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# Memorandum

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| Subject | **Town of Orleans, MA**<br>**Water Quality and Wastewater Planning**<br>**Task Number 4.a.4 – Adaptive Management Plan**<br>**Draft Technical Memorandum on MEP Study Update Monitoring** |
| Project Number | 60476644 |
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## 1. Introduction

Orleans is developing an overall plan for wastewater and water quality planning that includes both structural and non-structural (non-traditional) components. Traditional collection and treatment is complemented by non-traditional solutions such as shellfish cultivation, floating constructed wetlands (FCW) and permeable reactive barriers (PRB). To evaluate this mixed planning approach to meeting water quality goals, it is expected that the Massachusetts Estuaries Project (MEP) “Linked Watershed-Embayment Model” (Howes, Ramsey and Kelley, 2002) will be used. This model provides an analysis of the impacts of decentralized solutions on overall nutrient concentrations at specific locations within waterbodies.

The original MEP model was set up, calibrated and verified using field data from 2001 through 2004. To accurately represent the impacts of nitrogen removal from different sub-embayments of the main estuarine systems in Orleans, the model should be based on current conditions. The purpose of this Technical Memorandum (TM) is to confirm that the data that was consolidated and documented in TM 4.a.1: *Baseline Monitoring* is applicable to updating the existing (MEP) model. Additional data that is required for the model to be parameterized, calibrated and verified are also identified.

## 2. Background

The Linked Watershed-Embayment Model is the foundation of the MEP Reports prepared for over fifty embayments throughout southeastern Massachusetts, including Pleasant Bay and Nauset Harbor. To provide a realistic picture of these complex ecological systems, the MEP model accounts for a number of features. Factors that impact nutrient loading to estuaries are a key aspect of accurate modeling. The MEP model accounts for land-based nutrient sources, attenuation, recycling and regeneration within sediment. Circulation, basin structure and depths as well as tidal hydrodynamics are also part of the model. Incorporating the interactions amongst these physical attributes of the estuary allows accurate prediction of the spatial distribution of nitrogen impacts. Model outputs are also validated using site specific data for salinity, total nitrogen and tides.

The following summarizes the field data used in the MEP model:

a. Hydrodynamics

- Bathymetry, basin structure, dispersion; and
- Site specific tide and current records.

b. Watershed Nitrogen Loading

- Watershed delineation;
- Stream flow and nitrogen load;
- Land-use analysis based on GIS as well as realistic estimates of septic nitrogen load; and
- Attenuation from streams, ponds and other wetlands (often field-validated).

c. Other data

- Salinity surveys
- Rate of nitrogen recycling based on sediment core evaluations;
- Dissolved oxygen record;
- Macrophyte survey; and
- Infaunal survey.

Because of this level of site-specific detail, the MEP model can be used to determine an estuary's nitrogen sensitivity and nitrogen threshold loading levels or Total Maximum Daily Loads (TMDLs). The model can also predict changes in nitrogen concentrations at specific locations that will occur as a result of changes to nitrogen loading rates. Once it has been set up for a particular estuarine system, this model is a powerful nitrogen management planning tool, enabling the impact of possible nitrogen-removal measures to be compared to TMDL goals. In addition, the model can be recalibrated to reflect the dynamic nature of the watershed, both in terms of changes in land-use characteristics as well as alterations in water flow, circulation and nutrient levels. Testing the results of different scenarios in a model that can be updated to reflect the dynamic nature of estuarine systems is critical to decision making and adaptive management.

## 3. Data Requirements of MEP Model

### a. MEP Model Setup and Requirements

The MEP "Linked Watershed-Embayment Model" is a set of estuary-specific numerical models of both fluid transport as well as water quality. It links watershed inputs to circulation and nutrient concentrations. The RMA-2 and RMA-4 models developed by Resource Management Associates (King, 1990) are used for characterizing and predicting tidal circulation and flushing as well as concentrations of constituents in the water column. The RMA-2 model is a two dimensional, depth-averaged finite element numerical representation used to simulate the fluid dynamics of estuarine systems.

