2009 Forecast
of the Summer Hypoxic Zone Size,
Northern Gulf of Mexico

Abstract

The June forecast of the size of the hypoxic zone in the northern Gulf of Mexico for July 2009 is that it will cover between 21,900 to 25,040 km^2 (8,456 to 9,668 mi^2) of the bottom of the continental shelf off Louisiana and Texas. There are two models used for this forecast. The Model 1 forecast (21,900 km^2) is based on the May nitrate-N loading from the Mississippi watershed to the Gulf of Mexico estimated by the US Geological Survey, and is considered the more accurate model because of the length of the water quality record. If the area of hypoxia becomes this large, then it will as large as at any time since systematic mapping of the hypoxic zone began in 1985. The Model 2 forecast is based on the May nitrate-N loading from the Mississippi River at Baton Rouge, LA.

Caveats: 1) This predictions discounts the effect of large storm events which will temporarily disrupt the physical and biological system attributes promoting the formation of the low oxygen zone in bottom waters; 2) The potential space on the shelf where hypoxia occurs is be limited by the bathymetry; 3) The predictions assume continued above average discharge through June and July.

Introduction

1). Hypoxic water mass

Hypoxic water masses in bottom waters of the northern Gulf of Mexico occur when the oxygen concentration falls below 2 mg l^{-1}. This hypoxic water is distributed across the Louisiana shelf west of the Mississippi River and onto the upper Texas coast, from near shore to as much as 125 km offshore, and in water depths up to 60 m (Rabalais et al. 2007). It has been found in all months, but is most persistent and severe in summer (Turner 2005; Rabalais et al. 2007). The July distribution of hypoxic waters may form in two distinct areas west of the Mississippi and Atchafalaya River deltas, but more often is a single continuous zone along the Louisiana-Texas shelf. A hypoxic zone formed east of the river delta n 2009, following high discharge of the Mississippi River. These areas are sometimes called "Dead Zones" because of the absence of commercial quantities of shrimp and fish in the bottom layer. The number of Dead Zones throughout the world has been increasing in the last several decades and currently number about 400+ (Diaz and Rosenberg 2008). The Dead Zone off the Louisiana coast is the largest in the entire western Atlantic and, as a large-scale phenomenon, was unlikely to have occurred before the 1970s.

Systematic mapping and monitoring of the area of hypoxia (dissolved oxygen < 2 mg l^{-1}) in bottom waters began in 1985. Its size has ranged between 40 to 22,000 km^2 during July and averaged 17,200 km^2 from 2000-2008 (excluding years when there were strong storms just before the hypoxia survey). The late July hypoxic zone size averaged 12,700 km^2 over the period 1985-2005, with a range from negligible in 1988 (a summer drought year for the Mississippi River basin) to 22,000 km^2 in 2002. There are no comparable coastwide data for other months, but monthly monitoring is conducted along two transects south of Cocodrie, LA, and the Atchafalaya delta.

Hypoxic water masses form from spring to fall on this coast because the consumption of oxygen in bottom water layers exceeds the re-supply of oxygen from the atmosphere. The re-aeration rate is negatively influenced by stratification of the water column which is primarily dependent on the river's freshwater discharge. The overwhelming supply of organic matter respired in the bottom layer is from the downward flux of organic matter produced in the surface layer. The organic matter production rate is directly related to the nitrogen supply rate from the Mississippi River watershed. The transport to the bottom layer is the result of sinking of individual cells (considered a minor contribution), as the excretory products of the grazing predators (zooplankton) that 'package' them as fecal pellets, or as aggregates of cells, detritus and mucus. The respiration of this organic matter declines as it falls through the water column (Turner et al. 1998), but the descent rate alongshore the Louisiana-Texas shelf is rapid enough so that sufficient oxygen consumption on the shallow shelf occurs in the bottom layer and sediments to create a zone of hypoxia that is constrained by the geomorphology of the shelf and water movement. Microbial decomposition degrades the organic matter and is the principle pathway for oxygen consumption. The significance of reducing nutrient loads to these coastal waters rests on this coupling between the organic matter produced in response to these nutrients and its respiration in the bottom layer (MRGOM WNTF 2001; Rabalais et al. 2002, 2007; SAB 2008; U.S. EPA 2008).

