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Independent Technical Review of FVCOM Modeling for Wastewater Dilution in Buzzards Bay and the North and South Rivers: Considerations for Regulatory Implementation

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Preface

This report presents the findings and recommendations of an independent technical review of hydrodynamic modeling using the Finite Volume Community Ocean Model (FVCOM) to simulate wastewater treatment plant (WWTP) effluent dilution in Buzzards Bay and the North and South Rivers, Massachusetts. The review was commissioned by WHOI Sea Grant, an independent, science-based program based at Woods Hole Oceanographic Institution, and supported by funding from NOAA Award NA24OARX417C0156. Its intent is not to critique the quality of the modeling work conducted by University of Massachusetts-Dartmouth researchers and the Massachusetts Division of Marine Fisheries (MA DMF), nor to question the regulatory decisions made by state agencies. Rather, it is meant to provide constructive scientific guidance on how to further strengthen confidence in the model results as they are considered for regulatory applications.

WHOI Sea Grant recognizes the substantial effort undertaken by the U. Mass research team and MA DMF to apply a high-resolution, data-intensive modeling approach under limited time and resource constraints. Given the importance of shellfish classification decisions to both public health and coastal economies, ensuring that the modeling tools used in this process are robust, transparent, and well-supported by data is essential. It is our hope that the Commonwealth of Massachusetts will provide additional resources to MA DMF to support the implementation of key recommendations made by the review team, including expanded model validation, improved uncertainty quantification, and engagement with interested parties. This review represents a step toward engaging modelers, regulators, and interested parties in a dialog that supports informed, science-based decision making.

Executive Summary

Coastal shellfish harvesting in Massachusetts is regulated to ensure public health, with water quality classifications guided by the National Shellfish Sanitation Program (NSSP). A key factor in these classifications is the dilution of wastewater treatment plant (WWTP) effluent, which can impact nearby shellfish beds. In response to FDA requests to clarify how dilution zones around WWTPs are calculated, the Massachusetts Division of Marine Fisheries (MA DMF) partnered with U. Mass-Dartmouth researcher Dr. Changsheng Chen's lab to use the Finite Volume Community Ocean Model (FVCOM) to estimate dilution zones around WWTP outfalls. The modeling evaluations have been completed for WWTPs in Scituate (discharging to the North and South Rivers), Ipswich (discharging to Greenwood Creek, which flows into the Ipswich River), Fairhaven (discharging to New Bedford Harbor), and New Bedford (discharging to the open waters of Buzzards Bay). These model results have informed recent reclassifications of shellfish growing areas, resulting in large-scale downgrading of shellfish harvest classification and prompting the desire for an independent scientific review to evaluate the model's application and reliability in regulatory decision making.

To address this need, WHOI Sea Grant coordinated an independent technical review of two FVCOM modeling reports that were available as of December 2024, focused on the Fairhaven and New Bedford WWTPs and the Scituate WWTP, as well as associated validation materials provided by Dr. Chen's team. Three experts in ocean modeling and coastal processes were asked to evaluate the model's approach, performance, and suitability for informing shellfish water quality classifications and management of wastewater and combined sewer overflow (CSO) discharges. The experts were selected from outside Massachusetts and had no conflicts of interest with Dr. Chen or his research team. After the independent reviews were completed, MA DMF and Dr. Chen and his team were provided the opportunity to submit written responses. Their comments were aligned with the findings and recommendations of the review, and no changes to the draft report were necessary. WHOI Sea Grant published the draft report in June 2025 and solicited public feedback, which was summarized and incorporated into the final report.

The technical reviewers of the modeling materials agreed that the existing modeling framework is appropriate for use in assessments of wastewater treatment plant effluent dilution. However, the reviewers felt that, given the usage of the model to inform regulatory decision-making, MA DMF and Dr. Chen and his team should undertake further validation and testing to strengthen confidence in the modeling results. They included several recommendations and requests for additional information. Their findings can be summarized as follows:

- Enhance model validation in the areas of interest
- Improve clarity and documentation of modeling methods
- Better address spatial and temporal uncertainty
- Consider decay and non-passive behavior of contaminants

Public commenters expressed concerns similar to the technical reviewers and made additional requests of MA DMF for more transparency in implementation of modeling and field data for decision-making when redefining shellfish growing area classifications. Based on this feedback, WHOI Sea Grant recommends several actions to strengthen confidence in the application of the FVCOM model for this regulatory purpose. These include expanding validation of hydrodynamics using local observational data, testing the passive tracer model through dye studies or comparisons with past field efforts, improving documentation of modeling methods, assessing uncertainty through multi-year simulations, and evaluating the potential influence of contaminant decreases via natural processes. WHOI Sea Grant also recommends more clearly documenting how modeling results and other data are used for regulatory decision-making and establishing an advisory board of scientists, managers, and shellfish industry representatives to provide ongoing guidance and promote transparency in the use of model results.

Background

To ensure that molluscan bivalve shellfish like oysters, clams and mussels harvested from nearshore waters are safe for human consumption, the US Food and Drug Administration (FDA) works cooperatively with state regulatory agencies and shellfish industry members through the National Shellfish Sanitation Program (NSSP). The guiding document is called the NSSP Guide for the Control of Molluscan Shellfish, which is usually updated every two years and documents the conditions which need to be met to maintain safe harvest and commerce of shellfish.

In Massachusetts (MA), the responsible state authority is the MA Division of Marine Fisheries (MA DMF) in partnership with the MA Department of Public Health and the MA Environmental Police. These agencies, with oversight from the FDA, must examine potential pollution sources in combination with sampling for microbial standards to evaluate a region's shellfish growing area classification. Based on these ongoing evaluations, coastal waters can be designated in one of five classifications: Approved for harvest, Conditionally Approved (conditions may be based on rainfall, wastewater treatment plant (WWTP) operation, etc.), Restricted, Conditionally Restricted, or Prohibited to the harvest of shellfish. For an area to have allowable shellfish harvest without significant restrictions, it must be classified as Approved or Conditionally Approved and in the open status.

One factor evaluated in this process is the proximity of growing areas to point sources of pollution. The FDA's recommended dilution levels that should be maintained around WWTP discharges (Section IV, Chapter II, .19 Classification of Shellfish Growing Waters Adjacent to Waste Water Treatment Plants) are:

- 1:1000 dilution zone is recommended to be a Prohibited area
- beyond the 1:1000 dilution zone is recommended to be Conditionally Approved, with conditions for being in the open or closed status depending on WWTP operation conditions.
- 1:100,000 dilution is recommended before an area could be considered Approved

Note that the FDA's guidance allows some flexibility for the use of data to justify the level of dilution chosen for classification, pending FDA approval.

Problem Description

The FDA has recently reviewed the MA shellfish growing area classifications and has asked the state to better justify the delineation of classification areas around WWTP discharges. In response, the state of MA enlisted the help of a team of hydrodynamic modelers based out of the University of Massachusetts - Dartmouth, led by Dr. Changsheng Chen, to identify dilution zones around WWTP discharge locations. Dr. Chen's team utilized the Finite Volume Community Ocean Model (FVCOM) to simulate WWTP discharges at four outfall locations at this time, but anticipates more WWTPs to be evaluated in the near future. At the time this review was initiated (December 2024), modeling results were available for the two facilities discharging into the New Bedford area (New Bedford and Fairhaven WWTPs) and the Scituate area (Scituate WWTP), which were the focus of this report.

Results from the FVCOM discharge modeling informed MA DMF of passive tracer volumetric dilution contours that has led to a reclassification and downgrading of thousands of acres of shellfish harvest area (Figure 1). For example, FVCOM model results suggest expansion of the Prohibited area around the WWTP that serves the City of New Bedford, MA. This WWTP discharges into the open waters of Buzzards Bay and a prohibited area surrounding the WWTP discharge is thus required. As a result, a number of shellfish farms and wild harvested areas fall within or close to the recommended 1:1000 dilution for a Prohibited zone. This has led MA DMF to reclassify the waters of several shellfish farms as Conditionally Approved (that were previously in Approved waters), but they have avoided classifying the farms as Prohibited (and closing the farms) at this time. In Scituate, modeling of the WWTP discharge there closed hundreds of acres of recreational shellfish area and further limited potential for shellfish aquaculture in the town.

Previous Classification **Current Classification**

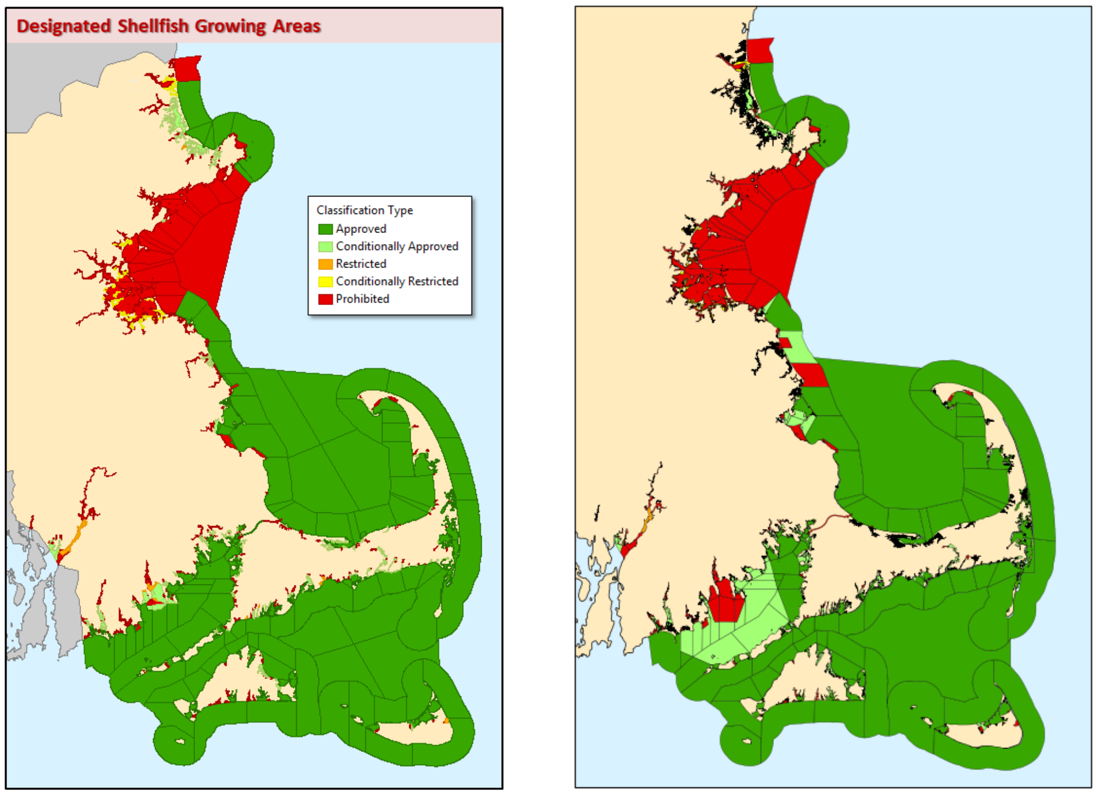

Figure 1. Left: Classification of designated shellfish growing areas prior to reclassification efforts. Figure from MassGIS (https://www.mass.gov/files/images/massgis/datalayers/dsga.png, Accessed on April 28, 2025). Right: Classification of shellfish growing areas as of February 10, 2025. Reclassification of shellfish growing areas near the New Bedford, Fairhaven, and Scituate, MA WWTPs was informed by FVCOM-modeled dilution contours. Areas previously classified as Approved were downgraded to Conditionally Approved due to proximity to the modeled WWTP outfalls, and the Prohibited Zone has been expanded. Colors indicate classification type Approved (dark green), Conditionally Approved (light green), Restricted (orange), Conditionally Restricted (yellow), and Prohibited (red).

A second challenge that significantly impacts the six shellfish farms and numerous shellfish harvesters in the region is that the City of New Bedford has legacy combined sewer overflows (CSOs) that can discharge raw wastewater with rainfall into the waters of New Bedford Harbor and the open waters of Buzzards Bay. Depending on the volume of discharge, varying volumes of receiving water are required to dilute the untreated sewage discharges to the NSSP standard fecal coliform level that allows for shellfish harvest for direct human consumption (14 colony forming units/100ml). When CSOs overflow, areas can be closed depending on conditions such as the volume of the overflow, where the overflow occurred, as well as bay and weather conditions. These CSO-related closures have resulted in the shellfish farms being closed about 60% of the time in 2024.

The FVCOM modeling results show that discharges from the New Bedford and Fairhaven WWTPs can flow into the shellfish growing areas where the farms are located and, therefore, those areas cannot be excluded as potential receiving waters for CSO discharge. While FVCOM modeling results **do not determine CSO closures**, MA DMF does use the model grid and bathymetry to estimate the volume of water within the model domain during high and low water conditions. Dr. Chen provided DMF with a static dataset of water volume that DMF utilizes to determine how much area needs to close in order to achieve the appropriate level of dilution following CSO discharge events. The volume of receiving water needed for dilution is calculated by using the volume of the CSO discharge reported by the City of New Bedford (pursuant to DEP regulation) and using a fecal coliform level for discharge water that is informed by MA DMF sampling and testing of past CSO discharges (400,000 CFU/100ml). It is possible that future use of model simulations under real-time environmental conditions could better inform MA DMF of the fate of CSO discharges in Buzzards Bay and allow for more precise closure delineations following CSO discharge events.

As such, there is significant interest among the shellfish harvest and manager community to ensure that the modeling undergoes an independent, peer-reviewed process to evaluate both the dilution model results for average conditions that inform shellfish growing area classification as well as their potential use for decision making following discrete CSO discharge events in the context of ensuring public safety. As an independent, science-based entity, WHOI Sea Grant has been asked to facilitate this review.

Methods of Review

WHOI Sea Grant sought independent technical evaluations of two reports summarizing the WWTP modeling results in Buzzards Bay and in the North and South Rivers as well as additional validation materials for the parent FVCOM model, the Northeast Coastal Ocean Forecasting System (NECOFS) provided by Dr. Chen and his team. Three technical experts in high resolution coastal ocean modeling who were unconflicted with Dr. Chen and his team were given six weeks to evaluate the materials provided. Reviewers were asked the following:

1) Provide a written summary and evaluation of the model in the context of the dilution of WWTP discharge.
2) Is the described approach for the modeling appropriate to identify dilution zones? If not, are there alternative approaches that could be used?
3) Is the model well validated based on the materials provided? Please describe in detail your perspective on the model's performance and validation.
4) If, in your opinion, the model is not well validated, please make recommendations as to what you think would be needed to further validate the model? E.g. additional observations, modeling scenarios, more details to the written documentation, etc.
5) The model has been used to assess the dilution zones associated with a continuous discharge of wastewater.
    - Based on your assessment of the modeling results and validation, does the model have the appropriate spatiotemporal resolution to evaluate the dilution of event-scale discharge from other point sources, i.e. CSO discharges?
6) Please comment on your perspective of the usage of this model for decision making for two purposes:

- To establish shellfish classification areas
- To predict the short-term impact of rainfall events and CSO discharges

Reviewers of materials provided by Dr. Chen's team will remain anonymous. Blinded review materials were provided to Dr. Chen and his team and MA DMF to respond to. WHOI Sea Grant also solicited public feedback on an initial draft of this report as well as the responses to reviews provided by Dr. Chen and his team and MA DMF. This public comment was open from June 2 – July 11, 2025. Commenters were given notice that comments received that followed the guidelines provided would be made public along with the final version of this report. WHOI Sea Grant has compiled these three reviews, the responses to reviews, and the public feedback into the following summary and recommendations. Responses to reviews by Dr. Chen and his team can be found in Appendix A, by MA DMF in Appendix B, and public comments can be found in Appendix C.

