Title and Approval Page (A1)

Quality Assurance Project Plan (QAPP) for Use of Secondary Data and Modeling in Red Brook Harbor to Support TMDL Development

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Partner Organization(s): Buzzards Bay Coalition, Buzzards Bay National Estuary Program

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Section A: Project Management

The following section provides background information for the project, *Modeling in Red Brook Harbor to Support TMDL Development*.

A4: Project Organization

The *Modeling in Red Brook Harbor to Support TMDL Development* project ("Project") is a partnership between the Town of Bourne, the Buzzards Bay Coalition (BBC), the Buzzards Bay National Estuary Program (BBNEP), and Jim Churchill a researcher retired from the Woods Hole Oceanographic Institution (WHOI). The project aims to develop tools in support of forming the scientific foundation for a nitrogen Total Maximum Daily Load (TMDL) for the Red Brook Harbor system. Specifically, the project will estimate watershed nitrogen loads to the system, and adapt a hydrodynamic/water quality model that will use these calculated loads as nitrogen input to the water quality model to examine the transport and concentration of nitrogen throughout the system. The model results will reveal which sub-watersheds most impact the system's nitrogen concentrations and can be used to formulate nitrogen load reductions needed to meet water quality standards.

This Quality Assurance Project Plan covers the use of secondary data to perform the loading analysis and model hydrodynamics and water quality. Joe Costa will lead the watershed nitrogen loading analysis, and Jim Churchill will lead the hydrodynamic/water quality modelling. See **Table 1** for a list of the specific members from each organization.

Table 1 Project Participants

Name	Title	Organization	Primary Responsibility
Stephanie Fitch	Conservation Agent	Town of Bourne	Project oversight, Project team member
Rachel Jakuba, PhD	Vice President for Bay Science	BBC	Project QA Manager, maintains the official approved QAPP, Project team member
Joe Costa, PhD	Executive Director	BBNEP	Loading QA Officer, Project team member
Jim Churchill	Emeritus Research Scholar	Retired, WHOI	Modeling QA Officer, Project team member
Meghan Selby	604b Program Coordinator	MassDEP	Project oversight
Suzanne Flint	Quality Assurance Officer	MassDEP	Approval of QAPP
Anthony Pepe	Quality Assurance Officer	EPA	Approval of QAPP
Ian Dombroski	Project Officer	EPA	Project oversight

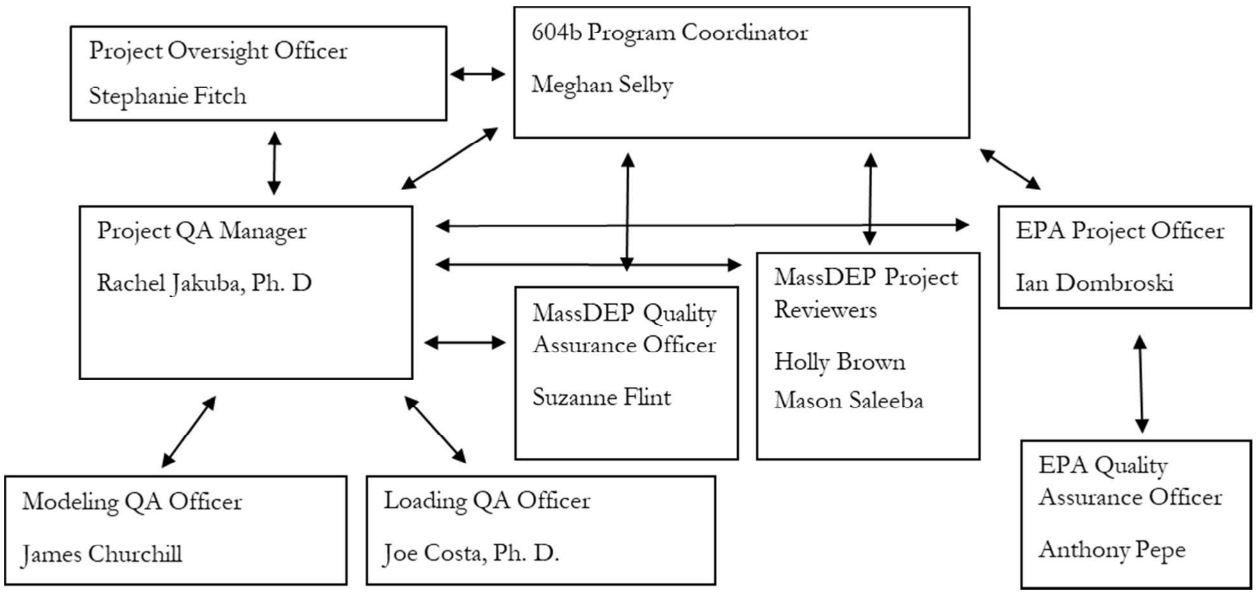


Figure 1. Project Organization Chart.

Roles of Project Participants

Stephanie Fitch will represent the Town of Bourne, which is the grantee. Stephanie will serve as the Project Oversight Officer and will work with project manager Rachel Jakuba to submit project reporting information to MassDEP.

Rachel Jakuba is the manager of the project. Rachel Jakuba will serve as the project QA manager and will maintain the official version of the Quality Assurance Project Plan (QAPP).

Joe Costa will estimate watershed nitrogen loads to Red Brook Harbor and serve as the QA Officer for the loading analysis.

Jim Churchill will examine the transport and concentration of nitrogen throughout the system and serve as the QA Officer for the modeling portion of the project.

Meghan Selby coordinate the MassDEP 604b Program and will oversee fiscal and reporting aspects of the grant project.

Suzanne Flint will review and approve this QAPP for MassDEP.

Holly Brown and Mason Saleeba will review project QAPP and model and loading assumptions for consistency with approved TMDL model approaches.

Anthony Pepe will review and approve this QAPP for EPA.

Ian Dombroski will provide project oversight for EPA.

A5: Problem Definition/Background

The Town of Bourne (Grantee) along with project partners including scientists from the Buzzards Bay National Estuary Program, Woods Hole Oceanographic Institution, and BBC, will investigate sub-watershed nitrogen loads and develop a hydrodynamic and water quality model for the Pocasset Harbor - Red Brook Harbor Estuary Complex. Red Brook Harbor (MA95-18; which includes Hen Cove and Hospital Cove) and Pocasset Harbor (MA95-17) are listed in the Massachusetts 2016 Integrated List of Waters as Category 5 Waters for nitrogen related impairments including estuarine bioassessments and Nutrient/Eutrophication Biological Indicators (Figure 2). Additionally, both waterbodies are listed for fecal coliform. This current project seeks to provide information for establishing a watershed nitrogen Total Maximum Daily Load (TMDL), while building on earlier work assessing benthic habitat and water quality in Red Brook Harbor. Under this current 604b project, the Grantee will develop tools and information needed to develop a site-specific nitrogen TMDL for Red Brook Harbor. This project will quantify existing and future watershed sources of nitrogen, calibrate a hydrodynamic and water quality model for current and build-out conditions, and conduct outreach to engage key constituencies. This information will be provided to MassDEP officials, along with the results of our previous 604b project to be considered in the development of a nitrogen TMDL for Red Brook Harbor.

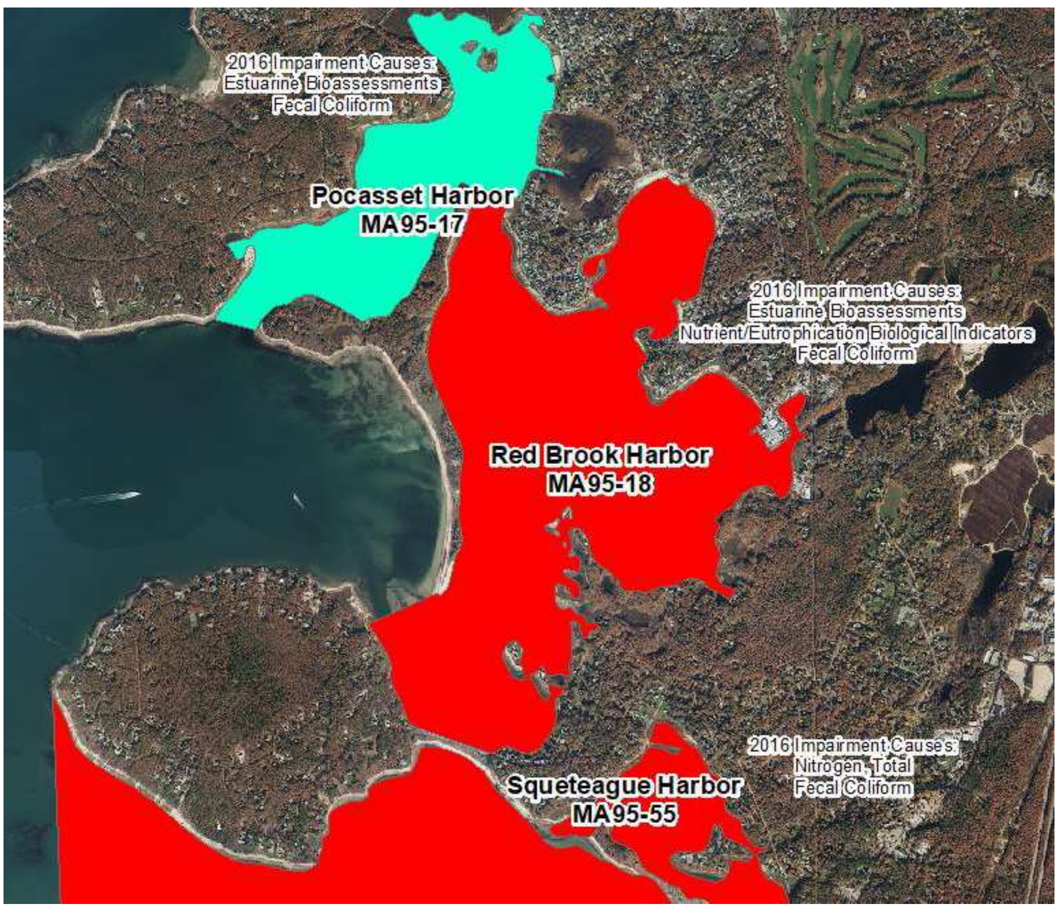


Figure 2. Map showing the MassDEP waterbody classifications.

A6: Project Task Descriptions

The full scope of work, with detailed project task descriptions, can be found in the project proposal (Appendix I. Proposal for *Modeling in Red Brook Harbor to Support TMDL Development*). An overview of the project tasks with relevant details is provided below.

Task 1: QAPP Development

This QAPP describes the quality management system and procedures, as well as the roles and responsibilities of the Project Team. The QAPP provides an overview of the project and quality assurance related to data used for the project. There is no new data collection associated with this QAPP.

The Project QA Manager, Rachel Jakuba, will be responsible for maintenance and distribution of the approved QAPP. The QAPP will be provided electronically as needed. This QAPP was developed after reviewing the guidance document Generic Quality Assurance Project Plan for Model Simulations in the Total Maximum Daily Load (TMDL) Program CN 388.0, rev. 2 and the approved QAPP for The Palmer River Source Tracking, Water Quality Trends Summary, and Watershed Plan project.

Task 2: Quantify existing watershed nitrogen sources

- Using realistic best-estimates of nitrogen loads, the project team will quantify existing watershed nitrogen sources in each subwatershed using the nitrogen loading model (NLM) as described and applied by Williamson et al (2017). NLM was originally developed by Valiela et al. (1997) for Waquoit Bay, MA.
- Deliverables: A text document will be created that describes methods and assumptions and a spreadsheet document with data by sub-embayment.

Task 3: Quantify future watershed nitrogen sources

- The project team will update the estimates developed in Task #2 to include realistic build-out conditions, which will be determined through conversations with the Bourne Town Planner.
- Deliverables: A second text document that describes methods and assumptions and a spreadsheet document with data by sub-embayment.

Task 4: Hydrodynamic/water quality model development, calibration, validation, verification and execution

- The project team will utilize a paired hydrodynamic/water quality model that uses the watershed nitrogen loading numbers developed in Task #2 to predict nitrogen concentrations in the harbor. The model to be used is the Unstructured Grid Finite Volume Community Ocean Model known as FVCOM (https://github.com/FVCOM-GitHub/fvcom). FVCOM is an open source code ocean community model that was developed for the estuarine flooding/drying process in estuaries and the tidal-, buoyancy- and wind-driven circulation in the coastal region featured with complex irregular geometry and steep bottom topography. The project team will adapt an existing version of the FVCOM model that was previously used to look at wastewater flows in Upper Buzzards Bay[1].
- The model will be calibrated to match water quality data collected by the BBC's Baywatchers Monitoring Program following an approved QAPP[2] (Figure 3).
- Deliverables: Output from the model in the form nitrogen concentration maps as well as a description of strengths/limitations of the model, results of the model sensitivity analysis, model loading, and model assumptions.

[1] Churchill, J., Cowles, G., & Rheuban, J. Assessing the Impact of Increased Effluent Discharge into Cape Cod Canal. Final Report. 45pp. (Buzzards Bay Coalition, 2017). Available from Project Manager Rachel Jakuba (jakuba@savebuzzardsbay.org).

