Research, Education, and Service

IIHR—Hydroscience & Engineering

Senior College

Class 3

November 2, 2021

Chris Jones, *Research Engineer*

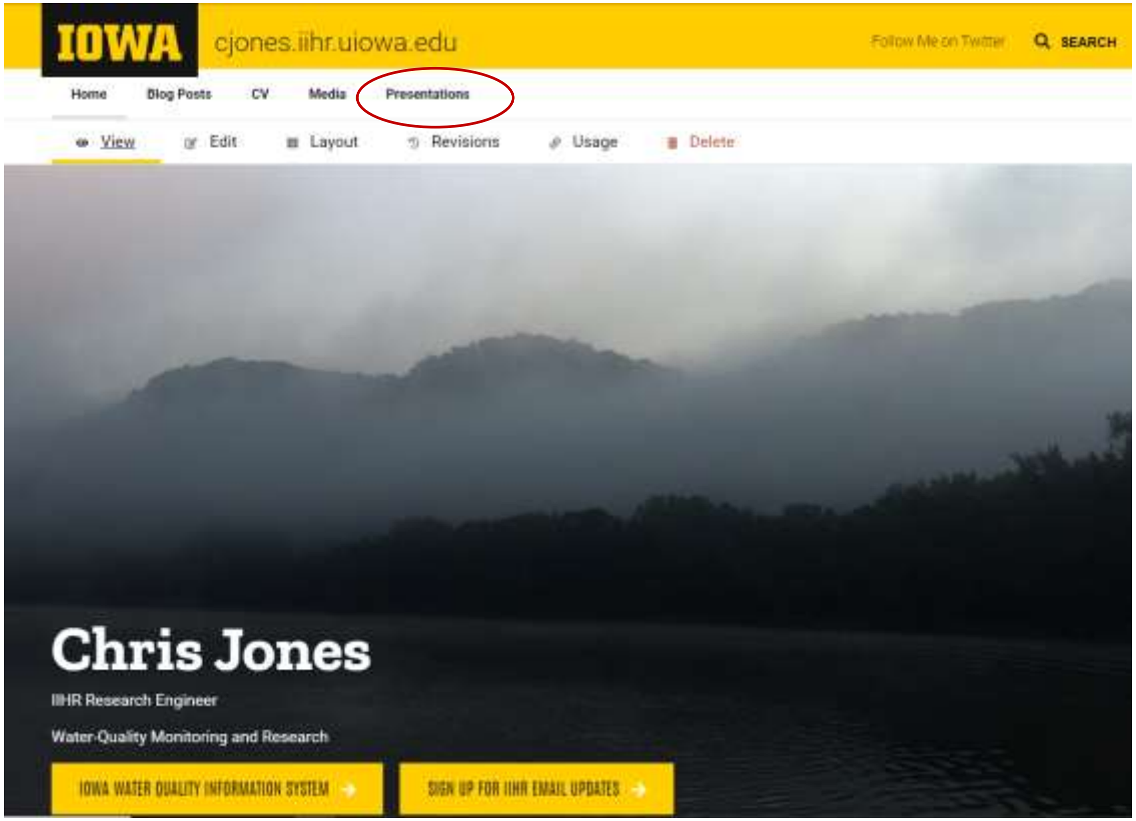
christopher-s-jones@uiowa.edu

IIHR Hydroscience & Engineering

The University of Iowa College of Engineering

Slides Available at:

https://cjones.iihr.uiowa.edu/



Class 2

- Water quality in Agricultural Landscapes: challenges
- Climate change, water quality, and agriculture
- Mississippi River and Gulf of Mexico

Mississippi River near Lansing, Iowa

In Iowa, we farm

- **88,000 Farm Operations**
- **30,500,000 Farmed Acres (12,700,000 Ha), 84% of the state's area.**
- **13,050,000 acres of corn (2.5 billion bushels, value $8.8 billion) U.S. rank: 1st**
- **9,800,000 acres of soybean (554 million bushels, value $4.8 billion) U.S.A. ranking: 1st**

- **21 million hogs; U.S.A. ranking: 1st**
- **8.4 million turkeys; U.S.A. ranking: 9th**
- **52-80 million laying chickens; U.S.A. ranking: 1st (15 billion eggs)**
- **4 million cattle (including calves) U.S.A. ranking: 6th**
- **210,000 milk cows (4.8 billion pounds of milk)**

- **Sheep and Goat production: 6th**
- **Oats: 7th**
- **Hay: 11th**
- **Corn for silage: 7th**

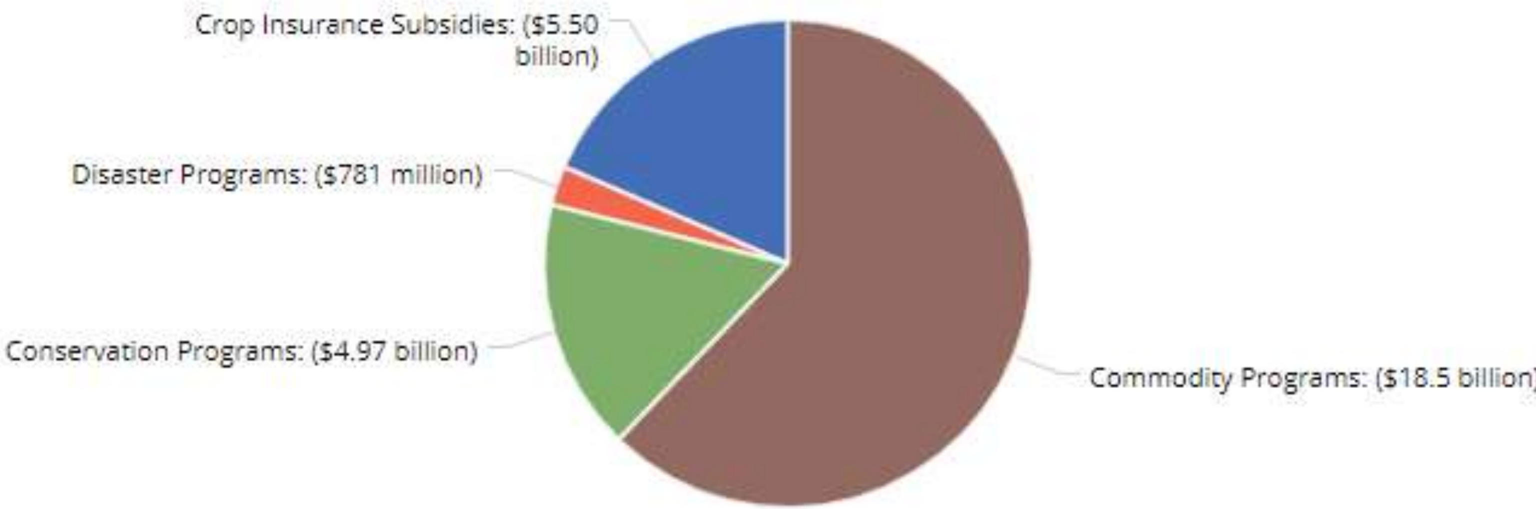
LEAKY SYSTEM

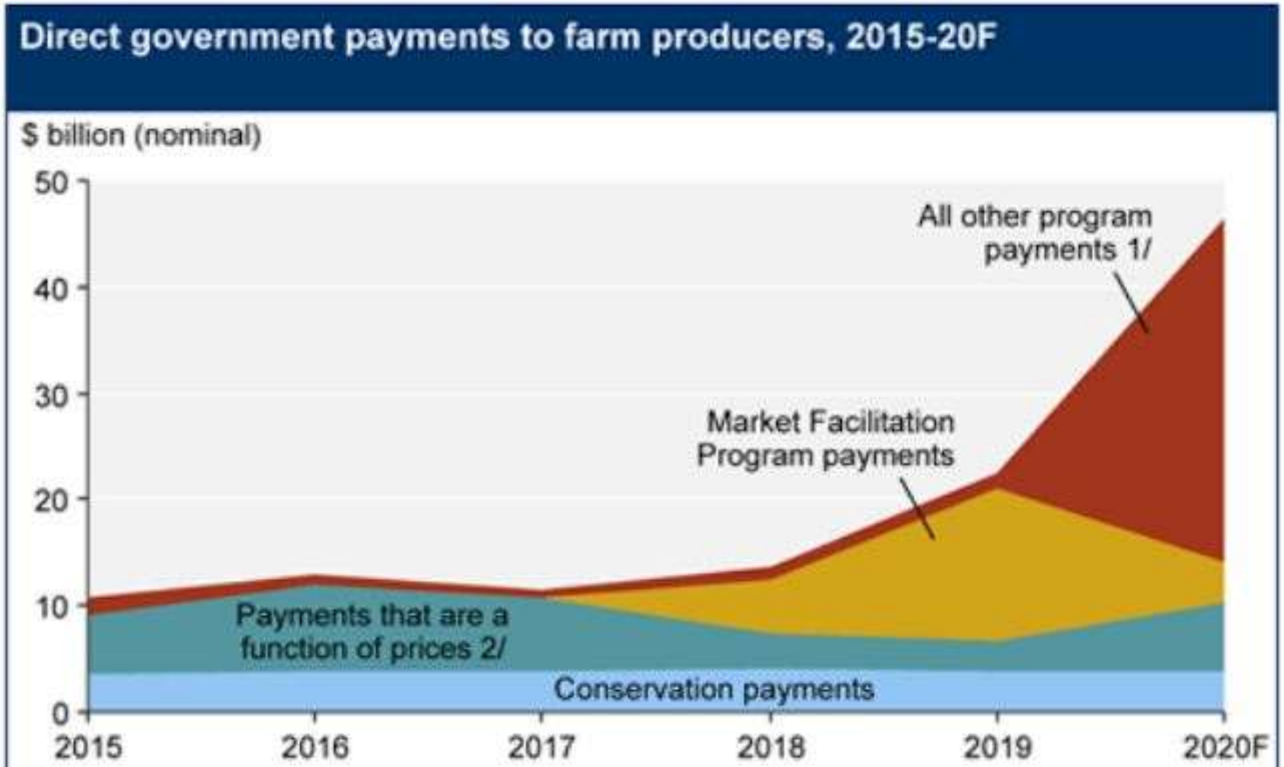
Economics

Value of Commodities: $30-40 Billion/year

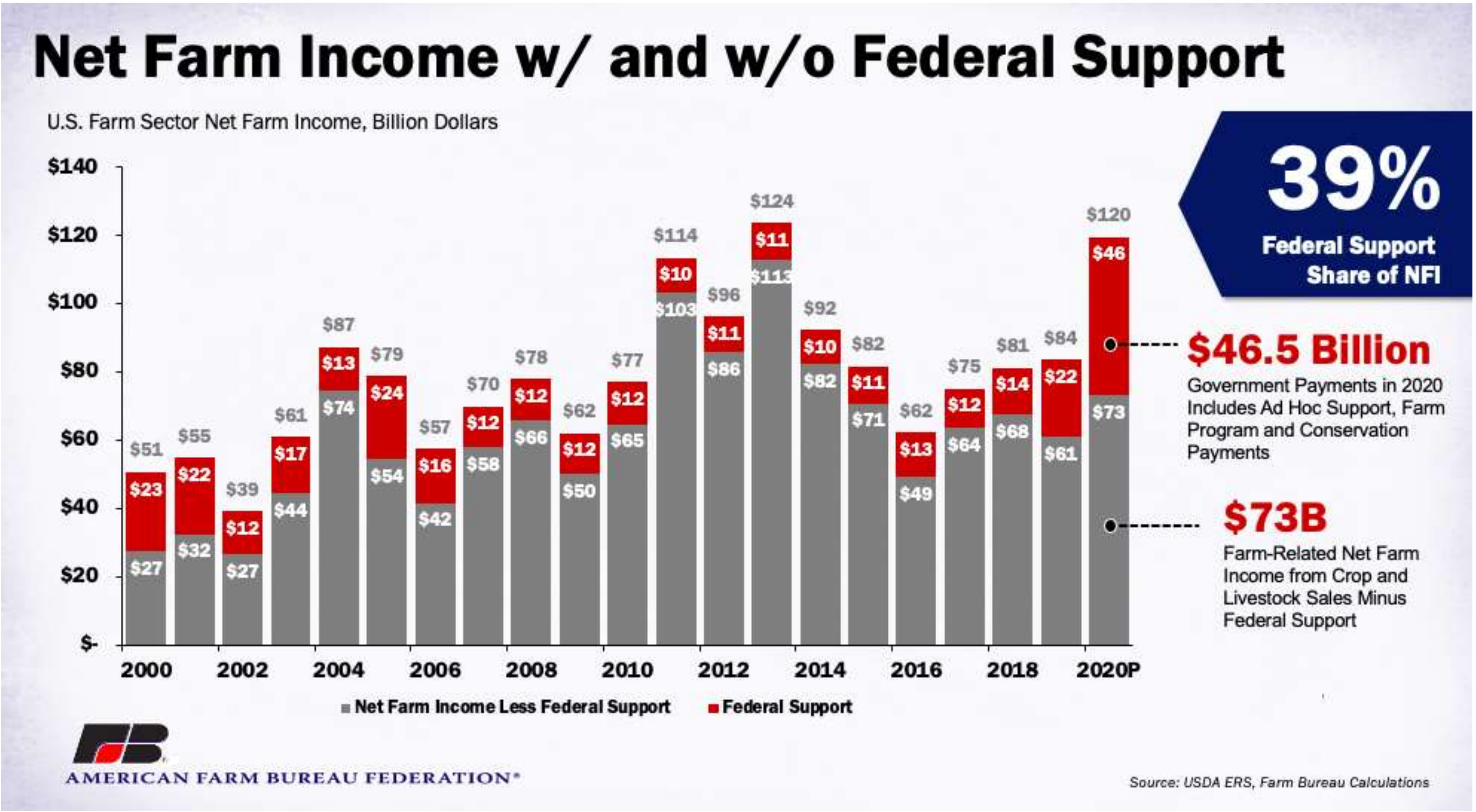
Iowa Farm Subsidy Information

Farmers received $29.8 billion in subsidies 1995-2016





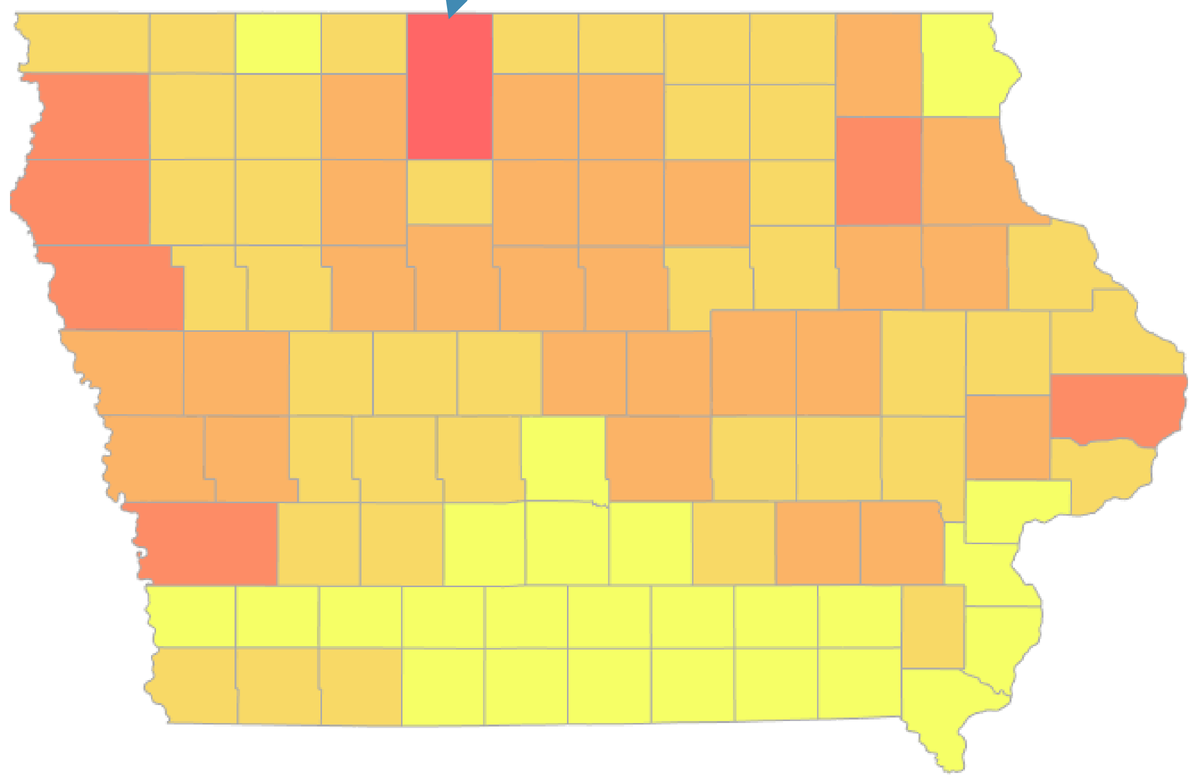
Note: F = forecast. 1/ "All other program payments" includes supplemental and ad hoc disaster assistance, which in 2020 includes payments from Coronavirus Food Assistance Programs and the Paycheck Protection Program. 2/ Includes Price Loss Coverage, Agriculture Risk Coverage, loan deficiency payments (excluding grazeout payments), marketing loan gains, certificate exchange gains, and dairy payments.
Source: USDA, Economic Research Service, Farm Income and Wealth Statistics.
Data as of December 2, 2020.



Farm income in 2020: $132,000/ household
Iowan income in 2020: $60,000/household

Kossuth County: $757M since 1995 ($29M/year)

Population: 15,165
$49,900/person



Transportation Industry

Corporate Food Giants

Walmart

GENERAL MILLS

Coca-Cola

Cargill

Tyson

Nestlé

ADM

The University of Iowa
College of Engineering

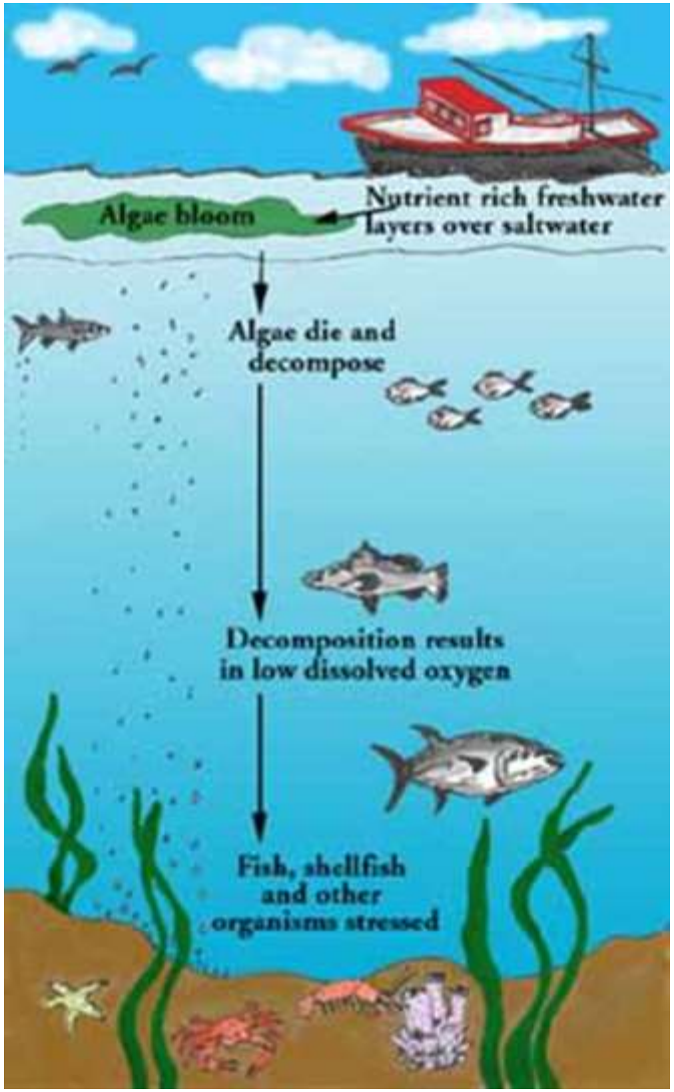
Consequences: Local

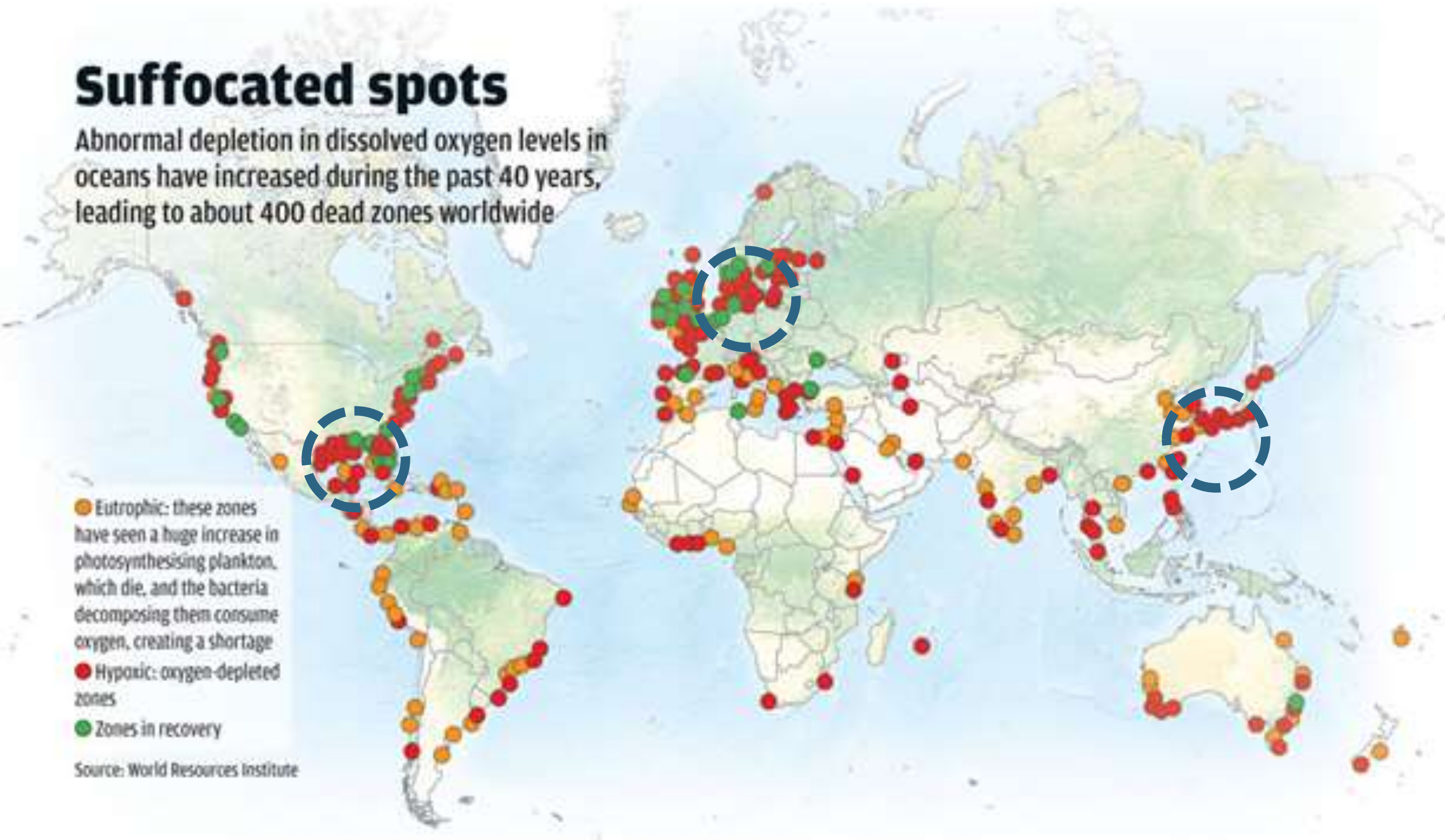
Consequences: Continental

What is Hypoxia?

