

Chesapeake Bay Hypoxic Volume Forecasts
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The 2008 Forecast - Given average Jan-May 2008 total nitrogen load of 300,400 kg/day, this summer's hypoxia volume forecast is 9.9 km³, the 6th highest on record (1st - 5th ranging from 10.6 and 12.1 km³. If the upper value of 12.3 km³ is reached, it will be the highest on record.

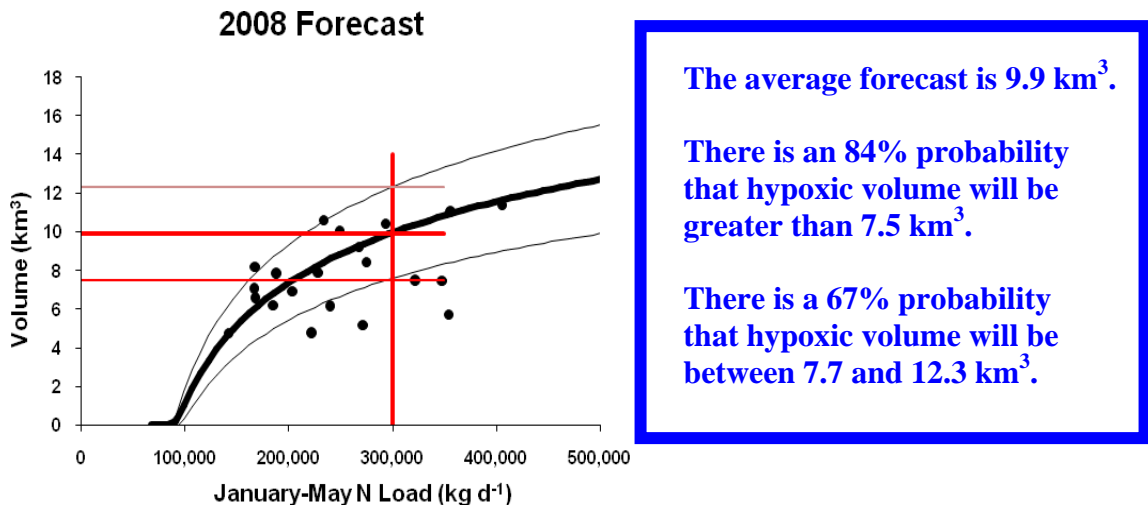
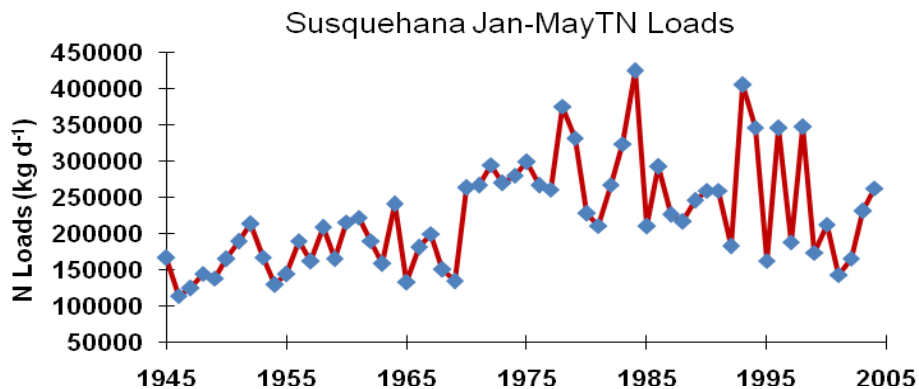


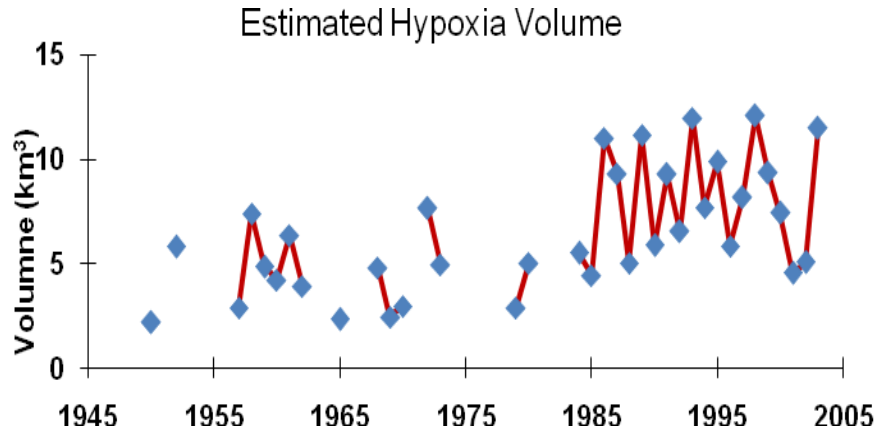
Figure 3. Dots represent observed volume and loads for 1986-2006. Dark and lighter curves represent means +/- one standard deviation of Monte Carlo model output. Vertical line represents 2007 Jan-May TN load. Horizontal lines represent the mean of hypoxic volume forecasts (middle), and the mean minus one standard deviation (lower) and mean plus one standard deviation (upper).

