Tracking the discharge of a waste water treatment plant in Casco Bay, Maine with a numerical coastal model.

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Ernest D. True , *Mathematics Dept., Norwich University, Northfield, VT 05663 USA*

Abstract

A finite-volume numerical coastal model (FVCOM) is applied to the circulation of currents in Casco Bay, Maine to examine the discharge from the Freeport Waste Water Treatment Plant (WWTP) which flows into Harraseeket River in Freeport, Maine. The coastal model incorporates bathymetry, tidal forcing, wind stress and river discharges from various sources. The horizontal resolution of coastline and island boundaries used in the study is sufficient to capture small eddy production and decay, and identify local circulation dynamics. In May 2003, a dye study of the WWTP discharge was conducted by the Maine Department of Marine Resources (MDMR). The results of the dye study are used to tune the numerical model and validate the dilutions, dispersion, residence times, time of travel, and extent of the wastewater discharge.

Although there were some faulty dye discharges during the dye study that were included in the recorded dye concentrations at two buoy stations, the numerical model shows good correlation with the dye study report. The application of the FVCOM numerical model to other wastewater treatment facilities may serve as an efficient aid for MDMR, whose responsibility includes establishing zones around discharge areas where commercial harvesting is prohibited.

An appendix of graphs to this document, Model-Appendix.pdf, serves as a supplement to this report. It compares the model output with the same ten transects Figures 11 through 20 provided in the report by Livingston(2007).

1. Introduction and background

One of the many responsibilities of the MDMR is to establish zones around wastewater treatment plants where shellfish harvesting is prohibited. Shellfish filter large volumes of water and can concentrate toxic microorganisms from human sewage. MDMR uses criteria from the National Shellfish Sanitation Program (NSSP) to determine safe areas for commercial shellfishing. The NSSP sets standards for shellfish sanitation in interstate commerce, which is supported by the United States Food and Drug Administration (FDA). One of the methods used by the MDMR to establish safe shellfishing areas near a wastewater treatment plant is to conduct a dye study. A fluorescent dye such as Rhodamine WT is injected into the discharge outflow pipes of the treatment plant as a tracer to represent the potential fecal coliform concentration of post-treatment, prechlorinated effluent. The dye is then tracked by boats or recorded at profile sites over a period of several days to measure the dilutions, dispersion and residence times in the surrounding waters.

In May, 2003, the MDMR, with the assistance of the Maine Department of Environmental Protection (MDEP) and EPA's Office of Environmental Measurement and Evaluation (OEME), conducted a dye study at the Freeport Wastewater Treatment Plant (WWTP) in Harraseeket River. The results of the study were reported by Livingston (2007). On May 13, dye was injected for two days at a continuous flow into the final mixing chamber of the effluent stream of the treatment plant. During the next 48 hours, the average plant flow discharge was taken to be 323,000 gallons per day, or 0.014 cubic meters per second, and the mean dye concentration was measured to be 5650 PPB at the outfall pipe. Five buoys were set out in the river to measure dye concentrations, temperature, and salinity. YSI 6920 Sondes units with rhodamine and conductivity probes were mounted on Buoys 1, 2 and 5 to collect Rhodamine, temperature and salinity every 15 minutes (Fig.1). Another sonde unit at the Freeport dock was used to record tidal elevations. Also, two boats were equipped for running transects and a third boat was used for conducting profiles. The EPA boat conducted zigzag transects up and down the western side of the estuary, gathering data during tidal flooding and ebbing from the upper reaches of the estuary out into Casco Bay. The MDMR boat was to cover the eastern side of the estuary, but experienced instrument failure with the fluorometer, and that data is not included in this study. Three dye studies were conducted in the Harraseeket estuary, and are fully described in Livingston(2007). This study only covers the study that was conducted May 13-15, 2003, which was the longest and most comprehensive of the three studies. The data that was recorded at buoys 1,2 and 5 can be obtained from the appendix to the report by Livingston(2007). The complete details of the dye study, including instruments, calibration, preliminary measurements and charts of EPA boat transects are in Livingston(2007), and will not be reproduced in this article.

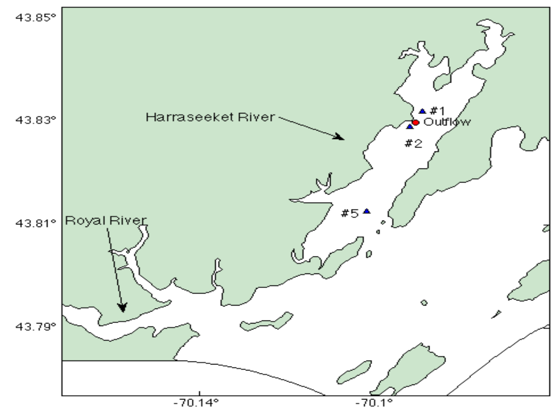

Figure 1. Harraseeket River computational zone, with locations of Buoys 1,2, and 5.

