Reducing the Gulf of Mexico Dead Zone: how integrated water quality modeling can help design cost effective solutions

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Once a TMDL has been set for a water body

A: This means that enforceable standards applying to both point and nonpoint sources are immediately triggered.

B: This means that enforceable standards applying only to non point sources are immediately triggerred.

C: This means that the sources of the impairment have been identified as well as the maximum daily load that the water body can sustain and still be unimpaired

D: No one knows what this means because a TMDL has never succesfully been developed .

GET IT YOU!!! YOU'RE AWESOME!!!!

- YOU GOT THAT GOOGLE APP DIDN'T YOU??
- YOU DESERVE AN A+ FOR DECIPHERING ACRONYM SPEAK!!!

Tile Drains being installed in agricultural land

Photos: Matt Helmers

Sizing the drain pipe

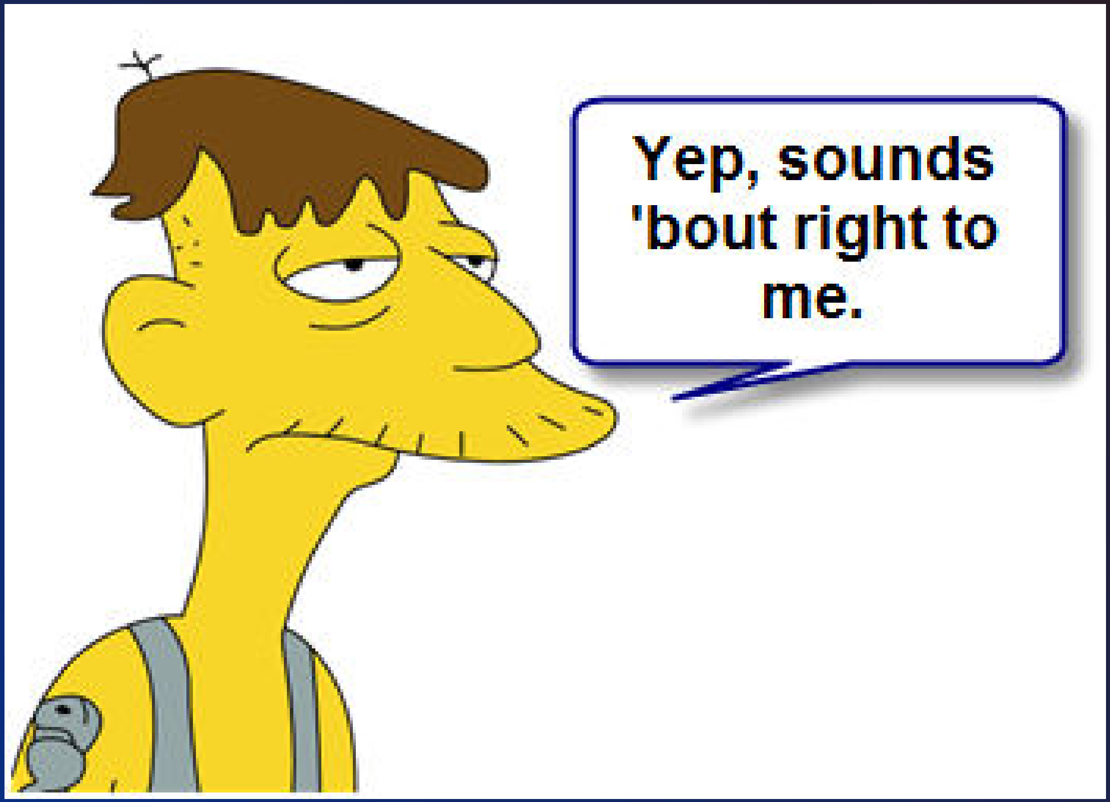
(slides from Chris Hay, Extension Water Management Engineer, ABE, South Dakota State University

Photo: ARS

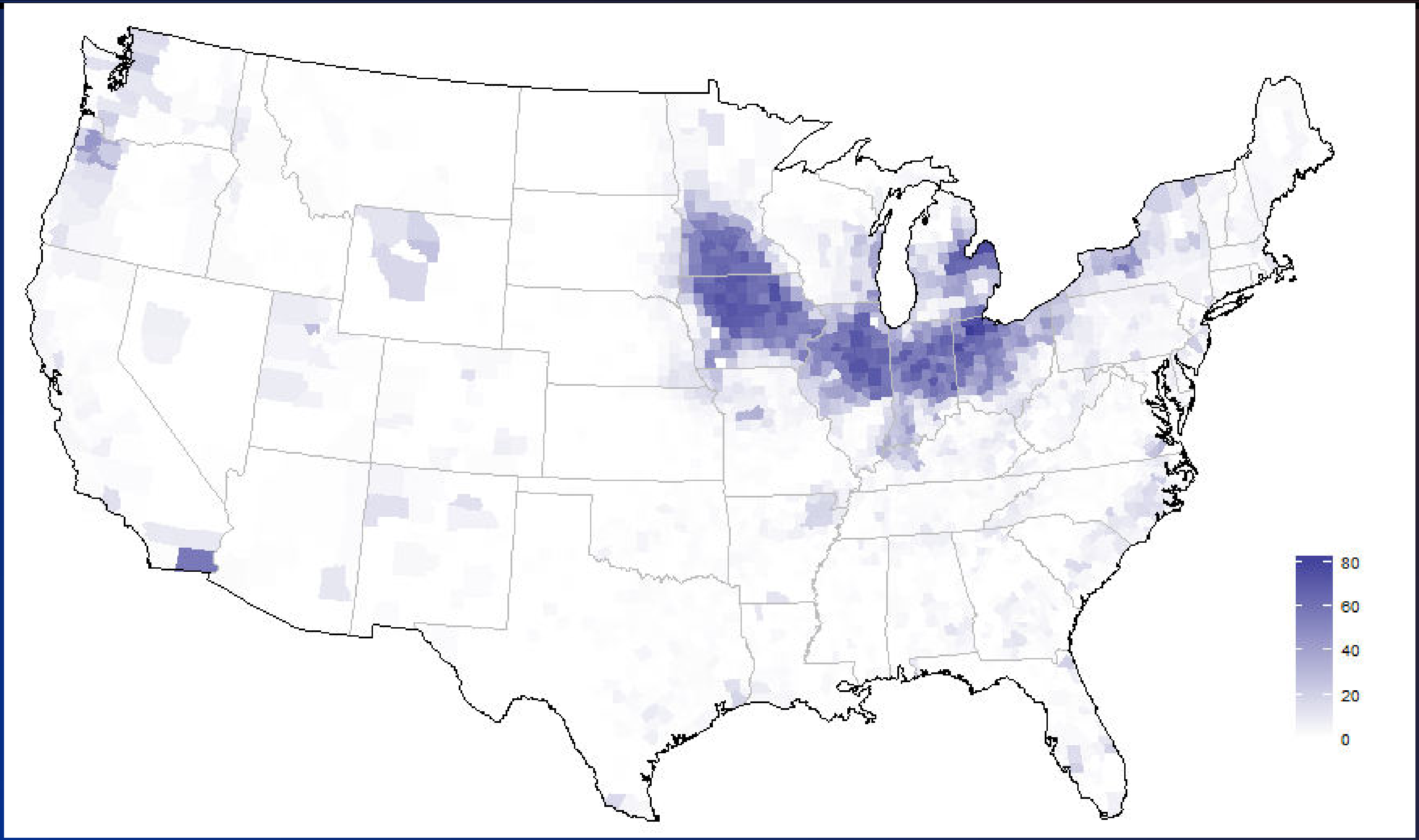
Installing tile drainage in agricultural fields

A:	Barely increases yields and profitably, but causes significantly increased nutrient (esp. Nitrogen) runoff
B:	Is a common practice over about a quarter of the cornbelt
C:	Can be regulated as a point source since the drain is clearly a conduit for the nutrient pollution
D:	Is a common practice over about 5% of the corn belt

WRONG ANSWER

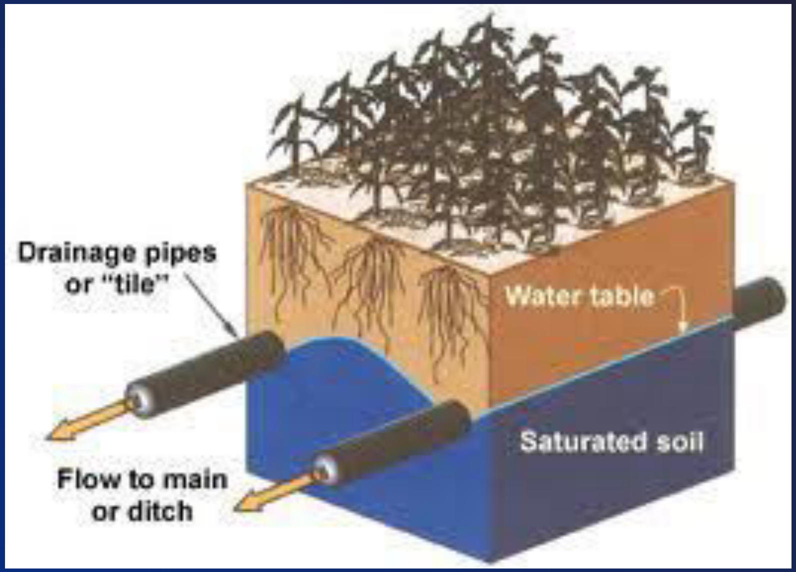

Yep, sounds 'bout right to me.

A lot of Cropland is Drained



Source: 2012 US Census of Agriculture

Nonpoint source or point source



Lowell Busman and Gary Sands

Runoff of these nutrients from agricultural fields

A: Are key contributors to eutrophication and hypoxic zones in the midwest and other agriculturally intense watersheds

B: Are explicitly defined as nonpoint sources in the Clean Water Act and are exempt from permit requirements

C: Both A and B

D. Is not pollution since these are naturally occuring and all they do is contribute to plant growth --- clearly a good thing silly fools!

I am sorry, that's the

WRONG ANSWER!

I Cannot Believe You Knew the Answer

Gulf of Mexico Dead Zone and Watershed, MARB

http://www.umces.edu/people/boesch-gulf-mexico-hypoxia

The Gulf of Mexico

Image courtesy of Nancy Rabalais (Louisiana Universities Marine Consortium) and can be found on the Southern Regional Water Program web site.

The previous picture (taken in the Gulf of Mexico) depicts

A. The meeting of the hypoxic zone with the unaltered ocean

B. Icky sediment filled water the Mississippi River meeting up with pure blue ocean water.

C. Sludge dumped from an oil tanker on its way into port.

D. The solvent used in the BP oil spill to break up the oil for easier clean up

CARD


I'M SORRY,... BUT THAT'S THE WRONG ANSWER.

