pilot efforts, the Town has considered several options to address nitrogen loading in this watershed including: centralized sewering, a satellite wastewater treatment facility, innovative and alternative septic systems (I/A systems), shellfish aquaculture, stormwater improvements, permeable reactive barriers (PRBs), and fertilizer reductions.

Specifically within the Waquoit Bay watershed, the Town is evaluating several approaches in order to achieve total maximum daily load (TMDL) compliance.

Eel Pond and Childs River

- Fertilizer reduction
- Stormwater improvements
- Shellfish aquaculture
- Sewer extensions

Hamblin Pond/Quashnet River

- The Mashpee Watershed Nitrogen Management Plan calls for shellfish aquaculture in Hamblin Pond/Little River within Mashpee's currently permitted shellfish areas; the plan also calls for sewering in the Quashnet River watershed and in the Hamblin Pond/Little River watershed depending on the performance of its shellfish program.

Waquoit Bay Proper and Jehu Pond/Great River

- There is no threshold removal called for in the Waquoit Bay proper estuary. The Jehu Pond/Great River watersheds, which have a threshold removal target, are entirely within Mashpee. Mashpee is proposing the use of shellfish and sewering to address its nitrogen contribution in order to achieve the TMDL.

9.2.2 Fertilizer Management in Compliance with the Town's Approved Bylaw

As discussed in Chapters 3 and 4, Falmouth has enacted a fertilizer bylaw, based on the Cape Cod Commission (CCC) 208 Plan update. As a result of this, communities are afforded a 25 percent removal credit for nitrogen attributed to fertilizer. Based on the Massachusetts Estuaries Project

(MEP) Report Table IV-3, the Waquoit Bay System receives approximately 4,184 kg/yr throughout the system just from fertilizer runoff. The following summarizes those subwatersheds that have some portion within the boundaries of Falmouth:

- Childs River = 827 kg/yr total (207 kg/yr removal @ 25%).
- Eel Pond = 778 kg/yr total (195 kg/yr removal @ 25%).
- Quashnet River = 1,506 kg/yr total (377 kg/yr removal @ 25% if applied to entire system).
- Hamblin Pond/Little River = 346 kg/yr total (87 kg/yr removal @ 25% if applied to entire system).

9.2.3 Stormwater Management

The Town will continue best management practices to address stormwater impacts and consider the implementation of nitrogen reducing options where feasible as discussed in Chapter 3. The implementation of these practices in Falmouth allows the Town to receive a 25 percent reduction of nitrogen attributed to stormwater runoff credit per the CCC 208 Plan. Applying this credit to the estimated impervious surfaces load (as called out on MEP Report Table IV-3) of 4,575 would equate to approximately 1,143 kg N/yr reduction for the system. The following summarizes those subwatersheds that have some portion within the boundaries of Falmouth.

- Childs River = 781 (195 kg/yr removal @ 25% if applied to the entire system).
- Eel Pond = 389 kg/yr total (97 kg/yr removal @ 25%).
- Quashnet River = 2,711 kg/yr total (677 kg/yr removal @ 25% if applied to entire system).
- Hamblin Pond/Little River = 370 kg/yr total (93 kg/yr removal @ 25% if applied to entire system).

9.2.4 Shellfish Aquaculture

The Town is evaluating whether to pursue the use of shellfish aquaculture within portions of the Eel Pond and Childs River portions of Waquoit Bay based on the findings at the other locations currently being evaluated throughout Town. In addition, the Town of Mashpee is using shellfish aquaculture within Hamblin Pond/Little River (they are also proceeding with this in Jehu/Great River, but as discussed above, that subwatershed is completely outside of the Falmouth Town boundaries).

- Childs River = shellfish uptake is estimated between 390-630 kg/yr and denitrification is estimated to be between 195-315 kg/yr based on the Town's studies described in Chapter 3.
- Eel Pond = shellfish uptake is estimated between 1,170 and 1,890 kg/yr and denitrification is estimated to be between 585 and 945 kg/yr based on the Town's studies described in Chapter 3.
- Hamblin Pond/Little River = based on the Mashpee WNMP, 1,025 kg/yr removal is anticipated based on estimated harvest values within the first ten years at full implementation.

9.2.5 Permeable Reactive Barriers

As described in Chapter 3, PRBs have been considered in several watersheds. However, this technology was not identified for use at this time in the watershed and therefore a credit for nitrogen removal from PRBs is not being estimated. The Town may consider utilizing a credit in the future following further evaluation.

9.2.6 Childs River Wetland Restoration

The Town is currently exploring the potential for additional nitrogen removal within the Childs River subwatershed through the restoration of the Farley Bog and the upper Childs River. The bog covers approximately 12.4 acres and the restoration project would look to increase the nitrogen uptake in waters flowing through this system (ground and surface) prior to heading into the Childs River. The Town has received funding from the Falmouth Rod and Gun Club, Falmouth Community Preservation Committee, and the Town of Mashpee Conservation Commission.

At this time the extent of the nitrogen removal potential of the wetland restoration efforts has yet to be determined.

9.2.7 Sewer Extensions

The Town is considering potential sewer extension projects in both the Eel Pond and Childs River subwatersheds including within Antler Shores, Seacoast Shores, and the Seapit Peninsula. This could potentially address the nitrogen from a total of 225, 989, and 101 properties, respectively. Due to the dynamics between the Eel Pond and Childs River subwatersheds, sewer extensions located in Eel Pond will likely also benefit the nitrogen reductions efforts in Childs River and vice versa. The Town has started the process of evaluating long-term solutions for effluent discharge, and additional evaluations will be developed as part of subsequent Targeted Watershed Management Plan and Notice of Project Change (TWMP/NPC) documents submitted as part of this overall project.

The Town of Mashpee's approved plan also calls for sewering within the Childs River subwatershed, Quashnet River subwatershed, Hamblin Pond/Little River subwatershed, and also within the Jehu Pond/Great River and Sage Lot subwatersheds (although these last subwatersheds fall completely outside the Town boundaries of Falmouth).

9.2.8 Summary of Compliance Approach for Waquoit Bay

The Waquoit Bay estuary is a complex system of subwatersheds that fall within multiple town boundaries. The complexity of the systems and the multiple towns contributing to the nitrogen load make it difficult to detail a comprehensive compliance approach. Therefore, the following Table 9-1 outlines the overall nitrogen budget proposed for Waquoit Bay related to those portions to which Falmouth contributes in order to achieve nitrogen TMDL compliance, and incorporates to the extent known the Mashpee WNMP plan to address its nitrogen loading contributions to the system.

Table 9.1 Nitrogen Budget for Waquoit Bay Nitrogen TMDL Compliance

Watershed/ Subwatershed	Compliance Component – Nitrogen Removal Approach	Estimated Nitrogen Loading Reduction (kg N/yr)
Eel Pond	Fertilizer Bylaw (25% of fertilizer load)	195
	Stormwater BMPs (25% of impervious load)	97
	Shellfish Aquaculture (uptake)	1,170-1,890
	Shellfish (denitrification)	585-945
	Sewer Extensions (Total)	3,362-4,264
	Antler Shores(1)	*923-1,170*
	Seacoast Shores	*2,440-3,094*
	Total Eel Pond Estimated Reduction(2)	**5,409 – 7,391**
	Eel Pond Nitrogen Removal Goal	**3,241**
Childs River	Fertilizer Bylaw (25% of fertilizer load)	207
	Stormwater BMPs (25% of impervious load)	195
	Shellfish Aquaculture (uptake)	390-630
	Shellfish (denitrification)	195-315
	Sewer Extensions (Total)	3,202-4,061
	Seacoast Shores	*1,615-2,049*
	Seapit	*414-525*
	Mashpee Sewering	*1,173-1,487*
	Total Childs River Estimated Reduction	**4,124-5,408**
	Nitrogen Removal Goal	**5,274**
Hamblin Pond/ Little River	Mashpee Sewering	2,394-3,037
	Mashpee Shellfish	1,850
	Fertilizer Bylaw (25% of fertilizer load)	87
	Stormwater BMPs (25% of impervious load)	93
	Total Hamblin Pond Estimated Reduction	**4,424 – 5,067**
	Hamblin Pond Nitrogen Removal Goal	**3,734**
Quashnet/ Moonakis River	Mashpee Sewering	1,349-1,711
	Fertilizer Bylaw (25% of fertilizer load)	377
	Stormwater BMPs (25% of impervious load)	677
	Total Quashnet / Moonakis River Estimated Reduction	**2,403-2,765**
	Quashnet / Moonakis River Nitrogen Removal Goal	**3,035**
Total Waquoit Bay (without Jehu Pond/Great River)	**Total of Above Removals (2)**	**16,360 – 20,631**
	Total Removal Goals of the Above Watershed (3)	**15,284**

Notes:

1. The number of properties within the individual subwatershed boundary was used to calculate reduction, but due to the dynamics of the system will have impacts in both Eel Pond and Childs River.
2. Due to the complex flow dynamics of the Waquoit Bay system, overages in the estimated nitrogen reduction in Eel Pond may compensate for the deficit in Childs River.
3. Total removal goal based on values from Table VIII-3 from the 2013 MEP Report for Waquoit Bay.

As demonstrated above, the nitrogen removal goals within Eel Pond and Hamblin Pond/Little River can be achieved through the use of these approaches. However, a shortfall may result due to the variability of some of the removal options and the potential phasing of any sewering within this watershed. In addition, Childs River and Quashnet/Moonakis River thresholds may not be achieved depending on the performance of the proposed improvement. This is all related to the complexity of the system and the tidal flushing dynamics and therefore improvements in some of these subwatersheds will likely also have benefits to the adjacent ones especially when examining the Eel Pond and Childs River embayments.

Therefore, active monitoring of the water quality within the system will be necessary and will allow the Town to apply adaptive management approaches to best target sewer infrastructure implementation and gauge the performance of some of the other alternative approaches, namely shellfish.

The Town has also identified several options in the event that strategies from the proposed compliance plan approach are not sufficient including:

Eel Pond

- Use of I/A septic systems in the upper watershed.
- PRBs within the watershed.

Childs River

- Explore sewer extensions north of Route 28.
- Use of I/A septic systems in the upper watershed.
- PRBs within the watershed.

Quashnet River

- Explore use of I/A septic systems within Falmouth.
- Explore sewer extensions within Falmouth.

10. Public Outreach Efforts

10.1 Summary of Public Outreach Efforts

From 2014 through mid-2019 the Town of Falmouth actively participated in public awareness outreach efforts on water quality issues. The Water Quality Management Committee (WQMC) is the primary means of publicly disseminating Town decisions and strategic planning efforts towards restoring the impaired estuaries. Table 10.1 is a summary of WQMC meetings and publicly available archives relating to the activities of the WQMC.

Table 10.1 Summary of Meeting Records for the Falmouth Water Quality Management Committee

Year	Regular Committee Meetings	Number of Meetings Available Through FCTV	Number of Articles in Local Newspaper
2014	22	18	19
2015	17	17	17
2016	19	18	29
2017	19	12	24
2018	21	15	32
2019	9	4	8
Total Through June 1, 2019	107	84	129

During the past five and a half years the WQMC has held regular public meetings that typically occur on the first and third Thursday of each month. In accordance with the Massachusetts Open Meeting Law, the agenda for each WQMC meeting is publicly posted on the Town's website at least 48 hours prior to the meeting. Detailed minutes from each meeting are also publicly available on the Town's website. Current and archived agendas and minutes can be found at:

https://ma-falmouth.civicplus.com/AgendaCenter/Water-Quality-Management-Committee-39

The 2014 approved Comprehensive Wastewater Management Plan, various Technical Memos, and other engineering reports can also be found in the Agenda Center archives under the headings "Wastewater Division" and "Water Quality Planning."

Falmouth Community Television (FCTV) is a local non-profit media center that provides information of local interest to the community. As part of efforts for public awareness, FCTV is notified of every WQMC meeting. FCTV has videotaped over 75% of the meetings of the WQMC in the last five and a half years. All recorded meetings are broadcast repeatedly on local cable TV, and are available for viewing on the internet at FCTVs webpage and on the FCTVs YouTube channel. FCTV can be found at: http://www.fctv.org/v3/

The Enterprise is a local weekly newspaper produced for four towns on the Upper Cape. The Falmouth Enterprise edition reports mainly on issues of interest to residents of Falmouth. According to The Enterprise there are 6,900 Falmouth subscribers during the majority of the year, increasing to approximately 9,500 subscribers from June through September. On the Upper Cape as a whole, approximately 13,000 households are subscribers and have access to The Enterprise on the internet (personal communication). The Enterprise is notified of every WQMC meeting, and a reporter typically attends each meeting. Since 2014, numerous articles have been published primarily in the Falmouth edition (Table 10.1) of The Enterprise. Archives of articles are available at: https://www.capenews.net/

In addition to regular meetings on water quality issues, the WQMC has made a number of special efforts to reach out to the public on a variety of issues.

- Little Pond Sewer Service Area Project: In 2014 there were several public informational meetings, and supporting materials were distributed to the community to address questions and concerns about the project. These materials included a document outlining financial assistance for homeowners and a betterment memo (see Section 4.1.1 and Appendix 10.1).
- Fertilizer Bylaw: The Town initiated annual fertilizer mailings to homeowners and landscapers (see Section 3.6) in 2014. This letter is distributed every year to affected homeowners to remind them of the bylaw requirements.
- Innovative/Alternative (I/A) Septic Systems: In 2016, the Town partnered with the Buzzards Bay Coalition to host a workshop with five I/A vendors for homeowners interested in participating in the West Falmouth Harbor Shoreline Septic System Remediation Project (WFHSSSR) (see Section 3.4.2). Additionally, the Town produced a Frequently Asked Questions flier for homeowners interested in the WFHSSSR Project (see Appendix 10.2).
- Sharing of Technical Information: In 2017 several members from the WQMC were invited to meet with the Martha's Vineyard Commission to share Falmouth's knowledge and experiences in addressing water quality issues and to learn what approaches were being considered on Martha's Vineyard.
- Reports to Town Meeting: In 2015, 2016, and 2017 the WQMC presented a status report to Town Meeting on all activities currently in progress.

The Water Quality Management Committee will continue to work with the Board of Selectmen and relevant Town departments to inform the public and to provide a forum for open dialogue on water quality issues.

11. CWMP/TWMP Notice of Project Change Summary and Next Steps

11.1 Notice of Project Change – Project Narrative / CWMP Update Summary

11.1.1 Introduction

The Town of Falmouth (Town) is engaged in a multi-decade effort to restore the water quality and habitats in coastal ponds that have been degraded by excess nitrogen from human activities and land development. Beginning in 2007, Falmouth has focused its planning on the southern coastal ponds—Little, Great, Green and Bournes Ponds and Waquoit Bay—as these are considered the most impaired water bodies (Figure 11.1). Watershed by watershed, the Town is developing plans to restore these estuaries. The Massachusetts Department of Environmental Protection (DEP) approved the Targeted Watershed Plan for Little Pond on October 6, 2014. As outlined in that plan the Town has submitted its first Notice of Project Change, starting the process to address the Bournes Pond watershed by widening the inlet to restore tidal flushing and improve habitat. Both Massachusetts Environmental Policy Act (MEPA) Certificates (EEA #14154) for this project are included in Appendix 1.1.

Each estuary is unique, and the Massachusetts Estuaries Project (MEP) has collected a wealth of baseline information about nitrogen loads and the level of degradation in each pond. The Environmental Protection Agency (EPA) and the DEP have established a Total Maximum Daily Load (TMDL) for each estuary that the Town must meet in order to restore a healthy habitat. Falmouth's planning approach for each estuary evaluates cost, efficacy, and environmental impact using several approaches:

- The TMDL can be met with a combination of site-appropriate alternatives including:
  - Inlet widening/dredging
  - Aquaculture
  - Permeable reactive barriers
  - Wetland/habitat restorations
  - Innovative/alternative septic systems; and
  - Sewer extensions.

The Town is implementing an "adaptive management" approach as outlined in the Cape Cod Commission's Area-wide 208 Watershed Management Update. This approach acknowledges that there is uncertainty in project design and implementation. Projects will be carefully monitored, progress assessed, and plans restructured as necessary.

As requested in the MEPA certificate, the purpose of this Notice of Project Change is to provide updates on:

- Little Pond Sewer Service Area.
- Water quality monitoring throughout the planning area.
- Adaptive Management/ Pilot Projects.
- Nutrient reduction in the planning area.
- Permitting/Mitigation Section 61 Findings (See Chapter 12).

11.1.2 Little Pond Sewer Service Area Update

As discussed in Chapter 4, the first major phase of Targeted Watershed Management Plan (TWMP) implementation was the sewering of a significant portion of the Little Pond watershed. This has resulted in 95% of the 1,350 properties in the sewershed receiving sewer service to date, thereby reducing their impact on the estuary by eliminating their septic system discharges to the groundwater system. All properties in the sewershed are expected to be connected by the fall of 2019.

As identified in Table 4.3 the sewering of this area, combined with the credits for fertilizer management and stormwater Best Management Practices (BMPs), will allow the Town to meet the nitrogen TMDL goal for this watershed. The Town and United States Geological Survey (USGS) are actively monitoring the groundwater on the peninsula, and this data will be used to provide a greater understanding of the water-quality conditions before and after the installation of sewers.

11.1.3 Water Quality Monitoring and Watershed Compliance Plan Updates

As discussed in Chapters 2 and 5, the Town has collected an extensive amount of water quality data for the Little, Great, Green, and Bournes Ponds, in addition to Waquoit Bay and West Falmouth Harbor.

Chapter 3 summarizes all of the pilot project efforts undertaken since the 2014 Certificate through the writing of this report. Report sections documenting the information that has been gathered on various projects and nitrogen-reduction strategies during the last five years are summarized below:

3.2 Aquaculture

3.3 Eco-toilets (composting, packaged, and urine diverting toilets)

3.4 Innovative and alternative (I/A) septic systems

3.5 Permeable reactive barriers (PRBs)

3.6 Nitrogen Control Bylaw for fertilizer

3.7 Stormwater management

3.8 Inlet widening – Bournes Pond

The technical reports and supporting documents are located in the associated appendices (3.2 through 3.8).

Through analysis of the water quality data and pilot projects, the Town has developed compliance plans for each watershed, as detailed in Chapters 4 through 9 of this report. The following are the summary tables for each watershed within the planning area. Additional detail for each proposed plan is found in its respective chapter.

Table 11.1 Little Pond (Chapter 4) Nitrogen Budget: Updated Compliance Approach

Compliance Component – Nitrogen Removal Approach	Estimated Nitrogen Loading Reduction (kg N/yr)
Sewering	4,848
I/A Systems	340
Fertilizer (25% of fertilizer load)	158
Stormwater (25% of impervious load)	116
Aquaculture	29
Total Estimated Reduction	**5,461**
Nitrogen Removal TMDL Goal	**5,006**

Table 11.2 West Falmouth Harbor (Chapter 5) Nitrogen Budget: Updated Compliance Approach

Compliance Component - Nitrogen Removal Approach	Estimated Nitrogen Loading Reduction (kg N/yr)
Wastewater Treatment Improvement	8,792
I/A Systems	92
Fertilizer (25% of fertilizer load)	91
Stormwater (25% of impervious load)	285
Aquaculture	0
Total Estimated Reduction	**9,260**
Nitrogen Removal TMDL Goal	**8,472**

Table 11.3 Great Pond (Chapter 6) Nitrogen Budget to Achieve TMDL Compliance

Compliance Component – Nitrogen Removal Approach	Estimated Nitrogen Loading Reduction (kg N/year)
Fertilizer Bylaw (25% of fertilizer load)	425
Stormwater BMPs (25% of impervious load)	580
Aquaculture (uptake)	1,300-2,100
Shellfish (denitrification)	650-1,050
PRB at Shorewood Drive (300 feet)	1,325
Sewer Extensions (Total)	7,179-9,105
LPSSA (Great Pond)	*1,037-1,316*
TASA Subarea 1	*3,325-4,217*
TASA Subarea 2	*2,817-3,572*
Total Estimated Reduction	**11,459-14,585**
Nitrogen Removal TMDL Goal	**12,154**

Table 11.4 Green Pond (Chapter 7) Nitrogen Budget to Achieve TMDL Compliance

Compliance Component - Nitrogen Removal Approach	Estimated Nitrogen Loading Reduction (kg N/yr)
Fertilizer Bylaw (25% of fertilizer load)	227
Stormwater BMPs (25% of impervious load)	172
Stormwater – Captain's Lane Catchment Area	120
Aquaculture (uptake)	390-630
Shellfish (denitrification)	195-315
Mill Pond	491-961
Sewer Extensions (total)	2,058-2,610
Total Estimated Reduction	**3,653-5,035**
Nitrogen Removal TMDL Goal	4,453

Table 11.5 Bournes Pond (Chapter 8) Nitrogen Budget to Achieve TMDL Compliance

Compliance Component - Nitrogen Removal Approach	Estimated Nitrogen Loading Reduction (kg N/yr)
Fertilizer Bylaw (25% of fertilizer load)	121
Stormwater BMPs (25% of impervious load)	126
Aquaculture (uptake)	1,352-1,680
Shellfish (denitrification)	676-840
Inlet Widening (50% of controllable load)	1,995
Total Estimated Reduction	**4,270-4,762**
Nitrogen Removal TMDL Goal	4,162

Table 11.6 Waquoit Bay (Chapter 9) Nitrogen Budget to Achieve TMDL Compliance

Watershed/ Subwatershed	Compliance Component – Nitrogen Removal Approach	Estimated Nitrogen Loading Reduction (kg N/yr)
Eel Pond	Fertilizer Bylaw (25% of fertilizer load)	195
	Stormwater BMPs (25% of impervious load)	97
	Aquaculture (uptake)	1,170-1,890
	Shellfish (denitrification)	585-945
	Sewer Extensions (Total)	3,362-4,264
	Antler Shores	*923-1,170*
	Seacoast Shores	*2,440-3,094*
	Total Eel Pond Estimated Reduction	**5,409 – 7,391**
	Eel Pond Nitrogen Removal Goal	**3,241**
Childs River	Fertilizer Bylaw (25% of fertilizer load)	207
	Stormwater BMPs (25% of impervious load)	195
	Aquaculture (uptake)	390-630
	Shellfish (denitrification)	195-315
	Sewer Extensions (Total)	3,202-4,061
	Seacoast Shores	*1,615-2,049*
	Seapit	*414-525*
	Mashpee Sewering	*1,173-1,487*
	Total Childs River Estimated Reduction	**4,124-5,408**
	Nitrogen Removal Goal	**5,274**

Watershed/ Subwatershed	Compliance Component – Nitrogen Removal Approach	Estimated Nitrogen Loading Reduction (kg N/yr)
Hamblin Pond/ Little River	Mashpee Sewering	2,394-3,037
	Mashpee Shellfish	1,850
	Fertilizer Bylaw (25% of fertilizer load)	87
	Stormwater BMPs (25% of impervious load)	93
	Total Hamblin Pond Estimated Reduction	**4,424 – 5,067**
	Hamblin Pond Nitrogen Removal Goal	**3,734**
Quashnet/ Moonakis River	Mashpee Sewering	1,349-1,711
	Fertilizer Bylaw (25% of fertilizer load)	377
	Stormwater BMPs (25% of impervious load)	677
	Total Quashnet / Moonakis River Estimated Reduction	**2,403-2,765**
	Quashnet / Moonakis River Nitrogen Removal Goal	**3,035**
Total Waquoit Bay (without Jehu Pond/ Great River)	**Total of Above Removals**	**16,360 – 20,631**
	Total of Above Removal Goals	**15,284**

Notes:
1. Stormwater reduction range based on reduction of the entire system or only Childs River North.
2. Total removal goal based on values from Table VIII-3 from the 2013 MEP Report for Waquoit Bay.
3. Due to the complex flow dynamics of the Waquoit Bay system, overages in the estimated nitrogen reduction in Eel Pond may compensate for the deficit in the Childs River.

11.2 Next Steps

11.2.1 CWMP/TWMP for Great Pond Plan of Study

The Town has adopted the general approach of working west to east along its southern coastline. This allows traditional infrastructure to be extended from existing infrastructure, which is primarily located within the Town's downtown areas and the Little Pond Sewer Service Area.

Following the west to east approach, the Town has identified the Great Pond watershed as its next priority and will be seeking to develop and submit its next Targeted Watershed Management Plan for this waterbody. This update to the Comprehensive Plan/Notice of Project Change document provides a large portion of the components necessary for the development of a Targeted Watershed Management Plan/ Environmental Impact Report, and therefore the TWMP for Great Pond will focus on incorporating the following components into the work that has been outlined as part of this update:

1. Background
    a. This section would provide a brief background of the efforts that have led up to the proposed TWMP for Great Pond and reference this Update document.

2. Update and Recommended Effluent Discharge Site Selection

    a. This section will identify the proposed effluent discharge site(s) for flow collected through the proposed sewer area and will summarize additional effluent discharge site evaluations conducted subsequent to the submittal of this current Comprehensive Wastewater Management Plan (CWMP) Update/NPC.

    b. This section will also provide an analysis of the environmental and financial pros and cons of a half dozen discharge site options from two perspectives: a short-term option that accommodates the expected flow from the Great Pond watershed and a long-term option that would accommodate all of the present and future flow expected from the planning area.

3. Development of a Recommended Plan.

    a. This will outline the proposed service area and the extent of traditional and non-traditional elements proposed to address nitrogen loading within Great Pond watershed and possibly portions of Green Pond watershed (as necessary, based on design requirements).

    b. This section will also provide an update on the cost estimates for the proposed Recommended Plan to facilitate the Town's evaluation of funding opportunities. This section will also provide an updated implementation schedule regarding this.

4. Update of Environmental Impact Analysis.

    a. As necessary, this section will review the existing environment of Great / Green Pond to identify potential impacts during the next phase of implementation. The section will identify potential impacts and regulatory requirements and will rank various alternatives for this area.

5. Update the Section 61 Findings and Mitigation Measures

    a. Similar to the information found in this NPC, this section will provide an update for any Section 61 Findings and Mitigation Measures, as needed. It will also include an updated mitigation table relative to the specific work being proposed for the Great Pond TWMP.

It is our expectation that the other sections typically found in a CWMP or TWMP have been addressed through previous documents and the two Notice of Project Change documents (including this one). A Draft Targeted Watershed Management Plan/Draft Environmental Impact Report, as outlined above, is anticipated to be submitted for review and approval and will be followed by the Final TWMP/EIR.

As outlined in Chapters 6 and 7, the TWMP for Great Pond is anticipated to include portions of the Teaticket/Acapesket neighborhoods and parcels between the Little Pond Sewer Service Area and the Acapesket peninsula, as shown in Figure 6.2.

11.2.2 Regional Steps

11.2.2.1 Joint Base Cape Cod

The Town of Falmouth is actively participating in discussions and evaluations related to the potential use of the wastewater infrastructure at Joint Base Cape Cod (JBCC). This is a regional effort that includes JBCC, Falmouth, Barnstable, Bourne, Mashpee, and Sandwich.

11.2.2.2 Nitrogen Loading Allocation for Waquoit Bay Watershed

Falmouth is actively working with its neighboring communities of Mashpee and Sandwich in order to establish nitrogen loading allocations and responsibility for Waquoit Bay. It is anticipated that the communities will establish these allocations to aid in each community's approach to addressing the nitrogen impacts to this large shared watershed.

11.2.3 Overall CWMP Schedule Update

The following Table 11.7 is included to provide an update to the implementation and cost schedule presented in the 2014 CWMP/EIR and TWMP. This table outlines the specific steps and anticipated schedule for the upcoming TWMP for Great Pond and design of the project recommended in the TWMP (years 2019 through 2025). In the process of developing this TWMP, Falmouth must make an important decision in choosing a site for discharge of the treated effluent. The financing plan in Table 11.7 is consistent with Falmouth's originally stated policy of funding sewer projects in those years when new debt can replace retiring old debt, thereby not increasing the tax rate. The next funding window is Fiscal Year 2025. Town Meeting and the voters would have to approve a bond issue of $60 million in April/May 2024 to be effective at the start of Fiscal Year 2025 on July 1, 2024.

Table 11.7 also outlines the funding opportunities currently identified by the Town of Falmouth and the construction timetable for the years 2025 through 2040. Due to the overall size and complexity of the Town's South Coast Embayment Watersheds planning area, this project is anticipated to extend beyond 2040 in order to feasibly implement and achieve TMDL compliance.

Table 11.7 Estimated Costs and Financing Plans

Item	Action Item	2019	2020	2021	2022	2023	2024	2025
1	Little Pond Sewer Service Area Completed	X						
2	(A) CWMP Update/NPC; (B) Oyster Pond Draft CWMP Submitted to MEPA/DEP	X						
3	Capital Plan within debt limit: add third Sequencing Batch Reactor; plant upgrade		X	X	X			
4	Receive MEPA Secretary's Certificate for CWMP Update		X					
5	Evaluate Results of Remediation to date; Engineering Contract for Great Pond TWMP		X					
6	Draft TWMP for Great Pond Sewer Service Area; Decision on Discharge Site; Submit to MEPA/DEP		X	X				
7	Sec. Certificate for Draft TWMP; Final TWMP; Sec. Certificate for Final TWMP				X			
8	Town Meeting Sets Betterment Percentage					X		
9	Construction Design Funding; Ballot Vote					X		
10	SRF PEF Application Submittal					X		
11	Obtain Listing on the SRF Intended Use Plan						X	
12	$60M Town Vote Bond for Construction Contingent on 0% SRF Loan; Ballot Vote						X	
13	SRF Full Application Submitted - all required items must be in place						X	
14	State SRF Commitment; Bid Approval							X
15	SRF-Funded Construction Projects; On-going Adaptive Management							X

Program Funding and Timetable 2025-2040	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Town Construction of $60M																
Plan Next Construction Projects																
$40M Town Vote - Spring 2030						X										
Town Construction of $40M																
$XX Town Vote - Spring 2035 (1)											X					
Town Construction																

Notes:

CWMP = Comprehensive Wastewater Management Plan

NPC = Notice of Project Change

TWMP = Targeted Watershed Management Plan

PEF = Project Evaluation Form

SRF = State Revolving Fund

1. Due to the unknowns and uncertainties related to funding in the future, the Town has not identified the appropriation goal for 2035.

12 Section 61 Findings and Mitigation Measures Update

12.1 Introduction

The purpose of this Chapter is to identify and present the mitigation measures as identified in the approved Comprehensive Wastewater Management Plan and Final Environmental Impact Report and Targeted Watershed Management Plan (CWMP/FEIR/TWMP) with updates as applicable. Draft Section 61 Findings are outlined in the Massachusetts Environmental Policy Act (MEPA) Regulations 301 CMR 11.07, in accordance with M.G.L. c. 30, section 61 for all State agency actions. These regulations require that each agency, department, board, commission, and authority of the Commonwealth "review, evaluate, and determine the impact on the natural environment of all works, project or activities conducted by them and shall use all practicable means and measures to minimize damage to the environment." The regulation also states that, "Any determination made by an agency of the Commonwealth shall include a finding describing the environmental impact, if any, of the project and a finding that all feasible measures have been taken to avoid or minimize said impact."

The Secretary's Certificate requires that the Notice of Project Change (NPC) include a separate chapter on mitigation measures, including proposed and/or revised Section 61 Findings for State permits and a summary table of the mitigation measures proposed.

12.2 Draft Section 61 Findings for State Agency Actions

Anticipated State agency actions are listed below. These actions summarize permits and approvals that will likely be required for implementation of the Recommended Plan.

- U.S. Environmental Protection Agency (USEPA), National Pollutant Discharge Elimination System (NPDES) Permitting Program (as applicable), under 40 CFR Chapter 1, Section 122.26 (15) for NPDES Stormwater Permit for Construction Activities and review of developed Stormwater Pollution Prevention Plan (SWPPP).
- Department of the Army, New England District, Corps of Engineers (as applicable), Permit requirement under Section 10 of the Rivers and Harbors Act of 1899 (33 U.S.C. 403); Permit requirement under Section 404 of the Clean Water Act; Massachusetts Programmatic General Permit (PGP) or Category II or III Individual Permit.
- Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA) approval of the CWMP/FEIR/TWMP Document.
- Massachusetts Department of Environmental Protection, Ground Water Discharge Permit Program, pursuant to M.G.L. c. 21 s. 43 and its regulations at 314 CMR 5.00, BRP WP 11, for facility modifications with plan approval and/or for a new effluent discharge permit.
- Massachusetts Department of Environmental Protection, Sewer System Extension and Connection Permit Program, pursuant to M.G.L. c. 21 s. 43 and its regulations at 314 CMR 7.00, BRP WP 13, 17, or 18.

- Massachusetts Department of Environmental Protection, Chapter 91 License (as applicable), pursuant to M.G.L. c. 91, the waterways licensing program.
- Massachusetts Department of Environmental Protection, Notice of Intent (NOI) Wetland Protection Act (WPA) Form 3 (as applicable) and Falmouth Conservation Commission approvals (as applicable) for work within the 100-foot buffer to a wetland, per the wetlands regulations at 310 CMR 10.00.
- Massachusetts Department of Environmental Protection, Air Quality Permits (as applicable), BWP AQ 04 - Asbestos Removal Notification that may be required for Asbestos Pipe removal and BWP AQ 06 Construction/Demolition Notification.
- Massachusetts Department of Environmental Protection, Emergency Engine and Emergency Turbine Compliance. The program applies to all new emergency or standby engines with a rated power output equal to or greater than 37 kW or emergency turbines with a rated power output less than one megawatt constructed, substantially reconstructed, or altered after March 23, 2006.
- Massachusetts Department of Environmental Protection, Air Quality Permit BWP AQ 14, 15, 16, 17 Operating Permits. These are mandated for major sources of air pollution by the Clean Air Act Amendments of 1990. Massachusetts has incorporated this program in 310 CMR 7.00 Appendix D of its Air Pollution Control Regulations. In some cases, emissions from Wastewater Treatment Facilities (WWTFs) or odor control systems trigger this requirement.
- Massachusetts Department of Environmental Protection Bureau of Waste Site Cleanup, Filing of Utility Release Abatement Plan (as applicable), for excavation within known contaminated sites.
- Office of Coastal Zone Management (CZM) Federal Consistency Review, pre-consultation to determine applicability.
- Commonwealth of Massachusetts Department of Public Works Permit for work within State Highway Layouts. These will be required for any work proposed along Route 28.
- Massachusetts Division of Fisheries & Wildlife, The Natural Heritage & Endangered Species Program (NHESP), MESA (321 CMR 10.00) and/or the WPA (310 CMR 10.00) for work below mean high water line, in a fish run, or in priority or estimated habitats.
- Massachusetts Division of Marine Fisheries (DMF) as appropriate. DMF shall include consultation on potential impacts to diadromous fish species and mitigation measures as appropriate.
- Massachusetts Historical Commission (MHC) consultation/reviews for construction of new facilities and infrastructure.
- Cape Cod Commission (CCC) review for 208 Plan consistency.
- Town of Falmouth building permits for the construction of structures as part of the Recommended Plan.
- Town of Falmouth Wastewater Department for sewer connection permitting.
- The Town of Falmouth Conservation Commission for any proposed work within its jurisdiction.

The resulting planned mitigation measures are discussed in this Chapter. The following section summarizes the proposed mitigation measures.

All mitigation measures will be funded and implemented by the Town of Falmouth, its agents, representatives, and/or contractors in addition to any State agency actions required above.

12.3 Planned Mitigation Measures Design and Construction

As called for in the 2014 Secretary's Certificate, the following mitigation measures have been identified and updated as appropriate. These measures were outlined and identified in the approved CWMP/TWMP to limit negative environmental impacts and/or create positive environmental impacts during development and operation of the preferred plan. The schedule and costs for the implementation of mitigation are also discussed where appropriate.

12.3.1 General Construction Measures

During construction, the site(s) shall be secured to prevent unauthorized entry to the construction site and to protect existing and adjacent facilities and properties. Supplemental lighting, signs, railings, and construction barriers shall be used as necessary to provide safety to employees, construction workers, visitors, and the general public during the construction process in accordance with Occupational Safety and Health Administration (OSHA) and other applicable regulations.

Water used during the construction process and that generated from runoff on the site, will be controlled by proper site grading and by providing temporary berms, drains, and other means to prevent soil erosion. These means will also be used to reduce puddling and runoff on the site. Existing and new catch basins will be protected from siltation using hay bales, siltation fence, and catch basin inserts. At no time will the pumping of silt-laden water to surface waters, stream corridors, or wetlands be allowed. Pollution controls will also be provided to prevent the contamination of soils, water, and the atmosphere from the discharge of noxious or toxic substances and pollutants during the construction process.

Erosion control measures including hay bales, siltation fencing, and erosion control fabric will be used to provide sedimentation barriers where required. Temporary seeding and mulching may also be used to minimize soil erosion and provide soil stabilization on slopes. Diversion trenches may also be used on the uphill side of disturbed areas to divert surface runoff. Land disturbances will be kept to a minimum to reduce impacts and erosion. All erosion and stormwater control methods shall be in accordance with the USEPA NPDES General Permit requirements, Commonwealth of Massachusetts regulations, and the Town of Falmouth regulations. A SWPPP will be required as part of the NPDES General Permit for those areas exceeding the threshold limits.

The site(s) will be maintained free of waste materials, debris, and trash following each day of work. Waste and other debris will be collected and disposed of off-site periodically. At no time during construction will the dumping of spoil material, waste, trees, brush, or other debris be allowed into any stream corridor, any wetland, any surface waters, or any unspecified location. The permanent or unspecified alteration of stream flow lines is not allowed during construction. Recycling of waste and construction debris will likely be mandated as well and should always be considered during construction.

Construction noise from heavy equipment will normally be limited to within normal operating hours of 7:00 a.m. to 5:00 p.m. Dust controls, including the use of street sweepers and/or watering trucks, will be used to minimize air-borne dust as necessary.

The Town, in participation in the Massachusetts Clean Water State Revolving Fund (CWSRF), also actively requires the MassDEP Diesel Retrofit Program be followed and therefore requires that contractors working on their CWMP/TWMP related projects participate in this program in order to minimize construction-period diesel emissions.

Depending on the type of non-traditional project, various other regulatory reviews may be required including Massachusetts Historical Commission, Natural Heritage and Endangered Species Program, MassDEP/US Army Corps of Engineers for dredging and coastal projects, US Coast Guard, MassDEP/Falmouth Conservation Commission regarding wetlands and resource areas, and Division of Marine Fisheries. Each of these regulatory agencies may issue specific conditions and permit requirements related to the type of project.

12.3.2 Sewer Construction Mitigation

At such time as the Town moves into the construction phase, additional mitigation measures will be implemented, in addition to those identified in the general construction section. Police details and other traffic controls will be necessary to minimize traffic problems during sewer expansion construction. Detours and trucking routes will need to be identified prior to construction as part of detailed design and these routes will need to be designed to minimize impacts to surrounding residential areas not accustomed to heavy construction and increased vehicle traffic. Construction within the future sewer service areas will have to allow for safe travel of both pedestrians and vehicle traffic.

Sewer extensions are planned in the road layouts to avoid impacts to animal habitats, wetlands, historic areas, or potential archaeological sites. Construction in these areas will impact traffic (vehicle, pedestrian, and bicycle) in the roadways during construction. Construction procedures for traffic control, erosion protection, dust control, noise prevention, and wetland protection will be implemented as appropriate and documented in the Construction Plans and Specifications for any specific project. Use of trench boxes, bracing, and other shoring methods will be utilized to provide the necessary safety for workers and others at the construction site and are employed as part of the construction contractor's means and methods in accordance with OSHA requirements and Massachusetts open trenching laws.

To the extent practicable, any private property, including trees and vegetation, that is damaged during construction is to be repaired or replaced. All roads, both publicly and privately owned, impacted by construction associated with the implementation of the collection system shall be restored to a condition safe and appropriate for vehicular traffic. Any collection system components and lift stations to be constructed outside of road right-of-ways will be reviewed with the MHC during design. If required, archaeological monitors will be provided during construction as stipulated by MHC.

The collection system lift stations need to be located in low-elevation areas to be able to utilize gravity pipes for collection and subsequent pumping. Wetland regulations and permitting will be followed to minimize impacts to any adjacent wetlands.

Stormwater and construction runoff will be managed through the implementation of construction SWPPPs established prior to construction and regulated under USEPA NPDES General Permits for Construction.

Areas requiring sewers located within parts of Town identified as barrier beach will have to be designed and constructed to meet specific State requirements for work within these areas (Executive Order 181), and will have the following stringent requirements for the construction of sewers on a barrier beach:

1) All infrastructure must be protected from coastal flood hazards.
2) The sewers cannot promote additional growth on the barrier beach that would not have otherwise been allowed.

Previous discussions held with Massachusetts CZM, the agency that upholds Executive Order 181, have identified that the water quality benefits provided by the collection system extensions will greatly outweigh the slight risk that a catastrophic coastal hazard could damage some of the infrastructure. Collection system extensions will be designed to withstand reasonably expected coastal flood hazards; lift stations will be designed to withstand a 100-year storm, and all pipes and equipment suitably protected from wave action. Lift stations will be located outside of flood zones when possible and protected with a system of check valves in critical areas and generally protected from floods and natural hazards to the extent reasonable.

12.3.3 Wastewater Treatment Facility Site and Discharge Sites

In addition to those mitigation measures identified previously, the following measures will be provided at the existing Falmouth WWTF and any new discharge sites. The wastewater treatment system will process the wastewater collected from future sewer service areas. Removal of this local source of nitrogen will significantly reduce the amount of nitrogen entering the watersheds of the estuaries within the project planning area in order to make substantial progress towards achievement of the TMDLs during the 20-year planning period.

The greatest mitigation measure is the operation of an improved advanced wastewater treatment system designed for consistent nitrogen removal to 3 mg/L total nitrogen. Improvements to the WWTF will also provide significant removal of suspended solids and biochemical oxygen demand (BOD) in the effluent. This system will increase the production of biosolids (sludge) and increase the volume of treated water recharged to the water table. The sludge will be disposed of or reused at an approved off-site facility in accordance with MassDEP guidelines. The recharge will be monitored as part of an approved groundwater monitoring plan. Odor and noise mitigation measures will also be considered as part of the final design to minimize the impacts to adjacent properties during construction and operation.

Energy efficient design features to minimize greenhouse gas (GHG) release from the WWTF will be considered during preliminary and detailed design to maintain a high rating index of 50 or greater. GHG evaluations were completed as summarized in Chapter 7, Section 7.6.2 of the approved CWMP/TWMP and these evaluations should be considered during design of any expansions of the WWTF. Future expansions should be designed to meet a rating index of 50 or higher.

The following mitigation measures will be observed to avoid or minimize adverse environmental impacts:

- The WWTF improvements will take place on a previously developed parcel (existing Falmouth WWTF) and in existing structures.
- Any new lift stations will have exterior façades which will compliment and be consistent with neighborhood aesthetics.
- Vegetative screens will be employed, if determined necessary, for aesthetic reasons.
- Consultation with expert agencies will occur during the design phase and contact will be continued during construction if there is a resource that may be affected.
- Work will be halted if archaeological resources are uncovered during construction.
- The contractor will be required to thoroughly clean up the site before the contract is considered complete.
- Proper handling and storage of possible contaminants and hazardous substances will be required of the contractor, in addition to proper notifications.
- Access roads will be dampened to minimize construction dust if required.
- Debris will not be burned as a means of disposal.
- No construction work will normally be performed during evening, holiday, or weekend hours.
- A Resident Project Representative will be employed to ensure that the project area is kept clean and that mitigation measures are met.

12.4 Additional Mitigation Measures

12.4.1 Adaptive Management

The Town of Falmouth's CWMP includes the implementation of an adaptive management process to incorporate cost-effective non-traditional methods into the plan once they demonstrate feasibility. The adaptive management process will also monitor groundwater elevations, water quality, and performance at coastal embayments during construction and upon completion of the phased sewering and full-scale implementation of non-traditional methods (as applicable).

This adaptive management approach will enable the CWMP to be adjusted based on the monitoring results of the environmental and economic impacts associated with the construction of the new sewers or implementation of additional non-traditional projects in Falmouth. Coordination with MassDEP and the CCC will also be conducted and key factors incorporated into the adaptive management plan.

12.4.2 Climate Change Mitigation

The following provides a broader view of mitigation measures that could be evaluated or implemented in preparation of climate change planning. Given the significance of the Town's beaches and coastal wetlands as both a tourism and revenue draw, but also as natural buffers to coastal wave action, it is in the Town's best interest to implement strategies to protect these areas from detrimental impacts associated with climate change. As presented in Lewsey et. al. (2003) and the September 2011 *Massachusetts Climate Change Adaptation Report*, options to protect beaches and coastal wetlands include the following:

- Development of a Town-wide Hazard Mitigation Plan;
- Continue with long-term beach and coastal area monitoring;
- Strengthen regulations to protect ecological buffers such as coastal wetlands and estuaries;
- Use land acquisition and conservation restrictions to protect headwater streams and associated buffer areas in order to protect downstream conditions during periods of warming;
- Adapt permitting and regulatory criteria to protect and maintain natural stream flow as well as incorporate potential climate change impacts;
- Develop comprehensive land use plans which incorporate the protection of natural coastal resources such as beaches and wetlands;
- Employ land use protection tools to maintain, preserve, and restore ecological buffers; and
- Enhance engineered coastal protection systems where inland retreat or other accommodation is not an option.

As presented by Lewsey et. al. (2003), there are several ways in which the Town of Falmouth can protect shoreline residential and commercial infrastructure development, including:

- Introduce building codes that account for climate change effects such as sea level rise;
- Implement comprehensive land use planning to account for the impacts associated with sea level rise and climate change;
- Identify high hazard areas, i.e. those areas most likely to be subjected to detrimental effects of climate change such as sea level rise and introduce regulations to phase out development in high hazard areas;
- Link coastal property insurance rates with construction quality, i.e. ability to accommodate sea level rise, increased flooding, more frequent storm events;
- Implement economic and market-based incentives that promote sustainable development in coastal areas and/or deter development from high hazard areas; and
- Enhance coastal protection where retreat or other accommodation is not an option.

The Town has not made final decisions on these options.

The Falmouth Board of Selectmen appointed the Coastal Resources Working Group (CRWG) and charged this group to:

1. Identify key factors dictating the current condition of Falmouth's coastal sediment system;
2. Explore reasons for the current condition;
3. Develop future scenarios of the coastal zone based on physical processes and coastal management; and

4. Provide community outreach and recommendations concerning coastal processes and coastal management.

The CRWG was composed of volunteers with expertise in coastal geology, oceanography, coastal management, landowner issues, water quality, land use, ecology, and coastal navigation. This Group was active from May 2000 to October 2010, completing two reports, “The Future of Falmouth’s South Shore” in 2003 and "The Future of Falmouth’s Buzzards Bay Shore" in 2010.

In 2017, the Selectmen appointed the five-member Coastal Resiliency Action Committee. The purpose of this committee is to prepare action plans for submission to the Selectmen to address the risks and hazards to coastal infrastructure and coastal properties that may be caused by coastal erosion, storms, and sea level rise.