Setup of RMA-2 includes the following steps:

- Grid generation (mesh);
- Boundary condition specification;
- Calibration; and
- Validation.

The hydrodynamic model grid includes a series of nodes where grid lines connect. These nodes define the spatial dimension and the resolution of computational operations within the estuary. The grid is generated using bathymetric survey data that characterizes the varying depths of Pleasant Bay and Nauset Harbor estuaries. Aerial photographs were used to determine land boundaries, as well as surface area of salt marsh. Bathymetric surveys were taken using an Odem HydroTrac fathometer mounted on a 16 feet motorized skiff. Positioning data were collected using a differential GPS. Data were recorded digitally in real time, and were corrected for changes in tide level also logged during the survey period.

There are three types of boundary conditions in RMA-2; slip, tidal, and freshwater. Slip boundaries constrain direction of water flow to be shore parallel. Tidal elevation boundary conditions are established by the elevation of surface water that varies over time. This is measured as tide range and is defined by the offshore tide gauge. This boundary condition quantifies the head pressure of the system and is the basis of the circulation modeling. Freshwater boundary conditions are used for streams or rivers that input significant surface water flows. Once the grid and boundary conditions are established, the model is calibrated using tide measurements.

Tide gauges are placed at the inland extent of the estuary, in a central location in the main body of the embayment, as well as offshore to establish the boundary condition. The circulation through the system is measured by gauges within the sub-embayments. The model is verified by predicting tides at inner tide gauge locations, and by comparing modeled versus observed tide ranges. To improve model accuracy, friction coefficients are varied to match bottom types. The final calibration is based on a close match between measured and modeled tides in each of the locations where tide data was collected.

For model validation, an additional model run is made to compare computed versus observed tide data. In addition, current velocity measurements are made over a single tidal cycle using Acoustic Doppler Current Profiling (ADCP) for comparison with model predictions of flow rates. Data is collected along a transect at major transition points in the system, both during flood and ebb tides. Flow rate comparisons provide an independent validation of the hydrodynamic model to ensure that the model accurately represents the dynamics of the system.

**b. Water Quality**

The RMA-4 model is capable of simulating the process of advection and dispersion in aquatic environments and was employed by the MEP to study the effects of nitrogen loading in estuary systems. It is the constituent transport model counterpart of the RMA-2 hydrodynamic model. This model is able to compute changes in concentration of molecules of interest, both spatially and temporally.

Required inputs to the RMA-4 model include:

- Grid generation;
- Computed water elevations and velocities (validated as part of RMA-2 setup);
- Mass loading rate of parameter to be modeled; and
- Dispersion coefficients.

The grid mesh and the resulting hydrodynamic simulations derived from RMA-2 are used as inputs to the RMA-4 model. Water depth and velocity are computed at all nodes of the mesh. The transport of nutrients by advection is captured by this fluid model.

For total nitrogen (TN), the mass loading input is derived from estimates of wastewater loads from septic and treatment facility discharge, as well as nitrogen loads coming from impervious surfaces, fertilizer, benthic flux and atmospheric deposition. For each watershed, loading rates are established by a rigorous process that includes parcel-based land use evaluations, stormwater measurements and sediment core analysis.

Dispersion is modeled by setting the values of coefficients in different regions of the estuarine system based on a number of factors. Selection of dispersion coefficients (m2/second) used for each sub-embayment were developed during the calibration process. As the model was run, dispersion coefficients were incrementally changed until nitrogen concentrations calculated by the model match measured data. For model calibration, the mid-point between maximum and average modeled TN was compared to mean measured TN data at each monitoring station. The calibration target is expected to fall between the modeled mean and maximum TN because the monitoring data are collected during mid ebb tide. TN concentrations are linked to tides in the model. The model also simulates salinity and TN, and can therefore be compared to actual field measurements. Final dispersion coefficients are then compared to published values observed in estuaries.

