c1

NITROGEN BACKGROUNDER

The N Cycle Impacting Human Health and the Enviornment

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.

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Slide 1

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**

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NITROGEN BACKGROUNDER

Module 2:

The N-Cycle Impacting Human Health and the Environment

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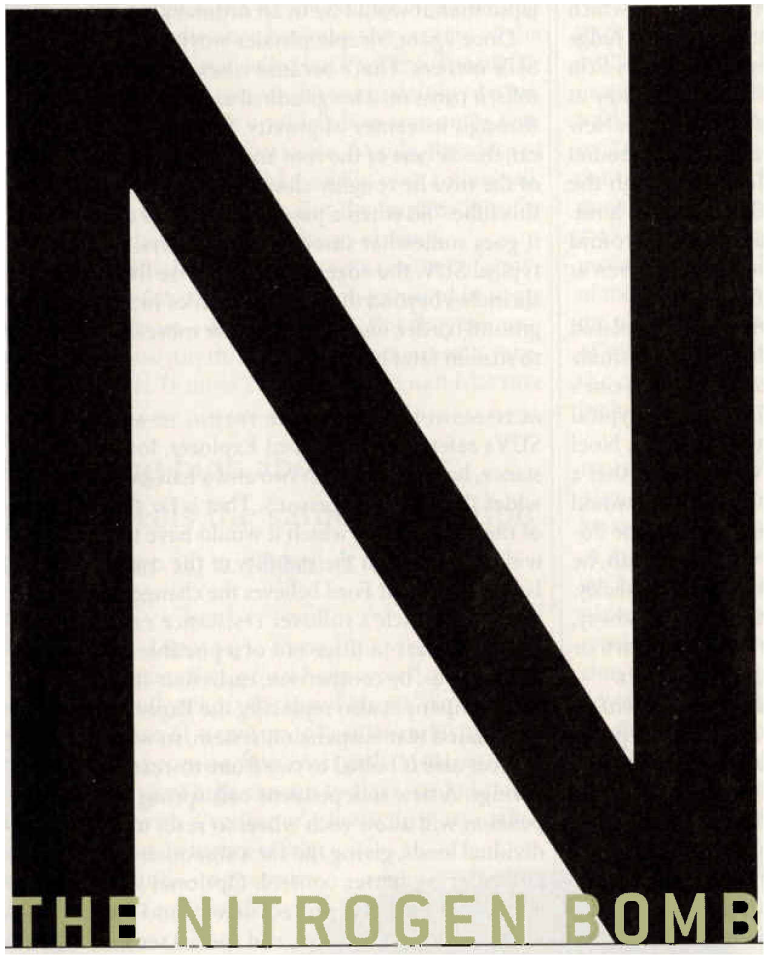
“BY LEARNING TO DRAW FERTILIZER FROM A CLEAR BLUE SKY, CHEMISTS HAVE FED THE MULTITUDES.

THEY'VE ALSO UNLEASHED A FURY AS THREATENING AS ATOMIC ENERGY”



Source: Discover Magazine

Nitrogen In the News

- GREEN REVOLUTION
- HABER-BOSCH
- FERTILZER
- ORGANIC NITROGEN FIXING BACTERIA
- HIGH EXPLOSIVES
- OKLAHOMA CITY
- LAUGHING GAS
- DENITRIFIERS
- N TRADING
- WORLD STARVATION
- OKLAHOMA CITY BOMBING
- ACID RAIN
- GREENHOUSE GASES
- GLOBAL WARMING
- TOXIC ALGAL BLOOMS
- DEAD ZONES
- EUTROPHICATION
- BLUE BABY SYNDROME
- SMOG

HOW DO WE CONNECT THE DOTS?

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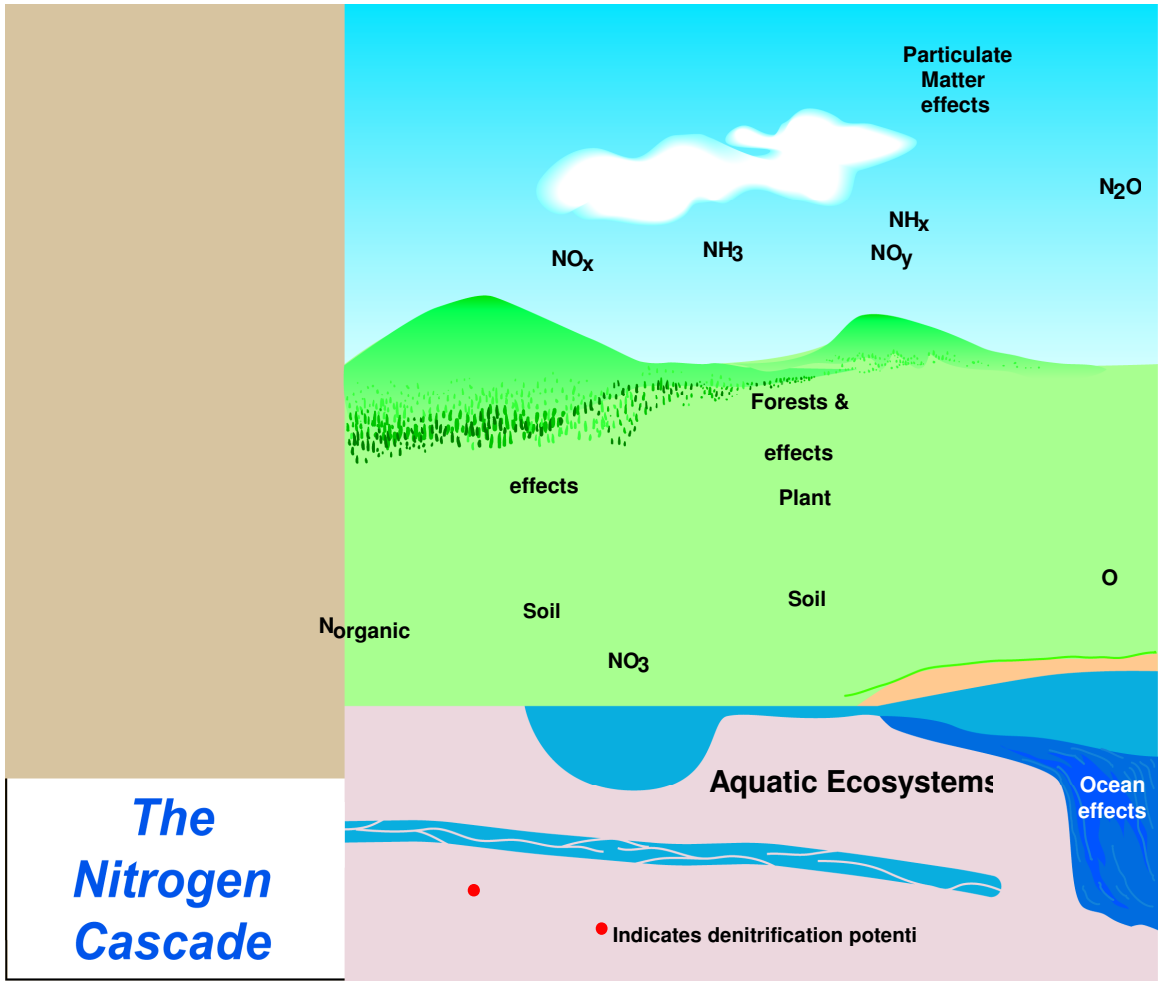
The Cascade: Our Organizing Construct



The Nitrogen Cascade

Source: Galloway, et. al.

- What is N, anyway?
- What forms does it take?
- Where is it found?
- Where does it come from?
- What does it do?
- So what?