[2] Williams, T. & Neill, C. Buzzards Bay Coalition Citizens' Water Quality Monitoring Program, "Baywatchers" 5 Year Quality Assurance Project Plan. (Buzzards Bay Coalition, 2019). Available from Project Manager Rachel Jakuba (jakuba@savebuzzardsbay.org).

Task 5: Hydrodynamic/water quality model run with build-out nitrogen loading

- The project team will take the model developed in Task #4 and run it again using the build-out scenario loading numbers developed in Task #3 to predict what the estuary nitrogen concentrations would be with the build-out loading.
- Deliverables: Output from the model in the form of spreadsheets and nitrogen concentration maps as well as a description of strengths/ limitations of the model, model loading and model assumptions.

Task 6: Project Outreach

- The project team will present the project results to at least two meetings of the appropriate town boards/committees such as the Board of Selectman, Conservation Commission and Board of Health. Project outreach will extend to officials involved in estuarine management and to members of the general public. Project partners will engage with officials from MassDEP who develop TMDLs. The BBC will also develop digital content on the project to be disseminated through its website and social media.
- Deliverables: Presentations to at least two municipal boards and digital stories about the project and its results posted on the BBC's website and social media.

Task 7: Project Coordination and Reporting

- The project team will submit progress reports and invoice packages quarterly, a draft final report two months prior to the contract end date, and a final report within one month of the contract end date. When publishing information about the project, an Acknowledgment of Support will made.
- Deliverables: Quarterly progress and fiscal reports, a Draft Final Report two months prior to the contract end date, and a Final Report.

Figure 3. Map of BBC water quality monitoring sites with project area locus map inset.

A7: Quality Objectives and Criteria

Data quality objectives and criteria for the project will ensure that data used are scientifically valid and defensible, with a high level of transparency and data-sharing capabilities. The end users of the final products of the project are US EPA Region 1, state agencies, and municipalities who will use the results and recommendations to inform land management decisions and regulations at a local level.

Water quality data will be gathered and assessed for inclusion in analyses. Only data that has been generated following a QAPP approved by the EPA and/or the MassDEP will be used. The data will be reviewed to ensure that it conforms to the following data quality objectives:

For field analysis:

Parameter	Method/ Range units	Sensitivity	Precision	Accuracy
Temperature	Thermometer -10°C to +100°C	0.5°C	0.5°C	1°C
Temperature	Digital Thermometer -50°C to +150°C	0.1°C	0.1°C	1°C
Temperature“	YSI 600XL, XLM, 6600, 6920, ProDSS, EXO2 -5 to +45°C	0.01°C	0.01°C	±0.15°C
Salinity	Hydrometer 1.000 to 1.050/ Specific Gravity	0.5 ppt	1 ppt	1 ppt
Salinity	YSI 600XL, XLM, 6600, 6920, ProDSS, EXO2 0 to 70 ppt	0.01 ppt	0.01 ppt	±1% of reading or 0.1 ppt, whichever is greater
Dissolved Oxygen/ Hach OX2P	Modified Winkler Titration/ ppm	0.5 ppm	1 ppm	1 ppm
Dissolved Oxygen	YSI 600XL, XLM, 6600, 6920, ProDSS, EXO2 0 to 50 mg/L and/or 0 to 500%	0.01 mg/L 0.1%	0.01 mg/L 0.1%	±2% of reading or 0.2mg/L, or 2% air saturation, whichever is greater

For lab analysis:

Parameter	Minimum Reporting Limit	Field precision	Laboratory precision	Accuracy
Dissolved nitrate + nitrite	0.25 µM	<30% RPD[b]	<10% RPD or detection limit, whichever is greater	75%-125% of matrix spike
Dissolved ammonium	0.25 µM	<30% RPD	<10%RPD or detection limit, whichever is greater	75%-125% of matrix spike
Total Phosphorus	0.5 µM	<30% RPD	<10% RPD or detection limit, whichever is greater	75%-125% of matrix spike
Dissolved orthophosphate	0.25 µM	<30% RPD	<10% RPD or detection limit, whichever is greater	75%-125% of matrix spike
Chlorophyll *a*	0.1 µg/L	<30% RPD	<10% RPD or detection limit, whichever is greater	75% - 125% of standard
Total dissolved nitrogen	0.5 µM	<30% RPD	<10% RPD or detection limit, whichever is greater	75%-125% of matrix spike
Particulate carbon & nitrogen	5.8 µM C, 0.7 µM N	<30% RPD	<10% RPD or detection limit, whichever is greater	75%-125% of matrix standard
Dissolved organic carbon	32 µM	<30% RPD	<10% RPD or detection limit, whichever is greater	75%-125% of matrix standard

Any water quality data that is excluded for not meeting the data quality objectives will be noted.

All other secondary data types will be gathered and assessed for inclusion in analyses based on the most recent, relevant files (see Table 3; see Section B1). The aerial imagery will be reviewed by local experts to assess its validity. Areas identified as developable land will be reviewed with municipal officials in developing build-out scenario conditions.

The model selection was based on using models that have been previously used in the area that are accepted as industry-standard, and known to produce results that calibrate well with real-world results.

For the modeling efforts, all input and parameterization (calibration) data for the model will be of a known and documented quality. Data will provide the maximum temporal and spatial coverage of the watershed drainage, if necessary and applicable. The data will be comparable with respect to previous and if possible future studies. Modeling data will be representative of the parameters being measured with respect to time, location, and the conditions from which the data are obtained.

Standard parameterization (calibration) and data management procedures will be implemented during modeling projects to ensure that modeling results are valid, reproducible, and comparable. The standard procedures include the following: (1) use of modeling techniques accepted within the professional industry, (2) parameterization (calibration) methods that can be performed repeatedly by a qualified person to obtain similar results, (3) documentation that is clear, concise, and thorough, and (4) the use of standard units for data management. Further details on the model to be used are provided in Appendix II.

<u>Completeness</u> is a measure of the amount of valid input data obtained during a process. The target completeness for models will be 100 percent – e.g., all available sources included. The actual completeness may vary depending on the intrinsic availability of monitoring data. Deficiencies in water quality, climatic, or stream flow data are outside of the control of the modeling effort and will be addressed as part of the assessment effort. In order to provide surrogate data, the most current statistical or stochastic methods will be used to extend or fill in missing time-series data. The normal-ratio will be used to fill precipitation gaps. Discharges will be linearly interpolated or estimated using other fitting methods such as regression analysis.

<u>Representativeness</u> is a measure of how closely the input or parameterization (calibration) data will reflect the physical characteristics of hydrology and water quality over time. Standardized monitoring plan design and the use of Standard Operating Procedures (SOPs) for discharge measurement, soils identification, land cover mapping, sample collection and handling, and acquisition of weather data are crucial to ensuring representative data quality. All model input or parameterization data sources deemed to be usable shall have had a QAPP in place prior to sample collection or be of known, documented and acceptable quality.

<u>Comparability</u> expresses the confidence with which one data set can be compared to another. Model output will be compared with relevant external sources of long-term observational records from Buzzards Bay. Data sources for comparison will include sea surface records from National Ocean Service tidal elevation stations and a long-term bottom temperature record near Cleveland Ledge acquired by the Massachusetts Division of Marine Fisheries.

<u>Acceptance Criteria for Model Parameterization (calibration)</u> is defined as the process of adjusting model parameters within defensible ranges until the resulting predictions give the best possible fit to the observed data. The acceptance criteria for model parameterization (calibration) define the procedures

whereby the difference between the predicted and observed values of the model are within an acceptable range, or are optimized.

Acceptance criteria for the modeling projects should be established in order to provide a numerical ruler for determining whether the model is an appropriate tool for TMDL decision-making. The model parameterization criteria based on recommended error percentages for seasonal, annual, and storm-based water yields are presented below (Table 2).

Graphical comparisons of model performance will also be used including time series plots of observed and simulated flows and state variables (see Appendix II for examples). Time series plots will be evaluated visually for agreement, or lack thereof, between the simulated and observed values. When observed data are adequate, or uncertainty estimates are available, confidence intervals will be calculated so they can be considered in the model performance evaluation.

Table 2. Acceptable Model Parameterization/Calibration Hydrology Criteria

Errors (Simulated-Observed)	Recommended Criteria
Error in Total Volume	10%
Error in 50% Lowest Flows	10%
Error in 10% Highest Flows	15%
Seasonal Volume Error – Summer	20%
Seasonal Volume Error – Fall	20%
Seasonal Volume Error – Winter	20%
Seasonal Volume Error – Spring	20%
Error in Winter Storm Volumes	20%
Error in Summer Storm Volumes	40%
Error in Salinity	5%
Error in Total Nitrogen Concentrations	20%

Model Corroboration (Validation) is defined as the comparison of modeled results with independently derived numerical observations from the simulated environment. Model corroboration is an extension of the parameterization (calibration) process. Its purpose is to assure that the calibrated model properly assesses the range of variables and conditions that are expected within the simulation. Although there are several approaches to validating a model, perhaps the most effective procedure is to use only a portion of the available record of observed values for parameterization. The rest is used for corroboration. Once final parameterization parameters are developed, simulation is performed for the remaining period of observed values and the goodness-of- fit between recorded and simulated values is reassessed. Wherever possible, this type of split-sample parameterization and corroboration procedure will be used for modeling projects. Details for how this will be accomplished for this project are in Appendix II.

The credibility of the model hinges on the deterministic ability to predict conditions over the entire range of observed data: in effect, validating the model. As with model calibration, model corroboration can be conducted either qualitatively or quantitatively. Qualitative corroboration involves expert judgment and test of intuitive behavior using "knowledge" of the behavior of the system in question but it is not formalized or statistically-based. Expert knowledge can establish model reliability through consensus and consistency. Expert judgment can also establish model credibility by determining if model-predicted behavior of a system agrees with best-available understanding of internal processes and functions (USEPA 2009, p65).

Model corroboration can also be quantitative in nature. This would involve comparing model predictions to independent empirical observations to investigate how well a modeler's description of the system fits the observational data. This procedure involves using statistical measures of goodness of fit and numerical procedures to facilitate calculations. This can be accomplished graphically or by calculating various statistical measures of fit between the modeler's results and observed data. (USEPA 2009, p65) For example, in Appendix II, 2009 velocity data from NOAA's CMIST program was used to compare with the model simulation.

Graphical methods can be used to compare the distribution of the model outputs to independent observations. The degree to which these two distributions overlap, and their respective shapes, provide an indication of model performance with respect to the data. (USEPA 2009, p65)

Quantitative measures include methods for calculating model bias or model bias and precision. For model bias a calculation can be made of mean error. The mean error calculates the average deviation between models and data by dividing the sum of errors by the total number of data points compared. For model bias and precision, a calculation of Mean Square Error or Mean Absolute Error can be made (USEPA 2009, p65-66)

In this project, a combination of the above qualitative and quantitative corroboration techniques will be used. The findings of the analysis will be documented in the final project modeling document, which will describe how the corroboration was conducted and the outcome of that effort.

Model Sensitivity analysis determines the effect of a change in a model input parameter or variable on the model outcome. The project team will qualitatively assess the sensitivity of model parameters during manual parameterization (calibration) through parameter perturbation. A summary of model sensitivity will be included in the final modeling report or technical memorandum. Details will include the variables modified for model parameterization (calibration), the percent modification (e.g. ± 10%), percent change in the modeling results, and the normalized sensitivity coefficient. Alternative algorithmic techniques for sensitivity and uncertainty assessment are available through several water quality modeling programs (Monte Carlo Simulation, first-order error analysis, or automated objective function optimization).

Model Uncertainty is broadly defined as the lack of knowledge regarding model input parameters and the processes the model attempts to describe. Our ability to define model uncertainty is marginalized by our limited ability to accurately describe complex processes. As a result, all engineering computations are attended to a degree of uncertainty due to the simplification of natural process and the limitations of input and parameterization (calibration) data. Computed values differ from observed ones, and the magnitude and frequency of these differences characterize the uncertainty of the best model estimate. Uncertainty analysis is the terminology associated with the examination of how the lack of knowledge in model parameters, variables, and processes propagates through the model structure as model output or forecast error. Sources of model uncertainty will be assessed and any areas of potentially significant uncertainty in the model will be described in the final report.

A8: Special Trainings/Certification

The qualifications for all team members performing analyses associated with this QAPP will be reviewed by the Project Manager. Individuals performing analyses will possess at least 5 years' experience using the tools necessary for the analyses. The FVCOM modelling work will be performed by Modeling QA Officer Churchill who has used the FVCOM model for over 10 years in numerous studies of estuarine water quality. Churchill has carried out similar modeling studies including to assess environmental impact of proposed wastewater discharge sites at the western end of Cape Cod Canal and off a site in eastern Buzzards Bay, and to evaluate the impact of wastewater discharge on carbonate chemistry near three discharge sites in western MA. The loading analysis will be performed by Loading QA Officer Costa who has extensive experience working with GIS data in the Buzzards Bay watershed and who served as a key reviewer of the watershed loading in the Massachusetts Estuary Project reports for Buzzards Bay embayments.

