Supporting Information

Environmental Science & Technology

Reassessing Hypoxia Forecasts for the Gulf of Mexico

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Model description - The model is a variant on the Streeter-Phelps dissolved oxygen model, commonly applied to river and estuarine systems. It simulates the concentration of decomposing organic matter (B) in oxygen equivalents (i.e., BOD, mg L^{-1}) and the dissolved oxygen deficit from saturation (D, mg L^{-1}) at increasing distances downstream from two point sources of loads; namely, the Mississippi and Atchafalaya Rivers. The mass balance equations are as follows:

$$dB/dt = -v dB/dx - aB$$

$$dD/dt = -v dD/dx + aB - bD$$

where t is time (d), x (km) is the distance from the point source, a is a first-order rate constant for organic matter decomposition (d^{-1}), and b is a first-order rate constant for vertical oxygen flux (d^{-1}). The calibration term, v (km d^{-1}), takes into account both the net westward advection (as in the original Streeter-Phelps model) and all other uncertainties in model structure, parameters, and drivers.

Assuming no upstream oxygen deficit, and ignoring longitudinal dispersion, the model's stead state solution is:

$$B = B_0 e^{-ax/v}$$

$$D = [a / (b-a)\ B_0(e^{-ax/v} - e^{-bx/v})]$$

The model assumes that subpycnocline oxygen consumption can be approximated as first-order decay of organic matter, and that oxygen flux across the pycnocline is first-order and proportional to the oxygen deficit (here defined as the difference between subpycnocline concentrations and 7 mgL^{-1}, the saturation value at typical Gulf surface water temperatures and salinity).

We also assumed that there is a relationship between the observed mid-summer hypoxia and that predicted at steady state, and that movement of sub-pycnocline water west of the Mississippi and Atchafalaya rivers could be modeled as a one-dimensional flow. In reality, the spring and early summer production of organic matter, its subsequent rapid westward movement along the surface, and its settling into the slower-moving bottom waters is a dynamic transition into the summer and early fall development of hypoxia. However, our ability to accurately simulate the year-to-year variability helps validate the use of point-source approximations, our parameterization, and steady state assumption. This assumption is also supported by the fact that the Gulf is highly stratified in the summer, which causes the subpycnocline water to be isolated from the unpredictable dynamics of the surface water flow, and the fact that most of the interannual variability in hypoxic area can be explained by variation in its length (Figure S2). Expansion beyond these simplifications with, for example, multi-layered, time-dependent detailed ecosystem models may add further insight into the transition periods; however, they also require significantly more parameter estimation, calibration, and field data.

Hypoxia characteristics and data -- Relatively slow, coastally-constrained flow, coupled with other biogeochemical and physical processes, produces the characteristic shape of the hypoxic zone. These hypoxic areas typically extend westward from the mouths of the Mississippi and Atchafalaya rivers as much as 500-600 km, past the Texas border. In contrast to their length, they are typically only 30-60 km wide and less than 10 meters thick. Hypoxic zone lengths and areas were derived from contours of bottom-water oxygen concentration less than 2 mg L^{-1} generated from field data using the Kriging interpolation method of Surfer® 7. Distances along the length of the hypoxic area(s) were measured using ArcView® software on imported Surfer®-generated contours. The characteristic shape of the hypoxic area, supporting the strong dependence on long-shore transport, leads to a significant simple linear regression of area with length (slope = 38.9; r^2 = 0.82, Figure S2). This strong correlation and the relatively slow, low-frequency currents observed in the bottom waters justify our assumption of a one-dimensional analysis.

