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Selectmen's Correspondence

February 4, 2020

A. Letter from Office of the Attorney General regarding Open Meeting Law Complaint.

B. Letter from Department of Environmental Protection regarding Permit Approval - Authorization to Operate Phase 6 Landfill Expansion.

C. Letter from Buzzards Bay Coalition requests the immediate approval as final of the Megansett-Squeteague Harbor Estuarine System total maximum daily loads for total nitrogen.

D. Letter from Sagamore Cemetery Association, M. Elizabeth Ellis who submitted a final report for project completed through CPA grants for work that was done to rehabilitation of 41 damaged gravestones. Extends its deepest thanks to all who contributed for this important public/private project.

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THE COMMONWEALTH OF MASSACHUSETTS
OFFICE OF THE ATTORNEY GENERAL

ONE ASHBURTON PLACE
BOSTON, MASSACHUSETTS 02108

MAURA HEALEY
ATTORNEY GENERAL

TEL: (617) 727-2200
www.mass.gov/ago

January 17, 2020

OML 2020 – 3

Robert Troy, Esq.
Troy Wall Associates
90 Route 6A
Sandwich MA 02563

RE: Open Meeting Law Complaint

Dear Attorney Troy:

This office received a complaint from Thomas Donovan on September 19, 2019, alleging that the Bourne Board of Selectmen (the "Board") violated the Open Meeting Law, G.L. c. 30A, §§ 18-25. The complaint was originally filed with the Board on August 15 and you responded on behalf of the Board by letter dated September 4.[1] In his complaint, Mr. Donovan alleges that the Board should not have held a single executive session on July 23 for the discussion of six real estate matters and litigation regarding the fire department union.[2]

We resolve this complaint by **informal action** in accordance with 940 CMR 29.07(2)(a), and find that the Board did not violate the Open Meeting Law by discussing several different topics in one executive session. The Open Meeting Law allows executive sessions to be held under one or more of ten proper purposes. G.L. c. 30A, §§ 20(a), 21(a). Public bodies may discuss multiple topics within a single executive session, provided all are appropriate for executive session, are sufficiently noticed, and the appropriate procedures are followed to enter into executive session. See G.L. c. 30A, § 21; OML 2013-195.[3] Therefore, we do not find that the Board violated the Open Meeting Law by holding one executive session for multiple topics.

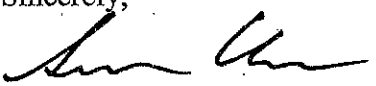
Although not specifically raised in the complaint, we take this opportunity to provide guidance to the Board on the use of executive session Purpose 6. Under Purpose 6, an executive session may be held to "consider the purchase, exchange, lease or value of real property if the chair declares that an open meeting may have a detrimental effect on the negotiating position of

[1] Unless otherwise specified, all dates refer to 2019.
[2] We decline to review any new allegations made in the request for further review. Our office does not conduct broad audits of public bodies and will address only allegations made in an Open Meeting Law complaint in order to give public bodies a chance to address those allegations. See OML Declination 4-22-15; OML Declination 8-25-2015; OML 2013-118; OML 2013-60.
[3] All previous determinations issued by the Division can be found on the Attorney General's website: https://www.mass.gov/the-open-meeting-law.

the public body." G.L. c. 30A, § 21(a)(6) ("Purpose 6"). Purpose 6 is intended to preserve confidentiality in negotiating the value of the property to be purchased, exchanged or leased to avoid putting the public body at a disadvantage in its negotiations for the property. See District Atty. for the Plymouth Dist. v. Selectmen of Middleborough, 395 Mass. 629, 631 (1985); OML 2016-50; OML 2019-10. General discussions regarding real property or the use of real property, where there is no negotiating position to protect, do not fall within executive session Purpose 6. See OML 2019-59; OML 2019-108.

We now consider the complaint addressed by this determination to be resolved. This determination does not address any other complaints that may be pending with our office or the Board. Please feel free to contact the Division at (617) 963 - 2540 if you have any questions.

Sincerely,



Sarah Chase
Assistant Attorney General
Division of Open Government

cc: Thomas Donovan
Bourne Board of Selectmen

This determination was issued pursuant to G.L. c. 30A, § 23(c). A public body or any member of a body aggrieved by a final order of the Attorney General may obtain judicial review through an action filed in Superior Court pursuant to G.L. c. 30A, § 23(d). The complaint must be filed in Superior Court within twenty-one days of receipt of a final order.

AS 1-30-20

B

Sundman, Nancy

From: Cochrane, Alison (DEP) <alison.cochrane@state.ma.us>
Sent: Thursday, January 23, 2020 9:08 AM
To: jmacleod-froman@townofbourne.com; Sundman, Nancy; Sala, George; Guarino, Terri; jidman@capecodcommission.org; Cooper, Greg (DEP); Fischer, John (DEP); Pickering, Seth (DEP)
Cc: Dakers, Mark (DEP)
Subject: Bourne Landfill Ph6 Expansion ATO
Attachments: Bourne Phase 6 ATO_SW10-0000008.pdf

See attached for the Authorization to Operate permit for the Phase 6 Expansion of the Bourne Sanitary Landfill.

Alison Cochrane
Environmental Engineer
Solid Waste Management Section
Bureau of Air and Waste

Mass Department of Environmental Protection
Southeast Regional Office
20 Riverside Drive
Lakeville, MA 02347
Phone: 508-946-2778 FAX: 508-947-6557
Email: Alison.Cochrane@mass.gov
Visit our web site: mass.gov/dep

Commonwealth of Massachusetts
Executive Office of Energy & Environmental Affairs

Department of Environmental Protection

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Charles D. Baker
Governor

Karyn E. Polito
Lieutenant Governor

Kathleen Theoharides
Secretary

Martin Suuberg
Commissioner

January 17, 2020

Mr. Daniel Barrett
Bourne Department of Integrated Solid Waste Management
24 Perry Avenue
Buzzards Bay, Massachusetts 02532

RE: PERMIT APPROVAL
Application for: BWP SW 10
AUTHORIZATION TO OPERATE
PHASE 6 LANDFILL EXPANSION (6.9 acres)
Application No. 19-SW10-000002-APP
Authorization No. SW10-0000008

AT: Bourne Integrated Solid Waste Management Facility
MacArthur Boulevard
Bourne, MA
Facility No. 39101 R.O.# 172356

Dear Mr. Barrett:

The Massachusetts Department of Environmental Protection, Solid Waste Management Section ("Department"), has completed its review of the permit application ("Application") listed above in regard to operation of Phase 6, of the Bourne Sanitary Landfill ("Landfill") and determined the Application is technically complete. Accordingly, the Application to Operate Phase 6 of the Landfill is **approved** with the conditions herein.

Application Summary

The initial Application was prepared and submitted by Sitec Environmental, Inc. ("Sitec"), Marshfield, Massachusetts, and submitted on September 24, 2019, on behalf of the Town of Bourne ("Town" or "Applicant"). The Application consisted of the following:

A. Authorization to Operate a Landfill Permit Application (BWP SW 10) received by MassDEP on September 25, 2019. The Application was divided into three parts:

- Part I Permit Application Forms
- Part II Operation and Maintenance Plan
- Part III Interim Construction Quality Assurance Report

B. Supplemental information prepared by Sitec, consisting of a response to MassDEP's October 2, 2019 comments, received by MassDEP on October 3, 2019 and October 8, 2019.

Based on its review of the above information, on October 10, 2019, MassDEP issued a partial approval to operate the Phase 6 Landfill Expansion for the placement of a buffer layer of select waste material and for the acceptance of leachate. At the time of the partial approval, construction of the Phase 6 double composite liner system was complete, with the exception of the connection to the existing Phase 4, Stage 2 liner and leachate collection systems.

Additional information was submitted on December 30, 2019, providing the information necessary for MassDEP to approve the full operation of Phase 6 of the Landfill for the acceptance of waste material. The additional information consisted of an updated version of the Construction Quality Assurance Report.

The initial Application and additional information was submitted electronically via the Massachusetts Executive Office of Energy and Environmental Affairs ePlace Portal at https://permitting.state.ma.us/CitizenAccess/ on September 25, 2019 and December 30, 2019, respectively.

The Application and Permit may be reviewed online at:
https://eeaonline.eea.state.ma.us/EEA/PublicApp/ using the "Site Name" Bourne Landfill and the "Search" tab. Under "Record Type", select the "Application" file with the September 25, 2019 "Application Date" and the "Authorization" file with the January 17, 2020 "Application Date".

APPLICATION REVIEW AND DECISION PROCESS:

The Application was submitted and reviewed pursuant to the provisions of 310 CMR 19.029(2): Applicable Permit Procedures and 310 CMR 19.033: *Permit Procedure for an Application for a Permit Modification or Other Approval.* According to these review procedures, MassDEP's decision regarding the proposed activities shall be either: a "Provisional Decision" pursuant to 310 CMR 19.033(4)(a); or a non-provisional decision pursuant to 310 CMR 19.033(4)(b). MassDEP has determined that non-provisional decision is appropriate for this Application.

MassDEP has reviewed the Application pursuant to 310 CMR 19.000: *Solid Waste Regulations* and MassDEP's *Landfill Technical Guidance Manual, May 1997* (the "Manual").

PROJECT BACKGROUND

The Landfill is located off MacArthur Boulevard (Route 28) in Bourne, Massachusetts on a 74-acre parcel of land that was Site Assigned by the Bourne Board of Health on June 16, 1972. The Landfill is owned and operated by the Town. Landfill operations conducted to date have

proceeded in the following order: Phase 1 Landfill (sub-phases A, B, C and D), Phase 2 Landfill, Phase 3 Landfill, Phase 2A/3A Landfill, and the currently active Phase 4 Landfill and Phase 5 Landfill areas. MassDEP approved for construction of Phase 6 on July 16, 2018.

Other ongoing operations at the Landfill site include composting, recycling, and operation of a residential recycling and waste transfer area, and operation of a Construction and Demolition debris transfer station.

The Landfill is abutted to the north by the Monument Beach Sportsmen's Club; to the south by a 25-acre parcel that is used by ISWM for solid waste handling/transfer operations and soil stockpiling and beyond that woodland that has recently been acquired by the Town of Bourne; to the east by primarily undeveloped land on the Joint Base Cape Cod ("JBCC") facility; and to the west by Route 28 and commercial and residential properties on the opposite side of the highway.

MEPA REVIEW

Pursuant to the Massachusetts Environmental Policy Act ("MEPA") statute M.G.L. C. 30, S. 61-62H and regulations 301 CMR 11.00, a Final Environmental Impact Report ("FEIR") was prepared for the Landfill and a Certificate (EOEA #11333) of the Secretary of the Executive Office of Environmental Affairs ("EOEA") was issued on November 29, 1999, stating that the FEIR adequately and properly complied with MEPA. The FEIR was prepared for the partial build-out of the Landfill including the processing, recycling, composting, and disposal aspects of the project at the anticipated maximum daily tonnage rate of 825 tons per day ("tpd").

In June 2003, the Town of Bourne submitted a Notice of Project Change ("NPC") to MEPA that requested that the landfill be allowed to accept municipal solid waste ("MSW") and municipal combustor ash ("MCA") for disposal. On August 7, 2003, the Secretary issued a Certificate which stated that no further MEPA review was required for this change.

The Town of Bourne submitted a NPC to the EEA on November 8, 2017, providing an update of the planned development for the entire site. Alternative development plans were described, including the "Preferred Phase 6" with potential further development of Phase 7 and Phase 8 landfill and the "No Further Build Phase 6" alternatives. The Secretary issued a Certificate on January 12, 2018 which determined that a Single Supplemental Environmental Impact Report ("SSEIR") was required. An SEIR dated May 9, 2018 was submitted to EEA and published in the Monitor on May 23, 2018 (EEA No. 11333). On June 29, 2018, the Secretary issued a Certificate on the SEIR and determined that the SEIR adequately and properly complies with MEPA and its implementing regulations. The Town of Bourne will submit a future NPC to address development of Phase 7 and Phase 8 of the Landfill.

SITE ASSIGNMENT

On June 16, 1972, the Bourne Board of Health issued a site assignment for the entire 74-acre site including Phase 1, Phase 2, Phase 3, and Phase 4 pursuant to Massachusetts General Laws, Chapter 111, Section 150A.

PHASE 6 DESCRIPTION

The Application details the design, construction, and operation of the Phase 6 Landfill. The design utilized some areas of the existing liner system and includes constructing a new primary composite liner and leachate collection system and a secondary composite liner with leak detection system in some areas. The Phase 6 area overlays approximately 4.9 acres of the southern sideslopes of the Phase 3, Stage 3 and Phase 4, Stage 2 Landfills as well as 6.9 acres of new land located to the south of the existing Landfill operations area.

The project also included the construction of a 125,000 gallon, glass coated steel, above ground tank and truck load out structure, located adjacent to and south of the southwest corner of Phase 6 and interconnected to the existing leachate storage tank and force main system.

The contract for construction of Phase 6 was awarded to David G. Roach and Sons, Inc. ("Roach") of South Barre, Massachusetts. Construction began in April 2019. Full time construction quality assurance oversight was conducted by Sitec. Roach retained the services of New England Liner Systems, Inc. for the procurement and installation of all geosynthetic liner system materials. Roach retained the services of GeoTesting Express for testing of geosynthetics and for soils conformance testing.

Within the current Application, Sitec certified that the Phase 6 double composite liner system was constructed in general conformance with the approved plans, technical specifications and Construction Quality Assurance Plan.

Phased Liner Construction

The Authorization to Construct application for Phase 6 detailed the design and construction of two alternatives for the Phase 6 Landfill, the "Preferred Phase 6" and the "No Further Build Phase 6". The "Preferred Phase 6" alternative is dependent on the development and approval of Phase 7 and Phase 8.