Models

2. Predictions using models

Models are used to summarize information, to test assumptions and to make predictions that may be useful for other purposes, including management. There are multiple models of the size of the hypoxic zone that are useful in evaluating the influence of nitrogen load and variations in ocean currents, climate, etc. These models do not always produce similar results, and model improvement is one focus of ongoing research. This model is primarily based on the nitrate+nitrite load delivered to the Gulf of Mexico by the Mississippi River in May. The residence time of the surface waters along this coast is about 2 to 3 months in the summer, hence the 2-3 month lag between the loading rate calculated in May and the size of the hypoxic zone in July. The ecosystem is evolving, however. The size of the hypoxic zone for the same amount of nitrogen loading increases each year, for example (see below). The model will eventually be adjusted to account for the limited space left on the shelf.

The simple statistical model used here is the most accurate model based on past performance (Turner et al. 2006, 2008). The prediction in 2006 and 2007, for example, was 99%

and 107%, respectively, of the measured size. Some of the variation is size is due to re-aeration of the water column during storms. Large storms ‘re-set’ the system to generate a smaller area of hypoxia for the same amount nitrogen loading. The size of the summer hypoxic zone in 2008 was less than predicted because of the influence of Hurricane Dolly. The long-term trend, however, is that the area of hypoxia is larger for the same amount of nitrogen loading (Figure 1; Turner et al. 2007). The explanation for this undesirable outcome is that there is a ‘legacy’ effect, which is to say, that organic material reaching the bottom is not completely oxidized in the same year that it is deposited. The source of this system change is hypothesized to be result of the delayed respiration of organic matter stored in the sediments that accumulates in one year to become a future oxygen demand function. A deterministic mass-balance model (Bierman et al. 1994) included an estimate of the sediment oxygen demand (SOD), based on a few *in situ* measurements, and estimated that SOD was between 22 to 30% of the total oxygen consumption in the bottom layer during summer. Another model, based on oxygen stable isotopes, concluded that benthic respiration was responsible for 73% of the oxygen consumption in the lower water column in summer 2001 (Quiñones-Rivera et al. 2007). These results suggest that the SOD will be higher with increasing organic deposition and accumulation, and significantly alter the net oxygen balance in bottom waters.

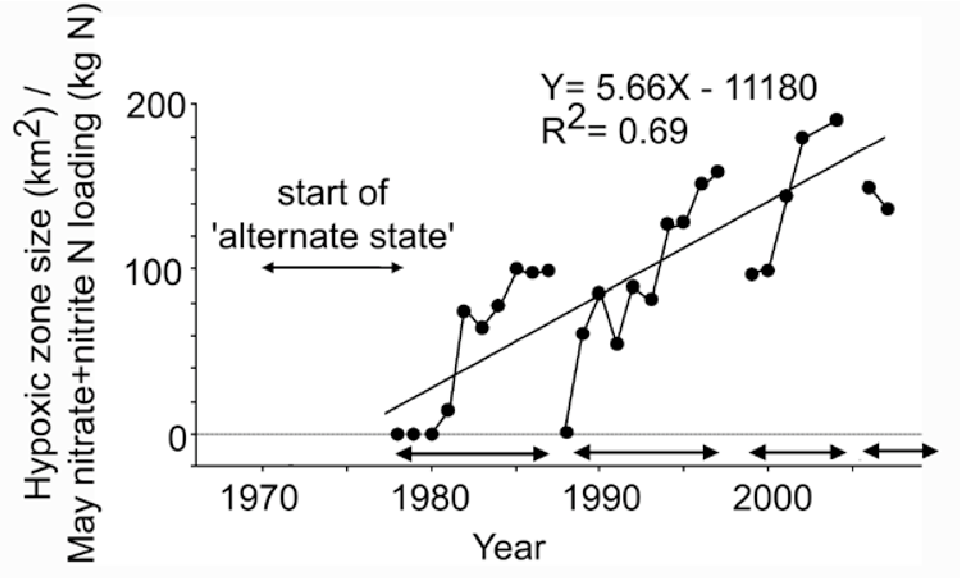

Figure 1. The relationship between the size of the hypoxic zone in July (km^2) and the May nitrate+nitrite N loading (kg N) to the Gulf of Mexico each year. A linear regression of the data is shown. The individual data points are in four chronologically-sequenced groups separated from each other when the data fall below the slope, and whose separation is coincidental with hurricane events. From Turner et al. (2008).

