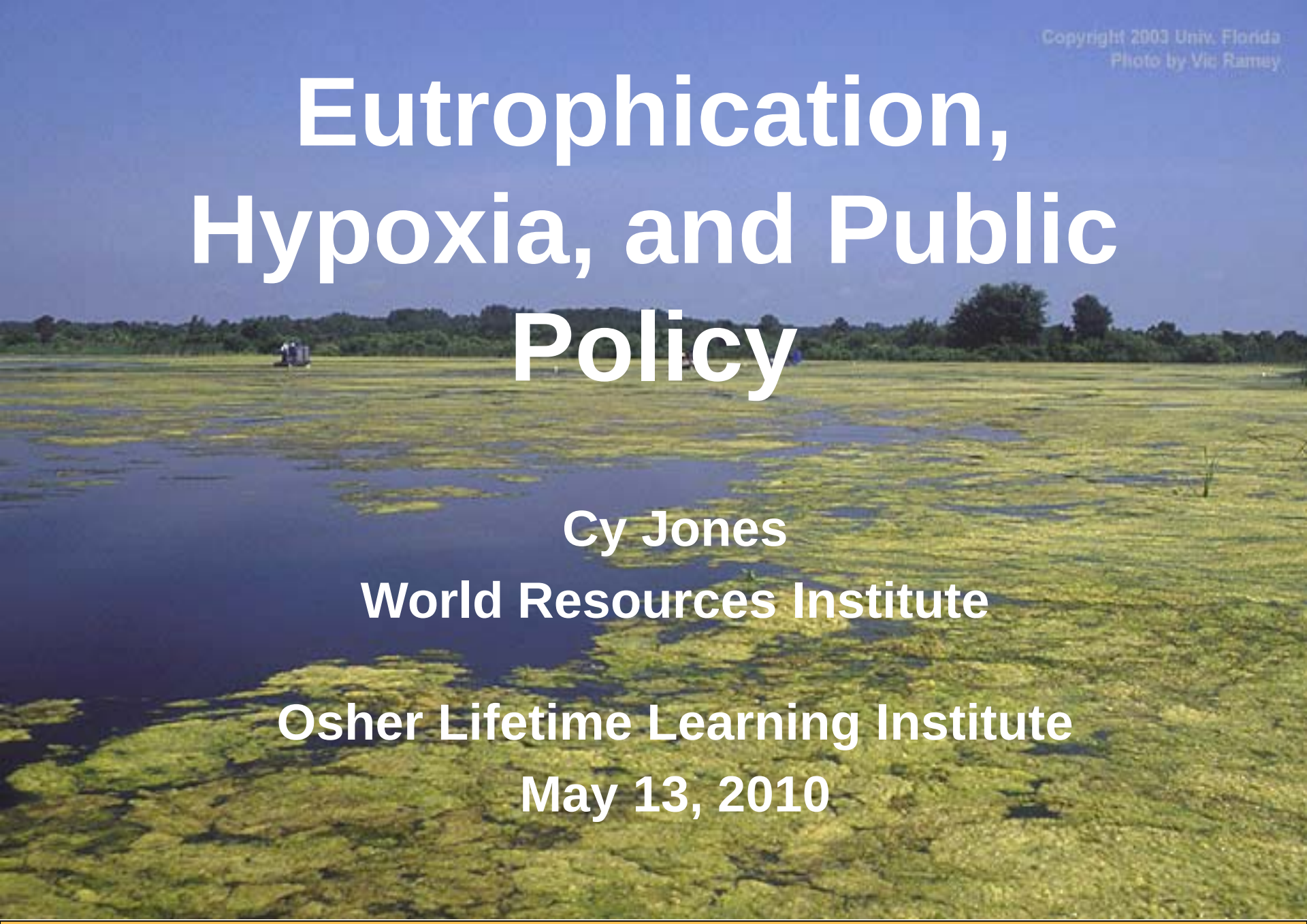


Eutrophication, Hypoxia, and Public Policy

Cy Jones

World Resources Institute

Osher Lifetime Learning Institute

May 13, 2010

Overview of Presentation

1. What Is Eutrophication
2. Consequences of Eutrophication
   - Hypoxia
   - Ecosystem Degradation
   - Loss of Ecosystem Services
3. Global Problem
4. Sources and Drivers
   - Nitrogen
     - Reactive Nitrogen
     - The Nitrogen Cascade
   - Phosphorus
   - Sources
5. Policies, Actions, and Strategies

Eutrophication:

The nutrient (nitrogen and phosphorus) over-enrichment of freshwater and coastal ecosystems

2008 Olympic Sailing Venue, Qingdao, China

Consequences:

Algae Blooms

Harmful Algae Blooms

Hypoxia and “Dead Zones”

Tai Lake, China

Chengdu, China

Charles River
Boston, Massachusetts

2009
Hampton Roads, Virginia

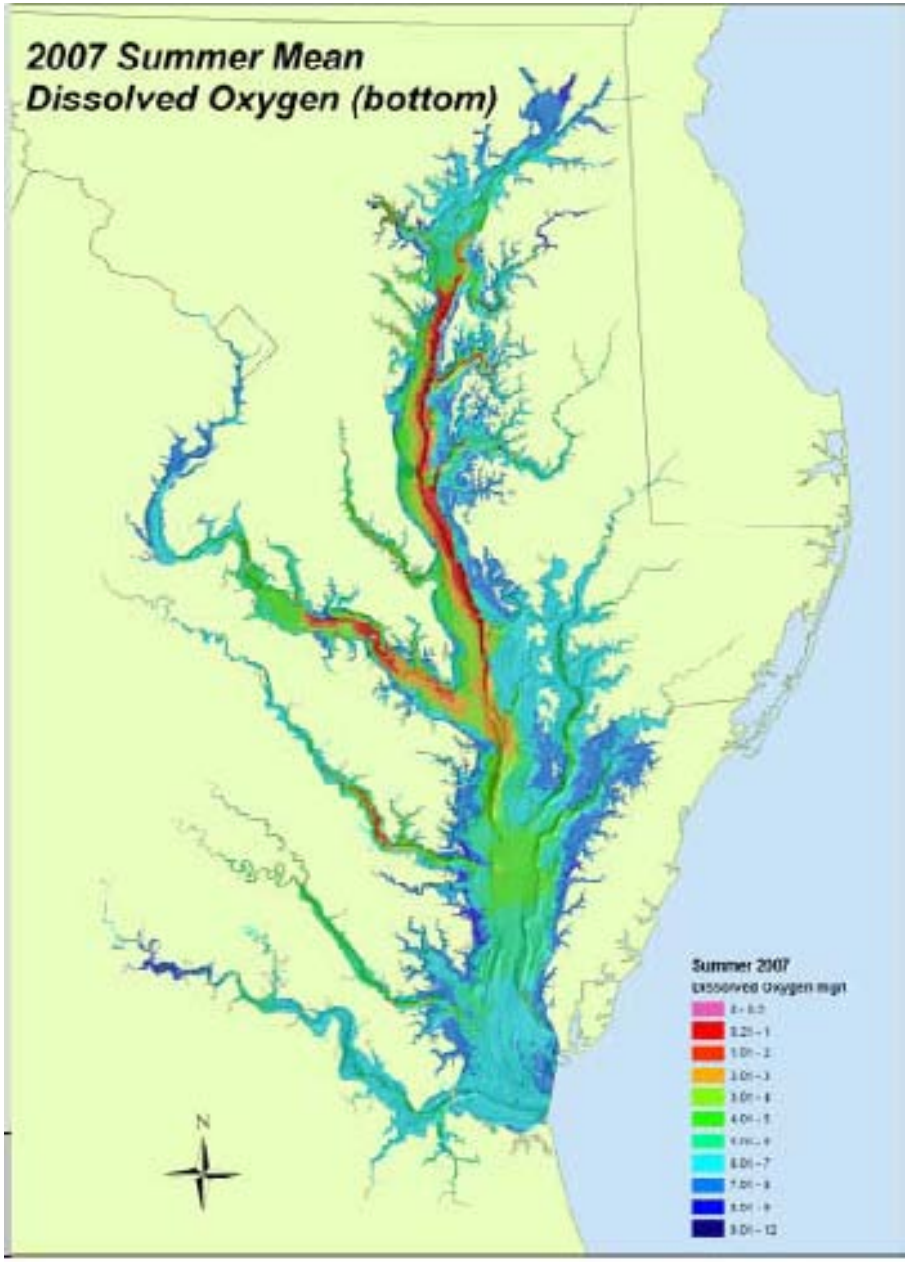
2007
Potomac River
Harmful Algae Bloom
Fish Kill