12.5 Mitigation Measures Summary Table

The following table summarizes those general mitigation measures that are identified above regarding future implementation of a specific TWMP. Funding of these measures is all anticipated to come from Town Funding and to be supported by various grant and loan opportunities including Natural Resources Conservation Service (NRCS), the Massachusetts State Revolving Fund (SRF) program, Southeast New England Program (SNEP) Grants, CZM Grants, amongst others.

Table 12.1 Mitigation Measures Summary

Category	Proposed Mitigation Measure	Implementation	Preliminary Schedule
General Construction - Site Access/Public Safety Impact	The site(s) shall be secured to prevent unauthorized entry to the construction site, and to protect existing and adjacent facilities and properties. Supplemental lighting, signs, railings, and construction barriers shall be used as necessary to provide safety to employees, construction workers, visitors, and the general public during the construction process in accordance with OSHA and other applicable regulations. Police details and detours will be implemented in accordance with Traffic Control Plans included with the Project Contract Documents.	Contractor	During Construction
General Construction - Stormwater	Provisions for stormwater management and erosion control shall be managed in accordance with the approved SWPPP and NPDES General Permit.	Contractor	During Construction
General Construction - Construction debris	The site(s) will be maintained free of waste materials, debris, and trash following each day of work. Waste and other debris will be collected and disposed of off-site periodically. At no time during construction will the dumping of spoil material, waste, trees, brush, or other debris be allowed into any stream corridor, any wetland, any surface waters, or any unspecified location. The permanent or unspecified alteration of stream flow lines is	Contractor	During Construction

Category	Proposed Mitigation Measure	Implementation	Preliminary Schedule
	not allowed during construction. Recycling of waste and construction debris will likely be mandated as well and should always be considered during construction.		
General Construction - noise and dust control	Normal construction hours will be between 7 am and 5 pm during normal business days. No work will be allowed on Holidays and the Contractor will be required to provide adequate dust control measures during construction.	Contractor	During Construction
Wastewater Facilities Construction Mitigation - resource areas	As necessary, appropriate Notice of Intent documents and Request for Determinations will be filed relative to work proposed with buffer areas or resource areas. Orders of Conditions, as received, will be incorporated into the Construction Documents.	Town / Contractor	Permitting Prior to Construction/ Mitigation during Construction through compliance with Order of Conditions.
Wastewater Facilities Construction Mitigation - flooding	To the extent practicable, facilities will be located out of flood hazard zones. Because lift stations are typically located in low lying areas to maximize gravity sewer service, additional provisions for coastal resiliency and flood protection will need to be made to mitigate impacts. During construction, management of dewatering and protection from storms will be required.	Town / Contractor	During design of facilities for coastal resiliency, and construction of the work.
Wastewater Facilities Construction Mitigation - Site Impacts	The WWTF improvements will take place on a previously developed parcel (existing Falmouth WWTF) and in existing structures.	Town / Contractor	During Construction
Wastewater Facilities Construction Mitigation - Aesthetics	Any new lift stations will have exterior façades which will compliment and be consistent with neighborhood aesthetics. Vegetative screens will be employed, if determined necessary, for aesthetic reasons.	Town / Contractor	During design and implemented during construction
Wastewater Facilities Construction Mitigation — Archeological	Development of a Post Discoveries Review Plan (if necessary). Work will be halted if archaeological resources are uncovered during construction.	Town / Contractor	Plan development prior to Bidding, implementation during construction
Wastewater Facilities Construction Mitigation - General	A Resident Project Representative will be employed to ensure that the project area is kept clean and that mitigation measures are met.	Town	During Construction

Category	Proposed Mitigation Measure	Implementation	Preliminary Schedule
Adaptive Management - TMDL Compliance	Implementation of an Adaptive Management process which will consider the performance of the demonstration projects and incorporate cost-effective non-traditional methods into the plan once they demonstrate feasibility. The Adaptive Management process will also monitor groundwater elevations, water quality, performance at coastal embayments during construction, and upon completion of the phased sewering and full-scale implementation of non-traditional methods (as applicable).	Town	Pre and post construction / implementation
Climate Change Mitigation	Town of Falmouth has created both a Coastal Resources Working Group and Coastal Resiliency Action Committee and participates on regional committees to assist with planning for and mitigation of potential impacts due to climate change in response to their projects.	Town	Pre and post construction / implementation

References

GHD Inc, September 2013. Comprehensive Wastewater Management Plan and Final Environmental Impact Report and Targeted Watershed Management Plan – Little Pond, Great Pond, Green Pond, Bournes Pond, Eel Pond, and Waquoit Bay Watersheds and Recommendations for West Falmouth Harbor Watershed, (CWMP/FEIR/TWMP)

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about GHD

GHD is one of the world's leading professional services companies operating in the global markets of water, energy and resources, environment, property and buildings, and transportation. We provide engineering, environmental, and construction services to private and public sector clients.

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Appendix – Chapter 2.1

Water Quality Data

University of Massachusetts Dartmouth
The School for Marine Science and Technology

Technical Memorandum

Final

PondWatch Nutrient Related Water Quality
Bournes Pond, Great Pond, Green Pond,
Little Pond, Oyster Pond, West Falmouth Harbor:

SMAST POST-MEP Sampling Assessment (2004-2017)

To:

Amy Lowell
Wastewater Superintendent
Department of Public Works
Town of Falmouth

From:

Brian Howes, Ph.D.,
Roland Samimy, Ph.D.,
Sara Sampieri, M.S.,
Dale Toner, M.S.

Coastal Systems Program
School of Marine Science and Technology (SMAST)
University of Massachusetts-Dartmouth
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January 18, 2019

Falmouth PondWatch

Introduction: The Coastal Systems Program (CSP) at the University of Massachusetts-Dartmouth (UMD) School for Marine Science and Technology (SMAST) is currently undertaking a detailed assessment of nutrient cycling in the bottom sediments of Bournes Pond, specifically related to the interaction between water quality and shellfish propagation of oysters in floating bags. The Bournes Pond sediment-water column nutrient assessment is being completed in the context of a synthesis of historic (post-MEP) nutrient related water quality in Bournes Pond as well. For the purpose of this assessment, the historic (pre-MEP baseline) data was related to post-MEP water quality data from 2004-2016 and data collected through the PondWatch Monitoring Program in the summer of 2017. The synthesis of the Bournes Pond nutrient related water quality data was also compared to parallel data from other Falmouth estuaries (particularly Green Pond and Great Pond) that have not had significant alteration of nitrogen inputs or outputs and that are currently monitored by the Falmouth PondWatch Water Quality Monitoring Program. Water quality characteristics from similarly structured nearby estuarine systems serve as external control for evaluating Bournes Pond water quality both before and after any large scale oyster deployment. The inter-estuarine comparison will provide the Town of Falmouth with a clear picture of the range of water quality conditions in Bournes Pond and the other 5 PondWatch estuaries, how Bournes Pond water quality compares to the other systems, and the scale of natural annual variation in these estuaries. The water quality information can also inform the Town as to which areas may be suitable for shellfish seeding and how the seeding of oysters in other Falmouth estuaries might affect nutrient cycling.

Background: Coastal salt ponds and estuaries are among the most productive components of the coastal ocean. These circulation-restricted embayments support extensive and diverse plant and animal communities providing the foundation for many important commercial and recreational fisheries. The aesthetic value of these systems, as well as the freshwater ponds of a town, are important resources to both residents and the tourist industry alike. Maintaining high levels of water quality and ecological health in these aquatic systems (fresh and marine) is fundamental to the enjoyment and utilization of these valuable resources for all coastal communities.

Nutrient over-enrichment is the major ecological threat to water quality in the salt ponds and estuaries within the Town of Falmouth, ultimately resulting in ecological degradation when nutrient loading exceeds the assimilative capacity (also called critical nutrient threshold) for new inputs. Of the various forms of pollution that threaten coastal waters (nutrients, pathogens and toxics), nutrient inputs are the most ubiquitous, insidious and difficult to control. This is especially true for nutrients originating from non-point sources, such as nitrogen and phosphorous transported in the groundwater from on-site septic treatment systems. On-site Title 5 septic treatment systems continue to be the primary mechanism for waste disposal within Falmouth's coastal watersheds.

As a result of nutrient loading to Falmouth's coastal watersheds, many of the 14 estuaries within the Town have been supporting signs of nutrient impaired water quality and resource loss for more than a decade. As a result, the University of Massachusetts-Dartmouth, specifically scientists from the Coastal Systems Program (School for Marine Science and Technology) has been conducting a unified and comprehensive water quality monitoring program (Falmouth

PondWatch) in six estuaries of the Town (West Falmouth Harbor, Oyster Pond, Little Pond, Great Pond, Green Pond and Bournes Pond) since the 1990's. These data established the nitrogen related water quality baseline (pre-MEP) employed by the Massachusetts Estuaries Project for modeling and assessment of these systems. On-going monitoring (post-MEP) is being used to gauge changes in these systems as nitrogen management alternatives are implemented, thus supporting adaptive management. This recent activity builds on the on-going tracking of water quality relative to inlet management that has been in effect since the beginning of the program.

Over the past decade, the Town of Falmouth has intensified its efforts to deal with the problem of estuarine impairment via nitrogen enrichment. Falmouth was fully engaged in the Massachusetts Estuaries Project (MEP), through the Coastal Systems Program-SMAST at UMass Dartmouth, to conduct a quantitative assessment of habitat quality in each of the Town's estuaries and to determine appropriate nutrient thresholds for restoration of these estuaries (essential for the Town's nitrogen management planning efforts). The MEP analysis of the above mentioned six estuaries was based in part on the baseline nutrient related water quality data collected under the PondWatch program, which continues to present. The relevant data required for the MEP assessment was provided to the Town in the MEP Nitrogen Threshold Reports. However, since these reports were completed previously, the nitrogen related water quality data only carried through 2003-2004. In 2014, the Town of Falmouth contracted with the Coastal Systems Program (CSP-SMAST) to update the nutrient related water quality baseline database used by the MEP to include all the Falmouth PondWatch water quality data collected since completion of the MEP analyses. Two separate technical memoranda were developed. The first updated the water quality baseline record for West Falmouth Harbor, Bournes Pond and Little Pond (2004-2012). The second technical memorandum updated the water quality baseline for Oyster Pond, Great Pond and Green Pond (2004-2014).

This Technical Memorandum has been developed to:

1. update and extend the water quality baseline to include the results of the summer 2017 PondWatch monitoring,
2. complete a trend analysis specific to data from each of the six estuaries,
3. complete a comparison of post-MEP water quality to historic (pre-MEP) total nitrogen, salinity and chlorophyll concentrations,
4. compare water quality conditions in Bournes Pond (site of ongoing oyster aquaculture) to other nearby and similarly structured estuaries,
5. serve as a baseline for quantifying the potential effects of oyster filtration on water column nutrient and chlorophyll concentrations as well as sediment-water column nutrient dynamics should large scale aquaculture deployments be undertaken.

The data presented herein is to provide a consistent citable data source from which to track improvements in these 6 estuaries relative to MEP TN thresholds as developed by the MEP and codified as TMDLs by the MassDEP, as management alternatives are implemented in coming years.

Description of the Falmouth PondWatch Program: The Town of Falmouth has long recognized the potential threat of nutrient over-enrichment of its coastal salt ponds and embayments. In the mid-1980s the Town enacted an innovative Nutrient Overlay By-law that tied watershed development to water quality within the adjacent embayment. The goal was to keep nitrogen concentrations in the receiving systems below thresholds to prevent impaired water quality. The water quality monitoring program, Falmouth PondWatch, was initially established to provide on-going nutrient related embayment health information in support of the

By-law. The Falmouth PondWatch Program is the longest continuously running research based nutrient related water quality monitoring program in existence in the New England region. The program was initiated in 1987 to address citizen concerns over perceived declining water quality in the Town's coastal salt ponds and embayments. Adapting basic research approaches, the program's initial goal was to involve trained citizen volunteers in the near simultaneous collection of comprehensive high quality data from a large number of sites (35 at present) under the same conditions of weather and tide in multiple estuaries. Such synoptic sampling would allow for comparison of water quality data across stations and across estuaries. With these comprehensive data sets, more intensive whole-ecosystem studies of Falmouth's impaired estuaries could be undertaken to compliment the monitoring program and guide the Town towards watershed based nitrogen management and estuarine restoration. The PondWatch Program was one of the first in the Commonwealth to focus on collecting long-term, quantitative data on nutrient related water quality in coastal environments.

The Town of Falmouth was a partner in the establishment of the PondWatch Water Quality Monitoring Program to collect baseline water quality data in specific south coast systems (West Falmouth Harbor, Oyster Pond, Little Pond, Great Pond, Green Pond, Bourne Pond). The town, in collaboration with researchers now at the Coastal Systems Program at SMAST (but who were previously located at the Woods Hole Oceanographic Institution), had partial funding from WHOI Sea Grant. PondWatch proved capable of collecting research quality data on small estuaries using trained volunteers, won numerous national awards and has served as the model for the subsequent monitoring programs that now cover most of the estuaries in the Commonwealth. The Program has supported dozens of management studies for the Town, including MEP nitrogen threshold reports and MassDEP TMDL's, in addition to numerous published research papers disseminating the information to the greater ecological community. Presently, the program is geared towards compliance monitoring as the Town moves beyond the MEP nitrogen threshold development phase and into implementation of nitrogen management actions to meet MassDEP/USEPA established TMDL's. To date, the program has been conducted by SMAST and PondWatch volunteers since 1997, with the Town of Falmouth renewing the partnership in 2016. The present effort provides a mechanism to continue the PondWatch post-MEP monitoring while keeping the data up to MEP Quality Assurance levels and providing the Town with a single consistently collected and analyzed dataset for its estuarine management efforts.

When the PondWatch Program was first started, the first three Ponds to undergo water quality monitoring in the Town of Falmouth were Oyster Pond, Little Pond and Green Pond. Monitoring was primarily initiated for making an initial assessment and for planning purposes as development within coastal watersheds had been rapidly progressing (1980' and 1990's). This initial effort was closely linked to the Town of Falmouth Planning Department relative to the Town's new (1980's) Nutrient Overlay Bylaw. The initial effort later grew to develop refined tools for gauging future nutrient effects from changing land-uses. The GIS database used in the MEP studies completed throughout the Town's estuaries is part of that continuing effort. Over time the PondWatch Water Quality Monitoring Program expanded to also collect water quality data from Great Pond, Bourne's Pond and West Falmouth Harbor. Because of these efforts, all PondWatch estuaries have completed Massachusetts Estuaries Project assessments and have USEPA accepted TMDL's (under the Clean Water Act) to support the Town of Falmouth's on-going restoration efforts.

Through this unique partnership between citizens, scientists, regulators and local government, information gained from the research is being swiftly and directly applied toward effective management decisions for these fragile coastal environments. Long-term monitoring is particularly important in our coastal embayments as it may take years to decades before activities occurring in watersheds have a measurable impact on these coastal systems. The consistent and continual water quality and ecological monitoring sustained by the PondWatch volunteers is particularly valuable in that, in addition to the routine sampling, it provides long-term nitrogen related water quality metrics to support a variety of ecological response analyses (infauna, eelgrass, macroalgae) presently being conducted by SMAST researchers across southeastern Massachusetts embayments. This comprehensive water quality and habitat information is crucial to developing appropriate long-term management plans, verifying standards, and furthering scientific understanding of the ecological processes that ultimately structure these environments.

The specific objectives of the Falmouth PondWatch Program continue to be:

- to provide a long-term data base of nutrient levels and environmental conditions on Falmouth's coastal salt ponds required for data-based management;
- to form the basis for the development and evaluation of various potential management and remediation options;
- to provide a high quality independent evaluation of the impacts of both natural and man induced alterations (e.g. changes to nutrient inputs or circulation) to pond water quality.
- to evaluate the effectiveness of implemented management programs aimed at protecting or improving nutrient related water quality and provide compliance monitoring in support of nitrogen TMDLs developed by the MassDEP post-MEP;
- to provide necessary data to evaluate impacts of the Falmouth Wastewater Treatment Facility on West Falmouth Harbor, and potential impacts from nutrient plumes emanating from the Mass Military Reservation on Bournes, Green and Great Ponds;
- to develop heightened public awareness of the cumulative impact of human activities on these ponds through interactive partnerships between citizens, scientists and resource managers to preserve the ecological health of these fragile coastal ecosystems.

Providing critical environmental data for identifying ecological degradation, isolating the causes of decline and developing management / remediation plans, the Falmouth Pondwatchers have set themselves apart from many monitoring programs in their mission to collect research-quality data for development of scientifically based management plans. After 28 years of monitoring, data from the program has been heavily utilized for guiding management decisions, notably reconstruction of the Little Pond culvert, modifications to the Green Pond Bridge, construction of the Oyster Pond Weir, and monitoring of potential impacts from the nutrient plumes from the Massachusetts Military Reservation (Bournes, Great and Green Ponds) as well as the plume from the Falmouth Wastewater Treatment Facility (West Falmouth Harbor). The importance of these long-term data sets cannot be overstated, taking into account year to year and site to site variations as well as allowing for long-term evaluation of various remediation measures. The PondWatch has continued to fulfill new needs as they arise including, TMDL compliance monitoring and assessment of innovative nitrogen management approaches being investigated by the Town of Falmouth (e.g. oyster culture). Finally, there has been an unforeseen benefit of this approach, the unique partnership which has developed between citizens, regulators and scientists, facilitating the development of cost effective yet environmentally sound management strategies. This partnership is essential as the Town moves forward with implementation of its estuarine management plans.

Unfortunately, the continual monitoring through PondWatch has documented that many regions within the Town’s coastal ponds continue to show water quality declines and are beyond the limits set by the historic nutrient By-law as well as the MEP developed embayment specific nitrogen thresholds and resulting USEPA/MassDEP Nitrogen TDML limits. In this context, the Coastal Systems Program was tasked with completing a summary of all the nutrient related water quality that has been collected in the estuaries monitored through the PondWatch Program for comparison to the estuarine specific nitrogen thresholds established through the MEP, keep the database current via annual updates and use the database to make inter-estuarine comparisons of water quality in Bournes Pond and others as a back drop for understanding the efficacy of oyster propagation as an in situ method for enhancing nutrient related water quality.

Per agreements with the Town of Falmouth to keep the water quality database up-to-date, the PondWatch data that is summarized in this Technical Memorandum is that which was collected post completion of the MEP analysis (2004/2005) for the six named estuaries above and compares data collected from sampling to 2017 to data collected up to 2012 as previously summarized in earlier memos submitted to the Town of Falmouth. The data has been assessed relative to the long-term (MEP) baseline and a trend analysis conducted on key metrics (TN, Chlorophyll-a, salinity and other relevant parameters as available). The component nitrogen forms and inorganic N & P have been included in the electronic spreadsheet containing all the data, consistent with the scope of work. The baseline assessment data for Bournes Pond, Great Pond, Green Pond, Little Pond, Oyster Pond and West Falmouth Harbor through 2017, is presented in graphical and tabular form to the Town, along with the complete QA'd database post-MEP provided electronically as a MS Excel spreadsheet.

The overall effort is specifically aimed at analysis and QA of PondWatch field and laboratory samplings, compiling and processing recent (2015-2017) PondWatch data and assessing temporal and spatial trends in key metrics associated with nutrient related water quality. This Technical Memorandum evaluates the 2016/2017 data relative to the 2004/2005-2014 summary of water quality data completed in 2014/2015. Additionally, data gaps were identified for future improvement of the monitoring program, trends assessed, the meaning of the different water quality parameters is explained and the present state of each estuary is assessed relative to the MEP nitrogen thresholds analysis. As relevant, the baseline and trends related to TMDL compliance are discussed and an inter-estuarine comparison of water quality conditions is provided with specific focus on Bournes Pond as it is currently the site of intensive testing of oyster propagation relative to large scale deployments to enhance water quality.

Compiled/tabulated Pond Watch sampling data for critical water quality parameters (2004/2005 - 2014 + 2015, 2016 and 2017) is included in summary tables as an attachment (1) to the Memo and the full database provided electronically as an integrated Microsoft Excel spreadsheet. In addition, latitude and longitude coordinates for each named sampling station has been provided (Attachment 2).

As part of PondWatch, the following measurements are typically conducted on each sampling date at each sampling station and form the water quality database utilized as a baseline for the MEP water quality modeling effort. The measurements also constitute the core data set for TMDL compliance monitoring as the Town of Falmouth moves forward with implementation of nutrient management strategies (O = On Site; L = Lab):

<u>Physical Measurements:</u>

(O) Total Depth
(O) Temperature
(O) Light Penetration (Secchi disk)

<u>Chemical Measurements:</u>

(L) Nitrate + Nitrite
(L) Ammonium
(L) Dissolved Organic Nitrogen
(L) Particulate Organic Nitrogen

(L) Total Nitrogen
(L) Chlorophyll
(L) Phosphate
(O) Dissolved Oxygen
(L) Salinity

In addition, PondWatchers record observations of pond state, weather and wind conditions, and any other pertinent information which may later prove useful to interpretation of the data such as algal blooms, fish kills or unusual odors. A detailed description of water quality in each pond is provided below.

POND SPECIFIC WATER QUALITY SUMMARIES

Summary of Nutrient Related PondWatch Water Quality Data – Bournes Pond (2004-2012, 2013, 2014, 2015, 2016, 2017)

Bournes Pond (Figure 1) exchanges tidal water with Vineyard Sound through a single armored inlet. The Bournes Pond watershed is relatively small and only moderately developed and while the inlet is undersized, restricting tidal flows, it still allows significant tidal flushing in the lower portion of the pond. The result is that the upper reaches of Bournes Pond are significantly impaired by nitrogen enrichment, but the lower reaches continue to support infaunal habitat and some eelgrass. The Sentinel Station (B-3) has a nitrogen threshold of 0.45 mg TN/L with a secondary threshold of <0.42 mg TN/L in Israel's Cove.

The TN time-series indicates that TN at all embayment stations (e.g. excluding B-5) has been increasing since the MEP assessment and update to 2014. Equally important monitoring from 2008 to 2017 indicates TN levels at the sentinel station to be >0.70 mg/L, well over the TMDL threshold (Figure 2). There has been some interannual variation with TN levels reaching a recent low in 2016 but rebounding in the upper reaches in 2017. Focusing on station B-3 (MEP sentinel station), it should be noted that average TN levels (Table 1) for the period 2004 to 2014 were the same (0.760 mg/L) as for the period 2015 to 2017 (0.76 mg/L). But average TN levels for both periods were higher than the baseline average TN concentration (0.67 mg/L) established by the MEP based water quality data collected from 1989 to 2003 (n=105). While the increases from 2004-2017 were relatively modest and the rise gradual, it did appear consistent with the rate of change in nitrogen loading to the Bournes Pond watershed over the past 15-20 years. It is important to consider that increasing / decreasing TN levels are also related to changes in tidal flow as these can be short-term and change quickly (e.g. storms, inlet dredging).

Flow from Vineyard Sound into Bournes Pond may have increased slightly in 2016 as average station salinities in 2016 (28-31 ppt excluding B-1, all station average 29.7 ppt) appeared higher compared to the 2004-2012 average salinity (27-30 ppt excluding B-1, all station average 28.8 ppt {Attachment 1, Table A}). The slightly higher salinity in Bournes Pond would indicate that water from the Sound that contains low TN concentrations which would slightly dilute the water in Bournes Pond is lowering TN levels. Conversely, in 2017 average salinity across all stations except station B-1 appeared slightly lower (25-31 ppt, all station average 28.5 ppt) compared to salinity levels for the period 2004-2012 (27-30 ppt) and there was an observable increase in TN levels in 2017. Since there is a measurable difference in salinity at the stations and since salinity typically increases with increases in tidal exchange (Attachment 1, Table A), at present we conclude that the small TN decrease in 2016 results mainly from slightly improved flushing whereas the slight increase in 2017 TN levels derive from a decrease in flushing (plausible considering how dynamic and sensitive inlets are to sediment transport and deposition) or possibly higher freshwater inflows in a high rainfall year.

The TN levels system-wide appear to be rising slightly since 2004, although the rise is variable. All stations are higher in 2004-2014 than the MEP baseline TN values, and all stations except B5 are also higher in 2015-2017 than pre-2004 (Table 1). Stations B1, B2, B3 and B6 show increased TN averages in 2015-2017 since 2004-2014 while the other stations show a lower average for the 2015-2017 period than 2004-2014. In addition, Bournes Pond has been consistently higher in TN than the threshold and the habitat impairments reflect the elevated nitrogen levels. Linear regression of TN on Sentinel Station (B-3) did not show a significant annual temporal trend (R^2=0.162), though there appears to be a slightly increased TN when comparing the average level for the period 2004-2012 (0.74 mg/L) vs. the period 2013-2017 (0.81 mg/L). Additionally, the average level for the period 2013-2017 is higher compared to the pre-2004 MEP baseline (0.670 mg/L).

Phytoplankton biomass/bloom activity has also been relatively unchanged from 2004-2017, and relatively high (average T-pigment levels 11.5, 12.4, 11.1 ug/L for 2004-2012, 2016, 2017 respectively, Figure 3). The level of chlorophyll-*a* and TN remain consistent with the level of habitat impairment noted previously by the MEP. There is no evidence of habitat improvement within this estuary and none is expected based on the water quality metrics.

Considering the most recent TN and salinity data, the temporal pattern of change in key water quality metrics suggests a rapid response in water quality once nitrogen management alternatives (tidal flushing, nitrogen load reduction) are implemented with increased tidal flushing likely driving the most rapid response.

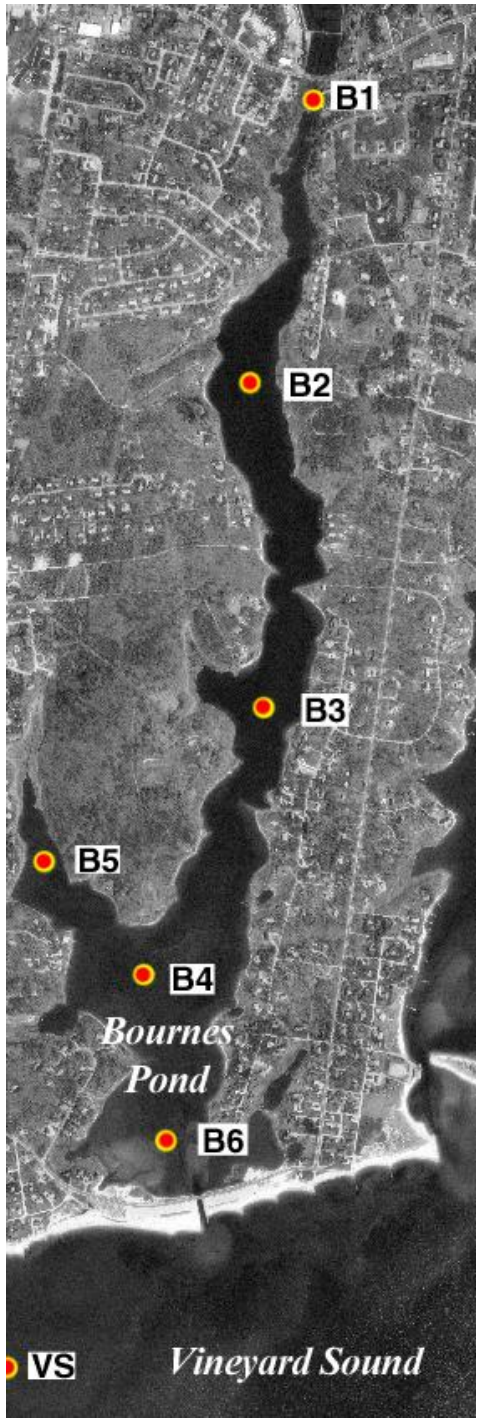
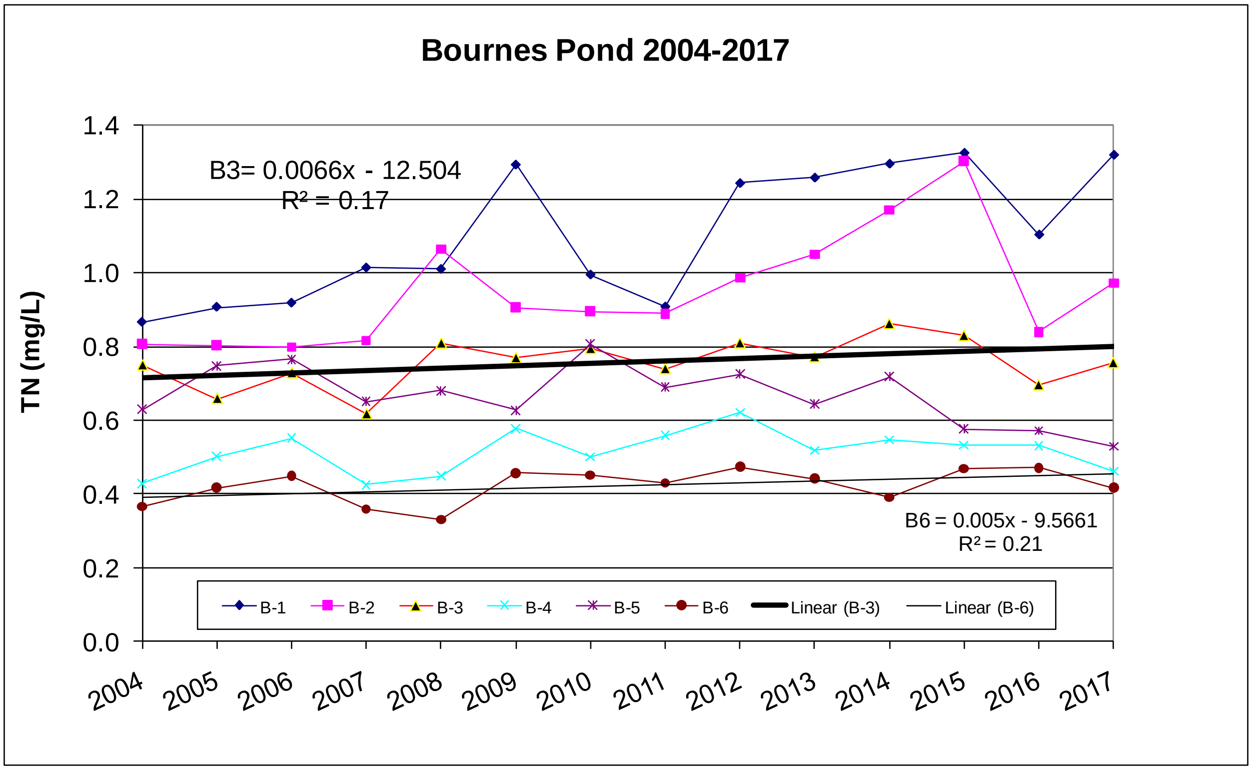


Figure 1. Bournes Pond water quality sampling stations for SMAST-PondWatch 2004-2017 and nutrient related water quality baseline used in the Massachusetts Estuaries Project (MEP) analysis.



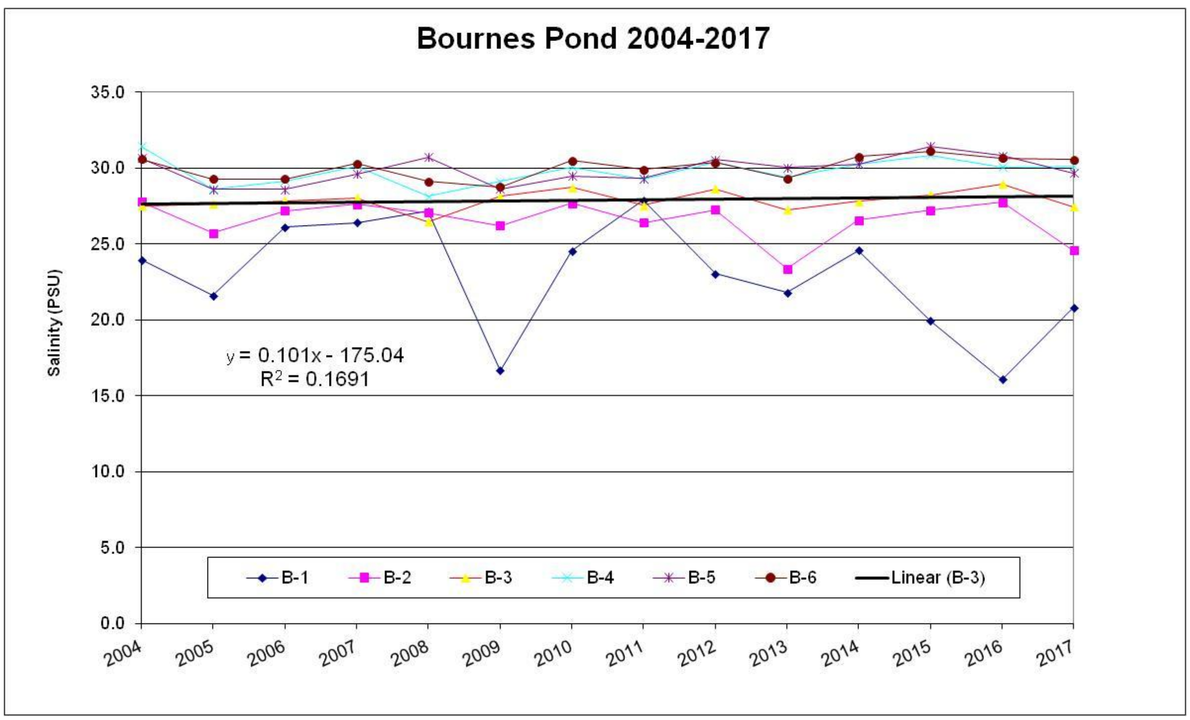


Figure 2. Annual averages for Bournes Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 1. Top: TN station averages. TN threshold 0.45 mg/L at sentinel station B-3 and <0.42 throughout the lower 1/3 of estuary to support eelgrass restoration. System remains above the TN threshold. Bottom: Salinity station averages. General gradient of fresher (inner) to more marine (outer) basins.

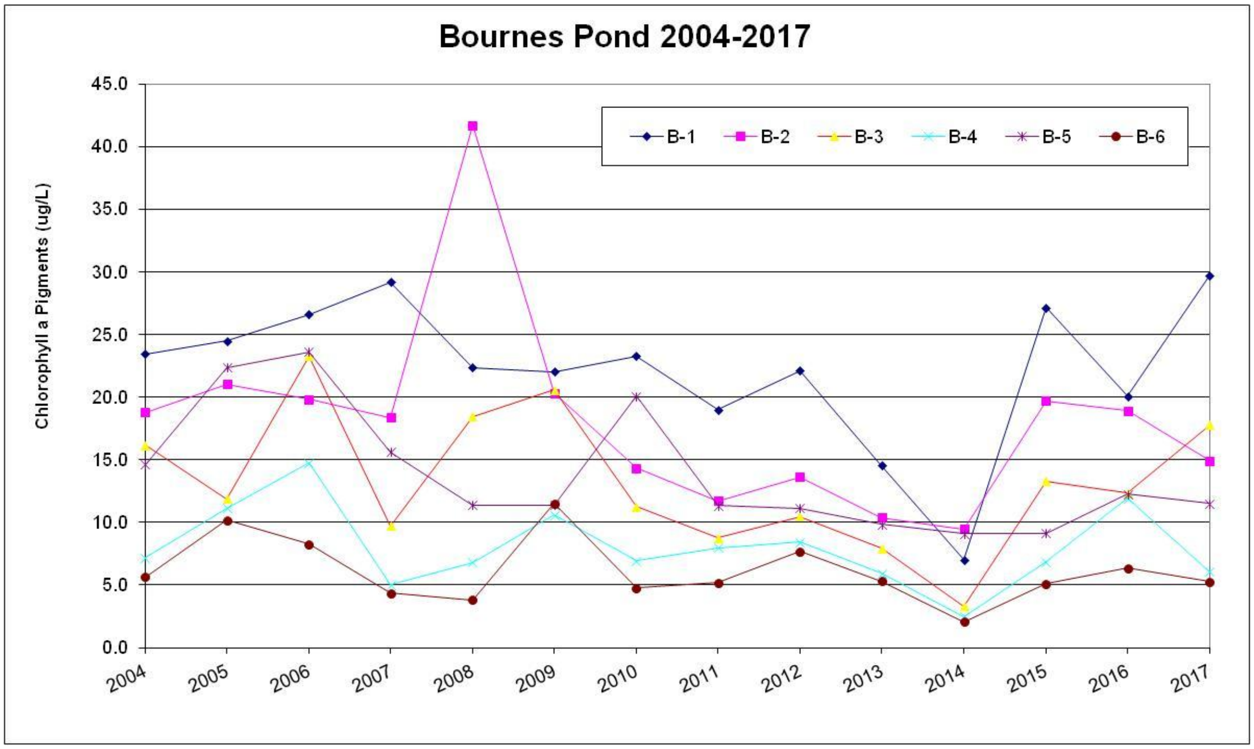


Figure 3. Annual averages for Bournes Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 1. Total chlorophyll-*a* pigment as indicator of phytoplankton biomass. Averages >10 ug/L are indicative of nitrogen enrichment.

Table 1. Bournes Pond total nitrogen (TN, mg N/L) averages by period. MEP is data prior to 2004. Sentinel Station B-3 has a TN threshold of 0.45 mg/L.

Bournes	**TN 2004 - 2014**			**TN**	**2015 - 2017**		**TN**
Station	**mean**	**s.d.**	**N**	**mean**	**s.d.**	**N**	**MEP**
B1	1.037	0.228	41	1.250	0.290	12	**0.928**
B2	0.927	0.228	85	1.038	0.445	24	**0.880**
B3	**0.755**	**0.189**	**80**	**0.760**	**0.144**	**24**	**0.670**
B4	0.514	0.123	87	0.507	0.096	23	**0.482**
B5	0.699	0.144	87	0.558	0.073	23	**0.674**
B6	0.415	0.073	86	0.452	0.085	23	**0.387**

Summary of Nutrient Related PondWatch Water Quality Data – Great Pond (2004-2012, 2013, 2014, 2015, 2016, 2017)

Great Pond (Figure 4) exchanges tidal water with Vineyard Sound through a single armored inlet. The Great Pond watershed is relatively small and dominated by residential development. The inlet is maintained by the Town of Falmouth and generally allows significant tidal flushing, as evidenced by the relatively short system residence time of estuarine waters. It appears that the tidal inlet is sufficiently maintained to not cause water quality impairments within Great Pond, as tidal exchange with Vineyard Sound serves to lower overall nitrogen levels. However, Great Pond remains impaired in its upper reaches and tributary basin (Perch Pond) by nitrogen inputs from its watershed even in its well flushed condition. The Sentinel Station (GT-5, in the lowermost tidal river reach) established by the MEP has a nitrogen threshold of 0.40 mg TN/L, and MEP modeling indicated that nitrogen concentrations in the lower main basin could reach <0.30 mg TN L^{-1} when the threshold at station GT-5 is met. This indicates that significant eelgrass habitat restoration would occur within the regions of the 1951 eelgrass coverage.

Continued monitoring by PondWatch since 2004 have consistently found TN levels above the threshold needed for restoration of water quality and associated infauna and eelgrass habitat. This is expected as there have been no significant nitrogen management actions that would affect estuarine nitrogen levels. In fact, TN levels appear to have been relatively stable with interannual variations making any trends difficult to quantify for all stations (Figures 5). Examination of pre-2004 versus 2004-2014 (previous analysis) and 2015-2017 (new data) TN levels does suggest that there has been a small increase in TN at each estuarine station in Great Pond (GRT-2,3,5,6) and Perch Pond (GRT-4) in the recent decade (Table 2), but TN levels appear unchanged between 2004-2014 and 2015-2017. The average TN concentration (GRT-2,3,4,5,6 combined) pre-2004 was 0.740 mg/L compared to 0.882 mg/L for the period 2004-2014 and 0.875 mg/L in the period 2015-2017. All TN data collected by PondWatch for Great Pond have documented that TN has remained elevated and well over the level supportive of high water quality and continues to present (2013-2017 annual means: 0.939, 0.735, 0.928, 0.820, 0.900 mg/L) with a parallel increase in total pigment (Figures 5 and 6). The linkage between nitrogen and phytoplankton production can be seen in the parallel inter-annual changes in chlorophyll-*a* levels with TN (more TN, more CHLA, Figure 6). In contrast salinity levels have remained relatively constant throughout much of the estuary, although the uppermost stations adjacent the discharge from the Coonamessett River show inter-annual variations (Attachment 1, Table B and Figure 5 bottom) particularly for the period 2006-2008. A closer examination of the TN and chlorophyll-*a* data shows the level of inter-annual change where over a six year period (2012-2017), levels of these key metrics appeared to decline for a few years (2012-2014) but then rebound in 2015, decline in 2016 (only TN) and rebound in 2017. This emphasizes the need for long term monitoring for determining real changes versus annually driven events. Additional investigation is underway to compare the maintenance dredging schedule for the inlet to the variation in TN levels measured in the preceding and following summers, as the variability observed over the period 2012 to 2017 maybe due to changes in the flushing through the inlet. This information is important, since it would indicate that a targeted inlet maintenance program for nitrogen management could help to offset some of the changes in watershed N loading.

Overall, it appears clear that Great Pond has not improved since 2004 and that all water quality metrics and particularly TN, chlorophyll-a and oxygen continue to document a nitrogen impaired system, mainly in the upper tributary (Coonamessett River estuarine reach, GRT-1 to GRT-3) and Perch Pond (GRT-4). Most significant to the habitat quality in this estuary is the observed elevated levels in TN greater than 0.80 mg N/L since 2004 (Figure 5). It would be useful to better determine the causes of the observed interannual variation in TN to allow a more sensitive determination of water quality changes once management actions are taken.

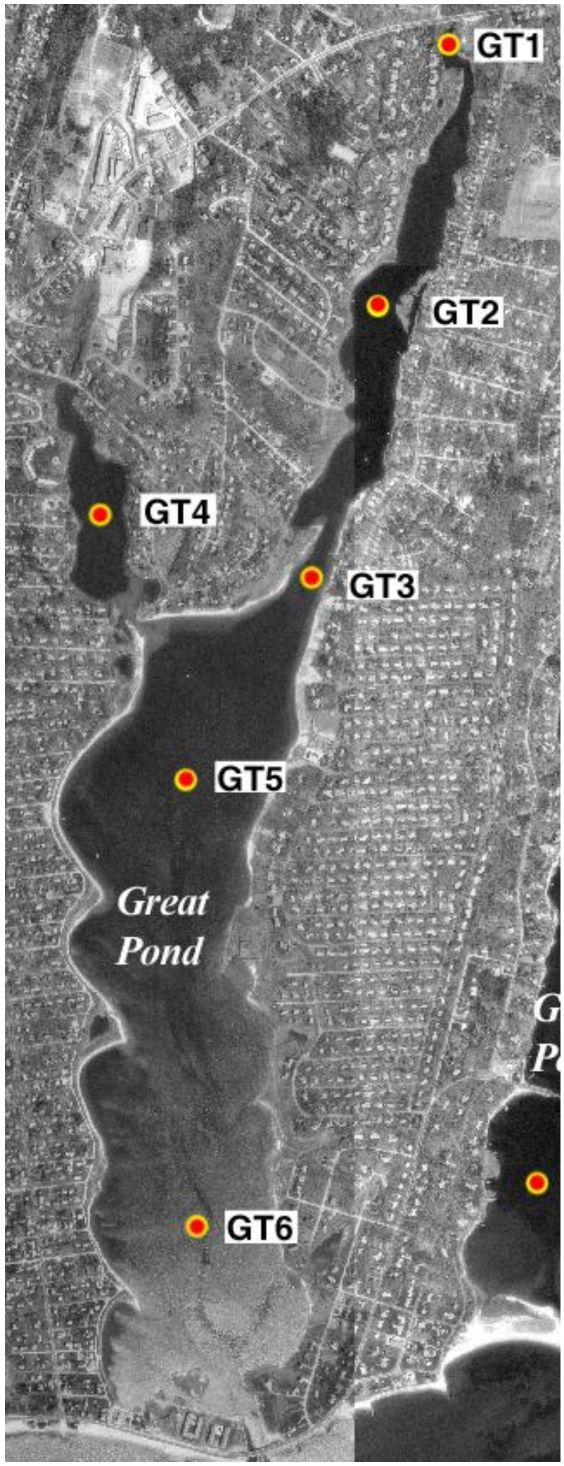
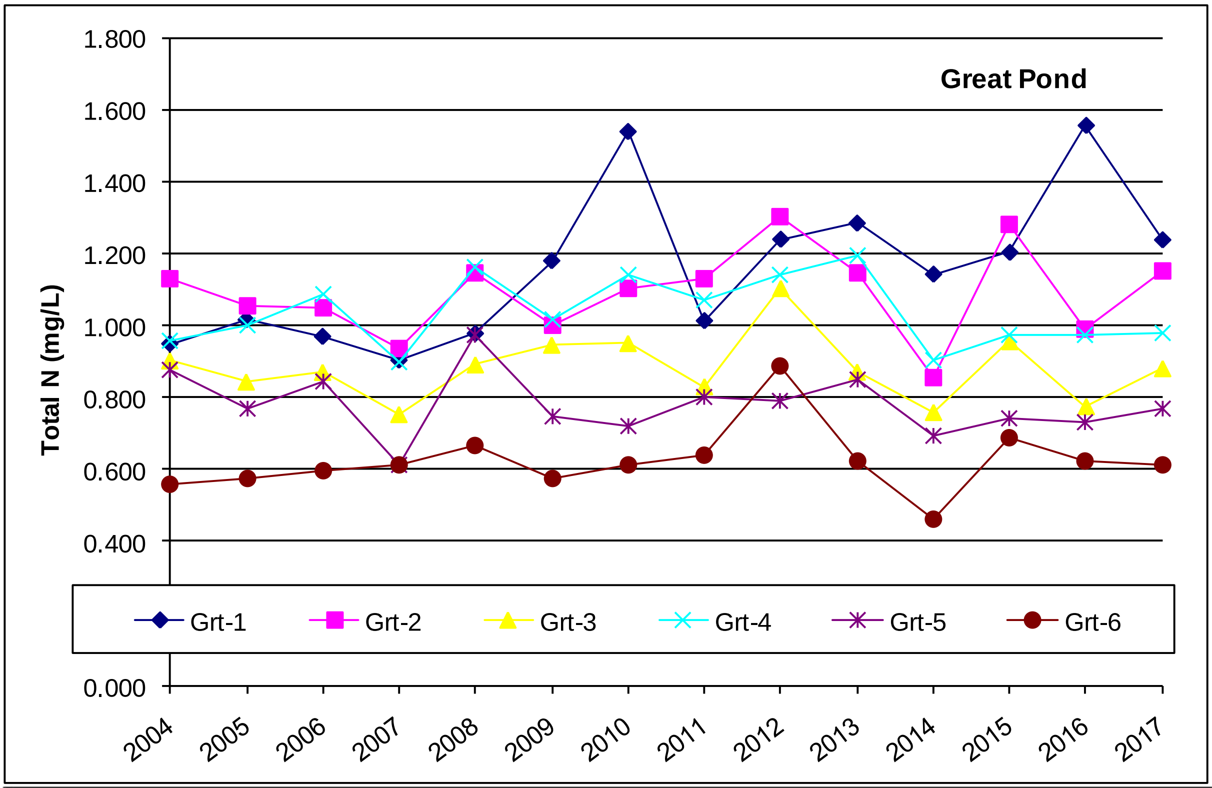


Figure 4. Great Pond water quality sampling stations for SMAST-PondWatch 2004-2017 and nutrient related water quality baseline used in the Massachusetts Estuaries Project analysis.



