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NITROGEN BACKGROUNDER

Integration--Case study

The **Nitrogen Backgrounder** is a set of five presentations (or modules) and a depository of supporting documents on the subject of reactive nitrogen (rN). At the request of the Associate Administrator for the Office of Policy, Economics, and Innovation (OPEI), National Center for Environmental Economics in the Office of Policy, Economics and Innovation (NCEE) organized and led an agency-wide effort to assemble the information and produce the material. Scientists and experts from throughout EPA, with special assistance from the Office of Water (OW), Office of Research and Development (ORD), the Office of Air and Radiation (OAR), and the Office of International Activities (OIA), contributed through a series of workgroup teams that met for almost two years. Staff from OPEI, ORD, and OW presented the material to EPA senior management at an all-day retreat in Annapolis, Maryland on February 21, 2008.

The intent of the Backgrounder is to provide a basic understanding among EPA staff and others of a complex and persistent environmental problem--excess rN in the environment that is not bound up in long-term storage, such as soil complexes. The presentations explain not just the science of rN, but also the sources, the environmental and economic impacts, Federal regulatory and non-regulatory activity to mitigate its adverse impacts, and challenges to successful management.

As is true for most environmental issues, the science is dynamic, as research sheds new light on processes and relationships, and the economic drivers for the generation and removal of rN change over time. Management in response evolves. The Backgrounder thus represents a snapshot in time of what is known about rN and EPA and other federal agencies' actions regarding its origins and control.

EPA United States Environmental Protection Agency

Slide 1

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c1 Draft presentation
ctsuser, 5/12/2009

Nitrogen Backgrounder

1	**OVERVIEW**
2	**THE N-CYCLE IMPACTING HUMAN HEALTH AND THE ENVIRONMENT**
3	**INTERVENTIONS, CONTROL OPTIONS, AND ECONOMICS**
4	**CHALLENGES**
5	**CASE STUDY: GULF HYPOXIA**

Nitrogen Backgrounder
Module 5

Case Study:
Gulf Hypoxia

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Outline

- Describe the phenomenon of hypoxia
- Identify sources of nutrient pollution
- Identify Management Strategies

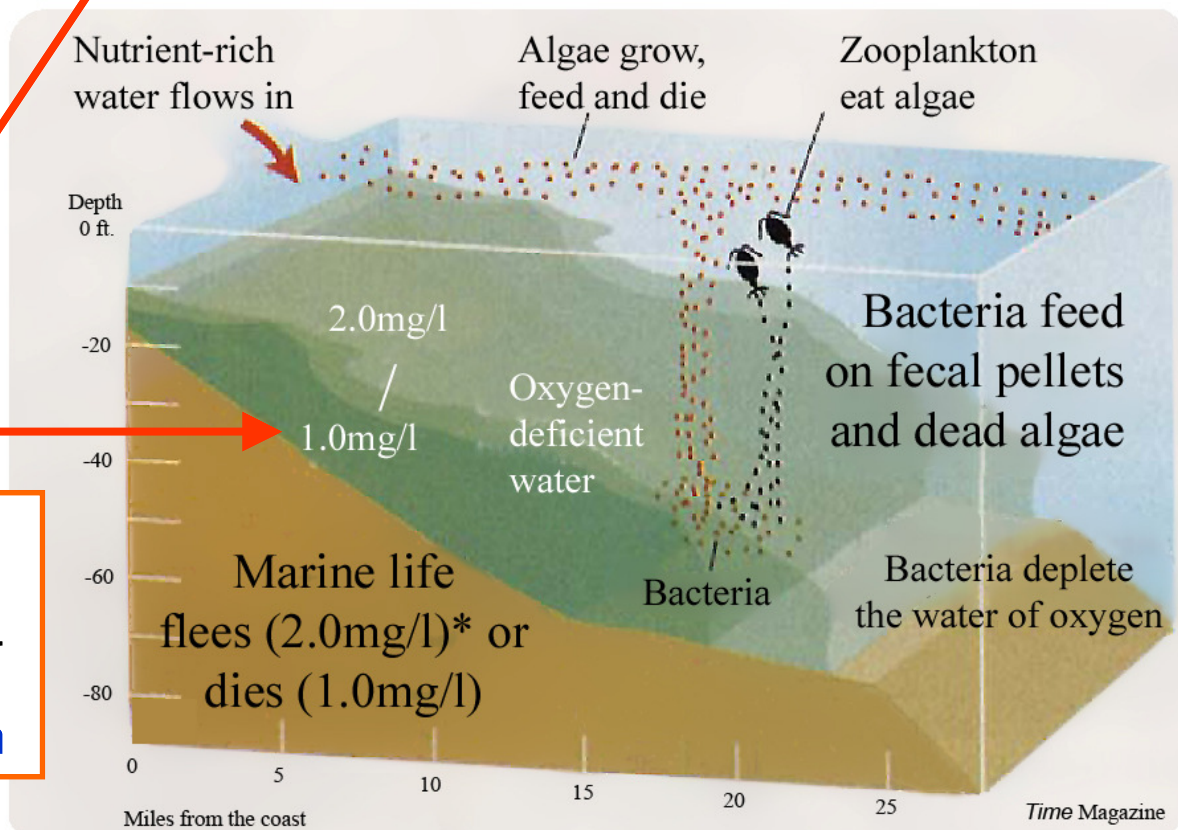
Learning Objectives:

- To understand how nutrients drive hypoxia and how nutrients can be managed
- To reinforce earlier concepts on nitrogen

What is Hypoxia?

- Hypoxia = dissolved oxygen concentrations < 2 mg/L
- Healthy waters = 4-9 mg/L
- Excess nutrients → Eutrophication (excess carbon production)

HYPOXIA



IMPORTANT FACTORS:
-Freshwater
-Warming of surface water

Water column stratification

- Dissolved oxygen concentrations are determined by a variety of factors, but in general the amount of oxygen in a waterbody reflects that balance between production and consumption. Hypoxia typically results when consumption of oxygen greatly exceeds production.

- Excess nutrients facilitate higher oxygen consumption rates through the production of excess organic matter. This generalized conceptual model shows the pathway by which nutrients fuel excess algal growth and organic matter production, which in turn leads to hypoxia. The phenomenon of excess algal growth is often referred to as eutrophication. As this excess algal biomass dies or is eaten, the organic matter is transferred to the bottom waters. Here, bacteria feed on this organic matter and consume oxygen while doing it. When bacteria deplete the oxygen below 2 mg/L, hypoxia sets in and impacts the myriad benthic marine life. Prolonged periods of hypoxia can drastically impact long-term habitat viability and displace marine populations such as shellfish and groundfish.

- Its important to note that the process of nutrients stimulating algal growth with subsequent settling of organic matter to the sea floor is one that occurs naturally throughout the year, not just in coastal marine systems but elsewhere in the ocean. The key difference, though, is the magnitude of the algal growth and export of organic matter to the sea floor.

- There are additional factors which can facilitate the onset of hypoxia. Freshwater and warming of the surface water both lead to a more stable water column, a physical process called stratification. A well-stratified water column resists other physical forces which mix the water column, which in turn would bring oxygen to the bottom.

Interim Effects of Eutrophicaton

- Excess nutrients → Eutrophication (excess carbon production)

- Harmful algal blooms
  - Fish and shellfish
  - Human health
- Invasive aquatic vegetation

Mechanism That Drives Hypoxia

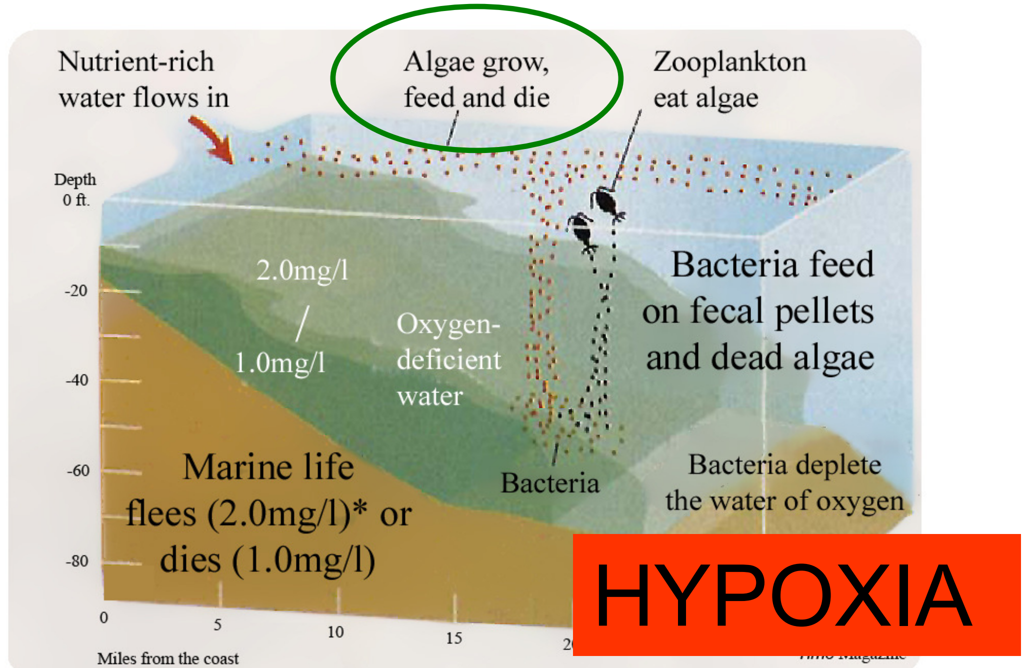
- Interim effect of nutrient pollution is called eutrophication--increase in the ecosystem's primary productivity (excessive plant growth and decay). Eutrophication is becoming an increasing environmental problem in coastal and inland waters.

