

Hypoxia in the Gulf of Mexico: Benefits and Challenges of Using Multiple Models to Inform Management Decisions

Multiple Models for Management (M3.2) in the Chesapeake Bay

February 25, 2013

Annapolis MD

Victor J. Bierman, Jr., LimnoTech

Donald Scavia, University of Michigan

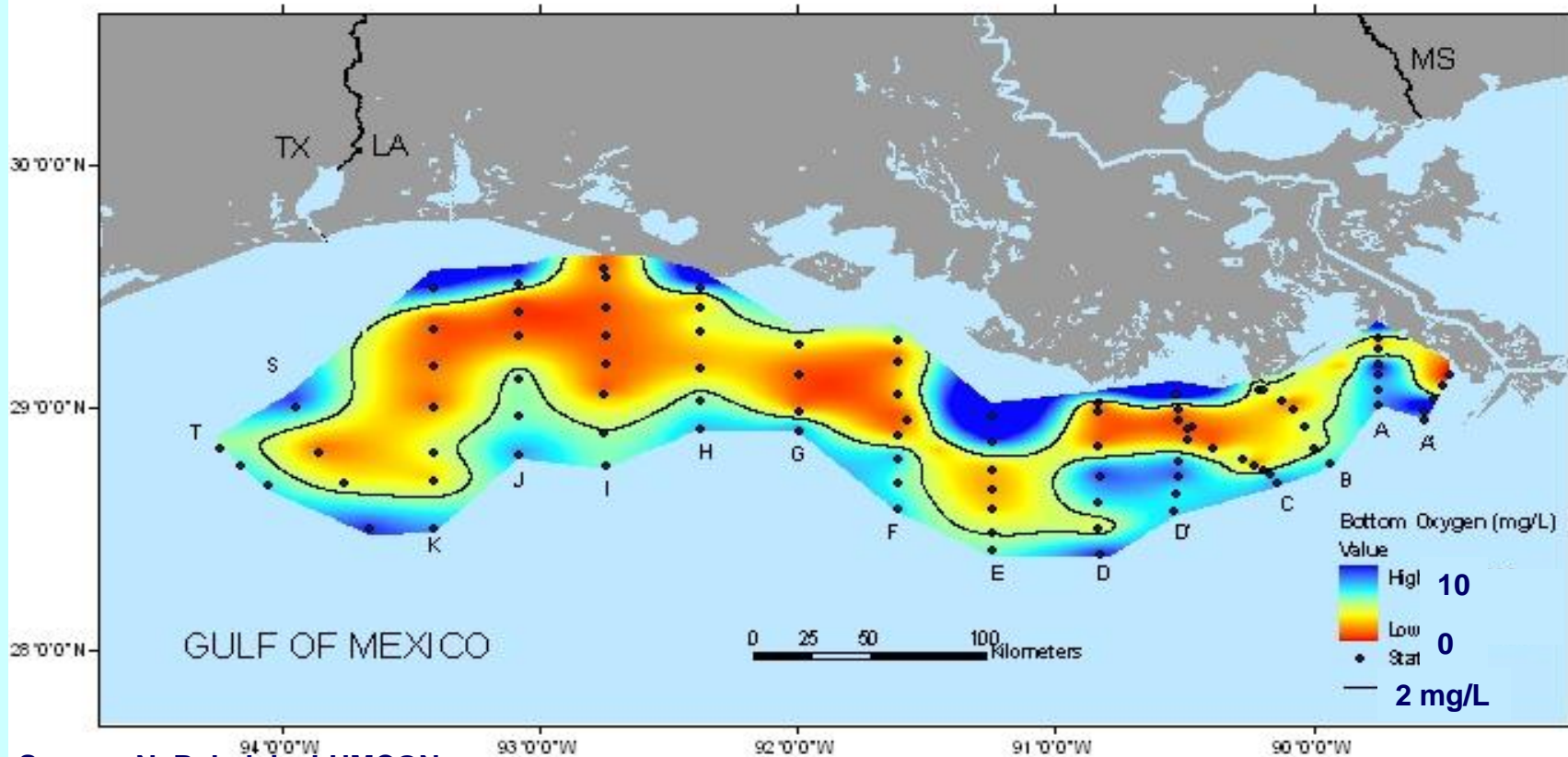


Water | Scientists
Environment | Engineers

WHY WAS THE MODELING WORK DONE?



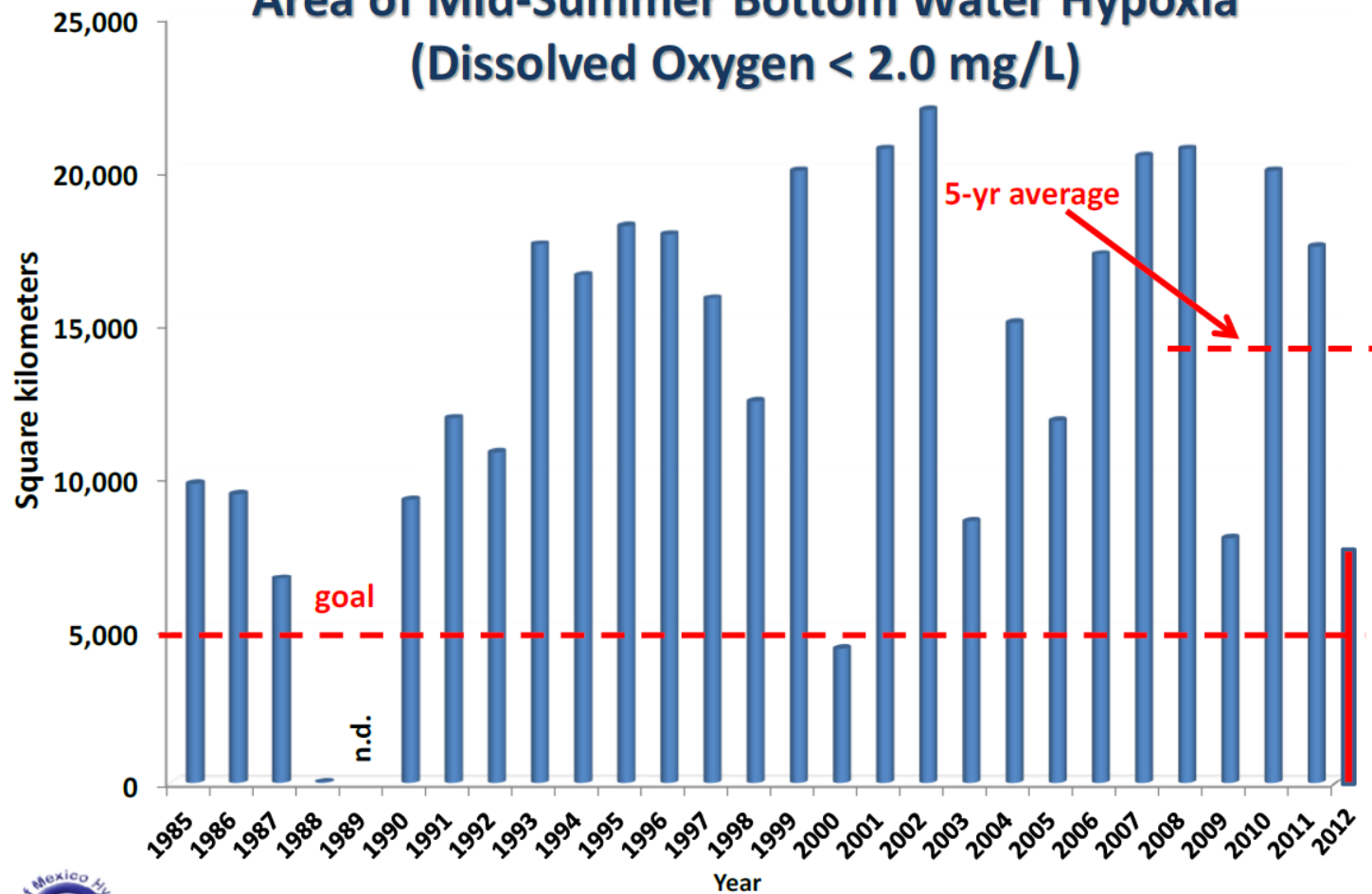
21 – 28 July 2007 Bottom-Water Hypoxia



Source: N. Rabalais, LUMCON

- up to 22,000 km² (= Massachusetts)
- 4 - 5 m nearshore to 35 - 45 m offshore
- 0.5 km nearshore to 100+ km offshore
- widespread and severe in Jun - Sep