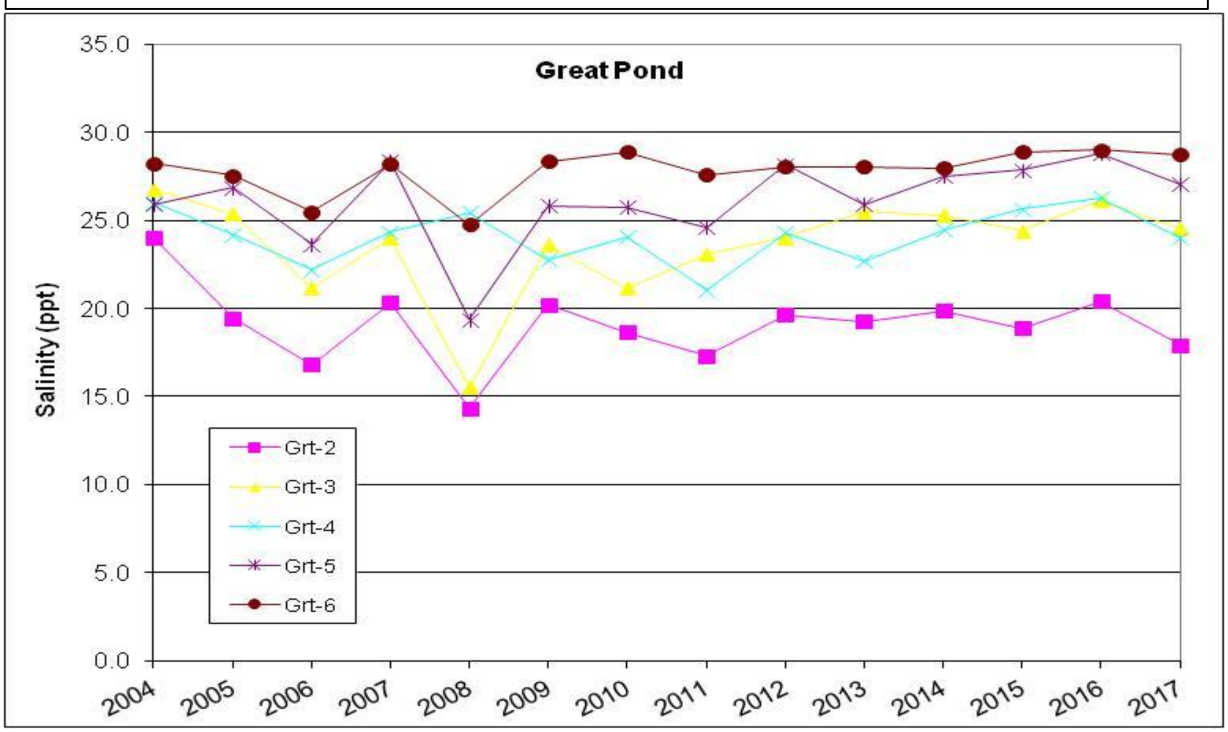


Figure 5. Annual averages for Great Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 4. Top: TN station averages. TN threshold at sentinel station (GT-5) is 0.40 mg/L. System remains above the TN threshold. Bottom: Salinity station averages. General gradient of fresher (inner) to more marine (outer) basins.

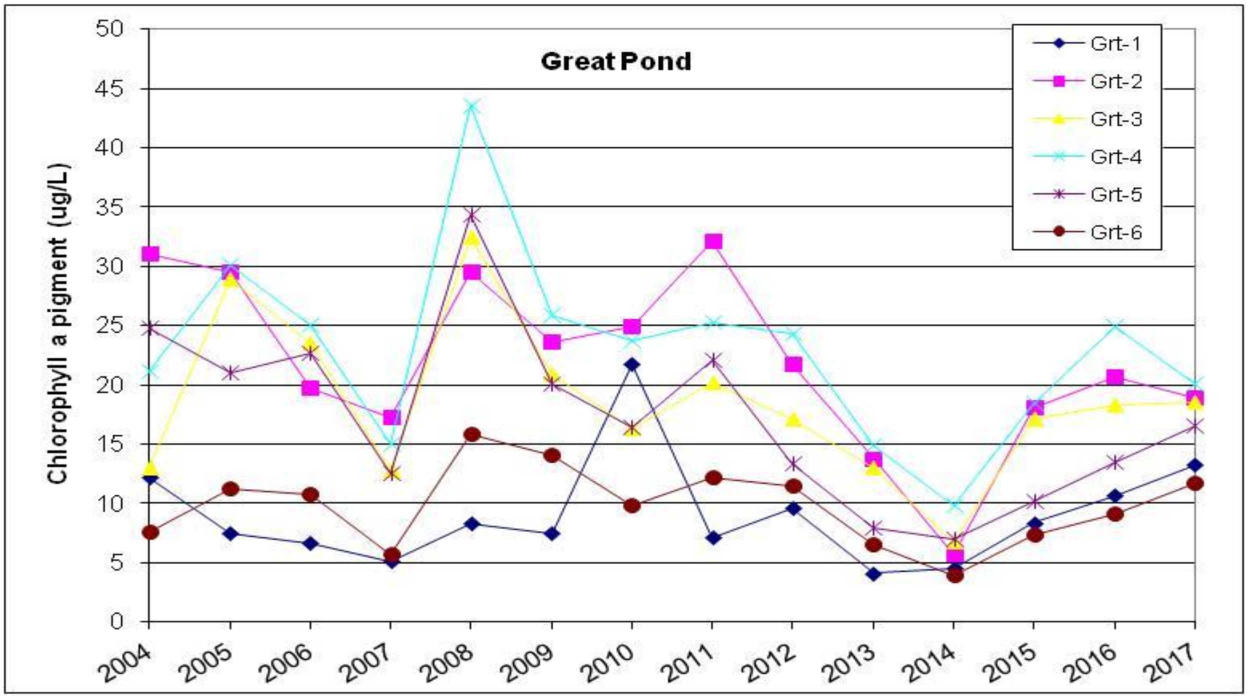


Figure 6. Annual averages for Great Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 4. Total chlorophyll-*a* pigment as indicator of phytoplankton biomass. Averages >10 ug/L are indicative of nitrogen enrichment.

Table 2. TN values (mg N/L) in Great Pond from 2004-2014, 2015-2017 and MEP averages pre-2004.

Great Pond	2004 - 2014			2015-2017			MEP
Station	**Mean**	**s.d.**	**N**	**Mean**	**s.d.**	**N**	**Mean**
Grt1	1.106	0.235	42	1.334	0.283	12	0.855
Grt2	1.075	0.238	86	1.136	0.264	24	0.881
Grt3	0.885	0.226	86	0.871	0.239	24	0.739
Grt4	1.041	0.272	85	0.976	0.235	24	0.895
Grt5	0.788	0.186	85	0.748	0.161	24	0.644
Grt6	0.619	0.167	85	0.641	0.128	24	0.543
TN values in mg N/L							

Summary of Nutrient Related PondWatch Water Quality Data – Green Pond (2004-2014, 2015, 2016, 2017)

Green Pond (Figure 7) exchanges tidal water with Vineyard Sound through a single armored inlet. The Green Pond watershed is relatively small, but is highly developed with mainly commercial and residential property using on-site septic disposal of wastewater. Based on the MEP analysis of Green Pond (2004), water quality data indicates a system which is significantly nitrogen impaired throughout its upper half, based primarily upon the very high chlorophyll-*a* levels and periodic oxygen declines. In contrast, the lower reaches support healthier conditions (moderately impaired/significantly impaired) based upon both the level and duration of observed oxygen depletion and chlorophyll-a levels. The Sentinel Station (GP-4) has a nitrogen threshold of 0.42 mg TN/L to generate TN levels of 0.40 in the lower basin below the Menahaunt Bridge. The threshold TN level was set at 0.40 mg TN L^{-1} to restore complete eelgrass coverage of the lower basin and 0.42 mg TN L^{-1} at the Sentinel Station to re-establish the marginal eelgrass beds (both conditions are required in this system).

Green Pond has had significant nitrogen enrichment and impaired habitat for decades and the 2004-2014 and 2015-2017 periods generally showed continued high nitrogen levels with associated low dissolved oxygen and high total chlorophyll-*a* levels. There was no detectable difference in TN levels in both periods, with near perfect agreement between the individual stations (Table 3 and addendum).

Elevated TN levels in 2015 and 2016 corresponded to increased levels in total pigment above 2014 levels with a slight drop in total pigment in 2017 but still at a level above what was observed in 2014. As in previous years, TN levels throughout this linear drown river valley estuary show a strong gradient of decreasing TN and decreasing chlorophyll-*a* from the headwaters to the tidal inlet (Figures 7, 8 and 9). The 2015, 2016 and 2017 chlorophyll-*a* levels show continuing large summer blooms consistent with the high TN levels which far exceed the nitrogen threshold for this system, particularly noticeable in the upper and mid monitoring stations (GP-1,2,2A,3). While the upper reaches in 2016 reached a summer average chlorophyll level of ~30 ug/L, mid and upper stations all reached levels between 15-25 ug/L (GP-3, GP-2A and GP-2 respectively), indicative of significant nitrogen impairment. The lowermost basin (GP-5) showed summer average chlorophyll levels in the period 2015-2017 between 6-12 ug/L, indicative of a lessened level of nitrogen enrichment due to proximity to the inlet and flushing with low nitrogen water from Vineyard Sound. It appears that blooms had been lower 2011-2014 but increased in the summers 2015, 2016 and 2017, although this may relate to the sampling frequency (only 4 samplings per year) of this highly temporally variable metric.

Equally problematic for restoration of this estuary is the finding that all stations have decreased water quality, since the 2004 MEP analysis. While estuarine TN levels are currently stable, it appears that this system will not improve its resource quality without positive action to manage its nutrient levels by the Town. Fortunately, the Town of Falmouth is fully engaged in activities to restore Green Pond and its other 13 estuaries, with some management actions already in place (e.g. Oyster Pond weir, West Falmouth WWTF upgrade). Additionally, innovative alternatives are being tested and others are in the planning or even permitting phase of implementation.

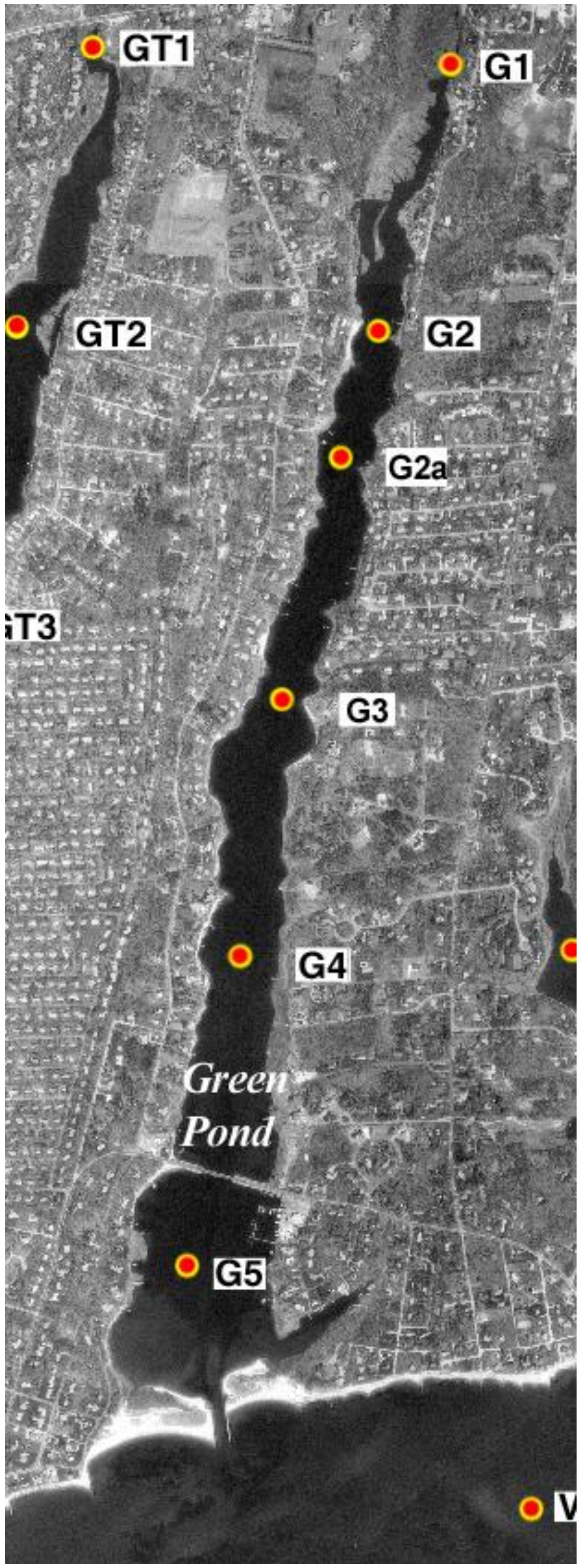
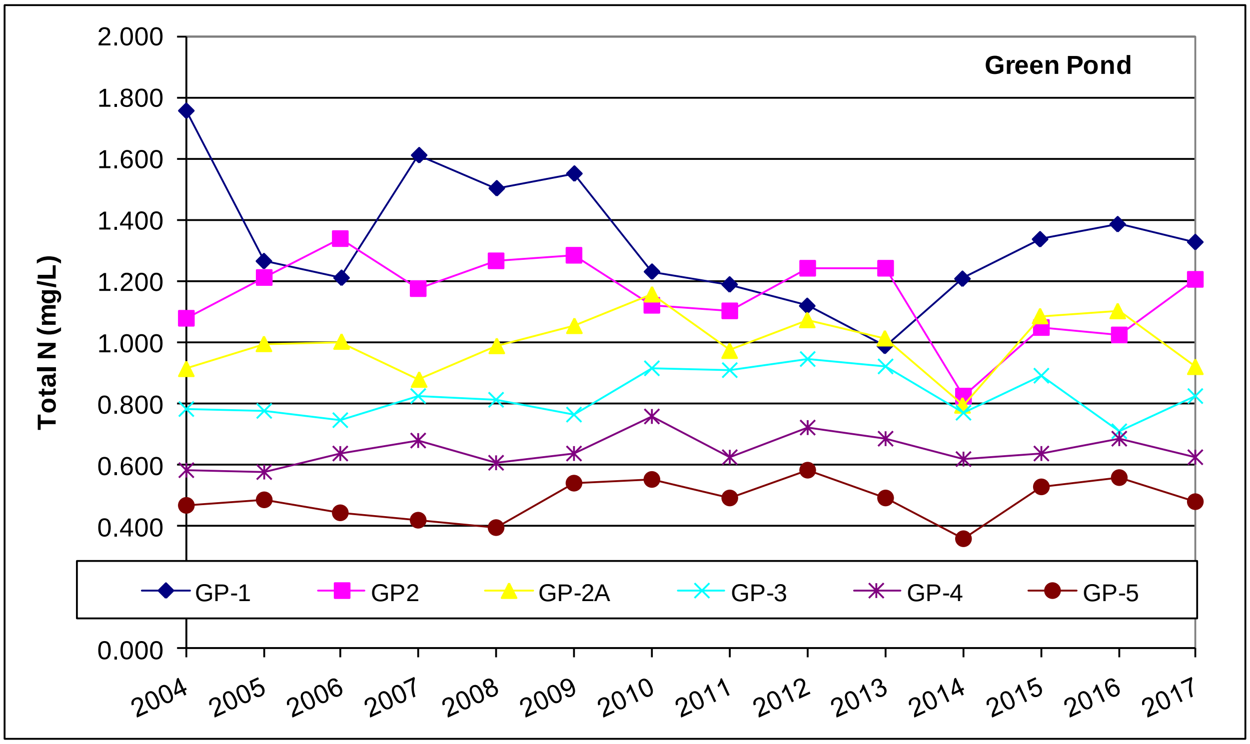


Figure 7. Green Pond water quality sampling stations for SMAST-PondWatch 2004-2017 and nutrient related water quality baseline used in the Massachusetts Estuaries Project analysis.



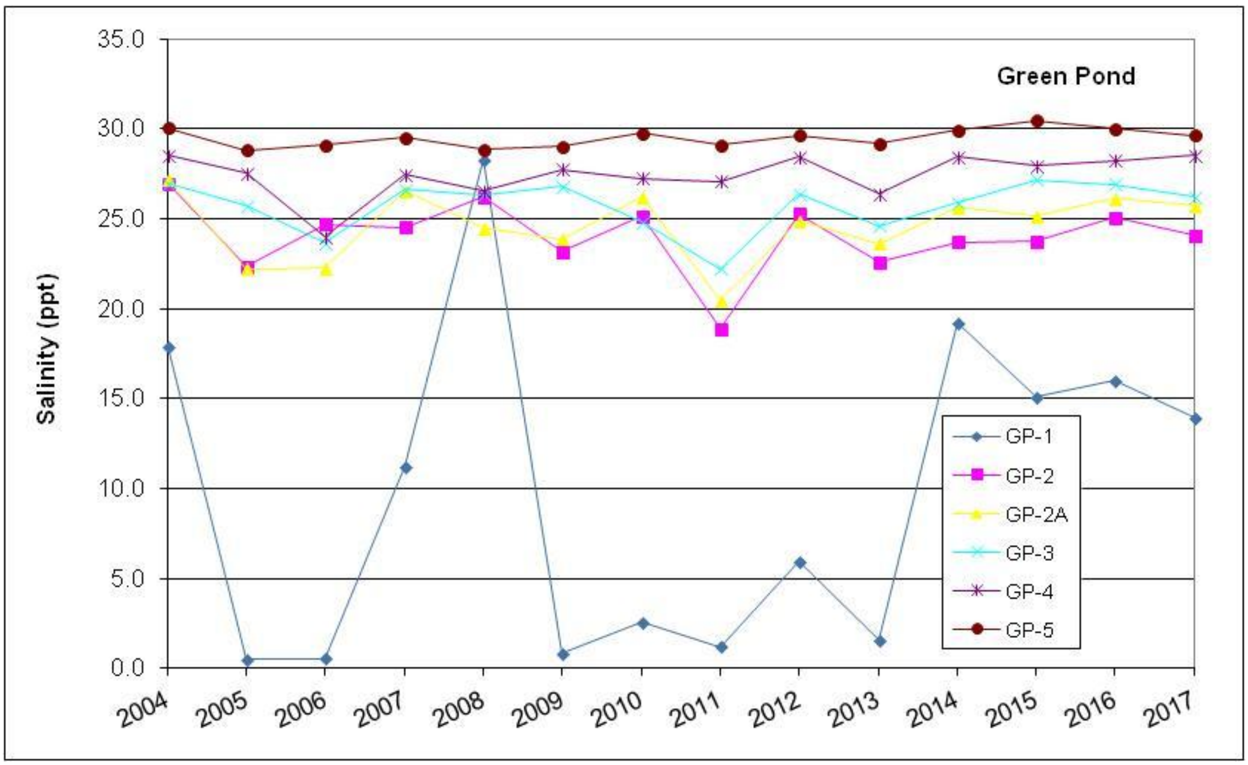


Figure 8. Annual averages for Green Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 7. Top: TN station averages. TN threshold is 0.42 mg/L to support eelgrass restoration. System remains above TN threshold. Bottom: Salinity station averages, general gradient of fresher inner to more marine outer basins. There appears to be a slight freshening in the mid (GP-3,2A) and upper (GP-2) portions of the system, likely related to occulsion of the tidal inlet.

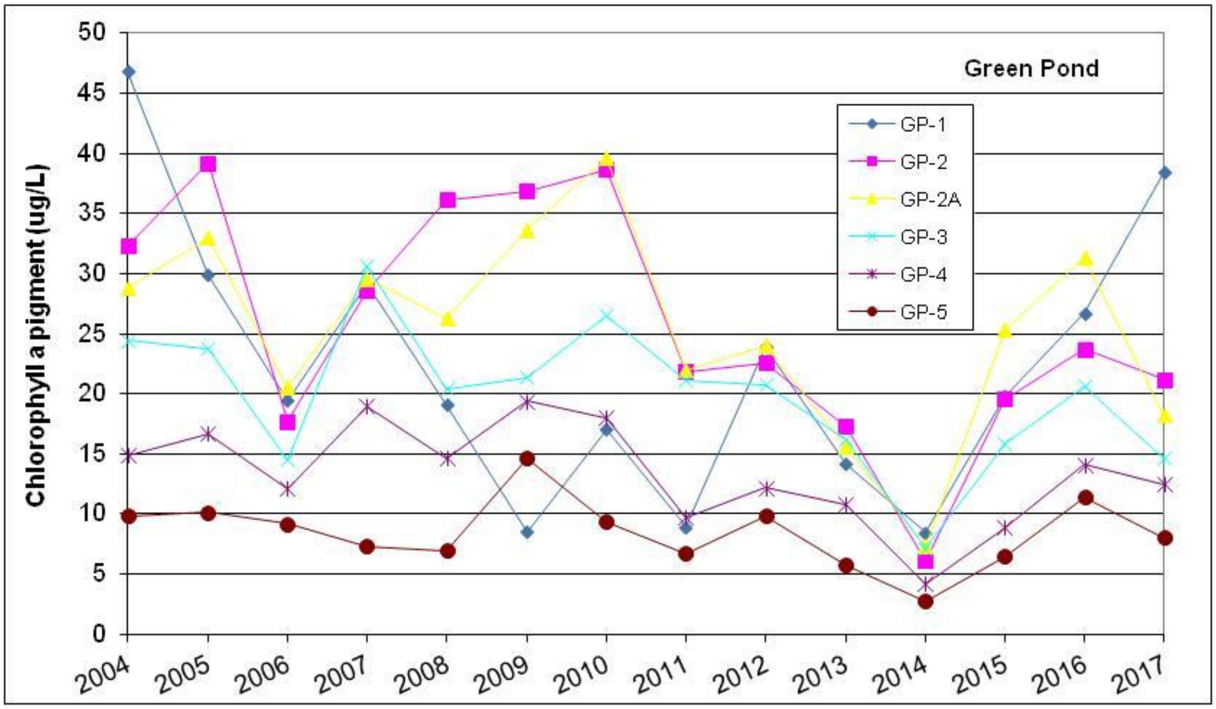
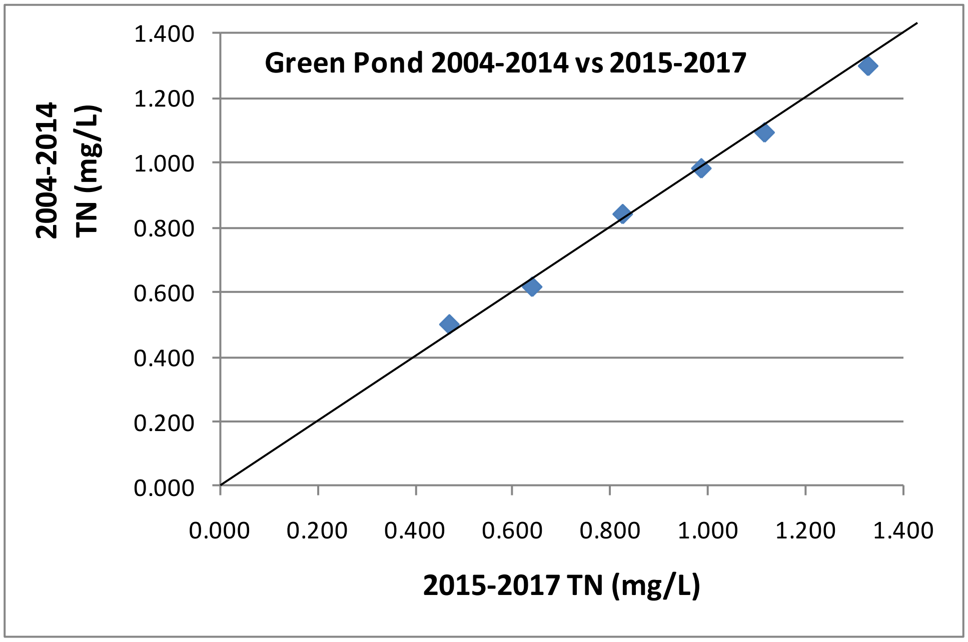


Figure 9. Annual averages for Green Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 7. Total chlorophyll-*a* pigment as indicator of phytoplankton biomass. Averages >10 ug/L are indicative of nitrogen enrichment.

Table 3. TN values (mg N/L) in Green Pond from 2004-2014, 2015-2017 and MEP averages pre-2004.

Green Pond	TN 2004-14			TN 2015-17			pre-2004
Station	Mean	s.d.	N	Mean	s.d.	N	MEP
GP1	1.327	0.357	43	1.300	0.327	12	1.364
GP2	1.115	0.248	81	1.095	0.254	24	0.988
GP2A	0.985	0.205	84	0.984	0.228	24	0.927
GP3	0.824	0.180	85	0.843	0.211	23	0.750
GP4	0.638	0.142	85	0.618	0.132	24	0.540
GP5	0.469	0.105	101	0.502	0.094	27	0.440



Addendum to Table 3. Plotting 2004-2014 versus 2015-2017 and comparing to 1:1 equality line shows very close agreement between the two time periods by station for Total Nitrogen, indicating the relative stability of TN levels in Green Pond since 2004, Linear regression yields a slope of 0.95 and R^2 of 0.997.

Summary of Nutrient Related PondWatch Water Quality Data – Little Pond (2005-2012, 2013, 2014, 2015, 2016, 2017)

Little Pond (Figure 10) exchanges tidal water with Vineyard Sound through a single armored inlet. The Little Pond watershed is relatively small, but is densely developed mostly with commercial and residential properties which until recently used on-site septic disposal of wastewater. As part of the Town's nitrogen management plan to restore its impaired estuarine waters, much of the watershed to Little Pond has recently been connected to the Town's WWTF (2017) removing much of the significant septic system nitrogen load to Little Pond. As this is an on-going recent event, its impact on Little Pond water quality has not yet occurred. However, in the near future, PondWatch expects to be tracking water quality improvements as "stored" septic nitrogen in groundwater is flushed out and nitrogen loading to the estuary declines.

In addition to sewering the Little Pond watershed, the water quality can also be improved by widening the undersized tidal inlet and keeping the present inlet free of sand which restricts flow periodically. Presently, and as a result of restricted flow, TN levels are causing water quality and habitat impairments resulting in the pond showing poor water quality throughout its tidal reach (LP-1, LP-2, LP-3). The Sentinel Station (LP-2) has a nitrogen threshold of 0.45 mg TN/L to support high quality habitat, which also results in TN levels of <0.42 in the lower basin (LP-3). Current TN levels remain far above these targets, but should begin to decline as the effects of sewering the watershed reach the receiving estuarine waters.

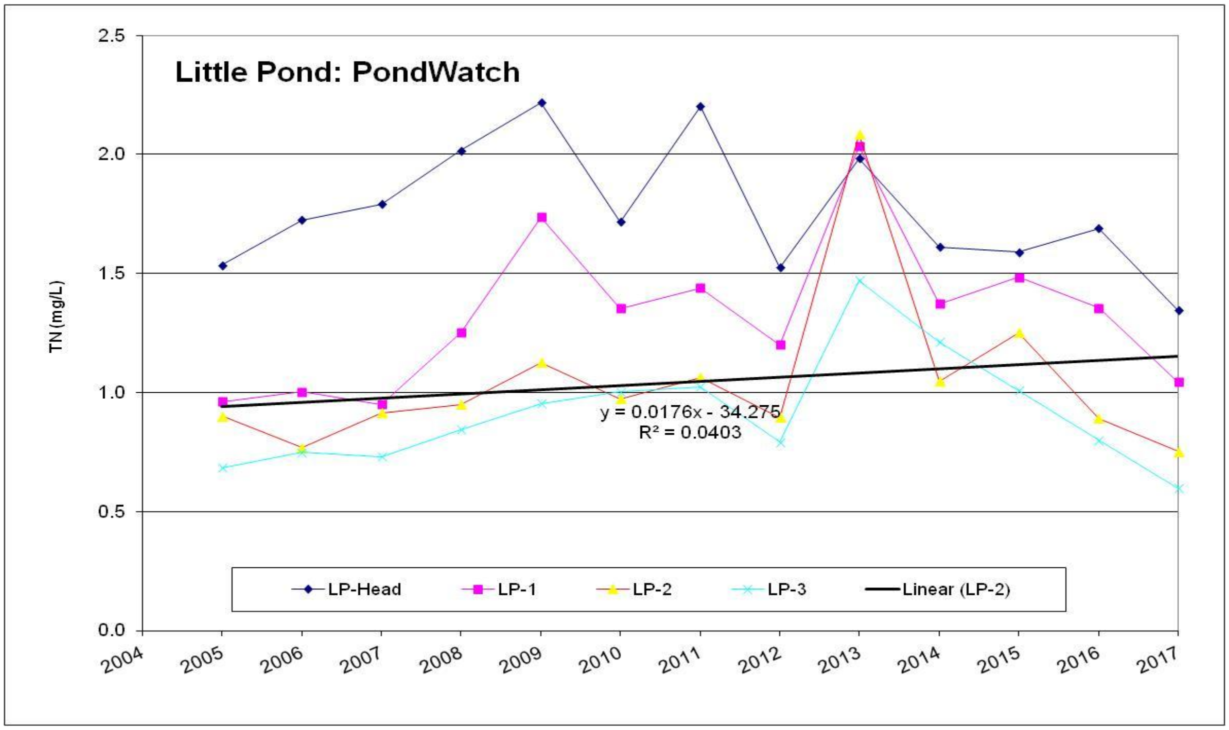
In contrast to the other estuaries, Little Pond does appear to have rapid changes in TN as can be seen in the time-series TN record (Figure 11). A rapid increase is particularly evident in the later years in the upper basin (LP-1), but at the other stations as well. Overall, the pattern is one of TN increases throughout the estuary, but this cannot be evaluated on a year by year basis, as inter-annual variation is apparent. In 2016, TN levels appeared to increase slightly at the upper stations (LP-Head and LP-1) while staying stable at LP-2 and LP-3. This may be associated with changes in watershed nitrogen inputs, but also likely linked to changes in tidal flushing affecting concentrations at the lower stations. By comparison, TN levels in 2017 appear to be lower at all stations than levels observed in 2016. Linear regression of TN on Sentinel Station (LP-2) did not show a significant (nor meaningful) annual temporal trend (R^2=0.04), consistent with the averages of pre-2004, 2004-2014 and 2015-2017 (see Table 4).

As previously mentioned, this is likely due to effective flushing of the system through the inlet to Vineyard Sound. As in previous years, variations in tidal flushing remain consistent with the observed inter-annual variation in salinity at each sampling station, which tended to be larger than observed in the other estuaries. Given the structure and location of the Little Pond inlet relative to local sand transport patterns under storm and non-storm periods, it appears that occlusion of the inlet by sand deposition and periodic clearing during periods of higher tidal velocities are linked to the variations in TN and salinity levels. This is supported by the variation in salinity, where relatively large inter-annual variations were observed and in general lower salinities at a station were coupled to higher TN levels (Figure 11). There appears to be a freshening throughout the basins in recent years likely related to occulsion of the tidal inlet. Keeping the existing inlet open and later widening it, should have a significant effect in lowering present TN levels and improving nitrogen related habitat quality within Little Pond.

Phytoplankton biomass/bloom activity did not show a clear pattern across the stations over 2005-2012 and there were no remarkable bloom events captured in the 2016 data. 2016 total pigment levels are not significantly different than levels observed in 2012 and in both cases remain well above (~14-22 ug/L) the 10 ug/L threshold indicating impairment (Figure 12). 2017 levels do appear slightly lower than 2016 observations, however, the levels remain between 10 and 20 ug/L which is still above the generally accepted impairment threshold. It appears that blooms were larger in the first part of the record (2004-2010), although this may relate to the lower sampling frequency (only 4 samplings per year) in the more recent summer sampling seasons of this highly temporally variable metric, although the impact of more recent oyster deployments cannot be discounted. The restriction of tidal exchanges creates a situation somewhat like a pond, where water quality parameters show weaker gradients, i.e. tend to be more evenly distributed than in a well flushed estuary. The lack of gradient shows clearly in the chlorophyll-*a* results for some years (2011, 2012, 2014), however, in other years there does appear to be more of a gradient (2006-2008, 2015, 2016, 2017). In some cases the chlorophyll-*a* data shows a more localized bloom (e.g. 2010) that interrupts the more typical longitudinal gradient from estuary head to inlet. Nonetheless, the level of chlorophyll-*a* and TN are consistent with the level of habitat impairment noted by the MEP. There is no evidence of habitat improvement within this estuary and none is expected based on the water quality metrics.

Fortunately, the temporal pattern of change in key water quality metrics suggests a rapid response in water quality once nitrogen management alternatives (tidal flushing, nitrogen load reduction) are implemented. As in previous years, inlet management should be consistently undertaken to maintain effective exchange of water from Vineyard Sound too Little Pond, however, load reductions will likely be necessary to bring nutrient concentrations down to the threshold level at the sentinel station.

Figure 10. Little Pond water quality sampling stations for SMAST-PondWatch 2005-2017 and nutrient related water quality baseline used in the Massachusetts Estuaries Project analysis.



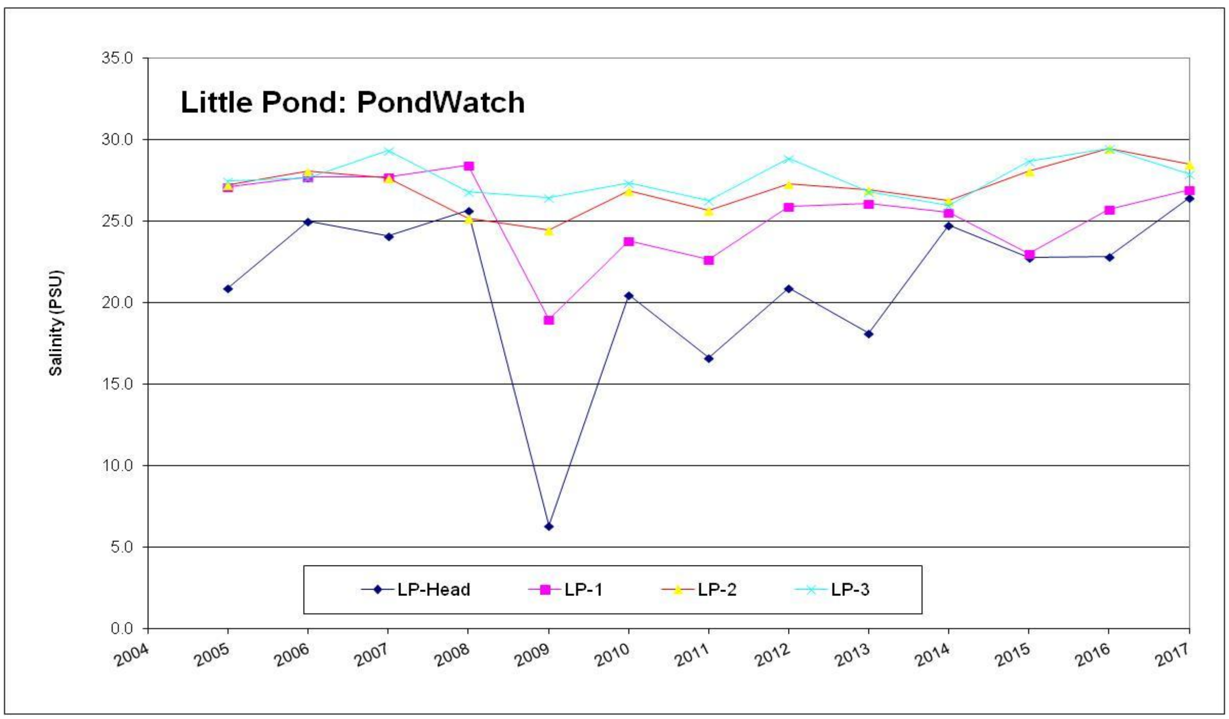


Figure 11. Annual averages for Little Pond nutrient related water quality post-MEP analysis 2005-2017 from SMAST-PondWatch for stations shown in Figure 10. Top: TN station averages. System remains above its TN threshold of 0.45 mg/L to support eelgrass restoration. Bottom: Salinity station averages at each station show general gradient of fresher inner to more marine outer basins.

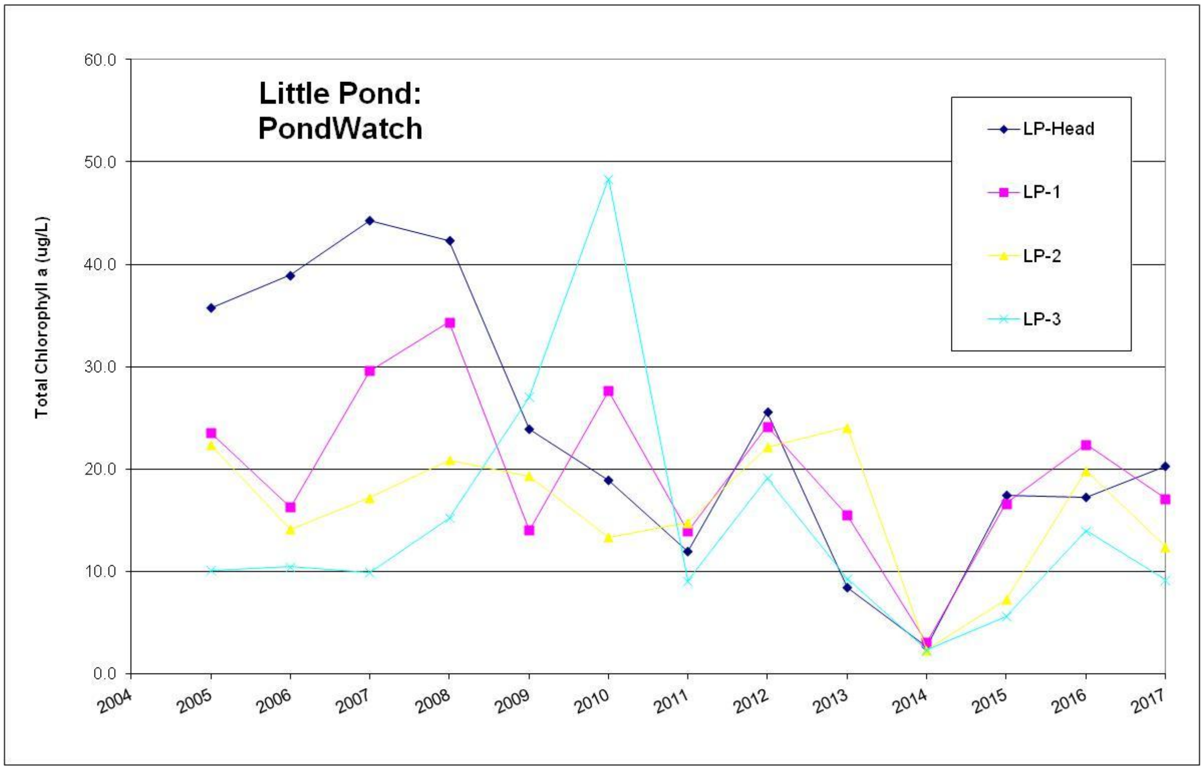


Figure 12. Annual averages for Little Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 10. Total Chlorophyll-*a* pigment as indicator of phytoplankton biomass. Averages >10 ug/L are indicative of nitrogen enrichment.

Table 4. TN values (mg N/L) in Little Pond from 2005-2014, 2015-2017 and MEP averages pre-2004. No significant consistent changes in TN were observed between the sampling periods. It is anticipated that TN levels should begin to decline over the next few years as the impact of removing septic nitrogen inputs begins to lower the nitrogen loading to this estuary.

Little Pond	TN 2005-2014			TN 2015-2017			MEP
Station	mean	s.d.	N	mean	s.d.	N	pre2004
Head	1.832	0.632	35	1.541	0.679	12	2.321
LP-1	1.314	0.542	73	1.309	0.447	21	0.942
LP-2	1.048	0.465	73	0.974	0.392	23	0.898
LP-3	0.918	0.363	71	0.802	0.274	24	0.745

Summary of Nutrient Related PondWatch Water Quality Data – Oyster Pond (2004-2014, 2015, 2016, 2017)

As is typical with other Falmouth embayments (Great, Green, and Bournes Pond) Oyster Pond (Figure 13) is separated from Vineyard Sound by a barrier beach and exchanges tidal waters through a single armored tidal inlet. However, unlike the other estuaries on the south shore of Falmouth, Oyster Pond has tidal flow control to maintain it as a brackish coastal pond. It also has a small saline lagoon between the inlet channel (Trunk River) and the pond, such that tidal flow enters the inlet and flows through the Trunk River, whose west branch flows to Oyster Pond through the shallow Lagoon. The beach and the opening to the lagoon are very dynamic geomorphic features due to the influence of littoral transport processes. Periodic sediment deposition, generally associated with storms, occludes the channel between the inlet and Lagoon which restricts the flow to Oyster Pond such that periodic dredging (bucket and drag line) is required to sustain the salt marshes within the Lagoon and the brackish nature of Oyster Pond.

Oyster Pond is situated such that managing it as a marine basin is not possible due to the distance from Vineyard Sound. Similarly, it is not possible to manage it as a fully freshwater pond, as there is periodic storm overwash bringing large volumes of salt water into Oyster Pond, therefore the best management option has been to manage the pond as a brackish water system, with salinities of the mixed surface layer between 2 and 4 ppt. This management option was determined from a multi-year assessment and options analysis conducted in the 1980's [1].

The weir installed between the Pond and Lagoon is set to maintain salinity in the preferred range by controlling tidal flooding. The weir requires that there be free flow between Vineyard Sound and the weir, such that the weir is the controlling structure. However, given the coastal processes, the channel between the lagoon and Trunk River becomes occluded with sand thereby reducing tidal flows, with the result that the pond water freshens over time. During fall/winter 2016 the channel became severely blocked and pond salinities declined to slightly less than 1.0 ppt, with negative impacts on phytoplankton communities (large blooms). PondWatch, in collaboration with the Town Department of Natural Resources, worked to resolve the blockage and salinity levels returned to ~2 ppt by summer. Presently, planning is underway to implement regular flow management. The salinity profiles show that the pond has generally been consistently brackish since the installation of the weir (previously salinity had risen to 24 ppt, with negative ecological consequences). Over the period 2004-2017, the pond water column completely mixed (vertically) on 2 occasions, 2008 and 2016, as can be seen in Figure 16. These events resulted in oxidation of bottom waters and loss of the very high inorganic nitrogen burden in the deep waters. It appears that Oyster Pond is gradually improving consistent with salinity management, with full restoration anticipated with the implementation of the Town's watershed nitrogen management actions, now being planned. Tracking of salinity is continuing as part of inlet management and nutrient related water quality monitoring will continue to assess the efficacy of planned watershed nitrogen management (nitrogen reducing septic systems or sewering or both).

It appears from the TN time-series (Figure 14, Table 5) that nitrogen levels in Oyster Pond may have increased from 2004-2014 to 2015-2017 in the upper mixed layer. However, given the periodic problems with maintaining tidal flows and the recent vertical mixing events, it is likely this is due to internal processes more than a significant increase in watershed nitrogen inputs.

[1] The control structure has functioned as designed since its installation and continues to function based on current PondWatch data. This was one of the first management projects implemented for estuarine restoration by Falmouth and underpinned by PondWatch results and SMAST scientists with ACRE engineers.

Historically the deep waters of the main basin supported ~8 mg N/L due to prolonged anoxia. With the recent mixing, this stored nitrogen is moved into the surface waters which increases the TN level. This will eventually result in improved conditions, once the pond flushes out to Vineyard Sound. Overall, the TN concentration still exists within a relatively stable range of year to year variation of ~0.3 mg N/L and no distinct long-term trend at the sentinel station (OP-3) and also in the mid basin (OP-2) is apparent. The upper semi-enclosed basin yields highly variable results (particularly CHLA), likely due to its structure and direct surface water inflows and periodic blockage of tidal inflows. Whatever the cause, considering the 2015-2017 data, there is evidence that there has been a short-term change in the nutrient related water quality of the Oyster Pond Estuary in the mixed layer (slight increase) and deep layer (decrease; Figure 14, Figure 15, Table E and 5). As a point of reference, the MEP developed TN threshold for Oyster Pond is 0.633, 0.588 and 0.548 mg/L depending on target bottom water oxygen minima (D.O.: 3.8 mg/L, 5.0 mg/L, 6.0 mg/L, respectively) to support infaunal restoration.

As noted above, salinity of the mixed layer of the pond has varied, with a tendency to have higher TN levels at lower salinities, either due to reduced flushing or a shift in the importance of phosphorus as a control on phytoplankton growth. Salinity in Oyster Pond has been decreasing since 2013 and there has been a corresponding increase in TN levels over the same period due to decreased flushing (Figure 16). However, in 2017 it is clear salinity went up with a corresponding decrease in TN concentration (as would be expected with the introduction of lower TN concentration water from Vineyard Sound). As a result, monitoring of the inlet for blockages is being intensified. It is critical to note that the weir should not be adjusted as it is virtually certain that flow issues stem from periodic Trunk River flow restrictions, not the weir adjustment. The weir is designed to maintain salinity in the 2-4 ppt range, which it did for 7 of the 12 recent years. It is more acceptable to have the salinity rise slightly than to have it drop to 1 ppt as it did in 2009 and again in 2016. It should be stressed that the issue of low salinity in the pond can likely be solved by Trunk River channel management and needs to be encouraged. No general gradient of fresher inner to more marine outer basins has been observed because Oyster Pond salinity is controlled to maintain the system as a freshwater pond.

While Oyster Pond appears to have not become more impaired since the MEP assessment, it also shows little sign of improvement. Although the large mass of nitrogen held within the pond waters has declined, the levels of nitrogen continue to drive the impairment of pond water quality. While the chlorophyll-*a* levels are generally moderate (average <10ug/L) in the middle and lower part of the system, there are periodic large phytoplankton blooms, e.g. 2011-2012 and 2015-2017 (Figure 15) and clear increase in total pigment in 2017 at station OP-1 in the upper portion of the Pond (~20-65 ug/L in the mixed layer, Table E, 2015-2017). Most importantly, each of the Oyster Pond basins becomes oxygen depleted each summer and the deep basin (OP-3) continues to be mainly anoxic with sulfidic bottom waters. This is the major impediment to improving benthic animal habitat in this estuary and while the deeper basin is hypoxic/anoxic due to its physical structure, restoration of the other basins (OP-1, OP-2) is possible with proper nutrient management.