A9: Documentation and Records

The QAPP, including any revisions and updates, as well as data and reports, will be maintained by the Project QA Manager. The first page of the QAPP will be dated to distinguish among different versions in case there are revisions made over the course of the project. The Project QA Manager will report on the project status in the quarterly reports, including any problems and the proposed recommended solutions. Clear documentation of the hydrodynamic model results and nitrogen loading analysis will be provided as part of the final report. The NetCDF files for the FVCOM model and the spreadsheets used for the nitrogen loading analysis will be made available to MassDEP at the project completion.

Section B: Data Selection and Management

This QAPP was developed with guidance from the EPA Requirements for Quality Assurance Project Plans (QA/R-5), EPA New England QAPP Guidance for Environmental Projects Using Only Secondary Data, and MassDEP Generic Quality Assurance Project Plan for Model Simulations in the Total Maximum Daily Load (TMDL) Program CN 388.0, rev. 2.

B1: Sources of Existing Data

A variety of secondary data will be used for the project, including spatial files for mapping and analysis, water quality data for analysis, literature sources for reference, municipal sewer data, and federal oceanographic data (Table 3). Much of these data are sourced directly from state (Mass GIS) of federal (NOAA) agencies that have their own quality assurance standards for releasing data.

Table 3. Sources of existing data (all data accessed and confirmed available April 2021.

Type [File Name]	Description/Title	Format	Source (Date)	Intended Use	Limitations	QA/QC
MassGIS Data: USGS Color Ortho Imagery (2019)	Color aerial "leaf off" ortho imagery for Massachusetts from 2019.	ArcGIS Layer	docs.digital.mass.gov (4/21/2021)	Spatial reference, parcel structure and data verification, refine impervious cover	NA	Companion NAIp, and other imagery will be inspected where needed
Cape Cod Commission Subwatersheds [Subwatersheds]	The subwatersheds within Barnstable County as delineated by Cape Cod Commission Water Resources staff and the MEP process.	.shp	Cape Cod Commission GIS portal (10/19/2018)	Pocasset Harbor sub-basin delineation	Does not include sub embayment areas including Red Brook Harbor. Inconsistencies with USGS must be reconciled.	NA
USGS GIS data	Simulated Groundwater-Contributing Areas to Selected Streams, Ponds, Coastal Water Bodies, and Production Wells, Plymouth-Carver Region and Cape Cod, Massachusetts	.shp	USFGS Masterson study (2017)	For determining less than and greater than 10 year travel time, refinements in subembayment subwatershed boundaries, and sub estuaries.	Somewhat coarse resolution, and must be continued to the coast with DEP subbasins and land use topography as proxy for groundwater divides on coastal peninsulas	Land surface topography from LiDAR used to define undocumented groundwater divides near the coast
MassGIS Data: Drainage Sub-basins [subbas]	statewide subbasins, including Red Brook Harbor	.shp	MassGIS (12/2007	subestuary watersheds within the Pocasset Harbor sub-basin		Outer bounds must be adjusted to conform to Cape Cod Commission Pocasset Harbor Subbasin and USGS groundwater model
1 ft contours for watershed [name created by user]	Downloaded from NOAA at https://coast.noaa.gov/dataviewer/#/	1ft	MassGIS (12/8/2010)	Reference for refining sub-basin delineations on peninsulas near the coast	None	NA
Impervious cover [imp_se3, imp_se5]	MassGIS Data: Impervious Surface 2005	.img	MassGIS (2005)	Land cover analysis, loading from impervious	Supplemented by building footprint coverage and MassDOT roads	NA

Type [File Name]	Description/Title	Format	Source (Date)	Intended Use	Limitations	QA/QC
MassGIS Data: Massachusetts Department of Transportation Roads [MassDOT_Roads]	Roads in MA	.shp	MassGIS (May 2022)	Spatial reference, general mapping, land cover analysis	Road width supplements impervious cover obscured by trees. Reported road widths generally reliable, but will be visually validated with aerial imagery.	NA
MassGIS Data: 2016 Land Cover/Land Use [lclu2016_gdb]	This statewide dataset contains a combination of land cover mapping from 2016 aerial imagery and land use derived from standardized assessor parcel information for Massachusetts	.gdb	MassGIS (issued 5/2019)	Land cover change analysis	Used for evaluating land use not evaluated by impervious, building footprint, wetlands, and DEP cranberry bog coverages.	Will confirm key features like cranberry bogs growing area and golf course greens and fairways from current aerials
MassGIS Data: MassDEP Wetlands (2005)	Wetland features from MassDEP including open water, marshes, swamps, tidal flats, etc.	.shp	Mass DEP(12/2017)	wetland attenuation	Planning level purpose only	NA
Town/State [TOWNS_POLY]	Political boundaries for MA	.shp	MassGIS (1/1/1998)	Spatial reference	NA	NA
Town Zoning Map	Zoning in the Town of Bourne	.shp	Town of Bourne Planning Dept. (latest available)	Buildout Analysis	NA	NA
Impairment Status	Mass DEP 2018/2020 Integrated List of Waters 305(b) and 303(d)	ArcGIS Layer	MassGIS (2022)	General reporting for water body segment impairments		NA
Sewer [Sewered_Areas]	Buzzards Bay NEP sewered data	.shp	Buzzards Bay NEP (6/2019)	Loading Analysis	NA	Determine whether sewered area stops at state boundary
Level 3 Parcel data [M036_parcels]	MassGIS Data: Standardized Assessors' Parcels database	.gdb	2020	residential and commercial loadings	Needs to be joined to structures for placement of septic systems, relevant to parcels that straddle watershed divides.	Visual inspection to confirm development

Type [File Name]	Description/Title	Format	Source (Date)	Intended Use	Limitations	QA/QC
US Census Tiger Data block [CENSUS2010BLOCKS_POLY]	MassGIS has processed a portion of the U.S. Census Bureau's 2010 data release for Massachusetts in order to assist GIS users who may need access to these demographic-related datasets.	.gdb	MassGIS (4/2012)	population and occupancy rate for residential loading	Must be adjusted for seasonal occupancy. 2020 data not available until after study is complete.	NA
Buzzards Bay Baywatchers Database	Buzzards Bay All Data, multiple tabs with data by parameter	.xlsx	Buzzards Bay Coalition (2021)	Existing TN concentrations, salinity of stations	NA	Obtain metadata and review acceptance criteria
SEMASS-FVCOM model simulation	Regional FVCOM-based model known as the Southeastern Massachusetts-FVCOM (SEMASS-FVCOM) executed for the period Jan 1, 2015 to Jan 1, 2016	NetCDF	SMAST Thredds server	Hydrodynamic model	NA	Review area of interest for data quality
CZM coastal boundary	½-arc-second product developed and distributed by the Massachusetts Office of Coastal Zone Management	GIS	Massachusetts CZM	coastal boundary for simple maps	NA	NA
Water velocity	Velocity data from fixed ADCPs acquired as part of the NOAA CMIST program and by a USGS study of Buzzards Bay circulation	NedCDF	NOAA and USGS - 2009.	Model verification	NA	NA
Tidal elevation series	Water level series collected from Red Brook and adjacent water bodies	Excel	Woods Hole Group - 1998	Model verification	NA	NA

B2: Intended Use of Existing Data

The intended use of existing data for each data file is summarized in Table 3. Water quality data and site location information files will be used for calibrating the hydrodynamic model. Spatial data files (e.g., aerial imagery, topography, elevation, sub-basin/watershed boundaries, hydrology, roads, land cover/imperious cover, water quality monitoring stations, town/state boundaries, pollutant source locations, sewer areas, etc.) will be used for spatial reference, data verification, and subwatershed delineation for land use change analysis.

B3: Limitations on the Use of Existing Data

The limitations on and quality control needed for the use of existing data are summarized in Table 3. Major limitations and quality control actions are described below.

Quality acceptance criteria of water quality data will be based on:

- Samples must be collected by trained personnel under an approved QAPP or similar document to meet representative data quality criteria.
- Samples must be analyzed in accordance with approved laboratory methods to meet similar precision, accuracy, and comparability data quality criteria.

Since Baywatchers Monitoring Program data meet the quality acceptance criteria for field sampling and certified laboratory methods, any data exclusions will be due to samples with concentrations below reporting limits. Water quality data will be reviewed to ensure that the data quality objectives of this QAPP are met before inclusion in the analysis for this project. Any data exclusions and the reason for excluding the data will be documented.

Geographic data must be available at a scale which will be useful at the smallest extent of project analysis. We will use subwatershed boundaries adopted by the Cape Cod Commission, MassDEP, and USGS. There are some inconsistencies among the datasets that will be addressed in the analysis using best professional judgement, with the greatest credence given to the USGS Model (Carlson et al., 2017). The final report will describe how any potential uncertainties may affect the results.

Land use cover data will primarily be used to assess loading not defined in assessors' data like certain agricultural land types and forest area. Certain features, like cranberry bog production area and golf greens will be digitized directly from aerial photographs. The watershed boundary, most recent existing land cover file, and grid net for 1:5,000 scale viewing will be loaded into ArcMap 10.8.1 and intersected with spatial data like parcels, land use and impervious cover.

Section C: Assessment and Oversight

This section addresses the activities for assessing the effectiveness of the implementation of the quality assurance and quality control activities. The purpose of the assessment is to ensure that the QAPP is implemented as described.

C1: Project Oversight

The project team will meet quarterly (as needed) throughout the project duration to assess project progress and ensure that data quality objectives are being maintained (see Task 1). Project tasks and associated products will be completed according to the schedule set forth in Section E.

The project roles of key personnel, are identified in Section A4. The Project QA Manager will review the project tasks as the project is undertaken and provide draft materials to MassDEP for review. Any changes to the schedule due to unforeseen challenges in completing project products will be brought to the attention of the project team.

C2: Project Oversight Documentation

The Project QA Manager will report progress to the Project Oversight Officer and MassDEP 604b Program Coordinators quarterly. If there are any issues with QAPP compliance, they will be documented in the quarterly reporting. If any of the issues warrant notice to EPA, the MassDEP 604b Program Coordinator will inform the EPA Project Officer.

C3: How to address quality issues

Any problems that arise during project implementation will be identified by the Project QA Manager and communicated to the Project Oversight Officer along with a draft plan for action. The draft plan for action may include consultation with other technical experts or seeking alternative data sources. If there are no other acceptable sources of data, the corrective actions may mean altering the acceptance criteria. However, based on the project team's use of the identified data sources for prior projects, no difficulties in meeting the acceptance criteria are expected. Any data limitations will be documented in project products.

Section D: Data Review, Verification, Validation, and Evaluation

This section addresses the QA activities that occur after the data collection of the project has been completed. Implementation of these elements ensures that the data conform to the specified criteria and achieve the project objectives.

D1: Data Verification & Validation

All secondary data will be reviewed to assess whether the data meet data quality acceptance criteria for use in analyses. The review process will include metadata review, documentation, and investigation (as necessary). The methods and reporting limits of water quality data will be reviewed and validated for use in analyses if the data meet the data quality objectives and criteria set in Section A7 and Section B3. Any data not meeting the data quality criteria will be excluded from analyses or properly justified for use if certain approaches (such as taking half the reporting limit) are appropriate.

A summary of laboratory qualifiers and validation criteria are described as follows:

J/E – estimated value above the reporting limit due to sample matrix or other issue; data should be acceptable unless otherwise justified for exclusion due to possible erroneous data bias or skew as a result of data point(s).

R – field duplicate; data compiled in the water quality database will be assessed for duplicate entries; field duplicate samples will both be included in a monthly average or be averaged for a daily value depending on the time step of data needed for model input.

U/ND – below reporting limit. If the reporting limit meets the data quality criteria, then half the reporting limit will be taken. Values that fall below the reporting limit are typically those for ammonium and nitrate+nitrite. The sum of these constituents is generally less than 3% of the total nitrogen value. The potential bias for using half the reporting limit versus the reporting limit is on the order of 1% of total nitrogen so not likely significant. If the reporting limit is greater than the data quality criteria, then case-by-case assessments will be made as to whether the data should be excluded (such as for dilution increases in the reporting limit due to sample interference). Alternative approaches may be used if a significant portion (e.g., more than 25%) of the data are less than the reporting limit (and greater than the water quality criteria used for assessment).

Other secondary data such as spatial files and written documents will be selected for use based on relevance, completeness, accuracy, quality, and age of data (i.e., most recent available source that meet criteria). Data may be rejected for use if metadata are incomplete, data are outdated or incomplete, or data are redundant. Low quality data will not be used for analysis (except possibly as a supporting reference) unless it is the only available data; justification for use of and limitations to the low-quality data will be noted in project products. Any files with draft indication will be followed-up with the originator for the final version, if available.

D2: Data Evaluation

Accurate and complete metadata are needed to ensure that the data source and collection/analysis methods are adequately defined and meet data quality objectives for comparability and representativeness. Metadata for all secondary data should include a data description, originator, source of access, publication date, time period and/or specific time and date collection information (for sampling data), and spatial domain information (such as projection/coordinate systems used; see Table 3). Additional metadata for sampling data sets should include the following: sampling and analysis plan, laboratory method, reporting limit, reporting units, field qualifiers or notes (e.g., missing values), and laboratory qualifiers.