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Topics We'll Be Covering

- Review of Historical Events and Trends
- Effects of Reactive N
  - In Atmosphere
  - On Land
  - In Water
- Future Outlook
- Research Needs
- Conclusions

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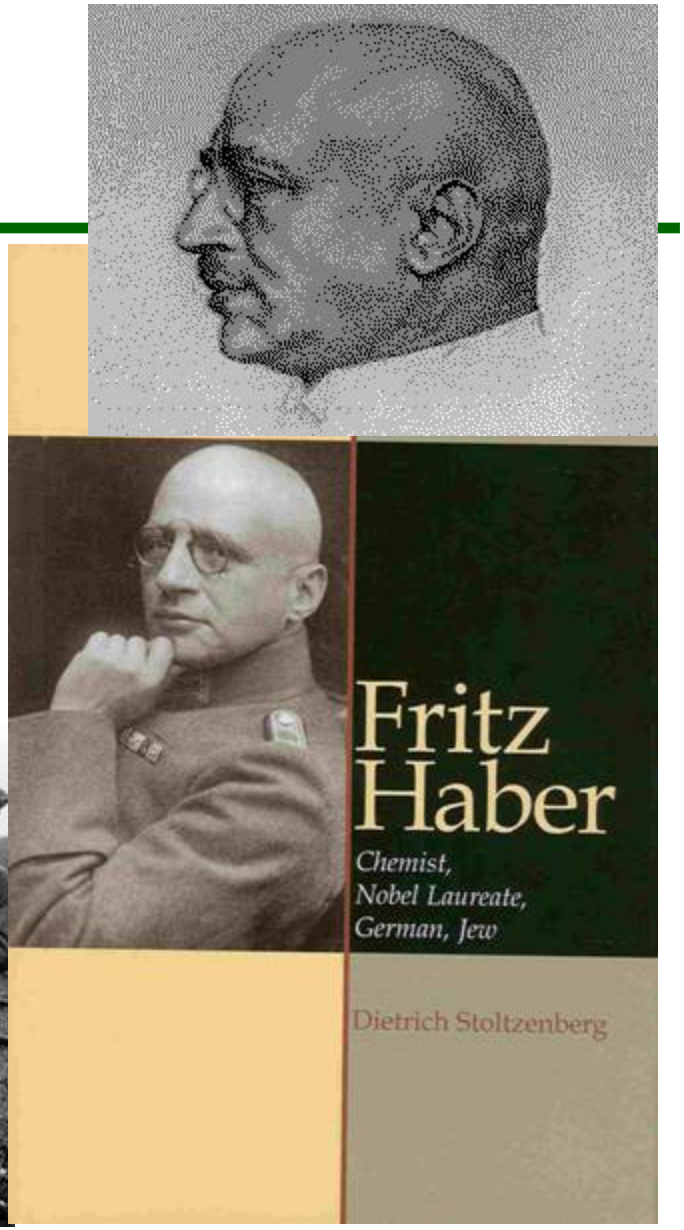
Starvation, War, Fertilizer, Explosives, and Genius



Result: The N-Problem

- Haber-Bosch Process

Hydrogen + Nitrogen → Ammonia → Nitrates,Nitrites

(from methane) (from air) (high T/P; Fe catalyst) (Fertilizer)

- Fertilizer to feed the multitudes… and explosives for other exploits

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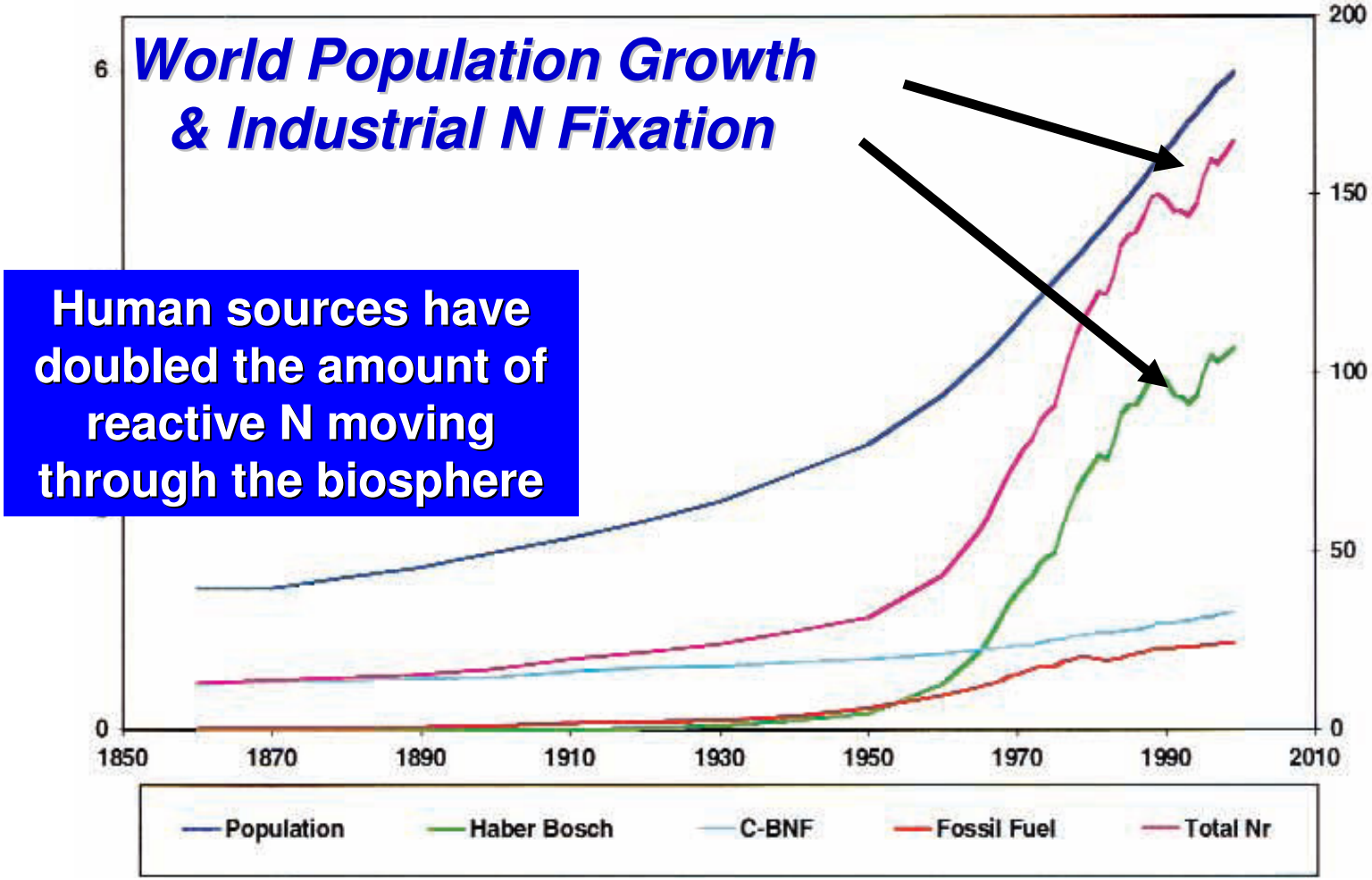
Why Be Concerned?