Reviewer Summary

Reviewers touched on many different aspects of the modeling work. *All three reviewers agreed that the existing modeling framework as well as the high-resolution Mass Coastal FVCOM and North and South Rivers FVCOM (NSR-FVCOM) are appropriate to be used for assessments of wastewater treatment plant effluent dilution*. This modeling team has extensive experience operating global, regional, and coastal ocean models, and among other things, has implemented passive tracer tracking and biogeochemical modeling assessments in numerous use cases using various iterations of the FVCOM modeling framework. Reviewers agreed that the unstructured grid and very high spatial (up to 4m horizontal and 0.5m vertical) and temporal (up to 0.3s) resolution allows for accurate depictions of complex land-ocean boundaries, which are critical to assess the likely path of wastewater in the modeling domain. Reviewers noted that the parent model, Northeast Coastal Ocean Forecasting System (NECOFS), is a highly respected and widely used ocean modeling tool. NECOFS has been extensively validated for numerous applications such as water levels, stratification, currents, storms, and flooding, building confidence in boundary conditions for many parameters, including but not limited to tides, currents, water temperature and salinity, and the atmospheric forcing has been validated for winds, sea pressure, air temperature, and humidity. Reviewers also agreed that the passive tracer simulations were well designed and can achieve the goals outlined — to document the possible spread of wastewater discharged from the assessed WWTPs.

Four main themes emerged from the review of the modeling work. These themes include: 1) validation of the results, 2) clarity in methodology, 3) uncertainty in simulation results, and 4) consideration of non-passive behavior of wastewater contaminants. The four themes are described in more detail below.

1 - Validation

All three reviewers felt that, although the parent model, NECOFS, was well validated, this particular use-case would benefit from additional work. Validation of the NSR-FVCOM model was not described in the materials provided. Validation of the Mass-Coastal FVCOM model for this use was focused on assessments of semidiurnal and diurnal tidal amplitudes and phases at 18 locations around the modeling domain. The modeling team found good agreement with most tide gauges with the exception of two, which they attributed to poorly resolved bathymetry in some locations. Reviewers identified that, given the usage of the model to inform regulatory decision making, an additional assessment of the models' performance would be important. Reviewers suggested that comparing model results to observations of hydrographic data and current speeds in the regions surrounding the WWTPs would improve confidence in overall model performance and capabilities. This type of assessment would evaluate how well the model simulates water flow, stratification, and mixing with the target regions. One reviewer identified that further validation of the NSR-FVCOM model may not be possible with the simulations as originally designed, as the model was forced with climatologies rather than specific years. Another reviewer suggested that the passive tracer application should be directly validated by implementing a dye tracer study and associated field campaign to fully document spreading and dilution of wastewater from modeled WWTPs.

Modeling results of the New Bedford and Fairhaven WWTPs suggest the spreading of material at the surface was more extensive than at depth. All three reviewers raised concerns about the behavior of the initial discharge and mixing of the wastewater into the Mass Coastal FVCOM model domain, and raised concerns about how that led to surface spreading of material surrounding the WWTPs. All reviewers noted that there was not sufficient evidence given that, with a well-mixed water column in Buzzards Bay, concentrations should be different at the surface than at depth. The modeling team hypothesized that the energetic environment generated from the mixing of laminar flow from the wastewater pipe with the turbulent flow of Buzzards Bay drives material to the surface. All three reviewers felt that it would be important to validate these results with data to fully document the processes driving the dilution and mixing of wastewater around Buzzards Bay.

2 - Clarity in methodology

All three reviewers identified elements of the provided reporting materials that would benefit from additional clarification of the methods used in the analysis. Reviewers requested more information and description of the tracer tracking model used in the simulations. All reviewers noted that there were discrepancies between the 1:1000 dilution contour that was shown and the 0.1% concentrations reported in the dilution maps. Reviewers felt that a more detailed description of how the 1:1000 dilution ratio was quantified was warranted. Reviewers also would have liked to have seen more description of how the modeling team implemented the WWTP discharge into the modeling domain. One reviewer suggested that the team might consider a description or methodology such as reported by Kessouri et al. 2021 (https://doi.org/10.1029/2020MS002296). Reviewers felt that the description and implementation of the model forcings, such as spatial and temporal resolution of the atmospheric model and riverine discharge and WWTP effluent associated characteristics, would also benefit from expansion. Reviewers asked for more details on the model grid structure, and whether fine scale engineered structures, such as breakwaters or jetties, were included in the modeling grid. Reviewers also identified opportunities for the modeling team to clarify some of the graphics shown, add additional tables that summarized the model experiments run and add additional citations to points made.

3 - Uncertainty in simulation results

Two of the three reviewers highlighted that the presented modeling results do not incorporate any information on spatio-temporal uncertainty. The results presented for Buzzards Bay included only one year, 2021, of model runs, and the dilution contours show averages over long periods of time. A discussion of why the year 2021 was selected for modeling of the New Bedford and Fairhaven WWTPs was not included in the reporting materials. One reviewer noted that considerable variation in winds, currents, stratification, and mixing might be expected from year to year that may affect the size and location of the dilution zones. This reviewer felt that it was important to either model additional years to fully document the spatio-temporal uncertainty, or at a minimum, put the modeled year into a broader context to fully understand how representative 2021 would be of a typical year. They also wondered why a monthly or seasonal product was the appropriate timescale to evaluate dilution contours, and would have liked to see this decision justified in the text. We note that the modeling in the North and South Rivers region was completed using seasonal climatologies of forcings, which may be more representative of average conditions, but one reviewer noted that this may hinder validation of modeling results. Reviewers felt that documentation of spatio-temporal uncertainty could in part be presented through maps of the standard deviation in modeled dilution contours for each season, and that other metrics such as salinity contours might also be useful for assessing model performance.

Reviewers also raised concerns that model accuracy and other process-based uncertainty, such as that associated with the initial mixing of WWTP effluent into the model domain (described above), were not incorporated into the dilution products. Reviewers felt that providing a confidence interval in the dilution contours would be important to bound the uncertainty in results, particularly because results are being used to inform regulatory decisions.

4 - Consideration of non-passive behavior of wastewater contaminants

Two reviewers identified that contaminants in wastewater discharge may not fully behave passively over time, but may decrease with time due to natural processes such as exposure to UV radiation. Reviewers asked if tracer degradation rates might influence the extent of the dilution zones identified. One reviewer suggested that a sensitivity analysis could be completed, implementing results of Kragh et al. 2022 and/or Delre et al. 2023 which show degradation rates of colored dissolved organic matter (CDOM) and microplastic particles when exposed to UV light. Reviewers felt as though a comparison of results with and without tracer degradation rates might also help to inform uncertainty in modeled results (see section 3, above).

Public Comment Summary

WHOI Sea Grant received seven submissions during the public comment period. All submissions followed the posted guidelines and commenters provided detailed and constructive input on the report along with their names and affiliations. The commenters were from a broad range of geographic areas in the Commonwealth where hydrodynamic modelling of WWTP outfall dilution was completed and included representatives of the shellfish aquaculture industry, wild harvesters, non-governmental organizations, and municipalities. The full comments can be found in Appendix C.

Industry commenters expressed frustration about changes in classification of shellfish growing areas, stating they have caused significant economic losses, even business shutdowns. Several noted that status downgrades to “conditionally approved” can have market implications for shellfish farms and cause the loss of access to overseas opportunities associated with international regulations on shellfish safety. Commenters noted that downgrading waters for harvest of shellfish also limits future farm development in affected areas. Implications for recreational harvest were said to be significant in certain areas and some commenters asked whether recreational harvest needed to be considered under the same commercial guidelines from the National Shellfish Sanitation Plan (NSSP).

Commenters raised concerns similar to peer-reviewers about the limited validation of model results and noted that there are other local data available which could be beneficial to model evaluation. Commenters also raised concerns about the model forcing data and pointed out the model can only be accurate with accurate data inputs. Given the gravity of the economic impact of regulatory changes informed in part by the modeling results, the commenters suggested a rigorous, data-driven assessment of WWTP effluent mixing to validate the model and ensure it accurately depicts the dilution and public health risk in a real-world setting.

Commenters requested more information than was provided in the modeling summary reports from the New Bedford/Fairhaven and Scituate WWTPs and specifically questioned certain aspects. Commenters suggested that their experience of prevailing water currents in Buzzards Bay differed from those suggested by the spatial structure of the dilution contours presented. From both the reporting materials provided and Dr. Chen's response to reviews, the commenters felt that it was still unclear whether certain structures or barriers that restrict flow were considered and incorporated into the model grid (i.e. West Island and Brandt Island causeways). Commenters suggested that using wind data from Massachusetts Bay as a proxy for Buzzards Bay brings uncertainty in the interpretation of model results as it was demonstrated that wind in these areas can be different. Finally, commenters raised concerns that the interpretation of modeling results in Buzzards Bay as suggesting that summer stratification drives spreading of effluent at the surface seems to disagree with other studies of the region. Commenters suggested that field data and more detailed model validation may help rectify these discrepancies.

Commenters also raised concerns that the hydrodynamic model does not consider the decay of microbial or other contaminants in the marine environment. Given the use of the model results to inform regulatory public health requirements, commenters felt that decay rates should be incorporated into the decision-making process. One justification provided by MA DMF for the lack of contaminant decay rates was that non-biological, unidentified contaminants may behave more like a passive tracer. Commenters questioned whether this was appropriate and if unidentified contaminants could be used to define these dilution zones and regulatory changes to harvest of shellfish. Commenters pointed out the WWTP dilution standards are FDA guidance that has some flexibility to incorporate empirical data on public health risks that allows for more localized, fine-tuning of closure areas and advocated for pursuing data use to help justify smaller dilution zones.

Finally, commenters suggested there were challenges with communication amongst parties in the process of implementing the hydrodynamic modeling and how these results, along with other data, have been used in informing regulatory changes in growing area status. There was a general request from commenters for further transparency in the decision-making process as to both data being used and hydrodynamic model application before regulatory decisions are made on areas important for harvest of shellfish. Participation in an advisory or work group with MA DMF and/or the FDA on this subject was seen as an appropriate step. Commenters advocated for more effort and funding to be put towards refinement of the modeling results before regulatory use.

Recommendations

Based on the outcomes of this peer review, WHOI Sea Grant notes that the modeling approach is highly sophisticated and likely to achieve the outcomes of documenting the dilution, dispersion, and mixing of wastewater effluent into receiving waters. However, reviewers identified key points that are critical to consider before implementing these results into regulatory decision making. As such WHOI Sea Grant proposes the following recommendations to the Commonwealth of Massachusetts:

1) Expand the validation of the hydrodynamics of the Mass-Coastal FVCOM and wind forcing data from WRF to include detailed information in and around the study domain.

We recommend expansion of the comparison of historical modeled conditions from the Mass-Coastal FVCOM and the atmospheric forcing model (WRF) to more observational data as a way to build confidence in this use of the FVCOM modeling framework for regulatory decision making. The WRF model-data intercomparison (provided for 2017 from Dr. Chen's response to reviewer comments) should be expanded to the targeted study areas and the years of WWTP dilution model, at a minimum. In addition to the existing comparison of FVCOM hydrodynamic model output to regional tide gauges, we recommend expanding the analysis to assess comparisons to, at minimum, historical temperature and salinity. The Massachusetts coastal zone is remarkably well studied historically through a number of existing long-term monitoring programs that have collected hydrographic data in both coastal and nearshore open waters. For example, the Buzzards Bay Coalition, a nonprofit organization, has maintained a water quality monitoring program at more than 200 locations throughout Buzzards Bay, including in and around New Bedford Harbor. Their data, spanning 1992 - 2018, have been made publicly available via Jakuba et al. (2021) (Figure 2), with data collected as recently as summer 2023 available on their program website (www.savebuzzardsbay.org). The Center for Coastal Studies, another nonprofit organization in the region, has also collected extensive hydrographic data in the study region, which may be useful for historical validation (https://www.capecodbay-monitor.org/). WHOI Sea Grant also maintains a network of sensors in the Cape Cod Bay, Buzzards Bay, and Duxbury Bay regions (Figure 2) that have collected high frequency (~15 minutes) water quality data, including relevant parameters temperature and salinity, extending back to 2004. Both archived and real-time data are freely available (https://seagrant.whoi.edu/regional-topics/water-quality/water-quality-monitoring-program/).

Relevant embayments have also been extensively studied through the Massachusetts Estuaries Project, with assessments completed through labs at U. Mass-Dartmouth that may also provide data for comparison. Other nonprofit or community organizations have also monitored water quality conditions in a number of relevant embayments, e.g. the North and South Rivers Watershed Association Water Quality Monitoring Program, who has indicated they are willing to share their data for such an effort.

In addition to historical temperature and salinity data, observations of current speed and direction can also inform the accuracy of the model's horizontal and vertical water velocity predictions. A monitoring station maintained by the NOAA National Ocean Service regularly measures ocean currents for the purposes of navigation and safety at the Cape Cod Canal (station CA0101, https://tidesandcurrents.noaa.gov/cdata/StationInfo?id=ca0101). Other regional datasets exist that may be useful for comparison to ocean currents, such as High Frequency Radar (HF Radar, e.g.

https://cordc.ucsd.edu/projects/hfrnet/), which provides information on surface currents. Although data do not extend into the regions very close to the WWTP outfalls, they may still have some relevance in comparing the model output across the broader domain.

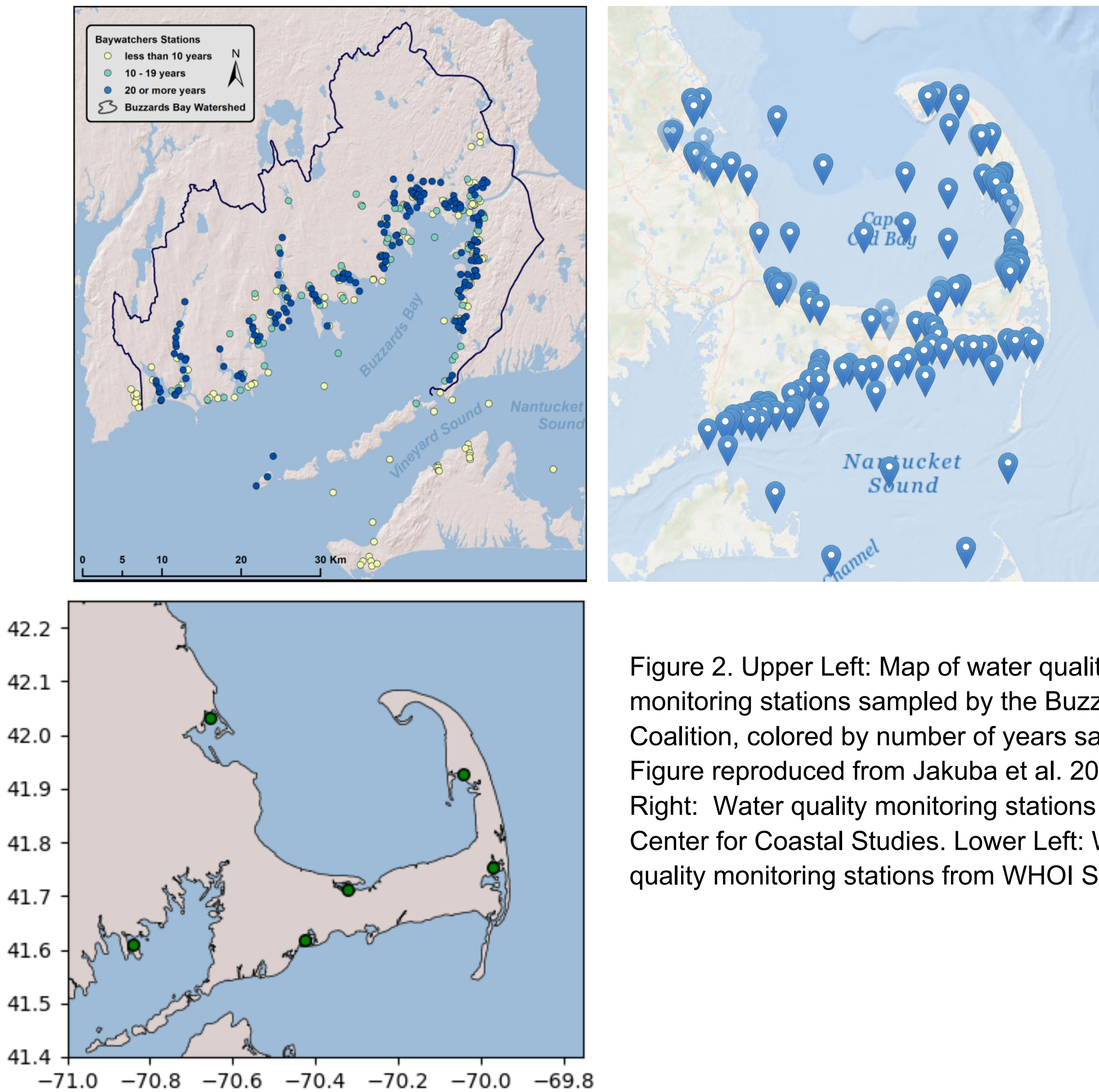

Figure 2. Upper Left: Map of water quality monitoring stations sampled by the Buzzards Bay Coalition, colored by number of years sampled. Figure reproduced from Jakuba et al. 2021. Upper Right: Water quality monitoring stations from the Center for Coastal Studies. Lower Left: Water quality monitoring stations from WHOI Sea Grant.