Other models that also predict or describe oxygen dynamics on this shelf are discussed in Bierman et al. (1994), Justic et al. (2003), Scavia and Donnelly (2007), and Scavia et al. (2003, 2004). The University of Michigan forecast site is: http://www.sitemaker.umich.edu/scavia

3. Model parameters for 2009

3b. Nitrogen loading to the Gulf of Mexico

Two similar models are used to make the predictions for the size of the hypoxic zone in July 2009. Model 1 is the updated model used in previous years. In this model, the total nitrate+nitrite N load to the Gulf of Mexico is based on the May discharge from the main stem of the Mississippi River and the Atchafalaya River. The concentration × discharge equals the nitrate-nitrite N load. The estimate of nitrate-nitrate N loading from the Mississippi River into the Gulf of Mexico is made by the United States Geological Survey (USGS), which publishes estimates of the flow-adjusted nutrient loads to the Gulf of Mexico. The nutrient load estimates include nitrate+nitrite N, total phosphorus (TP), and total nitrogen (TN), from the main channel of the Mississippi River and from the Atchafalaya River. The nitrate+nitrite N loading in May is about 89% of the TN loading ($R^2 = 0.91$). The USGS includes an estimate of the 95% confidence range for the nitrate-N load, which averages 41% of the predicted value. The USGS web site (http://toxics.usgs.gov/hypoxia/mississippi/) has more information on the calculation and data.

The Model 2 prediction uses the May nitrate-N loading in the Mississippi River at Baton Rouge, LA, and is otherwise the same as in Model 1. The advantage this data has is that there are usually two to three times more water quality measurements made, compared to the May USGS estimates. Exploratory trial runs were made to determine if other nutrients, e.g., phosphate, ammonium, or silicate, could be included to improve the predictive quality of the models. No other parameters were found that were statistically significant.

3b. Hypoxic zone data

These models use data for the size of the hypoxic zone in July because no comparable shelfwide data exist for other months. Data on the size of the hypoxic zone in late July from 1985 to 2008 are based on annual field measurements (data available at http://www.gulfhypoxia.net). The 2009 mapping cruise will be conducted on July 18-26 and the data posted daily at the same web site. The values for 1989 (no funding available) and 1978-1984 are estimated from contemporary field data. The values for before 1978 assume that there was no significant hypoxia then and are based on results from various models. Data for four years were not included in the analysis because there were strong storms just before or during the cruise (1998, 2003, 2005 and 2008). These storms, by comparison to the pre-cruise sampling and data collected during the cruise, disrupted the water column and re-aerated the water column. It may take several weeks, depending on water temperature and initial dissolved oxygen concentration, for respiration to reduce the dissolved oxygen concentration to <2 mg l^{-1} after the water column stratification is re-established.

Prediction for 2009

4. Predictions for July 2009

The forecast of the size of the hypoxic zone in the northern Gulf of Mexico for July 2009 is that it will cover 21,900 to 25,040 km^2 (8,456 to 9,668 mi^2) of the bottom of the continental shelf off Louisiana and Texas (Figure 2). The Model 1 estimate is considered the more reliable estimate because it has a longer data set and a better fit of the observed and modeled data. If the area of hypoxia becomes this large, then it will as large as at any time since systematic mapping of the hypoxic zone began in 1985. This Model 1 estimate is equivalent to an area about the size of the state of New Jersey. The average size of the annual hypoxia-affected area since 1990 has been approximately 15,350 km^2 (5,900 mi^2). The largest size was 22,000 km^2 (8,894 mi^2) in 2002. Tropical storms and hurricanes have the potential of disrupting the physical structure of the water column and aerating the bottom layer. If no strong storms appear, then this year's Dead Zone is predicted to be at least as large as previously measured, and to stretch into Texas continental shelf waters.

