University of Massachusetts Dartmouth
The School for Marine Science and Technology

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Dear Mr. Peschel:

As requested, we have reviewed the document[1] detailing the hydrodynamic and nitrogen model of the Great Bay Estuary relative to its appropriateness to support management decisions related to nitrogen concentrations as affected by nitrogen loading and system hydrodynamics. Our review also considered whether the model was appropriate for predicting nitrogen in-situ concentrations under different nitrogen loading scenarios. As part of this review, it was also necessary to examine if there is sufficient evidence to claim that nitrogen is a primary cause of water quality impairment and eelgrass loss in the Great Bay Estuary. It appears that the hydrodynamic/nitrogen model is sufficiently robust, calibrated and verified to make useful predictions of nitrogen concentrations and gradients in the Great Bay Estuary under different loading scenarios. However, it does not appear that the cause of ecological impairments in this estuary resulted from or recovery is being prevented by nitrogen enrichment, which is fundamental to conducting effective management. We recommend that the primary cause(s) of eelgrass loss be clearly determined prior to implementing any management actions.

Great Bay Estuary System Total Nitrogen Model[1] Review: HDR has been contracted to develop a hydrodynamic/nitrogen model of the Great Bay Estuary. They are using HDR's ECOMSED hydrodynamic model, which uses a three-dimensional time-dependent estuarine circulation model[2]. The model domain includes, Great Bay, Little Bay, upper and lower Piscataqua River and Cocheco River and includes an appropriate offshore boundary area. The model uses weather conditions (wind and incident solar radiation), river inflows, tide, temperature and salinity (at open boundaries) to predict water surface elevation, water velocity (3-D), temperature, salinity and turbulence throughout the estuary. The model has been used for similar studies around the world (see HDR report). As per good practice, the model output is compared to field observations to assess performance.

Hydrodynamic Model calibration used stage data from 2010, 2011 and 2017, of which the 2017 parameterization of the boundary salinity and temperature was the "best" of the 3 years, as new data was available. Temperature calibration (comparing predicted and observed) was very good for each of the 7 monitoring stations sampled throughout each of the 3 years. Salinity is highly variable due to the inter-annual differences and seasonal differences in freshwater input. Nonetheless, the model was well calibrated for salinity at most stations (less so for Squamscott River in 2010 and Lamprey River in 2011). The model is very well calibrated for temperature and salinity at both Great Bay stations in each year. These results are due to the stronger horizontal gradients in salinity in Squamscott and

[1] HDR Memorandum to Dean Peschel by C. Mancilla, T.W. Gallagher and N. Joshua. *Development of Great Bay Estuary System Total Nitrogen Model*, December 2, 2019.
[2] Blumberg and Mellor (1987) with Mellor and Yamada (1982) level 2 ½ turbulent closure scheme. Wetting/drying (flooding/draining tidal flats) was simulated (Flather and Heaps 1975) and incorporated into ECOMSED.

Lamprey basins compared to the more stable salinities in Great Bay. The salinity calibration is sufficient to give confidence in the model and it appears adequate to examine the effect of nitrogen loading on concentrations throughout the estuary.

Once the hydrodynamic model was calibrated and verified, a nitrogen model was added. This follows standard practice and was the approach used by the Massachusetts Estuaries Project (MEP) to allow for prediction of nitrogen concentrations and distribution (spatial gradient) in tidal estuaries under different nitrogen loading conditions. However, unlike the MEP where the sources and sinks of nitrogen were available and sediment recycling directly measured, the GBES nitrogen model was not as well supported by site-specific data. Therefore, the decision by HDR to build the nitrogen model based upon conservative transport was appropriate. It is important to note that the Great Bay Estuary does not appear to have the same level of water column-sediment exchange as the smaller MEP estuaries where the sediments are highly organic, resuspension is very low and nitrogen regeneration and denitrification play a significant role in nitrogen cycling. Great Bay has larger sandy and intertidal areas and sediment resuspension that supports the HDR approach. On a practical note, estuarine modeling is a sequential process where nitrogen models are developed and tested and may be refined as new datasets become available. Developing the conservative nitrogen model will allow testing of nitrogen loading and water column response in the Great Bay System. Moreover, since the model actually calibrated, the approach reduced the need for a model which includes all sources and sinks at this time.