Phase 6 is divided into at least two separate liner construction stages (Stage 1 and Stage 2) by the construction of a temporary berm that allows for the phased construction of the Phase 6 liner. Stage 1 construction is complete and is the subject of this approval.

Stage 2 is contingent upon whether Phase 7 is approved and constructed. If Phase 7 is not built, also known as the "No Further Build Phase 6" alternative, the southern sideslope would be constructed up to the existing grade as Stage 2. If Phase 6 Stage 2 is constructed, MassDEP is requiring that a Construction Certification Report be submitted to MassDEP prior to disposal of waste. An Authorization to Operate would also be needed prior to disposal of waste in Phase 6 Stage 2.

If Phase 7 is built, also known as the "Preferred Phase 6" alternative, the southern sideslope of Phase 6 will be excavated and that area will be part of the Phase 7 liner.

Phase 6 Landfill Disposal Volume

Construction of the Phase 6 Landfill adds approximately 920,000 cubic yards of disposal volume (approximately 570 acre-feet). Pursuant to the March 30, 2017, Phase 5 Landfill Authorization to Operate permit (BWP SW 10, Transmittal No. X272125) the Landfill is permitted to operate seven days per week and accept an annual average of 600 tons per day of waste, with a maximum of 700 tons per day not to exceed 4,900 tons per week. Waste approved to be disposed at the Landfill includes municipal solid waste ("MSW"), residual C&D material, waste-to-energy incinerator ash, and other non-MSW material. The definition of non-MSW for the purpose of the landfill operating permit includes construction and demolition waste residuals from a C&D processing facility, bulky waste, difficult to manage waste, special wastes that may be accepted pursuant to 310 CMR 19.061, and special wastes that have received prior written approval from MassDEP and only in accordance with MassDEP policy.

The Landfill accepts combustion ash from the Covanta waste-to-energy facility located in Rochester, Massachusetts, which currently constitutes the majority of the waste material accepted at the Landfill. Assuming that all of the gross volume will be utilized by ash, which has an in-place density of approximately 2,000 pounds per cubic yard (1.0 ton per cubic yard), the Phase 6 Expansion will have a maximum disposal capacity of approximately 920,000 tons. Currently, the Facility is accepting ash for disposal and daily cover, at a rate of approximately 230,000 tons per year. At that rate, the life expectancy of the Phase 6 will be about four years. Should ash acceptance cease or decrease, the Landfill life will be dependent upon the rate of MSW acceptance.

Double Composite Liner System with Leak Detection

The liner system for Phase 6 consists of existing components from the surrounding Phase 4, Stage 2 and Phase 3, Stage 3 Landfills, as well as a new double composite liner system with leak detection capabilities designed in accordance with 310 CMR 19.110. The liner was designed with a minimum 4-foot separation from the historical maximum high groundwater elevation to the top of the prepared subgrade layer for the liner.

The Phase 4, Stage 2 Landfill is an existing active landfill area and the Phase 3, Stage 3 Landfill is an existing inactive landfill area with either final or intermediate cover. Both these landfill areas are lined with a double composite liner.

A new double composite liner system was constructed over 6.9 acres and includes, from bottom to top:

- A subgrade layer placed where needed to provide structural support to the overlying liner system. The subgrade layer preparation work included the excavation and grading of existing, in-situ soils, overlain by;
- A low permeability soil layer comprised of 12 inches of compacted low permeability soil having a maximum in-place, saturated hydraulic conductivity of 1×10^{-7} centimeters per second, overlain by;

- A secondary geosynthetic clay liner ("GCL") fabricated of a layer of granular sodium bentonite encapsulated between two sheets of needle-punched geotextile will be placed above the low permeability layer. On sideslopes greater than 4:1. (4 foot horizontal to 1 foot vertical), this layer will extend only to a height that is 5 feet vertically above areas with a slope of less than 4:1, overlain by;
- A secondary geomembrane made of 60-mil thick textured high-density polyethylene ("HDPE") placed on top of the secondary GCL or low permeable soil and extending over the entire liner area, overlain by;
- A bi-planar, geocomposite drainage layer, consisting of an HDPE geonet bonded on both sides with a non-woven geotextile, placed on the secondary geomembrane covering the entire liner area, overlain by;
- A primary GCL placed above the geocomposite drainage layer covering the entire liner area, overlain by;
- A primary geomembrane made of a 60-mil thick textured HDPE placed above the primary GCL covering the entire liner area, overlain by;
- A primary drainage/protection layer placed above the primary geomembrane consisting of an 18-inch thick layer of clean sand having a minimum hydraulic conductivity of 1×10^{-2} centimeters per second, covering the entire liner area.

The Phase 6 Landfill liner was connected to the existing Phase 3, Stage 3 and Phase 4, Stage 2 Landfill liner systems by exposing the existing base liner materials as necessary to connect each element of the new liner system to the corresponding element of the existing liner system. All connections of the HDPE geomembranes were completely welded along the entire length.

An electrical leak location survey was conducted on the Phase 6 primary liner system.

Primary Leachate Collection System

The Phase 6 Landfill primary leachate collection system is designed to drain the primary liner system so that no more than one foot of hydraulic head will develop on the liner. The primary leachate collection system consists of the sand drainage layer and a system of 8-inch and 6-inch diameter HDPE perforated and solid pipes installed within the sand drainage layer leading to the primary leachate collection sump located along the toe of the western sideslope. The drainage pipes are embedded in 3/4 to 1-1/2 inch crushed stone placed above a filter fabric and a geocomposite drainage layer to prevent damage to the primary geomembrane layer. During construction, the design engineer requested and was approved to substitute crushed stone with additional protective geosynthetic materials for washed/rounded stone after providing MassDEP with an evaluation and supporting calculations.

The Landfill liner system base was graded with shallow swales that radiate from the leachate collection sump, to promote leachate drainage in the sand layer to the collection piping. The primary leachate header piping was installed along the centerline of the swale areas at a 1.0% (0.01 ft/ft) minimum slope with cleanouts extending to the top of the side slopes. There are lateral collection pipes located across the liner base that connect to the header pipes. The lateral pipes were placed at a minimum slope of 0.5% and a maximum spacing of 60 feet. All leachate

collected by the Phase 6 primary collection system is diverted to the Phase 6 primary leachate sump located along the toe of the Phase 6 western sideslope.

In addition, a 6-inch diameter HDPE solid pipe was installed to connect a Phase 4, Stage 2 leachate pipe located along the toe of the Phase 4, Stage 2 western sideslope to the Phase 6 primary leachate collection system. The connection to Phase 4, Stage 2 provides a hydraulic connection between Phase 4 and Phase 6 and will divert leachate from Phase 4 to Phase 6.

Due to accepting waste combustion ash as its primary waste stream, the Landfill has experienced plugging of the leachate collection piping. The Landfill's operators have determined that the chemical REDUX-300, is effective in keeping the leachate from coagulating and plugging the collection system. In response, the design for the Phase 6 liner system includes a chemical injection system in the primary sump as detailed below. A series of 1-inch diameter HDPE perforated pipe was installed along the first 100 feet of each collection header pipes and within the leachate sump area, which individually connect to solid wall pipes that run to the pump control panel area, where a chemical can be injected by a metering pump into each distribution line.

Secondary Leachate Collection System

The Phase 6 Landfill secondary leachate collection system, also known as the leak detection system, is designed to detect and collect any potential leakage through the primary liner and convey this leakage to the secondary leachate collection sump. The secondary leachate collection system consists of bi-planar geocomposite drainage material and 4-inch diameter HDPE perforated pipes embedded in 3/4 to 1-1/2 inch crushed stone with filter fabric wrapped around the stone to prevent damage to the secondary geomembrane layer. The collection pipes are located in the center of the troughs constructed approximately twenty feet wide and one foot deep with 12% side slopes. During construction, the design engineer requested and was approved to substitute crushed stone with additional protective geosynthetic materials for washed/rounded stone after providing MassDEP with an evaluation and supporting calculations.

Notification Leakage Rates and Action Leakage Rates were established for the current Landfill operation and are incorporated into this permit decision for the Phase 6 Landfill operation **(refer to condition #12).**

Leachate Sump

Leachate from both the primary and secondary leachate collection systems will flow to an internal sump located along the toe of the Phase 6 western sideslope, where submersible pumps will lift and transport leachate to either of the aboveground leachate storage tanks. The pump units are supplied with liquid level sensors and controls and recording flow monitors. Both the primary and the secondary leachate collection system flow rate will be recorded so that leachate generation volumes can be monitored and liner leachate leakage rates can be calculated.

Perforated 24-inch diameter HDPE piping was installed within the primary collection sump and the secondary sump. The 24-inch diameter pipes transition to 18-inch diameter solid wall riser

pipes that extend up the side slope to the top of the perimeter waste containment berm. The submersible pump units, along with 3-inch diameter flexible discharge hose for the primary system and 2-inch diameter flexible hose for the secondary system, electrical and liquid level sensor leads were placed down the riser pipes and positioned within the sumps.

The primary collection system pump unit has a capacity of 130 gallons per minute ("gpm") or about 187,000 gallons per day ("gpd"), based on a peaking factor of 3 being applied to the calculated maximum daily leachate flow of approximately 62,245 gpd as determined by the HELP Model calculations. The secondary collection system pump unit has a capacity of 40 gpm or about 57,600 gpd based on a peaking factor of 3 being applied to an assumed maximum secondary leachate (leakage) flow rate of 1,000 gpd per acre of landfill liner (18,700 gallons per day).

The pump discharge lines were connected to the existing dual 4 inch force mains that are located along the western side line of the Landfill, which run to the existing leachate storage tank located to the east of the Phase 3, Stage 3 Landfill, and to a new 125,000 gallon above ground leachate storage tank, located south of the southwest corner of Phase 6. As of the date of this Approval, construction of the new leachate storage tank is not yet complete, and the Phase 6 sump will discharge to the existing storage tank. Upon completion and prior to operation of the new storage tank, MassDEP is requiring that the Applicant provide MassDEP with a written certification statement demonstrating the tank was constructed in accordance with MassDEP regulations, requirements, the Manual, and the approved design **(refer to condition #4).**

The Town has a contract with a third-party transporter to load and transport leachate from the leachate storage tank for disposal at the Covanta waste-to-energy facility or the Middleborough Water Pollution Control Facility via tanker trucks on an as-needed basis. The total quantity of landfill leachate generated will be recorded and the leachate quality will be monitored in accordance with the approved plan and the disposal agreements with Covanta, the Middleborough Water Pollution Control Facility, and any other leachate disposal location.

Stormwater Management System

Phase 6 landfilling operations will prevent stormwater run-off from areas outside the Phase 6 Landfill from draining into the Phase 6 Landfill area. This run-off will be diverted to the south to existing Stormwater Basin No. 2 located on the 25-acre parcel that is to the south of the Landfill parcel. Control of stormwater run-off along the western side of the Landfill area will be managed by existing facilities that discharge to Stormwater Basin No. 1, located in the northwest corner of the property. The design stormwater flow rates were analyzed for the stormwater retention basins utilizing HydroCAD Stormwater Modeling program, which utilizes the TR-20 method for run-off calculations.

The existing stormwater management system is designed to control run-off and run-on from the 25-year, 24-hour rainfall event during operations and after final closure.

Stormwater Basin No. 1 will provide about 585,400 cubic feet of storage, which exceeds the storage volume required to accommodate the run-off from a 25-year, 24-hour storm event

(approximately 235,700 cubic feet) and is sufficient for managing the stormwater run-off from a 100-year storm event (approximately 379,800 cubic feet of storage) or from back-to back rainfall events.

Stormwater Basin No. 2 will provide about 777,400 cubic feet of storage, which exceeds the storage volume required to accommodate the run-off from a 25-year, 24-hour storm event (approximately 382,000 cubic feet) and is sufficient for managing the stormwater run-off from a 100-year storm event (approximately 551,700 cubic feet of storage) or from back-to-back rainfall events.

Landfill Gas Collection System

Landfill gas generated at the Landfill is collected, treated, and combusted on-site. The existing landfill gas collection system is comprised of vertical gas extraction wells connected to a main header system.

A conceptual design for the management of gas generated within the Phase 6 Landfill was submitted and includes the installation of 24 vertical landfill gas extraction wells with a 100 foot radius of influence, two temporary horizontal landfill gas collectors, gas condensate traps, and associated header pipes and control valves. The design also includes the installation of a new network of piping to collect generated landfill gases and convey them to a flare station for treatment. The existing flare station is located to the northeast of the Phase 2 Landfill area and prevents the occurrence of odors and the off-site migration of landfill gas.

The final details the landfill gas collection system will be submitted in a separate permit application prior to installation.

Financial Assurance Mechanism

The Town maintains a Financial Assurance Mechanism for closure and post closure costs. The Town has estimated a closure cost of $3,375,251.07 for Phase 6. The Town is funding the closure liability over a 4 year pay-in period. One payment totaling $843,812.77 has been made into the post closure fund. In accordance with 310 CMR 19.051 (12) (b) (2) the Town will review and adjust the Final Closure Cost Estimate and make subsequent payments to the Closure Account annually in March 2020, 2021, and 2022.

Deed Notice

A Notice of permit for Authorization to Construct the Phase 6 Landfill Expansion was recorded at the Barnstable County registry of Deeds on July 30, 2018.

APPROVAL AND CONDITIONS

MassDEP has determined the ATO for Phase 6 (6.9 acres) application is satisfactory and in accordance with the authority granted pursuant to Massachusetts General Laws, Chapter 111, Section 150A, hereby approves the Phase 6 Construction Certification and authorizes solid waste disposal operations in Phase 6 of the Landfill subject to the following conditions:

1. Life of Permit: This Authorization to Operate permit shall be valid until Phase 6 reaches capacity or for a period of five (5) years, whichever comes first. This Authorization to Operate also supersedes Condition 1 of the October 15, 2014, Authorization to Operate Phase 4, Stage 2, in that Stage 2 may continue to operate in conjunction with Phase 6.

