An Integrated Modeling System to Estimate Corn Belt Region Nutrient Load Impacts on the Seasonal Gulf of Mexico Hypoxic Zone

Dr. Catherine Kling, Professor & Lead PI
Dr. Philip W. Gassman, Associate Scientist
Dr. Yiannis Panagopoulos, Postdoc Researcher
Center for Agricultural and Rural Development, Dept. of Economics, Iowa State University

Dr. Manoj Jha, Assistant Professor
Civil Engineering Dept., North Carolina A&T State University, Greensboro, NC

Dr. Jeffrey Arnold, Agricultural Engineer
Dr. Michael White, Agricultural Engineer
USDA-ARS, Grassland, Soil and Water Research Laboratory (GSWRL), Temple, TX

Dr. Raghavan Srinivasan, Professor & Director
Spatial Sciences Laboratory (SSL), Texas A&M University, College Station, TX

Dr. Sergey Rabotyagov, Assistant Professor
Environmental Economics, School of Forest Resources, University of Washington, Seattle, WA

Dr. Monika Moskal, Assistant Professor & Director
Dr. Jeffrey Richardson, Postdoc Researcher
Remote Sensing & Geospatial Analysis Laboratory, School of Forest Resources, University of Washington, Seattle, WA

Dr. R. Eugene Turner, Professor
Coastal Ecology Institute, Louisiana State University, Baton Rouge, LA

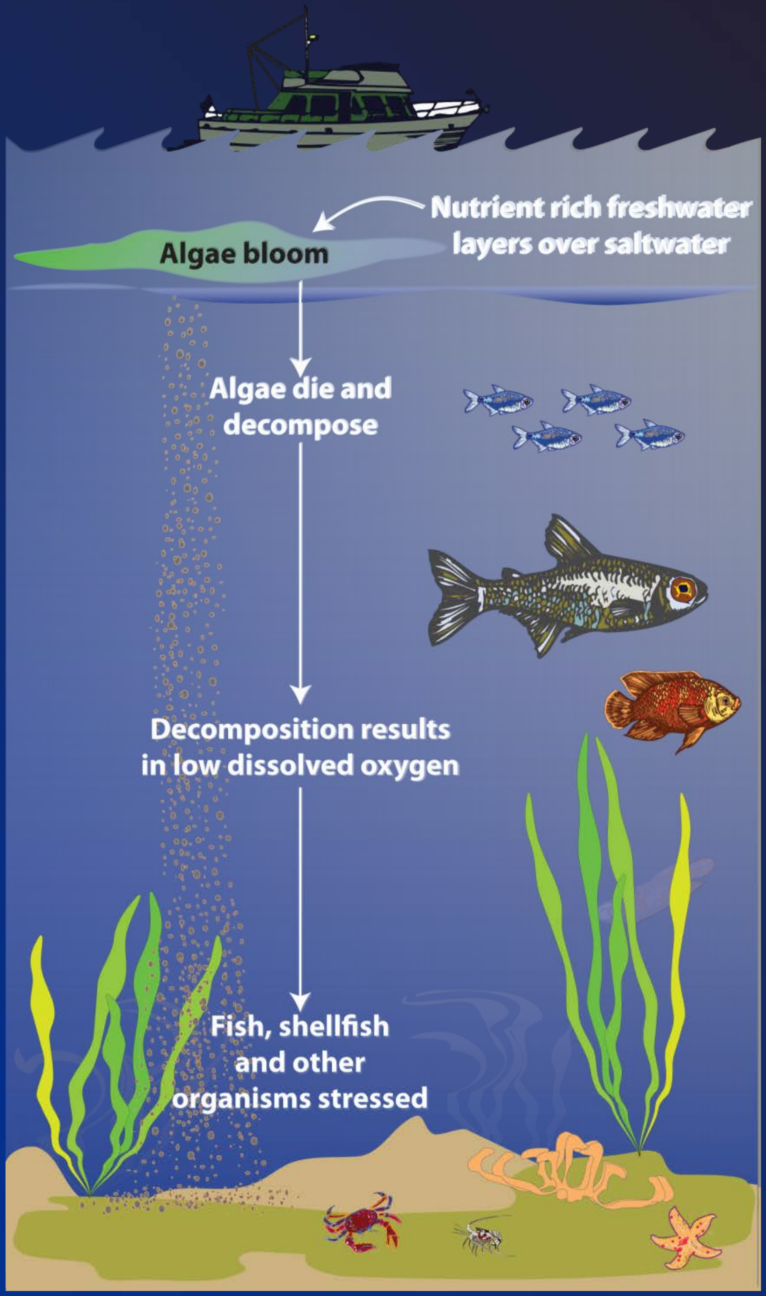
Dr. Nancy Rabalais, Professor & Executive Director
Louisiana University Marine Consortium (LUMCON), DeFelice Marine Center, Chauvin, LA

Presentation Overview

- Progress report on development of the modeling system
- Background information regarding Gulf of Mexico hypoxia and need for modeling system
- Development of refined subwatersheds for study regions
- Issues regarding available management data and other inputs

NSF Project Study Regions (UMRB & ORTB)

Primary source regions of nutrients to the Gulf of Mexico



Hypoxia = Dead Zone

•Often caused by elevated nutrient levels in water body

•Depleted oxygen creates zones incapable of supporting most life

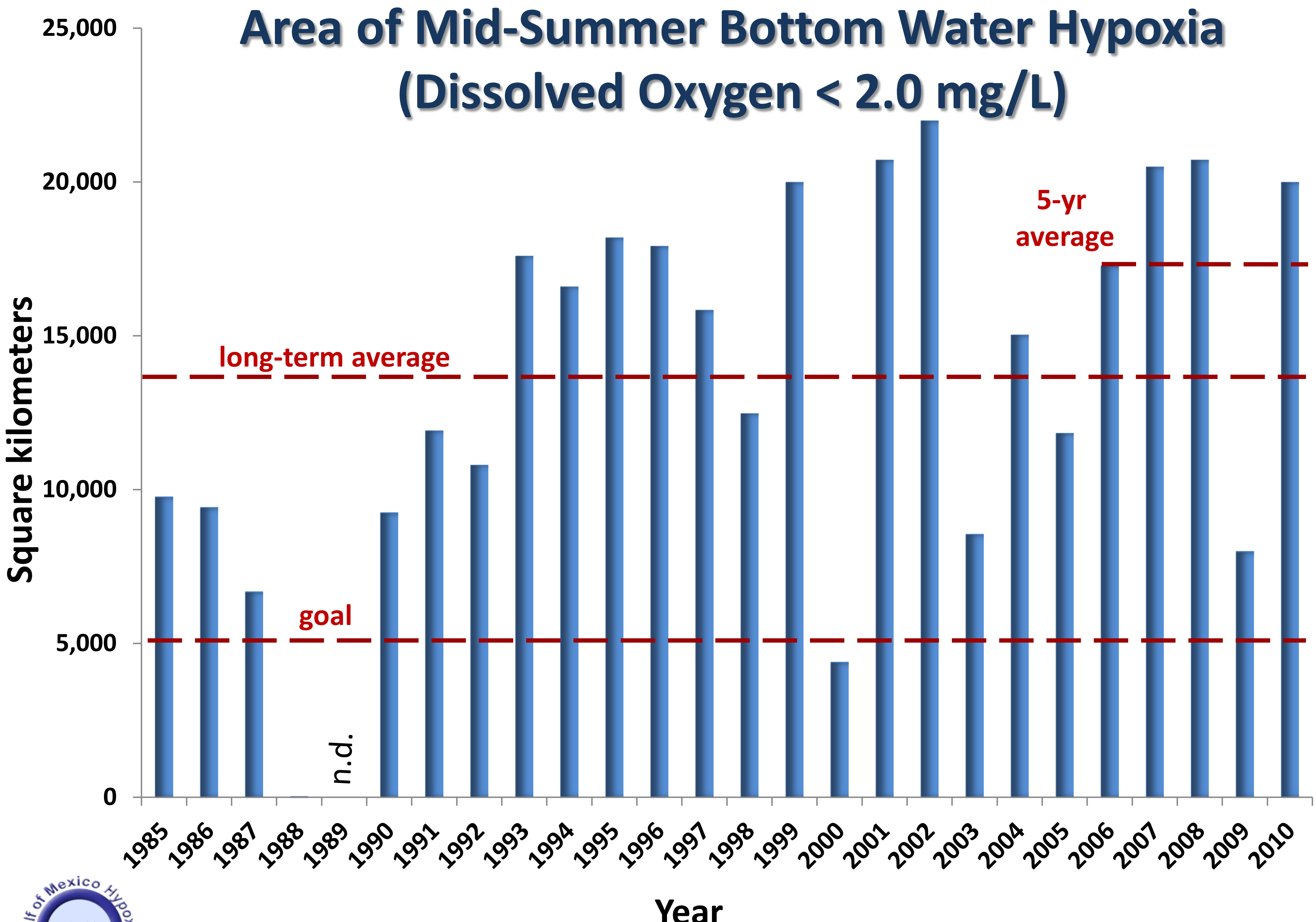
• Stressed marine and estuarine systems, mass mortality and dramatic changes in the structure of marine communities

