Evaluating the Efficacy of Nitrogen Control Measures for the Great Bay Estuary:

A Synopsis of Relevant Ecological Studies and Nutrient Trend Assessments

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EXECUTIVE SUMMARY

Great Bay estuary has been studied extensively from a number of perspectives. These evaluations include eelgrass mapping, tidal river dissolved oxygen (D.O.) monitoring and analyses, time variable data collection and assessment, as well as, hydrodynamic modeling. Based upon the information available, it is apparent that a number of physical, biological, and chemical factors influence the health of eelgrass in this system and mediate the impact of nitrogen on key water quality components. The available data and assessments show that changing nitrogen levels over time have not caused any apparent change in phytoplankton growth in the system which typically is the leading indicator of culture eutrophication in estuarine systems. Consequently, the available data and assessments indicate that nitrogen plays a minimal role in system water column transparency and, therefore, controlling nitrogen to improve system transparency to enhance eelgrass growth will not produce significant ecological benefits. Studies for the estuary have conclusively demonstrated that the existing system transparency is controlled primarily by natural processes including color dissolved organic matter (CDOM) entering the tidal rivers, turbidity, wind induced resuspension and seasonal rainfall patterns. Tidal river eelgrass populations cannot be enhanced as the existing level of CDOM and turbidity in these areas due to natural conditions precludes eelgrass reestablishment to historical levels.

D.O. levels in Great Bay, Little Bay and the Piscataqua River are generally good to excellent and do not appear to be significantly influence by phytoplankton growth occurring in the system. In the upper tidal rivers, such as the Squamscott River, the Cocheco River and the Lamprey River, periodic low D.O. occurs but is not correlated with elevated algal growth. In general, it appears that sediment oxygen demand (SOD) as well as other physical/hydrodynamic conditions in the tidal rivers are the primary factors influencing the occurrence of low D.O. The degree to which nitrogen controls can influence these conditions is not known at this time; however, it is expected to be relatively minor given that low D.O. conditions are occurring even on the tidal rivers with minimal algal growth (e.g., the Lamprey River averages 3 µg/l chlorophyll-a). To a certainty, a reduction in algal growth will not eliminate the low D.O. conditions found in these waters, as previously assumed. Further analysis of the factors influencing low D.O. conditions should occur before a nutrient reduction strategy is implemented to address this component.

The estuary does appear to be experiencing increased macroalgae growth at least intermittently, primarily in Great Bay. Macroalgae growth has not been reported as an issue affecting the tidal rivers and would not be expected to impact those areas given the physical setting. The ecological ramifications of increased macroalgae growth on Great Bay and the degree to which nitrogen concentrations are influencing these events has not been assessed. Macroalgae growth was reported to be minimal in the early 1980s through mid-1990s when annual average inorganic nitrogen levels were ranging approximately 0.1-0.15 mg/l. To avoid exacerbating macroalgae growth and the adverse ecological conditions that may be associated with excessive macroalgae growth, it is suggested that inorganic nitrogen levels in Great Bay and Little Bay be limited within this range. As macroalgae growth is an issue only from June to October and the system detention time is relatively short (about a week), it is also recommended that control strategies focus on this time frame for limiting inorganic nitrogen loads to the system.

Finally, in light of these conclusions, the approach used by New Hampshire Department of Environmental Services (DES) in the document entitled "Numeric Nutrient Criteria for the Great Bay Estuary" (June 2009) (hereinafter "2009 Criteria Report"), which focused on total nitrogen (TN) control to significantly improve system transparency and eliminate low D.O. conditions in the tidal rivers, should be withdrawn. Instead, an adaptive management approach should be implemented to assess the efficacy of inorganic nitrogen control on macroalgae populations in Great Bay using a 0.1-0.15 mg/l annual average inorganic nitrogen concentration range as the target. Implementing moderate biological nutrient removal (BNR) reductions, should be sufficient to achieve the target range and control macroalgae growth without having to implement limits of technology.

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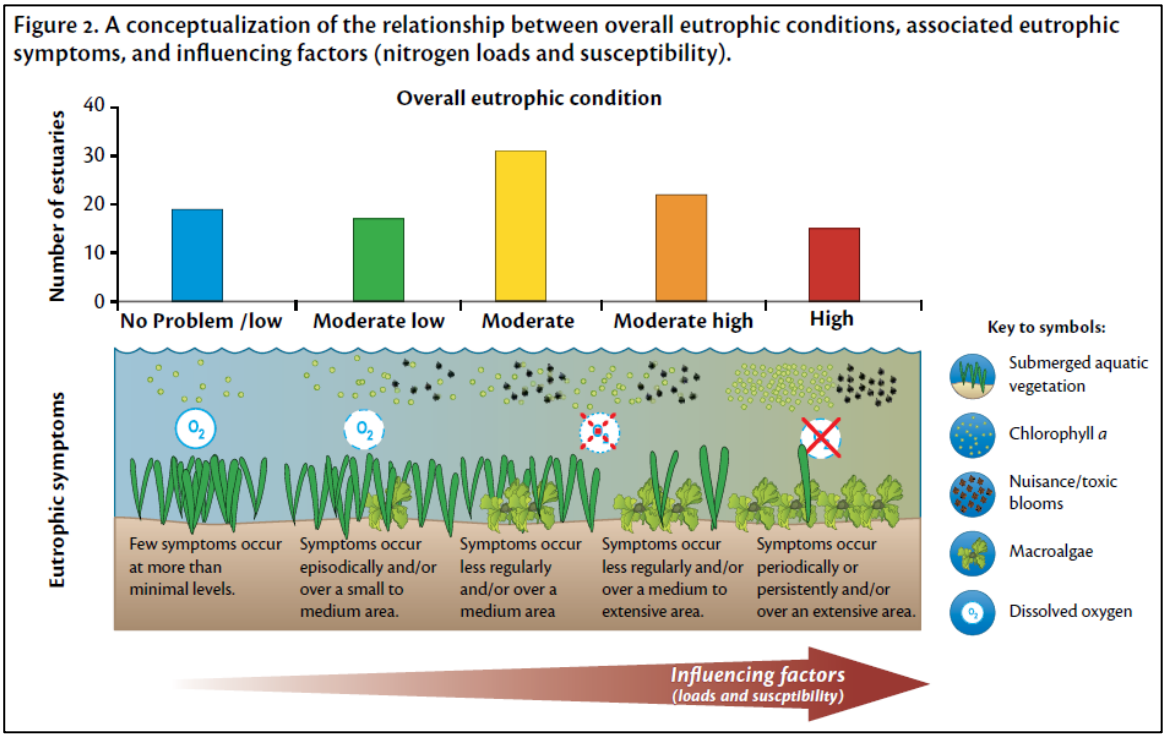
I. Introduction

In 2009, DES prepared the 2009 Criteria Report for the purpose of translating the state's narrative water quality standard for nutrients into numeric nutrient criteria.[1],[2] DES has used the 2009 Criteria Report as the basis for listing the Great Bay Estuary as nutrient impaired and therefore, EPA has included nutrient limits (3 mg/l TN) in National Pollutant Discharge Elimination permits for facilities in the Great Bay Estuary watershed. This paper will review the methodology used by DES in the 2009 Criteria Report including the scientific studies and reports relied on in developing the document; give an overview of the analyses and data collected after the 2009 Criteria Report was released; and finally, provide a technical evaluation of the scientific defensibility of the approach used to develop the 2009 Criteria.

II. 2009 Numeric Nutrient Criteria for the Great Bay Estuary

The 2009 Criteria Report is based upon a conceptual model of estuarine eutrophication used by the National Oceanic and Atmospheric Administration (NOAA)[3] relating external nutrient inputs to primary and secondary symptoms of eutrophication (see figure below).[4] Under this conceptual model, the primary symptoms of nutrient enrichment include phytoplankton blooms (measured by chlorophyll-a concentrations) and the proliferation of macroalgae. Secondary symptoms include the loss of submerged aquatic vegetation (e.g., eelgrass) and low D.O. concentrations.



[1] Documents previously provided to the peer reviewers in their initial peer review packet will be referenced hereafter with a small description of the document followed by "PR Doc. No." with the corresponding document number given in the packet. For instance, the first document on the list would be "Pennock 2004, PR Doc No. 1." The peer review packet is available at http://www.portsmouthwastewater.com/peerreview/index.html.

[2] 2009 Criteria Report, PR Doc. No. 8.

[3] 2009 Criteria Report, PR Doc. No. 8, at 4.

[4] NOAA, *Effects of Nutrient Enrichment in the Nation's Estuaries: A Decade of Change, Key Findings* (2007), at 1, Fig. 2, *available at* http://ccma.nos.noaa.gov/publications/eutroupdate/Key_findings.pdf.

The following discusses how the conceptual model was applied by DES to develop numeric criteria for TN to protect eelgrass, avoid macroalgae proliferation, and eliminate exceedances of the 5 mg/l minimum D.O. numeric criterion for the Great Bay Estuary.

A. Eelgrass Protection and Restoration

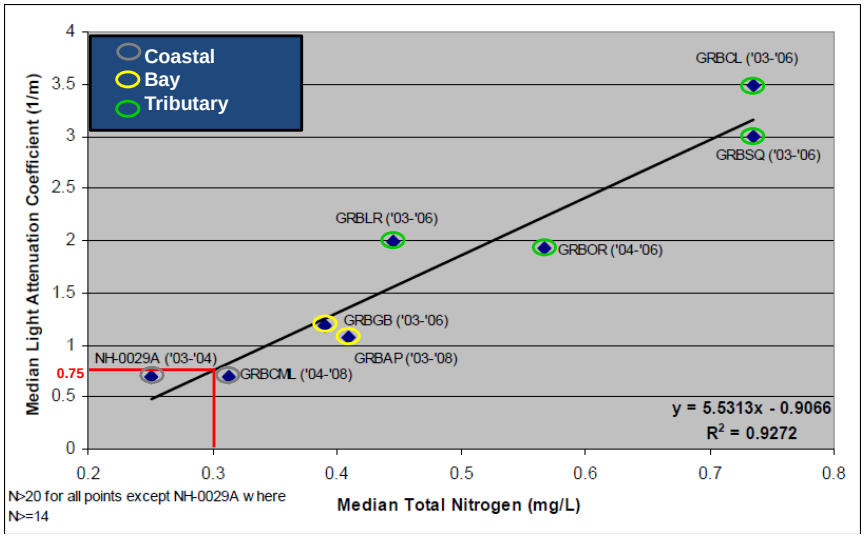
The conceptual model relating the adverse effects of excessive nutrients on eelgrass is primarily premised on the assumption that eelgrass loss is attributed to reduced water clarity.[5] Thus, the model assumes excessive nutrients contribute to eelgrass losses by causing increased phytoplankton blooms (which decrease water clarity) and promote the proliferation of epiphytes and ephemeral macroalgae species. Phytoplankton blooms and epiphyte proliferation block sunlight from reaching the leaf of the eelgrass.[6] Macroalgae block sunlight and compete with eelgrass for rooting sites on the sea floor. When the amount of light reaching the leaf is sufficiently reduced, eelgrass is lost from the affected area.

The nitrogen threshold for the protection of eelgrass was derived using a "weight of evidence" approach, considering: (1) the threshold for macroalgae proliferation, (2) regressions between TN and the light attenuation coefficient, (3) offshore waters background TN concentration, (4) reference concentrations in areas of the estuary which still support eelgrass, and (5) the thresholds that have been set for other New England estuaries.[7] The various thresholds represented by the evidence classes are summarized in the 2009 Criteria Report[8] and tabulated below:

Evidence	Threshold TN (mg/L)	Comment
Macroalgae	0.34 – 0.38	See discussion below
Light attenuation	0.25	3.0 meter restoration depth
	0.27	2.5 meter restoration depth
	0.30	2.0 meter restoration depth
Offshore boundary	0.20	Estimated median for Gulf of Maine
Reference site	0.34	75th Percentile for Portsmouth Harbor
Other Estuaries	0.35 – 0.38	From estuaries on Cape Cod

Based on a consideration of this evidence, DES proposed numeric nutrient criteria for TN based on the regression between multi-year average TN and light attenuation. Using a plot of median light attenuation coefficient versus median TN for the various water quality monitoring stations throughout the estuary (tidal rivers, bay and harbor), DES developed the regression in Figure 39 from the 2009 Criteria Report.[9] Figure 39 is presented below with the type of physical setting (estuary mouth/coastal, bay, and tributary) labeled to illustrate the locations of the various sampling stations and the criterion value selected to protect eelgrass growing at a depth of 2.0 meters (mean tidal level).

[5] *See* 2009 Criteria Report, PR Doc. No. 8, at 55.
[6] Epiphyte proliferation is not a significant contributor to eelgrass impairments in this system. *See* Attachment 1-Memorandum of Agreement Meeting Minutes, Re: Transparency, Macroalgae and Epiphyte Impacts to Eelgrass in the Piscataqua Estuary Assessment, at 1-2 (July 29, 2011) (see comments by Dr. Fred Short). Moreover, the numeric nutrient criterion for TN was premised on the effect of nutrients on water clarity.
[7] *See* 2009 Criteria Report, PR Doc. No. 8, at 16.
[8] 2009 Criteria Report, PR Doc. No. 8, at 66.
[9] 2009 Criteria Report, PR Doc. No. 8, at 67, Fig. 39.



Based on this relationship, DES predicted that attaining a median TN concentration of 0.30, 0.27, and 0.25 mg/L would produce corresponding light attenuation coefficients of 0.75, 0.60, and 0.50 per meter respectively, elsewhere in the system. The TN and transparency condition selected is that occurring at the mouth of the Harbor. The TN criteria and the corresponding light attenuation coefficients are intended to ensure a minimum light transmission of 22% at the restoration depth to support eelgrass (including an offset for epiphyte effects). In developing this regression, DES noted a Piscataqua Region Estuaries Partnership (PREP) study which characterized the various physical factors influencing light attenuation in the Great Bay system.[10] This study determined the significant components affecting light attenuation are water (32%), colored dissolved organic matter (CDOM, 27%), non-algal turbidity (29%) and phytoplankton chlorophyll-a (12%).[11] Of these, the conceptual model chosen only relates TN to phytoplankton effects. The 2009 Criteria Report also claims (but provides no analysis in support) that nearly half the non-algal turbidity (representing particulate organic matter and inorganic solids) is causally linked to TN concentrations based on a series of regression analyses.[12] Consequently, DES concluded that this component of light attenuation is also a function of the TN concentration.

As discussed above, the final TN criteria were primarily derived from a regression analysis relating light attenuation and TN. In plotting data from widely varying locations and habitats (tidal rivers, the bay, and mouth of the estuary), the assessment assumed a direct "cause and effect" relationship between TN and transparency. However, as will be discussed in greater detail later, the analysis accounted for none of the physical or chemical differences which influence transparency at the various locations and whether or how TN influences phytoplankton levels (the only route by which TN can impact transparency).[13] Nor did the analysis account for any confounding or covarying factors that might otherwise explain the regression (e.g., dilution, wetlands, CDOM inputs, turbulent mixing, watershed particulate runoff, etc.). Consequently, contrary to the conclusions in the 2009 Criteria Report, the analysis did not show that changes in TN concentration changes over time actually caused any increase in phytoplankton chlorophyll-a anywhere in the system, a decrease in system transparency or an increase in non-algal turbidity.

Most importantly, there was also no evaluation showing that changes in eelgrass populations coincided with decreases in water clarity over time.[14] Eelgrass cover in Great Bay was considered to be fully attaining designated uses throughout the period from 1990 through 2005 and then experienced a sudden, dramatic decrease in 2006, followed by a multi-year period reduced cover then slow recovery. If TN was responsible for this condition in accordance with the conceptual model, there should be a significant increase in TN and chlorophyll-a, and a decrease in transparency, between 2005 and 2006 with ongoing elevated concentrations of TN and chlorophyll-a

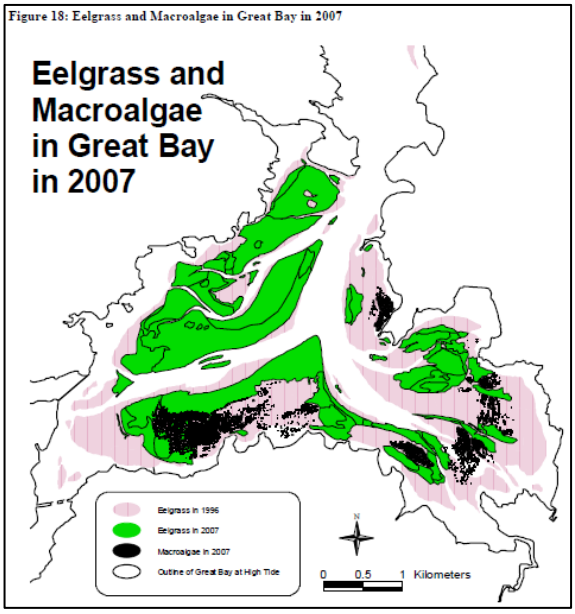
[10] 2009 Criteria Report, PR Doc. No. 8, at 61.
[11] *See* 2009 Criteria Report, PR Doc. No. 8, at 61.
[12] *See* 2009 Criteria Report, PR Doc. No. 8, at 64 – 65.
[13] *See* Chapra Analysis, PR Doc. No. 22.
[14] Later in this report we will present detailed information on short term changes in water clarity, associated with excessive rainfall, that appear to explain the pattern of changing eelgrass cover observed in Great Bay.

thereafter. These demonstrations would be necessary to confirm that the conceptual model relating TN to eelgrass loss is appropriate for this estuary and that the proposed TN criteria are needed to protect eelgrass. It should be noted DES did show presence/absence of eelgrass was related to transparency in upper tidal rivers but they never confirmed TN was the factor causing the poorer transparency in these areas. There was no demonstration that areas of lower eelgrass growth in Little Bay or the Piscataqua River were related to inadequate transparency.[15]

B. Macroalgae Growth

The macroalgae assessment within the 2009 Criteria Report is very limited. The conceptual model relating nutrients to macroalgae proliferation is premised on the concern that elevated nitrogen concentrations may stimulate excessive macroalgae growth that displaces eelgrass. The 2009 Criteria Report included Figure 18 depicting where macroalgae were growing in 2007.[16]

Figure 18: Eelgrass and Macroalgae in Great Bay in 2007



It should be noted that most eelgrass loss and macroalgae growth occurred in the southeast portion of the bay which is (1) shallower, (2) less flushed and (3) is the furthest away from the major tributary sources of TN. The best eelgrass habitat remained along the areas that receive the greatest hydraulic influence from tidal flows.

DES developed a TN criterion to minimize macroalgae growth assuming that in order to limit such growth TN must be reduced by 10 – 20% from a concentration of 0.42 mg/L (the median concentration from 2000 – 2008) based on one macroalgae survey from 2007.[17] This approach has some rather obvious uncertainties. The analysis did not evaluate or explain why macroalgae populations were not adversely impacting eelgrass populations in the 1990s when inorganic nitrogen levels (the nitrogen component that stimulates macroalgae growth) were actually higher than the levels observed in 2007 nor did the analysis show that the 2007 macroalgae level was actually limiting eelgrass regrowth. Subsequently, the eelgrass population increased by 400 acres from 2009-2011. This indicates that the macroalgae have not prevented eelgrass recolonization of beds lost in 2006.

Monitoring data for dissolved inorganic nitrogen (DIN)[18] in Great Bay at Adams Point, as reported in the 2013 PREP State of Our Estuaries Report (2013 PREP Report),[19] shows median DIN concentrations averaging about 0.1 mg/L (0.07 – 0.12 mg/L) in the period from 1974 – 1981, when eelgrass populations in Great Bay were considered healthy and macroalgae populations were not considered problematic.[20] DIN concentrations increased from about 0.1 mg/L in 1991, to 0.23 mg/L in 2000. Over this time period, eelgrass populations in Great Bay were considered

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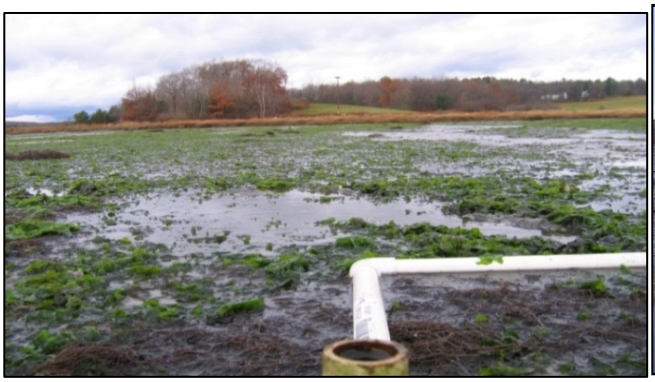
[15] Prior to issuing the criteria document the state/federal analysis concluded that (1) TN had not caused adverse impacts on the phytoplankton growth and the light regime and (2) the chosen conceptual model was inapplicable to this system. Attachment 2 - Philip Trowbridge, *et. al.*, PowerPoint Presentation, "Toward a New Conceptual Model for Nutrient Criteria Development in a New Hampshire Macrotidal Estuary" (Nov. 8, 2007); *see also* Chapra Analysis, PR Doc. No. 22.
[16] 2009 Criteria Report, PR Doc. No. 8, at 39, Fig. 18.
[17] 2009 Criteria Report, PR Doc. No. 8, at 37-38.
[18] DIN is the only nitrogen species that has been routinely monitored in Great Bay since 1974. However, DIN monitoring stopped after 1981 and resumed in 1991. TN was not routinely monitored until 2003.
[19] 2013 PREP Report, PR Doc. No. 22.
[20] *See* 2013 PREP Report, PR Doc. No. 22, at 57.

healthy, with the maximum reported areal extent of eelgrass occurring in 1996 (median DIN = 0.15 mg/L).[21] The concentration of DIN decreased from about 0.2 mg/L in 2007 to 0.12 mg/L in 2009, when the presence of nuisance macroalgae was documented in Great Bay. The data indicates that Great Bay eelgrass populations were apparently the healthiest when DIN concentrations were elevated and increased macroalgae have only been documented at lower DIN concentrations, similar to those concentrations prevalent in the late 1970s. It would seem that other factors are influencing the occurrence of macroalgae and that nutrient control, as proposed, may not likely to have the intended effect. As discussed herein, a more recent assessment bears out this concern.

A survey of macroalgae in Great Bay was conducted in 2008 and 2009 by Nettleton (March 2011)[22] documenting macroalgae at several sites along the coastline of Great Bay. Growth was very robust in several areas. The images below from the Nettleton Report illustrate macroalgae growth at the Lubberland Creek and Depot Road sites in November, 2008. Representative photos were taken at these same locations in 2012.[23] The 2012 observations found that the large intertidal macroalgae beds observed in 2008 and 2009 were no longer present.



Lubberland Creek, Nettleton, 2008

Lubberland Creek, Peschel, 2012

Depot Road, Nettleton, 2008

Depot Road, Peschel, 2012

[21] *See* New Hampshire Estuaries Project, 2003 State of the Estuaries Report, at 16 (eelgrass habitat has remained relatively constant over the past 10 years) (hereinafter "2003 PREP Report"), *available at* http://www.prep.unh.edu/resources/pdf/2003stateofthe-nhep-03.pdf.

[22] Jeremy C. Nettleton, *et. al.*, Tracking environmental trends in the Great Bay Estuarine System through comparisons of historical and present-day green and red algal community structure and nutrient content (Mar. 2011).

[23] Attachment 3 - Dean Peschel, Great Bay Municipal Coalition, Macroalgae Pictures taken on October 17, 2012.

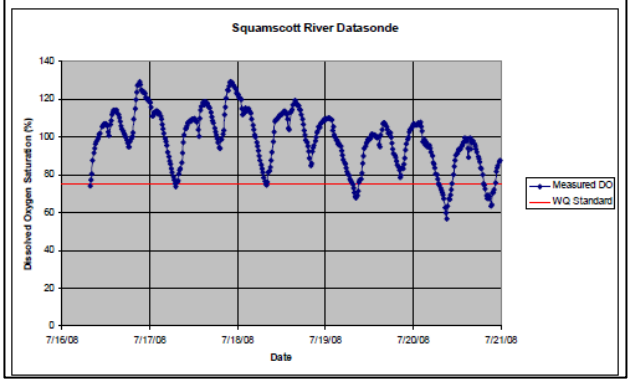
The same results were found in 2013 with certain areas devoid of macroalgae growth and other tidal flats now had robust growth.[24] Thus, macroalgae growth appears ephemeral and not well understood from a causal and ecological impact perspective.[25] As the TN/DIN levels in these years were comparable, one would have considerable difficulty identifying a TN threshold to control macroalgae growth from such data.

C. Dissolved Oxygen Criterion Compliance

Periodic low D.O. has been recorded in all of the upper tidal rivers, except for the Cocheco River.[26] D.O. conditions below 5 mg/l are very rare in Great Bay, Little Bay, or the Piscataqua River. The conceptual model relating the adverse effects of excessive nutrients on D.O. is premised on nutrients stimulating algal growth, followed by algal settling and decay, which is presumed responsible for low D.O.[27] DES evaluated phytoplankton chlorophyll-a and TN concentrations at the various trend stations, presenting the simple linear regression in Figure 17 (below) from the 2009 Criteria Report[28] as "proof" that primary productivity in the form of phytoplankton blooms is associated with a specific nitrogen concentration that causes low D.O. to occur.[29] No analysis of the significance of this "effect" however, was presented.

As with the transparency and TN regression, in Figure 17 the data from the mouth of the harbor, bays, and upper tidal rivers are all plotted on the same chart. DES claimed that the cause and effect relationship between TN and D.O. impairment is demonstrated by the observation that diurnal D.O. concentrations vary from super-saturation to sub-saturation, which is indicative of in-situ photosynthesis and respiration.[30] Appendix B, Figure 1 from the 2009 Criteria Report was intended to demonstrate that TN caused high and low D.O. to occur.[31]

Figure 1: Example of diurnal swings of dissolved oxygen saturation measured in the tidal portion of the Squamscott Rivers using an in-situ datasonde



The diurnal pattern presented in this figure is complex and does not indicate that algal respiration is the cause of the varying D.O. conditions. DES provided additional simple linear regressions of the trend station data to develop a TN criterion based on compliance with the minimum D.O. standard, but concluded that these data, from infrequent surface grab samples, were inadequate for criteria derivation. Consequently, DES relied on an evaluation of D.O. data from the continuous monitoring datasonde locations, observed during the summer months between 2000 and 2008, to establish TN and chlorophyll-a criteria to protect against exceedances of the D.O. water quality standard.