Yes, that is the correct answer!

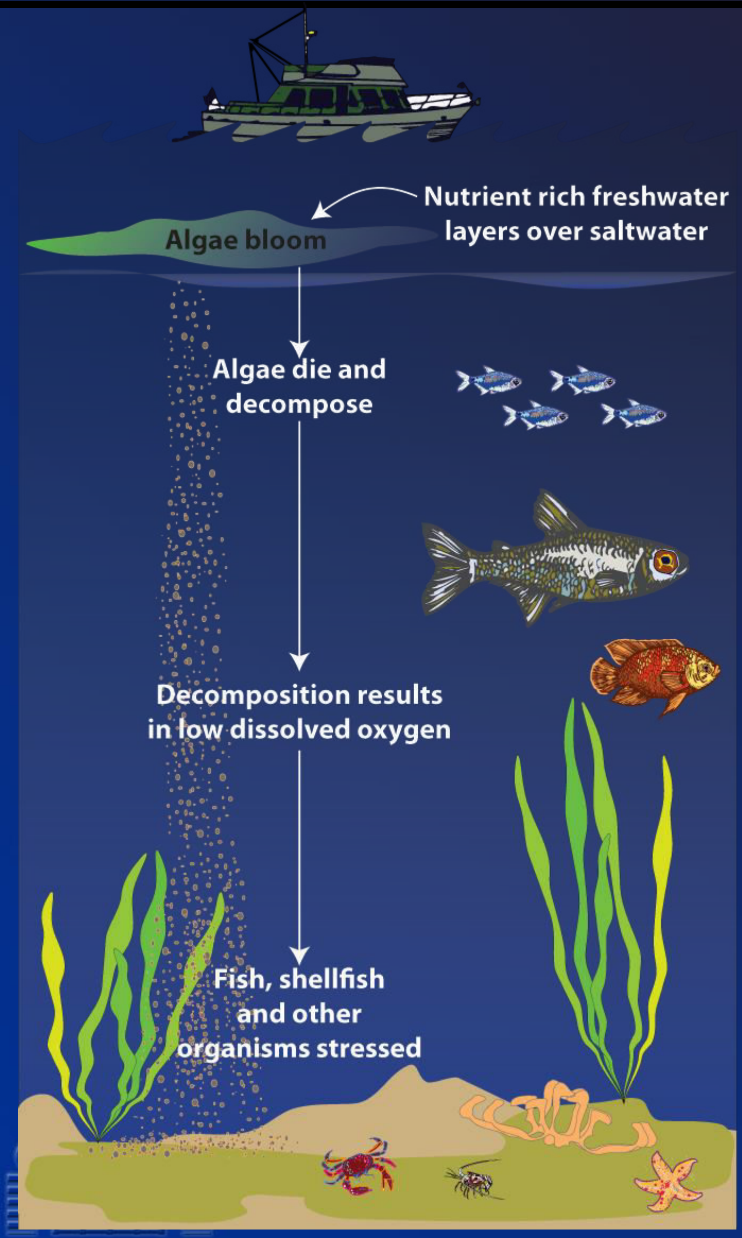
Hypoxia in coastal and freshwater systems

A. Occurs when the oxygen content of saltwater is significantly higher than normal
B: Refers to an annually recurring area of the Gulf where oxygen levels are so high that many organisms become huge
C: Refers to the way most undergraduates feel after their first economics lecture.
D. Refers to an annually recurring area of the Gulf where oxygen levels are so low that anything that cannot swim out of the zone dies

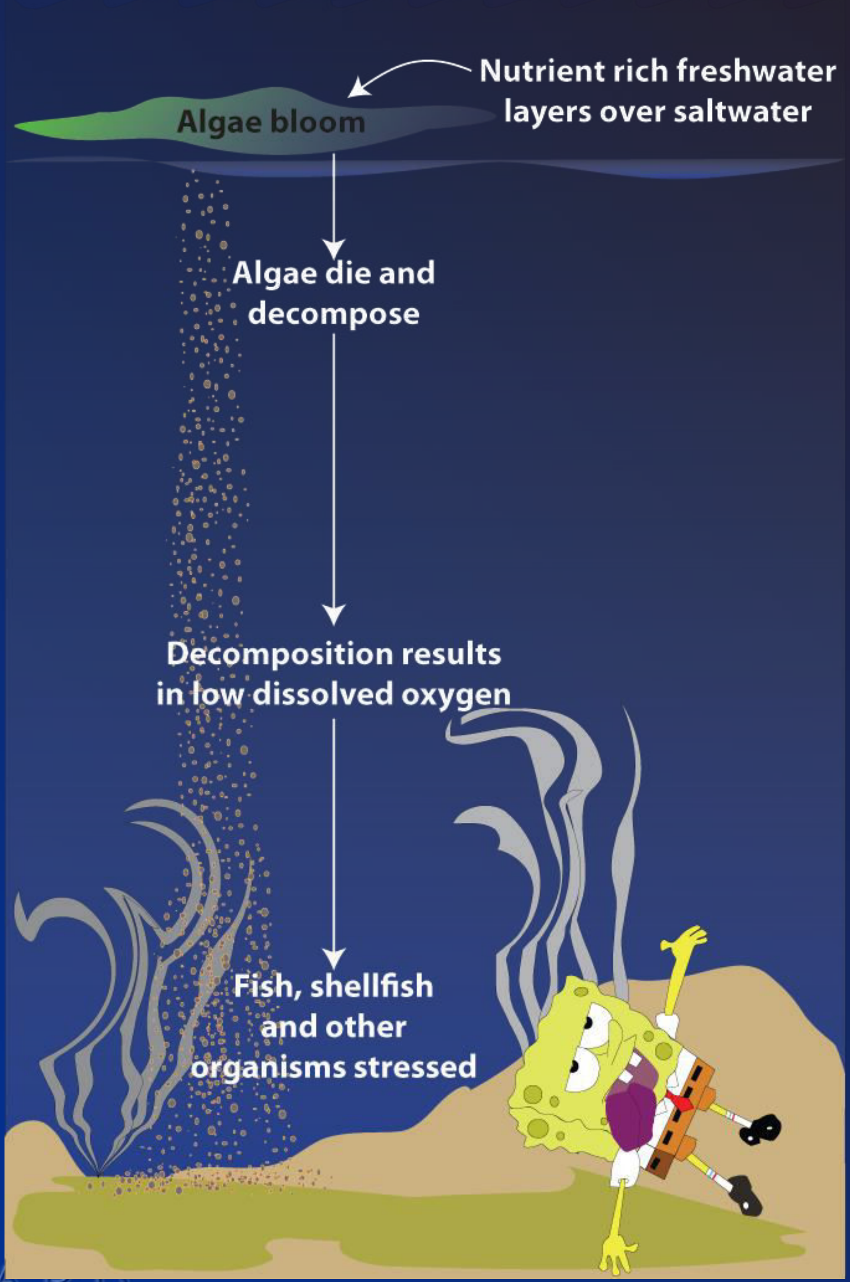

GOOD ANSWER! BUT IT'S NOT WHAT WE'RE LOOKIN' FOR!

That is Right!!

Hypoxia = Dead Zone



- 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 (Diaz and Rosenberg, 1995).
- In other words ….



Intelligent life is threatened

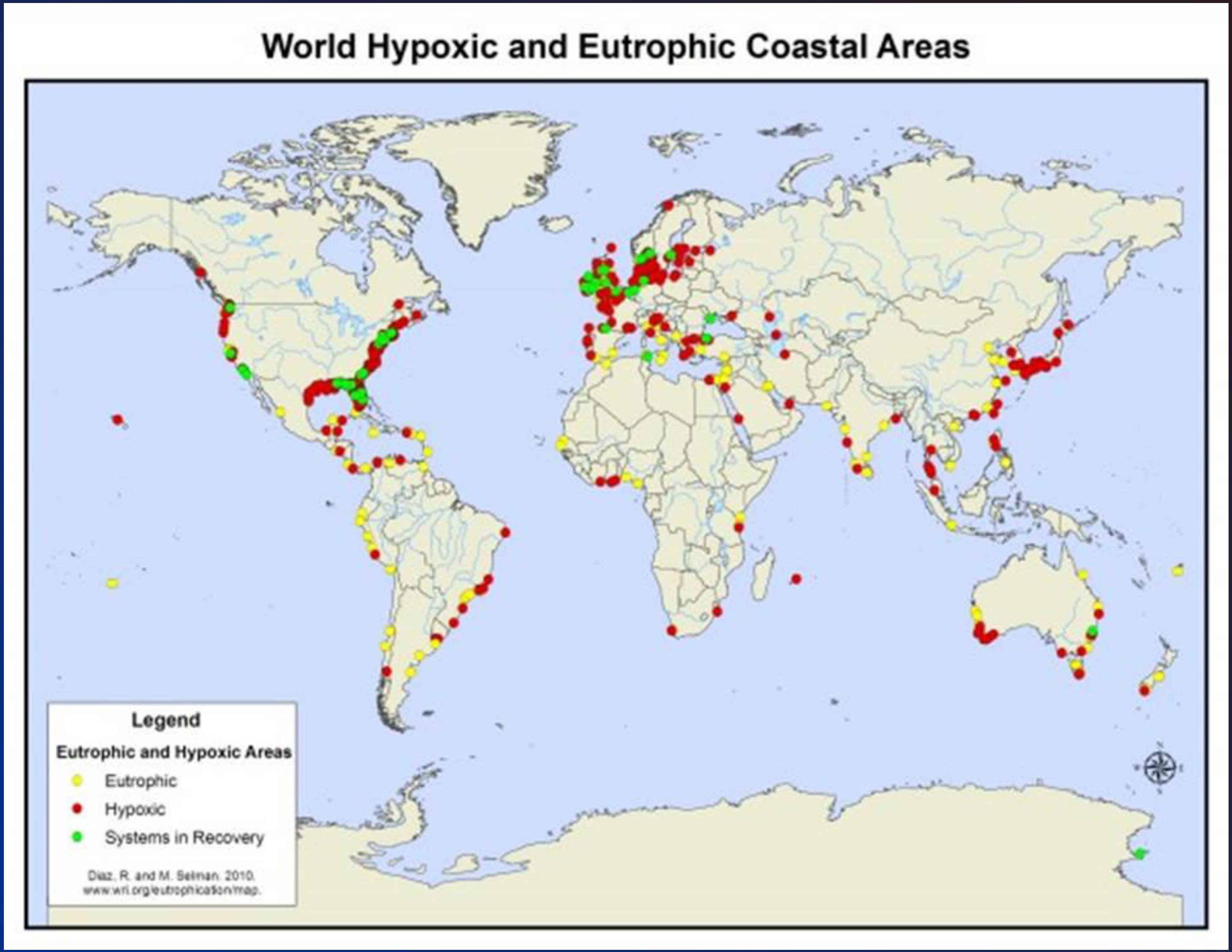
The number of hypoxic zones around the world is about

A.	1000
B .	150
C:	400
D.	25

Nope, that’s not right.