It appears that the non-point and point sources loads are relatively well constrained. Point source loads are directly measured and account for about one third of the total loading, which makes up for some of the uncertainty in the non-point source data. The comparisons of the nitrogen loading from the 7 rivers measured versus computed show good agreement, although a root mean square (rms) error or other estimate of the fit to the 1:1 line would be helpful. Based upon visual inspection, the fit is sufficient to support the nitrogen model.

Comparisons of the predicted nitrogen concentrations and observed nitrogen concentrations on a daily basis shows good agreement at each of the 5 monitoring stations. While there are some periods of disagreement (Great Bay 2017), the main Great Bay station and other 3 stations generally agreed well with the observations in the time-varying conservative transport nitrogen model. Overall, this analysis lends confidence that the model is adequately calibrated and validated for predicting water column nitrogen concentrations under different nitrogen loading scenarios.

If nitrogen is a primary factor controlling eelgrass coverage/recovery (see next section), then nitrogen loading ~200 kg/ha/yr results in a growing season TN concentration of 0.36 mg/L. This is a relatively low TN concentration and was found by the MEP to generally support high quality eelgrass habitat in shallow basins. Under this loading condition one would not reasonably expect that resulting TN concentrations would be significantly impacting eelgrass resources. In Great Bay eelgrass has had high coverages at historically higher TN concentrations (>0.4 or even 0.5 mg/L). This represents evidence that a 200 kg N/ha/yr loading or even greater loadings should be protective of eelgrass in this system (if nitrogen is even the principle factor causing or contributing to eelgrass impairment). It is important to note that our previous analysis indicated that the Eelgrass Coverage-NLM relationship (Latimer and Rego 2010) should not be used to define an acceptable nitrogen loading threshold for a TMDL. However, if that approximate approach to threshold analysis were to be used, a value of 200 kg N/ha/yr is accommodated as there is no justification for selecting a lower value, e.g. 100 kg N/ha/yr. The eelgrass coverage and nitrogen concentration data from Great Bay are consistent with the

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higher estimate, as protective of eelgrass resources, although it is likely, based upon historical data, that even a higher loading rate may still be protective of eelgrass habitat.

Linkage Between Nitrogen and Eelgrass Decline is Not Supported by Observations: Although the hydrodynamic/nitrogen model has value for predicting changes in nitrogen concentrations and resolving gradients throughout the Great Bay Estuary, the role of nitrogen in resource impairments within this system has not been sufficiently documented by available data. Therefore, it is likely that managing the water and habitat quality within this estuary based upon nitrogen probably won't have the positive ecological effects that are sought. Reviewing the variety of documents indicates the following:

(a) N concentrations are relatively low within this estuary compared to other New England estuaries and chlorophyll-a concentrations are also low (typically <5 ug/L) compared to basins impaired by nitrogen enrichment. This does not indicate a nitrogen impaired system.

(b) Dissolved inorganic nitrogen concentrations have historically been on the level of 0.1 mg N/L or ~7 uM, above the level that is generally thought to create non-limiting nitrogen availability for phytoplankton (e.g. phytoplankton production has sufficient N so N is not the limiting factor). This availability of N suggests that other factors are controlling phytoplankton biomass in this system. The issue of nitrogen controlling phytoplankton biomass and therefore water column transparency is not supported by the system response to nitrogen reductions in wastewater discharges from Dover and Rochester WWTFs. Even with the large decrease in nitrogen loading, there was little observed change in phytoplankton biomass, again calling into question if nitrogen is an important factor in water quality and eelgrass decline in this system.