Depleted oxygen creates zones incapable of supporting most life

53% of U.S. estuaries experience hypoxia for at least part of the year



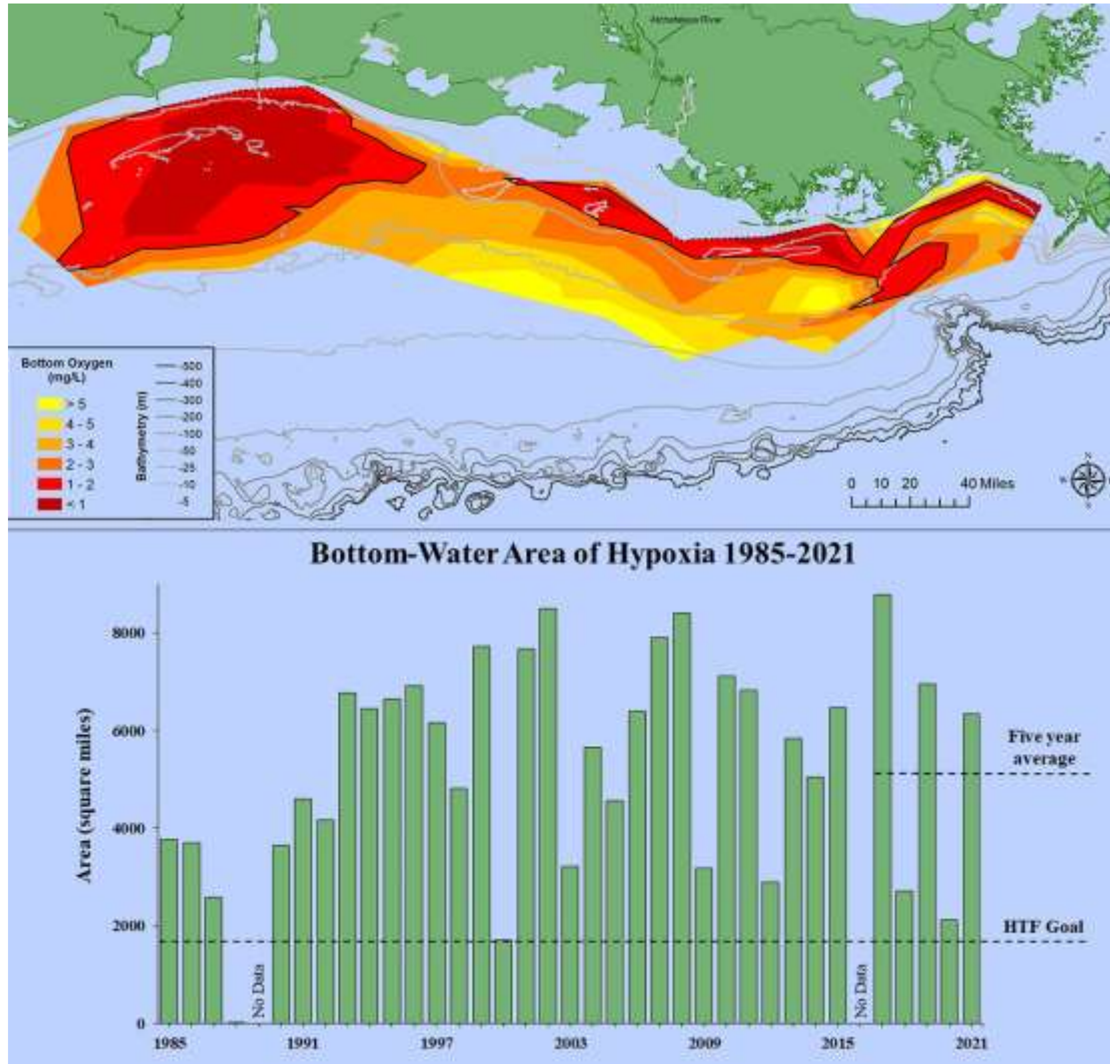

Suffocated spots
Abnormal depletion in dissolved oxygen levels in oceans have increased during the past 40 years, leading to about 400 dead zones worldwide
Eutrophic: these zones have seen a huge increase in photosynthesising plankton, which die, and the bacteria decomposing them consume oxygen, creating a shortage
Hypoxic: oxygen-depleted zones
Zones in recovery
Source: World Resources Institute

Drivers of Hypoxia

Nitrogen
Phosphorus
Silica
Weather

Gulf Hypoxia Task Force
Formed in 1997

Federal Members:
EPA
USDA
NOAA
USACE
Interior (USGS)
Dept of Justice
Office of Science and Technology



Graphic credit: Louisiana Universities Marine Consortium

Hypoxia Task Force

State and Tribes:

Arkansas Soil and Water Conservation Commission

Illinois Dept of Agriculture

Iowa Dept of Agriculture and Land Stewardship

Louisiana Dept of Env Quality

Minnesota Pollution Control Agency

Mississippi Dept of Env Quality

Missouri DNR

Tennessee Dept of Agriculture

Wisconsin DNR

Mississippi Band of Choctaw

Prairie Island Indian Community

ASSESSMENT

Characterization of hypoxia: distribution, dynamics, and causes. Lead: **Dr. Nancy Rabalais**, Louisiana Universities Marine Consortium.

Ecological and economic consequences of hypoxia. Ecological co-lead: Dr. Robert Diaz, Virginia Institute of Marine Science. Economics co-lead: **Dr. Andrew Solow**, Woods Hole Oceanographic Institution, Center for Marine Policy.

Sources and loads of nutrients transported by the Mississippi River to the Gulf of Mexico. Lead: Mr. **Donald Goolsby**, U.S. Geological Survey.

Effects of reducing nutrient loads to surface waters within the basin and Gulf of Mexico. Upper watershed co-lead: Dr. Patrick Brezonik, University of Minnesota. Gulf of Mexico co-lead: **Dr. Victor Bierman**, Limno-Tech, Inc.

Evaluation of methods to reduce nutrient loads to surface water, ground water, and the Gulf of Mexico. Lead: **Dr. William Mitsch**, Ohio State University.

Evaluation of social and economic costs and benefits of methods (identified in topic #5) for reducing nutrient loads. Lead: **Dr. Otto Doering**, Purdue University.

2001 ACTION PLAN

2001 Action Plan & Reassessment

Action item 11 of the 2001 Action Plan called for an assessment of progress in achieving the three goals of the Action Plan (Coastal, Within Basin, and Quality of Life) and for decisions on a future course of action. The call for a reassessment resulted in several products including a proposal and timeline for the process, several symposia, teams to compile data, a Science Advisory Panel and background documents.

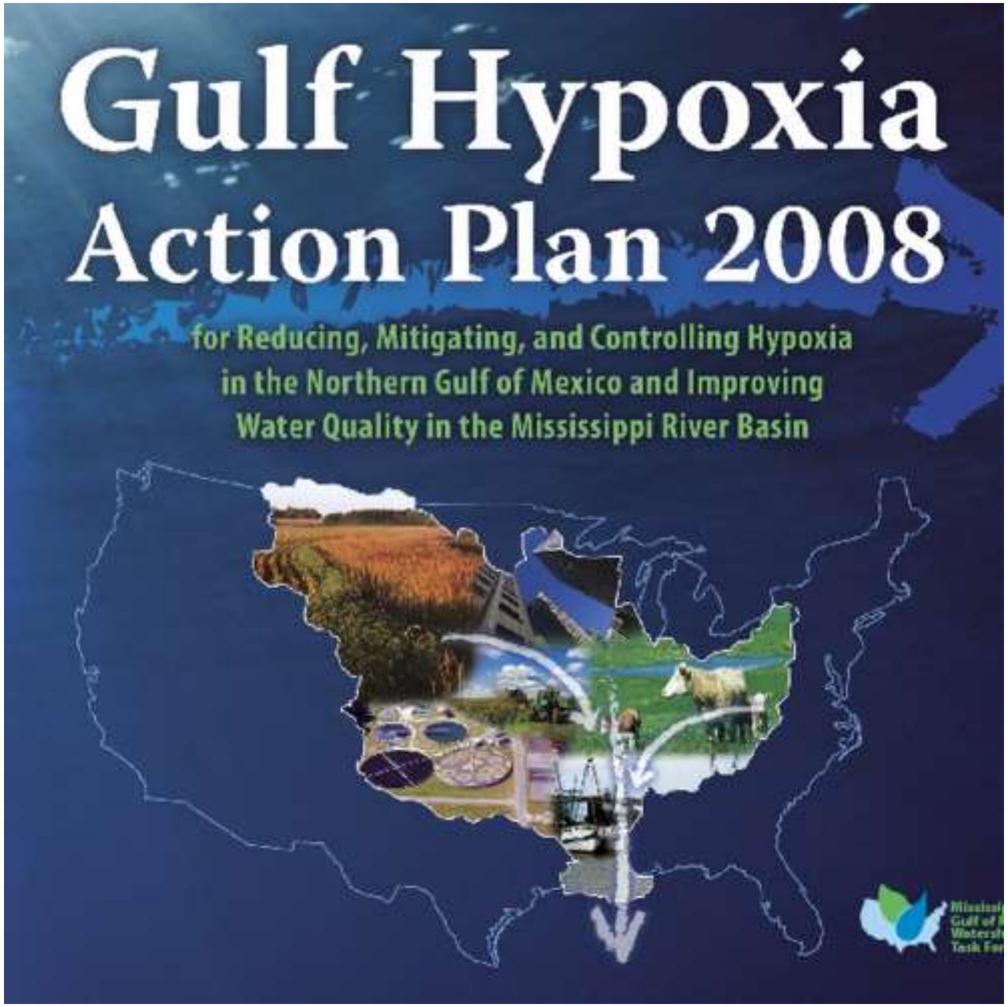
2008 ACTION PLAN

Two Main Points:

Emphasize State Nutrient Reduction Plans

Dual Nutrient Reduction Effort

11 ”Key Action Items”

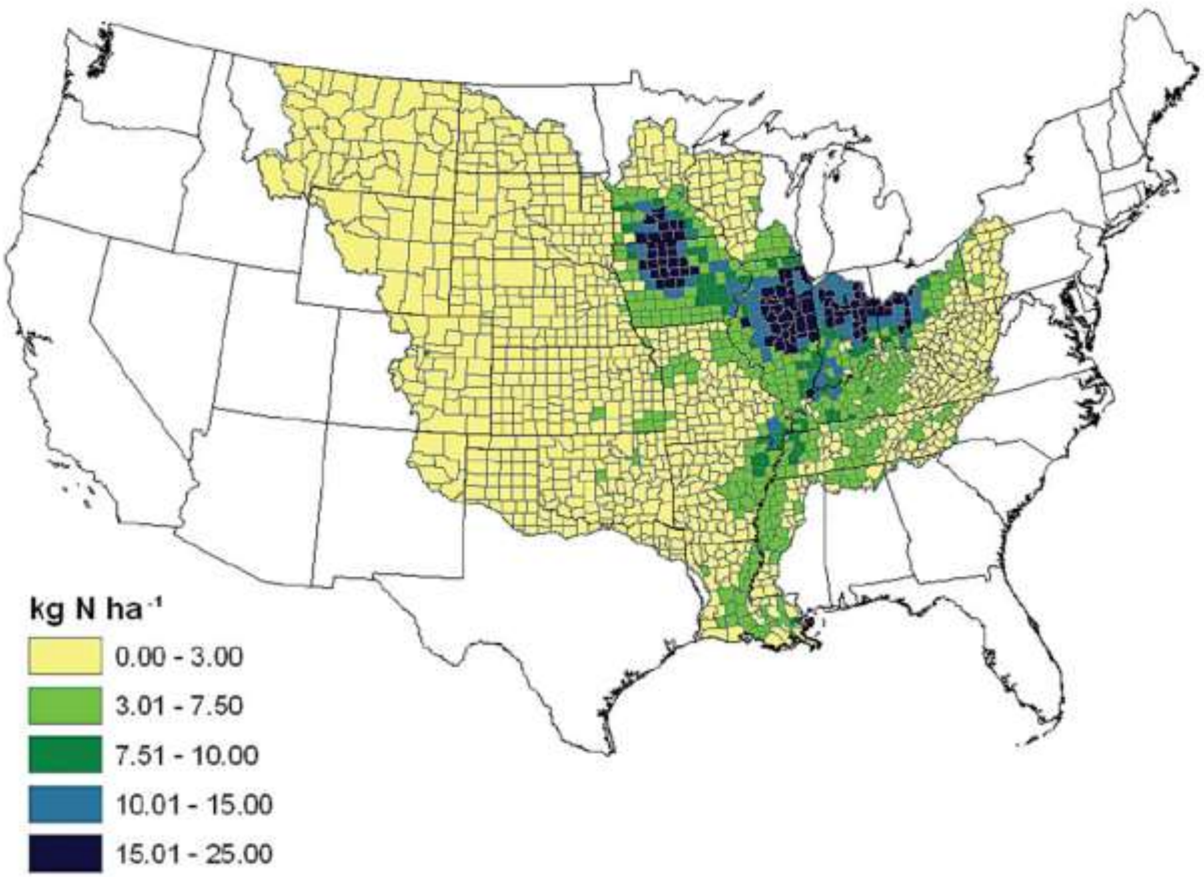


Formed committee to reassess 2015 objective

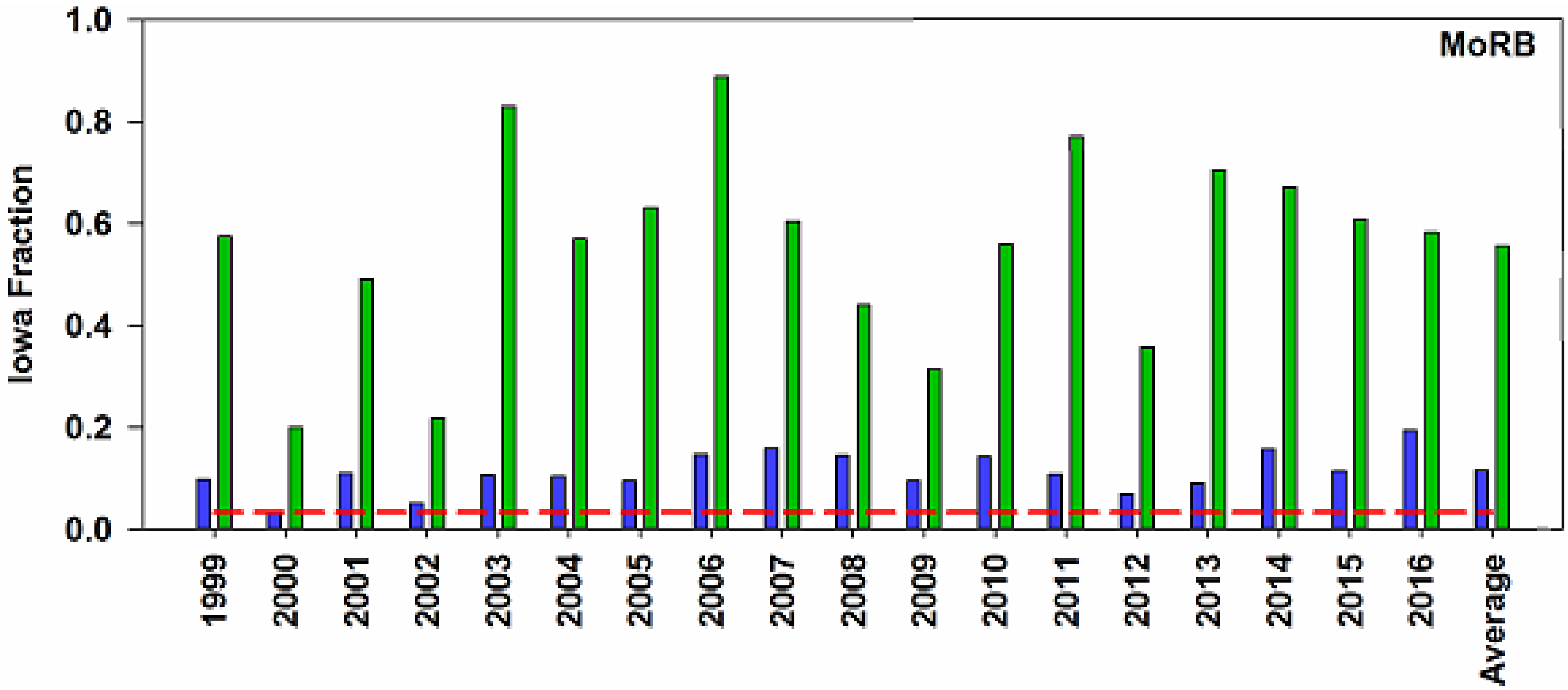
HTF Goals

In 2015, the HTF announced that it would retain the original goal of reducing the areal extent of the Gulf of Mexico hypoxic zone to less than 5,000 km^2 and extend the time of attainment from 2015 to 2035. The HTF also for the first time agreed on an interim target of a 20 percent nutrient load reduction by the year 2025 as a milestone toward reducing the hypoxic zone to less than 5,000 km^2 by the year 2035. For more details, read the 2015 Press Release or download the full HTF Goal Framework. To learn more about how the HTF is tracking its progress toward these goals, see Tracking Outcomes and Metrics to Measure Progress.