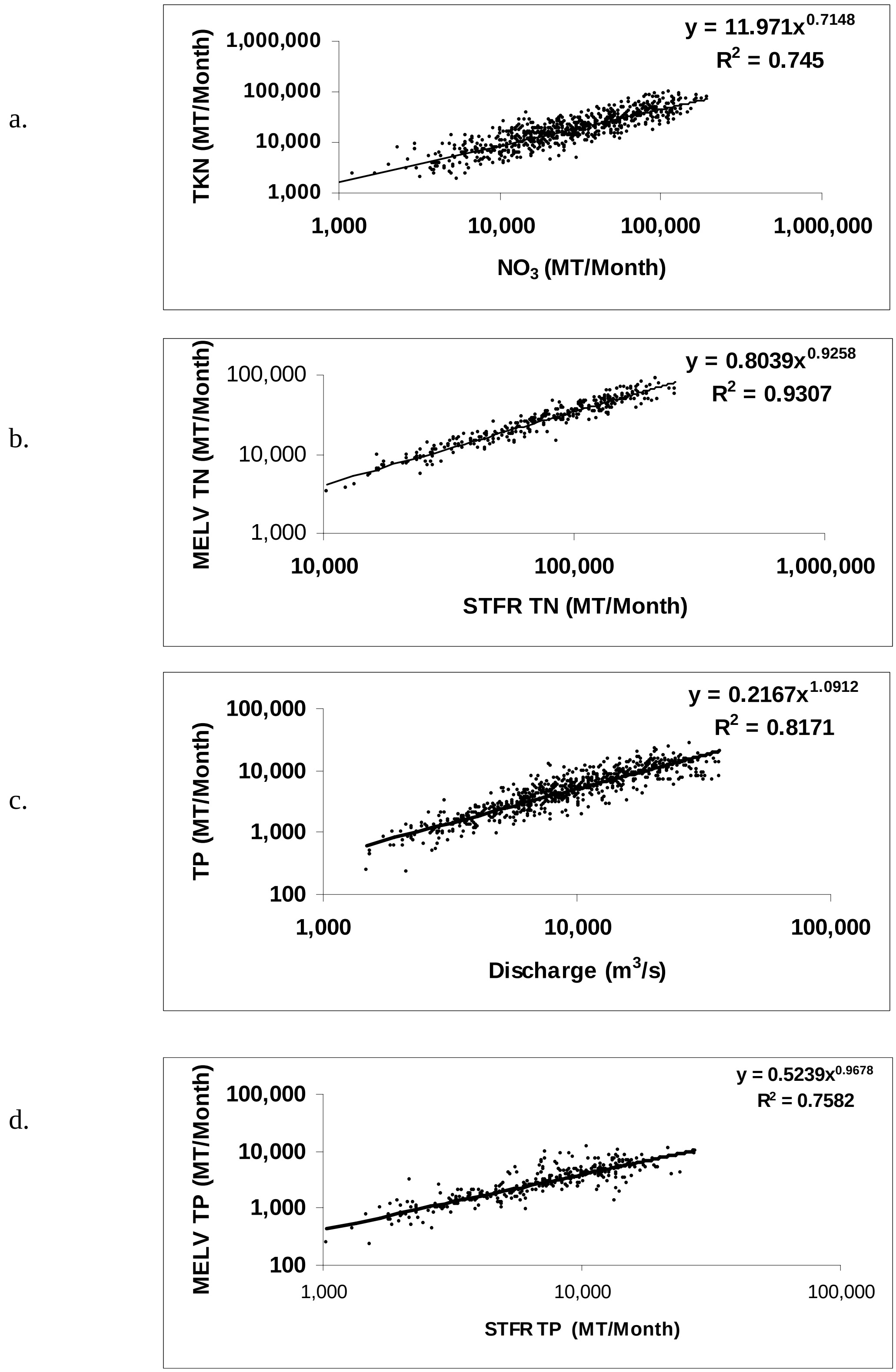

Figure S1. Regressions used to reconstruct historical TN and TP loads.

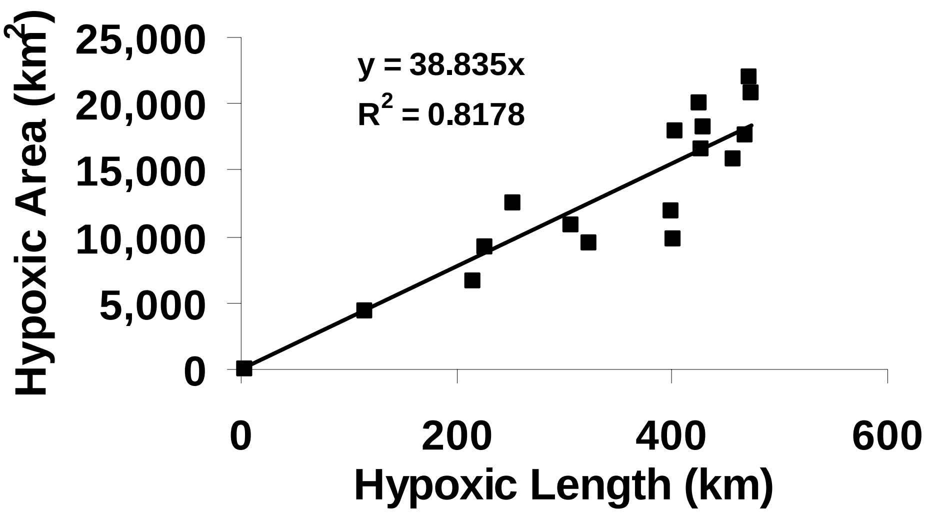

Figure S2. Relationship between hypoxic region length and area.