- Nutrients can trigger harmful algal blooms, shown in the photos in the previous slide, which in turn can harm aquatic life and human health. Invasive aquatic vegetation can also take hold of aquatic systems and interfere with navigation and recreation.

- In terms of hypoxia, though, it's the accumulation and settling of the organic carbon that is produced as algae that is the greatest impact.

Why are Nitrogen AND <u>Phosphorus</u> important?

- Coast marine systems more N-limited than P-limited
  - Low ratio → N:P
- Large N loads over time shift this ratio to relative P-limitation
  - High ratio → N:P
- P loading from land becomes important in fueling hypoxia



- Phosphorus is also an important player in hypoxia.
- Typically, coastal marine systems are more nitrogen limited than phosphorus limited. Relative to other nutrients such as phosphorus, the Nitrogen to Phosphorus ratio is low.
- However, when these systems receive large loads of nitrogen, the N:P ratio can shift to where the ratio is high and phosphorus becomes the limiting nutrient. This is what has happened in the Gulf.

Concept: Nutrient pollution can shift nutrient ratios

- Large nitrogen and phosphorus inputs from the MS River Basin to the Gulf have shifted the nutrient ratios in the coastal marine system over time.

N:P to N:P

Why is this important?

- Thus, its important to understand how anthropogenic inputs of nitrogen, phosphorus, and other elements like carbon can cause shifts in the natural nutrient ratios.

- Another example is atmospheric anthropogenic carbon dioxide which has been absorbed by the ocean and led to the beginning of ocean acidification.

Liebig's Law of the Minimum

- Growth is controlled not by the total resources available, but by the *scarcest* resource
  - "Living things grow until something they need runs out."
- Shifting nutrient resources can shift the marine foodweb in <u>unpredictable</u>, <u>unintended</u> ways

Hypoxia Around the World

- Globally…

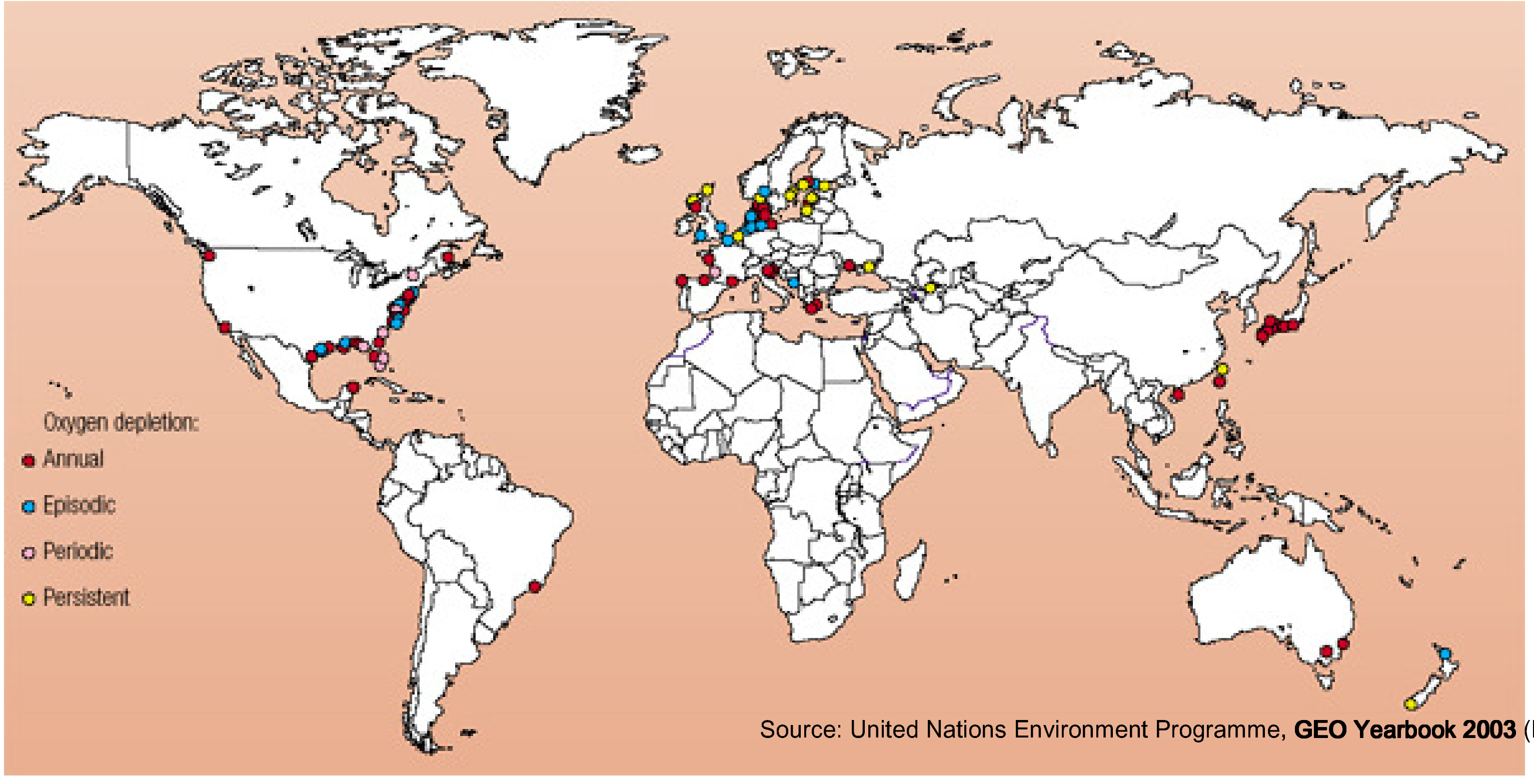
  …201 coastal hypoxic zones, 40% increase from 2000 to 2004,

  …hypoxia caused by nutrient pollution due primarily to non-point source nutrient runoff.

- Human activities have increased nutrient pollution dramatically in the past century through…

  …<u>domestic</u> wastewater,
  …<u>industrial</u> wastewater,
  …<u>agricultural</u> wastewater,
  …<u>atmospheric deposition</u> from domestic and industrial emissions.

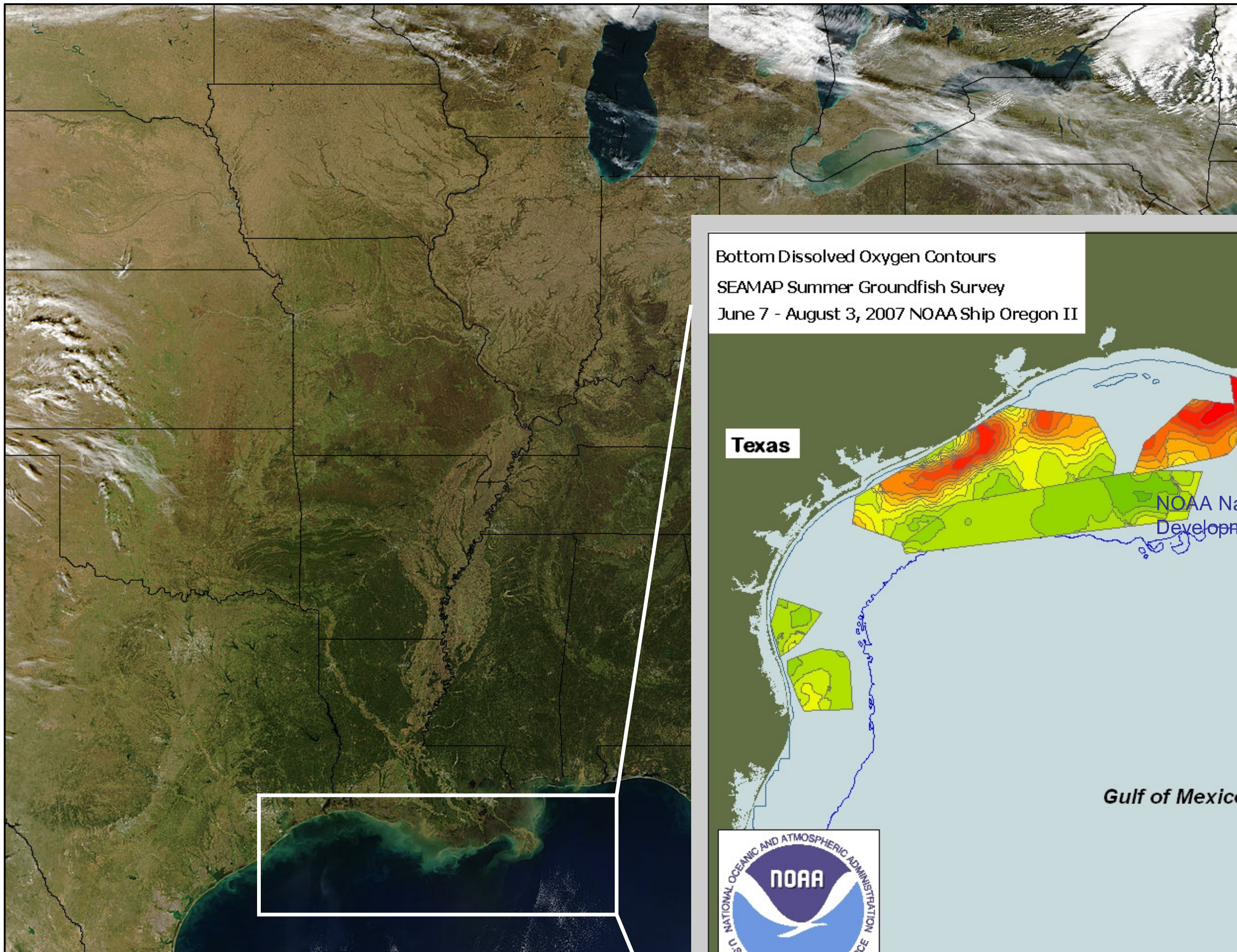
Global Distribution of Oxygen-depleted Coastal Zones