2) Test and validate the passive tracer modeling via a dye study, such as using the fluorescent dye tracer Rhodamine WT.

We recommend a detailed evaluation of the mixing and dispersion of wastewater in the immediate vicinity of the outfall pipes, as well as a thorough assessment of the passive tracer model in comparison to field observations. This could be completed via a number of possible approaches, with the most extensive being a field campaign that collects detailed, high resolution observations of tracers associated with wastewater discharge, such as temperature and salinity, and flow fields immediately surrounding the discharge locations. Fluorescent dye, such as Rhodamine WT, is commonly used to assess the dilution and dispersion of a passive tracer, and has been used in many applications to determine the transport and mixing of wastewater from point sources. Complementing field measurements of flow fields and hydrographic data with an injection of a fluorescent dye from WWTP infrastructure allows for tracking via sensors that are sensitive to the passive tracer down to very low concentrations.

In the absence of resources for an additional field campaign, FVCOM modeling for the Fairhaven facility discharging into New Bedford harbor could be compared to a previous dye tracer study that was completed in 2001 by Applied Science Associates, Inc (https://buzzardsbay.org/download/asa-flushing-report-jan03.pdf). This study was designed to assess the flushing of wastewater within New Bedford Harbor, and extensive field data was collected along with several Rhodamine WT releases from the Fairhaven WWTP which were monitored for numerous days post discharge. This report included both field campaigns and short- and long-term modeling to document the likely spread and contribution of wastewater to waters of New Bedford Harbor.

3) Expand on the assessment of uncertainty in results by modeling WWTP discharge in additional years.

Several reviewers noted that the existing materials used to inform regulatory decisions did not account for or document spatio-temporal uncertainty in modeled results, nor were the presented results bound by a confidence interval. We recommend that this gap be addressed through several mechanisms, each of which may require additional investment of resources. At minimum, we suggest that, using the existing passive tracer output presented in the reporting materials, the seasonal variability in dilution contours should be assessed via a quantification of the spatial variance over the timeframes analyzed. Second, if model runs already exist, hindcasts of multiple years of Mass-Coastal FVCOM should be evaluated to determine whether 2021, the year modeled for WWTP discharge tracking, is representative of typical conditions in the region. This approach would not implement additional tracer tracking work, but would focus on a deeper understanding as to whether the oceanographic conditions, and thus the tracer dilution and dispersion, modeled in the year 2021 are consistent and may be applicable to other years. Finally, the passive tracer modeling work could be expanded to include multiple years of study, and the interannual variability in dilution contours could be assessed.

4) Expand on the description and documentation of the modeling methodology used.

We recommend that the modeling team more fully document the methods and missing information described in the “Review Summary - Clarity in Methodology” section detailed above. The modeling team should clearly define the model grid and ensure that all structures that restrict water flow are accurately depicted. There is also some confusion about how and what data were used for atmospheric forcing and interpretation of modeling results and we recommend the modeling team expand on the description of these data.

5) Complete an evaluation of sensitivity of dilution zones to tracer degradation rates

As described in the “Review Summary - Consideration of non-passive behavior of wastewater contaminants” section, contaminants in wastewater may not behave as a passive tracer, but may degrade over time due to exposure to natural environmental conditions. We recognize that there are many potential contaminants in wastewater effluent, and implementation of individual tracer degradation rates may not be feasible. The assumption of no tracer degradation also represents the most conservative approach with respect to public health and safety. That being said, as suggested by peer reviewers, we recommend an assessment of the sensitivity of the dilution contours with and without passive tracer degradation rates be undertaken. This analysis would explore how the dilution contours may vary with differing degradation rates, and provide some insight into how sensitive the tracer model is to this process.

6) Massachusetts Division of Marine Fisheries should clearly define the parameters used for regulatory decision-making

Amongst interested and affected parties, there is a mixed understanding of how these modeling results were used to inform regulatory decision-making. There is also still confusion about model usage for closures related to Combined Sewer Overflow discharges. MA DMF should clarify model usage and clearly document the parameters considered as part of redefining shellfish growing area designations, including what dilution contours from the hydrodynamic modeling were considered and ultimately adopted and what field data were evaluated, particularly if lower dilution rates were used.

7) Create an advisory board to provide input and feedback on modeling results and implementation of results by the Massachusetts Division of Marine Fisheries.

Finally, we recommend that MA DMF consider the development of an advisory board with members that include representatives of key communities that participate in and are affected by decisions on how to implement results of assessments of point sources of dilution. Members might include scientists – both with expertise in modeling and oceanography as well as expertise in public health, pathogens, and shellfish biology, representatives of shellfish aquaculture and wild-harvest industries, and state and federal managers and policymakers. Such a board would ensure transparency in decision making and trust in how model or field study results are interpreted and applied via associated policy changes.

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Appendix A - Dr. Changsheng Chen, UMass Dartmouth, response to scientific peer reviews of modeling reports

Response to scientific peer reviews of two modeling reports:

1) Modeling Assessment of Spreading of the Scituate Waste Water Treatment Plant in the North-South Rivers, Massachusetts

2) Estimation of the Sewage Water Dilution from Wastewater Treatment Plants in New Bedford and Fairhaven, Massachusetts

Reviewers were also provided additional related resources from the Chen lab.

Provided by: Dr. Changsheng Chen, UMass Dartmouth

Responses to Review#1

Comment 1*: How have the authors proposed uncertainty be represented in the analysis product? For example, the model was only run for one year and the maps provided average over significant lengths of time for such a widely varying system. The issue surrounding temporal uncertainty- how representative 2021 is, and if the current simulation should be considered that -is important to consider when using these results to decide regualtion. Could the standard deviation over each seasonally averaged period be showcased as a map? Can the authors do the same with salinity from the same embayment and compare that to a longer run they have already? This would at least speak to the interannual variation expected in this region over time. This point is critical for the evaluation of event-based discharges as was asked of us in the review process. The products are currently insufficient as provided to evaluate events as they are largely time-averaged currently.*

Responses: The modeling of the wastewater treatment plant (WWTP) was performed by tracking the concentration of dye released from the outfall. This effort focused initially on the North River, where scenarios were considered using both seasonally averaged and maximum forcing conditions. The dilution maps generated account for both normal and extreme conditions. The dispersion of the outfall tracer is primarily governed by flow advection and mixing. The uncertainty in these processes includes both physical and numerical errors. Physical errors stem from the accuracy of meteorological forcing, while numerical errors are associated with model resolution and the parameterization of mixing and bathymetry.

The meteorological data employed to drive the model were derived from the regional NECOFS reanalysis product, which has assimilated all available observed data to minimize model uncertainty. We conducted extensive tests to evaluate the convergence of the tracer model through comparisons with dye releases and experiments demonstrating the sensitivity of the spatiotemporal variability of the diluted tracer to model resolution. At the regional scale, such as Georges Bank, convergence can be achieved with model resolutions approaching 100 meters (as detailed in our provided paper). In our research on predicting the initial spread of radionuclides from the Fukushima Dai-ichi Nuclear Power Plant, we determined that a model resolution of approximately 5 meters is necessary to accurately resolve the infrastructure of the plant and align with observations. Our WWTP model has been employed by FVCOM users in other states (as referenced), where it was shown that configurations around 100 meters can effectively reproduce the dilution of WWTP effluent.

The bathymetric data used in our WWTP configuration were obtained from high-resolution 1-meter Lidar data and the 5-meter resolution CUDEM (Continuously Updated Digital Elevation Model) dataset, both of which have been thoroughly validated.

We acknowledge that we are not the first to utilize FVCOM to evaluate the impacts of WWTP effluent on New Bedford and Fairhaven. An initial assessment, supported by MIT/WHOI Sea Grant, investigated the influence of wastewater effluent on coastal ocean acidification in Buzzard Bay, led by PIs Scott Doney, Jennie Rheuban, Jim Churchill, and Geoff Cowles. This study involved measurements of dissolved inorganic carbon and total alkalinity, along with nutrients such as NO3- + NO2, NH4+, PO4-3, SiO4-, TN, PON, and POC. The early version of FVCOM used in that study operated at a horizontal resolution of approximately 100 meters, and even with this relatively coarse resolution, the model successfully reproduced the spatial and temporal variability of wastewater influences in alignment with observed data.

For the 2021 simulation, the FVCOM was configured with a horizontal resolution of up to 4 meters based on convergence tests of tracer simulations. Unlike previous models, this update integrates high-resolution satellite sea surface temperature data to enhance predictions of water stratification and is informed by reanalysis meteorological forcing as well as validated boundary conditions from NECOFS. These improvements have significantly reduced the uncertainties within the model. Notably, flow in Buzzard Bay is predominantly affected by tidal currents, and the simulated tides have undergone extensive validation against observational data.

We concur with the reviewer on the necessity of incorporating an assessment of uncertainty within the simulation. This can be accomplished without technical challenges, but it does require personnel support. We can categorize the primary sources of model uncertainty and integrate them into the simulation process. While we don't believe this would result in significant changes to the outcomes, it is valuable to provide stakeholders with explicit ranges of uncertainty.

Regarding interannual variability, we think that the model should be operated in forecast or nowcast mode to adequately track the dilution of wastewater from WWTPs, given the significant spatiotemporal variability observed. In the North River case, we focused on presenting seasonal means and extreme weather scenarios to assess averaged and worst-case conditions, which inadvertently filtered out the short-term (hourly to daily) temporal and spatial variability of the wastewater influent. For outfalls in New Bedford and Fairhaven, we conducted real simulations utilizing discharge records, enabling us to capture both short-term and monthly or seasonal variability. While we did calculate the standard deviation, it was not included in the report. However, we have provided the Division of Marine Fisheries (DMF) with the hourly simulation results to facilitate straightforward access.

We want to clarify that the dilution simulation results serve as an alternative reference for DMF, but the final decision, to our understanding, is based on integrating this data with additional analyses conducted by DMF.

Comment 2: There are several other forms of uncertainty – performance based in the hydrodynamic simulation (which the authors have tried to address by providing substantial model evaluation). This one is the most constrained – but process-based uncertainty remains. Here, the vertical mixing described in the results of the simulation whereby bottom waters were readily *mixed and dispersed at the surface seems like a process that while simulated should also be evaluated somehow. Maybe salinity observations could help? Model based mixing errors are a notorious issue for modelers everywhere and this pathway seems critical to this issue.*

Another process-based uncertainty emerges with the design of the inert tracer. It seems likely that the tracer was allowed to behave passively, when in reality the wastewater would degrade or be naturally broken down as it is exposed to light (Dizer et al. 1993, others) as well as it exists in the natural environment. This timescale was not included in the considerations for the residence times or dilution metrics provided.

In addition, only two WWTP discharge outfalls were considered providing additional uncertainty as to how the region would be impacted by more outfalls. A simulation with 26 locations assuming the discharge is like that of the ones they have data from could be useful in the interim to just understand where and when the outfall has the largest impact.

Finally, the analysis currently largely lack of consideration for the habitat or organism at the center of concern and management. While the authors provide some output on the bottom, which seems like the natural location for them to reside, there is not much attention made to the organism's phenology and or their potential ability to clear the material from its system?

Responses: We completely agree that validating mixing versus stratification with observations is essential. By assimilating high-resolution satellite-derived sea surface temperature (SST) data into the model, we observed improvements in vertical stratification at a regional scale. We acknowledge that the contribution of salinity to stratification requires justification with observational data. In our simulation, we included freshwater discharges and found that the dispersion of wastewater influent is primarily driven by tidal and wind-induced flows, which are orders of magnitude stronger horizontally than vertically. Although stratification can affect the vertical dispersion of the tracer, its influence is of secondary importance. We believe that both temperature and salinity measurements around the outfalls can assist in further model validation.

Regarding the conservative tracer simulations, we did not account for the degradation of wastewater concentration due to light exposure. To address this, it would be necessary to incorporate a water quality model that considers both biological and chemical processes. We have developed the Northeast Coastal Ocean Acidification Model (NeBEM), which was initially validated in Massachusetts Bay, incorporating the Boston Harbor outfall. In comparisons with UG-RCA, a water quality model used to assess the impact of the MWRA outfall in Boston Harbor, we found that NeBEM yielded more promising results. We could utilize NeBEM to address the reviewers' comments if additional funding is available to support the necessary personnel.

While the New Bedford and Fairhaven outfalls are two significant WWTP influents, there are 26 wastewater outfall sites along the coast. Unfortunately, we lacked comprehensive discharge data from these 26 outfalls at the time of the simulation. The data we received indicated that discharges from these outfalls mainly occur during wet weather events with significant rainfall. Despite considering only two major outfalls, our model predicts a significant influence of WWTP influents on local marine environmental conditions. The situation could become even more severe temporarily if all 26 outfalls were added. Technically, it would not pose a problem to include these additional outfalls in the model simulation, provided the relevant data is available.

As mentioned in our response to the major comment above, the dilution simulation results serve as a reference point for DMF (Division of Marine Fisheries), but we understand that the final decision will be based on integrating this model data with additional analyses conducted by DMF, which consider the habitat and organisms involved. If we wish to enhance the model's role in assessing the impact of WWTP influents, we should incorporate water quality modeling, like what we did for the MWRA outfall in Boston Harbor. However, this integration requires personnel support.

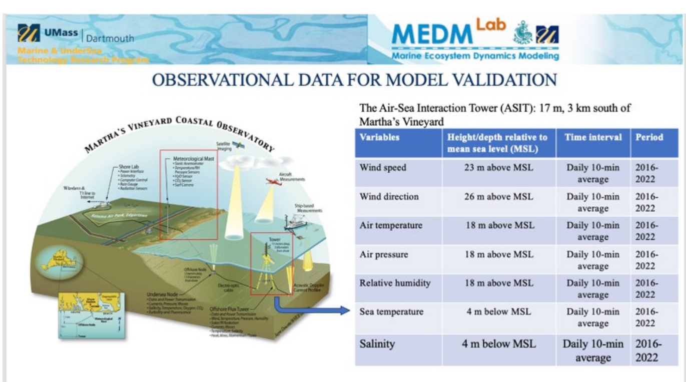
General Questions for the report for further consideration:

QS. 1: Spinup time 1-2 weeks is short. Do the authors begin that simulation from rest or from a semi-spun up state based on the forecast model at coarser resolution?

Answer: The model was initialized using our 39-year hindcast simulation results from NECOFS, which encompasses Buzzard Bay with a horizontal resolution of approximately 100 meters. Thus, it is not spun up from a rest state. The primary justification for the spin-up period lies in the water exchanges between the bay and wetlands, which allows for the system to reach an equilibrium state over a few days (approximately 5-6 semi-diurnal tidal cycles). Therefore, the 1-2 weeks of spin-up time is adequate given the hindcast-generated initial and boundary conditions.

QS. 2: What is the resolution of the atmospheric forcing from WRF and does it sufficiently cover the nooks and crannies of the complicated coastline simulated?