Hypoxia in the Chesapeake Bay – The level of oxygen in the waters of the Chesapeake Bay is a critical factor in determining the health of the Bay’s ecosystem.

The loads of nitrogen, one of the key drivers of hypoxia in the Bay has increased dramatically since the 1950s. The plot below shows the average Jan-May loads of total nitrogen from the Susquehanna River, the primary load to the main stem of the Bay.



These loads have driven the increase in the volume of water with oxygen concentrations below 2 mg/l, the definition of hypoxia for the Bay. The graph below of estimates of those volumes show how it has increased during this same time period.



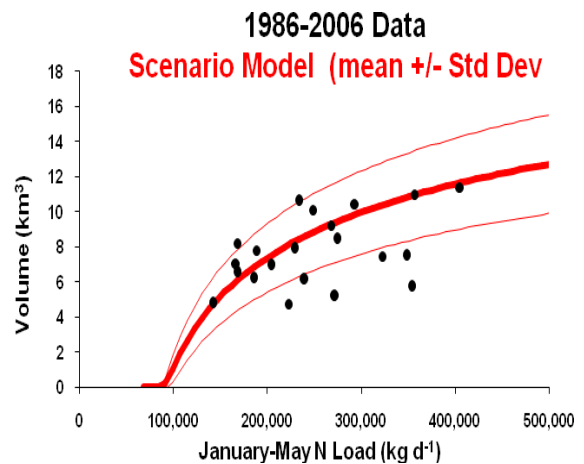
These two data sets were used to develop and test the model used for hypoxia scenario development and forecasts.

The model - The forecast was done with a model that was developed to assess the impacts of changes in nitrogen loads on Chesapeake Bay hypoxia (Scavia et al 2006). While it was originally designed to estimate the extent of nitrogen load reduction needed to reach a particular goal for hypoxia volume (see Figure 1), it can also be used to forecast hypoxic volumes for a given year, based on the average January-May loads.

The model is an adaptation of a river model that predicts oxygen concentration downstream from point sources of organic matter loads using two mass balance equations for oxygen-consuming organic matter, in oxygen equivalents (i.e., BOD), and dissolved oxygen deficit. The equation for dissolved oxygen (DO), solved at steady state is:

$$DO = DO_s - \frac{k_1 BOD_u}{k_2 - k_1} \left(e^{-k_1 \frac{x}{v}} - e^{-k_2 \frac{x}{v}} \right) - D_i e^{-k_2 \frac{x}{v}}$$

where DO = the dissolved oxygen concentration (mg/L), DO_s = the saturation oxygen concentration, k_1 = the BOD decay coefficient (1/day), k_2 = the reaeration coefficient (1/day), BOD_u = the ultimate BOD (mg/L), x = the downstream distance (km), v = stream velocity (km/day), and D_i = the initial DO deficit (mg/L). This approach to modeling coastal and estuarine hypoxia has also been used successfully for Gulf of Mexico hypoxia (Scavia et al. 2003, 2004). In this application,



the parameter, ν , is a calibration term that integrates all model and data uncertainty.

Recalibration - The original model was calibrated and tested against 1950-2003 nitrogen load and hypoxic volume estimates assembled by Hagy (2002). The Chesapeake Bay Program provided load and hypoxic volume updates for 1986-2006, and even though the new estimates varied little from the original ones (Figure 1); the model was recalibrated for this application to the new 1986-2006 estimates.

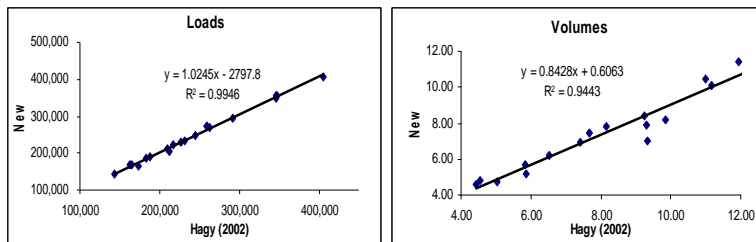


Figure 1. Comparison of Hagy (2002) and CBP estimates of Loads and Volumes

As in the original application, most of the interannual variability was captured by varying only the calibration term, ν , and initial deficit, D_i , from year to year (Figure 2). Therefore Monte Carlo simulations and forecasts were based on 1000 runs made with values of ν and D_i selected randomly from normal distributions.