2. Reserve Capacity: Notwithstanding the capacity and waste-type restrictions in this permit, the Landfill may accept additional waste **upon request** to, and written approval by MassDEP. MassDEP may grant such approval if it determines that a capacity shortfall may occur, and that alternate disposal facilities are not able to handle the shortfall adequately.

3. Regulatory Compliance: The Town shall operate and maintain the Facility, including Phase 2A/3A, Stages 1 and 2, Phase 4, Phase 5, and Phase 6 in accordance with MassDEP regulations, requirements, the Manual, or as specified by this permit. This includes, but is not limited to, 310 CMR 19.043(5) *Standard Conditions*, 310 CMR 19.051 *Financial Assurance Requirements*, and 310 CMR 19.130 *Operation and Maintenance Requirements*. There shall be **no** deviation from the approved plan without prior written approval from MassDEP.

4. Leachate Storage Tank: Upon completion and prior to operation of the new storage tank, the Town shall submit a written certification statement from the supervising engineer demonstrating the tank was constructed in accordance with MassDEP regulations, requirements, the Manual, and the approved design. In addition, as part of this permit approval, the Town shall submit to MassDEP the final as-built layout drawing for the leachate storage tank. The submitted drawing shall depict the as-built leachate pump station, leachate storage tank, and all piping and appurtenances as shown in drawing titled "Leachate Storage Tank Site Plan" of the ATC Application for Phase 6.

5. Waste Types and Tonnage Limits: The Town may accept an average of 600 tons per day of waste with a maximum of 700 tons per day not to exceed 4,900 tons per week. The Town shall not accept more than 219,000 tons of waste for disposal per year. Waste approved to be disposed at the Landfill includes municipal solid waste (MSW), residual C&D material, ash and other non-MSW material. The definition of non-MSW for the purpose of this permit includes construction and demolition waste residuals from a C&D processing facility, bulky waste, difficult to manage waste, and other special wastes that have received prior written approval from MassDEP and only in accordance with Department policy.

The overall Facility tonnage, including recycling, composting, and disposal remains at a maximum materials acceptance rate of 825 tons per day as established during the EIR process.

6. Hours of Operation: The Town may operate the Facility seven days per week, fifty-two (52) weeks per year, Monday through Saturday 7:00 AM to 4:00 PM and Sunday from 7:00 AM to 12:00 PM.

6. Buffer Waste Layer: The Town shall use all appropriate care to protect the liner system when depositing the first lift of the waste into the cell.

7. Nuisance Conditions: The Town shall ensure that Facility operations do not create nuisance problems with vectors, odors, dust, noise, litter or other nuisance conditions. Measures shall be undertaken immediately to mitigate any potential impacts from nuisance conditions including temporarily ceasing operation on any given day. Operations shall be modified to prevent these conditions from reoccurring.

8. Landfill Gas Monitoring Consultant Services: The Town shall continue to engage the services of a third-party consultant, experienced in the optimization of the performance of landfill gas collections systems, to review the landfill gas collection system performance and advise the Town regarding necessary adjustments to the system vacuum and/or design based on temperature, methane, oxygen, and nitrogen levels. Performance data shall be collected at each landfill gas extraction well at least monthly, or more frequently as necessary. Adjustments to the landfill gas extraction rate shall be made as appropriate to maintain maximum efficiency, control landfill soil gas migration and emissions including odors. The results of each test and records of each adjustment to the landfill gas collection system shall be recorded and maintained on-site for MassDEP review upon request.

9. Waste Inspections: The Town shall conduct waste inspections for banned waste and other unacceptable materials in accordance with MassDEP's recycling rules, the approved Waste Ban Plan, or as required by this permit. Routine operations shall include supervised unloading and inspection of all waste for unacceptable materials including asbestos, hazardous materials, and waste ban materials. All unacceptable materials shall be managed in accordance with procedures contained in the operation and maintenance plan and as modified by this permit.

10. Asbestos Inspection Protocol: The Town shall adhere to the following protocol for testing and inspecting incoming waste material to prevent the acceptance and processing of Asbestos Containing Materials (ACM).

    a. A sign shall be posted at the entrance to the Facility identifying acceptable and unacceptable materials received at the Facility. The sign must clearly state that ACM is not accepted at the Facility.

b. An on-site asbestos inspector certified by the Massachusetts Department of Labor Standards Asbestos Program for landfill / transfer station type operations shall visually inspect all incoming loads of waste in order to determine the presence and/or likelihood of ACM. In addition to classroom certification, inspectors must have a minimum of forty (40) hours of on-the-job training and/or experience in identifying potential ACM and sampling protocols. A minimum of two employees shall maintain an asbestos inspector license. All other operations staff shall attend asbestos awareness class.

c. For each load where ACM is suspected the Town shall notify the MassDEP Southeast Regional Office, Solid Waste Management Section, by telephone (508) 946-2828 within two (2) hours after identifying the load as containing suspect ACM. The Town shall also submit a written report that identifies the source (name of hauler and vehicle license number), and, if known, the generator name and address, the type, quantity, handling procedures and disposition of the suspect ACM, to the MassDEP Southeast Regional Office, Solid Waste Management Section via facsimile (508-946-2865) within two (2) hours of observing the suspect ACM. If facsimile is not available, the Town shall notify the MassDEP Southeast Regional Office, Solid Waste Management Section via telephone within two (2) hours (508) 946-2828, and submit a written report via mail within twenty-four (24) hours, of observing the suspect ACM.

Pursuant to 310 CMR 19.061(2) certain asbestos-containing asphaltic roofing and siding materials may be disposed of in any landfill permitted by MassDEP to accept solid waste pursuant to 310 CMR 19.000. Provided the requirements of 310 CMR 7.15(10) "Requirements for the Removal of Asbestos-containing Asphaltic Roofing and Siding Materials" are followed and best management practices are used to prevent emissions at the Landfill, and if the Town determines that the only suspect ACM within a waste load is **intact** and **unbroken** vinyl asbestos tile and asphalt based asbestos-containing siding products and asphalt based asbestos-containing roofing materials, then the load may be disposed at the Landfill. The load does not require notification to MassDEP. The load should not be culled, compacted or otherwise handled in a manner that causes breakage of the suspect ACM material. Recyclable materials that are banned from disposal pursuant to 310 CMR 19.017, should be culled from the load prior to disposal, whenever this can be performed without causing a threat to worker safety and/or result in a discharge of asbestos to the environment. Recyclable materials that are likely to be contaminated by exposure to asbestos containing materials do not need to be culled and may be transferred for disposal.

11. Leachate Management: The Town shall operate and maintain the leachate collection and handling equipment at the Landfill in accordance with 310 CMR 19.130(30), the approved plan or as required by this permit. At a minimum, the Town shall conduct quarterly analysis of the leachate for the parameters listed at 310 CMR 19.132(2)(h) or as required to comply with the monitoring requirements and standards of all leachate disposal permits. The quantity of leachate generated shall be reported in the Facility Inspection reports required pursuant to Condition #16.

12. Leachate Monitoring: Upon commencement of operation of Phase 6, periodic Secondary Leachate Collection System (SLCS) flow rates shall be determined and submitted to

MassDEP bi-monthly, by the 15th calendar day of the subsequent month. SCLS flow rates shall be measured each week on a daily basis.

Notification Flow Rates (NTF) shall be one-hundred (100) gallons per acre per day (gpad) for any single day and an average of fifty (50) gpad, calculated on a 30-day running average basis.

Action Flow Rates (AFR) shall be two-hundred (200) gpad for any single day and an average one-hundred (100) gpad, calculated on a 30-day running average basis.

Unless otherwise approved by MassDEP, the Town shall, for each SLCS flow rate exceedance of either NFR, notify MassDEP by the next business day, evaluate the operations and maintenance at the Landfill, conduct an assessment to evaluate the appropriateness of the Notification Flow Rate, and take other actions as deemed appropriate by MassDEP.

If the SLCS exceeds either AFR, the Town shall notify MassDEP by the next business day, schedule a meeting with MassDEP, and submit an engineering evaluation report within thirty (30) days of the exceedance, unless an alternate schedule is approved by MassDEP.

MassDEP reserves the right to modify the NFR and the ALR and the frequency and/or method of SLCS measurements, and/or the required responses at any time.

13. Cover Requirements: The Town shall apply daily, intermediate, and final cover materials at the Landfill in accordance with 310 CMR 19.130(15), the approved plan, or as required by this permit.

14. Stormwater runoff: The Town shall control and collect all stormwater in contact with solid waste and/or daily cover within the Phase 6, leachate collection systems such that the contact water is not allowed to flow into unlined areas of the site.

15. Environmental Monitoring: At a minimum, the Town shall conduct quarterly environmental monitoring of all existing groundwater, surface water, and soil gas monitoring points at the Landfill in accordance with MassDEP regulations, as modified by MassDEP through review of monitoring data and the CSA. All sampling results including leachate sampling shall be submitted to MassDEP within 60-days after the scheduled sampling period or as required to notify MassDEP of any exceedances.

16. Facility Inspections: The Town shall provide for the Facility to be inspected on a bi-monthly basis by a Massachusetts Registered Professional Engineer, or other qualified professional approved by MassDEP. An inspection report shall be submitted to MassDEP no later than 14 days following the inspection. The report shall address all aspects of the Facility including the compost and recycling operations, the C&D transfer operations, all Landfill disposal operations, leachate volumes, leachate management, stormwater controls, and all other site features. The report shall indicate whether all

items are in compliance and propose remedies and establish a schedule for correcting any problems.

17. Records: The Town shall maintain daily logs at the Facility at all times to record the operational information required pursuant to 310 CMR 19.130(34) with copies periodically forwarded to the Board of Health. The Town shall retain copies of all personnel training records regarding operation and maintenance procedures, health and safety training, asbestos training, first aid, emergency procedures and any other training. All logs and records shall be available for Department review upon request.

18. Financial Assurance Mechanism: The Town shall continually maintain the approved financial assurance mechanism, revise the cost estimates, and submit the revised estimates in accordance with 310 CMR 19.051.

19. Annual Report: The Town shall submit an Annual Report to MassDEP by February 15th of each year which summarizes the facility operations for the previous calendar year on a form as provided by MassDEP.

20. Facility Modification(s): The Town shall submit a permit modification application to MassDEP for review and approval for any activities proposed to be conducted on the site assigned property including any construction or substantial changes or additions to site operations.

21. Local, State, Federal Requirements: The Town shall fully comply with all applicable local, state, and federal laws, regulations, and policies, by-laws, ordinances and agreements. Applicable federal regulations include, but are not limited to, 29 CFR Part 1910, OSHA standards governing employee health and safety in the workplace.

22. Permit Limitations: The issuance of this conditional approval is limited to the construction certification and operation of the Phase 6 (6.9 acres), lined disposal area and does not relieve the Town from the responsibility to comply with all other regulatory or permitting requirements. MassDEP reserves the right to require additional assessment or action, as deemed necessary to protect and maintain the environment free from objectionable nuisance conditions, dangers or threats to public health or the environment.

RIGHT TO APPEAL

Right to Appeal: This approval has been issued pursuant to M.G.L. Chapter 111, Section 150A, and 310 CMR 19.033: Permit Procedure for an Application for a Permit Modification or Other Approval, of the "*Solid Waste Management Regulations*". Pursuant to 310 CMR 19.033(5), any person aggrieved by the final permit decision, except as provided for under 310 CMR 19.033(4)(b), may file an appeal for judicial review of said decision in accordance with the provisions of M.G.L. Chapter 111, Section 150A and M.G.L. Chapter 30A no later than thirty days of issuance of the final permit decision to the Applicants. The standing of a person to file an appeal and the procedures for filing such an appeal shall be governed by the provisions of M.G.L. c. 30A. Unless the person requesting an appeal requests and is granted a stay of the terms and conditions of the

permit by a court of competent jurisdiction, the permit decision shall be effective in accordance with the terms of 310 CMR 19.033(3).

Notice of Appeal: Any aggrieved person intending to appeal a final permit decision to the Superior Court shall first provide notice of intention to commence such action. Said notices of intention shall include MassDEP Authorization No. SW10-0000008 and shall identify with particularity the issues and reason why it is believed the final permit decision was not proper. Such notice shall be provided to the Office of General Counsel of MassDEP and the Regional Director for the regional office which processed the permit application, if applicable at least five days prior to filing of an appeal. The appropriate addresses to send such notices are:

Office of General Counsel
Department of Environmental Protection
One Winter Street
Boston, MA 02108

Regional Director
Department of Environmental Protection
20 Riverside Drive
Lakeville, MA 02347

No allegation shall be made in any judicial appeal of a final permit decision unless the matter complained of was raised at the appropriate point in the administrative review procedures established in 310 CMR 19.000, provided that a matter may be raised upon showing that it is material and that it was not reasonably possible with due diligence to have been raised during such procedures or that matter sought to be raised is of critical importance to the environmental impact of the permitted activity.

If you have any questions or comments regarding this approval letter, please contact me at (508) 946-2847 or Alison Cochrane (508) 946-2778 or at the letterhead address.

