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MEMORANDUM

TO: John C. Hall

FROM: Bill Hall and Ben Kirby

DATE: October 30, 2018

RE: Applicability of Latimer and Rego Susceptibility Assessment to Great Bay Estuary

The journal article by Latimer and Rego (Empirical relationship between eelgrass extent and predicted watershed nitrogen loading for shallow New England estuaries. Estuarine, Coastal and Shelf Science 90 (2010) 231 – 240), presents a relationship between eelgrass loss and areal nitrogen loading rate that is a function of estuarine susceptibility. As Estuarine Susceptibility decreases, the reported relationship becomes more tenuous. Estuarine Susceptibility is described in a supplement with the article that relates susceptibility to nitrogen-induced eelgrass impairment based on measures of dilution potential and flushing potential.

Dilution Potential

Latimer and Rego (2010) define Dilution Potential based on the inverse of the estuarine volume (cubic meters) adjusted from national criteria done by NOAA (Bricker et al., 1999), as follows (Table 1):

Table 1

Dilution Potential	Percentile	1/Volume (m^{-3})	Equivalent Volume (m^3)
Low	33rd	$<8.45 \times 10^{-7}$	$< 1.18 \times 10^{6}$
Moderate	67th	$> 2.15 – 8.45 \times 10^{-7}$	$1.18 – 4.65 \times 10^{6}$
High	99th	$< 2.15 \times 10^{-7}$	$> 4.65 \times 10^{6}$

The adjustment was made to scale down the size class for the estuaries in the Latimer and Rego (2010) study from the much larger estuaries evaluated by NOAA.

Flushing Potential

The supplement to Latimer and Rego (2010) describes flushing potential as follows:

> Tidal range data were obtained from the nearest NOAA tidal station to each estuary (NOAA, 2009a, b). Freshwater influence is calculated as the ratio of freshwater input and estuarine volume. The criteria for categorizing freshwater influence are different between the NOAA assessment (Bricker et al., 1999) and a recent published article (Scavia and Liu, 2009). However, this difference only affected 12 of the 62 estuaries. For those estuaries that were different, the NOAA categories are consistently larger; that is, NOAA's assessment gave greater freshwater influence than Scavia. When combined with tidal range, this difference affected the same 12 estuaries; and again, the NOAA criteria gave higher values of estuaries with greater flushing potential than Scavia (see table).

The supplement does not indicate how Flushing Potential is evaluated. It refers to tidal range and freshwater influence (the ratio of freshwater input to estuarine volume). Latimer and Rego discuss Flushing Potential evaluation with regard to assessments by NOAA (Bricker et al., 1999) and Scavia and Liu (2009). A review of Scavia and Liu (2009) indicates that an "Analysis of the efficiency factor suggests that estuaries with the ratio of river inflow to estuarine volume (Q/V) greater than 2.0 per year are less susceptible to nutrient loads, and those with Q/V between 0.3 and 2.0 per year are moderately susceptible." (at 3474) In this paper, estuarine efficiency refers to phytoplankton growth (i.e., the conversions of nitrogen load to algal production). Although Latimer and Rego (2010) combine tidal range with freshwater input to assess Flushing Potential, Scavia and Liu (2009) do not.

> We explored how predicted estuarine efficiency, $\varepsilon=\alpha/21.8$, varied with different estuarine properties and found the most useful relationship with the ratio of river discharge to estuarine volume (Q/V) (Figure 3, Supporting Information). <u>Note that Q is the river discharge, not the sum of that discharge and ocean inflow</u>, which is convenient because the latter is more difficult to estimate.
>
> (Scavia and Liu at 3476 – 3477) (Emphasis Added)

It is not apparent how Latimer and Rego (2010) factor in tidal range when evaluating susceptibility with regard to Flushing Potential.

<u>Overall Susceptibility</u>

The overall susceptibility for eelgrass to respond negatively to increasing nitrogen load is evaluated based on a consideration of the Dilution and Flushing Potentials, as described in the supplement to Latimer and Rego (2010):

> The classification of the estuaries into susceptibility categories is determined by heuristically combining the dilution and flushing potential classes. For example, an estuary with low flushing potential and low dilution potential will fall into the high susceptibility category. Thus, for those in this category, hypothetically, a given nitrogen loading rate would have greater ecological effect. In contrast, those estuaries that have a high flushing potential and high dilution potential will hypothetically exhibit lesser effects for a given nitrogen loading rate.