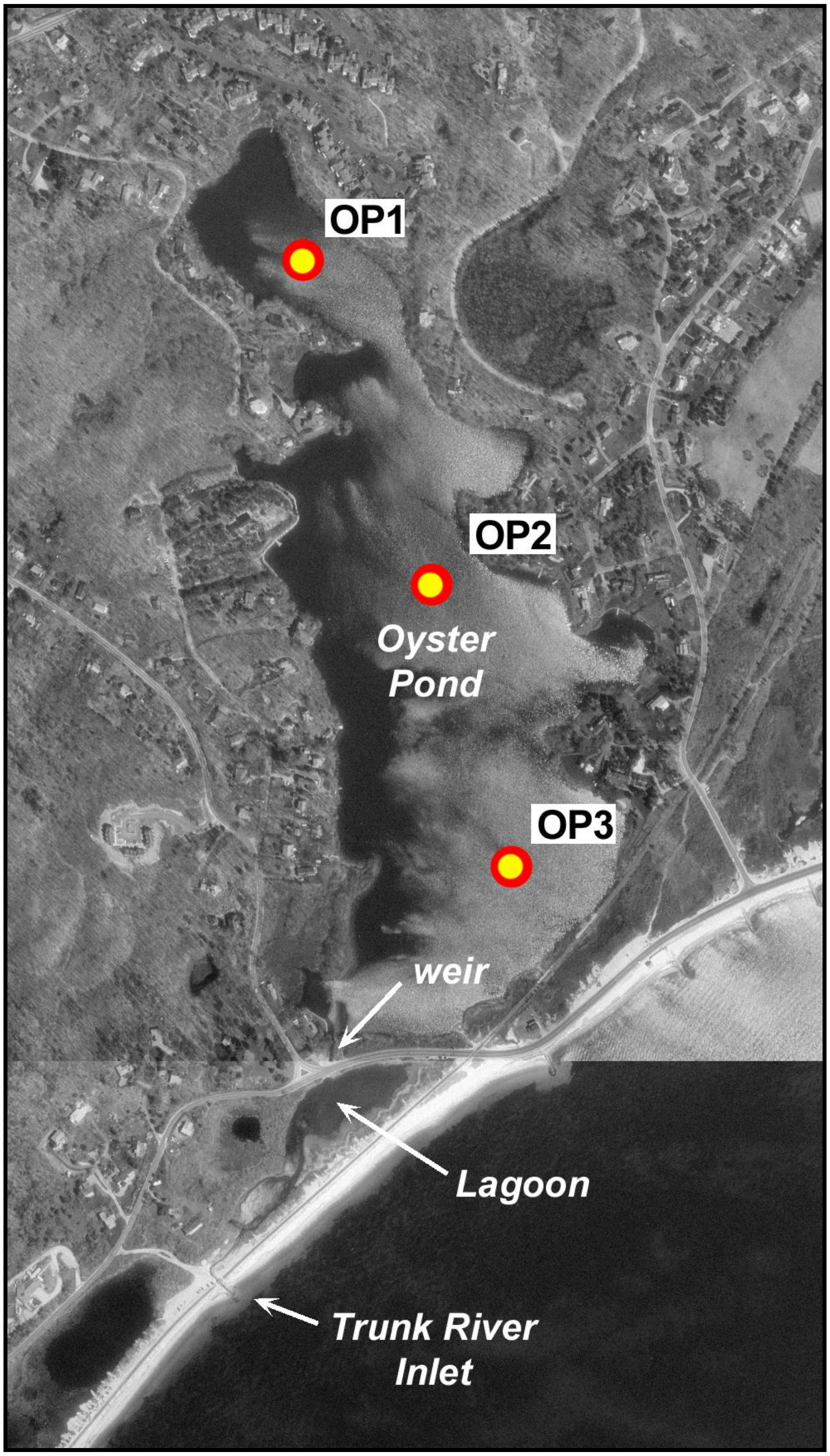
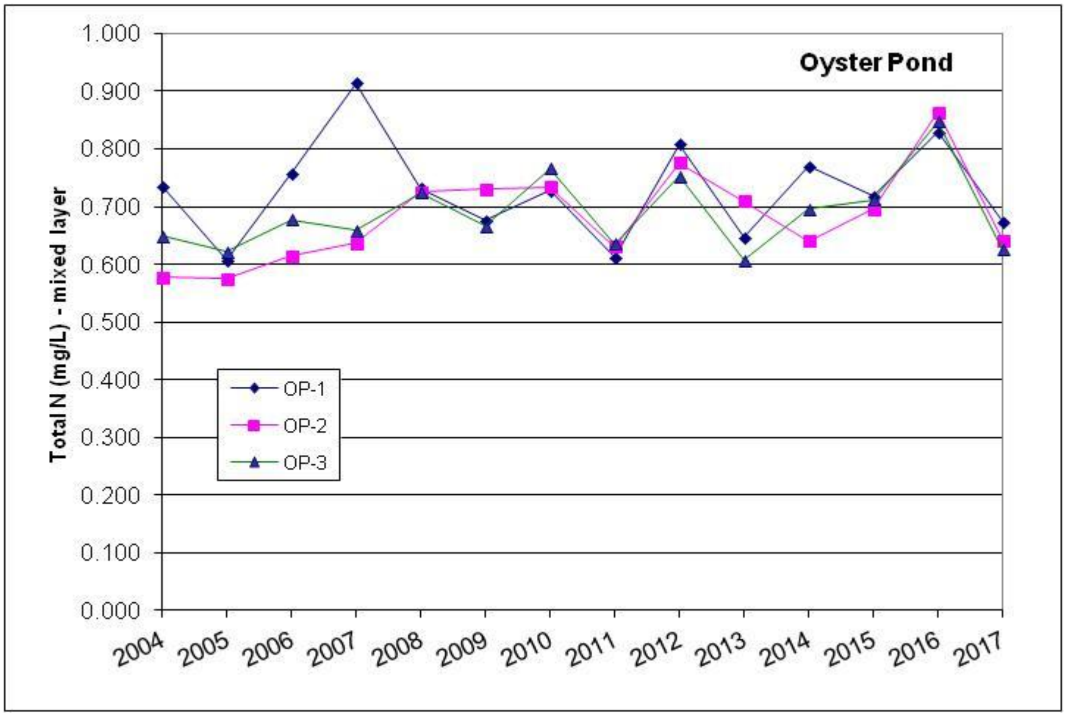


Figure 13 Oyster Pond water quality sampling stations for SMAST-PondWatch 2004-2017 and nutrient related water quality baseline used in the Massachusetts Estuaries Project analysis.



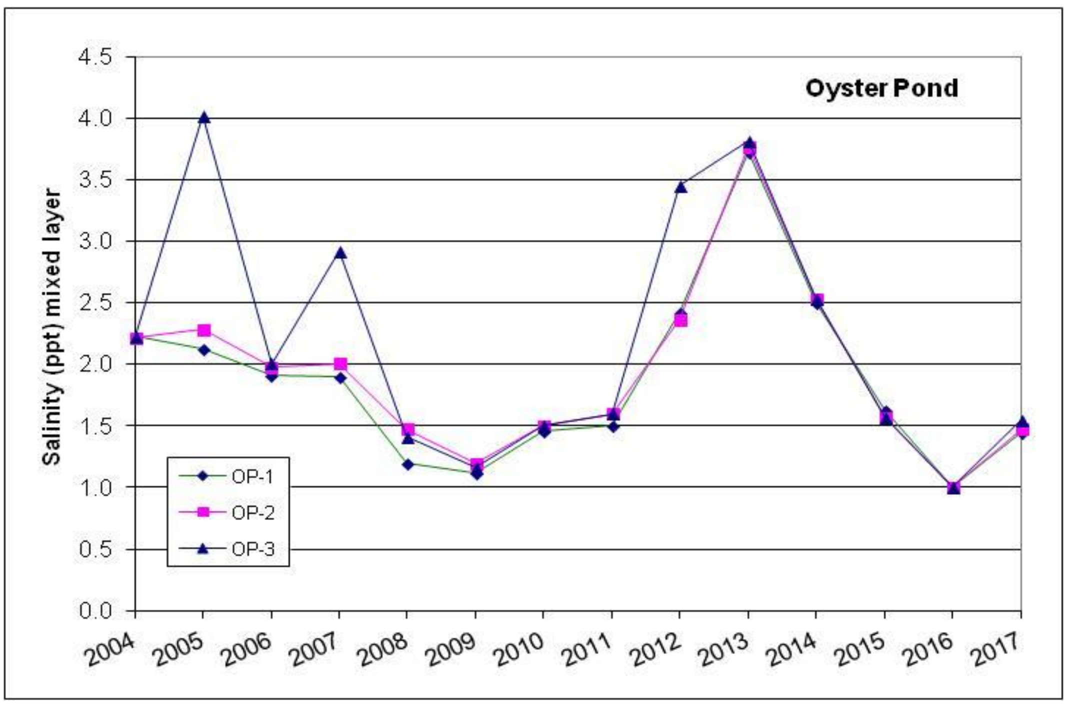


Figure 14. Annual averages for Oyster Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 13. Top: TN station averages at stations shown in Figure 13. Bottom: Salinity station averages.

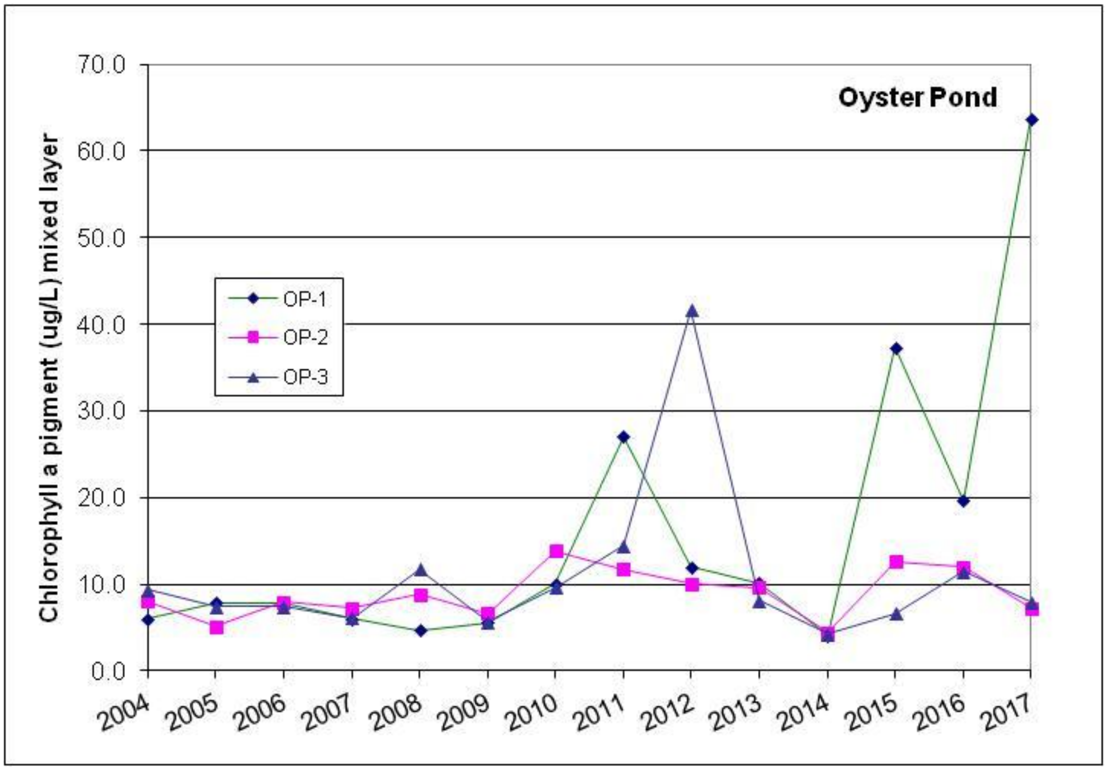


Figure 15. Annual averages (mixed layer) for Oyster Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 13. Total chlorophyll-*a* pigment as indicator of phytoplankton biomass. Averages >10 ug/L are indicative of nitrogen enrichment..

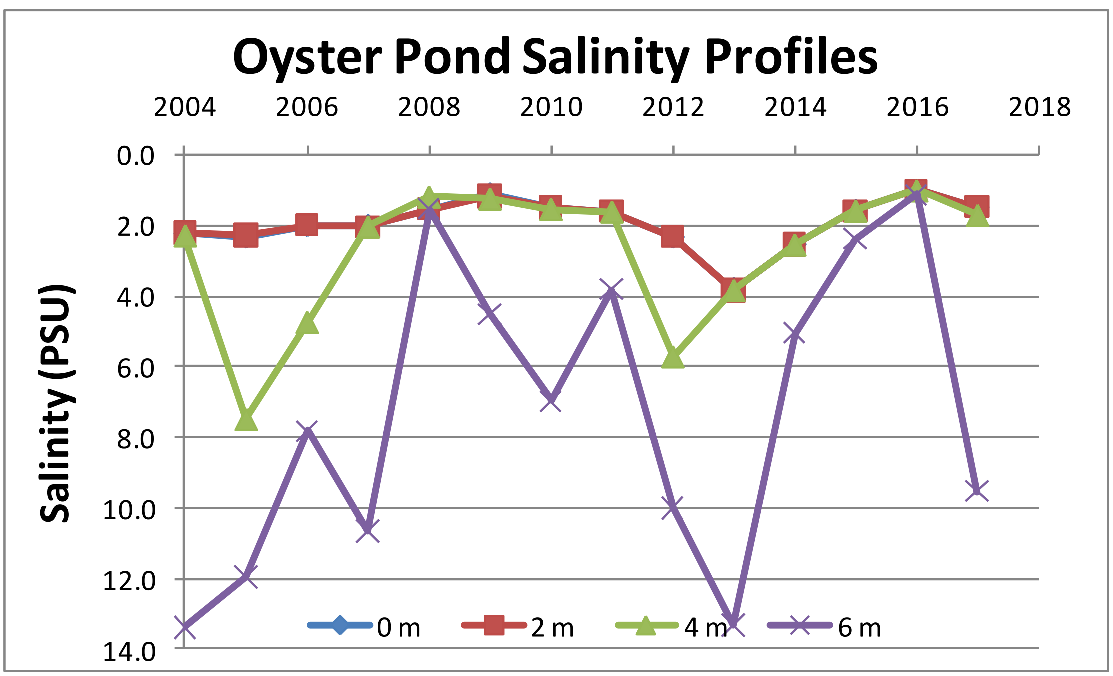


Figure 16. Oyster Pond Salinity profiles 2004-2017 at the deep station (OP-3). The pond has been salinity stratified each year except for 2008 and 2016, when the pond inlet was blocked and salt water inflows were highly restricted.

Table 5. Profiles of TN values (mg N/L) in Oyster Pond from 2004-2014, 2015-2017. Oyster Pond is typically density stratified with resulting anoxic bottom waters with high TN.

Oyster Pond		TN 2004-14			TN 2015-17		
Station	**Depth (m)**	**Mean**	**s.d.**	**N**	**Mean (m)**	**s.d.**	**N**
OP-1	**0**	0.683	0.109	39	0.751	0.206	12
OP-1	**2**	0.787	0.211	35	0.730	0.139	12
OP-1	**4**	2.654	1.190	39	1.971	1.193	12
OP-2	**0**	0.688	0.129	35	0.752	0.217	12
OP-2	**2**	0.638	0.116	36	0.706	0.196	12
OP-2	**3.25**	0.679	0.173	36	0.745	0.168	12
OP-3	**0**	0.724	0.120	36	0.757	0.206	13
OP-3	**2**	0.628	0.116	36	0.681	0.173	12
OP-3	**4**	0.680	0.119	35	0.747	0.153	11
OP-3	**6**	8.334	4.830	34	4.842	2.945	12

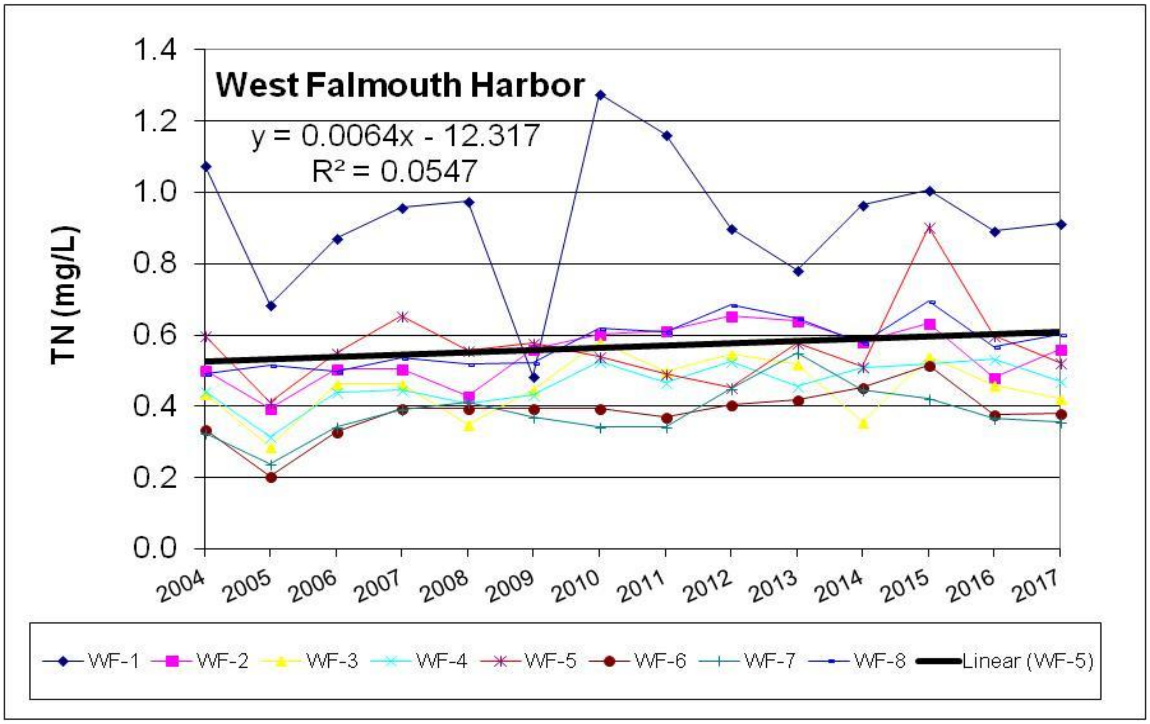
Summary of Nutrient Related PondWatch Water Quality Data – West Falmouth Harbor (2004-2012, 2013, 2014, 2015, 2016, 2017)

West Falmouth Harbor (Figure 17) exchanges tidal water with Buzzards Bay through a single armored inlet. PondWatch originally incorporated this Harbor system into its monitoring program to capture nitrogen increases and habitat changes associated with the new (at that time) nitrogen load originating from the new groundwater discharge of treated effluent from the West Falmouth Waste Water Treatment Facility (WWTF). This original WWTF has been upgraded with a lowering of nitrogen to the Harbor. The present monitoring effort is to document the changes in estuarine TN levels and associated habitat quality as the previous high nitrogen plume from the groundwater discharge from the old WWTF is replaced by the significantly lower nitrogen plume from the upgraded WWTF which went online in 2005. It was anticipated that based on the groundwater flow rate, the prior plume would have been partially flushed through by now, but it appears that residual nitrogen is still moving through the system (likely similar to the events with the decommissioning of the old MMA WWTF). Continued monitoring aims to capture these effects and the additional WWTF modifications that were completed in 2016 to improve the denitrification and sludge handling systems within the treatment plant. As in many cases the water quality monitoring data is the best determinant that the nitrogen reductions have reached the estuary.

It appears from the TN time-series (Figure 18, Table 6) that 2004-2014 and 2015-2017 nitrogen levels in portions of West Falmouth Harbor (WF-3,4,5,7) continue to trend upwards or are stable. The near stable conditions support the contention that the WWTF groundwater plume has not yet been “flushed out”, with the consequence that nitrogen loading to the Harbor continues to increase slightly. The change in plume loading was not expected to be rapid as there is generally not a crisp delineation between the old plume’s trailing edge and the new lower nitrogen plume’s leading edge. More importantly, it has taken some time for the new WWTF to realize its nitrogen reduction due to logistics of plant operations. As such, nitrogen loads in the initial years were not lowered to the target level as quickly as planned. However, sentinel station WF-5 in Snug Harbor has been variable, with a large bloom at WF-5 in 2015 paralleling a spike in TN, which was not repeated in 2016 and 2017 where TN levels returned to the longer-term baseline. Given the variation in TN levels, it will likely take 3 years of monitoring after the old WWTF plume is "flushed out" to document a real improvement in water quality. At present it is not known if the low in 2017 is part of the natural variation or the first year of a new trend. It is therefore critical that monitoring continue in this sensitive system. As a point of reference, the MEP determined TN threshold at the sentinel station is 0.35 mg/L to support eelgrass restoration. Presently, the system remains above its TN threshold.

The changes in TN levels do not appear to be due to changes in tidal flushing as salinity continues to be relatively constant from year to year in the open water basins. Significantly, the chlorophyll-*a* levels, indicators of phytoplankton biomass/blooms, tend to mirror the TN levels, showing stable or declining levels where TN is stable or declining (Figure 19). However, there does appear to be some annual variability in this measure from 2014 to 2017. As such, it is important to continue to monitor this parameter. During the summer sampling season, it may also be useful to deploy in situ moorings in key areas such as the sentinel station to measure chlorophyll at a higher frequency for a longer duration, once it appears that conditions have changed. That will provide a clearer picture of the timing and intensity of phytoplankton biomass/blooms, a critical indicator of habitat impairment. While the TN to chlorophyll relationship exhibited in West Falmouth Harbor has been shown in numerous estuaries by the MEP, the relationship of TN to phytoplankton biomass shown here, increases confidence that management of nitrogen inputs will result in less blooms and clearer waters, as needed for eelgrass restoration.

Figure 17 West Falmouth Harbor water quality sampling stations for SMAST-PondWatch 2004-2017 and nutrient related water quality baseline used in the Massachusetts Estuaries Project analysis.



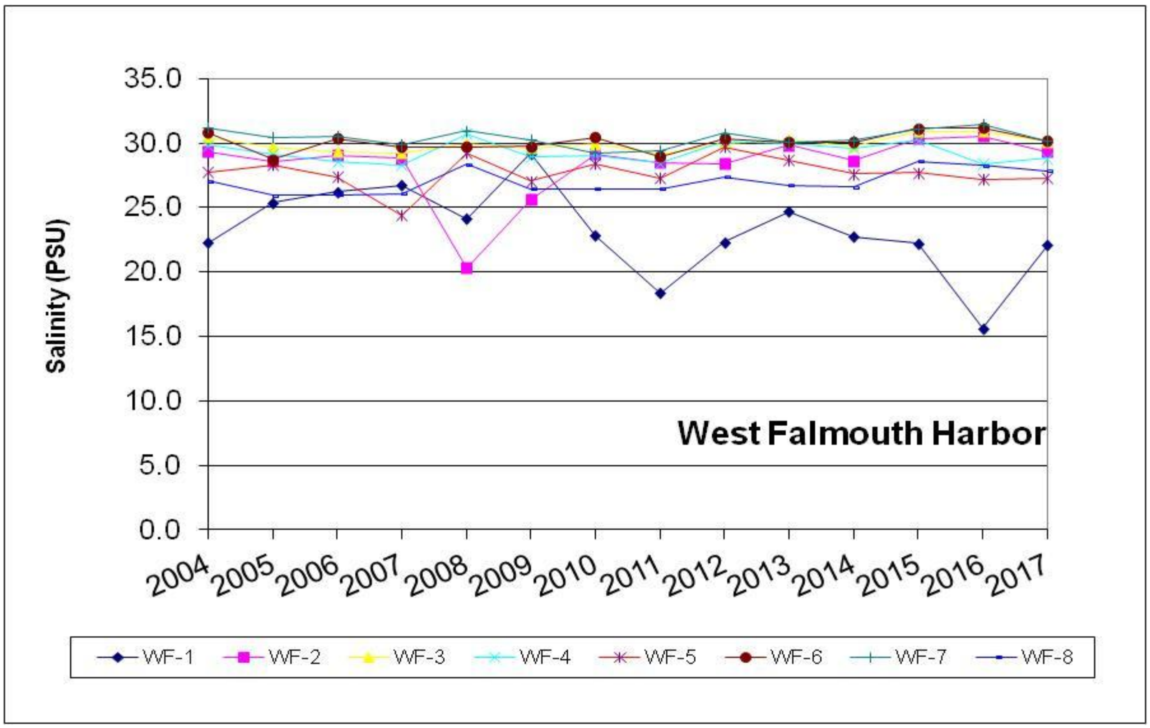


Figure 18. Annual averages for West Falmouth Harbor nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch at stations shown in Figure 17. Top: Total Nitrogen station averages. Bottom: Salinity station averages. General gradient of fresher inner to more marine outer basins.

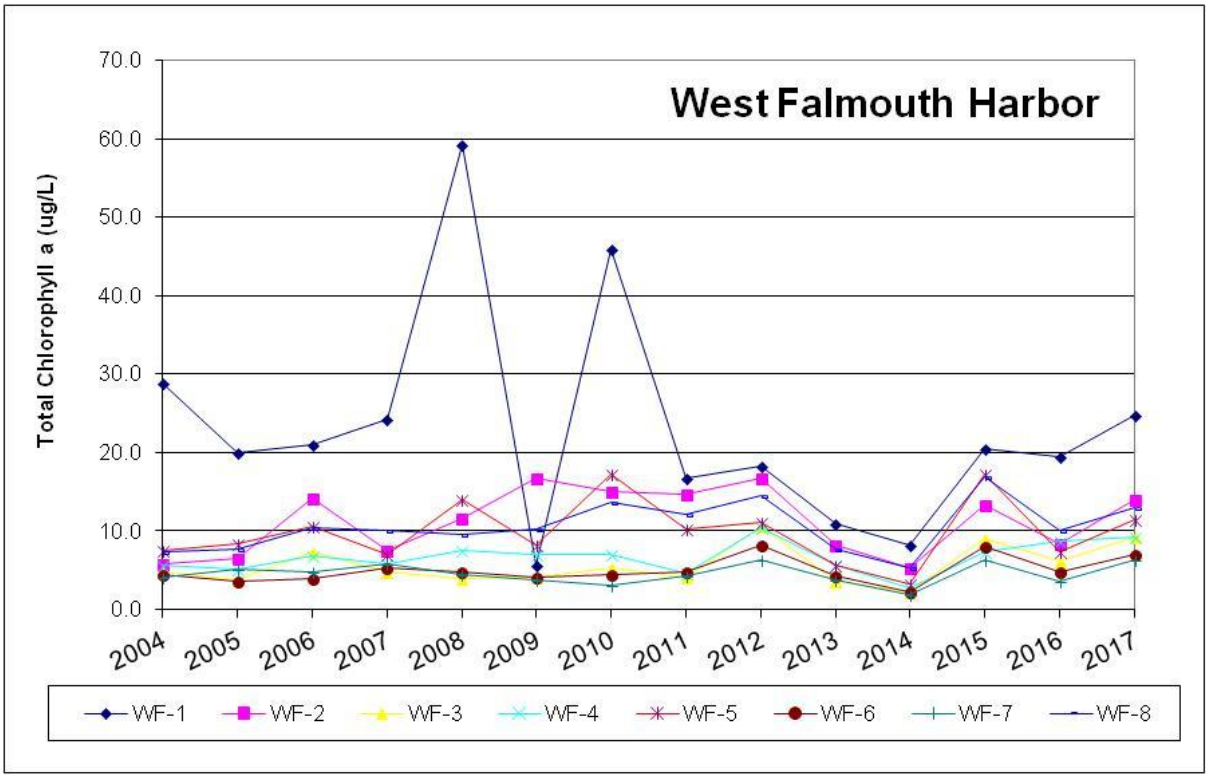


Figure 19. Annual averages for West Falmouth Harbor nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 17. Total chlorophyll-*a* pigment as indicator of phytoplankton biomass. Averages >10 ug/L are indicative of nitrogen enrichment.

Table 6. TN values (mg N/L) in West Falmouth Harbor from 2004-2014, 2015-2017 and MEP averages pre-2004.

WF Hbr	TN 2004-2014 West Fal Hbr			TN 2015-2017 West Fal Hbr			MEP
Station	mean	s.d.	N	mean	s.d.	N	pre-2004
PWF1	0.890	0.337	65	0.936	0.258	29	0.742
PWF2	0.548	0.131	78	0.555	0.147	27	0.482
PWF3	0.444	0.115	80	0.477	0.128	32	0.415
PWF4	0.452	0.104	85	0.488	0.119	31	0.389
PWF5	0.531	0.117	79	0.561	0.184	51	0.444
PWF6	0.373	0.090	85	0.420	0.104	32	0.343
PWF7	0.366	0.085	83	0.384	0.098	32	0.346
PWF8	0.567	0.132	213	0.614	0.144	60	0.506

CONCLUSIONS

The past decade of SMAST-PondWatch water quality monitoring allows for some conclusions relative to the West Falmouth Harbor, Oyster Pond, Little Pond, Great Pond, Green Pond and Bournes Pond Estuaries within the Town of Falmouth.

A key concern for municipal managers relates to potential changes in water quality that may have occurred after completion of the Massachusetts Estuaries Project assessment. The water quality data collected in the period 2004-2017 generally indicates only small TN increase and more often, relatively consistent conditions with measurable interannual variation. This is not surprising since nitrogen management activities are in planning/permitting (e.g. Bournes Pond Bridge, Little Pond inlet, septic nitrogen reductions in Oyster Pond watershed) or that have been implemented relatively recently (e.g. West Falmouth WWTF upgrade, Little Pond sewer project) and have not yet impacted estuarine water quality due to lag times. These projects represent a significant effort by the Town of Falmouth to restore its estuaries and the results should begin to be seen from completed projects over the next few years and for the suite of actions over the next 5-10 years. The multi-year record described in detail above represents a major turn about in the Town's estuarine habitat quality, where there has been consistent or worsening habitat and water quality over the past decades.

More specifically:

1) All of the estuaries monitored by the Falmouth PondWatch Program have supported and continue to support nitrogen enriched waters with associated water and habitat quality impairments, particularly in their upper reaches. None of the systems have shown demonstrable improvement in water quality since the MEP assessments were completed. The general trend is for relatively consistent TN levels, with some basins showing possible small increases (2004-2017). It appears that without the planned nitrogen management actions, the Town of Falmouth can expect TN levels to increase as projected by the MEP and for habitat impairments to continue or to increase. However, it is important to note that there is no evidence of an imminent rapid decline in nitrogen related water quality, although conditions will gradually decline over time or stay consistently impaired until management actions are implemented.

2) Although improvements have been made to the West Falmouth Harbor WWTF to lower nitrogen loading to West Falmouth Harbor, it appears that the previously generated plume of nitrogen enriched groundwater from the prior treatement facility has not yet fully been "flushed" out of the aquifer. The result is that Mashapaquit Creek and adjacent Snug Harbor (WF-1 and WF-5, respectively) show TN levels over the past 8 years greater than 15% that found in the years preceeding 2004. It is significant that 4 of the 7 estuarine stations show increases greater than 10%. That said, Snug Harbor will certainly show declining TN levels as the new WWTF plume fully impacts the Harbor.

3) Resolving the restriction of tidal inflows to Little Pond due to sand occluding the undersized inlet is the final step in the restoration of Little Pond since the large investment in sewering the watershed. The impact of the sewer project (2017) has not yet been recognized in the water quality measurements as it will take a few years until the nitrogen stored in the groundwater system is flushed out. Based upon the watershed hydrology and comparison to other studies, significant estuarine restoration will occur gradually and continue over the next decade with the full improvement taking a bit longer (as is the case in West Falmouth Harbor). Upgrading the tidal inlet will accelerate the observable improvements in this system.

4) Bournes Pond shows a clear increase in TN at the Sentinel Station (B-3). Again, all stations in these latter 2 estuaries are showing small to moderate increases in TN over the past decade since the MEP analysis, consistent with their continued impaired habitat quality. The findings for both Little and Bournes Ponds are consistent with the gradual increase in nitrogen loading from continuing watershed development projected by the MEP as these watersheds approach build-out.

5) Falmouth PondWatch needs to undertake an evaluation of inlet maintenance relative to water quality within the associated estuaries as a means to economically lower the baseline TN levels, in concert with other nitrogen management alternatives being considered by the Town. Nitrogen management needs to consider tidal flushing in concert with watershed nitrogen management, particularly in Great Pond and possibly Green Pond, but especially relative to improving water quality in Little and Bournes Ponds.

Going forward it appears that continued monitoring in a consistent manner to provide comparable data over time is important to ensure that documentation of changes in baseline levels of key nutrient related metrics are captured, relative to management actions and meeting the USEPA/MassDEP TMDL. In addition, in West Falmouth Harbor, both lower loading from the WWTF resulting in declines in basin TN and gradual increases in watershed nitrogen inputs resulting in increases in TN in receiving waters needs to continue to be documented, as this estuary is on its way toward restoration of its nitrogen impaired habitats.

It appears that once again the role of the Falmouth PondWatch Program is changing to be part of adaptive management and compliance monitoring for these estuaries relative to their restoration. It appears that the baseline is sufficiently robust to be able to document the coming improvements in estuarine health that the Town of Falmouth and its citizen stewards have worked these many years to achieve.

ATTACHMENT 1

**Compiled/Tabulated PondWatch Sampling Data for each Water Quality Parameter:
Total Nitrogen, Salinity, Chlorophyll-*a* Data Collected Post-MEP**

**A. Bournes Pond (B)
(2004 – 2014, 2016)
Total Data Set Provided in Digital Format**

**B. Great Pond (Grt)
(2004 – 2014, 2016)
Total Data Set Provided in Digital Format**

**C. Green Pond (Grn)
(2004 – 2014, 2016)
Total Data Set Provided in Digital Format**

**D. Little Pond (LP)
(2005 – 2012, 2016)
Total Data Set Provided in Digital Format**

**E. Oyster Pond (OP)
(2004 – 2014, 2016)
Total Data Set Provided in Digital Format**

**F. West Falmouth Harbor (PWF)
(2004 – 2012, 2016)
Total Data Set Provided in Digital Format**

Table A. Annual station averages for Bournes Pond SMAST-PondWatch sampling 2004-2017. Key metrics are presented as TN (total nitrogen), salinity and chlorophyll-*a* as an indicator of phytoplankton biomass. TN and chlorophyll-*a* levels indicate ecologically significant unabated nitrogen enrichment and is consistent with impaired nitrogen related habitat quality in the upper and mid Bournes Pond basins. Sentinel station is in yellow highlight. Full database provide electronically.

TN	Bournes Pond														2004 - 2017		
mg/L	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	mean	s.d.	N
B1	0.865	0.906	0.918	1.013	1.009	1.294	0.994	0.907	1.244	1.259	1.297	1.326	1.103	1.321	1.085	0.254	54
B2	0.807	0.804	0.798	0.816	1.064	0.906	0.896	0.890	0.987	1.050	1.171	1.302	0.840	0.972	0.952	0.291	109
B3	**0.750**	**0.658**	**0.728**	**0.616**	**0.809**	**0.769**	**0.794**	**0.739**	**0.810**	**0.772**	**0.862**	**0.830**	**0.695**	**0.756**	**0.756**	**0.179**	**104**
B4	0.428	0.501	0.552	0.425	0.449	0.578	0.501	0.558	0.621	0.519	0.546	0.532	0.531	0.461	0.513	0.117	110
B5	0.629	0.748	0.766	0.650	0.680	0.627	0.807	0.690	0.725	0.644	0.718	0.577	0.571	0.529	0.670	0.144	110
B6	0.365	0.417	0.449	0.359	0.330	0.457	0.451	0.430	0.473	0.442	0.391	0.469	0.471	0.417	0.423	0.077	109
Salinity	**Bournes Pond**														**2004 - 2017**		
PSU	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**mean**	**s.d.**	**N**
B1	24.0	21.6	26.1	26.4	27.2	16.7	24.6	27.9	23.1	21.8	24.6	20.0	16.1	20.8	22.8	7.4	55
B2	27.8	25.7	27.2	27.6	27.1	26.2	27.7	26.4	27.3	23.4	26.6	27.2	27.8	24.6	26.6	4.2	110
B3	**27.5**	**27.7**	**27.9**	**28.1**	**26.5**	**28.2**	**28.7**	**27.6**	**28.7**	**27.3**	**27.8**	**28.3**	**29.0**	**27.5**	**27.9**	**1.9**	**108**
B4	31.4	28.6	29.2	30.1	28.1	29.1	30.1	29.3	30.4	29.4	30.3	30.9	30.1	30.1	29.8	1.3	109
B5	30.7	28.6	28.6	29.6	30.7	28.6	29.5	29.3	30.6	30.1	30.3	31.4	30.8	29.7	29.9	1.1	112
B6	30.6	29.3	29.3	30.3	29.1	28.8	30.5	29.9	30.4	29.3	30.8	31.1	30.7	30.6	30.0	1.2	110
T-pig	**Bournes Pond**														**2004 - 2017**		
ug/L	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**mean**	**s.d.**	**N**
B1	23.5	24.5	26.6	29.2	22.4	22.0	23.3	19.0	22.1	14.5	7.0	27.2	20.1	29.7	22.3	11.6	55
B2	18.8	21.0	19.8	18.4	41.7	20.3	14.4	11.7	13.6	10.4	9.5	19.7	18.9	14.9	18.2	14.0	109
B3	**16.2**	**11.9**	**23.3**	**9.7**	**18.5**	**20.6**	**11.3**	**8.8**	**10.5**	**7.9**	**3.3**	**13.3**	**12.4**	**17.8**	**13.3**	**10.9**	**107**
B4	7.2	11.1	14.8	5.0	6.8	10.6	6.9	8.0	8.4	6.0	2.5	6.8	11.9	6.1	8.0	5.0	111
B5	14.6	22.4	23.6	15.6	11.4	11.4	20.1	11.3	11.1	9.8	9.1	9.1	12.3	11.5	13.8	10.6	112
B6	5.7	10.2	8.3	4.4	3.8	11.5	4.8	5.2	7.7	5.3	2.1	5.1	6.4	5.3	6.1	4.4	110

Table B. Annual station averages for Great Pond SMAST-PondWatch sampling 2004-2017. Key metrics are presented as TN (total nitrogen), salinity and chlorophyll-*a* as an indicator of phytoplankton biomass. TN and chlorophyll-*a* levels indicate ecologically significant unabated nitrogen enrichment and is consistent with impaired nitrogen related habitat quality in Great Pond basins. Sentinel station is in yellow highlight. Full database provide electronically.

Total N (mg/L)		Falmouth PondWatch Program: Great Pond													2004 - 2017		
Station	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
Grt1	0.949	1.016	0.969	0.903	0.978	1.181	1.541	1.013	1.240	1.285	1.143	1.204	1.558	1.239	1.157	0.262	54
Grt2	1.130	1.055	1.049	0.938	1.146	0.999	1.102	1.130	1.302	1.146	0.855	1.263	0.992	1.153	1.088	0.244	110
Grt3	0.903	0.844	0.871	0.754	0.892	0.947	0.951	0.831	1.105	0.872	0.759	0.957	0.776	0.881	0.882	0.228	110
Grt4	0.959	0.999	1.085	0.898	1.163	1.016	1.141	1.071	1.141	1.197	0.903	0.974	0.975	0.979	1.027	0.265	109
Grt5	0.878	0.768	0.844	0.615	0.977	0.747	0.720	0.800	0.792	0.853	0.694	0.740	0.734	0.771	0.779	0.181	109
Grt6	0.557	0.577	0.598	0.611	0.664	0.576	0.612	0.638	0.889	0.626	0.464	0.687	0.625	0.612	0.624	0.159	109

Salinity (ppt)		Falmouth PondWatch Program: Great Pond													2004 - 2017		
Station	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
Grt1	0.5	0.2	0.1	0.8	30.9	7.7	6.5	0.4	7.0	1.1	8.7	2.0	1.0	2.2	5.329	10.153	54
Grt2	24.0	19.4	16.8	20.3	14.3	20.2	18.7	17.3	19.6	19.3	19.9	18.9	20.4	17.9	18.985	10.072	110
Grt3	26.8	25.4	21.2	24.0	15.5	23.6	21.2	23.1	24.0	25.5	25.3	24.4	26.2	24.6	23.589	7.826	110
Grt4	26.0	24.2	22.2	24.3	25.4	22.8	24.1	21.1	24.3	22.7	24.5	25.6	26.3	24.0	24.123	3.763	109
Grt5	25.9	26.9	23.7	28.4	19.4	25.8	25.8	24.6	28.2	25.9	27.5	27.9	28.8	27.1	26.116	4.691	109
Grt6	28.2	27.6	25.5	28.2	24.8	28.3	28.9	27.6	28.0	28.1	28.0	28.9	29.0	28.7	27.833	3.189	109

Total Pigments (ug/L)		Falmouth PondWatch Program: Great Pond													2004 - 2017		
Station	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
Grt1	12.1	7.5	6.6	5.1	8.3	7.4	21.7	7.2	9.6	4.1	4.5	8.3	10.7	13.2	9.029	9.741	54
Grt2	31.1	29.6	19.7	17.3	29.5	23.6	24.9	32.1	21.8	13.8	5.7	18.0	20.7	18.9	21.857	14.257	110
Grt3	13.0	28.9	23.5	12.8	32.5	20.9	16.4	20.2	17.1	13.0	6.7	17.1	18.3	18.6	18.502	10.900	110
Grt4	21.2	30.1	25.0	15.0	43.5	25.9	23.7	25.2	24.3	14.8	9.9	18.4	24.9	20.1	22.964	11.706	109
Grt5	24.8	21.0	22.7	12.5	34.3	20.1	16.4	22.1	13.3	7.9	7.0	10.2	13.5	16.6	17.315	14.892	109
Grt6	7.6	11.2	10.7	5.7	15.8	14.0	9.8	12.2	11.4	6.5	3.9	7.3	9.2	11.7	9.784	5.124	109

Table C. Annual station averages for Green Pond SMAST-PondWatch sampling 2004-2017. Key metrics are presented as TN (total nitrogen), salinity and chlorophyll-*a* as an indicator of phytoplankton biomass. TN and chlorophyll-*a* levels indicate ecologically significant unabated nitrogen enrichment and is consistent with impaired nitrogen related habitat quality in the upper and mid Green Pond basins. Sentinel station is in yellow highlight. Full database provide electronically.

Total N (mg/L)				Falmouth PondWatch Program: Green Pond											2004 - 2017		
Station	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
GP1	1.759	1.267	1.213	1.613	1.505	1.554	1.233	1.191	1.121	0.990	1.210	1.339	1.388	1.330	1.321	0.348	55
GP2	1.081	1.210	1.342	1.179	1.268	1.282	1.122	1.102	1.243	1.245	0.828	1.049	1.027	1.208	1.110	0.248	105
GP2A	0.915	0.996	1.004	0.880	0.989	1.055	1.158	0.974	1.074	1.014	0.795	1.087	1.103	0.921	0.985	0.209	108
GP3	0.782	0.776	0.749	0.828	0.812	0.764	0.918	0.908	0.947	0.920	0.768	0.893	0.712	0.825	0.828	0.186	108
GP4	0.586	0.579	0.637	0.677	0.607	0.637	0.761	0.624	0.722	0.688	0.617	0.638	0.688	0.627	0.634	0.139	109
GP5	0.465	0.488	0.446	0.421	0.394	0.542	0.555	0.493	0.583	0.494	0.361	0.528	0.561	0.480	0.476	0.103	128

Salinity (ppt)				Falmouth PondWatch Program: Green Pond											2004 - 2017		
Station	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
GP1	17.9	0.5	0.6	11.2	28.3	0.8	2.6	1.2	5.9	1.6	19.2	15.1	16.0	14.0	9.6	10.8	55
GP2	26.9	22.3	24.7	24.5	26.2	23.2	25.2	18.9	25.3	22.6	23.7	23.8	25.1	24.1	24.1	6.3	111
GP2A	27.2	22.2	22.3	26.5	24.5	23.9	26.3	20.4	24.9	23.6	25.6	25.2	26.1	25.8	24.7	5.5	107
GP3	27.0	25.8	23.7	26.6	26.3	26.8	24.8	22.2	26.4	24.6	25.9	27.2	26.9	26.2	25.8	4.1	110
GP4	28.5	27.5	24.0	27.5	26.6	27.8	27.3	27.1	28.5	26.4	28.4	28.0	28.2	28.5	27.4	3.7	112
GP5	30.1	28.8	29.1	29.5	28.8	29.0	29.8	29.1	29.7	29.2	29.9	30.5	30.0	29.6	29.5	1.5	134

Total Pigments (ug/L)				Falmouth PondWatch Program: Green Pond											2004 - 2017		
Station	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
GP1	46.8	29.9	19.5	29.1	19.1	8.5	17.1	8.9	23.8	14.2	8.5	19.8	26.7	38.4	22.4	21.4	55
GP2	32.3	39.2	17.7	28.6	36.1	36.9	38.7	21.9	22.6	17.2	6.1	19.5	23.7	21.2	25.9	15.6	111
GP2A	28.8	33.0	20.5	29.6	26.3	33.7	39.6	21.9	24.0	15.6	7.3	25.3	31.3	18.2	25.3	14.3	108
GP3	24.4	23.8	14.5	30.6	20.4	21.4	26.5	21.1	20.8	16.2	7.1	15.9	20.6	14.6	19.8	10.8	110
GP4	14.9	16.7	12.1	19.0	14.6	19.4	18.0	9.7	12.2	10.8	4.2	8.9	14.1	12.5	13.3	6.9	112
GP5	9.8	10.1	9.2	7.3	6.9	14.6	9.3	6.7	9.8	5.7	2.8	6.5	11.4	8.0	8.5	4.4	134

Table D. Annual station averages for Little Pond SMAST-PondWatch sampling 2005-2017. Key metrics are presented as TN (total nitrogen), salinity and chlorophyll-*a* as an indicator of phytoplankton biomass. TN and chlorophyll-*a* levels indicate ecologically significant unabated nitrogen enrichment and is consistent with impaired nitrogen related habitat quality in Little Pond basins. Sentinel station is in yellow highlight. Full database provide electronically.