Sources of Nitrogen in Mississippi Basin

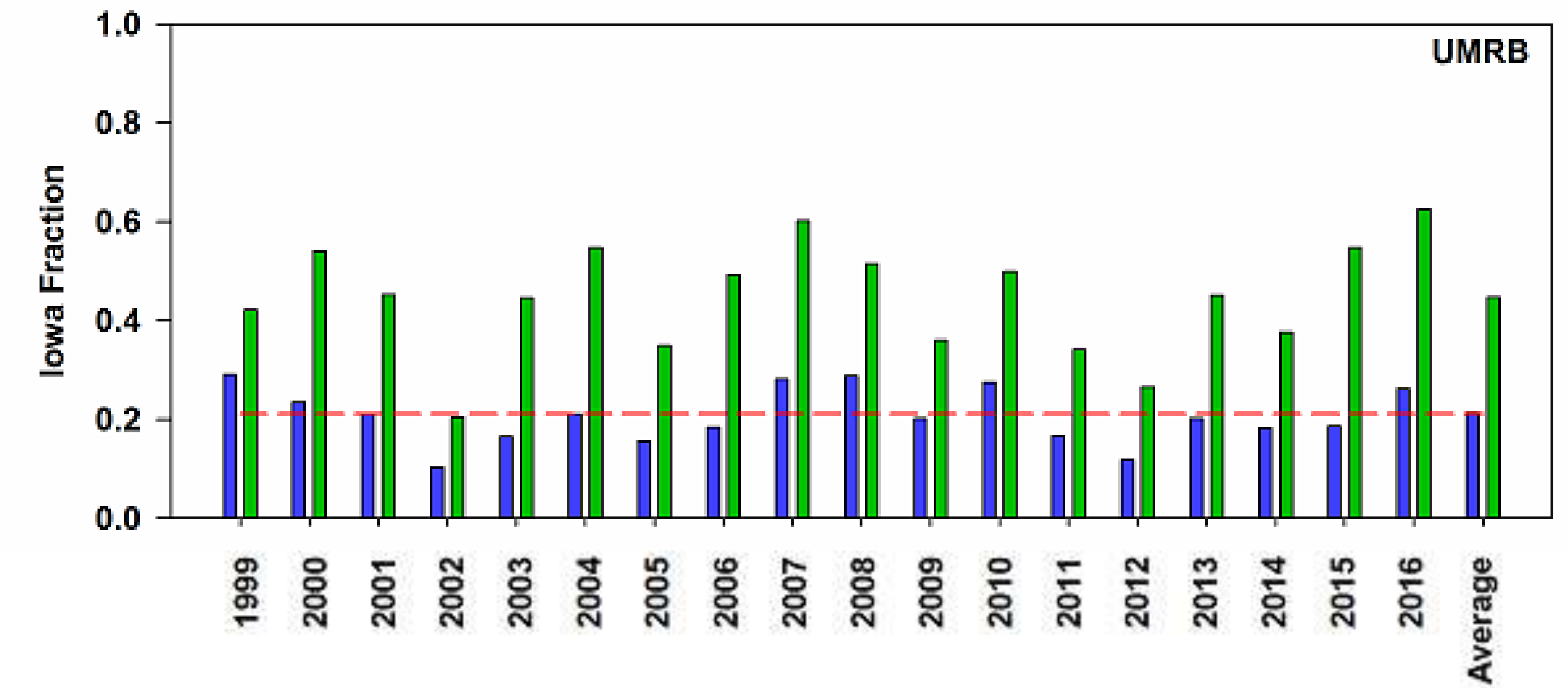


Missouri



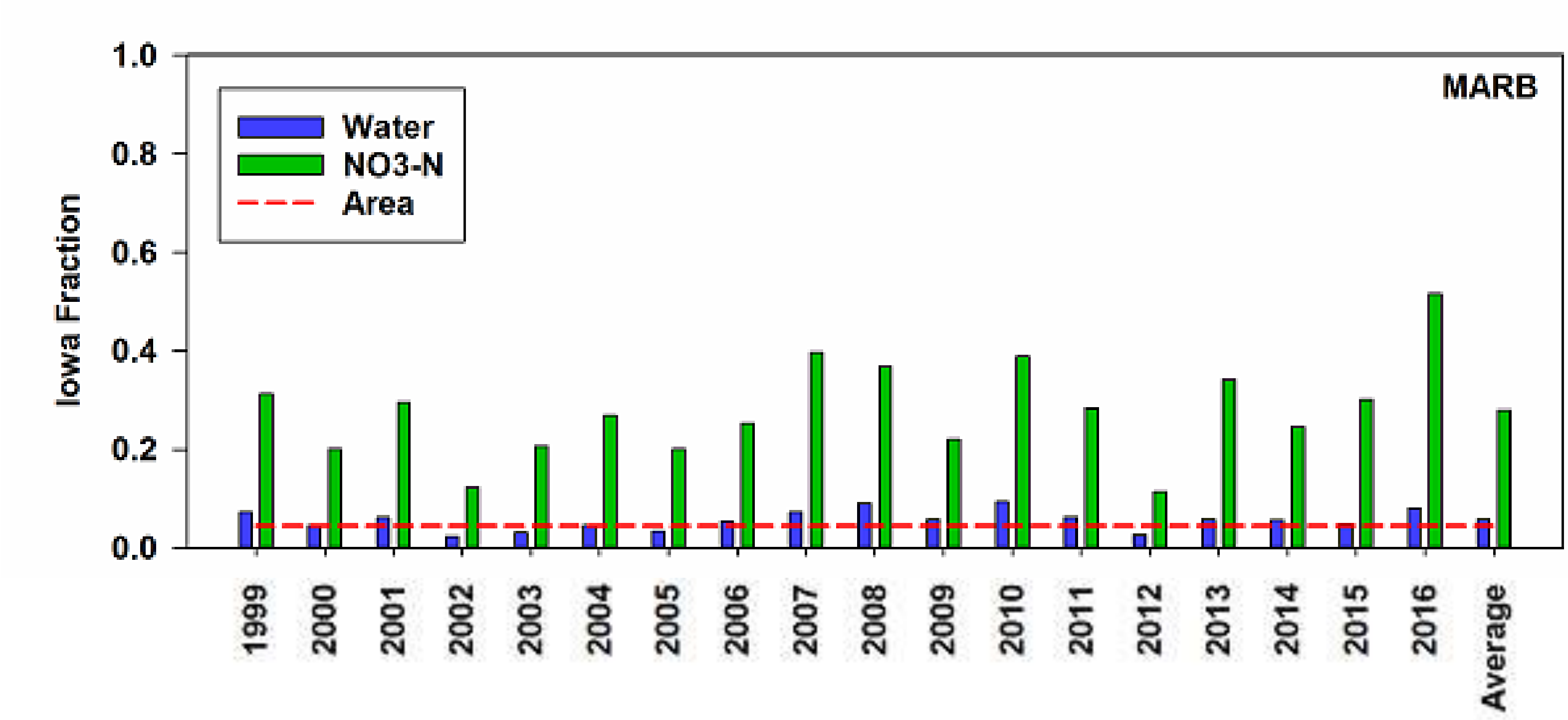
3.3% of the land
12% of the water
55% of the nitrate

Upper Mississippi



21% of the land
21% of the water
45% of the nitrate

Mississippi-Atchafalaya-Gulf of Mexico



4.5% of the land
5.9% of the water
29% of the nitrate

Consequences of Nutrient Pollution Upstream

Nitrate-nitrogen is regulated drinking water contaminant

Nitrate toxic to larval forms of aquatic life

Both N and P promote algae and cyanobacteria blooms

Cyanobacteria produce toxins

Over abundance of primary producers reduces biodiversity

Water turbidity

Methemoglobinemia

Nitrate (NO_3^-) → water → formula →

Baby's stomach

bacteria
$NO_3^- \rightarrow NO_2^-$

→ **Baby's circulatory system**

$2NO_2^- + O_2 \rightarrow 2NO_3^-$

Adult's stomach

bacteria
$NO_3^- \rightarrow NO_2^- \rightarrow NO^-$

Cancer?

> Environ Monit Assess. 2020 Oct 23;192(11):724. doi: 10.1007/s10661-020-08652-0.

Health and economic impact of nitrate pollution in drinking water: a Wisconsin case study

Paul D Mathewson [1], Sydney Evans [2], Tyler Byrnes [3] [4], Anna Joos [3], Olga V Naidenko [2]

Affiliations + expand

PMID: 33095309 DOI: 10.1007/s10661-020-08652-0

We estimate that annually, 111-298 combined cases of colorectal, ovarian, thyroid, bladder, and kidney cancer in Wisconsin may be due to nitrate contamination of drinking water. Each year, up to 137-149 cases of very low birth weight, 72-79 cases of very preterm birth, and two cases of neural tube defects could be due to nitrate exposure from drinking water. The direct medical cost estimates for all nitrate-attributable adverse health outcomes range between $23 and $80 million annually.

Iowa Nutrient Reduction Strategy

Iowa Department of Agriculture and Land Stewardship

DNR

Iowa State University

Nitrogen or Phosphorus?

Nitrogen moves primarily as nitrate-N with water

Phosphorus moves primarily with eroded soil

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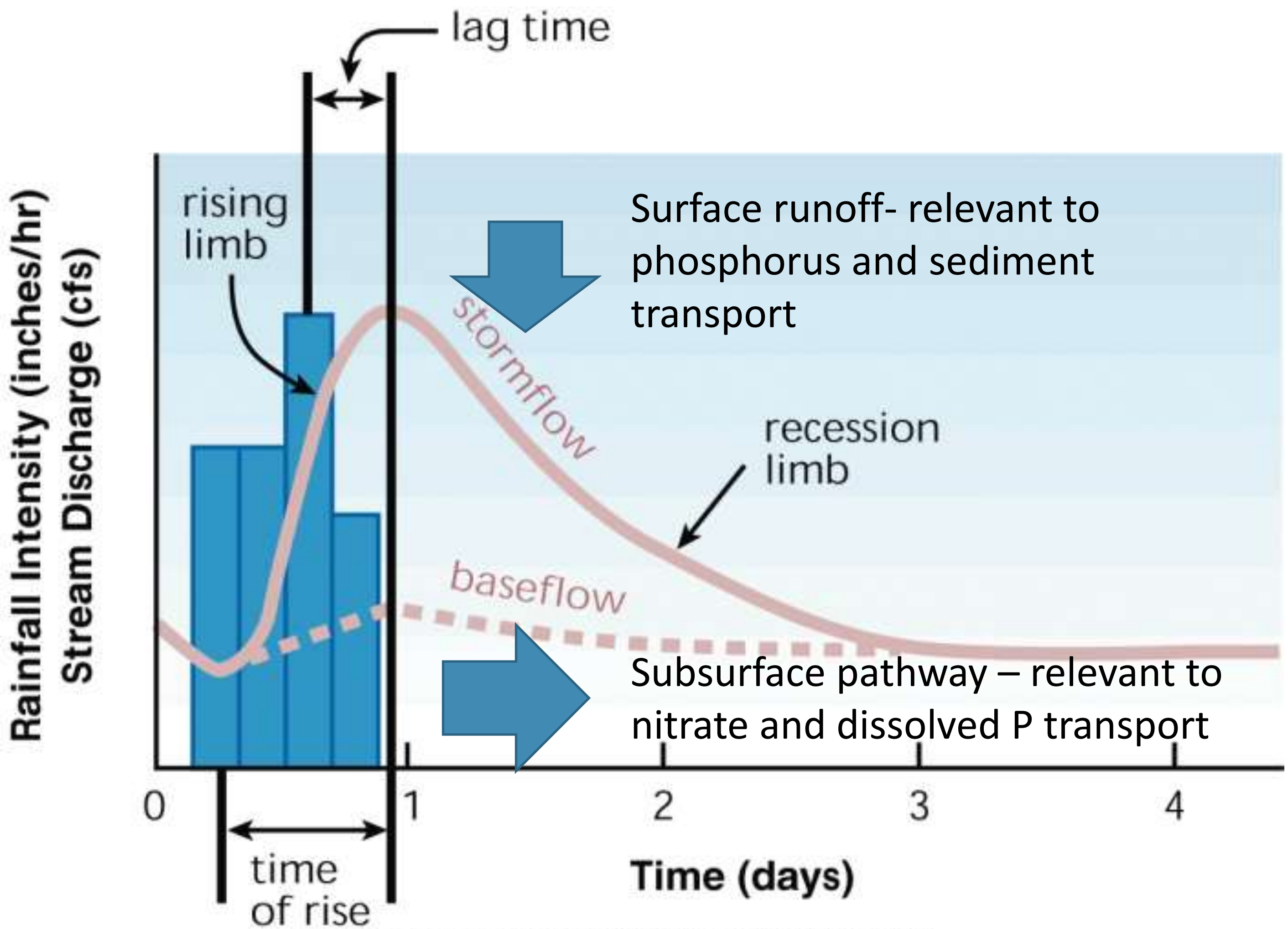
Different Hydrologic Pathways



Surface runoff- relevant to phosphorus and sediment transport

Subsurface pathway – relevant to nitrate and dissolved P transport

Nitrogen Reduction Practices

	Practice	% Nitrate-N Reduction [Average (Std. Dev.)]
Nitrogen Management	Timing (Fall to spring)	6 (25)
	Source (Liquid swine compared to commercial)	4 (11)
	Nitrogen Application Rate	Depends on starting point
	Nitrification Inhibitor	9 (19)
	Cover Crops (Rye)	31 (29)
Land Use	Perennial – Land retirement	85 (9)
	Living Mulches	41 (16)
	Extended Rotations	42 (12)
Edge-of-Field	Drainage Water Mgmt.	33 (32)*
	Shallow Drainage	32 (15)*
	Wetlands	52
	Bioreactors	43 (21)
	Buffers	91 (20)**

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Phosphorus Reduction Practices

	Practice	% Phosphorus-P Reduction [Average (Std. Dev.)]
Phosphorus Management	Producer does not apply phosphorus until STP drops to optimal level	17 (40)
	Source (Liquid swine compared to commercial)	46 (45)
	Incorporation	36 (27)
	No-till (70% residue) vs. conventional tillage (30% residue)	90 (17)
	Cover Crops (Rye)	29 (37)
Land Use	Perennial – Land retirement	75 (-)
	Pasture	59 (42)
Edge-of-Field	Buffers	58 (32)

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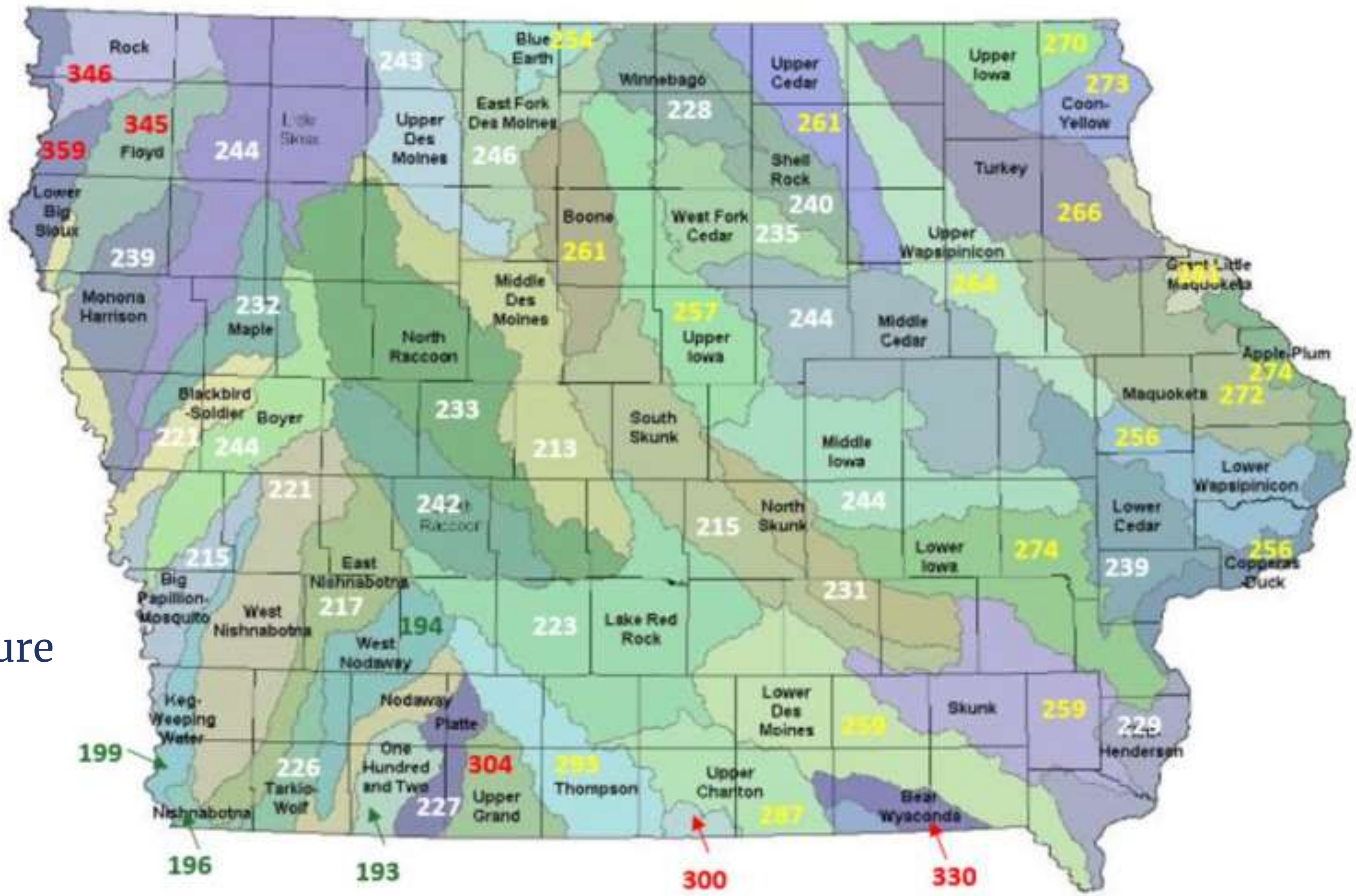
Crop Management

Terraces and Contour Farming

Fertilizer Management: Nitrogen

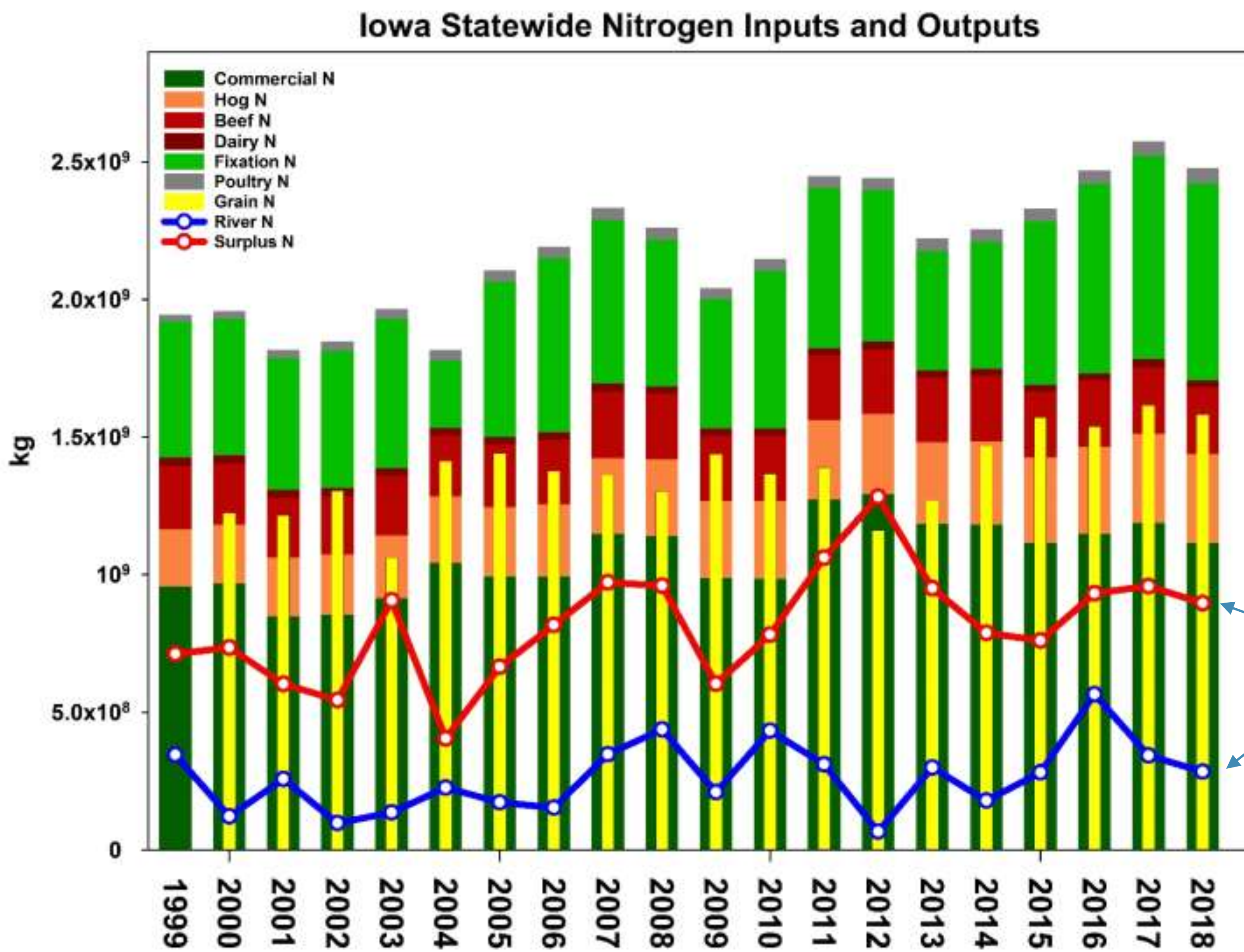
Fertilizer management (timing, source, rates)
Nitrification inhibitor 9% reduction
Sidedress

Spring application 6% reduction
Sidedress 4-7% reduction
Manure compared to fertilizer -3 to 4%
Fertilizer rate reduction 10%