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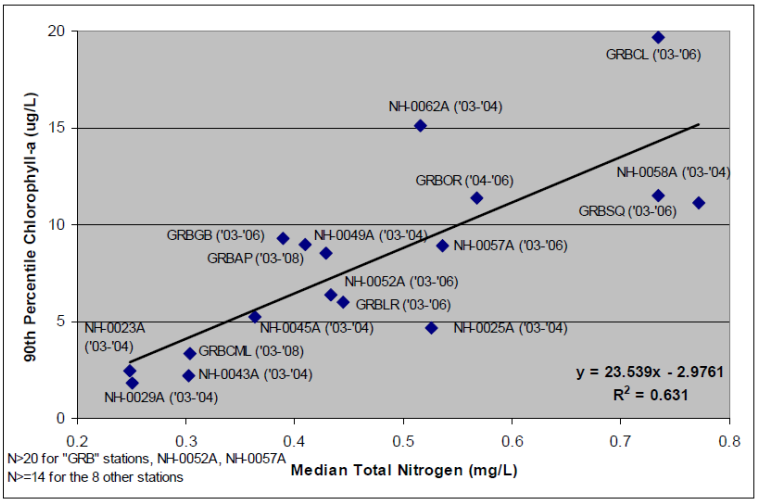
[24] *See* Attachment 4 – Dean Peschel, Great Bay Municipal Coalition, Macroalgae Pictures taken on October 11 or 15, 2013.
[25] *See* 2013 PREP Report, PR Doc. No. 22, at 44 ("[A] substantial increase in the abundance of nuisance macroalgae is an emerging problem for the bay and increased monitoring and research effort is needed to better understand this issue.").
[26] *See* 2009 Criteria Report, PR Doc. No. 8, at 47, Table 7 (results for the Cocheco River Assessment Zone and Trend Monitoring Station NH-0058A); *see also* DES, *Amendment to the New Hampshire 2008 Section § 303(d) List Related to Nitrogen and Eelgrass in the Great Bay Estuary* (Aug. 2009), at 19-20, *available at* http://des.nh.gov/organization/divisions/water/wmb/swqa/2008/documents/20090813_303d_list_update.pdf (hereinafter "Amended 2008 § 303(d) List"); DES, *New Hampshire's 2012 Section 305(b)/303(d) List Technical Support Document*, at 18, Table 4-C, *available at* http://des.nh.gov/organization/divisions/water/wmb/swqa/2012/documents/gbnitrogen-2012-303d-tsd.pdf.
[27] *See* 2009 Criteria Report, PR Doc. No. 8, at 45.
[28] 2009 Criteria Report, PR Doc. No. 8, at 36, Fig. 17.
[29] 2009 Criteria Report, PR Doc. No. 8, at 31.
[30] *See* 2009 Criteria Report, PR Doc. No. 8, at B-3.
[31] 2009 Criteria Report, PR Doc. No. 8, at B-7.

It noted that 90th percentile chlorophyll-a concentrations (bloom condition) and median TN concentrations were between 3.3-9.3 µg/L and 0.30-0.39 mg N/L at stations (Portsmouth Harbor (i.e., the ocean) and Great Bay) where the datasonde measurements rarely exceeded the D.O. standard. It also noted that, for datasonde stations (tidal rivers) that frequently exceeded the D.O. standards, the 90th percentile chlorophyll-a concentration and median TN concentration were 12.1-14.3 µg/L and 0.52-0.74 mg N/l, respectively. From these observations, DES set criteria for 90th percentile chlorophyll-a at 10.7 µg/l and median TN at 0.45mg/l as the midpoint between stations that rarely exceed the D.O. standard and those where the D.O. standard is exceeded more frequently.[32] Achieving the 90th percentile chlorophyll-a concentration was asserted to be sufficient to achieve a minimum D.O. of 5 mg/l in the tidal rivers.

The assumption that phytoplankton blooms are associated with increasing median TN concentration (i.e., Figure 17 from the 2009 Criteria Report), has never been substantiated and is at odds with the findings of the most recent State of the Estuary Report. The 2013 PREP Report noted that algal levels in the estuary have not materially changed over a 30 year period (1980 – 2010) despite wide fluctuations in DIN.[33] In providing this regression as proof of a "cause and effect" relationship between algal growth and minimum D.O., DES again failed to consider the numerous confounding or covarying factors that may influence D.O. at a particular location. In fact, this evaluation only shows that chlorophyll-a and TN levels covary with each other based on location in the estuary, not that TN controls the chlorophyll-a levels at these stations. Stations at the mouth of the estuary, which experience the greatest dilution with ocean water, naturally have the lowest concentrations of phytoplankton and TN, while tributary stations with the least dilution experience the highest concentrations. This is no surprise and does not prove the efficacy of TN control or demonstrate that TN is controlling minimum D.O. at these locations. In fact, it is plainly inapplicable given (1) the amount of inorganic nitrogen available to support algal growth and the minimal growth present and (2) the low D.O. condition occurs even where algal growth is much lower.[34]

Figure 17: Relationship between Nitrogen and Chlorophyll-a Concentrations at Trend Stations



DES' claim of cause and effect based on diurnal D.O. swings is similarly misplaced. At best, diurnal swings in D.O. indicate phytoplankton photosynthesis and respiration is occurring. These observations should not be confused with the claim that TN/90th percentile algal growth causes a specific level of low D.O. in the tidal rivers. Such a

[32] *See* 2009 Criteria Report, PR Doc. No. 8, at 51.
[33] 2013 PREP Report, PR Doc. No. 22, at 16.
[34] As Dr. Chapra stated:

> For a regression analysis to be scientifically defensible, confounding factors that influence the response variable (chlorophyll-a) must be controlled so that the stressor variable (total nitrogen) is the only factor (or at least the primary factor) influencing the response. DES did not considered [sic] confounding factors when it prepared this simple regression. Consequently, all that can be determined from this analysis is that chlorophyll-a levels and total nitrogen levels co-vary. Such omission of confounding factors leads to what are formally called in the statistics literature 'spurious correlations.'

Chapra Analysis, PR Doc. No. 25, at 5.

claim first requires a demonstration that increasing TN concentrations have resulted in increasing phytoplankton in the estuary, but this has not occurred. It also requires a demonstration that low D.O. coincides with algal blooms, but no such demonstration was made. The occurrence of low D.O. in tidal waters is influenced by numerous factors (e.g., tidal translation, stratification, SOD, marsh drainage, photosynthesis-respiration, etc.). Without considering the magnitude of these other factors or the D.O. regime, it is impossible to support its claim that a specific nitrogen and algal level is responsible for low D.O. in the tidal rivers.

III. Critical Evaluation of Available Watershed Data and the 2009 Numeric Nutrient Criteria Derivation

A. Analysis of Eelgrass Criteria Derivation

i. History of Eelgrass Cover

Historically, the main eelgrass populations in the estuary have always been located in Great Bay and Little Bay (about 2,400 acres in 1981 and 2,500 acres in 1996) and Portsmouth Harbor/Little Harbor (approximately 300 acres in 1981 and 316 acres in 1996).[35] These populations have been severely reduced on several occasions by wasting disease, first reported in 1931. In the late 1980s, dramatic eelgrass declines occurred throughout the system, again due to wasting disease. While the eelgrass population of Great Bay rebounded completely in the early 1990s, the population in Little Bay has never recovered to pre-1980's wasting disease levels (33 acres in 1996 versus 252 acres in 1981). The reason for this lack of eelgrass recovery in Little Bay is unknown, as water quality is better in this area as compared to Great Bay where full recovery occurred.[36] In 2011, the Little Bay eelgrass population reached its highest level since 1988 – over 48 acres, which is 50% greater than the level reported in 1996 when Great Bay eelgrass coverage was at its apex, but still much lower than the 1980 cover.

Historical information on the occurrence of eelgrass[37] indicates that eelgrass populations existed in the lower section of most of the upper tidal rivers (i.e., the Squamscott River, the Lamprey River, the Oyster River, and the Bellamy River) that receive considerable "dilution" from the Bay. However, eelgrass has not existed in many of these areas since at least 1980. The upper areas of these rivers have not had eelgrass since the 1960s. The cause for this change in eelgrass population is unknown.[38] Small eelgrass beds (<10 acres) were present in the Upper and Lower (North) Piscataqua River through the early 2000s but most of the acreage was lost by 2005. The cause of the eelgrass loss is unknown.[39] The Lower (North) Piscataqua River eelgrass levels began declining between 2006 and 2010 and now eelgrass is largely absent from this area. The Lower (South) Piscataqua River eelgrass beds have been in the 5-10 acres range since 1980. Beds at the mouth of Portsmouth Harbor have declined since 2004, even where water transparency is highest. These declines have occurred at both shallow and deep locations and the cause for the declines is unknown.[40]

Eelgrass acreage in Portsmouth Harbor, Little Harbor, and Sagamore Creek have also varied significantly over time. In 1981, these regions had an aggregate cover of 300.1 acres. Eelgrass cover was not mapped in these areas for the period from 1982 to 1995. In 1996, eelgrass cover was estimated to exceed the 1981 levels in Portsmouth Harbor and Little Harbor, with an aggregate of 317.5 acres. Then, from 1999 through 2005, the aggregate eelgrass cover for these regions varied within a relatively narrow range from 95% to 111% of the 1981 benchmark. The

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[35] The methods for mapping eelgrass have varied overtime, with aerial surveys being employed since 1990. Recent assessment of the methods indicate they do not meet NOAA "standards" and should be considered "field recognizance level" data. *See* Attachment 5 - Technical Memorandum from James R. Gaynor & Muriela S. Robinette, New England EnviroStrategies, Inc. to Dean Peschel, Great Bay Municipal Coalition, RE: Peer Review of Eelgrass Mapping (July 26, 2013).

[36] *See* 2008 § 303(d) Report, PR Doc. No. 6, at 13.

[37] An excellent summary on the historic distribution of eelgrass in the Great Bay Estuary is presented in the 2008 § 303(d) Report, PR Doc. No. 6, at 8 - 15.

[38] *See* 2008 § 303(d) Report, PR Doc. No. 6, at 11-14.

[39] *See* 2008 § 303(d) Report, PR Doc. No. 6, at 11-14.

[40] Beem and Short 2008, PR Doc. No. 4.

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aggregate eelgrass cover for these regions began to decrease from 2006 to 2010, to 170.7 acres. The data for 2011 showed an increase in aggregate cover to about 212 acres.

ii. Evaluation of Recent Eelgrass Cover Data

The eelgrass monitoring data for the Great Bay Estuary is summarized in the Environmental Data Reports prepared by PREP.[41] Historical data on eelgrass coverage in the Great Bay Estuary from 1981 to 2011 is presented in Table HAB2-1 (below) from the 2012 PREP Environmental Data Report.[42] Data are provided for individual rivers and bays. The most complete data are for Great Bay, which contains at least 80% of the eelgrass in the entire estuary.

As demonstrated in the chart, over the period from 2006 to 2008, there was a dramatic drop in eelgrass cover in Great Bay, Little Bay and the Portsmouth Harbor area. Eelgrass in Great Bay plummeted from 2,165 acres to 1,319 acres in 2006 and remained low through 2008. Based on these data, DES amended the 2008 Section § 303(d) List for the Great Bay Estuary to identify Great Bay as impaired for eelgrass.[43] The amended § 303(d) list now claimed that linear regressions of annual eelgrass cover showed a significant decreasing trend in all locations for the period from 1990 to 2008[44] and that eelgrass in the North Piscataqua River were essentially wiped out.[45]

Table HAB2-1: Eelgrass coverage in the Great Bay Estuary

Year	Winnicut River	Squamscott River	Lamprey River	Oyster River	Bellamy River	Great Bay	Little Bay	Upper Piscataqua River*	Lower Piscataqua River North*	Lower Piscataqua River South*	Portsmouth Harbor*	Little Harbor	Sagamore Creek	Total
1981	0.0	0.0	0.0	a	3.4	2130.7	252.0	0.5	60.1	5.1	227.7	68.8	4.1	2752.3
1986	2.2	0.0	0.0	a	a	2015.2	a	a	a	a	a	a	a	
1987	2.2	0.0	0.0	a	a	1685.7	a	a	a	a	a	a	a	
1988	0.0	0.0	0.0	a	a	1187.5	a	a	a	a	a	a	a	
1989	0.0	0.0	0.0	a	a	312.6	a	a	a	a	a	a	a	
1990	15.9	0.0	0.0	a	a	2024.2	a	a	a	a	a	a	a	
1991	23.4	0.0	0.0	a	a	2255.8	a	a	a	a	a	a	a	
1992	7.3	0.0	0.0	a	a	2334.4	a	a	a	a	a	a	a	
1993	6.9	0.0	0.0	a	a	2444.9	a	a	a	a	a	a	a	
1994	13.8	0.0	0.0	a	a	2434.3	a	a	a	a	a	a	a	
1995	7.8	0.0	0.0	a	a	2224.9	a	a	a	a	a	a	a	
1996	7.6	0.0	0.0	14.0	0.0	2495.4	32.7	1.6	20.9	10.2	245.6	70.1	1.8	2900.0
1997	7.5	0.0	0.0	a	a	2297.8	a	a	a	a	a	a	a	
1998	10.0	0.0	0.0	a	a	2387.8	a	a	a	a	a	a	a	
1999	10.2	0.0	0.0	0.0	0.0	2119.5	26.2	0.5	7.4	4.0	244.0	50.1	3.0	2464.9
2000	0.0	0.0	0.0	0.0	0.0	1944.5	7.5	1.6	3.8	7.6	260.5	60.9	0.9	2287.3
2001	4.1	0.0	0.0	0.0	0.0	2388.2	10.9	2.0	9.7	10.7	274.2	45.3	2.2	2747.3
2002	3.5	0.0	0.0	0.0	0.0	1791.8	4.3	0.5	8.0	9.3	268.9	63.1	2.3	2151.7
2003	3.5	0.0	2.2	0.0	0.0	1620.9	14.2	2.9	22.9	9.2	270.1	54.7	2.2	2002.8
2004	4.2	0.0	0.0	0.0	0.8	2037.6	12.8	0.7	13.5	6.5	225.2	65.8	2.5	2369.8
2005	9.1	0.0	0.0	0.0	0.0	2165.7	25.8	0.4	14.5	9.6	232.5	47.9	6.1	2511.7
2006	0.8	0.0	0.0	0.0	0.0	1319.8	12.2	0.8	10.8	11.6	217.6	52.1	0.9	1626.5
2007	0.0	0.0	0.0	0.0	0.0	1245.3	0.1	0.0	0.4	5.6	201.3	42.7	0.6	1496.0
2008	0.0	0.0	0.0	0.0	0.0	1394.9	0.0	0.0	0.0	3.9	183.8	41.4	2.3	1626.4
2009	0.1	0.0	0.0	0.0	0.0	1700.6	0.0	0.0	0.0	6.4	155.0	30.2	0.5	1892.8
2010	0.0	0.0	0.0	0.0	0.0	1722.2	0.3	0.0	0.0	3.5	128.0	42.5	0.2	1896.8
2011	0.0	0.0	0.5	0.0	0.0	1623.2	48.2	0.0	0.0	6.9	178.8	31.6	1.5	1890.6

Units = Acres a = not mapped Total coverage includes all mapped eelgrass of all densities
* The acreages for 1981,1996-2008 include beds from both the NH and ME sides of the Piscataqua River but not the tidal creeks along the Maine shore.

[41] PREP, Environmental Data Reports, *available at* www.stateofourestuaries.org.
[42] PREP, Environmental Data Report December 2012 Technical Support Document for the 2013 State of Our Estuaries Report, (Dec. 2012), *available at* http://prep.unh.edu/resources/pdf/2013%20SOOE/2012%20PREP%20Env%20Data%20Report%20FINAL%20Compressed%20Adobe6.pdf (hereinafter "2012 PREP Environmental Data Report").
[43] *See* Amended 2008 § 303(d) List.
[44] *See* Amended 2008 § 303(d) List, at 13 - 18.
[45] Beem and Short 2008, PR Doc. No. 4, at 3, Fig. 2.

An example of these temporal regressions is presented below in Figure 2 from Beem and Short (2008). These regressions show changes in eelgrass biomass with time for sites in the Lower Piscataqua River (Outer Cutts Cove, OCC), further upstream in the Piscataqua River (proceeding upstream. T1, T3, and R2) and a site in Little Bay (Dover Point, DP). The declines in eelgrass biomass began in 2001 for the furthest downstream stations (OCC and T1), while declines at T3 and R2 began two years later. The decline in Little Bay occurred in 2006. The cause of these declines was not identified in that report.

Subsequent to this determination and applying the criteria in the 2009 Criteria Report, DES claimed that the eelgrass loss throughout the system was caused by nitrogen. However, the significant reductions in eelgrass cover did not coincide with any increase in TN or chlorophyll-a. Rather, an exceptionally wet rainfall pattern occurred, beginning in 2005, with 2005, 2006, and 2008 being the three highest precipitation years for the entire period of record as illustrated in the graphic below from data collected by NOAA.

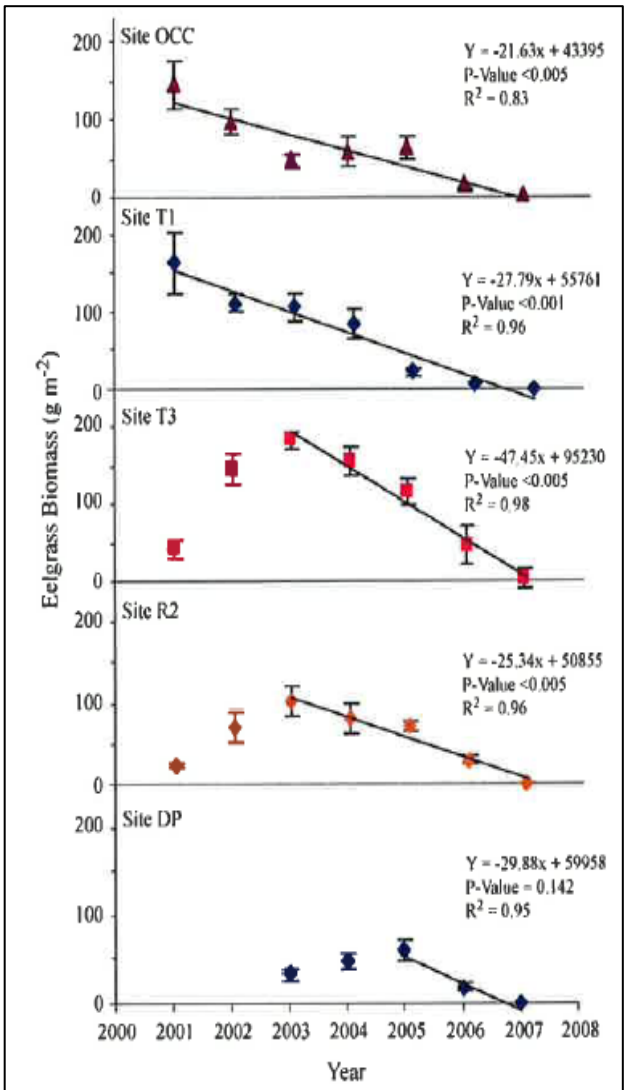
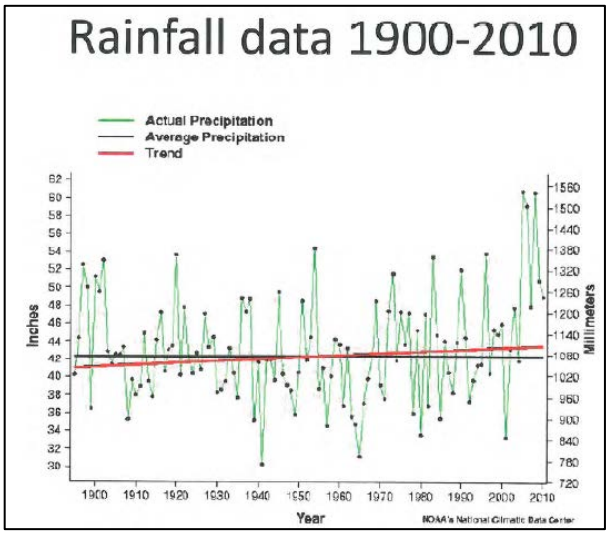
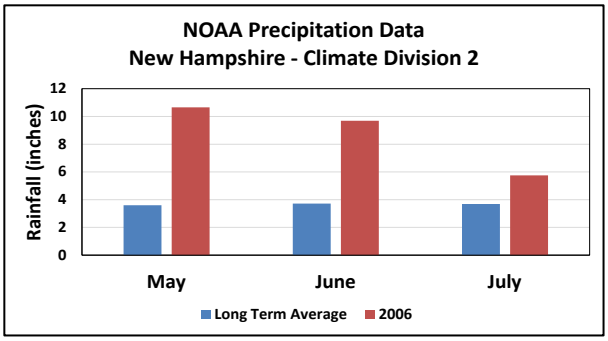


Fig. 2 Simple regressions of the effects of time on mean (±SE) eelgrass biomass. Sites are presented moving up-estuary

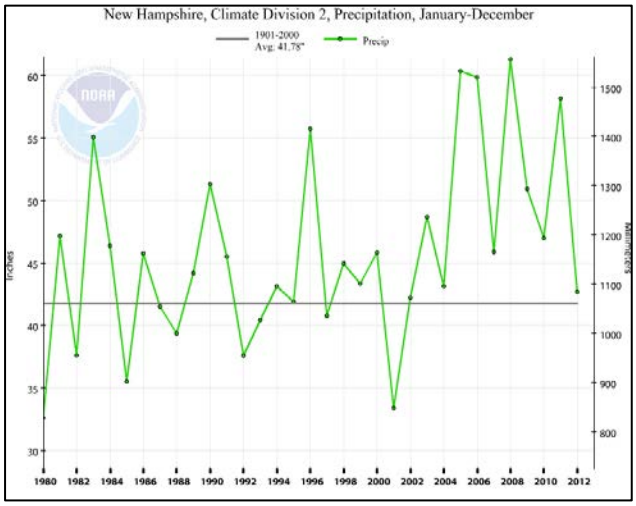




Moreover, a massive storm (known as the "Mother's Day storm") affected the region at the beginning of the 2006 growing season and record rainfall continued thereafter. This was the wettest growing season in over 100 years with 26 inches of rain occurring between May – July as illustrated above.

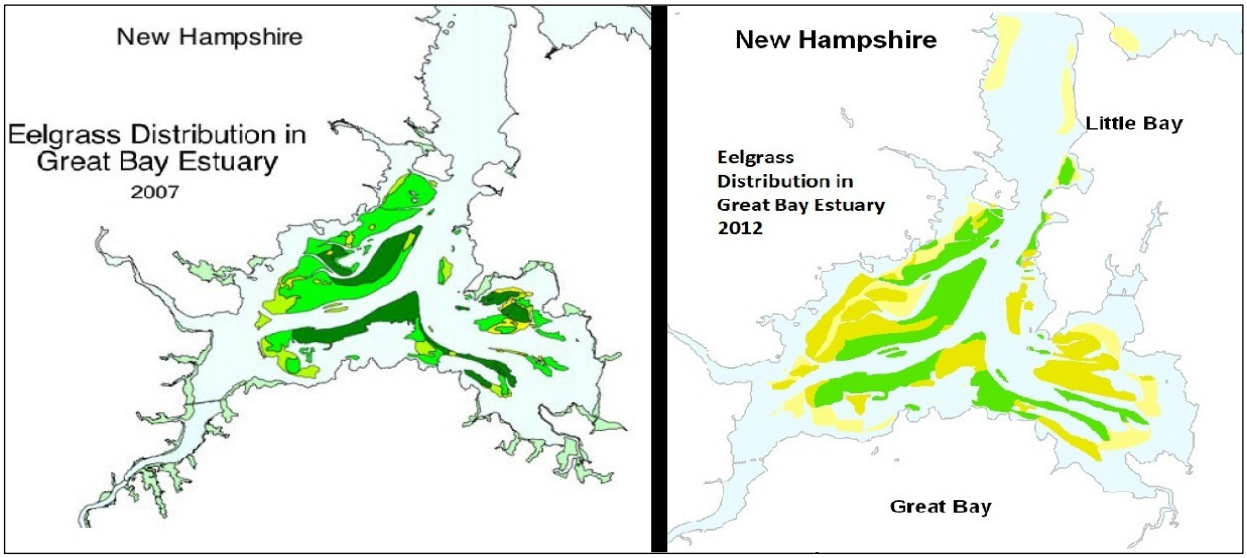
This storm stirred up the Bay and kept the water turbid for months.[46] Eelgrass cover in Great Bay remained depressed over the subsequent two years. Eelgrass cover in Great Bay began to recover from 2009 to 2012. During this time significantly "drier" weather conditions prevailed, relative to the prior years, as illustrated below in the rainfall summary since 1980. Nonetheless, this was a "wetter than average" period.

Over this period, eelgrass cover increased from a low of 1,250 acres to over 1,700 acres. In Little Bay, eelgrass cover was almost completely absent in 2009 and 2010, but then increased dramatically in 2011 to 48.2 acres, its highest level since the outbreak of wasting disease in 1989.



A similar pattern was also seen in Portsmouth Harbor; eelgrass cover continued to decline in 2009 and 2010, but then rebounded sharply (about a 40% increase) in 2011. The eelgrass losses occurring in the Lower Piscataqua River (North and South) persisted beyond 2007, even though the water quality (*i.e.,* transparency and algal levels) in this region was quite good.[47] These data suggest that the amount of precipitation occurring, in particular extreme weather events causing month long water quality declines, is likely controlling eelgrass health in this system.