By Jove I think that's it!

Hypoxia and eutrophication globally



From World Resources Institute at http://www.wri.org/map/world-hypoxic-and-eutrophic-coastal-areas

Nitrogen and Phosphorus (nutrient) deliveres to the Gulf of Mexico

A:	Originate primarily from Oklahoma City
B:	Originate primarily from the irrigated area west of the Missouri River
C:	No one knows because this stuff is too hard to trace and who care anyway?
D.	Originate from both urban and rural sources with a big chunk coming from agricultural row crop land in the central corn belt.

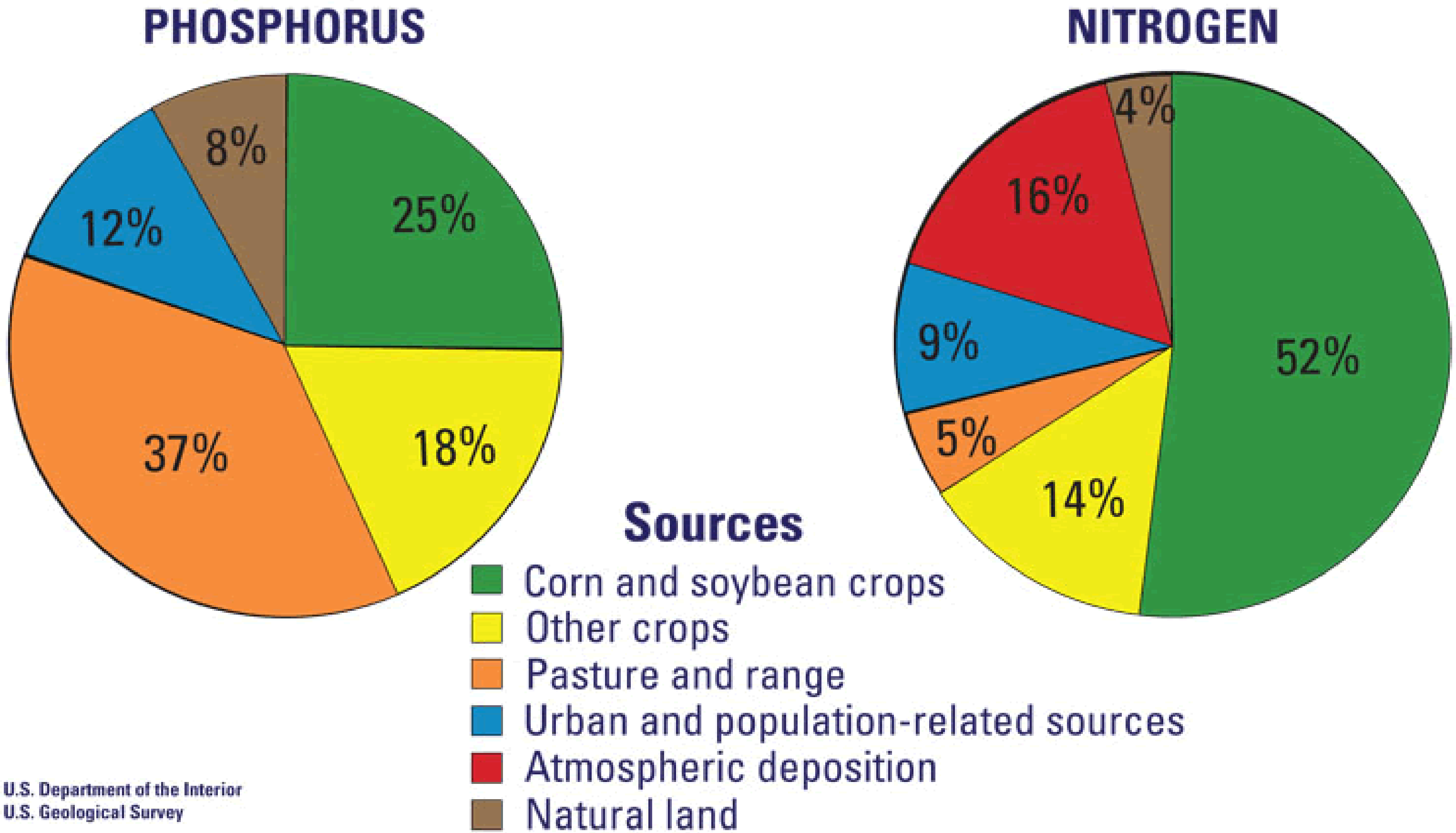
That's FALSE!!
Because I said so!

CARD

Did you really guess the right answer?

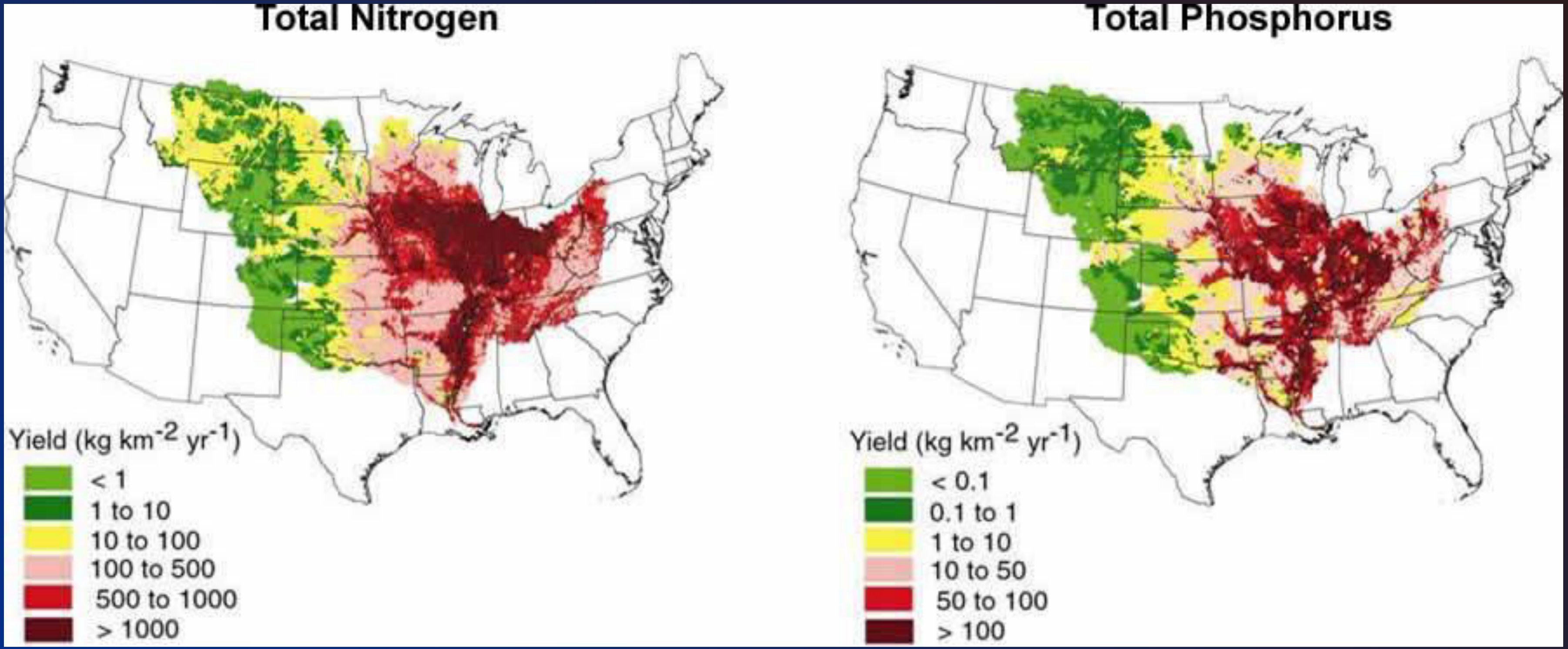
USGS
science for a changing world

Sources of nutrients delivered to the Gulf of Mexico



U.S. Department of the Interior
U.S. Geological Survey

Nutrient deliveries to the Gulf of Mexico
Source: USGS



- **52% of N from corn and soybean**

The size of the 2015 ‘dead zone’ in the Gulf was about the size of:

A: Connecticut

B: Norman, OK

C: New Jersey

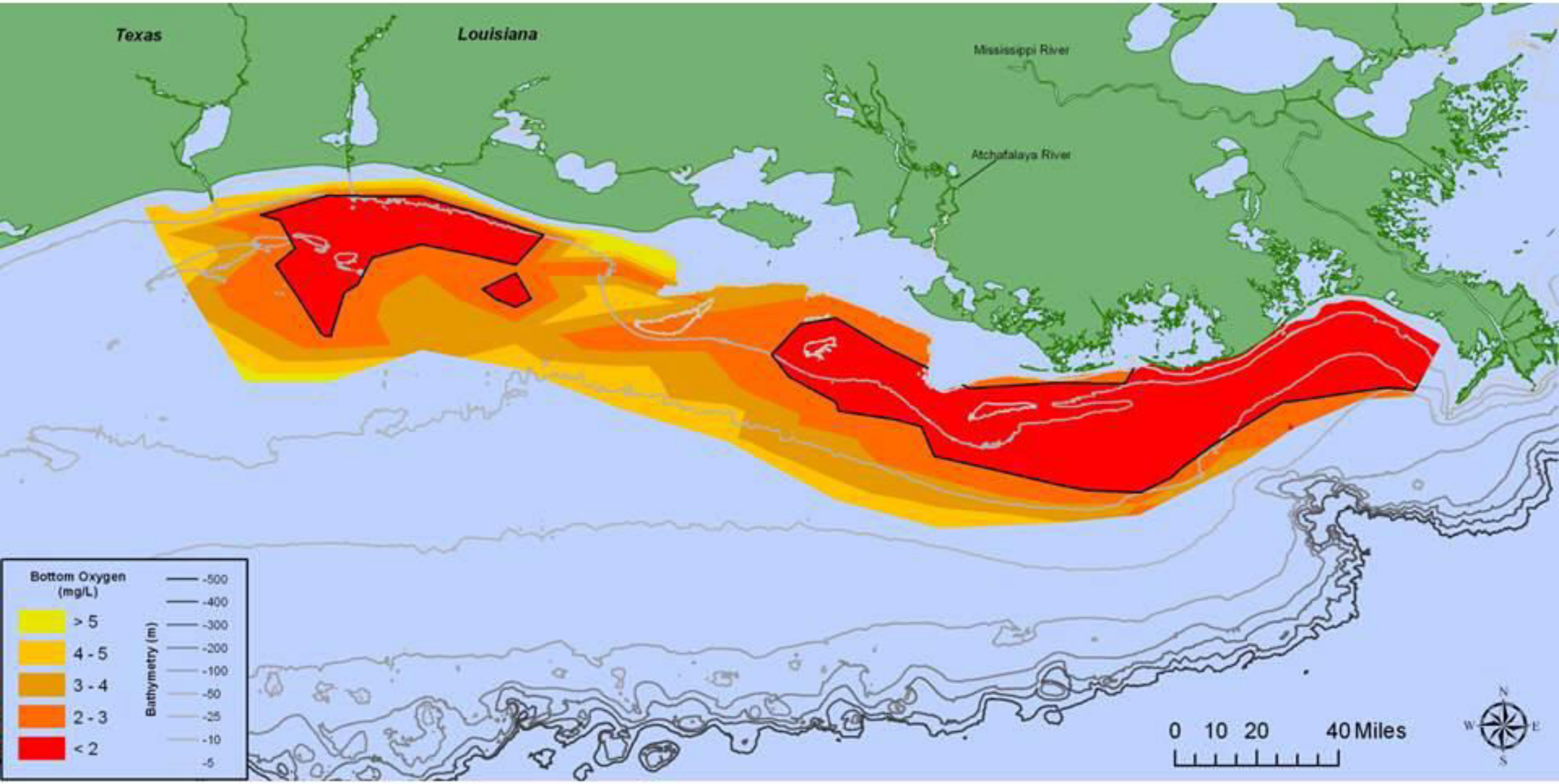
D. Oklahoma

X

Sorry, that’s the wrong answer!

Right on Target!

Bottom-water Dissolved Oxygen – 2014

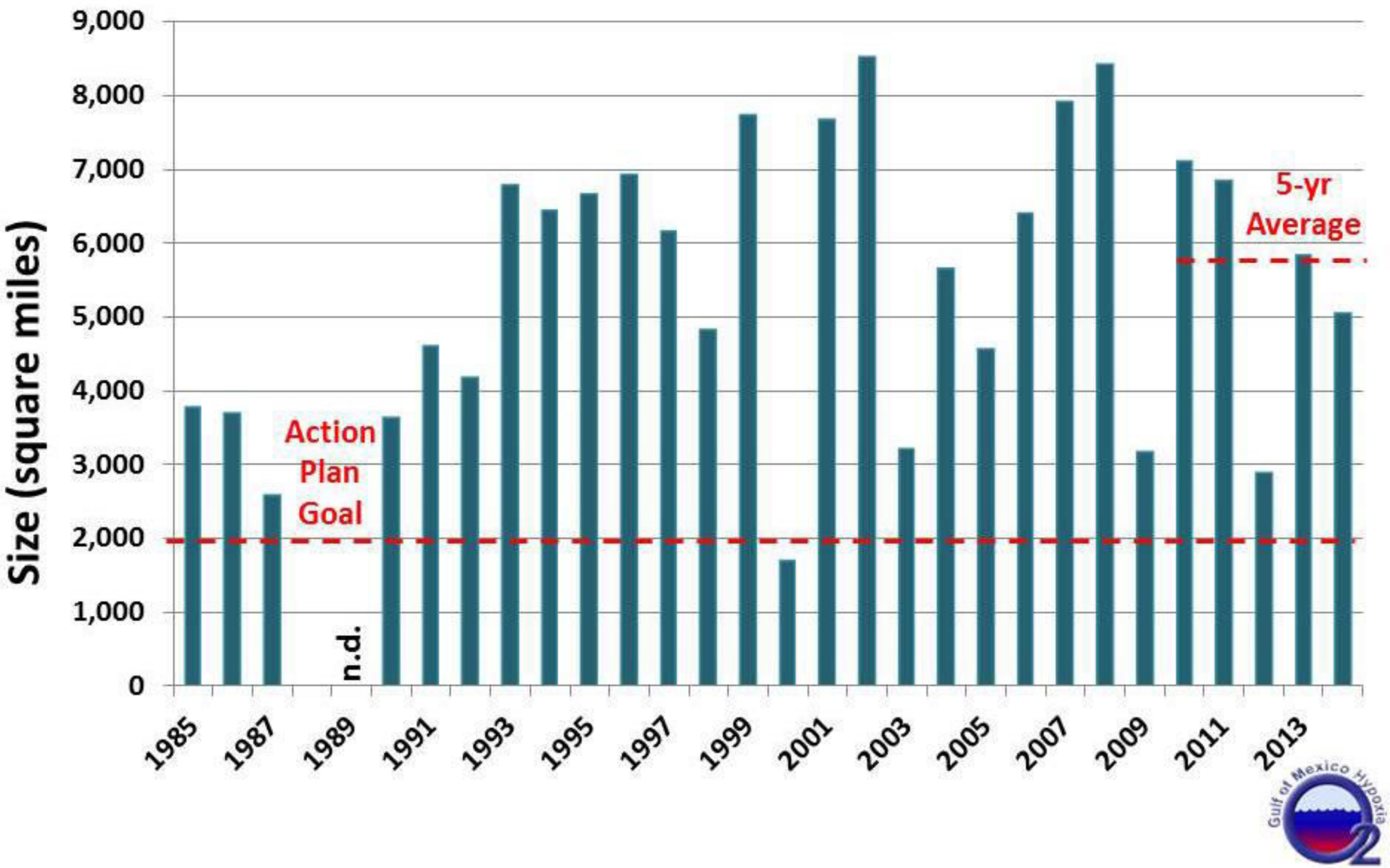


Distribution of bottom-water dissolved oxygen July 27-August 1 (west of the Mississippi River delta), 2014. Black line indicates dissolved oxygen level of 2 mg/L.

Data source: Nancy N. Rabalais, LUMCON, and R. Eugene Turner, LSU

Funding sources: NOAA Center for Sponsored Coastal Ocean Research and U.S. EPA Gulf of Mexico Program

Northern Gulf of Mexico Hypoxia



How does this harm ecosystem services?

Micro (species) level

– death, reduced reproductive success, interruptions of food webs, lost habitat, increased predation

Macro level (fish stock, catch etc.) in Gulf of Mexico

– Minimal evidence of impacts
– Mobile species exit zone, move outside,
– Evidence lacking or no real effect?

What abatement options exist?

- Structural Practices
  - Buffers
  - Grassed Waterways
  - Denitrification, controlled drainage
  - Wetland restoration

Photo courtesy Missouri NRCS

What abatement options exist?

- In field Management Practices
  - Reduced (no) tillage
  - Manure, fertilizer management/reduction
  - Cover crops, rotation changes
  - Land retirement

Panoramic view of gamma grass-big blue stem planting
http://www.fsa.usda.gov/Internet/FSA_Image/ia_767_15.jpg

Many Abatement Options

Buffers and Terracing

Reduced tillage

Grassed Waterways

Our Research

Rabotyagov, S., T. Campbell, M. White, J. Arnold, J. Atwood, L. Norfleet, C.L. Kling, P.W. Gassman, A.M. Valcu, J. Richardson, R.E. Turner, and N.N. Rabalais, "Cost-Effective Targeting of Conservation Investments to Reduce the Northern Gulf of Mexico Hypoxic Zone," ***Proceedings of the National Academy of Sciences*** 111:52(2014): 18530-18535

Results of a large integrated model, purpose to estimate the costs of achieving reductions in hypoxic zone size.

1. Landscape scale watershed-based model of agricultural land use
   - How do changes in agricultural practices change nutrient runoff at each location
   - How much of these nutrients get to the gulf
   - How much do these practices cost