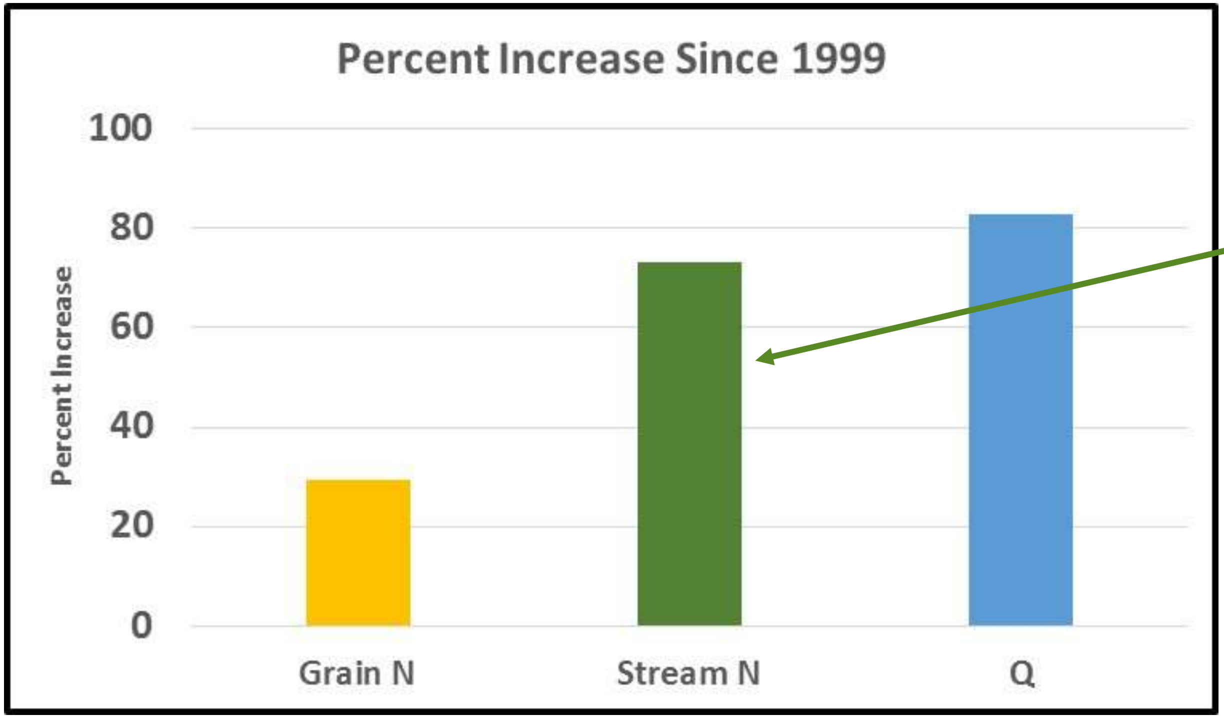


Commerical N + N generated by manure

N inputs exceed grain N by 1.4 billion pounds statewide
On average, about 1/3 makes it into our water



About 32% of "surplus" makes it to streams

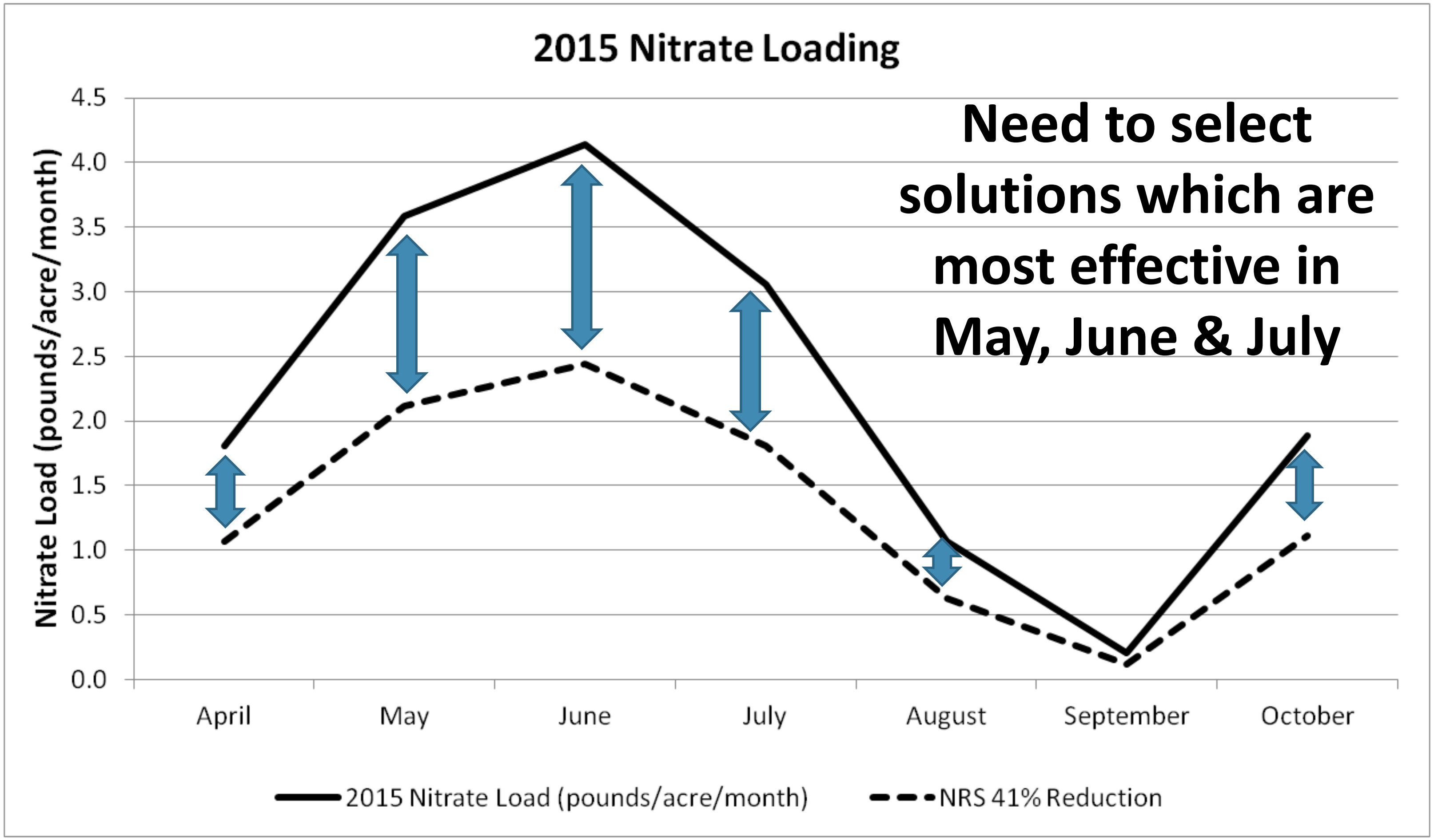


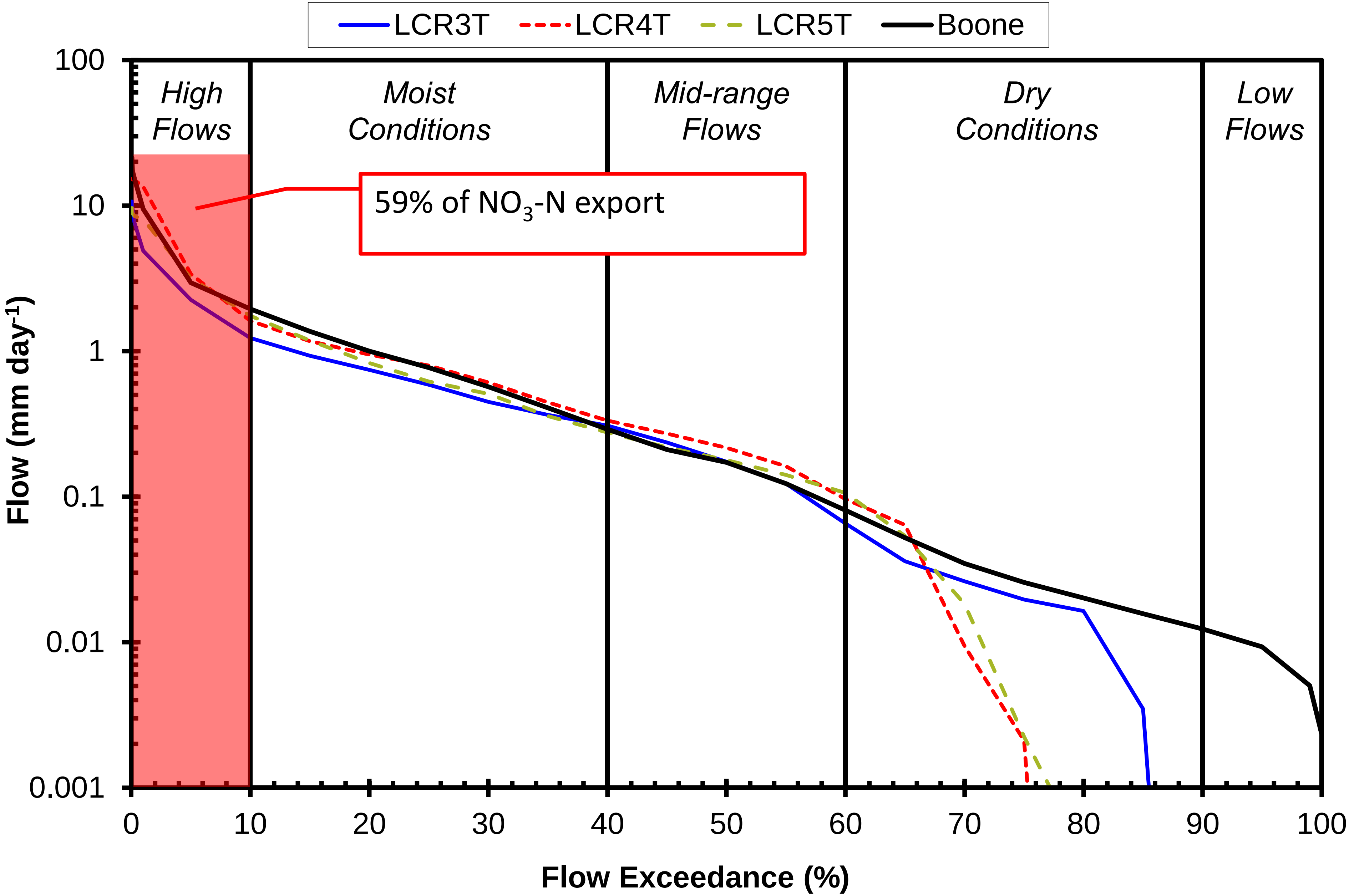
339 million pounds more

Since 2002, 14 million hogs → 24 million hogs

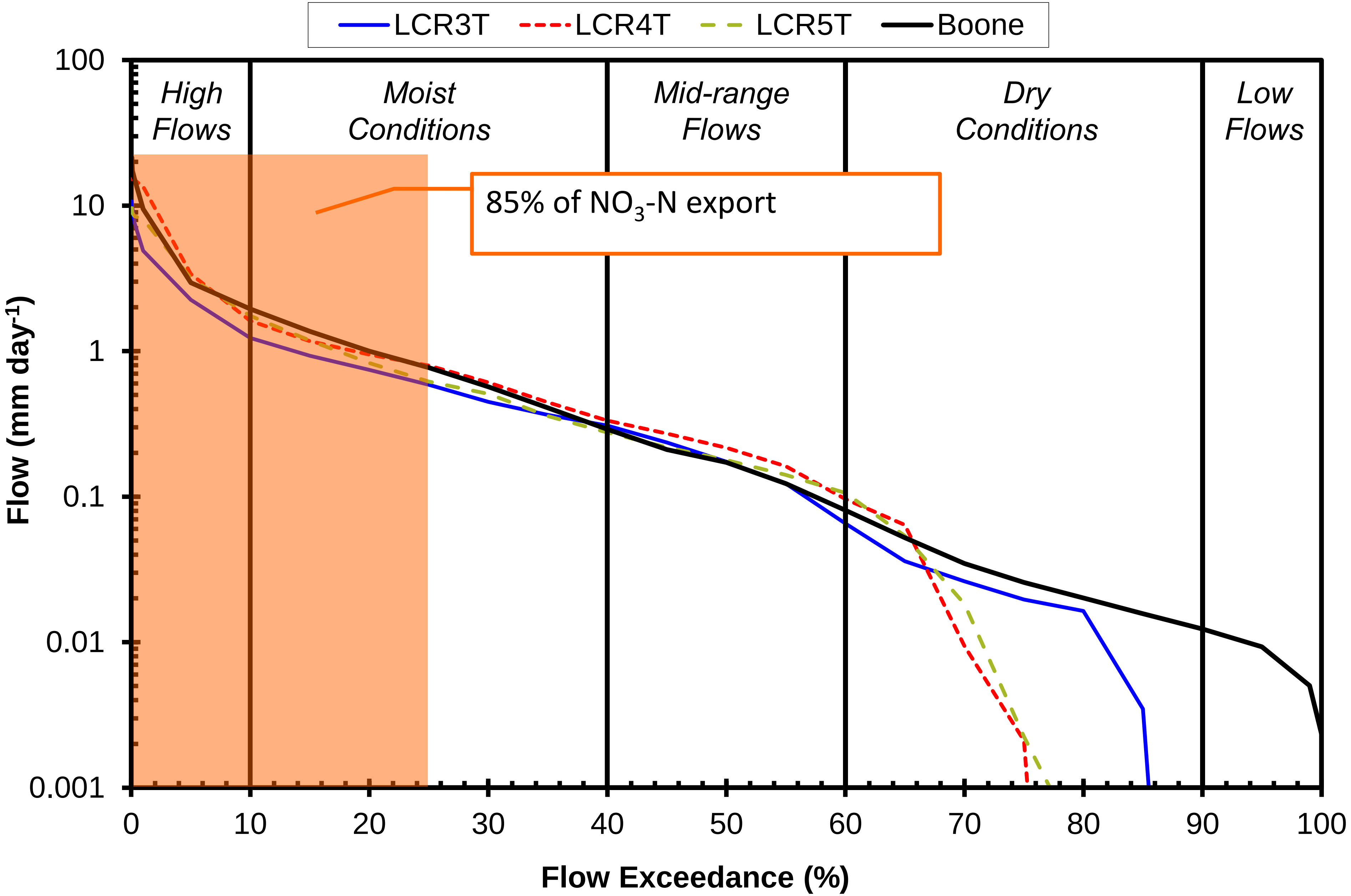
Extra 189 million pounds of N

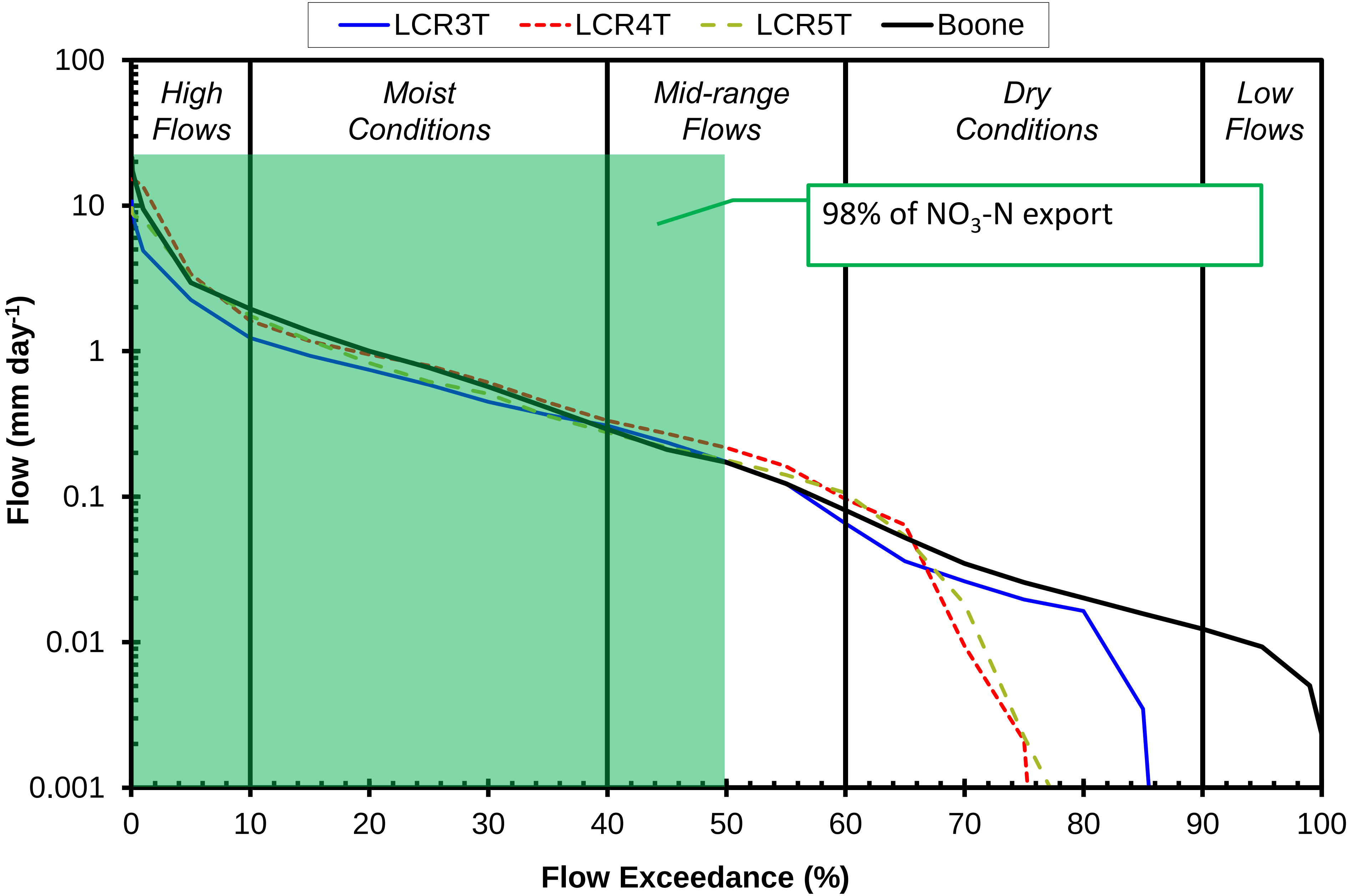
Water Quality Practice Selection





LCR3T
LCR4T
LCR5T
Boone
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
59% of NO3-N export
Flow (mm day-1)
Flow Exceedance (%)
100
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
70
80
90
100


LCR3T
LCR4T
LCR5T
Boone
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
85% of NO_3-N export
Flow (mm day^{-1})
100
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
70
80
90
100
Flow Exceedance (%)



LCR3T
LCR4T
LCR5T
Boone
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
98% of NO_3-N export
Flow (mm day⁻¹)
100
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
70
80
90
100
Flow Exceedance (%)

Fertilizer Management: Phosphorus

P application rates – reduce based on soil test P 17% reduction

Use manure instead of commercial P 46% reduction

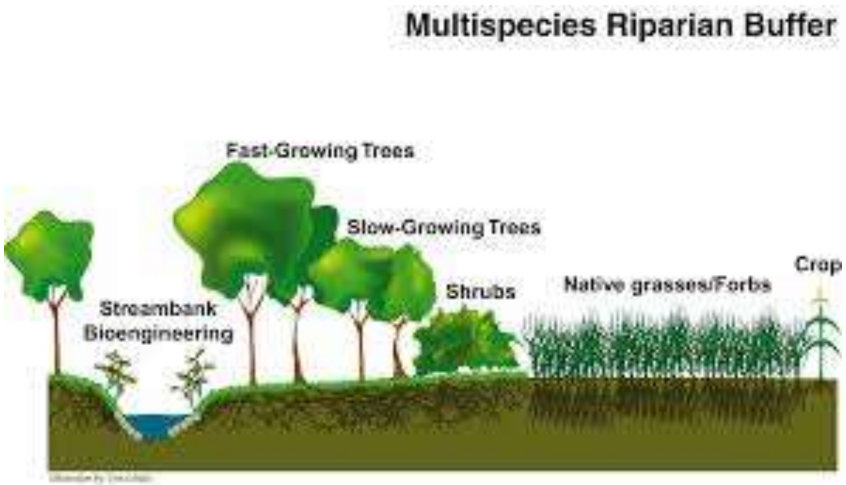
Improved incorporation of fertilizer 24-36%

Tillage Avoidance

In the 1950s and 60s, university researchers showed that leaving stubble from the last harvest on the field and planting crops like corn through the stubble protected moisture and produced better yields