2. The Numerical Model

For this study, the FVCOM numerical model is applied on an unstructured triangular grid of the Harraseeket River. FVCOM, developed by Chen et al. (2003), is a prognostic, unstructured grid, finite-volume, free surface, three dimensional primitive equation coastal and estuarine model. The default setup applies the Mellor and Yamada (1982) level 2.5 turbulent model scheme for vertical mixing, and the Smagorinsky (1963) scheme for horizontal mixing. The model allows for a wet/dry treatment in the intertidal zone, river discharge as a point source with separate temperature/salinity assignments, and hourly wind stress applied uniformly across the surface of the computational domain. The computational domain for this study is a triangular unstructured mesh consisting of two zones: the outer zone which includes all of Casco Bay (see Fig. 2), and a higher resolution nested zone which includes the Harraseeket River in the northwest region of the Bay(see Fig. 3). The Harraseeket zone consists of triangles whose sides are of length 50 meters or less. The triangular grid was created using Triangle (Shewchuk) and BATTRI (Smith et al.*)*, a graphical Matlab interface for Triangle. The domain is enclosed by the boundary curves as shown in Figure 2. The vertical structure is represented by using 11 terrain-following equally spaced levels at each nodal depth. This means that the dye concentration, as well as temperature and salinity is being computed at 10 depths at each node and saved every 15 minutes. Likewise, the current velocities are also computed at the center of each triangle at each of the 10 depths. The shoreline and islands of the outer zone are sampled with nodes at intervals of 150 m or less, and generally at intervals of 900 m along the outer boundary. The curved outer boundary of the Harraseeket zone begins just south of the Royal River in Yarmouth and continues to a location on shore

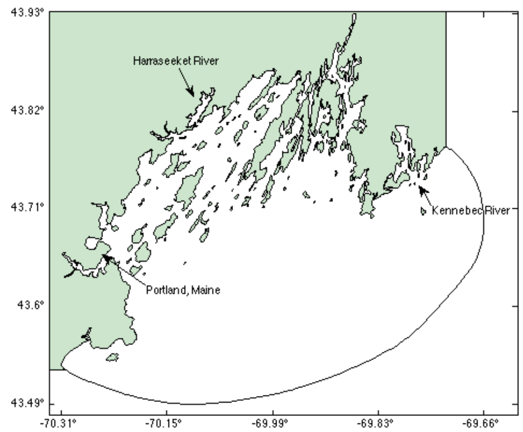

Figure 2. Casco Bay, Maine

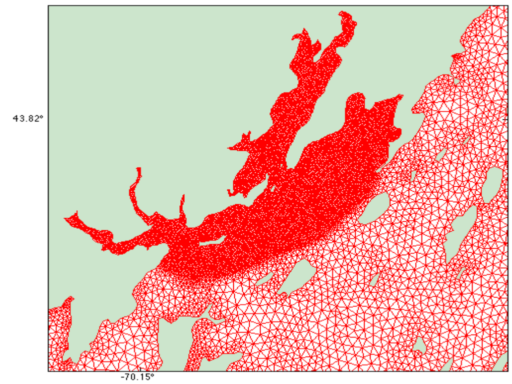

Figure 3. Portion of Casco Bay mesh with nested high resolution mesh of Harraseeket region .

near Little Flying Point in Freeport. The National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed an integrated topographic-bathymetric digital elevation model (DEM) of Portland, Maine (DEM, 2008). This high resolution bathymetric data provides water depths on 10 m squares for all of Casco Bay. The bathymetry for the numerical model used here is derived from this data.

3. Initializing the Model

The hourly wind data from the NOAA buoy # 44007 in Casco Bay for May of 2003 is applied uniformly across the computational domain. During May 11-15, average wind speed was a mild 3.6m/sec with an average direction from the southeast. The National Ocean Service Center (NOS) of NOAA provides historical hourly tidal recordings at the Portland tide gauge (NOS station 8418150), which is located on the Maine State Pier in Portland harbor (http://tidesonline.nos.noaa.gov/). The major tidal constituent in Casco Bay is the semi-diurnal lunar tide (M2) with a period of 12.42 hours. The water levels at this gauge can range up to 2.3 m above mean sea level. The amplitudes and phases for seven tidal constituents, S2, M2, N2, K1, K2, O1, Q1 were interpolated from the ADCIRC Tidal Constituent Database (Mukai et al., 2002) onto the 115 nodes of the outer boundary of the model domain. The ADCIRC tidal data slightly overestimates the M2 and K1 amplitudes at the Portland tide gauge, so these amplitudes were adjusted accordingly.

The ten stations maintained by the Friends of Casco Bay (FOCB) provide a synoptic survey of temperature and salinity for Casco Bay. The FOCB data for May 2003 was kriged onto the nodes of the numerical model to initialize temperature and salinity on the computational domain. In addition, temperature and salinity measurements at buoys 1,2 and 5 were also used in the initialization process.

For small volumes of water, freshwater input from rivers and streams can influence current flows, temperature and salinity. There is some historical stream flow data for the Royal River in Yarmouth, available at the Gulf of Maine Watershed Information and Characterization System (http://gm-wics.sr.unh.edu). The data covers the years 1949-1998. An effort was made to correlate stream flow for the Royal River for May 2003 by comparing its flows with the Kennebec flow rates which are known for May 2003. By comparing flow rates at times when monthly data is available for both rivers, an estimate is made for a flow rate of 6 m^3/sec. There are also 2 small streams flowing into the north area of Harraseeket River. No flow rates could be found for these, but based on comparative size with the Royal River, a flow rate of 0.25 m^3/sec was assigned to each of these streams. Finally, the wastewater treatment plants in Yarmouth and Freeport discharge an average fresh water flow which are taken to be 0.03 m^3/sec and 0.014 m^3/sec respectively.

4. Results

For comparison, the total volume of water in Harraseeket River during low tide is about 3,750,000 m^3. For this study, the Freeport WWTP discharges about 323,000 gallons per day (1222.7 m^3/day).