• 400 worldwide

Louisiana Universities Marine Consortium (LUMCON) Lab

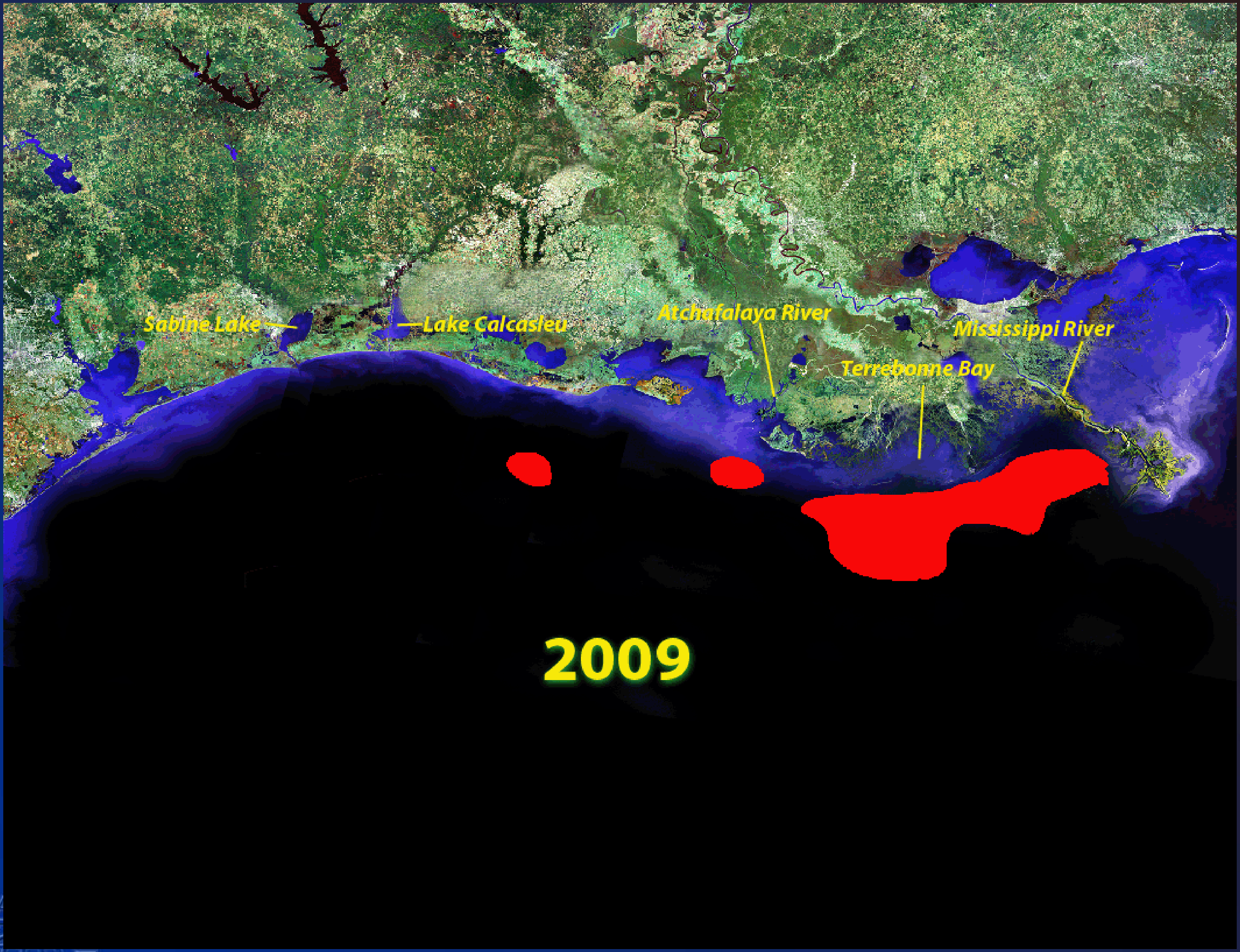
Nancy Rabalais: “Queen of the Dead Zone”

Device used to measure oxygen levels



Data source: N.N. Rabalais, Louisiana Universities Marine Consortium, R.E. Turner, Louisiana State University

Funded by: NOAA, Center for Sponsored Coastal Ocean Research

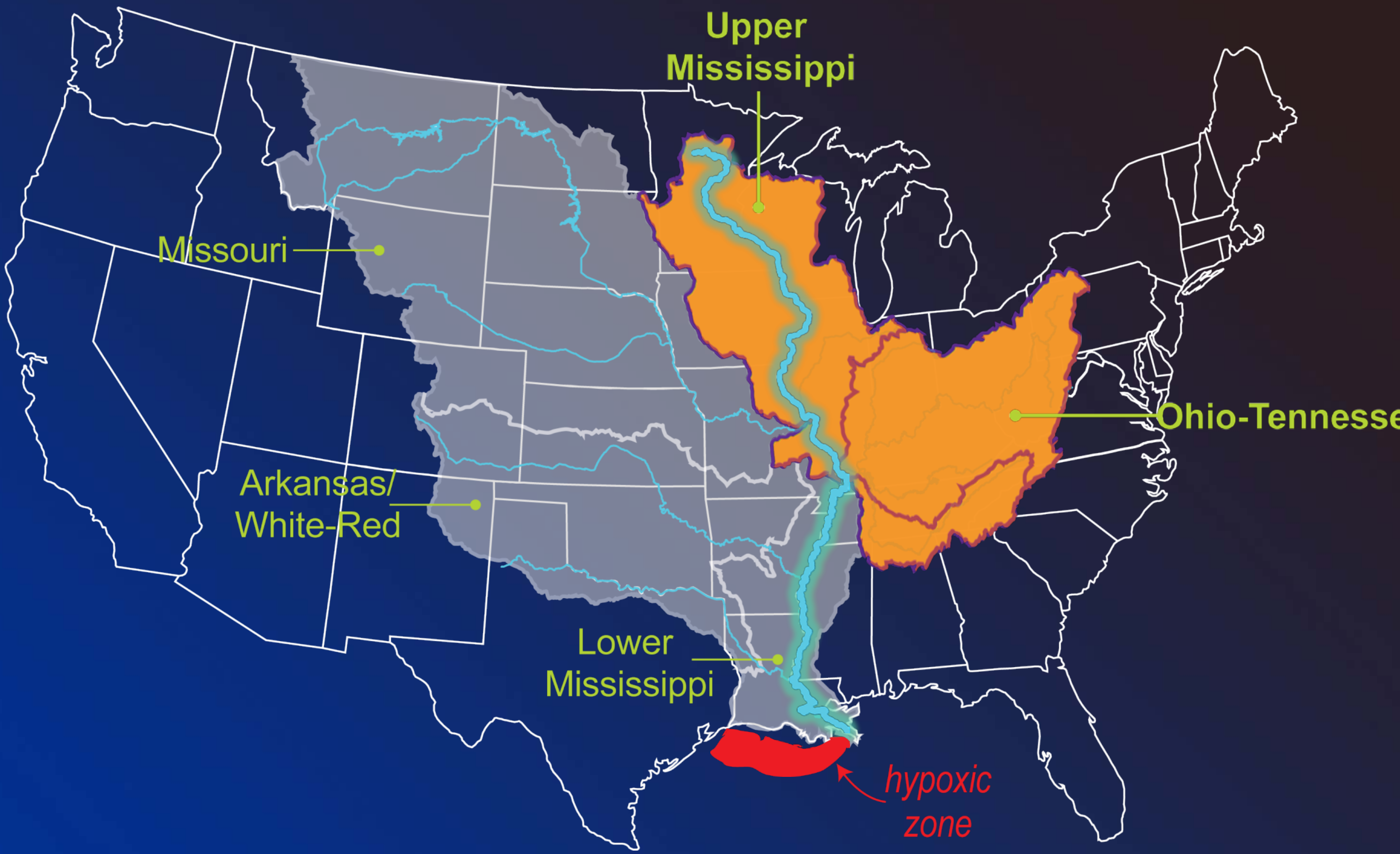

Sabine Lake
Lake Calcasieu
Atchafalaya River
Mississippi River
Terrebonne Bay
2009

Modeling Objectives

- Simulation objectives:
  1) Estimate nutrient loads from UMRB and ORTB for baseline conditions and alternative scenarios
     - Function of economic signals (genetic algorithm approach)
  2) Maintain static (baseline) loads for other MARB regions
  3) Estimate resulting impact on the size of the hypoxic zone
     - Regression models developed by Gene Turner that estimate hypoxic zone size as function of nitrate

- Will evaluate a mix of bioenergy-related and other management practice/land use scenarios