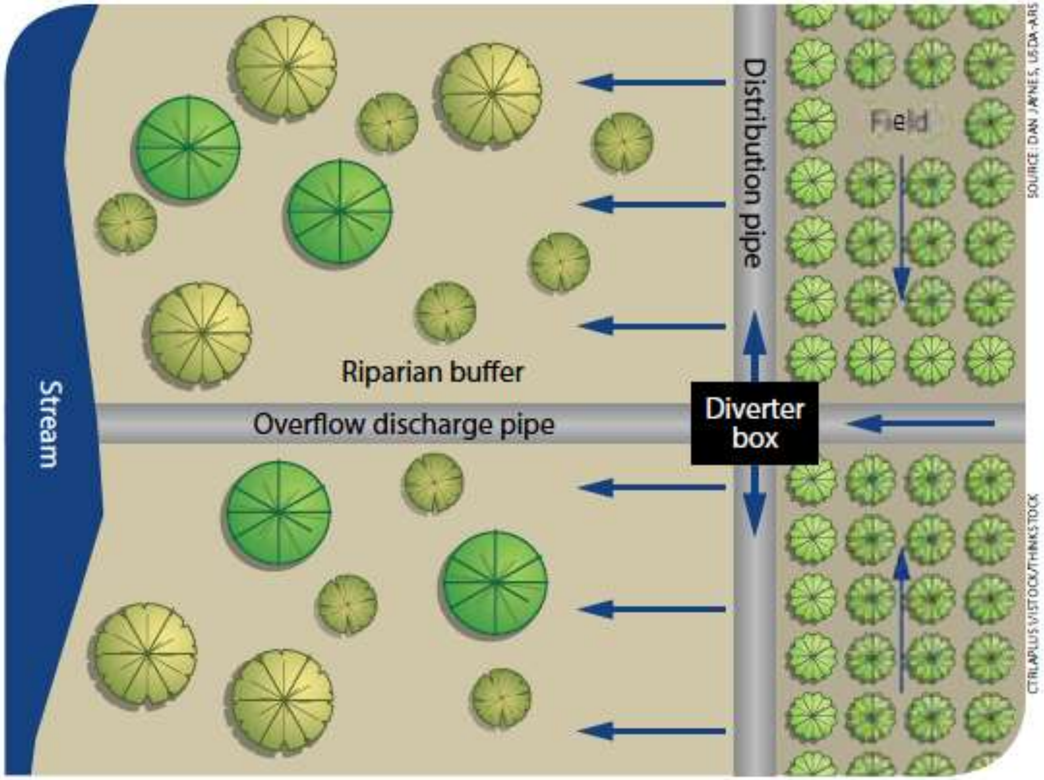
Edge of Field Practices

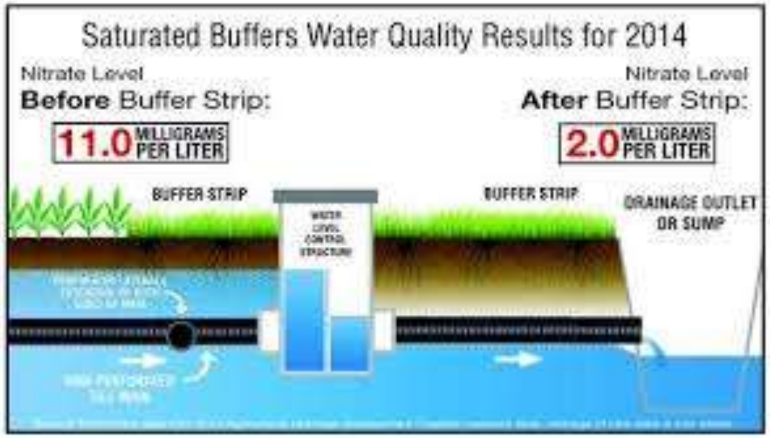
Riparian Buffers



Important caveat: Only works for water that interacts with active soil zone below the buffer. Tile drainage bypasses the process.

Saturated Buffers





50% reduction

Ponds and WACOBs

Wetland Construction

Contents lists available at ScienceDirect

ELSEVIER

Ecological Engineering

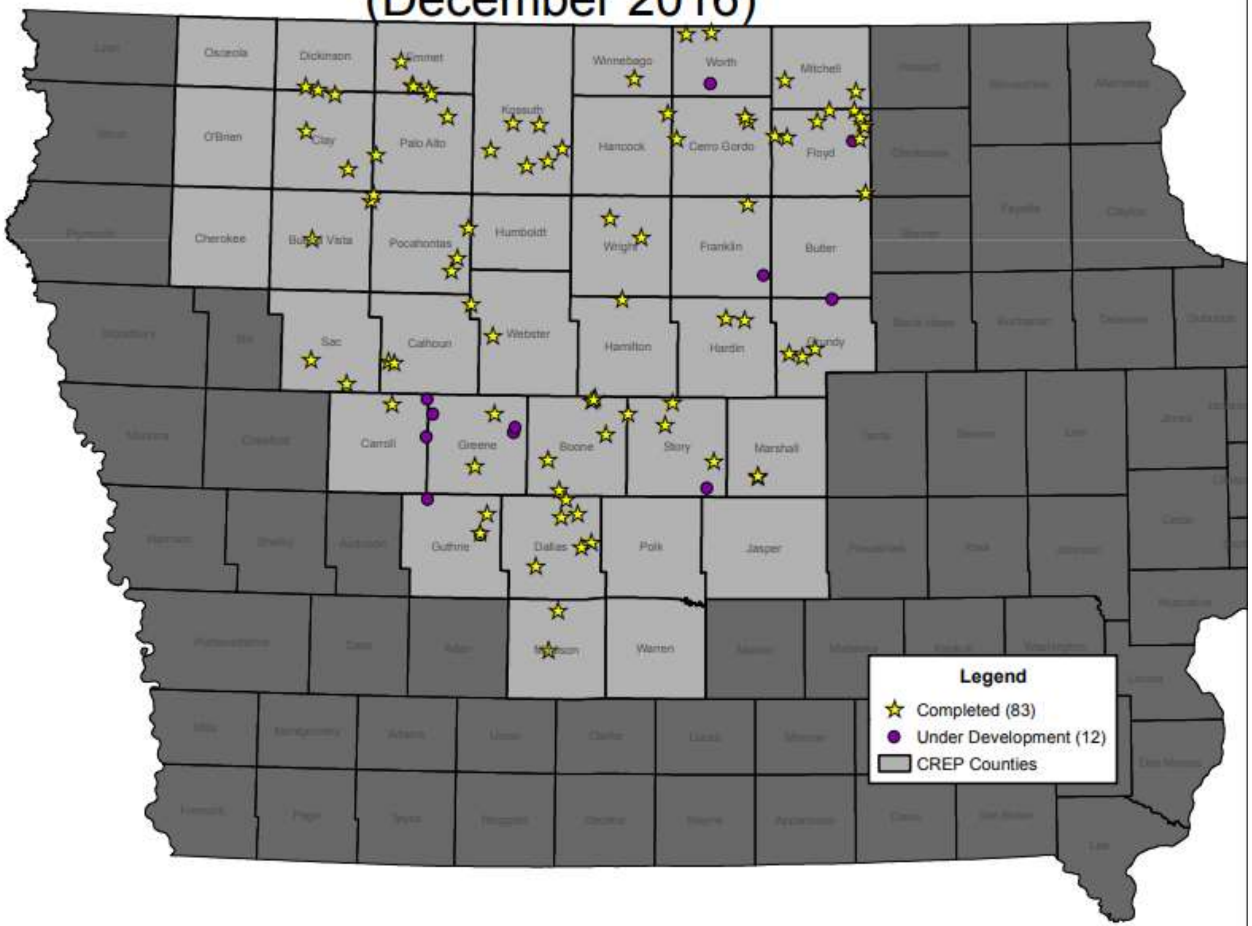
journal homepage: www.elsevier.com/locate/ecoleng

Estimating nitrate-nitrogen retention in a large constructed wetland using high-frequency, continuous monitoring and hydrologic modeling

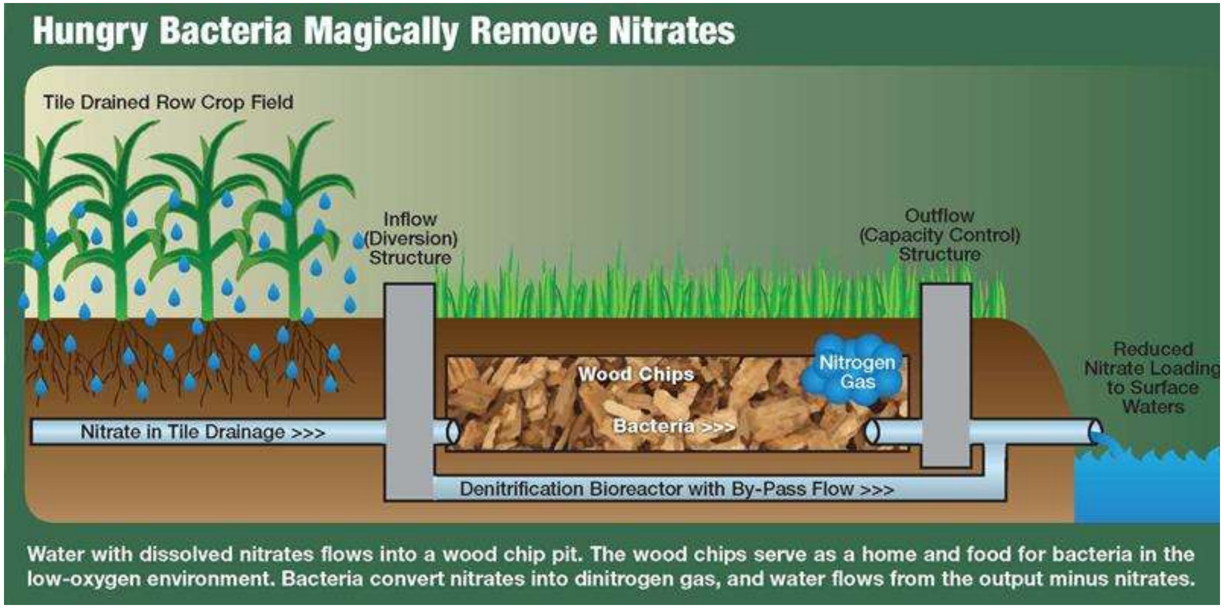
C.W. Drake[a,*], C.S. Jones[a], K.E. Schilling[b], A. Arenas Amado[a], L.J. Weber[a]

[a] IIHR-Hydroscience and Engineering, University of Iowa, Iowa City, IA, USA
[b] Iowa Geological Survey, University of Iowa, Iowa City, IA, USA

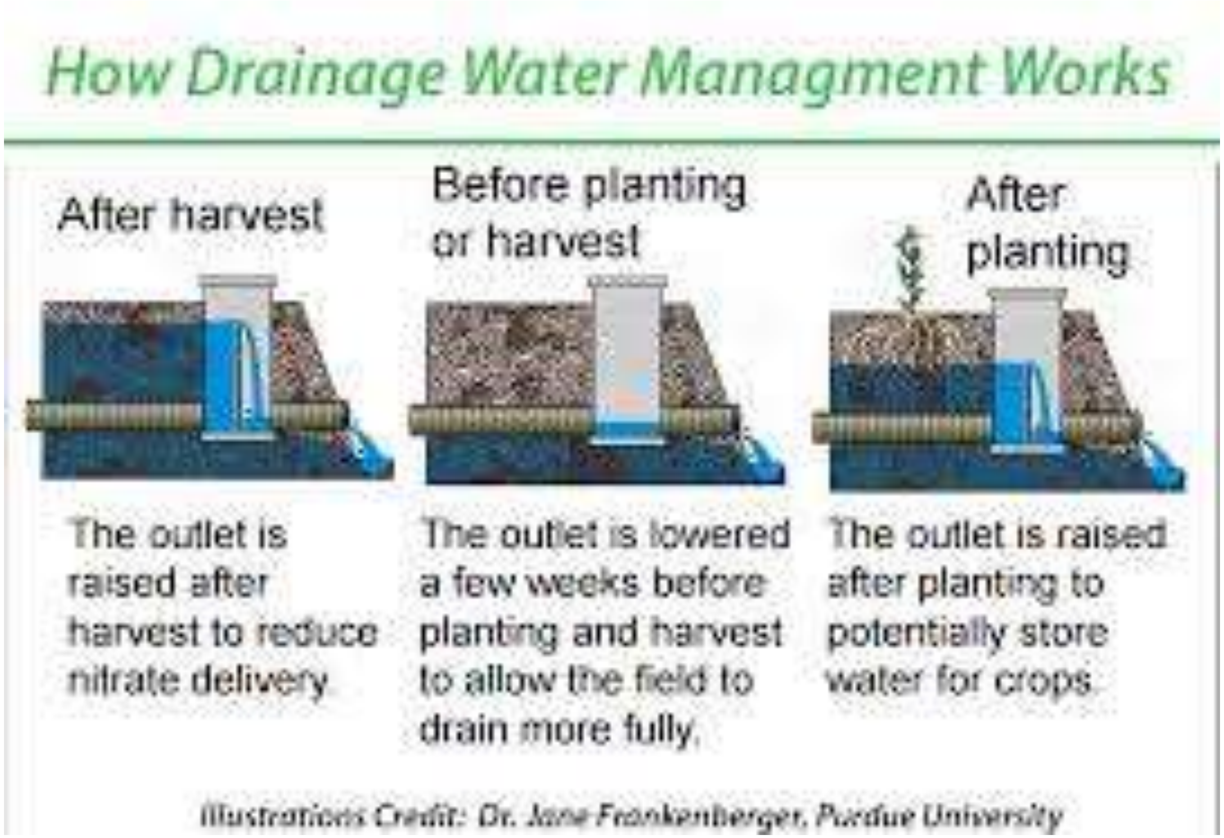
IOWA CREP STATUS
(December 2016)



Woodchip Bioreactors



Drainage Water Management



Two Stage Ditch

In-Ditch Weir

Ecologically-Based Practices

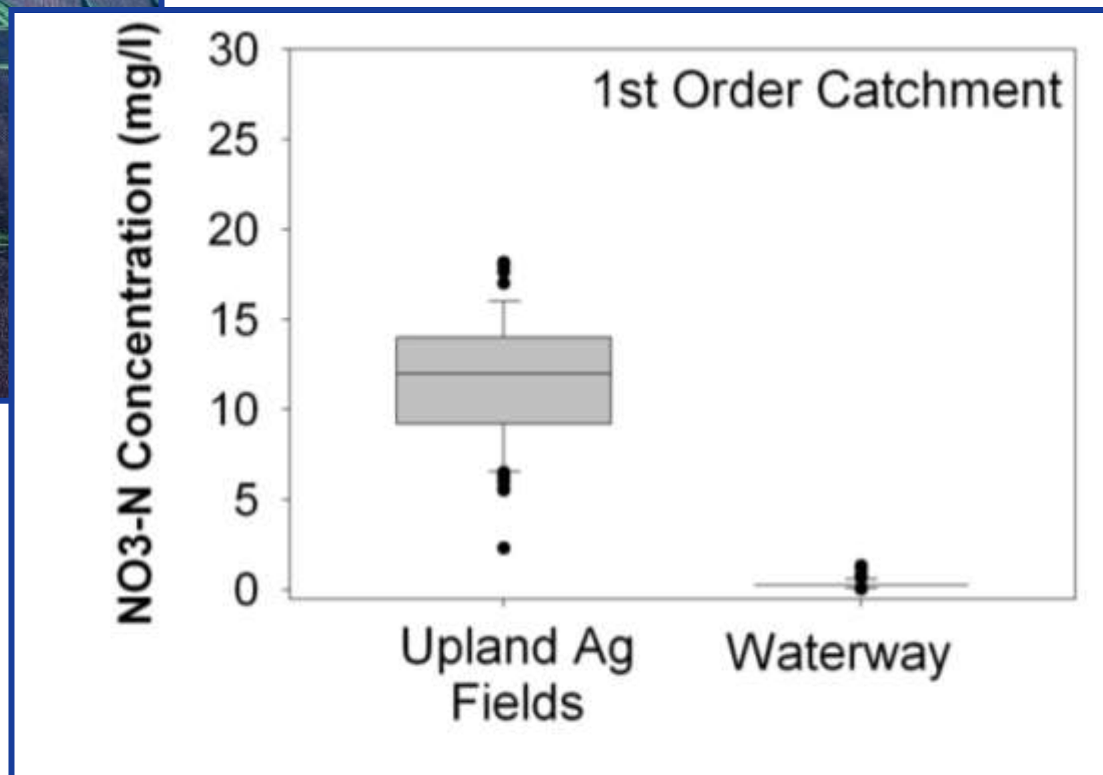
Cover crops

A **cover crop** is a crop planted primarily to manage soil erosion, soil fertility, soil quality, water, weeds, pests, diseases, biodiversity and wildlife in an *agroecosystem*

Cover crops are grasses, legumes or forbs planted to provide seasonal soil cover on cropland when the soil would otherwise be bare—i.e., before the crop emerges in spring or after fall harvest

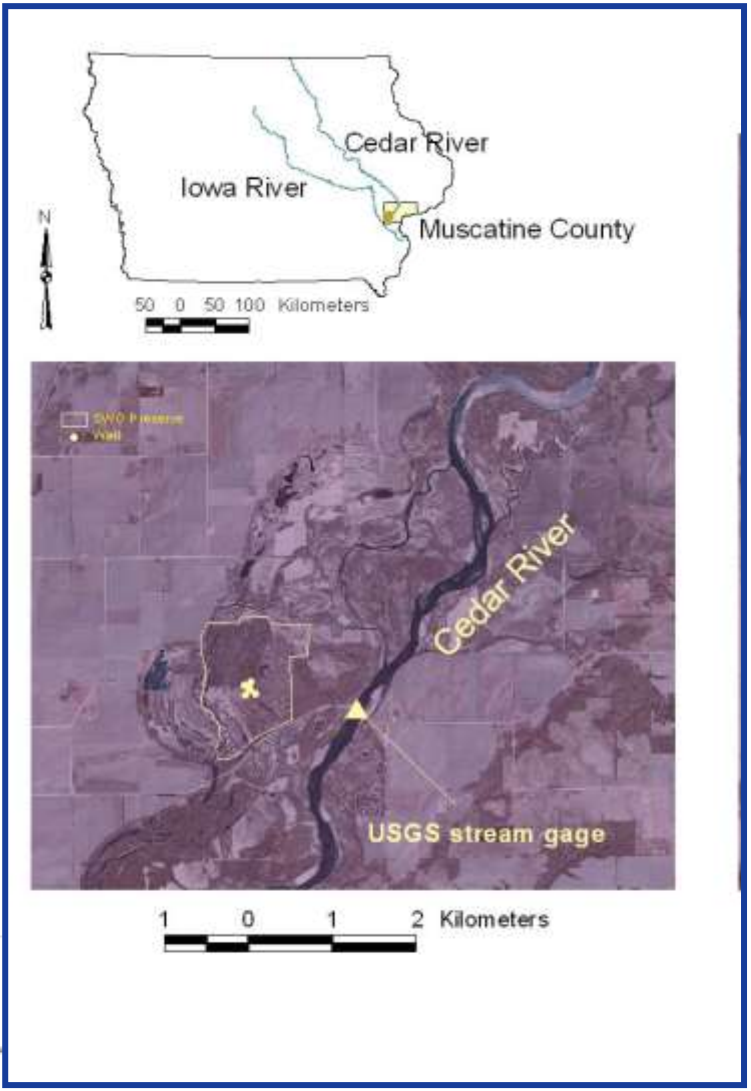
30-40% reduction in nitrogen and phosphorus