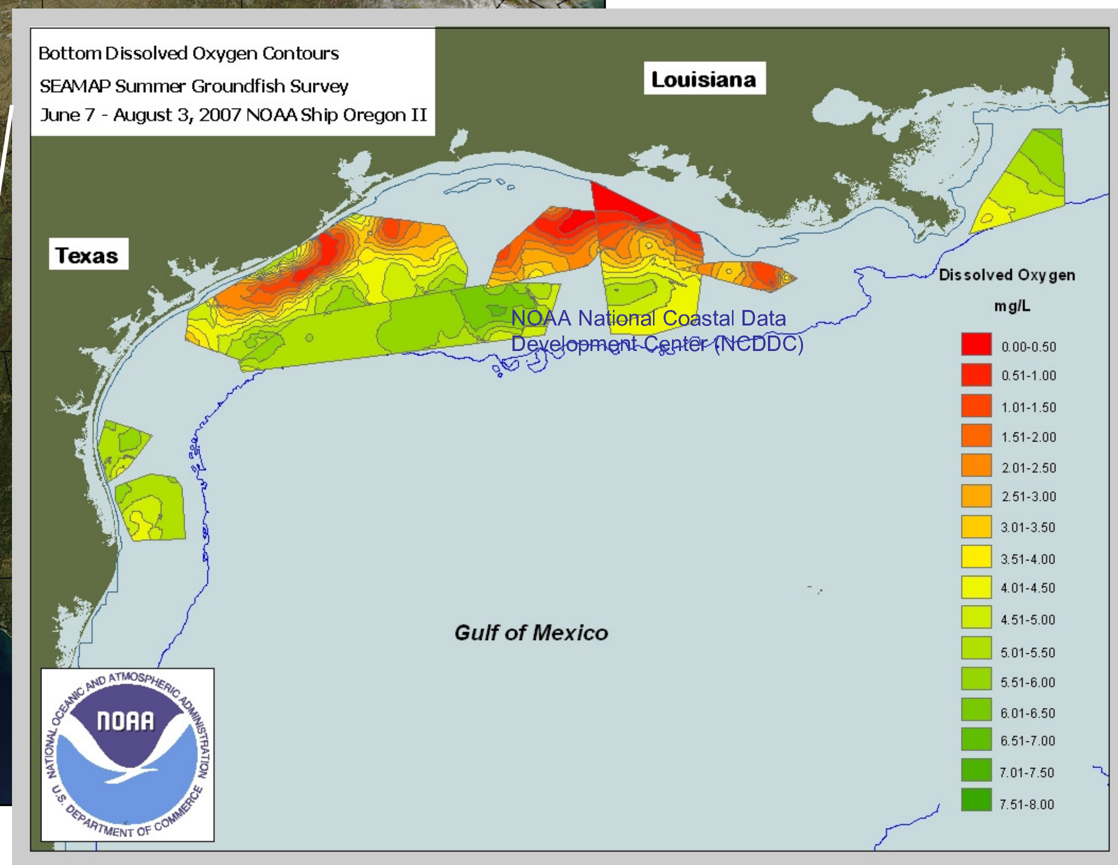


Source: United Nations Environment Programme, **GEO Yearbook 2003** (Nairobi: 2004)

Annual – yearly events related to seasonal stratification
Episodic – events occurring at irregular intervals > 1 year
Periodic – events occurring at regular intervals < 1 year
Persistent – year-round hypoxia

Extent of Hypoxia in the Gulf of Mexico

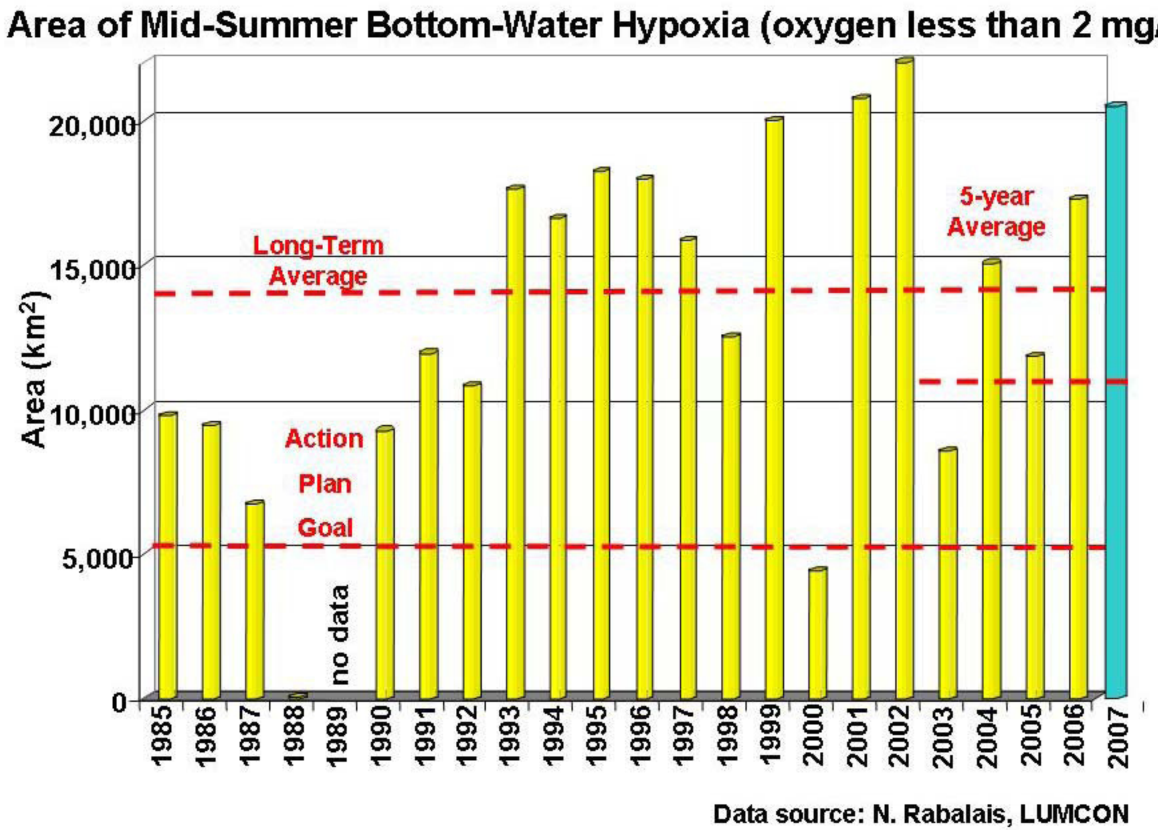




Credit: Jacques Descloitres, MODIS Rapid Response Team, NASA/GSFC

- The extent of hypoxia can be seen in the series of pictures in the previous slide.
- The large satellite view shows the majority of the MS River basin that feeds into the northern Gulf of Mexico. You can see the algal growth in the surface waters offshore of Louisiana and Texas. Nutrients are driving this response.
- In the top inset, bottom water dissolved oxygen concentrations are mapped from a recent hydrographic survey. Areas of orange and red depict areas of lowest dissolved oxygen concentration.

Extent of Hypoxia in the Gulf of Mexico



Effects of Hypoxia:

•Shellfish and groundfish and the potential loss of fisheries

•Foodweb alteration and loss of biodiversity

•Ecological hysteresis: Can it recover to what it was?