TN (mg/L)			Falmouth PondWatch Program: Little Pond											2005 - 2017)		
Station	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean	s.d.	N
Head	1.534	1.725	1.791	2.016	2.217	1.717	2.200	1.525	1.983	1.611	1.590	1.688	1.346	1.758	0.650	47
LP-1	0.962	1.003	0.951	1.252	1.735	1.351	1.440	1.200	2.035	1.372	1.484	1.355	1.043	1.351	0.641	95
LP-2	0.900	0.768	0.916	0.951	1.126	0.974	1.062	0.894	2.085	1.049	1.251	0.890	0.752	1.030	0.447	96
LP-3	0.683	0.749	0.731	0.843	0.955	1.003	1.025	0.792	1.471	1.211	1.008	0.799	0.599	0.889	0.345	95
Salinity (PSU)			Falmouth PondWatch Program: Little Pond											2005 - 2017)		
Station	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean	s.d.	N
Head	21.0	25.1	24.1	25.7	6.3	20.5	16.7	20.9	18.2	24.8	22.8	22.9	26.5	20.6	9.1	49
LP-1	27.1	27.7	27.8	28.5	19.0	23.8	22.7	25.9	26.1	25.6	23.1	25.8	27.0	25.1	6.5	98
LP-2	27.3	28.1	27.7	25.2	24.5	26.9	25.7	27.3	27.0	26.3	28.1	29.5	28.5	27.0	3.6	97
LP-3	27.5	27.7	29.4	26.9	26.5	27.4	26.3	28.9	26.8	26.0	28.7	29.5	27.9	27.8	2.8	95
T-pigment (ug/L)			Falmouth PondWatch Program: Little Pond											2005 - 2017)		
Station	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean	s.d.	N
Head	35.8	38.9	44.3	42.3	23.9	18.9	11.9	25.6	8.4	2.6	17.4	17.2	20.2	24.6	21.0	48
LP-1	23.5	16.3	29.6	34.3	14.0	27.6	13.9	24.1	15.4	3.0	16.6	22.4	17.1	20.7	16.7	98
LP-2	22.3	14.1	17.2	20.9	19.3	13.4	14.7	22.1	24.1	2.3	7.2	19.8	12.4	16.5	13.8	97
LP-3	10.1	10.4	9.9	15.2	27.1	48.3	9.1	19.1	9.2	2.3	5.6	14.0	9.1	15.4	28.0	94

Table E. Annual station averages for Oyster Pond SMAST-PondWatch sampling 2004-2017. Key metrics are presented as TN (total nitrogen), salinity and chlorophyll-*a* as an indicator of phytoplankton biomass. TN and chlorophyll-*a* levels indicate ecologically significant unabated nitrogen enrichment and is consistent with impaired nitrogen related habitat quality, particularly benthic infauna. Full database provideD electronically.

Total N (mg/L)		Falmouth PondWatch Program: Oyster Pond														2004 - 2017		
Station	**Depth (m)**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
OP-1	**0**	0.745	0.530	0.683	0.705	0.667	0.646	0.725	0.622	0.767	0.648	0.767	0.695	0.878	0.679	0.699	0.138	51
OP-1	**2**	0.721	0.685	0.833	1.194	0.817	0.723	0.730	0.602	0.849	0.647	0.773	0.742	0.780	0.668	0.772	0.196	47
OP-1	**4**	1.674	1.509	3.649	2.638	2.550	4.109	3.256	2.867	2.737	2.624	1.924	1.451	1.149	3.315	2.494	1.215	51
OP-2	**0**	0.617	0.498	0.659	0.758	0.692	0.832	0.738	na	0.791	0.640	0.677	0.711	0.906	0.640	0.704	0.156	47
OP-2	**2**	0.548	0.589	0.597	0.570	0.635	0.628	0.703	0.687	0.790	0.692	0.614	0.686	0.829	0.603	0.655	0.141	48
OP-2	**3.25**	0.567	0.620	0.588	0.583	0.843	0.731	0.762	0.575	0.746	0.827	0.622	0.692	0.858	0.684	0.696	0.172	48
OP-3	**0**	0.733	0.642	0.716	0.736	0.789	0.734	0.818	0.609	0.763	0.620	0.757	0.777	0.860	0.607	0.733	0.146	49
OP-3	**2**	0.648	0.548	0.622	0.568	0.671	0.605	0.675	0.602	0.697	0.579	0.701	0.649	0.789	0.604	0.641	0.133	48
OP-3	**4**	0.587	0.676	0.692	0.673	0.714	0.660	0.776	0.696	0.846	0.622	0.632	0.711	0.905	0.666	0.696	0.130	46
OP-3	**6**	15.257	8.401	10.503	10.880	5.198	5.495	6.748	2.487	6.666	14.237	1.022	3.833	2.991	7.702	7.423	4.651	46
mixed layer		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
OP-1	**0-2**	0.735	0.607	0.758	0.915	0.732	0.677	0.728	0.612	0.808	0.647	0.771	0.719	0.829	0.674	0.734	0.171	98
OP-2	**0-3.25**	0.578	0.575	0.615	0.637	0.726	0.730	0.735	0.631	0.776	0.710	0.641	0.696	0.864	0.642	0.685	0.157	143
OP-3	**0-4**	0.649	0.622	0.677	0.659	0.725	0.666	0.767	0.636	0.753	0.607	0.697	0.712	0.848	0.626	0.690	0.141	143

Total Pigments (ug/L)		Falmouth PondWatch Program: Oyster Pond														2004 - 2017		
Station	**Depth (m)**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
OP-1	**0**	6.4	11.2	7.3	5.6	3.9	5.7	7.2	8.0	8.2	7.6	3.3	5.5	10.6	9.6	7.2	5.5	52.0
OP-1	**2**	5.8	4.5	8.3	6.5	5.4	5.4	13.0	46.1	15.8	12.7	4.6	9.2	12.0	9.6	9.6	8.2	52.0
OP-1	**4**	130.0	57.0	125.8	82.6	159.4	256.1	44.2	181.8	53.1	53.2	27.0	97.5	57.5	172.2	105.2	87.5	51.0
OP-2	**0**	4.6	3.6	7.8	6.2	6.2	6.7	9.2	na	7.4	6.9	4.5	24.5	12.2	7.1	8.4	10.4	51.0
OP-2	**2**	5.2	4.0	7.9	7.0	7.7	5.9	13.2	12.6	10.9	8.4	4.4	7.6	11.4	6.5	7.9	5.2	51.0
OP-2	**3.25**	14.3	7.7	8.1	8.6	12.6	7.4	19.2	10.9	12.0	14.9	4.4	5.9	12.6	8.4	10.5	6.8	51.0
OP-3	**0**	4.8	2.8	6.4	4.8	5.2	2.8	7.9	11.2	8.7	6.3	4.1	5.6	9.8	6.3	6.1	4.1	52.0
OP-3	**2**	8.5	3.3	6.7	4.3	4.9	6.3	8.2	12.2	10.0	8.0	4.0	5.7	10.3	6.5	6.8	4.4	51.0
OP-3	**4**	14.8	16.1	9.2	9.3	25.2	7.9	12.8	20.2	106.2	10.1	4.8	8.8	16.1	11.1	20.0	31.8	50.0
OP-3	**6**	134.2	158.0	47.4	82.4	37.2	25.7	102.4	91.8	46.5	49.4	13.0	82.6	44.2	72.9	69.9	53.6	48.0
mixed layer		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
OP-1	**0-4**	6.1	7.8	7.8	6.0	4.7	5.6	10.1	27.0	12.0	10.1	4.1	37.4	19.6	63.8	40.2	67.8	0.8
OP-2	**0-3.25**	8.0	5.1	7.9	7.3	8.8	6.7	13.9	11.8	10.1	9.6	4.4	12.6	12.0	7.3	8.9	7.8	0.7
OP-3	**0-4**	9.4	7.4	7.4	6.1	11.8	5.7	9.6	14.5	41.6	8.2	4.3	6.7	11.5	8.0	10.9	19.5	1.6

Salinity (ppt)		Falmouth PondWatch Program: Oyster Pond														2004 - 2017		
Station	**Depth (m)**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
OP-1	**0**	2.1	2.1	1.9	1.9	1.5	1.1	1.5	1.5	2.6	3.7	2.5	1.6	1.0	1.5	1.9	0.7	52
OP-1	**2**	2.4	2.1	1.9	1.9	2.3	1.1	1.5	1.5	2.3	3.8	2.5	1.7	1.0	1.4	2.0	1.0	51
OP-1	**4**	2.0	2.1	2.1	1.8	1.5	1.0	1.4	1.4	2.0	3.8	2.4	1.5	0.9	1.3	1.8	0.7	52
OP-2	**0**	2.2	2.2	2.0	2.0	1.5	1.2	1.5	na	2.3	3.8	2.5	1.6	1.0	1.5	1.9	0.7	51
OP-2	**2**	2.2	2.3	2.0	2.1	1.4	1.2	1.5	1.6	2.4	3.8	2.5	1.6	1.0	1.5	1.9	0.7	51
OP-2	**3.25**	2.2	2.4	2.0	2.0	1.5	1.2	1.5	1.6	2.4	3.7	2.5	1.6	1.0	1.5	2.0	0.7	51
OP-3	**0**	2.2	2.3	2.0	2.0	1.5	1.1	1.5	1.6	2.3	3.8	2.5	1.6	1.0	1.5	1.9	0.7	52
OP-3	**2**	2.2	2.3	2.0	4.7	1.5	1.2	1.5	1.6	2.3	3.8	2.5	1.6	1.0	1.5	2.2	1.7	51
OP-3	**4**	2.3	7.5	2.0	2.0	1.2	1.2	1.5	1.6	5.7	3.8	2.5	1.6	1.0	1.7	2.7	2.0	50
OP-3	**6**	13.4	12.0	7.8	10.7	1.5	4.5	7.0	3.8	10.0	13.3	5.0	2.4	1.1	9.5	7.6	5.1	51
mixed layer		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
OP-1	**0-2**	2.2	2.1	1.9	1.9	1.9	1.1	1.5	1.5	2.4	3.7	2.5	1.6	1.0	1.5	1.9	0.9	103
OP-2	**0-3.25**	2.2	2.3	2.0	2.0	1.5	1.2	1.5	1.6	2.4	3.8	2.5	1.6	1.0	1.5	2.0	0.7	153
OP-3	**0-4**	2.2	4.0	2.0	2.9	1.4	1.2	1.5	1.6	3.5	3.8	2.5	1.6	1.0	1.6	2.2	1.6	153

Table F. Annual station averages for West Falmouth Harbor SMAST-PondWatch sampling 2004-2017. Key metrics are presented as TN (total nitrogen), salinity and chlorophyll-*a* as an indicator of phytoplankton biomass. TN and chlorophyll-*a* levels indicate ecologically significant unabated nitrogen enrichment particularly in the inner reaches and is consistent with impaired nitrogen related habitat quality, particularly eelgrass in the inner basins. Sentinel station is in yellow highlight. Full database provide electronically.

TN (mg/L)			Falmouth PondWatch Program: West Falmouth Harbor												2004 - 2017		
Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	mean	s.d.	N
PWF1	1.078	0.686	0.872	0.959	0.977	0.486	1.277	1.162	0.899	0.782	0.966	1.006	0.893	0.904	0.892	0.318	97
PWF2	0.501	0.394	0.506	0.505	0.430	0.562	0.603	0.613	0.653	0.640	0.582	0.635	0.480	0.534	0.542	0.138	109
PWF3	0.437	0.286	0.466	0.465	0.348	0.446	0.581	0.499	0.548	0.457	0.357	0.542	0.461	0.422	0.447	0.123	116
PWF4	0.443	0.315	0.441	0.446	0.408	0.434	0.526	0.467	0.528	0.456	0.509	0.488	0.515	0.469	0.455	0.113	120
PWF5	0.599	0.410	0.551	0.653	0.556	0.578	0.538	0.492	0.455	0.543	0.511	0.555	0.598	0.522	0.553	0.153	136
PWF6	0.336	0.205	0.329	0.396	0.395	0.394	0.395	0.372	0.406	0.418	0.454	0.487	0.377	0.381	0.383	0.096	121
PWF7	0.324	0.238	0.345	0.391	0.411	0.371	0.342	0.344	0.451	0.446	0.394	0.421	0.368	0.358	0.367	0.090	119
PWF8	0.493	0.514	0.497	0.537	0.521	0.522	0.618	0.610	0.684	0.649	0.579	0.672	0.568	0.603	0.572	0.138	282

Salinity (PSU)			Falmouth PondWatch Program: West Falmouth Harbor												2004 - 2017		
Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	mean	s.d.	N
PWF1	22.3	25.4	26.2	26.7	24.1	29.2	22.8	18.3	22.3	24.7	22.7	22.2	15.6	22.1	23.1	6.0	102
PWF2	29.3	28.6	29.1	28.8	20.3	25.6	29.1	28.5	28.4	29.8	28.6	30.3	30.6	29.3	28.4	3.4	116
PWF3	30.4	29.7	29.3	29.2	30.0	29.6	29.9	29.1	30.0	30.2	29.8	30.9	30.9	30.1	30.0	1.0	117
PWF4	29.8	29.2	28.6	28.3	30.7	29.0	29.1	28.4	30.2	30.0	29.6	30.2	28.4	28.8	29.3	1.5	124
PWF5	27.7	28.3	27.4	24.4	29.3	27.0	28.4	27.3	29.7	28.7	27.6	27.7	27.2	27.3	27.7	2.7	144
PWF6	30.8	28.7	30.4	29.7	29.7	29.7	30.4	28.9	30.4	30.1	30.1	31.1	31.2	30.1	30.2	1.3	122
PWF7	31.2	30.5	30.6	29.9	30.9	30.3	29.2	29.4	30.8	30.1	30.2	31.1	31.4	30.2	30.4	1.1	121
PWF8	27.1	25.9	26.0	26.1	28.4	26.5	26.5	26.4	27.4	26.7	26.6	28.6	28.2	27.9	27.0	2.1	284

Total Pigment (ug/L)			Falmouth PondWatch Program: West Falmouth Harbor												2004 - 2017		
Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	mean	s.d.	N
PWF1	28.8	20.0	21.0	24.2	59.3	5.6	46.0	16.6	18.3	10.9	8.2	20.5	19.5	24.8	25.0	26.5	101
PWF2	5.8	6.5	14.2	7.4	11.5	16.8	15.0	14.7	16.7	8.1	5.3	13.3	8.4	14.0	11.3	8.0	115
PWF3	4.8	3.8	7.3	4.8	4.0	4.2	5.3	4.1	10.7	3.6	2.2	9.1	6.2	9.3	5.8	3.8	117
PWF4	5.7	5.0	6.8	5.8	7.4	6.9	6.9	4.6	10.5	5.6	2.7	7.3	8.8	9.2	6.6	3.8	124
PWF5	7.5	8.3	10.5	7.0	14.0	8.1	17.2	10.2	11.1	5.6	3.2	17.2	7.3	11.4	10.4	7.5	141
PWF6	4.5	3.6	3.9	5.2	4.8	4.1	4.4	4.7	8.2	4.2	2.3	8.0	4.8	7.0	5.0	2.7	122
PWF7	4.1	5.1	4.8	5.8	4.4	3.8	3.0	4.3	6.2	3.8	1.9	6.2	3.6	6.3	4.5	2.6	122
PWF8	7.4	7.6	10.4	10.1	9.6	10.3	13.7	12.2	14.4	7.6	5.2	16.9	10.0	13.0	10.4	6.2	284

ATTACHMENT 2

PondWatch Station Location (coordinates)

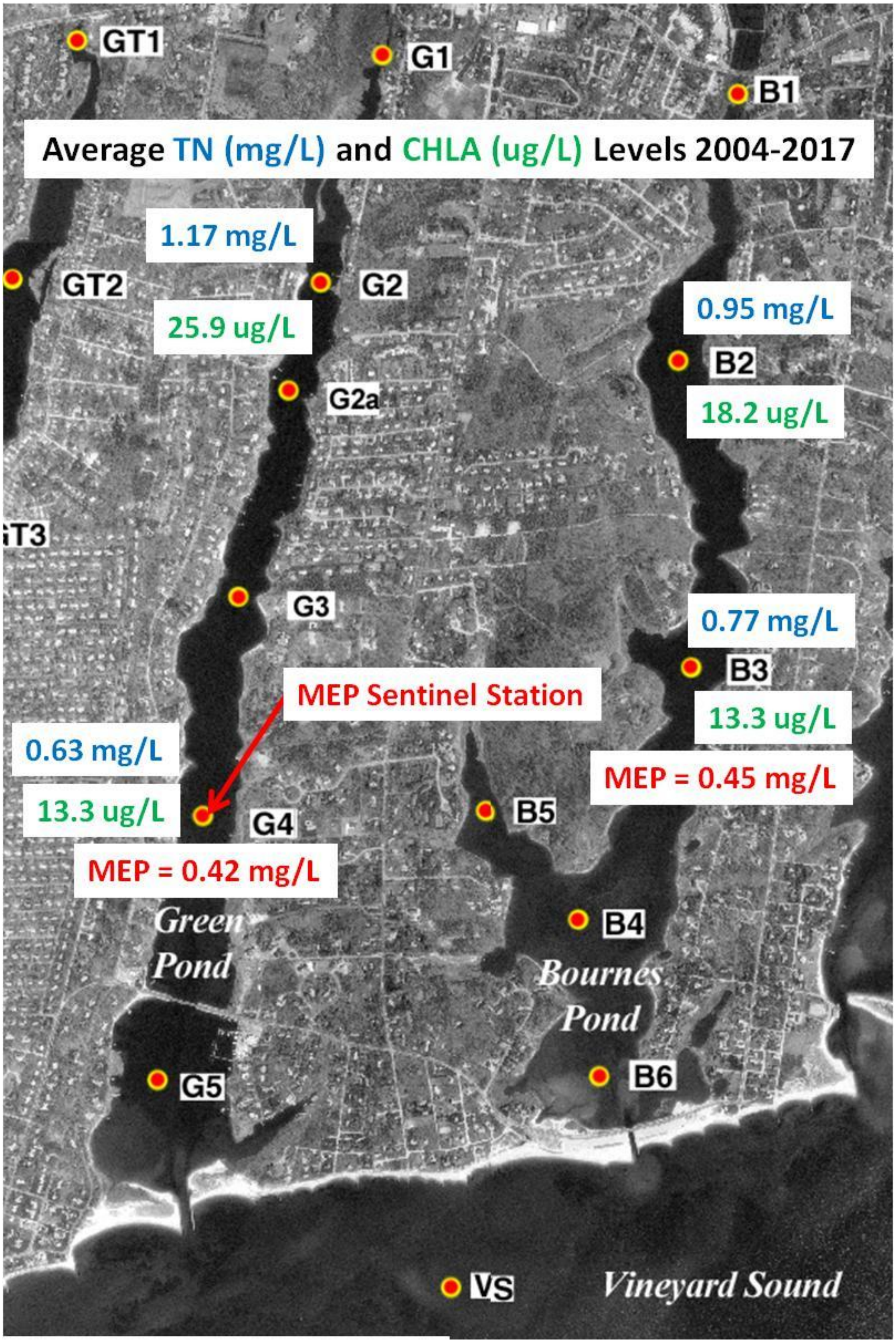
Estuary	Station	Lat		Lon	
Bournes Pond	BP1	41	34.5473	70	33.1064
	BP2	41	34.3255	70	33.1394
	BP3	41	33.7118	70	33.2026
	BP4	41	33.3261	70	33.4195
	BP5	41	33.443	70	33.6227
Great Pond	GTP1	41	34.6531	70	34.4303
	GTP2	41	34.2902	70	34.5759
	GTP3	41	33.8942	70	34.7187
	GTP4	41	33.9875	70	35.0868
	GTP5	41	33.6433	70	34.9631
	GTP6	41	33.0918	70	34.9358
Green Pond	GP1	41	34.5929	70	33.8342
	GP2	41	34.3068	70	33.9414
	GP2A	41	34.9389	70	34.0018
	GP3	41	33.8092	70	34.1282
	GP4	41	33.3842	70	34.2079
	GP5	41	33.0545	70	34.2546
Little Pond	LPHEAD	41	33.4576	70	35.4993
	LP1	41	33.4078	70	35.4925
	LP2	41	33.1797	70	35.4101
	LP3	41	32.9071	70	35.3579
Oyster Pond	OPHEAD	41	32.7424	70	38.5021
	OP1	41	32.7341	70	38.414
	OP2	41	32.5029	70	38.3191
	OP3	41	32.3629	70	38.2476
West Falmouth Harbor	WFH1	41	36.528	70	38.2314
	WFH2	41	35.8842	70	38.5383
	WFH3	41	35.9785	70	38.6815
	WFH4	41	36.2533	70	38.4792
	WFH5	41	36.4078	70	38.4076
	WFH6	41	36.4029	70	38.6285
	WFH7	41	36.3766	70	38.9981
	WFH8	41	35.7079	70	38.2383
Vineyard Sound	VS1	41	32.6798	70	34.2327

ATTACHMENT 3

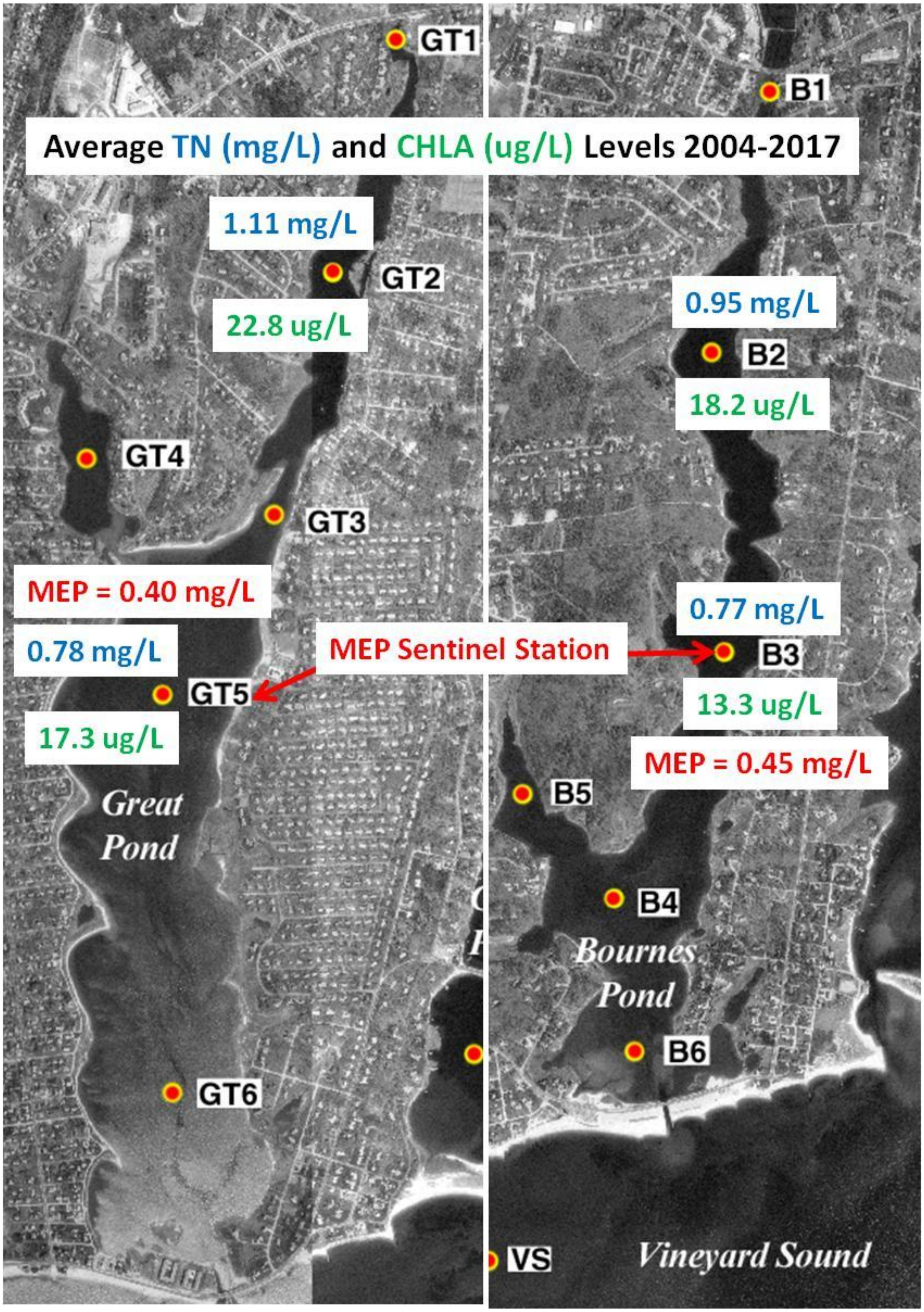
Comparison of Total Nitrogen (TN), Chlorophyll-a (CHLA) and MEP Threshold at Sentinel Station and Upper Station

A). Bournes Pond vs. Green Pond

B). Bournes Pond vs. Great Pond



A). Green Pond (left panel) vs. Bournes Pond (right panel) TN and CHLA levels.



B). Great Pond (left panel) vs. Bournes Pond (right panel) TN and CHLA levels.

Appendix – Chapter 7.2

Diagnostic Assessment of Nutrient Cycling in Mill Pond

Report dated 9/28/18

Town of Falmouth - Partnership with Coastal Systems Program

School for Marine Science and Technology

University of Massachusetts Dartmouth

Diagnostic Assessment of Nutrient Cycling in Mill Pond

Submitted by:

UMD-SMAST Coastal Systems Program:

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Submitted to:

Town of Falmouth

September 28, 2018 (revised FINAL)

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Acknowledgements

The authors acknowledge the contributions of the Massachusetts Estuaries Project for data that allowed for a long-term comparison of flow and nutrient conditions in Mill Pond. Without this comparison, understanding the watershed inputs and nutrient dynamics of Mill Pond would have been less certain. Instead, this data could bring certainty to our calculations of water flow and nutrient dynamics in Mill Pond to provide the appropriate recommendations for restoration.

The authors would like to thank Mr. Brian Handy, owner of the Backus Brook cranberry bogs, for providing insights into bog operations and assisting with developing potential management alternatives related to bog operations.

The authors also acknowledge the work of Mathew Charette of Woods Hole Oceanographic Institute and high school student Owen Filault for the sediment core collection and burial analysis for the determination of nitrogen and phosphorus burial in Mill Pond. Their efforts and generosity made it possible to quantify all major sinks of nitrogen and phosphorus removal in Mill Pond.

In addition, the authors are grateful for the technical support provided by Sara Sampieri, Jennifer Benson, Micheline Labrie, and Paul Mancuso, as well as interns of the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth.

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I. INTRODUCTION

Scientific staff from the Coastal Systems Program (CSP) at the University of Massachusetts-Dartmouth (UMD), School for Marine Science and Technology (SMAST) has been actively collecting data for the nutrient assessment of Mill Pond and the related assessment of the ecological health of the Mill Pond system. This report focuses on the results of the Diagnostic Assessment of Nutrient Cycling in Mill Pond conducted from August 2015 through March 2018 and the data collected during this assessment is also a component of a Master's Thesis (A. Unruh, 2018). Scientists from the CSP-SMAST completed a comprehensive assessment of Green Pond under the Massachusetts Estuaries Project (MEP), which revealed that nutrient loading from its watershed has been adversely affecting the estuarine receiving waters of Green Pond within the Town of Falmouth. Further, the MEP found that some of the nitrogen load from the watershed above Rt. 28, which discharges initially to Backus Brook and Mill Pond before reaching Green Pond is removed during transport through the freshwater systems. However, the MEP evaluation did not assess the specific effect of nutrients on Mill Pond or determine the health of this basin. Mill Pond is a constructed freshwater pond, discharging to the head of the Green Pond Estuary, through a culvert under Rt. 28. Mill Pond receives freshwater through direct groundwater discharges and surface water discharge from an active cranberry bog. While the Town has been working on the restoration of the Green Pond estuarine system, more recently concerns have been raised about the declining ecological health of Mill Pond. This 16-acre freshwater pond is currently exhibiting signs of severe habitat impairment e.g. over-abundance of aquatic plant growth, periodic oxygen depletion of bottom waters and extremely poor water clarity. These impairments are mainly the result of nutrient over-enrichment from its watershed sources transported by freshwater inflows. As such, it has been the subject of preliminary assessment efforts by SMAST scientists over the past 2 years with partial support from the Town of Falmouth.

II. DATA COLLECTION AND MODELING APPROACH

The goal of the present study is to understand the role nutrients are having in driving the observed habitat impairment of Mill Pond as well as to determine appropriate management actions that can be implemented to affect restoration of this aquatic system. Data was collected to quantify:

- the nitrogen and phosphorus loads to Mill Pond from the various watershed sources as transported by surface water and groundwater,
- in-pond measurement of recycled nitrogen and phosphorus from sediments under aerobic and anaerobic conditions,
- dissolved oxygen conditions in the pond bottom waters and how that drives phosphorus recycling and controls water column phosphorus levels,
- distribution, density and nutrient content of aquatic plants pond-wide and
- water residence time and the major factors controlling it
- major controls on the annual cycle of nitrogen and phosphorus in pond waters.

Assessment of the sources and sinks of nitrogen and phosphorus to the pond allowed for the development of a detailed nutrient budgets for the Mill Pond system. Understanding the nutrient balance of the pond is the basis for formulating a list of likely management strategies and a comparison of their cost and practicality for restoring the water quality of this system. It is critical that any future management actions implemented in Mill Pond maintain or increase the ponds current nitrogen removal capacity for the benefit of the down-gradient Green Pond Estuary.

Data Collection

Stream flow measurements and water sampling were conducted to determine the nitrogen and phosphorus loads entering and leaving Mill Pond beginning in August 2015. Sampling and flow measurements continued through April 2018 for the Diagnostic Assessment of Nutrient Cycling in Mill Pond based upon the prior works supplemented by additional needed data collection funded in part by the Town of Falmouth (2017). Sampling occurred weekly May through October and at least biweekly November through April. Water levels were determined using a vented stage recorder (10-minute intervals) with periodic direct measures of volumetric flow to construct a stage-discharge relationship (e.g. rating curve) for determining continuous volumetric flow rate ($m^3\ hr^{-1}$) for the inflow and outflow streams. Coupling the volumetric flow rate with the measured nutrient concentrations yields detailed nitrogen and phosphorus loading into and out of Mill Pond.

In-pond assessments of nutrient cycling from the sediments and associated production of di-nitrogen gas (Denitrification) were conducted in October 2016, May 2017, and June 2017. All sediment nutrient fluxes were assessed under aerobic conditions for nitrogen and phosphorus flux from the sediments and di-nitrogen gas production[1]. Additionally, the May 2017 cores were assessed for nutrient regeneration under anoxic conditions to allow projection of fluxes during the periods of anoxia in Mill Pond during the summer. The duration of Mill Pond anoxia was determined by deploying a YSI 6600 Multi-parameter Water Quality Monitor with optical dissolved oxygen, chlorophyll-a, and temperature sensors recording at 15-minute intervals, 30 cm above the pond bottom. Bi-weekly calibration samples for dissolved oxygen and chlorophyll were collected throughout the deployment period, June 14, 2017 to November 1, 2017.

Nitrogen and phosphorus loads from stormwater flowing into Mill Pond via the 2 identified stormwater outfall pipes were also measured. Stormwater pipes were located at an upper northeast location (off Prince Henry Avenue) and a northwest location (off Pontes Avenue). Stormwater related nutrient loads into these sections of the pond were assessed during two storm events: 1) August 7, 2017 and 2) September 8, 2017.

The bathymetry of Mill Pond was determined by manual depth measurements to the nearest centimeter and using a Garmin 76 handheld GPS unit to determine LAT and LON. A more manual

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[1] Denitrification in sediments is mainly through coupled nitrification-denitrification, where oxygen in overlying waters supports the nitrification step. When the bottom waters are devoid of oxygen (anoxic) nitrification ceases resulting in much lower or no denitrification.

approach was required for the bathymetry survey owing to shallow depths and dense vegetation that made use of acoustic devices problematic. The bathymetric survey of Mill Pond was completed in June 2016. Coordinates and depths were compiled into x-y-z coordinated systems to produce a bathymetric map and for the determination of pond volume to support calculation of pond residence time.

A vegetation survey was conducted by CSP-SMAST scientists in May 2017 to determine the types of plants and coverage in the pond. Aquatic vegetation was collected in October 2017 using 0.25 sq. meter quadrats to determine the biomass and the nitrogen and phosphorus content of the plants. An aquatic vegetation assemblage map was produced by digitizing the locations of the dominant plant communities colonizing Mill Pond.

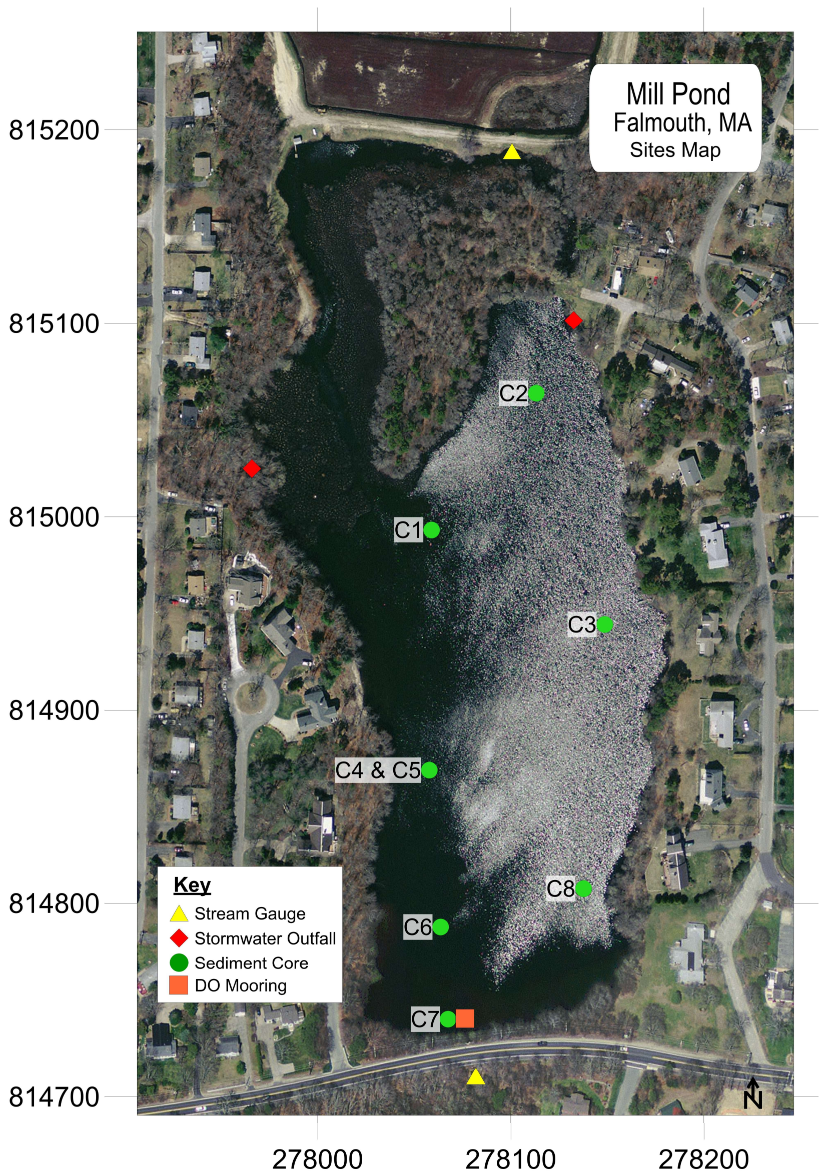

Figure II-1. Location of stream gauges, stormwater discharge pipes, sediment coring sites, and YSI 6600 Water Quality Monitoring (DO) mooring.

Box Model

A box model was constructed to understand the nutrient dynamics in the pond during an annual hydrologic cycle. Water and nutrient inputs and outputs were measured for one annual cycle. Sources of water included stream flow-in, groundwater, precipitation, and storm water discharges. Sinks of water include stream flow-out, evaporation, and cranberry bog irrigation. The model was calibrated by assessing the mass balance of water volume and salt load. Once the model was calibrated, nitrogen and phosphorus loads were input to the model, resulting in a mass of nitrogen and phosphorus into and out of the pond with the difference being that load either attenuated or generated by the pond. Since nitrogen and phosphorus are non-conservative parameters (they are consumed or generated by biological and chemical processes), these nutrients will not appear balanced in the budget. In many studies, the processes responsible for nitrogen attenuation are generally attributed to microbial processes that occur in the sediments. For this study, the parameters related to in-pond nitrogen attenuation by sediments was quantified through measurement of sediment nutrient flux, di-nitrogen production, and sediment burial throughout the year. The nitrogen and phosphorus loads associated with these processes were input to the model to "close" the nitrogen/phosphorus budget. Thus, quantifying the nutrient dynamics of Mill Pond.

III. RESULTS

Mill Pond Water Quality Conditions

Understanding the Mill Pond water quality conditions and critical nutrient for management is vital to choosing an appropriate management solution. State regulation, 314 CMR 04, defines dissolved oxygen and temperature conditions suitable for Class B surface waters. Class B waters are used for fish habitat, other aquatic and wildlife habitat, migration, reproduction, and growth, secondary contact recreation, and crop irrigation. These waters shall maintain a minimum dissolved oxygen concentration of 5.0 mg/L for 16 hours of any 24-hour period and never drop below 3.0 mg/L. Temperature shall remain less than 28.3˚C, never rising more than 1.7˚C due to discharge (e.g. cranberry bog). In Class B waters where, natural background conditions of dissolved oxygen are lower and temperature higher, both parameters shall not exceed the natural background conditions.

Concerned citizens of East Falmouth have noted that during the warm summer months Mill Pond becomes thickly vegetated and the water develops a rotten-egg smell (hydrogen sulfide) that is particularly strong at the outflowing stream, under Rt. 28. These observations are consistent with a highly eutrophic pond (nutrient enriched). As part of the health assessment of Mill Pond dissolved oxygen, total chlorophyll-a pigments, total phosphorus, and secchi depth (water clarity) were used to determine the Carlson Trophic Status of Mill Pond during the growing season (oligotrophic, mesotrophic, eutrophic, or hypertrophic). From June through October, dissolved oxygen conditions were below 5.0 mg/L and the Carlson Trophic Status parameters (secchi, total phosphorus, and chlorophyll-a pigment) indicate that Mill Pond is eutrophic. This is supported by the Cape Cod Ponds[2] standards for highest water quality, which indicates a freshwater pond is impaired when TN, TP, and chlorophyll-a concentrations exceed 310, 10, and 1.7 µg/L, respectively. Due to the poor water quality, a full assessment of Mill Pond is necessary to develop an appropriate management plan to restore this impaired system.

In most freshwater systems, additions of phosphorus will cause phytoplankton blooms or increased macrophyte growth (limiting nutrient). Occasionally, nitrogen can be limiting or co-limiting with phosphorus. A nitrogen-limited system will have blooms or increased macrophyte growth when nitrogen is added to the system. Co-limited systems are limited by both nutrients, which may change seasonally. Identifying the limiting nutrient of the pond is important for developing appropriate management solutions, as phosphorus-limited systems needs phosphorus management and nitrogen-limited need nitrogen management. The nutrient limitation of Mill Pond was determined by determining the effect of additions of inorganic nitrogen, phosphorus, nitrogen + phosphorus and no additions on phytoplankton production. Production was determined from net oxygen production in incubations of pond water. The treatments were incubated in Mill Pond at 0.5-meter depth for 12-hours. Winkler bottles with dissolved oxygen concentrations higher than initial were presumed to have net oxygen production hence photosynthetic activity related to the nutrient addition. The assessment revealed that Winkler bottles with control (no nutrient addition), P addition, N addition, and N+P addition had increased dissolved oxygen concentrations. The N+P addition showed the greatest photosynthesis, with phosphorus next and nitrogen also showing some increase but less than the phosphorus addition. Photosynthesis in the control was from available nutrients in the pond water. The lower oxygen in the dark incubation is mainly the result of respiration of phytoplankton in the pondwater. The higher oxygen production in the N + P addition likely results from the uptake of P and the availability of additional N as the background N pool is depleted. This pattern has been seen in other similar experiments in Oyster Pond and Cockeast Pond and the explanation is consistent with the second highest production being in the P addition, which appears to have become nitrogen limited with such a large addition of P. Ultimately, these results are consistent with phosphorus being the primary nutrient that needs to be controlled, as also found in other ponds throughout Cape Cod.

[2] Eichner, E. M., T. C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, B. Smith, M. Fenn. 2002. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Pp. 22-23.

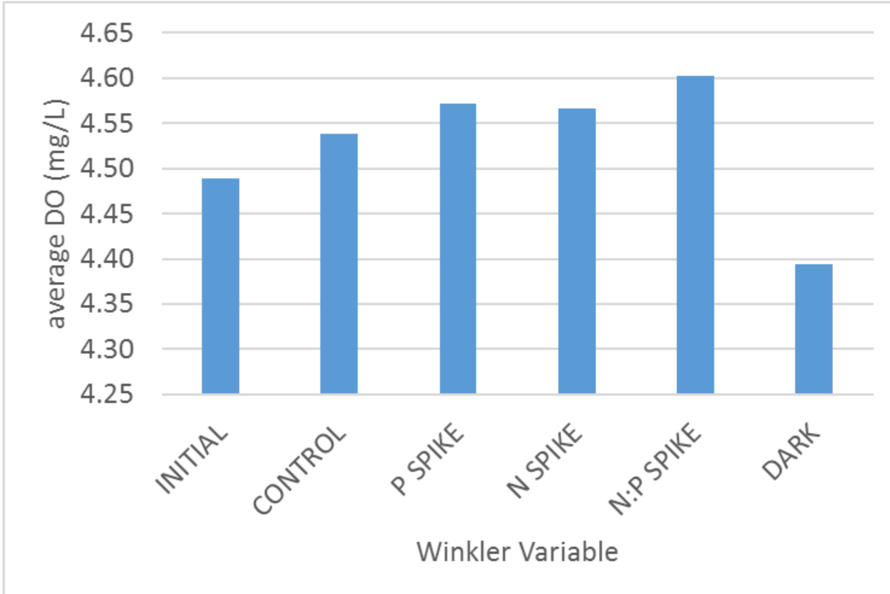

Figure III-1. N versus P limitation experiment. Initial treatment is the dissolved oxygen in the Winklers at the start of the experiment. Control (no additions), P addition, N addition, N+P addition, dark incubation, waters were incubated in Mill Pond for 12 hours at 0.5 meter depth. Dissolved oxygen concentrations over initial conditions indicate oxygen production by photosynthesis.

Mill Pond Watershed Land-use and N and P Loading

The sub-watershed to Mill Pond had a land-use analysis at the time of the MEP assessment of the Green Pond watershed (2001)[3]. The MEP found that the Mill Pond sub-watershed was primarily built out, but it is possible that land-use based loads may have changed from 2001 to 2016. Therefore, the MEP land-use loading analysis was updated to confirm that present (2016) nutrient loads to Mill Pond via direct groundwater inflow are accurate (the surface water inputs were directly measured as part of the present study. Land-use and parcels in the Backus Brook GT10, Backus Brook LT10, and Mill Pond subwatersheds were reviewed for new development that may have occurred since the completion of the MEP analysis and added into the land-use loading model (*Appendix A – Mill Pond Sub-watershed*). There are 11 and 7 new residential builds in the Backus Brook LT10 and Mill Pond sub-watersheds, respectively. The new builds account for a 1% nitrogen load increase from 4242 in 2001 to 4344 kg unattenuated N/year in 2016.

---

[3] Howes, B.L., J.S. Ramsey, S.W. Kelley, R.I. Samimy, D.R. Schlezinger, E. Eichner. 2005. Massachusetts Estuaries Project: Linked Watershed-Embayment Management Modeling to Determine Critical Nitrogen Loading Thresholds for Great Pond, Green Pond and Bournes Pond, Falmouth, MA. Final Report to MA Department of Environmental Protection and USEPA, 162 pp. Published by MassDEP.

Using the 2001 land-use nitrogen loading to the watershed model, the inflow and outflow nitrogen loads of Mill Pond are 2138 and 1585 kg attenuated N/year, respectively. The nutrient assessment of 2005-2007 validates these loads, which measured average inflow and outflow nitrogen load as 2464 and 1416 kg N/year, only 13% higher and 11% lower than the modeled, respectively, attributable to inter-annual differences in hydrology. For the current 2015-2017 study, the updated land-use nitrogen loading to the watershed model using 2016 land-use data from the Town of Falmouth generated inflow and outflow nitrogen loads to Mill Pond of 2185 and 1627 kg attenuated N/year, respectively. These modeled nutrient loads did not compare that well with the measured average inflow and outflow nitrogen loads of 1462 and 961 kg N/year respectively, in-flowing load being 33% lower than modeled and out-flowing load being 41% lower than the modeled nutrient loading values. This difference in modeled versus measured load is almost entirely from differences in groundwater contributions to Mill Pond as 2013-2016 had May-October precipitation almost half of average levels. During the 2015-2017 study period, the average groundwater elevations were significantly lower, resulting in lower stream flows and nutrient loads as well as lower nutrient loads from direct groundwater discharge to Mill Pond. In contrast, the 2005-2007 nutrient assessment, average groundwater elevations were very similar to the long-term average groundwater elevation in this area. Since the nitrogen concentration of the inflowing water remains nearly the same, less groundwater discharge would result in a lower nitrogen load in the short-term. Due to the differences between the modeled and measured nitrogen load, the measured nitrogen load was flow corrected for comparison purposes. Flow correction is the ratio of land-use modeled to measured flows at the Mill Pond output stream (1.01 in 2005-2007 and 0.77 in 2015-2017). Using this ratio, 2015-2017 measured inflow and outflow nitrogen loads were flow corrected to 1908 and 1254 kg N/year, 13% and 23% lower than the modeled, respectively (**Table III-1**). While these do not represent the actual loads, the flow corrected loads are useful for comparative purposes to understand the nutrient dynamics of Mill Pond and the magnitude of inter-annual variation. The flow corrected loads reveal 24% and 10% difference in the respective 2005-2007 and 2015-2017 inflow / outflow measured loads.

The notable difference observed in the inflow load is likely due to irrigation practices followed by the operator of the cranberry bog immediately up-gradient of Mill Pond, which directly affects the measured flows during both timeframes. Bog operation both pumps water from Mill Pond and returns water to Mill Pond confounding the inflow volume measurements. As such, the measured inflows needed to be corrected for the recycling of water (and associated nutrients). Water inflow volumes relied significantly on the modeled water inflows as this was considered more appropriate by the technical team for calculating water flow and ultimately nitrogen load into Mill Pond. The measured stream outflow volume and nutrient loads were unaffected by the recycling.

Table III-1. Nitrogen load to the 2001 and 2016 watershed changed by only 1% and is represented as the unattenuated load – modeled. Attenuated nitrogen loads were both predicted by the models and measured in-field. Major differences in modeled and measured attenuated nitrogen loads is caused by differences in groundwater (GW) elevations. Rainfall infiltrating the ground affects the groundwater elevations and increases stream flows from direct input. Rainfall prior to 2005 was greater than the rainfall prior to 2015, driving the major differences in as indicated above, adjusted measured flows were used for comparison of modeled and measured nitrogen loads and 2005-2007 and 2015-2017 nitrogen loads.