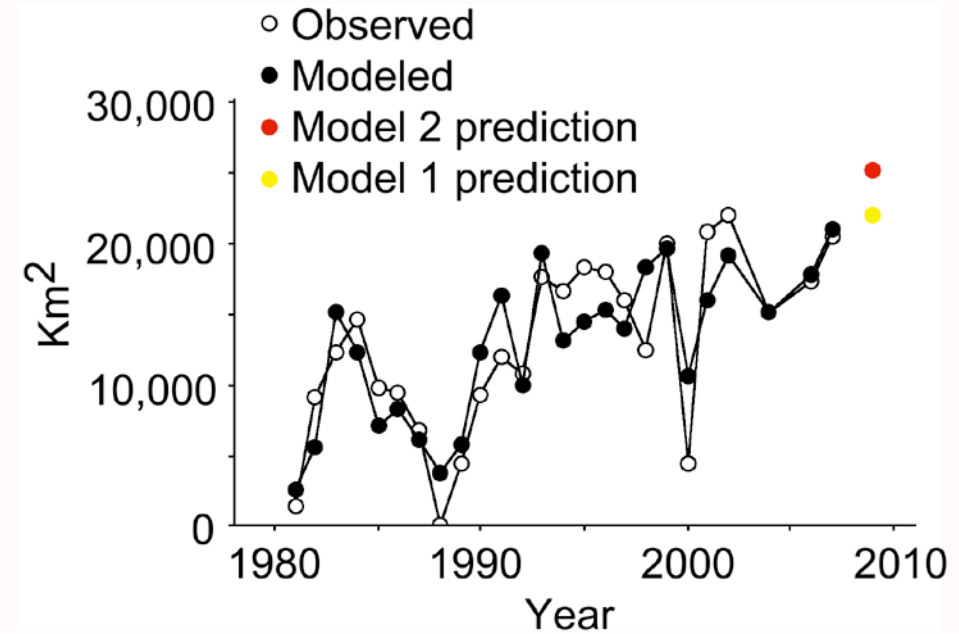

Figure 2. The measured size, the modeled size (Model 1), and the predicted the size of the hypoxic zone for 2009 (Model 1 and 2). Model 1 is the oldest model that uses data for nitrate-N loading (USGS estimates) to the Gulf of Mexico (GOM) from 1980 to present. Model 2 is the new model that uses estimates of nitrate+nitrite N loading in the Mississippi River at Baton Rouge, LA, from 1997 to present.

Supporting information on the dissolved nitrate+nitrite N concentration in the Mississippi River at Baton Rouge, LA, the nitrogen flux from the Mississippi River to the Gulf of Mexico, river discharge, and Model 2 predictive capabilities are in the Appendix. A post-cruise assessment will be made at the end of the summer and posted on the same website where this report appears.

Acknowledgments

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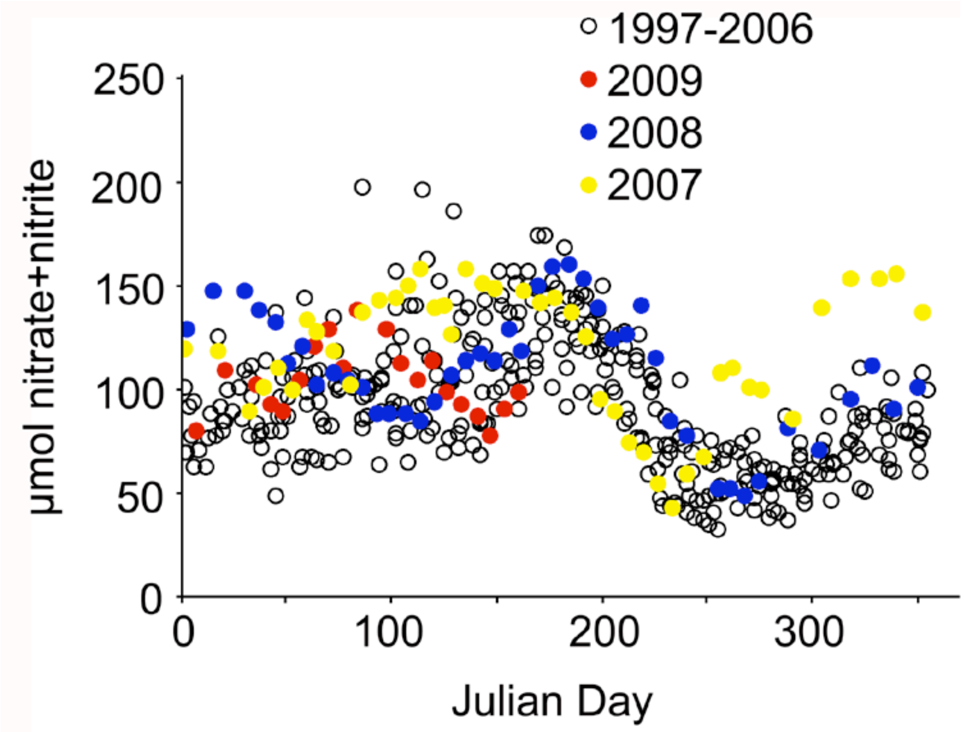
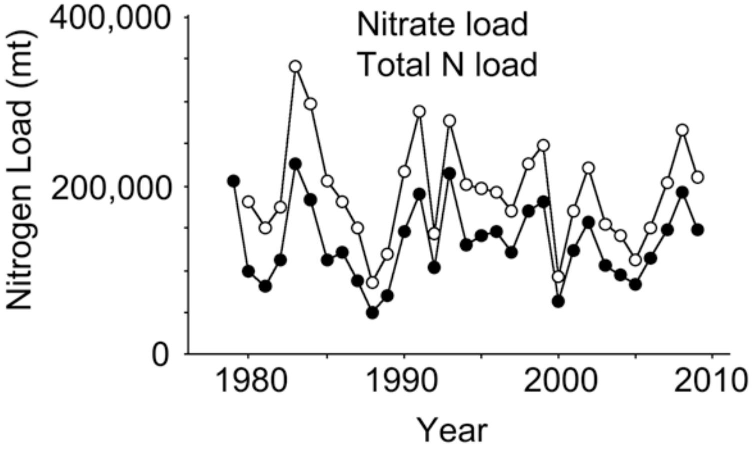
Appendix I consisting of supporting information on:

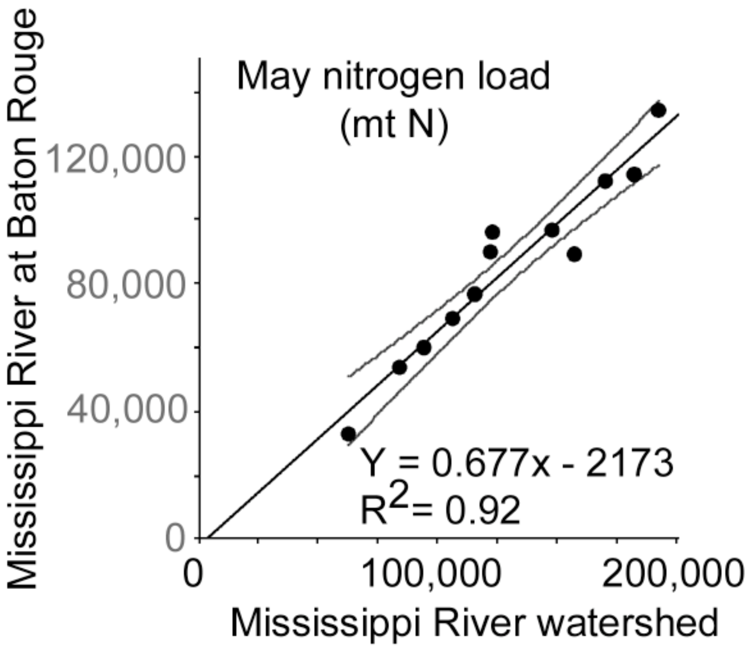
Dissolved nitrate+nitrite N concentration in the Mississippi River at Baton Rouge, La
Nitrogen flux from the Mississippi River to the Gulf of Mexico
River discharge
Model 2 predictive capabilities



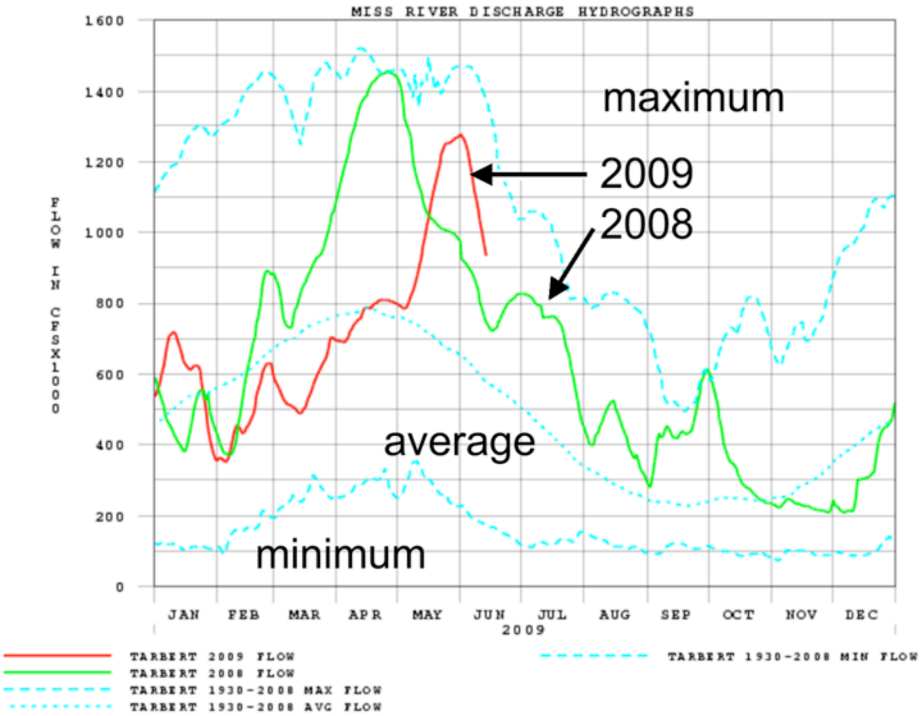
Appendix Figure 1. Nitrate+nitrite N concentration at Baton Rouge from 1997 through May, 2009.