(c) Eelgrass has historically been prevalent at higher nitrogen concentrations than in the present period of decline. Valiela and Cole (2002) noted that TN loadings were calculated to be about 250 kg/ha-yr in the mid-1990s when there were extensive eelgrass beds within the Great Bay system.

(d) Eelgrass in this system has been lost from wasting disease and other factors have been indicated as to controlling coverages (light attenuation from non-phytoplankton, e.g. CDOM, turbidity from resuspension, unstable or unsuitable sediments, etc). As noted in the 2014 Peer Review[3], "*Eelgrass growth, abundance and distribution are also controlled by temperature, nutrient availability (primarily nitrogen and phosphorus), tidal range, water motion, wave action, water residence time, bathymetry, substrate type, substrate quality, severe storms, disease, plant reproduction and anthropogenic disturbances* […] (Kenworthy, 13). As of this writing it does not appear that alternative causes of the recent eelgrass decline have been examined except for documented losses due to wasting disease in the previous decade. Furthermore, eelgrass has historically declined and rapidly recolonized over short time scales (1-3 years). At present, the question is why has there not been the same full recolonization as previously observed, even though there is large coverage of eelgrass in Great Bay.

(e) Two other pathways for nitrogen to effect eelgrass coverages is through large accumulations of drift macroalgae and stimulation of epiphytic growth on eelgrass leaves. Macroalgae has been examined relative to eelgrass coverage/decline but does not appear to explain the decline and cannot explain the decline/recolonization cycles in previous years. As stated in the Peer Review, "*The data and arguments provided in the DES 2009 Report to support the weight of evidence for a relationship between nitrogen concentration, macroalgal abundance and eelgrass loss are neither compelling nor scientifically defensible.* [Subsequent data from 2008, 2009, and 2010 indicate]

[3] Bierman, V., Diaz, R., Kenworthy, W. and Reckhow, K. February 13, 2014. Joint Report of Peer Review Panel for Numeric Nutrient Criteria for the Great Bay Estuary. New Hampshire Department of Environmental Services. June, 2009.

macroalgae were not limiting eelgrass growth" (Kenworthy, 27). Similarly, although epiphytes have been observed on Great Bay eelgrass the levels have not been sufficient to explain the declines in eelgrass coverages. This was also pointed out in the Peer Review[2], "If *epiphytes are not contributing significantly to light attenuation, and chlorophyll-a is only a minor contribution to light attenuation, nitrogen cannot be directly implicated as the major cause of light attenuation and eelgrass declines in the Great Bay estuary"* (Kenworthy, 12).

Based upon: 1) the lack of clear linkages between nitrogen concentrations and phytoplankton biomass, 2) the fact that phytoplankton appear to play a minor role in light attenuation and 3) the lack of observed effects on eelgrass of epiphytes and macroalgae, it is not proper to implement nitrogen management actions to restore eelgrass in Great Bay at this time. Restoration of eelgrass coverages demands a clear understanding of the cause of the decline so that the costs of actions can be justified and the desired response can be predicted with a reasonable degree of certainty. Determining the cause(s) of the eelgrass decline is fundamental to design of any actions for promoting eelgrass coverage. This is standard practice in estuarine restoration. The lack of a clear linkage was also stated by the Peer Reviewers, "*There is no basis for a scientifically defensible linkage between nitrogen impairment and eelgrass impairment presented in the report"* (Kenworthy, 19).

We appreciate the opportunity to review and comment on the modeling and approaches for nitrogen threshold development for eelgrass restoration/protection in Great Bay. However, at this time we strongly recommend that the cause(s) of the recent decline in eelgrass coverage be quantitatively determined and that further nitrogen reductions not be implemented until a reasonable understanding of the factors controlling eelgrass dynamics in this system is developed. Fortunately, if nitrogen was involved in the eelgrass loss in Great Bay, it appears that the current nitrogen loading level (post reductions in Dover and Rochester WWTF) should be adequately protective.

Sincerely,

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