Data and associated metadata will be evaluated to ensure data are complete and comparable for use in analysis based on the following procedure:

- Evaluate whether data meets the data quality objectives in Section A7.
- Exclude data that have not been collected and analyzed using similar and approved field and laboratory analysis methods by trained personnel.
- Sort each parameter by value and assess laboratory qualifiers or other data flags. Add a new qualifier column that identifies the data qualifier or flag and either input a numeric value (such as half the reporting limit) or exclude the value from analysis in the parameter value column (with justification).

- Transform all data to a common measurable unit by parameter (e.g., mg/L).
-
- Review the distribution of values for each parameter to identify outliers and values less than the reporting limit (to determine if the data are skewed).
- Document justification and process for any data amendments, corrections, or exclusion.

Model validation data will examine simulated and observed values to assess whether critical parameters attain acceptable levels of agreement. The refinement of parameters will reflect the scientific literature, best professional judgement, and not exceed reasonability. The rationale for any model adjustments will be documented in the final report.

Section E: Project Schedule

Task 1: QAPP Development. This task will begin in March 2021 and be completed by April 2023.

Task 2: Quantify existing watershed nitrogen sources. This task will begin in May 2023 and be complete by August 2023.

Task 3: Quantify future watershed nitrogen sources. This task will begin in May 2023 and be complete by September 2023.

Task 4: Hydrodynamic/water quality model development, calibration and execution. This task will begin in April 2023 and be complete by May 2023.

Task 5: Hydrodynamic/water quality model run with build-out nitrogen loading. This task will begin in May 2023 and be complete by July 2023.

Task 6: Project Outreach. This task will begin in September 2021 and be complete by December 2023.

Task 7: Project Coordination and Reporting. This task will begin in April 2021 and be complete by December 2023.

Section F: Project Reporting

A final project report will be developed by the project team and submitted to MassDEP. The report will be available to the public. The report will describe the results of this project including figures. Draft and final project products will be generated in common or publicly-available programs that are compatible with end user systems for ease of maintenance or updates in the future such as Microsoft Office (e.g., Word for written reports, Excel for spreadsheets, CSVs for analysis), ArcMap Desktop 10.6.1 (e.g., geodatabase of spatial files and/or map packages of project maps), and QGIS Desktop 3.4.1 (e.g., two vector files of automated subwatershed delineations to be included in a geodatabase and/or map packages). All MS Excel spreadsheets files will include metadata on data sources, corrections, and exclusions (by whom and on what date). Model files will be maintained in industry standard file formats used for open source models. All MS Word reports (as applicable) will document QA/QC procedures either within the report or as an attachment. The final report will identify all sources of data used in the project and they will be either provided as attachments to the final report or be available upon request.

References

Carlson, C. S., Masterson, J. P., Walter, D. A., & Barbaro, J. R. (2017). Development of simulated groundwater-contributing areas to selected streams, ponds, coastal water bodies, and production wells in the Plymouth-Carver region and Cape Cod, Massachusetts (No. 1074). US Geol. Surv.

Environmental Protection Agency. 2001. EPA Requirements for Quality Assurance Project Plans. EPA QA/R-5.

Environmental Protection Agency. EPA R-5 Checklist for Review of Quality Assurance Project Plans.

Environmental Protection Agency. 2010. New England Quality Assurance Project Plan Program Guidance. EQAQAPP2005PG2

Environmental Protection Agency New England. October 2009. Guidance for Environmental Projects Using Only Existing (Secondary) Data. Revision 2.

Valiela, I., Collins, G., Kremer, J., Lajtha, K., Geist, M., Seely, B., Brawley, J., Sham, C. H. (1997). Nitrogen loading from coastal watersheds to receiving estuaries: New method and application. *Ecol. Applicat*. 7, 358–380. doi:10.1890/1051-0761(1997)007[0358:NLFCWT]2.0.CO;2

Williamson, S.C., Rheuban, J.E., Costa, J.E., Glover, D.M., and Doney, S.C. (2017) Assessing the Impact of Local and Regional Influences on Nitrogen Loads to Buzzards Bay, MA. *Front. Mar. Sci*. 3: 279. doi: 10.3389/fmars.2016.00279

Appendix I. Proposal for Modeling in Red Brook Harbor to Support TMDL Development

File attached.

Appendix II. Model Details

A2.1. Background

The modeling approach will be to use flow and water property (e.g. temperature and salinity) data generated by a high-resolution hydrodynamic model as input to a second, water-quality, model that will simulate the transport and mixing of nitrogen introduced into Red Brook Harbor. This modeling will be carried out in two phases. In the first, existing hydrodynamic model data (from 2015) will be used as input to the water-quality model. The model and model data will be assessed/validated using available historical data of water velocity, sea surface elevation and salinity from Red Brook Harbor and Buzzards Bay. In the second phase, a focused hydrodynamic model (with the grid encompassing Red Brook Harbor and the adjacent waters of Buzzards Bay) will be formulated using the grid of the existing model and executed for recent time periods as a check to confirm that there have been no significant changes since 2015. This model will be assessed/validated using field data acquired during the course of this study.

The work on each phase will have a distinct purpose. The modeling of the first phase will give an assessment of how well the nitrogen loading supplied by the watershed analysis coupled with the hydrodynamic/water quality modeling reproduces the measured nitrogen distribution in the harbor. Potential issues with the magnitude and distribution of the watershed loading and with importance of benthic loading will be explored and identified. The modeling of the second phase will have the advantage of contemporaneous field data for model assessment/validation and will benefit from the insight gained from the first modeling phase.

Because tidal flows are a dominant factor in the dispersion of nutrients in Red Brook Harbor, it may be expected that these two modeling phases will produce similar results. The two-phase modeling approach will test this expectation, and provide valuable insight for future studies of this type. Details of the two modeling phases are given below.

A2.2. Hydrodynamic Model – Phase-1

A2.2.1. Model Description

The hydrodynamic model data to be accessed are the product of the Finite-Volume Community Ocean Model (FVCOM: Chen et al., 2006; Cowles, 2008), an open source model with over 4,000 registered users that has been applied in a wide array of coastal and open ocean studies. FVCOM operates by solving the equations of motion on an unstructured grid, with elements that can be aligned with coastline and bathymetric irregularities. To produce a 3-dimensional solution, FVCOM employs a sigma-coordinate system, in which the vertical component of the model domain is divided into a fixed number of layers (20) that follow changes in model terrain. Layer thickness for each of the 20 layers is thus proportional to water depth.

This project will utilize output from a regional FVCOM-based model known as the Southeastern Massachusetts-FVCOM (SEMASS-FVCOM), which includes the Massachusetts and Rhode Island coastal zones as well as Long Island Sound. SEMASS-FVCOM has been employed, and its results extensively evaluated, by Modeling QA Officer Churchill for studies of tidal energy in the Massachusetts coastal zone (Hakim et al., 2013; Cowles et al, 2017) and the dispersal of bay scallop larvae in Buzzards Bay (Liu et al., 2015).

A2.2.2. Grid Setup

To better resolve the hydrodynamic processes in our area of interest, the computational mesh of SEMASS-FVCOM has been refined for the coastal zone of Buzzards Bay with a focus on Red Brook Harbor. The resulting horizontal-grid resolution varies from 2 km over the open ocean to 50 m along the coastline of Buzzards Bay and within Red Brook Harbor.

The model bathymetry has been interpolated from a composite dataset. The majority of the model domain is encompassed by the 3-arcsecond Gulf of Maine bathymetry product (Twomey and Signell, 2013) and the 1/3-arcsecond Nantucket Inundation Digital Elevation Model (NOAA: Eakins et al., 2009). The bathymetry data in the Buzzard Bay region are from three principal sources: NOAA/NOS multibeam surveys (±3 m horizontal accuracy; ±30-50 cm vertical accuracy), USGS SWATH surveys (±10 m horizontal accuracy; ±10-60 cm vertical accuracy), and public-domain Lidar data (±3 m horizontal accuracy; ±30 cm vertical accuracy) [see https://www.sciencebase.gov/catalog/file/get/5a4649b8e4b0d05ee8c05486?f=__disk__47%2Fe6%2Fe3%2F47e6e33457d26c61857a0ace39a61b7e182da858&transform=1&allowOpen=true]. The data set includes measurements from a dedicated SWATH survey of Red Brook Harbor (± 5 m horizontal accuracy; ± 50 cm vertical accuracy) conducted by USGS in 2009 (Turecek et al., 2012).

The coastal boundary of the model domain has been derived from a high-resolution (1/2 arc-second) product developed and distributed by the Massachusetts Office of Coastal Zone Management.

A2.2.3. Boundary Forcing

The model is driven at the open boundary by sea surface elevation constructed from the six primary tidal constituents (M2, S2, N2, K1, O1 and M4). The phase and amplitude of these constituents and the associated regional barotropic response have been extensively evaluated during the course of prior work (Cowles et al., 2017). Values of the salinity and temperature of water flowing into the domain are also set at the open boundary, and specified from a hindcast of a large-scale Gulf of Maine / Southern New England FVCOM-GOM model developed by Dr. Changsheng Chen of U. Mass. Dartmouth (NeCOFS, 2017).

A2.2.4. Surface Forcing

At the surface, SEMASS-FVCOM is driven by net heat flux and surface wind stress, which are also derived from the regional 30-year FVCOM-GOM hindcast (NECOFS, 2017). The wind field in Buzzards Bay during 2015 (the year of the model results used for this study) displays a strong seasonality. The southwest sea breeze dominates the Buzzards Bay wind field from late spring to early fall. By contrast, winds from late fall to early spring are characterized by synoptic events with the strongest wind magnitudes directed from NW and NE. These characteristics of the 2015 wind field are typical of the seasonal wind field in Buzzards Bay (Liu et al., 2015). In addition to utilizing wind and heat flux data to force the model at the surface, the model simulations also employ surface temperature (SST) derived from the NOAA 4 km-resolution product. SST is assimilated into the model using a Newtonian relaxation (nudging) approach, which adjusts the modeled SST to best match the observed SST.

A2.2.5. Freshwater Input

Freshwater is input into the model domain at discrete points along the coastal boundary. The locations of the freshwater entry points into Buzzards Bay are based on the watershed delineations of the Buzzards Bay National Estuary Project, which established 32 watersheds draining into the bay (Figure A1). Notably, there are three fresh water entry points into Red Brook Harbor. As there is only one long-term record of

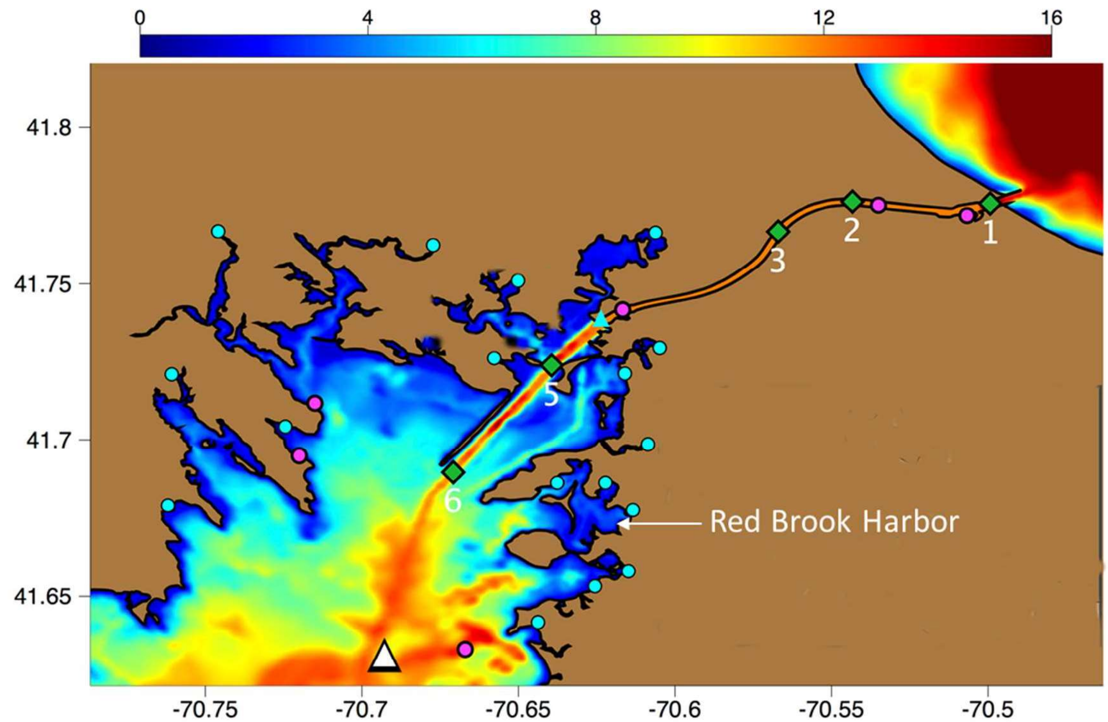


Figure A1. A portion of the FVCOM-SEMASS domain in upper Buzzards Bay with bathymetry (m). Also shown are measurement locations for CMIST upward-looking ADCP (numbered green diamonds), tidal harmonic elevation stations (magenta circles), and Mass Division of Marine Fisheries long-term bottom temperature record (white triangle) as well as the locations for point sources of freshwater input to the upper bay (cyan circles).

freshwater influx into the bay (from a gauge in the Paskamansett River in Dartmouth; USGS 01105933), the freshwater flow from the other watersheds is estimated by multiplying the gauged flow of Paskamansett River by the ratio of a given watershed's area to the area of the Paskamansett River watershed. This will be compared with a review of freshwater flow estimates from MEP reports for waterbodies on Cape Cod. In Phase 2, short-term measurements of freshwater flow from Red Brook Pond into Red Brook be collected (described below).