   National CEAP Assessments: Major NRCS/USDA effort

2. Hypoxic zone model – how does change in nutrient change size of hypoxic zone

3. Evolutionary Algorithm: simulation-optimization framework – what is least cost way to achieve hypoxia reduction goal

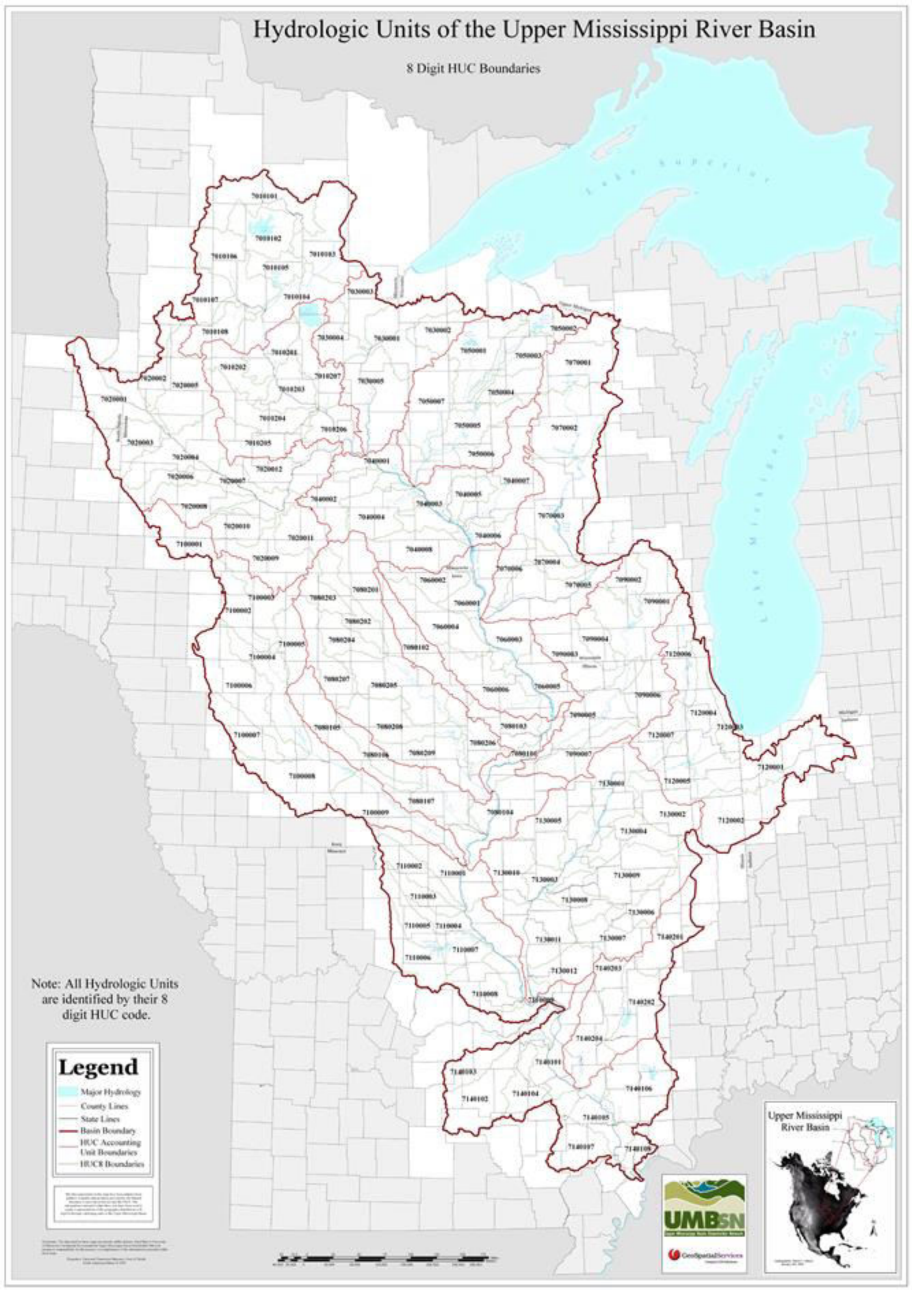
Soil and Water Assessment Tool

- 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 Team

Gulf of Mexico Dead Zone and Watershed, MARB

http://www.umces.edu/people/boesch-gulf-mexico-hypoxia



1. CEAP (USDA,NRCS Team)

- Used 3 years of detailed farm management data, NRI, soil survey, conservation plan records, 47 years of weather to populate model
- 131 sub-basins in UMRB
- Six conservation scenarios:
  1. Baseline: Assessment of existing set of conservation practices
  2. Erosion Control Critical areas only
  3. Erosion Control Critical All needed areas
  4. Nutrient Management Critical area only
  5. Nutrient Management All
  6. BACK, retire all agricultural land

2. Empirical hypoxic zone model

$$Hypoxic\ Zone_t = \beta_{intercept} + \beta_{hurricane} Hurricane_t +$$

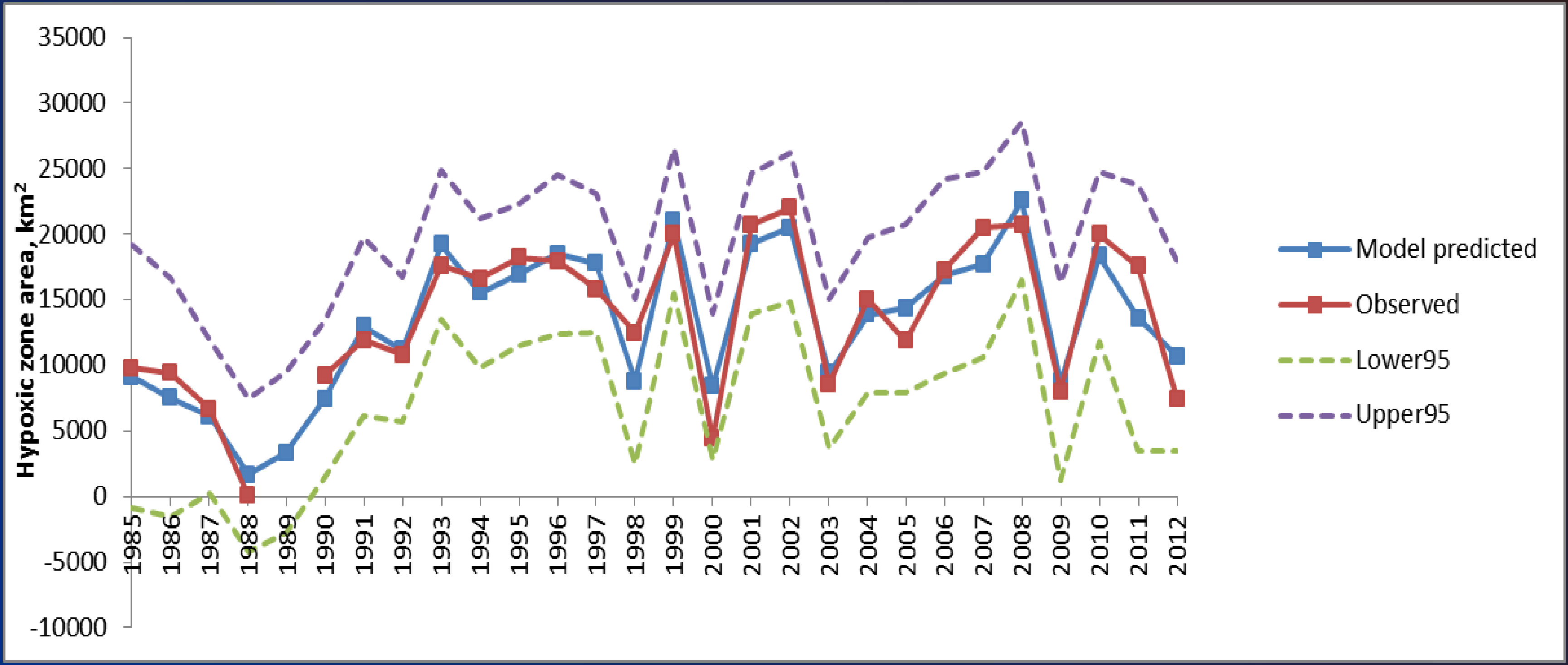
$$\beta_{current} Current_t + \beta_{hurrSN} Hurricane_t * log10(Nstock5_t)$$

$$+\beta_{hurrSP} Hurricane_t * log10(Pstock5_t) + \beta_N P_t$$

$$+\sum_{i=0}^{5} \beta_{i,N} N_{t-i} + \beta_{Nstock5} Nstock5_t + \beta_{Pstock5} Pstock5_t + \varepsilon_t$$

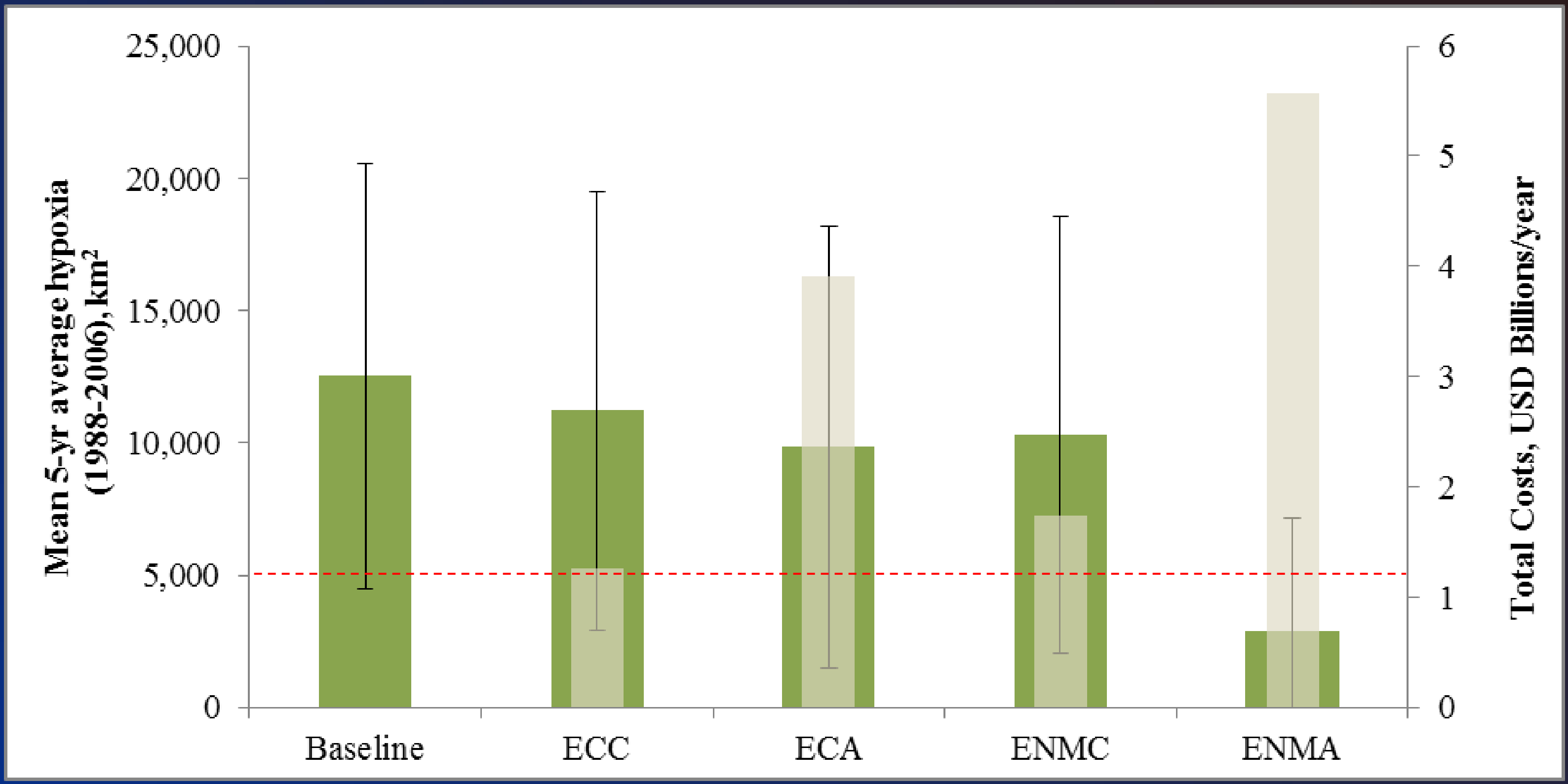
- Rabotyagov: model allows lagged nutrient inputs without using up many degrees of freedom (Polynomial distributed lag model)
- USGS data estimates, LUMCON data on size of zone

Model performance



- Regression R^2=0.95 (we are mostly interested in the structural part, as opposed to prediction)
- Leave 2011 and 2012 observations out of estimation and see how well the model does in terms of prediction