Very truly yours,

Mark Dakers, Chief
Bureau of Air and Waste
Solid Waste Management Section

D/AC
W:\BAW\Solid Waste\1 MUNICIPALITIES\Bourne\Landfill\Phase 6\ATO\Bourne Phase 6 ATO_SW10-0000008.doc

ec: Bourne Board of Selectmen
jmacleod-froman@townofbourne.com
nsundman@townofbourne.com

Bourne Department of Public Works
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Bourne Board of Health
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Bourne Integrated Solid Waste
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pgoddard@townofbourne.com

Cape Cod Commission
jidman@capecodcommission.org

Sitec Environmental, Inc.
rquinn@sitec-engineering.com

DEP – BOSTON
ATTN: G. Cooper
J. Fischer

DEP – SERO
ATTN: S. Pickering
M. Dakers

C

buzzards BAY COALITION

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TOWN OF BOURNE
BOARD OF SELECTMEN

January 21, 2020

Barbara J. Kickham, TMDL Section Chief
MA Department of Environmental Protection
Watershed Planning Program
8 New Bond Street
Worcester, MA 01616

Re: Buzzards Bay Coalition Requests the Immediate Approval as Final of the Megansett-Squeteague Harbor Estuarine System Total Maximum Daily Loads for Total Nitrogen (CN-452.0)

Dear Ms. Kickham,

The Buzzards Bay Coalition (Coalition) has reviewed the Draft Megansett-Squeteague Harbor Estuarine System Total Maximum Daily Loads for Total Nitrogen (CN-452.0) dated August 2019 (draft Megansett-Squeteague TMDL). The Coalition urges the Massachusetts Department of Environmental Protection (MassDEP) to send the draft Megansett-Squeteague TMDL to the US Environmental Protection Agency (EPA) to approve as final. This letter follows our comments at the public meeting in Falmouth on December 19, 2019.

The draft Megansett-Squeteague TMDL confirms the need for nitrogen reductions. The TMDL forms the basis for the towns of Falmouth and Bourne to create plans for how they will reduce nitrogen pollution in the Megansett-Squeteague watershed to meet the TMDL. Delay in TMDL approval will postpone and hinder local action on nitrogen reductions and lead to further degradation of Megansett and Squeteague Harbors.

The Coalition is a membership-supported non profit organization dedicated to the restoration, protection and sustainable use and enjoyment of Buzzards Bay and its watershed including the watersheds of all three estuary systems. The Coalition is supported by more than 10,000 individuals, families, and businesses throughout the region including over 1,400 members affected by water quality in Falmouth and 647 members affected by water quality in Bourne.

The Coalition requests that the MassDEP and EPA consider the following comments in assessing whether these TMDLs successfully achieve water quality standards in Megansett and Squeteague Harbors.

Background:

The Towns of Falmouth and Bourne thrive on clean, productive and beautiful marine waters. Swimming, fishing, boating, fin-fishing, and shellfishing all support the local economy. However, as recognized by the draft TMDLs, the continued degradation of water quality due to nitrogen pollution in these estuaries reduces their recreational and commercial values.

The Federal Clean Water Act requires the Commonwealth of Massachusetts to identify waters that fail to meet water quality standards. The state is required to draft TMDLs establishing the maximum load (amount) of pollution from all sources that the identified water may receive and still meet water quality standards. The nitrogen capacity of Megansett and Squeteague Harbors were evaluated through the Massachusetts Estuaries Project (MEP) and the Megansett-Squeteague MEP report was finalized in 2015. The MEP report documented impairment of the water bodies and the need for nitrogen reductions.

The water quality in Megansett and Squeteague Harbors is degraded by nitrogen pollution. High nitrogen loads from septic systems, stormwater, and fertilizers cause low dissolved oxygen levels, elevated algae levels, loss of eelgrass, and decreased diversity and quantity of marine animals living on the seafloor. During the past 28 years, the Coalition has collected water quality data from three sites in Squeteague Harbor, and five sites in Megansett Harbor that clearly documents this impairment, including common incidences of dissolved oxygen levels less than 6 mg/L. Without reduction, these nitrogen loads could lead to further water quality and habitat degradation including fish kills, unpleasant odors and scums, and loss of critical marine animal communities.

Major Findings of the TMDL:

Both Megansett and Squeteague Harbors are listed as waterbodies needing at TMDL for nutrients. There has been significant decline in eelgrass coverage since 1995 in Megansett Harbor and the benthic infauna habitat has been degraded in Squeteague Harbor and the Megansett Channel. The draft Megansett-Squeteague TMDL establishes a target threshold concentration for total nitrogen in outer Megansett Harbor of 0.35 mg/L at the sentinel station MG2. The draft Megansett-Squeteague TMDL asserts that water quality standards for the entire system will be met when this target concentration is met, which will lead to improved water clarity, restoration of eelgrass habitat, and high quality habitat for seafloor species.

To meet the target thresholds and obtain water quality standards requires reductions in the watershed nitrogen loads of all three areas (17% in Megansett Harbor, 7.5% in Megansett Channel, and 5.6% in Squeteague Harbor), which equates to a 12% reduction to the whole system. The draft Megansett-Squeteague TMDL presents a scenario of meeting the target threshold via reductions from septic systems. A 19.3% reduction of the existing load from septic systems would achieve the target threshold nitrogen concentration of 0.35 mg/L at the sentinel station.

TMDL Implementation:

The draft Megansett-Squeteague TMDL presents a single scenario for nitrogen load reduction focused on septic system load removal. Targeting septic systems is prudent since the majority of the total controllable nitrogen load is from septic systems. It is now the responsibility of the Towns to develop and implement a Comprehensive Wastewater Management Plans (CWMP) that will assess the most cost-effective options for achieving the target nitrogen watershed loads, including possible sewering at either centralized or de-centralized (i.e., neighborhood scale) locations and the use of nitrogen-reducing septic systems.

The Coalition looks forward to working with the Town of Falmouth, Town of Bourne, MassDEP, EPA, and local stakeholders in the development and implementation of CWMPs for Megansett and Squeteague Harbors. The Coalition has partnered with homeowners around the watershed to upgrade to nitrogen-reducing septic systems, including 30 homeowners around West Falmouth Harbor in collaboration with the Town of Falmouth. This effort has shown the capability of the systems to provide significant nitrogen reductions and the Coalition is ready to provide information on the learnings of these efforts for application in places such as the Megansett-Squeteague watershed.

Comments:

In order to expeditiously proceed with nitrogen reduction planning and implementation, the Coalition urges the MassDEP to send the draft Megansett-Squeteague TMDL to the EPA to approve as final as soon as possible. However, we request that EPA and MassDEP consider the following comments in the implementation of these TMDLs and in their future updates. We do not suggest that any of the issues discussed below justify re-evaluation or further delays in issuance of the draft Megansett-Squeteague TMDL.

1. **The TMDLs' categorization of all septic systems into the Load Allocation is inaccurate.**

The MEP technical report acknowledges that the geology of Cape Cod and the Islands allows water to move rapidly through the ground, and the draft TMDL includes stormwater from impervious surfaces within 200 feet of the shoreline as point sources and includes it in the Waste Load Allocation. Septic systems within the watershed of Megansett-Squeteague Harbor should also be included in the Waste Load Allocation. The rapid movement of wastewater from septic systems to coastal waters, without significant attenuation of nitrogen, makes it appropriate to consider septic systems as part of the Waste Load Allocation. Nevertheless, we encourage EPA to finalize the draft Megansett-Squeteague TMDL, but suggest that MassDEP and EPA develop a methodology for allocating septic systems into the Waste Load Allocation portion of TMDLs in order to more effectively regulate septic systems as the primary point source of nitrogen in southeastern Massachusetts estuaries.

2. **The effects of climate change on water quality have not been adequately addressed in this TMDL; a larger Margin of Safety should be considered in future TMDLs.**

The TMDL states that "MassDEP believes that impacts of climate change should be addressed through TMDL implementation with an adaptive management approach in mind." Research into the Coalition's long-term water quality database, attached here, indicates Buzzards Bay waters are warming. At the same time, the relationship between nitrogen concentrations and algae growth (as measured by algal pigment concentrations) has shifted, with higher levels of algae growth occurring in more recent years than 25 years ago at the same nitrogen concentration. This shift in the relationship suggests that with a warming climate, greater algae growth and ecological impairment may occur than expected based on historic nitrogen concentrations.

The draft TMDL anticipates that an adaptive management approach will be utilized to assess the effectiveness of the TMDL and CWMP implementation. The adaptive management approach provides an opportunity to incorporate new understandings such as the effect of temperature on algae growth. To restore water quality, it is critical that adaptive management is effectively implemented and additional steps are taken if necessary.

3. **Eelgrass recovery targets may require lower nitrogen thresholds.**

Extensive eelgrass loss has occurred over the last century in Megansett Harbor with a very dramatic decline between 1951 and 1995. Since 1995, additional significant losses have occurred, with almost 40% of the remaining eelgrass disappearing between 1995 and 2012. The draft TMDL's primary restoration focus for the outer basin of Megansett Harbor is the recovery and protection of eelgrass habitat. A nitrogen threshold of 0.35 mg/L at sentinel station MG2 was selected as a target for restoring eelgrass.

The total nitrogen concentration at station MG2, as measured by the Baywatchers Monitoring Program fluctuated around the threshold level of 0.35 mg/L between 2000 and 2013. During this time period, eelgrass loss occurred. This suggests that the total nitrogen threshold of 0.35 mg/L may need to be maintained consistently for a number of years for eelgrass restoration to occur or that a lower total nitrogen concentration is required. Monitoring of both the nitrogen concentrations and eelgrass recovery will be required to assess whether nutrient reductions result in consistently lower nitrogen concentrations at the sentinel station and whether this allows for eelgrass recovery. Adaptive management plans need to anticipate and react to this monitoring information.

4. **An implementation schedule and monitoring plan should be promptly developed.**

The establishment of this TMDL anticipates that actions will be taken to meet the TMDL so that Megansett and Squeteague Harbors will be restored and meet water quality standards. We encourage MassDEP to work with the towns to develop a timeframe for TMDL implementation

and a plan for monitoring. The timeframe should lay out a set of milestone goals that the towns can work towards achieving.

The TMDL states that "existing monitoring programs which were designed to thoroughly assess conditions and populate water quality models can be substantially reduced for compliance monitoring purposes." The TMDL indicates that about half the current effort would be sufficient to observe water quality changes. The MassDEP should clearly define what exactly it means by this.

Since 1992, through its Baywatchers Monitoring Program, the Coalition has performed summertime water quality monitoring in Megansett and Squeteague Harbors. This data forms the long-term water quality monitoring records used in the development of the MEP report that the TMDL is based upon. The Coalition intends to continue our water quality monitoring program and provides our data free of charge to any interested parties.

Funding for the Baywatchers Monitoring Program comes from a variety of sources including grants from federal and state sources, private foundations, and member contributions. For much of its history, the Coalition has received significant annual funding (~$125,000) from the MA State Legislature. There is $75,000 to support the Baywatchers Monitoring Program in the FY20 State Budget. As we consider how to modify our program with limited resources, MassDEP needs to clarify what it will require for monitoring of TMDL compliance.

Summary:

The issuance of this TMDL is a critical step in restoring the water quality of Megansett and Squeteague Harbors. The draft TMDL confirms the need for nitrogen reductions and requires the towns of Falmouth and Bourne to create plans for how they will reduce nitrogen to meet the TMDL. The Coalition urges the MassDEP to send the draft Megansett-Squeteague TMDL to the EPA to approve as final so that the towns of Falmouth and Bourne can begin planning for how to meet the required nitrogen reductions.

Sincerely,

Mark Rasmussen, President
Buzzards Bay Coalition

Attachment

cc: Kathleen Theoharides, MA Secretary of Energy & Environmental Affairs

Martin Suuberg, MassDEP Commissioner
Patti Kellogg, Bureau of Water Resources, MassDEP – SERO
Kenneth Moraff, US EPA

Town of Falmouth
- Board of Selectmen
- Water Quality Management Committee
- Conservation Commission
- Board of Health
- Planning Board
- Wastewater Department

Town of Bourne
- Board of Selectmen
- Sewer Commissioners
- Conservation Commission
- Board of Health
- Planning Board
- Department of Public Works

US Congressman William Keating
Representative David Vieira
Representative Dylan Fernandes

Cape Cod Commission

Biogeosciences, 13, 253–265, 2016
www.biogeosciences.net/13/253/2016/
doi:10.5194/bg-13-253-2016

Biogeosciences
Open Access

Spatial and temporal trends in summertime climate and water quality indicators in the coastal embayments of Buzzards Bay, Massachusetts

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Received: 10 July 2015 – Published in Biogeosciences Discuss.: 14 August 2015
Revised: 4 December 2015 – Accepted: 13 December 2015 – Published: 15 January 2016

Abstract. Degradation of coastal ecosystems by eutrophication is largely defined by nitrogen loading from land via surface water and groundwater flows. However, indicators of water quality are highly variable due to a myriad of other drivers, including temperature and precipitation. To evaluate these drivers, we examined spatial and temporal trends in a 22-year record of summer water quality data from 122 stations in 17 embayments within Buzzards Bay, MA (USA), collected through a citizen science monitoring program managed by Buzzards Bay Coalition. To identify spatial patterns across Buzzards Bay's embayments, we used a principle component and factor analysis and found that rotated factor loadings indicated little correlation between inorganic nutrients and organic matter or chlorophyll *a* (Chl *a*) concentration. Factor scores showed that embayment geomorphology in addition to nutrient loading was a strong driver of water quality, where embayments with surface water inputs showed larger biological impacts than embayments dominated by groundwater influx. A linear regression analysis of annual summertime water quality indicators over time revealed that from 1992 to 2013, most embayments (15 of 17) exhibited an increase in temperature (mean rate of 0.082 ± 0.025 (SD) °C yr^{-1}) and Chl *a* (mean rate of 0.0171 ± 0.0088 $\log_{10}$ (Chl *a*; mg m^{-3}) yr^{-1}, equivalent to a 4.0 % increase per year). However, only seven embayments exhibited an increase in total nitrogen (TN) concentration (mean rate 0.32 ± 0.47 (SD) μM yr^{-1}). Average summertime $\log_{10}$(TN) and $\log_{10}$(Chl *a*) were correlated with an indication that the yield of Chl *a* per unit total nitrogen increased with time suggesting the estuarine response to TN may have changed because of other stressors such as warming, altered precipitation patterns, or changing light levels. These findings affirm that nitrogen loading and physical aspects of embayments are essential in explaining the observed ecosystem response. However, climate-related stressors may also need to be considered by managers because increased temperature and precipitation may worsen water quality and partially offset benefits achieved by reducing nitrogen loading.