Mississippi River Basin and its Major Subbasins

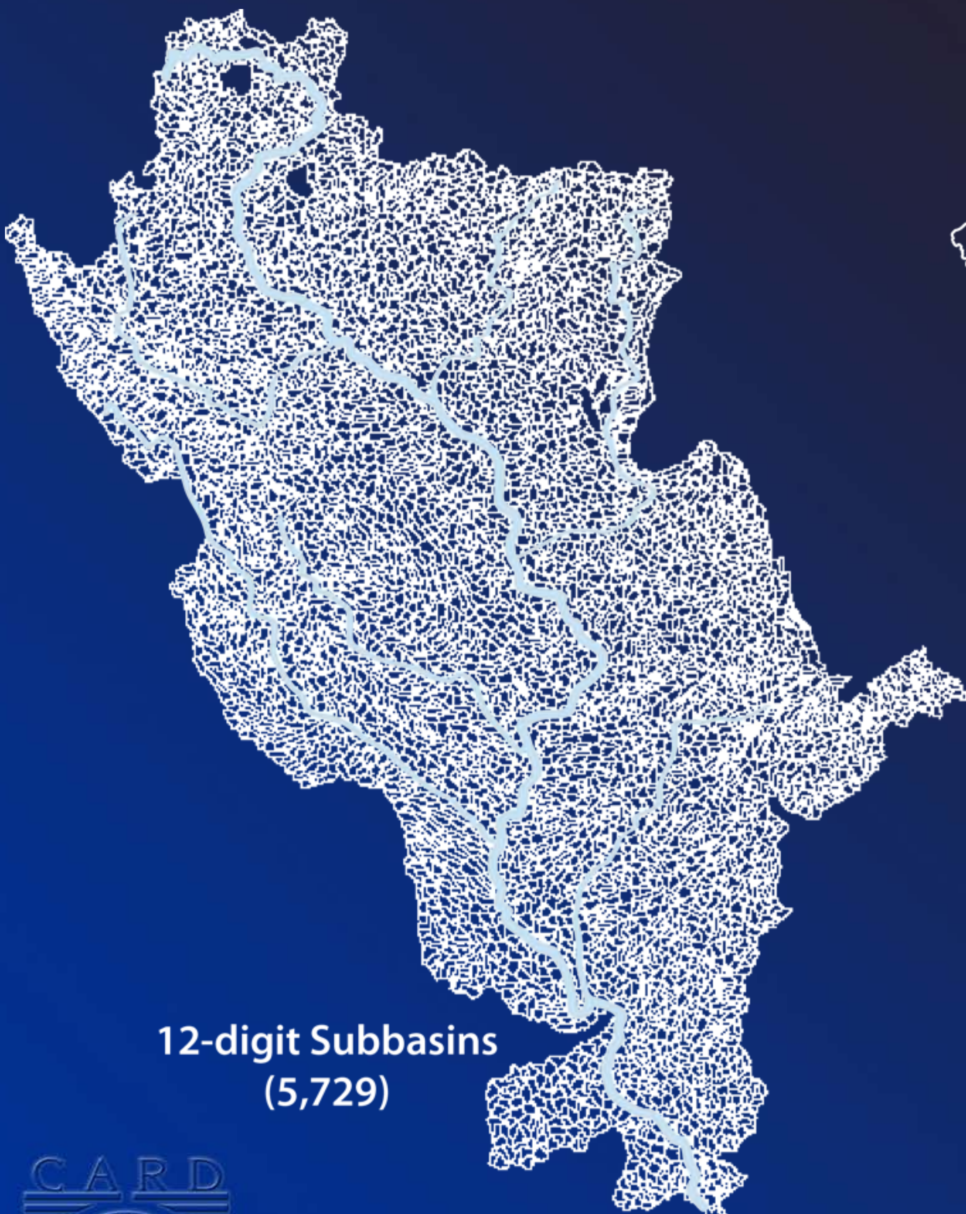


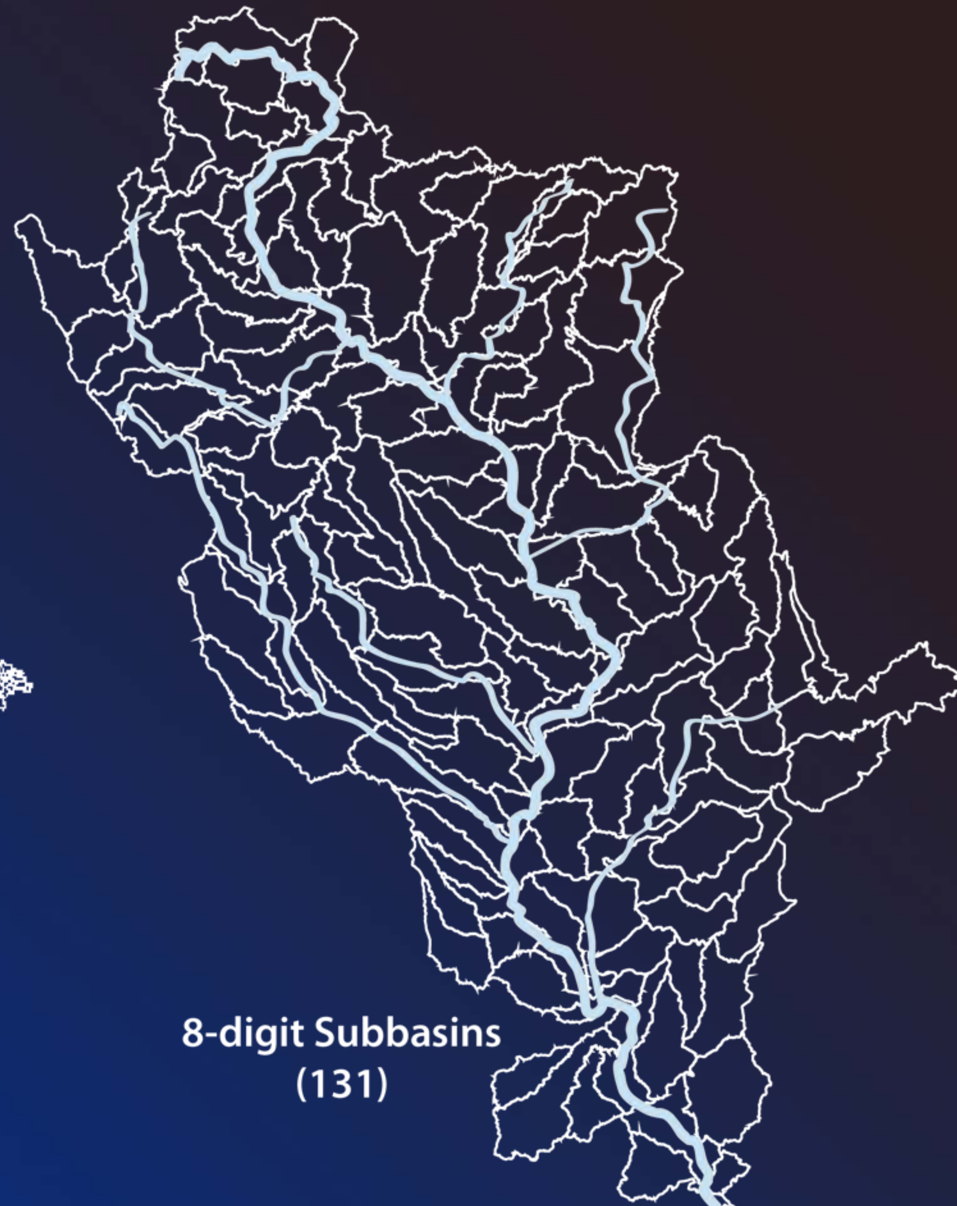
Delineation of Subwatersheds

- Previous applications of SWAT for the UMRB and ORTB have used USGS “8-digit watersheds” to define the subwatersheds for the SWAT simulations
- In this study, subwatersheds are being delineated at the “12-digit watershed” scale, which is a major refinement
- Refined approach will provide improved options for performing “targeted scenarios” and other scenarios
- Drawback: greatly increases required computer runtime

Example: 8-digit vs. 12-digit Subwatershed Configurations for the Raccoon River Watershed in West Central Iowa