A2.2.6. Execution and Data Archiving

The model was executed for a previous project in which Churchill served as Principal Investigator. The model simulation period extended from Jan 1, 2015 to Jan 1, 2016. The model was executed with a 2-s time step, which required 110,000 core-hours of wall time on 2.6 GHz Intel Haswell Xeons. The two-dimensional fields of sea surface height and depth-averaged velocity, and the three-dimensional fields of velocity, temperature, salinity, and the vertical turbulent eddy diffusivity and viscosity were archived at hourly intervals into NetCDF format files. The total dataset (1.5 TB in size) is accessible through the

SMAST Thredds server at:
http://www.smast.umassd.edu:8080/thredds/catalog/buzzards/BBC_WW/catalog.html.

A2.2.7. Model Verification Carried Out to Date

Significant validation of the SEMASS-FVCOM has been carried out by Churchill and colleagues utilizing long-term observational records from Buzzards Bay. These included velocity data from fixed ADCPs acquired by NOAA (Pruessner et al., 2007) and the USGS as well as tidal constituents from the National Ocean Service database.

Sea Surface Elevation – The model simulation of sea surface elevation was compared with the sea surface elevation records from the six National Ocean Service tidal elevation stations within upper Buzzards Bay and the Cape Cod Canal (Figure A2). Surface elevation was extracted from the model hindcast at the grid points nearest each station. Phase and amplitude of the principal regional tidal constituents (M2, S2, N2, K1, O1 and M4) were then computed from the observed and modeled surface elevation time series using harmonic analysis (T-Tide; Pawlowicz et al., 2002). To quantify model skill, the observed and modeled tidal constituents were used to construct annual time series of tidal elevation at each NOS site. As illustrated by a comparison of modeled and observed tidal records for July 2015 (Figure A2), the modeled tidal elevations are in close agreement with the observations through the complete lunar cycle at all six stations. The model skill was assessed by the root mean square error (RMSE) and the dimensionless Willmott score (Willmott, 1981), which carries the value of 0 (no agreement) to 1 (perfect agreement). RMSE values for the six sites as calculated from the annual time series ranged from 3.4 to 8 cm, whereas

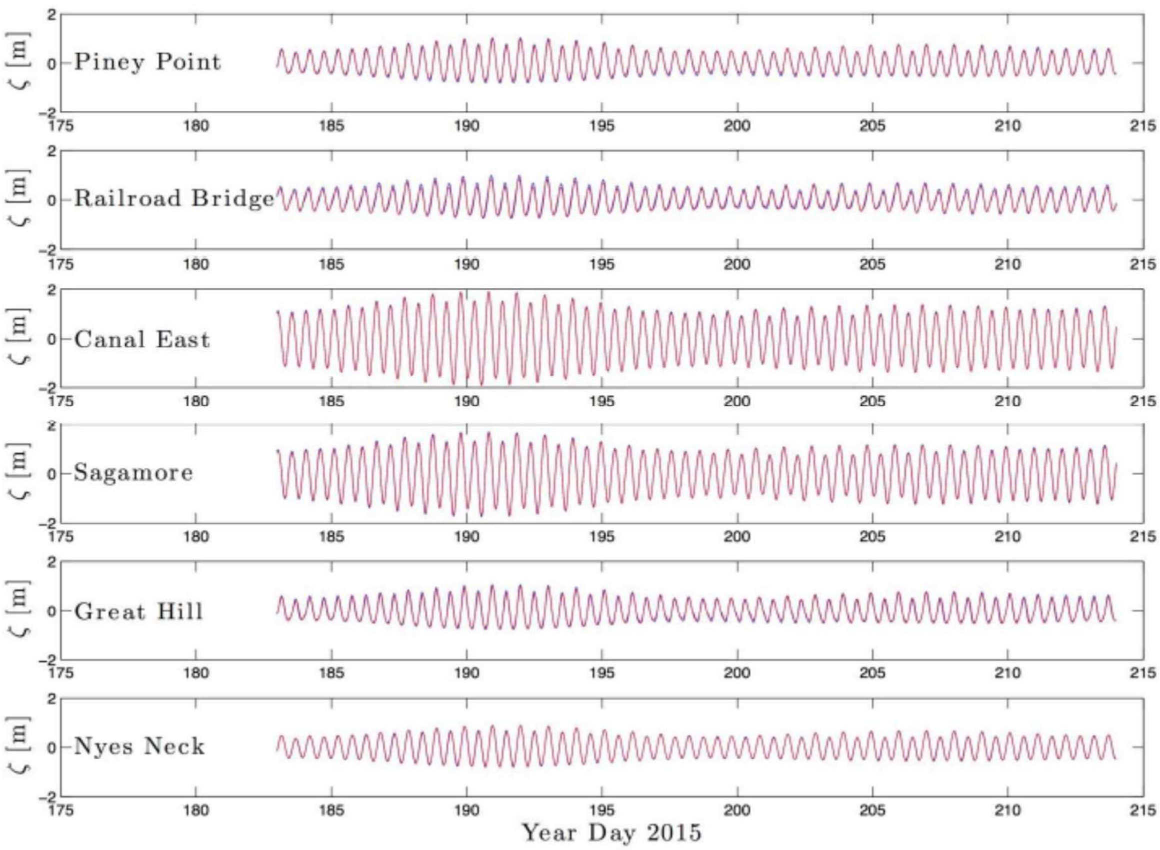


Figure A2. Comparison of time series of tidal surface elevation [m] from measurements (blue) and modeled (red) at the six NOS tidal stations in Buzzards Bay during July 2015. The model-produced series is overlain over the observations and is often the only visible series above.

Willmott scores ranged from 0.96 to 1.0.Velocity – The model skill in simulating currents in upper Buzzards Bay was evaluated with water velocity measurements acquired by bottom-mounted, upward-looking ADCPs deployed for 1-3 months in 2009 of as part of the NOAA CMIST program (Pruessner et al., 2007; see Figure A1 for locations). The ADCP velocity data were archived at 6-min intervals and extend vertically in 1.0-m bins from 2.5 meters above bottom to ~2 m below the surface.

To compare SEMASS-FVCOM velocities with these measurements, the model was run for the duration of the CMIST period (1 June 2009 - 31 July 2009). The depth-averaged modeled and measured velocities are closely aligned in magnitude and phase, with the modeled velocities capturing the diurnal and spring-neap variation of the depth-averaged velocities at all five sites (Figure A3).

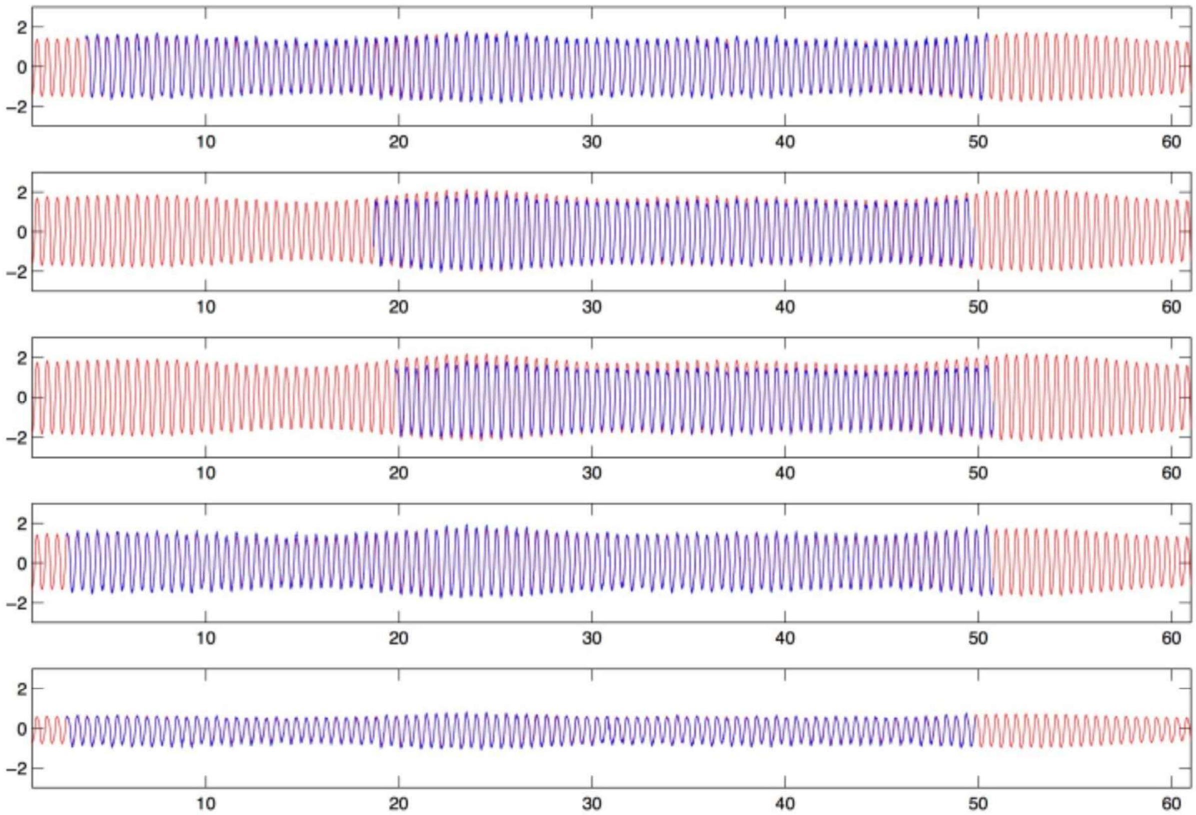


Figure A3. Comparison of time series of depth-averaged velocities (m s^{-1}) for the CMIST period (June-July, 2009). Time is days since June 1, 2009. The red line is the model-computed value and the blue line is the observed. The comparisons for CMIST Stations 1,2,3,5,6 are arranged from top to bottom. Note that the observations cover different time periods, while the model results fully encompass each measured series.

The depth-averaged velocity time series were decomposed into the principal tidal constituents (M2, S2, N2, K1, O1 and M4) using the MATLAB routine T-Tide (Pawlowicz et al., 2002). From these harmonic constituents, annual time series of the tidal flows of both the observed and model-computed currents were reconstructed. Comparison of model- and data-derived vertically averaged tidal flow magnitude at the five CMIST sites gave Willmott scores ranging from 0.96 to 0.99 and RMSE values from 5 to 25 cm s^{-1}.

The reconstructed time series were used to compare the model- and measurement-derived vertical profiles of mean velocity magnitude at each CMIST site. The vertical shear and magnitude of the measurement- and model-derived velocities are in close agreement at the CMIST stations in upper Buzzards Bay (Figure A1, Figure A4).

Based on the above comparison, the model is judged capable of closely reproducing flows in the upper portion of Buzzards Bay.

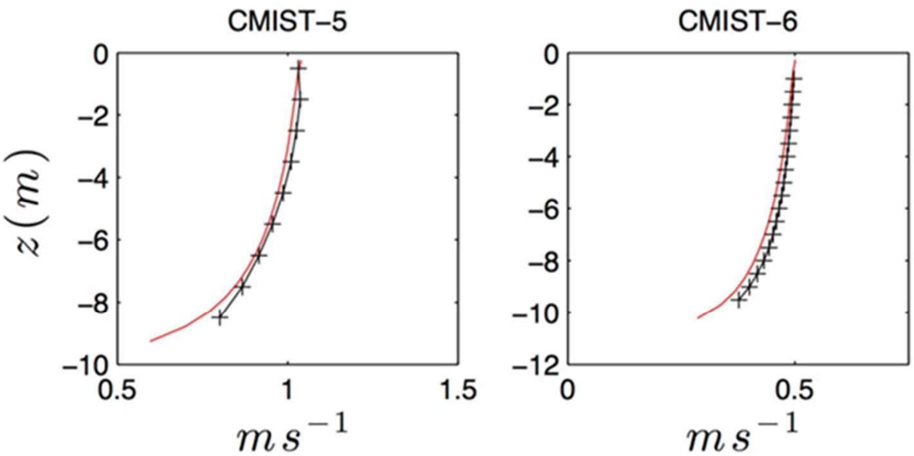


Figure A4. Profiles of modeled (red solid lines) and observed (black lines with + symbols) annual mean velocity magnitude at CMIST ADCP locations in upper Buzzards Bay (Figure A1).

A2.2.8 Further Model Validation

As part of this project, further assessment of the model's performance will be carried out with a focus on the area within and in the vicinity of Red Brook Harbor. As with the prior validation work, the model results will be compared with measured series of sea surface elevation and water velocity. Comparison of model and measured salinity in Red Brook Harbor will also be undertaken.