1 Introduction

Long-term monitoring of coastal water quality is critical to identifying environmental degradation, quantifying the effects of management strategies, and improving our understanding of coastal ecosystem dynamics. Extensive monitoring of estuaries in the United States reveals that many US coastal waters are impacted by eutrophication (Bricker et al., 2007, 2008). In the US northeast, increases in population density, coastal development, and heavy reliance on residential septic systems have elevated nutrient loading rates (e.g., Valiela et al., 1997; Howarth et al., 2002). Many coastal wa-

ters show higher levels of phytoplankton biomass, greater variation in water column dissolved oxygen, loss of submerged aquatic vegetation, and decreases in fish and shellfish abundance associated with eutrophication (Ryther, 1954; Nixon, 1995).

In addition to nutrient enrichment, coastal waters may be influenced by climate change, which has the potential to exacerbate the effects of eutrophication (Rabalais et al., 2009, 2010; Doney et al., 2012). For example, recent studies documenting climate-related changes to coastal waters suggest that increasing precipitation or warming may initiate phytoplankton blooms by increasing the delivery of nutrients (Najjar et al., 2010), changing phytoplankton growth rates (Eppley, 1972), or changing the phenology of regularly occurring phytoplankton blooms, causing a trophic mismatch between primary and secondary producers (Brander, 2010). Warming or increased freshwater inputs to coastal waters can also alter circulation patterns and enhance vertical stratification, which may exacerbate bottom-water hypoxia or anoxia as a result of eutrophication (Testa et al., 2008; Kemp et al., 2009; Rabalais et al., 2010; Murphy et al., 2011; Lennartz et al., 2014).

In this work, we focus on Buzzards Bay, Massachusetts (USA; 41.55° N, 70.80° W), a shallow, elongated estuary (~ 11 m deep and covering ~ 600 km^2) bordered by southern Massachusetts and Cape Cod. The coastline of Buzzards Bay consists of small, river-fed and groundwater-fed embayments distributed along the mainland (west) and Cape Cod (east) side of the estuary, respectively. Many of the embayments of Buzzards Bay are classified by the Massachusetts Department of Environmental Protection as nutrient impaired pursuant to Federal Clean Water Act section 303(d) because they do not meet surface water quality standards due to high levels of nitrogen loading (Sullivan et al., 2013). Many of these embayments also show signs of nutrient-related declines in water quality such as widespread losses in submerged aquatic vegetation (Costello and Kenworthy, 2011).

Century-scale records of climate indicators in the US northeast suggest changes in the major physical drivers controlling productivity in Buzzards Bay. The 2014 National Climate Assessment (NCA) identified the US northeast as one of the regions with the largest increases in temperature, precipitation, and high-intensity rainfall events (Walsh et al., 2014). Between 1894 and 2011, the NCA reports an average land-based temperature increase of ~ 1.1 °C (Walsh et al., 2014) for the US northeast, and long-term records of coastal ocean water temperature from Woods Hole, MA, suggest that water temperatures have increased by 1.9 °C since the late 1800s (Nixon et al., 2004). Recent studies have found oceanic warming at rates in the northwest Atlantic of up to 0.26 °C yr^{-1} since 2004 (Mills et al., 2013), and ocean temperature during the first half of 2012 was one of the warmest on record in the past 150 years. This event was attributed to less cooling from the atmosphere (Chen et al., 2014) and provides a glimpse of what the future may hold under climate warming. In addition to temperature change, the US northeast has had a ~ 15 % increase in overall rainfall and a 71 % increase in heavy precipitation events since the late 1800s (Walsh et al., 2014; see also Spierre and Wake, 2010), which may drastically change freshwater and nutrient delivery rates to coastal waters.

Short-term studies documenting water quality changes in Buzzards Bay are limited. Turner et al. (2009) analyzed trends in water quality between 1987 and 1998 at eight sites primarily in central Buzzards Bay. Although Turner et al. (2009) did not observe an overall trend in annual temperature across their 11-year record, they did find a significant increase in May temperatures, suggesting that spring warming may have occurred during that period. They also found that water column nutrients and chlorophyll *a* (Chl *a*) either remained the same or declined over their study period, which was related to improvements to a large municipal wastewater treatment facility that discharges into the open waters of Buzzards Bay (New Bedford, MA). Climate driven changes to Buzzards Bay, coupled with limited analyses of coastal nutrient trends, justifies the need to revisit long-term water quality data sets to investigate climate-related signals and biogeochemical climate synergies.

Here, we present the results of an analysis of 22 years of summertime water quality data collected through a citizen science monitoring program in the coastal embayments across Buzzards Bay. The Buzzards Bay Coalition (www.savebuzzardsbay.org), a local non-profit organization, maintains an innovative, long-term, citizen science water quality monitoring program. Since 1992, program volunteers have sampled summer water quality from approximately 200 sites across Buzzards Bay each year, with station coverage concentrated primarily in the coastal embayments. This program has engaged hundreds of local citizen scientists, and data from the monitoring program is used for education, outreach, and management actions to protect the waters of Buzzards Bay (Buzzards Bay Coalition, 2011). This monitoring program has provided baseline data, spurring nutrient reduction efforts such as the expansion of sewering and upgrading of wastewater treatment facilities that have occurred in several subwatersheds. This water quality data set provides a unique perspective across both space (regionally) and time with coverage of coastal embayments along a gradient of nitrogen loads and different geomorphologies while also having multi-decadal coverage over a period of rapid climatic change.

2 Methods

2.1 Data collection

The data for this analysis were collected through a long-term citizen science program to understand the water quality of coastal Buzzards Bay. Water samples were collected by citizen volunteers who measured temperature (calibrated ther-

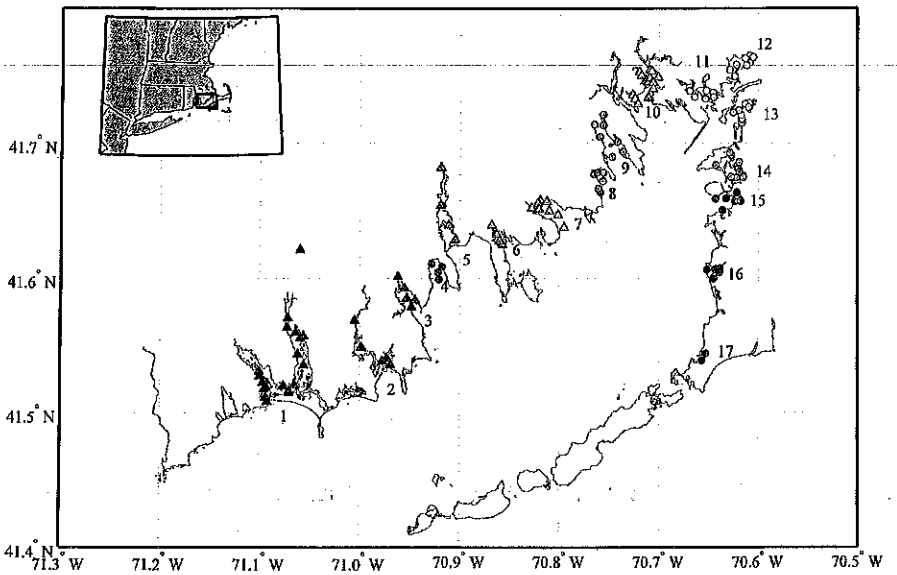

Figure 1. Study area of Buzzards Bay, MA (USA). Dots show individual sampling locations; different colors and numbers correspond to the 17 embayments across the estuary where the gradient from red to blue indicates geographical location around Buzzards Bay in Figs. 3 and 4. Circle symbols indicate the embayment is classified as "groundwater-fed", while triangles indicate the embayment is classified as "river-fed". Embayment numbers correspond to data in Tables 2, S1, and S2.

mometers), salinity (field hydrometer), and dissolved oxygen (DO; modified Winkler titration, Hach OX2P test kits) weekly from late May through September typically between 06:00 and 09:00 local time. In July and August, water samples were collected during two to four sampling events from a subset of sites during the last 3 hours of an outgoing tide. Water samples were either filtered on site or after immediate transport to a laboratory and were kept on ice in the dark while being transported (1992–1996 Woods Hole Oceanographic Institution; 1997–2008 University of Massachusetts Dartmouth; 2009–2013 Marine Biological Laboratory). Inorganic nutrient nitrate and nitrite ($NO_3^- + NO_2^-$) were analyzed spectrophotometrically by automated Cd reduction (Johnson and Petty, 1982) and orthophosphate (PO_4^{-3}) by the molybdenum blue method (Johnson and Petty, 1983). Ammonium (NH_4^+) was measured using the phenol hypochlorite method (Strickland and Parsons, 1972). Dissolved inorganic nitrogen (DIN) was defined as the sum of $NO_3^- + NO_2^- + NH_4^+$. Total dissolved nitrogen (TDN) was measured as nitrate following persulfate digestion (D'Elia and Steudler, 1977). Particulate organic carbon (POC) and nitrogen (PON) were measured by elemental analysis (Sharp, 1974). Total nitrogen (TN) is defined as the sum of TDN and PON, and dissolved organic nitrogen (DON) is defined as the difference between TDN and DIN. Chlorophyll *a* (Chl *a*) and phaeopigments were measured following acetone extraction using standard spectrophotometric methods (Parsons et al., 1989). Beginning in 2002 at a select few sites, point measurements of temperature, salinity, DO, pH, and Chl *a* were collected using YSI600XL and YSI6600 datasondes (YSI). The program's methods are outlined in a quality assurance project plan that has been approved by the Massachusetts Department of Environmental Protection and the US Environmental Protection Agency (Williams and Neill, 2014).

2.2 Auxiliary data

We compared the water quality variables measured here to nitrogen loading estimates from the Massachusetts Estuary Project reports and the Buzzards Bay National Estuary Program (BBNEP) loading estimates using comparable loading assumptions to those summarized by Costa (2013). We compare the trends from this citizen science monitoring program to other publically available data sets from the same time period collected locally, including hourly air temperatures from the NOAA National Data Buoy Center (NDBC; buoy BUZM3, 41°23′48″ N, 71°2′0″ W) and daily water temperature recorded at the Woods Hole, MA, dock (Nixon et al., 2004; buoy BZBM3, 41°31′25″ N 70°40′16″ W). We also compare the water quality data set to monthly precipitation records collected by the Massachusetts Rainfall Program from April to June from three rain gages located around Buzzards Bay from the towns of Dartmouth, East Wareham, and Falmouth, where there were no missing data for the years 1992 to 2013.

2.3 Data analysis

The purpose of this analysis was to examine embayment-scale patterns in water quality rather than within-embayment patterns. The monitoring program expanded over time and

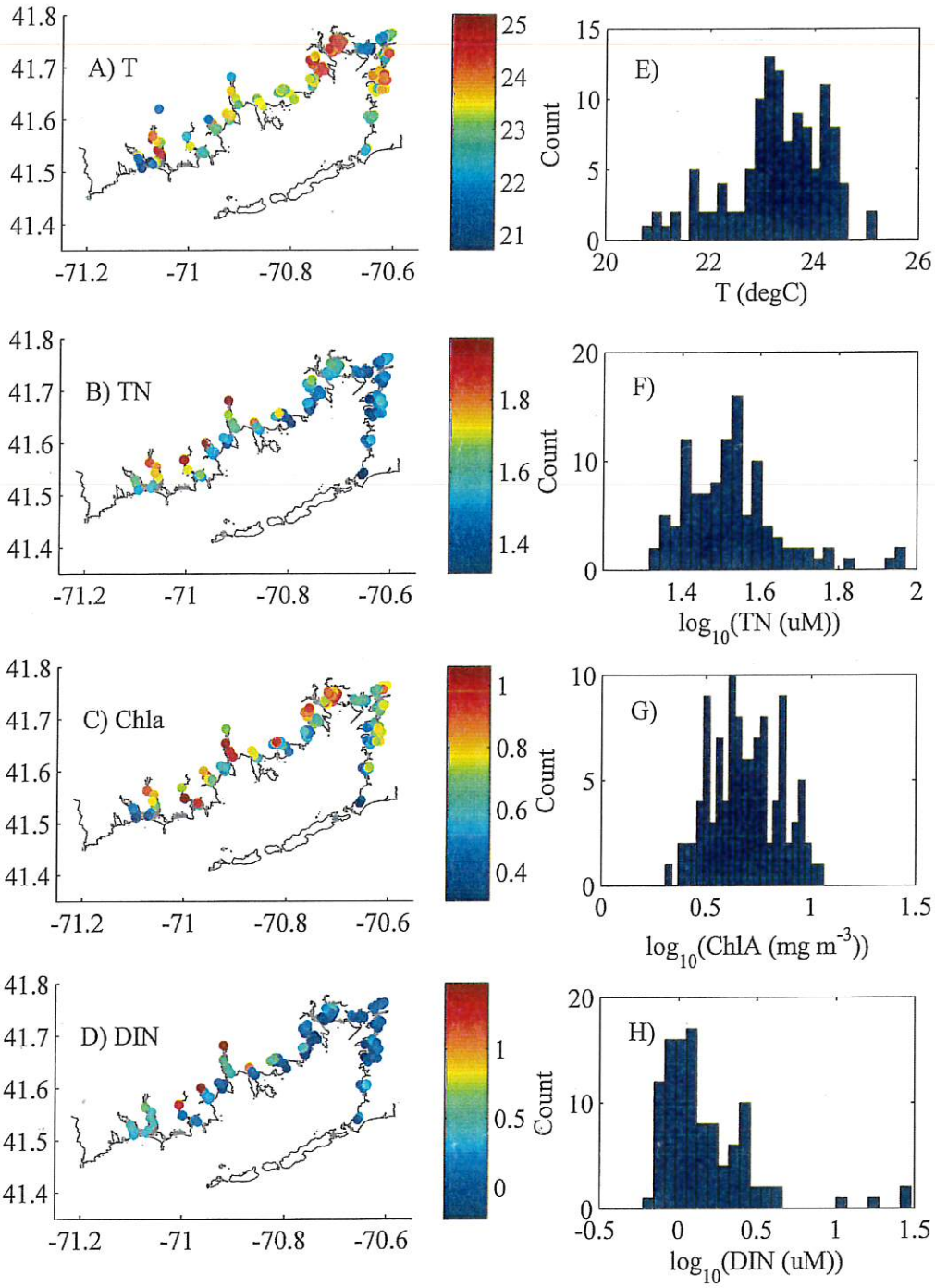

Figure 2. Spatial variability and distributions of mean summer **(a, e)** temperature (T), **(b, f)** total nitrogen (TN), **(c, g)** chlorophyll a (Chl a), and **(d, h)** dissolved inorganic nitrogen (DIN) from 2012 as an example year. TN, Chl a, and DIN have been $\log_{10}$-transformed. The units are the same for the corresponding left and right panels.