	2001 Long-term modeled	2005 - 2007 measured	2005 - 2007 flow-corrected measured	2016 Long-term modeled	2015 - 2017 measured	2015 - 2017 flow-corrected measured
Total Rainfall (inches)	53	43	43	53	46	46
Rainfall ≥0.2 (inches)	40	32	32	40	35	35
Feet to GW level	6.43	5.75	5.75	6.43	7.30	7.30
Unattenuated - modeled						
MP Inflow (kg/yr)		3210			3275	
MP Outflow (kg/yr)		4242			4344	
Attenuated N Loads - modeled and measured						
MP Inflow (kg/yr)	2138	2464	2418	2185	1462	1908
MP Outflow (kg/yr)	1585	1416	1390	1627	961	1254
Attenuation						
By Water Shed[1]		33%			33%	
By Pond[2]		56%			61%	
By Watershed + Pond[3]		67%			71%	

Notes:
1. Calculated using LU Model Inflow and Unattenuated Inflow
2. Calculated using LU Model Inflow, Unattenuated Inflow and Outflow, and Flow-corrected Outflow
3. Calculated using Flow-corrected outflow and Unattenuated Outflow

By pairing inflows and outflows with sample nutrient concentrations to determine load in and out of Mill Pond and then subtracting flow out from flow in, this investigation revealed that the combined nutrient attenuation within the watershed and pond prior to discharging to the head of Green Pond for 2005-2007 and 2015-2017 removed 67% and 71% of the nitrogen load, respectively. The attenuation of nitrogen within Mill Pond alone was 56% and 61%, respectively (**Table III-1**). The congruence of in-pond attenuation over a decade indicates that changes in the watershed have not drastically affected the nutrient dynamics of Mill Pond.

Cranberry Bog Operation

Currently water from Backus Brook passes through 52 acres of active cranberry bog before entering Mill Pond. Similar to other cranberry operations, the use of fertilizer is necessary to maintain the cranberries. Without the addition of fertilizer to replace the nutrients lost during harvest, productivity declines once the sediment pool of nutrients becomes depleted. As the water in Backus Brook moves through the bog channels it is potentially exposed to the addition of fertilizers that wash off of the bog during significant rainstorms that too closely follow the fertilization. In the case of Mill Pond, the bog operator uses a low P fertilizer ratio (18%/1%/18%, N/P/K) which was designed by the Cranberry

Experiment Station to meet bog needs at a lower dose than standard fertilizers and to reduce nutrient loss in bog outflows.[4]

The flow from Backus Brook into Mill Pond varies due to cranberry bog flooding practices. Usually, at the start of October, the bog operator places boards in the culvert, stopping flow into Mill Pond and allowing the bog to begin flooding. At the time of harvest, the bog operator also pumps a large volume of water from the pond to the bog. The bog remains flooded throughout the harvest and sometimes into November. In late October to early November the boards are removed, allowing the impounded water to flow into Mill pond again. Starting in December the bogs are flooded for the winter. In the last week of February, the boards are removed and flow into the pond resumes. During both periods when the bogs are being flooded, flow into the pond is greatly reduced, increasing the water residence time of Mill Pond. The reduced volumetric inflow results in parcels of water entering the pond at the time of board emplacement which are not flushed out until after the boards are removed. Conversely, once the boards are removed, flows become very high (for a short period), making the water residence time very short, about 1 day and flushing out the pond. When Backus Brook flow is unaffected by the water control boards in the culvert, the water flows freely into the channel running between bog and pond. During these prolonged periods water withdrawals from this channel to the pond are occasionally made by irrigation pump for frost protection in April and May and cranberry irrigation in June – September pond water can also move into the channel/pump as well.

Stormwater Nitrogen and Phosphorus Loading

Nutrient loads from storms can significantly affect the water quality of small ponds, due to the high nutrient concentrations of runoff from roads and other impervious surfaces. The amount of nitrogen and phosphorus loading from stormwater runoff depends on the amount of rain in a storm, elapsed days since the previous storm and total rainfall in significant storms (>0.20") in the year. Mill Pond receives stormwater from two outfall pipes. The pipe outlets are in the northwest and northeast corners of the pond, near Prince Henry Avenue and Pontes Avenue, respectively (**Figure II-1**). Flow and nutrient concentration measurements were collected during two storm events (August 8 and September 7, 2017). The sampled storms were selected based on expected rainfall of a small (0.20" to 1") and large storm event (> 1"). Generally, it is expected to see more nitrogen and phosphorus loading with large storms, however, the nitrogen and phosphorus load per storm is also affected by the intensity of the storm (velocity of water flow) and days since previous rain storm. Based on the ten-year average precipitation for small and large storm events, stormwater contributes, on average, 4.1 kg N and 1.1 kg P / year to Mill Pond (**Table III-2**).

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[4] This new low nutrient fertilizer is recommended by CSP-SMAST in flow through bog settings like Backus Brook as a Best Management Practice (BMP) and the grower has been using it already.

Table III-2. Flow weighted concentrations and loads separated by storm and stormwater outfall pipe. Total direct discharges of stormwater nutrient loads and volumes are presented for each measured storm and annually, based on the long-term significant rainfall average (events >0.2").

Summary of Mill Pond Falmouth Stormwater Assessment			
	Storm	Storm	Annual
Collection Dates	8/8/2017	9/7/2017	precip ≥ 0.2
Precipitation (in)	0.48	1.22	34.3
Days between Rain Events	13	2	-
Storm Pipe: PA - Pontes Avenue			**per year**
Flow [m^3]	11	111	1866
TN [mg/L] flow weighted	2.4	0.8	-
TP [mg/L] flow weighted	0.5	0.3	-
TSS [mg/L] flow weighted	85	14	-
TN Load [g]	26	83	2094
TP Load [g]	5.4	28	580
TSS Load [g]	914	1575	55416
Storm Pipe: PHA - Prince Henry Avenue			**per year**
Flow [m^3]	25	87	2104
TN [mg/L] flow weighted	1.4	0.6	-
TP [mg/L] flow weighted	0.3	0.2	-
TSS [mg/L] flow weighted	36	11	-
TN Load [g]	36	50	2035
TP Load [g]	8.2	18	553
TSS Load [g]	904	989	47328
Total Load (PA + PHA)			**per year**
Flow [m^3]	36	198	3970
TN Load [kg]	0.062	0.133	4.1
TP Load [kg]	0.014	0.047	1.1
TSS Load [kg]	1.8	2.6	103

Surfacewater Flows and Nutrient Loads Into and Out of Mill Pond

Surface water inflow and outflow from Mill Pond is the main source and sink of nitrogen and phosphorus in the nutrient mass balance of the pond. Surface water inflow / outflow volume and mass transport of nitrogen and phosphorous was determined based on flow and stage measurements, as well as water quality sampling undertaken up-gradient and down-gradient of Mill Pond in Backus Brook. Flow measurements were merged with nutrient concentrations obtained from the water sampling program to calculate N and P load into and out of Mill Pond.

Flow into Mill Pond comes from Backus Brook, a ground water fed stream that runs through an active cranberry bog before entering Mill Pond. The flow from Backus Brook into Mill Pond varies due to cranberry bog flooding practices (*Cranberry Bog Operation*). To refine the amount of water (from Mill Pond) used for flooding and irrigation to more accurately determine the nitrogen and phosphorus loads into Mill Pond from Backus Brook, associated with bog operations, flow rates and pump run times are needed. Unfortunately, communication with the cranberry bog operator was established late in the study so that these data are not available at this time, but the operator was very forthcoming as to examine approaches to further reduce nutrient discharges for the restoration of the pond. . Therefore, alternate methods were developed to quantify the stream inflow volume (see below).

The first method used to quantify stream inflow was through the measurement of stream velocity and stage to create a stage-discharge relationship (rating curve). Discharge from Backus Brook to Mill Pond was measured just below the culvert where water flows over a control board and into a channel that flows directly into the Mill Pond. A stream gauge was deployed from August 2015 to April 2018, measuring stream stage every 10 minutes. A total of 108 direct measures of volumetric flow were also made during this deployment period. These flow measurements correlated with stream stage. Traditionally, a single rating curve is applied to a channel to predict stream flow. However, due to cranberry bog operation, boards were added or removed over the year for cranberry harvest and winter flooding of the bogs. The number of boards directly affects the flow into the channel through the culvert. In addition, the irrigation and flooding practices are affected using a pump house located further down the channel to draw water out of the channel, also affecting stage in the channel. The irrigation and flooding practices, pull water from the channel as needed for cranberry bog operations with the effect that some water measured through the culvert might be pumped back to the bog before it reaches the pond (*Appendix C*). These practices complicated the development of the rating curve and the application of a single rating curve to this channel. Therefore, to accurately quantify the volume of water entering Mill Pond, multiple rating curves were constructed based on specific periods, differentiated by annual harvest, summer irrigation practice, and winter flooding practice. Although, this is not a traditional method for determining volume of water on a long-term basis, the manipulation of flow required this approach. The use of different rate curves based upon bog operations allowed accurate measurements of flow as each discrete "rating curve" captures the specifics of the manipulated flow condition and in the aggregate, the overall flow characteristics of the system. This method of flow prediction closely matches the 108 directly measured flows (**Figure III-2**). Changes in flow from Backus Brook to Mill Pond occur most noticeably during harvest and winter flood, with irrigation activity affecting the late spring and summer flows (**Figure III-2**). This method accurately quantifies the stream flow from Backus Brook into the pond channel, but is not solely representative of the water and associated nutrient loads entering Mill Pond, due to the cranberry bog irrigation and flooding practices.

The second method used to quantify stream inflow was through the comparison of flow characteristics generated through the comprehensive assessment of Green Pond during completion of the MEP nutrient threshold analysis, graduate dissertation research (Samimy, 2013), and the current Mill Pond nutrient assessment. During the MEP assessment, stream flow and nitrogen concentrations measurements collected in 2005-2007 were used to calibrate the MEP land-use model. The congruence of the 2005-2007 measured flows with modeled flows indicated accurate model prediction for contributing area flow (**Table III-3**). The 2005-2007 measured inflow was 11% greater than the modeled, while the measured outflow was only 2% greater than the modeled. In 2015-2017, the measured inflow was 20% less than the modeled long-term inflow, with the outflow being about the same, 24% less. Differences in annual flows are attributed to interannual variations in regional precipitation and groundwater levels. Hydrologic conditions in 2005-2007 were close to the long-term average conditions used in the MEP land-use model. In contrast, the 2015-2017 hydrologic conditions were much different, generating lower flows than the long-term average conditions used in the model. To examine interannual differences the ratios of inflow and outflow volume were determined for each available time period. The ratio of outflowing to inflowing water is 1.02 (2005-2007), 1.06 (2015-2017), and 1.12 (MEP Long-Term). Similar ratios of outflowing to inflowing water indicate that the surface water inputs and groundwater inputs compared to the surface water output has not changed dramatically in the last decade. The small differences in these ratios are likely the result of the irrigation and flooding practices of the bog. The congruence of outflow to inflow ratios, means that a flow correction for the inflowing stream can be calculated using the MEP water balance (part of the land-use model) which excludes water recycling in bog operations. Since the inflow stream in both 2005-2007 and 2015-2017 studies is affected by cranberry bog operation, the outflow stream is used for the flow correction calculation. The flow-corrected inflow is calculated as:

Flow-corrected Inflow = Measured Inflow * (Measured Outflow/MEP Outflow from Water Balance)

Since the pond is in steady state, the flow-corrected inflow can be used as an accurate representation of the water and associated nutrient load entering Mill Pond, unaffected by the cranberry bog operations.

Discharge from Mill Pond to Backus Brook was measured just below Rt. 28 as the water flowed out of the concrete culvert, into the short channel entering the headwaters of the Green Pond Estuary. A recording stream gauge was deployed from August 2015 to April 2018, measuring stream stage every 10 minutes. A total of 107 flow measurements were made during this deployment period. These flow measurements correlated well with water level yielding a high quality single rating curve. This method of flow prediction closely matches the flows measured in the field (**Figure III-3**).

The predicted inflow (flow-corrected) and outflow was merged with nutrient concentrations to determine the load of N and P entering / exiting Mill Pond (**Table III-4**). Over the two-year period, an average of 62 and 1441 kg yr^{-1} phosphorus and nitrogen, respectively, entered Mill Pond via surface water flow. After biological activities within the pond ecosystem, 47 kg P yr^{-1} and 961 kg N yr^{-1}, was discharged from Mill Pond via surface water outflow.

Table III-3. Comparison of flow and nitrogen characteristics relative to the inflow / outflow streams of Mill Pond for data sets collected for long-term modeled flow (30 years), 2005-2007 measured flow and nutrient, and 2015-2017 (drought years) measured flow and nutrient studies.

Stream Discharge Parameter	Backus Brook to Mill Pond		Mill Pond to Green Pond		Stream OUT/IN Discharge Ratio	Data Source
Days of Record	730		730		730	
Flow Characteristics						
Stream Average Discharge 2005-2007 (m3/day) - measured	6880		7029		1.02	(1)
Stream Average Discharge 2015-2017 (m3/day) - measured	4979		5286		1.06	(2)
Contributing Area Average Discharge (m3/day) -modeled	6186		6899		1.12	(3)
Nitrogen Characteristics						
	2005-2007	2015-2017	2005-2007	2015-2017		
Stream Average Nitrate + Nitrite (mg N/L)	0.507	0.489	0.154	0.159		(1), (2)
Stream Average Total N Concentration (mg N/L)	0.920	0.900	0.594	0.546		(1), (2)
Nitrate + Nitrite as Percent of Total N (%)	55%	54%	26%	31%		(1), (2)
Total Nitrogen (TN) Average Measured Stream Discharge (kg/d)	6.75	5.23*	3.88	3.44*		(1), (2)
TN Average Contributing Area Attenuated Load (kg/d)	5.86	5.98	4.34	4.46		(3)
TN Average Contributing UN-attenuated Load (kg/d)	8.79	8.98	11.62	11.90		(3)
Attenuation of Nitrogen in Watershed + Pond (%)			67%	71%		

(1) 2005-2007 from Roland Samimy Dissertation Data Set
(2) 2015-2017 from Mill Pond Nutrient Assessment gauge site data. *Flow corrected for comparison
(3) from 2001 and 2016 MEP GGB land use database for 2005-2007 and 2015-2017, respectively

Although the comparison of the flow characteristics generated through the three assessments reveals significant differences in annual flows (hydrologic variability), the nitrogen concentrations in / out of the pond were relatively constant (**Table III-3**). The concentration of stream flow water into Mill Pond is the same in 2015-2017 as it was in 2005-2007. Differences in annual flows can be attributed to observed variations in regional precipitation and groundwater levels. However, it should be noted that in each analysis of flow the ratio of outflowing to inflowing water was relatively constant (1.02, 1.06, and 1.12). Similar ratios of outflowing to inflowing water indicate that (1) the inflows and outflows have been accurately quantified and (2) additional surface water inputs and groundwater recharge (%) have occurred nor is there a new unquantified discharge pathway for pond water. The small differences in these ratios are likely the result of the irrigation and flooding practices of the bog.

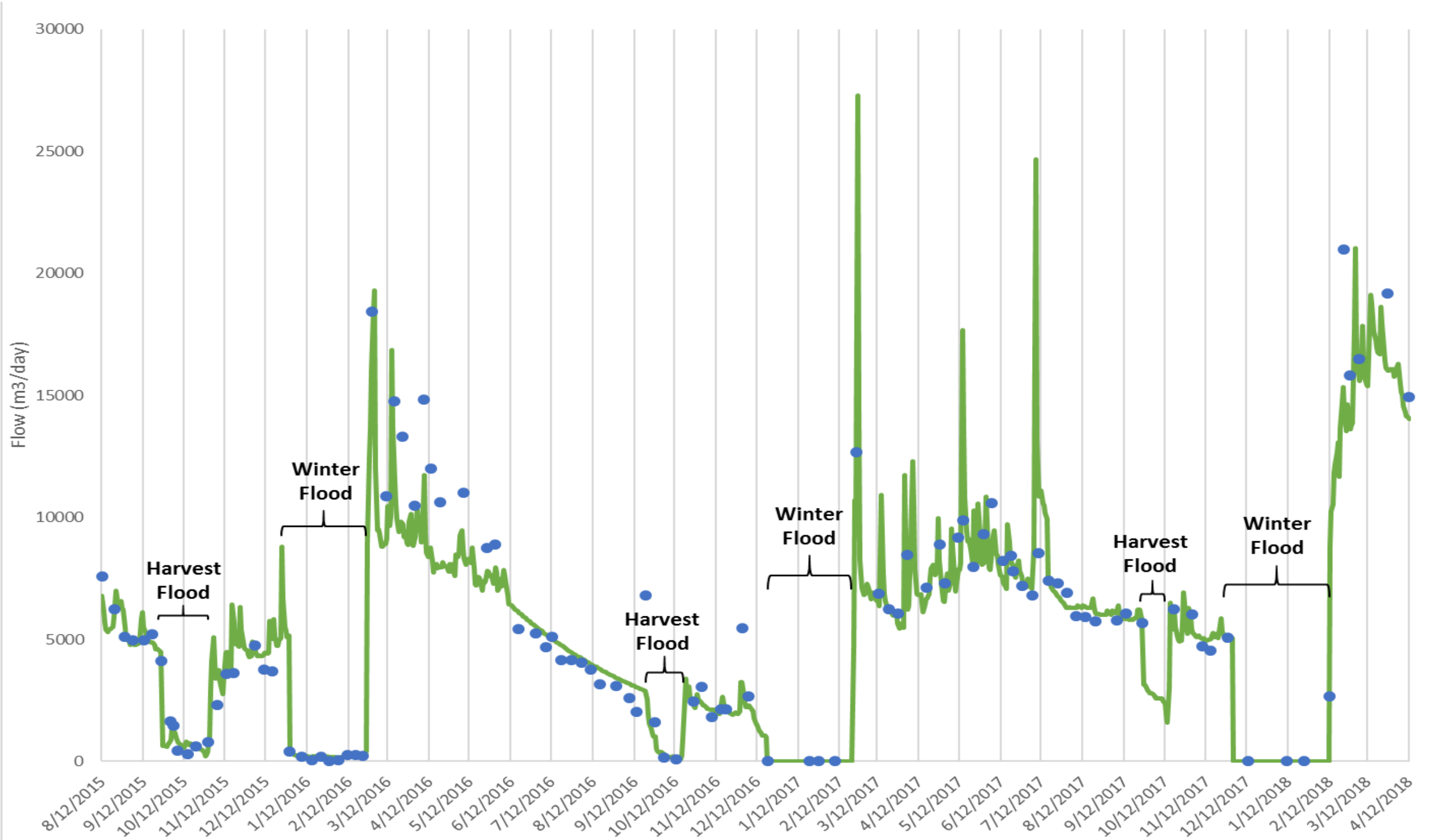


Figure III-2. Measured versus predicted flow at the inflowing stream of Mill Pond. Measure flows depicted by blue circles. Predicted flow represented by green line. Proximity of the green circle to the blue line indicates that the prediction of flow is representative of what was measured in the field. Note: Cranberry bog irrigation practices affected the stage in the channel and/or caused additional flow through the culvert. Therefore, this stream flow should be viewed as a qualitative representation of the flow in the channel, the quantitative determination of water volume that entered Mill Pond used the adjustment for water withdrawals and discharges by the bog.

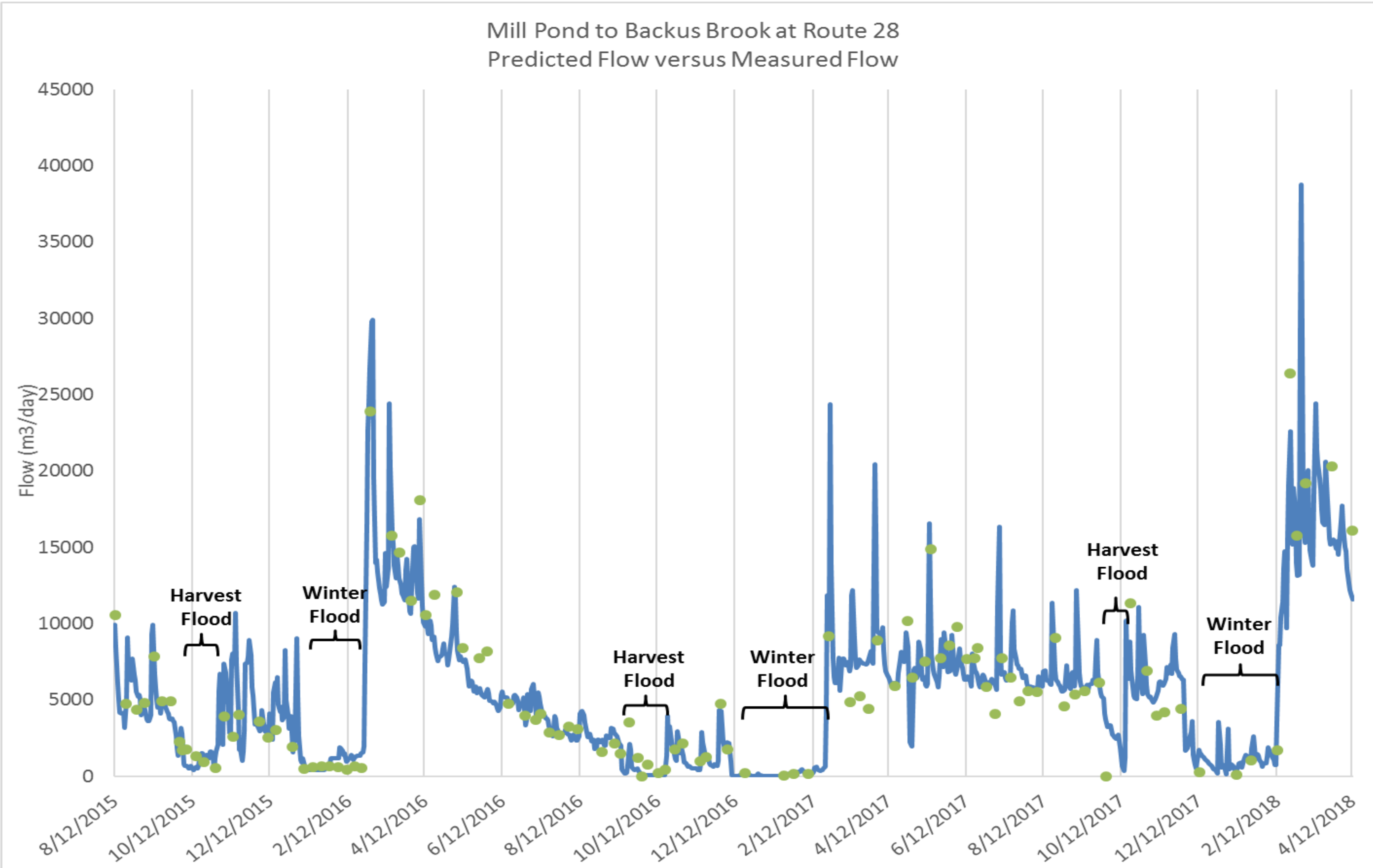


Figure III-3. Measured versus predicted flow at the outflowing stream of Mill Pond. Measured flows depicted by green circles. Predicted flows represented by blue line. Proximity of the green circle to the blue line indicates that the prediction of flow is representative of what was measured in the field. This stream flow is a quantitative representation of all the water flowing from Mill Pond.

Table III-4. Mill Pond inflow / outflow water flows and nutrient loads based on averaged daily load, separated by annual harvests (beginning of October) and averaged over the two-year sampling period. MP IN and MP OUT is the measured stream flows and associated loads. MP IN-corrected is the flow corrected for bog operations and associated loads. MP IN-corrected is not affected by cranberry bog operations, whereas MP IN includes bog operations and therefore, is not an accurate representation of nutrient load entering Mill Pond (it is included only for reference).

Stream	12 month Period	Average Volume m3/d	Salt kg/d	PO4 kg/d	TP kg/d	NH4 kg/d	NOx kg/d	DIN kg/d	DON kg/d	TDN kg/d	TN kg/d	POC kg/d	PON kg/d
MP IN	Oct 2015 - Sept 2016	4735	191	0.09	0.22	0.13	2.34	2.47	1.29	3.75	4.26	5.95	0.51
MP IN -corrected	Oct 2015 - Sept 2016	4607	185	0.09	0.21	0.13	2.25	2.37	1.26	3.63	4.12	5.76	0.49
MP OUT	Oct 2015 - Sept 2016	5139	198	0.04	0.14	0.07	0.96	1.03	1.43	2.46	2.89	3.73	0.43
MP IN	Oct 2016 - Sept 2017	4967	216	0.07	0.15	0.14	2.41	2.60	1.37	3.93	4.47	6.48	0.54
MP IN -corrected	Oct 2016 - Sept 2017	4164	199	0.06	0.14	0.13	2.22	2.40	1.27	3.64	4.13	5.98	0.50
MP OUT	Oct 2016 - Sept 2017	4644	206	0.04	0.12	0.08	0.65	0.70	1.30	2.12	2.37	3.25	0.38
MP IN	2 yr average	4851	203	0.08	0.19	0.14	2.37	2.53	1.33	3.84	4.37	6.21	0.52
MP IN -corrected	2 yr average	4386	192	0.07	0.18	0.13	2.23	2.38	1.26	3.63	4.13	5.87	0.50
MP OUT	2 yr average	4891	202	0.04	0.13	0.08	0.81	0.86	1.36	2.29	2.63	3.49	0.41

Sediment Nitrogen and Phosphorous Cycling

Analysis of sediment phosphorus and nitrogen recycling (influx {uptake} / efflux {release}) is critical to the management of the pond, as nutrient regeneration from the sediments can be a significant source of nutrients to pond waters supporting phytoplankton production and aquatic plant growth through foliar uptake. Under aerobic conditions the sediment takes up (influx) oxygen, ortho-phosphate, total dissolved phosphorus, nitrite + nitrate, and releases (efflux) ammonium, total dissolved nitrogen, and di-nitrogen gas. During the warm summer months, the dissolved oxygen of the pond declines and the bottom water and surficial sediments become anoxic. Under hypoxic/anoxic conditions, the sediments become a source of iron, manganese, phosphorus, and nitrogen to the overlying water column. If the internal phosphorus load from the sediments in a pond is more significant than the external load from the watershed, then management of the benthic sediments is an appropriate management option.

Measurements of nutrient flux under anoxic conditions was undertaken in October 2016, May 2017, and June 2017 allowing for a more detailed understanding of the seasonal sediment dynamics. As expected, the data revealed that the sediment oxygen demand (SOD) is directly related to pond temperature, with the rate of sediment oxygen uptake (SOD) lowest in October (-29 mmol O_2/m^2/day)[5] and highest in June (-42 mmol O_2/m^2/day) (**Table III-5**). In the present study, sediment ammonium release was negatively correlated with increasing temperature. This is the result of ammonium uptake by the dense rooted macrophyte community which virtually covers the entire bottom of Mill Pond (submerged aquatic vegetation, SAV). In sediment flux experiments, it was noted that 23 of the 24 cores collected had SAV. The addition of plants to a sediment core, can greatly influence the water column nutrient concentrations, as plants take up inorganic nitrogen (NH_4^+ and NO_x^-) both through root and foliar uptake. Therefore, cores collected in June, containing actively growing SAV, have the lowest rate of NH_4^+ release (1016 µmol N/m^2/day) and highest uptake of NO_x (-896 µmol N/m^2/day). Although all eight cores collected on October 27, 2016 have SAV, it is past the growing season, and NH_4^+ release (1471 µmol N/m^2/day) is less affected by SAV inorganic nutrient uptake than in May and June. Nitrite + nitrate (NOx^-) uptake by the sediments strongly correlates with temperature and SOD, with the June cores having the highest uptake rate (-896 µmol N/m^2/day) and October cores having the lowest (-35 µmol N/m^2/day). However, the NOx^- uptake cannot solely be attributed to sediment uptake (denitrification), because macrophytes can also take up NOx^-.

Denitrification is a process that requires low oxygen conditions, a carbon source, denitrifying bacteria, and NOx^- (for direct denitrification) and/or NH_4^+ (for coupled nitrification-denitrification or anammox). It is expected, based on the carbon rich, anoxic sediments, with an oxic water column, and high nitrate levels (>10uM NOx^-), di-nitrogen gas (N_2) production would be present at detectable levels in the Mill Pond sediments. This process has been observed in other Cape Cod Ponds, such as Filends Pond, a similar flow through pond in Barnstable, where approximately 365 kg year^{-1} nitrogen removal by denitrification. Thus, it was expected that denitrification would be a major pathway for nitrogen

[5] Negative (-) values represent uptake by sediments; positive (+) values represent flux from sediment to overlying waters.

attenuation in Mill Pond. However, it has been shown in vegetated salt marsh sediments that plants outcompete denitrifying bacteria for nitrogen, unless high levels of nitrate or oxygen/ammonium are available. It maybe that oxygen is limiting nitrification which limits denitrification as cores with the lower oxygen uptake have the strongest N_2—N rates. In Mill Pond sediment cores showed a high degree of variation in denitrification, due to the difficulty in collecting cores in dense macrophyte areas, the periodic low oxygen in bottom waters and surficial sediments inhibiting coupled nitrification-denitrification, possibly shifting denitrification into the shallower waters and those sediments with high levels of nitrate in overlying waters (direct denitrification). The result was that the sediment cores verified that denitrification was occurring at a range of rates in Mill Pond sediments, that pond-wide denitrification would also need to be based on system nitrogen mass balance measurements (see below).

Phosphorus release was significantly controlled by the level of oxygen depletion in bottom waters. Under aerobic conditions, phosphate (inorganic plant nutrient) binds to oxidized iron (Fe^{3+}) and is stored in the surficial sediments. In the sediments, phosphate can be used by macrophytes and some portion can be released to overlying waters. In contrast, under hypoxic/anoxic conditions the bound phosphate in the iron-phosphate complex is released resulting in a pulse of phosphorus to the overlying waters. In Mill Pond where there is high uptake of phosphate by the rooted plants (and also phytoplankton) and phosphorus is in high demand, it appears PO_4^{3-} and TDP uptake by the cores is likely due to both the binding of phosphate by iron at the sediment surface and plant uptake. During each of the flux studies under oxic conditions phosphate was clearly being "taken up" by the sediment system from the overlying water. The uptake of phosphorus is higher at higher temperatures, except for the June 21, 2017 flux ($PO_4^{3-}$and TDP uptake rates of 51 and 67 µmol P/m^2/day, respectively), which was less than the May 30, 2017 uptake rates (93 and 106 µmol P/m^2/day, respectively). This is likely due to the oxygen depletion of bottom waters in June (**Figure III-6**). Therefore, cores collected on June 21, 2017 had experienced low oxygen conditions, although the core headspace was oxygenated before incubation. However, this oxygenation was likely insufficient to fully oxygenate the sediments for maximum PO_4^{3-} and TDP uptake at temperature.

Since through much of the summer (after mid-June) Mill Pond has hypoxic/anoxic bottom waters, so it was necessary to conduct incubations under hypoxic/anoxic conditions. Cores were collected in May 2017 and held under anoxic conditions for ~3-months. Under anaerobic conditions, ortho-phosphate and ammonium is released from the sediments into the overlying water. The rate of the PO_4^{3-} release is highest in the beginning and decreases over time, whereas NH_4^+ levels are mostly constant throughout the anaerobic period. PO_4^{3-} release is a combination of chemical release and remineralization by the microbial community. The initial high rates of PO_4^{3-} release results from the dissolution of the iron-phosphorus complex with a lower level of continuing remineralization lasting for about a month. The PO_4^{3-} release under hypoxic/anoxic conditions after the initial month was primarily from continuing remineralization without chemical binding. The highest rate of release occurred in the chemical release phase (116 µmol P/m^2/day). The lowest rate of release occurred under hypoxic/anoxic conditions (11 µmol P/m^2/day). The rate of anaerobic ammonium release is 1676 µmol N /m^2/day.

Table III-5. Sediment flux rates under aerobic conditions occurred in October 2016, May 2017, and June 2017. Influx to sediments is represented as negative rates* and efflux from the sediments to the overlying water is represented as positive rates. Flux of oxygen into the sediments and exchanges of ammonium (NH_4), nitrite + nitrate (NO_x^-), total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), and ortho-phosphate (PO_4^{3-}).

Oct-16 Aerobic Core ID	SOD Rate (mMoles/m2/d)	SOD S.E.	NH4 Rate (uMoles/m2/d)	NH4 S.E.	PO4 Rate (uMoles/m2/d)	PO4 S.E.	NO3 Rate (uMoles/m2/d)	NO3 S.E.	TDN Rate (uMoles/m2/d)	TDN S.E.	TDP Rate (uMoles/m2/d)	TDP S.E.
C1	-37	2	2099	263	-16	6	-23	9	2036	376	-47	24
C2	-42	1	639	90	-13	4	-28	10	543	453	-12	9
C3	-23	1	4044	436	-31	7	-17	10	3982	392	0	0
C4	-27	3	636	81	-34	9	-31	7	1675	753	-16	20
C5	-32	1	894	60	-25	6	-97	8	876	363	-21	10
C6	-18	2	1015	100	-29	4	-48	30	1080	330	-26	3
C7	-27	3	1548	147	-10	3	-12	7	2038	361	-9	15
C8	-23	1	892	105	-15	4	-19	14	1144	365	-22	12
AVERAGE	-29	2	1471	160	-22	5	-35	12	1672	424	-19	12

May-17 Aerobic Core ID	SOD Rate (mMoles/m2/d)	SOD S.E.	NH4 Rate (uMoles/m2/d)	NH4 S.E.	PO4 Rate (uMoles/m2/d)	PO4 S.E.	NO3 Rate (uMoles/m2/d)	NO3 S.E.	TDN Rate (uMoles/m2/d)	TDN S.E.	TDP Rate (uMoles/m2/d)	TDP S.E.
C1	-46	4	573	24	-94	24	-699	162	-145	476	-131	27
C2	-47	3	831	138	-82	3	-454	59	1093	327	-102	13
C3	-49	2	2056	176	-99	5	-586	46	2034	698	-109	18
C4	-32	1	1161	39	-124	4	-550	48	666	111	-109	20
C5	-25	0	443	108	-70	5	-409	16	1412	324	-78	15
C6	-21	0	298	63	-93	8	-211	10	672	703	-94	16
C7	-27	1	837	47	-116	20	-335	24	1152	117	-140	20
C8	-39	2	4439	419	-68	10	-499	28	4361	876	-87	20
AVERAGE	-36	2	1330	127	-93	10	-468	49	1406	454	-106	19

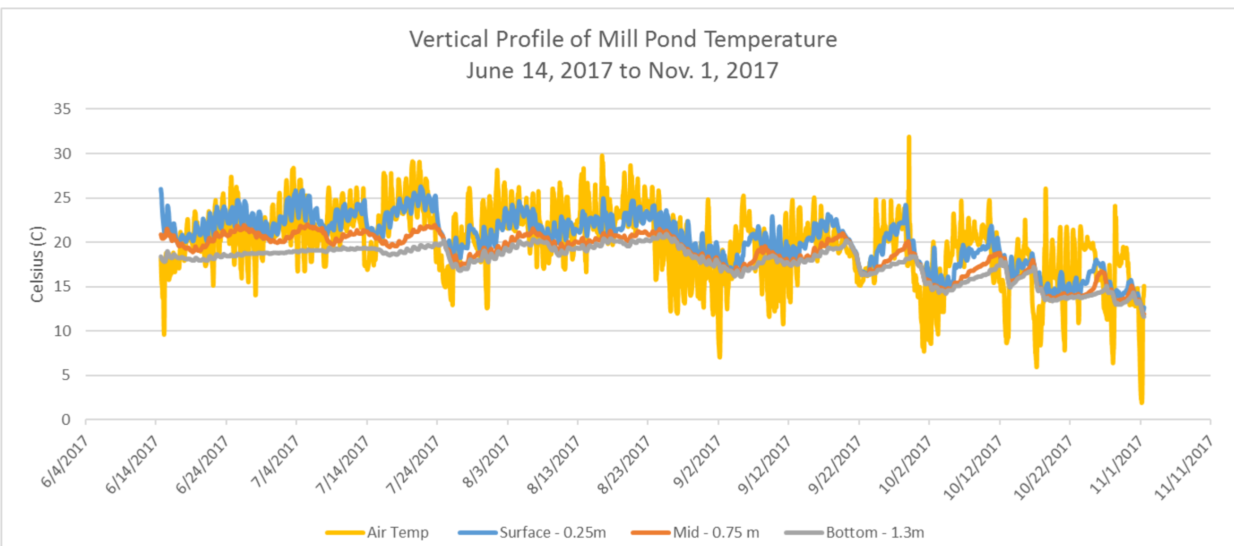
Jun-17 Aerobic Core ID	SOD Rate (mMoles/m2/d)	SOD S.E.	NH4 Rate (uMoles/m2/d)	NH4 S.E.	PO4 Rate (uMoles/m2/d)	PO4 S.E.	NO3 Rate (uMoles/m2/d)	NO3 S.E.	TDN Rate (uMoles/m2/d)	TDN S.E.	TDP Rate (uMoles/m2/d)	TDP S.E.
C1	-72	3	6403	419	-40	11	-1189	190	6209	477	-68	28
C2	-41	1	1013	118	-45	8	-789	44	1579	552	-33	7
C3	-40	2	1177	179	-70	8	-946	139	669	33	-82	15
C4	-38	2	-329	12	-37	6	-832	41	-1827	236	-38	9
C5	-36	2	691	91	-51	9	-787	117	1999	378	-40	7
C6	-36	2	-610	26	-58	5	-791	46	-1458	260	-117	27
C7	-48	3	-501	16	-58	4	-1032	6	-3329	307	-100	29
C8	-29	2	286	212	-53	7	-800	27	141	250	-56	8
AVERAGE	-42	2	1016	134	-51	7	-896	76	498	312	-67	16

May-17 Anaerobic Core ID			Anaerobic NH4 Rate (uMoles/m2/d)	Anaerobic NH4 S.E.	Chemical PO4 Rate (uMoles/m2/d)	Chemical PO4 S.E.	Anaerobic PO4 Rate (uMoles/m2/d)	Anaerobic PO4 S.E.				
C1			2106	114	113	16	15	5				
C2			1217	65	136	18	22	6				
C3			1689	177	121	16	12	2				
C4			1766	183	107	16	11	5				
C5			2056	140	84	12	15	2				
C6			608	50	37	3	5	2				
C7			1263	103	84	9	-1	5				
C8			2701	203	242	29	6	19				
AVERAGE			1676	129	116	15	11	6				

Temperature, Dissolved Oxygen Conditions, and Degree of Mixing in Mill Pond

State regulation, 314 CMR 04, defines dissolved oxygen and temperature conditions suitable for Class B surface waters. Class B waters are used for fish habitat, other aquatic and wildlife habitat, migration, reproduction, and growth, secondary contact recreation, and crop irrigation. These waters shall maintain a minimum dissolved oxygen concentration of 5.0 mg/L for 16 hours of any 24-hour period and never drop below 3.0 mg/L. Temperature shall remain less than 28.3˚C, never rising more than 1.7˚C due to any man-made discharge. In Class B waters where, natural background conditions of dissolved oxygen are lower and temperature higher, both parameters shall not exceed the natural background conditions.

The degree and duration of water column stratification was assessed in Mill Pond using a vertical array of three temperature recorders at a single location. In general, the pond is thermally stratified, with warmer surface waters as a result of high summer atmospheric temperatures and direct insolation and cooler bottom waters due in part to groundwater discharge (**Figure III-7**). Water column mixing occurs periodically during summer with significant drops in atmospheric temperature, cooling the surface water.



Summer stratification was found to temporarily breakdown during periods of cooler weather. For example, a 6-degree Celsius temperature drop on July 24 resulted in a vertical mixing event and destratification. However, within a day or two atmospheric temperatures returned to normal summer conditions, and the pond restratified. Similarly, from August 22 to September 1, the pond destratified nightly (**Figure III-4**).

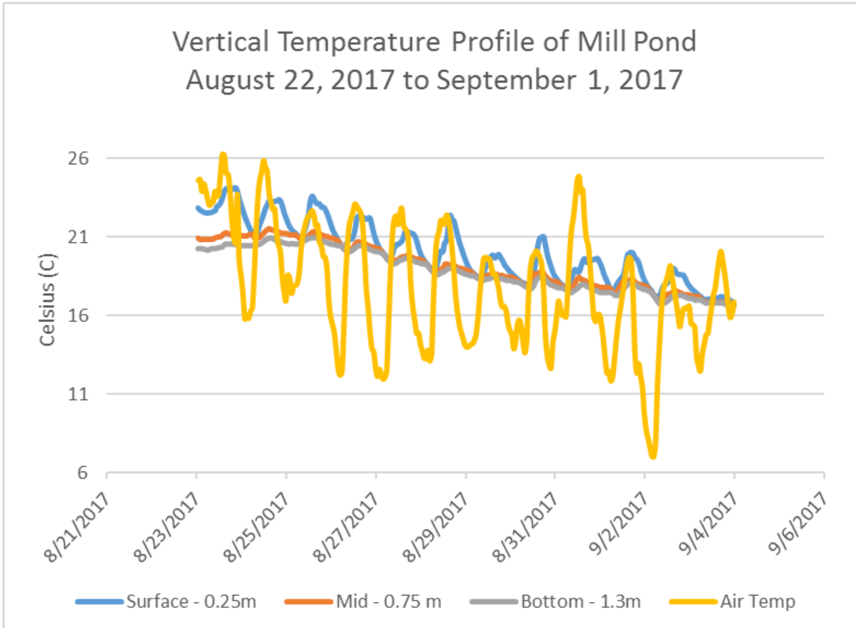
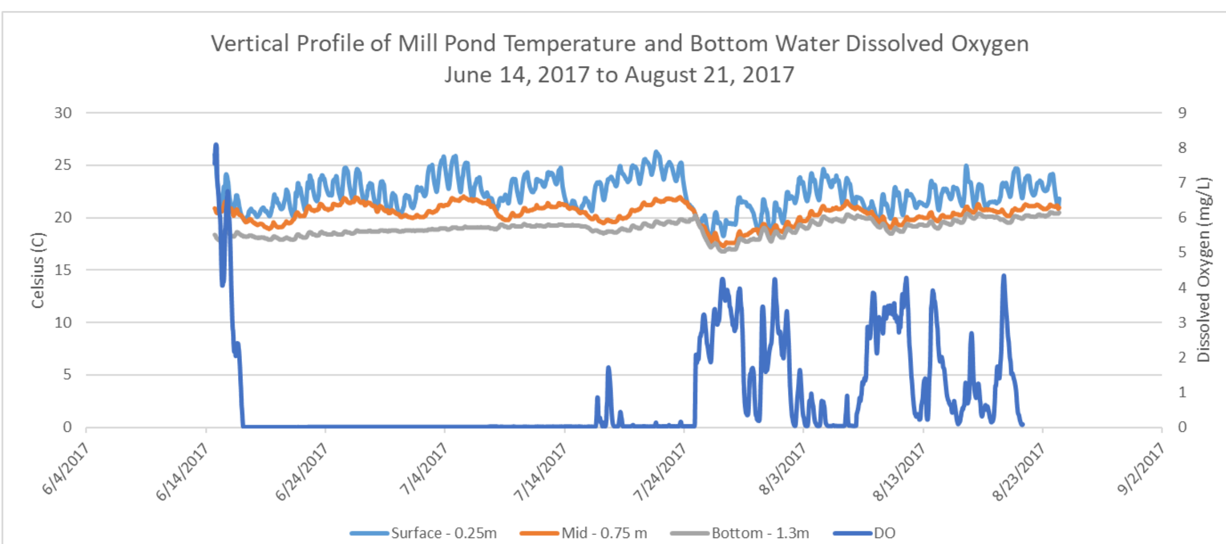


Figure III-5. Temperature profile from August 22 to September 1, 2017 reveals that the water column was isothermal each night, indicative of unstratified conditions. However, with warming of surface waters during the day time the pond becomes vertically unmixed.

As the surface water cools to temperatures less than the bottom water, it becomes heavier and sinks to the bottom and the pond destratifies. Oxygenated surface water oxygen then mixes with anoxic bottom water, increasing dissolved oxygen conditions of the bottom water (**Figure III-5**), affecting biogeochemical cycling in the sediments. This physical change in the pond can prevent the phosphorus release from the sediment by oxygenating the bottom water and possibly the sediment surface.



A YSI 6600 Multi-parameter Water Quality Monitor with optical dissolved oxygen, chlorophyll-a, and temperature sensors, was moored within Mill Pond and programmed to measure parameters every 15-minutes 30 cm above the bottom from June 14, 2017 to November 1, 2017, but the recorder failed August 21. However, bi-weekly calibration samples for dissolved oxygen and chlorophyll were collected from June through October. The available continuous record showed anoxia (*i.e.*, <0.5 mg/L) in the bottom water from June 16 to July 25 (39 days). After July 25, the pond destratified and bottom water oxygen concentrations increased slightly to 4 mg O_2/L, but still less than 314 CMR 04 State regulation (DO >5.0 mg/L). From July 25 to August 21 the oxygen conditions remained sub-standard, varying between oxic and hypoxic/anoxic (**Figure III-6**). The duration of Mill Pond hypoxia/anoxia after August 21 was roughly estimated using the biweekly calibration measurements (**Table III-6**), which indicate frequent periods of anoxia interspersed with hypoxic periods. The frequency of anoxia and brevity of hypoxia was insufficient to fully oxidize the surficial sediments, so that phosphorus release was more or less continuous until November 1, resulting in 138 days of bottom water anoxia. The length of bottom water anoxia relates to the release of phosphorus and ammonium from the sediments. The rate of ammonium released from the sediments is relatively constant throughout the anaerobic period. The rate and the number of days the pond is anoxic (138 days) determine the amount of ammonium released. Phosphorus release was determined by integrating the chemical release phase and the continuing anoxic microbial remineralization phase. Two rates, chemical (lasting 34 days) and anoxic (lasting 104 days) determine the amount of phosphorus released. The total mass of P released during the anoxic period (138 days) was very close to the total measured release during the anoxic incubation (120 day). The oxic, chemical, and anoxic nutrient flux rates are multiplied by the respective number of days to determine total nutrient regeneration load to Mill Pond (described in the *Nutrient Dynamic Assessment with Box Model*).

The level of total chlorophyll-a pigment indicates phytoplankton blooms in Mill Pond. These blooms appear to correlate with periods of lowest dissolved oxygen. As dissolved oxygen, readings reached 0.0 mg O_2/L on June 16 and August 5, there was a chlorophyll bloom in progress. Unfortunately, the chlorophyll measurements between June 24 and July 21 were confounded by the extremely high fluorescence, possibly due to the fluorescence of facultative anaerobes with accessory pigments or from benthic vegetation in the region of the sensor. Accurate measurements of total chlorophyll a pigment resumed after July 21 at which point, daily chlorophyll concentrations remain around 2-4 µg/L until a large bloom started on July 31, reaching 34 µg/L on August 5 (**Figure III-6**). Chlorophyll levels greater than 1.7 ug/L are typical of impaired aquatic systems.

Table III-6. Tabulated water quality data for the YSI 6600 Multi-parameter Monitor. Measurements of total depth, secchi depth, dissolved oxygen, temperature, chlorophyll-a, pheophytin-a were collected at the mooring biweekly. Winkler dissolved oxygen measurement of pond bottom water on July 10 is inaccurate due to sample collection error.