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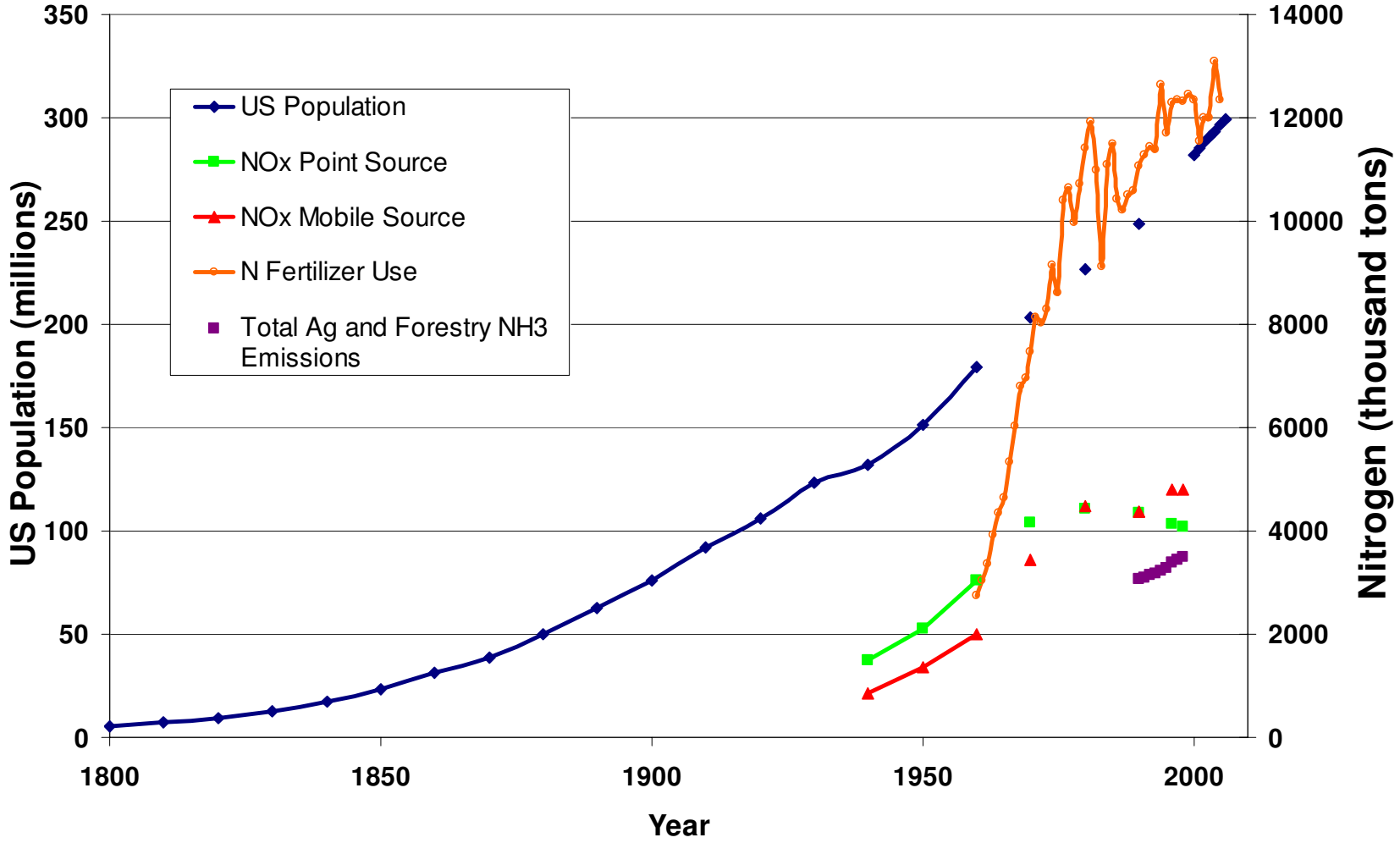
US Population and Nr Emissions



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Other Major Source: Soils

- What the previous slide does not show is how much rN is released from long-term storage, such as soils
- In the Mississippi watershed, nearly half of the rN may be coming from the mineralization of soils

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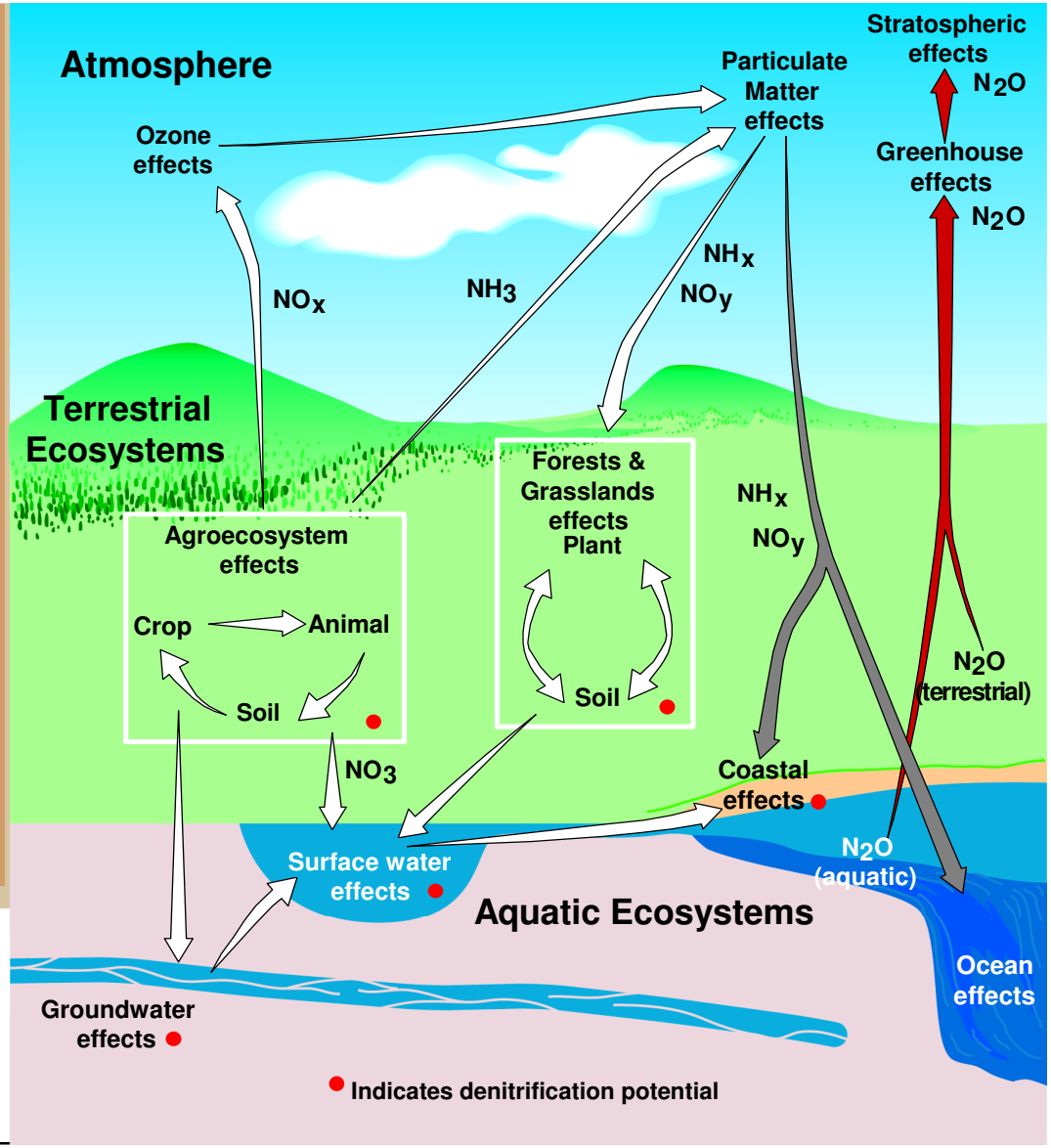
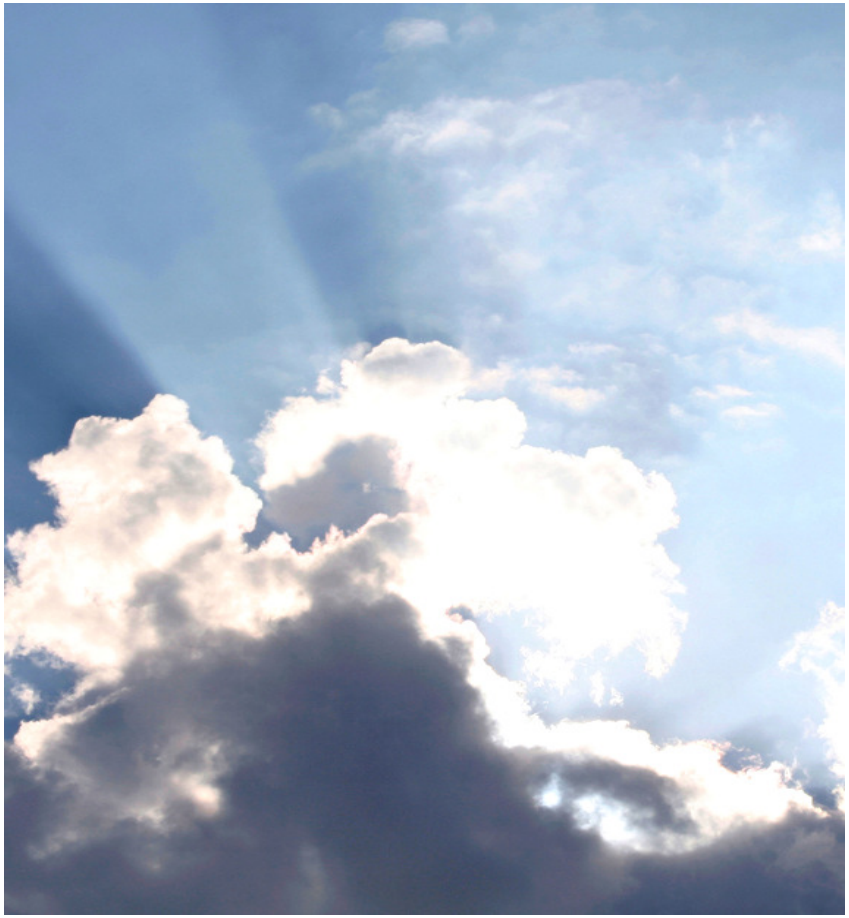
N Cascade Guide To Effects