many sites were only sampled transiently, and to minimize spatiotemporal aliasing, we chose to include only 122 sites in this analysis (Fig. 1), chosen as follows: first, sites were grouped into 27 spatially separate embayments, and second, sites were included in the analysis only if they were sampled both during the first and last 5 years of the time series and had at least 15 years of data collected. Embayments were classified as "river-fed" (Fig. 1, triangles) if the embayments had

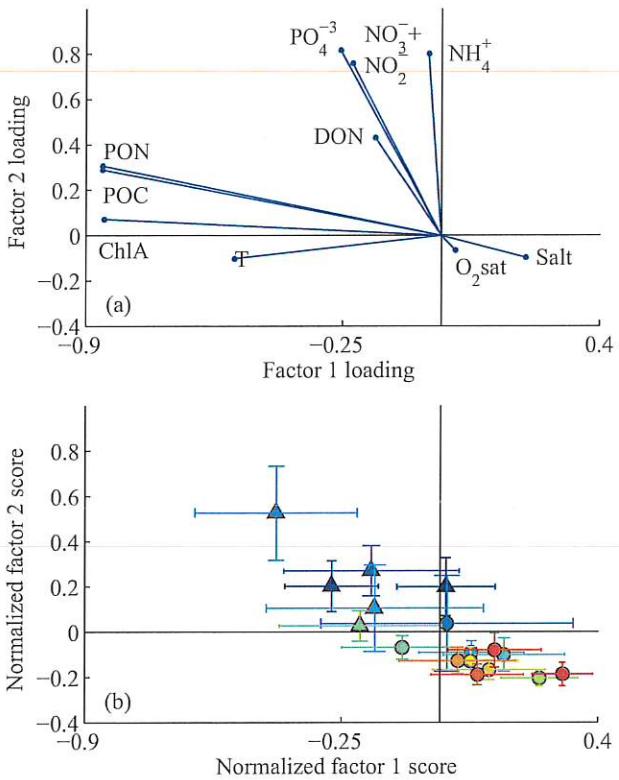

Figure 3. Factor analysis biplots show rotated **(a)** factor loadings and **(b)** mean factor scores across all years for the individual embayments. Factor scores have been normalized by the factor loadings to plot on the same axes. Colors in factor scores correspond to coloring of embayments shown in Fig. 1. Error bars in **(b)** are the mean ±1 standard deviation. Triangles are "river-fed" embayments, circles are "groundwater-fed".

large surface water inputs; otherwise, they were classified as "groundwater-fed" (Fig. 1, circles). Embayments classified as river-fed tended to have higher variability in mean salinity across the embayment, consistent with sampling across a classical estuarine gradient (Table S1 in the Supplement). Only data collected during July and August were considered for the analysis of mean summertime water quality because, for the majority of the data set, nutrient parameters were only available from these months. Samples within each embayment and across sampling events were then averaged in order to calculate each embayment's annual summertime mean water quality. Chl *a* data were $\log_{10}$-transformed (Campbell, 1995) prior to averaging and further analysis. Volunteers performed Secchi disk measurements; however, Secchi depth data were not analyzed because a large number of measurements of Secchi depth came from shallow sites at low tide where the sediment surface was visible, and thus Secchi depth did not characterize water clarity.

We performed principal component analysis (PCA) and factor analysis (FA) to examine the spatial patterns among water quality variables. Identifying patterns in water quality

Table 1. Factor loadings from principal component and factor analysis. Of the 12 original factors, the 4 with eigenvalues >= 1 were retained for rotation. Values closer to 1 or −1 indicate strong correlation between the factor and the original data for a variable, while values closer to 0 indicate little or no correlation. Loadings > 0.5 are bold for visibility.

Variable	Factor 1	Factor 2	Factor 3	Factor 4
PON	**−0.86**	0.31	0.17	0.07
POC	**−0.86**	0.30	0.14	0.16
Chl *a*	**−0.85**	0.08	0.18	−0.03
T	**−0.54**	−0.12	−0.30	0.50
PO_4	−0.26	**0.81**	−0.29	0.15
NH_4	−0.03	**0.81**	0.26	−0.01
NO_3+NO_2	−0.22	**0.76**	0.20	−0.10
Salinity	0.22	−0.10	**−0.86**	−0.09
DOsat	0.04	−0.07	−0.20	**−0.90**
DON	−0.16	0.44	0.43	0.18

can be complicated by covariance between forcings (nutrients) and ecosystem responses (Chl *a*). PCA develops new, uncorrelated variables from linear combinations of the measured observations. In addition to using PCA and FA to reduce the number of dimensions in the data space, the resulting FA variable loadings onto each factor and factor scores for each embayment can help explain some of the relationships between measurements. PCA has been used in other shallow coastal systems to quantify spatial patterns in water quality (Boyer et al., 1997; Caccia and Boyer, 2005) and develop eutrophication indicators from the eigenvector that explains the largest amount of variance in the data set (Primpas et al., 2010; Fertig et al., 2014). PCA and FA were applied to the summertime averages from all embayments. All years with missing data in any variable were discarded and data were standardized prior to PCA to have zero mean and unit variance. Principal components with eigenvalues < 1 were discarded for the FA. The remaining principal components were then rotated using an iterative, orthogonal rotation (VARIMAX) using Matlab code from Glover et al. (2011). Reported factor scores have been normalized by the largest factor loading to scale from −1 to 1.

To determine if water quality indicators have changed over time, linear regression through time was then applied to the summertime embayment means using the associated standard error to weight the data points accordingly (Glover et al., 2011). Linear regression was also applied to water and air temperatures and precipitation data. Normality of residuals was tested with Shapiro–Wilk tests. Type-II regression was performed on property–property correlations with uncertainty in both independent and dependent variables (York, 1966; Matlab code from Glover et al., 2011). We test differences between regression characteristics using a paired *t* test with pooled error variance.

3 Results and discussion

Buzzards Bay, MA, represents a natural laboratory to observe the combined impacts of nutrient loading, management action, and climate change on coastal waters. The coastal waters of Buzzards Bay exhibited considerable spatial (Fig. 2) and temporal variability (Fig. S1 in the Supplement) in both physical (Table S1) and water quality parameters (Table S2). Our regional view of Buzzards Bay documents the changes in water quality of the coastal embayments over time. The purpose of this analysis is not to characterize in great detail the fine-scale, local changes in water quality within each embayment; thus, our aggregating, embayment-scale perspective may not reflect changes in localized water quality drivers at the individual sampling stations. Although this analysis only includes measurements from July and August, summertime water quality is relevant to managers because that is when many adverse impacts are likely to be observed, for example, hypoxia, benthic algae accumulations, or eelgrass stress due to temperature (Moore and Jarvis, 2008; Moore et al., 2011).

3.1 Spatial patterns in water quality

The PCA and FA of the embayment summertime means revealed substantial correlations among water quality indicator variables (Fig. 3a). There were four factors with eigenvalues ≥ 1 that explained 75 % of the total variance in the data set. Many variables typically considered telltale signs of eutrophication, including elevated POC, PON, and Chl *a* loaded heavily on the first factor (Primpas et al., 2010; Fertig et al., 2014), suggesting that the first factor may represent a particulate biological signal in the data set (Table 1). Temperature also loaded heavily onto the first factor, suggesting positive correlation between biological response variables and temperature. The second factor grouped inorganic nutrients, $NO_3^- + NO_2^-$, NH_4^+, and PO_4^{-3}, and the variability in the inorganic nutrient species was approximately orthogonal to Chl *a* (Fig. 3a, Table 1), indicating little correlation between DIN or PO_4^{-3} and Chl *a* concentration. Salinity (Salt) loaded most heavily onto the third factor, which likely reflects relative inputs of freshwater, while the fourth factor likely reflects the strong thermodynamic relationship between temperature and dissolved oxygen saturation (DOsat; Table 1).

There are several possible explanations for the lack of correlation between DIN and Chl *a*. First, shallow, high-productivity coastal lagoons may be dominated by other primary producers such as macroalgae, submerged aquatic vegetation, or microphytobenthos, resulting in rapid uptake and biological conversion of inorganic nitrogen to organic nitrogen by benthic producers, which would not be part of the sampled water column nitrogen pool (McGlathery et al., 2007; Glibert et al., 2010). Second, this pattern would also be seen if production was not nitrogen limited; however, this is an unlikely explanation as most embayments had low inorganic N / P ratios (calculated from Table S2 as DIN / PO4).

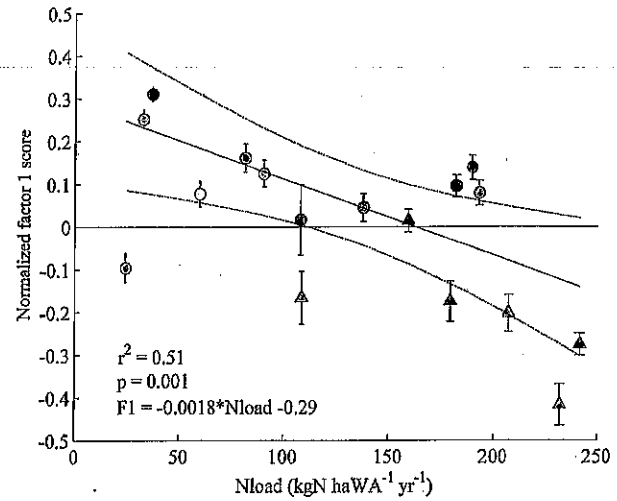

Figure 4. Average factor 1 score from each embayment fitted to nitrogen load estimated by the Buzzards Bay National Estuary Program (Costa, 2013) normalized by estuarine water area. Colors correspond to embayments in Fig. 1. Dotted lines are 95 % confidence intervals for the fit and error bars are standard error. Triangles are "river-fed" embayments, and circles are "groundwater-fed".

The mean N / P ratio was lower than 7 in every embayment, well below the Redfield ratio of 16 : 1 (Redfield et al., 1963), suggesting that primary production may be limited by nitrogen during this time of year (Howarth and Marino, 2006; Howarth et al., 2014; Hayn et al., 2014). Third, in nitrogen-limited systems, primary producers can draw down DIN to low levels even under high TN (Hayn et al., 2014). $NO_3^- + NO_2^-$ and NH_4^+ trends varied with increasing, decreasing, and stable concentrations over time (described in more detail below, Sect. 3.2). Of the seven embayments with increasing trends in TN, only two embayments (nos. 1 and 7) also had increasing trends in DIN. In both cases, the rate of TN increase was 2.88 and 6.46 times larger than the rate of DIN increase, suggesting that changes in DIN may not reflect changes in TN. If this monitoring program measured only summertime DIN as an indicator of water quality, the program would not capture the degree of eutrophication in Buzzards Bay (Souchu et al., 2010; Glibert et al., 2014).

Comparing factor 1 and factor 2 scores shows a clear spatial pattern among embayments that reflects a combination of the dominant morphology and relative nutrient loadings (normalized by estuarine water area), which varied by over 1 order of magnitude across the embayments (Fig. 4). Embayments with negative factor 1 and positive factor 2 scores were largely riverine dominated, located on the northwestern side of Buzzards Bay (Figs. 1, 3b, triangles), and tended to have lower salinities. These embayments also had the largest watersheds, were generally the most urbanized, and had larger nutrient inputs per unit of embayment water area (Fig. 4). In contrast, embayments that were lagoonal systems with little

Table 2. Linear fits for temperature, TN, and Chl *a*. Significant fits are bolded. Embayment numbers correspond to locations shown in Fig. 1.