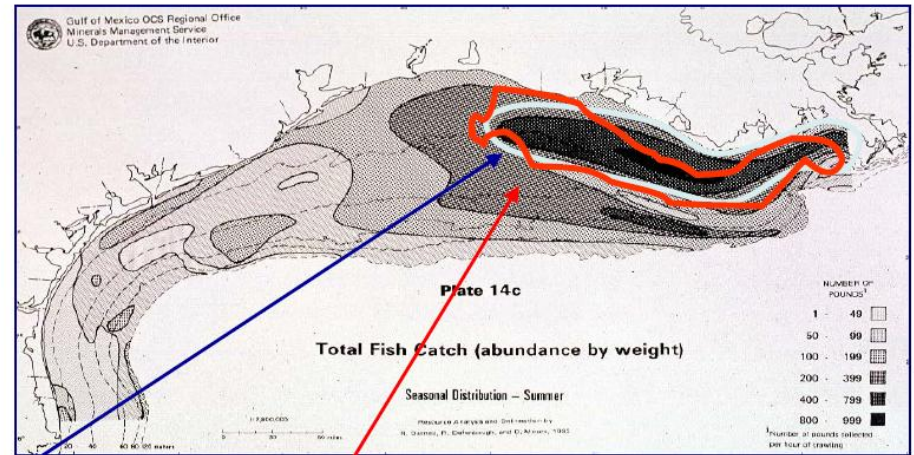
Area of Mid-Summer Bottom Water Hypoxia (Dissolved Oxygen < 2.0 mg/L)



Data source: N.N. Rabalais, Louisiana Universities Marine Consortium, R.E. Turner, Louisiana State University
Funded by: NOAA, Center for Sponsored Coastal Ocean Research

Hypoxic Zone can lead to habitat loss

Pre-Hypoxia Fish Catch (1961-1965)



Optimal fish & shrimp habitat in 1960's

1997 Dead zone: devoid of bottom fish & shrimp

Source: Kevin Craig, Duke

Potential commercial impacts ...



- Commercial fish and shellfish harvest
 - 1.7 billion pounds
 - \$705 million
- Higher annual yield of finfish, shrimp and shellfish than the south and mid-Atlantic, Chesapeake and New England areas combined



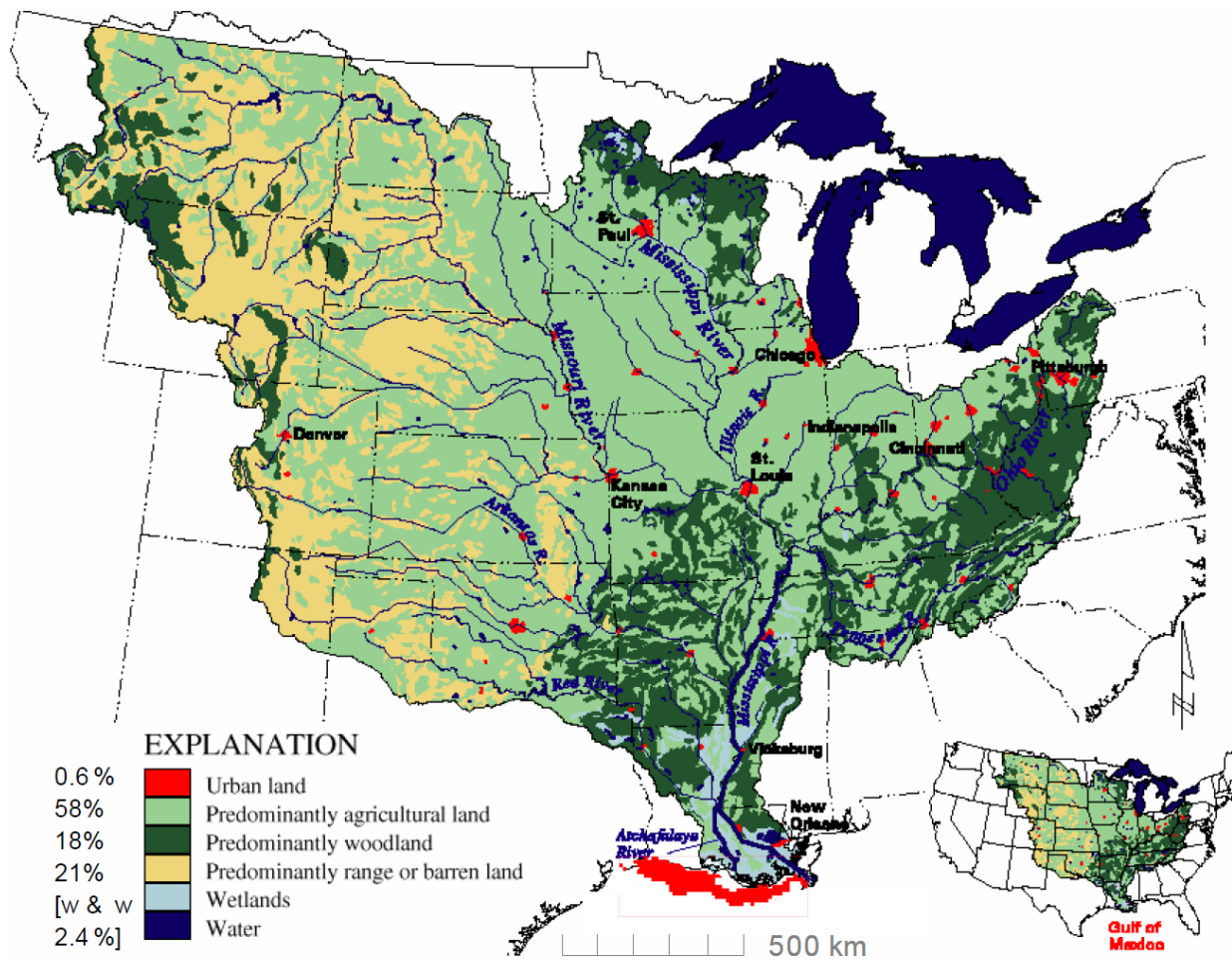


FIGURE 1-1 Mississippi River basin, major tributaries, land uses, and typical summertime extent of northern Gulf of Mexico hypoxia (in red). The Mississippi River basin extends over 31 U.S. states and covers 41 percent of the conterminous U.S. SOURCE: Reprinted, with permission, from Goolsby (2000). © by the American Geophysical Union.