- Atmospheric
  - climate change
  - tropospheric ozone and fine particulate matter
  - nutrient and acid deposition
- Terrestrial
  - fertilization
  - species alterations
  - soil saturation and mineral depletion
- Aquatic
  - acidification
  - eutrophication
  - groundwater contamination



The Nitrogen Cascade

Atmospheric Effects



- Climate change
- Tropospheric ozone and fine particulate matter
- Nutrient and acid deposition

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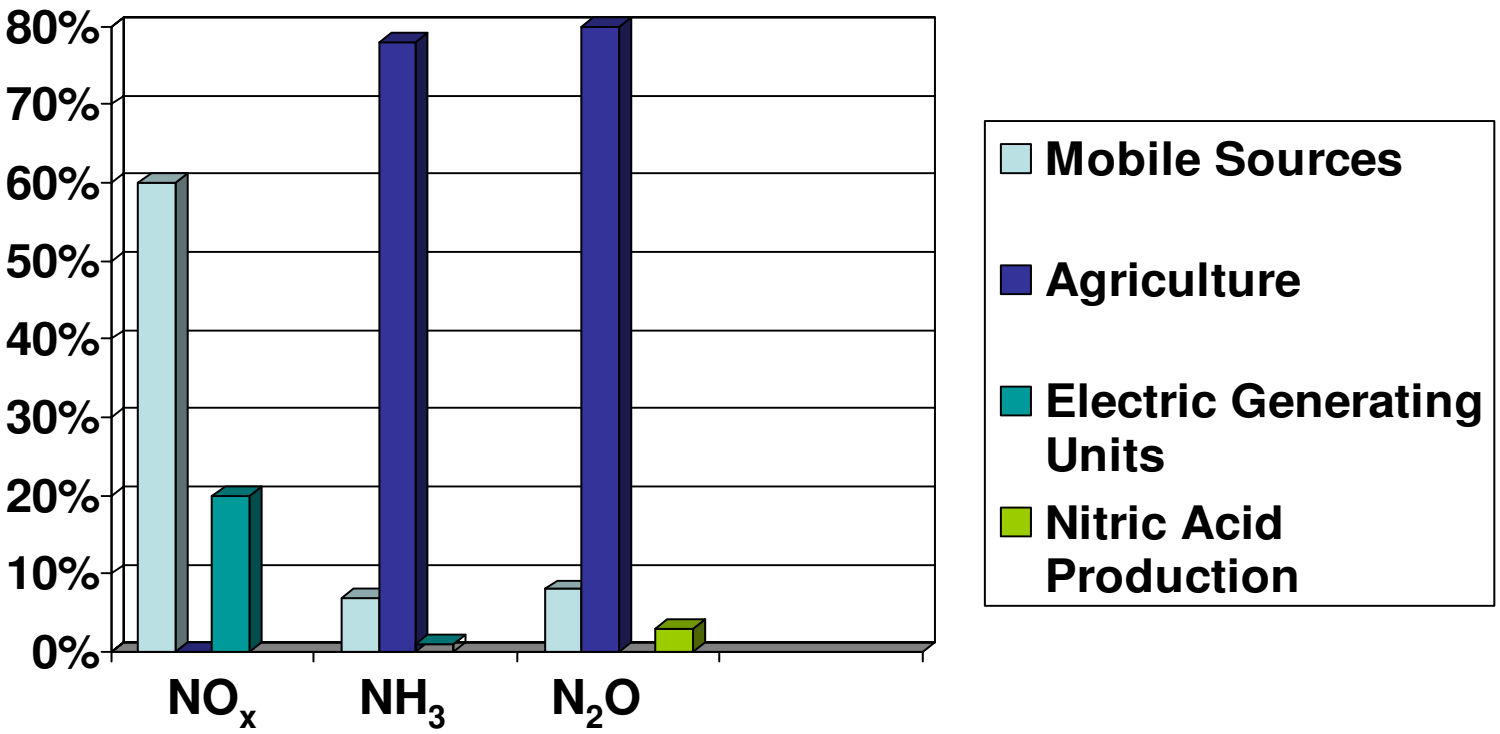
Major Sources of NO_X, NH_3, and N_2O

Annual Emissions: NO_X (2004), NH_3 (2002), and N_2O(2005)



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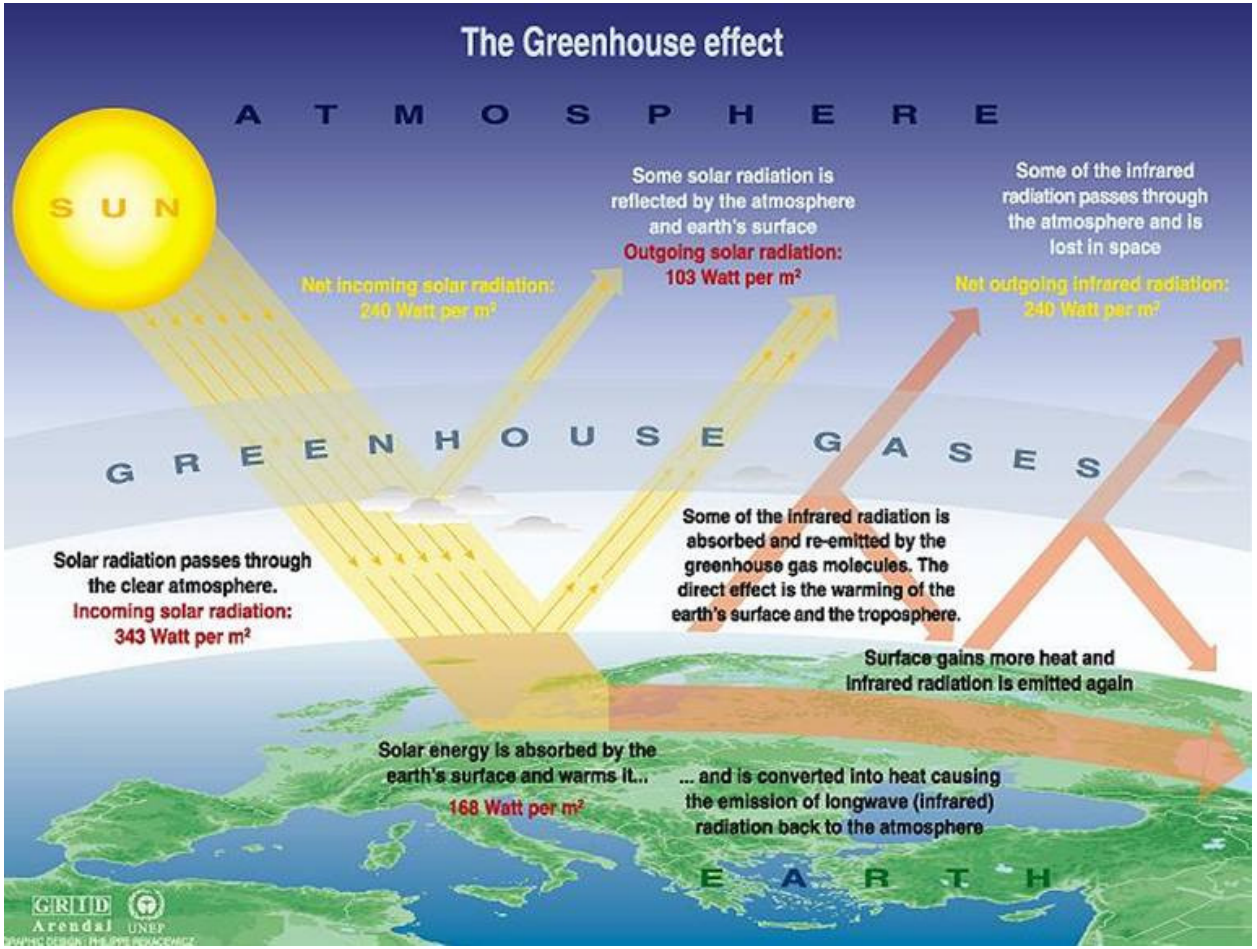
- Soil releases of nitric oxide (NO) and nitrous oxide (N2O), a green house gas, are not included in these emission inventories. These releases occur on farm fields and downstream as well as in the natural environment.
- Ammonia emissions are an important source of N to the environment. As we continue to successfully achieve NOx emissions reductions, ammonia emissions will increase in importance