Scenario evaluation



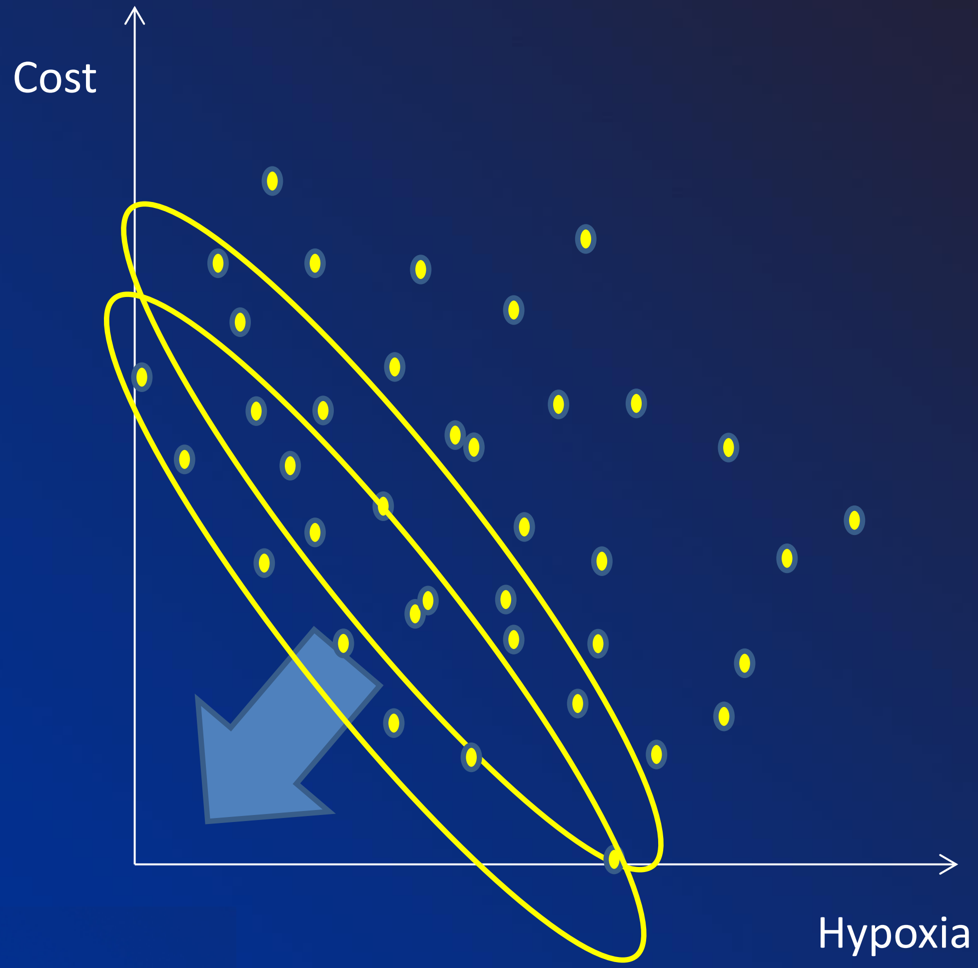
- Application of CEAP scenarios to all watersheds
- Land retirement everywhere eliminates hypoxia

3. Evolutionary Algorithm

- Can we do better by targeting? Instead of treating all 848 sub-watersheds, can we aggressively treat some and achieve cost savings and dead zone reductions?
  - 848 subwatersheds in five major basins
  - 6 options for each subwatershed
  - Thus, 6^{848}= REALLY BIG NUMBER

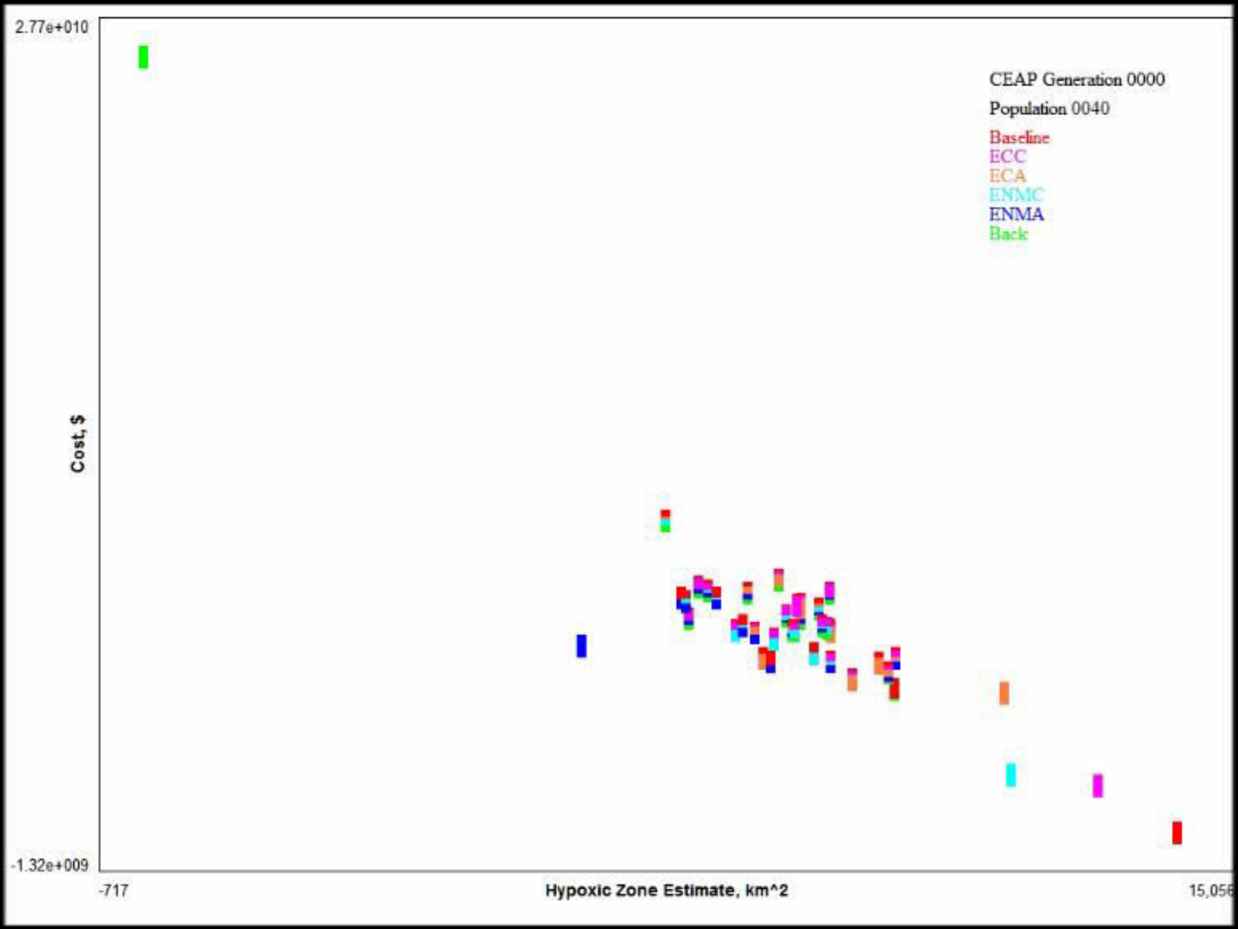
- Evolutionary algorithms are methods to intelligently search through these options without having to evaluate them all

Evolutionary Algorithm --intuition



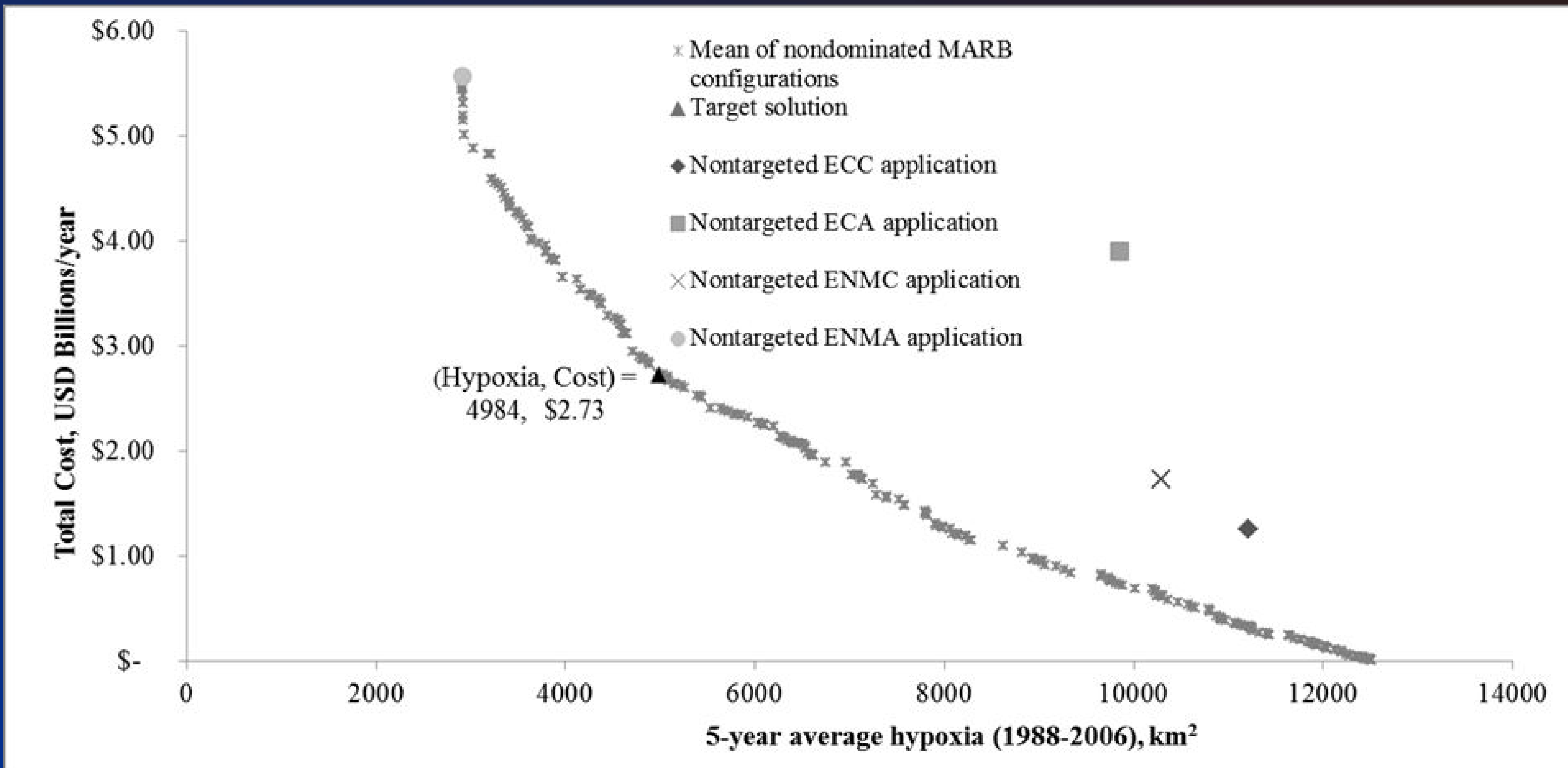
1. Assign each sub watershed one of the six scenarios, evaluate costs and nutrients
2. Do this a bunch of times , create set of yellow dots (each represents a watershed configuration)
3. Keep “best” options (circled) and use those to inform selection of new ones to try
4. Generate new ones and select the best to keep
5. Stop when satisfied, now have a Pareto frontier of options

http://www.jove.com/video/4009/spatial-multiobjective-optimization-agricultural-conservation