– The model simulation of sea surface elevation will be compared with the sea surface elevation records acquired in the vicinity of Red Brook Harbor as part of a study of flushing in the Harbor conducted by the Woods Hole Group (Jachec and Hailton, 1999). The elevation records are from tide gauges set out at seven locations (Figure A5) over 19-25 September 1998 and recovered over 5-6 November 1998.

Figure A5. Locations of tide gauges set out by the Woods Hole Group in the autumn of 1998.

Assessment of the model skill will rely on the dominance of the tidal signal in the area of the measurements. Reproduction of the tidal signal over the measurement time period will be accomplished using 2015 model data following the methodology described in A2.2.7. This will first involve extracting the surface elevation signal from the model hindcast at the grid points nearest each tidal. Phase and amplitude of the principal regional tidal constituents (M2, S2, N2, K1, O1 and M4) will then computed from the observed and modeled surface elevation time series using harmonic analysis (T-Tide; Pawlowicz et al., 2002). The tidal constituent phases and amplitudes at each measurement point will then be used to reconstruct the tidal elevation signal at that point for the measurement time period. This will be compared to the measured elevation signal to determine how well the model represents the magnitude of the tides in Red Brook Harbor and the attenuation of the tidal signal moving inshore from the mouth of the harbor.

Velocity – The model skill in simulating currents in Buzzards Bay will be further evaluated using water velocity measurements acquired by three bottom-mounted, upward-looking ADCPs deployed off the towns of Bourne and Falmouth during 1999 (Figure A6). One ADCP was set out as part of the NOAA CMIST program described above, and the other two were deployed as part of a study of bay circulation conducted by the USGS. Using the methodology described above (A.2.7), the model will be assess by determining how well it reproduces the depth-averaged currents and the vertical profile of mean velocity measured at the three sites.

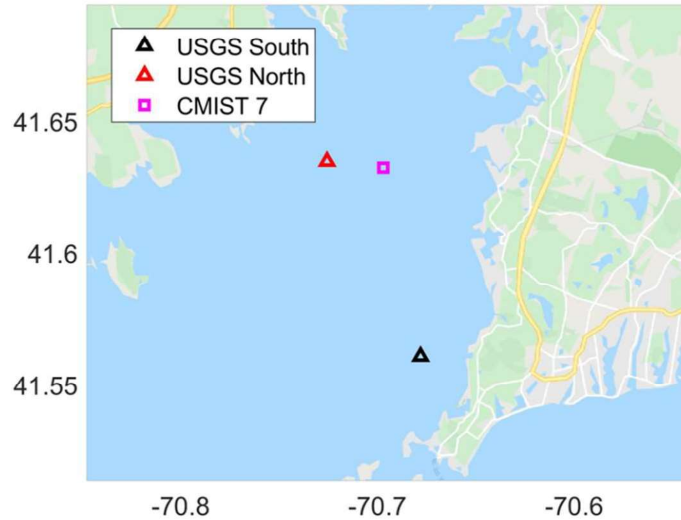


Figure A6. Locations of velocity measurements (from upward-looking ADCPs) that will be used for additional model verification as part of this program. Velocities were acquired at each station during autumn and winter of 2009.

Salinity in Red Brook Harbor – For the goals of this project, a critical model property is the salinity distribution within Red Brook Harbor, as the fresh water influx and the delivery of nutrients to the Harbor typically coincide. The performance of the model in reproducing salinities in Red Brook Harbor will be judged using salinity data acquired through the Baywatchers program, the Buzzards Bay Coalition's long-term citizen-science monitoring project. As part of this program, water samples, and companion temperature and salinity measurements, are collected by citizen volunteers from a variety of coastal locations. Sample collection is done over the spring and summer months and during the last three hours of an outgoing tide. The water samples are transported to the Marine Biological Laboratory where they are analyzed for inorganic nutrients, nitrate and nitrite, (NO_3^- and NO_2^-), ammonium (NH_4^+) and total dissolved nitrogen (TN; the sum of NO_3^- + NO_2^- + NH_4^+). 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 U.S. Environmental Protection Agency (Williams and Neill, 2019).

A total of 16 Baywatcher collection sites are located within Red Brook Harbor (Figure A7). The data from these sites will be used to quantify how well the model reproduces the spatial distribution and seasonal variation (over the spring and summer months) of salinity within the Harbor.

Figure A7. Buzzards Bay Coalition's monitoring stations within Red Brook Harbor (red dots). As part of the Coalition's long-term citizen-science monitoring program (the Baywatchers Program), water properties (including temperature, salinity and nutrient concentrations) have been acquired at these stations since 2003.

A2.3. Hydrodynamic Model – Phase-2

A2.3.1. Model Description

The same model described above for Phase 1 will be used in Phase 2.

A2.3.2. Grid Setup

The grid setup described above for Phase 1 will be the basis of that used in Phase 2. However, the Phase-2 grid will be focused to only the area encompassing Red Brook Harbor and the adjacent waters of Buzzards Bay.

A2.3.3 Model Forcing

The same model forcing described above for Phase 1 will be applied in the Phase 2 modeling. One exception will be the forcing at the seaward boundary of the modified model grid, which will be supplied by the data from the larger-scale, NECOFS, model (http://fvcom.smast.umassd.edu/necofs/).

A2.3.4. Freshwater Input

To confirm the appropriateness of the freshwater input values used in the Phase 1 model, and to supply time series of fresh water and nutrient fluxes for the Phase-2 modeling, field measurements will be collected to determine freshwater flux from Red Brook Pond to Red Brook Harbor. The measurement will be acquired at the outlet from Red Brook Pond to the Herring Run leading to Red Brook Harbor (Figure A8). This outlet channels the full discharge from the pond to the harbor.

Figure A8. Location (red *) of discharge and water level sampling at the outlet of Red Brook Pond

Time series of the temperature and salinity of the water entering the harbor, as well as the water level of Red Brook Pond, will be acquired using paired U20 water-level and U24 conductivity/temperature loggers placed near the Red Brook Pond outlet (Figure A8, Lat/Long: 41.6774, -70.61120). The loggers will be synchronized to collect data every 15 minutes starting at the top of the hour and will be deployed for six months. Every two weeks throughout the deployment, the loggers will be checked (with data download) to ensure that their locations remain constant, fouling is managed and data is captured at regular intervals. An additional U20 logger will be deployed above the high-water mark. This will provide barometric pressure measurements needed to calculate pond water level from the pressure measurements acquired by the underwater U20 logger. The activities will be undertaken following the protocols in an approved QAPP (Parker et al., 2022).

Discrete discharge measurements at the Red Brook Pond outlet (Lat/Long: 41.6774, -70.6112; Figure 8) will be acquired using a YSI Sontek FlowTracker2 handheld Acoustic Doppler Velocimeter. The Velocimeter will produce a measure of the total flow (m^3/s) of water entering Red Brook Harbor from Red Brook Pond. These flux measurements will be taken at regular intervals (1-2x per month) throughout the water level logger deployment period. These flux measurements will be combined with the water level measurements from the U20 loggers to produce a stage height to discharge volume correlation. This correlation will, in turn, be applied to the stage height series to produce a time series of freshwater flow from Red Brook Pond to Red Brook Harbor, which will be incorporated into the model. The activities will be undertaken following the protocols in an approved QAPP (Neill, 2022).

A.2.3.5 Model Validation

The same model validation procedures described above for Phase 1 will be used in Phase 2.

A2.3.6 Model Execution and Data Archiving

Model execution and data archiving will follow the procedure described above for Phase 1.

A2.4. Nitrogen Tracking Model

A2.4.1. Model Description

The nitrogen tracking simulations will be carried out using the high-resolution, three-dimensional velocity fields generated by the hydrodynamic model will and will focus on the transport and mixing of TN discharged into Red Brook Harbor.

The nitrogen tracking simulations will solve the diffusion-advection equation in three dimensions with a source term applied along the coast. Denoting the effluent TN concentration as C_E, the equation is expressed as

$$\underbrace{\frac{\partial C_E}{\partial t}}_{A} = -\underbrace{\left[u\frac{\partial C_E}{\partial x} + v\frac{\partial C_E}{\partial x} + w\frac{\partial C_E}{\partial z}\right]}_{B} + \underbrace{K_H\left[\frac{\partial^2 C_E}{\partial x^2} + \frac{\partial^2 C_E}{\partial y^2}\right]}_{C} + \underbrace{K_V\frac{\partial^2 C_E}{\partial z^2}}_{D} + \underbrace{SS}_{E}$$

where: x, y and z are the east, north and vertical coordinates, respectively; t is time; u, v and w are the east, north and vertical velocity components; K_H and K_V are the horizontal and vertical diffusivities; and SS is the source of TN introduced at the coast.

The solution of the above equation will carried out within model 'tracer' control volumes surrounding each model node. Vertically, each control volume will be divided into 20 evenly spaced layers, corresponding to the hydrodynamic model's sigma-layers. Solving for the change in TN concentration (term *A* above) in each layer of each control volume will entail determining the advective fluxes (term *B*) of TN through the boundaries of the control volume layer (including through the layer's vertical boundaries), and the diffusive TN fluxes through the layer's horizontal (term *C*) and vertical (term *D*) boundaries. The advective fluxes will be determined using the velocities output from the hydrodynamic model. Values for K_V will be taken from the output of the hydrodynamic model (K_V depends on the vertical shear of the horizontal velocity) with a minimum value of 0.3 $\times 10^{-2}$ m^2 s^{-1} imposed. The horizontal diffusivity, K_H, will initially be set to a uniform value of 0.2 m^2 s^{-1}. These may be altered as part of the model assessment/validation process described below.

The input of TN (term *E*) will occur in the control volumes along the shoreline of Red Brook Harbor a rate (mass per unit time) of $V{*}C_{influx}$, where V is the volume rate of influx into the Red Brook Harbor system and C_{influx} is the TN of the flow entering the system. For a control volume at which fresh water is input to the Red Brook Harbor system (Figure A1), V will be set to the volume rate of fresh water discharge applied in the hydrodynamic model (A.2.5) and C_{influx} will be set to a representative TN of water entering the node. This representative TN will be determined from the set of TN measured at or near the fresh water input site by the Baywatchers program (Figure A1) and may vary seasonally and with fresh water influx. For other control volumes along the shoreline of Red Brook Harbor, V will be set to the volume rate of groundwater flux entering the control volume and C_{influx} will be set to the concentration of TN in this groundwater flux. These values of *V* and C_{influx} will be determined as part of the nutrient loading component of the project.

A2.4.2. Model Validation

The model code was formulated (in MATLAB) by Modeling QA Officer Churchill for use in a MIT Sea Grant-funded project aimed at quantifying the impact of municipal effluent discharge on the carbonate system of coastal waters. As part of previous projects, the code has been subject to considerable testing (i.e., by comparison of modeled and observed effluent concentration patterns).

For this project, the model simulation will be performed for all of 2015. The simulation results will be checked for mass conservation (that the accumulated TN in the model domain equals the amount input through groundwater and surface flow minus the amount lost at the open oceanic boundary).

The modeled TN distribution in Red Brook Harbor will be subject to comparison with the TN determined from the Baywatcher sampling in the Harbor (Figure A7), focusing on the spatial and seasonal distribution of TN. If necessary, model parameters (e.g., groundwater TN flux and horizontal diffusivity) will be adjusted to optimize the model/observation comparison.

A2.5. References

Chen, C., Beardsley, R., Cowles, G. (2006). An unstructured-grid Finite-Volume Coastal Ocean Model (FVCOM) System, *Oceanography,* 19 (1), 78–89.

Cowles, G. W. (2008). Parallelization of the FVCOM coastal ocean model, *International Journal of High Performance Computing Applications,* 22 (2), 177–193.

Cowles, G.W., Hakim, A.R., and Churchill, J. H. (2017) A comparison of numerical and analytical predictions of the tidal stream power resource of Massachusetts, USA, *Renewable Energy*, 114 (4), 215-228.

Eakins, B. W., Taylor, L. A., Carignan, K. S., Warnken, R. R., Lim, E., Medley, P. R. (2009). Digital elevation model of Nantucket, Massachusetts: Procedures, data sources and analysis, National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service, National Geophysical Data Center, Marine Geology and Geophysics Division.

Hakim, A. R., Cowles, G. W., and Churchill, J. H. (2013). The impact of tidal stream turbines on circulation and sediment transport in Muskeget Channel, MA. *Marine Technology Society Journal, 47*(4), 122-136. doi:10.4031/mtsj.47.4.14

Jachec, S. M., and Hailton, R. P. Jr. (1999). Flushing Characteristics of the Red Brook and Megansett Harbor System: Field Measurements and Numerical Modeling, *prepared for the Town of Bourne MA by the Woods Hole Group, 81 Technology Park Drive, East Falmouth MA*, 65 pp.

Liu, C., Cowles, G. W., Churchill, J. H., and Stokesbury, K. D. (2015). Connectivity of the bay scallop (Argopecten irradians) in Buzzards Bay, Massachusetts, U.S.A. *Fisheries Oceanography, 24*(4), 364-382. doi:10.1111/fog.12114.