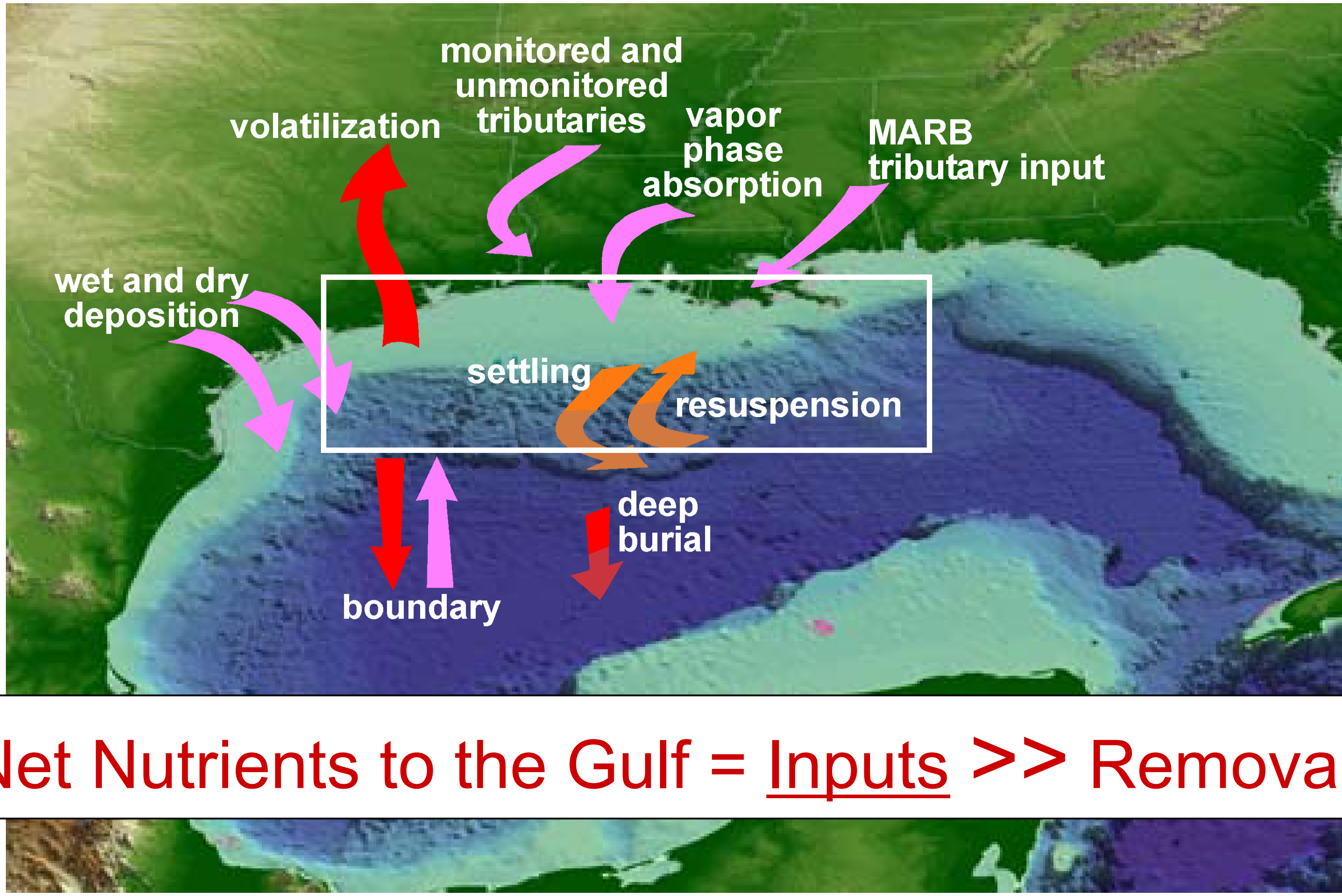
- This graph shows the areal extent, in square km's, of the hypoxic zone. The top red dotted line shows the long-term average of the hypoxic zone area. The middle dotted lines shows the 5-year running average. The bottom dotted lines indicates the area which the Multi-Agency Hypoxia Task Force hopes to achieve through reductions in nutrient loads from the MS River basin. I'll expand on the role of the Task Force in managing nutrient reductions later in the presentation.

- Some of the more widely understood effects of hypoxia at scales such as this include:

- -detrimental effects on shellfish and groundfish and the potential loss of fisheries
- -foodweb effects which lead to loss of biodiversity which supports healthy marine ecosystems

- And there's the question of hypoxia causing ecological hysteresis or a limitation on returning the system back to its natural state.

Gulf of Mexico Nutrients (N and P) Budget



Net Nutrients to the Gulf = <u>Inputs</u> >> Removal

- As I mentioned earlier, dissolved oxygen concentrations are a balance between production and consumption. The same is true for nutrients in the northern Gulf of Mexico which, in turn, ultimately drive oxygen consumption.

- This conceptual diagram depicts the various nutrient inputs to and outputs from the northern Gulf of Mexico represented here as the white rectangular box. Some of the major inputs of nutrients are river and tributary loads and atmospheric deposition.

- Some of the major outputs of nutrients from the northern Gulf of Mexico are physical transport and biogeochemical removal through processes such as denitrification.

- Now that I've described the phenomenon, I'll go into some detail describing the inputs and sources of nutrients relative to the ouputs and sinks.

Sources of Nutrient Pollution in the Mississippi River Basin

- Urbanization
  - Municipal wastewater
  - Stormwater, residential runoff
- Industrialization
  - Atmospheric emissions
  - Industrial wastewater
- Agricultural development and production
  - Long-term <u>intensive nutrient fertilization</u>
  - <u>Soil nutrient losses</u> due to widespread farming practices, e.g. tilling

- The major sources of nutrients to the MS River basin, both point and non-point, are the result of urbanization, industrialization, and agricultural development. These activities have led to nutrient inputs from wastewater, stormwater, atmospheric discharge, and agricultural runoff.

- Excess nitrogen and phosphorus delivered from the Midwestern Cornbelt states due to long-term agricultural practices is the primary cause of the Gulf of Mexico hypoxic zone.

- Application of commercial fertilizer to enhance grain yield for the growing human population since the 1950s has amplified the nitrogen pollution from agricultural fields to surface waters. Farming practices, such as tilling and soil turnover, have also led to nutrient losses from the soil.

Concept: MASS BALANCE

- Nitrogen and phosphorus inputs from the MS River Basin to the Gulf have created a nutrient imbalance in the coastal system

ANTHROPOGENIC NUTRIENT SOURCES

Natural Background Nutrient Sources

Sinks

- Its important to point out that there are natural nutrient sources within the MS River basin and that delivery to the Gulf of Mexico occurs naturally. Its the anthropogenic inputs of nutrients, both point and non-point, which ultimately throw the Gulf system out of balance.

Sinks for Nutrients (Removal)

- Biological uptake into biomass
  - Flood plains
  - Wetlands: freshwater and coastal marine
- Sediment burial
- Denitrification: $NO_3 \rightarrow N_2$ gas
  - Flood plains
  - Wetlands: freshwater and coastal marine

Net Nutrients to the Gulf = <u>Inputs (Sources)</u> >> Outputs (Sinks)

Landscape Modifications:

- Enhance nutrient loadings
- Historical loss of sinks
- Disconnect sources from sinks

- Theoretically over the long-term, nutrient sources are offset by nutrient sinks. There are a variety of types sinks and mechanisms through which nutrients are removed from the system within the MS River basin in a way that would limit them as drivers of Gulf hypoxia.

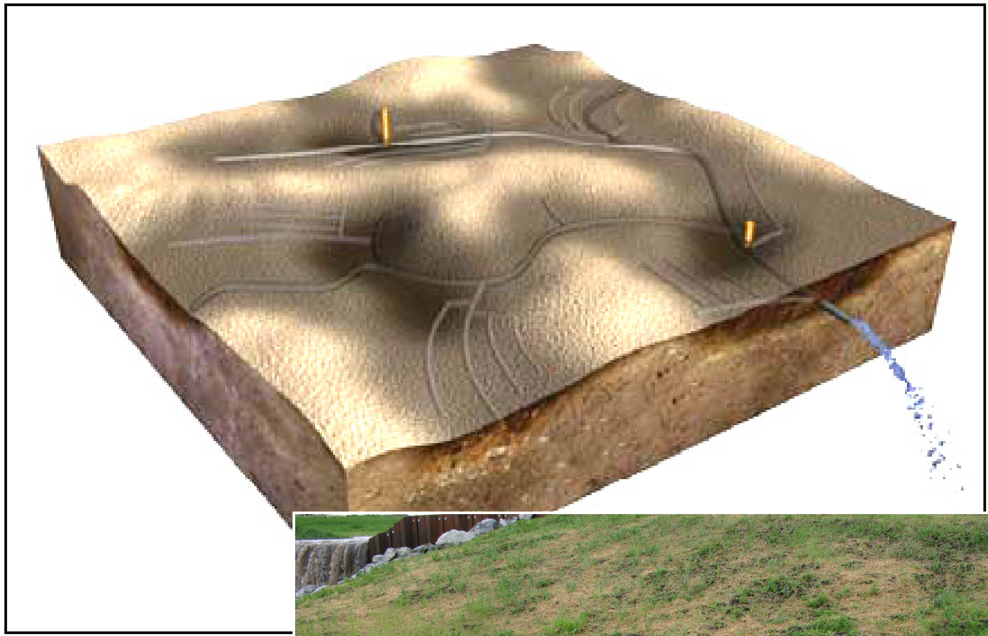
- They include biological uptake and incorporation into plant and animal biomass, sediment burial in rivers and tributaries, and the conversion of nitrate to nitrogen gas via denitrification. The removal processes occur over large areas of the MS River basin in sinks such as flood plains and wetlands.

- But what we see in the MS River basin and the Gulf of Mexico is a deviation from this balance between nutrient sources and sinks.

- Physical modifications of ecological landscapes have confounded this imbalance. In effect, these conversions have enhanced nutrient loadings and disconnected the sources from their sinks.

- In the next two slides I'll show examples of how landscape modification contributes to the problem.

Landscapes Modification: Tile Drainage Systems



Tile drains have accelerated nutrient loadings to receiving waters

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- On the local scale, tile drainage systems have contributed to enhanced nutrient delivery.

- Tile drains are applied to farmlands to enhance water drainage from the soil surface. A network of porous piping is laid below the soil surface in accordance with the subsurface water flow. These networks of pipes are connected at a terminal nodule which feeds into an endpipe. Here, the aggregate surface water collects and drains into a ditch, which in turn drains into a receiving waterbody. Tile drains facilitate not only water flow from the field, but also the nutrients which are applied to the top soil or reside in the soil itself.

- Conversion of fertile Mid-western prairie to tile-drained row-crop agriculture beginning in the 1780s has increased nutrient delivery to surface waters.