Grassed waterways – letting wet spots be wet

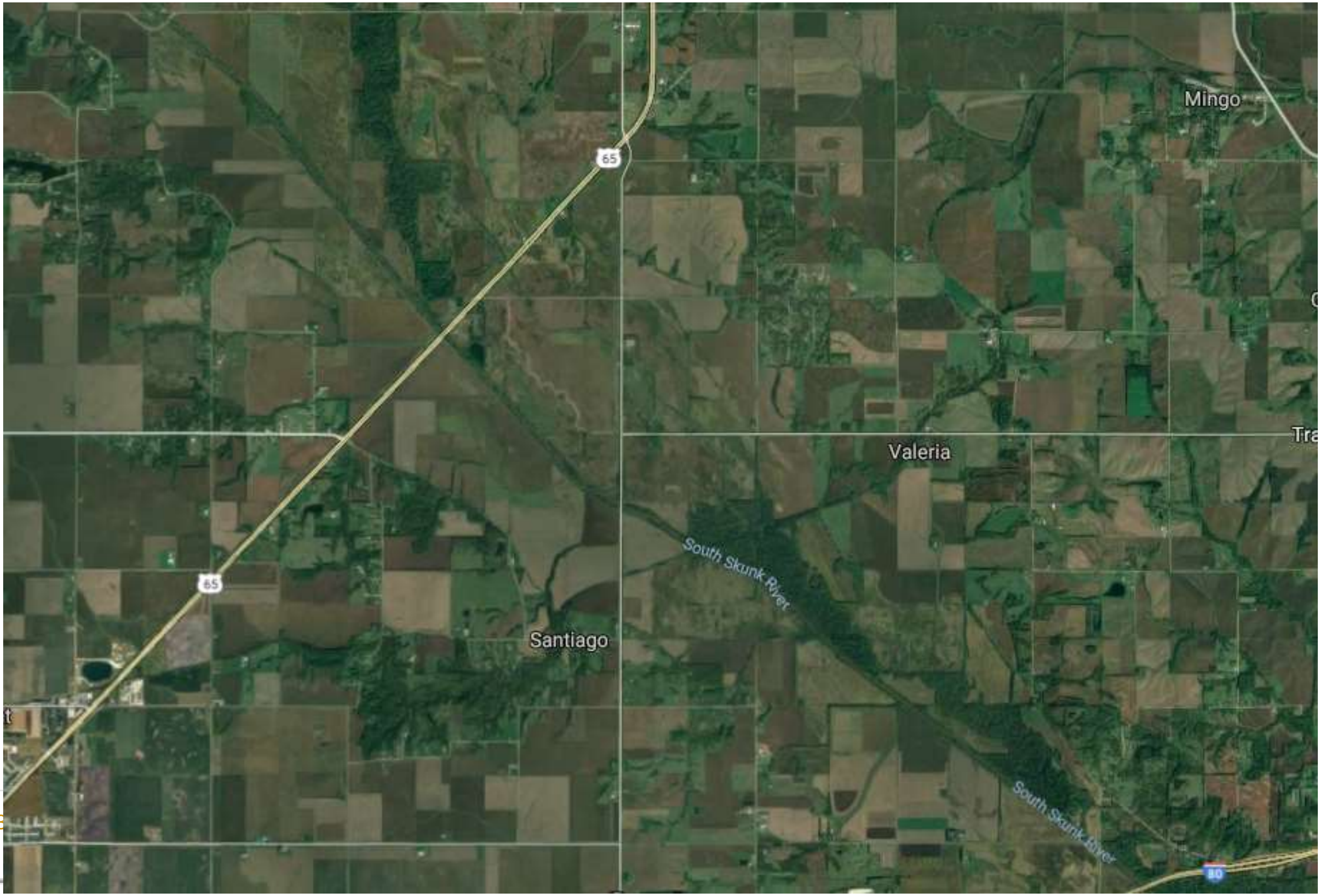


Schilling et al., 2007

Restore N processing in floodplains



Re-meander streams / stream restoration



Re-meander streams / stream restoration

Economics of N loss

Cost of Nitrogen: $0.33-$0.50/pound (today about $0.55/lb)

Cost to remove nitrogen using BMPs: $2-$10/pound

Average statewide load: 600 million lbs

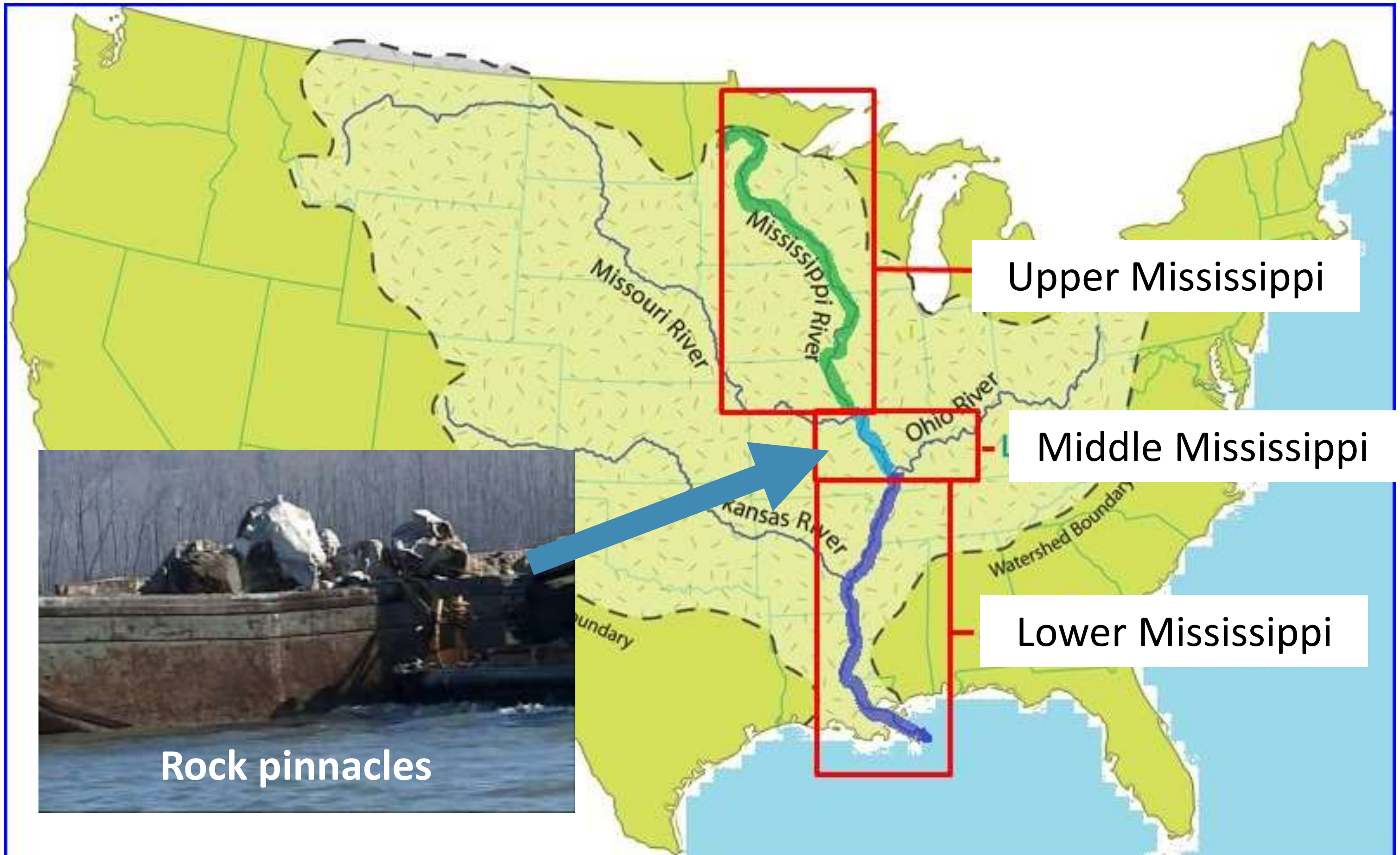
45% reduction = 270 million lbs/year

$540M to $2.7B/year

Economics of Nitrogen Loss

- **2016 production costs (labor, land, seed, machinery, chemicals, insurance, fertilizer) for corn following soybean, assuming a yield of 180 bushels per acre: $719/acre**
- **Value of N lost to streams ($17.74) was 2.5% of production cost during a wet year (2016)**
- **Cover Crops cost $30/acre, which increases production costs 4.2% for corn, 5.6% for soybean**
- **Cover Crops sequester 31% of lost nitrogen ($5.50).**
- **All Iowa C/SB acres in cover crops: $563M/year, $175/Iowan.**
- **Yield benefit would have to be 8 bushels of corn, 3 bushels of soybean**

Mississippi River


Upper Mississippi
Middle Mississippi
Lower Mississippi
Mississippi River
Missouri River
Ohio River
Kansas River
Watershed Boundary
Rock pinnacles

Longest Rivers

Nile: 4130 miles

Amazon: 3976 miles

Yangtze: 3917 miles

Missouri-Mississippi: 3902 miles

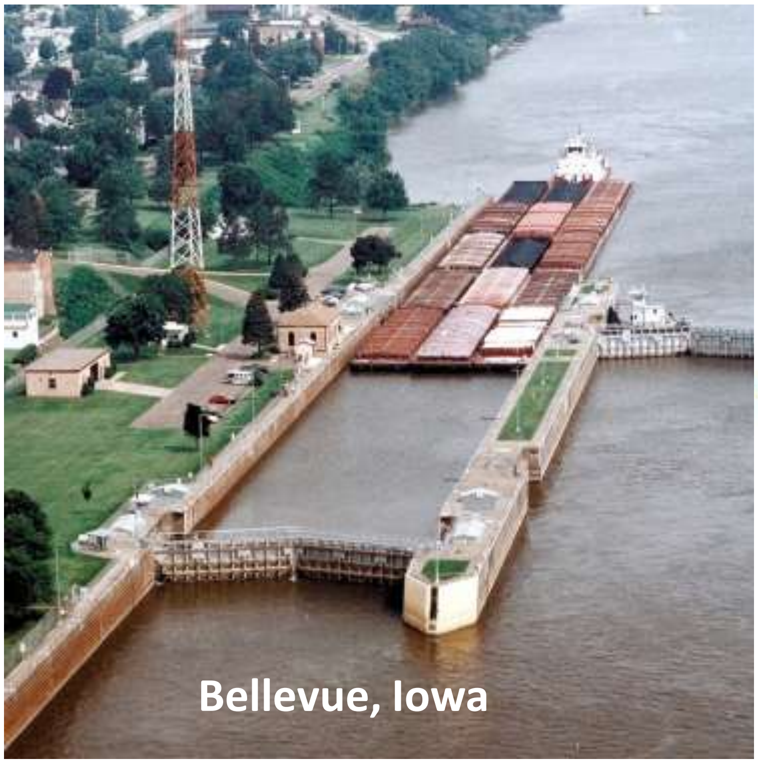
Missouri: 2341 miles

Mississippi: 2340 miles

Mississippi and Missouri have both been shortened by 100s of miles

Oxbow Lakes

Upper Mississippi River



History of Lock and Dam System on Upper Mississippi

Government has been trying to enhance navigation since the early 1800s

Rapids at Keokuk and Rock Island

Shallow depth (1-3') for 200 miles below St. Paul, very crooked

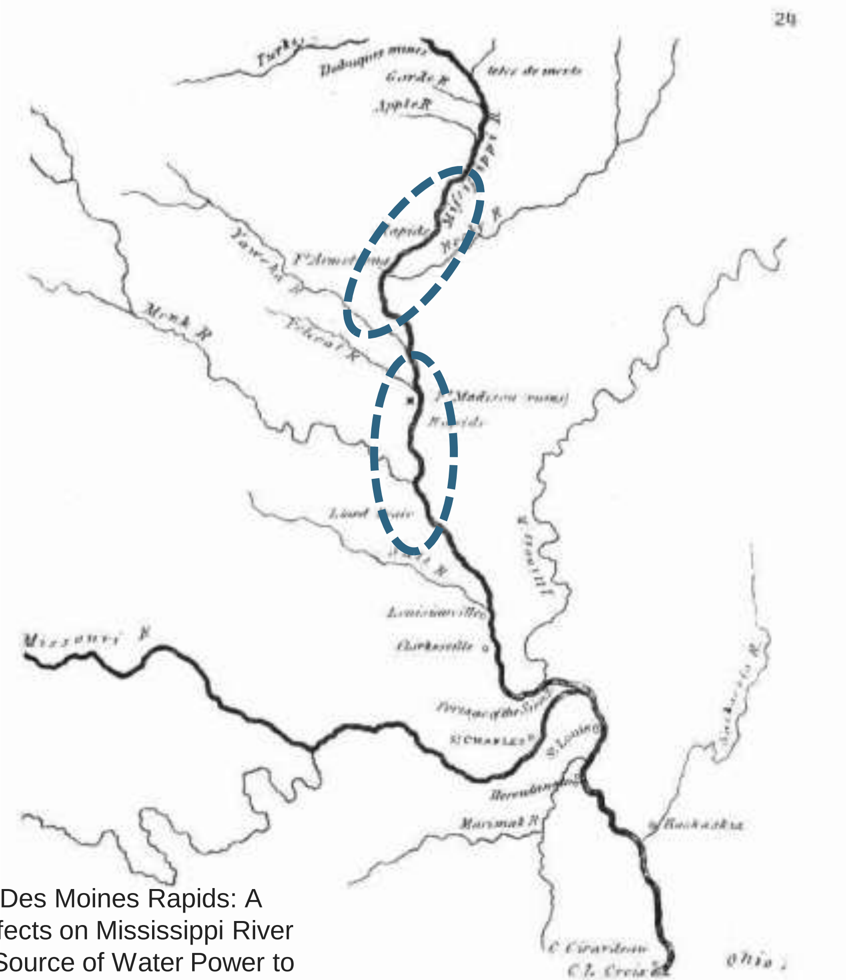


Fig. 3. Map of the Upper Mississippi River, by Giacomo Constantine Beltrami, 1823.

Enders, D.L., 1973. The Des Moines Rapids: A History of Its Adverse Effects on Mississippi River Traffic and Its Use as a Source of Water Power to 1860.

1866

Congress appropriates $400,000 for 4 foot channel from St. Paul to St. Louis

History of Lock and Dam System: "9 foot project"

1920's: farmers single biggest economic group in U.S.

Agriculture clamored for inland waterway to compete with railroads

1924:
Ad hoc commission led by Herbert Hoover proposed St. Lawrence Seaway, connection of Lake Michigan to Illinois R and Mississippi River, and 9-ft Upper Mississippi River Channel

Newton Bill

Called for USACE to complete by 1929:

(1) a 9-foot channel in the Ohio River from Pittsburgh to Cairo as authorized in 1910;

(2) a 6-foot channel in the Missouri River between Kansas City and the Upper Mississippi River as also authorized in 1910;

(3) a 9-foot channel in the Upper Mississippi from Cairo to the Illinois River6-foot project both authorized in 1910

(4) 6-foot channel in the Upper Mississippi River from Minneapolis to the mouth of the Missouri River, located just above St. Louis, as authorized in 1907.

Congress had originally mandated a 1922 deadline for the completion of the 6-foot channel. By the end of that year, however, the 15-year-old project remained less than half complete.

Cleveland Newton

6’ or 9’ ??

Concluded if there was a channel, it should be 9’

Also said channel should not be built
- Need was not sufficient
- Environmental Disaster

knew that the only feasible way to provide a 9’foot depth was through a series of locks and dams that would transform the river from a free-flowing stream into interconnected lakes.

Hall feared that these slack-water pools would create vast swamps of stagnant and polluted water. He was also concerned about the effect of slack-water navigation on indigenous wildlife.

Charles Hall

House Bill 137 (1932)

Appropriated $124,000,000 for 26 Locks and Dams

Construction generally proceeded upstream → downstream

System completed around 1940

L-D 26 replaced in 1990

L-27 added in 1964

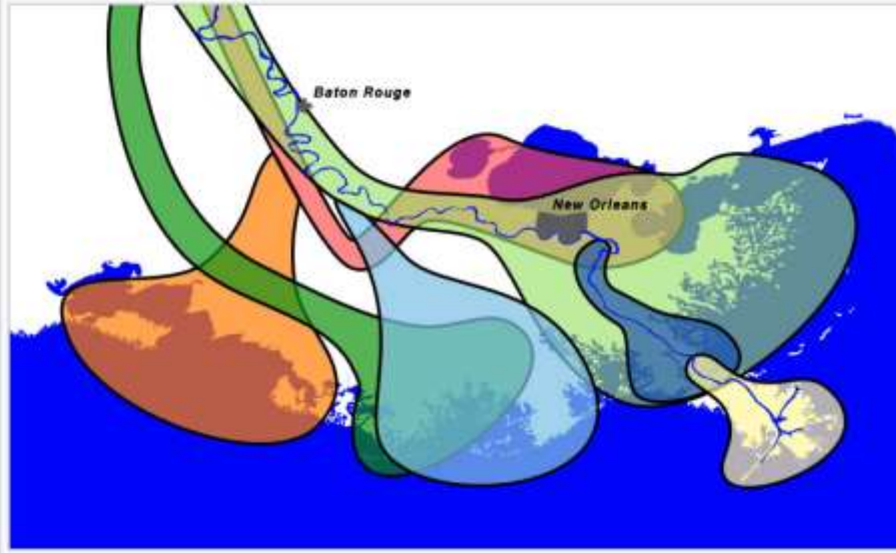
Upper Mississippi is now far bigger than a century ago

Environmental Consequences?

- Birds
- Fish
- Recreational boating
- Farms
- Erosion

River is undersized for its valley

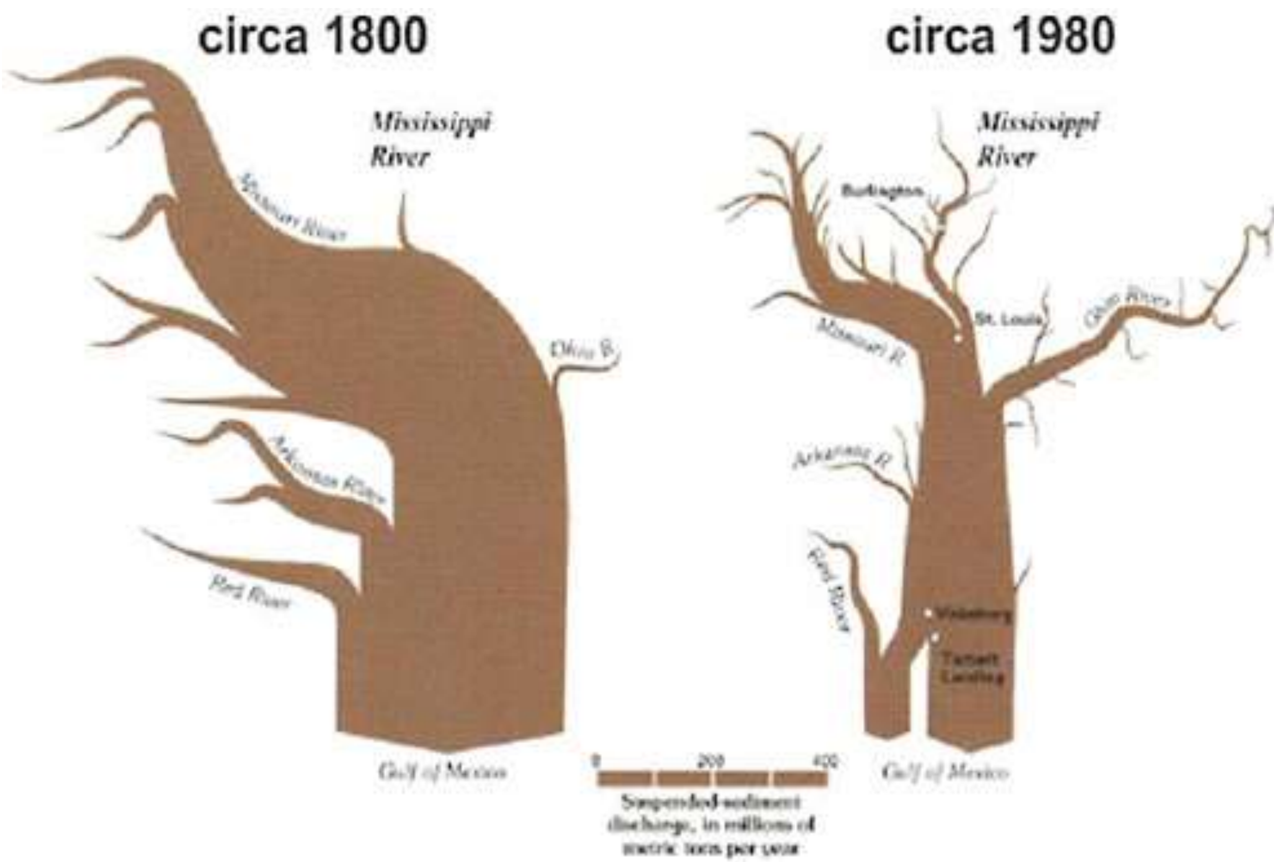
Mississippi Outlet wanders



Mississippi Delta lobes

(orange)	Salé-Cypremort	4,600 years BP[11]
(pink)	Cocodrie	4,600–3,500 years BP[11]
(green)	Teche	3,500–2,800 years BP[11]
(light green)	St. Bernard	2,800–1,000 years BP[11]
(light blue)	Lafourche	1,000–300 years BP[11]
(blue)	Plaquemine	750–500 years BP[11]
(yellow)	Balize	550 years[11]