12-digit vs. 8-digit Subwatershed Delineations for the UMRB





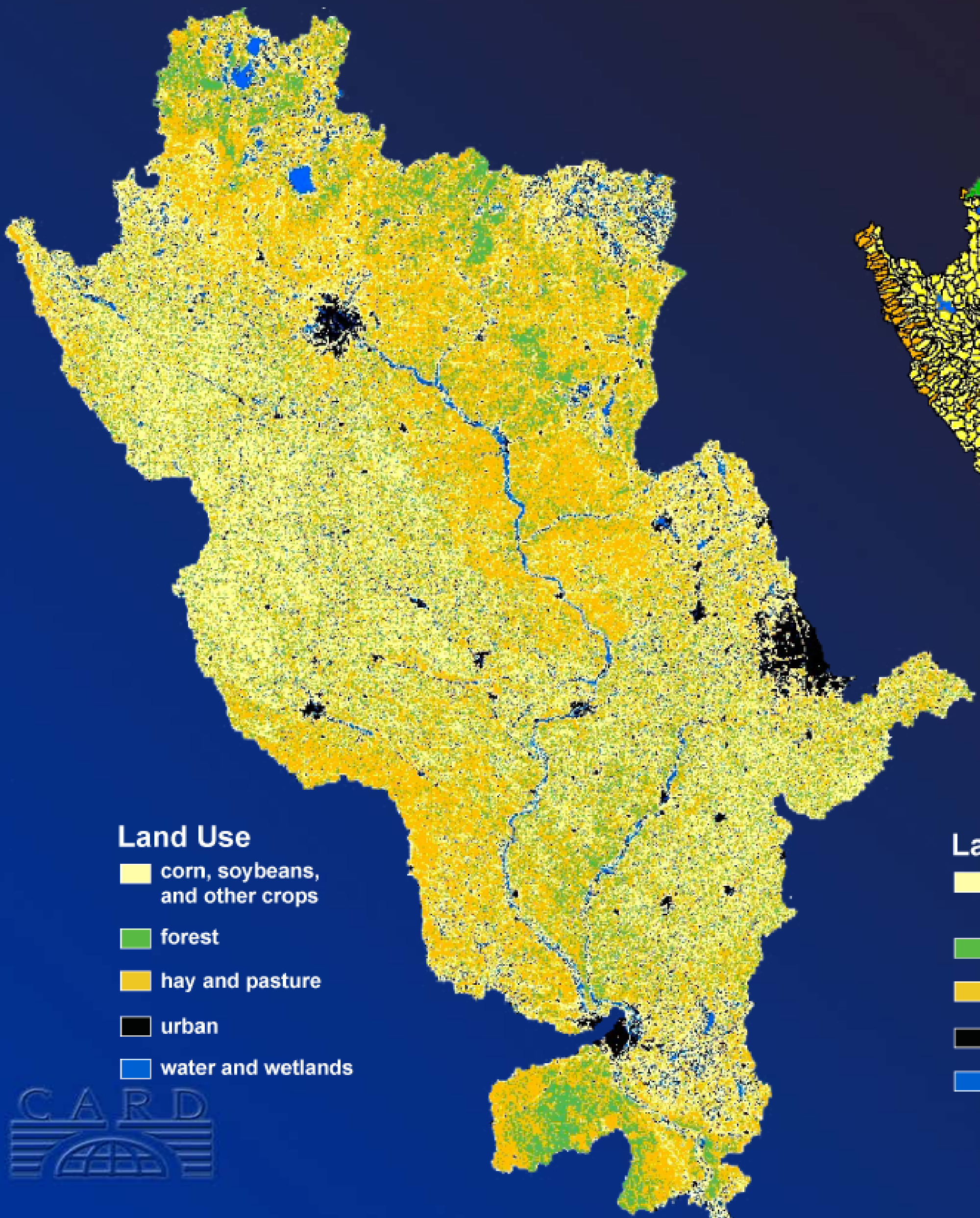
CARD

12-Digit Models Now Operational

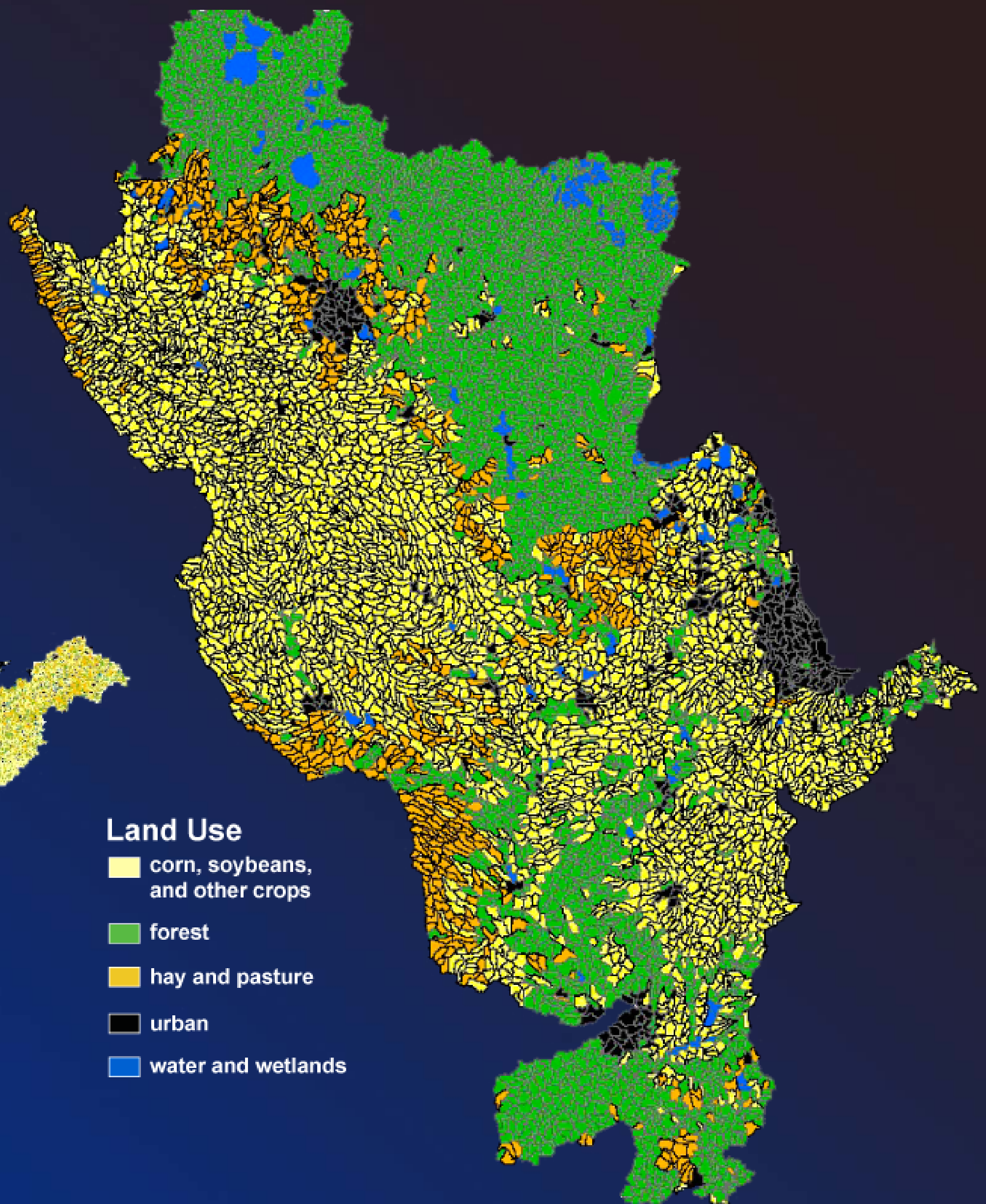
- 12-digit models have been constructed with overlays of land use, soil, and topographic data
  - Land Use based on USDA-NASS remote sensed Cropland Data Layer (CDL) for 2007 to 2009
    -http://www.nass.usda.gov/research/Cropland/SARS1a.htm
  - Soil Data: USDA-NRCS 1:250,000 STATSGO Database
    -http://soils.usda.gov/survey/geography/statsgo/
- Initial uncalibrated simulations indicate that SWAT is generating reasonable water balances for the two study regions

CARD

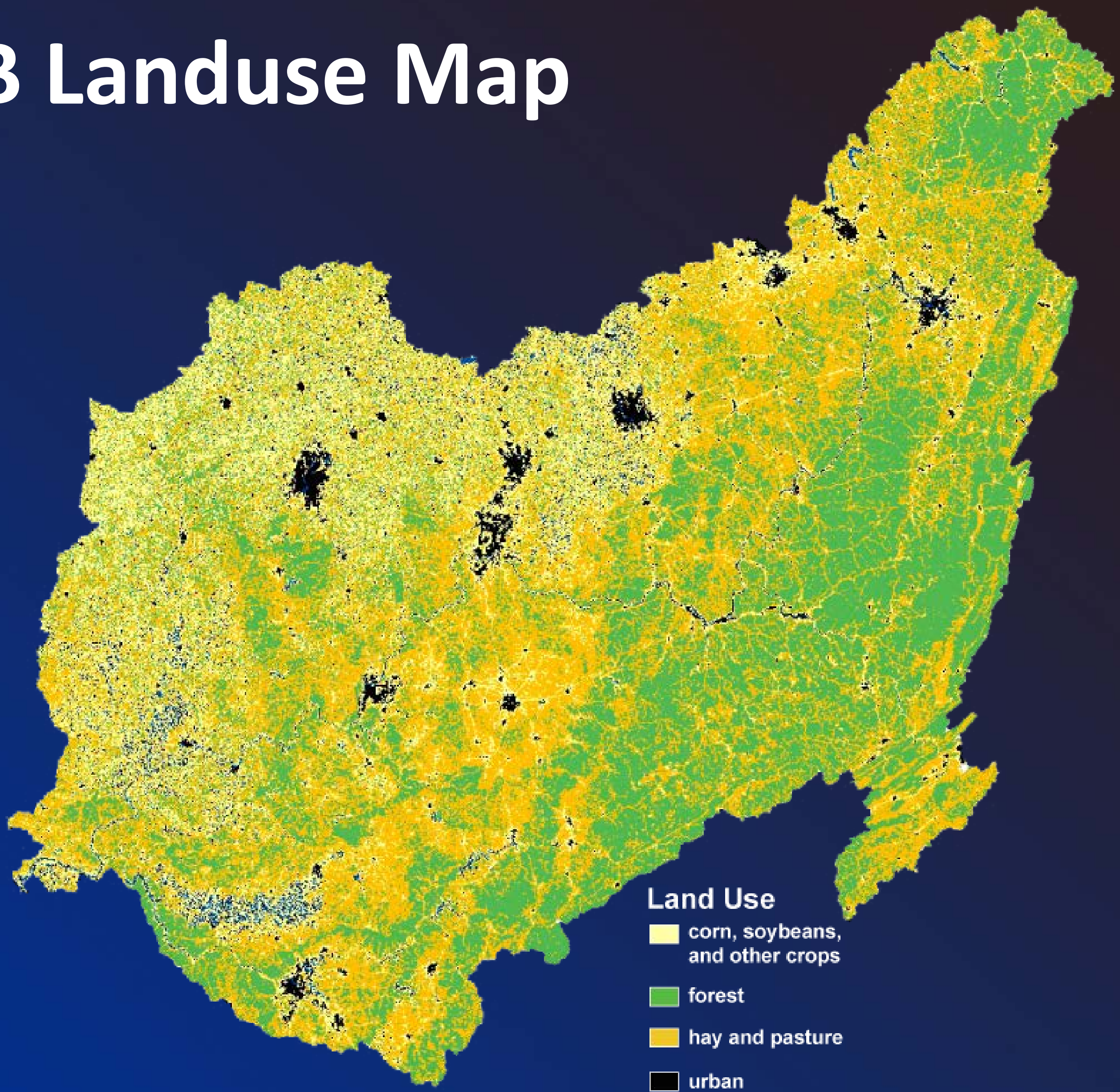
UMRB Landuse Map



UMRB Map based on dominant landuse



ORTB Landuse Map



Management Data

- Initial 2-digit models lack detailed management data
- Current phase of model development focused on incorporating tillage, tile drainage, nutrient application, and other management data
- Lack of detailed management data poses challenges for accurately representing management systems in the study regions

CTIC Tillage Surveys (1989 - 2008)

- CTIC: Conservation Tillage Information Center
  - West Lafayette, Indiana, U.S.
- Conducted National Crop Residue Management Survey of tillage type by crop for U.S. counties
- Adapted by Karen T. Baker of USGS to estimate tillage distributions at the 8-digit watershed scale
  - Data Series 573, USGS, http://pubs.usgs.gov/ds/ds573/

Crop Residue Management Survey

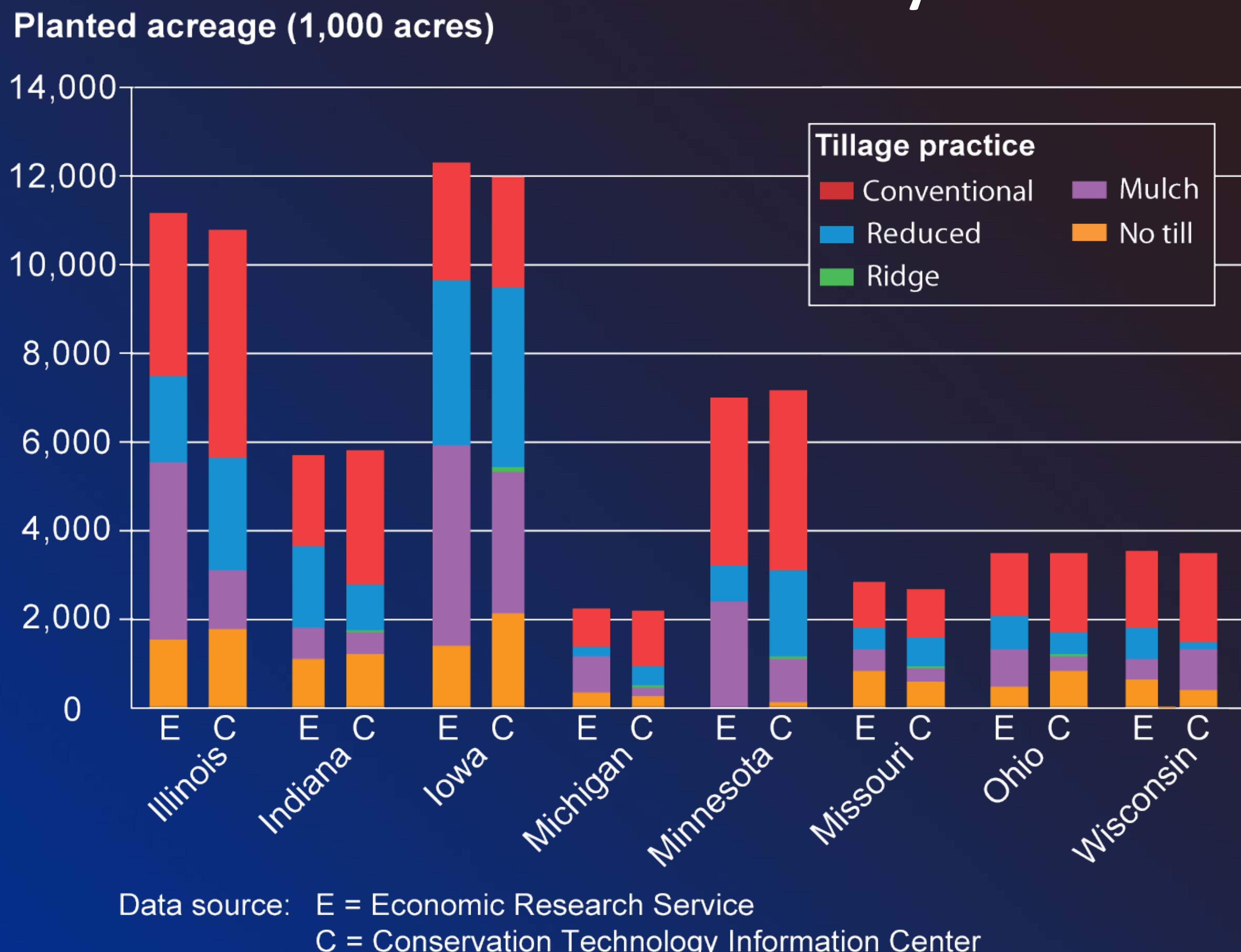
Tillage Types:

- Conventional-till
- Reduced-till
- Conservation till
    - No-till
    - Ridge-till
    - Mulch-till

Crops:

- Corn
- Small Grains
- Soybeans
- Cotton
- Grain Sorghum
- Forage
- Permanent Pasture
- Other Crops
- Fallow

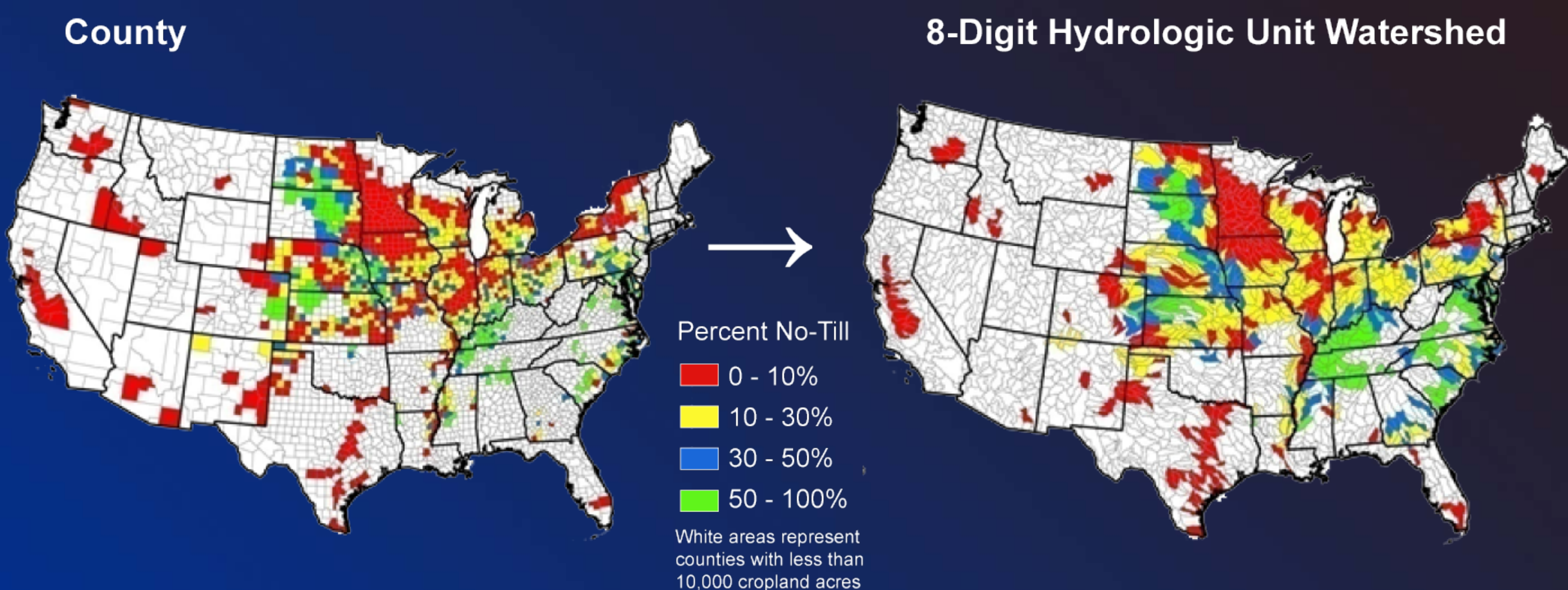
Corn Survey Results: 2000



Adapted from: Baker, N.T. 2011. Data Series 573. U.S. Geological Survey, Reston, VA. http://pubs.usgs.gov/ds/ds573/

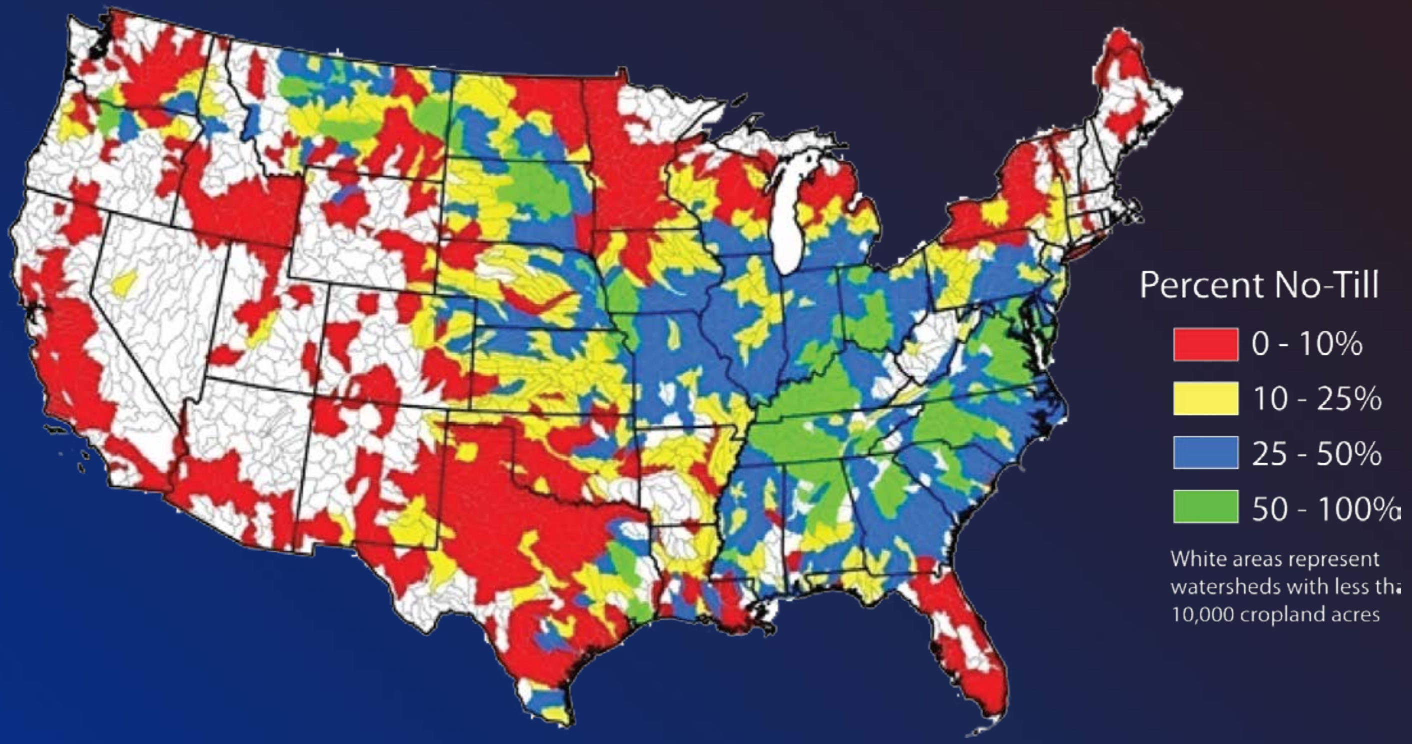
Conversion of County-Level Survey Data to Watershed-Level Data

Percent No Till for Corn



Source: Baker, N.T. 2011. Data Series 573. U.S. Geological Survey, Reston, VA. http://pubs.usgs.gov/ds/ds573/

Spatial Pattern of No Till for All Crops in U.S.



Source: Baker, N.T. 2011. Data Series 573. U.S. Geological Survey, Reston, VA.
http://pubs.usgs.gov/ds/ds573/

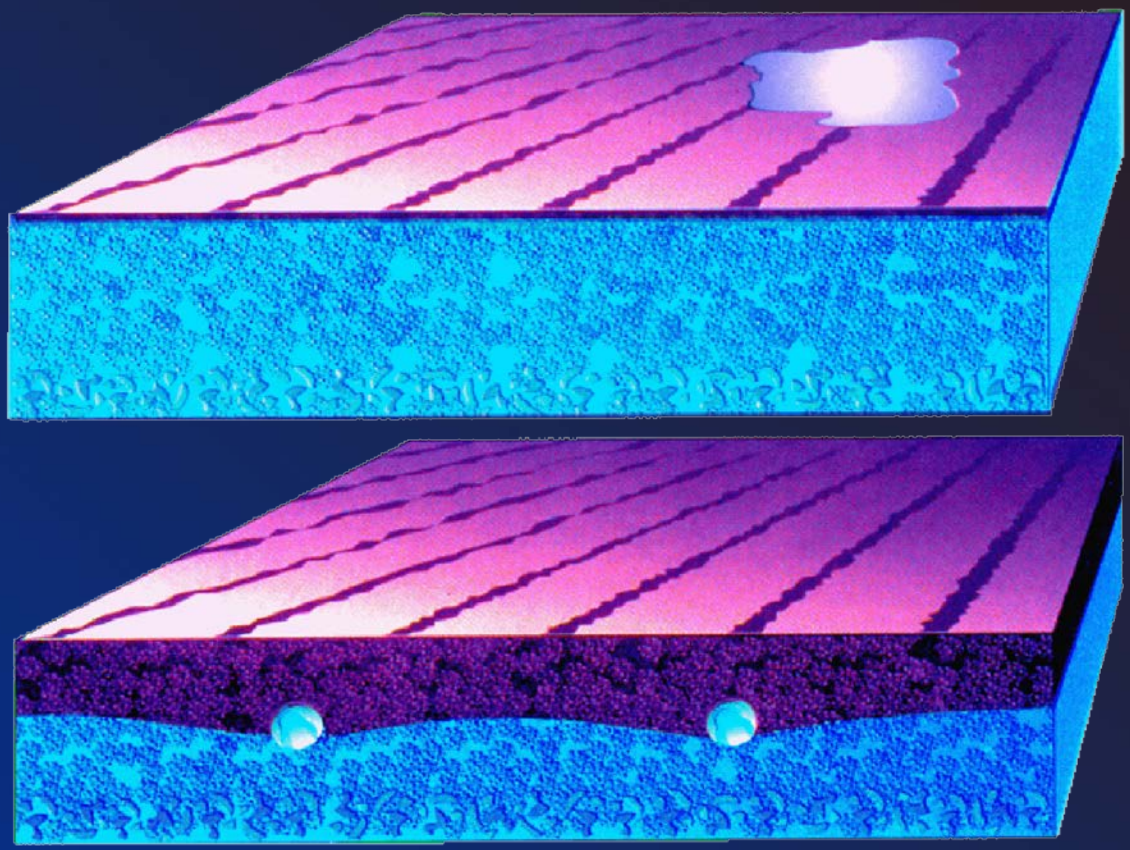
Subsurface Tile Drains

- Extensively used in portions of the UMRB and ORTB that are characterized by poorly drained soils and thus need to be drained in order to be cropped