Landscape Modification: Re-engineering the Atchafalaya and Mississippi Rivers

- Levees – Disconnect river from floodplain
- Dams – Trapping of sediment and erosion of coastal wetlands
- River diversions – Increased buoyancy to water column

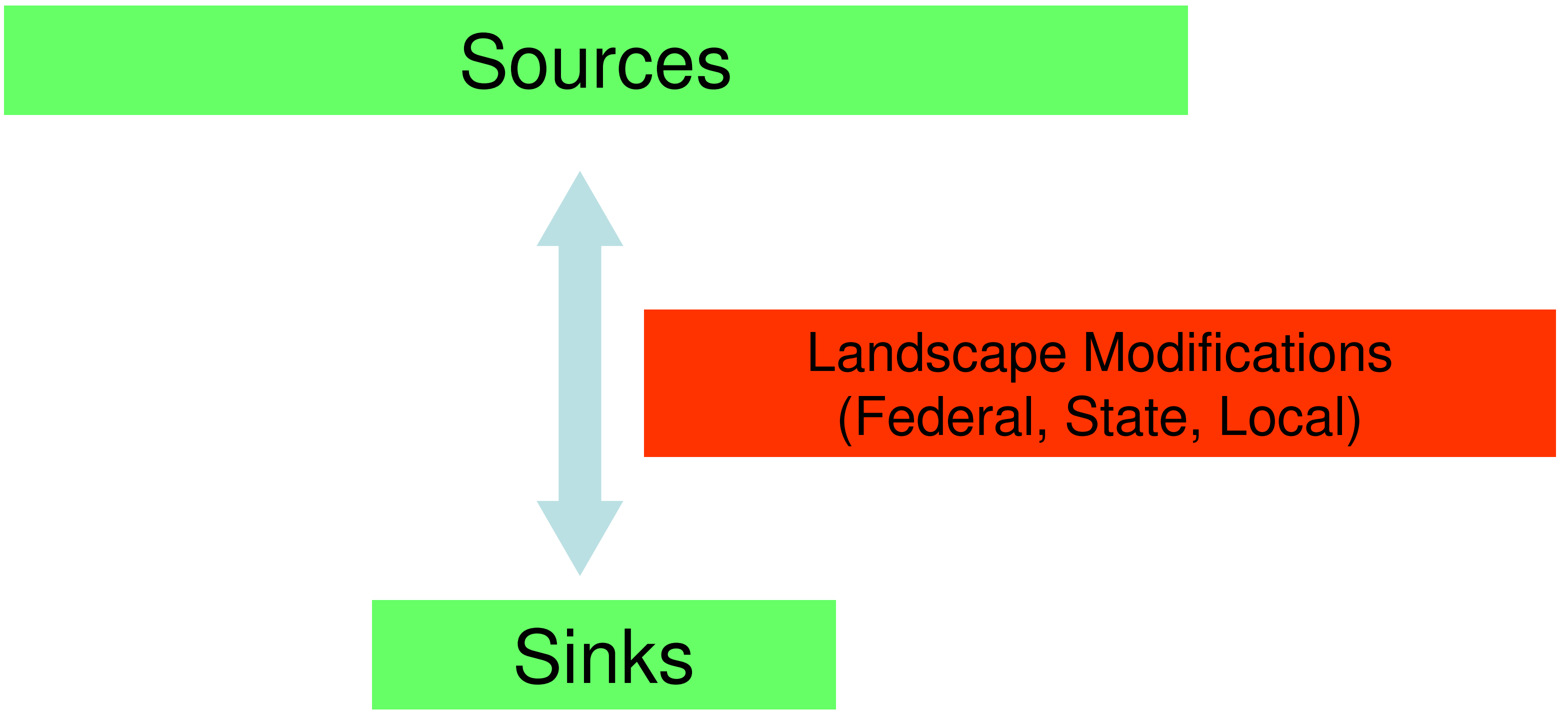
- Over the large scale of the MS River basin, levees, like the one shown at the top, have precluded the natural flooding of the MS River. Natural flooding of the river is one way nutrients are lost from the terrestrial system before they reach the Gulf.

- Dams along the MS River, like the one on the left, have withheld sediment which would have reached the coast and sustained coastal wetlands. These wetlands, in turn, can absorb nutrients before they reach the Gulf.

- Large freshwater diversion from the MS River to the Atchafalaya has increased water column stratification over the hypoxic zone. Atchafalaya River flow has doubled since the early 1900's and has increased the freshwater delivered to the coastal surface waters. In effect, this leads to water column stratification, a condition which resists mixing and delivery of oxygen to the sea floor.

Concept: MASS BALANCE and MANAGEMENT

- Management decisions modulates nutrient flow between sources and sinks



- Revisiting the concept of mass balance of nutrients, its important to recognize the role of management in modulating this dynamic between sources and sinks.

- Management decisions, such as those which lead to landscape modifications noted in the previous two slides, can have a profound impact on the flow, or lack thereof, between sources and sinks.

Nutrient Sources: Mississippi River Sub-basin Fluxes

- Upper MS, OH, TN River Sub-basins
  - 84% nitrate-N and 64% total P flux
  - Tile-drained, corn-soybean landscapes are nitrogen "leaky"
  - Potential targets for nutrient reductions to reduce the size of the Gulf hypoxic zone

- <u>MS River Basin Point Sources</u> contribute 22% of N load (doubling since 2000) and 34% of P load delivered to the Gulf

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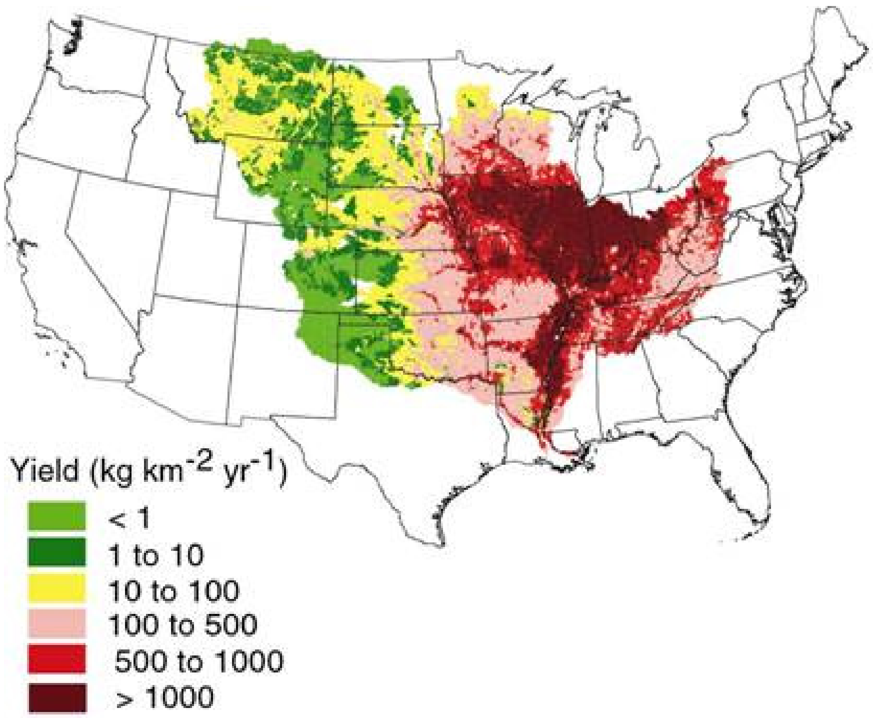
- Getting to the issue of nutrient sources a little further, we see that the Upper MS River, Ohio, and TN sub-basins contribute the majority of nitrogen and phosphorus to the Gulf, about 84% nitrate-N and 64% total P.

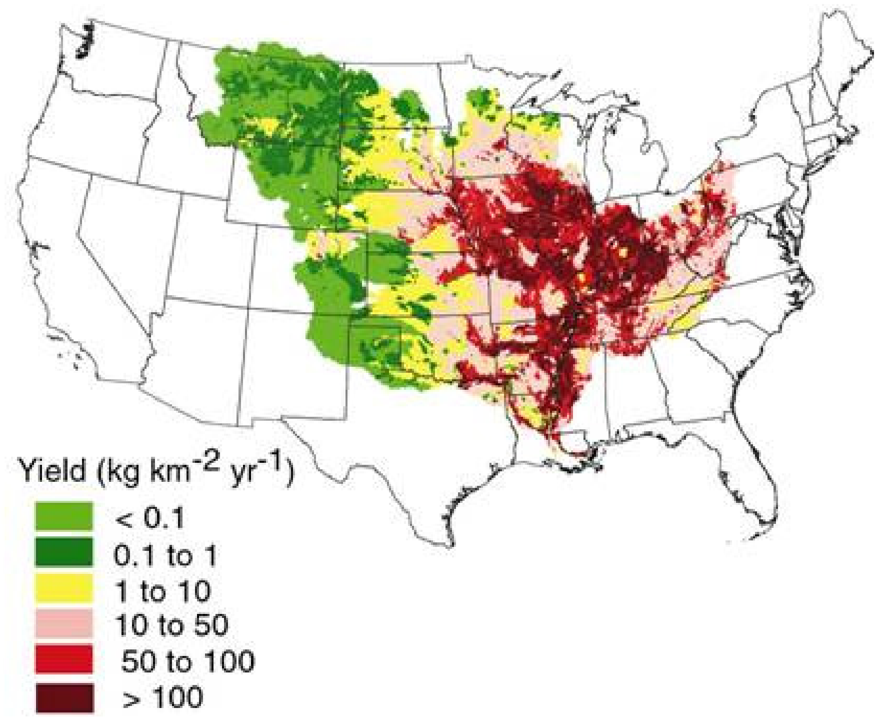
- These sub-basins represent tile-drained, corn-soybean landscapes, which under current management systems, are very nutrient "leaky".

- Point sources from the entire MS River basin contribute one-fifth and one-third of the nitrogen and phosphorus loads delivered to the Gulf, respectively.