As demonstrated below, eelgrass acreage increased significantly from 2007 to 2012, with new eelgrass beds now documented in Little Bay.[48]

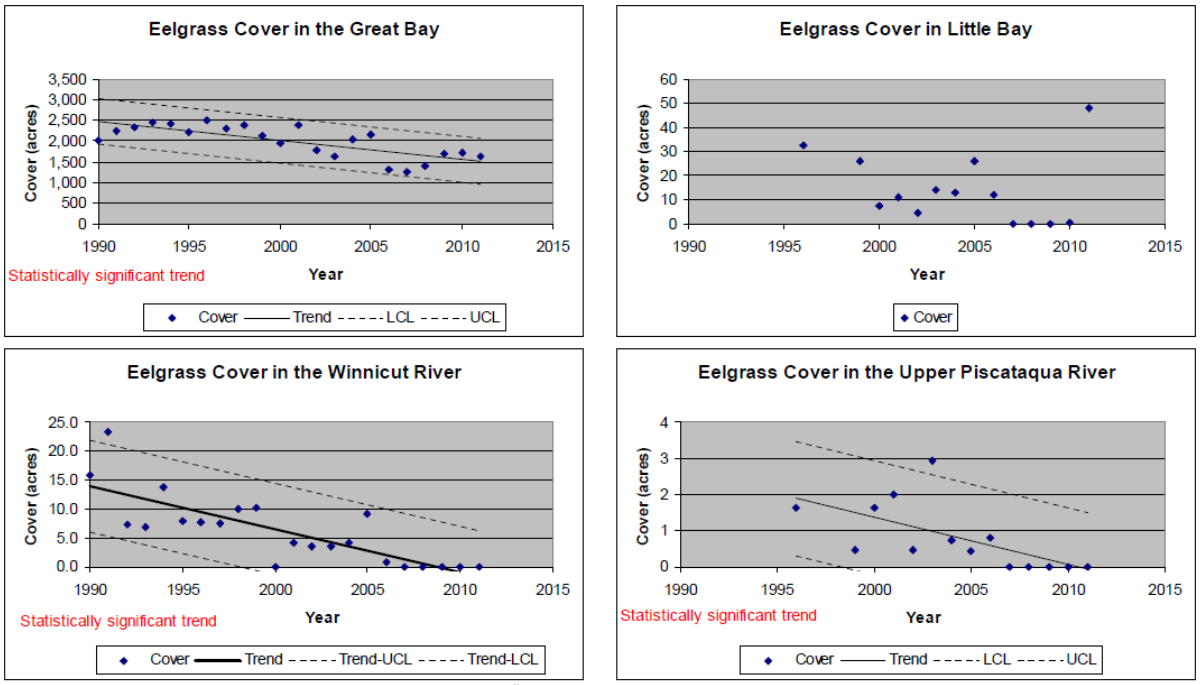


[46] Personal communication between John Hall and Drs. Jones and Langan, University of New Hampshire Jackson Laboratory.
[47] The early reports for 2013 eelgrass cover show a slight decline which was not unexpected as it was a very wet during the early growing season.
[48] The data used to generate this figure comes from the following documents: Fred Short "Eelgrass Distribution in the Great Bay Estuary for 2007", at 5 (Nov. 3, 2008) *available at* http://www.prep.unh.edu/resources/pdf/eelgras_distribution_in-unh-08b.pdf; Fred Short, "Eelgrass Distribution in the Great Bay Estuary for 2012", at 5 (Aug. 23, 2013), *available at* http://www.prep.unh.edu/resources/pdf/Eelgrass_Report_dated_20130823-unh-2012.pdf. Note that the 2012 distribution was augmented based upon Attachment 6 - Memorandum from Normandeau Associates, Inc. to the Great Bay Municipal Coalition, RE: Preliminary Eelgrass (*Zostera marinea*) Survey, at 4 (Oct. 18, 2012). The lighter color is intended to represent eelgrass density; however, the reliability of such this component is unknown as it was not developed under a quality assurance plan.

iii. Evaluation of Other Relevant Data

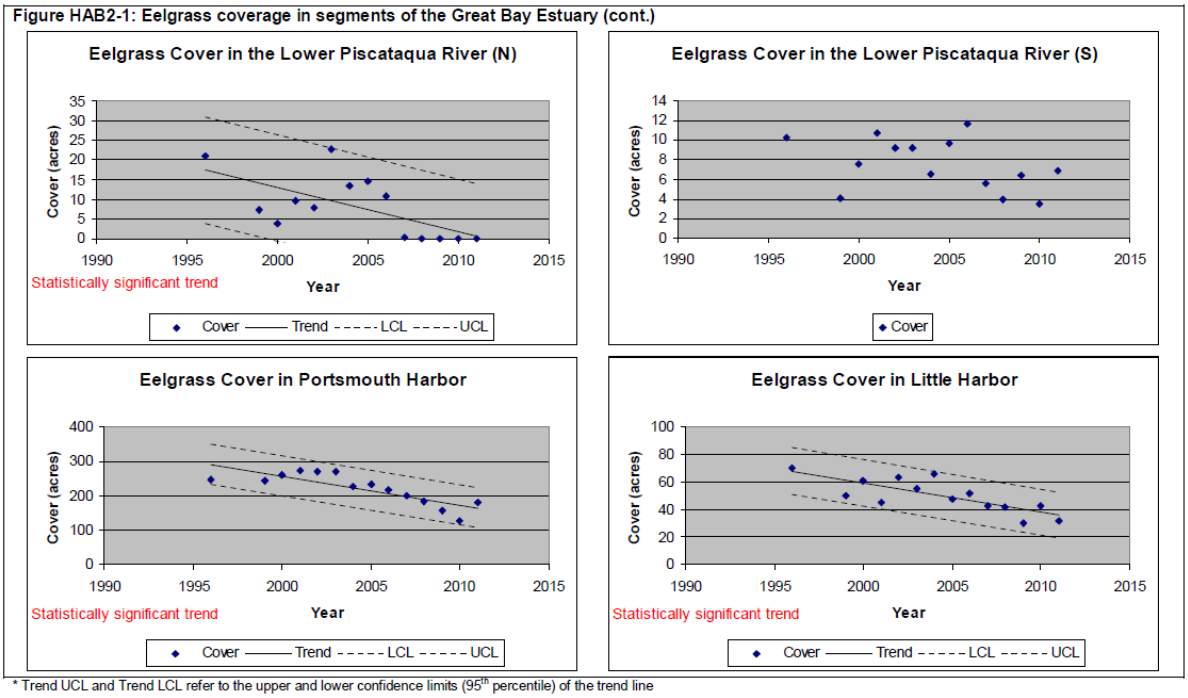
As discussed above, several regions in the Great Bay Estuary (the upper tidal rivers, the Upper and Lower (South) Piscataqua River, and Little Bay) experienced eelgrass losses prior to 2005 and the cause of these losses is not known. Other areas, specifically Great Bay and Portsmouth Harbor, reported good eelgrass cover through 2005 (see figures below).[49]

Figure HAB2-1: Eelgrass coverage in segments of the Great Bay Estuary



* Trend UCL and Trend LCL refer to the upper and lower confidence limits (95th percentile) of the trend line

Figure HAB2-1: Eelgrass coverage in segments of the Great Bay Estuary (cont.)



* Trend UCL and Trend LCL refer to the upper and lower confidence limits (95th percentile) of the trend line

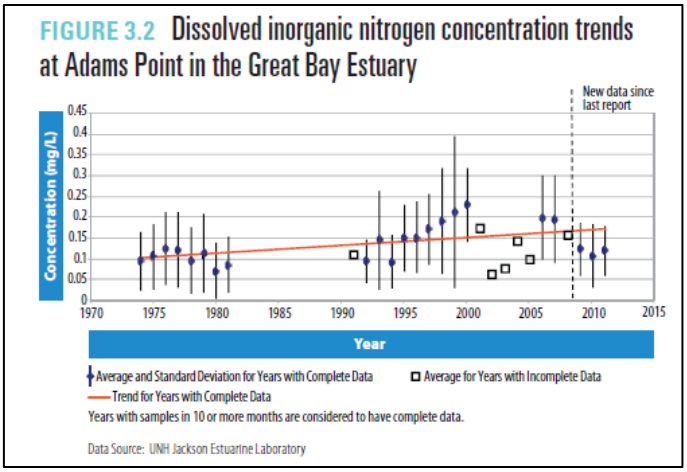
[49] 2012 PREP Environmental Data Report, at 133-134, Fig. HAB2-1.

A marked decline in eelgrass cover occurred in Great Bay and the Portsmouth Harbor region, starting in 2006. If the conceptual model described eelgrass impairment in the Great Bay Estuary, these losses should be associated with an increase in TN and phytoplankton chlorophyll-a and a decrease in water clarity. However, as described below, data from the 2012 PREP Environmental Data Report along with studies and evaluations provided by the PREP Technical Advisory Committee (TAC) demonstrates nitrogen induced algal growth was not the cause, though some significant rainfall related changes in transparency did occur.

a. Water Quality Data

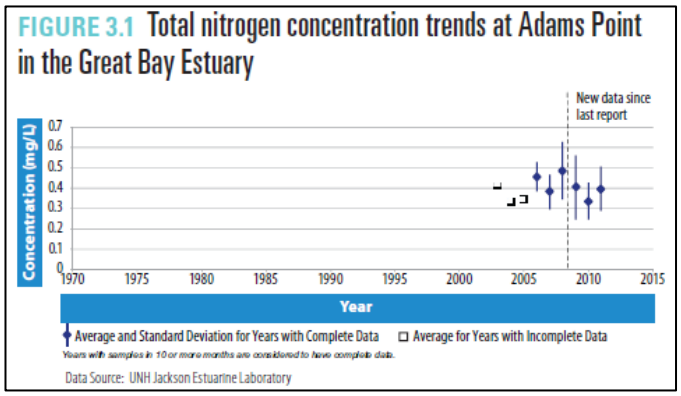
i. Nutrient Trends and Phytoplankton Growth

Historical monitoring data for nitrogen, phytoplankton chlorophyll-a, and suspended solids are summarized in the 2012 PREP Environmental Data Report. The only long-term monitoring data for nitrogen is for DIN (below).[50]



These data show stable median DIN concentrations in the late 1970s averaged around 0.1 mg/L. DIN concentrations increased to their highest reported levels over the period from 1991 – 2000, exceeding 0.2 mg/L, when eelgrass coverage was at or near maximum levels.[51] DIN concentrations in 2006 were equal to or less than the concentrations observed in the late 1990s. Subsequently, PREP noted that the DIN median concentrations in 2009-2011 decreased to approximately the same levels found in the late 1970s: "The DIN concentrations in the last three years fell below the average trend line to 0.116 mg/L. These levels are comparable to the DIN concentrations that were measured for some of the years in the 1970s."[52] Based upon these data, it is not apparent that DIN levels have changed over time, though a short-term increase was observed. Declining eelgrass populations do not coincide with increases in observed DIN concentrations.[53]

The available data for TN at Adams Point are illustrated in Figure 3.1.[54] TN data are only available for the period from 2003 – 2011 and pre-2006 data is incomplete. These data generally follow the trends shown in the DIN data for the limited period where the data are complete (2006 - 2011). As with the DIN data, the TN data appear relatively constant and do not indicate any significant change related to the varying eelgrass

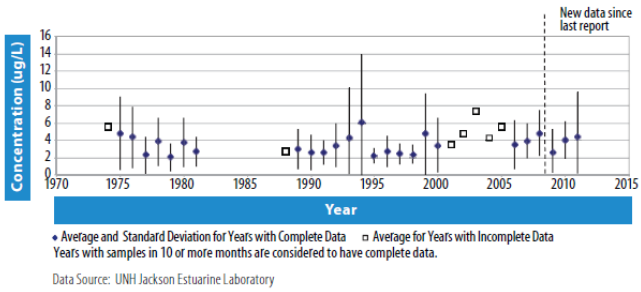


[50] 2013 PREP Report, PR Doc. No. 22, at 15, Fig. 3.2; *see also* 2012 PREP Environmental Data Report, at 57, Fig. NUT2-4.
[51] The cause of this reported change in DIN concentration is unknown and does not appear to coincide with any demonstrated change in point or non-point source loading.
[52] 2013 PREP Report, PR Doc. No. 22, at 14.
[53] It is recognized that the degree of plant growth occurring in the system will affect DIN by converting it to plant biomass. However, plankton and eelgrass levels have been largely consistent through 2005, so this factor, while important would not seem to be the cause of the changing annual concentrations.
[54] 2013 PREP Report, PR Doc. No. 22, at 15, Fig. 3.1; *see also* 2012 PREP Environmental Data Report, at 73, Fig. NUT2-6.

population, while declines from 2009-2011 are noted. Based on the last three years, the long term average TN decreased (like DIN), and is now approximately 0.38 mg/l.

Figure 4.1 presents the phytoplankton chlorophyll-a in Great Bay at Adams Point over the period from 1974 to 2011.[55] Over this period[56], chlorophyll-a median concentrations have generally remained quite low given the available inorganic nitrogen levels, within a narrow range (2 – 6 µg/L), with no significant trend, as noted by PREP: "Measurements of chlorophyll-a in the water in Great Bay since 1975 have not shown any consistent long-term trends, nor were there any short term changes in the last three years (Figure 4.1)."[57] These observations confirm that the increasing DIN level did not cause an increase in phytoplankton growth and that phytoplankton growth is not presently limited by DIN input.[58] The DIN level in Great Bay, Little Bay, and the Piscataqua River is capable of supporting 10 - 20 times the observed level of plant growth. Consequently, some other factor (e.g., system hydrodynamics and water clarity) must be limiting plant growth.[59]

FIGURE 4.1 Chlorophyll-a trends at Adams Point in the Great Bay Estuary



These data show that, in 2006, when the eelgrass cover in Great Bay experienced a very significant reduction, phytoplankton levels exhibited a median concentration below 4 µg/L with no significant increase or decrease in concentration before or after 2006. This level is relatively low and falls within the bracket of phytoplankton concentrations prevalent in the 1990s, when the eelgrass population was not considered to be impaired.[60] Consequently, the conceptual model linking eelgrass loss to a TN-induced increase in phytoplankton causing a decrease in water clarity is clearly not supported by the relevant data.

ii. Suspended Solids Data

Figure 7.1 illustrates the trend in suspended sediment in Great Bay at Adams Point over the period from 1976 to 2011.[61] From the late 1970s to 2000, median total suspended solids (TSS) concentrations have generally remained constant at the same time DIN concentrations increased twofold. From about 2002 – 2010, suspended sediment concentrations in Great Bay doubled compared to the concentration previously observed (e.g., 20 mg/L versus 10 mg/L). Over this same period, DIN concentrations decreased from the high concentrations seen in 1999 and 2000 to the lowest levels since the 1970s. These observations would indicate that the supposed causal link between nitrogen and particulate organic carbon (POC) does not exist as phytoplankton growth, the alleged source of POC, did not change. In addition, as TSS concentrations remained relatively constant from 2002 to 2007, the sudden decrease in eelgrass cover in 2006 cannot be explained by these data.

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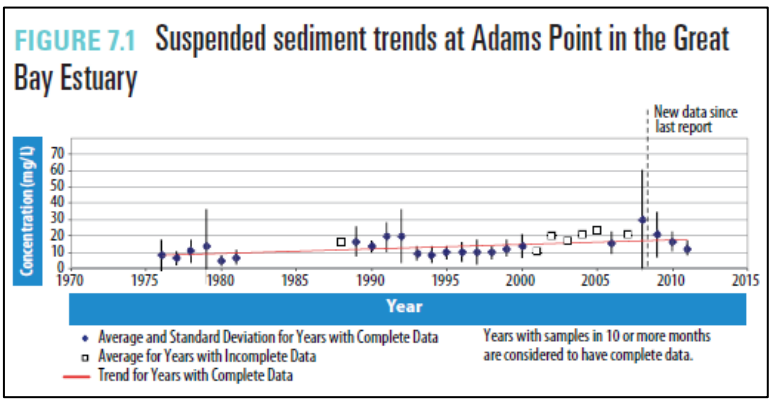
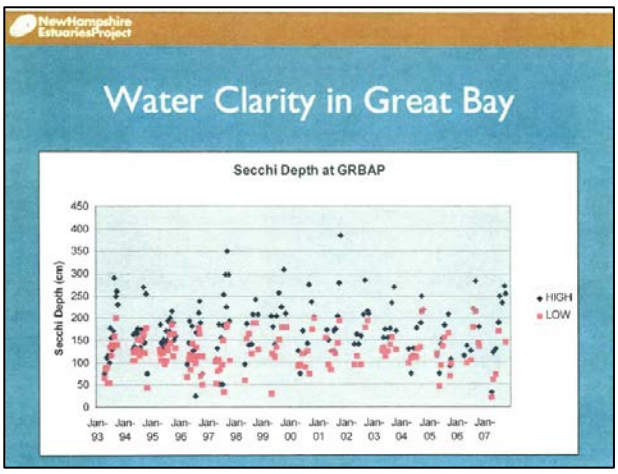
[55] 2013 PREP Report, PR Doc. No. 22, at 17, Fig. 4.1; *see also* 2012 PREP Environmental Data Report, at 93, Fig. NUT3b-2.
[56] Data monitoring was incomplete for the period from 2001 – 2005.
[57] 2013 PREP Report, PR Doc. No. 22, at 16.
[58] Chapra Analysis, PR Doc. No. 25, at 3, n. 3 ("For example, a 100 µgN/L level of dissolved inorganic nitrogen in Great Bay has the potential to grow about 30 µg/L chlorophyll-a. This is an absolute upper limit as is borne out by the fact that the median algal growth in Great Bay is one tenth of this potential. This indicates that other factors (i.e., water column transparency, detention time, nutrient recycle, etc.) are controlling the amount of plan growth that occurs.").
[59] 2013 PREP Report, PR Doc. No. 22, at 16 ("How has the amount of algae in the estuary changed over time? Microalgae (phytoplankton) in the water, as measured by chlorophyll-a concentrations, has not shown a consistent positive or negative trend in Great Bay between 1975-2011.").
[60] *See* 2012 PREP Environmental Data Report, at 93, Fig. NUT3b-2.
[61] 2013 PREP Report, PR Doc. No. 22, at 22, Fig. 7.1; *see also* 2012 PREP Environmental Data Report, at 144, Fig. NUT3a-2.

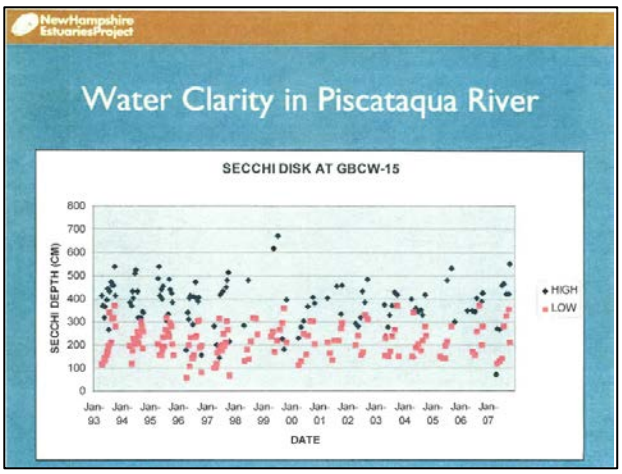


The spike in TSS concentration post-2006 is consistent with the loss of eelgrass at this time. Under these conditions, increased re-suspension of sediment is expected to occur in shallow waters if the eelgrass is not present to anchor the sediments.[62] The increase in eelgrass cover in 2009 – 2011 would be expected to reduce the amount of re-suspension, and the TSS data for this time period reflect this expectation. Thus, the changing TSS levels appear to be the result, not the cause, of eelgrass population changes.[63]

iii. Transparency Data

Long term Secchi depth measurements (a transparency measurement) are available for two areas in the estuary- Adams Point and the Lower Piscataqua River. These data are presented below[64]:





These data indicate that transparency has not changed significantly in the 20 year period of record in areas with large eelgrass populations. The data are remarkable in that it is clear that water transparency is highly influenced by the tidal condition and dilution from ocean waters entering the bay. At low tide, much poorer transparency occurs, presumably because of the greater influence of the tributaries on water quality (i.e., algal growth does not dramatically increase at low tide). As demonstrated by Morrison *et al.* (2008), the tributaries are well documented to have high CDOM levels that markedly impact transparency as the dilution from saline waters decreases.[65]

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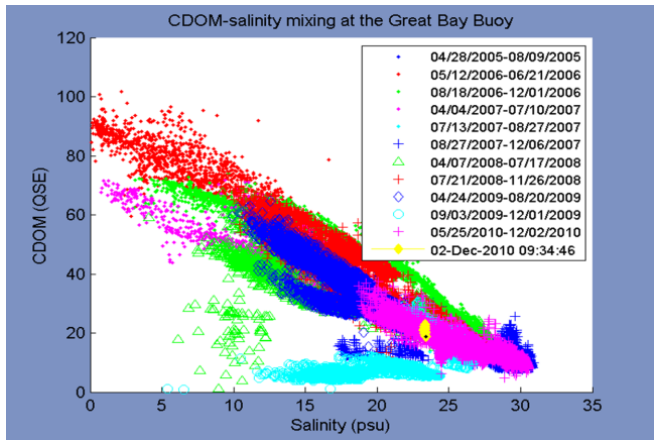
[62] *See* 2013 PREP Report, PR Doc. No. 22, at 22.

[63] Regarding the 2009 Criteria Report assertion that phytoplankton cause a much higher transparency impact due to additional organic (volatile) solids generated, this is plainly incorrect. HydroQual conducted a survey in August 2010 of organic and inorganic solids in Great Bay. *See* Technical Memorandum from Thomas W. Gallagher and Cristhian Mancilla, HydroQual to John Hall, Hall & Associates RE: Review of New Hampshire DES Total Nitrogen Criteria Development for the Great Bay Estuary (Jan. 10, 2011). That analysis confirmed that organic solids were only 15% of the total suspended solids. *Id.* at 4. Of the organic solids a substantial percentage would be of terrestrial origin given the low algal growth present.

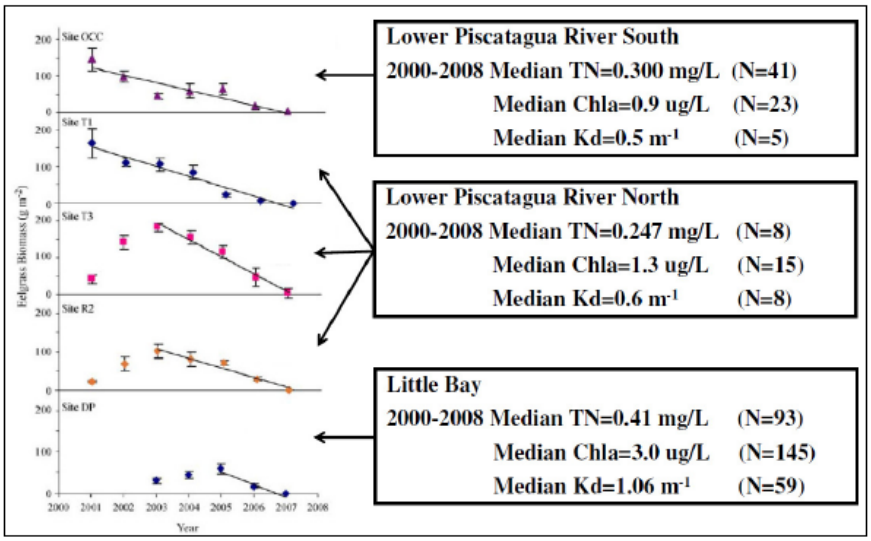
[64] *See* Attachment 7 - Philip Trowbridge, PowerPoint Presentation "Nutrient Criteria Development for the Protection of eelgrass in NH's Estuaries" (Mar. 25, 2008).

[65] *See* Attachment 8 - Philip Trowbridge, PowerPoint Presentation "Summary of Light Availability and Light Attenuation Factors for the Great Bay Estuary" (Feb. 14, 2007); *see also* Morrison *et al.* (2008), PR Doc. No. 7, at 27.

These data are consistent with the phytoplankton and TSS data presented above and indicate that the "TN increase-transparency decrease" paradigm is not applicable in this system. Limited field measurements of transparency are also available for the lower Piscataqua River, in the area researched by Beem and Short (2008). These data, presented below, indicate that the eelgrass declines occurred despite an acceptable level of incidental light (Kd-0.75m^{-1}) and much lower TN levels.[66]



In summary, the water quality monitoring data shows that DIN concentrations doubled through the 1990s, when eelgrass cover was robust in Great Bay and the Portsmouth Harbor area. Over this same period, average chlorophyll-a levels remained essentially unchanged at less than 4 µg/L. Similarly, TSS levels remained unchanged at about 10 mg/L. This was also a period of average rainfall conditions. These data confirm that the increasing nitrogen levels did not trigger increased primary productivity which is an essential precursor for the use of the eelgrass/TN-transparency conceptual model. In 2006, when sudden decreases in eelgrass cover occurred, the median concentrations of DIN, phytoplankton, and TSS were unchanged from the prior years when eelgrass cover was robust. From 2009 – 2011, DIN levels dropped back to the level observed in the 1970s, while phytoplankton levels again remained essentially unchanged. This observation indicates that factors other than nitrogen-induced eutrophication were responsible for the major eelgrass loss occurring after 2006. The data also confirms that the algal component of transparency is minor and algae do not comprise a major fraction of the turbidity measured. In any event, as no significant change in algal growth occurred in over 30 years, no significant change in transparency could be caused by this factor.



b. PREP and TAC Findings - 2003 - 2013

The observations presented above regarding inapplicability of the conceptual model to describe conditions in the Great Bay Estuary are not new. Many of these observations were reported in the PREP State of the Estuaries (SOE) reports and by the TAC. Water quality in the Great Bay Estuary has been tracked and documented by PREP, beginning in 2000, in its SOE reports which are prepared every three years. For example, the 2003 PREP Report presented information on eelgrass distribution in Great Bay for the period from 1986 – 2001.[67] The 2003 PREP

[66] *See* Gallagher June 30, 2010, PR Doc. No. 13, at 22, Fig. 12. It is noted that the number of transparency samples available for the Piscataqua River stations is quite low.
[67] 2003 PREP Report, at 16.