- Subsurface tile drains have proven to be very effective for enabling cropping of “wet soils”
  - -Estimated that >95% of the original wetland areas in Iowa, Illinois, Indiana, and Ohio have been eliminated

- Unexpected consequence: excellent conduits of nitrate from cropped landscapes to Corn Belt stream systems
  - -also some transport of phosphorus and pesticides

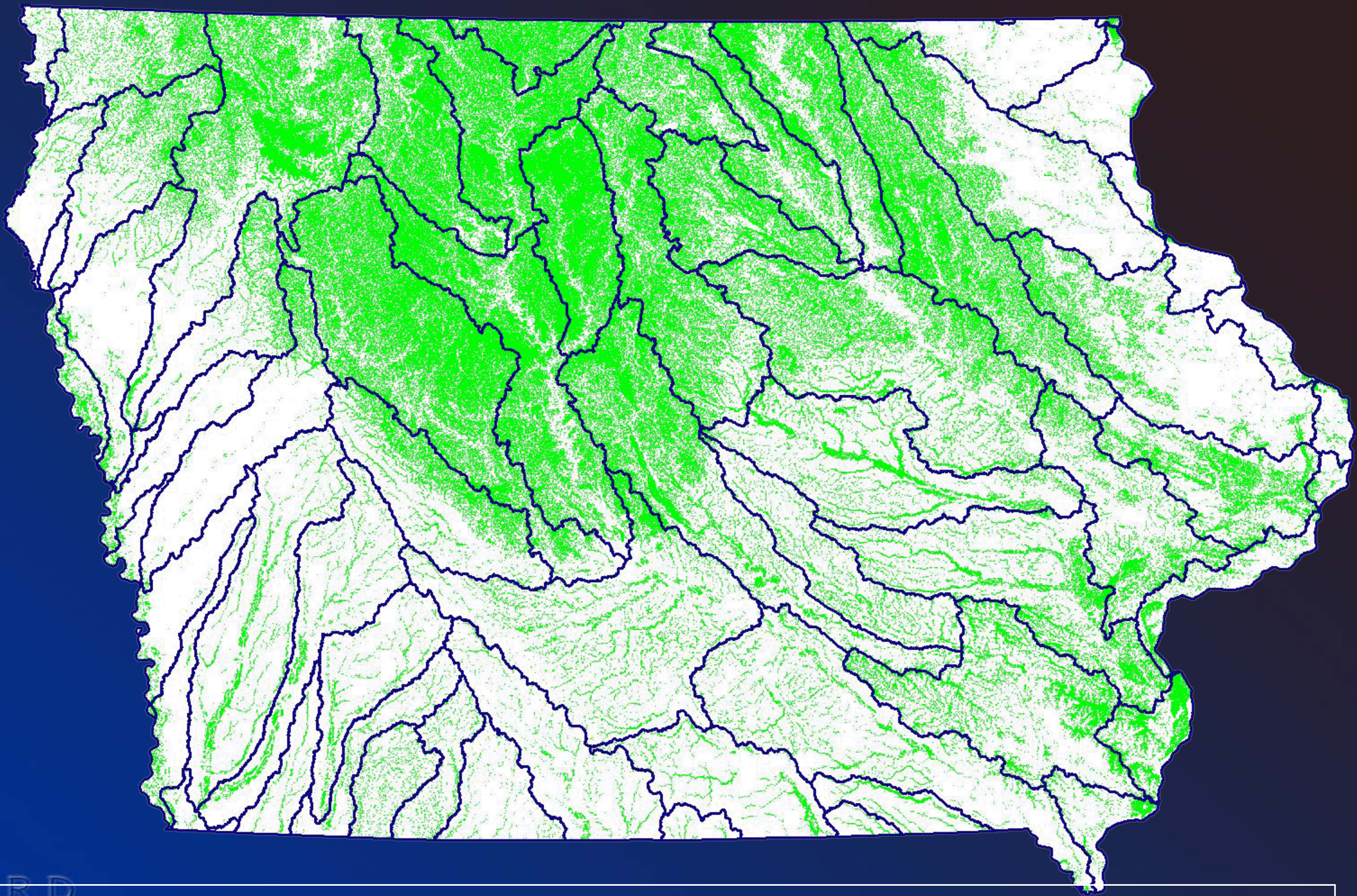
Effects of Tile Drainage on Soil Water



Adapted from: Zucker, L.A. and L.C. Brown (eds.). 1998. Agricultural Drainage: Water Quality Impacts and Subsurface Drainage Studies in the Midwest. Ohio State University Extension Bulletin 871. The Ohio State University.

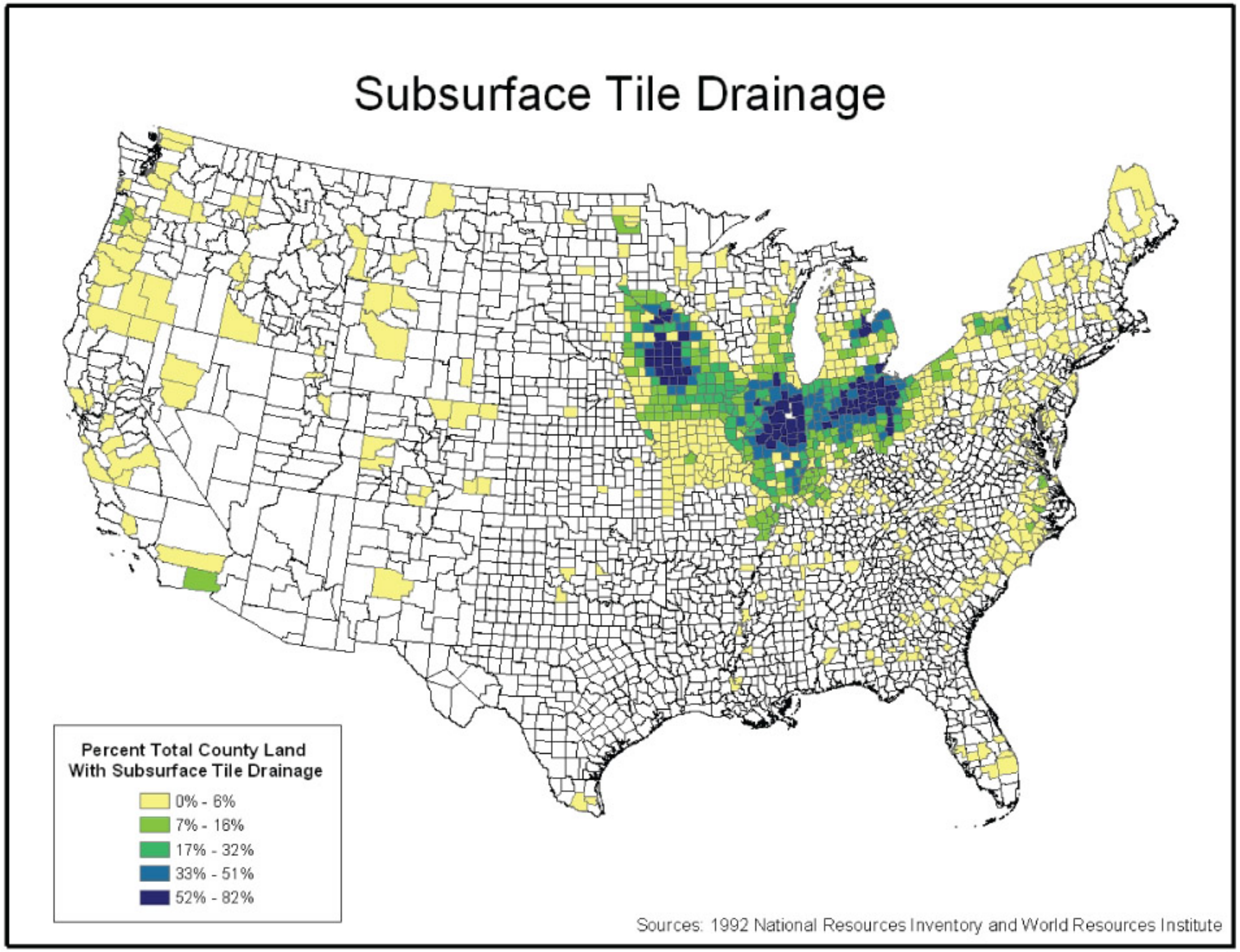

NHEL
76.3
4871
T 7699
NHEL
77.5
1442
T 2943
Putnam
IA
50.6

Locations of Hydric (Wet) Soils in Iowa



Data generated by C. Wolter, Geological Survey, Iowa Dept. of Natural Resources, Iowa City, Iowa;
Software developed by D. James, USDA National Soil Tilth Lab., Ames, Iowa

Subsurface Tile Drains by County for the Conterminous U.S.