The FVCOM numerical model was run for one month to simulate the circulation in the Harraseeket River beginning May 1, 2003. The model provides a dye tracer module, which was used to replicate the dye experiment conducted by MDMR during May 13-15, 2003. The dye was inserted in the model beginning at 9:00AM, EDT of May13, and continued for 48 hours. The calculations for determining the model dye concentration follows the description provided in Livingston(2007), assuming a continuous effluent flow of 323,000 GPD from the Freeport WWTP discharge pipe. According to Livingston(2007), the flow rate and dye concentration were checked hourly during daylight hours by analyzing a sample of the effluent from the manhole on Cushing Briggs Road in the outfall pipe. The average concentration of dye over the 48 hours was 5650 PPB. Based on these measurements, a uniform dye concentration of 5650 PPB was applied at the discharge pipe in the model throughout the 48 hour period.

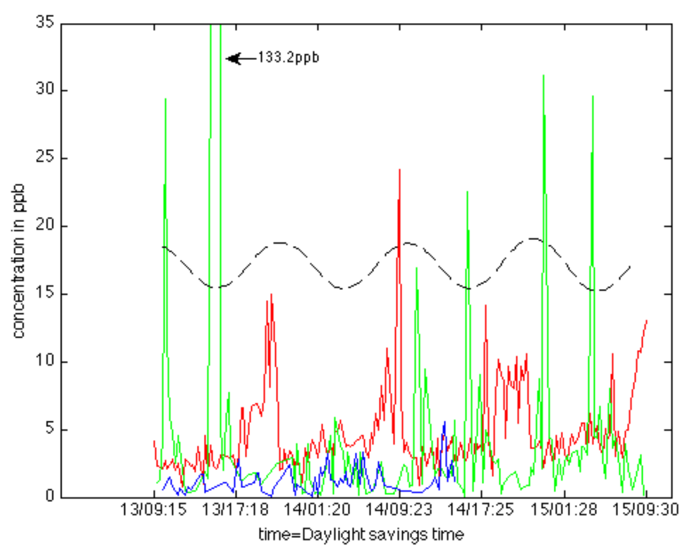

Figure 4. Dye concentrations in PPB: red=Buoy#1, green=Buoy#2, blue=Buoy#5

The dye concentrations for buoys 1,2 and 5 are reported in Appendix B in freeport_append07.pdf. This data of dye concentrations from Appendix B is plotted in Figure 4. All measurements were taken at a depth less than 1m. The tidal elevations from the Freeport Dock data are shown in black to compare the variation in dye concentrations with flooding and ebbing. The sudden spikes in concentrations at Buoys 1 and 2 may be explained partially by three reported stratifications. These occurred at Buoy 2 on May 13 at low flood tide at 16:25 hrs, and Buoy 1 on May 14 at 17:55 and May 15 at 9:25 during high tide. These stratifications of high dye concentrations occurred in the top meter of the water column. In addition, an unintentional slug of dye was discharged on May 13 at 13:30 hrs at slack low tide. At Buoy 2, a reading of 133.2PPB was recorded at 15:30 hours. This probably contributed to the higher concentrations on the flood tide at Buoy 1 beginning at 17:45. The high dye concentrations in Figure 4 for buoys 1 and 2 are separated by roughly 12 hours. The unexpected discharge and the stratifications would affect subsequent measurements, making it difficult to compare observed dye concentrations with the model output.

The dye concentrations shown in Figure 4 can be compared with the model dye concentrations. The model dye concentrations are taken at the closest nodes to Buoys 1,2 and 5, which would be within 20m. In order to highlight the variation of dye concentration with tidal flows, the spikes in concentrations as shown in Figure 4 were removed from the data, and a 4 point running average was applied to lightly smooth the observed data. Results are shown in Figure 5. At Buoy 1, just north of the outfall pipe, the dye concentrations increase with the flood tide, as expected. At Buoys 2 and 5, south of the outfall, the dye concentrations increase with the ebb tide.

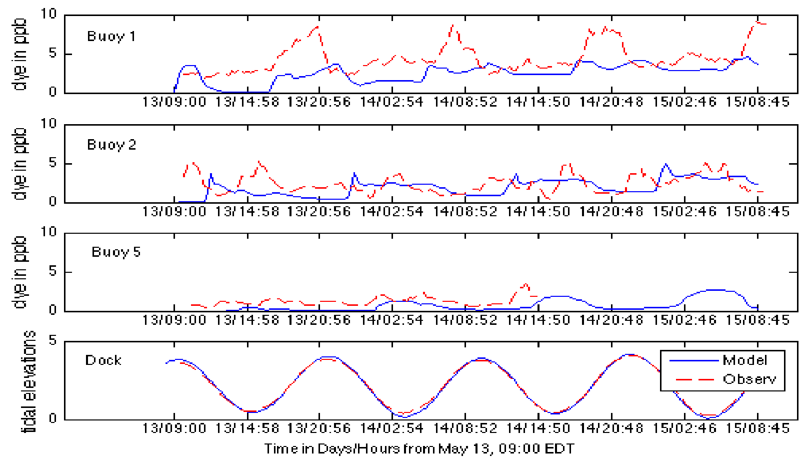

Figure 5. Comparison of dye concentrations at Buoys 1,2,5, and tidal elevations at the Freeport Dock.