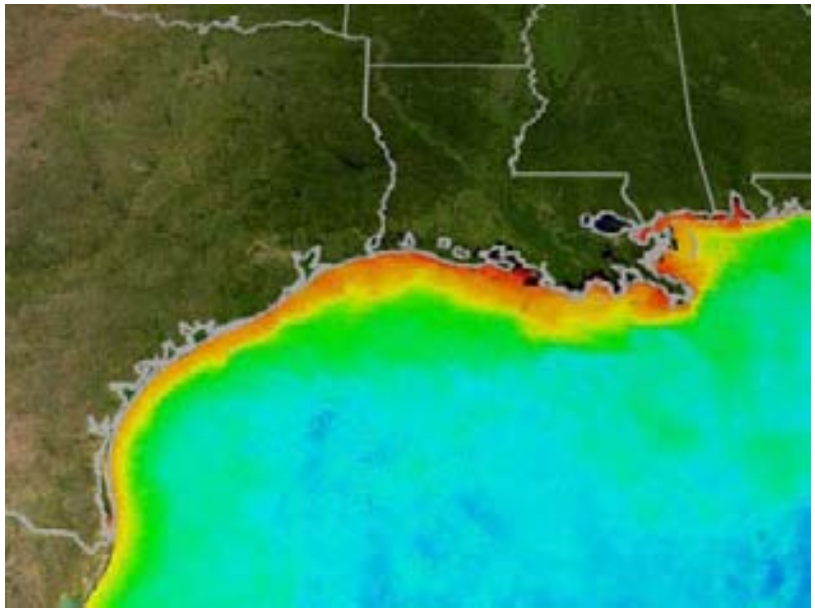
Red algal bloom at Leigh, near Cape Rodney, NZ.

PHOTO BY MIRIAM GODFREY. USED BY PERMISSION OF NIWA SCIENCE.

Dorena Reservoir, Oregon, U.S.A.
Harmful Algae Bloom - Public Health Warning

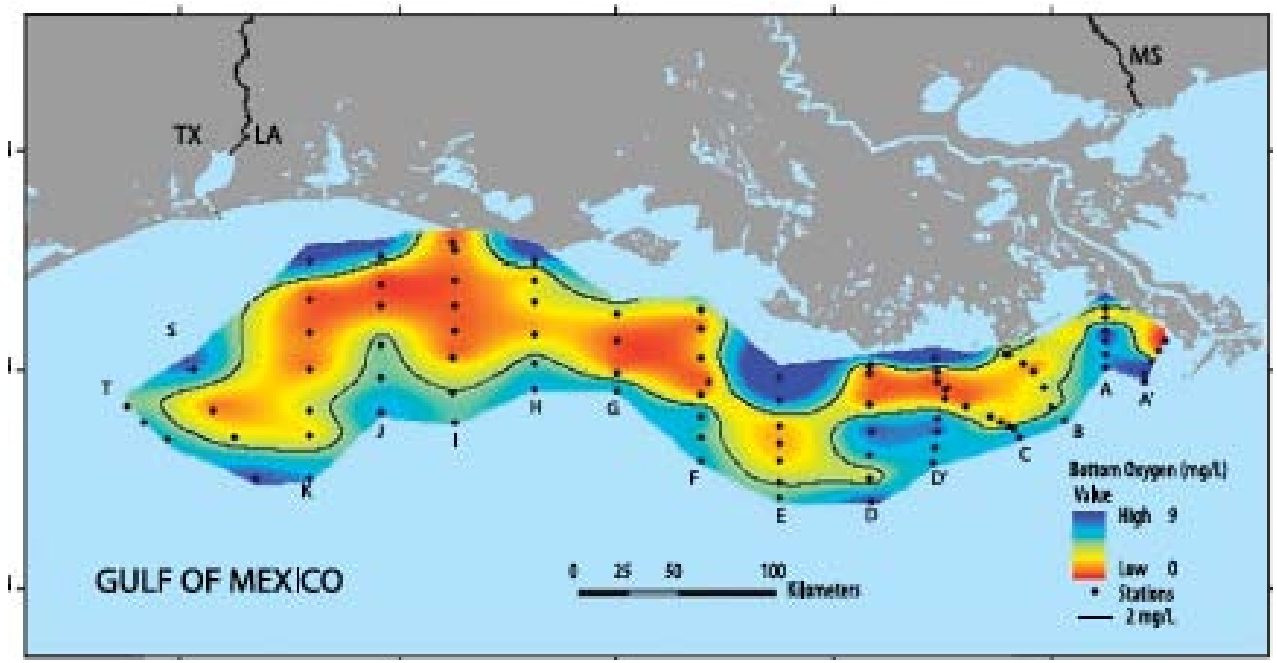
“Dead Zone”
Chesapeake Bay
U. S. East Coast
2007





Algae Density
Gulf of Mexico
Southern U. S Coastline
2004

“Dead Zone”
Gulf of Mexico
Southern U. S Coastline
2007



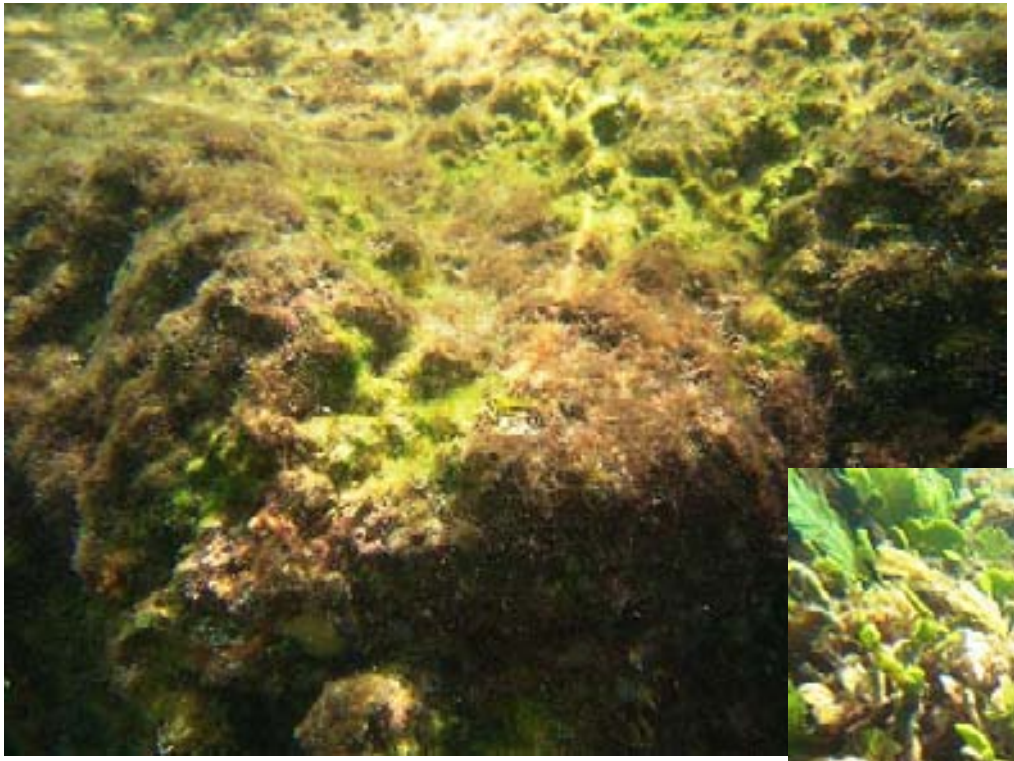
Consequences:

Algae Blooms

Harmful Algae Blooms

Hypoxia and “Dead Zones”

Ecosystem Degradation



Algae covering coral

Culpera invading coral

Seagrass Loss

Greenwich Bay (Narragansett Bay, Rhode Island)

Chautauqua Wildlife Refuge, Illinois

Consequences:

Algae Blooms

Harmful Algae Blooms

Hypoxia and “Dead Zones”

Ecosystem Degradation

Loss of *Ecosystem Services*

Ecosystem Services:

Provisioning

Regulating

Supporting

Cultural

Ecosystem Services:

Provisioning

- **Food (including seafood and game), crops, wild foods, and spices**
- **Water**
- **Pharmaceuticals, biochemicals, and industrial products**
- **Energy (hydropower, biomass fuels)**
- **Fibers**

Ecosystem Services:

Regulating

- **Carbon sequestration and climate regulation**
- **Waste decomposition and detoxification**
- **Purification of water and air**
- **Crop pollination**
- **Pest and disease control**

Ecosystem Services:

Supporting

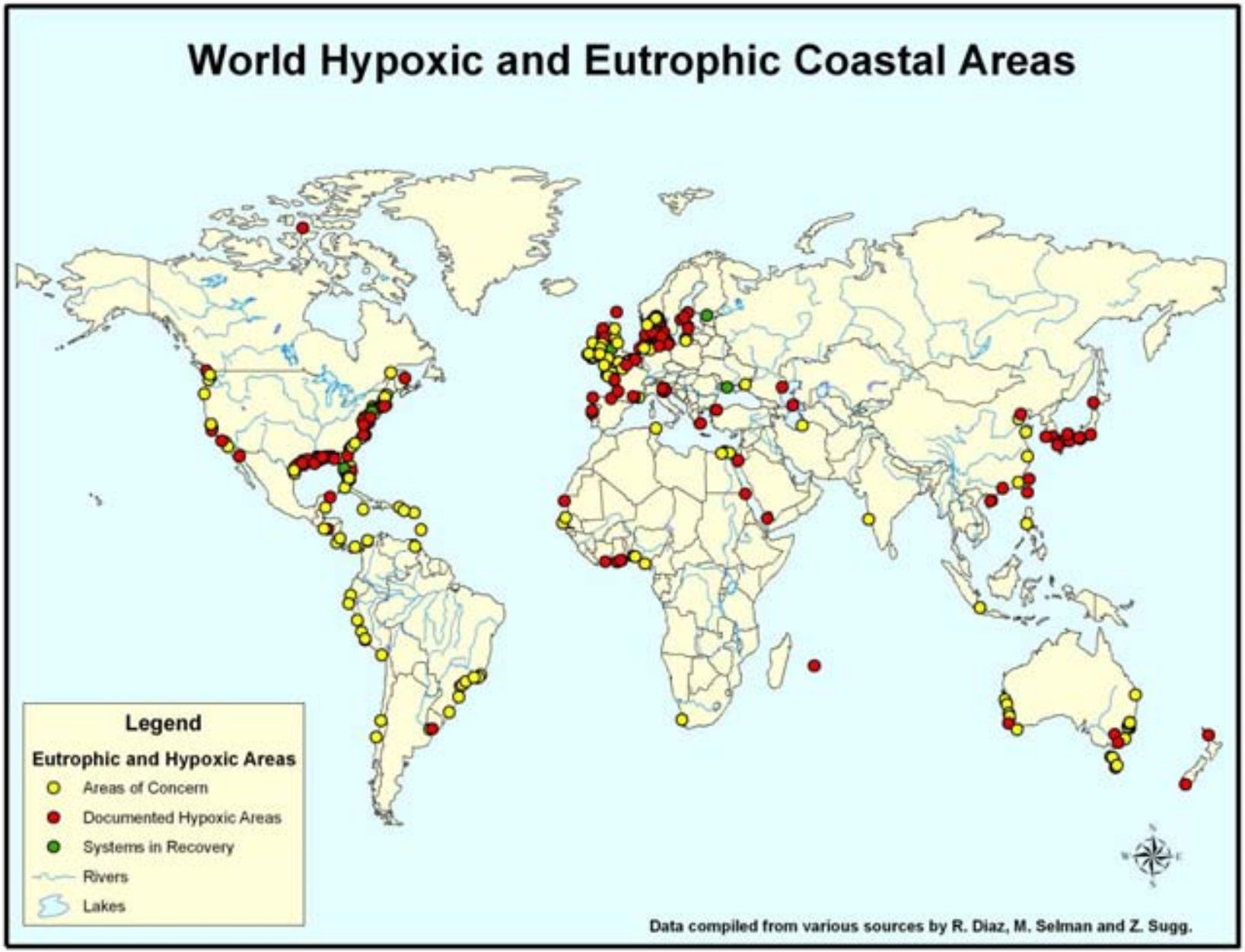
- **Nutrient dispersal and cycling**
- **Seed dispersal**
- **Primary production**

Ecosystem Services:

Cultural

- **Cultural, intellectual and spiritual inspiration**
- **Recreational experiences (including ecotourism)**
- **Scientific discovery**

Global Extent of Problem


World Hypoxic and Eutrophic Coastal Areas
Legend
Eutrophic and Hypoxic Areas
Areas of Concern
Documented Hypoxic Areas
Systems in Recovery
Rivers
Lakes
Data compiled from various sources by R. Diaz, M. Selman and Z. Sugg.

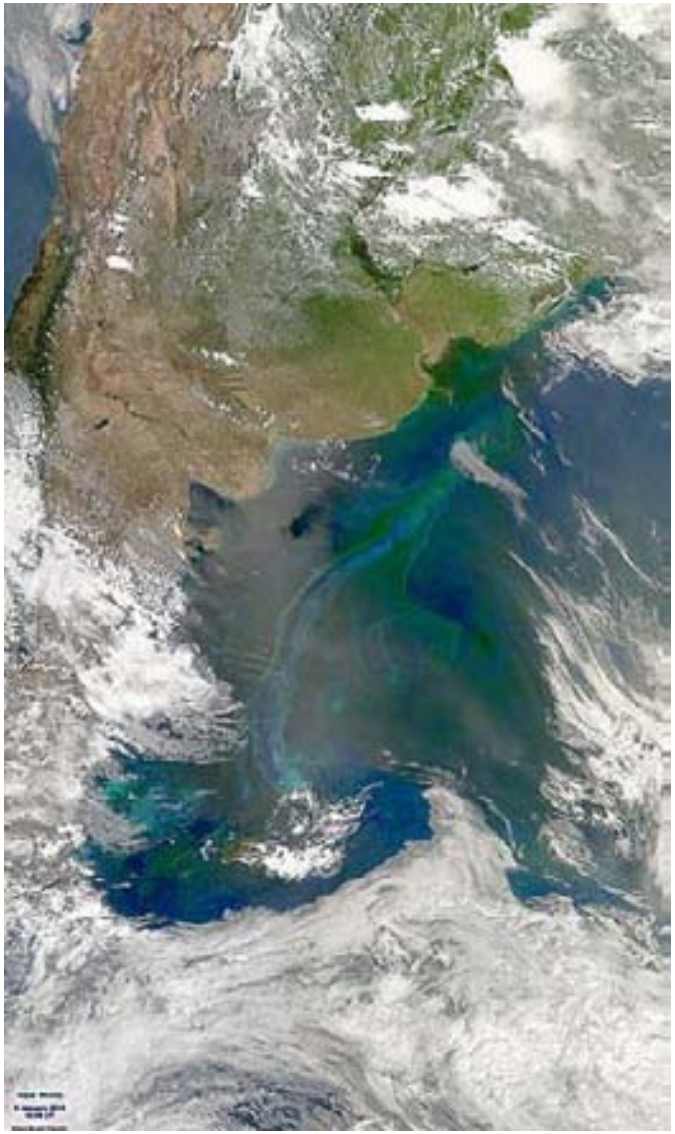
Baltic Sea

Bay of Biscay

East Frisian Islands
Wadden Sea

Mauritania


haze
North Sea
Glasgow
50 km
N



Patagonia

La Jolla, California

Yellow Sea

Chou Lake, China

Dianchi Lake, China

Qingdao, China

Sources and Drivers

Reactive Nitrogen:

Nitrogen compounds that are

Biologically active
Chemically reactive
Radiatively active

Sources and Drivers

Reactive Nitrogen (Nr):

Creation of Nr

- Production of NH3
  - Artificial fertilizer
  - Industrial feedstock
- Biological Nitrogen Fixation by Crop Cultivation
- Fossil Fuel Combustion

Sources and Drivers

Reactive Nitrogen (Nr):