Report noted that eelgrass cover has been mapped every year in Great Bay from 1986 – 2001.[68] The entire estuary system (Great Bay, Little Bay, tidal tributaries, Piscataqua River and Portsmouth Harbor) was mapped in 1996, 1999, 2000, and 2001. The extent of eelgrass in Great Bay was constant for the past 10 years at approximately 2,000 acres following a dramatic decline in 1989 to 300 acres (15% of normal levels) due to wasting disease.[69] Over this time period, the levels of nitrate-nitrite have increased from approximately 5 µM (0.070mg/L) to about 8 µM (0.11 mg/L).[70] The Report notes that *"[d]espite the increase[e] … there have not been any significant trends for the typical indicators of eutrophication"* (i.e., lower D.O. and higher chlorophyll-a).[71] Consequently, the Report noted that the nitrogen load *"to the Bay appears to have not reached the level at which the undesirable effects of eutrophication occur*."[72]

The 2006 PREP Report evaluated conditions in the estuary through 2004. It noted that eelgrass cover in Great Bay declined by 17 percent between 1996 and 2004. The eelgrass cover in 1996 represents the greatest extent of eelgrass in Great Bay (2,421 acres) on record. In 2004, eelgrass cover was 2,008 acres. The 2006 PREP Report noted that "the possible effects of increasing DIN are still being debated because the system is unique, both hydrodynamically and biologically."[73] The Report further noted that "the specific cause of the decline in eelgrass cover and biomass is not known", but appeared to be related to a reduction in the amount of light reaching the plants.[74] However, measurements of light penetration or transparency were not provided to support this concern. Later measurements provide credence to this observation.

In 2005, the TAC was formed to review and assess conditions in the estuary in an effort to develop scientifically defensible numeric nutrient criteria. The TAC was initially tasked with reviewing the significant information available for the estuary. At the June 2006 TAC meeting, the conceptual model relating excessive nutrient loads to aquatic life impairments in estuaries (*i.e.,* increasing phytoplankton, low D.O., loss of submerged aquatic vegetation (eelgrass), and the occurrence of macroalgae) was discussed. A review of the estuary data indicated that "phytoplankton and D.O. are not showing apparent problems but eelgrass is" suggesting that eelgrass use attainment is the most sensitive target.[75] "The data show increasing nitrogen concentration and decreasing eelgrass, but do not show a strong linkage between increasing nitrogen and decreasing water clarity."[76] The TAC noted that this linkage needs to be established if eelgrass is going to be the target.[77] The June 2006 TAC meeting concluded with the agreement that an evaluation of an eelgrass-water clarity model for the system was needed, noting, "[t]he biggest issue is clarifying whether nitrogen is responsible for water clarity changes in Great Bay." [78]

The third TAC meeting (February, 2007) included a presentation on light availability for eelgrass. The data show that "measured light attenuation factors accurately predicted where eelgrass was present and absent. However, there were no valid relationships between the light attenuation factors and water quality parameters, such as chlorophyll-a, suspended solids."[79] Approximately half of the variability in light attenuation was explained by changes in salinity, a surrogate for CDOM entering the system. The TAC determined that additional

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[68] 2003 PREP Report, at 16.
[69] 2003 PREP Report, at 16.
[70] 2003 PREP Report, at 8.
[71] 2003 PREP Report, at 8 (emphasis added).
[72] 2003 PREP Report, at 8 (emphasis added).
[73] New Hampshire Estuaries Project, State of the Estuaries 2006, at 12 (hereinafter "2006 PREP Report"), *available at* http://www.prep.unh.edu/resources/pdf/2006_state_of_the-nhep-06.pdf.
[74] 2006 PREP Report, at 20.
[75] TAC June 2006 Meeting Minutes, at 2, *available at* http://www.prep.unh.edu/programs/nutrient.htm (follow "June 15, 2006 Minutes" hyperlink).
[76] TAC June 2006 Meeting Minutes, at 2.
[77] TAC June 2006 Meeting Minutes, at 2.
[78] TAC June 2006 Meeting Minutes, at 2.
[79] TAC February 2007 Meeting Minutes, at 2, *available at* http://www.prep.unh.edu/programs/nutrient.htm (follow "February 20, 2007 Minutes" hyperlink).

instrumentation should be added to the buoy in Great Bay to confirm the degree to which factors were influencing light attenuation. This instrumentation was added and the new data were reported at the fourth TAC meeting (December, 2007). The data show that light attenuation is largely controlled by turbidity and CDOM, with chlorophyll-a accounting for only a small percentage of the overall light attenuation. In reviewing these results, the TAC commented that "*this study showed that the classic model of eelgrass shading by phytoplankton blooms does not describe the Great Bay Estuary*."[80] Additionally, in 2008, a group of TAC members, including the author of the 2009 Criteria Report, concluded that the nitrogen-induced eelgrass loss via transparency model was not applicable. The presentation materials with this conclusion are attached.[81]

The 2009 PREP Report was issued following the release of the draft criteria document and cited TN as the cause of eelgrass impairment in the estuary, which exhibited a significant decreasing trend with the addition of the 2006 data. Subsequently, the 2013 PREP Report again clarified that the heightened concern over TN impacts on eelgrass populations was overstated, if not misplaced. The 2013 PREP Report noted the following with respect to monitoring data for the estuary:

- Algae (phytoplankton) blooms in the estuary have not increased in over 30 years with annual algal levels average about 3-4 µg/l in this system;[82]
- Macroalgae are an "emerging problem" that requires further investigation to assess its significance;[83]
- The existing TN level for the Bay is averaging 0.38 mg/L TN and 0.116 mg/L DIN. DIN levels, which control macroalgae growth, are now comparable to those measured in the 1970s;[84]
- The effect of nitrogen loads on the system is not "fully determined" and requires "additional research";[85] and,
- Eelgrass have rebounded in Little Bay to the highest level in decades.[86]

Based on these most recent observations and conclusions, it is apparent that the need for stringent TN reduction to protect estuarine resources is an open question.

c. Detailed Study on System Transparency

At the recommendation of the TAC,[87] Morrison *et al.* (2008)[88] evaluated the factors contributing to light attenuation in Great Bay using hyperspectral remote sensing data and data from moored sensors. Data from the Great Bay Coastal Buoy (at Adams Point) was used to develop a multivariate model of water clarity with phytoplankton, CDOM, and non-algal particles (*e.g.,* turbidity). Data was also collected from the major tidal tributaries. Based on data collected in 2007, these University of New Hampshire researchers determined that phytoplankton were responsible for approximately 12% of the overall light attenuation, with CDOM and non-algal

[80] TAC December 2007 Meeting Minutes, at 2 (emphasis added).
[81] *See* Attachment 2 - Philip Trowbridge, *et. al.*, PowerPoint Presentation "Toward a New Conceptual Model for Nutrient Criteria Development in a New Hampshire Macrotidal Estuary" (Nov. 8, 2007);
Attachment 7 - Philip Trowbridge, PowerPoint Presentation "Nutrient Criteria Development for the Protection of eelgrass in NH's Estuaries" (Mar. 25, 2008); Attachment 8 - Philip Trowbridge, PowerPoint Presentation "Summary of Light Availability and Light Attenuation Factors for the Great Bay Estuary" (Feb. 14, 2007); Attachment 9 - Philip Trowbridge, PowerPoint Presentation "NH Estuaries Project Environmental Indicators" (June 15, 2006).
[82] 2013 PREP Report, PR Doc. No. 22, at 16-17.
[83] 2013 PREP Report, PR Doc. No. 22, at 44.
[84] 2013 PREP Report, PR Doc. No. 22, at 14.
[85] 2013 PREP Report, PR Doc. No. 22, at 12.
[86] 2013 PREP Report, PR Doc. No. 22, at 20.
[87] *See* Attachment 7 – Philip Trowbridge, PowerPoint Presentation "Summary of Light Availability and Light Attenuation Factors for the Great Bay Estuary" (Feb. 14, 2007).
[88] Morrison *et al.* (2008), PR Doc. No. 7.

particles responsible for the bulk of the observed light attenuation as illustrated below in a graphic from the Morrison *et al.* (2008) report.[89]

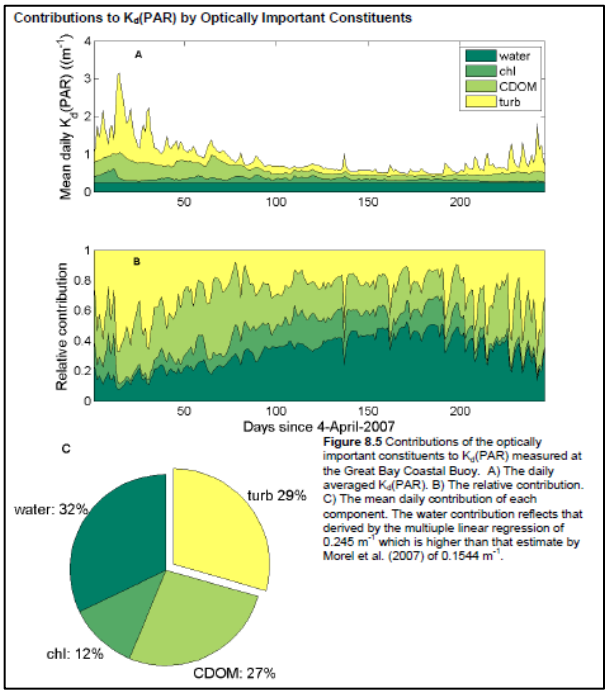

Figure 8.5 Contributions of the optically important constituents to K_d(PAR) measured at the Great Bay Coastal Buoy. A) The daily averaged K_d(PAR). B) The relative contribution. C) The mean daily contribution of each component. The water contribution reflects that derived by the multiuple linear regression of 0.245 m^{-1} which is higher than that estimate by Morel et al. (2007) of 0.1544 m^{-1}.

CDOM concentrations were demonstrated to vary with salinity and magnitude of riverine inputs, confirming its terrestrial origin. Non-algal particle concentration also varied with river flow and with wind-driven re-suspension. Based on the hyperspectral aerial imagery, the best water clarity was found in Great Bay, Little Bay, and the Lower Piscataqua River assessment zones. Water clarity in these areas were determined to be sufficient to support eelgrass growth and that the "[a]bsence of eelgrass from these zones would indicate controlling factors other than water clarity". However, water clarity in the upper tidal rivers (the Lamprey River, the Squamscott River, etc.) was insufficient to support eelgrass growth, with survival depths less than a meter. CDOM and non-algal particulates were primarily responsible for this lower water clarity, and prevent sufficient light penetration, regardless of the phytoplankton concentration present.[90] Thus, based on this detailed study, it is apparent that controlling TN in order to significantly improve transparency in the tidal rivers and bays will not and cannot achieve such results.

The study by Morrison *et al.* (2008) evaluated water quality conditions in the Great Bay estuary during 2007, <u>after</u> the major eelgrass decline in 2006. Based on this assessment, water clarity did not impair eelgrass growth in 2007. But this does not explain the dramatic reduction in eelgrass that occurred in 2006, which he did not investigate. Consequently, the Coalition through HydroQual, initiated an assessment of events and available data which occurred in 2006.[91] As it turns out, water clarity in Great Bay and Little Bay was dramatically reduced May through July of 2006 due to extreme weather events, but this reduction was not adequately represented in the routine monitoring conducted for these waterbodies. This extreme reduction in light penetration (and very low salinity due to high freshwater input) would be expected to significantly impair eelgrass growth. Data on the light attenuation coefficient and CDOM in the Bays clearly illustrates the problem encountered at that time, as explained below and illustrated in Figure 1.

[89] *See* Morrison *et al.* (2008), PR Doc. No. 7, at 26, Fig. 8.5.
[90] *See* Morrison *et al.* (2008), PR Doc. No. 7, at 48 (discussion of Eelgrass Survival Depth in Upper Tidal Rivers).
[91] Hydroqual and Hall & Associates prepared this evaluation for the July 2012 meeting with PREP Technical Advisory Committee.

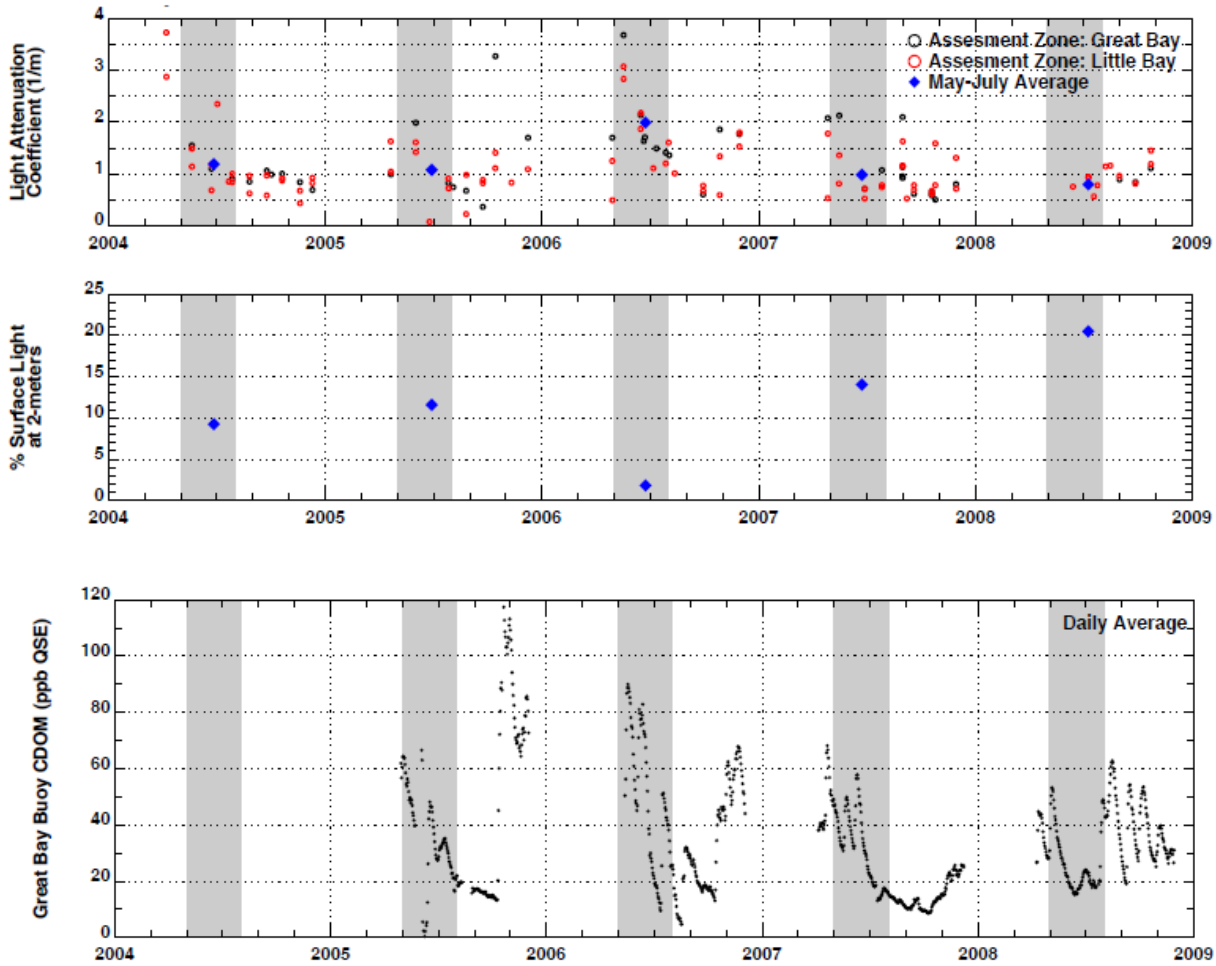

Figure 1. Great Bay and Little Bay Measured Light Attenuation Coefficients and Great Bay Buoy CDOM Measurements (2004-2008)

In the two years preceding 2006, light attenuation reduced surface light to about 10% of the incident irradiance at a depth of two meters, on average, at the start of the growing season.[92] In 2006, the light attenuation coefficient significantly increased such that the incident light was reduced to about 2% at two meters submergence. This reduction in clarity occurred simultaneously with the observed major eelgrass die off. In the following years, light attenuation was significantly improved, but eelgrass cover remained depressed in Great Bay until 2009.

The cause for this major reduction in water clarity in 2006 is clearly increased CDOM and turbidity due to excessive rainfall. Precipitation records for New Hampshire[93] show that annual average rainfall for the past 30 years was relatively normal from 1980 – 2004, as illustrated previously.[94] The subsequent five year period experienced significantly higher rainfall including the three highest annual rainfall years (2005, 2006, and 2008) in the past 118 years (1895 – 2012).

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[92] It is generally reported that eelgrass need at least 22% of the incident irradiance at the surface to support growth (assuming 4% light reduction due to epiphytes). Adequate light is obtained with the observed light attenuation coefficients in Great Bay due to the tidal variation in depth of submergence which provides, in general, sufficient light for eelgrass growth. *See* Fred Short, *Eelgrass Distribution in Great Bay Estuary for 2010, A Final Report to the Piscataqua Region Estuaries Partnership* (June 15, 2011), *available at* http://prep.unh.edu/resources/pdf/eelgrass_mapping_in_unh-10.pdf.
[93] *See* NOAA, National Climatic Data Center, http://www.ncdc.noaa.gov.
[94] Figure regarding Average Rainfall Data from 1900-2010, *supra* at 12.

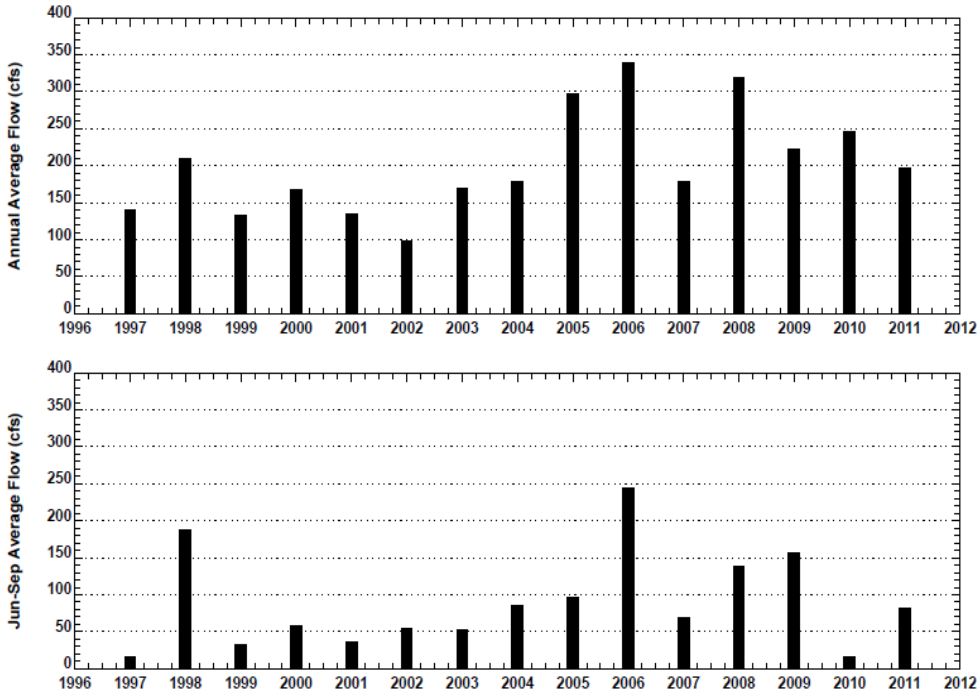


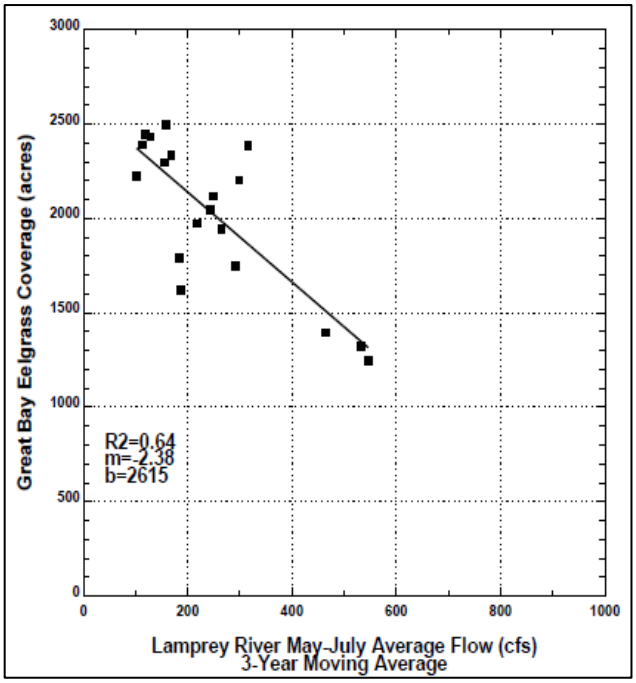
Figure 5. Exeter River Estimated Flow at the Dam (1997-2011)

In 2006, the rainfall in May and June exceeded the expected average for the two months by 13.24 inches (20.35 inches vs. 7.11 inches) as illustrated previously.[95] This rainfall caused a significant increase in the amounts of CDOM and non-algal particles delivered to the system as demonstrated by the increased tributary flows caused by the increased precipitation. Summer flows in particular increased dramatically over those occurring prior to 2005 as illustrated above in the flow records for the Exeter River.[96] This increased runoff, with corresponding CDOM and non-algal particle loads, significantly depressed light transmission through the water column over the entire estuary.

The CDOM and non-algal particles are naturally occurring and originate from terrestrial sources as determined by Morrison *et al.* (2008). The picture presented to the right illustrates the color contributed to the water column from these sources. Thus, it is apparent why water clarity decreased significantly in 2006, in response to the excessive rainfall.[97]

Photograph taken on October 31, 2012 in Rollinsford, NH showing naturally high CDOM in river water used to operate a turbine on Salmon Falls River.

[95] Figure regarding NOAA Precipitation Data New Hampshire- Climate Division 2, *supra* at 12.
[96] HydroQual Squamscott River Analysis, PR Doc. No. 19, at 22, Fig. 5.
[97] A detailed summary of current Bay transparency was also conducted in 2010, a relatively drier period than 2006. That survey measured light transparency, CDOM, turbidity, and phytoplankton. *See* Technical Memorandum from Thomas W. Gallagher and Cristhian Mancilla, HydroQual to John Hall, Hall & Associates RE: Review of New Hampshire DES Total Nitrogen



Eelgrass populations were evaluated as a function of the May-July tributary flow (an indicator of increased CDOM load to the system during the peak eelgrass growth period). A three year rolling average was used to reflect the recovery time for the system. As demonstrated in the graph above, eelgrass fair quite well during lower rainfall/flow years and poorly during high rainfall years. This is entirely reasonable given the degree to which tributary CDOM sources would impact system transparency. For Great Bay, the transparency level must be greatly reduced to offset the light received during low tide. Optimal conditions for eelgrass growth occur during very dry summers or extended periods of lower rainfall/drought. Much lower rainfall occurred in the 1950's and an extended drought in the mid-1960's. This would explain the ability of eelgrass to inhabit more of the upper tidal rivers during this period, as reported in the 2008 § 303(d) report.

d. Effect of Naturally Occurring CDOM on Eelgrass Viability in the Tidal Rivers

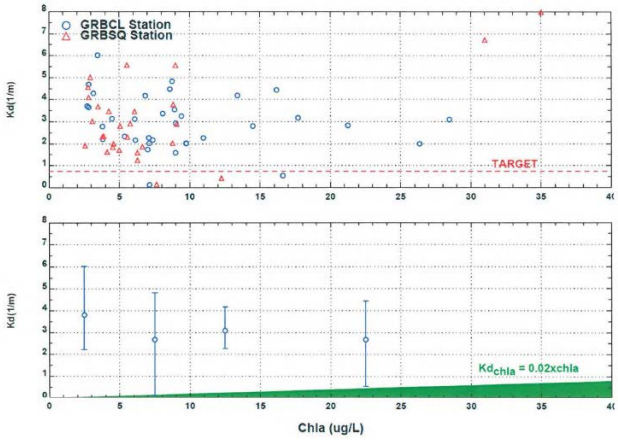
Since CDOM and non-algal particles are conveyed into Great Bay primarily from the freshwater portions of the upper tidal rivers, the concentration of these constituents is significantly higher in the rivers than in Great Bay. As a consequence, the tidal rivers are no longer able to support eelgrass growth as noted by Morrison *et al*. (2008).[98] This situation is natural and unrelated to nitrogen concentration. Evaluations of light extinction and chlorophyll-a data for the Squamscott River, the Lamprey River, and the Upper Piscataqua River confirm that (1) light transmission, in general, is very poor in these areas and (2) chlorophyll-a is a very minor component of the overall light extinction coefficient as illustrated in the following charts.[99] Light transmission is plainly inadequate to support eelgrass growth in these tributaries due to CDOM input.