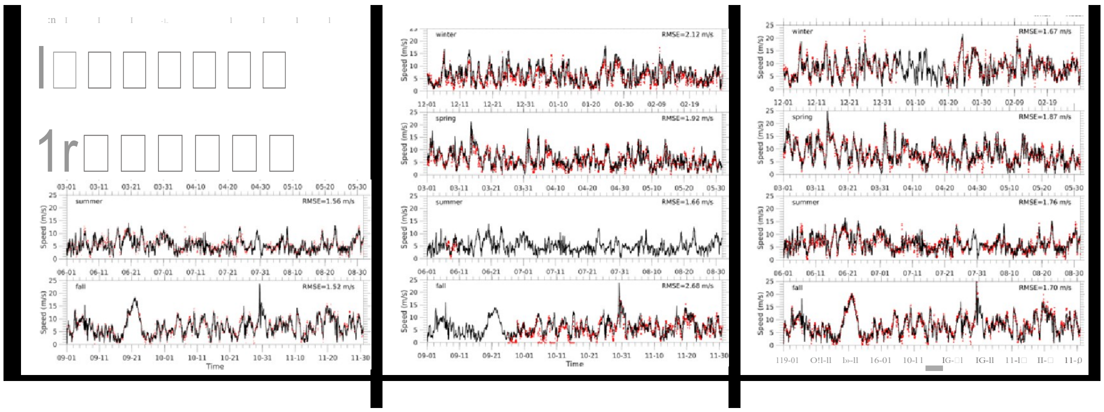
Answer: The atmospheric forcing from WRF operates at a resolution of 3 km. We have compared the WRF-predicted wind with observed data along the coast in previous years. The WRF model employed in these comparisons is the same one used for the WWTP project, though we increased the resolution to 1 km in the offshore wind farm development region. The simulated wind at the observational sites is approximately 3 km, and the results are very promising. We have included some slides from our conference presentations to illustrate the model's performance.



UMass Dartmouth
Technology Research Program
MEDM Lab
Marine Ecosystem Dynamics Modeling

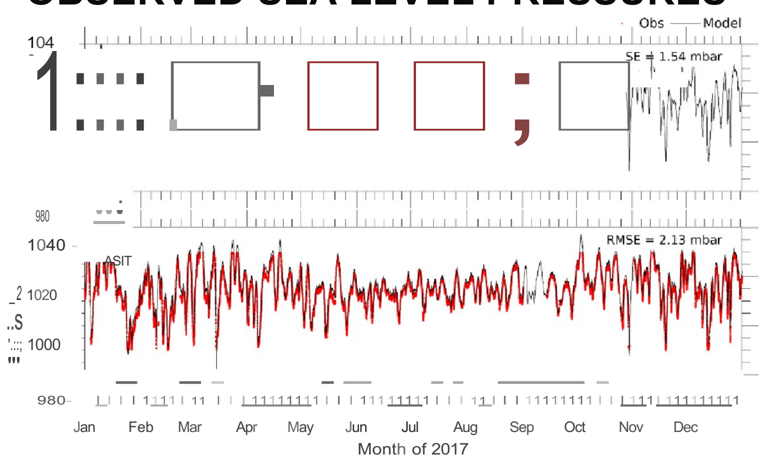
WIND SPEED COMPARISONS AT18-23 M ABOVE MEAN SEA LEVEL (MSL)

MVCO_ASIT MVCO_MET WHOI_MET



UMass Dartmouth
Technology Research Program
MEDM Lab
Marine Ecosystem Dynamics Modeling

COMPARISONS BETWEEN MODEL-SIMULATED AND OBSERVED SEA LEVEL PRESSURES

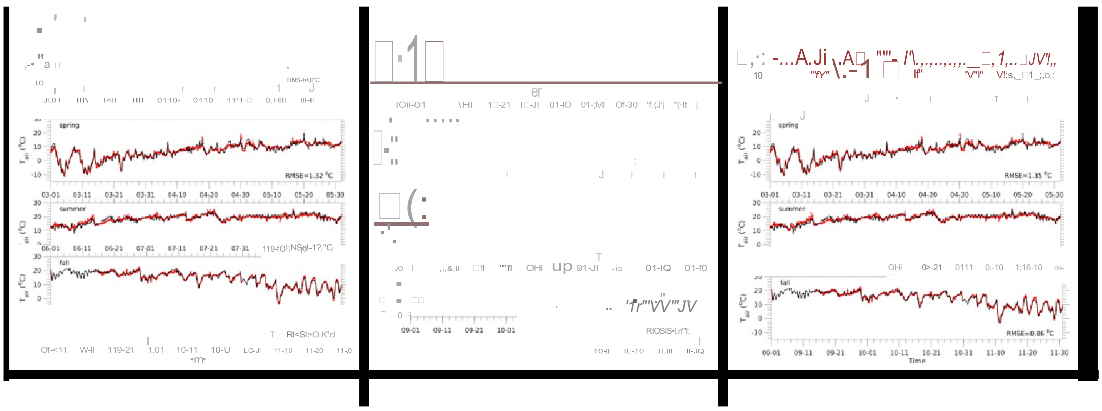


UMass Dartmouth

MEDM Lab Marine Ecosystem Dynamics Modeling

AIR TEMPERATURE COMPARISONS AT 18 M ABOVE MSL

MVCO_ASIT | MVCO_MET | WHOI_MET



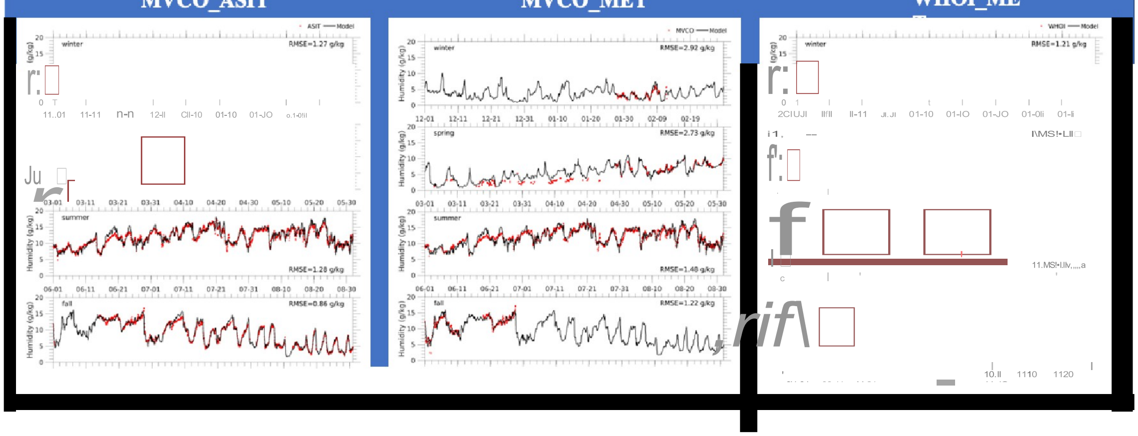
UMass Dartmouth

Technology Research Program

MEDM Lab Marine Ecosystem Dynamics Modeling

AIR HUMIDITY COMPARISONS AT 18 M ABOVE MSL

MVCO_ASIT | MVCO_MET | WHOI_ME



QS. 3: Where did they get the WWTP data to force the rivers and are other variables available like temperature and salinity? Were those properties included for the WWTP discharge in the simulation?

Answer: It appears there may be some misunderstanding regarding our methodology. We did not utilize WWTP data to directly force the river discharges. Instead, we implemented the WWTP discharge through the FVCOM river discharge numerical module. All river discharges incorporated into the model included temperature and salinity data, which differ significantly from the passive tracer used for the WWTP discharge.

The temperature for river discharges is derived from a hydrological model known as the "Water Balance Model" (WBM). The simulated temperatures from WBM have been validated against observed river temperature measurements. Salinity, on the other hand, is set to zero, as the input sources are located far inland from the coast.

QS. 4: Why are monthly average maps the appropriate product to use to address this issue?

Answer: We have provided the Division of Marine Fisheries (DMF) with hourly model output data, including animations that illustrate the temporal and spatial variability of the WWTP-diluted waters. However, DMF expressed a preference for monthly averaged dilution maps. They require these averages as an alternative reference to determine which months should be designated for closures or openings.

While the monthly average maps offer a simplified overview, the temporal and spatial variability of diluted waters is still considered in DMF's analysis. It's important to note that this report serves as a summary of the modeling activities. We also hold regular meetings with scientists and managers at DMF to discuss the model results in detail.

We just want to clarify again that the dilution simulation results serve as an alternative reference for DMF, but the final decision, to our understanding, is based on integrating this data with additional analyses conducted by DMF

QS. 5: What do the authors consider for year-to-year variation in the dilution value simulated?

Answer: Yes, we do take interannual variability into account, primarily based on the seasonal variability of winds, even though we conducted a single-year simulation for the outfalls in New Bedford and Fairhaven. For the outfall in the North River, we analyzed seasonal averages and extreme weather conditions over a 40-year period from 1978 to 2017.

In our findings for the outfalls in New Bedford and Fairhaven, we observed that the distribution of WWTP-diluted water varied significantly with changing wind patterns, in addition to tidal influences. This underscores the importance of conducting a real-time simulation over a year. We propose to continue running simulations in successive years to better examine interannual variability; however, this effort is constrained by funding limitations.

QS. 6: The simulation was only for one year – how was 2021 chosen and why is it representative?

Answer: That's a good question. The modeling was conducted under a contract with DMF, and the selection of the year 2021 was made through a review process led by DMF.

2021 was chosen because it experienced a range of representative weather conditions, including Nor'easter storms (e.g., the Nor'easter on January 4), hurricanes (e.g., Hurricane Henri on August 22), and heatwaves. Additionally, DMF has comprehensive WWTP discharge records for both New Bedford and Fairhaven outfalls, which indicate significant variability in discharge rates, ranging from 15 MGD to 60 MGD at the New Bedford outfall. This variability is particularly pronounced during the summer months when water stratification occurs.

QS. 7: *Are all the WWTP sites that exist in the region considered? Or are some not included in the simulation*?

Answer: See our responses to Comment 2.

QS. 8: *Could Figure 5 be compared to the WRF model used? How well does it perform*?

Answer: See our answer to QS. 2.

QS. 9: How was dilution determined in the simulations? What definition of residence time was considered?

Answer: Dilution in the simulations was determined by analyzing the concentration of WWTP water over the simulation period. This can be represented as a snapshot or through hourly, daily, monthly, or seasonal averaging of the concentration.

Since the WWTP water is injected continuously throughout the year, based on the discharge records, rather than a single point injection at a time, the residence time is calculated based on the total influent of the WWTP water in the system at any given moment. This approach allows for a more accurate representation of how the WWTP discharge interacts with bay water over time.

QS. 10: How are the modelers conveying uncertainty in their estimates? There are several estimate of various kinds of uncertainty provided – performance estimates as well as variance of the target variable over a year. Can the modelers combine these somehow or translate these into a confidence interval somehow? There are some examples of this in Kessouri et al (year?).

Answer: See our responses to Comment 2.

QS. 11: Doesn't fecal coliform bacteria degrade with UV? Did the modelers consider adding this kind of decay to their tracer design? A sensitivity to this kind of forcing – an example can be found in these works (Kragh et al. 2022; Delre et al 2023) could be implemented in the longer run and help contribute to the process based evaluation or the uncertainty/confidence interval discussion.

Answer: See our responses to Comment 2.

QS. 12: Could the modeling team add the WWTP sites that served as sources for the dye experiments to Figures 6-9?

Answer: Yes, we can add those WWTP sites to Figures 6-9. We have re-conducted the experiments with improved forcing conditions and refined coastal geometry in the Fairhaven bridge area and along the coast. Additionally, we have included the WWTP discharge from the Dartmouth outfall in our analysis. These updates will be reflected in the revised report.

QS. 13: Even if dye was not released from all the WWTP, was the freshwater delivery considered from all the FW sources depicted in the earlier figure?

Answer: In our simulation, the WWTP discharge was treated as dye rather than as freshwater. While we accounted for the contribution of WWTP discharges, our focus was specifically on their role as sources of dye. Freshwater discharges from rivers can alter water density and subsequently affect water currents; however, the WWTP discharge was regarded solely as dye for the purposes of this study.

QS. 14: What about human engineered barriers that have been inserted into the system -like the storm/flood walls around the harbor etc? are these physical features included in the simulation's high resolution LIDAR based bathymetric forcing? Are they an issue for the WWTP dispersal?

Answer: Yes, the model incorporates human-engineered barriers, including storm and flood walls around the harbor. The model grid covers both land and ocean areas using dry and wet treatment to accurately simulate storm-induced coastal inundation. Additionally, the grid is configured based on high-resolution LIDAR bathymetry data at a 1x1 meter resolution, allowing for precise representation of these physical features and their potential effects on WWTP dispersal.

Recommendations –

1. *Consider expanding the simulation beyond one year and expanding the uncertainty estimates into a confidence interval that includes several aspects of modeled uncertainty surrounding the dilution metric. This could be achieved either through expanding the current run, or by looking in the current run at the extent of a particular isohaline associated with the dilution metric and then using that isohaline in longer simulations to explore uncertainty, its not clear what simulations this study has access to be this group has a lot of experience and model fields already to draw from.*

Response: That is exactly what we propose to do. However, this will require sufficient personnel support.

2. *Consider augmenting the evaluation with some other evaluation of the WWTP outfall – like salinity or temperature observations from the discharge to instill confidence in the simulated fine scale mixing implicated in the distribution of the pollutants by the modeling team in their explanation in the report.*

Response: Temperature and salinity measurements could provide valuable information for evaluating the hydrodynamic model, particularly regarding the accuracy of water stratification. This can be accomplished with support to conduct hydrographic surveys.

3. *Work to further define this threshold with the biology in mind. For example, the WWTP discharge is highest in the autumn in New Bedford but the model suggests that the dilution thresholds experience seasonality and are most severe in winter through spring in 2021. If you were to bring in the biology of the oysters and other shellfish – what months are they harvested, when are they growing the fastest and eating the most? How long does the bacteria from the WWTP remain a threat to humans within the shellfish after they ingest it? Could the farms remain open but harvest delayed in certain months?*

Response: his can be addressed by incorporating a water quality model simulation alongside the current dye-dilution-based WWTP model, which also requires sufficient personnel support.

4. *In line with this last question above – the model estimates are largely provided at the surface with some attention paid to the bottom conditions, but where are the farms mostly? Are the organisms growing at the surface in the intertidal or are they mostly at the bottom and what depths typically do they reside? Can the dilution estimates be expanded in the subsurface to better align with their habitat? Is bottom appropriate or do the farms allow the cages to reside higher up in the water column?*

Response: The WWTP model estimations involved dye being injected throughout the water column rather than solely at the surface. The model output includes a comprehensive 3-D spatiotemporal distribution of the diluted water. The figures in the report are illustrative examples depicting distribution at the sea surface. We can analyze conditions at any depth in the water column. Based on our findings, the largest spread of the WWTP-diluted water occurred at the sea surface.

5. *The forecast recommendation from the author team at the end seems useful to help build out some of the products described above in the future. If this was to proceed, then convening regular meetings with managers and the forecasters to co-produce and co-design the products expected and build trust in the model simulation seem warranted.*

Response: If the forecast system is established, it is essential to hold regular meetings with managers to ensure that the products meet management requirements.

Responses to Review#2

Comment 1: *However, since the dilution model results will inform shellfish growing area classification and support potential decision-making processes, it is crucial to ensure that the simulated dilution maps are accurate and able to quantify the uncertainties. For example, is it possible to evaluate the model simulated 1:1,000 contour with observations, such as Rhodamine dye injections as described in True (2008), the reference provided by Dr. Chen, and quantify the uncertainty in the spatial location of the 1:1,000 contour?*

Response: We believe that dye tracers are the most effective tool for validating the spatiotemporal distribution of wastewater treatment plant (WWTP) diluted water. While previous dye experiments were conducted at the Plymouth outfall, none have taken place at the New Bedford and Fairhaven outfalls.

As an alternative, we propose first applying our model to the Plymouth outfall, using data from the past dye experiments for validation. Given the significant variability in the local marine environment, it is essential that the validation experiment occurs during the same period as the dye release. Unfortunately, since our priority has been to address concerns related to the outfalls in the North River, Scituate, and New Bedford/Fairhaven, we have not received funding to conduct such a model validation experiment.

It should be noted that our model was configured based on insights from our past dye experiments. We have conducted extensive tests to evaluate the convergence of the tracer model through comparisons with dye releases, demonstrating the sensitivity of the spatiotemporal variability of the diluted tracer to model resolution. At a regional scale, such as Georges Bank, convergence can be achieved with model resolutions approaching 100 meters, as detailed in our provided paper. In our research on predicting the initial spread of radionuclides from the Fukushima Dai-ichi Nuclear Power Plant, we found that a model resolution of approximately 5 meters is necessary to accurately capture the plant's infrastructure and align with observational data.