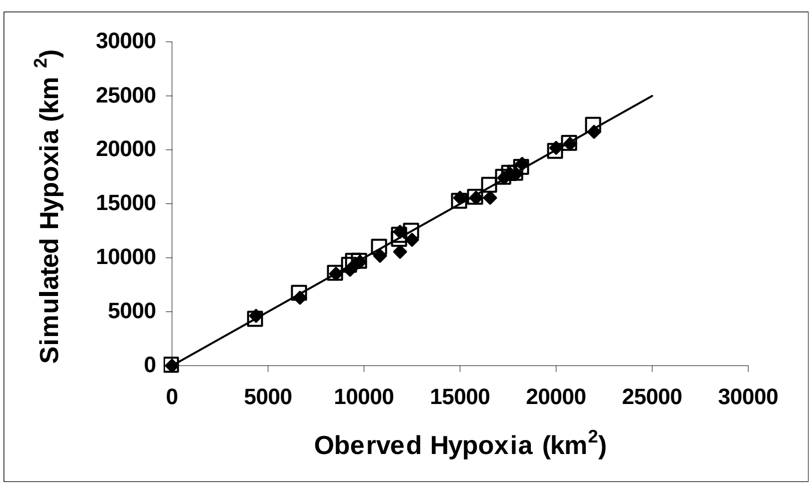

Figure S3. Calibration results for TN-driven (squares) and TP-driven (diamonds) models. Solid line represents perfect agreement

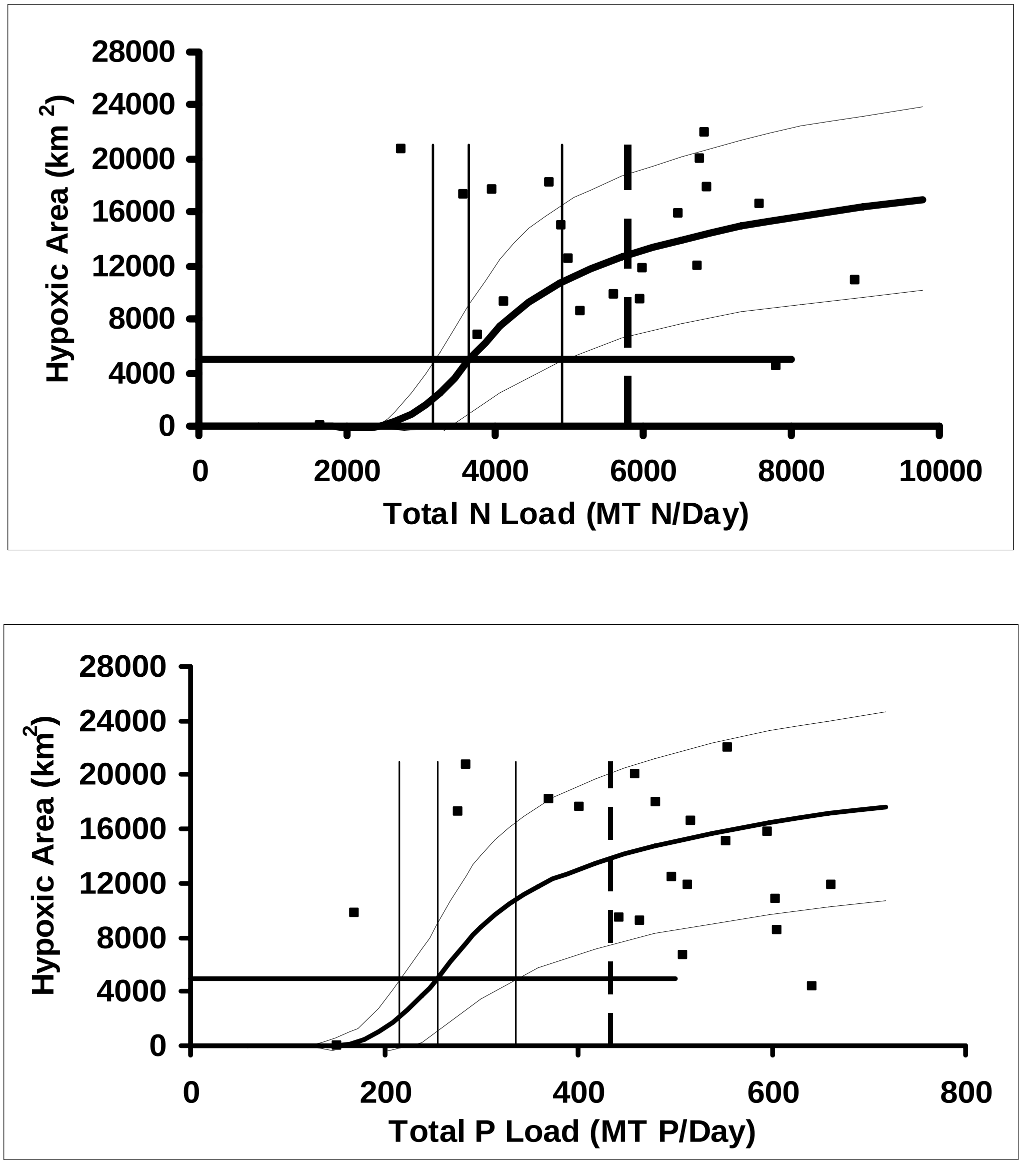

Figure S4. Response of Gulf hypoxia to reductions in TN (a, top) and TP (b, bottom) loads. Model output is represented as mean ± standard deviations of 1000 Monte Carlo simulations. Horizontal black line represents action plan goal for hypoxia. Vertical lines represent 1980-1996 mean loads (dashed; far right), and mean ± one standard deviation loads required to achieve the goal.