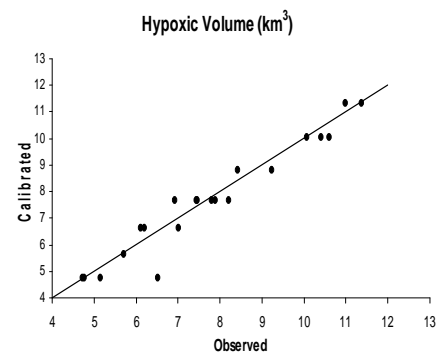


Figure 2. Predicted vs. Observed Volume

For more information on the role and importance of oxygen in the Chesapeake, check out this website from the Chesapeake Bay Program:

<http://www.chesapeakebay.net/dissolvedoxygen.aspx?menuitem=14654>

For more information on this and other Chesapeake Bay ecosystem forecasts, check out their Eco-check website: <http://www.eco-check.org/>

Additional Background - The causes and consequences of oxygen depletion in Chesapeake Bay have been the focus of research, assessment, and policy action over the past several decades (Boesch et al. 2001). During that period, this 11,000 km² estuary has been the subject of a series of intergovernmental agreements (EPA 1983, 1987, 1992, 2000) focused on reducing the impacts (Diaz and Rosenberg 1995, Brietburg et al. 1998) of nutrient over enrichment (Malone et al. 1993) from its 167,000 km² watershed. The latest agreement, Chesapeake 2000 (EPA 2000), recommits the parties to nutrient reduction goals established under the 1987 agreement. The 1987 goal stipulated a 40% reduction of nitrogen and phosphorus loads relative to a baseline based on 1985 point

source loading and diffuse source loading expected in an average rainfall year during the 1980s. In addition, Chesapeake 2000 adopts the broader goal of taking sufficient action by 2010 to correct nutrient- and sediment-based water quality problems, such that Chesapeake Bay is no longer designated as "impaired" under the U.S. Clean Water Act. An ongoing scientific re-evaluation of whether the load reduction goals are adequate to meet the water quality goals will likely be needed.

Models have played an important role in advising the public policy debate on load reduction goals (Boesch et al. 2001, Malone et al. 1996) by predicting water quality responses expected from different nutrient load reduction scenarios, by providing insights into internal dynamics affecting oxygen and nutrient concentrations, and by evaluating potential responses to changes in key drivers such as freshwater inflow. While models can provide such insights, and their use in ecological forecasting is growing (e.g., Clark et al. 2001, Valette-Silver and Scavia 2003), they must always remain caricatures of nature, subject to both known and unknown uncertainties and errors (Oreskes et al. 1994, Sarewitz et al 2000). For that reason, it is wise to use several independent models and modeling approaches for guiding important and expensive policy action. Such comparisons among multiple modeling approaches have been useful for analysis of eutrophication in other coastal systems (Scavia et al. 2004) and in the Great Lakes (Scavia and Chapra 1977, Bierman 1980).

Chesapeake Bay models for guiding policy on nutrient loading have taken a variety of forms. Some have used complex mechanistic ecological simulation models imbedded within hydrodynamic models to simulate detailed biophysical interactions and dynamics (Cercio and Cole 1993, 1994; Cercio 1995a, b). Others have used statistical approaches correlating properties of management interest, such as anoxic and hypoxic volumes and freshwater and nitrogen loads (Hagy et al 2004). Both approaches are useful, yet both have limitations. Complex mechanistic models aid in understanding the internal dynamics of the ecosystem and in discerning complex impacts in 3-dimensions. However, they generally involve many parameters, are difficult to calibrate, are limited in their ability to quantify uncertainties, and require very large input data sets (e.g., winds, solar radiation, river flows, etc). The required inputs are hard to compile historically and virtually impossible to specify on the multi-decadal timescales required for forecast scenarios. Evaluating a range of input conditions (e.g., wet vs. dry years; Cercio 1995a, b) can provide useful bounds on forecasts; however, whereas essential relationships, such as the effects of hydrodynamics and nutrient loads on hypoxia have been successfully reproduced by mechanistic models, the simulations depend upon myriad assumptions about model structure and parameterizations. This is not to discount the value of simulation models, but rather to point out that mechanistic models, as they have been implemented for management for the Chesapeake Bay, have tended to be very complex because so much is asked of them.

Statistical approaches (e.g., regression), on the other hand, address relationships directly and can usually quantify the uncertainty in relationships. They are, however, only correlative, do not represent biophysical processes.

Our approach offers a middle ground, using a simple model that is based in biophysical processes and focused directly on key variables of management interest -- hypoxic volumes and nitrogen loads. With this rather simple model formulation, we can limit the

number of parameters, tightly constrain the uncertainties, create functional as opposed to purely statistical relationships between the key management control variable (nutrient loads) and the expected environmental response (hypoxic volume), and apply statistical methods to quantify model uncertainty.

Each of the three modeling approaches is ultimately grounded in field observations and provides quantitative relationships among important properties. Their comparison can be instructive from both modeling and policy guidance perspectives. In this paper, we describe our simple, biophysically based model and compare its forecasts and scenarios with those of previous work and existing policy goals.

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