4000 BC
2600 BC
2300 BC
2000 BC
1000 BC
1 AD
1000 AD
2010 AD



Source: USGS, https://www.nap.edu/read/13019/chapter/4#37

Water Budget

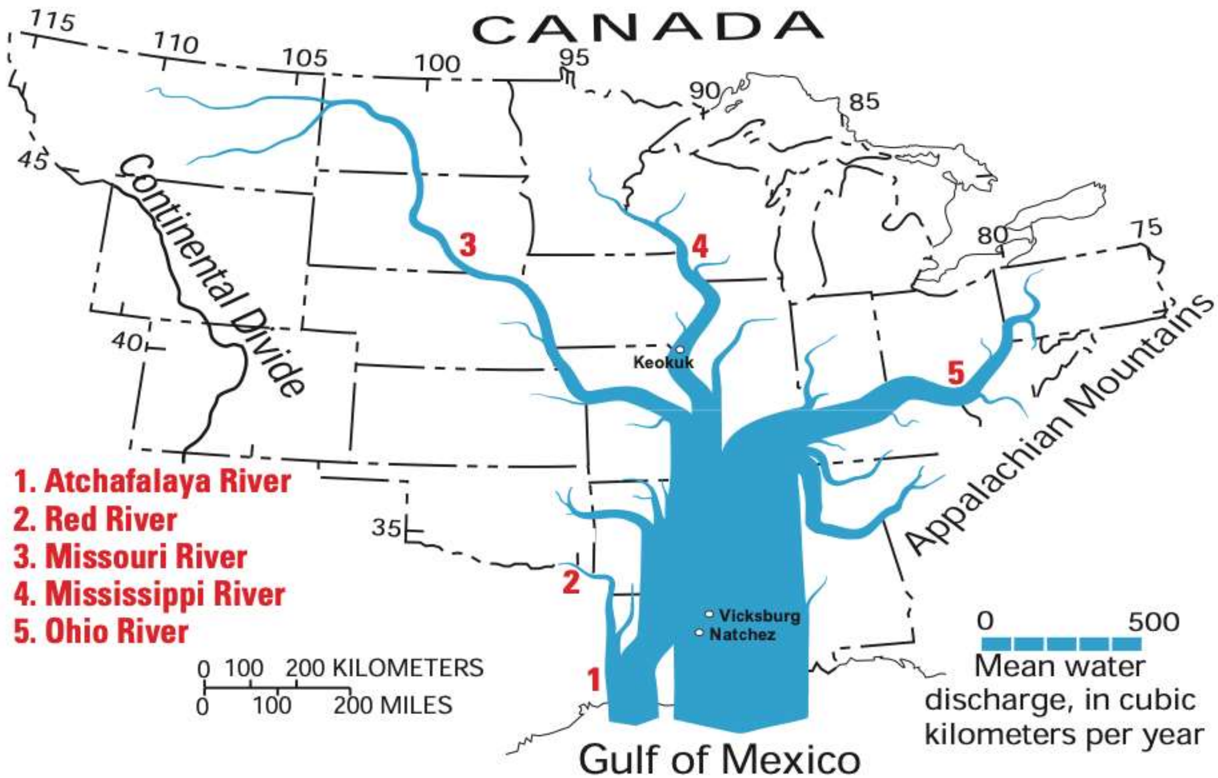
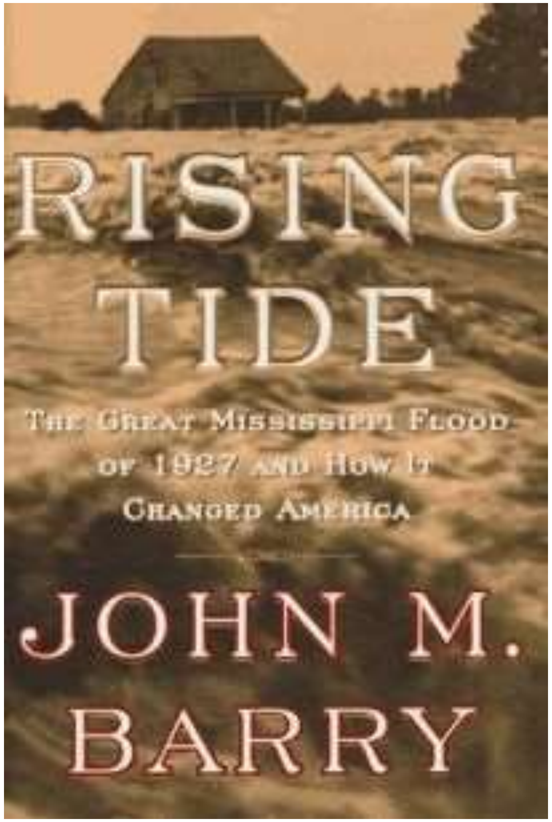


Figure 1. Mississippi River basin with major tributaries and state boundaries. The width of a river indicates its mean water discharge (modified from Circular 1133, Figure 5).

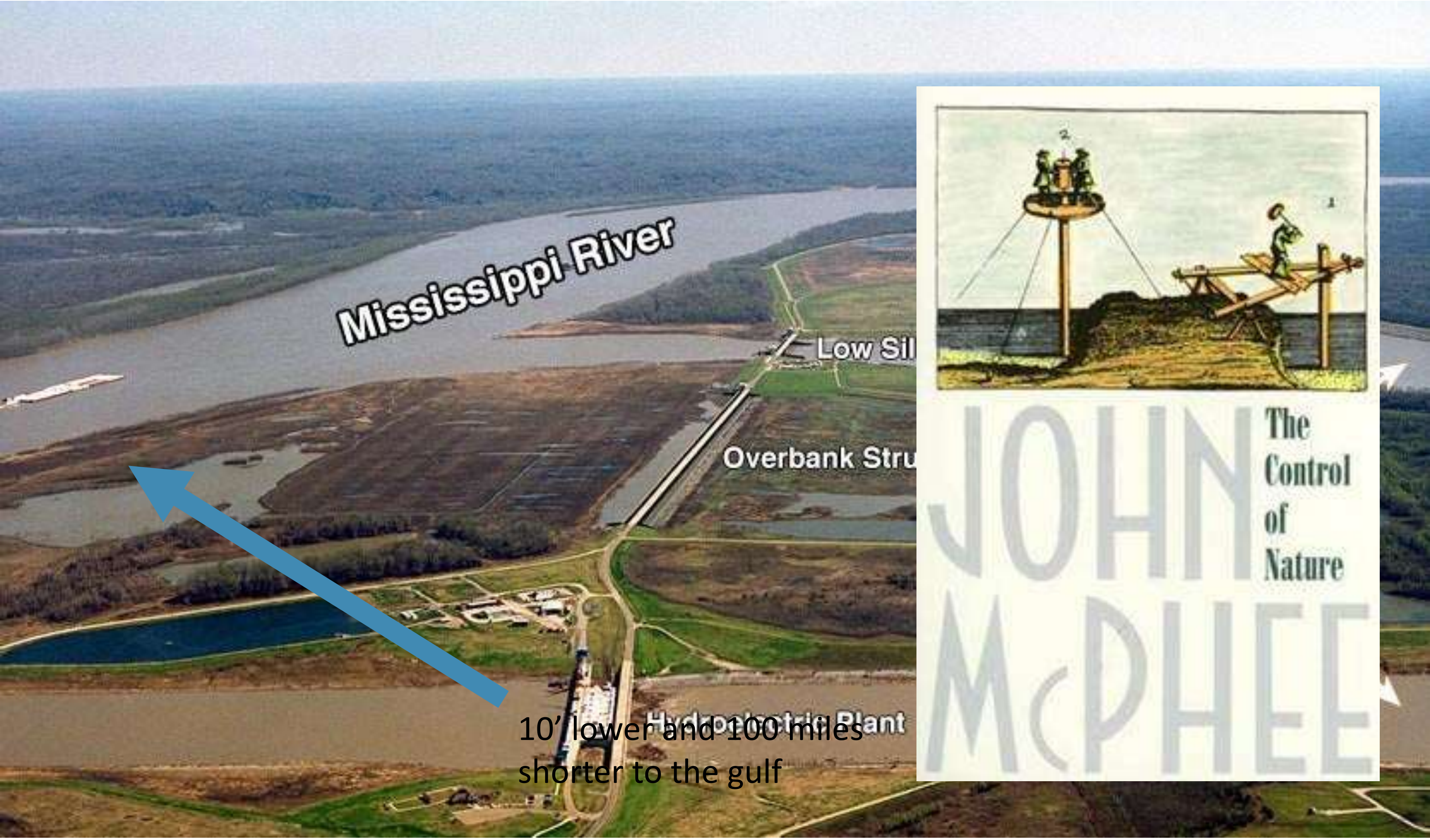
https://pubs.usgs.gov/fs/2005/3020/pdf/FS2005_3020.pdf

Meander Cutoffs

1927 Mississippi River Flood



Old River Control Structure



10’ lower and 100 miles shorter to the gulf

Coastal wetlands disappearing

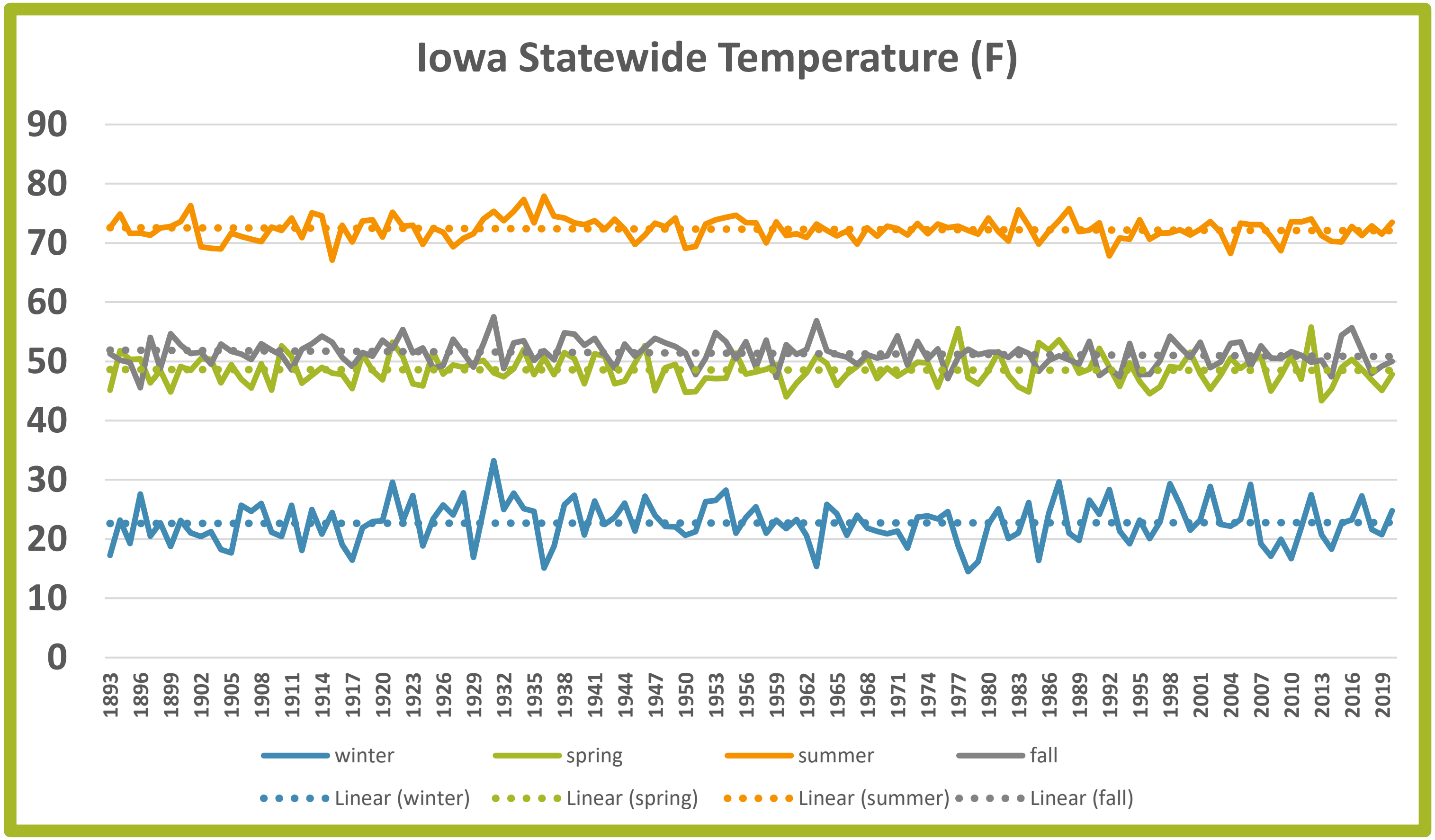
Sediment cutoff

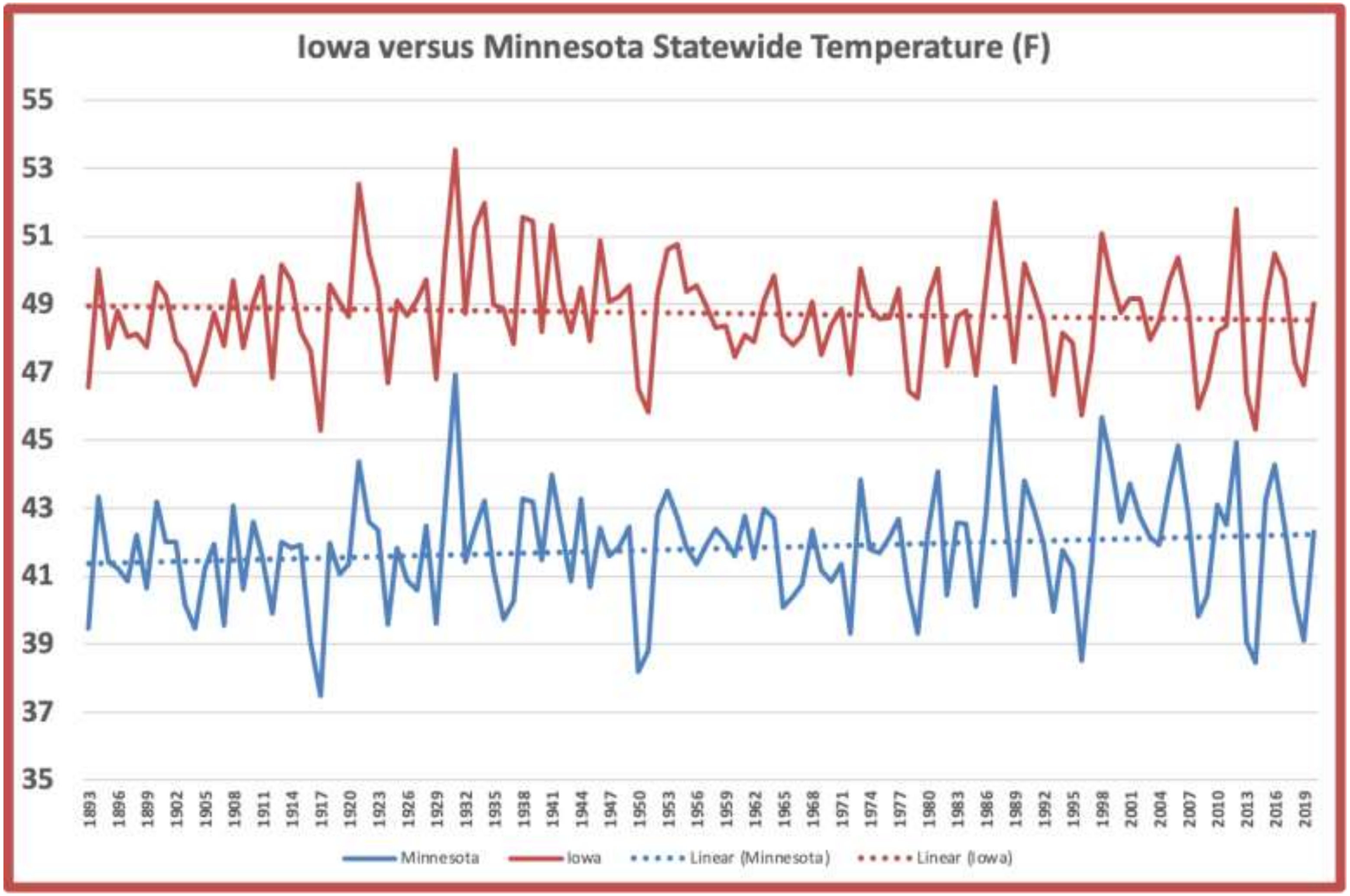
Subsidence

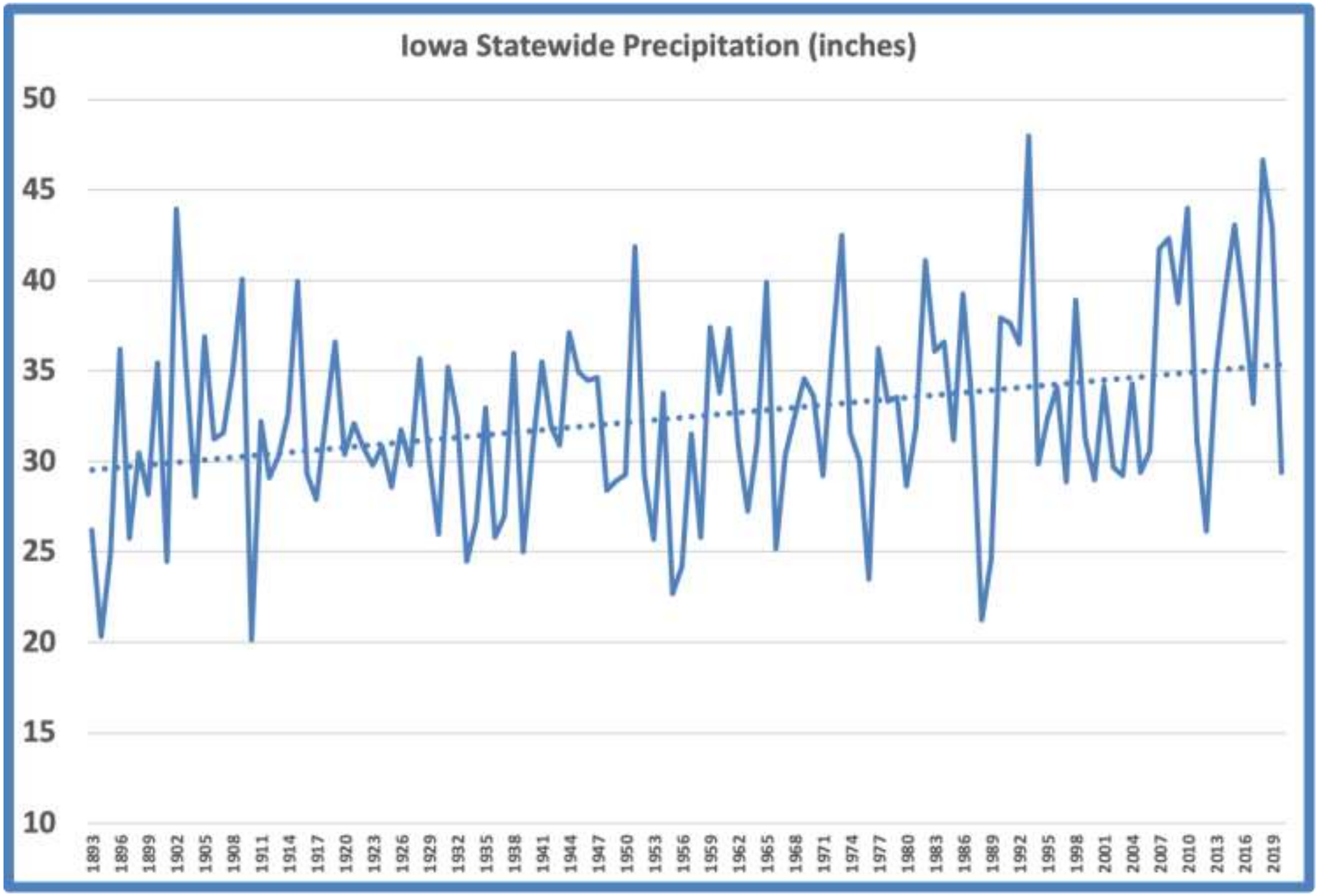
Climate Change

Lose 50 acres per day

Iowa Temperature since 1893




Iowa versus Minnesota Statewide Temperature (F)
55
53
51
49
47
45
43
41
39
37
35
1893 1896 1899 1902 1905 1908 1911 1914 1917 1920 1923 1926 1929 1932 1935 1938 1941 1944 1947 1950 1953 1956 1959 1962 1965 1968 1971 1974 1977 1980 1983 1986 1989 1992 1995 1998 2001 2004 2007 2010 2013 2016 2019
Minnesota
Iowa
Linear (Minnesota)
Linear (Iowa)