The differences in observed and model dye concentrations can be explained partially by a number of factors. The three stratifications discussed above contribute to subsequent fluorometer readings at the buoys, resulting in major fluctuations. During May 13-15, the flow from the discharge pipe varied from 125,000 GPD to 346,000 GPD, with maximum flows during midmorning. The model assumes a continuous flow rate of 323,000 GPD. The dye concentration was checked during daylight hours at the manhole on Cushing Briggs Road in the outfall pipe. The average concentration was 5650 PPB, but varied over the 48 hour period from a low of 3640 PPB to 11200 PPB. The average concentration does not include high readings on the morning of May 14 of 69000,19000, and 18500 PPB starting one hour after high tide. Notice in Figure 5 the rise in dye concentration at Buoy 5 shortly after. The model dye injection assumes a continuous injection of 5650 PPB. Very small eddies can also lead to fluctuations in dye concentrations that may not be seen in the model flow circulation. The stream flow from the two streams at the northwest and northeast regions of Harraseeket River also play a role in the dynamics near the outfall pipe, especially at low tide. The unknown volumes from these streams will also vary throughout the day, and the estimates used in the model may not be accurate. The model shows lower peaks in the dye values at Buoys 1 and 2. The timeseries of values at Buoy 5 is shorter. At all three buoys there is a slight increase in dye concentration over the 48 hour period. Given all the variability of flow rates and stratification issues, the model shows reasonable agreement with the overall variability due to tidal fluctuations and ranges in concentration. The fourth graph in Figure 5 illustrates the close agreement in tidal elevations between the model and the elevation data recorded at the Freeport Dock.

In the report by Livingston(2007), there are graphs showing the results of ten transects of fluorometer readings taken at numerous locations at different times during May 13-15. These same ten graphs appear in the Model-Appendix, where the corresponding model dye concentrations have been included with the concentrations from the study. At each location of each transect, the entire model data was searched for the nearest node at the nearest time a measurement was taken in the study. The results from the model were then plotted with colored squares to compare with the observed transect data that was plotted with colored circles. These ten graphs are used to compare the results from the dye study with the model in space and time.

A. Determine the distance from the outfall where a 400:1 dilution of the effluent occurs.

The numerical model computes the dye concentration at more than 10,000 locations (nodes) in the Harraseeket zone, each at 10 depths from surface to bottom below each node for a total of over 100,000 locations, and is saved every 15 minutes. The model provides the concentrations in PPB. The corresponding dilution is obtained by dividing the mean injected flow rate (5650 PPB) by the concentration at a particular location. The concentration associated with a dilution of 400:1 or less would be 14.125 PPB or higher. During the period May 13-15, the entire model output data set is searched for all those locations where the dye concentration is below the 400:1 dilution at least once. The only location was at the outflow pipe. By comparison, the locations of less than 600:1 dilutions from the model all occurred within 100m of the outfall. Figure 13B in the report by Livingston(2007) shows a dilution of 400:1 or less more than 1000 ft south of the outflow pipe during flood tide of May 13 at 16:26:30 hrs. This may be due to the unintentional slug of dye that was discharged at 13:30 hrs, 2 hours before low tide. Figure 13B also shows dilutions between 400:1 and 1000:1 above the outfall around 19:50 hrs on May 13, 2 hours before high tide. This corresponds to the high concentrations recorded at Buoy 1 just above the outfall beginning at 17:45 hrs. It's possible that such high concentrations were also caused by the unintentional injection of dye at 13:30 hrs. But no dilutions of that magnitude were computed from the model, as shown in the model-Figure 13B in the Model-Appendix.

B. Determine the distance from the outfall where a 1,000:1 dilution of the effluent occurs.

In order for the MDMR to select an acceptable zone around the Freeport WWTP during normal operating conditions, one criteria is that a minimum dilution of 1,000:1 must be met. Commercial shellfishing would be prohibited within a zone where dilution is less than 1,000:1. However, if a malfunction should occur that would lead to a discharge of partially treated effluent, another zone with a minimum dilution of 10,000:1 would be required. Once again, the model output was searched for locations where these dilutions are met at least once during the 48 hour dye injection. The results are shown in Figures 6 and 7. The dilutions below 1,000:1 in Figure 6 all occurred 3m or more below the surface. In the Model-Appendix, Figures 1 and 2 show dilutions below 2000:1 and 4000:1 for comparison. To determine the affect of wind on the spreading of dye at the surface, a separate simulation was conducted with the model. The only change was to replace the May 2003 wind data with the July 2003 data, which is typical of summer winds from the southwest. During the period July 13-15, the average wind speed was 3.7 m/sec and the direction was almost exclusively from the south. But the results as compared with Figures 6 and 7 were not significantly different.

In Figure 13B of the report, dilutions between 1,001:1 and 10,000:1 from the MDMR dye study were recorded in the upper northeastern region of Harraseeket River on late afternoon of May 13 during the flood tide transect. But the model does not show any locations in the upper northeast region with dilutions less than 10,000:1 at this time (see the corresponding Model-Figure 13B in the Model-Appendix). Again, these higher dye concentrations from the study in the upper regions of the estuary during the flood tide may be due to an unintentional slug of dye that was introduced earlier in the afternoon. Table 9 in the report shows a list of samples collected at the Manhole on Cushing Briggs Road. On May 13 at 15:30 hours, low tide, a sample of 11,200 PPB was recorded. To determine the fate