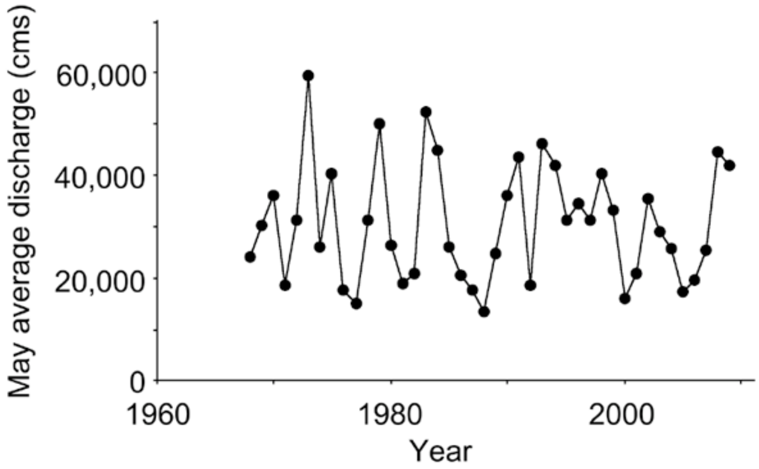
Appendix Figure 2. Nitrate N and Total (TN) loading from the Mississippi River watershed to the Gulf of Mexico in May. Data are from the US Geological Survey (http://toxics.usgs.gov/hypoxia/mississippi/nutrient_flux_yield_est.html).



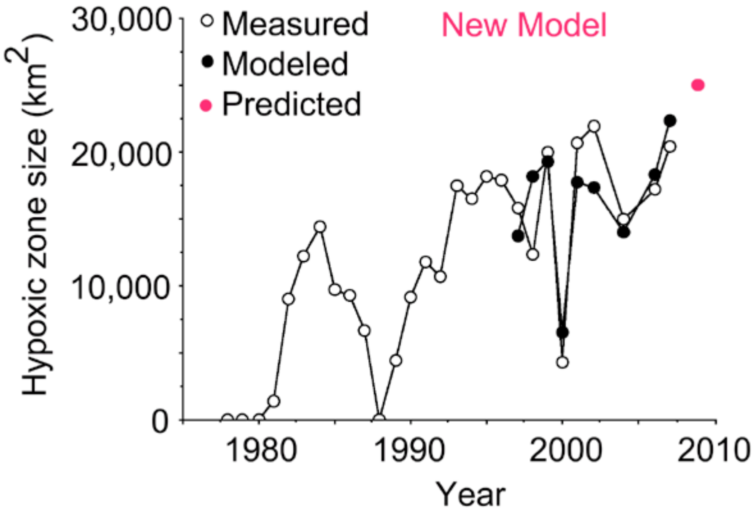
Appendix Figure 3. The relationship between the May nitrate+nitrite N loading at Baton Rouge (Y axis) and from the entire watershed. A linear regression of the data is shown. The data are for 1997 to 2008. These data were used to develop a model of the predicted size of the hypoxic zone (in July), using the same approach as for the other model, but consisting of fewer observations.



Appendix Figure 4. Mississippi River discharge (1000 cubic feet per second) at Tarbert Landing, MS from 1930 to 12 June 2009. http://www.mvn.usace.army.mil/eng/edhd/tar.gif



Appendix Figure 5. The average May discharge of the Mississippi River to the Gulf of Mexico.



Appendix Figure 6. The results of a new statistical model (Model 2) estimating the size of the hypoxic zone in the summer (July) based on the nitrate+nitrite N loading in May at Baton Rouge, LA.