Dr. Hunter Carrick

USEPA Science Advisory Board- Lake Erie Phosphorus Objectives Review Panel

Question-1: Please comment on whether the evaluation of the models was adequate to inform how model results should be interpreted, given differences in model complexity and scale. Please identify any additional analyses that may be needed to improve future development and interpretation of the load-response curves for the eutrophication response indicators.

Pro: The overall approach using ensemble modeling makes inherent sense. The models were rigorously tested and subjected to a systematic set of validation procedures (e.g., sensitivity analyses), suggesting that the problems of melding various scale-dependent elements of the models were adequately addressed and simulated. The triangulation on this set of results represents another, important validation of the results. The models can be compared with previous work, as number of them have been previously applied to this problem, both in Lake Erie and elsewhere. The model results (for the most part) have been published in the primary literature, and thus, reviewed by experts in this field.

Con: The suite of models used here are similar in a sense, because they were related to one another in their approach. It would have been good to see some non-traditional approaches taken to see if the same level of validation was achieved (e.g., neural net, non-parametric approach).

Question-2: Please comment on whether the recommended targets reflect the best available information on the drivers of cyanobacteria growth and seasonal hypoxia in Lake Erie and are appropriate to meet the nutrient Lake Ecosystem Objectives.

Pro: The P targets identified here supported a reasonable conclusion based upon the data available at this time. These load limits should bring about changes in the frequency and persistence of harmful algal blooms (HAB) in the western basin of Lake Erie, assuming there is a strong link between external loads and internal lake dynamics. An important metric to keep in mind is the concentration of P in the lake itself. Other analyses have shown that a value of 30 ug/liter or less should reduce HABs in Lake Erie (see Millie et al. 2012).

Con: The link between HABs and hypoxia in Lake Erie is difficult to ascertain. I do not think we understand the link, let alone can quantify it just yet, given the relatively scant data available, and the complexity of this ecosystem-level dynamic. For instance, one issue we need to consider is the occurrence of seasonal spring blooms (mainly diatoms) and their role in contributing to hypoxic events during the summer's that follow (see work by Lashaway and Carrick 2010; Twiss et al. 2012; Wilhem et al. 2014). Most recently, Reavie et al. (2016) published results that showed the amount of phytoplankton biomass produced during typical spring diatoms blooms significantly outweighed that produced by summer cyanobacteria blooms.

Question-3: Please comment on whether scientifically-sound phosphorus load reduction recommendations to address Cladophora growth in the Eastern Basin of Lake Erie could be developed at this time.

Pro: It was good to see the report produced this January 2016- "State if knowledge of *Cladophora* in the Great Lakes". That document illustrates a number of gaps in our understanding around this issue. It looks as though there are in-lake sources of P that promote the growth of *Cladophora*. In order to decipher the link between *Cladophora* and invasive mussels, more research is needed.

Con: Many algae are capable of storaging large amounts of P internally (in their cells) through luxury consumption (see work by Higgins, Price and Carrick, Rier). Understanding the time lag effect of P storage versus *Cladophora* growth is essential in addressing how to apply P load reductions to the control of *Cladophora* growth.

Question-4: What recommendations can the SAB provide for development of an approach to help determine whether consideration of nitrogen control, in addition to phosphorus, is warranted in Lake Erie to prevent harmful algae blooms and manage hypoxia?

Pro: Nitrogen (N) is an important contaminant to surface waters worldwide, and concentration limits have been set by USEPA because N (in high enough concentrations) can be directly toxic to animals and humans. Moreover, there is ample evidence that points to nitrogen, as well as, phosphorus as a key element that can promote algal growth in Lake Erie (e.g., work by Moon and Carrick; Guildford et al.; North et al.) and elsewhere (see work by Howarth, Paerl, Conley and others). As such, I do not believe that nitrogen can be left out of this discussion. The main idea here is that N will be controlled as a function of the recommended management practices in the watershed for P. This approach has been used before.

Con: This aspect of the analysis could have been enhanced. N is cycled in very different ways compared with P, and as such, some further consideration should be paid to this issue (binding to soil, transport, and utilization by plankton).

Question-5: Please comment on the use of FWMC and any other approaches that should be considered to account for inter-annual variability in hydrology in assessing progress in reducing tributary loadings of phosphorus to the Lake.

Pro: The application of flow-weighted mean concentrations (FWMC) is a reasonable approach for assessing targets, because the seasonal delivery of nutrients to Lake Erie appears to be driven by large spring loads.

Con: It may be problematic to assume that load limits should be so tightly linked to flows. While I understand the rational for this approach, we are likely to experience large, more singular rainfall (and therefore runoff events) in the future. These weather patterns appear to be the new norm, where run-

off is delivered through more episodic events. The use of FWMC assumes that precipitation patterns will follow past patterns, which is probably not true.

Question-6: Please comment on the value of applying the existing eutrophication models on an ongoing basis to periodically evaluate phosphorus loading targets and eutrophication response indicators. What key elements should be included in the adaptive management approach to successfully implement and evaluate our nutrient reduction goals for Lake Erie?

Pro: I like the consistency of the ensemble approach used here; it represents a link to previous work and improvements in the modeling efforts and computations. The models use relatively simple response variables that can be (and have been) measured over time (e.g., chlorophyll, cyanobacterial abundance). That said, I hope we can learn from the past. We need to be collecting more data not less. All of these models are data limited and their predictions are ONLY as good as the data on which they are based.

Con: Because most of the models are data limited, we should be looking for ways to enhance our ability to collect quality data and incorporate them into modeling efforts. The use of in situ instruments can be used to this end, and could greatly enhance our ability to make predictions in time and space