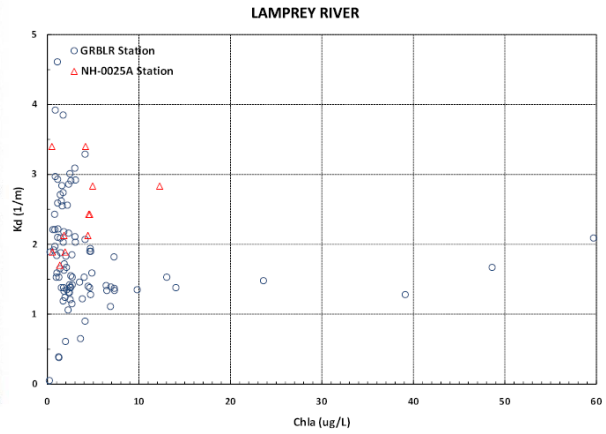
The charts (below) show that even with chlorophyll-a level <5 µg/l, typical Kd levels range from 2-4 in the Lamprey and the Squamscott Rivers. This confirms that CDOM and turbidity, not algal growth, controls transparency in the tidal river systems. For both systems, transparency "improves" at higher algal levels, presumably because the conditions that promote greater algal growth (lower stream flows/greater detention times) also serve to reduce CDOM inputs. In any event, transparency levels at low algal growth (<10 µg/l, i.e., the prevalent condition) is insufficient to support eelgrass, rendering TN control ineffective for allowing eelgrass repopulation of this area.

Criteria Development for the Great Bay Estuary (Jan. 10, 2010) (the results of that survey show transparency similar to 2007 levels and algal concentrations in the range of 2 – 4 µg/L of chlorophyll-a).

[98] Morrison *et al.* (2008), PR Doc. No. 7, at 48.

[99] The data for these evaluations was summarized in the 2009 Criteria Report but never analyzed. *See* 2009 Criteria Report, PR Doc. No. 8, at 58, Table 8 (light attenuation coefficients). The impact of chlorophyll-a on the transparency measurement (Kd) is based on the equation by Morrison contained in the 2009 Criteria Report. *Id.* at 61.

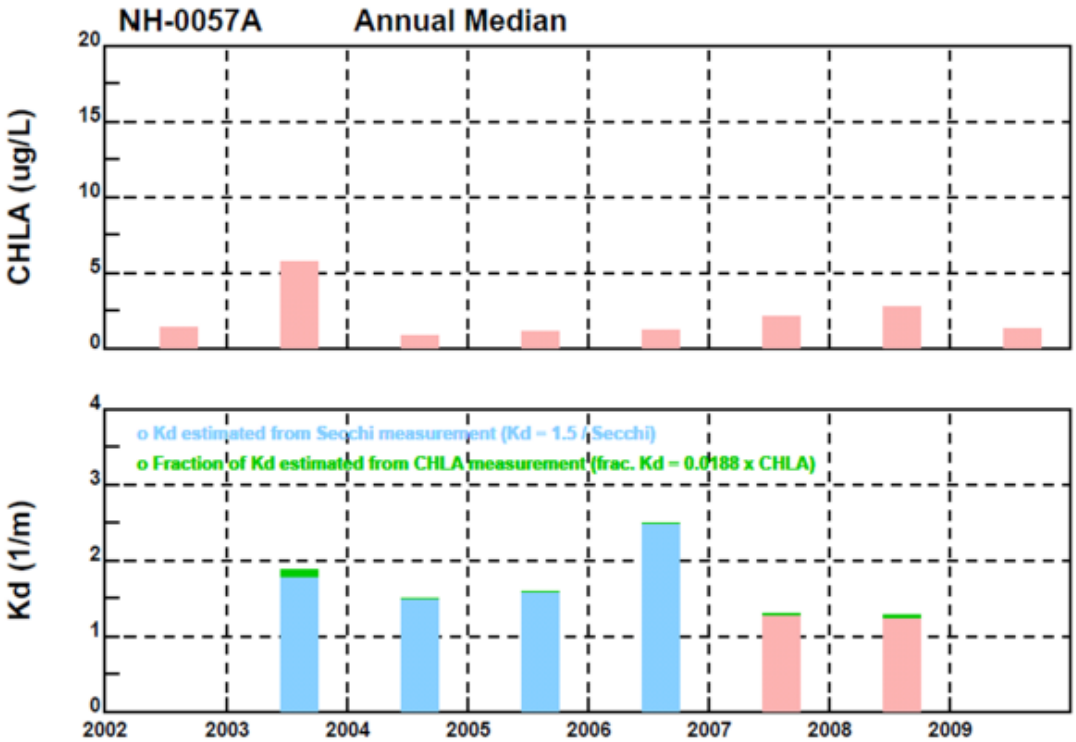




Squamscott River Transparency Chart **Lamprey River Transparency Chart**

The figure below shows that the Upper Piscataqua River has generally much better transparency than the other tidal rivers because it has far greater dilution from the ocean. However with chlorophyll-a typically averaging 1-3 ug/l, it is apparent that TN induced algal growth area has little effect on transparency in this tidal river. Consequently it is apparent that TN controls cannot restore water clarity in the waterbody.

Upper Piscataqua River Transparency Chart



e. Other Information

In an effort to resolve the significant uncertainty surrounding the derivation of the 2009 Criteria, DES and the Great Bay Municipal Coalition (including the municipalities of Dover, Durham, Exeter, Newmarket, Portsmouth, and Rochester, New Hampshire) entered into a Memorandum of Agreement (MOA) in 2011,[100] to collect additional data and conduct evaluations to better understand the relationship between nitrogen and use impairments in the estuary. This agreement included technical meetings to review the uncertainties with the transparency, macroalgae, and epiphyte lines of evidence associated with eelgrass loss. The first meeting for the MOA occurred on July 29, 2011, to discuss the various lines of evidence used in the 2009 Criteria Report.[101] Dr. Fred Short (University of New Hampshire), who has been studying eelgrass in this estuary for over two decades, provided the following comments to the MOA group:

- Transparency is not a major issue impacting eelgrass in Great Bay due to the shallow nature of the Bay and the tidal range. Eelgrass in Great Bay receive sufficient light for growth when the tide is out.[102]
- Epiphytes are not and never have been a significant problem to eelgrass in the estuary.[103]

The last meeting of the MOA occurred on September 26, 2011. This meeting included presentations on nutrient loading (Phil Trowbridge, DES), water quality sampling and hydrodynamic model development for the Squamscott River (Tom Gallagher, HydroQual), and macroalgae in Great Bay (Art Mathieson, University of New Hampshire). Professor Mathieson indicated that macroalgae are now present in Great Bay in greater amounts than in the 1980s.[104] Ammonia and nitrate are the primary nitrogen forms stimulating macroalgae growth, but the level of DIN needed to control macroalgae in the estuary is not known.[105] Dr. Mathieson also observed that some invasive macroalgae species may have very low nutrient needs.[106] This is an area that requires further research.

These observations were generally echoed in a response from Professors Langan and Jones[107] to a series of questions posed by the cities of Dover, Rochester, and Portsmouth (January 1, 2013).[108] Dr. Jones and Dr. Langan are TAC members (Dr. Jones is the Committee Chair) and each have conducted numerous studies of the Great Bay estuary. The letter from the cities posed questions concerning the cause of eelgrass losses in the estuary. In their response (February 19, 2013), the Professors noted the following:

- Chlorophyll-a levels remain "present at relatively low levels" in many areas of the estuary.[109] TN reductions would likely not significantly improve transparency through this mechanism, although no study has been conducted to address the degree of algal growth reduction due to TN control.[110]
- They have "not seen any analysis or even a comprehensive consideration of all of the factors that would enable discerning the relative influence of each on what happened to eelgrass in 2006. Emerging research on sediment re-suspension in Great Bay suggest extreme runoff events, like what happened during 2006, cause highly significant sediment re-suspension" which significantly reduces transparency.[111]

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[100] Attachment 10 - Memorandum of Agreement between the Great Bay Municipal Coalition and New Hampshire Department of Environmental Services relative to Reducing Uncertainty in Nutrient Criteria for the Great Bay/Piscataqua River Estuary (June 2011).
[101] *See* Attachment 1 - MOA July 29, 2011, Meeting Minutes.
[102] MOA July 29, 2011, Meeting Minutes, at 1.
[103] MOA July 29, 2011, Meeting Minutes, at 1.
[104] *See* Great Bay Municipal Coalition Nitrogen Meeting Minutes, PR Doc. No. 16, at 4.
[105] Great Bay Municipal Coalition Nitrogen Meeting Minutes, PR Doc. No. 16, at 4-5.
[106] Presentation notes by Dr. Art Mathieson "Algal Blooms/Problems in the Great Bay Estuary System", at 5.
[107] Langan and Jones Letter, PR Doc. No. 24.
[108] Mayors Letter to Langan and Jones, PR Doc. No. 23.
[109] Langan and Jones Letter, PR Doc. No. 24, at 2.
[110] Langan and Jones Letter, PR Doc. No. 24, at 2.
[111] Langan and Jones Letter, PR Doc. No. 24, at 2.

- Data on macroalgae in the estuary are sparse, although "anecdotal accounts suggest increase[s] have occurred, although it is also well accepted that macroalgal blooms are ephemeral and unpredictable. … No studies have demonstrated mechanisms for macroalgae growth causing decrease[s] in eelgrass populations."[112]

f. Conclusion

The 2009 Criteria for the protection of eelgrass are premised on the conceptual model that relates the loss of eelgrass habitat to decreasing water clarity based on the following progression: (1) the load of nitrogen entering the estuary increases; (2) the increasing nitrogen load stimulates the growth of phytoplankton that reduces light transparency through the water column; (3) light transparency is reduced to the point where eelgrass growth is adversely affected; and, (4) initially healthy eelgrass meadows are lost, proceeding from deeper areas of the habitat to shallower areas. Eelgrass meadows in Great Bay, Little Bay, and Portsmouth Harbor were not declining from 1990 – 2005, when DIN concentrations increased to their highest levels in Great Bay. The sharp eelgrass declines began in 2006 and are completely unrelated to TN concentration, which has actually declined significantly since 2006. As discussed below and confirmed by DES' assessment of estuary system data, the conceptual model of eelgrass loss due to TN-induced decreasing light transparency does not explain the conditions occurring in the Great Bay estuary. Although DIN loads to the estuary have apparently increased from mid-1990s through 2008, then decreased from 2009-2011, it has not resulted in any significant change in phytoplankton in the water column or a decrease in water clarity. The loss of eelgrass from the upper tidal rivers is unrelated to nitrogen concentrations and occurred long before 1980. DES acknowledged that the historical cause of this change is "unknown."[113] Presently, high levels of CDOM and natural turbidity from non-algal particles limit transparency in the upper tidal rivers. This certainly prevents eelgrass growth in these areas. This is a natural, not TN-induced condition. Analyses of the available data confirm that CDOM, not TN induced, algal growth, controls transparency levels, when such conditions limit eelgrass.

Regarding Great Bay, the sharp eelgrass declines have been tied to extreme wet weather occurring in 2005, 2006, and 2008, an occurrence also found in other estuarine systems.[114] TN and phytoplankton levels did not change during this period. Thereafter, from 2009-2011 once drier weather conditions prevailed, eelgrass beds rebounded by 400 plus acres in Great Bay and Little Bay. Some researchers have suggested that there may be levels of nitrate/DIN (in excess of .050 mg N/L) that could be "toxic" to eelgrass. There is nothing in the existing data which would suggest such an effect is occurring in the Great Bay Estuary. In fact, the available data supports the conclusion that nitrate "toxicity" to eelgrass has not occurred in Great Bay. DIN concentrations have exceeded 0.05 mg N/L throughout the entire period of record (1974 – 1981; 1991 – 2011). From 1990 to 2005, the eelgrass meadows in Great Bay were considered healthy as DIN concentrations varied from 0.05 mg N/L to 0.22 mg N/L. The peak eelgrass meadow cover in Great Bay occurred in 1996 when the median nitrate level in Great Bay was 0.09 mg N/L.[115] Thus, there is no apparent relationship between TN levels, algal growth and eelgrass health in this system. There is a relationship between poor transparency and increased wet weather related to system wide CDOM inputs. This condition is natural and has no connection to TN concentrations that covary with elevated CDOM.

Based on a review of available data and studies, it is apparent that while eelgrass populations have varied, there is no apparent relationship to TN in the system and certainly no connection to phytoplankton-induced transparency

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[112] Langan and Jones Letter, PR Doc. No. 24, at 3.
[113] *See* 2009 PREP Report; 2008 § 303(d) Report, PR Doc. No. 6, at 11 - 15.
[114] In 2011 eelgrass beds declined 40% in Chesapeake Bay. This rapid decline was caused by Hurricane Irene and Tropical Storm Lee. *See* Robert J. Orth, *et al.*, *2012 Distribution of Submerged Aquatic Vegetation in Chesapeake Bay and Coastal Bays*, Virginia Institute of Marine Science, College of William and Mary (Oct. 2013), *available at* http://web.vims.edu/bio/sav/sav12/index.html.
[115] *See* 2012 PREP Environmental Data Report, at 49, Fig. NUT2-3.

impacts. Algal levels remain, on average, quite low given the amount of nitrogen present in this system. This verifies that the system, in general, is still not suffering adverse effects of cultural eutrophication, related to phytoplankton growth (as PREP itself concluded in 2006).[116] It also demonstrates that TN is not the factor limiting algal growth at this time. The available inorganic nitrogen is capable of supporting far greater algal biomass, but this has not occurred. System hydrodynamics and reduced light penetration due to CDOM are the most likely explanations for the reduced algal growth occurring in Great Bay, Little Bay, and the Piscataqua River.[117]

As algal levels in both Great Bay and Little Bay have remained largely constant over time, this parameter could not have caused a significant change in system transparency over time or triggered the 2006 eelgrass decline. For that same reason, controlling TN cannot produce a significant improvement in system transparency or induce a system wide eelgrass recovery. Increased rainfall, CDOM inputs, and extreme weather are the most likely cause of changing eelgrass populations. Recent increases in eelgrass populations in both Little Bay and Great Bay have occurred despite the existing nitrogen levels, which are well above those claimed necessary for eelgrass restoration in the 2009 Criteria Report. This also indicates that system transparency for Great Bay and Little Bay is sufficient to allow eelgrass recovery, as long as wet weather conditions do not persist during the growing season. When such wet weather conditions persist, eelgrass are expected to fare poorly due to the impact of increased CDOM on system transparency.

The only area of the system with documented increased macroalgae growth is Great Bay. The data regarding macroalgae support the conclusion that increases have occurred, though conditions vary widely from year to year. The ecological significance of this condition is still uncertain. The data do not indicate that eelgrass growth (repopulation) is precluded by macroalgae at this time. The ability to control this form of plant growth is not known, although such efforts would need to focus on DIN reduction.

B. Analysis of the Transparency Endpoint Regression Methods

When DES attempted to apply its conceptual model (relating increasing nitrogen concentration to increasing phytoplankton in Great Bay/Little Bay to decreasing water clarity to reductions in eelgrass beds), this linkage could not be established because phytoplankton levels in Great Bay/Little Bay did not change despite significant changes in nitrogen entering the estuary. Moreover, eelgrass beds did not decrease in coverage over the period when nitrogen concentrations were increasing (1990 – 2000). The Morrison study, also, confirmed that the low level of algal growth occurring in Great Bay/Little Bay had a minor impact on system transparency (about 12%).[118] These observations should have been (and originally were) sufficient to conclude that the classic conceptual model for eutrophication did not apply in the Great Bay Estuary due to the site-specific characteristics of the estuary (e.g., hydraulic residence time, natural CDOM and non-algal particles, and depth of Great Bay) that prevent excessive phytoplankton primary productivity.

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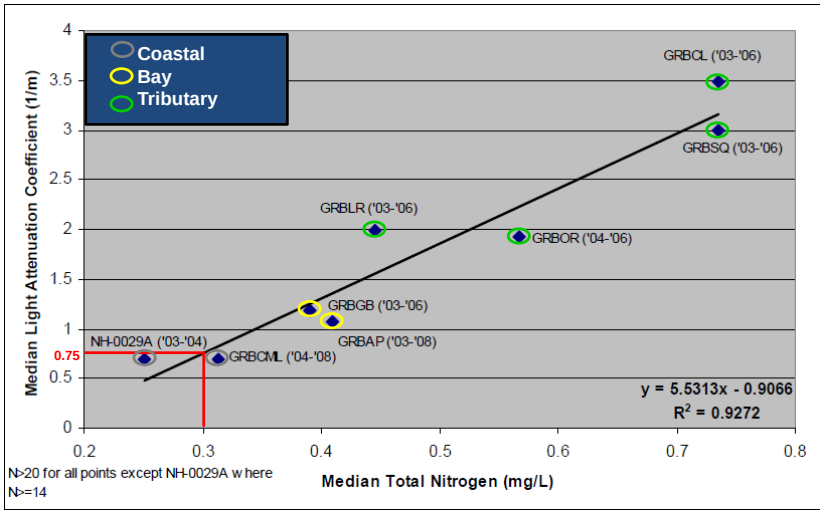
[116] Massachusetts Department of Environmental Protection has evaluated numerous estuarine systems along Cape Cod and for several other tidal rivers tributary to Narragansett Bay relying upon the Massachusetts Estuaries Project 2003 report entitled "Site-Specific Nitrogen Thresholds for Southeastern Massachusetts Embayments: Critical Indicators- Interim Report." The Report states that waters are considered "excellent to good" if the following indicators exist: "Eelgrass beds are present, macroalgae is generally non-existent but in some cases may be present, … chlorophyll-a levels are in the 3 to 5 µg/L range … total nitrogen levels of 0.30-0.39 mg N/L." Report, at 18. Indicators for waters classified as "unimpaired," include "chlorophyll-a levels are in the 3 to 5 µg/L range and nitrogen levels are in the 0.39 – 0.50 range. … eelgrass is not present … and macroalgae is not present or present in limited amounts even though a good healthy aquatic community still exists." *Id.* The current TN levels within Great Bay are already at the lower end of the protective range (Great Bay-Little Bay average 0.35-0.42 mg/l) falling within the "excellent to good" category.

[117] *See* Technical Memorandum from Thomas W. Gallagher and Cristhian Mancilla, HydroQual to Great Bay Municipal Coalition, RE: Calibration of Great Bay Estuary Hydrodynamic Model and Incremental Nitrogen Estimation (November 11, 2013) (hereinafter "HydroQual Hydrodynamic Model").

[118] Morrison *et al.* (2008), PR Doc. No. 7, at 5.

To overcome this impediment to nutrient criteria derivation, after consultation with EPA, a new regression approach was developed as illustrated below in Figure 39 from the 2009 Criteria Report.[119] This regression analysis combined multi-year median concentrations from trend stations in tidal rivers, Great Bay, and Portsmouth Harbor to claim a causative link between light attenuation and TN (i.e., the greater transparency found at the mouth of the estuary was caused directly by the lower TN concentration at that location).



The resulting "stressor-response" evaluation included a very impressive coefficient of determination ($R^2 = 0.93$), suggesting a very strong relationship between TN and transparency. However, this analysis is fundamentally flawed since basic principles of ecological data assessment were violated and the alleged TN-transparency relationship is plainly inapplicable given the more detailed data assessments available.

The regression analysis in Figure 39 shows light attenuation increasing significantly as TN concentration increases. The regression implies that the TN concentration itself causes an increase in light attenuation. This is not defensible because TN has no such physical property. As a "nutrient control", this effect on light attenuation can only be caused by an increase in phytoplankton if the conceptual model is correct. However, the data confirm that phytoplankton chlorophyll-a did not increase in this system in response to changing DIN loads. Based on the study by Morrison *et al*. (2008), light attenuation is primarily controlled by CDOM and non-algal particles that covary with TN concentration in the various areas of the Estuary.[120] This fact was confirmed by DES in Figures 21 (salinity v. TN)[121] and Figure 37 (turbidity v. TN) to the 2009 Criteria Document.[122] To address the deficiency, the document claims that increases in TN caused an increase in non-algal particles without presenting a conceptual model to explain how this could occur.[123] However, there is no objective scientific basis for this claim and, in any event, even if correct, would provide no basis for generating a TN criteria that applies to point sources unrelated to the "phenomena."

As noted by Dr. Chapra, the methods used to develop the regression analysis presented in Figure 39 and derive the TN criteria for the estuary are not scientifically defensible.[124] First, there is no showing of a causal relationship between TN, algal growth, and light attenuation at any specific location in the estuary (i.e., the proposed conceptual model was never verified) and no assessment of confounding factors that covary with light attenuation was presented. In fact, the entire relationship can be explained by changing CDOM and/or dilution for the various locations. Shortly after DES released the 2009 Criteria Report, an EPA Science Advisory Board (SAB) panel was

[119] *See* 2009 Criteria Report, PR Doc. No. 8, at 67, Fig. 39.
[120] DES recognized this influence, but did not abandon their approach. *See* Attachment 11 – Email from Philip Trowbridge, DES to Jim Latimer, EPA, Re: comments on NH estuaries N criteria document (Nov. 19, 2008) ("The comment that seems hardest to refute is that nitrogen is correlated with light attenuation. Nitrogen was not proven to be the causative agent for light attenuation. Moreover, nitrogen is a component of all the factors causing attenuation (phytoplankton, CDOM, particulate organic matter) so a correlation would be expected.").
[121] 2009 Criteria Report, PR Doc. No. 8, at 43, Fig. 21.
[122] 2009 Criteria Report, PR Doc. No. 8, at 65, Fig. 37.
[123] *See* 2009 Criteria Report, PR Doc. No. 8, at 63.
[124] Chapra Analysis, PR Doc. No. 25, at 7-8.

convened to review such simplified stressor-response (regression) methods being used elsewhere by EPA to support numeric nutrient criteria development. The final SAB report was issued in April, 2010.[125] EPA subsequently published guidance on the use of "stressor-response" relationships to derive numeric nutrient criteria in November, 2010.[126] As discussed below, the SAB recommendations and EPA's guidance confirm the regression approach, as used to generate the 2009 nutrient criteria is not defensible.

i. SAB Recommendations

The SAB convened on September 9, 2009, to consider draft guidance prepared by EPA on the use of stressor-response analyses to develop numeric nutrient criteria and issued a 46 page critique on April 27, 2010 of those simplified methods.[127] The SAB reiterated that the simple, regression-style methods similar to those used in the 2009 Criteria Report may be inadequate (and misleading) for developing numeric nutrient criteria when nutrient responses are significantly influenced by other factors.

> The statistical methods in the Guidance require careful consideration of confounding variables before being used as predictive tools. … Without such information, nutrient criteria developed using bivariate methods may be highly inaccurate.[128]

Moreover, if criteria developed from a stressor-response analysis are to be applied to a specific waterbody, specific conditions particular to that waterbody must be considered to ensure that application of such criteria is appropriate.

> Numeric nutrient criteria developed and implemented without consideration of system specific conditions (e.g., from a classification based on site types) can lead to management actions that may have negative social and economic and unintended environmental consequences without additional environmental protection.[129]

ii. EPA 2010 Stressor-Response Guidance

The EPA subsequently finalized its stressor-response guidance (2010 Stressor-Response Guidance) following the recommendations made by the SAB.[130] The 2010 Stressor-Response Guidance presented detailed information on the need to confirm the applicability of the conceptual models and to classify the data by ecological setting. EPA reiterated that data classification is particularly important to ensure that only similar systems are being assessed.

> Classifying data is a key step in analyses of stressor-response relationships because the expected responses in aquatic ecosystems to increased N and P can vary substantially across different sites.[131]

EPA also reiterated that the observed system response to a parameter should be confirmed before a regression should be considered appropriate for criteria derivation.

> Before finalizing candidate criteria based on stressor-response relationships, one should systematically evaluate the scientific defensibility of the estimated relationships and the criteria derived from those relationships. More specifically, one should consider whether estimated

[125] SAB Stressor-Response Review, PR Doc. No. 10.
[126] EPA Stressor-Response, PR Doc. No. 14.
[127] SAB Stressor-Response Review, PR Doc. No. 10.
[128] SAB Stressor-Response Review, PR Doc. No. 10, at 24.
[129] SAB Stressor-Response Review, PR Doc. No. 10, at 38.
[130] EPA Stressor-Response, PR Doc. No. 14.
[131] EPA Stressor-Response, PR Doc. No. 14, at 55.

> relationships **accurately** represent known relationships between stressors and responses and whether estimated relationships are **precise** enough to inform decisions.[132]
>
> [E]xploratory data analysis can indicate other variables that should be included in the classification analysis. In particular, other variables that are strongly correlated with the stressor variable or with the response variable should be evaluated for inclusion in classification analysis.[133]
>
> [M]any confounding variables must be considered when estimating the effects of nitrogen/phosphorus pollution on a measure of aquatic life in streams (e.g., a macroinvertebrate index).[134]
>
> The possible influences of confounding factors are the main determinants of whether a statistical relationship estimated between two variables is a sufficiently accurate representation of the true underlying relationship between the two variables …[135]

It is apparent that the regression presented in the 2009 Criteria Report as the basis for the final recommended TN criteria, did not consider either of these core principles to generating scientifically defensible criteria.[136] The regression methods failed to evaluate "confounding factors" to ensure the relationship was "reliable" and failed to properly classify the data by waterbody type, to eliminate the effects of the changing physical conditions on the parameters of interest.

iii. The Chapra Assessment

Dr. Steven Chapra prepared an expert review of the 2009 Criteria Document focusing on the regression analyses used by DES to derive the TN criteria.[137] Dr. Chapra determined that the simple linear regressions, presented as the basis for concluding that increasing TN concentration caused the adverse D.O. and transparency responses in the estuary, contained several fundamental errors. The fundamental errors common to all of these analyses are:

1) The analyses combine data sets from greatly different physical settings; this is a simply not acceptable.
2) The predicted impacts from algal growth on transparency and DO are physically impossible, but that reality was not recognized by the document author.
3) None of the co-varying or confounding factors that must be considered to allow such regression analyses to produce reliable results were conducted.