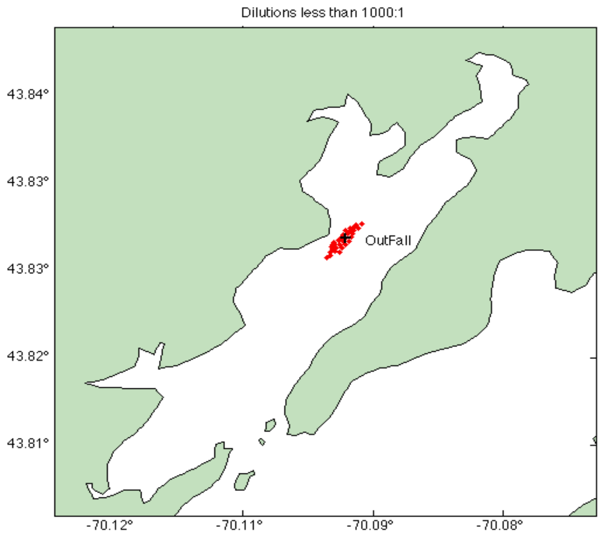

Figure 6. Dilutions below 1,000:1

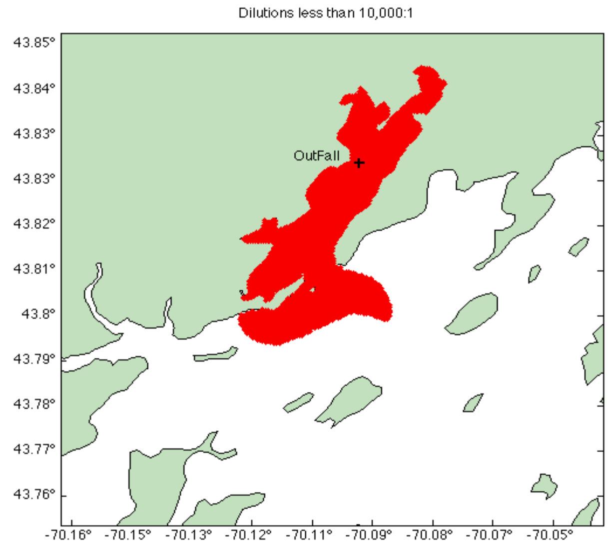

Figure 7. Dilutions below 10,000:1

of this slug of dye, a particle tracking module in FVCOM was used that applies the model velocity field to track a set of particles over a time period. A set of 7 particles was placed at the surface around the outfall pipe and released on May 13 at 16:00 hours at the beginning of flood tide. Two of these particles that started between shore and the outfall pipe moved to the northwest region of the estuary, but the other 5 particles moved to the upper northeast region above Bartol Island in less than 4 hours. Around 20:00 hours, Buoy 1 began recording dye concentrations up to 14.5 PPB. The results from the model do show a slight buildup of dye concentration in the upper northeast region over the 48 hour period of dye injections, but the concentrations never exceed 4 PPB. With regard to Figure 13B in the report, there were dilutions below 10,000:1 in the upper northeast region above Bartol Island around 19:30 hours, and then dilutions greater than 10,000:1 along a section of the transect from Bartol Island toward the outfall. This portion of the transect from Figure 13B is just northwest of the particle paths created from the model that moved closer to the deeper channel, so it's possible that this section of the transect missed the dye slug movement. The readings below 1,000:1 along the rest of the transect to the outfall coincide with the higher readings at Buoy 1.

It's important to make note of this large slug of dye that was injected at the beginning of the 48 hour dye study. It is still in the water, and tends to produce lower dilution samples in some regions than would otherwise be recorded. It's especially important when dye concentrations are extrapolated to higher flow rates from the treatment plant.

C. Determine the distance from the outfall where a 10,000:1 dilution of the effluent occurs.

The MDMR measured dye concentrations outside the Harraseeket River as far as Moshier Ledge and south of Moshier Island. This is where the outflow from the Harraseeket River meets the waters from Broad Sound. Broad Sound is the deepest sound in Casco Bay and is the source of large volumes of deeper colder water that enters the inner regions of Casco Bay. The surface currents in Broad sound can be up to 40 cm/s (1.3 ft/s). During the ebb tide, the water that flows from the

Harraseeket River joins some discharge from the Royal River and the bay between Wolf Neck and Flying Point. The Harraseeket River channel runs directly into Broad Sound channel, and mixes with surrounding waters. The flood tide tends to return this mixed water back through the channel and into Harraseeket River. The steep topographic gradients in this region lead to small eddies and strong mixing. The zone of red dots in Figure 7 shows where a dilution of 10,000:1 or less occurred at least once during the 48 hour dye study.

D. The time it takes for the effluent to travel various distances from the outfall.

In the event of a malfunction at the WWTP which may lead to the release of partially treated or untreated effluent to the bay, the MDMR would need time to announce a temporary closure of commercial harvesting near the outfall pipe. Of course, the movements of partially treated effluents depend on location and tides. For example, near Buoy 1, the surface and bottom speeds during the 48 hour dye study are shown in Figure 8. At the surface, the mean speed is 17 cm/s, while the bottom mean speed is 9 cm/s. But once a particle leaves this location, it enters another location in the velocity field and experiences a different speed and direction. Again, the particle tracking module in FVCOM that applies the model velocity field to track particles over time was used. A set of 17 particles was placed at the surface around the outfall pipe and released on May 13 at 9:00 hours and tracked for four hours. The paths of the particles are displayed in Figure 9. The starting position of each particle is represented by its number in black, while the red numbers denote the final position after four hours. The black line segment of 500m is a reference to distance travelled by each particle. Similarly, particle trajectories in Figure 10 show the dispersion over four hours beginning with the next flood tide which began around 15:00 hours. The particle paths in Figures 9 and 10 only show the distance particles may travel from the outfall during the first four hours of the ebbing and flooding periods when currents are strong. But the dilutions along these paths can't be known if there is a faulty discharge without knowing the conditions at the plant and the degree at which the effluent is untreated. The figures can only suggest a zone for temporary closure within a four hour window until more is known about a malfunction at the treatment plant.