The WWTP model has also been utilized by FVCOM users in other states, where configurations around 100 meters have effectively reproduced WWTP effluent dilution. For the Massachusetts coast, the 3-4 meters' resolution we employed in the WWTP model is sufficient to achieve convergence of the dye tracer from the outfall.

We hope to secure funding to conduct a dye experiment for the New Bedford and Fairhaven outfalls, or at least at one of these two locations. Such an experiment would provide us with a valuable dataset for solid model validation.

QS. 1: Tracer-tracking model:

Could Dr. Chen and his team provide more information on how they implemented the tracer-tracking model? For example, what is the concentration of the passive tracer, and does it vary with *the discharge rates of the WWTP? How was the 1:1000 contour defined, considering it appears inconsistent with the 0.1% dye concentration in their plots in Document 02?*

Answer: The wastewater from the WWTP is injected at the outfall using the discharge volume rate, with an assumed concentration of the passive tracer fixed at a unit value of 1.0. While the discharge volume can vary, the concentration of the passive tracer remains constant at this unit level when it is injected.

The 1:1000 contour is defined as a line representing a concentration of 1/1000 of the initial tracer concentration. The simulation aims to address the question: If the WWTP injects wastewater with a fixed unit concentration, how does this concentration change relative to its initial value of 1.0 as it disperses? To determine the actual concentration in the water column at the outfall, one can multiply the known chemical concentration of the WWTP discharge water by the model-simulated concentration.

Regarding the 0.1% dye concentration, it represents a dilution of 1/100, rather than 1/1000. If Document 02 is indeed a report, it may contain a typographical error.

QS.2: Surface versus bottom dye concentrations:

The surface concentration around the WWTP outfall is much higher than at the bottom, where the WWTP pipe is located. While Dr. Chen and his team have provided explanations such as the energetic vertical mixing and the interaction of the laminar flow from the WWTP pipe and oceanic currents, I wondered if the WWTP pipe generated laminar flow has been reproduced in the model. Additionally, are there observation data to validate the much higher surface concentration than the bottom source region?

Answer: Thank you for your insightful question. In our model experiment, the WWTP wastewater was injected as a point source at the bottom, and we did not simulate a physical pipe structure. Consequently, the model does not explicitly resolve the laminar flow within the pipe. Instead, we treat the wastewater as a tracer that immediately interacts with the surrounding ocean water upon discharge.

Unfortunately, we were unable to locate observational data on WWTP wastewater concentrations specifically around the New Bedford and Fairhaven outfalls that could be used to validate our model results regarding the higher surface concentrations. However, in our previous assessments for the outfall in Boston Harbor conducted for the Massachusetts Water Resources Authority (MWRA), we did have nutrient data that provided a basis for validating the FVCOM-UG-RCA water quality model. The model demonstrated robustness in capturing observed nutrient concentrations in that setting.

The design used for the Boston Harbor outfall was applied to the New Bedford and Fairhaven outfalls, based on the assumption that the validated numerical approach is applicable to other outfalls as well.

We also hope to conduct surveys to measure WWTP concentrations and spreading around the New Bedford and Fairhaven outfalls in the future. This could be carried out effectively if funding is secured, and such data would provide a solid basis for validating our model.

QS. 3: WWTP contaminant decay rate:

Is it necessary to consider the decay rate of contaminants discharged from WWTP? To what extent does the decay of tracer affect the accuracy of the simulated contour lines at 1:1,000 and 1:100,000?

Answer: Yes, it is necessary to consider the decay rate of contaminants discharged from the WWTP when modeling their behavior in the environment. The decay of the tracer can significantly affect the accuracy of the simulated contour lines at both the 1:1,000 and 1:100,000 concentrations, particularly over time and distance. A higher decay rate would lead to a quicker reduction in concentration, thereby impacting the delineation of these contour lines.

We first want to clarify that the dilution simulation results serve as an alternative reference for the Division of Marine Fisheries (DMF). However, the final decision, to our understanding, is based on integrating this model data with additional chemical and biological data analyses conducted by DMF. We also assume that the decay rate of contaminants and other relevant factors have been considered in the final assessment by DMF.

To simulate the decay rate of contaminants in modeling, it is necessary to incorporate a water quality model that considers both biological and chemical processes. We have developed the Northeast Coastal Ocean Acidification Model (NeBEM), which was initially validated in Massachusetts Bay, incorporating the Boston Harbor outfall. In comparisons with UG-RCA, a water quality model used to assess the impact of the MWRA outfall in Boston Harbor, we found that NeBEM yielded more promising results. We could utilize NeBEM to address the reviewers' comments if additional funding is available to support the necessary personnel.

Suggestions for additional model validations:

(1) If observations of temperature, salinity, and velocity are available near the New Bedford and Fairhaven WWTPs or within New Bedford Sound (which receives effluent from the majority of the 26 WWTPs), it would be beneficial to evaluate how well the model simulates these variables, as well as stratifications and local circulations.

Response: We concur with the reviewer that these measurements could serve as a reference for validating the model at the local outfall scale.

(2) I would also recommend evaluating the simulated passive dye distribution. Conducting realistic dye release experiment could be one option, as demonstrated by Chen et al. (2008) in their study at Georges Bank and by True (2018) in a tidal estuary in Maine. Both studies used FVCOM model to simulate dye dispersion. A realistic dye release could be implemented within the model domain, considering the logistical or resource requirement, or directly from the New Bedford pipe (if

feasible). This would allow for testing whether the observed surface dye concentrations are higher than those at the source at the bottom, as suggested by the model simulations. Additionally, besides releasing realistic dye from the WWTP pipe, another approach to verify the high surface concentration would be to collect vertical water samples to measure concentrations associated with the dilution process originating from the WWTP pipe.

Response: This is a great suggestion, and we completely agree that it is a necessary step. Given the challenges in assessing the impact of model uncertainties on the WWTP-diluted water simulation, we believe that conducting dye tracer studies is the most effective approach for validating the spatiotemporal distribution of wastewater treatment plant (WWTP) diluted water. This was successfully done for the Plymouth outfall in the past and should also be done for the New Bedford and Fairhaven outfalls.

Comments on the usage of this model for decision-making

To establish shellfish classification areas

First of all, I believe this model could be a valuable tool to establish shellfish classification areas, given the already achieved good model performance and many applications of FVCOM in studying material transport process. However, before applying the model to establish shellfish classification areas, I would suggest (1) enhancing confidence in the model simulated hydrodynamics (temperature, salinity, stratification and circulation) in the regions that near the WWTPs; (2) evaluating the module simulated dilution map with realistic dye studies or other concentration measurements to assess the accuracy of the simulated passive tracer; (3) analyzing the spatial uncertainty associated with the model-generated concentration contours, such as those at a 1:1,000 scale, to understand the reliability of the predictions. By undertaking these additional evaluations, I think this model could be a useful and reliable tool to inform the establishment of shellfish classification areas.

Response: To address the first suggestion, we plan to conduct surveys to measure temperature, salinity, and circulation in the vicinity of the WWTPs. This can be accomplished through collaboration with Professor Micheline Labrie, Director of the Coastal System Program (CSP) at the School for Marine Science and Technology (SMAST), UMass Dartmouth. The CSP has a long-standing record of conducting field measurements for nitrogen removal in eutrophic estuaries in Massachusetts.

For the second and third suggestions, we can collaborate with Professor Miles Sundermeyer at SMAST/UMass Dartmouth, who specializes in dye experiments in marine environments. Comparing model outputs with empirical dye results is the most effective way to estimate spatial uncertainty. This will be feasible contingent on executing the dye experiment.

All these efforts require additional sufficient personnel support.

To predict the short-term impact of rainfall events and CSO discharges

Dr. Chen and his team have been operating NECOF for many years and have validated the atmospheric forcings from WRF. Therefore, I believe it is technically feasible for their group to incorporate the Mass Coastal-FVCOM model into their forecasting system to predict the short-term impact of rainfall events. My question is: how fast can the forecast run be completed, given the very short time step and fine grid cells used in the Mass Coastal-FVCOM model. This will also depend on the forecast duration and the available computational resources.

The flooding/drying capability, as detailed in Document 03, indicate that model can simulate areas that are periodically flooded by tide or occasionally inundated by extreme storm conditions. However, I lack experience with the FVCOM model and am unsure how FVCOM handles the CSO discharges and its overall model stability. In addition to measuring the discharge from CSO, it would be important to measure the concentration of contaminates to inform the concentration of the released passive dye, rather than assuming a concentration of 1 (as mentioned in Document 03). Furthermore, evaluating the model simulated hydrodynamics in regions where CSO discharges occur, comparing the simulated dilution maps against available observations, and identifying potential uncertainties associated with model configurations would be important.

Responses: The NECOFS forecast operation has indeed incorporated the Mass Coastal-FVCOM model with a resolution of approximately 10 meters. The WWTP model used for the Massachusetts coast is a modified version of the Mass Coastal-FVCOM model, with a refined local grid around individual WWTP outfalls of about 4 meters. It takes approximately 3-4 computational hours to complete a 5-day forecast using the Mass Coastal-FVCOM model. We anticipate that the 5-day forecast using the updated version with WWTP data could be completed in around 6 hours, which is about 1-2 hours longer than the current model.

As mentioned earlier, the dilution simulation results will serve as an alternative reference for the Division of Marine Fisheries (DMF). However, it is our understanding that the final decision will be based on a combination of our model data and additional chemical and biological analyses conducted by the DMF. We could implement a similar strategy to convert the WWTP simulation into a continuous 24/7 forecast operation, which would provide the DMF with real-time dilution maps reflecting the temporospatial variability of WWTP effluent. The DMF manager could then integrate the model data with their own information (e.g., concentrations of contaminants and their decay rates) to produce a real-time assessment of contaminant dispersion.

Responses to Review#3

We have carefully reviewed the comments and questions provided by the reviewer. Most of the inquiries are directly related to the two reports, and we find them to be constructive and valuable.

We have conducted dye-tracking modeling experiments for the New Bedford and Fairhaven outfalls for 2021, incorporating improved forcing conditions and refined coastal geometry, particularly in the Fairhaven Bridge area and along the coast. Additionally, we have included the WWTP discharge from the Dartmouth outfall in our analysis. We will ensure that the reviewer's detailed comments and suggestions are taken into account as we prepare the revised report.

In this response, we will address only the major comments.

Comments on "Estimation of the Sewage Water Dilution from Wastewater Treatment Plants in New Bedford and Fairhaven, Massachusetts"

***Comments**: The validation of the Mass Coastal FVCOM model results is limited, although the parent model, NECOFS, has been extensively validated. In Section 4, the model's tidal amplitude and phase were successfully validated against observations from 18 tidal gauges. However, the evaluation could be strengthened by incorporating validation of additional physical parameters, such as current speeds, water temperature, and salinity. Furthermore, the external validation section (file: USCG_Annual_Report_2024_model_validation_section.pdf) focuses exclusively on the NECOFS results from 2017. Conducting a comprehensive validation of the Mass Coastal FVCOM model results for 2021, with a broader range of features, would enhance the assessment of its performance and improve reliability.*

Response: We acknowledge the reviewer's observation regarding the limitations in validation. The challenge arises from the lack of comprehensive data around the WWTP outfalls in Massachusetts. We have provided a link to our work on water quality assessment in Boston Harbor/Mass Bay, conducted under contract by MWRA, which utilized the same physical model as that used for the New Bedford and Fairhaven outfalls. Each year, a detailed validation of water currents, temperature, salinity, and stratification was conducted in Mass Bay, accounting for the impacts of the outfall from Boston Harbor. Our comparisons with observational data demonstrate that the model effectively reproduces the spatiotemporal variability of key physical variables relevant to water quality.

In contrast to our current dye-tracking model, the work conducted for MWRA incorporated a water quality model named UG-RCA, which underwent validation through comparison with observations. The data for this comparison included temperature, salinity, dissolved oxygen, chlorophyll-a, nitrate, ammonium, phosphate, silicate, dissolved organic matter, and particulate organic matter. Data were sourced from the MWRA monitoring program, which comprised seven "near-field" stations near the MWRA outfall, 27 "far-field" stations in Mass Bay and Cape Cod Bay, and 19 "harbor" stations in Boston Harbor, with varying sampling frequencies. Water samples were collected at five standard depths at all near- and far-field stations, except for certain shallow far-field stations sampling only three depths. Nutrients, organic substances, and dissolved oxygen were analyzed based on protocols developed by Libby et al. (2003, 2004). Additionally, primary productivity was measured at stations close to the MWRA outfall. The data were either downloaded from http://www.wmra.state.ma.us/ harbor/enquad/trlist.html or provided directly by MWRA.

The validation experiments conducted in Boston Harbor/Mass Bay illustrate the capability of both physical and water quality models to reproduce the water quality conditions resulting from wastewater inputs at the outfall. We can conduct similar measurements around individual WWTP outfalls, such as those in Boston Harbor; however, this requires sufficient personnel support to conduct such measurements. The WWTP dye-tracking model experiment is currently constrained by limited funding, which restricts our capacity to conduct parallel assessments.

It is also important to note that our model configuration is informed by insights gained from our previous dye experiments. We have conducted extensive tests to evaluate the convergence of the tracer model through comparisons with dye releases, highlighting the sensitivity of spatiotemporal variability of the diluted tracer to model resolution. At a regional scale, such as Georges Bank, convergence can be achieved with model resolutions approaching 100 meters, as detailed in our published work. In our research on predicting the initial spread of radionuclides from the Fukushima Dai-ichi Nuclear Power Plant, we determined that a model resolution of approximately 5 meters is necessary to accurately represent the plant's infrastructure and to align with observational data.

The WWTP model has also been successfully utilized by FVCOM users in other states, where configurations around 100 meters have effectively reproduced WWTP effluent dilution. For the Massachusetts coast, the resolution of 3-4 meters employed in our WWTP model is sufficient to achieve convergence of the dye tracer from the outfall.

We hope to secure funding to conduct a dye experiment at the New Bedford and Fairhaven outfalls, or at least at one of these locations. Such an experiment would provide us with valuable data for robust model validation.

Comments on "Modeling Assessment of Spreading of the Scituate Waste Water Treatment Plant in the North-South Rivers, Massachusetts"

Comments: *However, I have some concerns on the experiment setup and result presentation. (1) Why was the model applied to a climatologically seasonal case but not for an exact year or for an exact period? The current application disables direct model validation weakening the conclusion. Model validation of one-year simulation (for example, 2020, when the shellfish bed was closed) may be needed. (2) It seems that the result sections (3–4) were not organized by topics, i.e., effects of tides, effects of wind. I listed all the detailed comments as followed.*

Response: We appreciate the reviewer's concerns regarding the experiment setup and presentation of results. In 2020, there was significant public concern about the impact of the shellfishing bed closure in the North River, MA, on the state's shellfish industry. In response, the Division of Marine Fisheries (DMF) reached out to us to estimate the area affected by the WWTP effluents from the North River outfall.

Our primary objectives were to assess the influence area under both climatological mean conditions and extreme weather conditions for each season. The climatological mean scenarios represent averaged conditions, while the extreme weather scenarios signify the worst-case conditions. This is why we applied the model across multiple years under climatological conditions. The dilution maps generated from these simulations serve as references for the DMF in their analysis, and some areas have since been reopened based on the DMF's final analysis, which integrated our model data with other observational data.

When we applied the model to the New Bedford and Fairhaven outfalls, we shifted our approach to running the model for a specific year. Additionally, we are considering rerunning the model for the North River outfall over several years in the future, which would enable us to examine both short-term and long-term variability of the WWTP effluents. However, this will depend on securing the necessary funding.

We believe that a resolution of 3 to 4 meters is sufficient to capture the dispersion of the passive tracer over the wetland-tidal creek-estuarine-shelf complex. We agree that further validation through observational data should be conducted to confirm our findings. For additional context, we refer you to our explanations regarding convergence experiments, which compared dye concentrations over Georges Bank, as well as observations of radionuclides from the Fukushima Dai-ichi Nuclear Power Plant along the Japanese coast.