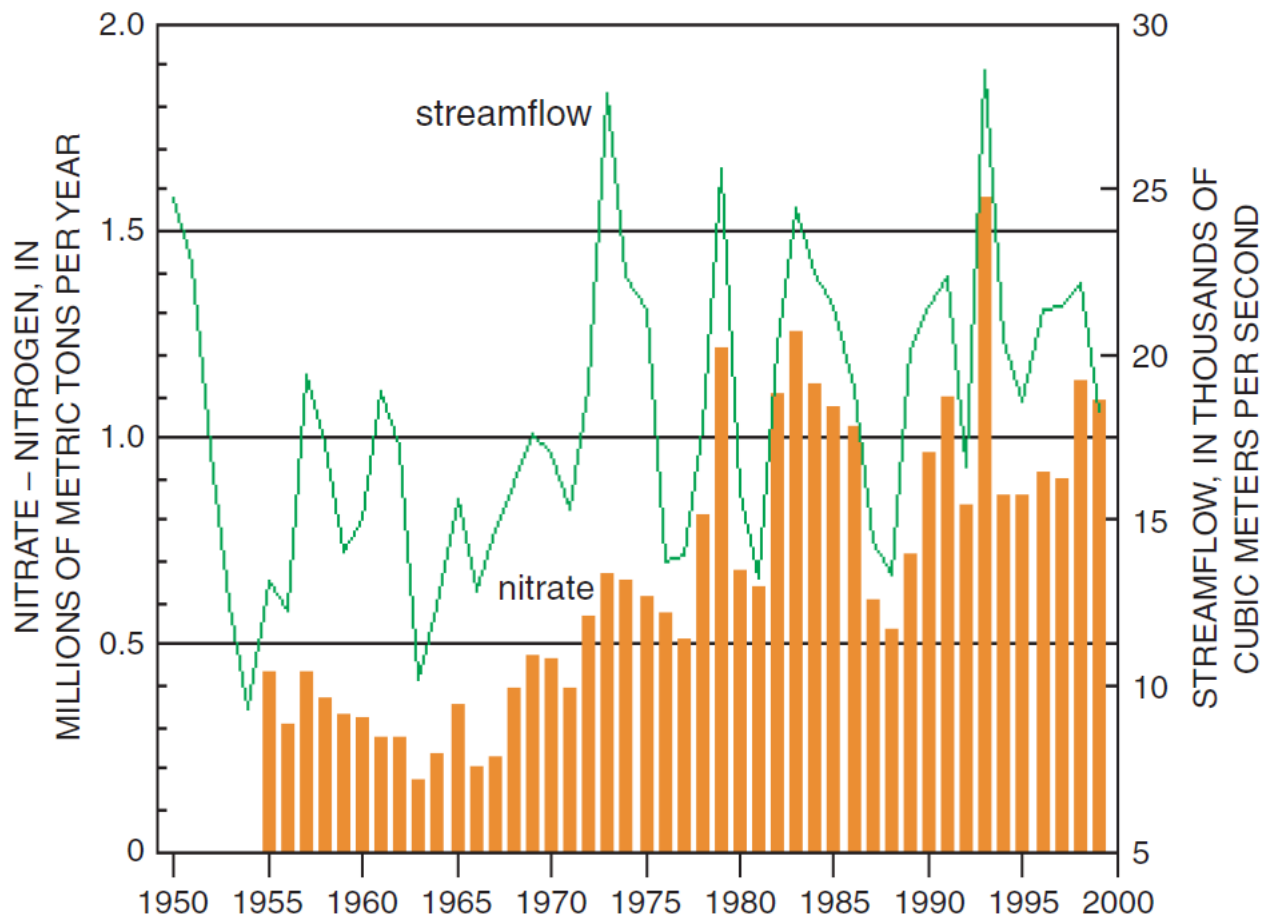


FIGURE 2-8 Annual flux of nitrate from the Mississippi River basin to the Gulf of Mexico, 1955-1999, and mean annual streamflow, 1950-1999.

SOURCE: Reprinted, with permission from Goolsby (2000). © 2000 by American Geophysical Union.

**HOW MANY MODELS WERE USED
AND WHO DEVELOPED THEM?**



Three load-response models

- Bierman et al. (1994)
 - WASP-based mechanistic model
 - Nitrogen, phosphorus, silicon
 - Three-dimensional
 - Dynamic steady-state for summer average DO concentrations
- Justić et al. (1996)
 - Oxygen flux model
 - Nitrogen
 - One-dimensional vertical in core of hypoxic zone (Station C6)
 - Monthly time-variable DO concentrations
- Scavia et al (2003)
 - Oxygen flux model
 - Nitrogen
 - One-dimensional horizontal downstream or river inputs
 - Summer steady-state areas of hypoxia