Consequently, if dilution potential and flushing potential are high, susceptibility is low. If both values are low, susceptibility is high. However, if the two values give opposing results (e.g., one high potential, the other a low potential) it is not apparent how susceptibility is evaluated. To get a sense of what this heuristic evaluation looks like, the data summary provided in the Latimer and Rego (2010) supplement was sorted to evaluate how the various potential evaluations were combined to assess susceptibility. (Table 2).

A review of the data in Table 2 indicates that estuaries are predicted to have low susceptibility when the Flushing and Dilution Potential paired evaluations are designated as high and moderate. Estuarine susceptibility is predicted to be moderate when the Flushing and Dilution Potential paired evaluations are designated as high and low or moderate and moderate. Finally, estuarine susceptibility is predicted to be high when the Potential pairs are designated as low and moderate.

Table 2 – Overall Susceptibility Evaluation from Latimer and Rego (2010)

Flushing Potential	Dilution Potential	Susceptibility	Count
High	Moderate	Low	6
High	Moderate	Moderate	1
High	Moderate	High	-
High	Low	Low	-
High	Low	Moderate	5
High	Low	High	-
Moderate	High	Low	7
Moderate	High	Moderate	-
Moderate	High	High	-
Moderate	Moderate	Low	-
Moderate	Moderate	Moderate	2
Moderate	Moderate	High	1
Moderate	Low	Low	-
Moderate	Low	Moderate	-
Moderate	Low	High	-
Low	High	Low	-
Low	High	Moderate	9
Low	High	High	-
Low	Moderate	Low	-
Low	Moderate	Moderate	-
Low	Moderate	High	5

Evaluation of Great Bay Estuary

An evaluation of the Flushing Potential and Dilution Potential for Great Bay Estuary was prepared based on a review of the Hydrological Parameters for New Hampshire's Estuaries. (Phil Trowbridge, 2007; PREP Reports & Publications. 130. Available online at https://scholars.unh.edu/prep/130). This PREP document presents estimates of the surface area, depth, total volume (mean water, mean high water, mean low water), and freshwater volume (mean water) for the various aggregate waterbodies that make up the Estuary. In addition, the report also provides estimates of the average daily flow for the rivers within the Great Bay Estuary watershed. These parameters were used to develop Flushing Potential and Dilution Potential estimates for Great Bay, Little Bay, and the Great Bay Estuary. (Table 3)

Table 3 – Susceptibility Evaluation for Great Bay Estuary

Waterbody	Volume at MWL (m^3)	$1/V_{mean}$	Dilution Potential	River Flow (cfs)	Q/V (1/yr)	Flushing Potential
Great Bay	2.25E07	4.45E-08	High	565.5	2.6E-04	Low
Little Bay	4.01E07	3.37E-08	High	80.1	2.1E-05	Low
Great Bay – Little Bay	6.26E07	2.92E-08	High	645.6	1.1E-04	Low
Great Bay Estuary	1.77E08	8.03E-09	High	1090.6	8.7E-05	Low

Based on this characterization, Great Bay Estuary and its sub-areas would be characterized as "moderate" for susceptibility because Dilution Potential is "high" and Flushing Potential is "low". However, this assessment does not include a consideration of tidal range. As noted in the discussion above, Latimer and Rego (2010) implied that tidal range is an important consideration with regard to Flushing Potential, but they did not explain how this parameter was factored into their analysis.

Scavia and Liu (2009) did not consider tidal range (e.g., ocean inflow) because it is difficult to estimate. However, they did describe how they believed Flushing Potential influenced the ability of phytoplankton to grow in response to nutrient load.

> In this analysis, efficiency appeared to decrease roughly with the inverse square root of Q/V: $\varepsilon = 0.908(Q/V)^{-0.47}$ ($R^2 = 0.53$), where ε represents mean values arising from the 75 estimated normal distributions. This is logical because load generally increases with inflow (Q) and, for a given estuarine volume, one would expect the system to be less efficient in processing that load and, in fact, be overloaded for high values of Q. Conversely, for a given nutrient load, larger volumes should allow more time for biogeochemical processing and thus more efficient conversion. (at 3476 – 3477).