The RMA-4 model can be utilized to predict both spatial and temporal variations in total nitrogen and other constituents for a given embayment system. In 10-minute intervals, the model computes concentrations over the entire finite element grid. For the MEP, the RMA-4 model was used to predict tidally averaged total nitrogen concentrations under different load scenarios. For Orleans, this model can serve as a valuable tool for estimating the effects of different water quality management strategies.

## 4. Data Needs for Model Update

Data for the following parameters are used to develop, calibrate and validate the RMA-2 and RMA-4 models:

- Tide elevations and ranges (RMA-2);
- Tidal velocity measurements (RMA-2);
- Bathymetry (RMA-2);
- Total nitrogen concentrations (RMA-4);
- Salinity (RMA-4);

- Nitrogen load data (RMA-4); and
- Background nitrogen from ocean (RMA-4).

To revise the hydrodynamic model (RMA-2) for Nauset Harbor and Pleasant Bay, there are a number of assessments required to enable recalibration. An updated bathymetric survey and tide gauge measurements are needed because the inlet conditions that established the model's grid and boundary conditions (respectively) have changed. Three surveys that include these parameters have been completed recently for Nauset Harbor and Pleasant Bay as noted:

- Dredging study of Nauset Harbor (Woods Hole Group, 2015, report pending);
- Sidescan sonar for bathymetry in Pleasant Bay and Nauset Harbor (Center for Coastal Studies/Cape Cod National Seashore, 2014 – 2015, report pending); and
- Tide monitoring including time series monitoring of the flood tide cycle at the Nauset inlet (SMAST report pending).

These data should be sufficient for generating an updated grid and boundary condition specification, but may need to be supplemented with updated tide gauge data at inland stations to recalibrate this model.

For the water quality model (RMA-4), it is expected that updated total nitrogen and salinity measurements from the 34 Pleasant Bay monitoring stations as well as the ocean reference station will be adequate for calibration and verification. In Nauset Harbor, only three of the 15 stations used for model calibration and verification have current data. Therefore, to calibrate this model, three years of data from ten additional monitoring stations are recommended. Updated values for the nitrogen concentration in the ocean reference station should also be used when the model is re-run.

MEP uses 26.25 mg N/l, and 90 percent of actual water usage from town records to predict the mass of nitrogen entering an estuary from an average single family residential property. To enable MEP model runs to more accurately verify the results of the amended Comprehensive Wastewater Management Plan (CWMP), updated water use records and land use information should be used in order to revise the nitrogen load data for input to RMA-4. In addition, the concentration of TN below the soil absorption systems of a statistically significant number of septic systems should be measured. This will validate the foundational assumption that is used to calculate the nitrogen load input to RMA-4.

## 5. Recommended Plan

To update the MEP model for Pleasant Bay and Nauset Harbor, the first step is to prepare a Scope of Work with SMAST. The following specific items must be confirmed as being needed or meeting needs:

a. Adequacy of recently-completed bathymetric and tide surveys in Pleasant Bay and Town Cove;

b. Number and locations of monitoring stations needed in Nauset Harbor;

c. Number of years of data needed from additional monitoring stations in Nauset Harbor;

d. Need and locations of additional stations to acquire tide data on elevation, velocity and ranges;

e. Updated land use (collected for amendment of CWMP); and

f. Advisability of revising the assumption used for septic nitrogen load value.

Once the details of these items are defined, a Scope of Work will be submitted as TM 4.b.4: *MEP Study and Report Updates and Implementation Analysis Plan*. A key aspect of this Scope will be initiating water quality monitoring at additional stations in Nauset Harbor during the 2016 season.

## 6. References

King, Ian P. (1990). "Program Documentation - RMA2 - A Two Dimensional Finite Element Model for Flow in Estuaries and Streams." Resource Management Associates, Lafayette, CA.

Howes, B.L, J.S. Ramsey, and S.W. Kelley. 2002. Nitrogen Modeling to Support Watershed Management: Comparison of Approaches and Sensitivity Analysis. Final Report to MassDEP and USEPA. Published by MassDEP. 94pp