- Source: Air office, EPA

GHGs are necessary for life as we know it on Earth (But too much of a good thing can be problematic.)



Nitrous Oxide releases from natural and agricultural soils can increase global warming by causing more reflected suns rays to be returned to earth. N20 is a small part of the greenhouse gas budget (~5%) but is a very potent GHG.

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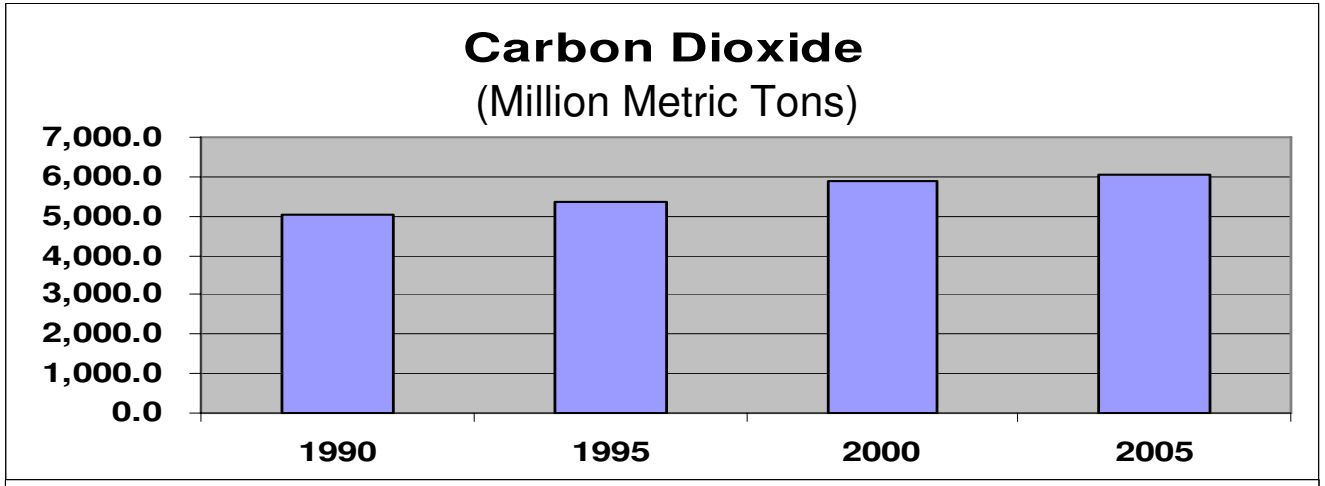
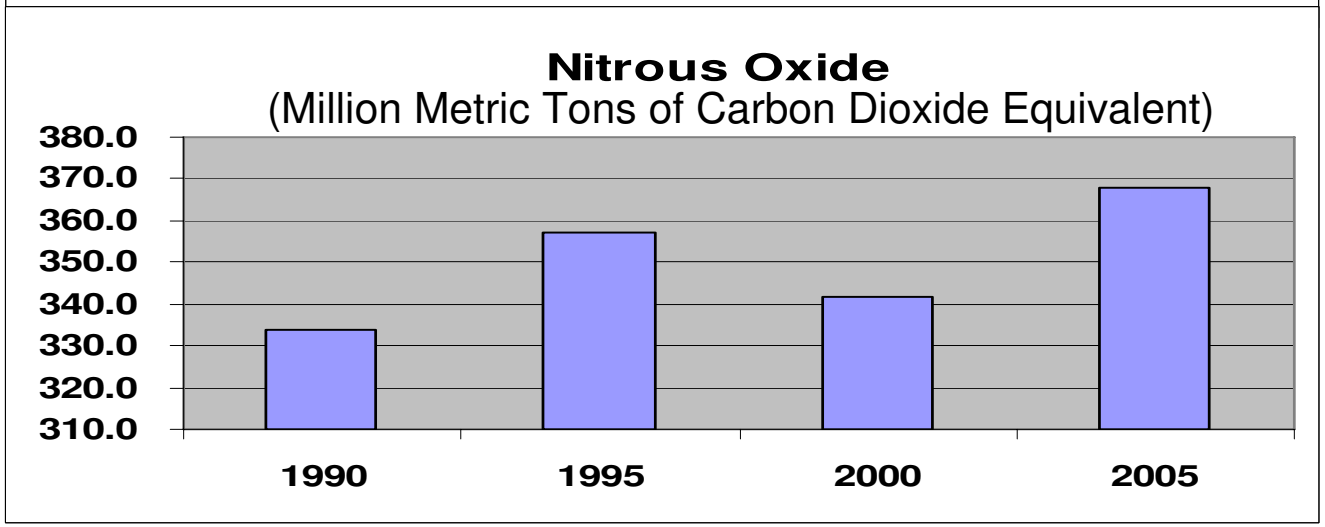
Trends in U.S. CO_2 and N_2O Emissions