Date	Time	Sample Depth (m)	Total Depth (m)	Secchi Depth (m)	Winkler DO (mg/L)	YSI 55 - DO (mg/L)	TEMP (C)	CHLA (ug/L)	PHEO (ug/L)	% Chla	T. PIG (ug/L)
05/17/17	11:22	0.15	1.50	1.50	NS	9.4	17.7	1.6	0.5	76%	2.1
05/17/17	11:15	0.50	-	-	NS	9.3	16.4	NS	NS	NS	NS
05/17/17	11:15	1.00	-	-	NS	10.3	14.8	2.3	1.9	54%	4.2
05/17/17	11:15	1.25	-	-	NS	10.2	14.1	NS	NS	NS	NS
06/14/17	15:50	1.20	1.55	ND	7.4	ND	ND	3.17	4.61	41%	7.79
07/10/17	12:05	0.15	1.60	1.25	NS	5.1	23.2	4.0	3.6	53%	7.5
07/10/17	12:05	0.50	-	-	NS	5.0	22.1	ND	ND	ND	ND
07/10/17	12:05	1.00	-	-	NS	<2.0	19.0	ND	ND	ND	ND
07/10/17	12:05	1.20	-	-	2.6	<2.0	ND	3.97	3.55	53%	7.52
07/10/17	12:05	1.50	-	-	NS	<2.0	ND	ND	ND	ND	ND
7/24/2017	10:30	0.15	1.20	1.00	NS	2.2	20.8	3.5	4.1	46%	7.6
7/24/2017	10:30	0.50	-	-	NS	2.3	20.8	ND	ND	ND	ND
7/24/2017	10:30	0.95	-	-	1.9	ND	ND	20.54	7.74	73%	28.28
7/24/2017	10:30	1.00	-	-	NS	<2.0	20.4	ND	ND	ND	ND
8/7/2017	10:04	0.15	1.24	1.00	NS	3.4	21.4	2.6	2.4	52%	5.0
8/7/2017	10:04	0.5	-	-	NS	2.7	21.0	ND	ND	ND	ND
8/7/2017	10:04	0.95	-	-	2.8	ND	ND	2.4	3.5	41%	5.9
8/7/2017	10:04	1.00	-	-	NS	<2.0	20.5	ND	ND	ND	ND
8/21/2017	9:43	0.15	1.23	1.23	NS	3.7	22.1	0.7	1.6	32%	2.4
8/21/2017	9:43	0.50	-	-	NS	3.3	21.7	ND	ND	ND	ND
8/21/2017	9:43	0.95	-	-	1.5	<2.0	ND	4.24	4.05	51%	8.29
8/21/2017	9:43	1.00	-	-	NS	<2.0	20.1	ND	ND	ND	ND
9/6/2017	9:50	0.15	1.22	1.22	NS	6.3	20.4	3.0	1.3	69%	4.3
9/6/2017	9:50	0.50	-	-	NS	5.9	18.5	ND	ND	ND	ND
9/6/2017	9:50	0.95	-	-	4.3	2.5	16.9	4.4	2.6	63%	7.1
9/6/2017	9:50	1.00	-	-	NS	ND	ND	ND	ND	ND	ND
9/25/2017	14:20	0.15	1.20	1.20	NS	4.5	20.0	2.58	3.90	40%	6.48
9/25/2017	14:20	0.95	-	-	2.1	ND	ND	3.67	4.62	44%	8.29
9/25/2017	14:20	1.00	-	-	NS	<2.0	ND	ND	ND	ND	ND
10/19/2017	9:00	0.15	1.20	0.40	NS	ND	ND	9.38	5.58	63%	14.96
10/19/2017	9:00	0.90	-	-	1.2	ND	ND	9.95	4.21	70%	14.16
11/1/2017	13:15	0.15	1.02	1.40	NS	8.48	12.8	1.70	3.21	35%	4.90
11/1/2017	13:15	0.50	-	-	NS	7.51	12.3	ND	ND	ND	ND
11/1/2017	13:15	1.00	-	-	NS	7.55	11.9	ND	ND	ND	ND
11/1/2017	13:15	1.10	-	-	4.8	ND	ND	2.47	5.51	31%	7.98

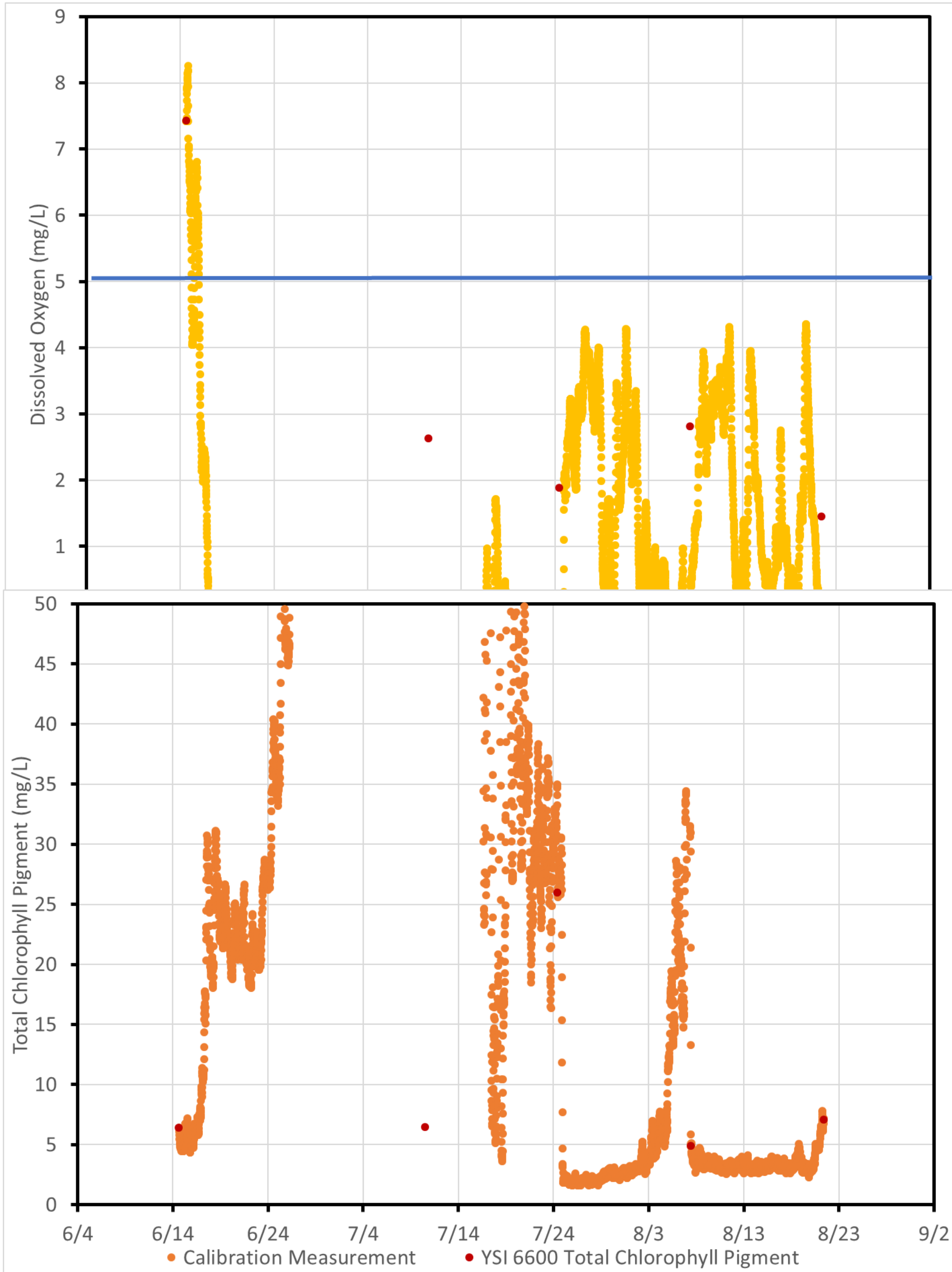


Figure III-7. TOP: Dissolved oxygen concentration (mg/L) of Mill Pond bottom water. The yellow line is the YSI 6600 DO record, red circles represent the in-field calibration measurements, and the horizontal blue line is the State regulation for minmum dissolved oxygen. BOTTOM: Chlorophyll-a concentrations (µg/L) of Mill Pond bottom water represented by the orange line. Red circles represent the in-field calibration measurements.

Dissolved oxygen (DO) concentrations measured at 0.5-meter depth at 18 locations around the pond found the highest concentrations near the inflow from the channel and along the West-side of the pond, with decreasing dissolved oxygen levels as the water moves toward the outlet. Lower DO was found along the eastern side of the pond than the western side (**Figure II-1**). Even with a high density of macrophytes, the pond sediments consume so much oxygen that the surface waters on the East-side of the pond become hypoxic/anoxic. The high rates of oxygen uptake by the sediments and plants/phytoplankton within the water column at night. In locations with the highest dissolved oxygen at 0.5 m depth, the dissolved oxygen at 1-meter was still less than 2 mg/L, indicating that the bottom water throughout the pond was hypoxic/anoxic. Also indicating that low dissolved oxygen in the Northeast section of the pond, could be related to the shallow depths.

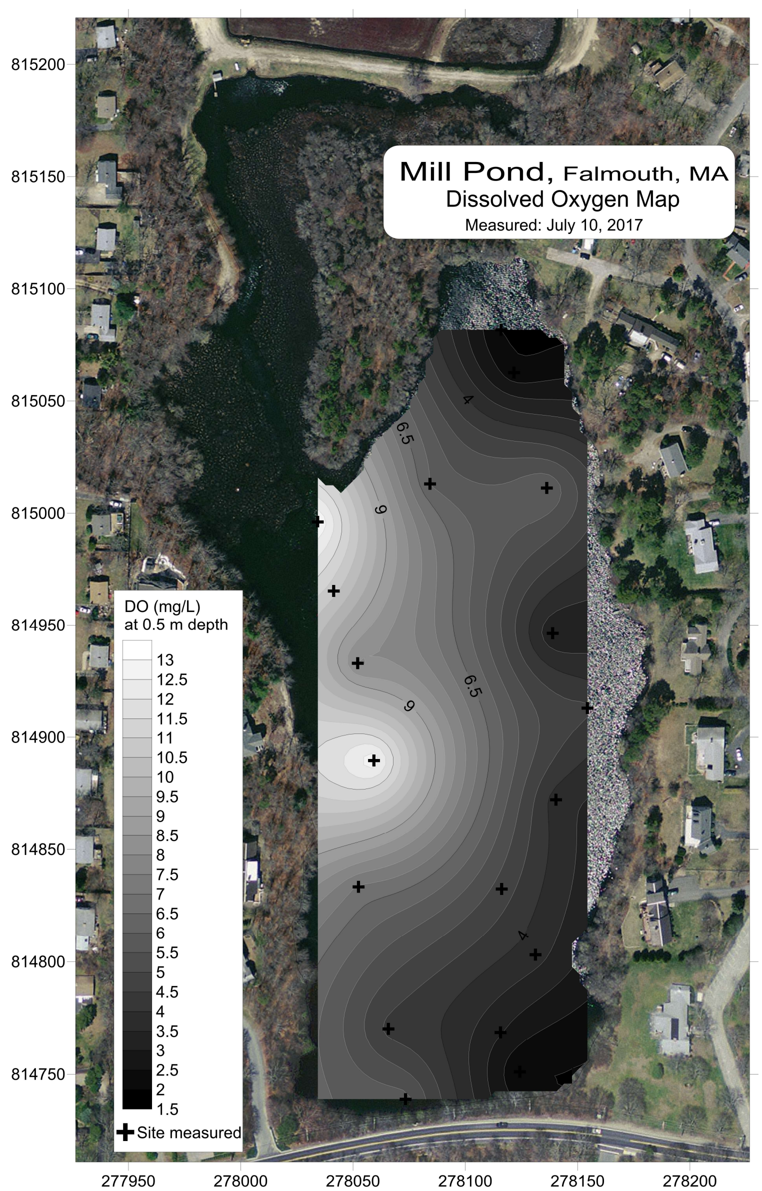


Figure III-8. Distribution of dissolved oxygen in Mill Pond at 0.5 meter depth determined from measurements at 18 locations (7/10/2017).

Rooted Macrophyte and Bathymetric Survey

Macrophyte distribution throughout Mill Pond was determined by identifying the macrophyte species in the pond and marking their location with GPS to create a distribution map. Locations of macrophytes were digitized and labeled accordingly using Geographic Information System (GIS) Mapping Software (**Figure III-9**). There are 10 dominant species of aquatic vegetation and one macroalgae in Mill Pond. Floating aquatic vegetation includes: watershield, yellow water lily, and watermeal. Submerged aquatic vegetation includes: bladderwort, milfoil, pondweed, and curly leaf pondweed. Emergent aquatic vegetation includes: Canada rush, bayberry bush, and sedges. The one type of macroalgae is filamentous green algae. Many of the submerged and floating aquatic vegetation cohabitate the same areas in the pond, making the plant density and biomass very high.

Plant density was assessed by SCUBA diver surveys at eight sites in May and June 2017. The average percent coverage is reported in **Table III-7**.

Table III-7. Aquatic vegetation total percent coverage at each of the 8 survey sites.

Site	SAV % Coverage
MP1	95%
MP2	100%
MP3	100%
MP4	95%
MP5	95%
MP6	90%
MP7	80%
MP8	80%

Macrophyte biomass was assessed in October 2017 by collecting aquatic vegetation inside a 0.25 square-meter quadrat placed at the sediment surface. All macrophytes were collected in each of three quadrats placed at two locations in the pond. The macrophytes were sufficiently rinsed off and patted dry for determination of wet weight, and then dried at 64 ˚C to constant weight for dry weight. The average wet and dried biomass per square meter was 11.1 and 0.98 kg/m^2, respectively. The macrophytes nitrogen and carbon content was determined using a PE2400 Series II CHN Elemental Analyzer. Phosphorus content was determined on the same samples by acid digestion. The plants averaged 36.6% carbon by weight, 2.8% nitrogen and 0.06% phosphorus (of dry weight). The nitrogen and carbon content were used to determine the total mass of C and N held within the vegetation per unit area of pond bottom (**Table III-8**). Using macrophyte density, biomass, nitrogen content, and surface area of the pond from bathymetric analysis, the mass of N and P held by the aquatic plants pond-wide in summer is estimated to be approximately 453 kg nitrogen and 9.8 kg phosphorus. The N:P ratio of the plants is approximately 102 N: 1P.

Table III-8. Concentration (%)and weight of nitrogen, carbon and phosphorus held in aquatic vegetation at the end of the growing season, per square meter.

Location	Quadrat	Wet Biomass (g/m^2)	Dry Biomass (g/m^2)	%N Of Dry Biomass	%C Of Dry Biomass	%P Of Dry Biomass	g N/m^2	g C/m^2	g P/m^2
NE SHORE -	**Q1**	2472	175	2.6	32.8	0.03	4.5	57	0.047
NE SHORE -	**Q2**	2371	191	2.4	33.0	0.13	4.6	63	0.250
NE SHORE -	**Q3**	2911	206	2.7	38.9	0.03	5.6	80	0.063
NW SHORE	**Q1**	3025	344	3.9	38.6	0.07	13.3	133	0.242
NW SHORE	**Q2**	3183	315	2.5	37.5	0.05	7.7	118	0.147
NW SHORE	**Q3**	2686	243	2.8	38.8	0.07	6.7	94	0.170
Average		2775	246	2.8	36.6	0.06	7.1	91	0.153

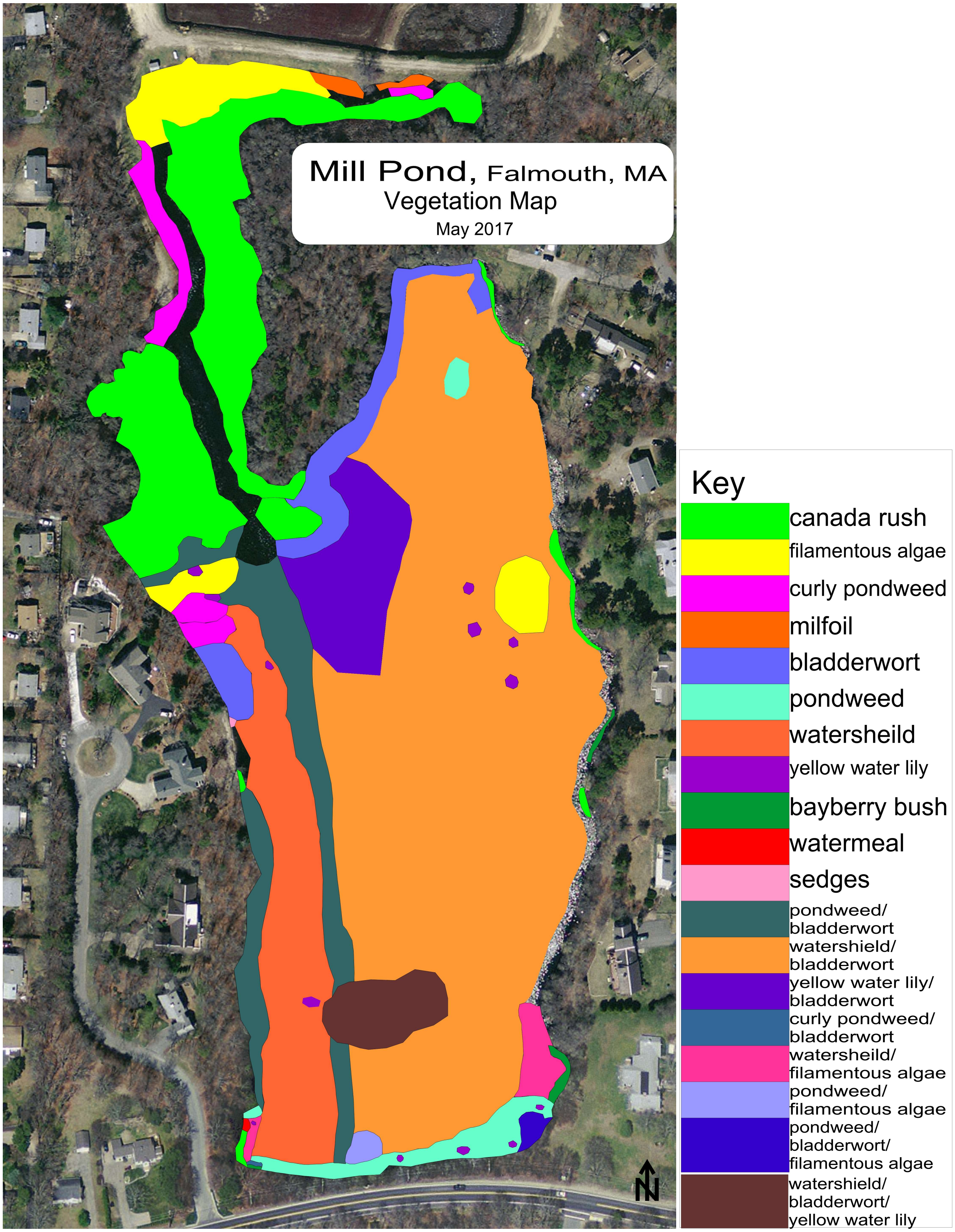


Figure III-9. Rooted vegetation map. Macrophyte and macrophyte assemblages greater than five sq. meters are depicted with color.

Due to shallow depths and dense vegetation, pond bathymetry was determined during a June 2016 survey using manual depth measurements to the nearest centimeter and a Garmin 76 handheld GPS unit for LAT LON. Over 400-point depth measurements were compiled into x-y-z coordinated systems to produce a detailed bathymetric map of Mill Pond (**Figure III-10**).

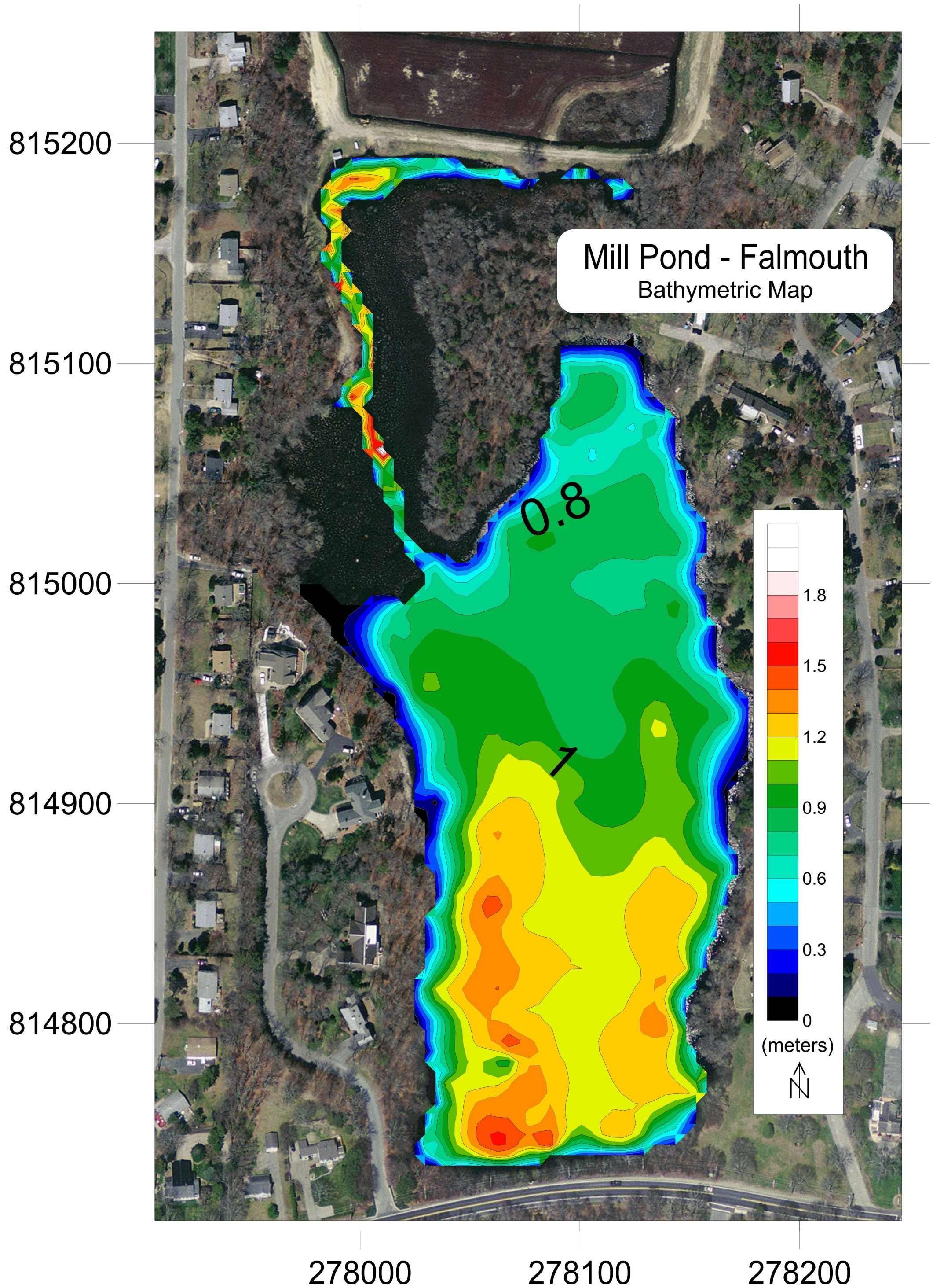


Figure III-10. Bathymetric Map of Mill Pond, representing the benthic morphology of the pond.

Determination of Water Residence Time in Pond

Mill Pond is a 15.6-acre pond, dominated by surface water in and out flows. The bathymetric study revealed that pond has a volume of 36,050 m^3. During the 2015-2017 assessment, the pond average daily discharge was 4,891 m^3/day, resulting in an average annual water residence time of 7.4 days. However, water residence time during the summer is more critical to pond dynamics. In 2016 and 2017, the June – August residence time was 7.2 days and 5.3 days, respectively. The difference in these two summers is attributed to the interannual hydrological conditions, which reveal that 2016 was a dry year and 2017 was a wet year.

Due to cranberry bog irrigation and flooding practices and natural seasonal variations in the inflows, the flow in / out of the pond varies throughout the year, with the most noticeable variations occurring during harvest (October) and winter (December- February) floods (**Figure III-11**). To harvest the cranberries and protect the plants during the winter, the bogs are generally flooded. This requires the bog operator to place boards in the outflow culvert between the bog and Mill Pond. These boards stop almost 100% of the surface water flow from the bog into the pond. However, residual pond water, groundwater, and precipitation allow water to flow from Mill Pond into Backus Brook. During the period of study, the outflowing surface water flowed continuously, with lowest flows occurring in January, averaging approximately 550 m^3/day, going as low as 50 m^3/day on a single day. Highest flows occurred in March, averaging, 11,200 m^3/day, going as high as 30,000 m^3/day for a single day. Large variations in stream flow is the major determinant of residence time of water in the pond (Figure III-12). During the low flow period, January through mid-February, water entering when the boards are emplaced may not be discharged until the boards are removed restoring surface inflow (approximately 60 days). In contrast, during the high flow period in March, a parcel of water may move through the pond in as little as one day.

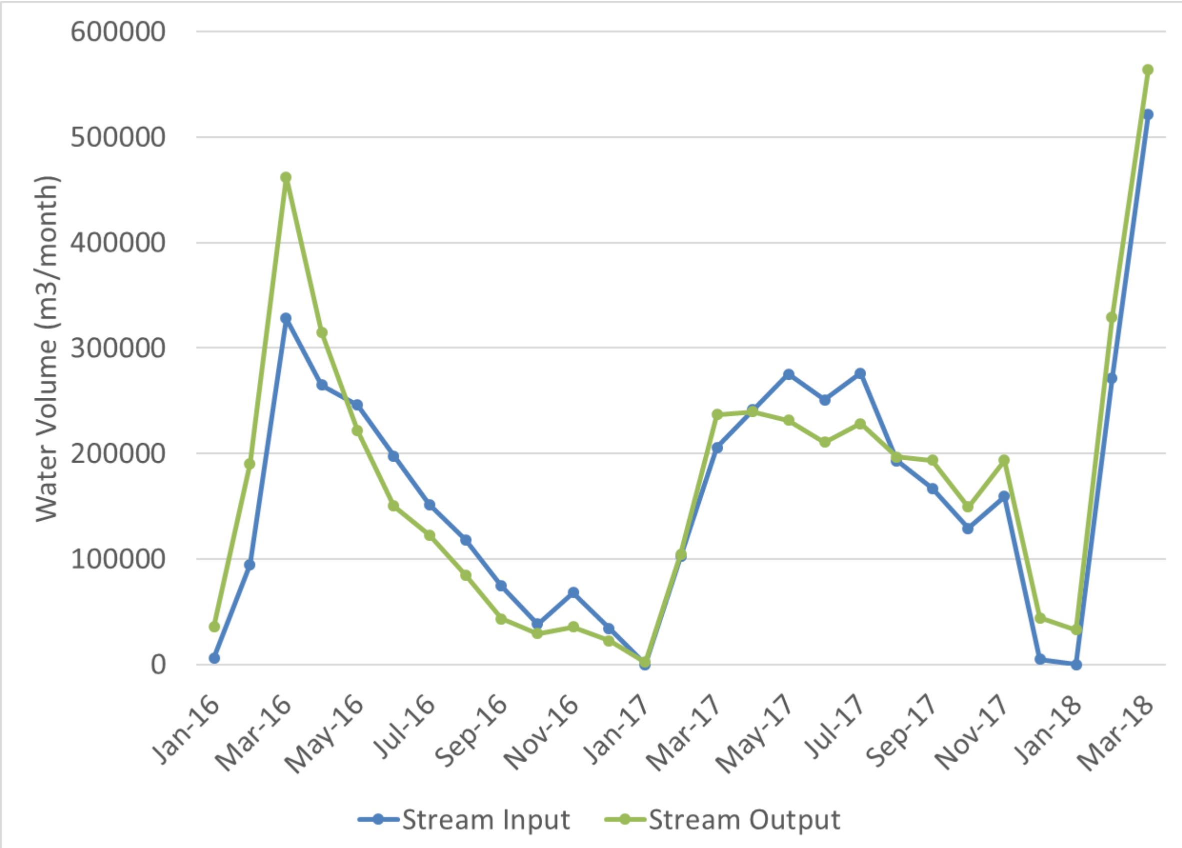


Figure III-11. Monthly water volumes of surface water inflow and outflow, showing the strong variation in flows over a year. Note: groundwater inputs are not included in the inflowing water volume.

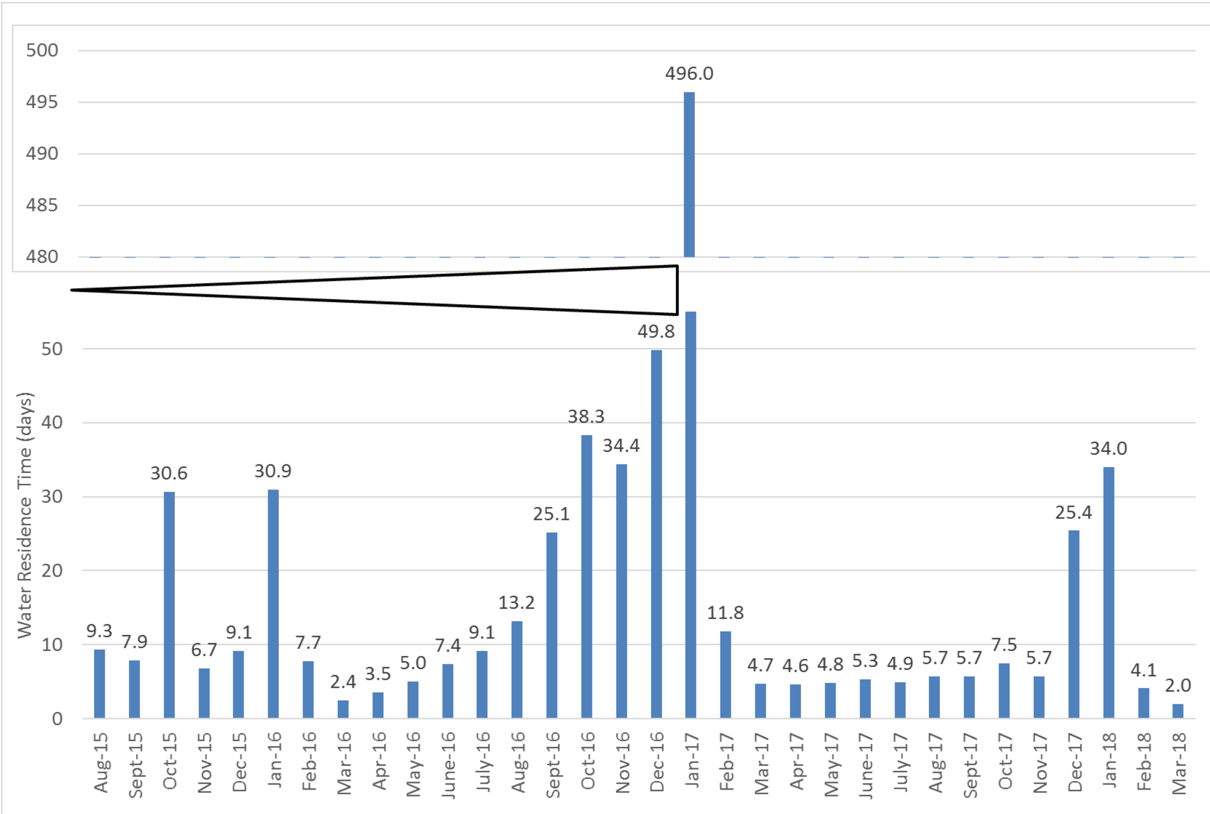


Figure III-12. Water Residence Time for each month of the current study. High water residences occur during harvest and winter flood, with the lowest residence time occurring in March and April after bog flood waters are released.

Irrigation practices were also found to increase the water residence time in the pond by changing the flow dynamics of the pond when water is pumped from the channel back to the bog for irrigation. This practice causes the input flows to appear higher than the outflows, as a result of the return of non-infiltrated irrigation water re-entering the pond (double counting) needs to be corrected for in the raw inflow data (**Figure III-11**). This flow dynamic typically occurs between April and September when bogs are irrigated for frost protection (April and May) and irrigation (June-September).

Sediment Burial Analysis

Nitrogen and phosphorus can be lost from pond waters through burial of organic matter from plants and phytoplankton in bottom sediments. Burial of N and P was assessed by Dr. Matthew Charette and Owen Filiault, in October 2016. They collected a single 50-centimeter core at the center of Mill Pond. The sediment was comprised of a silty surface gradually becoming sandier with depth (**Figure III-14**). At approximately 20 centimeters, there was a thick sand layer. Water content was greatest in the fine sediment layers in the top 20 cm of the sediment column (**Figure III-13**).

137-Cesium and 210-Lead profiles were used to determine the rate of sediment accretion and the associated mass of N and P over recent decades. Profiles of 137-Cesium typically show two cesium peaks, each peak relating to a very specific atmospheric Cesium event. The larger peak identifies mid-1960s nuclear tests and the smaller peak is from the Chernobyl nuclear accident in 1986. Profiles of 210-Lead generally show highest levels near the sediment surface where it is deposited and declines with depth due to decay. 210-Lead is deposited on Earth's surface at a constant rate, and immediately begins to decline through radioactive decay at a known rate (Appleby & Oldfield, 1978). The sediment core collected from Mill Pond varied from these general patterns in 137-Cesium or 210-Lead (**Figure III-16** and **Figure III-15**). Based on handling procedures the elevated 137-Cesium peak and a spike in 210-Lead at the bottom of the core are likely due to the bottom of the core being contaminated with surface sediment when it was harvested and capped.

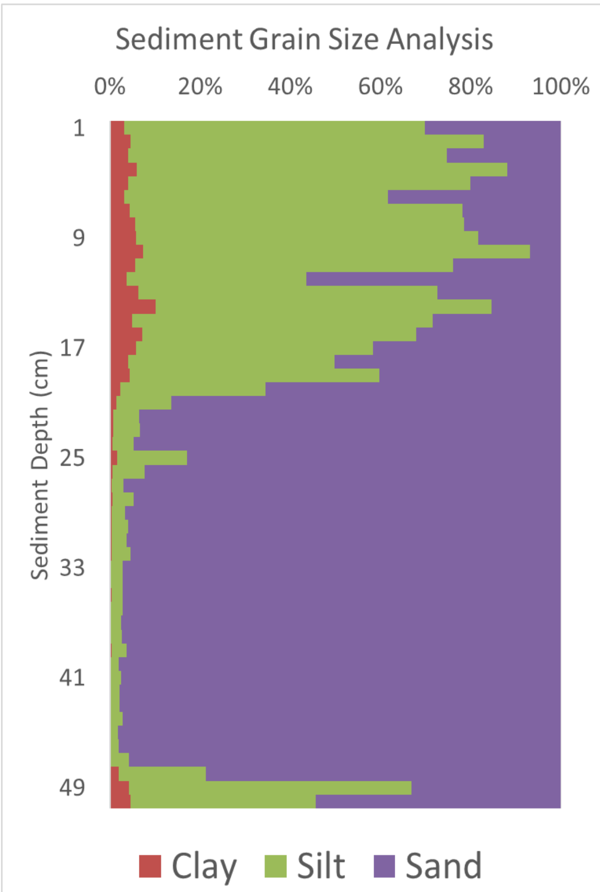


Figure III-14. Sediment grain size assemblage at depth. Figure provided by Matt Charette (WHOI).

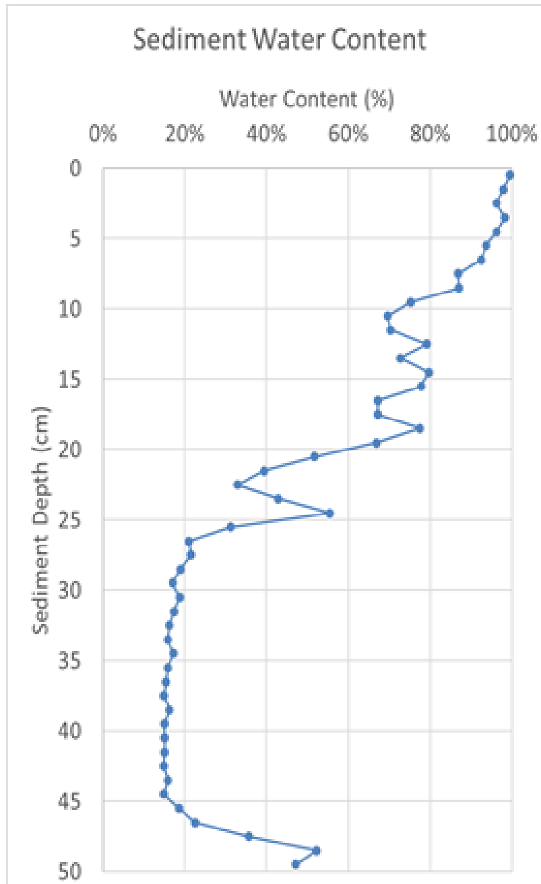


Figure III-13. Sediment water content at depth. Figure provided by Matt Charette (WHOI).

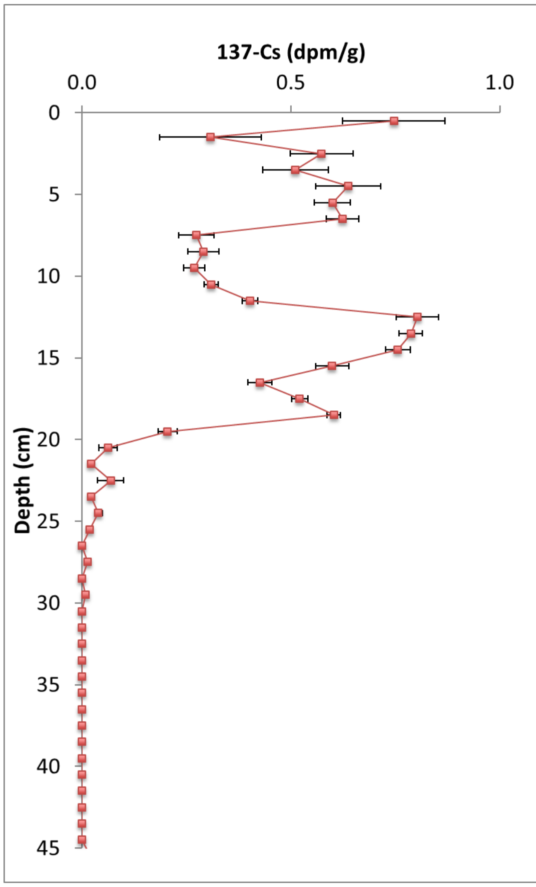


Figure III-16. 137-Cesium at depth. Modified from figure provided by Matt Charette.

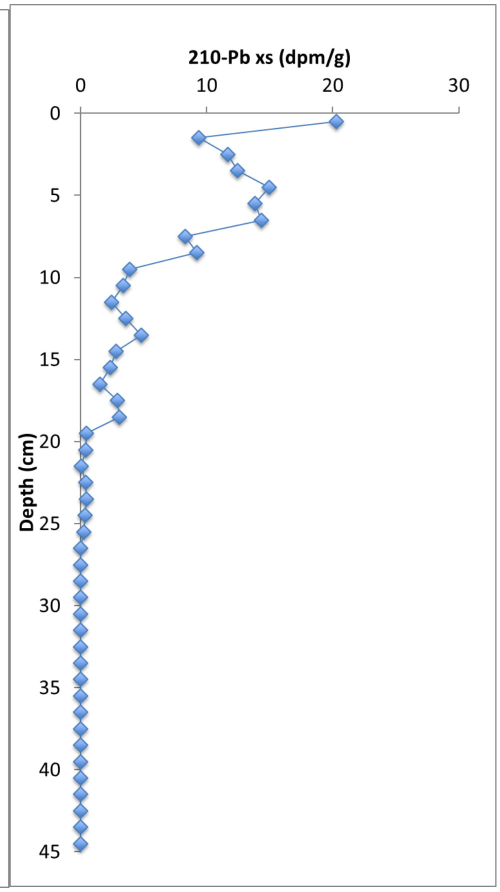


Figure III-15. 210-Lead at depth. Modified from figure provided by Matt Charette.

For the sediment accretion calculations, given the likelihood of contamination at the bottom of the core from handling, only data from the upper 45 cm was used. The recent rate of sediment accretion was determined by the amount of sediment that has accumulated over lower 137-Cesium peak the bottom of the peak corresponds to ~1966, suggesting 20-centimeters of sediment had accumulated post 1966. This approximate accretion rate was used to calculate average nitrogen and phosphorus burial per year, assuming steady state. The average annual burial rate of nitrogen and phosphorus was determined to be approximately 921 kg N per year and 24 kg P per year over the entirety of Mill Pond.

Nutrient Dynamic Assessment with Box Model

Box Model Calibration

A variety of numerical tools can be employed to better understand the dynamics of aquatic systems. In the case of an estuary, which is extremely dynamic due to tidal exchange, a time varying linked hydrodynamic/water quality numerical model would be needed to realistically represent changes in the system based on varying nutrient inputs and outputs to the system. In the case of fresh ponds, including Mill Pond, a simpler yet robust approach is to employ a "steady state" box model to represent the system as a function of set volumes of water in and out of the system as well as constituent loads in and out of the system. Regardless of which tool is utilized, the first step in using a numerical tool is calibration of the model.

To allow integration of the water flow and nutrient loading data and to aid in evaluating management alternatives, a box model was developed for Mill Pond, which was independently verified using salt (chloride) balance. If the pond is in steady state and all sources and sinks were measured and accounted for correctly, then the volume of water and mass of salt entering (+) and exiting (-) the pond should sum to zero. Two water and salt balances were created for two hydrologic years, October 2015 to September 2016 (2016) and October 2016 to September 2017 (2017).

Initially, the model was constructed using measured (inflow / outflow, stormwater, precipitation) and modeled (groundwater, evaporation) input and output terms. The box model developed using 2016 water values appeared to balance well (within 4%), whereas the model developed using the 2017 water values for flow did not balance as well (within 17%). Similar results were obtained using the conservative constituent (chloride). The salt balance was within -6% and 20% for the same 2016 and 2017 periods (**Table III-10**) when comparing mass of salt into the pond versus salt out of the pond.

Table III-9. Measured water inflow, water outflow, stormwater, and precipitation and modeled groundwater, and evaporation per day used for model calibration. Groundwater values are flow-corrected based on flow ratios discussed in *Mill Pond Water Quality Conditions*.

Water Balance	2016 (m^3/day)	2017 (m^3/day)
Vstream input	4735	4967
Vgroundwater*	531	480
Vprecipitation	182	235
Vevaporation*	-89	-89
Vstream output	-5139	-4644
Vstormwater	13	16
Vcranberry irrigation	?	?
Total Inputs	5462	5699
Total Outputs	-5228	-4733
Vsum	234	966
Balance	4%	17%
Notes: * indicates modeled from MEP landuse database		

Table III-10. Measured salt mass at the inflow, outflow, stormwater, and precipitation and modeled groundwater, and evaporation per day used for model calibration.

Salt Balance	2016 (g/kg)	2017 (g/kg)
Sstream input	190768	216111
Sgroundwater	13278	12001
Sprecipitation	4745	6122
Sevaporation	0	0
Sstream output	-197204	-205409
Sstormwater	315	390
Scranberry irrigation	?	?
Total Inputs	209106	234623
Total Outputs	-197204	-205409
Ssum	11902	29215
Balance	6%	12%

Further investigation revealed that the greater difference in water and salt balance found in 2017 than 2016 (**Table III-9**, **Table III-10**) were associated with water withdrawals/return associated with cranberry bog irrigation. Based on the results of the box model runs using 2016 and 2017 input terms, bog irrigation during 2016 appeared to have minimal water recycling (*i.e*., double counting of flows) as water removals did not return via the channel into the pond. Alternatively, bog irrigation in 2017 appears to have been significant and had significant water return to the pond. This interannual difference appears to result from groundwater levels returning after the drought years of 2013-2016 and the high rainfall summer of 2017 (2x precipitation May-September than drought summers). The result would be that the bog would be more consumptive in 2016, with little water returning to the pond compared to 2017, and it is this water return that appears to be causing the greater departure in box model output from observed data in 2017 (*Appendix C*).

Given the observations, it was possible to deal with the issues associated with irrigation return flow on the stream input measurements to provide a more accurate input term for the model. Using the measured (outflow, stormwater, precipitation) and modeled (inflow, groundwater, evaporation) input and output sources of water, a water balance unaffected by bog irrigation was developed. The result of correcting for return flow is that the 2016 and 2017 water budgets balance, within 2% and 3%, respectively (**Table III-11**).

The calibrated model (balanced for water volumes) was validated using the salt loads (specific conductance/salinity) for each water source and output). Salt is commonly used for this purpose, as it is conservative by nature (as opposed to nutrients). Salt is not transformed via biological processes the way nitrogen and phosphorus can be. Specific conductance as a measure of salt concentration was measured with stream inflow / outflow and stormwater volume measurements. The result compared very well with the water balance in the box model, salt balanced within 3 and -3% for 2016 and 2017, respectively **Table III-11**, **Table III-12**). This indicates that almost all the sources and sinks of water have been identified and the model is sufficient robust for examining nitrogen and phosphorus inputs and losses, as well as making initial predictions over the effects of hydrologic or nutrient loading modifications on pond nutrient levels and nitrogen attenuation rates.

Table III-11. Measured water outflow, stormwater, and precipitation and stream water inflows (adjusted for recycled irrigation water), groundwater, and evaporation per day used for model calibration.

Stream Input Corrected Water Balance	2016 (m^3/day)	2017 (m^3/day)
Vstream input*	4607	4164
Vgroundwater*	531	480
Vprecipitation	182	235
Vevaporation*	-89	-89
Vstream output	-5139	-4644
Vstormwater	13	16
Vcranberry irrigation	?	?
Total Inputs	5334	4896
Total Outputs	-5228	-4733
Vsum	107	163
Balance	2%	3%
Notes: * indicates modeled from MEP landuse database		

Table III-12. Measured salt mass at the outflow, stormwater, and precipitation and modeled water inflow, groundwater, and evaporation per day used for model calibration.

Stream Input Corrected Salt Balance	2016 (g/kg)	2017 (g/kg)
Sstream input	185633	181179
Sgroundwater	13278	12001
Sprecipitation	4745	6122
Sevaporation	0	0
Sstream output	-197204	-205409
Sstormwater	315	390
Scranberry irrigation	?	?
Total Inputs	203971	199691
Total Outputs	-197204	-205409
Ssum	6767	-5717
Balance	3%	-3%

Nitrogen Mass Balance

The calibrated and validated model was used to determine the net movement of nitrogen in and out of the system as well as the relative importance of each source of nitrogen load. Nitrogen loads can come from external, internal, and recycled sources and are represented as such in **Table III-13**. Nitrogen loads defined in the analysis of surface water flow in / out, stormwater, land-use, groundwater, and precipitation as well as sediment regeneration, denitrification, and burial were used to determine the nitrogen mass balance of Mill Pond (net in or out).