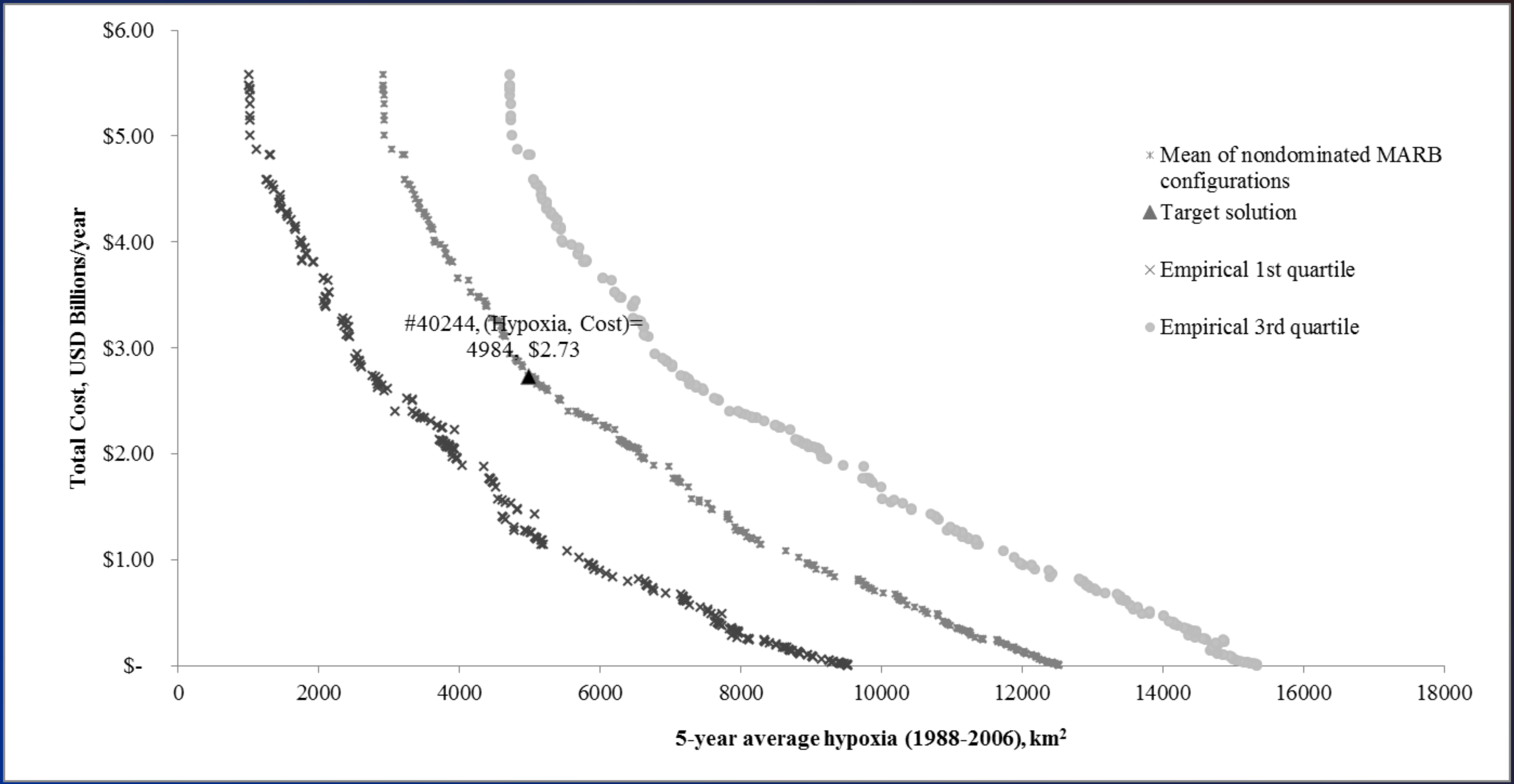


2.77e+010
-1.32e+009
Cost, $
-717
Hypoxic Zone Estimate, km^2
CEAP Generation 0000
Population 0040
Baseline
ECC
ECA
ENMC
ENMA
Back

Final Frontier

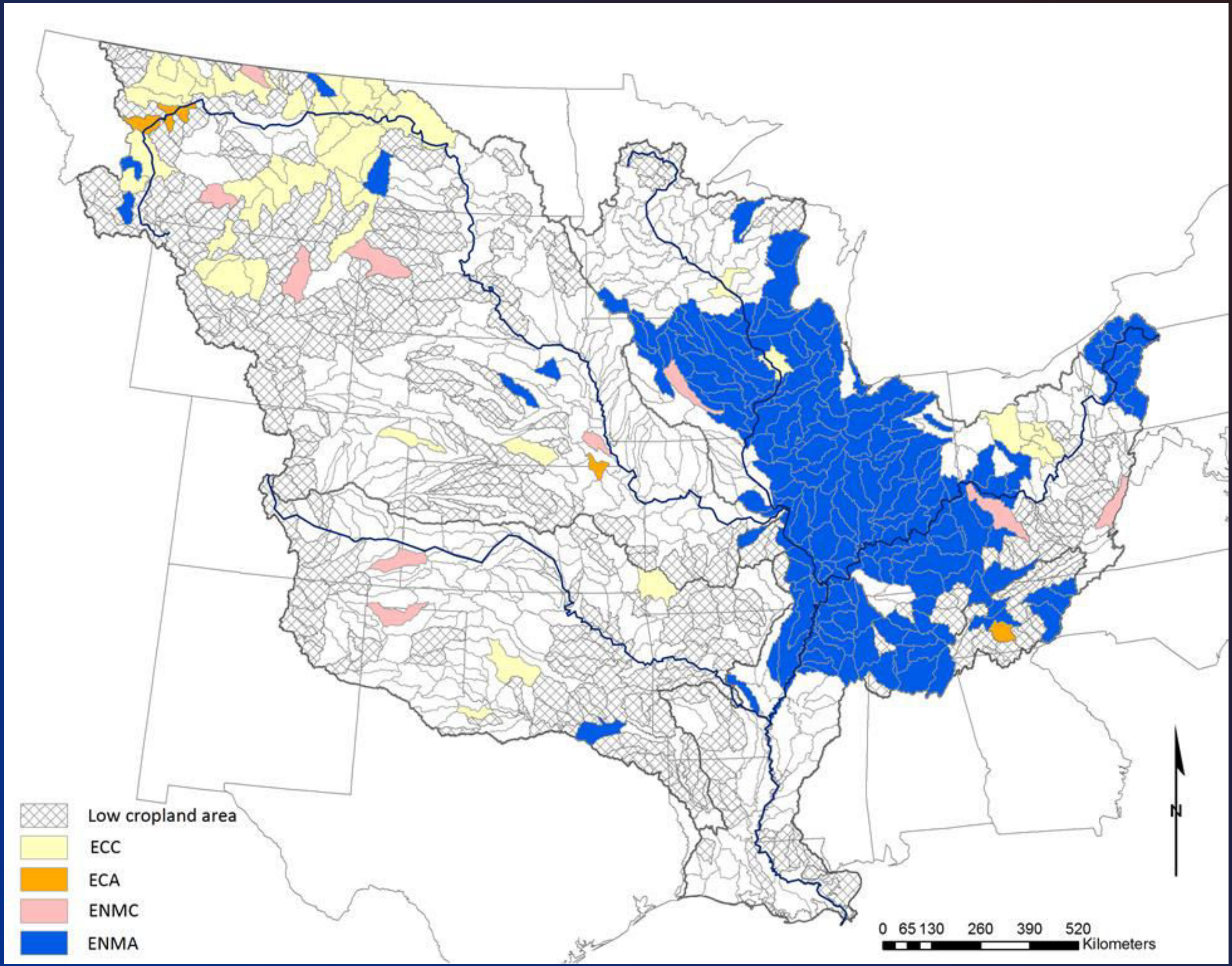


Variability is large



- Empirical 90% CI for 5,000 km^2 is (8.7,10300)

Solution for expected goal attainment



- Recall even ENMA is targeted treatments
- 18% of CEAP cropland selected for treatment