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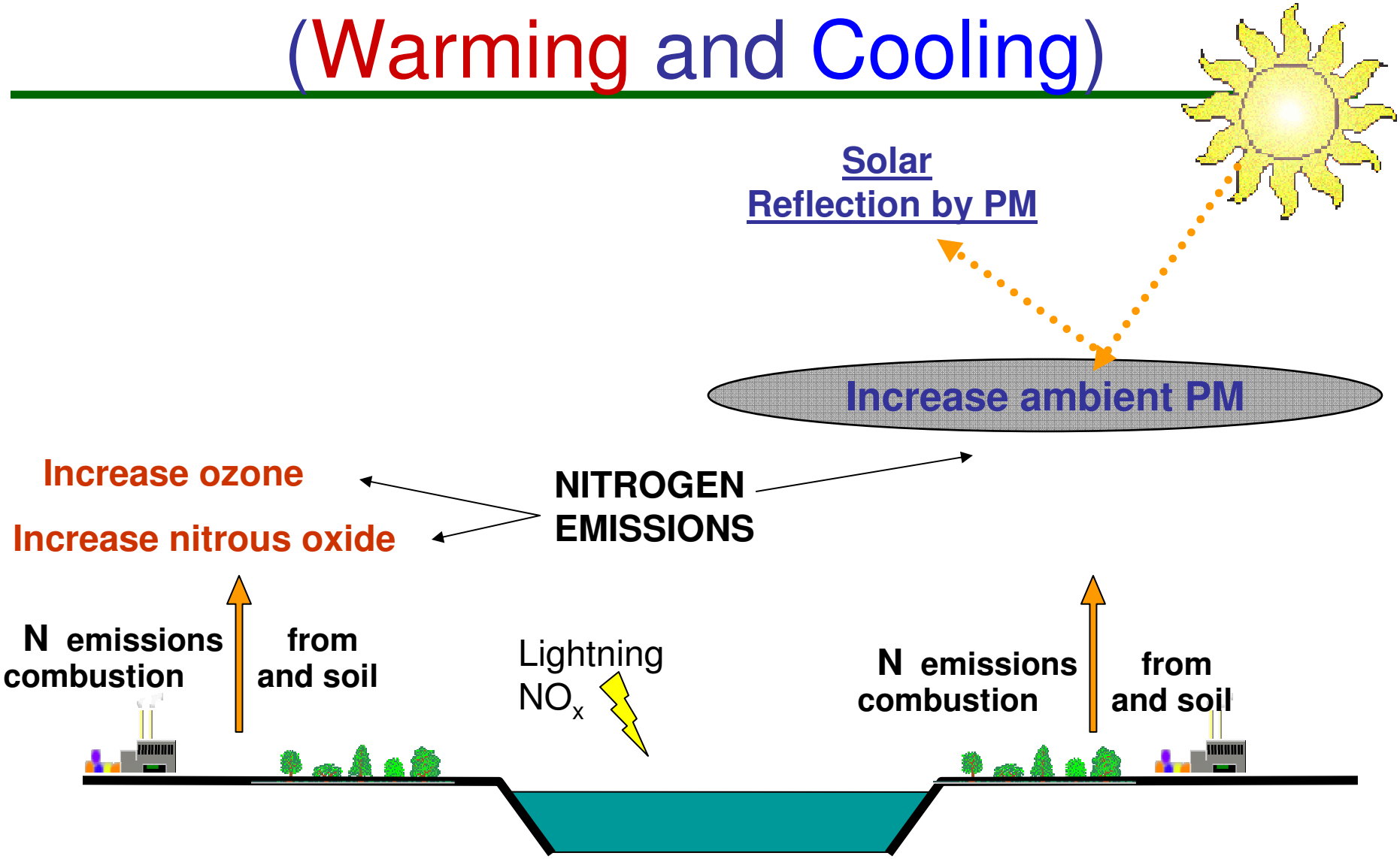
Nitrogen-Climate Interactions (Warming and Cooling)



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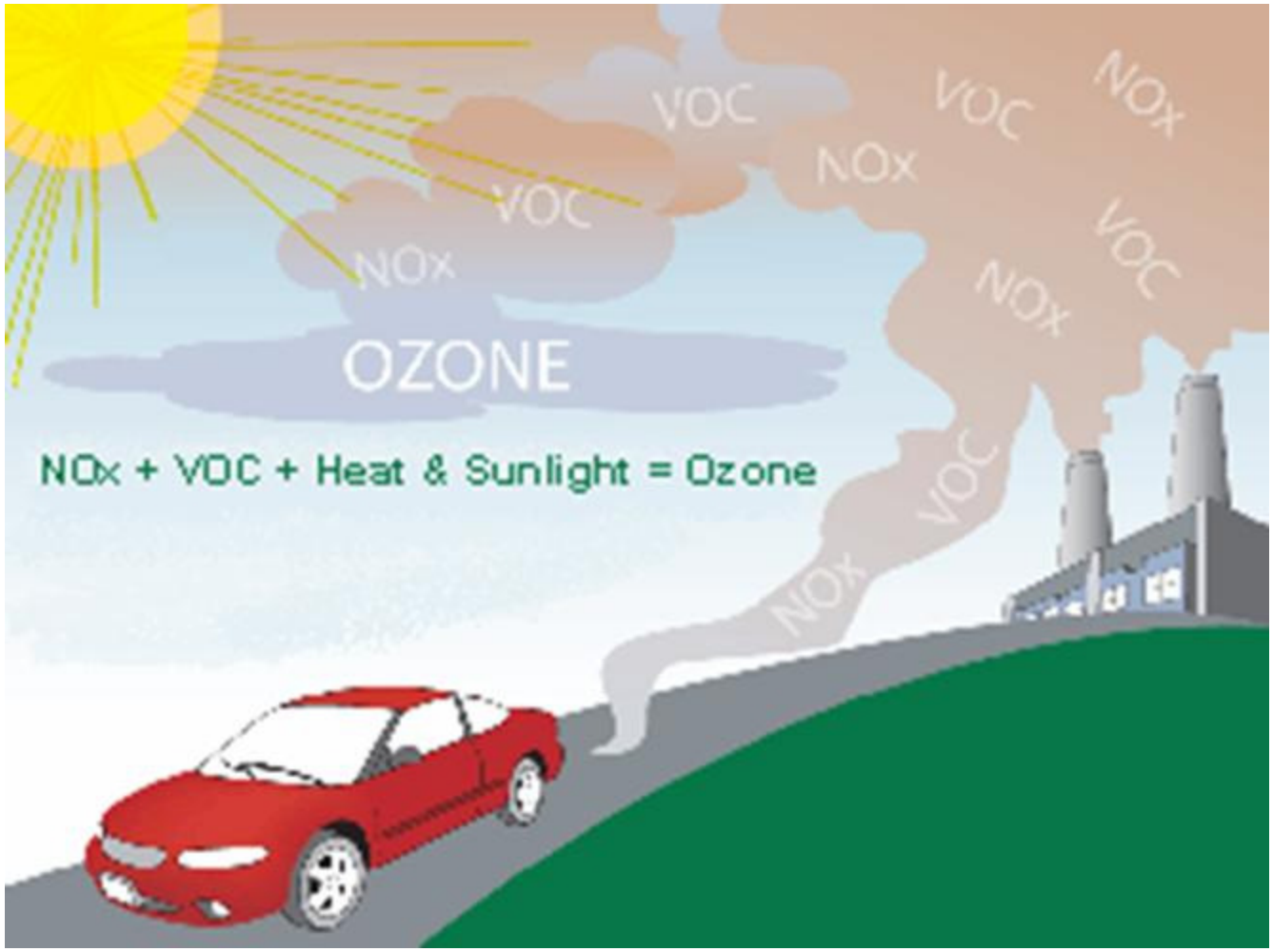
- Other nitrogen emissions are more complicated when we talk about climate change effects.
- Ozone is a GHG and increases warming; whereas, particulate matter (e.g., ammonium nitrate) increases cloud reflectivity and serves more of a cooling function.