		Temperature ($°C\,yr^{-1}$)					TN ($\mu M\,yr^{-1}$)					log_{10}(Chl *A*; $mg\,m^{-3}$) yr^{-1}				
Embayment name	no.	slope	SD	r^2	p	n	slope	SD	r^2	p	n	slope	SD	r^2	p	n
Westport River	1	**0.096**	**0.006**	**0.373**	**0.003**	22	**0.97**	**0.09**	**0.23**	**0.023**	22	**0.015**	**0.001**	**0.40**	**0.002**	22
Slocums River	2	**0.092**	**0.009**	**0.273**	**0.013**	22	−0.02	0.19	0.00	0.934	21	0.004	0.003	0.05	0.346	21
Apponagansett Bay	3	**0.082**	**0.007**	**0.279**	**0.011**	22	**0.63**	**0.16**	**0.47**	**<0.001**	22	**0.015**	**0.002**	**0.41**	**0.001**	22
Clarks Cove	4	**0.080**	**0.011**	**0.280**	**0.016**	20	**0.63**	**0.08**	**0.42**	**0.002**	20	**0.014**	**0.002**	**0.26**	**0.026**	19
New Bedford Harbor	5	**0.115**	**0.008**	**0.448**	**0.001**	20	−0.81	0.24	0.15	0.090	20	**0.014**	**0.004**	**0.53**	**<0.001**	20
Nasketucket Bay	6	**0.108**	**0.016**	**0.231**	**0.024**	22	**1.25**	**0.09**	**0.49**	**<0.001**	21	**0.044**	**0.001**	**0.79**	**<0.0001**	21
Mattapoisett Harbor	7	**0.096**	**0.007**	**0.349**	**0.004**	22	0.25	0.07	0.16	0.068	21	**0.014**	**0.001**	**0.36**	**0.004**	21
Aucoot Cove	8	**0.065**	**0.007**	**0.222**	**0.027**	22	**0.38**	**0.05**	**0.33**	**0.005**	22	**0.019**	**0.001**	**0.52**	**<0.001**	22
Sippican Harbor	9	**0.087**	**0.009**	**0.202**	**0.036**	22	0.23	0.08	0.13	0.113	21	**0.021**	**0.001**	**0.68**	**<0.0001**	21
Wareham River	10	**0.055**	**0.005**	**0.230**	**0.024**	22	0.12	0.04	0.03	0.444	22	**0.022**	**0.001**	**0.76**	**<0.0001**	22
Onset Bay	11	**0.082**	**0.007**	**0.369**	**0.003**	22	0.06	0.04	0.02	0.520	22	**0.009**	**0.001**	**0.27**	**0.013**	22
Buttermilk Bay	12	0.008	0.009	0.002	0.852	21	−0.04	0.06	0.00	0.769	21	**0.019**	**0.001**	**0.73**	**<0.0001**	21
Bel Pond and Phinneys Harbor	13	**0.096**	**0.010**	**0.339**	**0.006**	21	0.20	0.06	0.14	0.089	22	**0.018**	**0.002**	**0.61**	**<0.0001**	22
Red Brook Harbor and Pocasset Harbor	14	**0.090**	**0.006**	**0.326**	**0.005**	22	**0.58**	**0.06**	**0.37**	**0.004**	21	**0.018**	**0.001**	**0.62**	**<0.0001**	21
Megansett Harbor	15	**0.076**	**0.006**	**0.257**	**0.016**	22	0.17	0.06	0.13	0.114	21	**0.019**	**0.002**	**0.59**	**<0.0001**	21
West Falmouth Harbor	16	0.068	0.009	0.169	0.057	22	**0.78**	**0.05**	**0.64**	**<0.0001**	22	**0.019**	**0.002**	**0.41**	**0.006**	17
Quissett Harbor	17	**0.101**	**0.008**	**0.406**	**0.001**	22	0.06	0.05	0.02	0.5650	21	0.0037	0.0021	0.02	0.5239	21

riverine input and were more saline tended to have positive factor 1 and negative factor 2 scores (Figs. 1, 3b circles).

We found strong evidence of a more negative factor 1 score, or biological signal (and reduced water quality), in embayments with a higher total nitrogen loads (organic plus inorganic; Fig. 4), similar to other shallow coastal estuaries and other studies in the Buzzards Bay region (e.g., Benson et al., 2013). Using the factor 1 score rather than Chl *a* or TN as an ecosystem indicator incorporates nutrient availability, organic matter, and Chl *a* into a combined variable that would be sensitive to changes in any of these variables. Over the observational time span, embayments with consistently large positive values of factor 1 had good water quality, agreeing well with other ecosystem indicators such as eelgrass extent (Latimer and Rago, 2010; Costello and Kenworthy, 2011; Benson et al., 2013). Five of the six embayments with normalized factor 1 scores $<=0$ are federally listed as nutrient-impaired waters, further supporting using factor 1 as an indicator of the biological response to nutrient loading. The relationship we found is consistent with estuaries which are not saturated with nutrients along a conceptual nutrient-load–ecosystem-response curve (Glibert et al., 2010). The separation of the river-dominated and lagoonal systems along the nutrient loading gradient (Fig. 4, Glibert et al., 2010) further supports the pattern of embayments in factor space (Fig. 3b).

3.2 Temporal trends in water quality

We found long-term, statistically significant positive trends in temperature in 15 of the 17 embayments (Fig. 5a, Table 2), and on average across all embayments, Buzzards Bay warmed at a rate of 0.082 ± 0.025 (SD) $°C\,yr^{-1}$ (Table 1) during summer. Temperature trends from the citizen science database agreed well with both July–August air temperature trends (NDBC buoy BUZM3, $0.091 \pm 0.069\,°C\,yr^{-1}$, $r^2 = 0.422$, $p = 0.004$, data not shown) and water temperature recorded at the Woods Hole dock ($0.12 \pm 0.005\,°C\,yr^{-1}$ SD, $r^2 = 0.596$, $p < 0.0001$). The regional warming observed across Buzzards Bay embayments may have substantial implications for biological processes that are strongly temperature dependent (see below, Sect. 3.3).

There were also statistically significant increasing trends in Chl *a* in 15 of the 17 embayments, with a mean slope of 0.0171 ± 0.0088 log_{10}(Chl *a*; $mg\,m^{-3}$) yr^{-1} (SD, Fig. 5b, Table 1) or increasing at a mean rate of $4.0\,\%\,yr^{-1}$ (95 % confidence interval, 3.0–5.0). The increase in Chl *a* alone is symptomatic of degrading summer water quality across Buzzards Bay. Higher Chl *a* concentration in most embayments implies increasing water column light attenuation and decreasing light reaching the benthos that can have strong impacts on ecosystem functioning. Loss of eelgrass is common when less than 20 % of incident light reaches the sediment surface (e.g., Dennison et al., 1993). Although we do not have direct measurements of light attenuation, the widespread rate of increase in Chl *a* ($4\,\%\,yr^{-1}$) across Buzzards Bay was consistent with declines in bay-wide eelgrass extent (loss of $3.5\,\%\,yr^{-1}$; Costello and Kenworthy, 2011).

However, the corresponding long-term trends in summer nutrient concentrations (Figs. 5c, 6, 7) suggest that nutrient levels may not be the sole factor driving the degradation in water quality (see Sect. 3.3, below, on climate impacts). Of the 17 embayments, only 7 had statistically significant increasing trends in TN with a bay-wide mean trend of 0.236 ± 0.523 (SD) $\mu M\,yr^{-1}$, and no embayments had declining trends (Fig. 5c, Table 1). Ten embayments exhibited no statistical trends in TN (Fig. 5c) possibly due to high interannual variability in individual nitrogen species that may reflect local sources or changes in nutrient loading.

Inorganic (Fig. 6) and organic (Fig. 7) nutrient temporal trends varied considerably across the embayments with increasing, decreasing, and consistent concentrations over time (Figs. 6, 7). NH_4^+ and $NO_3^- + NO_2^-$ declined in 5 and 1 em-

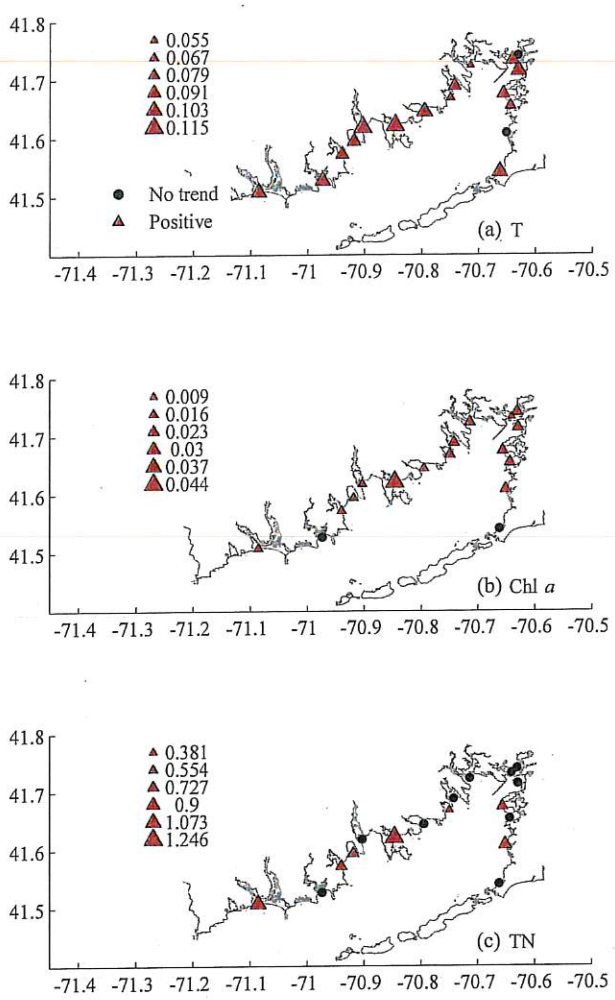

Figure 5. Slopes from long-term trend analysis for **(a)** temperature (°C yr^{-1}), **(b)** chlorophyll (Chl *a*; log_{10}; mg m^{-3} yr^{-1}), and **(c)** total nitrogen (TN; μM yr^{-1}). Red triangles indicate statistically significant increasing trends and black circles indicate no statistical trend. The size of the triangles indicates the magnitude of the slopes.

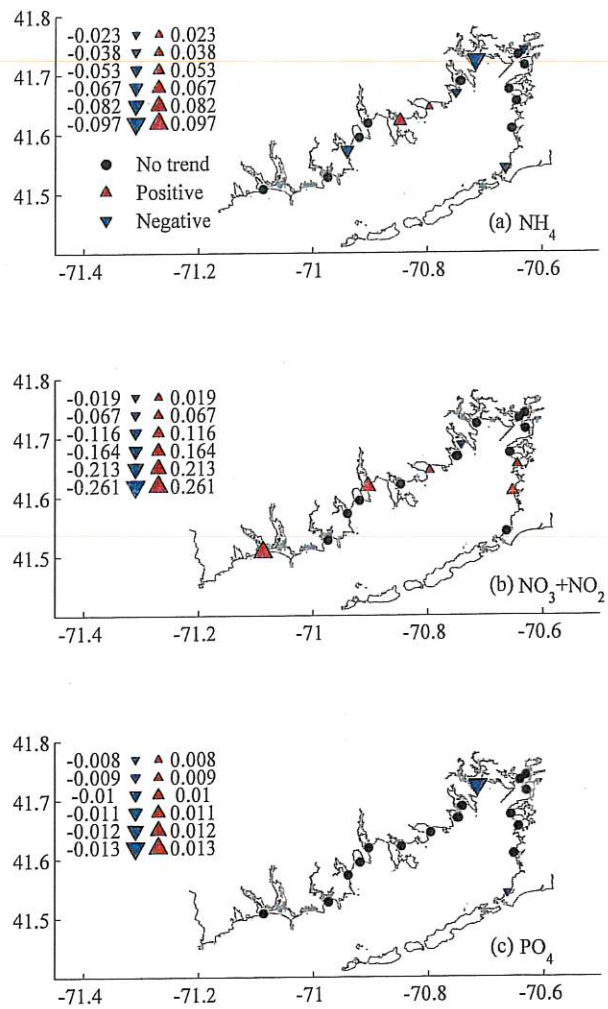

Figure 6. Slopes from long-term trend analysis for **(a)** ammonium (NH_4^+; μM yr^{-1}), **(b)** nitrate + nitrite (NO_3^-+NO_2^-; μM yr^{-1}), and **(c)** phosphate (PO_4^{-3}; μM yr^{-1}). Colors and symbols indicate statistically significant trends and direction, while the size of the points indicates the magnitude of the slopes.

bayments, increased in 2 and 5 embayments, and remained the same in 10 and 11 embayments, respectively, while PO_4^{-3} declined in 2 embayments and remained the same in 15. Increases in DON, PON, and POC occurred in a few embayments (Fig. 7), and the observed trends in PON and POC could reflect the increase in Chl *a* (and live phytoplankton biomass) as PON and POC were correlated with Chl *a* ($r = 0.62$, $p < 0.0001$ and $r = 0.61$, $p < 0.0001$, respectively; not shown). However, although nearly all embayments exhibited strong increasing trends in Chl *a*, only three embayments increased in POC and PON (Fig. 7a, b), suggesting that live phytoplankton biomass may not be the only factor driving the increase in Chl *a*. West Falmouth Harbor (Fig. 1, no. 16) is notable as the only embayment where NO_3^-+NO_2^-, DON, PON, and Chl *a* all increased significantly through time (Figs. 6b, 7b, c), consistent with changes in nitrogen loads, which increased by a factor of about 3 between the mid- to late-1990s and 2003 and have since remained constant (Hayn, 2012; Howarth et al., 2014; Hayn et al., 2014). As a result of the considerable declines in water quality, efforts to better manage nitrogen loads into West Falmouth Harbor have led to the recent addition of nitrogen removal to a wastewater facility that discharges into the groundwater upstream of the embayment.