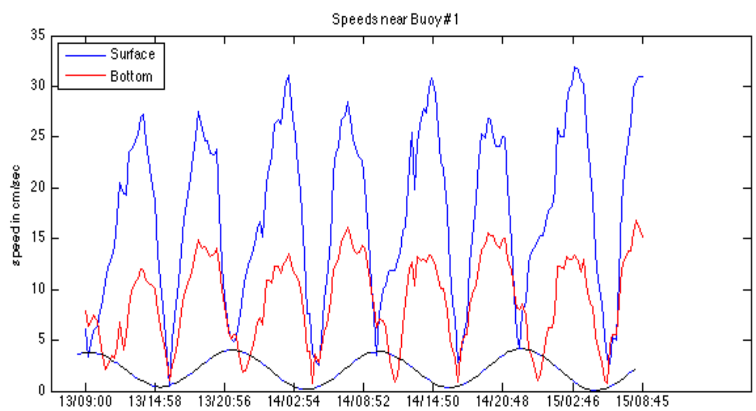

Figure 8. Surface and Bottom speeds near Buoy #1
Tidal elevations are shown in black

E. Residence time following a faulty discharge.

In the event of a possible malfunction which might release partially treated or untreated effluent to the River, the MDMR may want to know how long it will be before harvesting can begin again after the faulty discharge has been contained. The dye injection stopped on the morning of May 15 both in

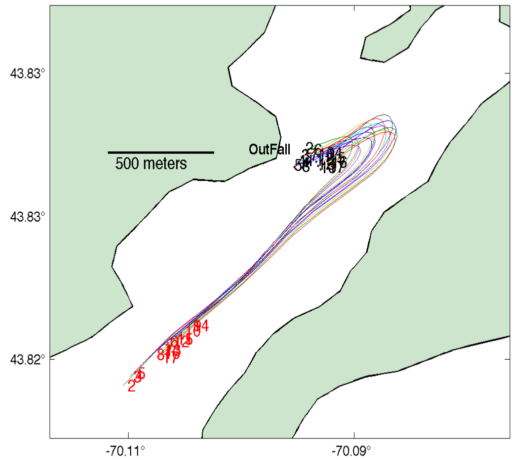

Figure 9. Particles at ebb tide

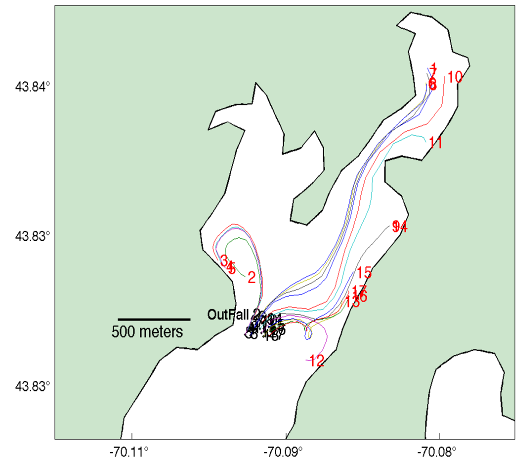

Figure 10. Particles at flood tide

the MDMR dye study and the numerical model. The numerical model continued to measure dye concentrations up to May 17, and the concentrations are shown at the locations of buoys 1,2 and 5 in Figure 11. This figure is the same as Figure 5, but extends to May 17. At each buoy, the concentrations have decreased to less than 3 PPB by midnight of May 15, which meets the criteria for safe commercial harvesting.

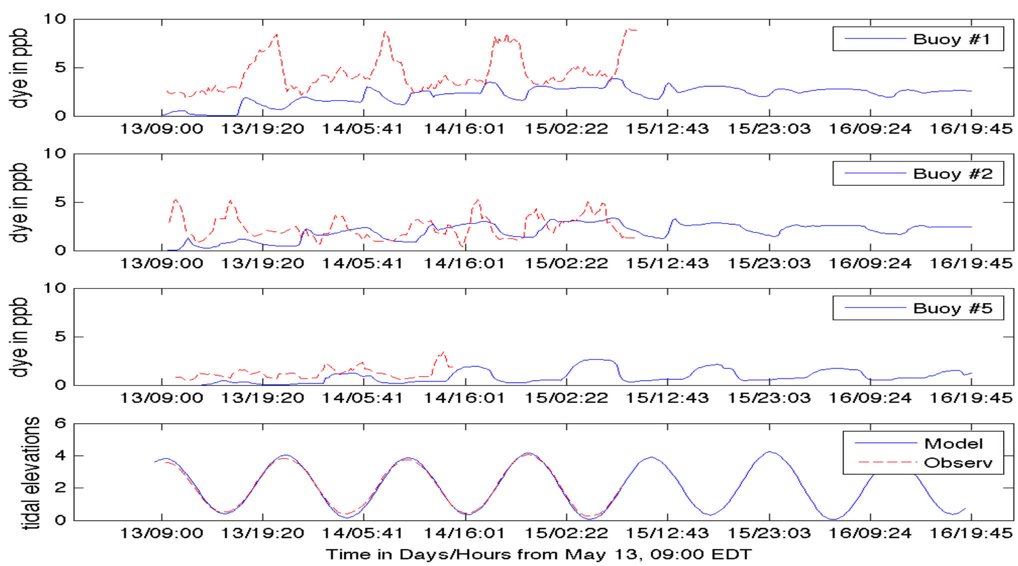

Figure 11. Dye concentrations during May 13-17, 2003

F. Dilution zone for a WWTP maximum flow of 750,000 GPD.

The Freeport WWTP has a maximum licensed design flow of 750,000 GPD. In the report of Livingston(2007), Section 7.1, a number of calculations were carried out to interpolate the dye study data for larger flows of 400,000 GPD and 550,000 GPD at the outfall pipe. The calculations indicate that the area impacted by dilutions less than 1,000:1 south of the outfall do not change with increasing