Ground Level Ozone



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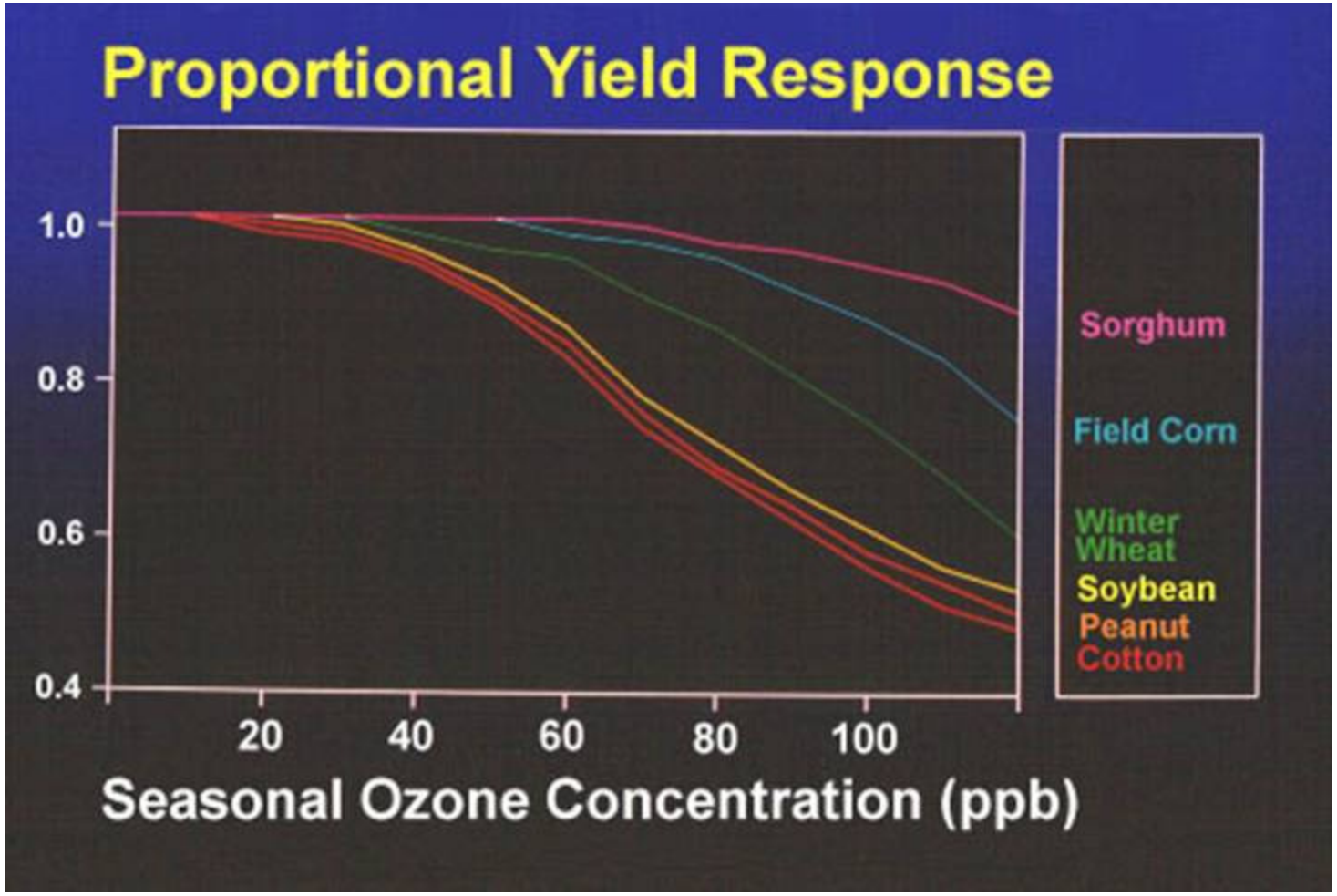
Ground Level Ozone

- The primary component of smog
- Sometimes called “bad ozone” to distinguish it from “good ozone”
  - Both types of ozone have the same chemical composition (O_3).
  - “Good ozone” occurs naturally in the upper portions of the earth’s atmosphere and forms a layer that protects life on earth from the sun's harmful rays.
  - “Bad” ozone is harmful to breathe
- Not emitted directly into the air, but forms when emissions of nitrogen oxides (NOx) and volatile organic compounds (VOCs) “cook” in the sun.
- Emissions from industrial facilities, electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are the major man-made sources of NOx and VOCs.
- Mainly a summertime pollutant, because sunlight and hot weather accelerate its formation
- Ozone levels can be high in both urban and rural areas, often due to transport of ozone, or the NOx and VOC emissions that form ozone

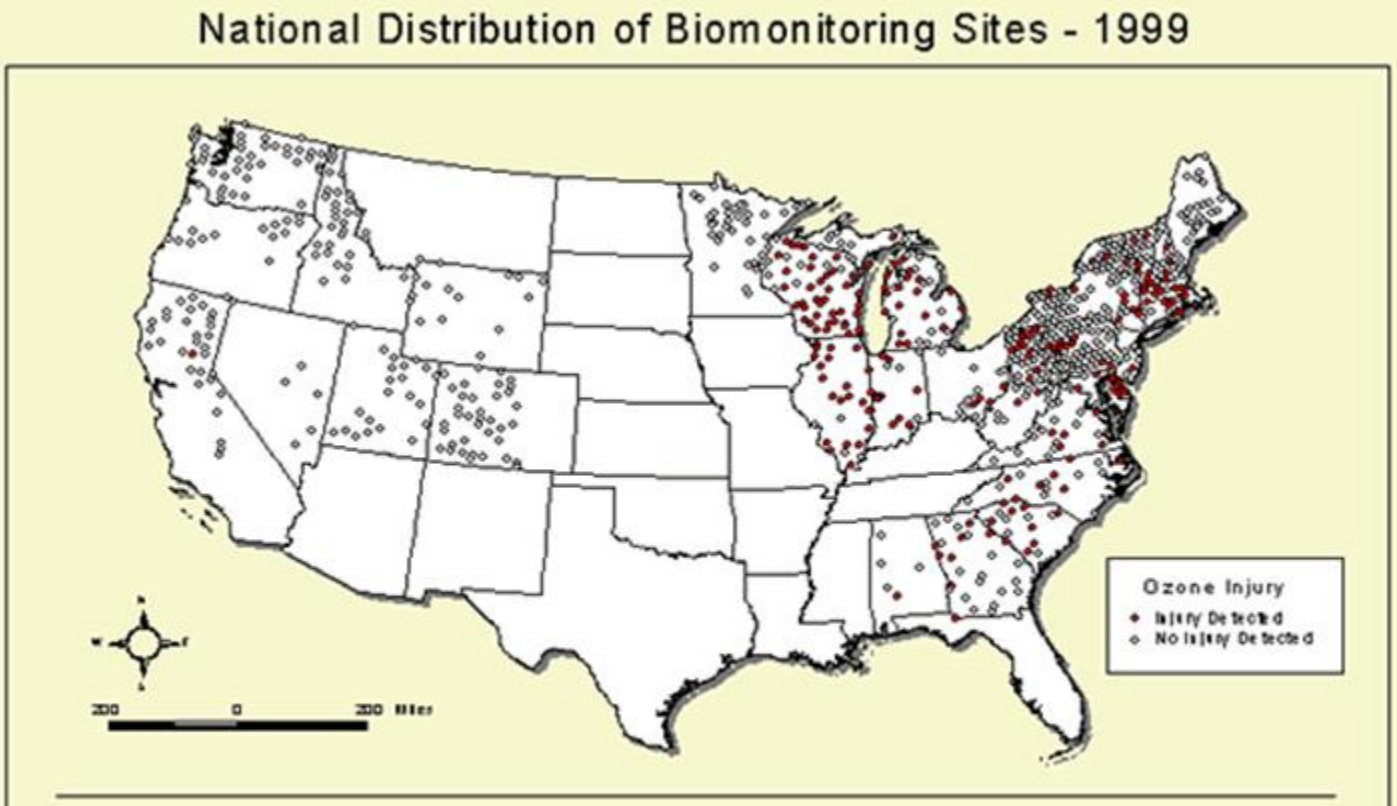
Ozone Damage to Crops



- Field research to measure effects of seasonal exposure to ozone on crop yield has been in progress for 36 years at USDA.
- Current 8 hour ozone standard is 80 PPB.

- http://www.ars.usda.gov/Main/docs.htm?docid=8453

Ozone Damages Forest Ecosystems, Trees, Ornamental Plants, and Crops



The national distribution of ozone biomonitoring sites in 1999. Red symbols indicate where ozone-induced foliar injury was detected on sensitive plants. Open symbols indicate no injury.