Nutrient delivery to the Gulf of Mexico

- Many Midwestern and Eastern watersheds have higher "delivered yields"



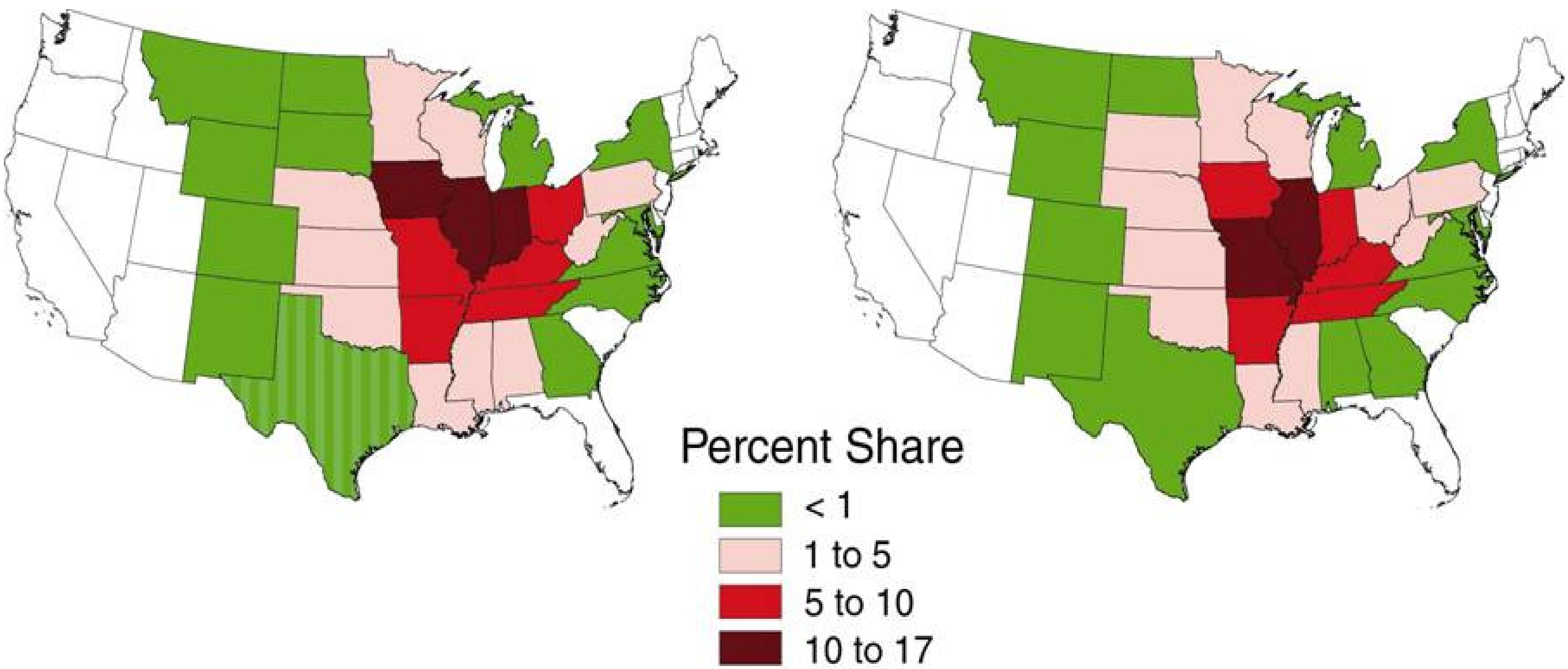


- In work by Richard Alexander of the U.S. Geological Survey and co-workers, they have identified, through a model called SPARROW, the areas of highest delivered nutrient yield to the Gulf.
- On the left of the previous slide is the delivery yield or load for nitrogen. On the right you is the distribution of load for phosphorus.
- The areas of highest yield for either nutrient, shaded in red, are from the mid-Western states and along the MS River. Large portions of the western part of the MS River basin have very little delivered nutrient loads to the Gulf.

Nutrient Delivery to the Gulf of Mexico

State shares of the total nutrient flux

Nitrogen **Phosphorus**



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- Alexander et al, *Environ. Sci. Techn.,* in press

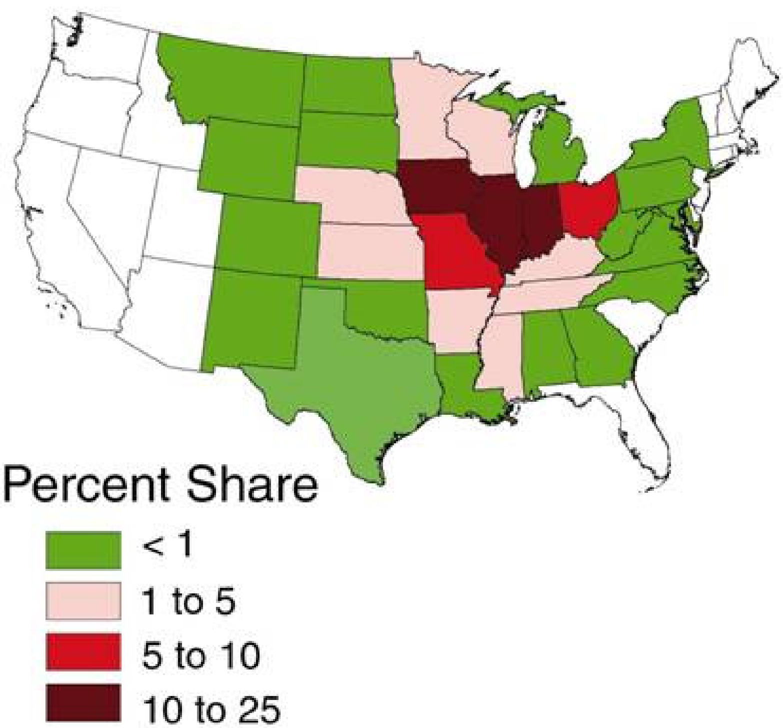
- To refine it further, they’ve identified the states with the greatest share of the total nitrogen and phosphorus load to the Gulf denoted in dark red.

- Again, the western MS River basin states contribute relatively less to the overall nutrient loads delivered to the Gulf.

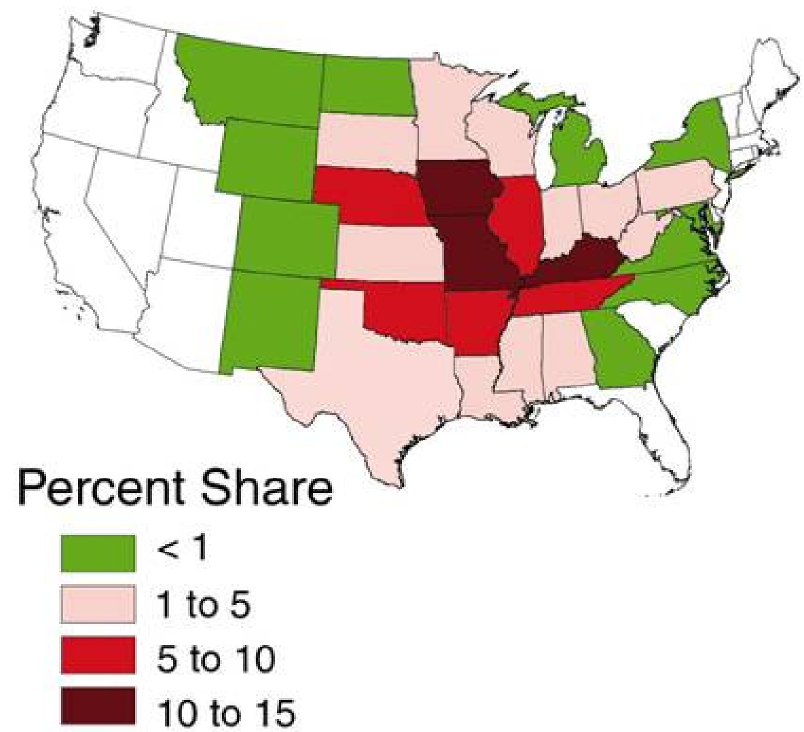
Nutrient delivery to the Gulf of Mexico

State shares of the total nutrient flux by source

Nitrogen
Corn/soybeans

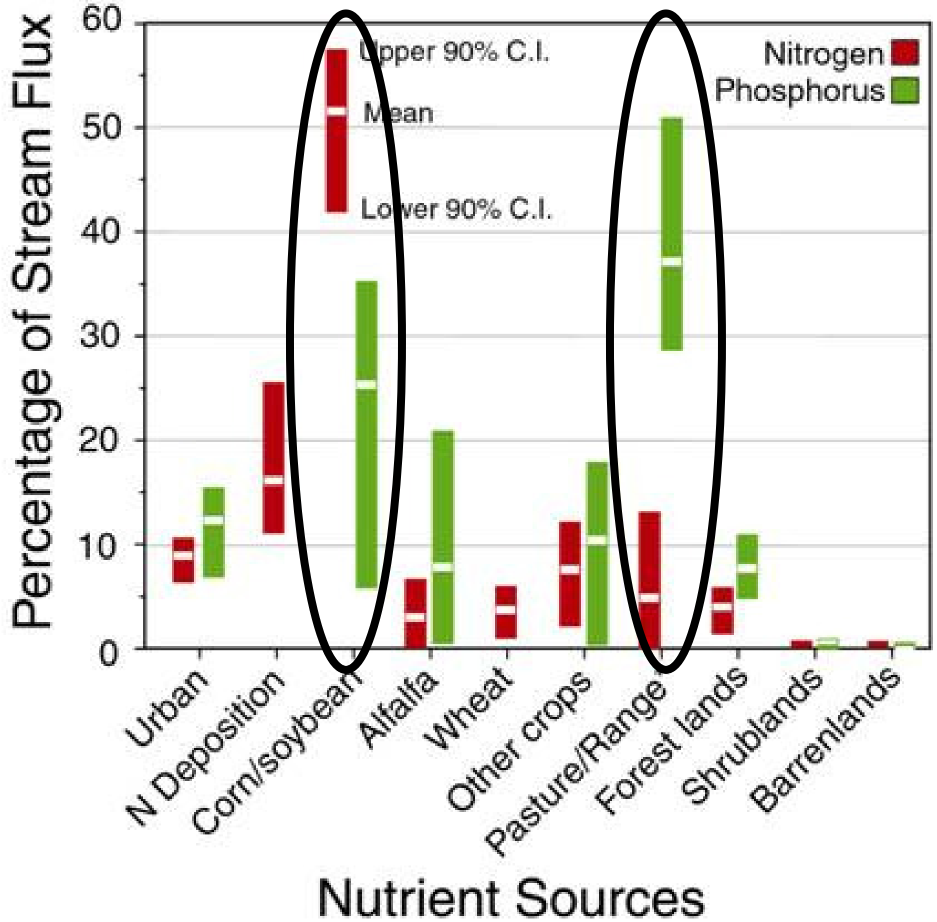


Phosphorus
Pasture/range lands



- When nutrient delivery is analyzed by source or land use practice, nitrogen and phosphorus loads are distributed a bit differently.
- Corn and soybean agriculture in the dark red states are the largest sources on nitrogen.
- However, when you look at phosphorus, pasture and range lands contribute the most. States which were not large contributors of nitrogen, such as OK, KS, TN, and MO, turn out to be large contributors of phosphorus from their pasture and range lands.