Appendix B – MA Division of Marine Fisheries response to scientific peer reviews of modeling reports

Response to scientific peer reviews of two modeling reports:

1) Modeling Assessment of Spreading of the Scituate Waste Water Treatment Plant in the North-South Rivers, Massachusetts

2) Estimation of the Sewage Water Dilution from Wastewater Treatment Plants in New Bedford and Fairhaven, Massachusetts

Reviewers were also provided additional related resources from the Chen lab. Provided by: Massachusetts Division of Marine Fisheries ("MA DMF")

Select comments and responses from review #1

Major concerns surrounding the treatment of *uncertainty* in the products provided:

Reviewer Comment: How have the authors proposed uncertainty be represented in the analysis product? For example, the model was only run for one year and the maps provided average over significant lengths of time for such a widely varying system. The issue surrounding temporal uncertainty- how representative 2021 is, and if the current simulation should be considered that - is important to consider when using these results to decide regulation. Could the standard deviation over each seasonally averaged period be showcased as a map? Can the authors do the same with salinity from the same embayment and compare that to a longer run they have already? This would at least speak to the interannual variation expected in this region over time. This point is critical for the evaluation of event-based discharges as was asked of us in the review process. The products are currently insufficient as provided to evaluate events as they are largely time-averaged currently.

DMF Response: Time-averaged products were asked of Dr. Chen's group because DMF is using the output to inform the overall classification of shellfish growing areas around wastewater treatment plant outfalls. Assigned classifications speak to the overall sanitary quality and potential public health risks associated with consuming shellfish from the growing area and are semi-permanent in nature (i.e., do not change due to discrete events) . Currently, the model is not being used to respond to discrete events. However, future use of the model could include making status change closures (not long-term classification closures) informed by nowcast output driven by contemporary parameter values. The fact that the model simulation covers only a single year is a valid concern. However, results from additional years would likely support either that closures based on 2021 forcings sufficiently capture the variability or that broader Prohibited areas are required.

Reviewer Comment: process-based uncertainty emerges with the design of the inert tracer. It seems likely that the tracer was allowed to behave passively, when in reality the wastewater would degrade or be naturally broken down as it is exposed to light (Dizer et al. 1993, others) as well as it exists in the natural environment. This timescale was not included in the considerations for the residence times or dilution metrics provided.

DMF Response: Dr. Chen was not charged with modeling biological parameters such as pathogen decay because the dilution ratios for sanitary classification require accounting for chemicals or otherwise poisonous or deleterious substances like pharmaceuticals or industrial chemicals (e.g., PFAS) that are not removed during the treatment process, not monitored, and that persist in the marine environment. Pathogen decay is very pathogen specific. For example, fecal bacteria is more likely to persist and propagate in warmer months and viruses are more likely to persist in colder months. Thus, the high-risk season is different for different pathogens and does not overcome the need to dilute chemicals. Additionally, the classification of shellfish growing areas is meant to be stable and not change from season to season. DMF takes the efficacy of pathogen effluent removal into consideration when choosing which level of dilution is appropriate for the Prohibited buffer zone.

Reviewer Comment: Finally, the analysis currently largely lack of consideration for the habitat or organism at the center of concern and management. While the authors provide some output on the bottom, which seems like the natural location for them to reside, there is not much attention made to the organism's phenology and or their potential ability to clear the material from its system?

DMF Response: Model output provided dilution contours for the surface and bottom because there is floating aquaculture in the domain receiving the effluent discharges. Phenology is not relevant to this analysis and because the discharge is continuous (not discrete events) and some pathogens such as norovirus have a zero tolerance and cannot be tested/monitored continuously organism clearing rates would not factor into shellfish growing area classification decisions. It would however factor into closure duration decisions for discrete emergency discharge events.

Reviewer Comment: Why are monthly average maps the appropriate product to use to address this issue?

DMF Response: As mentioned earlier, classification designations are not dynamic like emergency discharge closures implemented by changing the status to closed. DMF asked for monthly and seasonal averages for dilution contours because the area classified as Prohibited dictates long-term closures in all seasons. DMF has to err on the side of public health when it comes to human sewage discharges, but taking the worst-case scenario is a bit too draconian and would have put long-existing aquaculture operations out of business. Seasonal and monthly average dilution contours allowed DMF to visualize effluent dilution and dispersal patterns in a manner that helped inform long-term classification decisions that aim to balanced public health protection with minimizing closure impacts to industry.

Reviewer Comment: Doesn't fecal coliform bacteria degrade with UV? Did the modelers consider adding this kind of decay to their tracer design? A sensitivity to this kind of forcing – an example can be found in these works (Kragh et al. 2022; Delre et al 2023) could be implemented in the longer run and help contribute to the process based evaluation or the uncertainty/confidence interval discussion.

DMF Response: See earlier comment on chemicals in WWTP effluent that do not degrade at relevant time scales.

Recommendations –

Reviewer Comment: Work to further define this threshold with the biology in mind. For example, the WWTP discharge is highest in the autumn in New Bedford but the model suggests that the dilution thresholds experience seasonality and are most severe in winter through spring in 2021. If you were to bring in the biology of the oysters and other shellfish – what months are they harvested, when are they growing the fastest and eating the most? How long does the bacteria from the WWTP remain a threat to humans within the shellfish after they ingest it? Could the farms remain open but harvest delayed in certain months?

DMF Response: Shellfish are harvested year-round. Dilution zones around WWTP outfalls are a precautionary measure mandated by the National Shellfish Sanitation Program to account for a plethora of different pathogens including some that have a zero tolerance in food products and for any number of known and unknown toxics that could be introduced into the waste stream and are not tested. The only feeding rate that would matter is periods of no feeding at all and there is no practical way to monitor that. If the shellfish are pumping, they are potentially accumulating pathogens/toxins. Thus far, no farms have been closed as a result of reclassifications due to dilution zones around WWTP outfalls.

Reviewer Comment: In line with this last question above – the model estimates are largely provided at the surface with some attention paid to the bottom conditions, but where are the farms mostly? Are the organisms growing at the surface in the intertidal or are they mostly at the bottom and what depths typically do they reside? Can the dilution estimates be expanded in the subsurface to better align with their habitat? Is bottom appropriate or do the farms allow the cages to reside higher up in the water column?

DMF Response: See earlier comment

Select comments and responses from review #2

However, since the dilution model results will inform shellfish growing area classification and support potential decision-making processes, it is crucial to ensure that the simulated dilution maps are accurate and able to quantify the uncertainties. For example, is it possible to evaluate the model simulated 1:1,000 contour with observations, such as Rhodamine dye injections as described in True (2008), the reference provided by Dr. Chen, and quantify the uncertainty in the spatial location of the 1:1,000 contour?

DMF Response: The New Bedford WWTP is up for permit renewal and the EPA is planning to conduct a dye study that would offer an opportunity for model validation.

Reviewer Comment: WWTP contaminant decay rate: Is it necessary to consider the decay rate of contaminants discharged from WWTP? To what extent does the decay of tracer affect the accuracy of the simulated contour lines at 1:1,000 and 1:100,000?

DMF Response: Dr. Chen was not charged with modeling biological parameters such as pathogen decay because the dilution ratios for sanitary classification require accounting for chemicals or otherwise poisonous or deleterious substances like pharmaceuticals or industrial chemicals (e.g., PFAS) that are not removed during the treatment process, not monitored, and that persist in the marine environment. Pathogen decay is very pathogen specific. For example, fecal bacteria is more likely to persist and propagate in warmer months and viruses are more likely to persist in colder months. Thus, the high-risk season is different for different pathogens and does not overcome the need to dilute chemicals. Additionally, the classification of shellfish growing areas is meant to be stable and not change from season to season. DMF takes the efficacy of pathogen effluent removal into consideration when choosing which level of dilution is appropriate for the Prohibited buffer zone.

Reviewer Comment: The flooding/drying capability, as detailed in Document 03, indicate that model can simulate areas that are periodically flooded by tide or occasionally inundated by extreme storm conditions. However, I lack experience with the FVCOM model and am unsure how FVCOM handles the CSO discharges and its overall model stability. In addition to measuring the discharge from CSO, it would be important to measure the concentration of contaminates to inform the concentration of the released passive dye, rather than assuming a concentration of 1 (as mentioned in Document 03). Furthermore, evaluating the model simulated hydrodynamics in regions where CSO discharges occur, comparing the simulated dilution maps against available observations, and identifying potential uncertainties associated with model configurations would be important.

DMF Response: While DMF is not currently using model output to inform closure decisions around CSO discharges, if DMF pursued that the simulation would be constrained by discharge volumes reported by flow meters in the CSOs and assumed fecal bacteria concentrations informed by DMF testing of discrete CSO point source discharges.

Select comments and responses from review #3

Reviewer Comment: The validation of the Mass Coastal FVCOM model results is limited, although the parent model, NECOFS, has been extensively validated. In Section 4, the model's tidal amplitude and phase were successfully validated against observations from 18 tidal gauges. However, the evaluation could be strengthened by incorporating validation of additional physical parameters, such as current speeds, water temperature, and salinity. Furthermore, the external validation section (file: *USCG_Annual_Report_2024_model_validation_section.pdf*) focuses exclusively on the NECOFS results from 2017. Conducting a comprehensive validation of the Mass Coastal FVCOM model results for 2021, with a broader range of features, would enhance the assessment of its performance and improve reliability.

DMF Response: EPA dye study of New Bedford WWTP outfall planned.

Reviewer Comment: Page 4, 4th paragraph. Is it better to validate the model before presenting the dilution maps?

DMF Response: With limited funding and the need to make classification decisions ASAP based on the best available science, DMF asked for the dilution maps.

Reviewer Comment: I believe this model is well-suited for establishing shellfish classification areas in the near future. However, the report appears to lack detailed quantification of the areas covered by the 1000:1 dilution lines. It would be helpful to include temporal plots of the prohibited, conditionally approved, and approved areas for shellfish farming. For instance, visualizing changes in the prohibited area within Buzzards Bay or within the 5 m isobath could provide valuable insights.

DMF Response: The classification decisions are made by DMF and take into consideration many factors outside the model results. For example, effectiveness of treatment in deactivating

viruses, whether the plant has holding capacity in the event of treatment disruption, redundancy in alarms to alert operators to failure, and demonstrated effectiveness in communicating with DMF.

Reviewer Comment: In the "Summary and Suggestions" section, suggestions to shellfish industry should be provided.

DMF Response: This study represents just a fraction of the information used to inform shellfish growing area classification decisions. Dr. Chen was tasked with simulating the dispersal and straight dilution of WWTP discharges. DMF as regulators must consider all standards and considerations of the National Shellfish Sanitation Program in final classification decisions.

Appendix C - Public comments on review of modeling approach on WWTP dilution

Comment 1

To whom it may concern,

My name is Philip Chiaraluce, I own and operate Edgewater Oyster Farm which is located in the Wareham River. I am deeply concerned about the potential reclassification based on hydrographic modeling. I'm not questing the effectiveness of the modeling, I am questioning whether or not we can make judgements that will put hard working folks out of business based on a hypothetical situation. We have had zero instances of illness because of fecal content. If that was the case, then I would absolutely want to make sure that something was done to remedy the situation, but again, that's not the case here. I feel like reclassification should be taking into account hard actual tested data like water quality samples looking for fecal content and or dye tests to prove the validity of the hydrographic modeling. To potentially shut an industry down based on a hypothesis makes zero sense to me. It's very hard for me to not see this as another example of government overreach! Be an absolute travesty to watch an industry with such a deep history in our community get obliterated because of an idea and not facts!

Sincerely,
Philip Chiaraluce
Edgewater Oyster LLC
EdgewaterOyster@outlook.com

Comment 2

To Whom it May Concern,

I am writing on behalf of the Ipswich shellfish community. Last August the FDA came to Ipswich and did an audit of our shellfish flats, specifically areas N5 (Ipswich River) and N4 (Eagle Hill/Plum Island Sound). It was a boat ride up the halfway up N5 area and a minimal ride around N4 area. Then we waited for months to get a response of any decision back from them about any possible changes. We were told the Dr. Chan was doing multiple model studies and that it would take time to get those results. Finally after months of waiting the DMF came to a selectboard meeting and presented the results of the modeling studies. Now at this time the N5 (Ipswich River) had been kept closed to all harvesting of shellfish, huge economic loss for the commercial clammers. At the meeting the DMF made a presentation of the modeling studies and showed the two options we could be looking at one was the results of a 1000 to 1 dilution and the other was 320 to 1. The 1000 to 1 was an impact that would have closed all of N5 and close to ¾ of N4, which would have not just affected Ipswich but Rowley and Newbury as well. They told us in the meeting the with how well our treatment plant operated that they were able to keep it at 320 to 1. This conclusion was by far what we were looking for but better then the 1000 to 1. Unfortunately by the time this decision was made the economic loss was already made, there was no consideration for the clammers and the loss that they would be impacted with. DMF's chart showed that the N5 is only 15% of the yearly harvest from the commercial diggers. That being said that 15% very significant, because when the river is open they are able to dig seven days a week and get their 300lb limit every day. Were as in other areas like N4 or N7 they are not able to get the 300lb limit due to the lack of shellfish. DMF gave us results from 2023 for N5 and they said that with 72 harvesters the total loss was $336,661, which comes out to roughly $4675 per digger. The past couple years N5 had opened later and later due to large amounts of rain, this year would have most likely opened on time due to having two good water test come back good. But with the waiting for the modeling results to come back and no response from DMF and FDA the river was kept closed with no discussion with the town.

We have had multiple meetings with or local, state and federal delegations over this matter and there never seems to be a definite answer for why other then they can't test for the unknowns. It seems to come down to the testing of the unknowns like pharmaceuticals and heavy metals. We ask why can't we test and the answer is cost and procedure. I feel that if you are going to make such a significant impact on a community's livelihood that you would go down every avenue you could to make sure that everything is looked at to the fullest. There needs to be more hands on testing other then computer system modeling. They could do more studies from what comes out of the out flow pipe, water dying to see how long it takes to dilute and see if dredging the river could make an impact. Thank you again for you all for your consideration and hard work in this very important matter, we greatly appreciate all the help. If there is anything we can do on our end to help now or in the future please let us know.

Best
Officer Matthew Bodwell
Natural Resource Officer
mbodwell@ipswichpolice.org

Comment 3

Hello, my name is Mike Ward and I grow oysters for a living in Mattapoisett. I bought no oyster seed in 2025 and am going out of business. This model application and how it is used in the regulatory application is the straw that broke my back. A prediction is I won't be the last.

There continues to be no data saying the water and/or animals are unsafe or doesn't meet regulations in Nasketucket bay, on my grant.

I have no knowledge on whether hydrodynamic modeling is appropriate for shellfish area classification. However others who know more say the concept is fine so I'll agree. What I have heard is that these models are tricky to implement. Don't listen to me ask someone who knows more, please! They need multiple rounds of data (read water and/or animal testing) as inputs because greater New Bedford watershed is unique as is every other watershed. If you read between the lines of the modelers feedback they are saying in their academic way that this application needs more data.

Being from the private sector I don't understand why WHOI and the modelers can't just come out and say; using hydrodynamic modeling makes sense for this application, but using the model as implemented here to make regulatory decisions is not appropriate. Read the detail, that is what I read. The report does say more data is needed, the report does say the Division of Marine Fisheries and Dr. Chen basically agree with the conclusions. Yet there is no plan to gather more data. Regulatory decisions continue to be made with this model application.

Four of the five aquaculture sites being effected are in Nasketucket bay. Please look at a map or better yet a chart, you will find Nasketucket bay to the east. Please ask a sailor, a recreation fisherman or better yet find the Buzzards bay current chart. The currents carry the CSO water east on the flood and west on the ebb, not north and south, once it leaves New Bedford.

The implementation of the model defies common sense.

1. No currents were measured. For example currents coming out of the New Bedford dike are different then New Bedford outer harbor and Nasketucket bay. I guess specific currents don't matter.

2. Water and/or animals were not tested to verify the model implementation. Not in New Bedford, not in Nasketucket bay, not anywhere. I guess the real world doesn't matter.
3. The limited data used was gathered for the sewage treatment plants license renewals and then they must have just guessed. The sewage treatment plants die only test out a few miles. Regulatory decisions were made well past what the treatment plants cared about.