NECOFS (2017) Northeast Coastal Ocean Forecasting System (NECOFS) Main Portal http://fvcom.smast.umassd.edu/necofs/. Accessed: 2017-05-20.

Neill, C. (2022) Quality Assurance Project Plan for Monitoring Flow and Chemistry of Streams and Rivers Draining to Buzzards Bay. 55 pp.

Parker, V., Jakuba, R., Goulart, D., and Neill, C. (2022) Buttonwood Brook – Apponagansett Bay Restoration Action Plan 5 Year Quality Assurance Project Plan for Buttonwood Brook Water Quality Sampling. 40 pp.

Pawlowicz, R., Beardsley, B., Lentz, S. (2002). Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE, *Computers and Geosciences,* 28 (8), 929–937.

Pruessner, A., Fanelli, P., Paternostro, C. (2007). C-MIST: An automated oceanographic data processing software suite. in: *Proceedings of the OCEANS 2007 Conference*.

Turecek, A.M., Danforth, W.W., Baldwin, W.E., and Barnhardt, W.A., 2012, High-resolution geophysical data collected within Red Brook Harbor, Buzzards Bay, Massachusetts, in 2009: U.S. Geological Survey Open-File Report 2010-1091, https://pubs.usgs.gov/of/2010/1091/.

Twomey, E.R. and Signell, R.P. (2013). Construction of a 3-arcsecond digital elevation model for the Gulf of Maine, U.S. Geological Survey Open-File Report 2011–1127, 24 pp, https://pubs.usgs.gov/of/2011/1127/.

Williams, T., and Neill, C. (2019). Buzzards Bay Coalition Citizens' Water Quality Monitoring Program, "Baywatchers", 5 Year Quality Assurance Project Plan.

Willmott, C. J. (1981). On the validation of models, Physical Geography, 2 (2), 184–194.

Appendix III. Watershed Nitrogen Loading Details

A3.1. Background

The nitrogen loading will be estimated in each sub-watershed of the Red Brook Harbor system by combining parcel-level land-use data for each sub-watershed with best-estimates of nitrogen loads and nutrient attenuation.

A3.2. Land-Use Analysis

The goal of the watershed nitrogen loading analysis is to develop spatially-resolved nitrogen loading data that will be incorporated into the nitrogen tracking model to understand how the nitrogen from each sub-watershed impacts the receiving water body. This will be accomplished through a thorough GIS analysis.

A3.2.1 Watershed Boundaries

We will use sub-watershed boundaries adopted by the Cape Cod Commission, Massachusetts DEP, and a USGS Groundwater water model. There are some inconsistencies among the data sets that will be addressed in the analysis using best professional judgement, with the greatest credence given to the USGS Model (Carlson et al., 2017). The final report will describe how any potential uncertainties may affect the results. Where freshwater ponds exist, the sub-watersheds will be further partitioned to differentiate where groundwater from parcels flows into a freshwater pond or directly to the embayment.

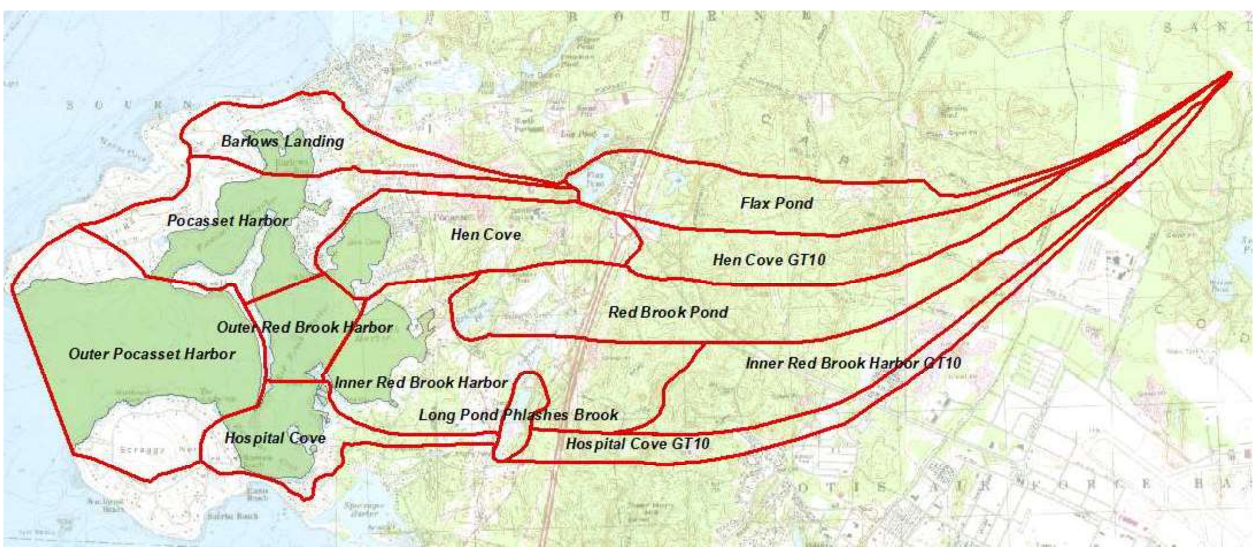


Figure A3.1. Study Area. Red lines show approximate areas for each sub-watershed.

Besides these sub-watersheds, all sub-watersheds abutting the coast will be further subdivided to create a 100m buffer to allow for the septic systems within this 100m buffer to be assigned a somewhat higher loading rate as per the Nitrogen Loading Model (NLM) model.

A3.2.2 Water Budget

A first order water budget will be developed based on annual precipitation and sub-watershed area. This first order water budget will be used for the calculation of net nitrogen transmissivity for each sub-watershed polygon and nitrogen model calibration. For this analysis, the area of sub-watershed polygon will be multiplied by annual precipitation. Annual precipitation for the site will be estimated from the mean of data for National Weather Service stations in East Sandwich, Barnstable, and Town of Falmouth data during the past 30 years . For precipitation falling directly on the estuary, 100% of the rainfall volume will be used. For land polygons, we will adopt a recharge rate after a review of estimates for the Sagamore lens from USGS, the Cape Cod Commission, and in previous MEP TMDL reports for the eastern shore of Buzzards Bay (typically 50% to 60% of the annual precipitation volume is presumed to reach the estuary after losses from evapotranspiration and withdrawals.

Two USGS sub-watersheds have divided flows, including flows outside the Pocasset Harbor Estuary Complex watershed. These sub-watersheds are Flax Pond and Inner Red Brook Harbor/Long Pond (Fig. A3.1). The amount of flow that leaves the watershed versus being conveyed will be estimated taking into account the approximate boundary perimeter lengths and any creeks that may convey surface flow.

A3.2.3 Nitrogen Sources

Geographic data must be available at a scale which will be useful. Watershed loadings that are based on calculated areas of land use types will based on various spatial cover GIS sources that represented that land use category best. The GIS sources are described in Table 3 and include the MassGIS Standardized Assessors' Parcels database. Whatever coverage is used, it will be validated and refined with heads-up digitizing to match 2021 imagery. Land use cover data will primarily be used to assess loading not defined in assessors' data like certain agricultural land types and forest area. Certain features, like cranberry bog production area and golf greens will be digitized directly from aerial photographs. The watershed boundary, most recent existing land cover file, and grid net for 1:5,000 scale viewing will be loaded into ArcMap 10.8.1 and intersected with spatial data such as parcels, land use and impervious.

Once the land-use analysis is complete, the project team will provide the materials to Town of Bourne officials (e.g., Conservation Agent, Town Planner) for review and feedback to ensure that things are accurately characterized and up-to-date.

A3.3. Nitrogen Loading Calculation

The GIS Analysis will identify the number and land area of various features (e.g., residential homes, impervious surfaces, lawns, cranberry bogs, etc.) in each sub-watershed. Nitrogen loading in each sub-watershed will be estimated by pairing this information with nitrogen loading coefficients for each type of feature and taking into account transmission rates and attenuation as the nitrogen goes from the source to the estuary. This will be done using the nitrogen loading model (NLM) as described and applied by Williamson et al (2017). NLM was originally developed by Valiela et al. (1997) for Waquoit Bay, MA and has been used for studies of a number of locations in southeast New England (e.g., Latimer and Charpentier, 2020, Valiela et al., 2016). The nitrogen loading coefficients will use realistic best-estimates of nitrogen loads with local information used when possible. This approach means that coefficients will not use built-in safety factors like Title 5 design loads. In addition, the unique nature of this area with respect to seasonal occupancy will be taken into account to adjust census occupancy rates. There are two facilities with groundwater discharge permits in the study area. For these two facilities, actual flows and concentrations will be obtained to determine the appropriate nitrogen load. The nitrogen loading coefficients to be utilized will be provided to MassDEP for review.

Watershed nitrogen attenuation will be estimated from available stream load data, including from nearby sites and assumptions from previous MEP reports. MEP reports have typically used a value of 50% nitrogen attenuation loss for pond watersheds. Attenuation assumptions will be provided to MassDEP for review and may be adjusted to take other scientific studies into account.

In addition to estimating nitrogen loading under present-day conditions, nitrogen loading will be estimated under 'build-out' conditions. The build-out scenario will constitute a potential future where all developable land is fully developed. The aim of this scenario is to capture a realistic potential future to aid in planning and guiding potential mitigation strategies. To ensure that, developable parcels will be discussed with the Town Planner as the build-out scenario is being developed, and the town will review the analysis.

Net loading to any estuary segment is the sum of unattenuated watershed loads times water transmissivity times nitrogen transmissivity for all upgradient segments.

A3.4. References

Latimer, J. S., and Charpentier, M. (2010) Nitrogen inputs into seventy-four southern New England estuaries: Application of a watershed nitrogen-loading model. *Estuar. Coast. Shelf Sci.* 89,125–136.doi:10.1016/j.ecss.2010.06.006

Valiela, I., Owens, C., Elmstrom, E., and Loret, J. (2016) Eutrophication of Cape Cod estuaries: Effect of decadal changes in global-driven atmospheric and local-scale wastewater nutrient loads. *Mar. Pollut. Bull.* 110, 309–315. doi:10.1016/S0269-7491(01)00316-5

Valiela, I., Collins, G., Kremer, J., Lajtha, K., Geist, M., Seely, B., Brawley, J., Sham, C. H. (1997). Nitrogen loading from coastal watersheds to receiving estuaries: New method and application. *Ecol. Applicat*. 7, 358–380. doi:10.1890/1051-0761(1997)007[0358:NLFCWT]2.0.CO;2

Walter, D. A., Masterson, J. P., and Hess, K. M. (2004) Ground-Water Recharge Areas and Traveltimes to Pumped Wells, Ponds, Streams, and Coastal Water bodies, Cape Cod, Massachusetts, Scientific Investigations Map I-2857, 1 sheet.

Williamson, S. C., Rheuban, J. E., Costa, J. E., Glover, D. M., and Doney, S. C. (2017) Assessing the Impact of Local and Regional Influences on Nitrogen Loads to Buzzards Bay, MA. Front. Mar. Sci. 3: 279. doi: 10.3389/fmars.2016.00279

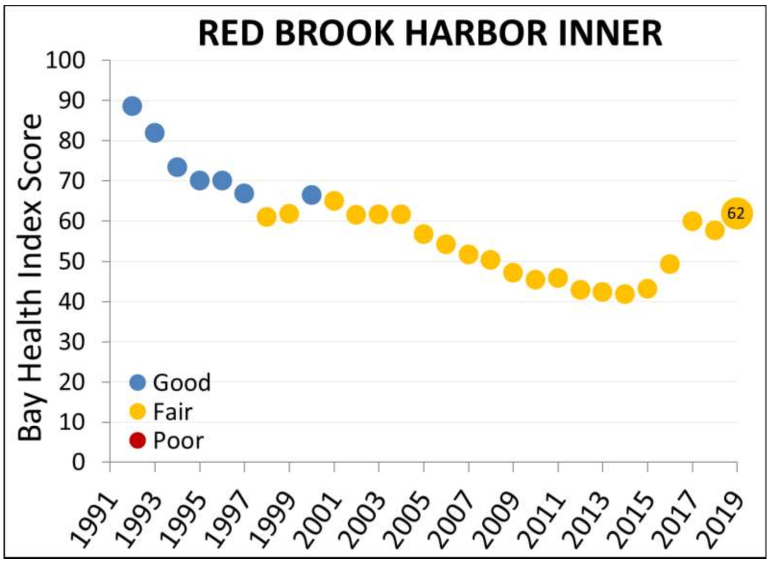
PROPOSAL

PROJECT NARRATIVE

Modeling in Red Brook Harbor to Support TMDL Development

Background

The Red Brook Harbor system, located in the Town of Bourne on the western side of Cape Cod, is home to Cape Cod's largest full-service marina and Hen Cove beach. As revealed by water quality monitoring data collected since 1992 by the Buzzards Bay Coalition, the water quality of Red Brook Harbor has declined over the last 25 years. The monitoring data (approximately weekly measurements of dissolved oxygen, temperature, salinity, and water clarity acquired from late May to late September, and nitrogen and chlorophyll measurements taken on 4 dates in July and August) have tracked declining water quality through the Bay Health Index score for inner Red Brook Harbor. The Bay Health Index score is calculated by combining data including dissolved oxygen, water clarity, nitrogen levels, and abundance of algae. The water quality decline is a result of excessive nitrogen loading from non-point pollution sources, including wastewater from septic systems, road runoff, and lawn fertilizers. In the last few years, water quality has rebounded somewhat, although it still remains classified as only "fair".