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[132] EPA Stressor-Response, PR Doc. No. 14, at 65 (emphasis added).
[133] EPA Stressor-Response, PR Doc. No. 14, at 56-57.
[134] EPA Stressor-Response, PR Doc. No. 14, at 11.
[135] EPA Stressor-Response, PR Doc. No. 14, at 65.
[136] As Dr. Chapra concluded:

> A cursory review of the 2009 Numeric Nutrient Criteria Document confirms that is [sic] did not rely on accepted, scientifically defensible methods. The evaluation errors were extensive and included virtually every major factor that EPA has identified in its final Stressor-Response guidance document, including:
>
> - Combining data from different biotypes that affect D.O. and transparency;
> - Failing to consider co-varying pollutants and parameters;
> - Failing to evaluate key confounding factors;
> - Presuming that the pollutant was the cause of the changing system response parameter when the available data confirmed it was not; and,
> - Failing to assess the accuracy and reliability of the suggested relationships based on data and studies from specific areas within the Great Bay system.

Chapra Analysis, PR Doc. No. 25, at 14.
[137] Chapra Analysis, PR Doc. No. 25.

4) The results are directly at odds with published State of the Estuary reports and tributary assessments confirming that TN has not caused material changes in algal growth nor is it controlling minimum DO, verifying these analyses have no connection to the documented system response to TN and algal growth.[138]

Based upon this review, Chapra concluded that the 2009 Criteria Report did not use scientifically defensible methods and it failed to apply stressor-response methods in a manner accepted by the scientific community: "*The methods applied are, in fact, grossly incorrect, internally inconsistent and have produced results that bear no reasonable relationship to reality.*"[139] Given these observations that are supported by the SAB recommendations and federal guidance on acceptable "stressor-response" methods, it is apparent that the criteria values generated in the 2009 Criteria Report are not based on acceptable scientific methods and the simplified regression approach used to derive the criteria needs to be amended.

Regression methods may serve as a useful tool to derive numeric nutrient criteria when specific data processing and conceptual model confirmation guidelines are followed. These methods have proven particularly useful in stable aquatic settings such as lake analyses. The recommendations made by the SAB and the EPA 2010 Stressor-Response Guidance on the use of regressions in developing numeric nutrient criteria identify basic requirements for the defensible use of such methods. However, the 2009 Criteria Report utilized simple linear regression methods that failed to follow these recommendations by presuming a cause and effect relationship that was demonstrated to be inappropriate for the Great Bay Estuary by specific studies for the estuary. Given the failure to confirm the simplified relationship reflected actual system responses or to analyze whether confounding factors may skew the results, application of these methods was not scientifically defensible. Moreover, the simple regressions were developed by combining hydrologically distinct areas of the estuary without any attempt to assess whether the physical differences significantly affect the system response to nutrients. These fundamental oversights render the results speculative and demonstrably misplaced. Based on the detailed studies of this estuary, a mechanism other than algal-induced changes to water column transparency and D.O. should be investigated.

C. Analysis of Macroalgae/ Epiphytes Issues

The conceptual model used by DES to justify the proposed criteria also considered the possible adverse effects of increasing nutrient concentrations on eelgrass growth through a proliferation of macroalgae (thought to displace eelgrass and prevent their recolonization) and/or a proliferation of epiphytes (which reside on the eelgrass and block light from reaching the leaf).[140] Macroalgae are present in all estuarine waters to varying degrees. Increasing nitrogen inputs and higher water temperatures can stimulate the growth of macroalgae species which can entangle, smother, and otherwise impact eelgrass populations. Macroalgae are reported to have lower light requirements for survival than eelgrass and some only thrive in higher nitrogen environments.[141] However, some invasive species can grow even in low nutrient conditions.[142] Thus, the efficacy of nutrient control may be difficult to discern depending upon the conditions that have led to increases in macroalgae growth. In this system, the only areas with significant macroalgae growth are the more quiescent waters of Great Bay. None of the tidal rivers have any significant macroalgae growth documented, presumably because these plants cannot grow in areas of higher velocity caused by tidal currents. In particular, the tidal velocity and exchange in the Piscataqua River is quite high and would be expected to limit the ability of these transient species to root. Consequently, the discussion below will focus solely on macroalgae growth in Great Bay.

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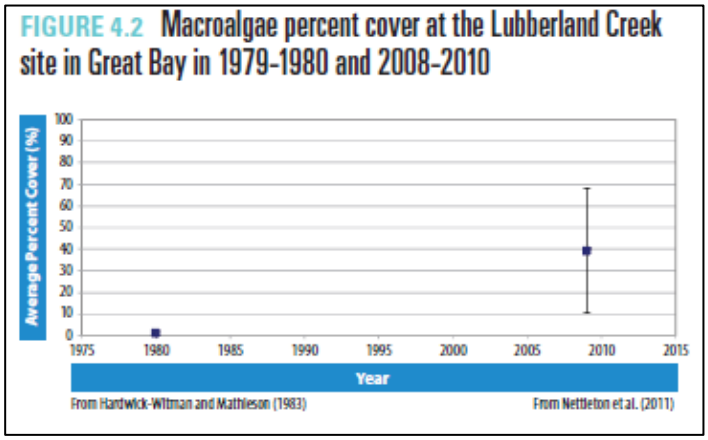
[138] Chapra Analysis, PR Doc. No. 25, at 8.
[139] Chapra Analysis, PR Doc. No. 25, at 1.
[140] 2009 Criteria Report, PR Doc. No. 8, at 55.
[141] 2009 Criteria Report, PR Doc. No. 8, at 37.
[142] Mathieson Presentation Notes, at 5.

i. Occurrence of Macroalgae in Great Bay

In the Great Bay estuary, a consistent monitoring program for macroalgae does not exist. Most of the available data are anecdotal, with only a few actual measurements. Baseline measurements were made by University of New Hampshire researchers (notably Dr. Art Mathieson) between 1972 and 1980 for a few locations.[143] These limited measurements identified very low levels of macroalgae in 1980.[144] As part of the ongoing eelgrass survey by Dr. Short *et al.*, macroalgae overgrowth was never reported as a significant concern prior to 2009.[145] More detailed measurements were made in 2007, via aerial imagery (Pe'eri *et al.*, 2008)[146] and in 2008-2010 by on-site survey (Nettleton, 2011).[147] The Pe'eri study was primarily conducted to evaluate the use of hyperspectral imagery as a tool for mapping macroalgae in Great Bay. Results for a survey conducted on August 29, 2007, were used to produce a comprehensive map of eelgrass and macroalgae in the estuary.[148] Based on this 2007 survey, it was estimated that macroalgae covered 137 acres in Great Bay and encroached into areas previously inhabited by eelgrass. Significant macroalgae growth was not documented in Little Bay and has not been reported in any eelgrass survey.

Based on the Pe'eri survey, it could not be determined if the macroalgae caused the eelgrass to decline in the Bay or if the decline of the eelgrass provided new areas for macroalgae to proliferate. Consequently, the 2009 Criteria Report concluded macroalgae were a concern, but only recommended a 10-20% TN reduction under the assumption that this would adequately control macroalgae growth.[149] This target was chosen based on nitrogen measurements from areas where significant macroalgae growth was not occurring. After 2007, the eelgrass recovered by approximately 450 acres in Great Bay, including areas that had more extensive macroalgae growth in 2007, after the dramatic eelgrass downturn of 2006.[150] This significant eelgrass recovery indicates that macroalgae growth was not the cause of the 2006 eelgrass downturn and that eelgrass recovery in the bay is not precluded by macroalgae growth.

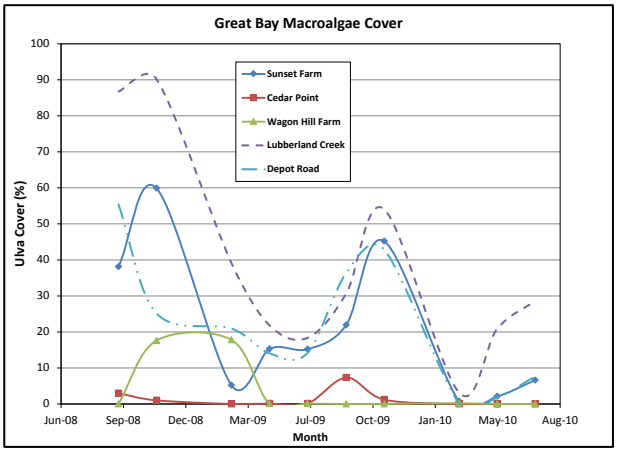


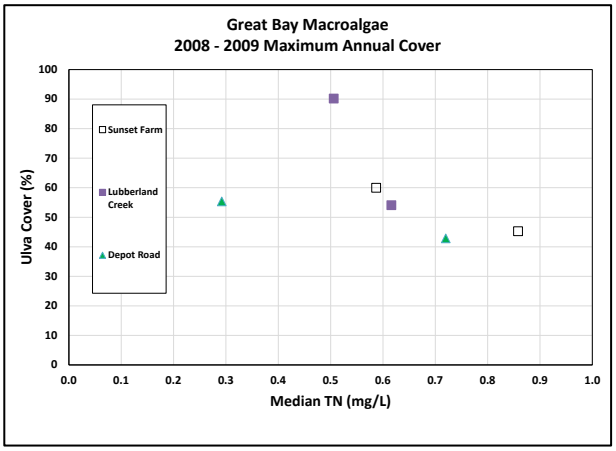
In 2008/2009, Nettleton completed an evaluation of macroalgae growth as part of a Ph.D. thesis, with Dr. Art Mathieson as his doctoral advisor.[151] The earlier University of New Hampshire baseline measurements by Dr. Mathieson (1980) and the more recent work by Nettleton (2011) are directly comparable because these studies mapped the areal coverage of macroalgae at a specific location in Great Bay, including Lubberland Creek. These

[143] *See* 2009 Criteria Report, at 37.
[144] *See* 2013 PREP Report, PR Doc. No. 22, at 17, Fig. 4.2*; see also* Great Bay Municipal Coalition Nitrogen Meeting Minutes, PR Doc. No. 16, at 4-5.
[145] *See* Eelgrass Distribution in the Great Bay Estuary Reports from 2000- 2008 prepared by Dr. Fredrick T. Short for Piscataqua Region Estuaries Project *available at* prepunh.edu/resources/pubs_by_date.htm.
[146] Shachak Pe'eri *et al.*, *Macroalgae and eelgrass mapping in Great Bay Estuary using AISA hyperspectral imagery,* New Hampshire Estuaries Project (2008), *available at* http://www.prep.unh.edu/resources/pdf/macroalgae_and_eelgrass-unh-09.pdf.
[147] *See* Jeremy C. Nettleton, *et. al.*, Tracking environmental trends in the Great Bay Estuarine System through comparisons of historical and present-day green and red algal community structure and nutrient content (Mar. 2011).
[148] 2009 Criteria Report, PR Doc. No. 8, at 39.
[149] 2009 Criteria Report, PR Doc. No. 8, at 38.
[150] *See* Figure, *supra* at 13 showing eelgrass acreage from 2007 to 2012.
[151] *See* Jeremy C. Nettleton, *et. al.*, Tracking environmental trends in the Great Bay Estuarine System through comparisons of historical and present-day green and red algal community structure and nutrient content (Mar. 2011).

results were summarized in Figure 4.2 from the 2013 PREP Report (see above).[152]

Nettleton (2011) also contained information on nutrient concentration and macroalgae biomass at several locations in Great Bay. A plot of those data (below) for Ulva (the predominant macroalgae species observed in Great Bay) cover are illustrated below from the surveys by Nettleton (2011). This information indicates that macroalgae cover is quite variable from year to year and location to location and that variability is not directly linked to nutrient concentration.





Macroalgae biomass and cover generally increase over the summer growing season (June – November) and typically peak in October/November but nearly disappear through the winter until the following June. Given the cycle of growth, it is apparent that this transient plant growth may not limit eelgrass recovery in areas where eelgrass has declined for other reasons. Eelgrass may begin to reestablish in the spring before macroalgae levels begin to shade out light in the late summer. Moreover, most of the macroalgae growth areas found by Nettleton do not affect eelgrass growth since they are intertidal locations, where eelgrass cannot survive well. Two of the study sites (Cedar Point and Wagon Hill Farm) had very low levels of biomass and cover relative to the other sites. These sites are characterized as having strong tidal currents which make them unlike the remaining three sites, which are mudflats located in the southern portion of Great Bay and have low currents. If the peak biomass and peak cover for the mudflat sites are plotted against the median TN concentration (the only form of nitrogen monitored) for each year, the graph suggests no meaningful relationship with increasing TN, and that attainment of even a 0.3 mg/l TN objective does not preclude such growth.

Macroalgae generally meet their nutrient needs from water column inorganic N.[153] Thus, it is more appropriate to look at DIN concentration with regard to macroalgae because this is the form of nitrogen believed primarily responsible for stimulating macroalgae. Monitoring for DIN in Great Bay at Adams Point by PREP was incomplete for 2008 so plots similar to those shown above cannot be prepared. However, the data for 2009 shows a median DIN concentration of 0.125 mg/L. By comparison, the median DIN for 1996 (when eelgrass cover was at a maximum in Great Bay) was reported at 0.15 mg/L. The fact that macroalgae were not considered problematic in 1996, indicates that other factors may be responsible for the recent proliferation or that these are opportunistic species capable of rapidly colonizing open habitat. It may be that the loss of eelgrass beds in 2006, due to excessive rainfall runoff, provided an opportunity for macroalgae to take residence in the Bay in 2007 or for a new invasive form of macroalgae to populate that requires far lower nutrient levels to periodically proliferate.

In a September 26, 2011 meeting, Dr. Mathieson indicated that the appropriate allowable level of DIN to control macroalgae in the estuary is not known at this time, but macroalgae problems were not observed in the early

[152] 2013 PREP Report, PR Doc. No. 22, at 17, Fig. 4.2.
[153] Great Bay Municipal Coalition Nitrogen Meeting Minutes, PR Doc. No. 16, at 4.

1980s, when DIN concentrations in the Bay were lower (averaging approximately 0.1 mg/l).[154] However, the present DIN level is comparable to that occurring in the 1970's when macroalgae impairment was not documented.[155] Thus, one would think that macroalgae levels should be comparable if this is the controlling parameter. As noted previously, the 2013 PREP Report found macroalgae are an "emerging problem" requiring further research.[156] Current macroalgae pictures[157] support this recommendation, showing that macroalgae growth, at least in areas of the Great Bay estuary focused on by Nettleton in 2008, have declined.

Depot Road, Nettleton, 2008

Depot Road, Peschel, 2013

Wagon Hill Farm, Nettleton 2008

Wagon Hill Farm, Peschel, 2013

The degree macroalgae are impacting system ecology in the Great Bay estuary is currently unknown. Moreover, it is unknown what a proper TN control level would be for controlling macroalgae growth. However, since macroalgae were not considered a "problem" in the estuary through the mid-1990's, ensuring pre-1990 DIN levels are maintained during the macroalgae growth season (June to October) should assist in controlling this algal form.

[154] These observations during the MOA discussions were generally echoed in a response from Professors Langan and Jones to a series of questions posed by the cities of Dover, Rochester, and Portsmouth. Langan and Jones Letter, PR Doc. No. 24. Drs. Jones and Langan noted that data on macroalgae in the estuary are sparse, although anecdotal accounts suggest increases have occurred. Langan and Jones Letter, PR Doc. No. 24, at 3.

[155] 2013 PREP Report, PR Doc. No. 22, at 14.

[156] 2013 PREP Report, PR Doc. No. 22, at 44.

[157] *See* Attachment 4 – Dean Peschel, Great Bay Municipal Coalition, Macroalgae pictures taken on October 11 and 15, 2013.

ii. Occurrence of Epiphytes in Great Bay

While the conceptual model of cultural eutrophication in estuarine environments includes adverse effects on eelgrass habitat due to epiphytes, the available data on epiphytes is more limited than the available data on macroalgae. Reports of excessive epiphyte growth have not appeared in various annual eelgrass surveys completed by Dr. Short. On July 29, 2011, a meeting of local technical experts was held to discuss the various lines of evidence used in the 2009 Criteria Report. Dr. Fred Short who has been studying eelgrass in the estuary for over two decades, commented: "Epiphytes are not and never have been a significant problem to eelgrass in the estuary".[158] Based on these observations, further assessment of this factor is not warranted at this time. As with macroalgae, more data are needed to quantify whether epiphytes are adversely influencing eelgrass habitats in the estuary and to assess the cause and resolution to such problems if they exist.

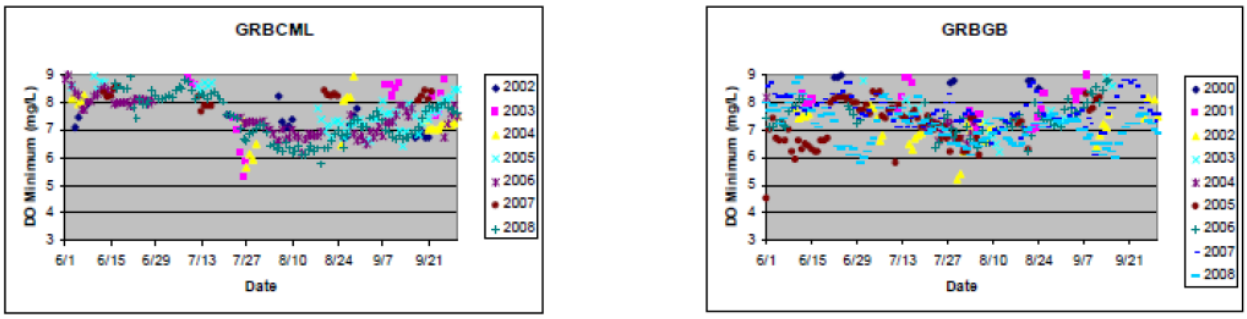
D. Analysis of Dissolved Oxygen Issues

The D.O. criteria from the 2009 Criteria Report are premised on a series of assumptions. These include: (1) TN inputs are triggering excessive algal growth above 10 µg/l in the tidal rivers; (2) the peak algal growth (represented by the 90th percentile chlorophyll-a concentration) is the cause of the low D.O. conditions; and, (3) reducing peak algal growth to less than 10 ug/l will ensure that minimum D.O. will remain above 5 mg/l. As stated in Appendix B to the 2009 Criteria Report, "[p]rimary productivity in the estuary is the reason for the oxygen depletion because high frequency measurements of D.O. have documented diurnal swings from super-saturation to depletion which are indicative of *in-situ* photosynthesis and respiration."[159] As discussed below, none of these assumptions are accurate and the methods used to reach these conclusions and derive the criteria target are not scientifically defensible or consistent with accepted methods for D.O. impact evaluation in aquatic systems.

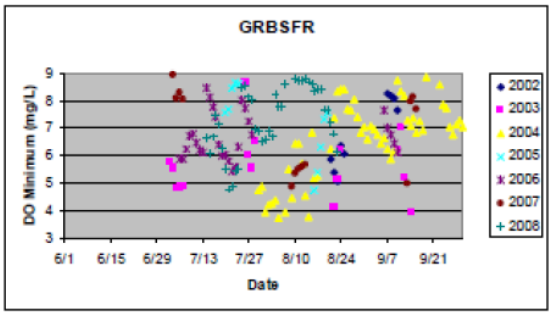
i. Assessment of Existing Conditions

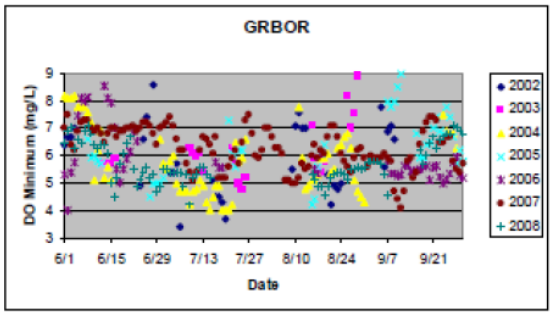
Significant data have been collected annually for the tidal rivers and several detailed studies have been conducted for the Lamprey and Squamscott Rivers to evaluate the causes of low D.O. conditions. These data demonstrate that all of the tidal rivers experience low D.O. conditions regardless of the chlorophyll-a level present.[160] Figure 30 from the 2009 Criteria Report (below)[161] provides a good view of the time variable nature of low D.O. conditions and how such conditions vary year to year.

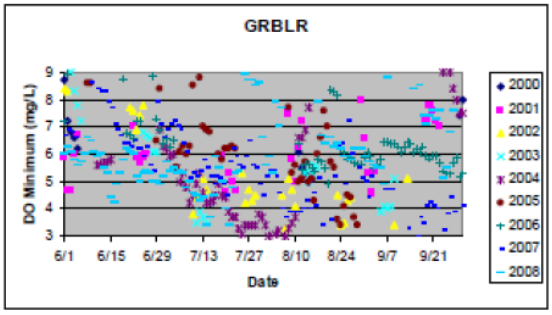
Figure 30: Daily Minimum Dissolved Oxygen (mg/L) Measured by Datasondes in Summer (June-September)

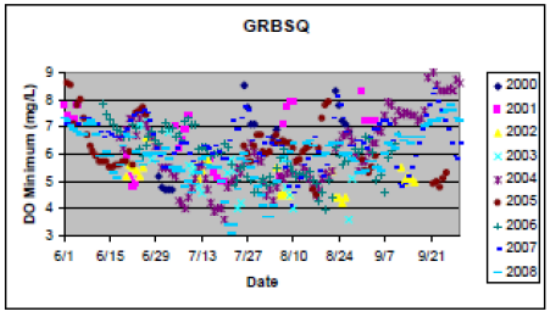


[158] Attachment 1- MOA Meeting Minutes for July 29, 2011, at 1.
[159] 2009 Criteria Report, PR Doc. No. 8, at B-3.
[160] *See* 2009 Criteria Report, PR Doc. No. 8, at 47, Table 7.
[161] 2009 Criteria Report, PR Doc. No. 8, at 53.









These data show low D.O. conditions do not occur at the harbor (GRBCML) or in Great Bay (GRBGB). The tidal rivers, however, all experienced low D.O. The following table summarizes the median and 90th percentile algal levels as reported by DES for the major tidal rivers with significant point source inputs:[162]

River	Median Chl-a (µg/L)	90th Percentile Chl-a (µg/L)	Min. Typical D.O.
Squamscott River (GRBSQ)	6.75	17.37	3.5
Lamprey River (GRBLR)	3.12	12.40	3.0
Oyster River (GRBOR)	4.21	14.63	4.0
Cocheco River	3.23	12.28	5.0
Salmon Falls River (GRBSFR)	4.04	12.90	4.5

The data presented in the 2009 Criteria Report indicates that low D.O. conditions are most frequent in the Lamprey River which has the lowest reported median and second lowest peak algal levels. The Squamscott River has periods of consistently low D.O. but these low D.O. periods are not as severe as in the Lamprey River. Low D.O. conditions in the other tidal rivers vary but appear less frequently or intensely, though algal levels are similar at all locations. The slight variation in the median and 90th percentile algal levels exemplified by the data could not possibly explain the differences in the range and frequency of low D.O. conditions occurring in these tidal rivers (*i.e.*, a 2 µg/l change in peak chlorophyll-a cannot physically produce a 1.5 mg/L difference in minimum D.O.).[163] These data indicate that factors other than algal concentration are controlling the occurrence of low D.O. in the system. For example, the Squamscott River has extensive tidal marshes that flood each day due to the tidal range in the Estuary as is illustrated by the picture below of the Squamscott River highlighting the extensive marsh areas below the Exeter Wastewater Treatment Plant (WWTP)).

It is widely known that low D.O. from such marsh areas can significantly influence D.O. levels. Tidal marshes along the other tidal rivers are far less extensive. When PREP evaluated the reasons for low D.O. conditions in 2006, it was noted that the cause of the condition was unknown, but could be "natural."[164]

[162] *See* 2009 Criteria Report, PR Doc. No. 8, at 33, Table 6A.
[163] Chapra Analysis, PR Doc. 25, at 6-8.
[164] 2006 PREP Report, at 14.

DES concluded, in the 2009 Criteria Report, that algal levels were the controlling factor for low D.O. conditions because low D.O. conditions do not exist in either Great Bay or Piscataqua River (Upper or Lower sections) where tidal exchange is greater and algal levels are lower. While this is certainly true, the physical settings and hydrodynamic conditions are dramatically different at these locations, precluding any direct comparison of the site-specific D.O. conditions. Unless these different conditions are accounted for (e.g., presence/absence of tidal marshes, effect of increased tidal exchange, variation in SOD at these locations, differing stratification effects, oxygen demanding loads, etc.), it is not scientifically defensible to conclude that changing algal levels are the determining factor for low D.O. conditions found in the tidal rivers but not elsewhere.[165] As discussed below, the detailed studies conducted on the Lamprey and Squamscott Rivers confirmed that peak algal levels are not responsible for the periodic low D.O. conditions, as low D.O. occurs during stratification and/or when algal levels in the system are minimal.[166]

ii. Review of the Detailed Assessments for the Lamprey and the Squamscott Rivers

The two most extensively studied tidal rivers in the Great Bay Estuary are the Squamscott and the Lamprey Rivers. These are the two largest rivers entering Great Bay and they have the most prevalent low D.O. conditions.

a. Lamprey River Study

A study by Pennock in 2005, evaluated the timing and location of low D.O. conditions in the Lamprey River.[167] An examination of D.O. saturation and salinity profiles for all of the survey profiles showed that variation in oxygen concentration in vertical profiles corresponds to variation in salinity. The vertical profiles suggest there is significant stratification in the upper reaches of the tidal portions of the river. The high salinity/low D.O. bottom waters rise up to the datasonde level during high tides, resulting in large fluctuations in both salinity and D.O. saturation. The study concluded that low D.O. was caused by stratification which became most pronounced during neap tide conditions. The stratification conditions prevent reaeration of lower levels of the water column, magnifying the effect of the system SOD. Thus, the cause of low D.O. in this system is not due to diurnal D.O. fluctuations associated with algal respiration as claimed in the 2009 Criteria Report, it is a factor of a stratification/SOD controlled condition.