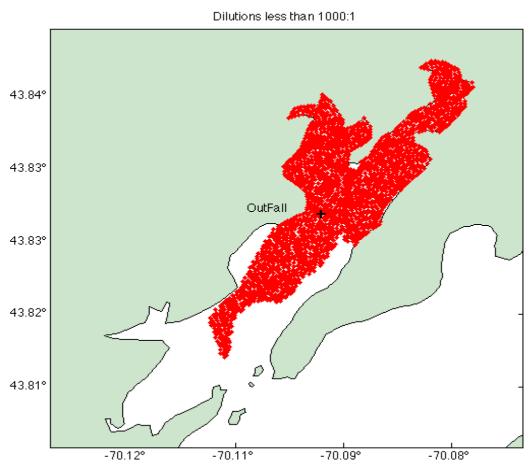

Figure 12. Dilutions less than 1,000:1 with a uniform flow rate of 750,000 GPD.

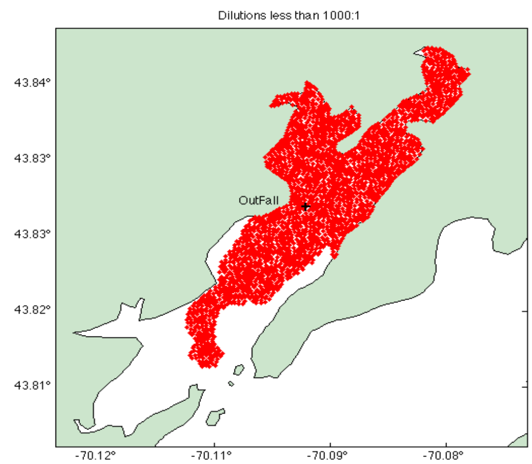

Figure 13. Dilutions less than 1,000:1. Created from 323,000 GPD model with correction factor 2.32.

flows, but there is an increase northeast of the outflow pipe. To relate to this, the numerical model was run again but using the higher uniform flow rate of 750,000 GPD at the outfall pipe to see how the 1,000:1 dilution zone would change. As with Figure 6, the model output was searched for locations where the 1,000:1 or less dilutions are met at least once during the 48 hour dye injection. The dye concentration remained at 5650 PPB. The results are shown in Figure 12. Assuming a uniform flow rate of 750,000 GPD, the 1,000:1 zone covers the estuary above the outfall, and extends southward almost to the outlet to Casco Bay.

To address the process of applying a linear interpolation of dye concentrations for higher flow rates, as formulated in the report (Section 7.1), a similar procedure was applied to the model dye concentrations for comparison. Since the flow rates remain constant in the model, and don't vary during the day, the correction factors as shown in Table 20 of the report are simply calculated for the model in terms of flow ratios. For example, by using the 323,000 GPD model simulation to predict the 750,000 GPD flow rates, the correction factor would be 750/323= 2.32. When the 323,000 GPD model run is adjusted with this correction factor, the results are shown in Figure 13. The comparison with Figure 12 is close, but not exactly the same, in part because the changes in the velocity field are not linear in the model equations, so current speeds do not necessarily follow the same ratio of 2.32 throughout the estuary.

To examine this further, both the 323,000 GPD and 750,000 GPD simulations were adjusted for 550,000 GPD, a flow rate that was discussed in the report. For the 323,000 GPD run, the correction factor is 1.7; for the 750,000 GPD run, the correction factor is 0.73. The 1,000:1 dilutions for 550,000

GPD from these interpolated flow rates are shown in Figures 14 and 15. The 1,000:1 dilution zones are similar, but the coverage from the 323,000 GPD model run extends to the south a little more.

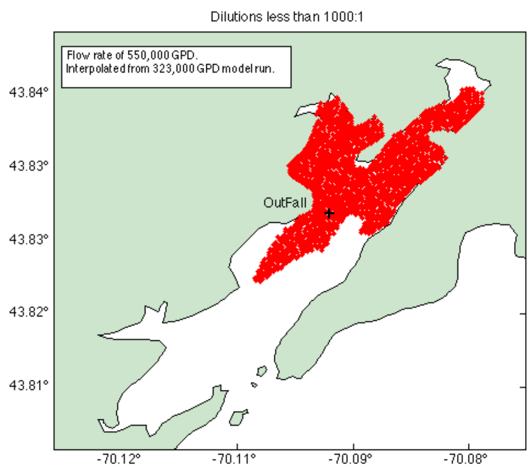

Figure 14. Dilutions less than 1,000:1 with flow rate of 550,000 GPD, interpolated from 323,000 GPD model run.

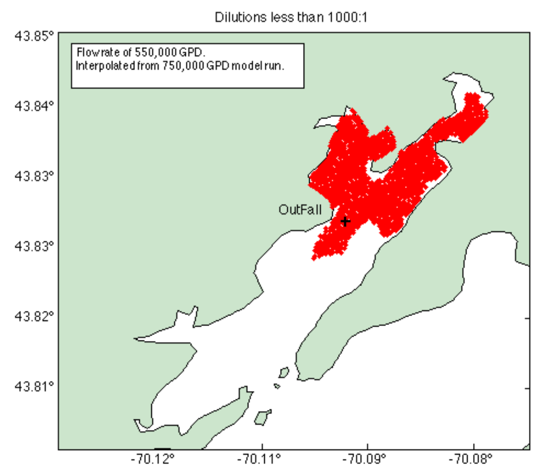

Figure 15. Dilutions less than 1,000:1 with flow rate of 550,000 GPD, interpolated from 750,000 GPD model run.