Solutions mapped

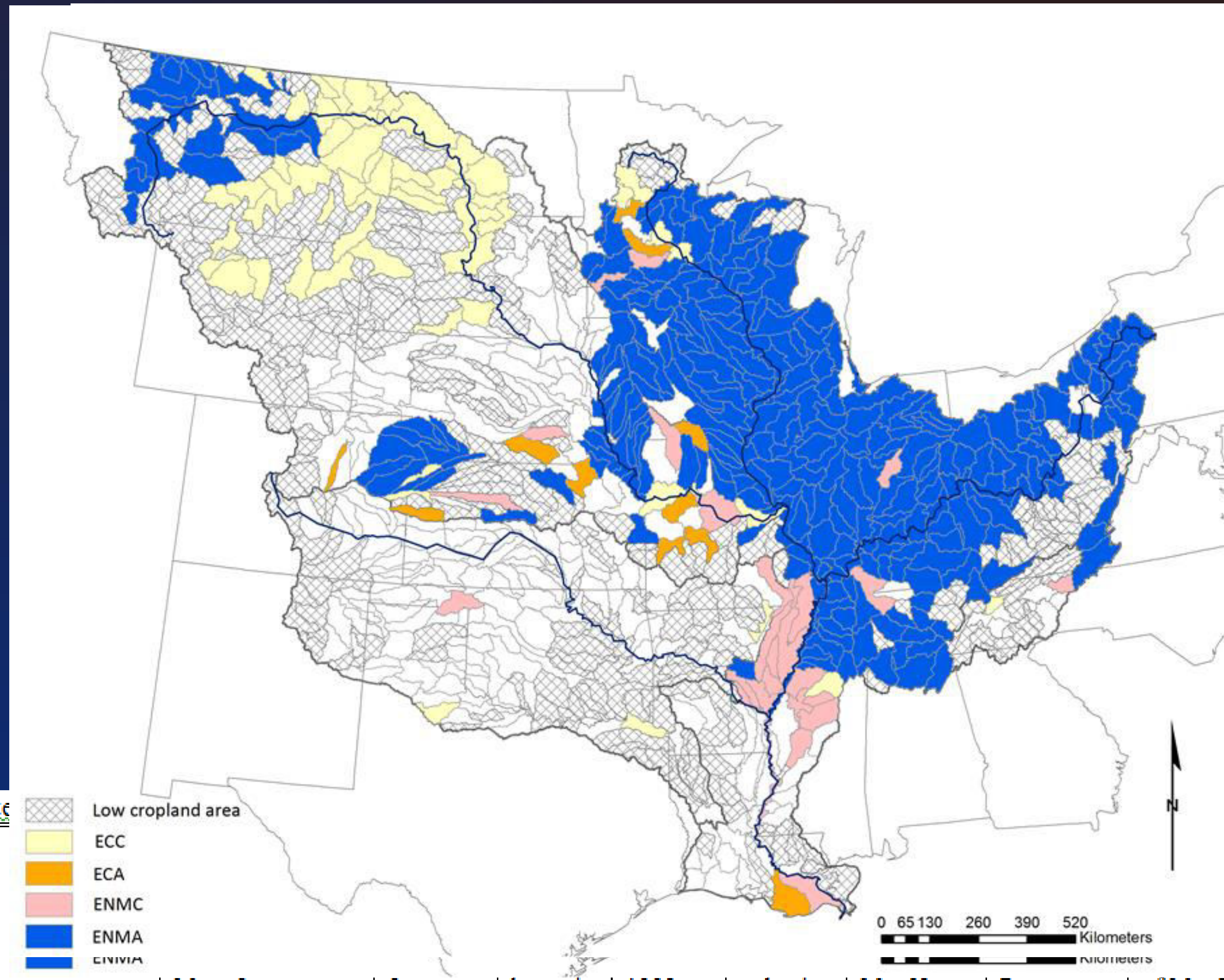
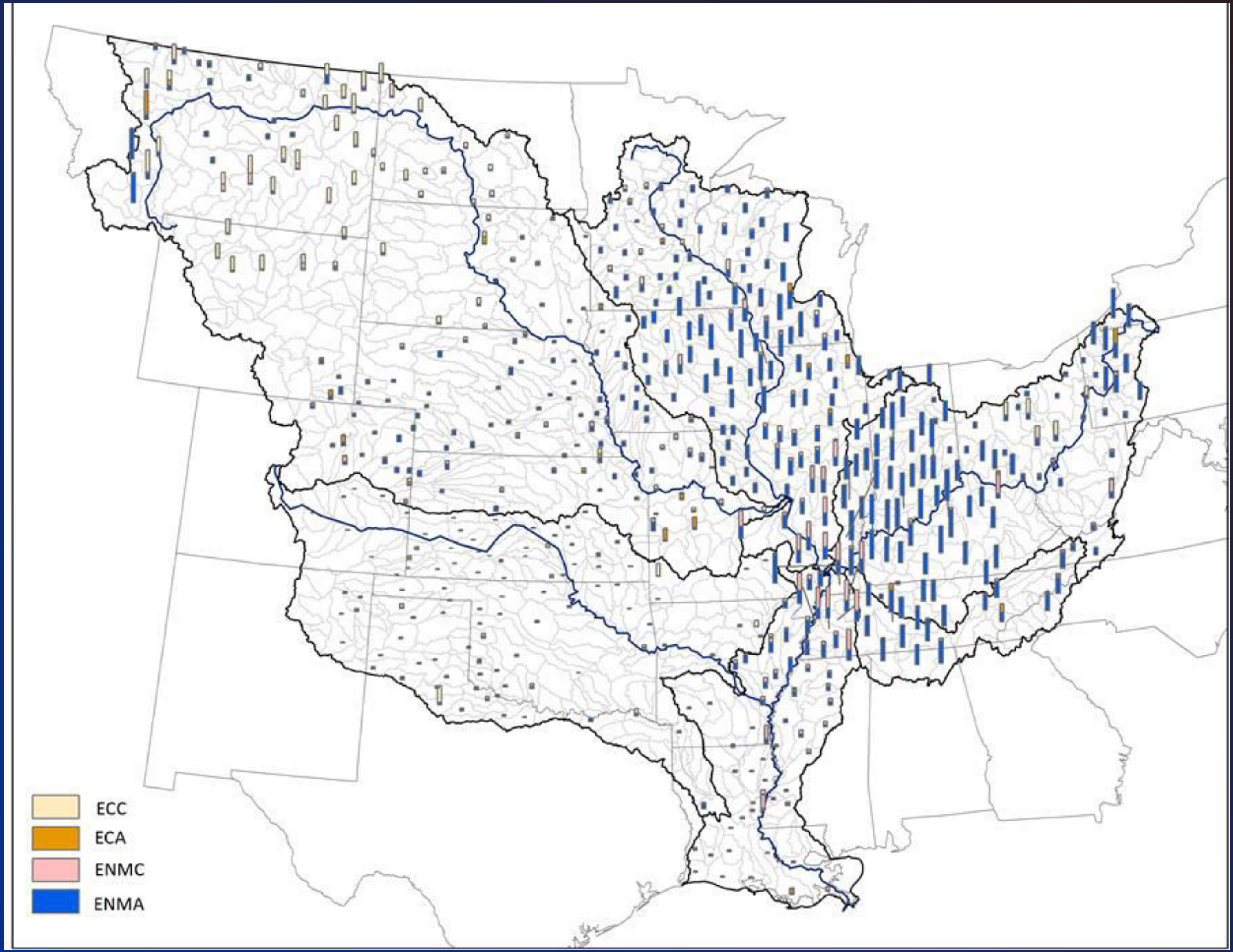


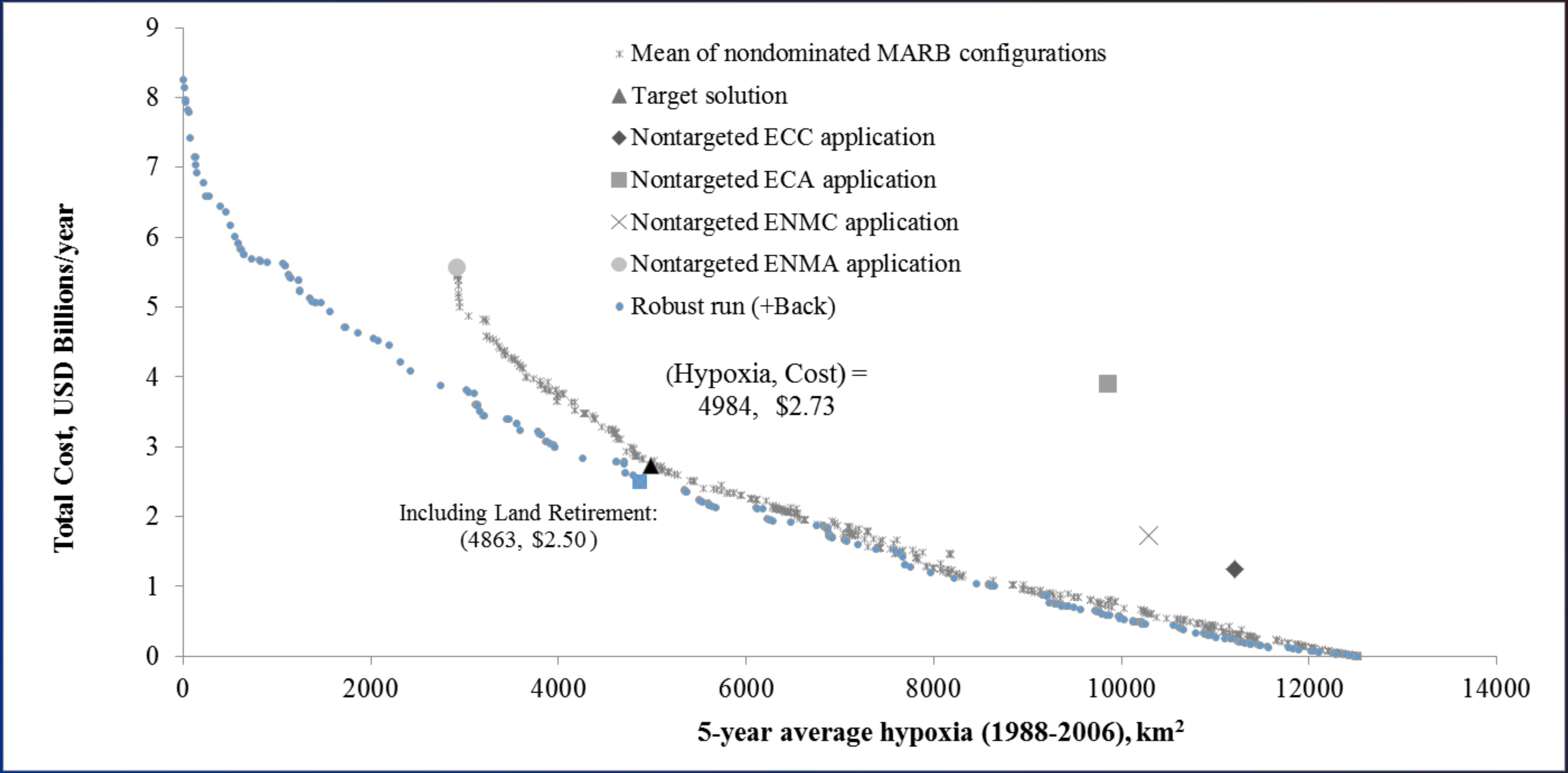
Table S4. Selecte

Percent reduction in mean 5-year hypoxia‡‡‡	Cost, $/year	Mean 5-year hypoxia, km²	5yr hypoxia	hypoxia level	1988-2006	reduction, %	May N reduction,%	P reduction,%	of May P reduction,%
0	0	12521.0	4026.4	250	5.3	0	0	0	0
10.0	280,157,155	11273.8	4222.5	225	15.8	2.6	1.5	5.5	3.1
20.9	704,808,376	9903.0	4004.2	198	21.1	6.3	2.3	8.6	3.9
31.0	1,081,050,060	8639.0	3913.1	173	21.1	9.0	3.0	12.2	4.7
40.8	1,541,367,866	7410.9	3501.4	148	26.3	12.4	3.5	14.2	5.0
52.5	2,310,022,852	5944.0	3121.2	119	31.6	16.1	4.7	17.2	6.3
60.2	2,731,814,534	4983.8	2877.6	100	47.4	18.7	5.3	19.2	7.1
70.2	3,970,484,639	3736.8	2468.1	75	63.2	22.4	5.3	22.8	6.9
76.7	5,572,462,555	2916.2	2156.1	58.3	84.2	25.1	4.9	24.6	7.2

Frequency of selection and distribution of scenarios selected



If we allow land retirement, relax a constraint:



- Land retirement is applied to roughly 18% of the treated area (about 26,000 km^2 (less than 6.6 million acres), or about 3% of total cropland

Expensive?

- ~600 million acres cropland in MARB
- $1.5 billion/year to achieve 40% reduction
- ~$3/acre averaged over all acreage
- Federal crop insurance subsidy = ??

Results

1. Empirical model suggests importance of targeting both N and P and of "legacy" nutrients
2. Additional conservation investments can be effective in reducing the size of Gulf hypoxia
3. Proposed approach highlights potential priority watersheds
4. Agricultural production can be maintained and hypoxia addressed but costs not trivial
5. Highlights value of developing and refining new technologies to retain nutrients (bioreactors, tile drain management)