Nutrient Sources to the Gulf of Mexico



- Nitrogen and phosphorus are affected by different sources and land uses

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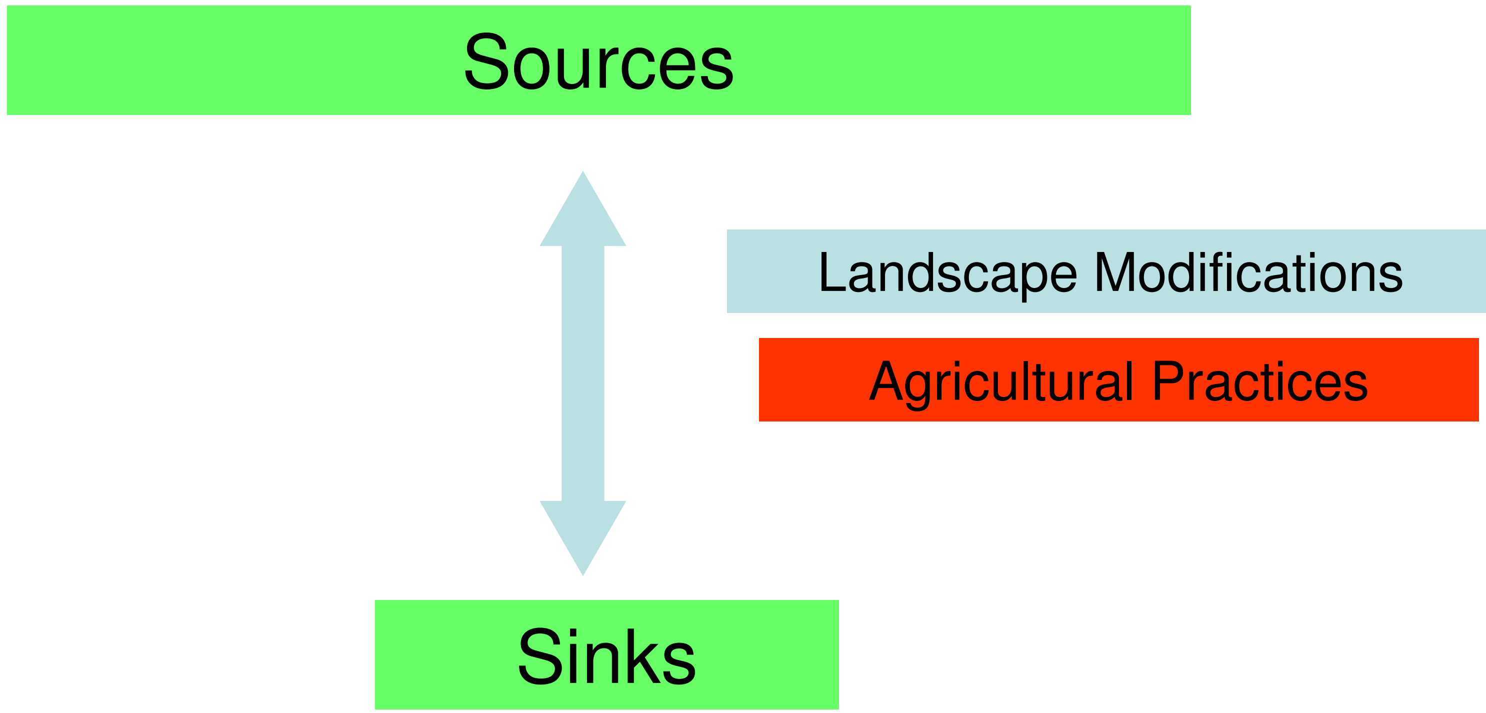
- To illustrate the point further, the graph on the right depicts nutrient loads as a function of source or land use.
- The circle to the left highlights corn and soybean agriculture as the largest source of nitrogen to the Gulf, but it does not contribute as much phosphorus as pasture and range lands, a distribution you saw in the previous slide.
- Additional sources are shown on the X-axis. They include other crops such as alfalfa and wheat as well as urban and atmospheric deposition. Also noted are the loads which come from natural landscapes such as forests, shrublands, and barrenlands. These represent a small fraction of the nutrients to the Gulf.
- This analysis by Alexander and co-workers is extremely useful because it identifies the principal sources, in terms of states and land use, of nitrogen and phosphorus, which in turn can help managers identify the areas of highest priority for nutrient reductions.

Concept: MASS BALANCE and MANAGEMENT

- Management decisions modulates nutrient flow between sources and sinks



Management Strategies for Nutrient Pollution: Protecting Water Quality and Social Welfare

- Gulf Hypoxia Task Force Action Plan (draft)
  - Coastal goal → Reduce hypoxic zone to < 5,000 km^2
  - Within-basin goal → Protect water quality
  - Quality of life goal → Protect social welfare

- All goals are <u>inextricably and positively linked</u>
  - Co-benefits of nutrient reduction include:
    - greenhouse gas mitigation for atmospheric point sources
    - improvements in wildlife habitat and recreational opportunities

One way in which states and the federal government is trying to manage nutrients and Gulf hypoxia is through the multi-state, multi-agency Gulf Hypoxia Task Force.

– In its latest draft Action Plan, released just recently, it outlines three goals:

  - Coastal goal to reduce hypoxic zone to < 5,000 km^2
  - Within-basin goal to protect water quality
  - Quality of life goal to protect social welfare

- All three goals are positively linked and have co-benefits. These include: greenhouse gas mitigation for atmospheric point sources and improvements in wildlife habitat, which in turn provide recreational opportunities.
-

Scientific Basis for Goals and Management Options: Setting Targets for Nutrient Load Reduction

- Gulf Hypoxia Task Force Action Plan (draft)
  - Dual nutrient control strategies (N and P):
    - BMPs for reducing agricultural non-point source loads
    - Best available technologies for non-agricultural non-point sources
    - Best available technologies and biological nutrient removal at major point source discharges
    - Development of freshwater (lakes, rivers, streams) N and P criteria for adoption into water quality standards

- EPA Science Advisory Board Recommendation
  - Reduce N loads by at least 45%
  - Reduce P loads by ~40%

- The Task Force Action Plan outlines strategies for reducing nutrients to the Gulf. The strategies are based on scientific analyses, such as that by Alexander et al.'s SPARROW modeling work, and technologies which are known to reduce nutrient loads.

- The strategies focus on addressing both nitrogen and phosphorus using the best agricultural management practices to reduce agricultural non-point source loads, the best available technologies to reduce NON-agricultural non-point source loads, the best available technologies to reduce point source discharges, and the development and adoption of numeric water quality standards by States which would protect water quality within the MS River basin.

- I'll discuss these management options in more detail in the next series of slides.

- The most recent scientific recommendation by the EPA Science Advisory Board, working on behalf of the Task Force, is a goal of reducing N loads by at least 45% and reducing P loads by ~40%.