As described above, increased flow for a given estuarine volume is associated with decreased efficiency (i.e., conversion of nutrient load into phytoplankton biomass) because it decreases residence time. Tidal flushing also influences residence time. Based on the hydrological parameters for Great Bay Estuary summarized by Trowbridge (2007), tidal range (e.g., tidal prism) can be compared with the mean estuarine volume of the estuary. (Table 4)

Table 4 – Tidal Exchange in Great Bay Estuary

Waterbody	Vol. at MWL (m^3)	Vol. at MHW (m^3)	Vol. at MLW (m^3)	Tidal Prism (m^3)	Prism/V_{MHW}	Prism/V_{MWL}
Great Bay	2.25E07	4.17E07	4.62E06	3.71E07	0.89	1.65
Little Bay	4.01E07	5.06E07	2.97E07	2.09E07	0.41	0.52
Great Bay – Little Bay	6.26E07	9.23E07	3.43E07	5.80E07	0.63	0.93
Great Bay Estuary	1.77E08	2.32E08	1.25E08	1.07E08	0.46	0.61

The tidal exchange in Great Bay Estuary is very large, with 52% - 165% of the mean water level volume exchanged with each tidal cycle. This high level of exchange results in less time for biogeochemical processing of nutrient loads, reducing susceptibility from "moderate" to "low."

<u>Conclusion</u>

Latimer and Rego noted "the ecological response to nitrogen loading to an estuary will be modulated by its physical characteristics." (at 234). Based on the hydrodynamic characteristics of Great Bay Estuary, overall the system would be classified as low susceptibility for nutrient impacts based on a consideration of Dilution Potential and flushing due to tidal exchange. This classification is confirmed when the actual eelgrass extent and nitrogen loading rate are considered relative to the findings in Latimer and Rego, as illustrated below for Great Bay.

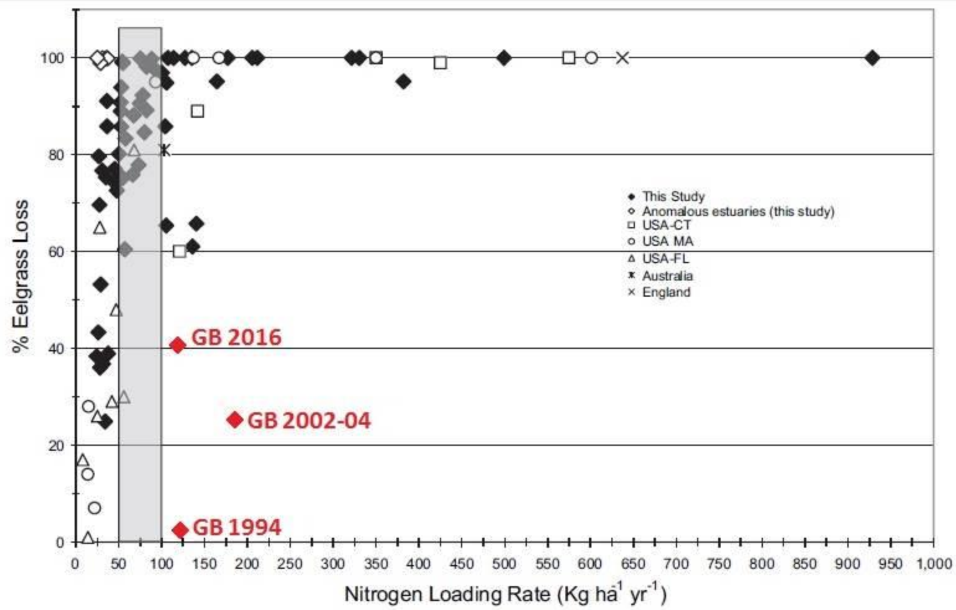

Fig. 3. Plot of eelgrass loss (percent) vs. nitrogen loading rate (Kg N ha^{-1} yr^{-1}) (including other published values). Data sources: (Valiela and Cole, 2002; Steward and Green, 2007; Vaudrey, 2008b); note not all of the data from the literature are for *Zostera Marina*. Gray bar is the loading threshold range from the literature 50 - 100 Kg ha^{-1} yr^{-1}).

The figure illustrates the response of Great Bay eelgrass loss to nitrogen loading rate based on information developed by the University of New Hampshire (Jackson Laboratory) and the Piscataqua River Estuary Partnership (PREP). The Great Bay response data are superimposed on the estuary response data provided by Latimer and Rego (2010) (at 236). Whereas Latimer and Rego reported that nitrogen loading rates greater than 50 Kg/hectare/year are likely to ha a significant deleterious effect on eelgrass habitat extent with 100% eelgrass loss at loading rates greater than 100 Kg/hectare/year, nitrogen loading rates to Great Bay have always exceeded these values while maintaining eelgrass habitat at levels well above most estuaries with loading rates well below 50 Kg/hectare/year. If we assume that the relationship developed by Latimer and Rego is reasonably accurate, then the hydrodynamic and other characteristics of Great Bay Estuary must predispose the estuary to very low susceptibility and, consequently, the Latimer and Rego relationship does not apply to Great Bay Estuary.