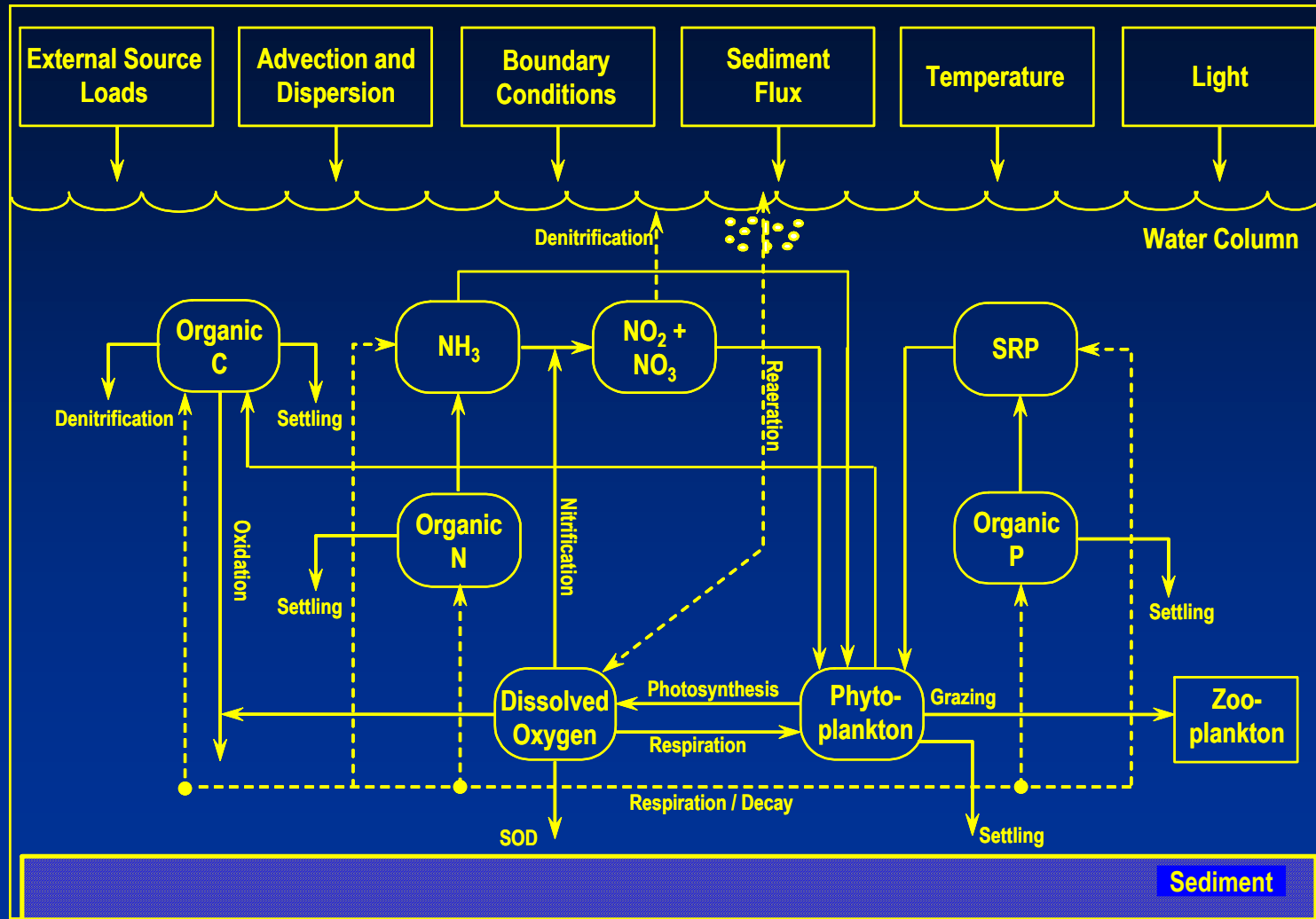
**HOW WIDELY DID THE MODELS
DIFFER?**

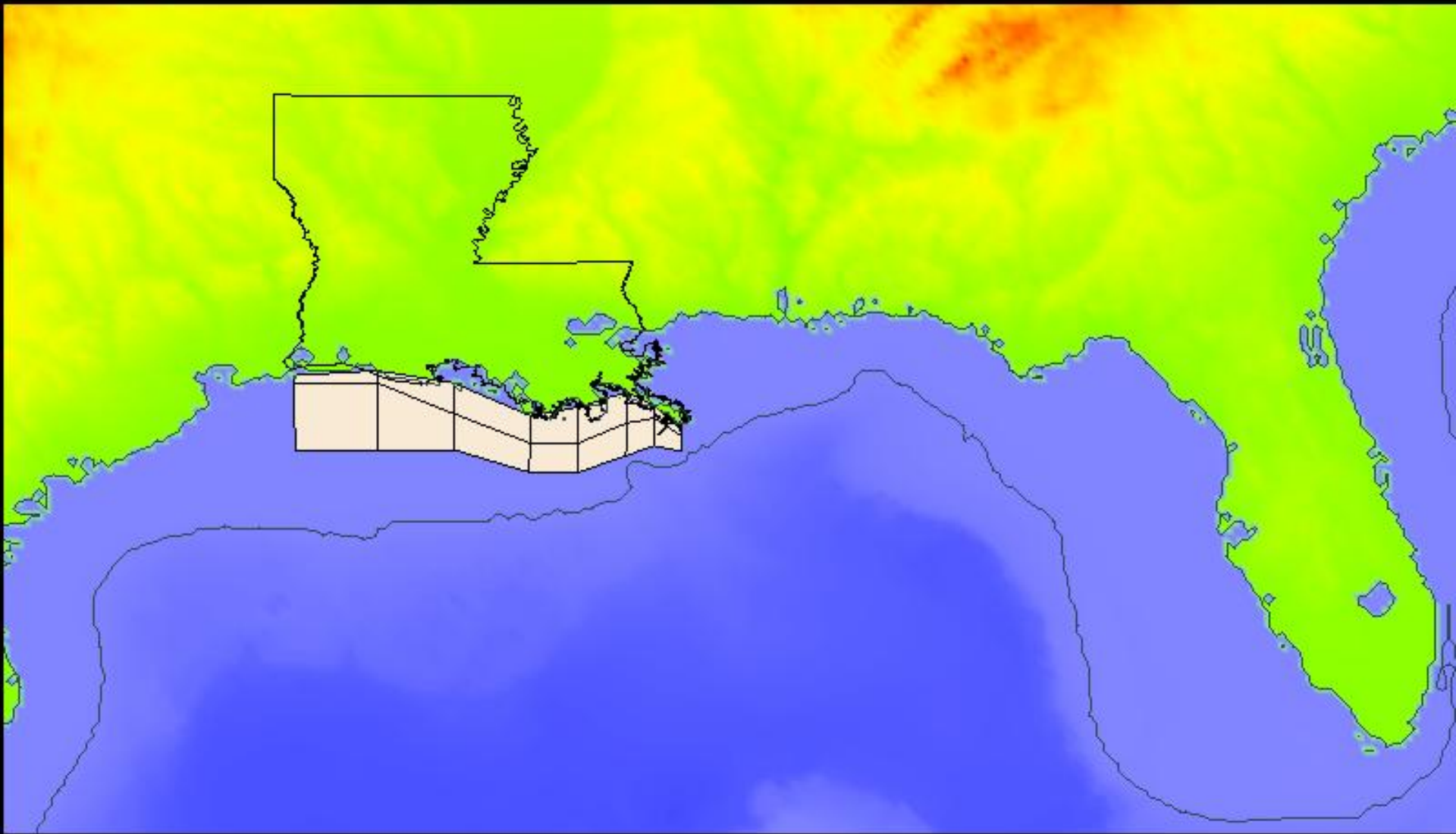


Key differences

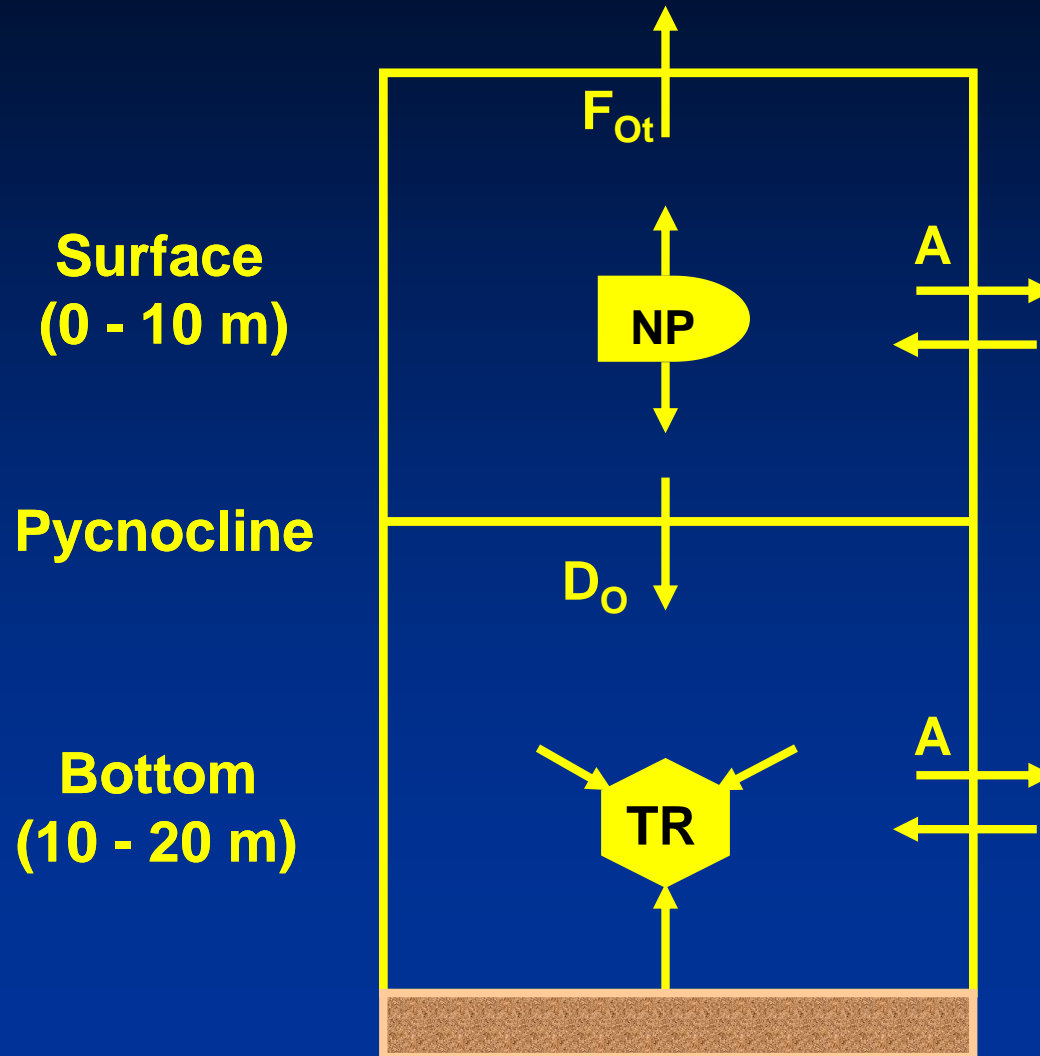
- Bierman et al. (1994)
 - Spatial distribution of DO concentrations
 - Limited to summer steady-state conditions (1985, 1988, 1990)
- Justić et al. (1996)
 - Monthly time-variable DO concentrations (1985-1993)
 - Limited to single point in space (Station C6)
- Scavia et al (2003)
 - Summer time-variable hypoxia areas (1985-2002)
 - Not compute DO concentrations

