

# The Economics of Dead Zones: Linking Externalities from the Land to the their Consequences in the Sea

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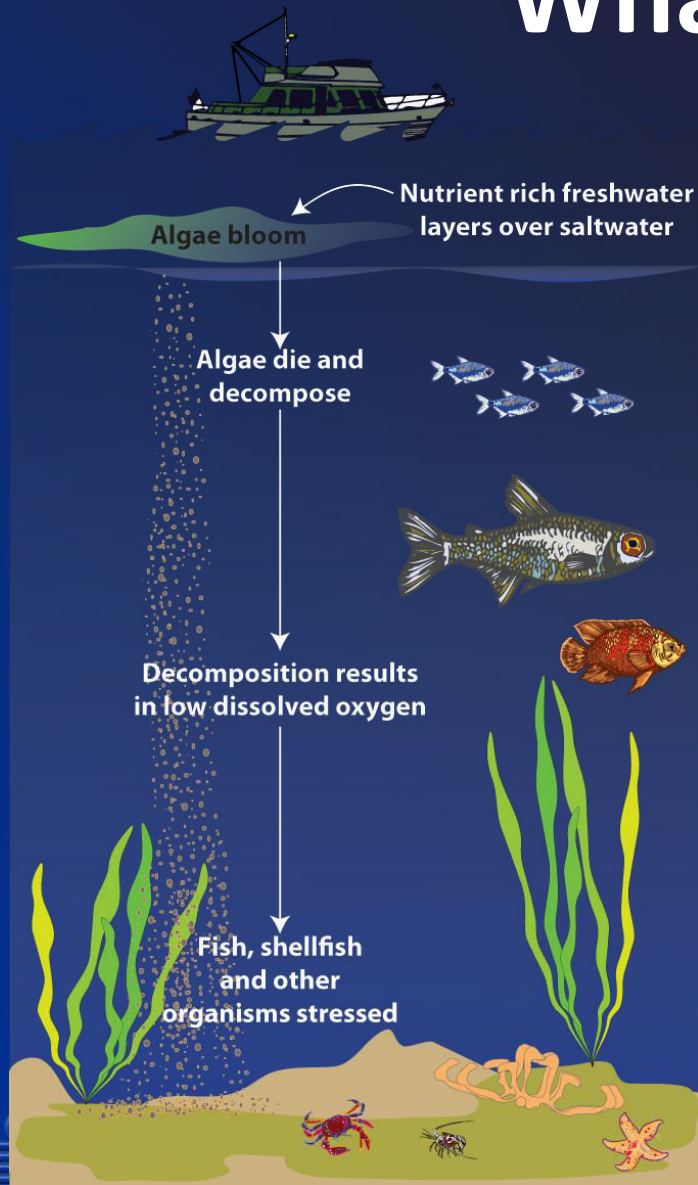


# Outline

- I. An Overview of the Causes and Locations of Worldwide Hypoxic Zones
- II. Economic Damages: Loss of Commercial Fisheries and other Ecosystem Services
- III. Challenges in Designing Cost Effective Approaches to Abatement
- IV. Hypoxia in the Gulf of Mexico: Integrated Modeling
- V. Research Needs and Future Directions

# I. An Overview of the Causes and Locations of Worldwide Hypoxic Zones

# What is hypoxia?



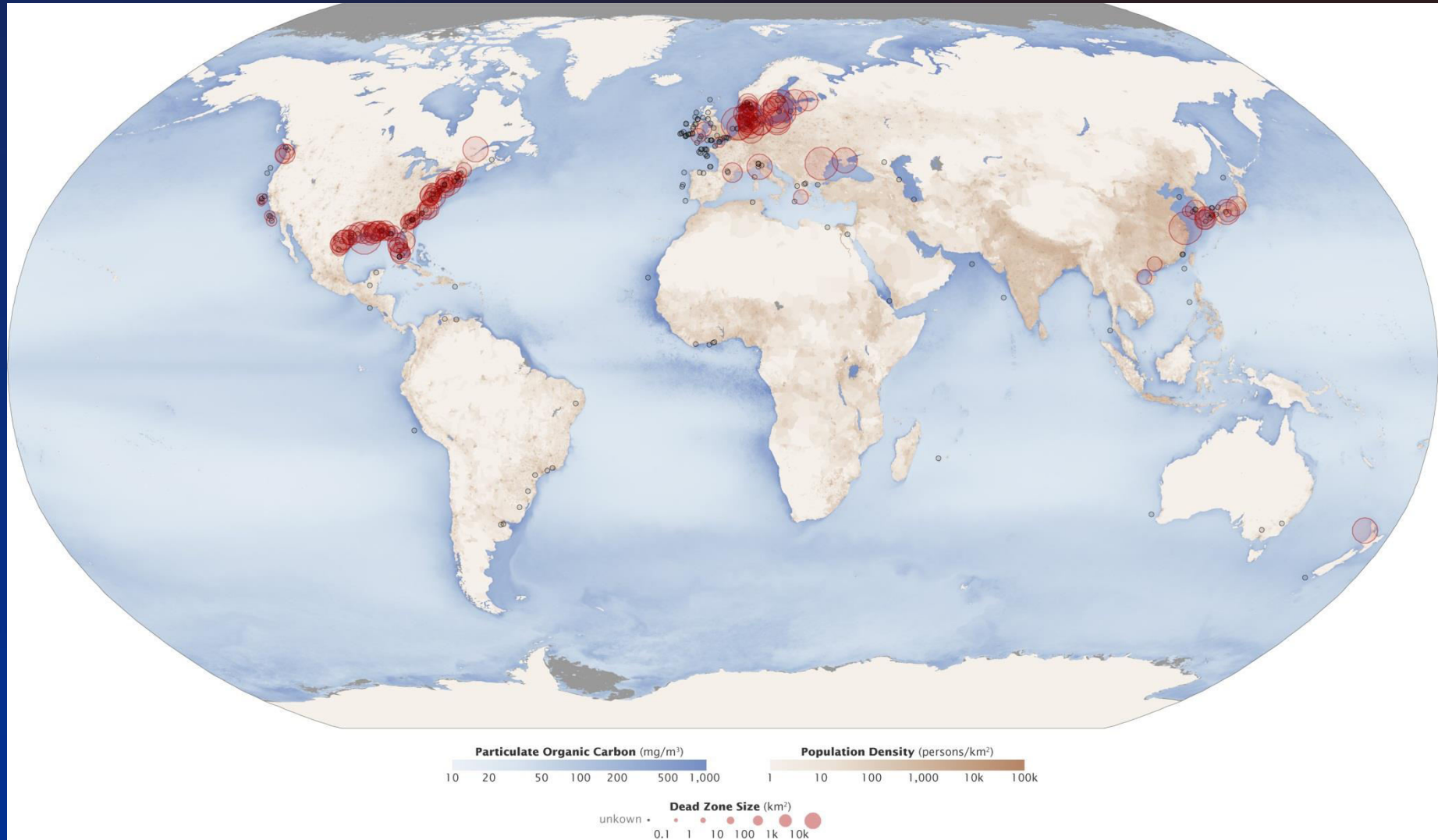
Common definitions  
(Steckbauer, et al, 2011):

oxygen levels  $< 2\text{mg/L}$   
organisms exhibit stress

oxygen levels  $< 0.5\text{ mg/L}$   
mass mortality

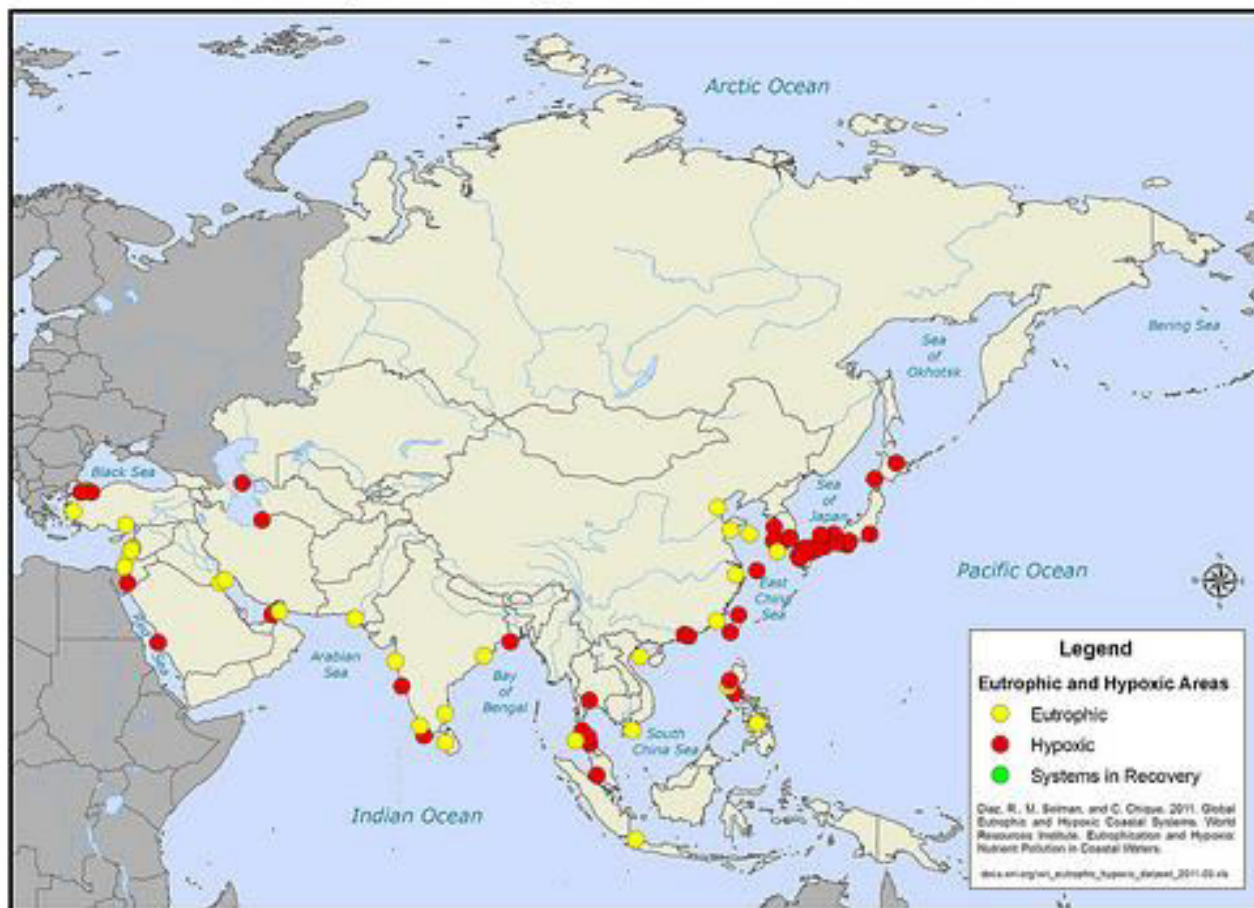
Normal levels  $> 3\text{ mg/L}$

# Location and Size of Hypoxic Zones



Data from Robert Diaz, Virginia Institute of Marine Science (dead zones); the GSFC Ocean Color team (particulate organic carbon); and the Socioeconomic Data and Applications Center (SEDAC) (population density).

## Eutrophic and Hypoxic Coastal Areas of Asia



# Duration and Recovery

- Duration (Diaz and Rosenberg, 2008):
  - About ½ hypoxic zones are seasonal, last 1-4 months
  - About 8% continuous
- Recovery of ecosystem (Diaz and Rosenberg, 2008):
  - quick if short duration (days, weeks)
  - slow or nonexistent if long/permanent
  - can revert to a different set of plants and animals (most opportunistic tend to colonize quickly)

## II. Economic Damages: Loss of Commercial Fisheries and other Ecosystem Services

# Physical Impacts

Rabalais et al. 2010

- Loss of habitat for bottom dwelling species
- Reduced habitat for pelagic species
- Direct mortality of organisms
- Increased predation
- Reduced food supply
- Changes in energy transfer

# Some Specific Examples...

Marty Smith papers etc.

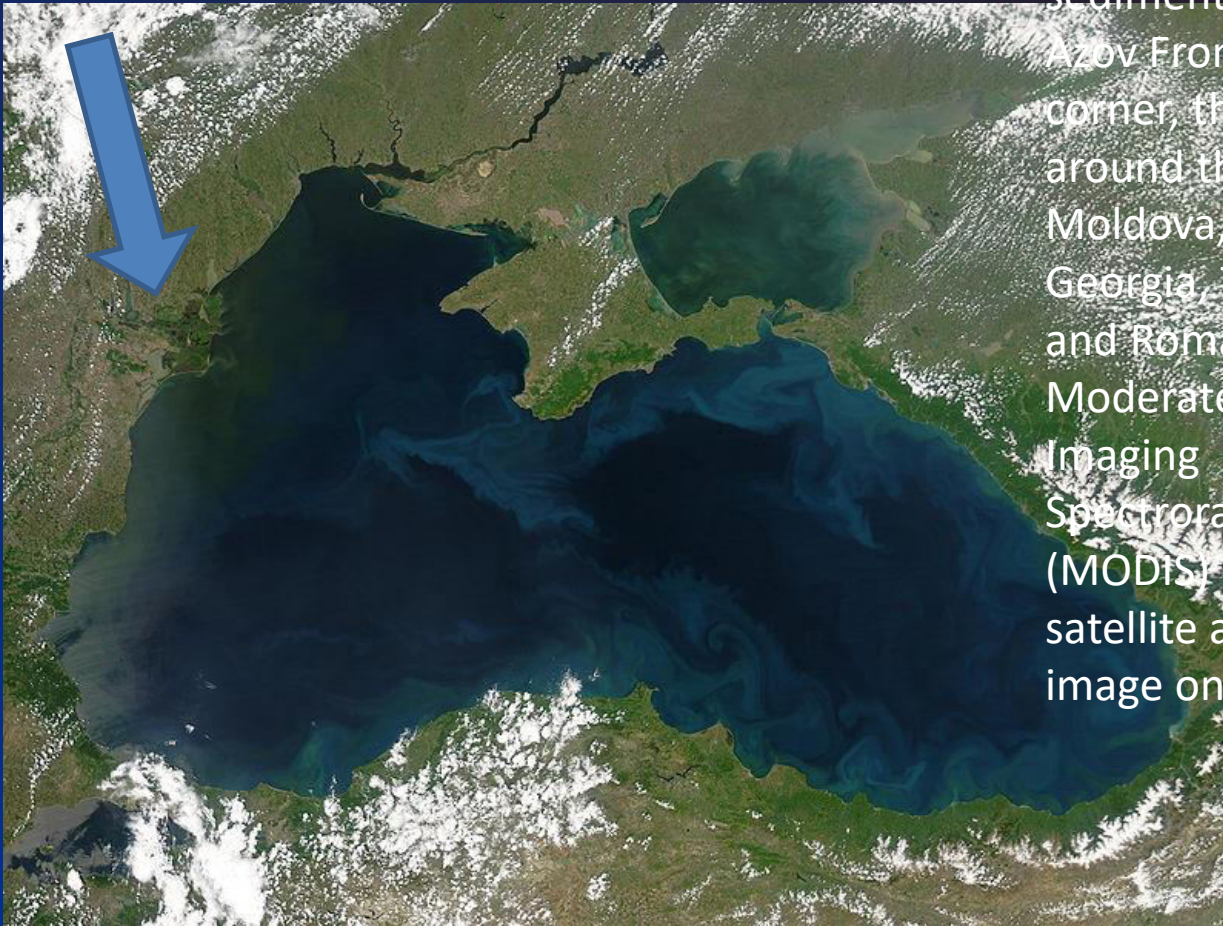




# The Black Sea

Most of the agricultural run-off enters from the Danube River

Phytoplankton blooms and plumes of sediment form the bright blue swirls that ring the Black Sea. sediment clouds the Sea of Azov. From the upper left corner, the countries around the Sea are Moldova, Ukraine, Russia, Georgia, Turkey, Bulgaria, and Romania. The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite acquired this image on May 22, 2004.



# Chronology of the Black Sea Events Related to Hypoxic Zone

1960s: large increase in agricultural nutrients,  
industrial and human waste contributions

1973: 2500 km<sup>2</sup> summer hypoxia

1978: 30,000 km<sup>2</sup>

1989: 40,000 km<sup>2</sup>, mass mortality of benthic  
organisms

Meanwhile....

1980s: collapse of economic, restructuring of  
agriculture and industrial activity in surrounding  
states lead to an abrupt decline in nutrient loading

# III. Challenges in Designing Cost Effective Approaches to Abatement

# What abatement options exist?

## Examples from Agriculture

- In field Management Practices
  - Reduced (no) tillage
  - Manure, fertilizer management/reduction
  - Cover crops, rotation changes
  - Land retirement
- Structural Practices
  - Buffers
  - Grassed Waterways
  - Denitrification, controlled drainage
  - Wetland restoration

# Conservation practices



# Land Retirement



Panoramic view of gamma grass-big blue stem planting

[http://www.fsa.usda.gov/Internet/FSA\\_Image/ia\\_767\\_15.jpg](http://www.fsa.usda.gov/Internet/FSA_Image/ia_767_15.jpg)

# Wetlands Restoration



# Efficacy and Cost of Practices

- Vary by
  - Pollutant
  - Field characteristics
  - Land use in watershed
  - Provision of other ecosystem services
- Ideally, all of these factors considered in efficient policy design

# Further Complications!

- Nonpoint (Segerson, Shortle and Dunn, etc.)
  - Measurement: costly to trace nutrients to source
  - Randomness: stochastic events (weather) have large effect on damages
- Spatial Aspect (Montgomery, Baumol and Oates)
  - Location of release affects damages
  - Damages are non-separable between fields

# In sum, have to deal with all of these aspects

- Enormous number of farm fields/decision makers
- Each : one or more land use/conservation practices  
Retire land (e.g., CRP), Reduce tillage, Terraces, Contouring, Grassed Waterways, Reduce fertilizer, better timing, etc.
- Costs and effectiveness vary across locations
- HOW? Use models to guide policy

# IV. Introduction to Integrated Modeling to Provide Policy Insight: Gulf of Mexico Hypoxia and CEAP Modeling Effort

(very preliminary, intended here to demonstrate concepts)



# CEAP-Hypoxic Zone Project

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**Lee Norfleet and Jay Atwood**, USDA-NRCS, Temple TX

**Raghavan Srinivasan**, Spatial Sciences Laboratory (SSL), Texas A&M University, College Station, TX

**Sergey Rabotyagov**, School of Forest Resources, University of Washington, Seattle, WA

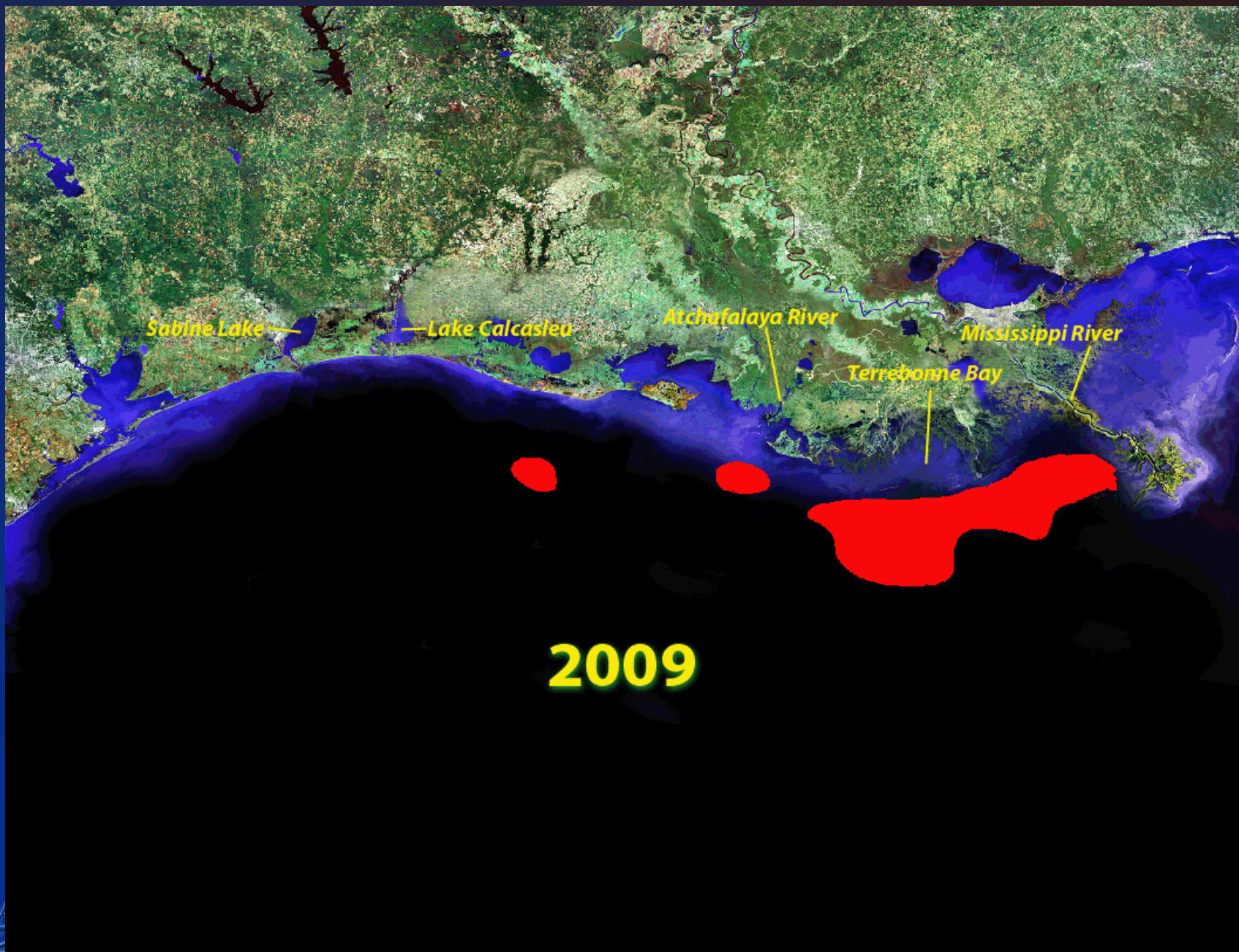
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**Nancy Rabalais**, Louisiana University Marine Consortium (LUMCON), DeFelice Marine Center, Chauvin, LA

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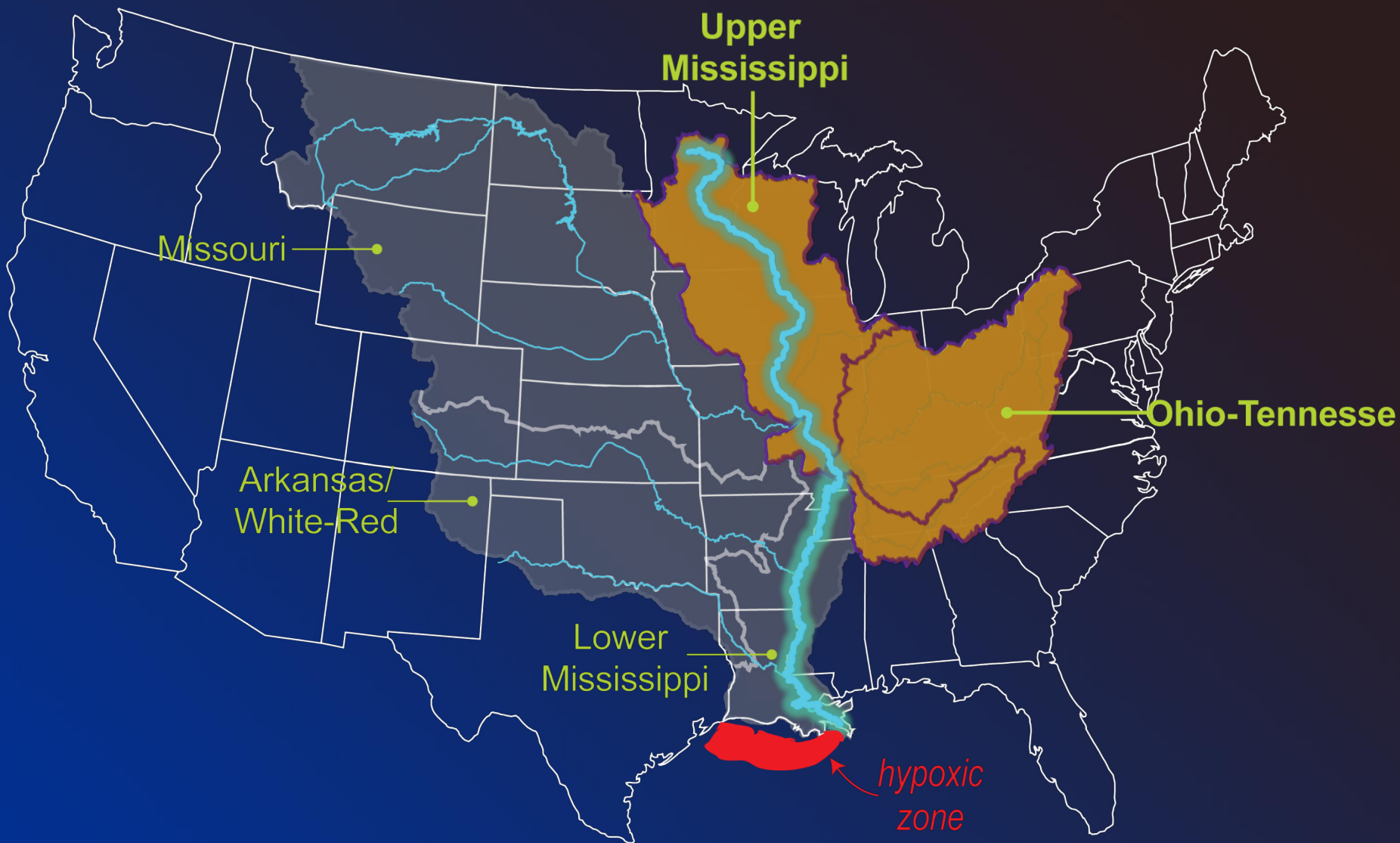




# Conservation Effects Assessment Project -Hypoxic Zone Project

- National CEAP Assessments: quantify the effects of conservation practices commonly used on cultivated cropland in major watersheds and to estimate the potential gains from additional conservation treatment
- Linked their model to model of hypoxic zone to assess effectiveness of their conservation treatment levels on hypoxic zone size and yearly variability

# Mississippi River Basin and its Major Subbasins

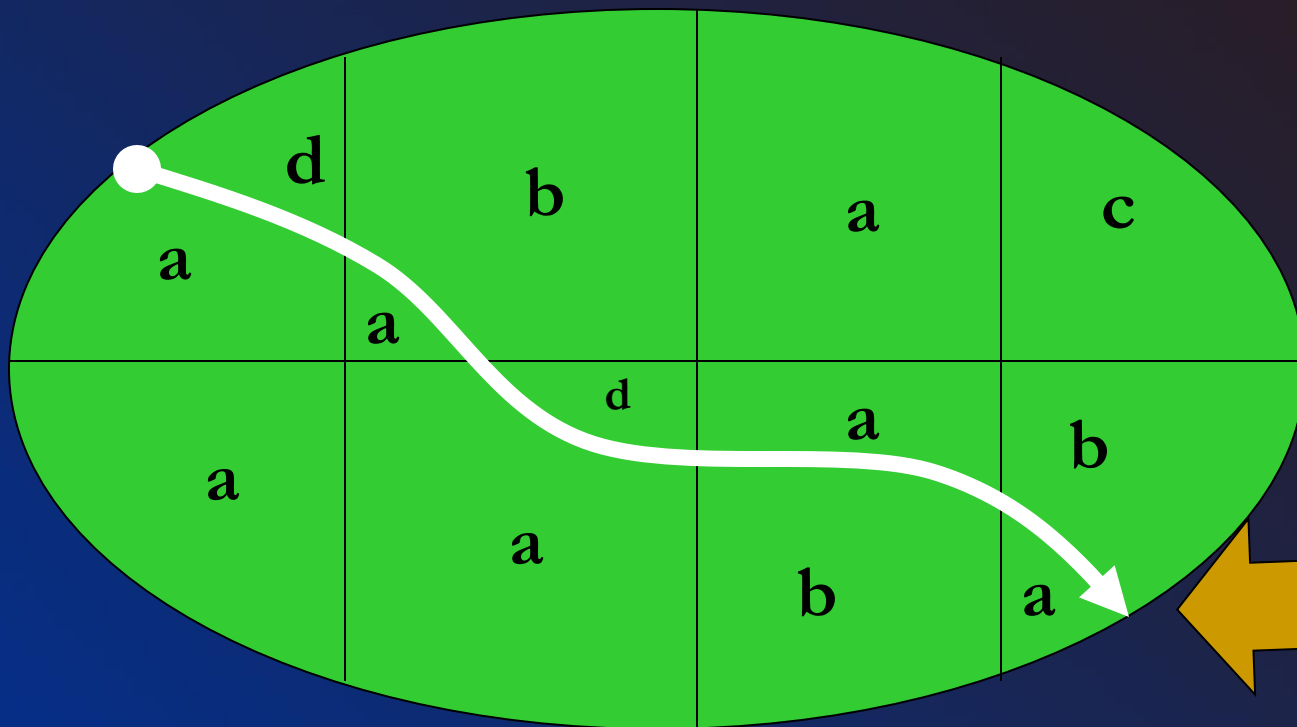


# Key Modeling Tool --- Soil and Water Assessment Tool (SWAT)

- Watershed-scale simulation model developed by USDA - Agricultural Research Service
- Predicts ambient (instream) water quality associated with a spatially explicit set of land use/conservation practices
- Gassman et al. (2007) identify over 250 publications using SWAT



**SWAT simulates water quality under any combination of landuse/abatement activities**



**SWAT:**  
N, P, and  
Sediment

**Watershed**

# Some Key Findings from Ohio-Tennessee River Basin

- **Adoption of conservation practices** has reduced have reduced loadings from cultivated cropland to rivers by 55 percent for sediment, 26 percent for nitrogen, and 32 percent for phosphorus.
- 24% of cropped acres (6 million acres) have a *high* level of need for treatment for sediment or nutrient loss, or both. 46% (11.5 million acres) have a *moderate* level of need for additional conservation treatment
- Additional conservation practices on these high-and moderate-need acres would further reduce edge-of-field losses of sediment by 83%, losses of nitrogen with surface runoff by 58 percent, losses of nitrogen in subsurface flows by 37 percent, and losses of phosphorus by 61 percent.

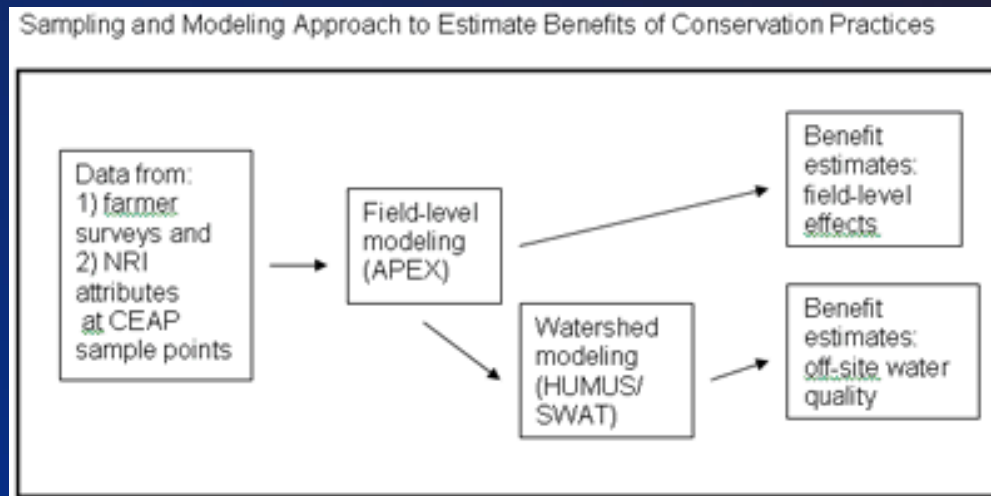
# Key Findings from Upper Mississippi River Basin

- Use of soil erosion control practices is widespread, but the most vulnerable acres require additional conservation practices.
- Complete and consistent use of nutrient management practices is generally lacking; 62% of acres require additional treatment to reduce the loss of nitrogen or phosphorus
- Treatment of erosion alone can exacerbate the nitrogen leaching problem by re-routing surface water to subsurface flow pathways
- About 38 percent of the acres are adequately treated for sediment, nitrogen, and phosphorus loss. Conversely, about 62 percent of the acres still require additional conservation treatment to reduce sediment and/or nutrient losses to acceptable levels.
- Augmenting conservation practices already in use with needed improvements in nutrient management on under-treated acres in the region, nitrogen savings could be more than doubled.



# CEAP Modeling Approach

The Cropland Component uses a **sampling and modeling approach** to estimate the benefits of conservation practices.



# Five CEAP Scenarios Considered for this study

Baseline: Assessment of existing set of conservation practices

ECC: Treatment of the 8.5 million critical under-treated acres with water erosion control practices.

ECA: Treatment of all 36 million under-treated acres with water erosion control practices.

ENMC: Treatment of the 8.5 million critical under-treated acres with nutrient management practices in addition to ECC.

ENMA: Treatment of all 36 million under-treated acres with nutrient management practices in addition to ECA.



# Scenario Details (UMRB example)

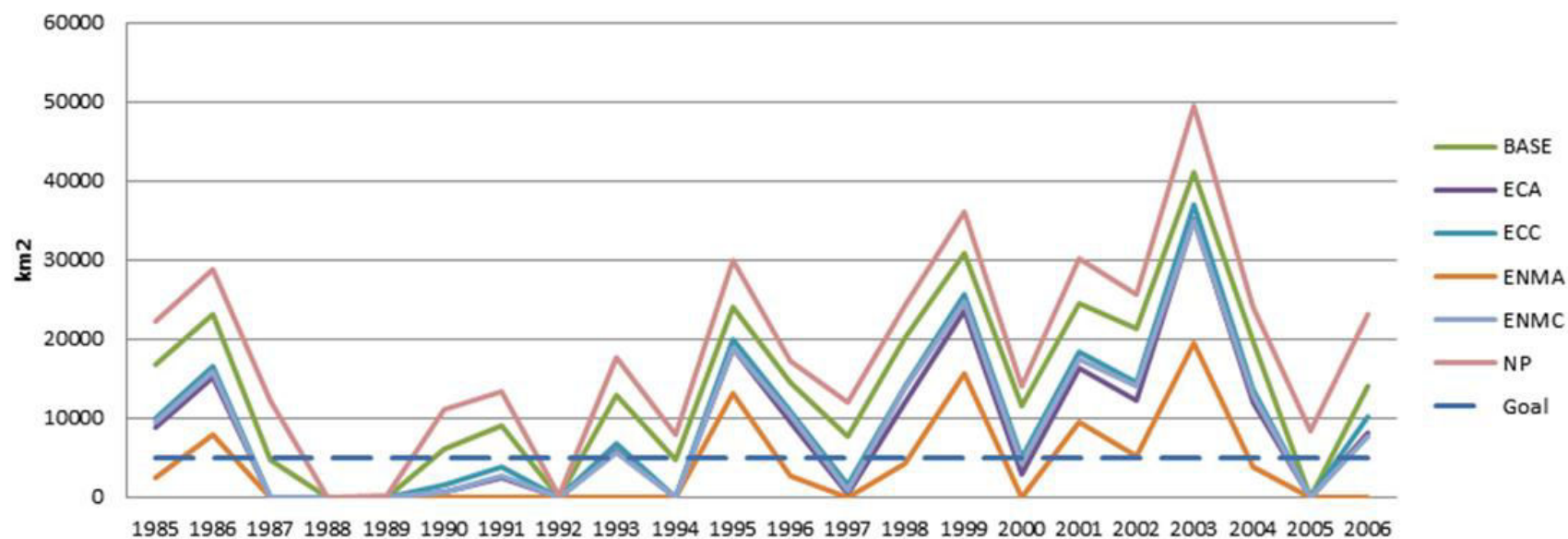
- ECA and ECC (Erosion Control)
  - Infield mitigation: terraces on high slopes, contour or strip cropping on all
  - Edge-of-field mitigation: fields near a waterway received a riparian buffer, filter strips elsewhere
- ENMA and ENMC (Nutrient Management)
  - Adjusted rate, form, timing, and method of application to be most efficient

**Estimated model:**

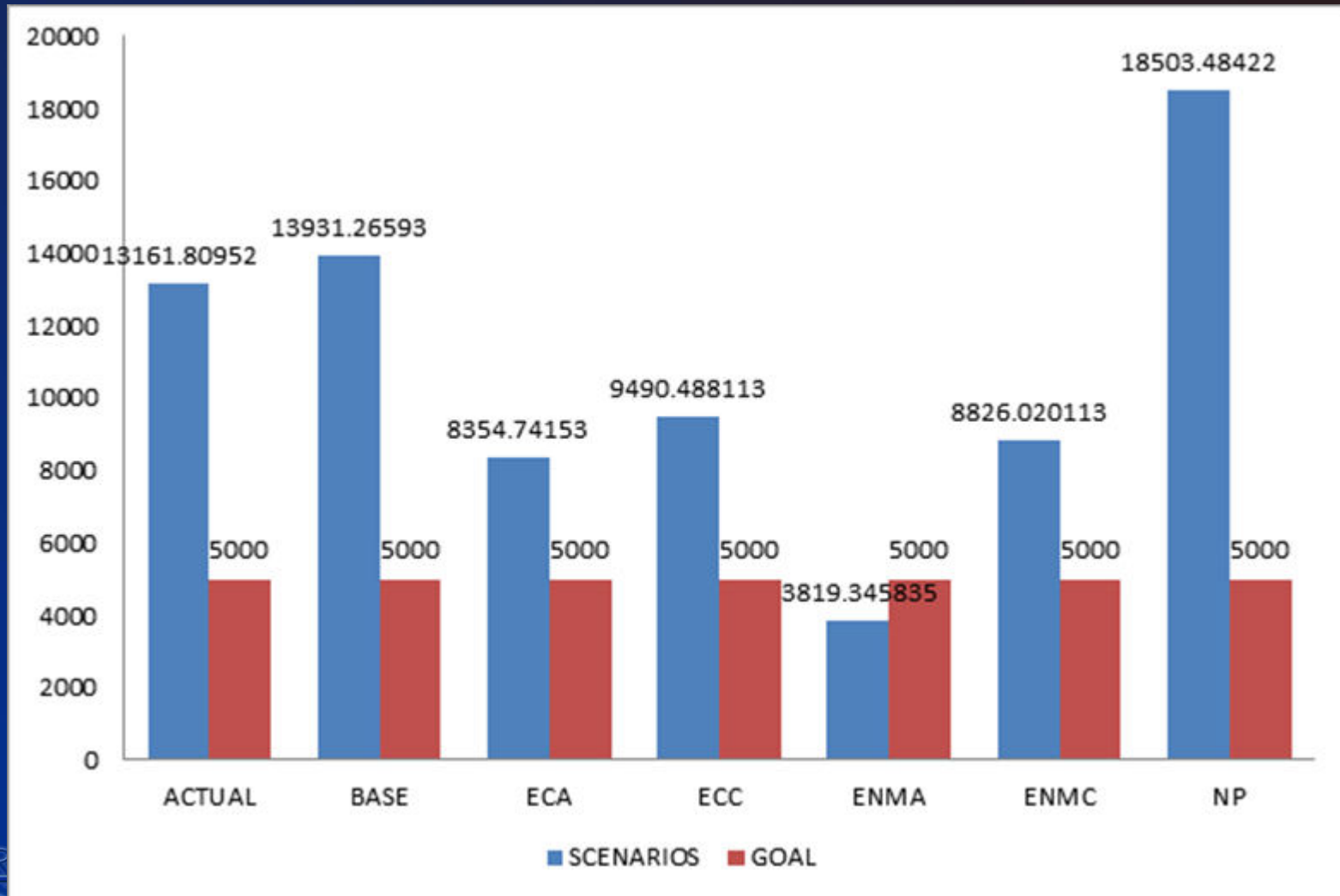
$$\begin{aligned} \text{HypoxicZone}_t &= \beta_{\text{intercept}} + \beta_{\text{hurricane}} \text{Hurricane}_t + \beta_{\text{current}} \text{Current}_t \\ &+ \beta_{\text{hurrrN}} \text{Hurricane}_t * N_t + \beta_{\text{hurrrP}} \text{Hurricane}_t * P_t + \beta_N N_t \\ &+ \sum_{i=0}^5 \beta_{i,P} P_{t-i} + \sum_{i=0}^5 \beta_{i,NP} N_{t-i} P_{t-i} + \varepsilon_t \end{aligned}$$

Where  $N_t = \log_{10}(N \text{ load at time } t)$  and  $P_t = \log_{10}(TP \text{ load at time } t)$ .

## Model-predicted size of hypoxic zone, CEAP scenarios



# Average Hypoxic Zone Under Four Scenarios



# Research Needs and Future Directions