Iowa Statewide Precipitation (inches)
50
45
40
35
30
25
20
15
10
1893
1896
1899
1902
1905
1908
1911
1914
1917
1920
1923
1926
1929
1932
1935
1938
1941
1944
1947
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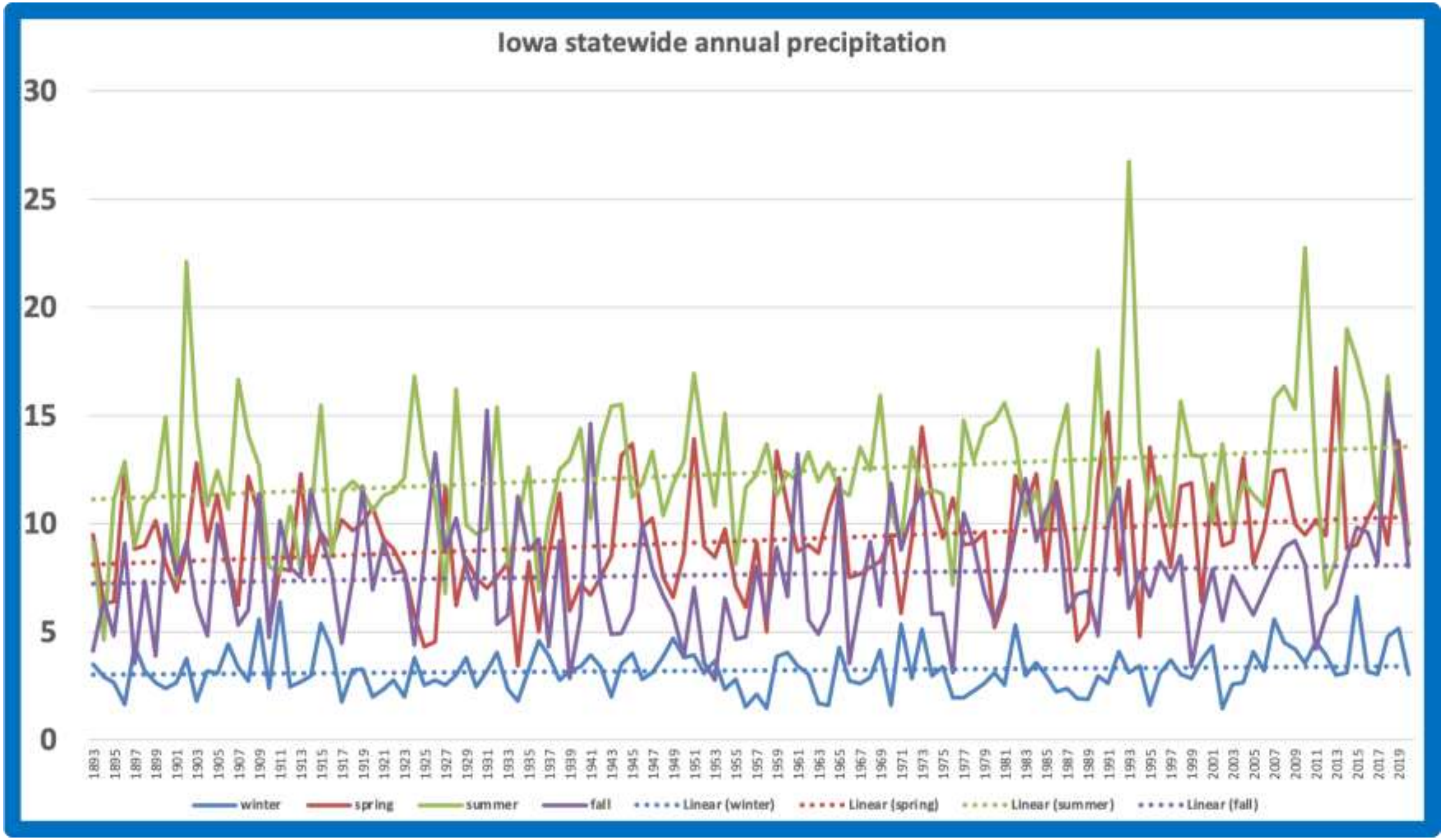
2013
2016
2019


Iowa statewide annual precipitation
30
25
20
15
10
5
0
1893
1895
1897
1899
1901
1903
1905
1907
1909
1911
1913
1915
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spring
summer
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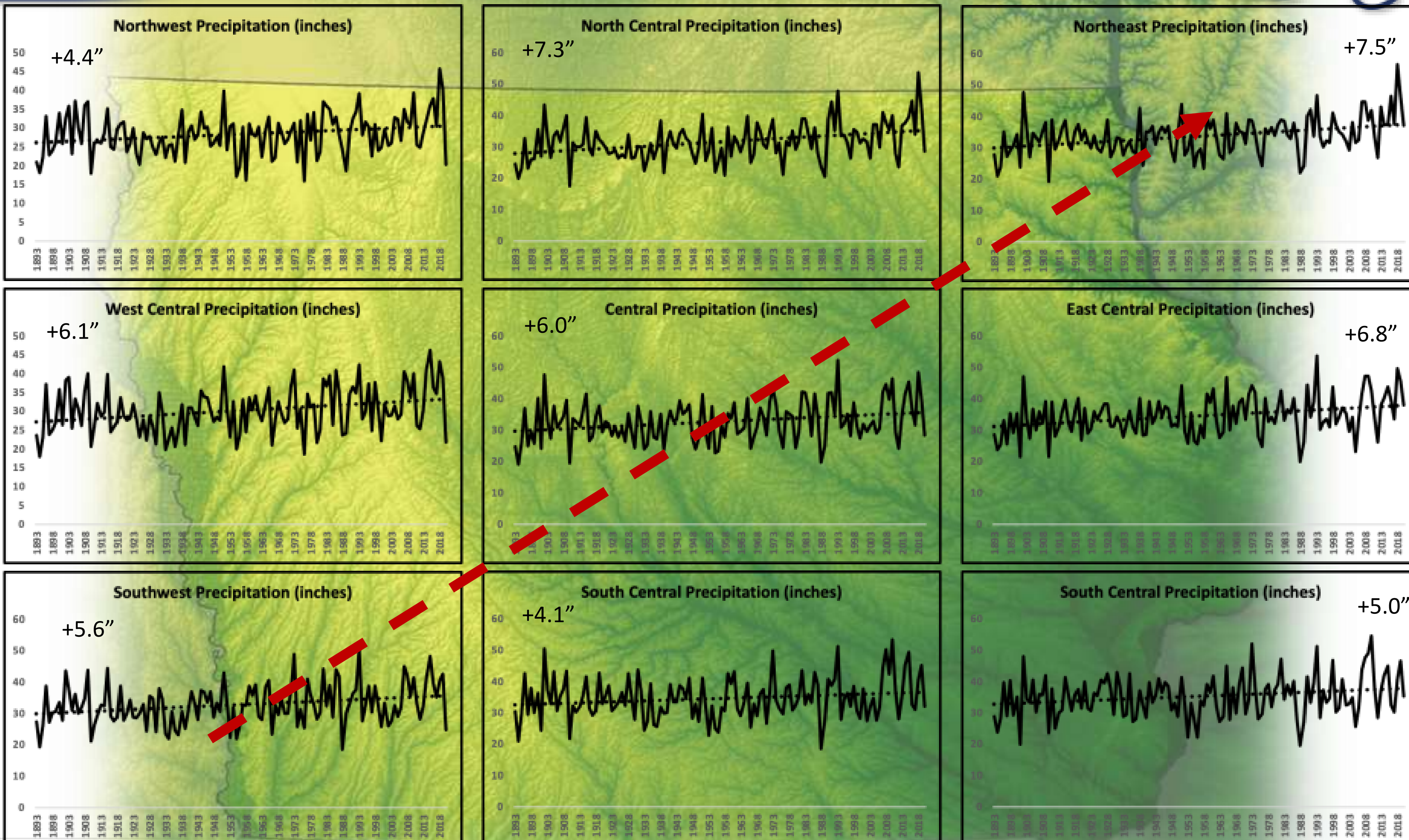
Linear (winter)
Linear (spring)
Linear (summer)
Linear (fall)



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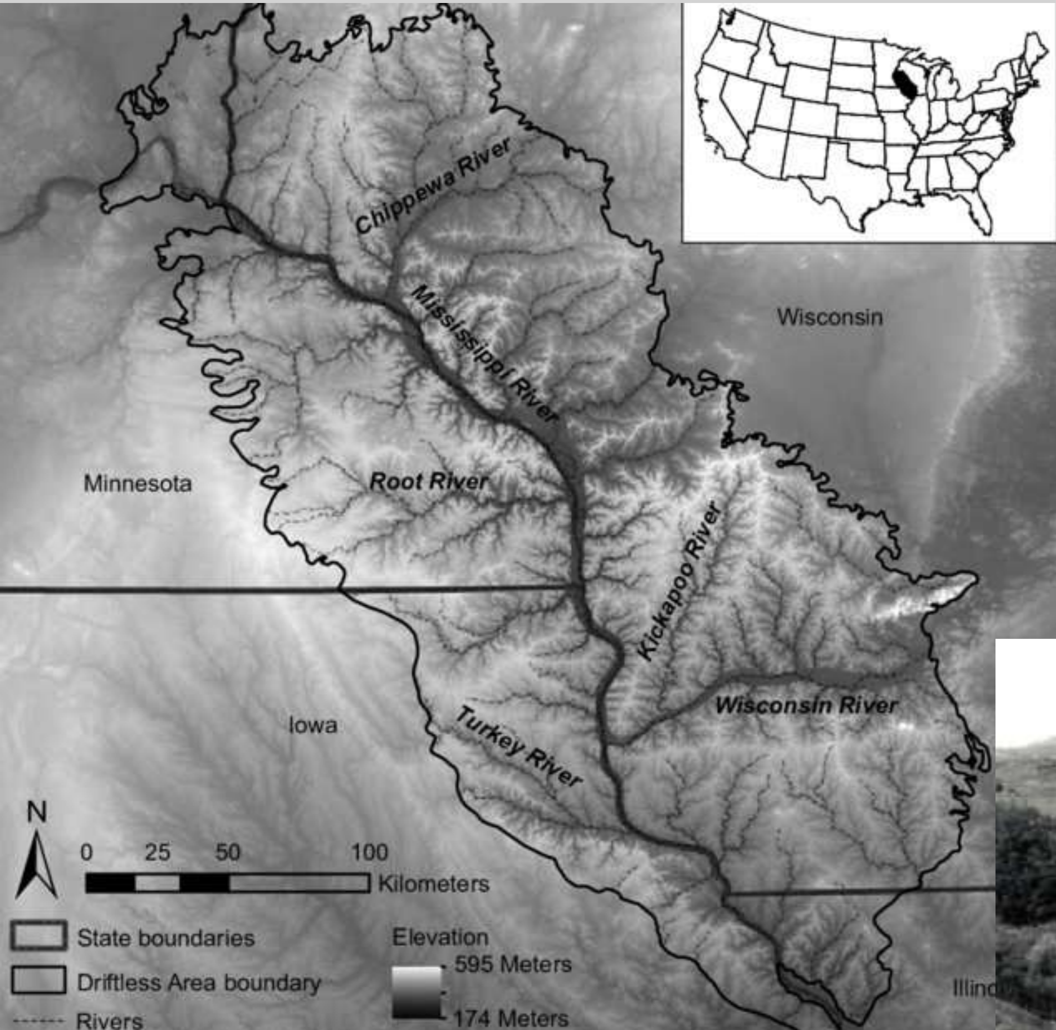


Credit: Shea, M.E., Schulte, L.A. and Palik, B.J., 2014. Reconstructing vegetation past: pre-Euro-American vegetation for the midwest driftless area, USA. *Ecological Restoration*, *32*(4), pp.417-433.

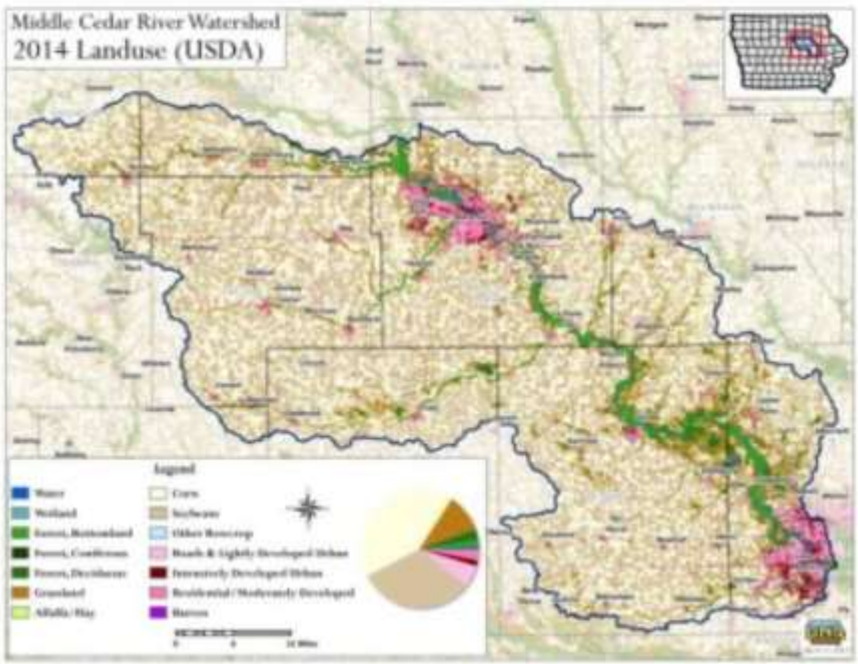
More Erosion/More P loss

Credit: USDA

More tile

Hand digging tile, Boone Co. IA. ca 1914
Source: 'An Iowa album: a photographic history, 1860-1920' by M. J. Bennet, University of Iowa Press, Iowa City, Iowa

More N loss: Middle Cedar Example



Iowa's Middle Cedar Watershed (credit: Middle Cedar Watershed Management Authority and Iowa DNR)

1200 miles new tile per year

1 acre of pattern tile = 1452' (0.275 mi)

1200 miles = 4364 acres

2018 N loss = 31.5 lbs/ac

New tile multiply N loss by 1.5 (15.9 lbs)

Increase watershed N load by 69,000 lbs

- 136 woodchip bioreactors (we currently have about 50 statewide), or,
- 3 constructed wetlands (currently we have about 100 statewide), or
- Around 7000 new acres of cover crops (currently we have million ac statewide).

Potential Impact of Climate Change on Subsurface Drainage in Iowa's Subsurface Drained Landscapes

R. Singh[1]; M. J. Helmers[2]; Amy L. Kaleita[3]; and Eugene S. Takle[4]

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Perry, Iowa

- **24-32% increase in annual precipitation**
- **Increase tile drainage flows**
- **Change distribution of flows within the calendar year**

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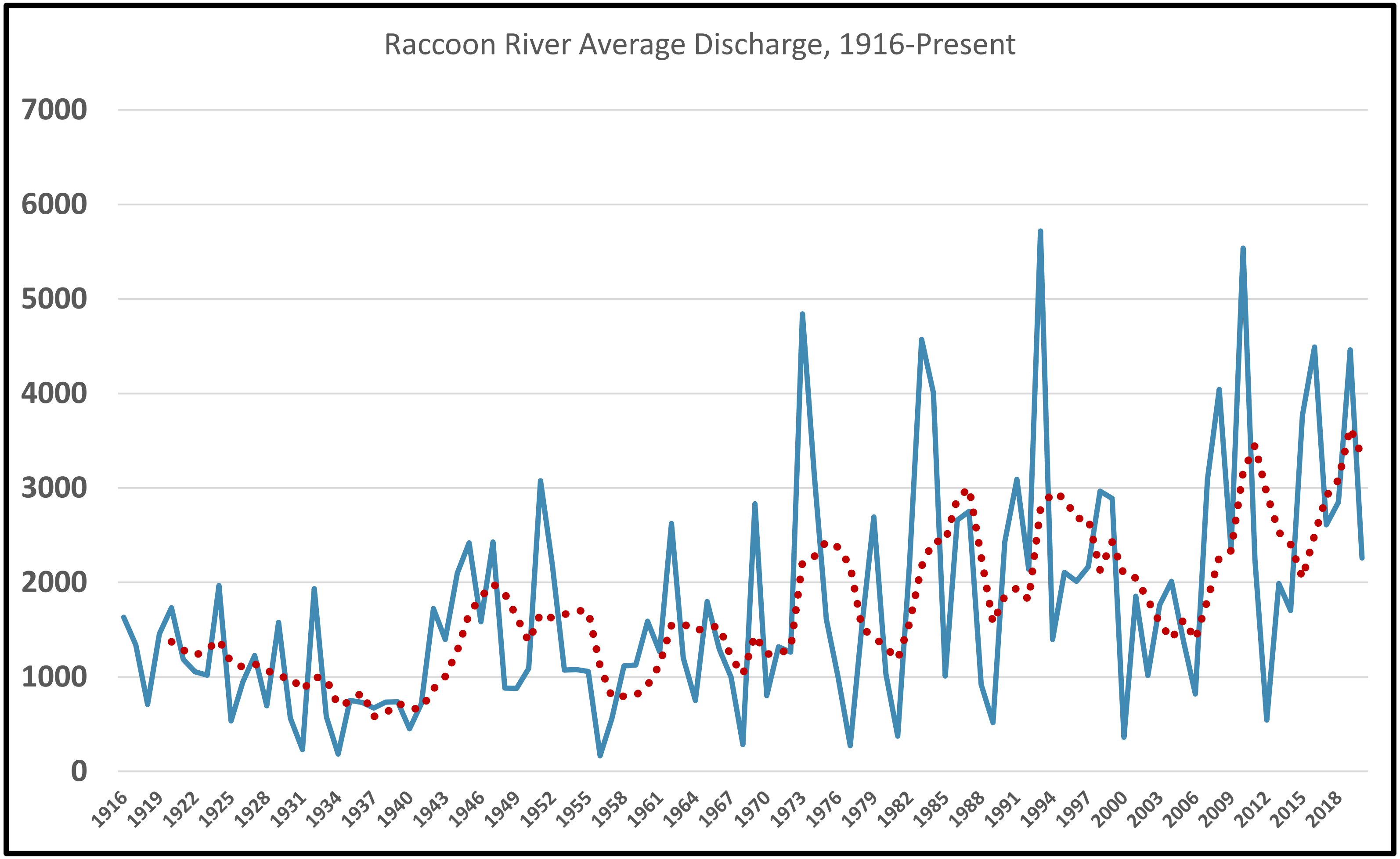
Raccoon River Average Discharge, 1916-Present
7000
6000
5000
4000
3000
2000
1000
0
1916
1919
1922
1925
1928
1931
1934
1937
1940
1943
1946
1949
1952
1955
1958
1961
1964
1967
1970
1973
1976
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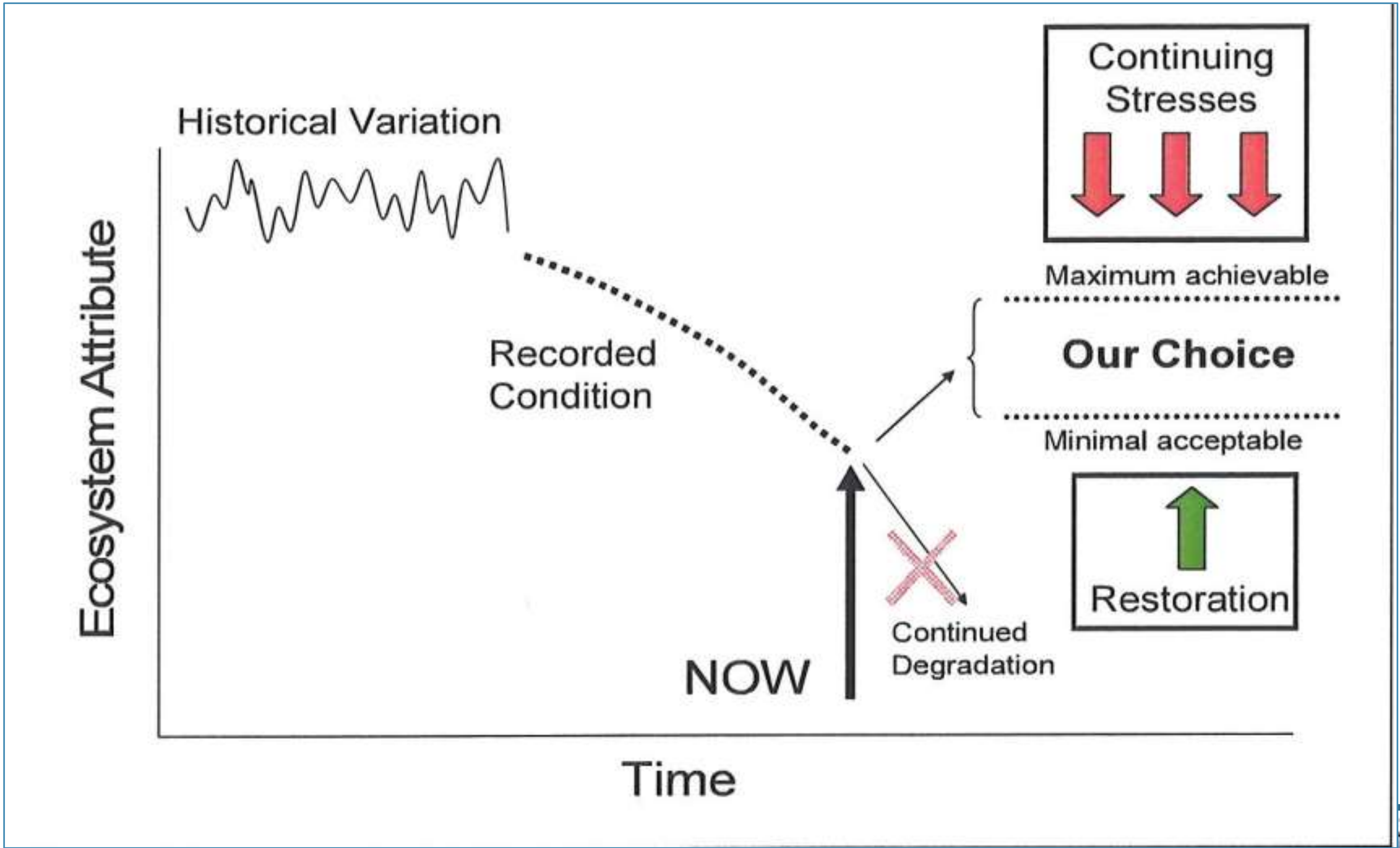
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
2015
2018



Continuing
Stresses
Historical Variation
Maximum achievable
Ecosystem Attribute
Recorded
Condition
Our Choice
Minimal acceptable
Restoration
Continued
Degradation
NOW
Time

Next Week

- Advancing solutions to water quality problems
- Costs to improving water quality
- What can the average person do to improve water quality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