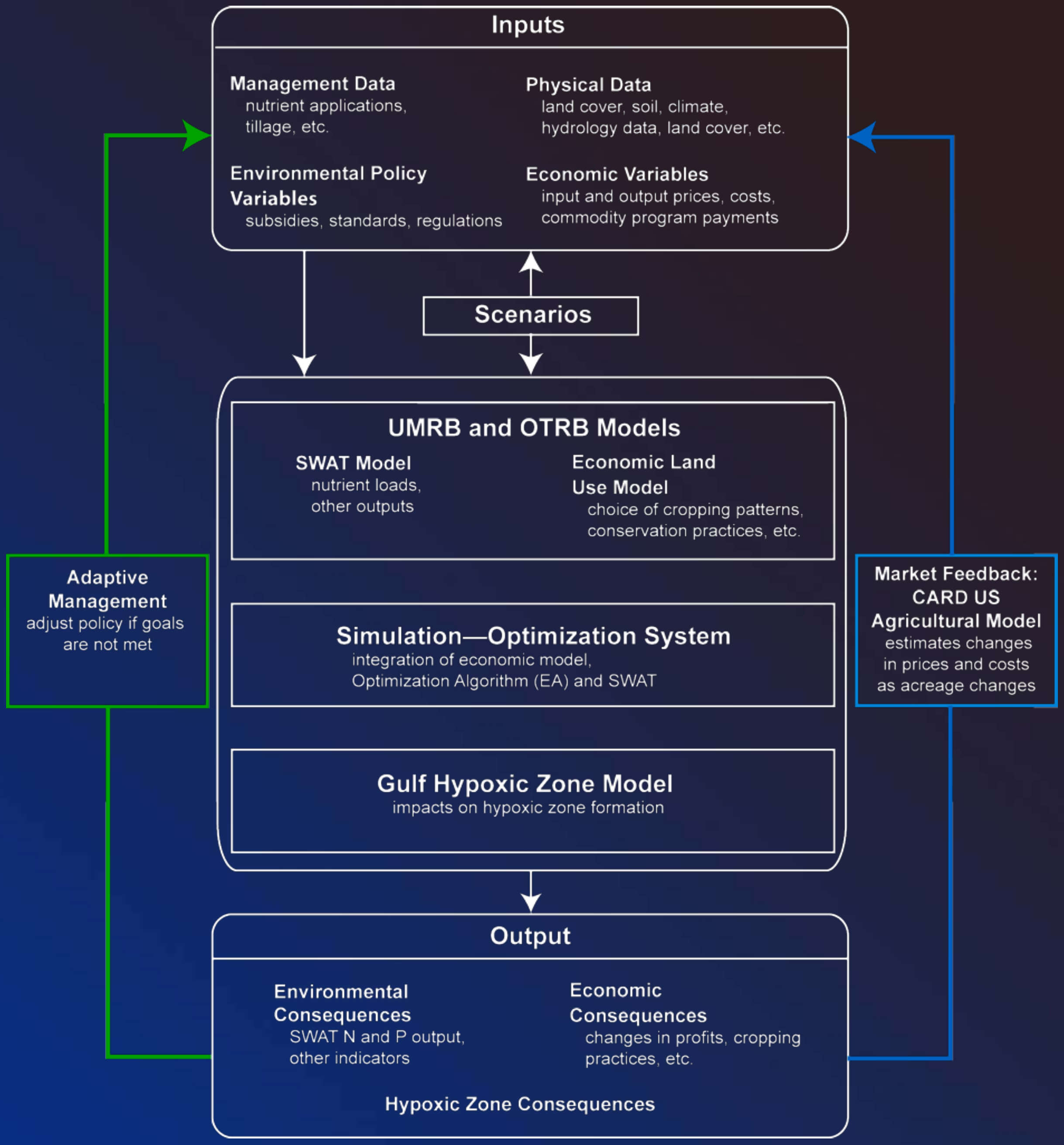
Estimation of Fertilizer and Manure Nutrient Inputs to Cropland

- Exact fertilizer and manure nutrient application rates are difficult to determine across the UMRB and ORTB
- Both survey and fertilizer sales data sources exist, but neither type of source is fully reliable
- Nutrient Use Geographic Information System (NuGIS)
  - -U.S. Nutrient balance database developed by the Inter. Plant Nutrition Institute (IPNI)
  - -Will be used to estimate nutrient application rates
  - -http://www.ipni.net/nugis

Next Steps

- Finish incorporating detailed management data into 12-digit models
- Also finish refinements of other components (e.g., other conservation practices, reservoirs, point sources)
- Perform calibration and validation of UMRB and ORTB 12-digit models and execute scenarios
- Also interested in comparing these models with UMRB and ORTB 8-digit models

Modeling System Flow Chart



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

Data from 12308 farm fields sampled in the drainage area:

- 3 years of detailed farm management
- Conservation district office conservation plan records
- National Resource Inventory and Soil Survey data
- 47 years of daily weather

- Detailed biophysical model of cultivated cropland with APEX model used as edge-of-field loads in SWAT
- Modeled other land types and point sources using SWAT

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:

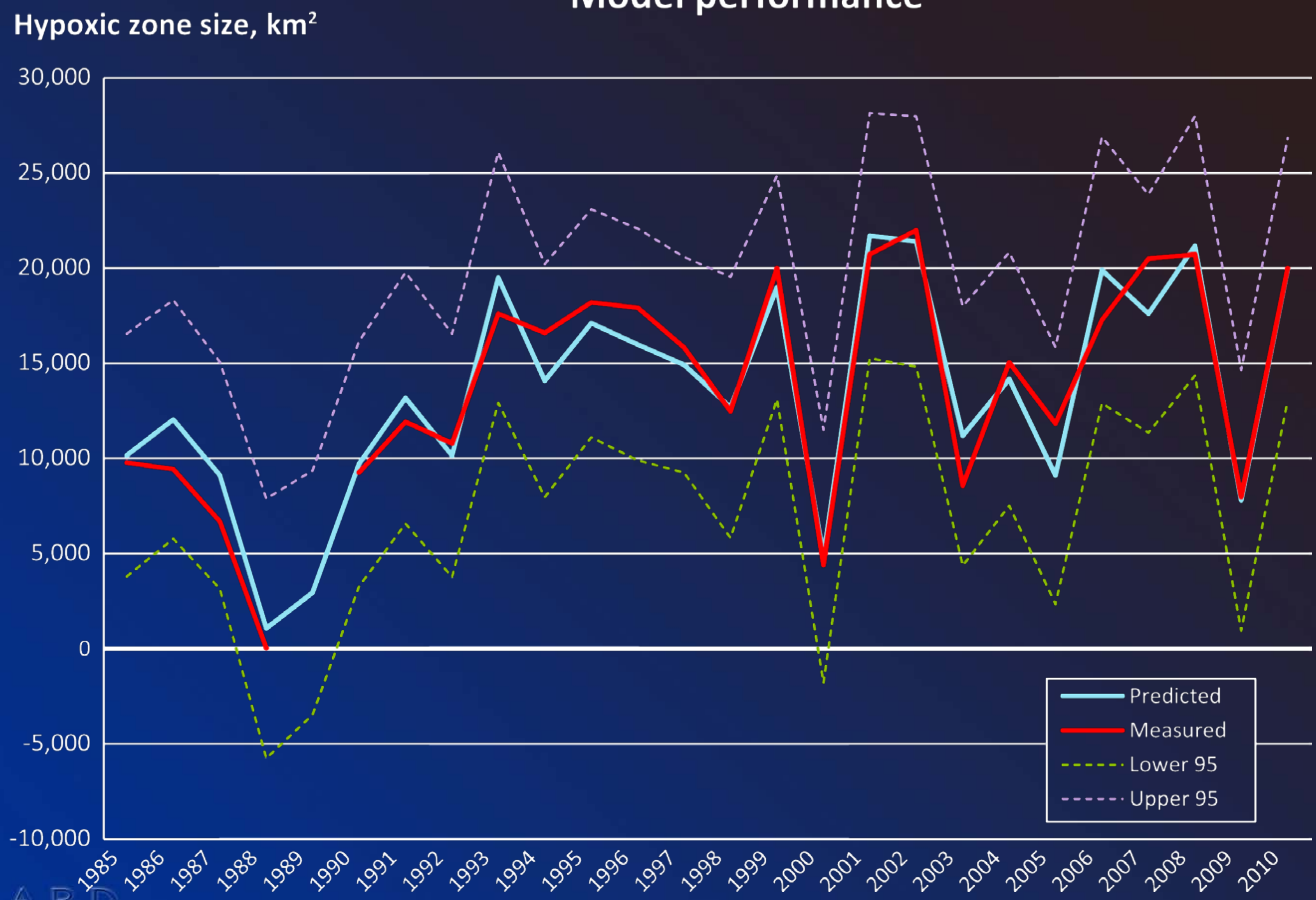
$$HypoxicZone_t = \beta_{intercept} + \underset{(-)}{\beta_{hurricane}} Hurricane_t + \underset{(-)}{\beta_{current}} Current_t$$

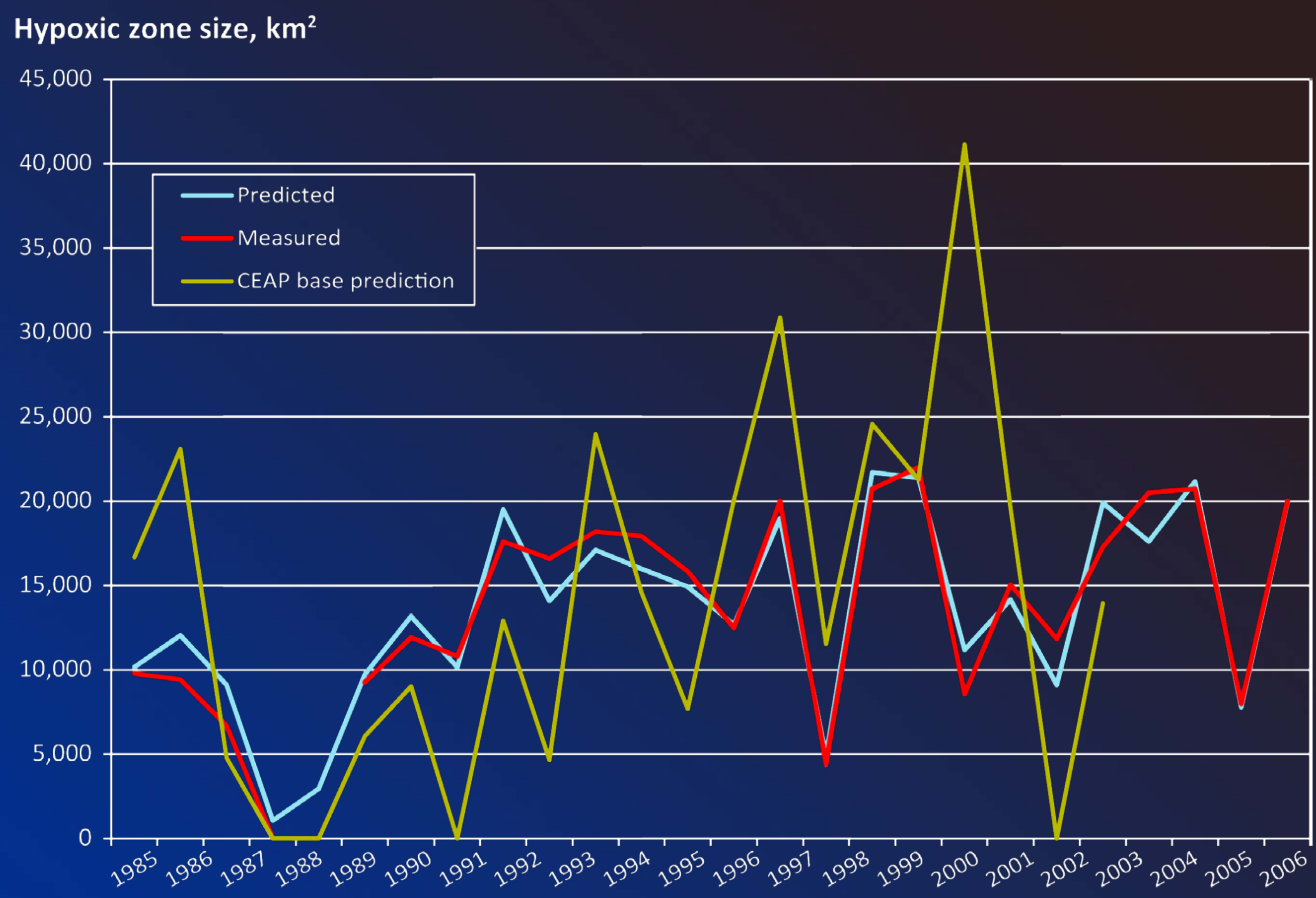
$$+\underset{(+)}{\beta_{hurrN}} Hurricane_t * N_t + \underset{(-)}{\beta_{hurrP}} Hurricane_t * P_t + \underset{(+)}{\beta_N} N_t$$