Most Effective Actions for Agricultural Non-Point Sources

- Implementation of Best Management Practices (BMPs)
  - Targeted fertilizer application
  - Taking high nutrient-yielding lands out of production
  - Installing riparian buffer zones
  - Constructed wetlands
  - Allow for natural flooding of lands

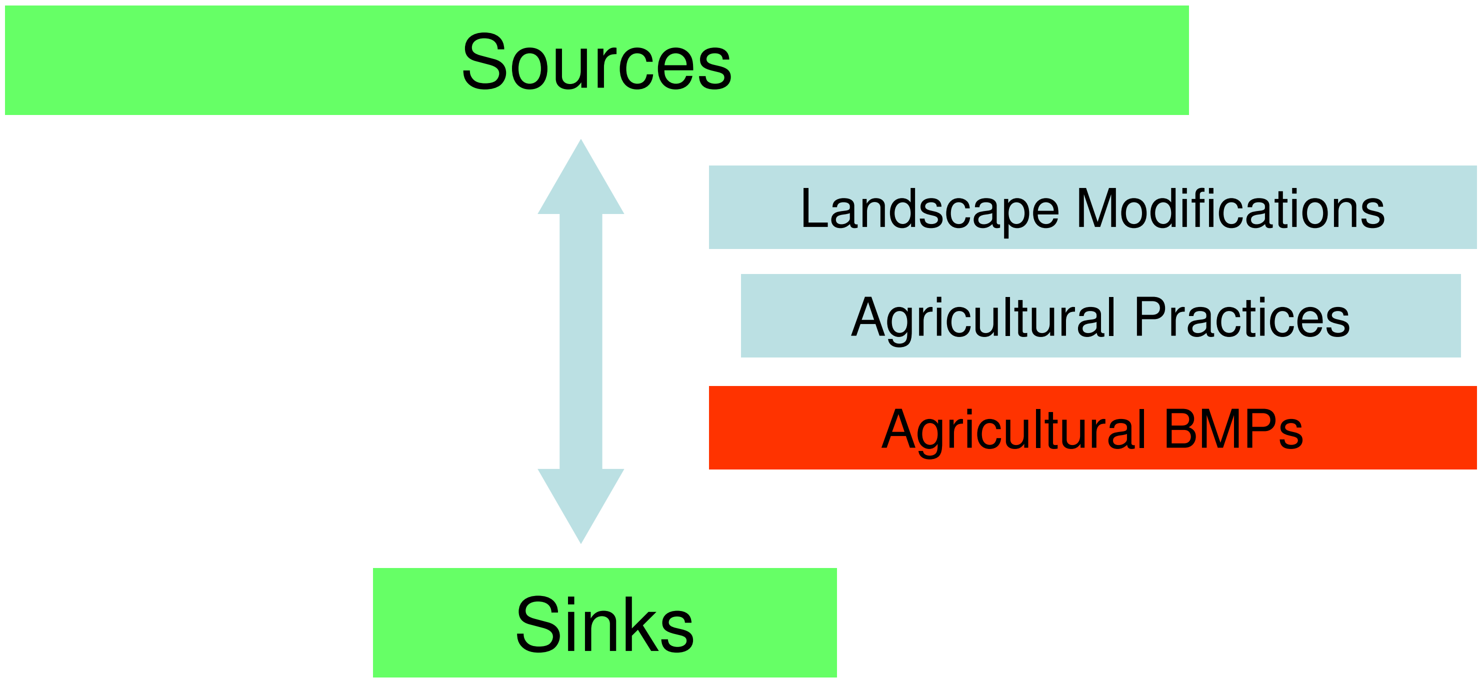
- In terms of agricultural non-point source nutrient pollution, best management practices or BMPs, are the most effective ways to achieve nutrient reductions.

- Some of the BMPs include:

1. Targeted fertilizer application.
2. Taking high nutrient-yielding lands out of agricultural production.
3. Installing riparian buffer zones between agricultural lands and receiving waters.
4. Constructing wetlands at the receiving ends of tile drains to remove nutrients before they enter the receiving waterbody.
5. Allowing natural flooding of lands and retention of nutrients by the soil.

Concept: MASS BALANCE and MANAGEMENT

- Management decisions modulates nutrient flow between sources and sinks



- Many BMPs manage nutrients toward their natural sinks

- Reflecting on the concept of mass balance again, agricultural BMPs are superimposed on other management decisions, which in turn modulate the flow of nutrients between sources and sinks.

- Many BMPs, such as the construction of wetlands or the installation of riparian buffer zones, approximate what the natural ecological landscape would do biogeochemically.

Most Effective Actions for Non-Agricultural Non-Point Sources

Atmospheric deposition and urban/suburban storm water runoff

- Tighter limits on the sources of NOx emissions
- Incorporating water quality benefits into decisions involving:
  - Retirement or retrofitting of old coal-fired power plants
  - NOx controls – e.g. extension of current summertime NOx standards to a year-round requirement
  - Emissions standards and mileage requirements for SUV's, heavy trucks and buses

- One way non-agricultural non-point nutrient sources can be reduced is to address atmospheric deposition and stormwater runoff from urban and suburban landscapes.

- Strategies include:
- Tighter limits on the sources of NOx emissions and incorporating water quality benefits into decisions involving:
  - Retirement or retrofitting of old coal-fired power plants,
  - NOx controls such as the extension of current summertime NOx standards to a year-round requirement,
  - Emissions standards and mileage requirements for SUV’s, heavy trucks and buses.

Effective Technologies for Municipal Point Sources

- Upgrade sewage treatment plants
  - Biological Nutrient Removal (BNR) technologies

- Potential for basin-wide permit limits for sewage treatment plant upgrades

- In terms of municipal point sources such as sewage treatment plants, these could be targeted for upgrades to secondary treatment using biological nutrient removal technologies.
- MS River basin-wide permit limits for sewage treatment plants based on these technology upgrades could then be implemented.

Effective Technologies for Industrial Point Sources

- For industries with high nutrient discharges
  - Use a targeted permit by permit approach
  - Evaluate for opportunities to reduce N and P discharges through Best Available Technologies (BATs) for pollution prevention, process modification, or treatment

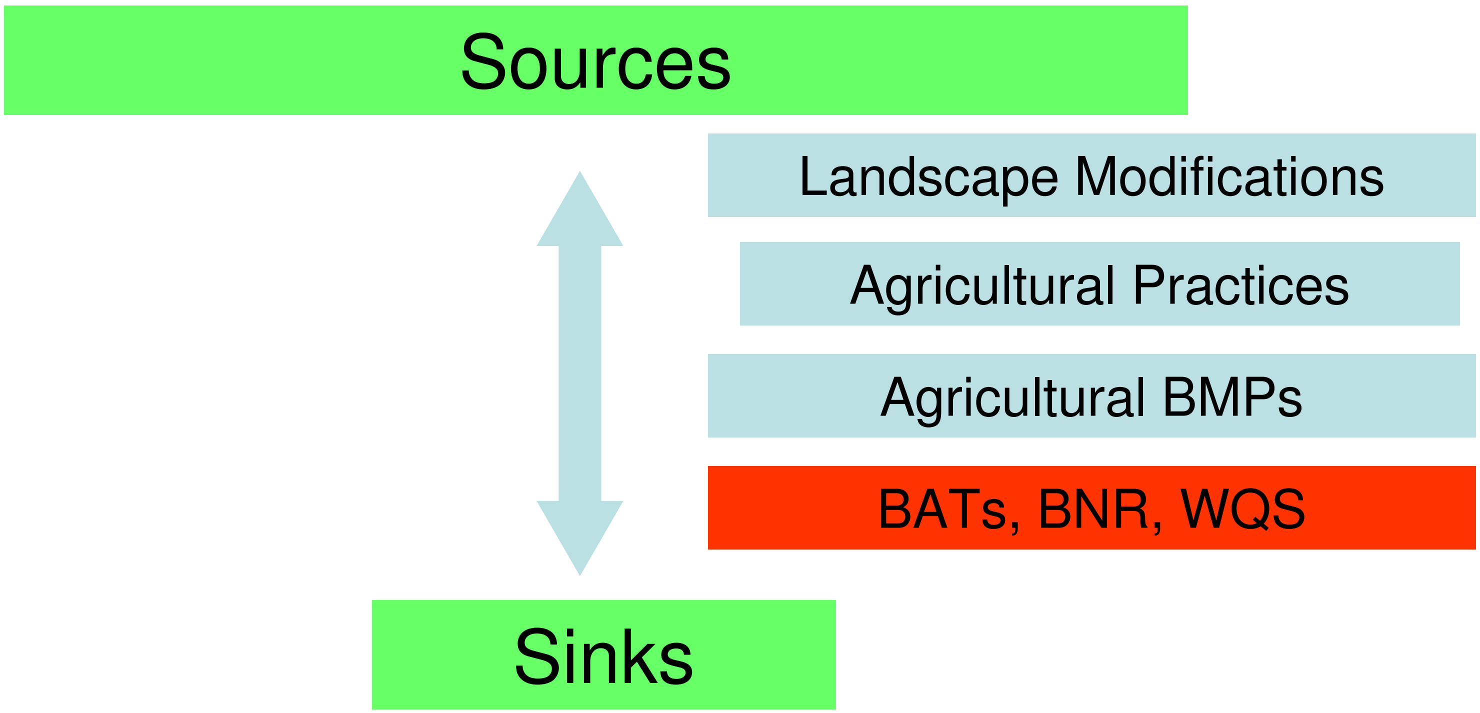
Development and Adoption of Numeric Water Quality Standards

- Drive water quality assessments and watershed protection management
- Create measurable, objective water quality baselines against which to measure environmental progress.

- Ancillary regulatory benefits:
  - easier and faster development of TMDLs,
  - quantitative targets to support trading programs,
  - easier to write protective NPDES permits,
  - increased effectiveness in evaluating success of nutrient runoff minimization programs.

Concept: MASS BALANCE and MANAGEMENT

- Management decisions modulates nutrient flow between sources and sinks



Piecing together additional management activities in the context of nutrient mass balance, you see that there are multiple layers of natural resource management which work against and in concert with one another to modulate nutrient flows between sources and sinks.

Summary and Conclusions

Describe the phenomenon

•Hypoxia is fueled by N and P

•Eutrophication → Hypoxia is a growing environmental and economic problem

•Ecological hysteresis

Identify Sources of Nutrient Pollution

- Long-term nutrient loads from point / non-point sources
- Agricultural sources the largest for N and P
- Landscape modifications

Identify Management Strategies

- Implementation of BMPs, BATs, BNRs
- Numeric water quality standards
- Ecosystem restoration

Management Challenges for Hypoxia

- Nutrient pollution occurs across a large geographic scale, but implementation occurs at State and local level
- National energy policies encouraging biofuel production
  - More agricultural production → more fertilizer, less land for nutrient capture
- Climate change will likely exacerbate the effects of nutrient pollution
  - Flooding → increasing nutrient delivery
  - Warming ocean → increasing Gulf stratification