3.3 Climatic impacts on water quality

Although changes in Chl *a* concentration over time (Fig. 5b) may be partially driven by increases in total nitrogen (Fig. 5c), the inconsistency of trends among different em-

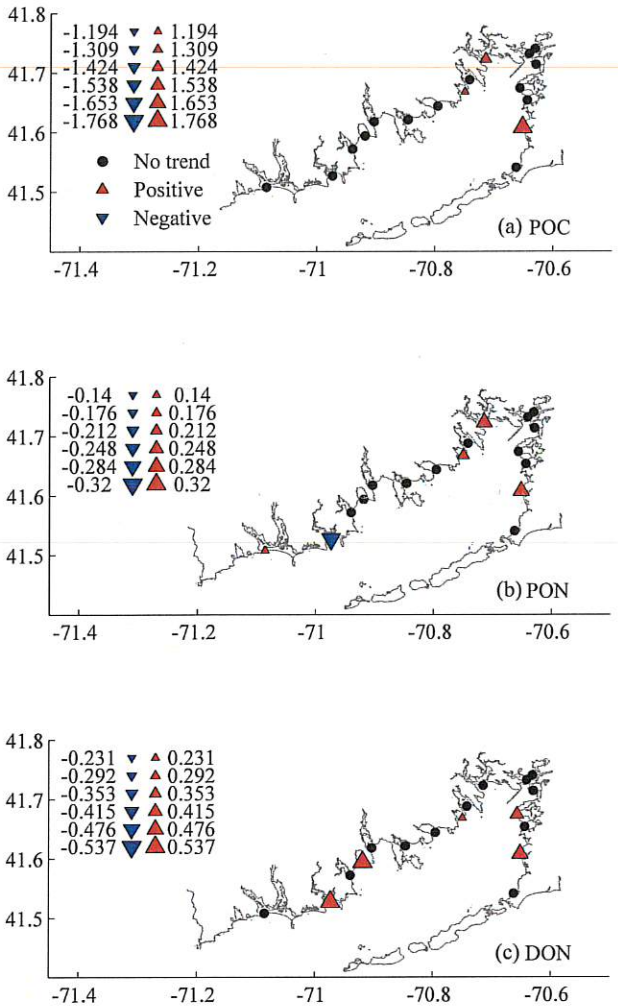

Figure 7. Slopes from long-term trend analysis for **(a)** particulate organic carbon (POC; $\mu M\,yr^{-1}$), **(b)** particulate organic nitrogen (PON; $\mu M\,yr^{-1}$), and **(c)** dissolved organic nitrogen (DON; $\mu M\,yr^{-1}$). Colors indicate statistically significant trends and direction, while the size of the points indicates the magnitude of the slopes.

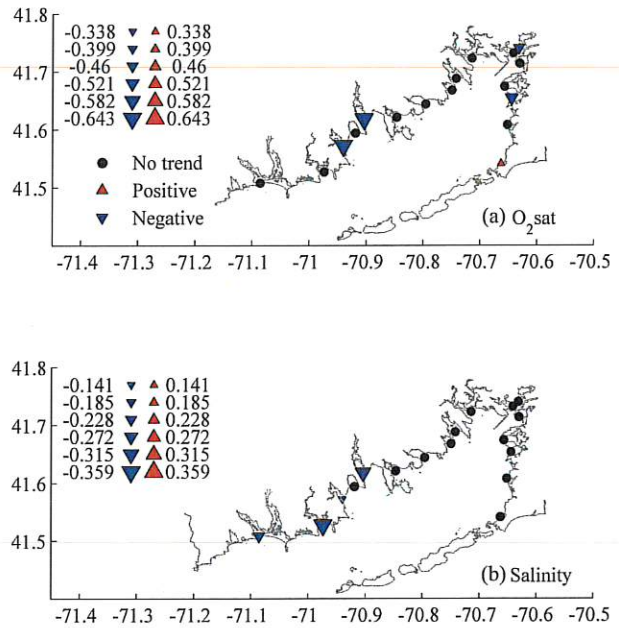

Figure 8. Slopes from long-term trend analysis for **(a)** oxygen saturation (O_2sat; $\%\,yr^{-1}$) and **(b)** salinity ($ppt\,yr^{-1}$). Colors and symbols indicate statistically significant trends and direction, while the size of the points indicates the magnitude of the slopes.

bayments suggests that other factors such as changing physical drivers may also be influencing water quality. Salinity declined in four of six embayments that were river-fed (Fig. 8b), and mean summer salinity in these embayments and six others (nos. 1, 2, 3, 4, 5, 10, 12, 13, 14, and 17) was strongly correlated to the April–June rainfall total ($p < 0.05$). However, there was no significant change in average April–June rainfall totals from 1992 to 2013 ($p > 0.05$, not shown). Combined with significant warming, these altered drivers may change hydrodynamics (e.g., flushing time) and lateral or vertical stratification. Vertical stratification has influenced water quality in a number of deeper coastal systems (Kemp et al., 2009; Rabalias et al., 2009; Murphy et al., 2011). Buzzards Bay is a relatively shallow estuary, however, with an average depth of ~ 2 m in the embayments and a maximum depth of ~ 11 m in open waters. The open waters of Buzzards Bay are rarely and only weakly stratified from wind shear and tidal cycling (Turner et al., 2009), so enhancement of vertical stratification is unlikely to influence water quality. This is further supported by trends in early morning dissolved oxygen saturation (O_2sat) in the coastal embayments because although declining water quality was observed in most embayments, only four displayed decreasing trends in mean oxygen saturation (O_2sat; Fig. 8a), suggesting that the coastal embayments are also well-mixed environments.

The warmer summertime temperatures we observed over the time series can also influence biological responses. Warmer temperature can enhance phytoplankton production (Eppley, 1972; Reay et al., 1999; Finkel et al., 2009). For example, for a typical phytoplankton growth Q10 (the increase in growth rate over 10 °C) of 1.88 (Eppley, 1972), the warming of 0.57 to 3.19 °C across the embayments would increase growth rates by ~ 3–22 % if no other factors are limiting. Increased summer temperatures may also stimulate nitrogen uptake rates, and thus primary productivity, as phytoplankton affinity for inorganic nitrogen has been found to increase with temperature (Reay et al., 1999). Ecosystem respiration can be correlated to temperature in coastal systems (Caffery, 2004), and thus warming can increase potential nutrient availability by enhancing the recycling of organic matter and nutrients.

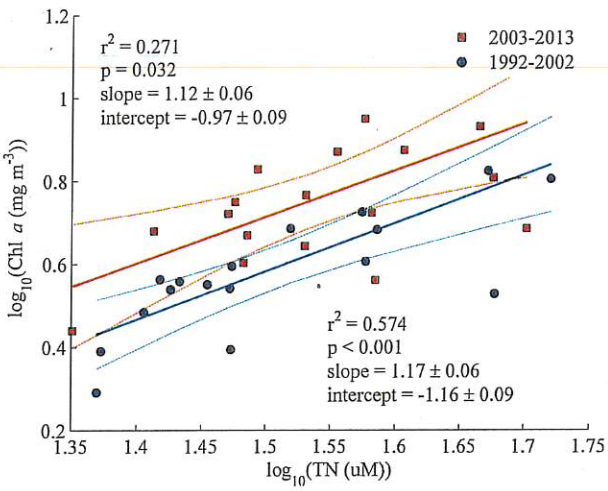

Figure 9. 1992–2002 and 2003–2013 average $\log_{10}$-Chl *a* fitted to $\log_{10}$-TN. Type-II regression accounted for uncertainty in both dependent and independent variables. Dotted lines are 95 % confidence intervals.

Increases in Chl *a* concentration over time may also be related to changes in the timing of seasonal phytoplankton blooms. Although the open waters of Buzzards Bay show sporadic blooms with no apparent seasonal cycle (Turner et al., 2009), measurements from inside New Bedford Harbor (Fig. 1, no. 6) suggest that blooms occur from March to October (Turner et al., 2009). If blooms occur in the other embayments similar to New Bedford Harbor, changes in timing of blooms caused by summer warming or changes to freshwater delivery may alias our measurements in any number of different ways as our analysis is limited to only July and August. It is interesting to note that while summertime Chl *a* in Buzzards Bay has increased, in nearby Narragansett Bay, RI (USA), there has been a 70 % decline in water column Chl *a* since 1960 and changes to the timing of phytoplankton blooms. These changes have been attributed to climate warming, changes in wind shear, and reduced benthic–pelagic coupling (Oviatt et al., 2002; Oviatt, 2004; Fulweiler and Nixon, 2009; Nixon et al., 2009) rather than modification of nitrogen inputs to the system (Nixon et al., 2008).

Higher primary production rates or changes in the timing of phytoplankton blooms in a warmer climate may explain the trends in Chl *a* (Fig. 5b) but not the fact that Chl *a* is increasing at a faster rate than DIN, DON, PON, and POC. Across the embayments, we found strong correlations between TN and Chl *a*, which differed during the first half and last half of the data set (Fig. 9), with an increased offset ($t = -2.113$, $df = 30$, $p = 0.0431$) and no change in slope ($t = 0.685$, $df = 30$, $p = 0.498$), a result remarkably similar to that found in Cartensen et al. (2011) for coastal systems across North America and Europe. This pattern was largely driven by a changing correlation between PON and Chl *a* (not shown; 1992–2002: $r^2 = 0.853$ $p < 0.0001$; 2003–2013: $r^2 = 0.754$, $p < 0.0001$) that may have been caused by several possibilities. First, increasing Chl *a* per unit of PON suggests that the ratio of live phytoplankton biomass to detritus has increased although more information would be needed to test this hypothesis. Second, increased eutrophication may also cause a more light-limited system, where phytoplankton increase Chl *a* : carbon ratio at the cellular level to compensate for increased shading through the water column (Geider et al., 1997). Third, an increase in the ratio of Chl *a* : PON could be due to warming influences on phytoplankton community composition. Blooms of the red-tide forming dinoflagellate *Cochlodinium polykrikoides* were first reported in 2005 and have since become a regular feature of late summer across Buzzards Bay (BBNEP, www.buzzardsbay.org). If new phytoplankton communities are present compared to historical data, they may have higher Chl *a* per unit of nitrogen or be able to utilize the existing PON pool in addition to DIN (Mulholland et al., 2009) and outcompete species requiring more labile nitrogen. Regardless of the cause, the increase in yield of Chl *a* per unit of nitrogen over time has implications for management because in order to restore water clarity to some threshold level, TN in many locations may need to be further reduced than would be predicted based on only historical measurements (Cartensen et al., 2011).

4 Conclusions

In this analysis, we found that (1) spatial patterns in water quality are driven by both nutrient loading and the geomorphology of the embayment, (2) significant summertime warming has occurred across the coastal embayments of Buzzards Bay which equated to nearly 2 °C over 22 years, (3) temporal trends in water quality indicators suggest that Chl *a* is increasing at a faster rate than inorganic and organic nitrogen species, and (4) the yield of Chl *a* per unit of total nitrogen has increased over the time series.

The analysis described here highlights the value of long-term monitoring of coastal systems, and the wealth of data across large temporal and spatial scales obtained by a well-managed citizen science monitoring program. We found many of the embayments of Buzzards Bay had poor or declining water quality, suggesting that further nutrient reduction efforts will be critical to improving the coastal waters of Buzzards Bay. We found that Chl *a* was increasing in more embayments than nutrients, which may be a result of multiple drivers of change such as temperature (Fig. 5a) and precipitation patterns (Walsh et al., 2014), in addition to anthropogenic watershed nutrient loading. To test these speculations of changing patterns of Chl *a* and nutrients, further investigations into spatial data sets with higher temporal coverage, such as satellite ocean color data, and investigations into other historical community composition data sets are warranted. An understanding of how nutrient loads to the

embayments of Buzzards Bay and embayment net community production have changed over time will clarify whether the changes in Chl *a* are a result of changes in nutrient flux to the system or are due to changes in physical drivers. If climate drivers alter the ecosystem response to nutrient availability, water quality management targets such as total maximum daily loads, calculated from historic ecosystem response curves, may not reach the desired improvements under future climate scenarios. Long-term stewardship of Buzzards Bay will likely require adaptive management that takes into account changing water quality baselines (e.g., Duarte et al., 2009) and forward-looking climate trends in order to maintain or restore ecosystem health.

The Supplement related to this article is available online at doi:10.5194/bg-13-253-2016-supplement.

Acknowledgements. We would like to thank the Buzzards Bay Coalition and the Buzzards Bay National Estuary Program for providing the data for this analysis. We thank more than 1074 citizen volunteers of the Buzzards Bay Coalition who collected the water quality samples and Mark Rasmussen for his leadership in sustaining the Baywatchers Program. We thank the laboratory of Brian Howes at the Woods Hole Oceanographic Institution (1992–1996) and the University of Massachusetts Dartmouth (1997–2008) and Hugh Ducklow, Matthew Erickson, and Richard McHorney at the Marine Biological Laboratory (2009–2013) for sample analysis. The Baywatchers Program was supported by funding from the Buzzards Bay Coalition member contributions, the Buzzards Bay National Estuary Program (US Environmental Protection Agency), the Commonwealth of Massachusetts, and private foundations. Support for this analysis was provided by the Woods Hole Partnership in Education Program, the Department of Interior Northeast Climate Science Center, and the John D. and Catherine T. MacArthur Foundation (Grant no. 14-106159-000-CFP).

Edited by: M. Tzortziou

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Sagamore Cemetery Association, Inc.

P.O. Box 679
Sagamore, MA 02561

Mr. Barry H. Johnson, Chairman
Community Preservation Committee
Bourne Town Hall
24 Perry Avenue
Bourne, MA 02532

January 25, 2020

Dear Mr. Johnson:

Although I did not see a requirement in my CPA paperwork to submit a final report for projects completed through CPA grants, I would feel remiss in not sending one.

The Cemetery Association was most fortunate to be aligned with an exceptionally talented craftsman, Michael Gallagher (Village Green Restoration) , who completed the rehabilitation of 41 damaged gravestones months ahead of schedule. The weather cooperated in this mission. Funds awarded were used with no overruns. In fact, the company donated time and expertise to restore several gravestones over and above those listed in the contract.

As project supervisor, it was a pleasure for me , personally, to enjoy the cooperation and support of many town entities: the Community Preservation Committee, Historical Commission, Historical Society, Preservation Society, Finance Committee, Selectmen and, of course, citizens.

Please advise me if you need a more detailed report and it will be forthcoming. The Sagamore Cemetery Association extends its deepest thanks to all who contributed to the fruition of this long dreamed for and important public/private project.

Sincerely,

M. Elizabeth Ellis

M. Elizabeth Ellis, Secretary
Sagamore Cemetery Association, Inc.

Cc Bourne Historical Commission, Bourne Historical Society, Bourne Society for Historic Preservation, Bourne Finance Committee, Bourne Board of Selectmen