All tidal river systems exhibit SOD due to the physical nature of the system which allows deposition of organic materials to occur. Many factors, both natural and man-induced, can influence the level of SOD. The component fractions contributing to SOD in the Lamprey River have not been delineated. The Lamprey River watershed is the

[165] Chapra Analysis, PR Doc. No. 25, at 6.
[166] *See* Langan and Jones Letter, PR Doc. No. 23, at 2-3; HydroQual Squamscott River Analysis, PR Doc. No. 19, at 13-14; *see also* Chapra Analysis, PR Doc. No. 25, at 7 ("Figure 29 [from the 2009 Criteria Report] presents minimum dissolved oxygen at the Trend Stations in relation to median total nitrogen. This type of analysis has no basis in the literature or any published method of acceptable DO impact assessment. TN does not have a direct effect on dissolved oxygen and attempting to relate these two parameters is not accepted within the scientific community.").
[167] Pennock 2004, PR Doc. No. 1.

largest in the estuary and would be expected to contribute substantial organic material during times of high runoff. Algal growth upstream of the tidal river as well as that occurring in the tidal river would add to the SOD. However, SOD is not a function of the peak algal level. It is generally controlled by the longer term system depositional inputs. The long term algal level for this system is quite moderate, averaging 3 µg/L - a level of algal growth not considered excessive for estuarine tidal rivers, particularly where the flushing rate is considerable. In any event, it is apparent that controlling TN and limiting peak algal concentrations to 10.7 µg/l, as concluded in the 2009 Criteria Report, cannot possibly result in preventing minimum D.O. below 5 mg/l in this system. The Lamprey River 90th percentile chlorophyll-a level is already well below this level and the minimum D.O. is in the 3.0 mg/l range.[168] Moreover, as the significance of the algal component for SOD is unknown, the degree of benefit that may be achieved through TN control is also unknown.[169]

b. Squamscott River Studies

This river system has been evaluated on several occasions to determine the causes of low D.O., the effect of treatment plant nutrient inputs and the benefit of algal control. The system has a large tidal exchange, is often turbid and appears to be generally well mixed. Extensive wetlands/tidal marshes line much of the waterway as illustrated above in the Google Earth image. Professor Jones conducted several surveys from 2005-2008 directed at evaluating the role of algal growth on system D.O.[170] Those studies found that algal concentrations were quite variable and could reach elevated levels (greater than 100 µg/L chlorophyll-a). However, low D.O. was not apparently related to the degree of algal growth occurring in the system.

> The areas where low DO levels occurred on the three dates were all distinctly different areas of the river, possibly reflecting different causes, tidal transport of low DO waters, or sample timing relative to conducive conditions. The nutrient and chlorophyll *a* levels at the different sampling sites in the Squamscott River did not appear to have any discernable relationship with DO levels.[171]

In 2011/12, additional sampling of the river was conducted by HydroQual under the 2011 MOA between the Great Bay Municipal Coalition and DES.[172] The MOA acknowledged that the causes of low D.O. were uncertain and that additional studies were necessary.[173] Detailed longitudinal testing was conducted by HydroQual under slack tide conditions during two surveys and datasondes were placed at several locations in the river to characterize the short term variations in D.O. Concurrent sampling occurred at the Exeter wastewater treatment facility, which is the largest point source on the river. The sampling results from the datasonde at the 101 Bridge regarding D.O. and chlorophyll-a are presented below.[174]

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[168] *See* 2009 Criteria Report, at 33, Table 6.
[169] HydroQual Squamscott River Analysis, PR Doc. No. 19; Pennock 2004, PR Doc. No. 1. at 9.
[170] Jones 2007, PR Doc. No. 3; Jones 2008, PR Doc. No. 5.
[171] Jones 2007, PR Doc. No. 3, at 3.
[172] HydroQual Squamscott River Analysis, PR Doc. No. 19.
[173] Attachment 10- Memorandum of Agreement, at 1-2.
[174] HydroQual Squamscott River Analysis, PR Doc. No. 19, at 38, Fig. 22.

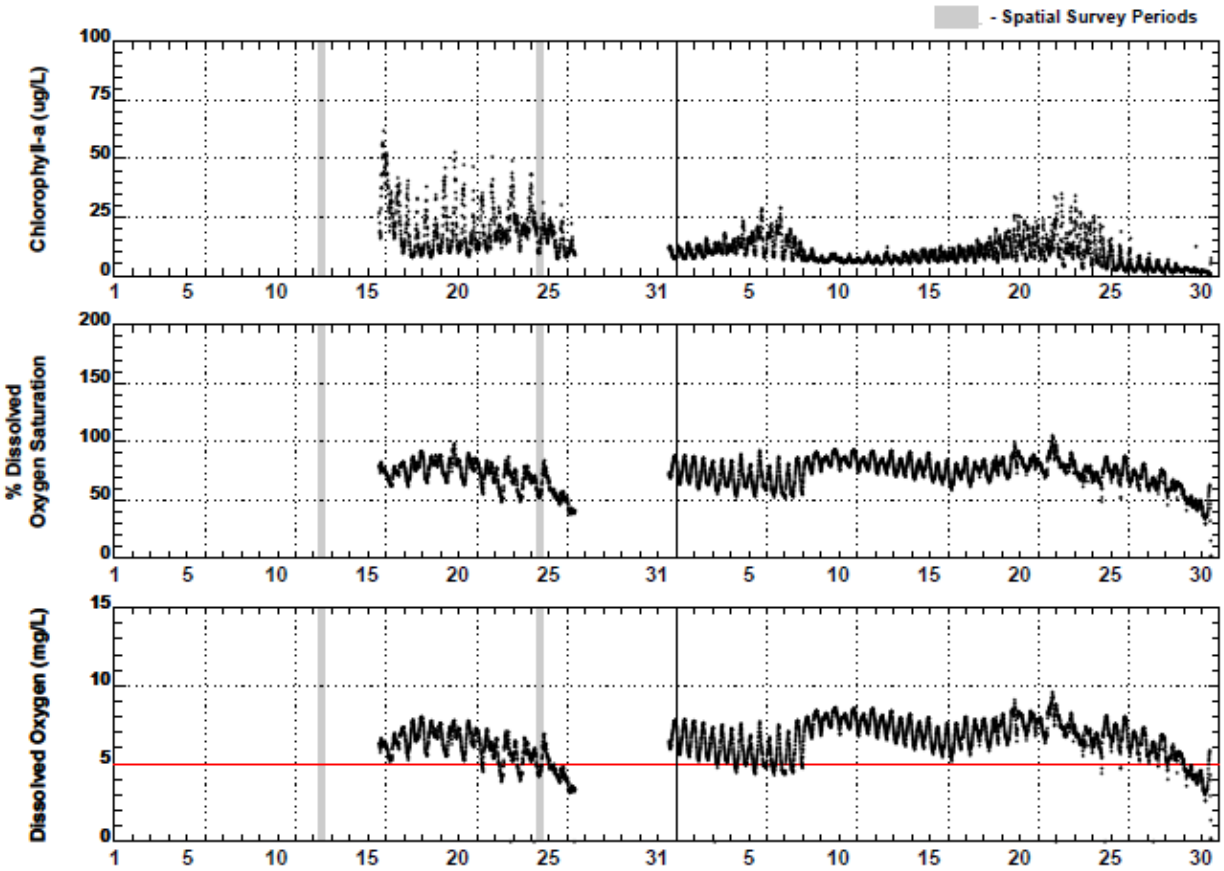


Figure 22. Squamscott River Aug-Sep 2011 Datasonde Measurements - Location: 101 Bridge (Chlorophyll-a, % Dissolved Oxygen Saturation, Dissolved Oxygen)

As with the prior Jones studies, low D.O. was verified (somewhat infrequently), but it was not correlated with elevated algal growth. This system, unlike the Lamprey River, did not exhibit significant stratification but was well mixed. The lowest D.O. conditions occurred when algal levels dropped, suggesting that algal photosynthesis offsets other causes of low D.O. in this system (*e.g.*, SOD and possibly low D.O. from the marshes). While these results were consistent with the prior findings by Jones, effluent sampling determined that Exeter's wastewater lagoons were a major source of algae to this system (a condition that does not exist in any other tidal river). For example, during the August 12, 2011, survey, the Exeter WWTP discharged 435 µg/L of chlorophyll-a, which raised concentrations in the river by 50 µg/L. This excess algae was likely instrumental in triggering additional algal growth and distinguishes the Squamscott River from all the other tidal rivers in the estuary. It also explains why the 90th percentile chlorophyll-a level in this system is greater than the other tidal river systems. HydroQual estimated that the typical algal discharge from the Exeter facility may produce a 10 µg/L increase in chlorophyll-a in the river under typical summer flow conditions.[175] This chlorophyll-a level will not be controlled by reducing TN, the load itself must be reduced.

Based on these results, it was determined that modeling algal dynamics should only occur after the Exeter facility was upgraded to eliminate the lagoons and algal inputs to the river. This would also eliminate the ability of the discharge to "seed" the system with algae. Eliminating the algal discharge was also expected to improve SOD below the discharge since it was likely that some of the algae from the lagoon would settle and contribute to the SOD load.

[175] HydroQual Squamscott River Analysis, PR Doc. No. 19, at 12.

Based on the available tidal river studies it is apparent that algal respiration is not the direct cause of periodic low D.O. and that the 90th percentile algal levels do not govern the occurrence of D.O. conditions less than 5 mg/L. Because the conditions contributing to low D.O. are different in each tidal river (e.g., degree of stratification, algal inputs from point sources, significant SOD, or low D.O. inputs from marshes) and these conditions are not governed by the degree of algal growth occurring in the system, it is not scientifically defensible to assume that TN control to 0.45 mg/l will eliminate or even significantly reduce the low D.O. conditions. The Lamprey River data confirms this would not occur and the relationship developed between chlorophyll-a and minimum D.O. is not physically possible.[176]

iii. Assessment of Regression Methods Used for Generating TN Criteria

Simplified regression methods were used to predict the degree to which TN was controlling minimum D.O. Each of these regressions presumed, but did not demonstrate, that TN was actually the parameter controlling these conditions.[177] As discussed below, the use of such correlations to derive criteria is not scientifically defensible, unless the relevant causal connections are verified and the relative effect of other known factors that could have caused the condition are evaluated. As discussed by Dr. Chapra, the 2009 Criteria Report approach to D.O. has the following fundamental flaws:

- The methods do not demonstrate "cause and effect";
- The methods failed to consider confounding and co-varying factors such as habitat and physical/chemical differences independently affecting the response variables;
- The methods failed to address first-order impacts (plant growth) that must precede any more complex impacts; and,
- The statistical methods, by themselves, do not verify that the changes in condition are biologically significant.[178]

For example, the D.O. regime in a tidal river is affected by dozens of factors. The graphic below from EPA's Technical Guidance on modeling D.O. in estuaries,[179] presents the major system inputs that must be assessed to understand why the resultant D.O. regime is occurring.

[176] Chapra Analysis, PR Doc. No. 25, at 9-10.
[177] *See* 2009 Criteria Report, PR Doc. No. 8, at 36, Fig. 17; at 49-50, Figs. 26-27, 29; at 67, Fig. 39.
[178] Chapra Analysis, PR Doc. No. 25, at 11-12.
[179] EPA, Technical Guidance Manual for Performing Wasteload Allocations, Book III – Estuaries, Part 1: Estuaries and Waste Load Allocation Models (May 1990), at 2-21, *available at* http://water.epa.gov/scitech/datait/models/upload/ 2006_10_24_models_wlabook3part1.pdf.

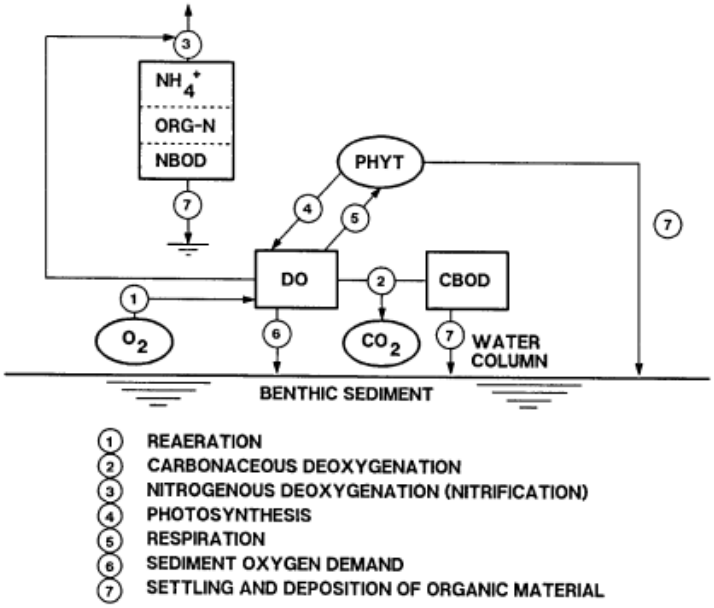


Figure 2-6. Basic variables and processes for dissolved oxygen.

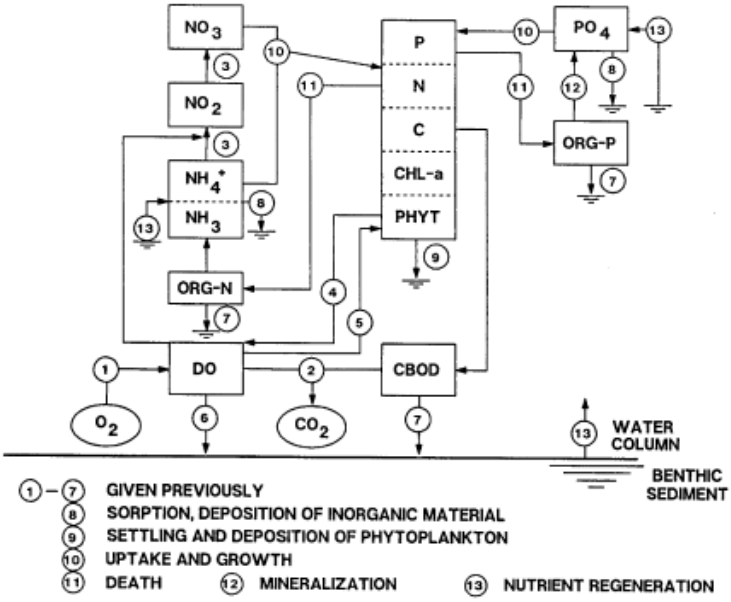


Figure 2-7. Standard variables for eutrophication and DO.

Many of these factors are time variable and temperature dependent. For this reason, the accepted methodology for evaluating factors governing D.O. conditions in a tidal river system is to model the system by properly accounting for its unique physical, chemical and biological conditions.[180] Rather than model the system, DES used a series of regressions and observations of minimum/maximum D.O. variability to "prove" that TN and algal growth were the "cause of the low D.O. in the system."[181] Several of these regression analyses from the 2009 Criteria Report are illustrated below.

[180] *See generally* EPA, Technical Guidance Manual for Performing Wasteload Allocations, Book III – Estuaries, Part 1: Estuaries and Waste Load Allocation Models, Introduction (May 1990).
[181] *See* 2009 Criteria Report, PR Doc. No. 8, at B-3; at 36, Fig. 17; at 49, Fig. 27.

Figure 17: Relationship between Nitrogen and Chlorophyll-a Concentrations at Trend Stations

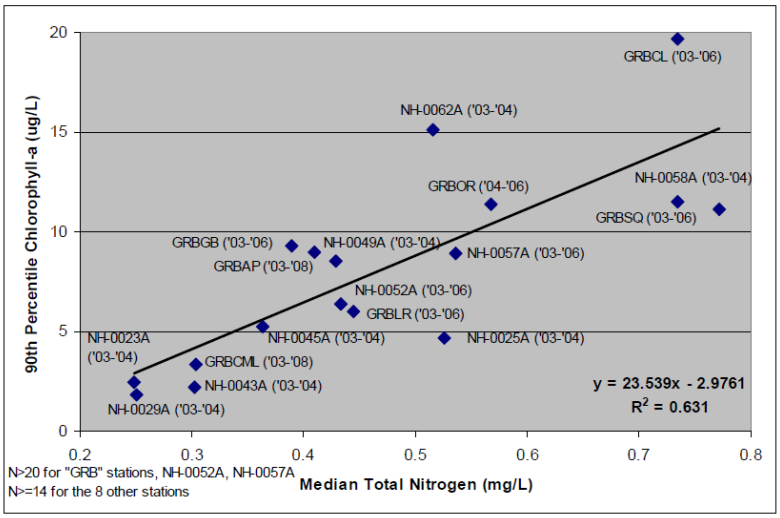
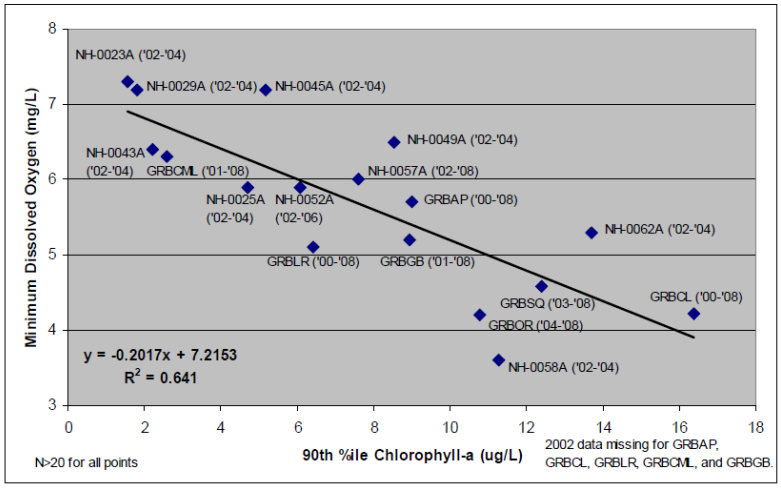


Figure 27: Relationship between Minimum Dissolved Oxygen and Chlorophyll-a at Trend Stations



As explained by the analysis of Dr. Chapra, this approach is fundamentally flawed and does not rely on a scientifically defensible methodology.[182] First, the algal response regressions used to claim that changing TN concentrations caused the varying levels of chlorophyll-a throughout the Estuary assumed that the only factor causing the change in algal growth was the TN concentration.[183] This is an obviously incorrect assumption as radically different physical settings were placed on the same graph (mouth of estuary, bays and tidal rivers of greatly varying detention time). Such an approach does not conform to any acceptable method of environmental data assessment as confirmed by EPA's Stressor Response guidance[184] and related Science Advisory Board critiques.[185] When using simplified methods, it is only appropriate to plot data from physically similar habitats since changing habitat factors are known to greatly affect D.O. regimes and algal responses. In any event, a scientifically credible assessment must account for stratification, detention time, marsh D.O. influences, SOD and upstream system inputs that vary from location to location. The analysis presented in the 2009 Criteria Report did not account for any of these factors. When only data from the upper tidal rivers are plotted, it is apparent that the TN-chlorophyll-a relationship does not hold (discussed below).

Second, the data for Great Bay shows that algal concentrations did not increase in response to a doubling of the instream DIN concentration. This observation confirms that the entire regression analysis is misplaced, as the regression (Fig. 17 from the 2009 Criteria Document) predicts a quadrupling of the chlorophyll-a concentration in response to a doubling in the median TN while the observed data in Great Bay show no material change.

Third, algal concentrations for the Squamscott River (a controlling point in these regressions labeled as GRBCL and GRBSR) are significantly influenced by the discharge of algae from the Exeter lagoons, while this condition exists nowhere else in the Estuary.[186] Therefore, claiming that the higher algal concentration in the Squamscott River

[182] Chapra Analysis, PR Doc. No. 25, at 1.
[183] *See* 2009 Criteria Report, PR Doc. No. 8, at 36, Fig. 17.
[184] *See* EPA Stressor-Response, PR Doc. No. 14.
[185] *See* SAB Stressor-Response Review, PR Doc. No. 10.
[186] HydroQual Squamscott River Analysis, PR Doc. No. 19, at 46, Fig. 30-31.

was due to the slightly higher TN level in the river is not scientifically defensible. The plots below, prepared by HydroQual, show the degree to which algae from the Exeter Lagoon explain the entire algal response of the River.

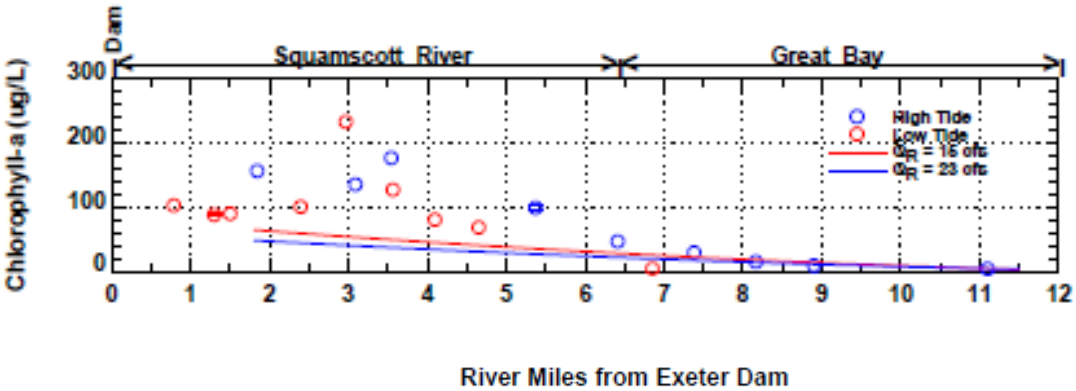


Figure 30. August 12, 2011 Spatial Profiles and Mass Balances
Chlorophyll, Nitrogen, Phosphorus

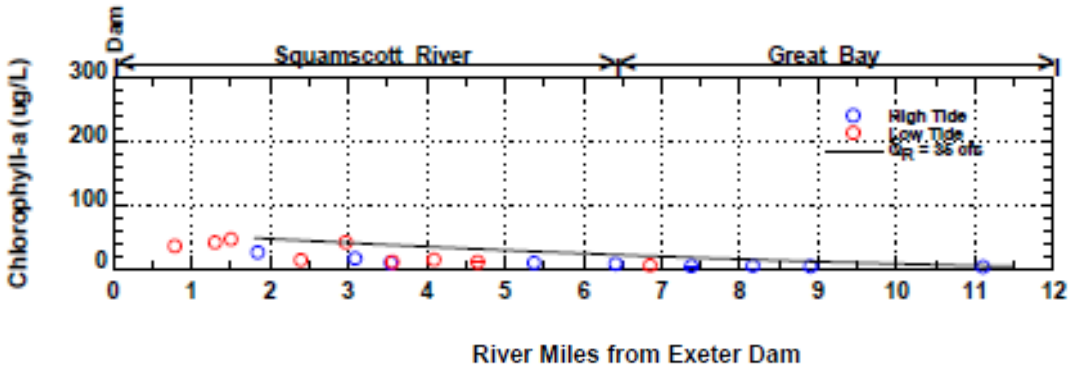
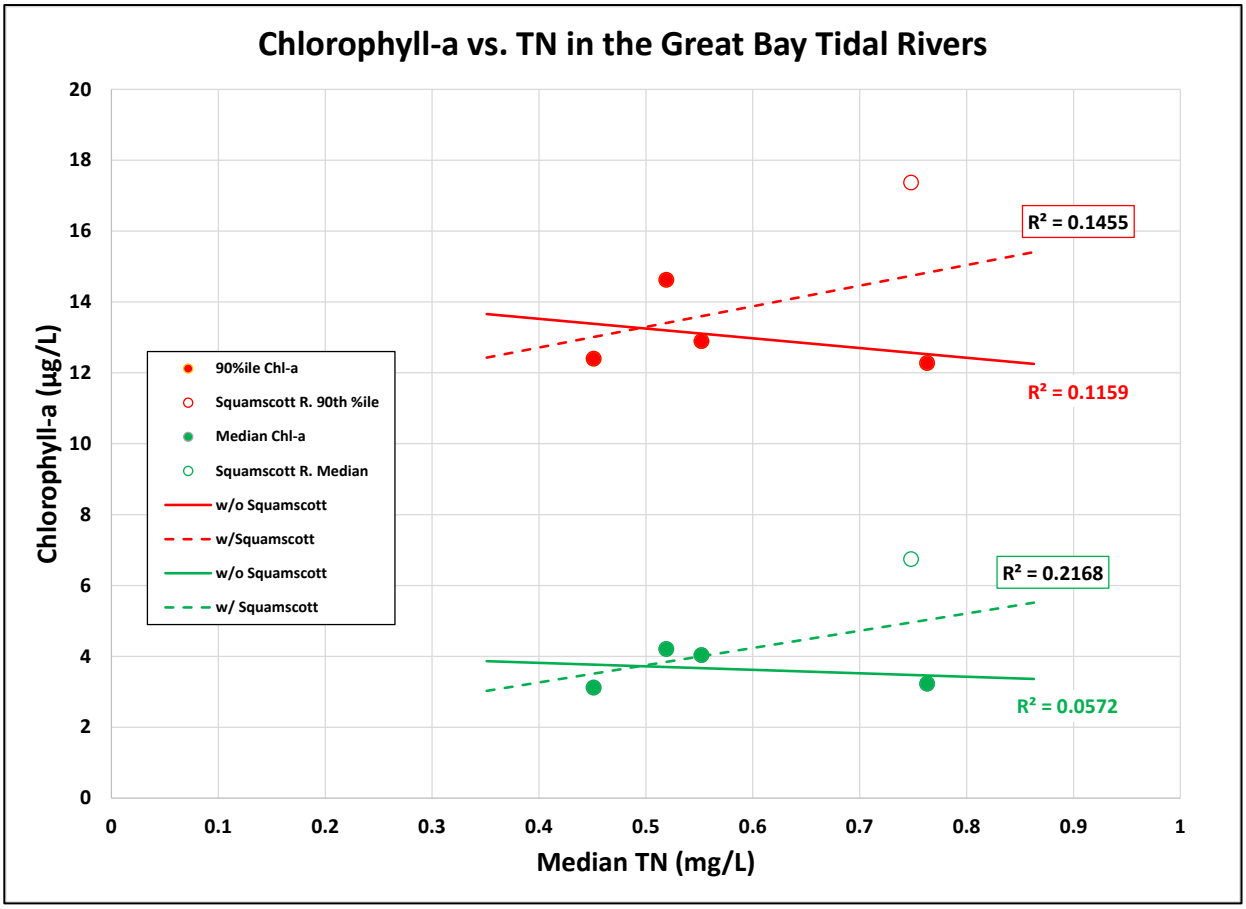


Figure 31. August 24, 2011 Spatial Profiles and Mass Balances
Chlorophyll, Nitrogen, Phosphorus

Consequently, plotting the data for the Squamscott River along with systems that did not have such external loads influencing ambient algal measurements to prove TN caused the differing condition was improper. When the Squamscott River data are removed from the regression, it is apparent that there is no meaningful relationship between TN concentration and the algal levels present in any of these tidal rivers.

