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.

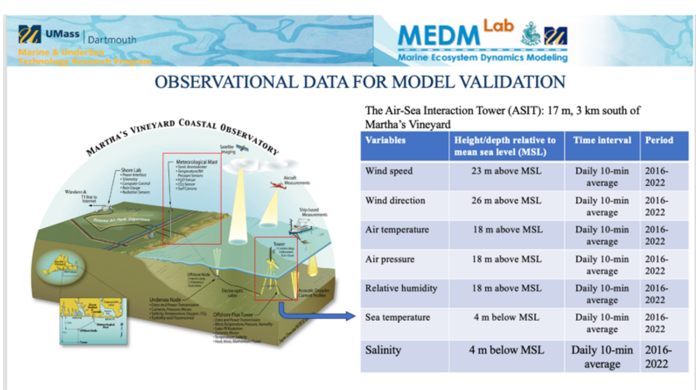
General Questions for the report for further consideration:

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.



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

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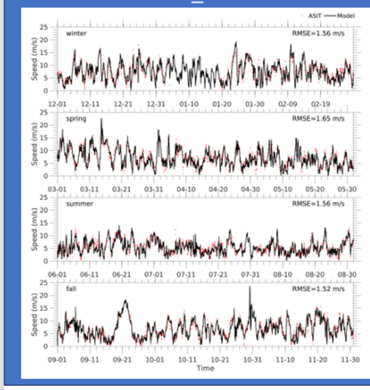

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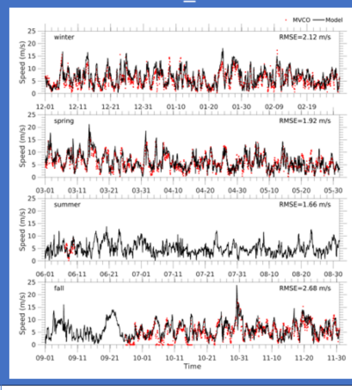

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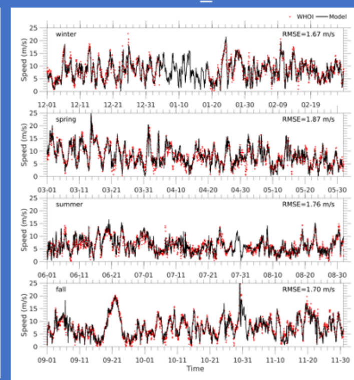

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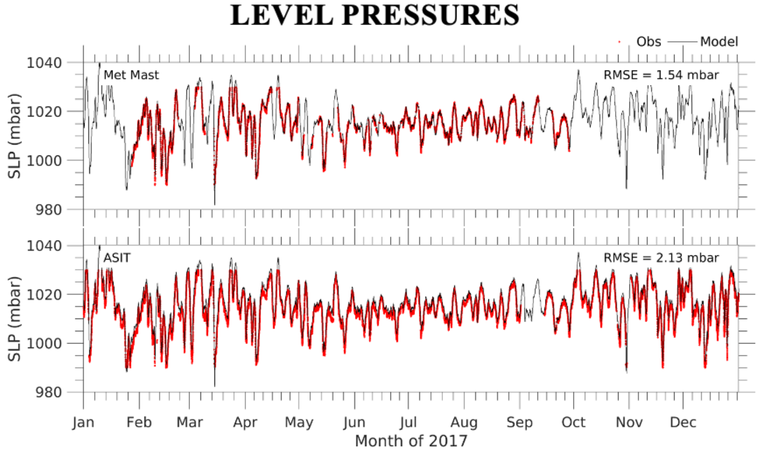
Marine Ecosystem Dynamics Modeling

COMPARISONS BETWEEN MODEL-SIMULATED AND OBSERVED SEA LEVEL PRESSURES



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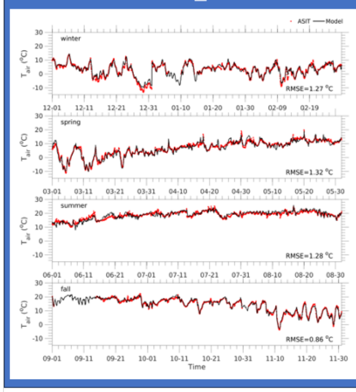
Marine & UnderSea Technology Research Program

MEDM Lab
Marine Ecosystem Dynamics Modeling

AIR TEMPERATURE COMPARISONS AT 18 M ABOVE MSL

MVCO_ASIT



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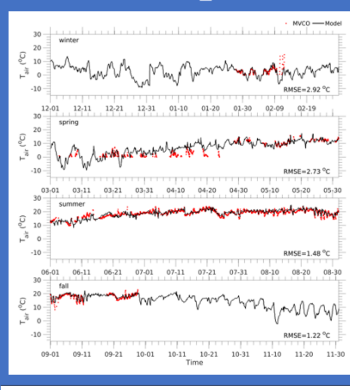
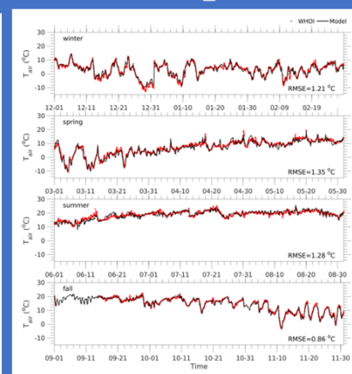


WHOI_MET



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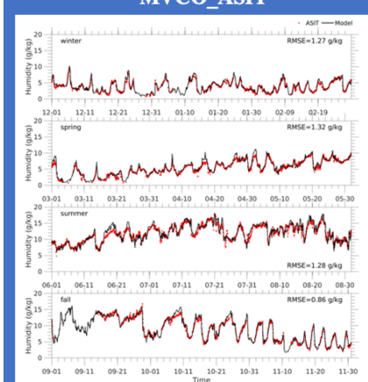
MEDM Lab
Marine Ecosystem Dynamics Modeling

AIR HUMIDITY COMPARISONS AT 18 M ABOVE MSL

MVCO_ASIT



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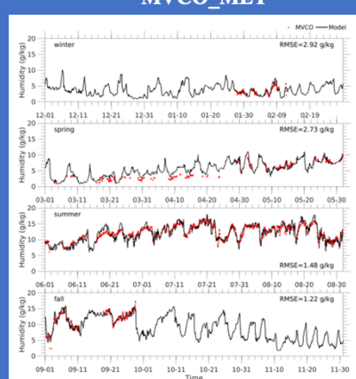
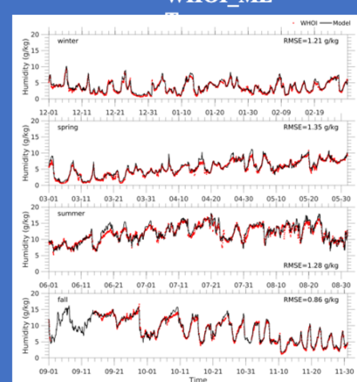


WHOI_ME



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.