5. Comparison of model with observed transects

The report of Livingston(2007) includes ten figures of the EPA boat transects. Each transect shows the fluorometer readings of dye concentrations near the surface at different times over the dye injection period May 13-15. Each transect can be compared with dye concentrations from the model. The results of the model were searched to find the nearest location and nearest time of every fluorometer reading from each boat transect. The model results were plotted in colored squares along with the observed readings that were plotted with corresponding colored circles for each of the ten transects. The model squares will be within 25m of the corresponding observed circles. The time difference between observed and model samples is less than 8 minutes. These differences in space and time can result in slight differences between observed and model readings. Moreover, a dilution of 1,000:1 corresponds to a dye concentration of 5.65 PPB; a dilution of 10,000:1 corresponds to 0.565 PPB. Thus, a concentration of 0.564 PPB would be colored blue, while that of 0.565 would be magenta, so colors for squares and circles may be different, but the actual concentrations can be quite close. Changes in flow rates from the outfall at night and during the day can also alter the circulation, especially at slack tide.The figures appear in the Model-Appendix. They are labelled as Model-Figure 11, 13A, 13B, 14, 15, 16, 17, 18, 19, 20 to coincide with the figure numbers in the report.

In general, the model data coincides well with the observed data, but there are locations where the model data disagrees. For example, below the outfall pipe near the town dock in Figure 11, the observed data shows dilutions between 1,001:1-10,000:1 that occurred around 12:15 hours, while the model data shows dilutions greater than 10,000:1. A reading of 29.4 PPB was recorded at Buoy 2 at

10:15 south of the outfall. There doesn't seem to be an explanation for this spike at Buoy 2, but if the reading is real, the ebb tide could have moved this high dye concentration south, resulting in higher fluorometer readings during the transect sampling period.

The differences in Model-Figure 13B were covered earlier in Section A. of the Results. In the Model-Figure 14, there is a west-to-east section below the outfall where model dye concentrations are generally about 20m south of the transect samples and run about 0.3 PPB higher. In Model-Figures 16 and 20, the model dyes are slightly lower than the observed readings in the southern sections of the transects. The transect in Model-Figure 16 took place a few hours after the high readings at the manhole (see Table 9 of the report) from 11:20 to 12:32 hours on May 14 of 69000,19000, and 18500 PPB starting one hour after high tide. These unexpected high concentrations would have moved south on the ebb tide and may have led to higher fluorometer readings at the southern part of the transect. In Model-Figure 20 from about 17:41:59 to 17:54:29 hours, the observed dye concentrations are higher than the model concentrations; the differences are all less than 0.62 PPB. There are four observed data points in Model-Figure 17 that appear to be on land. Perhaps the coordinates were entered in the final report incorrectly. These explanations for dye differences between observed and model results can only be viewed as speculation. There may be other reasons for the differences, but the variability in dye injections and flow rates at the outfall pipe cannot be ignored.

6. Conclusions

The FVCOM numerical coastal model has been applied to the dispersion of the effluent from the Freeport WWTP in Harraseeket River. The dye study reported in Livingston(2007) was used to compare the numerical model performance with observations. Although the model assumes uniform flow from the discharge pipe, and uniform injection of the dye over a 48 hour period, and does not include the unintentional high dye injections, the model manages to reproduce the general features of the May 2003 dye study. The important result to be obtained is the establishment of a safe zone about the outflow pipe in which shellfishing is to be prohibited. The zone produced by the model extends farther south of the outflow than the current prohibitive zone authorized by the MDMR, but would allow shellfishing along the southeast side of the River on the Wolf Neck western shoreline even when the plant's maximum flow rate of 750,000 GPD is used.

If a numerical coastal model can be used to predict an appropriate prohibitive zone around a waste water treatment plant, the MDMR could benefit from such an analysis. The information from the model results could also provide important features to consider prior to a dye study, such as designing careful boat transects to capture the main features of the dye dispersion, and select stationary buoy locations in the main stream of the dye dispersion for better data gathering. Another benefit of the numerical model study is that it is able to sample the dye at many more locations than is possible with transects and buoy locations. In particular, the dye concentrations can be determined from surface to bottom, where currents are very different. In the Harraseeket River, the water is well mixed, but at other locations, there can be salt wedges, upwelling, and moving eddies that would distribute the dye concentrations in complex ways. Also, a number of various scenarios can be conducted to answer “what if” questions, such as determining the prohibitive zone for higher flow rates or strong persistent winds that can move surface waters of effluent to unexpected locations.

In order for such a numerical model to be applied, some local data should be obtained first to adjust the model to the particular region. The data to collect should include temperature and salinity profiles in key locations around the site. Temperature and salinity data for this experiment was available at the five buoy locations and the Freeport dock, but temperature and salinity at the outer edges and near river outlets of the study site is important for interpolating and initializing the model. Since the water in Harraseeket River is well mixed, any density currents produced by salinity changes would be minimal compared with the tidally driven currents. Also, current measurements at various depths in a few locations should be taken to validate the model. For this study, there was no current data that might require adjustments to bottom friction or horizontal diffusion beyond the default settings.

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