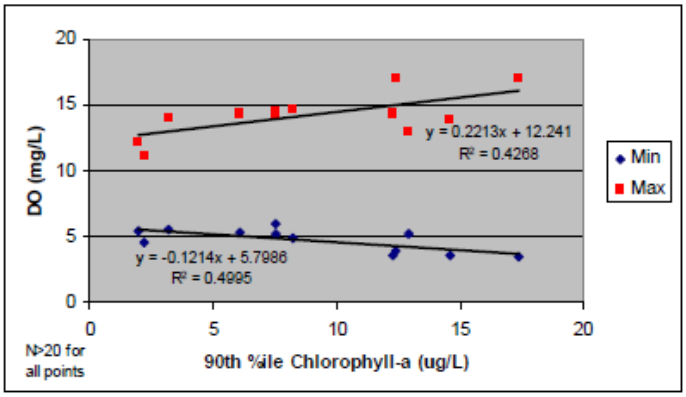


Fourth, the charts purporting to relate 90th percentile algal levels to minimum D.O. did not plot concurrent conditions; DES simply assumed that the 90th percentile algal level occurred with the minimum D.O. However, this did not actually occur, as documented by the individual river studies. The Lamprey River low D.O. occurred under periodic neap tides, regardless of algal levels present. Low D.O. conditions in the Squamscott River occurred when algal growth decreased.[187] As a matter of environmental data presentation and assessment, it was highly inappropriate to pair conditions that did not actually occur at the same time and imply that they did by plotting these as data sets in the regression analyses.

Finally, the D.O. regressions present correlations between unrelated observations. For example, Figure 26 from the 2009 Criteria Report (below)[188] presents a relationship between minimum or maximum observed D.O. and algal bloom concentration. As explained by DES, "[t]his figure clearly shows both a decrease in the minimum and an increase in the maximum dissolved oxygen concentrations with increasing chlorophyll-a concentrations. This effect would be expected when phytoplankton blooms oxygenate the water during photosynthesis and deplete oxygen during respiration."[189] The DES explanation and Figure 26 imply that these minimum and maximum D.O. observations occur simultaneously with the elevated algae levels, but this is not the case. The figure presents peak chlorophyll-a and the range of observed D.O. concentration at individual Assessment Zones, but these observations were not simultaneous. Consequently, the relationship between peak chlorophyll-a and the corresponding D.O. range is unknown.

[187] *See* HydroQual Squamscott River Analysis, PR Doc. No. 19, at 38, Fig. 22.
[188] 2009 Criteria Report, PR Doc. No. 8, at 49, Fig. 26.
[189] 2009 Criteria Report, PR Doc. No. 8, at 45.

Figure 26: Relationship between Dissolved Oxygen and Chlorophyll-a in Assessment Zones



If algae are completely absent, these relationships predict a diurnal D.O. swing of 6.4 mg/L (e.g., 12.24 mg/L – 5.80 mg/L). Such a range, if it is real, is unrelated to algal concentration. Again, removing the Squamscott River data influenced by the Exeter discharge, the high algal reading would have produced a flat line indicating that a 5 µg/l change in peak algal level would produce less than a 0.3 mg/l change in D.O.[190]

iv. Conclusion

In summary, the statistical methods utilized to derive the 0.45 mg/l TN criteria were misapplied and improperly assessed. These regressions are incapable of providing a reliable method for selecting appropriate nutrient criteria for D.O. protection purposes. It is apparent from the individual river studies that algal growth does not respond significantly to changing TN levels and that numerous other factors unrelated to TN are controlling D.O. in the various regimes. Whether or how such conditions can be regulated is not known and some are natural (e.g., Lamprey River periodic stratification). In this situation, the only scientifically defensible approach to deriving appropriate TN limits to address D.O. concerns is to model the system, accounting for the relevant physical, biological, and chemical factors influencing the response.

E. Limiting Nutrient Considerations

It is widely understood that nitrogen is typically the limiting nutrient in marine systems. Algal growth will be unlimited once inorganic nitrogen levels exceed about 50 µg/L.[191] DIN levels have been far above this level in Great Bay, Little Bay and the Lower Piscataqua River for decades. Nonetheless, algal levels remain low and have not responded significantly to changes in inorganic nitrogen levels. This means that DIN is not, in fact, what is limiting algal growth in this system. There are only two other likely conditions limiting algal growth in the Estuary – light penetration and detention time. Given the nature of the system, it is likely that both of these factors are playing a significant role.[192] The analysis by HydroQual using a calibrated hydrodynamic model, confirms this conclusion.[193] Light penetration in the tidal rivers is quite poor due to CDOM influences and this limits plant growth throughout the system. High inorganic nitrogen levels are not stimulating high algal levels as are found in other northeast and mid-Atlantic estuarine systems.[194] This was the same effect documented by EPA for Florida

[190] The study by Dr. Pennock confirmed that high diurnal D.O. variability in the Lamprey River was caused by stratified waters rising up to the level of the datasonde at high tide, not diurnal respiration. Moreover, as noted by Dr. Chapra, it is physically impossible for algal levels in the range of 10-15 µg/l to cause a 10 mg/l diurnal D.O. change as implied by this chart. To the degree that it provides any relevant information, Figure 26 from the 2009 Criteria Report confirms that the change in peak algal concentration has a minimal effect on the D.O. regime since the upper and lower regression lines are flat.

[191] *See* Hydroqual Hydrodynamic Model.

[192] *See* Hydroqual Hydrodynamic Model.

[193] *See* Hydroqual Hydrodynamic Model.

[194] 2003 PREP Report, at 8 (Over this time period, the levels of nitrate-nitrate have increased from approximately 5 µM (0.070mg/L) to about 8 µM (0.11 mg/L). The Report notes that, "<u>even with this increase, there have not been any significant trends for the typical indicators of eutrophication</u>" (lower D.O. and higher chlorophyll-a)).

Lakes with high color from natural inputs.[195] For this reason, limiting nitrogen will not have a meaningful effect on this system since other factors are already limiting algal growth. The exception to this condition was found in one survey of the Squamscott River where algal growth exceeded 100 µg/L (very eutrophic) and consumed all of the available nitrogen. This occurred downstream of the Exeter WWTP, which seeds algae into the waters from holding ponds. This type of condition has not been documented in the other tidal rivers from any reliable monitoring results. Because of the Exeter treatment pond impacts on algae in the Squamscott River, those facilities are being taken out of operation and are being replaced with a conventional activated sludge system.

For Great Bay, the detention time is a major factor limiting algal growth, as sufficient light is available to promote algal growth. HydroQual has determined that the typical detention time is in the order of 4-7 days, which explains why the phytoplankton level remains low.[196] This short detention times confirms that DIN, not TN is the proper control parameter for this system. Organic nitrogen does not have sufficient time to convert to inorganic forms so its regulation is unnecessary. Moreover, the only form of nitrogen affecting macroalgae growth is DIN. The only area of macroalgae concern is Great Bay. Therefore, DIN, not TN control should be the focus of any control efforts.

F. Report Conclusions and Options for Future Action

i. Weight of Evidence Regarding the 2009 Criteria

DES claimed that the nitrogen threshold for the protection of eelgrass was derived using a "weight of evidence" approach, considering: (1) the threshold for macroalgae proliferation, (2) regressions between TN and light attenuation coefficient, (3) offshore water background TN concentration, (4) reference concentrations in areas of the estuary which still support eelgrass, and (5) the thresholds that have been set for other New England estuaries.[197] Similarly, DES indicated that a weight of evidence approach was used to develop TN criteria for D.O. based on trend station data and datasonde measurements.[198] While the term "weight of evidence" is not defined in federal or state guidance, one presumes that such analysis necessarily considers <u>all</u> of the available relevant scientific information for the estuary and reaches a conclusion that is supported by the <u>majority</u> of the scientific information. As part of this analysis one would consider the certainty and validity of the analyses with respect to technical conclusions that were reached in the relevant studies for the system.

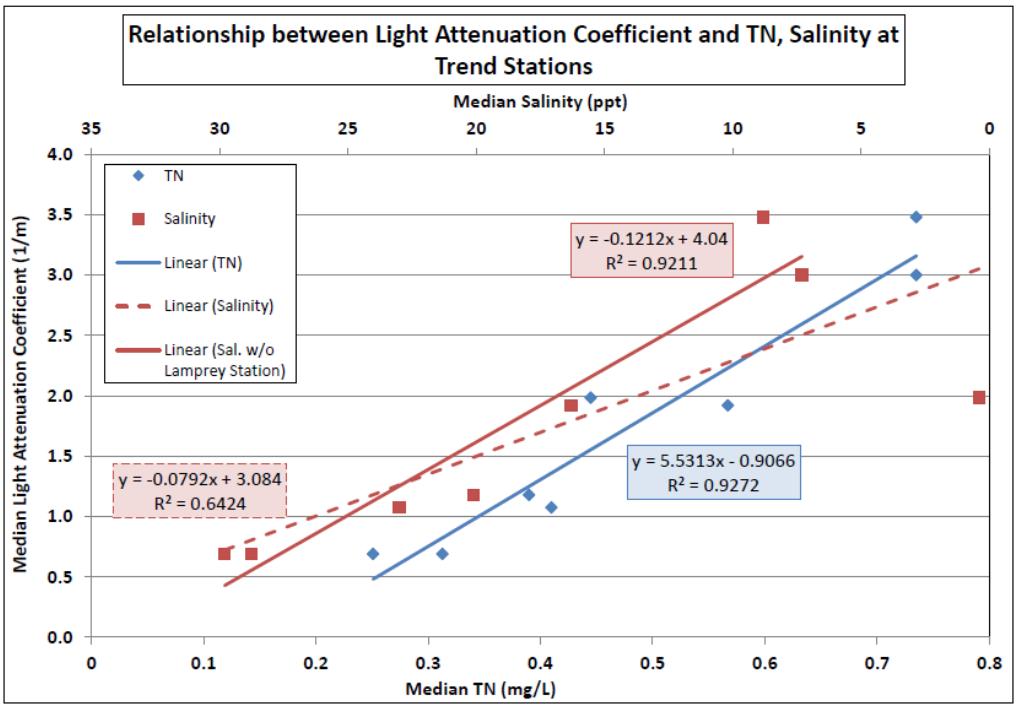
As discussed in prior sections (and summarized below), the overall data for the Great Bay estuary does not indicate that changes in nutrient level had any material influence on the changing pattern in eelgrass cover for this system or would ensure eelgrass repopulation in the estuary. The major eelgrass declines appear to have occurred in response to extreme wet weather conditions in 2006, which adversely affected eelgrass growth and survival. Prior to that time eelgrass populations were not considered impaired as they fluctuated within a range of cover, from year to year. The adequacy of water quality absent high rainfall conditions was confirmed empirically by the pattern of eelgrass growth in the estuary prior to 2006 and the detailed studies evaluating system transparency performed by Morrison *et al*. in 2007, after the extreme rainfall events. Finally, the major rebound in eelgrass that occurred following several years of drier conditions (including a major increase of eelgrass in Little Bay) confirms that existing water quality is generally sufficient to support eelgrass growth in Great Bay and Little Bay <u>in non-wetter than average years.</u> Controlling TN inputs will not alter this basic reality for this system.

The conceptual model used to derive the nutrient criteria was demonstrated to be inapplicable to the Great Bay estuary because it was apparent that changing TN levels from 1980 to the present did not cause a material increase in phytoplankton growth or decrease in system transparency. The system transparency, which does

[195] *See* Water Quality Standards for the State of Florida's Lakes and Flowing Waters, 75 Fed. Reg. 75,762, 75,778 (Dec. 6, 2010), *available a*t http://www.gpo.gov/fdsys/pkg/FR-2010-12-06/pdf/2010-29943.pdf.
[196] *See* Hydroqual Hydrodynamic Model.
[197] *See* 2009 Criteria Report, PR Doc. No. 8, at 16.
[198] *See* 2009 Criteria Report, PR Doc. No. 8, at 14.

periodically limit eelgrass growth, is controlled by CDOM and non-algal turbidity, not TN. These were the very conclusions reached by the TAC prior to the creation of the 2009 Criteria Report.[199] Thus, while transparency may now be limiting eelgrass growth in some areas (e.g., the tidal rivers), the inadequate transparency is not caused by excessive plant growth or TN loads but is a function of natural processes in the watershed that cannot be materially affected by wastewater facility improvements or other watershed TN reductions (i.e., stormwater controls).

As demonstrated by the graph below, system transparency is a direct function of the salinity in the system. Excluding the single point associated with the Lamprey River station that reflects primarily freshwater conditions (median salinity of 0.1 mg/l), the salinity versus Kd line precisely mirrors the TN versus Kd regression and has the same r^2= 0.92. This demonstrates that tidal dilution, not TN is the component controlling water column transparency in this system as would be expected given the detailed assessment of factors affecting water column transparency by Morrison and the minimal detention time of the system that does not allow for increased algal growth. Thus, the Kd versus TN relationship presented in the 2009 Criteria Document is just an artifact of the assessment as TN levels also decrease through the system as a function of salinity (i.e., tidal dilution). Obviously controlling TN inputs will not change the system Kd as the 2009 Criteria Document projected would occur.



Regarding the periodic occurrence of low D.O. in the tidal rivers, the preliminary assessments performed by the Jackson Laboratory researchers (Professors Pennock and Jones), as well as subsequent analysis by HydroQual, have indicated that increased algal growth is not correlated with low D.O. Rather low algal growth and neap tide conditions appear to be the primary factors coinciding with these conditions. Thus, low D.O. inputs from other sources and sediment oxygen demand are likely the primary D.O. control factors in this system. The lack of studies regarding these other system inputs prevents a full assessment of the conditions causing low D.O. It is apparent, however, that a slight change in the 90th percentile algal growth level (e.g., 10.7 to 12.0 µg/L chlorophyll-a) cannot possibly have caused a major change in system minimum D.O., as the underlying regressions for the 2009 Criteria predicted.

[199] TAC December 2007 Meeting Minutes, at 2.

Finally, the regression analyses relied upon to claim support for the proposed criteria using weight of evidence is fundamentally flawed as they failed to account for the numerous factors known to be controlling system transparency and D.O. in this estuary. By conducting analyses that plotted data from the harbor, tidal rivers and bays on a single plot, the effects of these factors and system hydrodynamics were improperly ignored, leading to an erroneous conclusion that slight variations in TN level and chlorophyll-a have a major impact on the D.O. and transparency regime. That conclusion is demonstrably false based on the numerous detailed studies conducted for this system and the informed opinions of the regional experts that conducted those studies. Thus, considering the "weight of evidence" in its entirety, the conclusions that stringent TN control is required to produce significant changes in system transparency and D.O. is not supported, if not demonstrably incorrect.

ii. Possible Adaptive Management Approach for Macroalgae

While it is evident that TN levels apparently play a minor role in influencing system transparency and D.O., macroalgae proliferation in Great Bay remains an area of uncertainty with basic research needed (e.g., is the growth presently excessive, are invasive species the problem, what degree of DIN control will limit macroalgae growth, etc.). The conceptual model used by DES attributes any macroalgae proliferation to excessive nitrogen in the system, but the available data does not support the hypothesis that changing DIN levels (the form of nitrogen relevant to macroalgae growth) was controlling macroalgae growth. A particular DIN threshold above which macroalgae proliferation becomes excessive has not been identified as such growth is quite ephemeral, independent of the nutrient level present. The following figure illustrates the changing DIN concentration at Adams Point, over time:

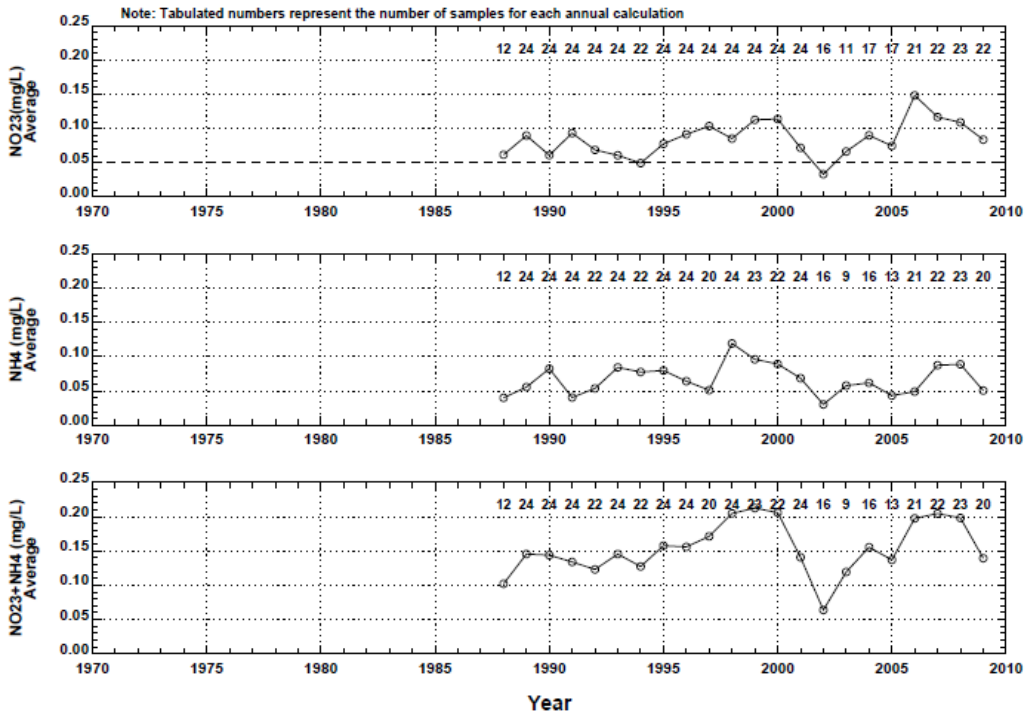


Figure 4. Measured Nitrogen at Adams Point, 1988-2009 high/low tides

It is possible that a "reference waters" approach may be useful in setting an initial control strategy for macroalgae, while the necessary research is conducted. In that regard, macroalgae were not considered excessive from 1990 - 1996, when eelgrass beds were the most extensive in the Bay, as reported by Short. This could serve as a

"baseline" period for identifying an acceptable DIN level for the Bay. Based on ambient data from that time period, DIN levels ranging 0.12 – 0.15 mg/L in Great Bay would have been considered acceptable, however, DIN concentration is sensitive to many sources and sinks. The DIN load to the Bay from point and non-point sources (excluding Piscataqua River inputs) were estimated to be significantly lower during the macroalgae growing season (June – September) and increased as a wetter rainfall pattern occurred. Presently, DIN levels at Adams Point are averaging 0.12 mg/l (2009-2011).[200] From June through October (typically a period of lower rainfall) point source contributions of DIN dominate the system and therefore provide a vehicle to potentially limit macroalgae growth.[201]

HydroQual has completed a hydrodynamic model of the system that accurately predicts the impact of wastewater contributions to various segments of the system.[202] An assessment of the impact of the existing wastewater facility contributions to long term DIN and TN levels from Rochester, Dover and Portsmouth were projected with the hydrodynamic model (Figures 20-27).

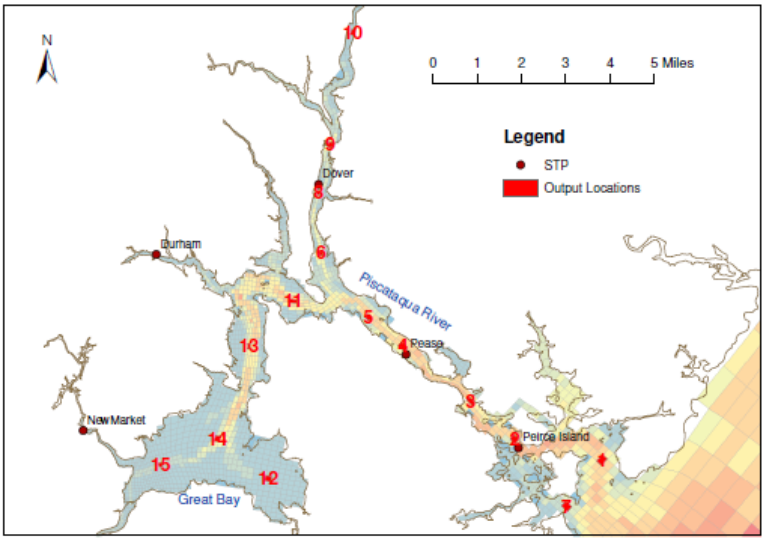
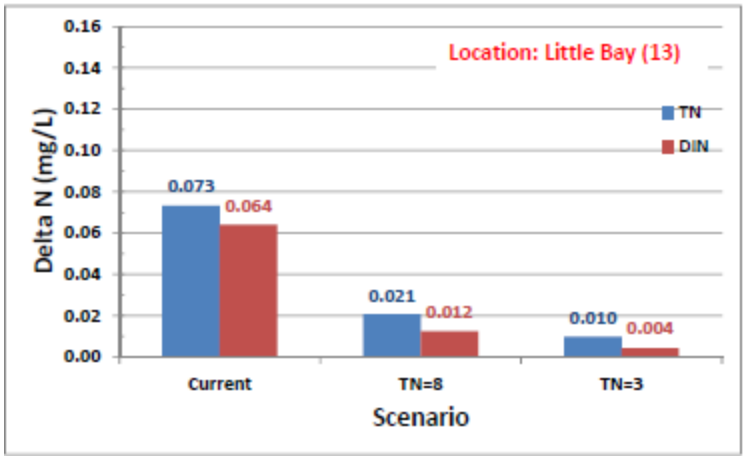


FIGURE 19. GBE5 Hydrodynamic Model Locations for Percent Effluent Calculations

The relative impact on DIN levels in Little Bay (Location 13 – a surrogate for Adams Point) are projected as follows:

Rochester	0.025 mg/l
Dover	0.014 mg/l
Portsmouth	0.004 mg/l

These results indicate Portsmouth has a relatively minor (negligible) impact on DIN levels in Little Bay, constituting about 3% of the DIN contribution on a long term basis, while Rochester and Dover constitute 21% and 12%, respectively. An assessment was conducted regarding the impact of requiring biological nutrient removal (BNR) at all major New Hampshire facilities contributing DIN loads to the system (Exeter, Durham, Dover, Newmarket, Portsmouth and Rochester).[203] Figure 27 below graphically represents the anticipated long term average reduction that should be reflected at Adams Point by implementing various levels of nutrient reduction for all of the major facilities.



Based on this analysis, the DIN levels at Adams Point should decrease by approximately 0.052 mg/l on an annual average basis from instituting basic BNR (8 mg/l TN) at the major facilities. If Portsmouth does not institute BNR due to

[200] 2013 PREP Report, PR Doc. No. 22., at 15.
[201] *See* Gallagher Jan. 16, 2012, PR Doc. No. 18.
[202] Hydroqual Hydrodynamic Model.
[203] *See* Hydroqual Hydrodynamic Report, at 26, Table 13b.

its minor effect on the system, DIN levels would decrease by 0.05 mg/l. The long term average DIN level (1992-2011) is 0.17 mg/l DIN. The projected reduction (TN=8 mg/l) would reduce this to approximately 0.11 mg/l.[204] This value is below that occurring in the 1990's when eelgrass growth was robust and macroalgae concerns were not reported. Based on the present multi-year average DIN levels occurring in the system reported by PREP (about 0.12 mg/l), instituting BNR would be expected to produce a long tern DIN level less of approximately 0.07 mg/l at Adams Point. That was the level of DIN occurring in the 1970s when minimal macroalgae growth was reported by Mathieson. Thus, the range of DIN anticipated to exist with the implementation of a moderate level of BNR (0.07-0.11 mg/l) should be highly protective of this system.

DIN reductions associated with implementing "limits of technology" (i.e., 3 mg/l TN) are plainly not required to achieve significant reductions in the bioavailable form of nitrogen that influences macroalgae growth in this system. As noted earlier, since point sources constitute a greater percentage of system DIN loadings from June-October, the relative benefit of DIN reduction during that time period will be even more pronounced than projected above.[205] Thus, maintaining long-term average DIN levels below 0.11 mg/l should be adequate to control macroalgae growth from being "excessive" based on the historical response of this system. Achieving this target level would only require about a 50% DIN reduction from the Rochester and Dover facilities given the existing conditions reported by PREP. Based on this assessment, a reasonably conservative, reference waters approach would be to implement BNR reductions at all facilities, except at the Portsmouth facility and with adjustments for the Rochester facility.[206] Allowing the Portsmouth facility to offset the impact of its facility through implementation of other measures (e.g., increased DIN reduction by Rochester), would produce greater benefits for the system and likely reduce the amount of energy needed to implement a protective nutrient reduction strategy for Great Bay Estuary. This "reference waters loading" approach should result in reduced macroalgae growth, assuming the additional macroalgae growth is not due to an invasive species with much lower nutrient growth needs. Consequently, it is also suggested that a macroalgae monitoring program be instituted to track the degree and type of macroalgae growth occurring in this system so that the efficacy of DIN reductions may be more accurately assessed in the future.

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[204] *See* Hydroqual Hydrodynamic Report, at 65, Fig. 29.
[205] *See* Gallagher Jan. 16, 2012, PR Doc. No. 18.
[206] Rochester has recently achieved about a 60% reduction in its DIN discharge by ensuring pretreatment of high strength landfill leachate. Further DIN reductions may be quite costly given the facility type (aerated lagoons) with limited control over oxygen levels.