Bierman Model Framework



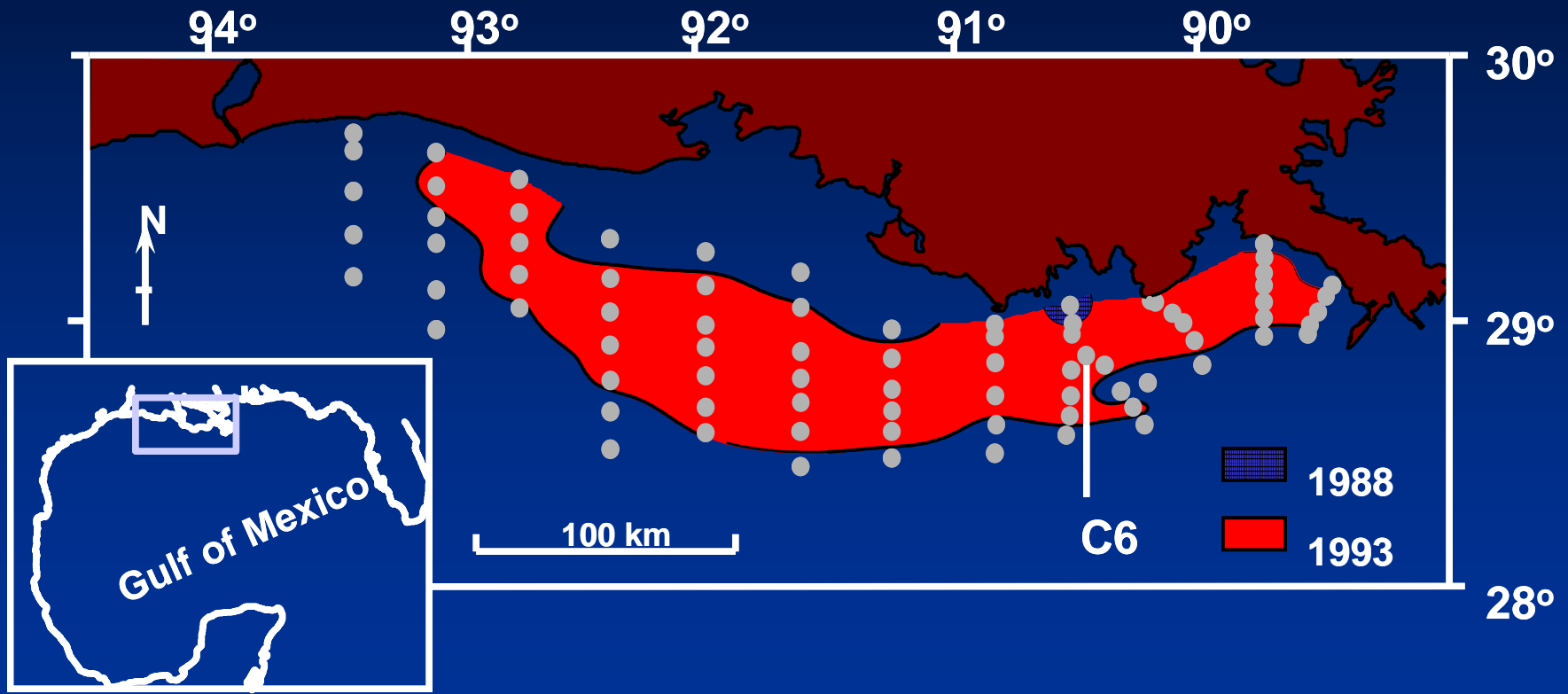


Justić Model Framework



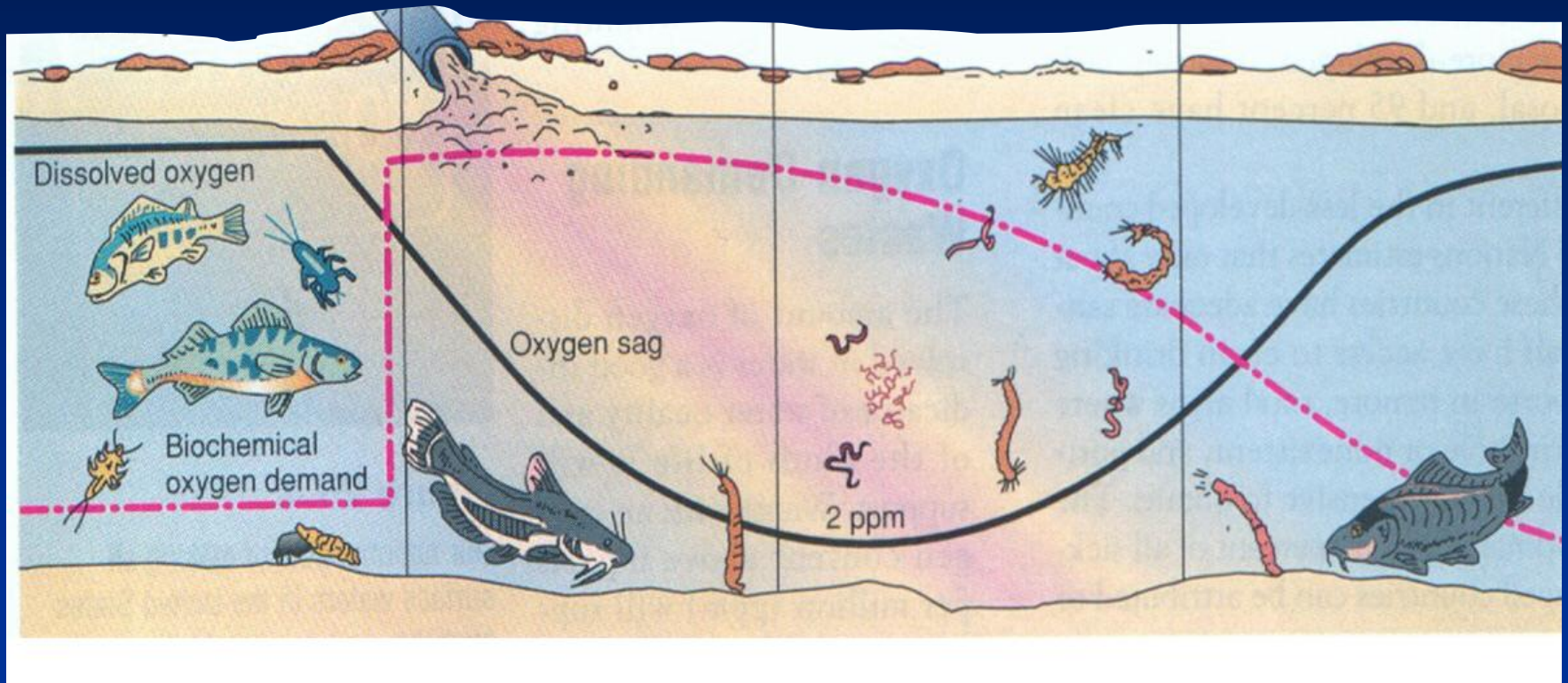
Justić Model Spatial Scale

Station C6 – Core of Hypoxic Zone



Scavia Model Framework

Classical Engineering River Model Streeter-Phelps DO Sag Curve



Application to Gulf Hypoxia

B = Organic Matter

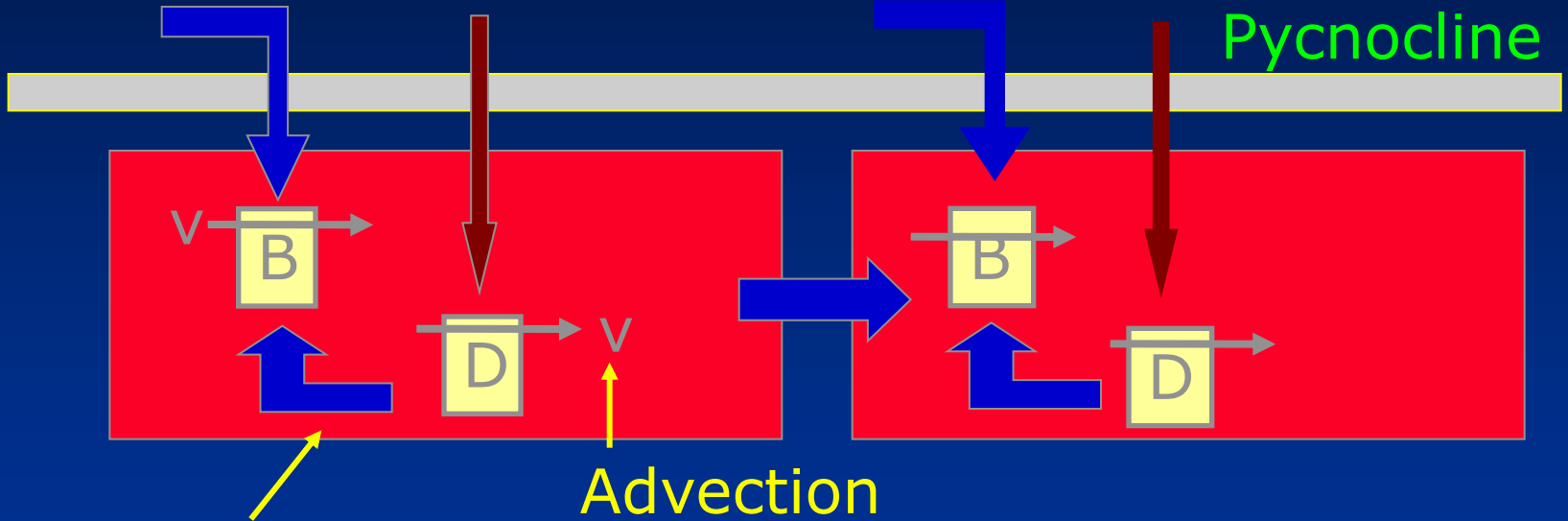
D = Dissolved Oxygen

Mississippi
Load $\sim N$

Diffusion

Atchafalaya
Load $\sim N$

Pycnocline

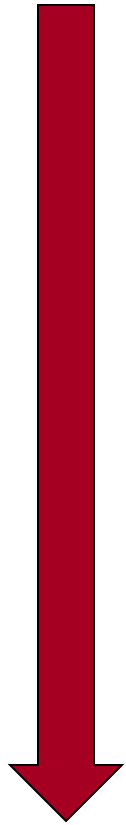


Organic matter
decay

**WHAT DECISIONS WERE BASED
ON MODEL RESULTS?**



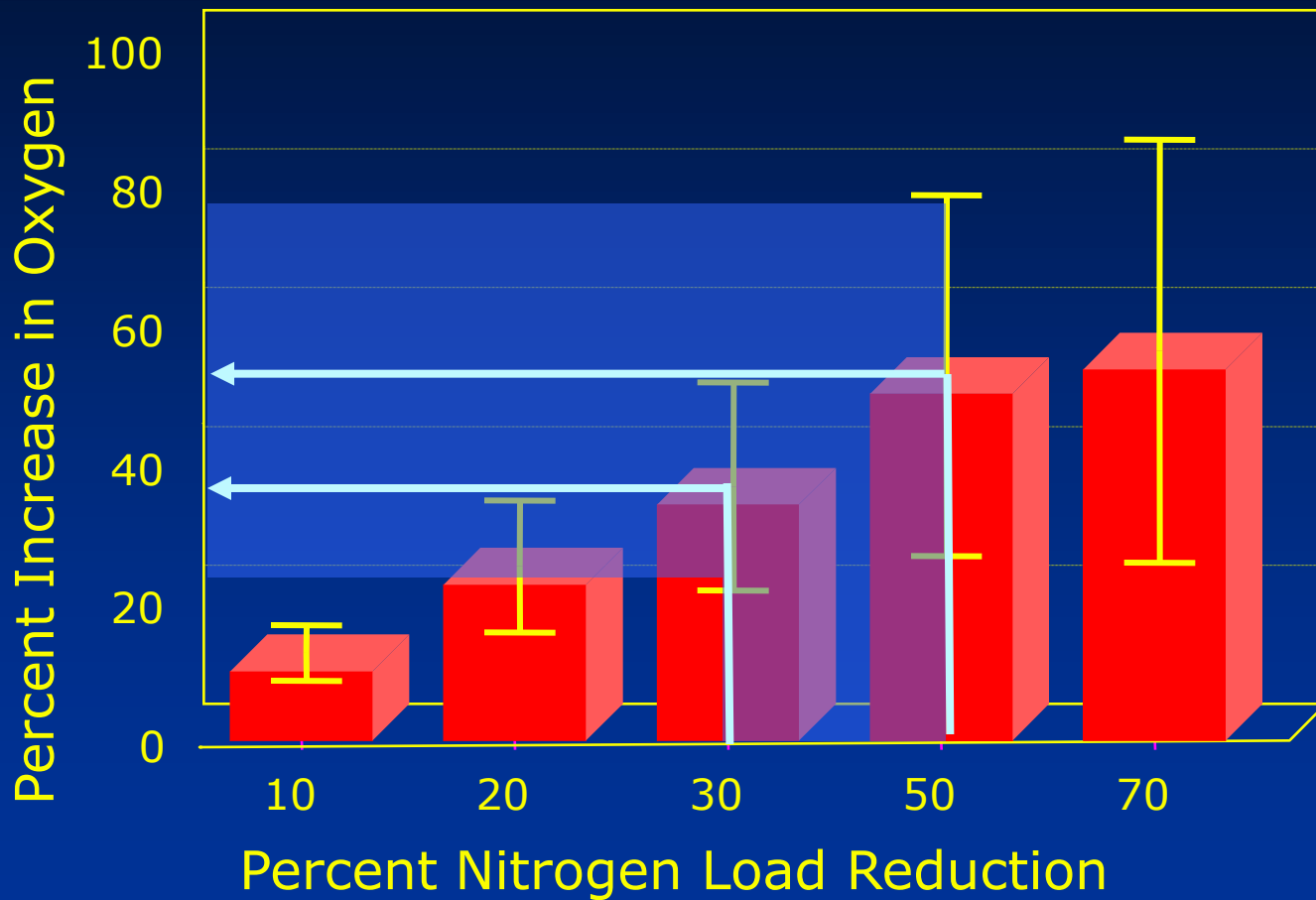
Timeline ...

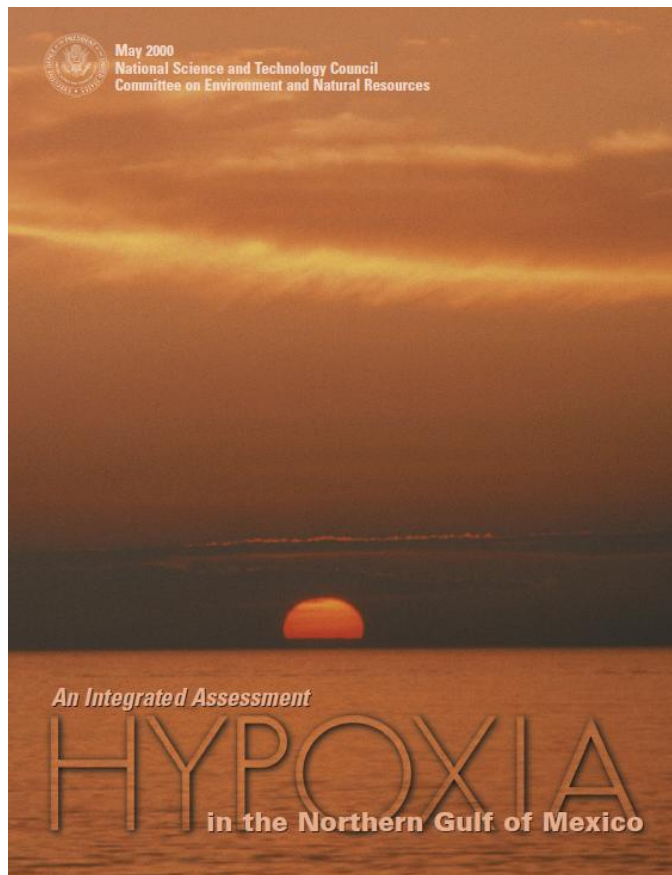


- 1994 First hypoxia model (Bierman et al. 1994)
- 2000 Integrated Assessment of Hypoxia
- 2001 First Gulf Hypoxia Action Plan (MR/GOM Watershed Nutrient Task Force)**
- 2004 Advice from Three Models (Scavia et al. 2004)
- 2007 Reassessing Hypoxia Forecasts – Nitrogen and Phosphorus (Scavia and Donnelly 2007)
- 2007 EPA Science Advisory Board Update
- 2008 Second Gulf Hypoxia Action Plan**

Effect of Reduced N Loads

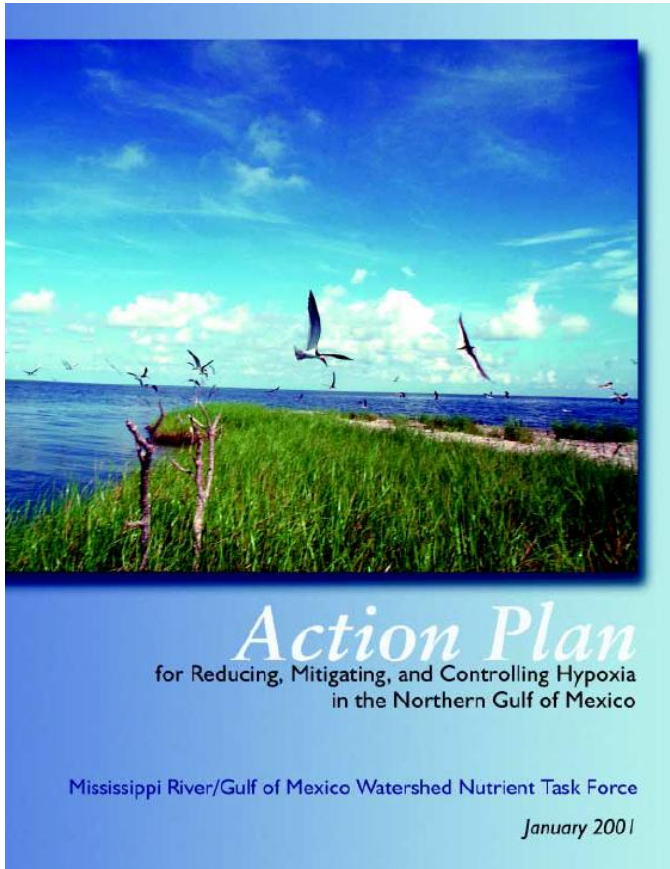
Gulf Hypoxia Changes





“A 40 percent reduction in total nitrogen flux to the Gulf is necessary to return loads comparable to those during 1955-1970.”

“Model simulations indicate that nutrient load reductions of about 20-30 percent would result in a ... 15-50 percent increase in bottom water dissolved oxygen concentrations.”



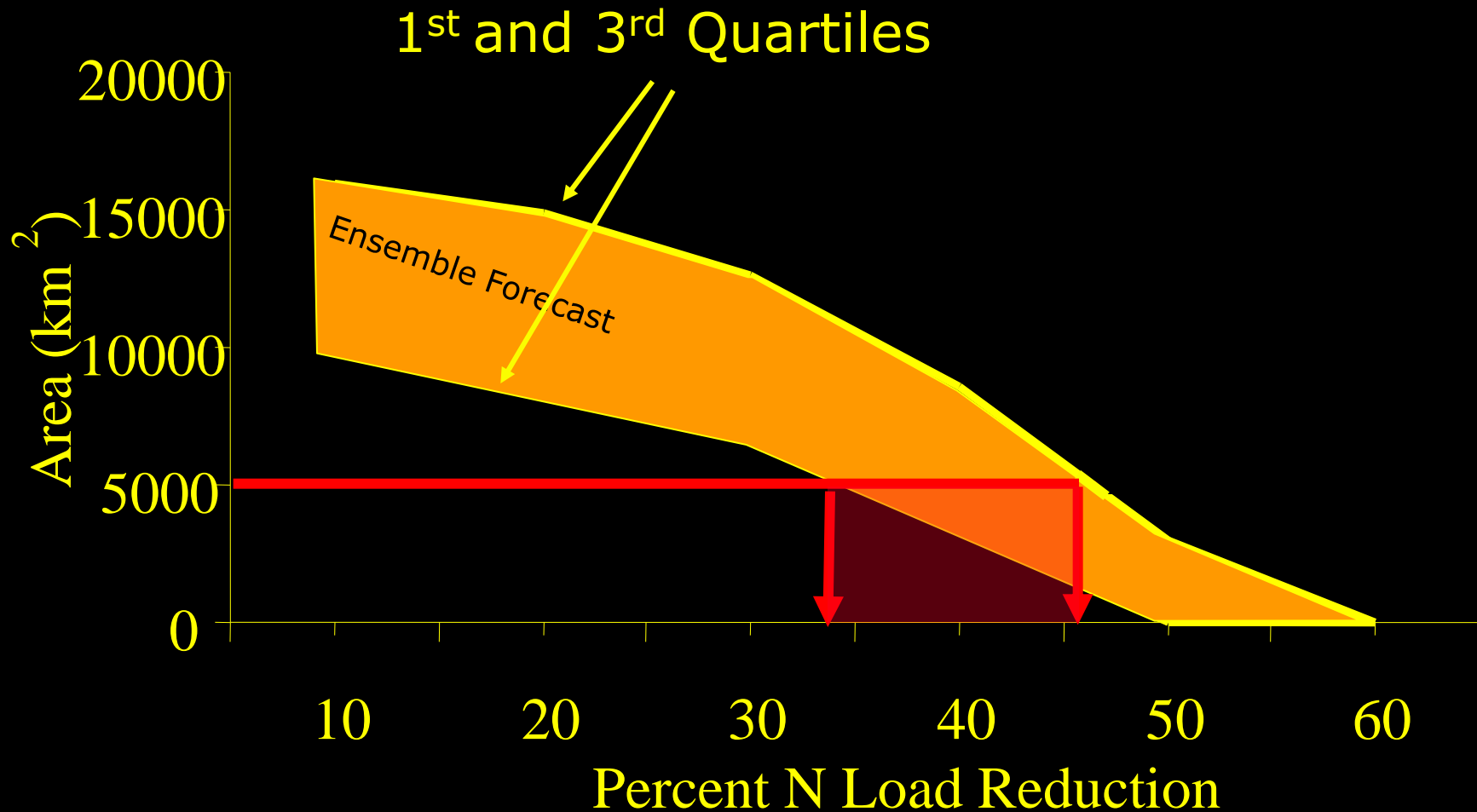
“By the year 2015 reduce the 5-year running average areal extent of the Gulf of Mexico hypoxia zone to less than 5,000 square kilometers “

“The best current science indicates that sub-basin strategies, in the aggregate, should be aimed at achieving a 30% reduction in nitrogen discharges to the Gulf “

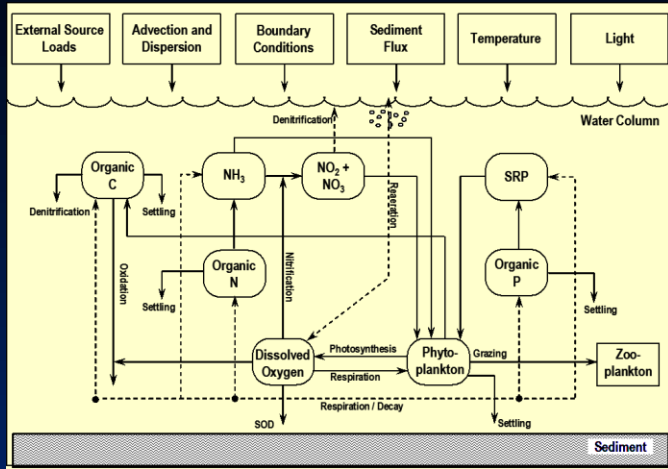
Justić model results for 1955-2000 ...

- For **actual nitrogen loads**, subpycnocline waters became **hypoxic in 19** of the 45 years, all since 1975
- For a **30 percent load reduction** scenario, subpycnocline waters became **hypoxic in only 12** of the most recent years, a 37 percent decrease

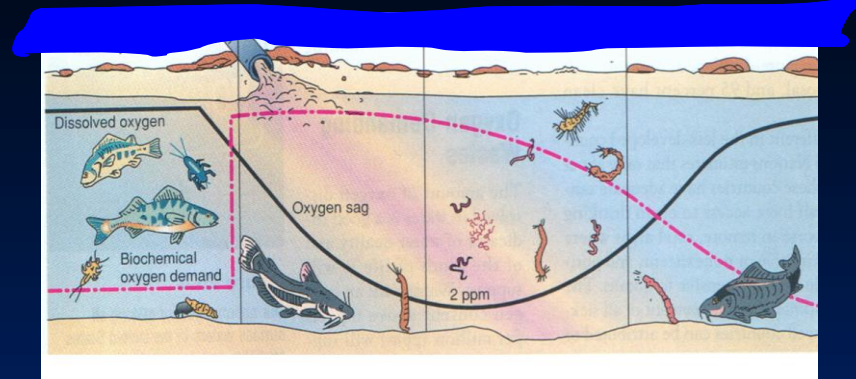
Effects of Reduced Load



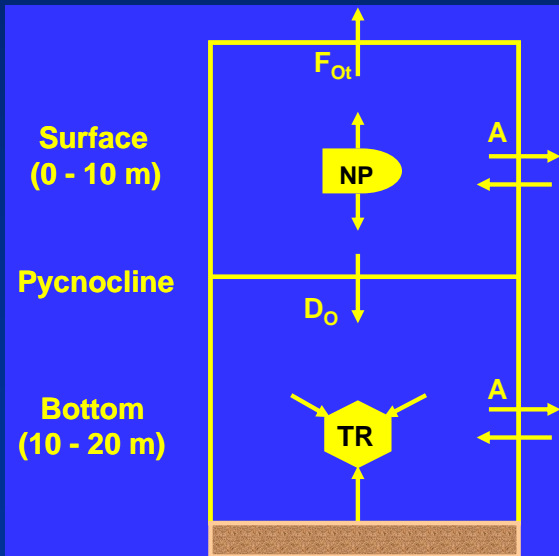
Bierman et al. (1994)



Scavia et al. (2003)

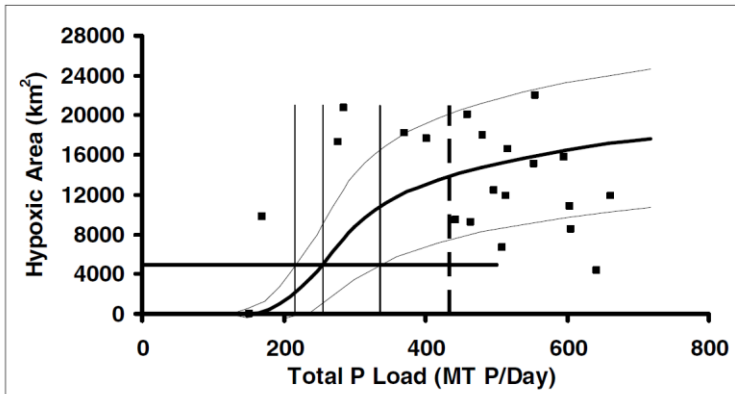
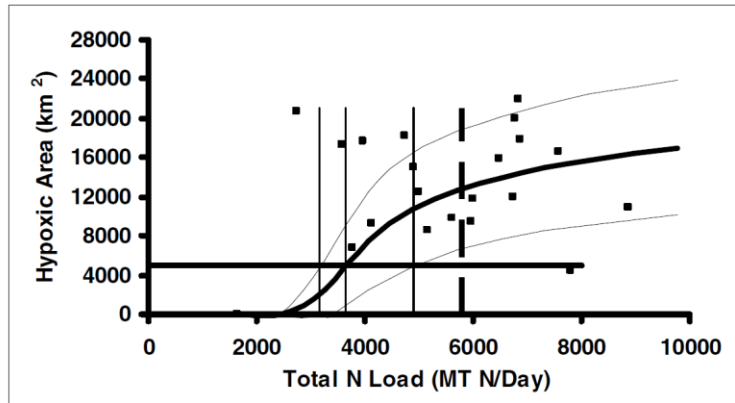


Justić et al. (1996)



**Advice from Three Models
(Scavia et al. 2004)**
**40-45% reduction in nitrogen
 load may be necessary**

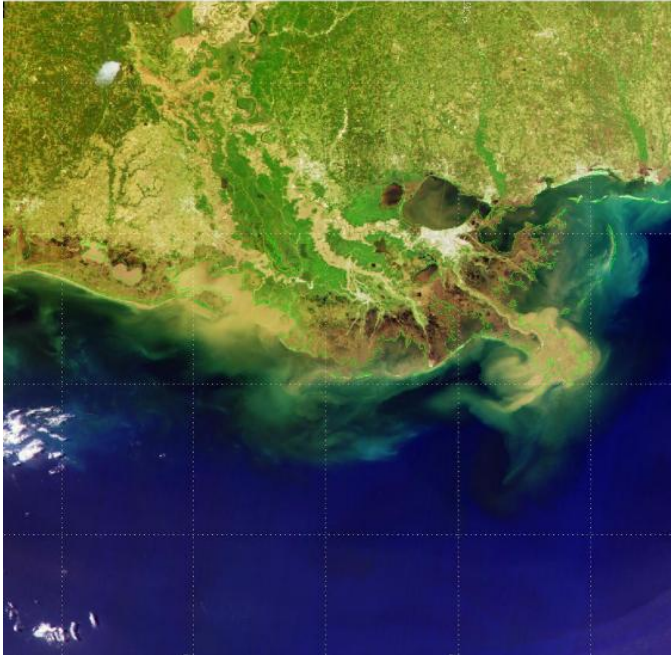
Scavia and Donnelly (2007) ...



- Extended Scavia et al. (2003) to include TP
- Scenario results suggested TN reductions of 37-45% and TP reductions of 40-50% to meet hypoxia area goal



Hypoxia in the Northern Gulf of Mexico An Update by the EPA Science Advisory Board



“ ... recommends a dual nutrient strategy targeting at least a 45% reduction in total nitrogen ... and at least a 45% reduction in total phosphorus ... ”

“ A number of studies have suggested that climate change will create conditions for which larger nutrient reductions ... 50-60% for nitrogen, would be required ... ”

Gulf Hypoxia Action Plan 2008

for Reducing, Mitigating, and Controlling Hypoxia
in the Northern Gulf of Mexico and Improving
Water Quality in the Mississippi River Basin



“The 5,000 square kilometer size of the hypoxic zone ... remains a reasonable goal ... it may not be possible to achieve this goal by 2015”

“ ... a dual nutrient strategy targeting at least a 45% reduction in riverine total nitrogen load and riverine total phosphorus load ... may be necessary“

**WHAT WERE THE EXTRA COSTS
OF MULTIPLE MODELS?**



Full cost accounting ...

- Estimated cost of hypoxia monitoring and research from 1985 to present:
\$20-40 million
- Cost of Bierman model:
Two orders of magnitude less
- Cost of Justić model:
Less than Bierman model
- Cost of Scavia model:
Federal government salary for 1 FTE

WHAT WERE THE BENEFITS OF MULTIPLE MODELS?



General benefits of multiple models ...

- Problems viewed from different conceptual and operational perspectives
- Same datasets are mined in different ways
- Provide multiple lines of evidence
- Reduced levels of risk in environmental management decisions
- Model diversity adds more value than model multiplicity

Simple and complex models ...

- Simple Models
 - Less extensive data requirements
 - Can test over longer periods of record
 - Limited number of parameters
 - Can more easily quantify uncertainty
 - Provide limited understanding of causal mechanisms
- Complex Models
 - More extensive data requirements
 - Can only test over shorter periods of record
 - Larger numbers of parameters
 - Provide more understanding of causal mechanisms

WHAT WERE THE CHALLENGES OF MULTIPLE MODELS?



Multiple models can be messy ...

- Different spatial and temporal scales
 - 1D, 2D, 3D
 - Steady-state and dynamic
 - Period of simulation
- Different metrics
 - Primary production and chlorophyll concentration
 - Dissolved oxygen concentration
 - Hypoxic area
- Different development histories
 - Model results not always in phase with management decisions

RECOMMENDATIONS FOR CBP MODELING?



An integrated approach ...

- No such entity as the “best” model independent of the scientific or management questions, and available data and resources
- Management decisions should be based on weight-of-evidence and collective scientific insights
 - Monitoring studies
 - Controlled experiments
 - Mathematical models
 - Case studies from other similar systems
- Suites or ensembles of models should be developed, ranging from simple statistical models to complex ecosystem models

References ...

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Victor J. Bierman, Jr.
Limno-Tech, Inc.
8320 W. Harrell Road
Oak Ridge, NC 27310
336-643-4538

vbierman@limno.com