Mike Ward
mward@bengolive.com

Comment 4

Thank you WHOI Sea Grant for conducting this technical review. I am an oyster grower in Mattapoisett (BB 23), and have a few questions/comments:

1. On page 3 it is noted that "the FDA's guidance allows for some flexibility in the use of data to justify the level of dilution chosen for classification, pending FDA approval." What standards concerning the sampling and analysis for this data collection would be necessary and what procedure would be required for FDA approval?
2. It is asked on page 8 if engineered structures were included in the modeling grid. Dr. Chen responded that storm and flood walls around the harbor were included. What about the West Island causeway in Fairhaven or the Brant Island causeway in Mattapoisett?
3. I strongly support the suggestion of an Advisory Board for transparency and trust as stated in the suggestion. As DMF states in their final response, this study constitutes just a fraction of the information used in their decision making. I think a better understanding of the totality of what goes into that decision making and a mechanism for input into that process is important as it has a tremendous impact on peoples' livelihoods.

Thank you for your consideration.

Bob Field
Mattapoisett, MA 02739
rfield@fieldengrg.com

Comment 5

BLUE STREAM SHELLFISH

10 July 2025

Dr. Matt Charette
Woods Hole Sea Grant
193 Oyster Pond Road, MS#2
Woods Hole, MA 02543

Dear Matt,

First, I would like to thank WHOI Sea Grant, you, Jennie and Josh for your interest in and support of maritime industries in the region. The overall technical expertise that WHOI Sea Grant provides is critical to support our marine environment and those industries associated with our coastline.

More specifically, I would like to thank you for providing technical input and review on the recent application of the FVCOM hydrodynamic model developed by Dr. Chen (Chen *et al.* 2023) and applied by the MA Division of Marine Fisheries to adjusting shellfish classification areas based on the model output. To that end, please accept this document as my response to the application of the FVCOM model for reclassifying the shellfish harvest areas in Buzzards Bay and to the review generated by three external reviewers and summarized by Dr. Rheuben in the draft manuscript entitled "*Independent Technical Review of FVCOM Modeling for Wastewater Dilution in Buzzards Bay and the North and South Rivers: Considerations for Regulatory Implementation*." These comments cover a range of issues from general to specific that I would like to see addressed.

Hydrodynamic modeling of marine systems can provide insight into forces controlling the system and predictive capabilities of outcomes driven by those forces. As is true with any modeling effort, the steps to properly apply a hydrodynamic model to a specific system involves developing the basic model, calibrating the model to the specifics of the system in question, verifying that the data used to construct the model are valid, and demonstrating that the model outcomes truly represent the real world situation. I will speak to each of these steps as it applies to the use of the FVCOM model to address the impact of the New Bedford/Fairhaven WWTP outflow into Buzzards Bay and surrounds.

As was noted by the reviewers and relayed in the draft manuscript, the FVCOM model as used by Dr. Chen is a well-developed model for exploring the dynamics of coastal systems (Chen *et al.* 2006). Dr. Chen has been using this model for numerous marine applications and seems to be highly qualified in managing its applications. In concept, the use of the FVCOM model for investigating the impact of WWTP outflows is well within the capabilities of the model. However the devil is in the details.

The ability of a hydrodynamic model to provide good information is entirely dependent on the

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data used to calibrate the model for the specific application in use. As noted by Williams and Esteves (2017), the accuracy of hydrodynamic model outputs is restricted by the quality and spatiotemporal coverage of available data. Calibration, where model parameters are adjusted to minimize the difference between simulated and measured values is a critical component to model application. As was also noted by the reviewers, the calibration step is where this model and its application, in its current stage of development, fails significantly. A few examples of inadequate calibration are outlined below.

Calibration:

1. A problem with the model that was pointed out early in our awareness of the modelling effort suggested there was a discrepancy in the geographic representation of the shoreline surrounding the causeway linking Sconticut Neck across Long Island to West Island. In viewing the original animations of dispersal generated by the FVCOM model, it was obvious that the presence of the man-made causeway, with a 20-foot opening restricting the flow between Buzzards Bay and Nasketucket Bay, was not integrated into the model. When pointed out to MA-DMF, the model was purportedly adjusted to account for this severe restriction in flow between Buzzards Bay and Nasketucket Bay. However, in the final report, the graphics suggest that the presence of the causeway induced water flow restrictions were not accounted for in the final model output (Figure 1 – blue circle).

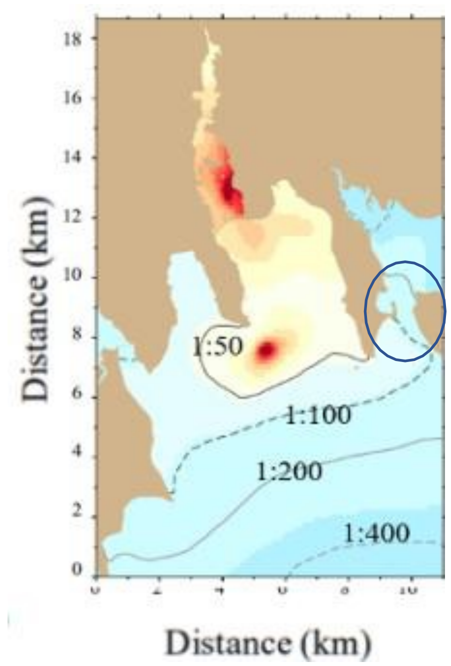
   

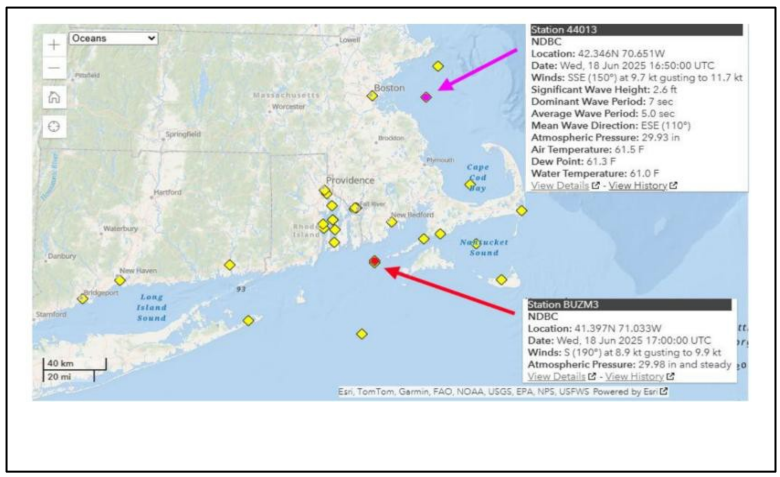
   Figure 1: A graphic representation of the geographic shoreline used for the Chen model (extracted from the Chen report)

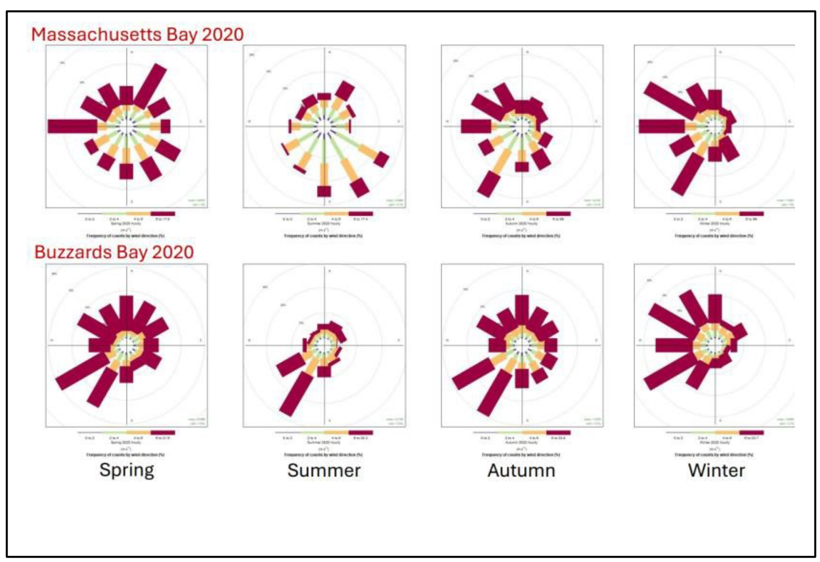
   Given the restriction to water flow between the New Bedford Inner Harbor and Outer Harbor resulting from the presence of the hurricane barrier (as noted in the Chen report), it is not inconceivable that the West Island causeway induces a profoundly severe restriction to Buzzards Bay water flowing between Long Island and West Island and into Nasketucket Bay, a much smaller and shallower passage than at the Hurricane Barrier.

   It also should be noted the area to the east of West Island (BB20 shellfish classification area) has remained open to harvest during the majority of emergency closures since Jan. 2024. This suggests that water impacted by discharges from the New Bedford/Fairhaven outfalls is not flowing into Nasketucket Bay from the 1.6 mile wide opening between Ram Island (Mattapoisett) and West Island at a level to affect closures. Therefore, can a 20-foot opening with a 4 foot depth through the West Island Causeway allow enough water to flow between Buzzards Bay and Nasketucket Bay on a tidal cycle to contaminate the entire 2.3 million cubic meters of Nasketucket Bay water volume?

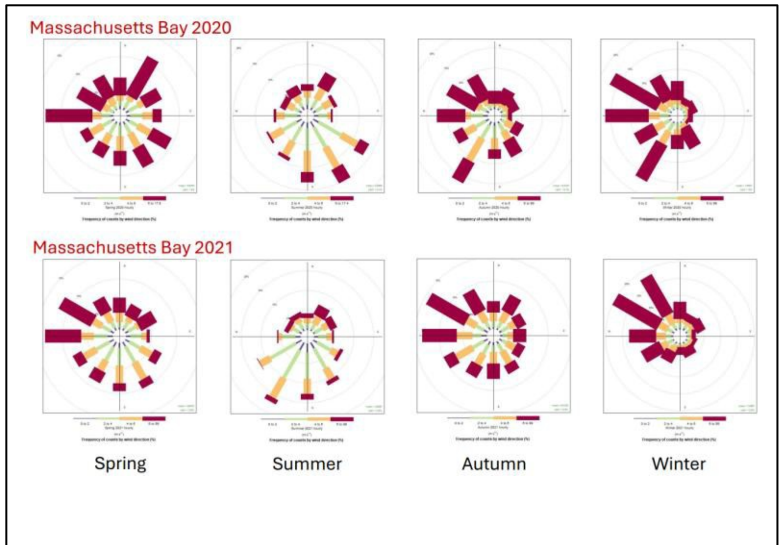
2. In the Chen report, the authors state “The WWTP dilution over the New Bedford and Fairhaven coasts was mainly driven by the advection and mixing due to strong semidiurnal tides and winds.” Given that wind is a critical element to the dispersion of the WWTP outflows, it is critical that the wind regime used in the model calibration be an accurate reflection of the actual wind pattern in the region. However, according to the report, the authors were not able to collect the Buzzards Bay wind data for 2021; therefore, they used wind data collected from the Massachusetts Bay NOAA buoy (#44013). This begs the question “Is the wind regime for Massachusetts Bay an adequate proxy for Buzzards Bay?”

   While the wind data for Buzzards Bay for 2021 is incomplete, there are complete records for 2020 at both the Mass Bay buoy (#44013) and the Buzzards Bay NOAA buoy (BUZM3) (Figure 2). Comparing the wind patterns between the two sites and using the seasonal breakdown reported by Chen *et al.*, it is very evident that the patterns were distinctly different in 2020 between Buzzards Bay and Massachusetts Bay (Figure 3). If one compares the wind patterns in Massachusetts Bay between 2020 and 2021 (Figure 4), you also can see distinct differences between the two years at the same site. Lastly, comparing the wind pattern for Mass Bay in 2021 as reported by Chen *et al*. in their Figure 5 to the wind pattern generated by my download of the same data from Buoy 44013, there are significant differences in the two patterns (Figure 5), primarily in the spring and autumn representations.





   Given that a model is only as good as the data used to calibrate it and given that wind is a key influence on dispersion patterns from the New Bedford WWTP outfall, it is clear from the wind data comparison presented here that the model has not been accurately calibrated to that important driver for hydrodynamic circulation in Buzzards and Nasketucket Bays. I suspect that, given the variability of seasonal and annual wind patterns, relying on just one year of wind data can be a potential source for considerable error in the model output. However this was not validated or verified.



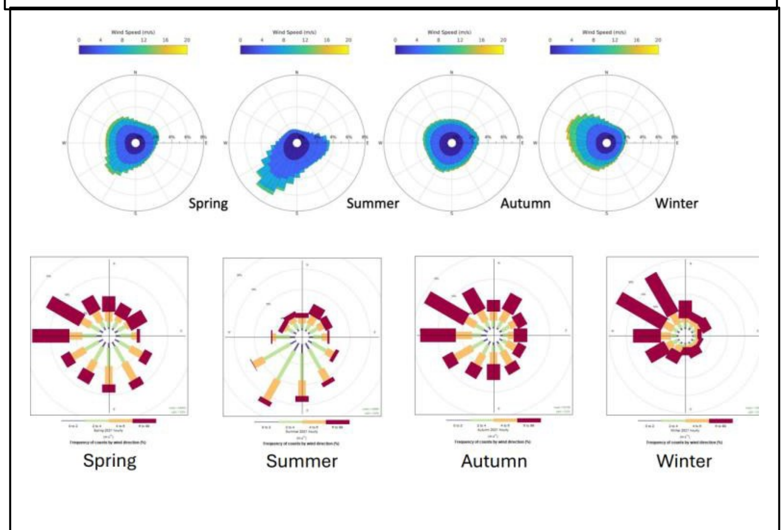


Figure 5: A comparison between Chen et al. interpretation of 2021

3. Stratification of the water column can have important effects on the dispersal of effluent from the WWTPs. In numerous passages at different points in the report by Chen *et al.*, the authors make reference to Buzzards Bay being thermally stratified in spring, summer and/or autumn. This observation is based on a publication by Li *et al.* (2015) that addresses thermal and density stratification across a wide geographic range (Bay of Fundy to Chesapeake Bay) and is based on output from the FVCOM model.

   However, when looking at a much finer scale to that of Li *et al.*, i.e. Buzzards Bay, there are conflicting reports as to the degree of stratification in the Bay. Rheuben *et al.* (2015) state "From wind shear and tidal cycling, the open waters of Buzzards Bay are rarely and only weakly stratified" where their observation was based on a publication by Turner *et al.* (2009.) This statement is further corroborated by a more recent paper studying Buzzards Bay by Scully and Zippel (2024), who state "During conditions of weak wind forcing, thermal stratification developed, but the water column was well-mixed when wind speeds exceeded 6m-s^{-1}." In referring to the wind patterns of Buzzards Bay, as discussed above, wind velocities of less than 6m-s^{-1} occur only in about 5% of the time that wind is influencing the bay. Otherwise the wind velocity routinely exceeds the threshold to mix the water column.

   As noted above with wind data, the installation of thermal/density stratification as a component to particle dispersal during the calibration of the model is highly suspect. When applying a hydrodynamic model to a specific and localized area, it is incumbent on the developers to use the most appropriate and applicable data. That is not the case with the current iteration of FVCOM as reported by Chen *et al.*

4. It is well established that enteric pathogens and associated indicator microbes are not well suited for survival outside of the avian/mammalian intestinal tract. Many factors, including salinity, temperature, turbidity, light exposure and biological interactions, can dramatically reduce (or enhance) the levels of microbes in the marine environment. To that end, there have been numerous studies that developed bacterial decay subroutines for their hydrodynamic modeling efforts to characterize human health risk from discharges from WWTPs (see for example Carvalho *et al.* 2006). It is not uncommon to see T_{90} time frames (the elapsed time where the microbial load of the effluent is reduced by 90%) of 4-6 hours. Treating the WWTP discharge dispersion as inert particles does not account for any allowance for reduction in microbial density or pathogenicity.