$$+ \sum_{i=0}^{5} \beta_{i,P}\, P_{t-i} + \sum_{i=0}^{5} \beta_{i,NP} N_{t-i} P_{t-i} + \varepsilon_t$$

where $N_t = log10(N\ load\ at\ time\ t)$ and $P_t = log10(TP\ load\ at\ time\ t)$.

Model performance




Hypoxic zone size, km²
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Predicted
Measured
CEAP base prediction
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
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2003
2004
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2006
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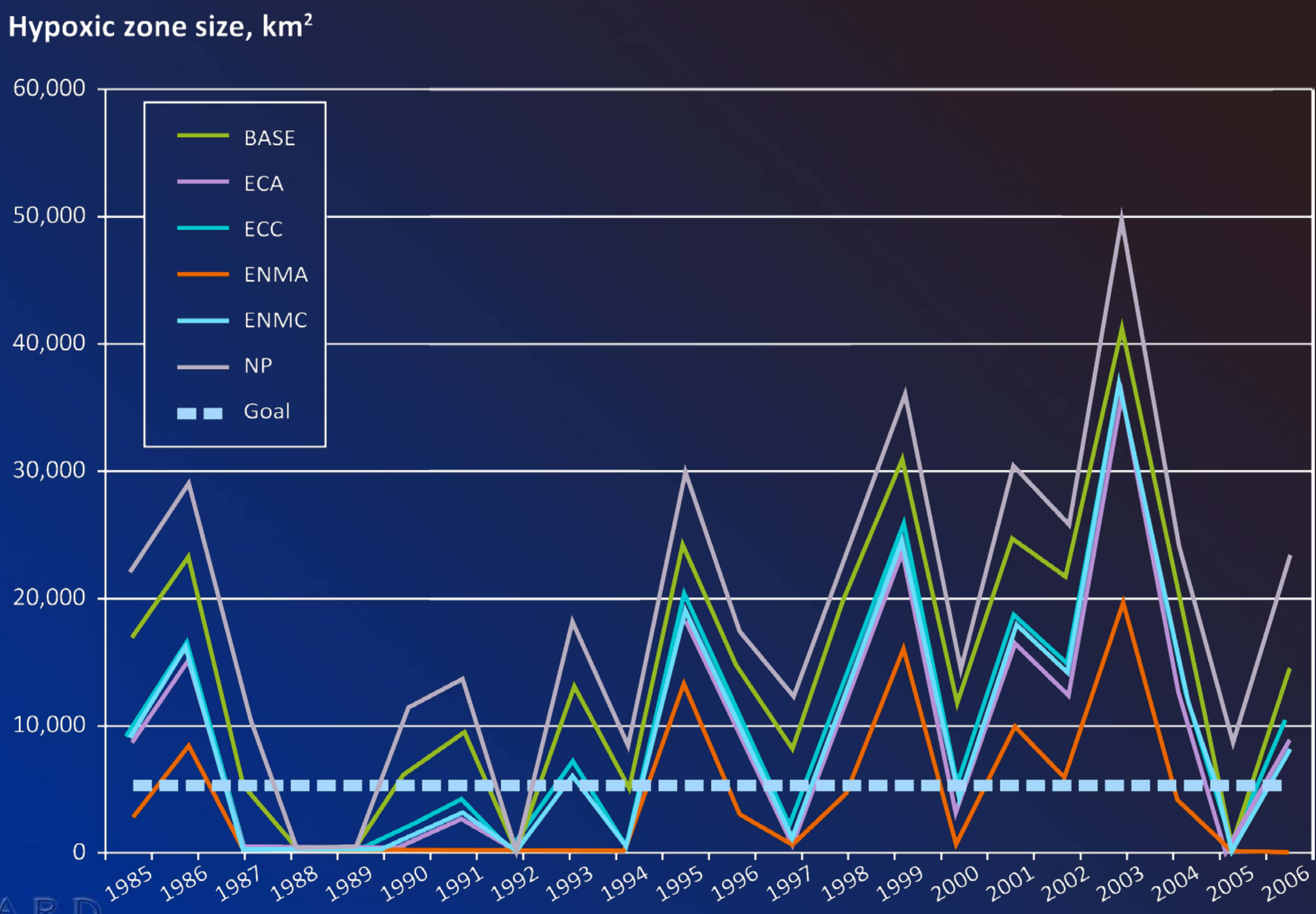
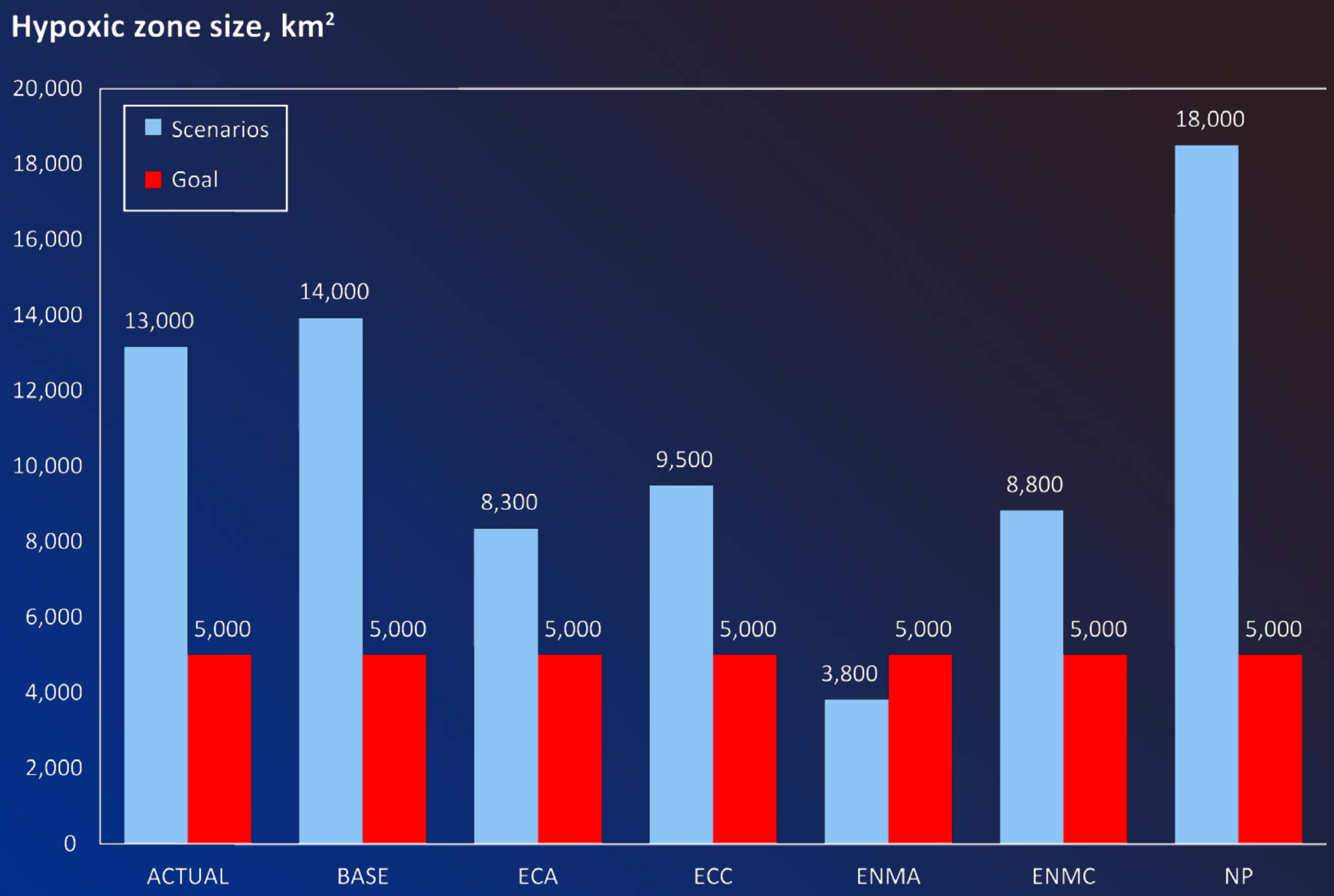


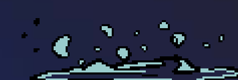
Hypoxic zone size, km²
60,000
50,000
40,000
30,000
20,000
10,000
0
BASE
ECA
ECC
ENMA
ENMC
NP
Goal
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006



Hypoxic zone size, km²
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Scenarios
Goal
13,000
14,000
8,300
9,500
3,800
8,800
18,000
5,000
5,000
5,000
5,000
5,000
5,000
5,000
ACTUAL
BASE
ECA
ECC
ENMA
ENMC
NP

Research Needs and Future Directions

- Valuing Damage to Ecosystem when:
  - Large areas impacted, SR mortality, alterations to food web, habitat, reproductive effects
  - but thus far, not major effects in aggregate
  - Uncertainty: LR effects, thresholds, irreversibilites, biodiversity effects…?
- Policy Design:



  - nonpoint source pollution, can voluntary (US) programs work?