Major Impacts on Humans

Food Production and Security

Energy Availability

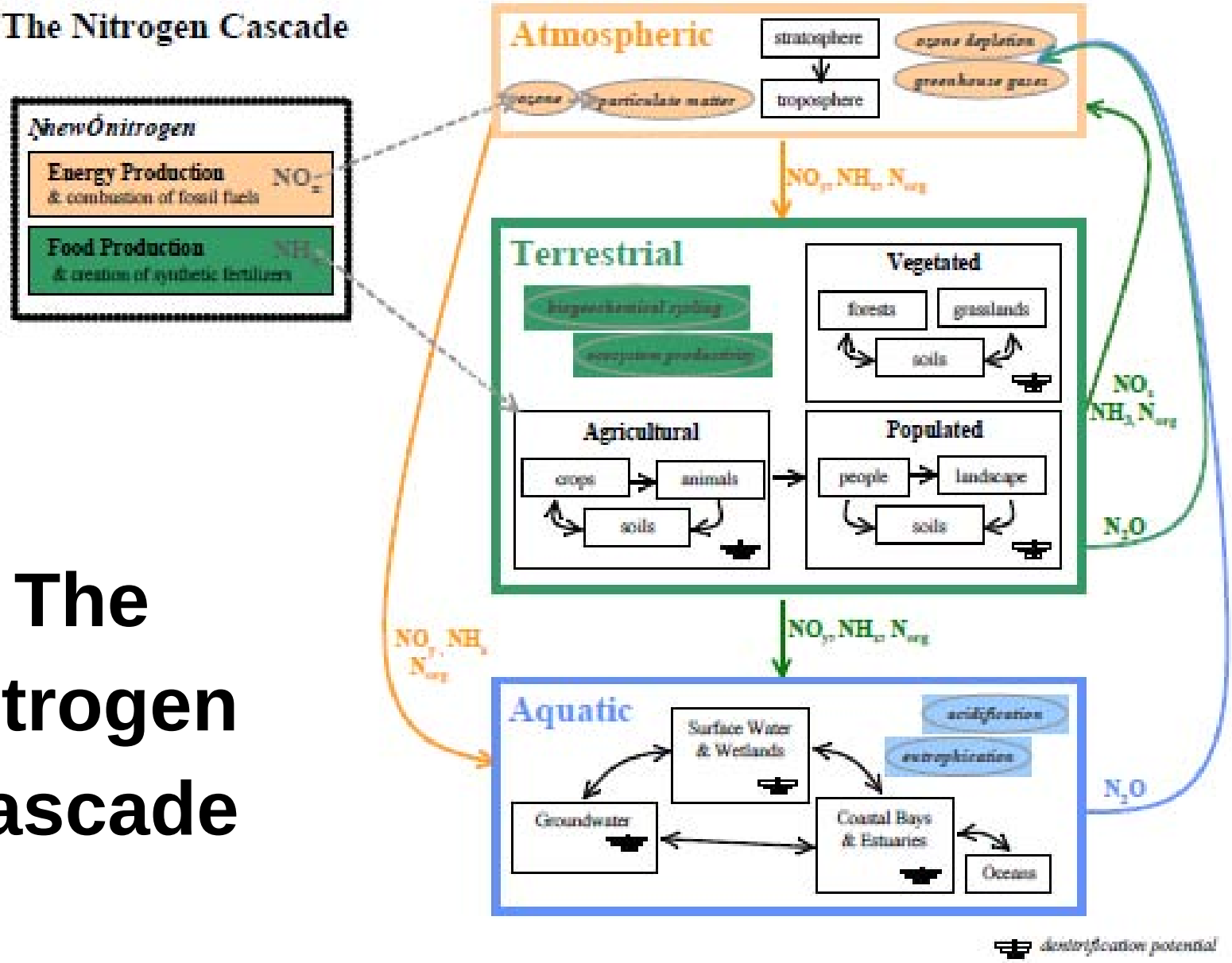
Sources and Drivers

Reactive Nitrogen (Nr):

Numerous Adverse Environmental Affects

- Photochemical smog
- Acid deposition
- Stratospheric ozone depletion
- Climate change
- Human health
- Eutrophication

The Nitrogen Cascade



The Nitrogen Cascade

Sources and Drivers

Phosphorus:

Anthropogenic phosphorus input

3X Natural P flux rate

Mining of rock phosphate for fertilizer production

Guano

Sources of Nutrients

Population Growth
and
Human Activities

Sources of Nutrients

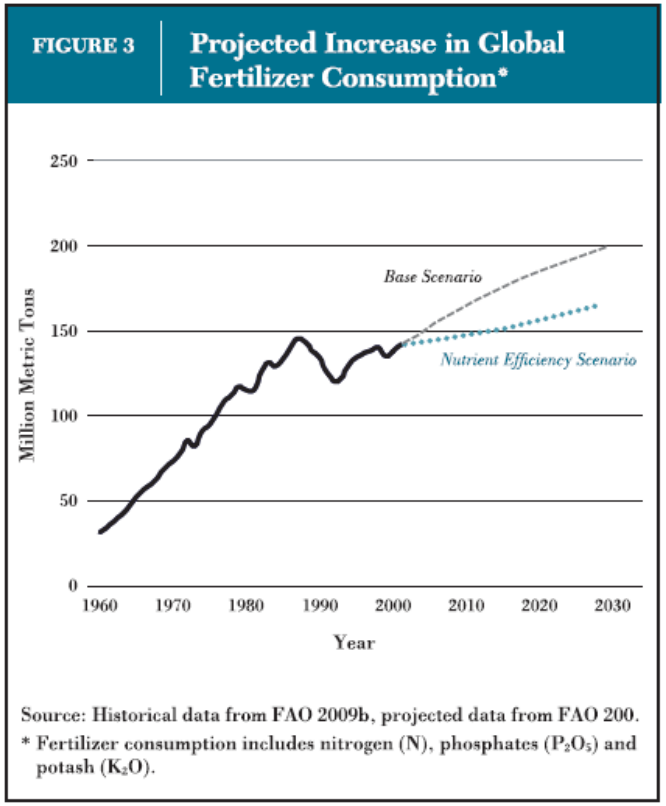
TABLE 1. Primary Sources and Pathways of Nutrients

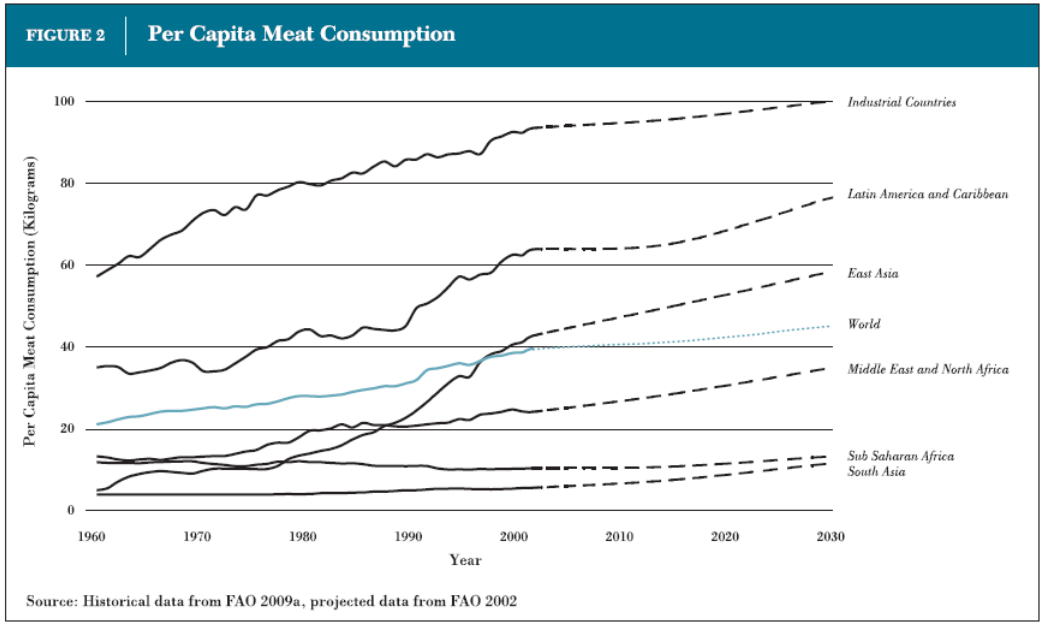
Sources	Pathways		
	Air	Surface Water	Ground-water
Sewage treatment plants		✔	
Industry	✔	✔	
Septic systems		✔	✔
Urban stormwater runoff		✔	
Agricultural fertilizers	✔	✔	✔
Livestock operations	✔	✔	✔
Aquaculture		✔	
Fossil fuel combustion	✔		

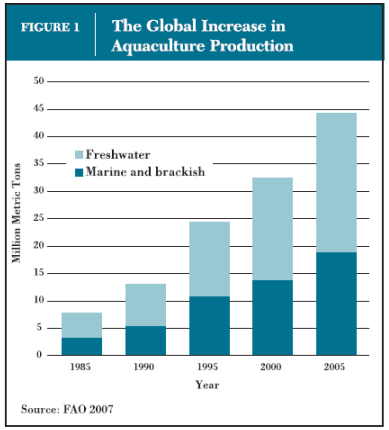
Manure Lagoon Spill

Aquaculture

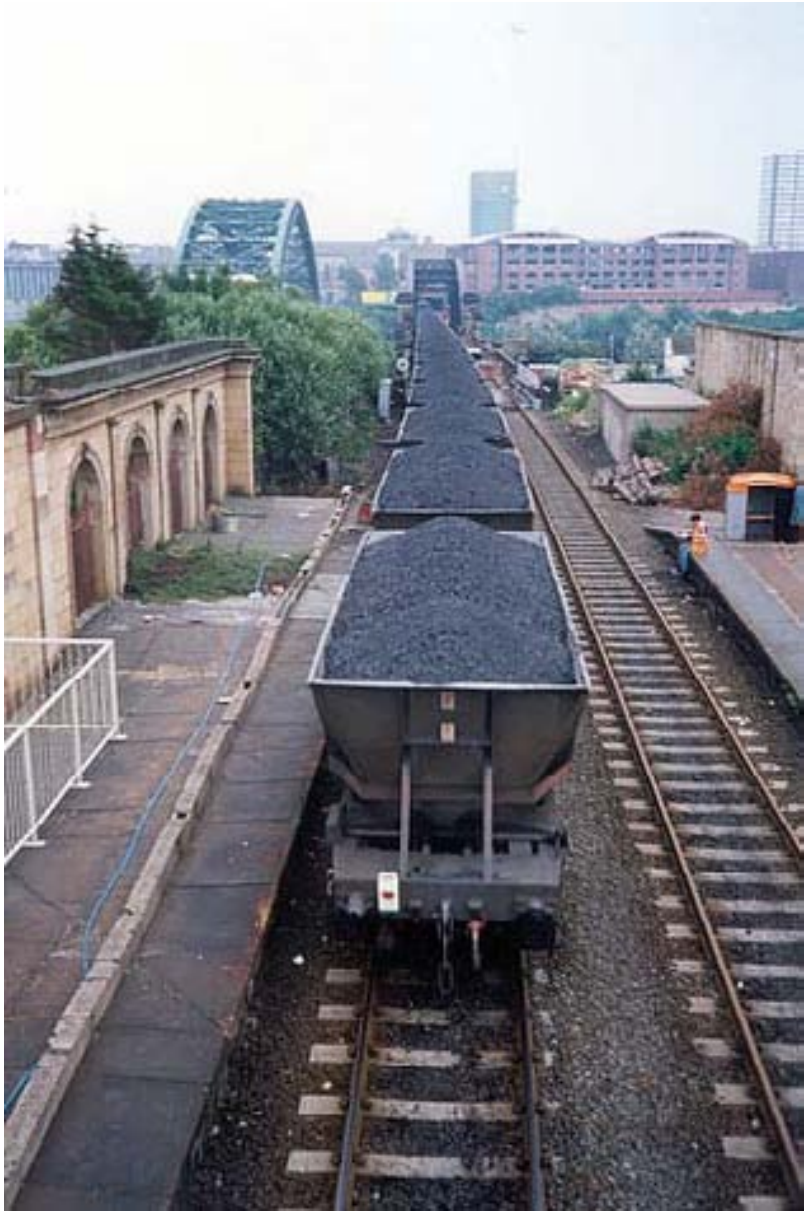
Sources of Nutrients - Agriculture



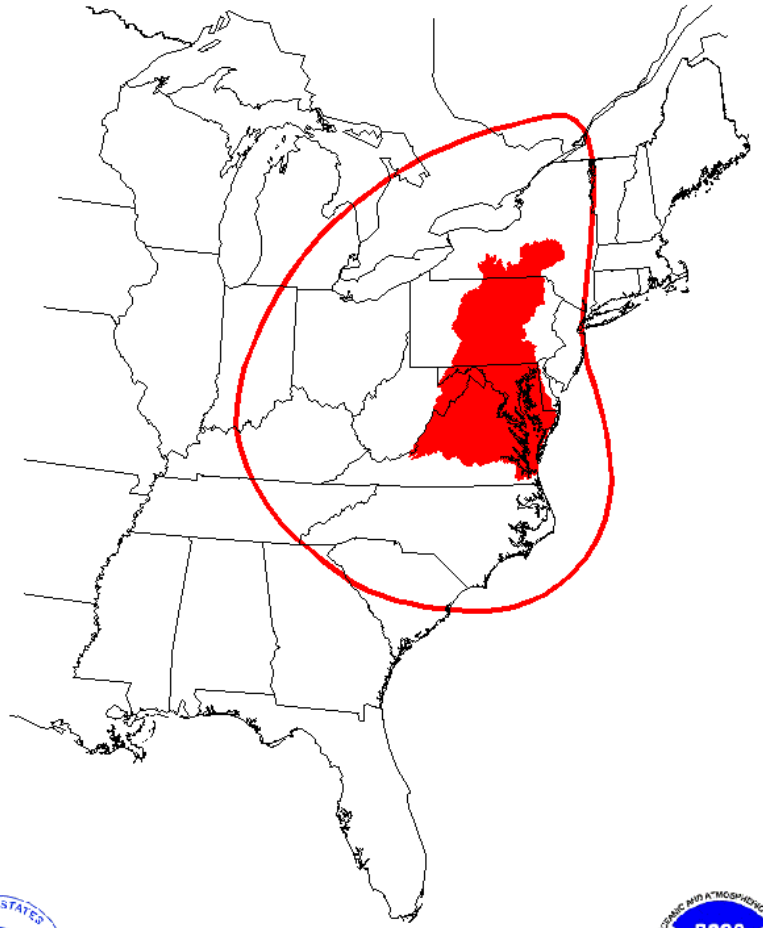





BANDOCK



PRINCIPAL OXIDIZED NITROGEN AIRSHED FOR:
CHESAPEAKE BAY



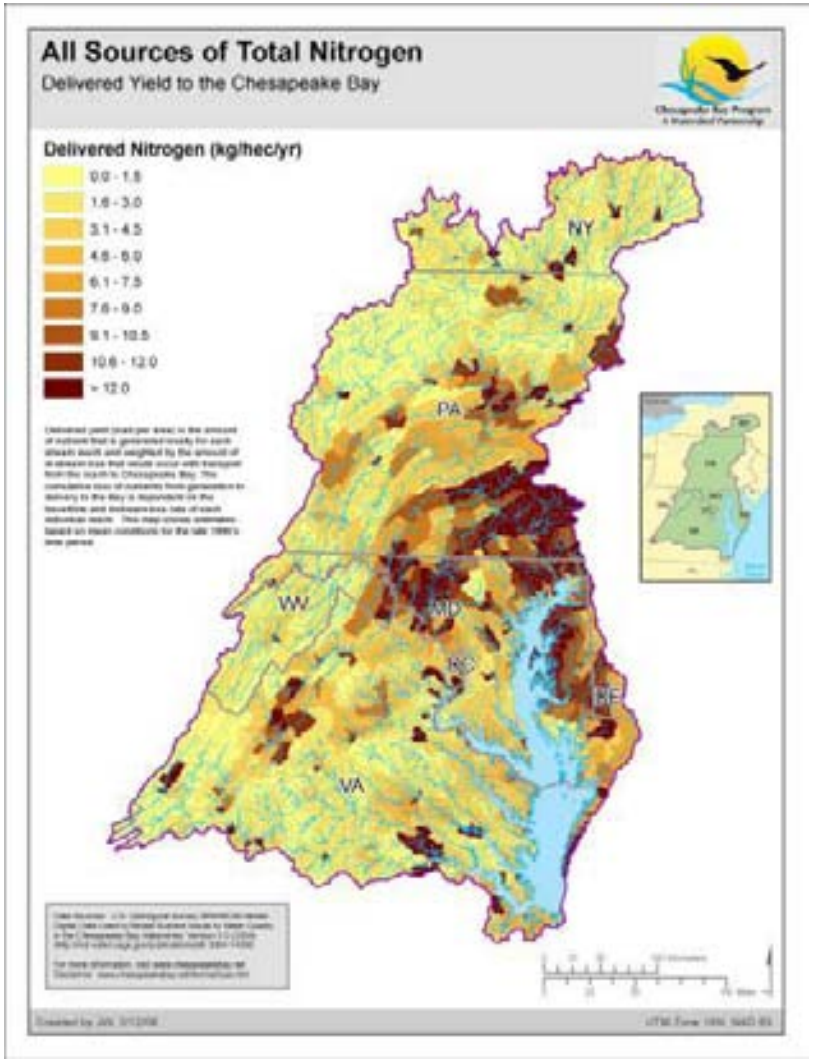
DEVELOPED BY R. DENNIS, ATMOSPHERIC SCIENCES MODELING DIVISION:
ARL, NOAA, and NERL USEPA

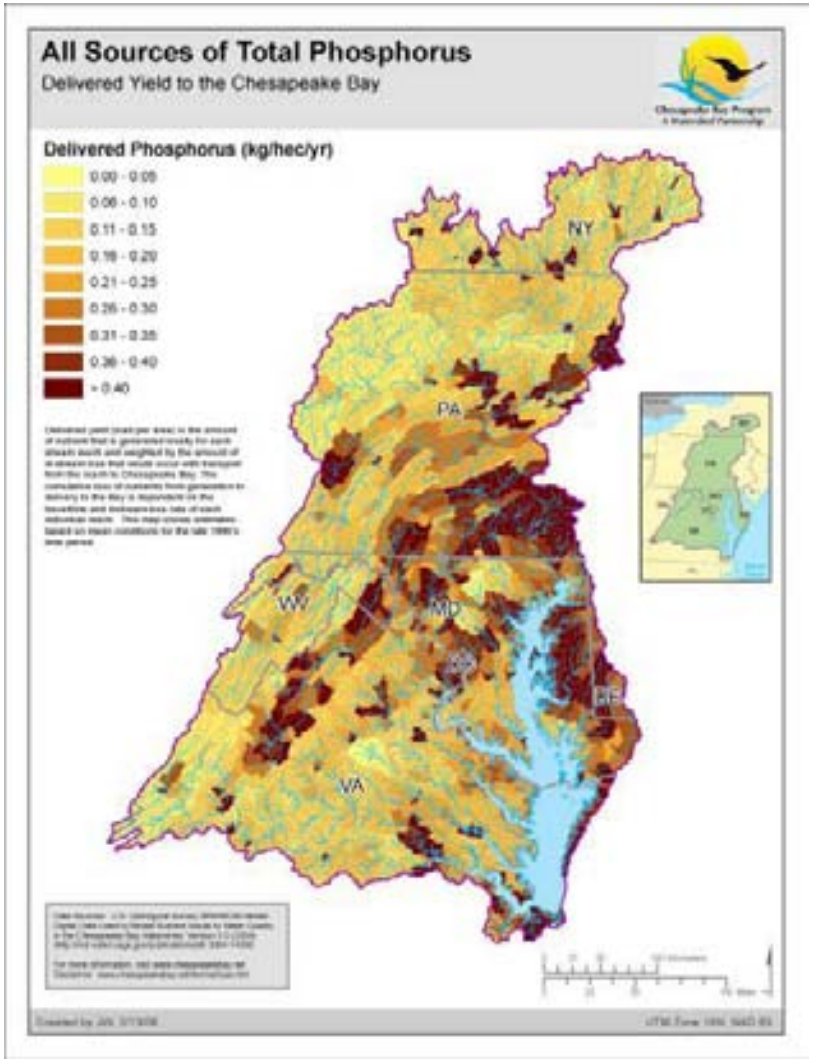
Sources of Nutrients – Atmospheric

TABLE 3. Global Nitrogen Oxide Emissions, 2000	
Region	**NO_x Emissions (1,000 metric tons)**
Asia (excluding Middle East)	37,722
Central America & Caribbean	3,881
Europe	25,536
Middle East & North Africa	7,572
North America	21,839
Oceania	3,381
South America	11,748
Sub-Saharan Africa	14,926
TOTAL	126,605
Source: WRI 2009	

Fossil Fuels and Agriculture

Chesapeake Bay





Mississippi River Basin

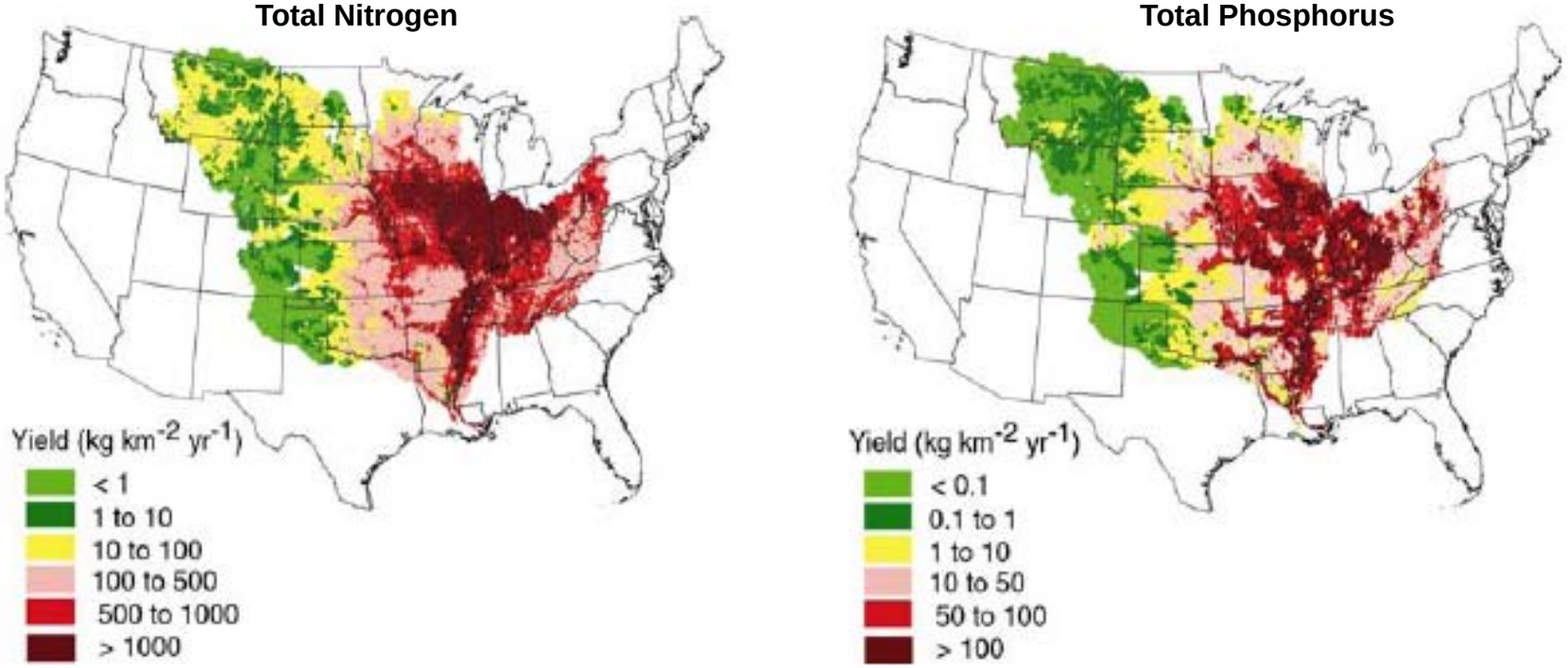
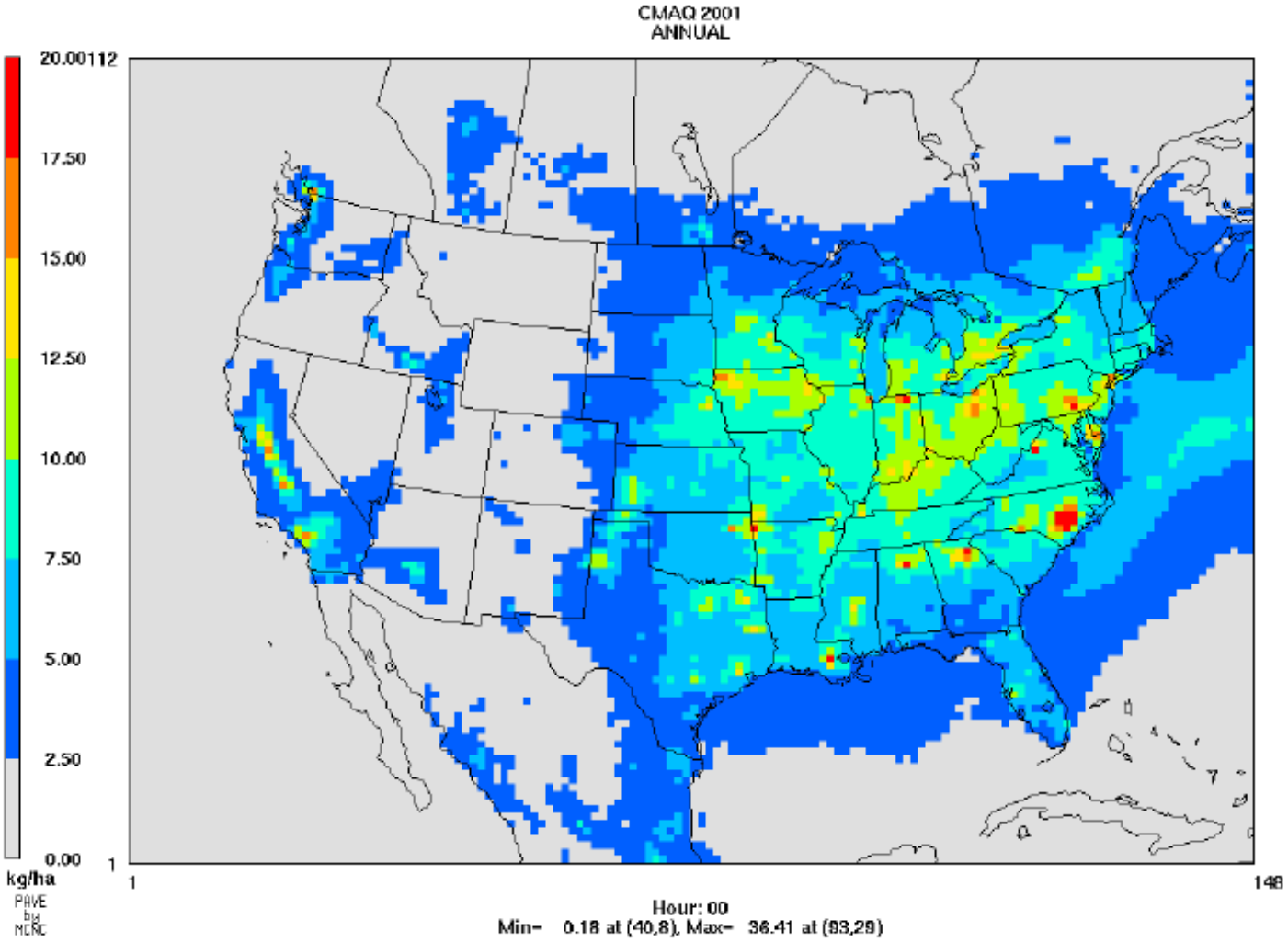


FIGURE 3. Total nutrient yield delivered to the Gulf of Mexico from sources in the Mississippi River basin. The map on the left shows total nitrogen yields, the map on the right shows total phosphorus yields. The large yields from agricultural areas are prominent on this map. These maps also show that large percentages of total nutrient yields derive from a relatively small number of watersheds across the river basin.
SOURCE: Reprinted, with permission, from Alexander et al. (2008). © by the American Chemical Society.

FROM:

Nutrient Control Actions for Improving Water Quality in the Mississippi River Basin and Northern Gulf of Mexico. National Research Council. Prepublication, December 2008.

TOTAL NITROGEN DEPOSITION (KG-N/HA)



Policies, Actions and Strategies

Policies, Actions and Strategies

Categories of Actions

- Improved use efficiency
- Improved practices
- Removal
- Source limitation
- Product substitution

Policies, Actions and Strategies

Programmatic Needs

- Research to address deficiencies in knowledge
- Outreach, education, communication
- Economic incentives
- Market-based programs
- New/better infrastructure
- New legal authorities

Policies, Actions and Strategies

Fruit, Low-hanging and Otherwise

- Energy conservation
- Hybrid vehicles
- End emission exemptions for old coal-fired power plants
- Improved agricultural practices, e.g.
  - Winter cover crops
  - No-till or conservation tillage
  - Precision agriculture
- No ethanol from corn
- Manure management
- “Sustainable” diets

References

Reactive Nitrogen in the United States; An Analysis of Inputs, Flows, Consequences, and Management Options (August 27, 2009 Draft)

USEPA Science Advisory Board Integrated Nitrogen Committee

Available at:

http://yosemite.epa.gov/sab/sabproduct.nsf/02ad90b136fc21ef85256eba00436459/c83c30afa4656bea85256ea10047e1e1!OpenDocument&TableRow=2.2

References

WRI Policy Notes

Eutrophication and Hypoxia in Coastal Areas: A Global Assessment of the State of Knowledge

Eutrophication: Sources and Drivers of Nutrient Pollution

Eutrophication: Policies, Actions, and Strategies to Address Nutrient Pollution

Available at www.wri.org

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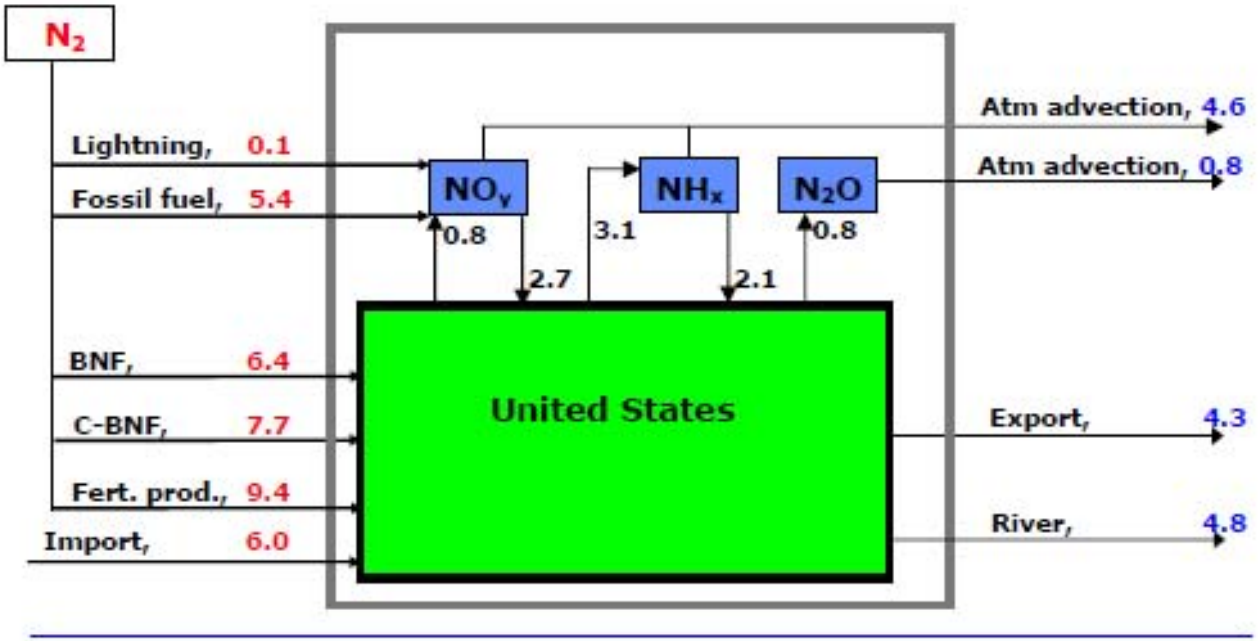
US Nitrogen Budget
Tg N yr-1



Nr Inputs: 35 Tg N

Nr Outputs: 14 Tg N

Nr Missing: 21 Tg N

Nr Storage: 5 Tg N

~ 2 Tg soils&vegetation

~ 3 Tg groundwater

Nr Denitrified to N2:

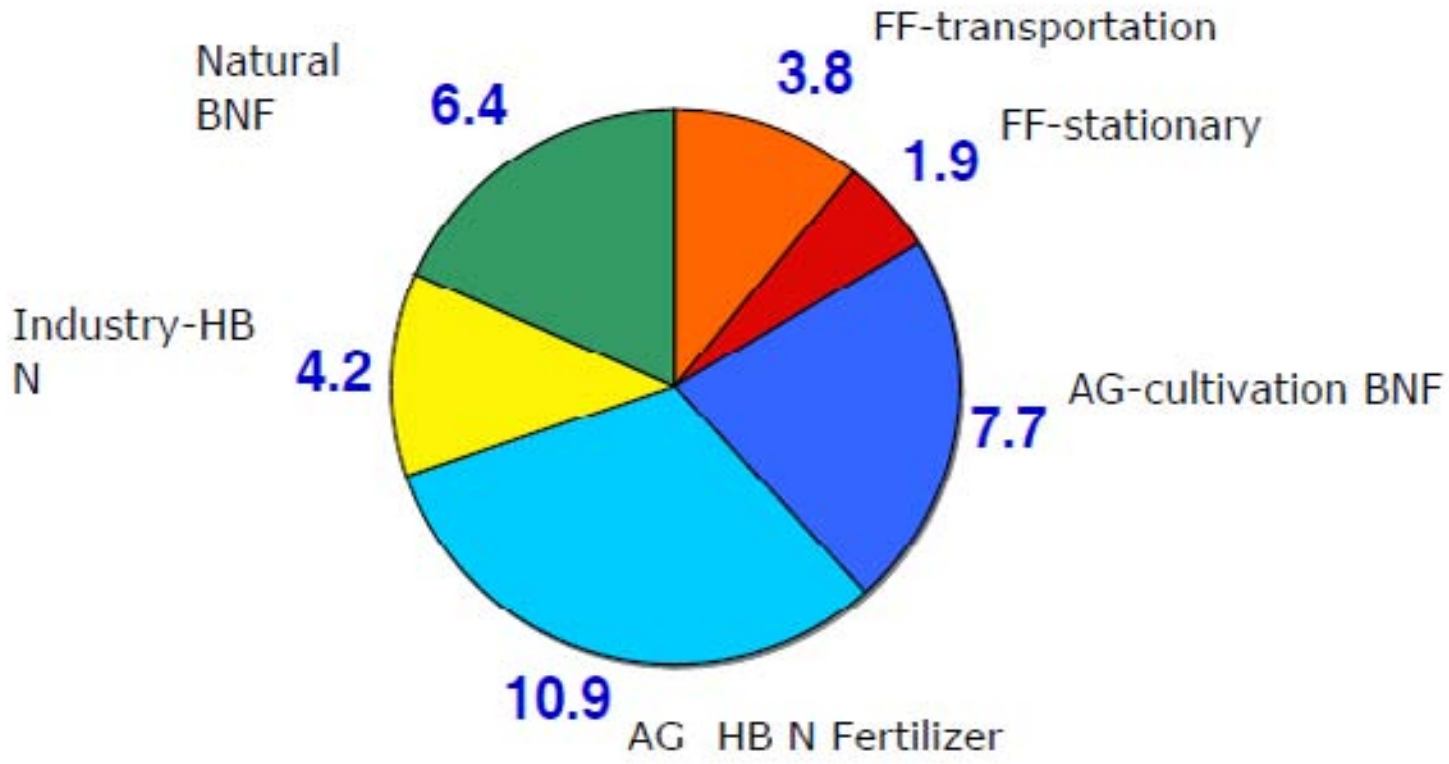
21 Tg N - 5 Tg N = 16 Tg N

Figure1- 2: US N Cycle

US 5X Natural Flux

Globally 2X Natural Flux

16 *Figure 1-1: New Nr introduced into the US, 2002, Tg N.*



HB – Haber-Bosch Ammonia Synthesis

Table 3-1. Reactive nitrogen fluxes for the USA, Tg N in 2002*

* Newly created reactive N

Nr inputs to *Atmospheric* compartment			Tg N/yr
N_2O-N emissions			0.8
	agriculture - livestock (manure) N_2O-N	0.03	
	agriculture - Soil management N_2O-N	0.5	
	agriculture - field burning ag residues	0.001	
	*fossil fuel combustion - transportation	0.1	
	miscellaneous	0.1	
NH_x-N emissions			3.1
	agriculture: livestock NH_3-N	1.6	
	agriculture: fertilizer NH_3-N	0.9	
	agriculture: other NH_3-N	0.1	
	*fossil fuel combustion - transportation	0.2	
	*fossil fuel combustion - utility & industry	0.03	
	other combustion	0.2	
	miscellaneous	0.1	
NO_x-N emissions			6.2
	biogenic from soils	0.3	
	*fossil fuel combustion - transportation	3.5	
	*fossil fuel combustion - utility & industry	1.9	
	other combustion	0.4	
	miscellaneous	0.2	
	total *Atmospheric* inputs		10.0

Nr inputs to *Terrestrial* compartment				
atmospheric N deposition[b]			6.9	19
	organic N	2.1		
	Inorganic NOy-N	2.7		
	inorganic-NHx-N	2.1		
*N fixation in cultivated croplands			7.7	21
	*soybeans	3.3		
	*alfalfa	2.1		
	*other leguminous hay	1.8		
	*pasture	0.5		
	*dry beans, peas, lentils	0.1		
*N fixation in non-cultivated vegetation			6.4	15
*N import in commodities			0.2	0.3
*Synthetic N fertilizers			15.1	41
(*9.4 produced in USA; *5.8 net imports to USA)				
	fertilizer use on farms & non-farms	10.9		
	non-fertilizer uses such as explosives	4.2		
manure N production			6.0	16
human waste N			1.3	3
	total *Terrestrial* inputs		43.5	100
Nr inputs to *Aquatic* compartment				
surface water N flux			4.8	

Nr inputs to *Terrestrial* compartment				
atmospheric N deposition[b]			6.9	19
	organic N	2.1		
	Inorganic NOy-N	2.7		
	inorganic-NHx-N	2.1		
*N fixation in cultivated croplands			7.7	21
	*soybeans	3.3		
	*alfalfa	2.1		
	*other leguminous hay	1.8		
	*pasture	0.5		
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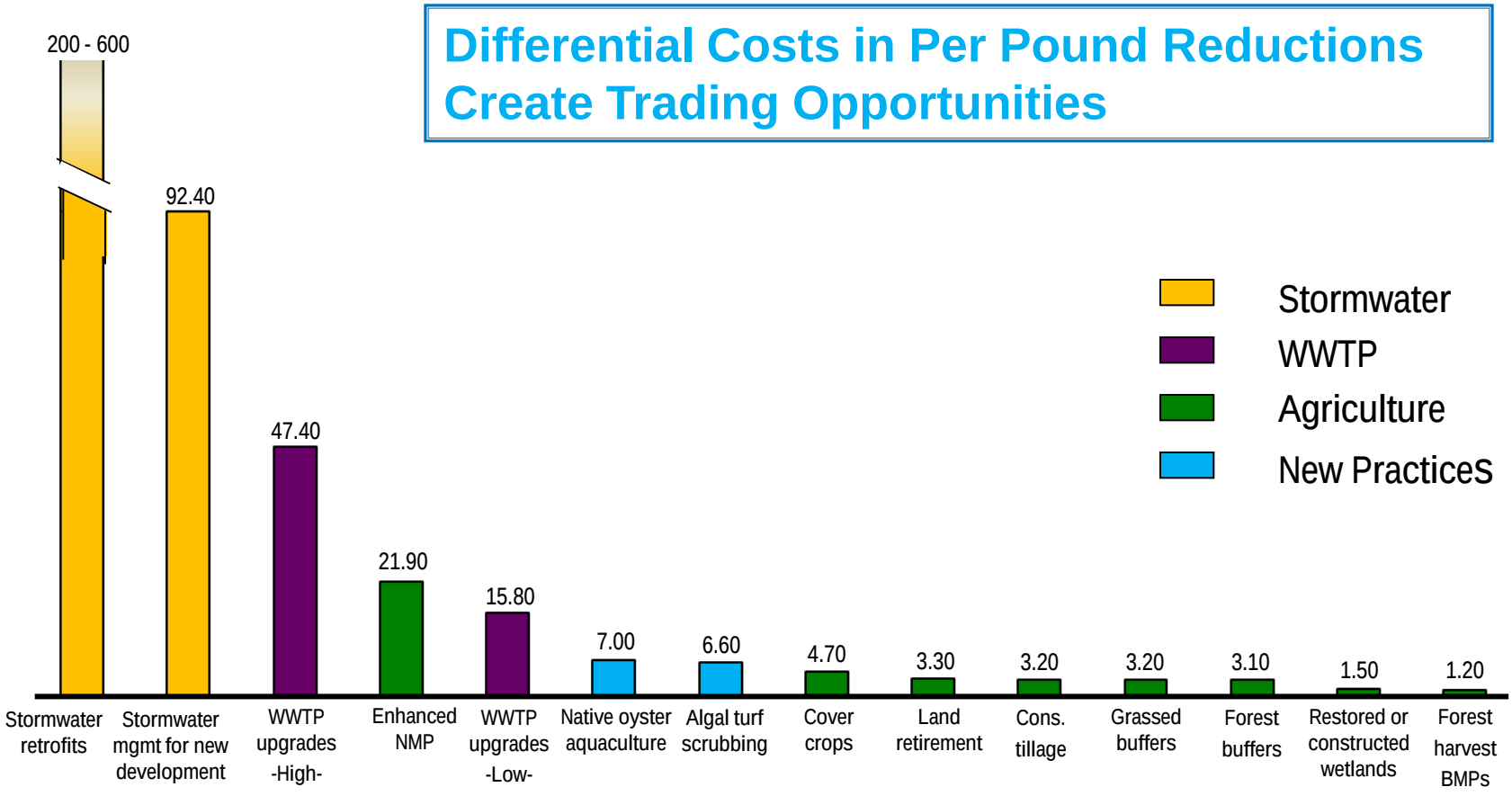
	fertilizer use on farms & non-farms	10.9		
	non-fertilizer uses such as explosives	4.2		
manure N production			6.0	16
human waste N			1.3	3
	total *Terrestrial* inputs		43.5	100
Nr inputs to *Aquatic* compartment				
surface water N flux			4.8	

Cost of Nitrogen Reduction

Dollars per pound of annual nitrogen reduction



Average Cost of Selected Nitrogen Reduction Measures (*Dollars per pound of annual nitrogen reduction*)

Building a Portfolio of Tools to Reduce Eutrophication (Illustrative)