Issue

Because of nitrogen pollution, Red Brook Harbor, Hen Cove, and Pocasset Harbor (see map) are all listed as impaired for estuarine bioassessments and fecal coliform on the Massachusetts 2016 303(d) Integrated List of Impaired Waters. Red Brook Harbor and Hen Cove are also listed as impaired for nutrient/eutrophication biological indicators. The impaired status of these areas requires development of a Total Maximum Daily Load (TMDL) of nitrogen input to Red Brook Harbor. A TMDL, the quantity of nitrogen loading that an estuary can sustain and still meet water quality standards, outlines the sources of nitrogen to the estuary and provide guidance on how much nitrogen loading from these sources should be reduced. This information is critical for the Town of Bourne as it develops management plans to restore water quality in Red Brook Harbor.

To develop nitrogen TMDLs, the Massachusetts Dept. of Environmental Protection (MassDEP) uses a site-specific approach of gathering information and performing modelling of each estuary. This scientific foundation for nitrogen TMDLs has been developed in many southeast Massachusetts estuaries by SMAST through the Massachusetts Estuaries Project (MEP). However, a Red Brook Harbor TMDL was not completed by the MEP, and SMAST is no longer under contract to MassDEP. Building on a previous 604b project, this project would supply critical new information needed for TMDL development.

Project Need and Justification

There is a clear need to develop a TMDL for the Red Brook Harbor system. This proposed project builds on an earlier 604b project in which the benthic habit and water quality in Red Brook Harbor were assessed. In the proposed project, we will develop additional tools towards forming the scientific foundation for a nitrogen TMDL for Red Brook Harbor system. Specifically, we will estimate watershed nitrogen loads to the system, and adapt a hydrodynamic/water quality model that will use these calculated loads as nitrogen input to the water quality model to examine the transport and concentration of nitrogen throughout the system. The model results will reveal which sub-watersheds most impact the system's nitrogen concentrations and can be used to formulate nitrogen load reductions needed to meet water quality standards.

Project Description

This project will estimate sub-watershed nitrogen loads that will be incorporated into a hydrodynamic/water quality model of the Red Brook Harbor system. The project, building on our previously funded 604b project, will support management planning by providing tools and information needed for site-specific scientific TMDL formulation in Red Brook Harbor.

The assessment and quantification of watershed nitrogen loading will use realistic best-estimates of nitrogen loads, rather than loads with built-in safety factors like Title 5 design loads. The assessment will incorporate parcel-level data (e.g., on land use, lot size, lawn area), census occupancy rates and seasonality, and other information to refine estimates of current watershed nitrogen loading. Watershed nutrient attenuation will be estimated from available stream load data and assumptions from previous MEP reports where concentration data is not available.

Watershed nitrogen loading, and resultant estuary nitrogen concentrations, will also be estimated under realistic build-out conditions, which will be determined by conversations with the Town Planner.

The manner in which watershed nitrogen loading influences the estuarine water quality will be determined by applying a coupled hydrodynamic/water quality model. The 3-D model, which has been applied by project team member Churchill in numerous studies of estuarine water quality, includes all of the southeastern New England coastal zone, with very high resolution (order 30-m horizontal and 20-cm vertical cell size) in Red Brook Harbor. It will be adapted to employ the watershed nitrogen loads estimated in this study. Similar to the methodology employed by the MEP, the model will be calibrated and validated using water quality data acquired by the Buzzards Bay Coalition's Baywatchers Monitoring Program (collected following a Quality Assurance Project Plan approved by the Massachusetts Department of Environmental Protection and the U.S. Environmental Protection Agency). The calibrated model will reveal how nitrogen loading from the various sub-watersheds is transported through the system, and will be used to estimate how nitrogen concentrations in Red Brook Harbor may be altered by targeted reduction of loading (e.g. by septic system upgrade of a given neighborhood) or by increased loading through realistic build-out.

A technical report will be produced to describe the results of project. The report will document how the watershed loading impacts the estuarine nitrogen concentrations under current, and build-out, conditions. The report will include a recommended watershed load limit and will include a discussion of the sensitivity of the estuarine nitrogen concentrations to the watershed loading, and describe all assumptions used in the analysis.

Project Outreach

Project outreach will extend to state and local officials involved in estuarine management and to members of the general public. The project results will be presented at meetings of appropriate town boards/committees, such as the Board of Selectmen, Conservation Commission, and the Board of Health. The Coalition will develop digital content on the project to be disseminated to the general public through its website and on social media. The Coalition website was visited about 450,000 times in 2019 and has over 10,000 followers on social media.

Project Team

The Town of Bourne successfully oversaw monitoring to support one of the first estuaries assessed by the Massachusetts Estuaries Project. The TMDL for Phinney's Harbor was completed in 2008. More recently, the MEP completed assessment of Megansett and Squeteague Harbors, which are on the border between Bourne and Falmouth.
The Town of Bourne is developing plans to reduce nitrogen pollution and meet water quality standards including developing new capacity for sewering through new wastewater treatment facilities as well as through innovative partnership agreements. Thus, the Town has comprehensive knowledge and experience with the importance of monitoring information for developing nitrogen management plans.

The Town of Bourne will partner with scientists from the Buzzards Bay National Estuary Program, the Woods Hole Oceanographic Institution, and the Buzzards Bay Coalition to accomplish this project. The project partners have successfully worked together in the past. The Town of Bourne and the Buzzards Bay Coalition partnered on a previous 604b project that has developed information on the benthic habitat and water quality for Red Brook Harbor. For the last five years the Town of Bourne and the Buzzards Bay Coalition have collaborated on projects funded by the U.S. EPA to explore the potential for expanding regional sewer service in Upper Buzzards Bay following the relocation of a municipal wastewater treatment plant outfall out of a sensitive area. The Woods Hole Oceanographic Institution developed a paired hydrodynamic/water quality model for that project. The Town has worked with the Buzzards Bay National Estuary Program to map stormwater networks and monitor stormwater discharges, including sites within the Red Brook watershed.

Project personnel include:

- Samuel Haines, Town of Bourne, Conservation Agent: Sam will oversee the project activities and coordinate outreach to town boards and committees.
- Joe Costa, Buzzards Bay National Estuary Program, Executive Director (resume attached): Joe will calculate the watershed nitrogen loading. Joe has calculated watershed nitrogen loading as part of the review process for MEP reports and for analyses published in peer-reviewed scientific publications.
- Jim Churchill, Woods Hole Oceanographic Institution, Oceanographer Emeritus (resume attached): Jim will develop, calibrate and execute the coupled hydrodynamic/water quality model for Red Brook Harbor. He has carried out numerous similar modeling studies [i.e., to assess environmental impact of proposed wastewater discharge sites at the western end of Cape Cod Canal and off a site in eastern Buzzards Bay, and to evaluate the impact of wastewater discharge on carbonate chemistry near 3 discharge sites in western MA]. He is currently applying his model to evaluate the transport and impact of microplastics in wastewater discharge at four sites in the MA coastal zone.
- Rachel Jakuba, Buzzards Bay Coalition, Science Director (resume attached): Rachel will perform project management and reporting activities, and develop outreach materials.
- Korrin Petersen, Buzzards Bay Coalition, Senior Attorney (resume attached): Korrin will perform project outreach. Korrin is currently managing outreach for the Upper Buzzards Bay project on expanding regional sewer service.

PROPOSAL
SCOPE OF SERVICES
Modeling in Red Brook Harbor to Support TMDL Development

TASK # 1: Quantify existing watershed nitrogen sources.
SUMMARY: Watershed nitrogen loading will be calculated using realistic best-estimates of nitrogen loads.
PERSONNEL: Joe Costa
DESIRED OUTCOMES: Text document that describes methods and assumptions and spreadsheet document with data by sub-embayment.
COST: $0
MATCH: $0, however this work is able to be done at no cost to the project due to federal funding to the Buzzards Bay National Estuary Program.

TASK # 2: Quantify future watershed nitrogen sources.
SUMMARY: The estimates developed in Task #1 will be updated to include realistic build-out conditions, which will determined through conversations with the Town Planner.
PERSONNEL: Joe Costa
DESIRED OUTCOMES: Text document that describes methods and assumptions and spreadsheet document with data by sub-embayment.
COST: $0
MATCH: $0, however this work is able to be done at no cost to the project due to federal funding to the Buzzards Bay National Estuary Program.

TASK # 3: Hydrodynamic/water quality model development, calibration and execution.
SUMMARY: A paired hydrodynamic/water quality model will be developed that uses the watershed nitrogen loading numbers developed in Task #1 to predict nitrogen concentrations in the harbor. The model will be calibrated to match water quality data collected by the Buzzards Bay Coalition's Baywatchers Monitoring Program following a Quality Assurance Project Plan approved by the Massachusetts Department of Environmental Protection and the U.S. Environmental Protection Agency.[1]
PERSONNEL: Jim Churchill, Rachel Jakuba
DESIRED OUTCOMES: Output from the model in the form of spreadsheets and nitrogen concentration maps as well as a description of strengths/limitations of the model, model loading and model assumptions.
COST: $29,248
MATCH: $4,490

TASK # 4: Hydrodynamic/water quality model run with build-out nitrogen loading.
SUMMARY: The model developed in Task #3 will be re-run with the build-out scenario loading numbers developed in Task #2 to predict what the estuary nitrogen concentrations would be with the build-out loading.
PERSONNEL: Jim Churchill

[1] Williams, T., and C. Neill (2014). Buzzards Bay Coalition Citizens' Water Quality Monitoring Program, "Baywatchers", 5 Year Quality Assurance Project Plan.

DESIRED OUTCOMES: Output from the model in the form of spreadsheets and nitrogen concentration maps as well as a description of strengths/limitations of the model, model loading and model assumptions.
COST: $9,048
MATCH: $0

TASK # 5: Project Outreach.
SUMMARY: Project outreach will extend to officials involved in estuarine management and to members of the general public. Project partners will engage with officials from MassDEP who develop total maximum daily loads. The project results will be presented at meetings of the appropriate town boards/committees, such as the Board of Selectmen, Conservation Commission, and the Board of Health. The Coalition will develop digital content on the project to be disseminated through its website and on social media.
PERSONNEL: Korrin Petersen, Rachel Jakuba, Sam Haines
DESIRED OUTCOMES: Presentations to a minimum of two municipal boards. Digital stories about the project and its results posted on the Coalition's website and social media.
COST: $5,000
MATCH: $0

TASK # 6: Project Coordination and Reporting
SUMMARY: Project reporting will occur in accordance with the terms outlined in the grand agreement.
PERSONNEL: Rachel Jakuba, Sam Haines
DESIRED OUTCOMES: Seven quarterly reports and a Final Draft Report and Final Report.
COST: $5,048
MATCH: $510

PROPOSAL
PROJECT BUDGET
Modeling in Red Brook Harbor to Support TMDL Development

Expense Items	604 (b) Amount	Cost Share (not required)	Total Amount
Applicant's Salary - By Title and salary range	$0	$0	$0
Subcontractual Services • Buzzards Bay Coalition (Outreach/reporting) • Churchill (Hydrodynamic/water quality modeling)	$6,000 $42,344	$5,000	$11,000 $42,344
Equipment	$0	$0	$0
Supplies (including printing, mailing)	$0	$0	$0
Travel (for mileage only @ 0.45 cents/mile)	$0	$0	$0
Other	$0	$0	$0
Total Amounts:	$ 48,344	$5,000	$53,334

OVERHEAD RATE (%) %

TOTAL REQUEST FOR GRANT:$ 48,344 604 (b) Funds

TOTAL COST SHARE: $ 5,000 (Not Required)

TOTAL BUDGET AMOUNT: $ 53,344

PROPOSAL

PROJECT MILESTONE SCHEDULE

Monitoring in Red Brook Harbor to Support TMDL Development

MONTH

TASK	1 J-21	2 F-21	3 M-21	4 A-21	5 M-21	6 J-21	7 J-21	8 A-21	9 S-21	10 O-21	11 N-21	12 D-21	13 J-22	14 F-22	15 M-22	16 A-22	17 M-22	18 J-22	19 J-22	20 A-22	21 S-22	22 O-22	23 N-22	24 D-22
Task #1 Quantify existing N sources	X	X	X																					
Task #2 Quantify future N sources			X	X	X																			
Task #3 Model development, calibration and execution	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
Task #4 Model run with build-out nitrogen loading															X	X	X	X						
Task #5 Project Outreach									X	X	X	X					X	X	X	X				
Task #6 Reporting				X			X			X			X			X			X			X	X	X

PROPOSAL

MAP OF PROJECT SITE WITH LOCUS MAP OF PROJECT AREA (INSET)

Modeling in Red Brook Harbor to Support TMDL Development

Map prepared by: Buzzards Bay National Estuary Program, 2870 Cranberry Highway, East Wareham, MA 02538 www.buzzardsbay.org March 22, 2018.