   As was mentioned in the Chen report, degradation of biological pathogens over time and distance are relevant to the shellfish area reclassification discussion but was not considered in model development or any of the deliberations on risk. While the DMF response to reviewer's comments notes that pathogens have different biological responses to the environmental conditions experienced once released with the effluent, the associated risk from pathogens in the effluent must be fully accounted for and microbial decay, regardless of the seasonality of the phenomenon, needs to be included. There needs to be refinement in the model predictions that recognizes and adjusts for a decline in survival and pathogenicity of microbes in the effluent.

   Examples of where microbial decay may prove to be an important explanation of data collected:

   - I have 35 years of fecal data collected 5 times a year adjacent to my farm site (a total of 174 data points) and only 1 sample in 35 years exceeds the fecal coliform 14 cfu/100 ml seawater threshold defined by the Model Ordinance (the one point was at 19 cfu/100 ml.) Those 174 data points represent a wide array of seasonal environmental conditions, including intervals of heavy rain conditions. If the persistence of fecal coliforms from the WWTP (or CSOs for that matter) is seasonal and if there is a human health risk associated, one would think that the fecal coliform monitoring of the waters surrounding the WWTP outfalls would reflect that risk at some point over the years. Not on my farm!
   - Additionally, with the recent increase in emergency closures being implemented by DMF for a different risk situation, the DMF lab has been testing for male- specific coliphage (MSC) viruses at our farm, another indicator defined by the Model Ordinance. With this testing, our farm has never come close to the critical threshold of MSC (50 pfu/100 g tissue) with our levels usually coming in a level of 6-11 pfu (background).

This entire modeling exercise is directed at identifying the human health risk associated with shellfish exposure to pathogens derived from the effluent from the WWTPs. Yet there is no acknowledgement as to the actual or predicted microbial exposure as the model only tracks inert particles released at the effluent sites.

DMF has argued that there are other WWTP effluent concerns focused around the presence of pharmaceuticals and contaminants in the waste water that are not accounted for but need to be managed. This is a specious argument given that there are no defined levels of risk for any of the contaminants cited by DMF and there are no thresholds of safety established. Without a known level of risk and a defined critical threshold, there is no justification for reclassifying areas based on speculation of the presence of "other contaminants." This is an example of the Precautionary Principle running amok!

Calibration is a critical first step in the development of a hydrodynamic model that represents true real-world events and to allow use of that model outcome in a regulatory decision-making process. It is clear that the current calibration of the FVCOM model to characterize the dispersal of effluent from the New Bedford/Fairhaven WWTPs is not adequate. Limited and improper data were used for calibration. The inappropriate calibration of the model is further exacerbated by the lack of adequate verification and validation of the model parameters and outcome. Verification is an initial assessment of the accuracy of the model results while validation actually compares the model output to real experimental data collected from the study site.

Verification:

The Chen reports includes a short section (Section 4) relaying efforts to validate their model. Their validation consisted of assessing the modelled tidal behavior within the region compared to 18 tidal gauges across the model domain, from New Hampshire to Rhode Island. Tide behavior is but one factor in predicting the dispersion of effluent from the WWTP outfalls and no effort was made to verify other important parameters, for example predicted wind behavior, temperature variations, stratification in the water column, and/or microbial decay. Sensitivity analysis addressing the relative contributions of the various parameters used to construct the model is one routine method of evaluating the level of confidence in the model output. No effort was reported to apply this test of model robustness.

A good example of a model verification process can be observed in Sankaranarayanan 2007 where model output was compared to real-time data collected for Buzzards Bay.

Validation:

Validation is where the rubber hits the road in terms of using the model as a tool for predicting environmental behaviors, in this case the dispersion of effluent from the WWTP point sources. Sometimes referred to as "ground-truthing," validation involves the comparison between the model outcome and empirical evidence collected by direct observation and measurement. Validation then allows the investigator to assess how reliable the model output is in terms of predicting behaviors of interest.

At no point in this entire exercise is there any evidence of attempts to validate the model to real data. There may be opportunities in the future, for example the upcoming EPA dye study of the New Bedford WWTP discharge for renewal of their NPDES license, supposedly scheduled for October 2025. But until those data are available and if the authors decide to apply that data to a simulated model run under the same conditions, the current first iteration model is not ready for prime time.

In my opinion, this is a fatal flaw in using this model to provide regulatory decision making. It is incumbent on the regulatory authority to determine that the information they are using to set regulations is an accurate representation of the environment that they are regulating. At this point in time, the FVCOM Model as developed by Dr. Chen *et al.* and applied to the discharge of the New Bedford/Fairhaven WWTP discharges is not a proven representation of the conditions surrounding the dispersal of discharge from the outfalls. And there is no reasonable justification for using this preliminary stage development of the FVCOM Model to establish regulatory decisions in the Commonwealth.

Although I do not profess to be conversant in the nuances of hydrodynamic modeling, in my experience an accurate and predictive model does not come from a one-iteration development process but requires multiple data sets (e.g. multiple years) that are relevant to the question being asked and multiple iterations of refinement following extensive verification and validation before it provides an accurate and trusted output. In my opinion, The Massachusetts Division of Marine Fisheries must retract the regulatory changes promulgated by application of the FVCOM model outcome until there are adequate data for calibration, the model data have been appropriately verified, and the model has been validated against real data collected through valid scientific monitoring. From all appearances, this effort was a rushed and incomplete effort to model WWTP dispersion and needs considerable more effort put into its calibration, verification and validation before it can be used for regulatory decisions. This translates to considerable more funding being invested in model development and application before it is a useful tool for decision making.

Thank you for the opportunity to provide comments regarding the application of the FVCOM Model to the New Bedford/Fairhaven WWTP outfalls for regulatory purposes.

Sincerely,

Dale F. Leavitt, PhD
Member – Blue Stream Shellfish

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Comment 6

NSRWA

July 11, 2025

Dear WHOI Seagrant:

The North and South Rivers Watershed Association (NSRWA) is an environmental nonprofit whose purpose is to protect our waters within the watershed to the North and South Rivers. Our organization represents over 1,500 members and provides environmental assessment, education, and outreach throughout the South Shore. We would like to submit the following comments and concerns regarding the draft "Independent Technical Review of FVCOM Modeling for Wastewater Dilution in Buzzards Bay and the North and South Rivers: Considerations for Regulatory Implementation". We are very familiar with the hydrodynamic modeling using FVCOM to simulate wastewater treatment plant (WWTP) effluent dilution in the North and South Rivers. We are also very familiar with the resultant reclassifications of shellfish growing areas, which downgraded the shellfish harvest classification across a large portion of our rivers. In 2022 we provided written comments to US EPA R1 and MA DEP regarding these changes. We appreciate WHOI Sea Grant's coordination of an independent technical review of the FVCOM modeling reports. We understand that input has been requested specifically on the independent technical review.

The independent technical review appears to have been well conducted. We agree with the reviewers that the UMass modeling team is well respected and highly qualified to conduct the FVCOM modeling. We also agree with technical reviews that:

1. More observational data should be incorporated into modeling and regulatory decision making. The reviewers are correct in stating that NSRWA have been monitoring the relevant embayments and would be willing to share our data.
2. Modelers and regulators should complete an evaluation of sensitivity of dilution zones to tracer degradation rates. Additionally, the contaminants of concern should be identified so that their degradation rates can be evaluated. The current approach only vaguely describes 'chemicals or otherwise poisonous or deleterious substances'.
3. Create an advisory board to provide input and feedback on modeling results and implementation of results by the Massachusetts Division of Marine Fisheries. This is of the highest priority to us. Currently the shellfish classifications are handed down with relatively no local input. The data sharing opportunities mentioned in point #1 above is a good example.

While we understand that comments were requested specifically on the independent technical review, we do wish to reiterate our basic concerns about the use of this modeling to downgrade local shellfish harvest classifications. For 55 years NSRWA has worked tirelessly to protect and improve the resources of our rivers. Some of our greatest successes have centered around reducing wastewater contamination. In the 1980s NSRWA brought a suit against the Scituate Wastewater Treatment Plant, forcing the town to address operational problems. Today, the plant regularly emits clean effluent into the river. In the 1990s we created a citizen led water quality monitoring program and targeted the improvement of storm drain systems to remove pollution, both continue today. This resulted in the opening of 293 acres of North River shellfish beds. In the 2000s we helped achieve funding for sewering Marshfield to stop failing septic systems from contaminating the South River. This led to the opening of 314 acres of South River shellfish beds from November 1 – May 31. These successes show the enormous benefit to water quality that is achieved through well-run, modern wastewater treatment plants. The discharge from the Scituate WWTP is highly monitored and has shown extremely low levels of contaminant discharge. Now, despite all of those decades of work, an overly conservative and somewhat arbitrary regulatory framework that is solely intended for commercial harvest has taken away a valuable public resource from the very people who are dedicated to protecting it. Public policy should balance public health with incentivizing clean up and control of pollution, not remove access to public resources because there is a chance of contamination from some undefined contamination sources. If anything, wastewater treatment plants are more able to control that kind of pollution than other land uses and accidents that might contaminate shellfishing waters. We continue to believe that the regulation of recreational shellfishing should:

1) not be based on commercial harvesting policies (NSSP, ISSC),
2) be based on specific, identified, real-world contaminants of concern, and
3) be supported through local decision making.

We greatly appreciate WHOI Seagrant for coordinating this independent technical review. We also appreciate the specific and well-defined recommendations from independent reviewers. We hope that those recommendations are implemented and that they result in additional opportunities to reclaim one of our most highly valued public resources.

Sincerely,

Alex Mansfield
Watershed Ecologist
North and South Rivers Watershed Association
alex@nsrwa.org

Comment 7

July 11, 2025

Dr. Matt Charette
Woods Hole Sea Grant
193 Oyster Pond Road, MS#2
Woods Hole, MA 02543

Dr. Charette,

It's with deep appreciation for this opportunity to submit comments, for not only the work that WHOI Sea Grant has enabled toward the review the FVCOM but also to the reviewers and FVCOM developers that I submit the below comments. By way of background, although I am not an aquatic or environmental scientist, my undergraduate degree in Biology and Marine Biology, more than two decades working for the Commonwealth of Massachusetts serving as the State's first Aquaculture Program Coordinator and departing as Commissioner of the Massachusetts Department of Agricultural Resources, and now as an oyster farmer and owner of a farm located in Dartmouth, MA (Shellfish Growing Area BB12.5), I am uniquely experienced to not only comment (to a limited degree) on the FVCOM model but to its current application as a state shellfish regulatory tool as well as the impact of that application on a shellfish farm business that has been significantly impacted by regulatory changes that were implement ted by MA DMF in January 2024.

To date, because of changes in regulation associated with MA shellfish growing areas implemented in January 2024, my farm has been closed 342 days or more than 61% of the time. These closures are a direct result of the use of the FVCOM model by the DMF to inform their regulatory approach. Unfortunately, from my perspective and in consideration of reviewer comments, it seems more work to validate the model for its intended application is required and as a result there appears to be a general disconnect between what the model was developed to do and how it is being applied – namely to determine the status of Massachusetts Shellfish Growing areas and to regulate shellfish harvest based on proximity to Waste Water Treatment Plants (WWTP) and Combined Sewer Outfall (CSO) discharges.

"Two reviewers identified that contaminants in wastewater discharge may not fully behave passively over time, but may decrease with time due to natural processes such as exposure to UV radiation." The model developer acknowledges "it is necessary to consider the decay rate of contaminants discharged from the WWTP when modeling their behavior in the environment." and that "the final decision, to (the model developers) understanding, is based on integrating this model data with additional chemical and biological data analyses conducted by DMF." To date it is not clear that such data has been used to validate the model's use for regulatory purposes. As a result the decisions on reclassification of growing areas and frequent closures to shellfish harvest appear to have moved ahead prematurely.

Although the reviewers agree that FVCOM is appropriate for tracking discharge from WWTP "All three reviewers felt that, although the parent model, NECOFS, was well validated, this particular use-case would benefit from additional work. Validation of the NSR-FVCOM model was not described in the materials provided. Validation of the Mass-Coastal FVCOM model for this use was focused on assessments of semidiurnal and diurnal tidal amplitudes and phases at 18 locations around the modeling domain."

Informed by the FVCOM model "…has led MA DMF to reclassify the waters of several shellfish farms as Conditionally Approved (that were previously in Approved waters), but they have avoided classifying the farms as Prohibited (and closing the farms) at this time." Although reclassifying shellfish growing areas as prohibited would obviously lead to the closure of shellfish farms, it's important to note that reclassification of growing areas to "conditionally approved" has negative impact on market and development opportunities for shellfish farms in Massachusetts. Massachusetts and Washington state are currently the only two states that are allowed to export shellfish products to the European Union (EU). Through this recent development, only shellfish harvested from growing areas classified as "approved" in Massachusetts and Washington state may be sold into the EU market. By reclassifying growing areas to "conditionally approved", the opportunity for shellfish farms to sell product into the EU is effectively eliminated. Furthermore, shellfish farm development in Massachusetts requires that farms be located in growing areas that are classified as "approved". Reclassification of growing areas to "conditionally approved" not only limits shellfish farm establishment but also has negative impact on the expansion of existing shellfish farms within "conditionally approved" growing areas. Clearly these limitations have a negative impact on farm development as well as any commercial shellfish harvest opportunity in the reclassified shellfish growing areas. Historically and to date, reclassification of shellfish growing areas in accordance with the National Sanitary Shellfish Program (NSSP) is heavily data dependent. Use of the FVCOM model to reclassify growing areas appeared to use little to no biological data as prescribed by the NSSP to determine the growing area reclassifications. In fact the reviewers agree Reviewers that "given the usage of the model to inform regulatory decision making, an additional assessment of the models' performance would be important."

"Dr. Chen's team utilized the Finite Volume Community Ocean Model (FVCOM) to simulate WWTP discharges at four outfall locations at this time, but anticipates more WWTPs to be evaluated in the near future." Based on the current uncertainties identified by reviewers and the acknowledgement of additional work needed by the model developers, given the significant negative impacts that have already been felt by shellfish growers as well as recreational and commercial harvest of shellfish, I strongly recommend that the model not be applied to any additional WWTP until further validation of the model that includes data specific to CSO and WWTP discharge on shellfish be completed.

The report indicates "FDA's **recommended** dilution levels that should be maintained around WWTP discharges (Section IV, Chapter II, .19 Classification of Shellfish Growing Waters Adjacent to Waste Water Treatment Plants)". It is important to note that these are recommendations, not mandated. Absent specific data associated with shellfish growing area classifications and closures of shellfish growing areas to harvest, given the significant impact such actions have on shellfish harvest, collection of data specific to the local WWTP operations, effluent treatment or local environmental characteristics should be done prior to any changes to regulations. A formulaic or modeling approach that will or have the potential to negatively impact recreational or commercial activities (including aquaculture businesses) associated with local aquatic resources should first be validated through physical data collection prior to implementation. It is clear from the WHOI report, reviewer comments and model developer acknowledgement, more work must be done to validate the FVCOM model before it is used as a regulatory tool.

As the report indicated, "Note that the FDA's guidance allows some flexibility for the use of data to justify the level of dilution chosen for classification, pending FDA approval." Acknowledged that the state "Shellfish Control Authority", MA Division of Marine Fisheries, has exercised discretion in establishing boundaries based on dilution factors, the extent to which, based on physical data, those boundaries can be further reduced remains a question.

"The reviewers agreed the existing modeling framework as well as the high-resolution models are appropriate for use in assessments of wastewater treatment plant effluent dilution." As one reviewer comments, the model does not account for or define what component of the effluent could have a negative effect on water quality or on the safety of shellfish for consumption. Again, as acknowledged by the report, more work needs to be done before the FVCOM model should be used as a regulatory tool.

The report frames that "It is our hope that the Commonwealth of Massachusetts will provide additional resources to MA DMF to support the implementation of key recommendations made by the review team, including expanded model validation, improved uncertainty quantification, and engagement with interested parties. This review represents a step toward engaging modelers, regulators, and interested parties in a dialog that supports informed, science-based decision making." I fully support this statement and look forward to opportunities for continued dialogue and work toward the dual benefits of supporting the historically strong safety of shellfish harvested from our Commonwealth's waters as well as the continued growth and development of shellfish aquaculture in Massachusetts.

Respectfully,

Scott J. Soares
Owner/Operator
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