Comparing the nitrogen load into Mill Pond to the load leaving the pond results in an estimate of how much N-load is attenuated (reduced) in transit through the pond system. Based upon the lower total nitrogen load (1055 kg yr^{-1}) discharged from Mill Pond in 2016 compared to that which entered Mill Pond from surface water inflow, its watershed (direct ground discharge) and precipitation (2553 kg yr^{-1}), the integrated attenuation in passage through Mill Pond in 2016 prior to discharge to the Green Pond estuary was 59% (i.e. 59% of nitrogen input to Mill Pond does not reach the Green Pond estuary). Nitrogen attenuation in passage through Mill Pond was even higher in 2017, with only 866 kg yr^{-1} of the 2429 kg yr^{-1} entering the pond being discharged to Green Pond, an overall attenuation of 64%. These attenuation rates compared well to that measured previously by the Massachusetts Estuaries Project (MEP, 2004) using a less refined approach which yielded a 67% attenuation rate.

As a cross check on the measure of N-attenuation, if all the nitrogen attenuation is taking place through biogeochemical process within Mill Pond, the sum of the attenuation processes (e.g. burial, denitrification) should equal the attenuated load discussed above. Burial accounts for 365 kg N removed per year. Based on a validated water budget and measurement of all input sources and the output nutrient concentrations reveal an uptake of 967 and 1,157 kg nitrate + nitrite and ammonia (NO_x, NH_4^+) in the pond. This uptake is directly translated into nitrogen gas through denitrification. Although direct measurement of sediment denitrification measured during three aerobic fluxes, revealed minimal nitrogen removal. Overall, burial and denitrification amounted to a net loss of 1332 kg N yr^{-1}, comparable to the 2016 attenuation, which was determined to be 1,498 kg N yr^{-1}, a 12% difference. Similarly, in 2017, the burial and denitrification amounted to 1,522 kg N yr^{-1} with the attenuated load of 1,563 kg N yr^{-1}, a 3% difference. Moreover, some of the "missing" nitrogen maybe associated with the irrigation practices followed by the operator of the up-gradient bog. Recall, in 2016 (drought year) water being used for cranberry bog irrigation may not have returned to the pond (*Appendix C – Potential Flow Dynamics of Backus Brook to Mill Pond and Bog Irrigation*), supported by the decreasing flows throughout the summer (**Figure III-2** and **Figure III-3**). Whereas in 2017 (wet year) part of the water used for irrigation returned to the pond, supported by the measured inflow being much higher than measured outflow, deemed double counted water (**Table III-4**). Nonetheless, the attenuation of Mill Pond in both years is comparable at 59% and 64% N attenuation in 2016 and 2017, respectively (**Figure III-13**) and is consistent with the integrated measure of attenuation determined by the MEP in 2004 (67% attenuation).

Table III-13. Nitrogen Mass Balance of the respective sources and sinks of nitrogen into and out of the pond. Attenuation processes responsible for nitrogen attenuation. Recycled nitrogen loads based on the nitrogen contained within aquatic vegetation or regenerated from the sediments.

Nitrogen Mass Balance	2016		2017	
	(kg/yr)	% of inputs	(kg/yr)	% of inputs
Input Loads:				
Nstream input	1514	59.3%	1368	56.3%
Ngroundwater*	962	37.7%	962	39.6%
Nprecipitation*	73	2.8%	94	3.9%
Nstormwater	5	0.2%	6	0.2%
Total Inputs	2553		2429	
Output Loads:				
Nstream output	-1055	-	-866	-
Nevaporation*	0	-	0	-
Ncranberry irrigation	?	-	?	-
Total Outputs	-1055		-866	
Pond Attenuation of N:	1498	59%	1563	64%
Attenuation Processes:		**% of atten. N**		**% of atten. N**
Nburial	-365	24%	-365	23%
Ndenitrification**	-967	65%	-1157	74%
Total Attenuation	-1332		-1522	
Recycled Loads:				
Nsediment regeneration	184		184	
Nplant	453		453	
Total Recycled	637		637	

Notes: * indicates modeled from MEP landuse database
** estimated from nitrate+nitrite uptake in the pond

The most significant sources of external nitrogen load to Mill Pond comes from stream inflow (58%) and groundwater (38%), with precipitation (3.5%) and stormwater outfall pipes (0.2%) making up less than 5% of the external nitrogen load. Nitrogen regeneration from the sediments is a significant source of recycled nitrogen, totaling 184 kg N / year. The anoxic period during the summer increases the rate of sediment ammonium release, also increasing the mass of bioavailable nitrogen for plant and phytoplankton uptake. Ultimately, we find that the in-pond nitrogen mass is related to both the external and internal inputs Figure III-17). However, there is a stronger correlation between the outflowing nitrogen to the in-pond nitrogen mass ($r = 0.82$) than the inflowing nitrogen to the in-pond nitrogen mass ($r = 0.61$). This indicates that in-pond attenuation and regeneration processes affect the nitrogen mass that entered the pond, and therefore more closely resemble the nitrogen mass leaving the pond.

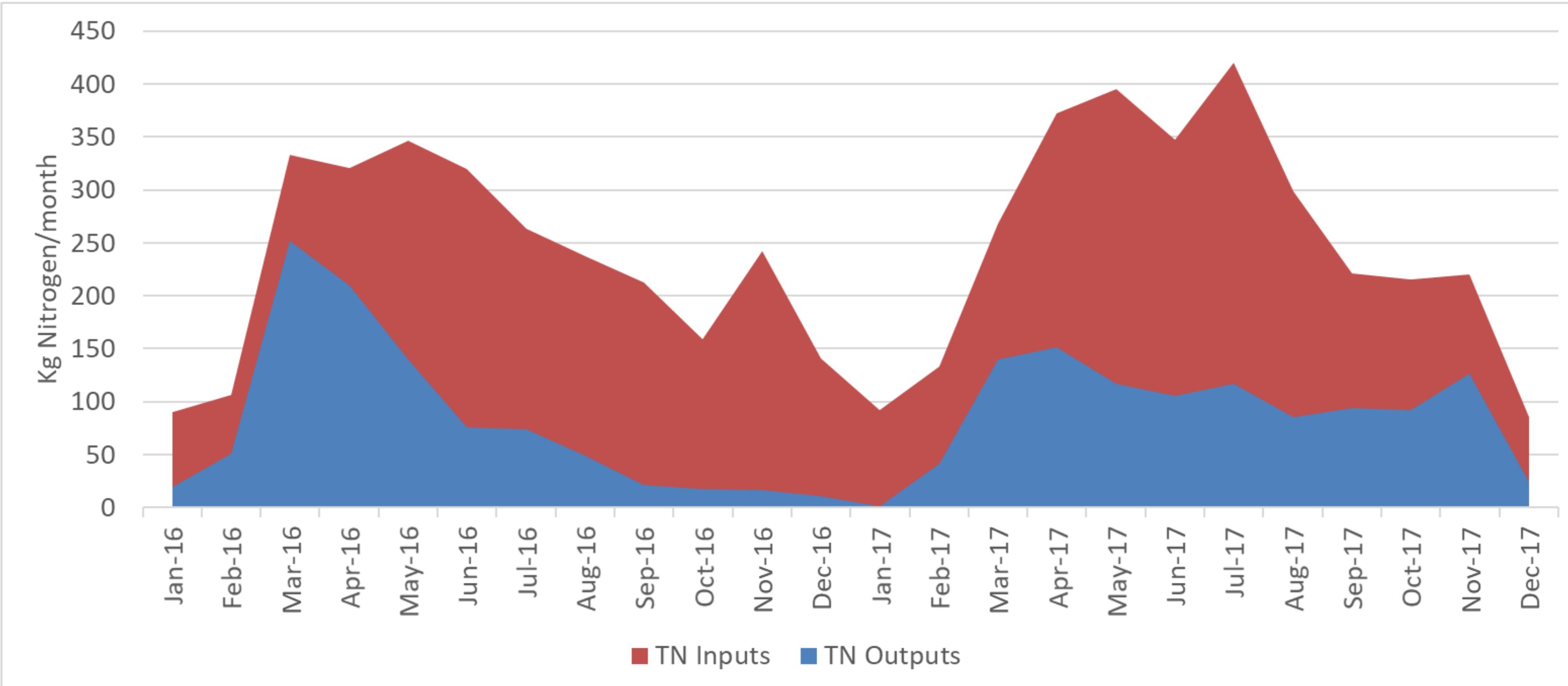


Figure III-17. Nitrogen dynamics of Mill Pond. The nitrogen mass of inputs (flow-corrected stream, groundwater, precipitation, and stormwater) and outputs (stream outflow) are in kg/month based on the flows and associated concentrations of each variable.

Phosphorus Mass Balance

Phosphorus loads to Mill Pond were determined as a component of the analysis of surface water flow in / out, stormwater, sediment regeneration, and burial. P-loads associated with each potential source/sink were assessed together to determine the phosphorus mass balance of Mill Pond. Similar to nitrogen, phosphorus loads can come from external, internal, and recycled sources and are presented as such in **Table III-14**.

Phosphorus moves very slowly with groundwater (e.g., 0.01-0.02 ft/d)[6], so the primary additions to surface water bodies tend to be direct discharges from stormwater runoff or stream inflows. Groundwater inputs tend to be limited to sources directly abutting the water body with variations in most residential settings depending on the age and distance of septic system leach fields, use of lawn fertilizers, and treatment of roof runoff. Measured phosphorus loads to Mill Pond comes primarily from the stream inflow and two stormwater pipes discharging into the pond, so other factors need to be estimated. There are approximately 40 houses within 100 m of the pond with many of the houses constructed in the 1950's. Using estimated phosphorus travel times and without detailed review of leach field distances, lawn size, or building sizes, these houses would contribute approximately 21 kg P year to Mill Pond via groundwater and another 0.5 kg P year would be added by precipitation/dry fall. More refined land use characterization would help to refine these estimates. Based on the monitoring completed during this project, the stream flowing into Mill Pond added 81 kg P in 2016 and 50 kg P in 2017, while the stormwater discharges added 1.4 kg P in 2016 and 1.7 kg P in 2017. Stream inputs would include cranberry bog P inputs. Collectively, these estimates and measurements sum to 100.2 kg P added to Mill Pond in 2016 and 70.3 kg P added in 2017.

Within the pond, phosphorus would be buried and regenerated from the sediments, altered, retained, and released by the plants, and some portion would flow out. Stream measurements showed that 53 kg P flowed out of the pond in 2016, while 42 kg flowed out in 2017. While these loads are different, the proportions of P inputs retained in the pond was approximately the same in the two years (48% in 2016 and 40% in 2017). This relationship suggests that processes impacting P sediment release and plant P uptake adjusted within the ranges seen in the two years to the changes in inputs and the variations in streamflow.

Review of sediment core incubations showed P release during the summer from anoxic sediments could be a significant addition, but this was relatively balanced by P uptake from aerobic sediments. As noted in the continuous monitoring, anoxic conditions began deeper in the pond in mid-June and lasted until late-July. Given the DO profiles measured during this period approximately half of the pond bottom could have been anoxic throughout this period, which would have been sufficient to release all the iron-bound P (*i.e.*, chemical release P). This release was 7.8 kg P, but some portion of this P would have been

[6] Robertson, W.D. 2008. Irreversible Phosphorus Sorption in Septic System Plumes? *Ground Water*. 46(1): 51-60.

returned to the sediments through the settling of particles and some portion flowed out of the pond since the residence time was estimated at approximately 7 days. The core incubation results also showed that little P would be released after the chemical release phase was completed; the average anaerobic P release was approximately 25% (2.2 kg P) of the chemical release phase. Finally, the core incubations showed that the sediments had roughly the same uptake rate as release rate when the sediments were aerobic. Collectively, the cores results suggest that the anoxic portions of the pond sediments would have been releasing P at roughly the same rate as the aerobic portions and that the area of each would have been similar. In the May and November profiles, aerobic conditions existed throughout the water column; this suggests that sediments throughout the pond would have been adsorbing P between at least December and April. Of course, all of this would have varied in real time due to changes in water inputs (*i.e.*, both precipitation and upstream bog releases), water outputs, and how much of the sediment surface was exposed to anoxia as winds altered the portion of the water column that was anoxic. Additional variations would occur depending on the rate of plant growth and sediment processes around the plant roots.

All of these P loads and removals were incorporated into box model calculations. The particulate phosphorus was calculated using the total phosphorus concentration minus the dissolved ortho-phosphate concentration which can very slightly overestimate the concentration. Phosphorus particle settling was estimated as 41 kg P in 2016, and 26 kg P in 2017. These are reasonable estimates for use in the box model to determine the main processes for phosphorus attenuation in the pond. Phosphorus loading in 2017 was significantly lower than 2016, with the pond attenuating an estimated 48 and 28 kg P in 2016 and 2017, respectively. Changes in phosphorus loading are probably related to changes in, specifically related to the cranberry bog operation. Ultimately, we find that the in-pond phosphorus mass is related to both the external and internal inputs (Figure III-18). However, there is a stronger correlation between the outflowing phosphorus to the in-pond phosphorus mass (r = 0.99) than the inflowing to the in-pond phosphorus mass (r = 0.84). This indicates that in-pond attenuation and regeneration processes affect the phosphorus mass that entered the pond, and therefore more closely resemble the phosphorus mass leaving the pond.

Table III-14. Phosphorus Mass Balance of the respective sources and sinks of phosphorus into and out of the pond (external loads). Sources and sinks of phosphorus occurring within the pond (internal loads). Recycled phosphorus loads based on the phosphorus contained within aquatic vegetation.

Phosphorus Mass Balance	2016		2017	
	(kg/yr)	% of inputs	(kg/yr)	% of inputs
Input Loads:				
Pstream input	77	77.2%	47	67.1%
Pgroundwater*	21	21.0%	21	29.9%
Pprecipitation*	0.5	0.5%	0.5	0.7%
Pstormwater	1.4	1.4%	1.7	2.4%
Total Inputs	100		70	
Output Loads:				
Pstream output	-53	-	-42	-
Pevaporation*	-	-	-	-
Pcranberry irrigation	?	-	?	-
Total Outputs	-53		-42	
Pond Attenuation of P:	48	48%	28	40%
Attenuation Process:		**% P atten.**		**% P atten.**
Pburial	-24	51%	-24	86%
Total Attenuation:	-24		-24	
Recycled Loads:				
Psediment uptake	-60		-45	
Pplant	9.8		9.8	
Total Recycled	-50		-35	
Notes: * indicates modeled from MEP landuse database				

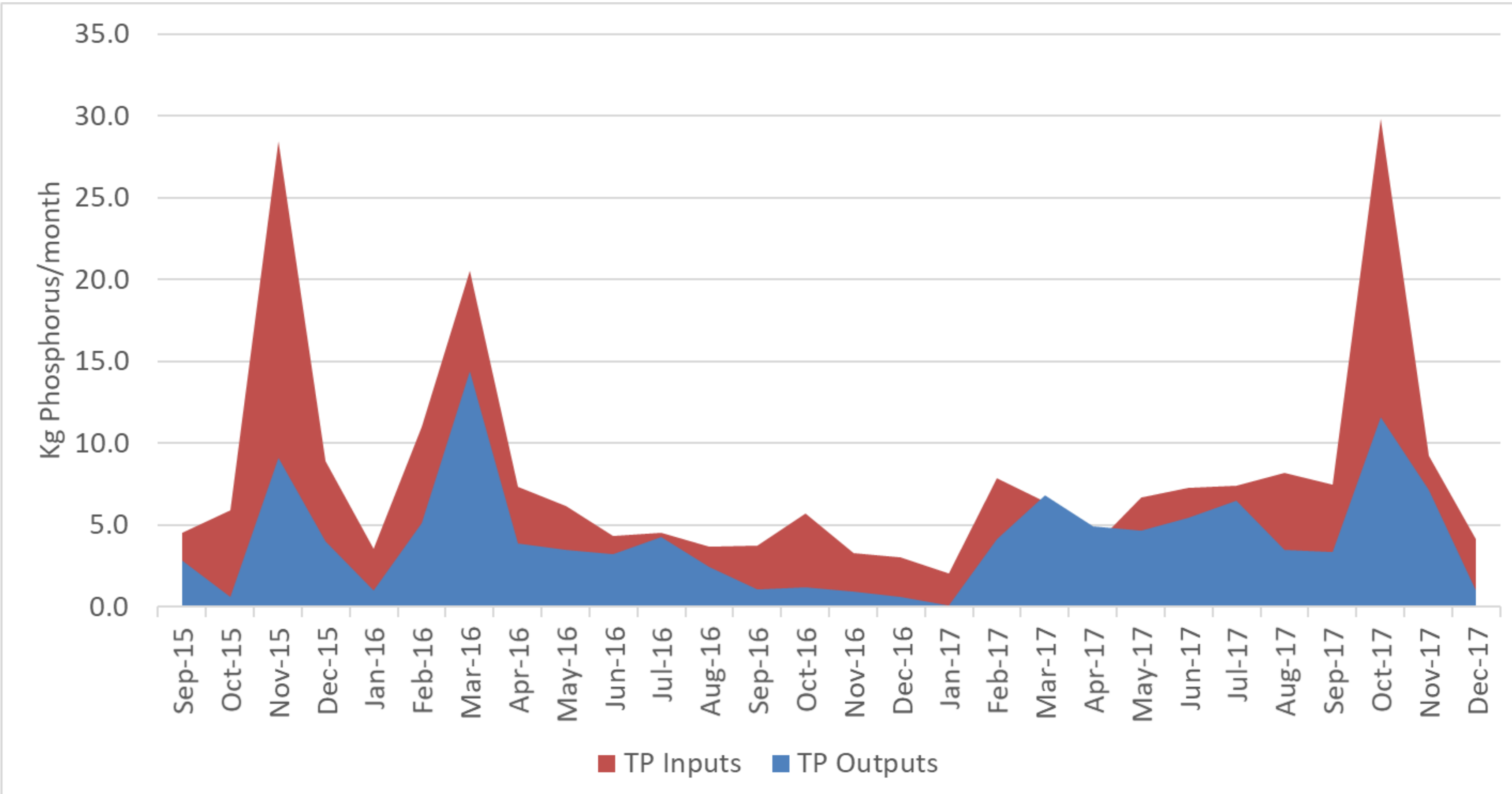


Figure III-18. Phosphorus Dynamics of Mill Pond. The phosphorus mass of inputs (flow-corrected stream, groundwater, precipitation, and stormwater) and outputs (stream outflow) are in kg/month based on the flows and associated concentrations of each variable.

IV. RECOMMENDATIONS

Mill Pond is a surface water dominated pond, receiving 90% of its water volume from Backus Brook, which flows through several cranberry bogs and is groundwater fed from the overall watershed. The annual stream inputs from Backus Brook are approximately 58% and 70% of the external nitrogen and phosphorus loads, respectively, to Mill Pond. The high concentration of nitrogen and phosphorus loading from anthropogenic activities has led to the significant impairment of the Mill Pond ecosystem. Due to high nutrient loading (N & P), Mill Pond is an eutrophic system, exceeding the Cape Cod ecoregion limits for freshwater ponds (TP ≤ 10 µg L^{-1}, TN ≤ 0.31 mg L^{-1}, chlorophyll-a ≤ 2.1 ug L^{-1}), causing persistent low dissolved oxygen and extreme algae and plant growth. Aquatic vegetation and algae have been able to thrive in the nutrient rich waters, covering approximately 95% of the pond sediment and water surface. Further, the cranberry irrigation and flooding operation periodically reduces the amount of flushing that occurs in Mill Pond, by reducing the flow of water through the pond. Slow moving water allows for increased particle settling and longer contact time at the sediment-water interface, increasing the opportunity for denitrification to occur, but also allowing the plant community extended access to available nutrients. In the case of Mill Pond, the high organic matter settling (~900 kg organic carbon) and high density of dead macrophyte material causes a high biological oxygen demand when it begins to decompose. During warmer months, when lower groundwater levels and lower stream flows often lengthen the residence time of water in the pond, more rapid warming of shallow waters causes intermittent temperature stratification and creates conditions for significant loss of dissolved oxygen in deeper waters. The low dissolved oxygen conditions in pond bottom waters results in noxious odors, release of phosphorus and ammonium from the sediments, a hypoxic/anoxic environment that is unsupportive for most organisms (particularly fish), and prevents denitrification from occurring in the sediments. The flushing time of Mill Pond is most important during the critical warmer months, June – September. This assessment revealed that cranberry irrigation during a dry summer (2016), will reduce the flow of water through the pond, increasing water residence time and lowering the pond level. However, in a wet summer (2017), the irrigation practices caused relatively little change in the flow of water through the pond, so water residence time and water levels stayed relatively consistent throughout the year. Based on the results of this investigation, Mill Pond is phosphorus-limited and management of the phosphorus load during critical summer months (June - September) is required. As part of the management strategy, it will be important to maintain or increase the high level of nitrogen attenuation in the pond for the health and restoration of Green Pond.

The impaired water quality in Mill Pond reflects both external and internal inputs of nutrients with Backus Brook stream input being the largest contribution. Management strategies to address the impairments must also address community acceptance, costs, and any potential downstream impacts on Green Pond. With all these considerations in mind, the CSP technical team recommends implementing several measures to improve water quality in Mill Pond:

(1) Potential Changes in Upstream Cranberry Bog Operations. Changes in cranberry bog operations upstream of Mill Pond have the potential for significant improvement to the pond water quality. As noted in the nitrogen and phosphorus budgets, Backus Brook is the primary source of both nutrients to Mill Pond. Given that cranberry bogs are often located along streams, strategies to address downstream transfer of nutrients have been reviewed at several bogs. A preferred option to preventing particle and plant debris transport into Mill Pond is to construct a 0.25+ acre detention pond

above the Mill Pond culvert, allowing plant debris, and particulates to settle out before entering Mill Pond, reducing the particulate N and P loads possibly 192 and 40 kg yr^{-1} respectively (Figure IV-1). This management alternative has been discussed with the bog owner, who is supportive of this option. CSP scientists also observed a lack of flushing during the harvest and winter bog floods, so it is recommended that boards placed for the floods be placed to exactly the height necessary to complete cranberry harvest and preserve the plants during winter. This adjustment would allow greater flow from the bog to the pond during the harvest and winter flood periods, thus helping flush the pond. Discussions with the bog owner indicated that this would be possible, but that the improvement in flushing would be dependent on the specific annual flows. Other recommendations included: a) alternating between "low P" and "no P" fertilizers to help reduce the P export from the bog (should have relatively little impact to the bog operation or harvests), b) removing the flood boards one at a time over a couple days to keep water velocities low and prevent scouring and mobilization/export of fine particles in the bog channels, and c) placing a metal grate between the bog and pond to catch debris and prevent the transport of plant detritus to Mill Pond (will require regular seasonal cleaning). Overall, these recommendations were discussed with the bog owner and he indicated a willingness to adjust some of the practices within his operation as part of a plan to improve the health of Mill Pond.

(2) Pond Macrophyte Management. As the macrophytes grow from March to October, they take up approximately 453 kg of nitrogen and 10 kg of phosphorus. This organic nitrogen and phosphorus is shifted to the sediments when the macrophytes die. As the macrophytes decay, the bacterial community consumes the oxygen in the overlying waters and if oxygen is sufficiently low, the macrophyte-associated nutrients are released back into the water column. Given the large macrophyte biomass currently growing in the pond each summer and the biological oxygen demand it represents, it is recommended that a macrophyte harvesting program be considered as an part of an adaptive management approach to lowering phosphorus levels of Mill Pond. Harvesting would likely occur only occasionally, and could be reduced once phosphorus levels drop sufficiently. This type of approach is currently used by the Town of Brewster (C. Miller pers. Comm.) and the Mill Pond approach could use guidance and protocols from their use. Permitting would likely have to further refine the implementation details. As the Town of Brewster has its own plant harvester, CSP staff have begun investigating this option for Mill Pond and potential access to the harvester. While the ultimate solution will require reducing nutrient inputs, macrophyte harvesting can accelerate the process. It should be noted that macrophyte harvest should be completed in the late summer/early fall to maximize biomass/P removal and conform to any time of year restrictions that might apply to Mill Pond for fish passage. If the macrophyte harvesting is performed during cranberry harvest when the water residence time of the pond is usually longer than 7 days, it will allow maximum deposition of any resuspended particles, preventing transport downstream to Green Pond. Additionally, the pond level will be low due to water usage for bog flooding, allowing for easier removal of macrophytes. Macrophytes nutrient removal can be measured by analyzing the plant material removed. If only conducted every few years new macrophyte growth will continue to take up nitrogen, carbon, and phosphorus in the sediments resulting in further "stored" phosphorus removals, potentially leading to higher pond dissolved oxygen levels over time which will have a major positive impact on reducing summer phosphorus loading to the water column. In addition, improving the sediment environment will also help improve nitrogen removal by denitrification, which would improve Green Pond to the extent it increases current nitrogen attenuation.

(3) Reducing Sediment Phosphorus Regeneration and Improving Bottom Water Oxygen. The regular anoxia in the bottom waters of Mill Pond is reflective of impaired conditions, including being well less than the MassDEP minimum for warm surface waters [5 mg/L; 314 CMR 4.05(b)]. Anoxia is due to the large amount of decaying biomass in the sediments and the anoxia creates conditions that favor the regeneration of nutrients into the water column, as well as the potential for nuisance conditions, such as release of hydrogen sulfide gas (*i.e.*, rotten egg smell). Measurements during the current effort indicated that the anoxic conditions contributed to the seasonal re-release of 10 kg of phosphorus and 184 kg of nitrogen into the Mill Pond water column. The re-release was the second largest phosphorus source to Mill Pond after the upstream additions from Backus Brook. Potential ways to address bottom anoxia in freshwater Cape Cod ponds typically include aeration/enhanced mixing, Alum applications, or dredging. These approaches are typically considered together with estimates of costs, discussion of implementation details, and regulatory permitting. As an example, an aerator would add oxygen to the bottom waters to address the biological oxygen demand in the sediments and higher DO concentrations would minimize the chemical conditions that cause the regeneration of nutrients. Use of aerators in freshwater ponds typically remove between 1/3 and 2/3 of regenerated phosphorus; performance will be dependent on the details of the aerator design and characteristics of the pond. Details of the aeration system could be developed through a public procurement and permitting process; there are a number of designs for aeration systems. Issues to address typically include pure oxygen or air addition, source of power (shoreline or solar), and community acceptance of impacts (*e.g,* costs, noise, and visual impacts, such as surface machines, shoreline generators or water surface disturbance). Alum (aluminum sulfate) application to pond sediments has also been found to be effective in lowering phosphorus levels in the 10 Cape Cod ponds/lakes where it has been used (e.g. Ashumet Pond, Hamblin Pond, Long Pond, etc.). Alum is used in ponds that might experience anoxia as it forms an insoluble precipitate that binds with phosphorus under both oxic and anoxic conditions. As opposed to iron which only works in oxic environments. In Mill Pond an alum treatment would reduce the phosphorus sediment regeneration by 70%, and a single application should last for approximately 10 years. The aerator also holds the phosphorus in the sediments but must be maintained for ~6 months per year forever. Either method should work in the case of Mill Pond, the only difference is the operating and maintenance expenses. Overall, an in pond action (aeration or alum) combination with proposed reductions in input sources e.g. cranberry bog management changes and in pond plant harvesting should provide a solid basis to restore Mill Pond. Implementation of management alternatives needs to have ongoing monitoring to support adaptive management, since over time if source reductions are implemented and in pond options are implemented, the in-pond actions may be able to be reduced or stopped. For example, the Alum treatment might last 20+ years.

(4) Removal of Dam at Route 28. Per request, the removal of the dam at Route 28 was evaluated as a potential management option. The concept would be to remove the dam, draining the pond and creating a small freshwater wetland. Implementing this option, would remove the ecological problems that the pond is experiencing, by removing the pond itself, which may have public resistance, given the public's interest in restoring the pond to past water quality. However, the main issue to be examined is the impact of removing the dam on Green Pond water quality. Shifting from a pond to a freshwater wetland has uncertain impacts on nitrogen removal. Freshwater wetland can either remove nitrogen or be net contributors of nitrogen to outflowing streams. In this case, to Green Pond. There are numerous studies showing either freshwater wetlands as sinks or sources of nitrogen, as has been found in s.e. Massachusetts by the Massachusetts Estuaries Project. As a pond, Mill Pond is currently attenuating

64% of the watershed nitrogen flowing through it before it discharges to Green Pond. Removing this attenuation would increase the nitrogen load to the nitrogen enriched waters of Green Pond by up to 1,400 kg N yr^{-1}**.**This represents additional nitrogen that would have to be removed from the watershed to meet the Clean Water Act requirements (TMDL). This additional nitrogen removal may be less than 1400 kg N yr-1 to the extent that the freshwater wetland may take up some nitrogen, but it is highly unlikely that it will be as effective as the current pond. Therefore, resources will have to be made available to implement other nitrogen removal technologies (sewering, IA system, etc.) will be required, in order to reduce the nitrogen load to the existing nitrogen load from the Backus Brook sub-watershed to Green Pond. Given the uncertainties in future attenuation rates, public acceptance of a wetland vs pond and likely costs, removing the dam is a low priority option and cannot be recommended at the present time.

Figure IV-1 Recommended location for a detention pond above the Mill Pond culvert to prevent particle and macrophyte debris transport. Site is part of the existing bog system.

Table IV-1. Possible N and P reduction (% of total inputs), cost, benefit, and level of effort associated with the recommended management scenarios. All options will reduce phosphorus into Mill Pond, the exact amounts required further analysis, but all were selected to have at least a 5-10% P reduction. *Pond aeration systems are effective for N and P reduction during operation.

Management Recommendations	Possible N and P Reduction %	Cost	Effort	Benefit
Bog alternates b/w "low P" and "no P" fertilizers	5-10%	Low	Low	will provide some reduction of P load from bog
Slow Release of Bog Flood Water	5-10%	Low	Low	**a)** prevent debris export from channels, **b)** nutrient pulse into pond
Increase Flow during Harvest & Winter Floods	5-10%	Low	Low	**a)** Increase turnover and nutrient attenuation
Grate b/w Bog and Pond	5-10%	Low	Medium	prevent N and P in plant debris export
Construct Detention Pond	15-50%	Medium	High	catch plant and bog debris, particulates
Macrophyte Harvesting	15%	High	High	**a)** reduce recycled nitrogen, **b)** phosphorus **c)** decaying macrophyte biomass in pond; improves use of pond for recreation
Aluminum Application	70% P 0% N	Medium	Low	reduce sediment P release
Pond Aeration System*	15-30%	Medium	Low	**a)** reduce noxious smell of low oxygen, **b)** reduce sediment P release, **c)** decrease sediment N release, **d)** increase denitrification

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V. APPENDIX

Appendix A – Mill Pond Sub-watershed

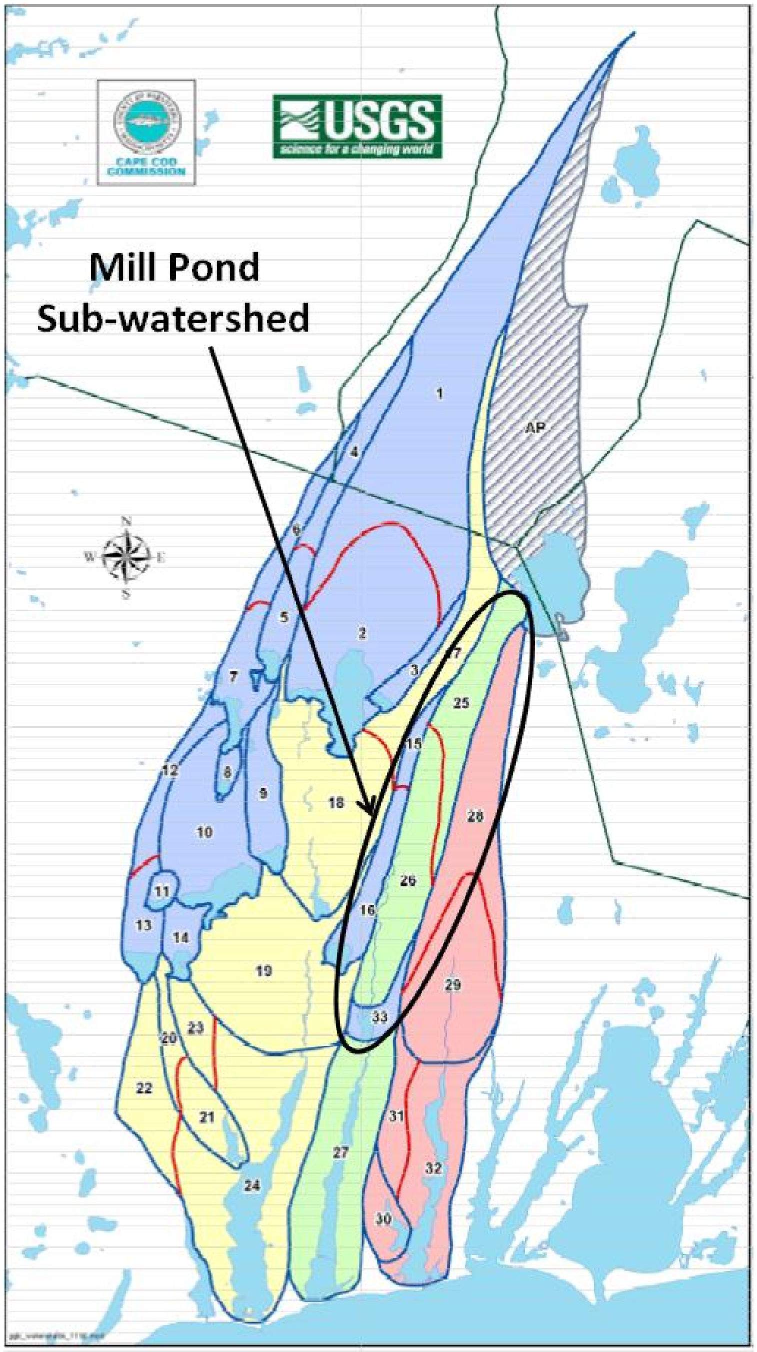
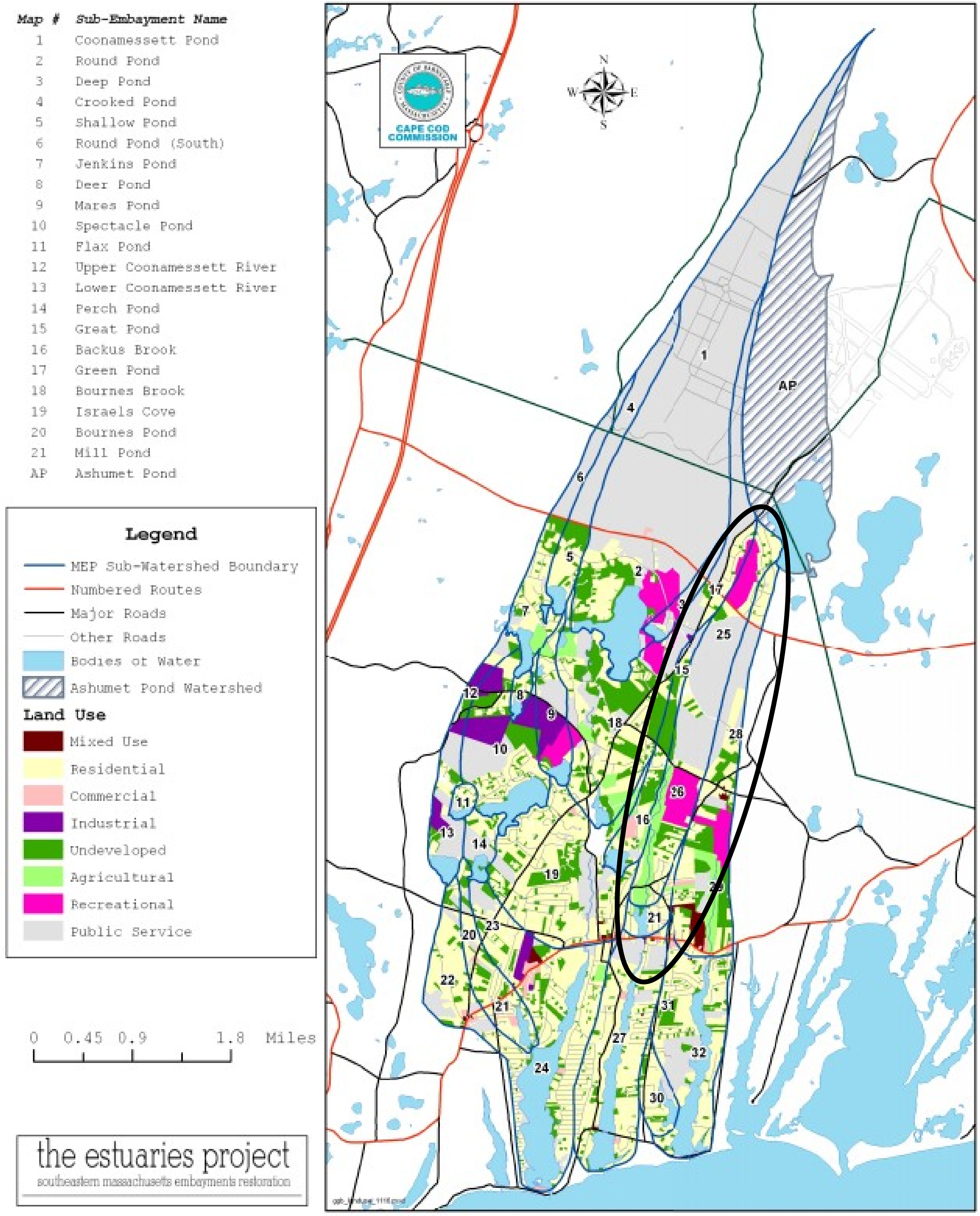
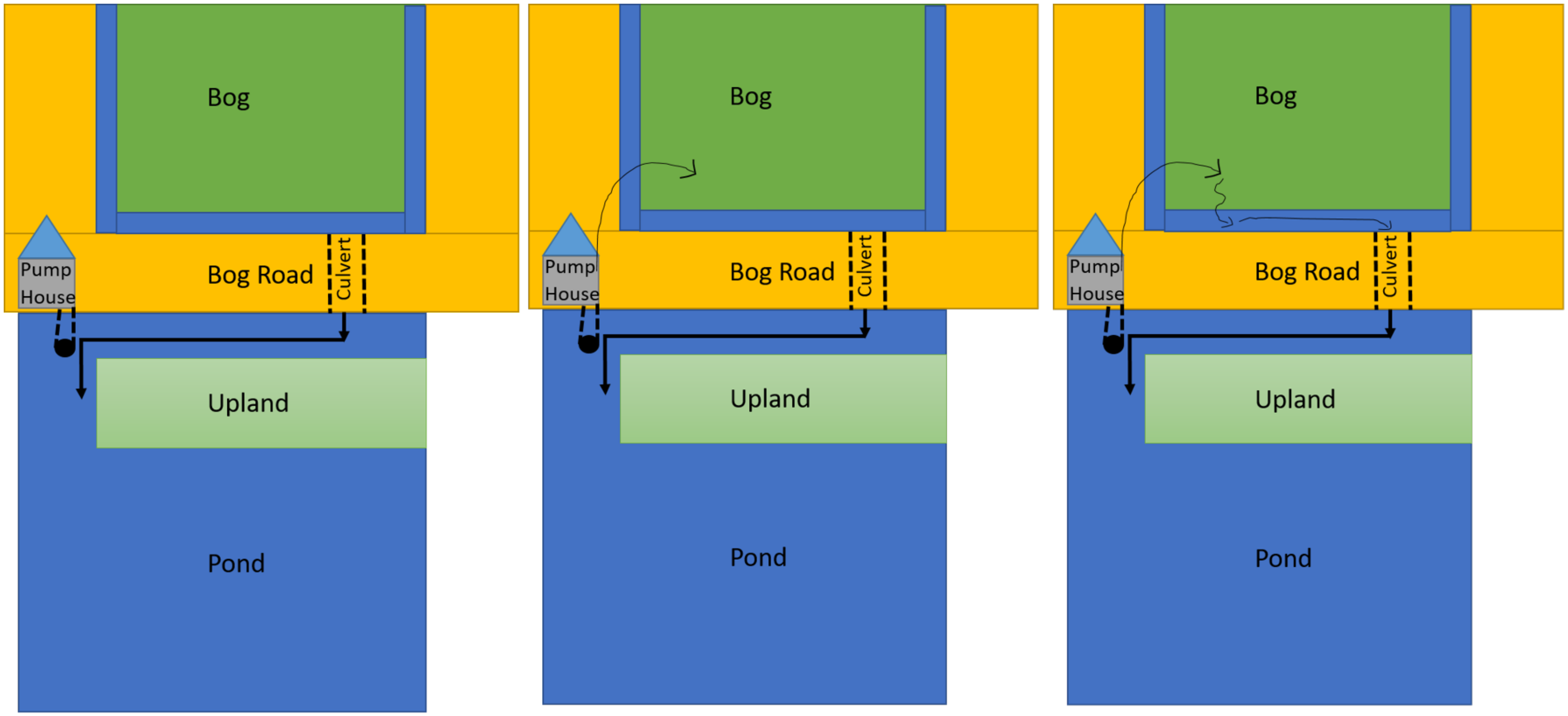


Figure V-1. Mill Pond and associated subwatersheds that will receive updated Land-use loading analysis: subwatersheds 25, 26, and 33.

Appendix B – Mill Pond Sub-watershed Land-Use Map



Appendix C – Potential Flow Dynamics of Backus Brook to Mill Pond and Bog Irrigation



Normal
Water flow when pump is not irrigating

Flow Constant and Stage Decreases
Irrigation decreases stage in channel and the water stays on bog

Flow Increase and Stage Decrease
Irrigation causes lower stage in channel and runoff from bog increases flow in culvert

Figure V-2. Schematic of possible flow dynamics for Backus Brook to Mill Pond stream flow.

Appendix D – Project Schedule

Table V-1. Project schedule.

Task	Task Description	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
1	**Update Mill Pond Watershed Land-use Loading**													**DONE**	
2	**Quantification of Surfacewater Flow and Nutrient Load In/Out of Mill Pond**													**DONE**	
3	**Determination of Water Residence Time in pond and Degree of Mixing**													**DONE**	
4	**Sediment Nitrogen and Phosphorous Regeneration / Loading plus Denitrification**								**Biogeochemical Analysis**					**DONE**	
5	**Analysis of Dissolved Oxygen Conditions in Mill Pond**													**DONE**	
6	**Rooted Plant Survey**													**DONE**	
7	**Reporting and Project Management**									**Synthesis and Report - DONE**				**Meetings**	

Appendix E – Letter and Survey to the Bog Operator

UMASS-Dartmouth School for Marine Science and Technology

New Bedford, MA

Diagnostic Assessment of Nutrient Cycling in Mill Pond

Dear Bog Operator:

I am writing to you to ask if you would assist the Town of Falmouth and the University by providing information related to the feasibility of improving the ecological health of Mill Pond, the freshwater basin before the Backus Brook discharges to the head of Green Pond. I have provided a brief overview of the project below, but if you have any questions, please feel free to call the Coastal Systems Program at UMASS-Dartmouth School for Marine Science and Technology (508)-910-6325 or email at aunruh@umassd.edu.

The purpose of the study is to complete a Diagnostic Assessment of Nutrient Cycling in Mill Pond. Mill Pond is a constructed freshwater pond, immediately up-gradient of the head of the Green Pond Estuary. Mill Pond is a flow through pond receiving inflow via Backus Brook from the inland watershed and discharging through a culvert under Rt. 28. While the Town has been working for several years on restoration of the Green Pond Estuary, only recent concerns have been raised about the declining ecological health of freshwater Mill Pond. This 16 acre freshwater pond is currently exhibiting signs of severe habitat impairment (over-abundance of aquatic plant growth, bottom water anoxia and extremely poor water clarity) most likely due to nutrient over-enrichment, possibly related to historic inputs from the watershed which are stored in the pond sediments. As such, it has been the subject of preliminary assessment efforts by SMAST scientists over the past year.

As part of the preliminary assessment and citizen concerns, CSP-SMAST was asked by the Town of Falmouth to complete a study to understand the role new versus recycled nutrients are having in driving the observed habitat impairment as well as determine appropriate management actions that might be taken to affect restoration of this aquatic system. Specifically, the study will aim to quantify the nitrogen and phosphorus inputs to Mill Pond from its watershed (surface and groundwater) as well as in-pond measurement of recycling of nitrogen and phosphorus from sediment regeneration. In addition, dissolved oxygen conditions in the pond bottom water and how they may accelerate phosphorus release to pond waters and resulting distribution and density of aquatic plants are being assessed. These activities coupled with ongoing hydrologic monitoring will more fully define the sources and sinks of nitrogen and phosphorus to the pond thus allowing the development of a detailed nutrient budget and water balance for the Mill Pond system. These efforts all form the basis for formulating a list of management strategies and a comparison of their cost and practicality for restoring the water quality in this system. While improving Mill Pond, attempts will also be made to ensure that whatever management actions are undertaken that the pond maintains (or increases) its current nitrogen removal capacity to protect the down gradient Green Pond Estuary.

If you are willing to assist in these efforts, we are only asking that you take 15 minutes in answering the questionnaire below pertaining to your knowledge of bog maintenance.

The decision to participate in this research project is voluntary. You do not have to participate and you can refuse to answer any question. Your name will not be public unless you indicate otherwise on the Questionnaire. Thank you.

Coastal Systems Program (SMAST)

Bog Maintenance Questionnaire for Mill Pond Falmouth, MA

1. Do you want your participation and/or responses to remain confidential? Yes No
2. Will you be willing to provide any maintenance records for irrigation and/or fertilizer application?
3. How long has this been an active bog? ____________years
4. Do you know the history of Mill Pond construction/ use for bog irrigation?

Water Use Questions

1. Do you irrigate the whole bog system using Mill Pond water?
2. How often are the bogs flooded by boarding the culvert to Mill Pond? ______per year
3. Is there a record of when the boards are placed and pulled between the bog and pond?
4. Have boards been placed or pulled from the weir at the bottom of the pond next to RT. 28?
5. How often is water pumped from Mill Pond to the bog? _____per year
6. Do you irrigate the bogs the same way every year?
    a. 2015?
    b. 2016?
    c. 2017?
7. Do you know the flow rate of the water pump and tractor pump?

Fertilization

1. How much fertilizer is applied? ____________
2. Do you use low P fertilizer (N%/P%/K%)? _____________
3. Do you apply the fertilizer with irrigation?
4. Which time(s) of the year is it applied? (circle all that apply)
    Early Spring Late Spring Early Summer Late Summer Fall
5. Do you use approximately the same amount of fertilizer every year?

Bog Maintenance

1. How often are the bog ditches mowed? ______per year
2. Are they cleared of debris?

3. Would you be willing to use a grate between the bog and the pond to prevent transport of plant debris to Mill Pond?

Thank you very much and I appreciate the time you have taken to help me gather data for my thesis.

If you are willing to provide any or all maintenance records for the bog. Please send with this questionnaire to:

Amber Unruh
706 Rodney French Blvd.
New Bedford, MA 02744
Phone: 508-910-6325
Email: aunruh@umassd.edu

If you have any additional information that wasn't covered in the questionnaire, but you would like to provide, please do so here.

NOTES: