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MEMORANDUM

TO: Great Bay Municipal Coalition

FROM: John C. Hall, Ben Kirby

DATE: May 29, 2014

RE: Compilation of Peer Reviewer Questions and Reponses

This memo compiles and summarizes the peer reviewer (Diaz, Reckhow, Bierman, Kenworthy) verbatim responses to the supplementary post peer review questions.

Robert J. Diaz, Ph.D.:

The majority of the dissolved oxygen data for the estuary are collected using continuous readings by datasondes. Were these datasonde records considered in your analysis?

> Yes, I used all the continuous DO records I could find in the material sent by Sally plus other records I found at the NEERS site and the national coastal assessment. I also considered single point DO measurements.

Were impacts of low dissolved oxygen to other organisms besides benthic infauna considered?

> Not directly. The 2009 Report specified that DO concentration was set to be protective of benthos. It did not mention pelagic species. However, a review of DO tolerance for pelagics, that would use Great Bay, would support a 5 mg/l or 75% air saturation threshold as being protective. For benthos this threshold is more than protective.

Kenneth H. Reckhow, Ph.D.:

Which of the variables included on the attached “master list of confounding factors” should be included in a Bayes Net analysis in order to account for the majority of the covariate issues?

> I can probably be most useful to you in addressing this question by asking you first to prepare an influence (“boxes and arrows”) diagram like that presented in Figure 2 in the attached paper. I have a pretty good idea of the causal relationships already, but I would like that to come from you. Start from the endpoints: (1) variables (e.g., nitrogen concentrations) that you can control with mgmt (e.g., TMDL) actions, and (2) variables (e.g., DO, eelgrass coverage) that are the primary measureable determinants of designated use. Then, include in your diagram important casual factors that are expected to be determinants of the effectiveness of mgmt controls on the WQ endpoints (e.g., DO, eelgrass coverage) of concern. I know that everything is connected to everything else, but from a practical standpoint, we will never achieve operational nutrient criteria that consider many of the factors (e.g., grazing, bioturbation, SOD,…) in the master list of confounding factors. In the end, I think that operational nutrient criteria (to maintain desirable levels of eelgrass coverage and/or DO) for Great Bay probably will be based on TN, salinity, TP, and possibly turbidity.

For modeling eelgrass in a Bayes Net, would it be appropriate to use a normalized metric such as the percent of eelgrass remaining relative to the acres observed in 1996? These data are provided in the attached spreadsheet.

> As we discussed last week, Ted, I think that your suggestion of a normalized metric for eelgrass coverage is a good idea.

Would it be possible to create two separate Bayes Nets to model different sections of the estuary depending on whether eelgrass or DO is the end point of interest? Could these models be used to determine the TN and Chlorophyll-a associated with significant changes in the endpoint (e.g., DO <5 mg/L or eelgrass loss >20%)?

> Yes, that can be done. With the probabilistic analysis provided by a Bayes net, we could also estimate the uncertainty in the analysis. This may lead NH DES and EPA to prefer to acquire more WQ data with a well-designed monitoring program to reduce uncertainty.

The salinity ranges most applicable to the Great Bay Estuary are the two zones used by NOAA for the National Estuarine Eutrophication Assessment: Mixing Zone (0.5 – 25 psu) and Seawater Zone (>25 psu). Would it be possible to use these ranges to discretize the salinity data in the Bayes Net models?

> Yes, that also can be done. As stated above, with the probabilistic analysis provided by a Bayes net, we could also estimate the uncertainty in the analysis. This may lead NH DES and EPA to prefer to acquire more WQ data with a well-designed monitoring program to reduce uncertainty.

Reckhow Summary:

Dr. Reckhow suggested using an influence diagram to visualize the relationships between causal factors, management controls, and water quality endpoints. This will help determine the most important confounding factors. Dr. Reckhow expects that TN, salinity, TP, and turbidity will be chosen as nutrient criteria to control DO and eelgrass coverage. Dr. Reckhow provided Figure 2 below as an example influence diagram.

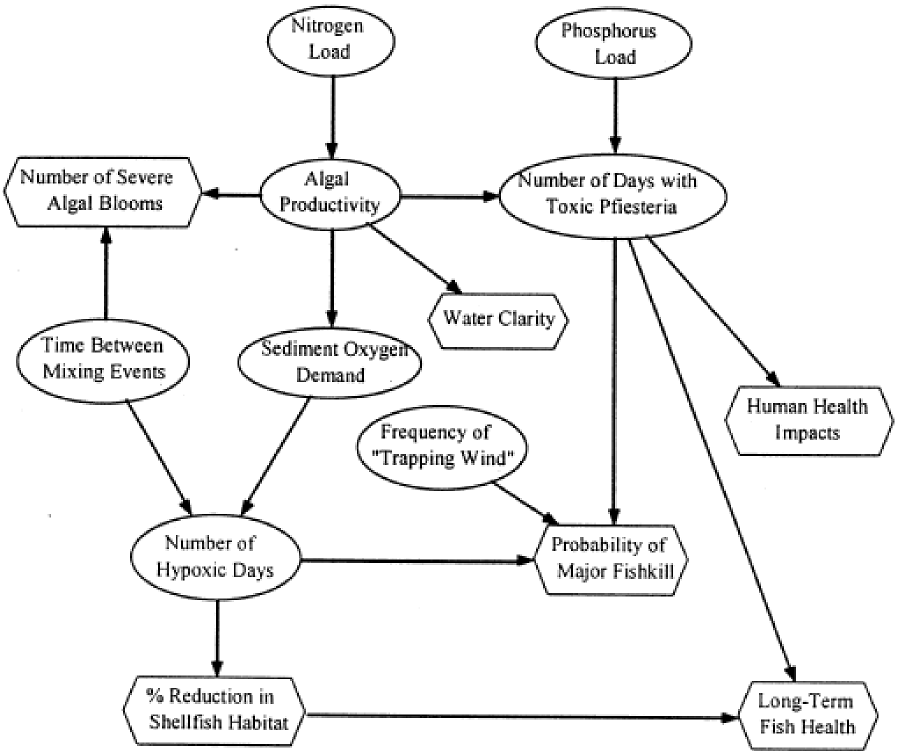

Figure 2. A graphical model of Estuarine response.

Borsuk, M., Clemen, R., Maguire, L., & Reckhow, K. (2001). Stakeholder values and scientific modeling in the Neuse River watershed. Group Decision and Negotiation , 10 (4):362.

Dr. Reckhow agreed that when modeling eelgrass in a Bayesian Network (Bayes Net) analysis, normalizing metrics (e.g. normalizing percent eelgrass to 1996 level) “is a good idea.” Dr.

Reckhow agreed that Great Bay Estuary can be modeled as separate Bayes Net analyses based on the end point of interest. As an additional benefit of the Bayes Net, the results can also estimate the uncertainty in the analysis.

Victor J. Bierman Jr., Ph.D.:

The report references over 20 confounding factors that influence the relationship between and among nitrogen dissolved oxygen, and eelgrass. What are the most important confounding factors that DES should prioritize for consideration?

> The number of individual confounding factors in our joint report was large. Our purpose was to be comprehensive and inclusive. However, not all of these factors are independent and some can be grouped into functional categories. It should also be recognized that the prioritization of these factors will differ among chlorophyll-a, dissolved oxygen and eelgrass. I suggest that potential confounding factors be grouped and quantitatively evaluated separately for each of these three water quality/ecological endpoints.
>
> In my opinion, the priority confounding factors for the relationship between ambient total nitrogen and chlorophyll-a concentrations are the following:
>
> 1. Physical
>   a. Hydraulic flushing rate
>   b. Water residence time
>   c. Salinity
>   d. Temperature
>   e. Transparency (underwater light attenuation)
> 2. Chemical
>   a. Nutrient availability (e.g., ammonium, nitrate, nitrite concentrations)
>   b. Phosphorus concentrations (total and soluble reactive forms)
> 3. Biological
>   a. Phytoplankton speciation
>
> Hydraulic flushing rate and water residence time are related because one is the inverse of the other. They can be determined using a hydrodynamic model or a mass balance model for salinity. If neither of these is available, salinity itself can be used as a surrogate parameter because it represents the influences of hydraulic flushing/water residence time, freshwater inputs, currents and tides.
>
> Transparency (underwater light attenuation) is actually a composite factor that represents the influences of colored dissolved organic matter (CDOM), total suspended solids (TSS), inorganic suspended solids (ISS), turbidity and chlorophyll-a.
>
> The relationship between total nitrogen and chlorophyll-a concentrations can be confounded by the magnitudes and relative proportions of the nitrogen forms generally

considered to be available for algal growth (e.g., ammonium, nitrate, nitrite). It could also be confounded by potential co-limitation by phosphorus during certain periods and/or in certain locations.

Phytoplankton speciation could be a confounding factor because carbon-to-chlorophyll ratio is a function of temperature, light and physiological condition, and can also vary among different functional groups of algae.

In my opinion, the priority confounding factors for the relationship between ambient total nitrogen and dissolved oxygen concentrations include all of the above factors for chlorophyll-a. The reason is that dissolved oxygen and chlorophyll-a are strongly coupled in aquatic systems through the production and consumption of organic carbon. The following additional confounding factors are also important:

1. Physical
    a. Bathymetry
    b. Depth
    c. Strength and duration of vertical stratification
    d. Wind
2. Chemical
    a. Sediment oxygen demand (SOD)
    b. Sediment total organic carbon (TOC)

A necessary condition for low dissolved oxygen is physical stratification/vertical stability of the water column. Bathymetry, depth and wind are all confounding factors that influence this condition. Sediment oxygen demand and total organic carbon are important confounding factors because oxygen depletion in bottom waters can be driven not only by consumption processes in the water column, but also by chemical-biological processes in the sediments, as represented by SOD and/or TOC.

As I pointed out on Page 31 of our joint peer review panel report, development of scientifically credible statistical relationships between nutrient concentrations as a causal variable and dissolved oxygen as a response variable is difficult under any circumstances. The reason is that dissolved oxygen dynamics in aquatic systems are complex and highly site-specific. It is significant to note that the EPA Technical Guidance Document for Stressor-Response Relationships (cited on Page 31 as EPA 2010b) does not contain a single example for dissolved oxygen as a response variable. My opinion is that process-based load-response models are a more appropriate approach for dissolved oxygen than the reference condition approach or empirical (statistical) stressor-response analyses. Such models could be used to link watershed loads directly to ambient dissolved oxygen concentrations, and then to develop TMDLs and or NPDES permit limits. They could also be used to back-calculate numeric nutrient concentration criteria corresponding to ambient dissolved oxygen concentration criteria.

I defer to Dr. Kenworthy on the priority confounding factors for the relationship between ambient total nitrogen concentration and eelgrass. I have read his response to this question and fully concur with his statements and opinions.

The report recognizes the importance of quantifying the impacts of epiphytic algae and macroalgae on the eelgrass ecology of Great Bay Estuary. Are there any mechanistic models that can be used to model the growth of epiphytes and macroalgae on and around seagrasses in estuaries? Did the models used by the Massachusetts Estuaries Project explicitly model macroalgae and epiphyte growth (e.g., in Pleasant Bay)?

A mechanistic (process-based) sub-model for epiphyte growth is included in the submerged aquatic vegetation (SAV) component of the 2010 Chesapeake Bay Eutrophication Model. The full report for this model can be found at:

http://www.chesapeakebay.net/content/publications/cbp_55318.pdf

This model does not include a sub-model for macroalgae. I am not aware of any mechanistic models for macroalgae.

The models used by the Massachusetts Estuaries Project were hydrodynamic models and nitrogen mass balance models. They did not explicitly represent macroalgae or epiphyte growth in Pleasant Bay or in any of the other Cape Code embayments.

The context for this question should be explored, perhaps in follow-up discussions with DES and the Communities. My concern is that use of an epiphyte model as a standalone tool might not be productive, but I would like to hear more about the potential intended use of such a model.

By way of background, the 2010 Chesapeake Bay Eutrophication Model explicitly represents SAV in terms of leaves, stems, roots, tubers and epiphytes. The epiphyte sub-model is only one component of the overall integrated hydrodynamic, sediment transport and water quality model. Another important component is a sophisticated bio-optical model. The bio-optical model computes light through the water column, and the epiphyte model computes light to the (SAV) leaf. Both of these sub-models are coupled to other physical, chemical and biological parameters in the overall integrated model.

Despite all of its complexity, and the skill and diligence of its developers, the model results for SAV are mixed and its ability to predict long-term trends in SAV area is minimal. On the other hand, the bio-optical sub-model appears well-developed and more reliable.

It is noteworthy that in developing the 2010 Chesapeake Bay TMDL, EPA used a dual approach for SAV and water clarity. They used the through-the-water light extinction results from the overall integrated model to determine SAV habitat areas (after subtracting defined no-growth zones), but did not use the model results for SAV. Instead, they used regression equations between observed SAV areas and observed loads

> of total nitrogen, total phosphorus and total suspended solids. Their approach is described in Appendix P – Chesapeake Bay TMDL, which can be found at:
>
> http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/FinalBayTMDL/AppendixPChlabasedSedAllocationsforJamesR_final.pdf
>
> Basically, this is a hybrid approach that combines results from a process-based model with those from a statistical model based on observed data.

One suggestion from the reviewers was that DES should develop site-specific thresholds for different sections of the estuary. If this were done, which of the important confounding factors would be effectively controlled?

> I requested clarification on this question through Ms. Suzanne Woodland. DES provided the following response:
> Our interest is this question is for the three response variables mentioned above. The term "effectively controlled" was admittedly confusing. We mean "control" in more of a mathematical context. Attached is a list of the covariates that were mentioned in the peer review.

Our question restated is, which among these covariates are most important to address (to control for) as new analyses are employed in the estuary, especially as they relate to the development of site specific thresholds for total nitrogen?

> First, I re-affirm that DES should develop site-specific thresholds for different sections of the estuary.
> In my answer to the first question above, I have already addressed what I believe are the priority confounding factors for chlorophyll-a, dissolved oxygen and eelgrass. My opinion is that these same factors should be addressed in development of site-specific thresholds for total nitrogen in different sections of the estuary.

Is chlorophyll-a an acceptable metric of phytoplankton levels in different parts of the system? Or, are measures of algal growth rates and primary productivity needed?

> It depends on the type of analysis. Chlorophyll-a is an acceptable metric for phytoplankton levels in different parts of the system for the reference condition approach and empirical (statistical) stressor-response analyses. In my opinion, chlorophyll-a is necessary but not sufficient for calibration of a process-based water quality model. The most scientifically sound approach for calibration of such a model is to use both chlorophyll-a concentrations (or biomass concentrations in terms of particulate organic carbon) and measurements of primary productivity. The former constrain computed standing-stock phytoplankton concentrations, and the latter constrain the underlying production rates in the model.

If phytoplankton growth in the Great Bay/Piscataqua River system is low and significant inorganic nitrogen is present in these areas, is it reasonable to conclude that TN is not presently limiting phytoplankton growth in these areas?

> It depends, in part, on whether the question is premised on observations of low chlorophyll a concentrations or observations of low primary production rates. Low chlorophyll a concentrations can be due to low primary production rates. However, even if primary production rates are high, low chlorophyll a concentrations can still be observed if hydraulic flushing rates are high and water residence times are low. It also depends, in part, on the (unstated) relationship between inorganic nitrogen and TN.
>
> As a very broad generalization, if phytoplankton "growth" is low and observed inorganic nitrogen concentrations are high, it might be reasonable to conclude that nitrogen is not the primary factor limiting phytoplankton growth rates under these conditions. However, a definitive conclusion should not be drawn without investigating the other potential confounding factors discussed above in my response to the first question.

Does the peer review conclude that the existing information (data and available studies for this estuary) is insufficient to demonstrate that TN levels are the likely cause of changing eelgrass populations and/or low DO that has occurred in this system?

> In my opinion, the panel does not have sufficient information to draw such a conclusion. Furthermore, it is not clear that this question will ever have a definitive yes/no answer. Any answer will necessarily depend on the acceptable levels of uncertainty and risk.
>
> As a starting point, I suggest that DES and the Communities develop a complete inventory of all available physical, chemical and biological data, and point and non-point source nutrient and solids loads from the watershed, for the entire Great Bay Estuary. It should include all of the confounding parameters in the joint peer review panel report and any additional parameters suggested by DES and the Communities. I suggest that this inventory be organized by individual years, and include the number, locations and frequency of sampling data for each parameter. Such an inventory would provide a good starting point for development of a strategic monitoring, modeling and research plan based on an adaptive approach.

Bierman Summary:

Dr. Bierman suggested grouping the confounding factors into functional categories to begin determining the most important to each of the three water quality/ecological endpoints. The priority confounding factors between TN and chl-a include physical (hydraulic flushing rate, residence time, salinity, temperature, transparency), chemical (nutrients) and biological (phytoplankton speciation) parameters. The priority confounding factors between TN and DO include all of the aforementioned factors and additionally bathymetry, depth, strength and duration of vertical stratification, wind, sediment oxygen demand (SOD), and sediment total organic carbon (TOC). Dr. Bierman reasserted that developing a scientifically credible causal relationship between nutrients and DO is difficult. Dr. Bierman believes that process-based load-response models for DO are more appropriate than reference condition or empirical stressor-response analyses. Regarding priority confounding factors for the TN/eelgrass relationship, Dr. Bierman deferred to Dr. Kenworthy's response.

When discussing water quality models applied to proximate estuaries, Dr. Bierman explained the 2010 Chesapeake Bay Eutrophication Model includes mechanistic sub-models for 1) computing light through the water column and 2) light reaching submerged aquatic vegetation (SAV) leaves. The first sub-model is reliable while the second sub-model has yielded mixed results and cannot accurately predict long-term trends in SAV area. However, to his knowledge, no mechanistic models for macroalgae exist. The Massachusetts Estuaries Project did not explicitly represent macroalgae or epiphyte growth.

Dr. Bierman discussed that chlorophyll-a alone is insufficient to calibrate a water quality model. Instead, both chl-a and measurements of primary productivity are required.

Dr. Bierman opined that it may never be known undoubtedly that TN levels are causing changes in eelgrass or low DO. This will always be an issue of acceptable uncertainty and risk.

Ultimately, Dr. Bierman suggests DES develop site-specific thresholds for sections of the Estuary. DES should begin by compiling all available data related to Estuary water quality, non-point and point source loads, and all of the confounding factors.

W. Judson Kenworthy, Ph.D.:

1. The report references over 20 confounding factors that influence the relationship between and among nitrogen dissolved oxygen, and eelgrass. What are the most important confounding factors that DES should prioritize for consideration?

> Yes, the number of potentially confounding factors identified by the panel is quite large, but not unlike the original list which has been reported in other eelgrass systems, such as the Chesapeake Bay, where they identified 22 factors (Orth et al. 2010). Based on our understanding of the ecology of eelgrass, the list can be reduced to a smaller subset of factors which can be quantitatively evaluated by a carefully designed concurrent process of assessment and elimination. The first, and probably the two most important questions scientists and managers in Great Bay should ask are; 1) How do you develop and implement a scientifically sound process of identifying the most important factors, and 2) how do you "rule out" which specific factors don't directly apply to the problem of setting numeric nutrient criteria for the protection of eelgrass? The final approach (model) you use to evaluate the problem should prioritize the most important factors and avoid over-parameterization by eliminating the factors which have minimal influence or simply don't apply to a particular location. As you will see below, some of the priority

factors can be collapsed into existing models (e.g., an eelgrass bio-optical model) which can be directly applied to the nutrient criteria problem.

One important initial step in this process of factor consideration has already been partially completed by DES and its' Great Bay collaborators. DES has already zoned the Bay into distinct geographically defined segments. This geospatial approach implicitly recognizes that there may be different (or similar) biological (e.g., eelgrass and macroalgae distribution), hydrological (e.g., currents, wave exposure, water residence time, salinity, optical properties) and geological characteristics (e.g., bathymetry, sediment type) in each segment, as well as different watershed features influencing the Bay's water quality (e.g. land use, nonpoint and point source nutrient discharges). Simply stated, this acknowledges that not all segments are alike and the list of priority and confounding factors in each segment that influence the growth and survival of eelgrass can be different (or similar) and significantly less than 20. As a practical and quantitative approach, spatial segmentation has been demonstrably successful for application to modelling and predicting the distribution of SAV in the Chesapeake Bay modelling program (Cerco and Moore 2001, Cerco et al. 2010). While zonation provides the spatial context for prioritizing and evaluating the most important factors, it reduces the scale of the problem and provides an opportunity to; 1) organize and simplify the structure of the models used to evaluate nitrogen cycling and loading processes and their effects on eelgrass in each segment, 2) more readily identify and model the bio-physical connectivity between segments (hydraulic flushing and residence times) as opposed to modeling the entire Bay, and 3) more easily and quantitatively link the water column and the substrate of the Bay to the specific watershed characteristics influencing nitrogen loading and the priority factors in each segment. Lastly, the process of designating specific zones allows for scientists to identify which segments are most immediately threatened by nitrogen loading and enables managers to prioritize actions in a framework of adaptive management. This will better enable state and municipal managers to determine how and when to allocate financial and infrastructural resources to remediate the impacts in particular segments as opposed to the entire Bay, which likely has segments which are not as seriously threatened as others.

Another important exercise would be to inventory what is known about the individual confounding factors in each zone. DES and its' collaborators have been monitoring several (not all) of the confounding factors in Great Bay, so you should first determine which of the factors from the list have been monitored. From the existing monitoring data and other sources of published and reported data you can create spatially articulated layers of information in a GIS format which will enable you to determine if there can be any further coalescence of the zones (similarities) to reduce the number segments to as reasonable a number as possible. From this exercise you will be able to determine which factors have been, and will be, adequately monitored, and where and when there are significant information gaps and data deficiencies. This important step will allow you to design a more informative and quantitative monitoring programs to support the implementation of appropriate models to use for the development of protective nutrient criteria.

Concurrently, you should be conducting an exercise to extract the most important and influential factors from the overall list. I stress concurrently, because it is entirely possible that you have either not monitored, or not quantitatively evaluated a factor (s) you have monitored. To evaluate the priority of importance in the large list of factors you should consider what is referred to as "potential eelgrass habitat". In principle, the concept of potential eelgrass habitat acknowledges that there is a combination of known factors which define the spatial and temporal limits for eelgrass growth and survival. Eelgrass abundance and distribution are affected by two factors: area available for eelgrass growth and conditions suited for eelgrass growth. Potential eelgrass habitat explicitly recognizes that no single factor (e.g., nutrient concentration) alone constrains the distribution and abundance of eelgrass. Based on empirical and observational data, scientific studies have identified the range of values that constitute optimum eelgrass growing conditions which includes several of the factors on the list. For example, I recommend you review a very applicable regional example of a process for evaluating the suitability of selecting potential eelgrass restoration sites in New England (Short et al. 2002). Short el al. (2012) provides a substantially reduced list of factors which they incorporate into a preliminary transplant suitability index (PTSI) to assess the suitability of sites considered for eelgrass restoration. In practice, the potential habitat suitability index (PHSI) you would use for establishing nutrient criteria in segments of Great Bay would be more complex than the Short et al. (2002) model developed more than a decade ago for small sites, but the principle approach is the same. More importantly, it is highly likely that a smaller subset of the most important factors will be common to many of the spatial zones so the model/approach used will have general application across several of the zones. But, it is also likely that there will be important differences revealed that weren't made evident by the simple linear regression approach previously used by DES. The main advantage you have in Great Bay which many other systems don't enjoy, is that you are dealing with the protection of primarily one species, eelgrass. This will make the process of factor prioritization and elimination much less complicated than in other locations like the Chesapeake Bay.

When considering the effects of nutrients on eelgrass, under almost all scenarios, there are seven primary factors which should be considered a priority in your assessment of potential eelgrass habitat. They are; light availability (light attenuation), water column bio-optical properties (chlorophyll a, suspended solids, CDOM), water depth (bathymetry, tide range), temperature, salinity, substrate quality (grain size, organic content), substrate stability (wave exposure, current velocity), water residence time, nitrogen delivery (loading) and competition by macroalgae. All of these factors can be monitored and quantified and some can be quantified by modeling. Whereas, there are several confounding factors of lower priority that are either not regularly monitored or not predictable, yet they may have influenced the historical distribution and abundance of eelgrass and could have an influence in future scenarios (e.g., severe storms, wasting disease).

Paramount in this process of factor consideration, defining potential eelgrass habitat for Great Bay, and setting nutrient criteria for the protection of eelgrass is the establishment of your short- and long-term goals. How much of the existing and potential eelgrass habitat can you reasonably expect to protect and restore? To a certain extent, DES partially attempted to do this by coupling of Kd (light attenuation) to water depth with the Koch model (2001). This accounts for a water column factor affecting potential habitat. However, there was no quantitative evaluation of the bathymetry or substrate quality to determine how much of the substrate at the target water depths could actually be occupied by eelgrass. Therefore, DES did not quantify the available potential habitat available. Occupation of eelgrass at a specified water depth is certainly a practical and useful target and has been used repeatedly as a conservation and restoration target. Largely because bathymetry and tide range are easily quantified, and under most circumstances tides are predictable and bathymetry changes very little over time unless there is an extreme event (severe storms). But, bathymetry alone cannot serve as the sole target, because the quality of the substrate or some other confounding factor affecting the substrate's stability (wave and current exposure) may prevent eelgrass from growing at a specified depth.

Sophisticated and quantitative modelling tools are available to address many of the factors and several of the tools can be used to aggregate and couple the factors. For example, the bio-optical model developed by Dr. Charles Gallegos can be used to assess the effects of the primary water column optical properties (Chl a, TSS, and CDOM) on Kd and depth of eelgrass growth, and when coupled to bathymetry, the model can be used to as a first step in predicting eelgrass potential habitat as a function of these optical properties (Gallegos 1994, Kenworthy et al. 2013). Wave exposure modelling tools are also available to help determine whether water depth and substrate conditions are suitable for the occupation of eelgrass. (http://products.coastalscience.noaa.gov/wemo/). Larger scale system wide water quality models are also available for coupling smaller sub-models to simulate the interaction of eelgrass with the environment and to predict eelgrass abundance and distribution (Cerco and Moore 2001, Cerco et al. 2010). These are just some examples of a number of modelling tools available for you to use that will substitute for the simple linear regression approach originally taken by DES.

2. What would be appropriate methods for using the historic eelgrass maps from 1949 to 1981 to determine impairments and areas for restoration?

2a. By the Communities: What factors would need to be considered to reliably use such information?

I will answer both questions of these questions at the same time. Historical eelgrass maps derived from data obtained prior to the technological advances made in the early 1980s with aerial photography and satellite remote sensing are notoriously unreliable for estimating areal coverage of seagrasses. In most cases the older maps are based on poor resolution and generally uncontrolled image quality. In most cases the imagery was obtained for other reasons then benthic habitat mapping and the specifications for acquisition did meet the requirements for underwater mapping. Furthermore, the older remotely sensed data is usually not verified by ground truth observations. Hence, there can be significant errors associated with uncertainty and false positives and the quality of the imagery may lead to significant errors of omission. Using older remotely sensed data requires a very high level of professional judgment to attain a reasonable confidence.

Older data developed from ground surveys can be useful for point estimates of presence or absence of eelgrass, but drawing reliable distribution maps from older surveys will depend to a large extent on the number of sampling points and distance between points. Some of the most important information that can be gained from older surveys are the other attributes of the sampling site; e.g., water depth with respect to tide level, substrate type, the distance from shore, shoreline characteristics, and location with respect to the landscape and watershed features. These attributes, especially water depth, could be very useful in helping set a goal for the maximum desired eelgrass depth you wish to attain in your management program. Presumably, the maximum depth of growth observed in the older surveys would represent a "potential" depth of maximum growth that eelgrass could achieve by managing water quality under present conditions (e.g., nitrogen). This assumes that the historical conditions were less impaired then they are at the present time. Hence, the adjacent landscape attributes, e.g.; whether the particular shoreline surveyed was rural or commercial, will give you some idea of whether the old survey was observing a pristine condition, an impaired condition, or something similar to what presently occurs today.

Lastly, you have an excellent eelgrass mapping survey that was initiated in 1996 and continues today. This survey provides very good estimates of areal coverage and changes in coverage over time in the different segments of Great Bay with very high confidence. These data have far more information in them that you have yet analyzed that can be directly applied to setting your management goals. I would strongly recommend that you use 1996 as your baseline for eelgrass distribution and further analyze these data in a spatial context, and if possible, in each separate segment with respect to; estuarine bathymetry, substrate quality, optical water quality, shoreline characteristics and watershed features to determine what the contemporary "potential" depth distribution is for eelgrass under the current conditions. Assuming you have a historical survey with sufficient attributes you could compare the contemporary result with the older data and come up with a reasonable estimate of the lower bounds of a maximum depth of growth for eelgrass. If you follow the historical progress of the Chesapeake Bay Program you will learn that they set their original SAV restoration depth from historical depth distribution information that was much deeper than could be reasonably achieved by contemporary management practices. In time, they have adapted to accept a shallower restoration depth (modified goal) and reconsidered the major factors responsible for controlling the distribution and abundance of eelgrass and effectively using the survey data, scientific information and modeling tools currently available for modification and use in Great Bay.

3. Is chlorophyll-an acceptable metric of phytoplankton levels in different parts of the system? Or, are measures of algal growth rates and primary productivity needed?

Yes, chlorophyll-a (Chl-a) is an acceptable metric of phytoplankton levels in different parts of the Great Bay System. It is not necessary to measure algal growth rates and primary productivity in a monitoring and assessment program for the purpose of establishing numeric nutrient criteria. Chlorophyll-a is an important factor controlling light absorption and scattering and directly affects light attenuation in the water column and on the leaves of eelgrass (epiphytes). However, light attenuation by Chl-a is just one of the three important optical factors that contribute to light attenuation and cannot be considered as either the only factor or the major factor. Light attenuation is also a function of the water itself, the total suspended material (TSS) and the colored dissolved organic matter (CDOM). All three of these factors will vary in space and time as a function of location in the Great Bay. For example, in the upper reaches of the riverine tributaries, CDOM is likely to be relatively more important than either of the other two factors. As indicated in my response to the first question, these three factors can be quantitatively assessed to predict their effects on eelgrass distribution and abundance by using a calibrated bio-optical model coupled with the known light requirements of eelgrass (Gallegos and Kenworthy 1996, Gallegos 2001, 2005, Kenworthy et al. 2013).

4. How can DES practically measure and use epiphytic algae as a diagnostic indicator? How can light shading of seagrasses from epiphytes be calculated?

It isn’t practical, nor is it cost effective, to incorporate measures of epiphytic algae into a broad scale long-term monitoring program until DES determines if there is a problem with epiphytes.. It is very important for DES to attempt to determine if there is a seasonal and inter-annual light attenuation problem associated with epiphyte biomass growing on the leaves of eelgrass in different segments of Great Bay. To accomplish this, I recommend that DES consider designing and establishing a set of sentinel sampling sites in representative locations in the different segments of Great Bay across a gradient of known water quality and eelgrass impairment (e.g., most impaired, moderately impaired, and least impaired). A general description of the design for this monitoring and assessment program includes, at a minimum, the following features. At each of the stations you would deploy artificial substrates, e.g., mylar plastic strips (Peterson et al. 2007) that mimic the density of the eelgrass canopy and the structure and height of the eelgrass leaves at three different depths with respect to eelgrass distribution (shallow, mid depth and deepest depth of growth). Periodically (e.g., monthly) you would monitor these stations to determine the biomass of epiphytes growing on the artificial leaves. Also, at some point in the seasonal growth cycle of eelgrass (spring, summer, fall, and winter) you would calibrate the biomass of the artificial substrates with the biomass of epiphytes actually found on plants in the vicinity of the artificial mimics. To quantify the potential effects of epiphyte biomass on eelgrass, I recommend that DES consider using a modification of the SAV Unit model for the Chesapeake Bay properly adjusted for conditions in Great Bay (Cerco and Moore 2001, Cerco et al. 2010).

5. We understand that, the Massachusetts Estuaries Project used a reference concentration approach to set Total Nitrogen restoration targets. We believe that the reference concentrations were often taken from the mouth of a harbor with the highest flushing rate. How does this approach avoid problems with the confounding factor of flushing rate?

The short answer to this question is that the MEP incorporated an estuarine hydrodynamic model to account for the flushing rate and linked it to a watershed nitrogen loading mass balance model. The reason that some of the reference concentrations were derived from locations close to the mouth of the embayments was because there were such severe eelgrass declines the only surviving eelgrass was located in proximity to the inlets. The reference concentrations derived from these stations were then applied in the linked models. It would not matter where they collected them as long as they corresponded with stable and healthy eelgrass beds and no other eelgrass occurred in the embayment under different total nitrogen concentrations. MEP did have to make some basic assumptions to use their approach. First of all, they had to assume that the temporal scale of their monitoring (eelgrass abundance and water quality) corresponded with the temporal scale of eelgrass beds dynamics. More specifically, those reference stations should not be expanding or declining. Second, they had to assume that there are no other significant factors (e.g., substrate quality) that would restrain the recovery of eelgrass once the appropriate threshold value was achieved by nitrogen remediation.

6. DES has questions about the interpretation of the articles cited on page 52 or the report (Wazniak et al, 2007 and Bensen et al., 2013).

There were no specific questions listed regarding my interpretation on page 52 of the Panel’s report. I did have a brief phone conversation with Ted Diers about this question and I was still uncertain as to what specific question to address. Rather than guess what the questions are, I will attempt to clarify the points I was making on page 52 of the Panel’s report. I inserted the section from the report below followed by my supplemental clarification.

To the best of my knowledge, only one system wide level study of the relationship between total nitrogen and eelgrass status has been published in the scientific literature (Wazniak et al. 2007). This study was conducted in the coastal bays of Maryland and Virginia and examined the long-term record for trends in eelgrass abundance and total nitrogen concentrations, chlorophyll a, total phosphorus, and dissolved oxygen). This study is informative for DES because it demonstrates statistically that in locations where total nitrogen concentrations exceeded 0.65 mg/l eelgrass was declining. The proposed DES total nitrogen criteria in Great Bay (annual median of 0.25 – 0.30 mg total nitrogen) are about half the threshold concentration identified by Wazniak et al. (2007), so it appears that the DES criteria are more conservative and potentially more protective of eelgrass than identified for the Maryland coastal bays. To help better identify the potential total nitrogen criteria for Great Bay, DES should also consider the results of a recent study conducted in collaboration with the MEP program in Massachusetts (Bensen et al. 2013). This study identified; 1) healthy and stable eelgrass beds as locations with long-term total nitrogen concentrations (2000-2010) of 0.45 mg/l and, 2) degrading or lost beds with concentrations of ≈0.55 and 0.65 mg/l, respectively (see Figure 2 in Bensen et al. 2013). These results corroborate values reported by Wazniak et al. (2007) discussed above, indicating that concentrations on the order of about 0.6 mg/l total nitrogen correspond with degrading eelgrass beds. However, as indicated above in my responses to questions #1 and #2, even where lower total nitrogen values in Great Bay are lower than 0.6 mg/l and are at the proposed DES criteria concentrations, eelgrass is declining. Again, suggesting the likelihood that other factors are affecting eelgrass distribution, abundance and survival in Great Bay.

In my phone conversation with Ted Diers he indicated that DES didn't understand where the 0.65 mg/l total N concentration came from in Wazniak et al. (2007). This value first appears in in Table 1 where they show the biological threshold of total nitrogen established by the Maryland Coastal Bays Program (MCBP 1999). This was a target threshold MCBP established in their management plan and Wazniak et al. attempted to evaluate the status of this threshold in the Coastal Bays with respect to trends in eelgrass abundance. I direct you to Figure 3a in Wazniak et al. (2007) where they show the total nitrogen levels and gradient of total nitrogen enrichment (concentrations) across the Maryland Coastal Bays. In many segments the threshold was exceeded. Later in the discussion in a section title "Impacts to seagrass" they refer to an inflection point and reversal of the trend in total nitrogen concentration over time shown in Figure 7a. The trend goes from declining to an inflection point and then to an increase. They state, and I quote: Throughout the coastal bays seagrass abundance has been increasing since monitoring began in 1986, with an overall 320% increase that may be related to historically improving nutrient trends. However, these increases have leveled off over the past several years (Fig. 9; Orth et al. 2004, 2006). One possible explanation is that seagrasses have occupied all viable habitat. However, recent analyses estimate that current seagrass coverage occupies 67% of the total potential habitat (area of suitable depth and sediment type) in the Maryland portion of the bays. Another hypothesis is that the leveling of seagrass abundance coincides with the inflection period of nutrient and chlorophyll a trend reversals, suggesting that seagrass coverage may also be in an inflection period and may begin moving toward a decline if current trends continue.

Likewise, the Bensen et al. (2013) study in the MA embayments drew a similar conclusion for the range of threshold values of total nitrogen that correspond with degrading or lost eelgrass beds. Despite the different approaches taken by these two studies, this agreement appears to be more than a coincidence and provides independent confirmation for a reasonable estimate of a total nitrogen threshold for eelgrass. I then pointed out in the Panel Report that even where total nitrogen values in great Bay were lower than 0.6 mg/l, eelgrass was declining. I will reiterate my original statement; it appears there could be other factors operating in Great Bay which are limiting eelgrass besides total nitrogen concentration. It is possible that the delivery of nitrogen (nitrogen loading) and not the measured instantaneous concentrations are affecting eelgrass. In Great Bay, where you have total nitrogen concentrations less than ≈ 0.6 mg/l, eelgrass has been declining since 1996. This could be corroborated by either measuring the nitrogen concentration or the isotopic composition of nitrogen in eelgrass tissue which are two other assessment tools DES can employ in their future monitoring programs to evaluated nitrogen effects.

Since we are discussing the Wazniak paper, I want to draw you attention to how that study utilized the concept of "potential eelgrass habitat" I discussed in my earlier response. This is found in the quote above that I extracted from the paper. The authors state that only 67% of the potential eelgrass habitat was occupied at the time of their study and hypothesize that the incomplete occupation may be a function of the recent inflection and reversal of the nutrient trends. While eelgrass coverage had been increasing during a period of declining nutrient enrichment, it has now leveled off and in fact, has since shown a substantial decline since nutrients began to increase after the inflection. This study demonstrates how the quantification of potential eelgrass habitat provides a reference point you can compare to the actual coverage to gain a better understanding of whether the current conditions (e.g., total nitrogen concentrations/loadings and eelgrass coverage) are meeting your long-term goals. Assuming your goal is to maintain coverage in the entire potential habitat.

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Kenworthy Summary:

Prior to analysis, Dr. Kenworthy suggested the Estuary should be partitioned into segments to account for spatial variation of physical, chemical, and biological factors. Regarding the confounding factors, prioritizing the most important and ignoring the least influential will help narrow the focus initially. Dr. Kenworthy listed primary factors affecting the relationship between nutrients and eelgrass: light availability, chlorophyll-a, suspended solids, CDOM, bathymetry, tidal range, temperature, salinity, substrate grain size and organic content, substrate stability (wave exposure, current velocity), water residence time, nitrogen delivery, and competition by macroalgae. Kenworthy discussed several water quality models and the suitability of their application to Great Bay Estuary.

Dr. Kenworthy discouraged the use historical eelgrass maps developed prior to the early 1980’s as they are “notoriously unreliable”. However, supplementary data from early ground surveys can provide potentially useful information to be compared with more recent data. Eelgrass mapping surveys beginning in 1996 are the most reliable and should be used in future analyses. Similar to the historical surveys, the recent eelgrass surveys include useful supplementary data such as water depth or substrate type which should be analyzed in unison with the eelgrass maps.

Dr. Kenworthy affirmed that chl-a alone is an acceptable metric to establish numeric nutrient criteria; algal growth rates and primary productivity are unnecessary. This should not be confused with Dr. Bierman’s statement where he said chl-a alone is not sufficient to calibrate a water quality model, but did not mention numeric nutrient criteria.

Kenworthy warned that epiphytes should not be monitored unless an epiphyte problem is identified. To measure epiphytic growth, he proposed a short-term monitoring program based on methods used in the *Peterson et al. 2007* study. Kenworthy added that other important factors affecting light attenuation are the water itself, TSS, and CDOM.

Dr. Kenworthy explained the assumptions of the Massachusetts Estuaries Project (MEP) reference concentration approach to setting TN targets. The first assumption was that the temporal scale of monitoring corresponded with the temporal scale of eelgrass bed dynamics. Secondly, MEP assumed that once below the TN target, no other factor would limit eelgrass recovery.

DES revealed they had questions regarding pg. 52 of the Peer Review Report but never provided specific questions. Dr. Kenworthy attempted to clarify his statements regarding the *Wazniak et* *al., 2007* and *Bensen et al., 2013* studies. Both of these studies observed a decrease or leveling off of seagrass abundance coinciding with increases in nutrients and chl-a. This suggests the possibility of a reasonable TN threshold for eelgrass though significant additional research would be required. Kenworthy also suggested that the TN load, not concentration, could be the primary parameter affecting eelgrass because TN concentrations are so low in Great Bay (~0.6 mg/L). Another possibility is that other non-TN factors are affecting eelgrass.

Dr. Kenworthy reiterated the concept of “potential eelgrass habitat” which could serve as a reference point to compare current and, to some extent, historical eelgrass abundance.