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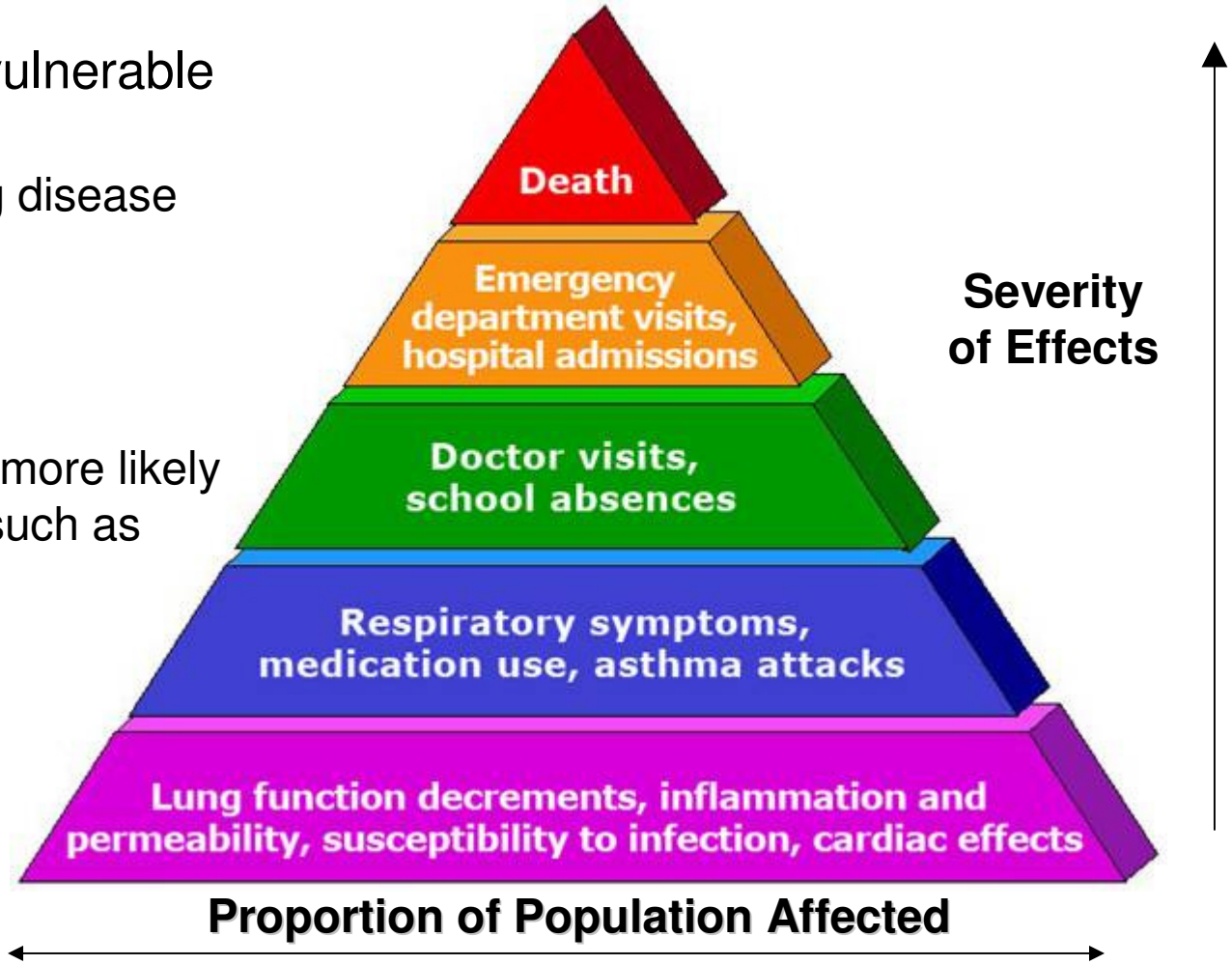
- Source: USDA Forest Health Monitoring Program
- Ground-level ozone is absorbed by the leaves of plants, where it can:
- Interfere with the ability of sensitive plants to produce and store food. This can lead to reduced growth, biomass production and/or yields.
- Make sensitive plants more susceptible to certain diseases, insects, other pollutants, competition and harsh weather.
- Reduce or change species diversity.
- Visibly injure the leaves of plants, harming the appearance of vegetation in national parks, recreation areas and cities.

Ozone Health Impacts: "Pyramid of Effects"

- Susceptible and vulnerable groups include:
  - People with lung disease such as asthma
  - Children
  - Older adults
  - People who are more likely to be exposed, such as outdoor workers



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Chicago Visibility

Chicago, < 10 ug/m^3 $PM_{2.5}$, 8/16/00

Chicago, 35 ug/m^3 $PM_{2.5}$, 8/26/00

In addition to health effects, ambient levels of fine particles cause visibility impairments of our cities and national parks. The picture on the right of Chicago is at the current standard of 35 micrograms per cubic meter.

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Health Effects of Particle Pollution

- Many scientific studies have linked breathing particle pollution to a series of significant health problems, including:
  - Aggravated asthma
  - Increases in respiratory symptoms like coughing and difficult or painful breathing
  - Chronic bronchitis
  - Decreased lung function
  - Premature death in people with heart and lung disease

Ammonia and NOx form one type of fine particle called ammonium nitrate. These particles travel deep into the lungs and can cause serious health effects.

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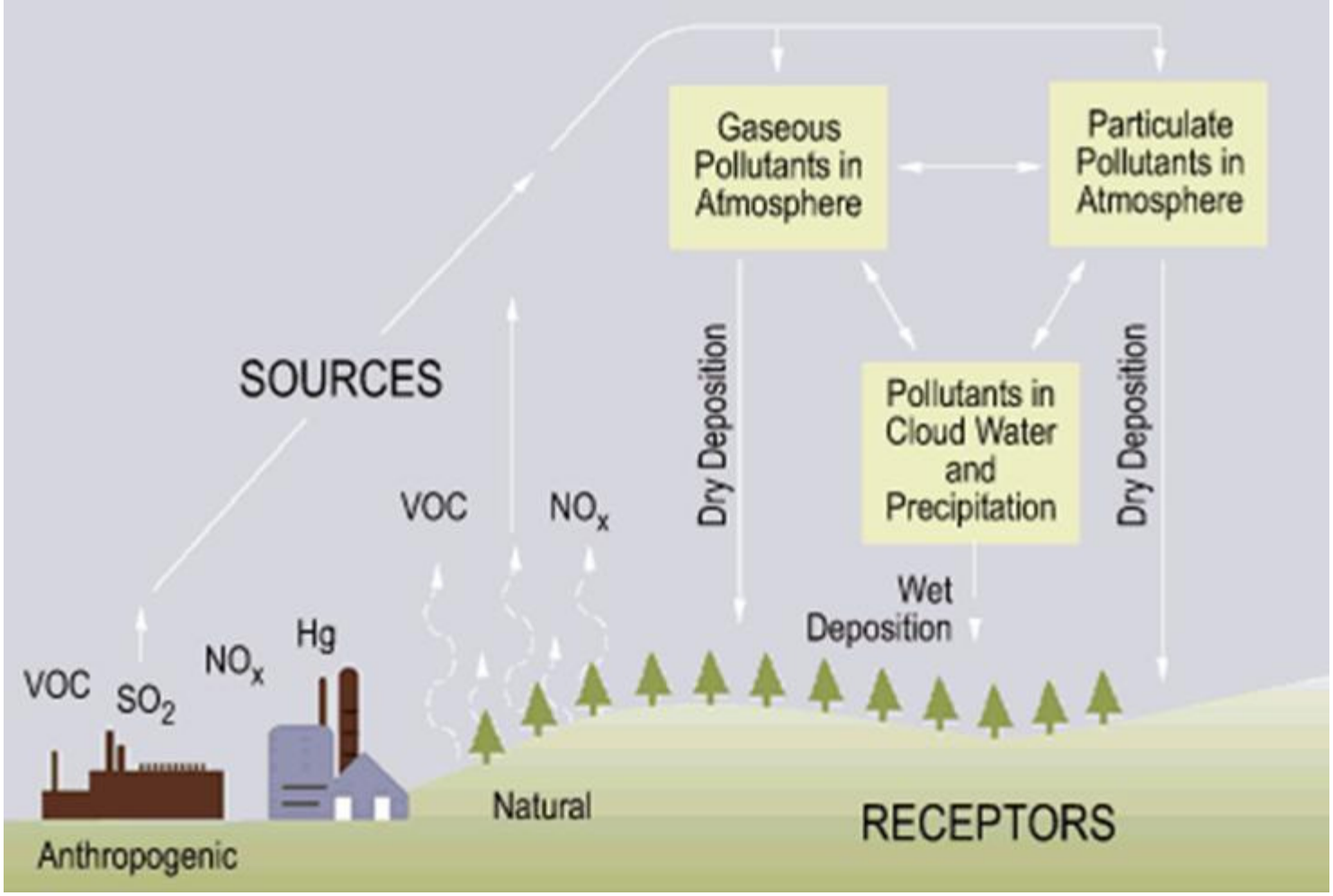
Wet and Dry N Deposition Loading



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The previous graphic does not include ammonia emissions which are also important.

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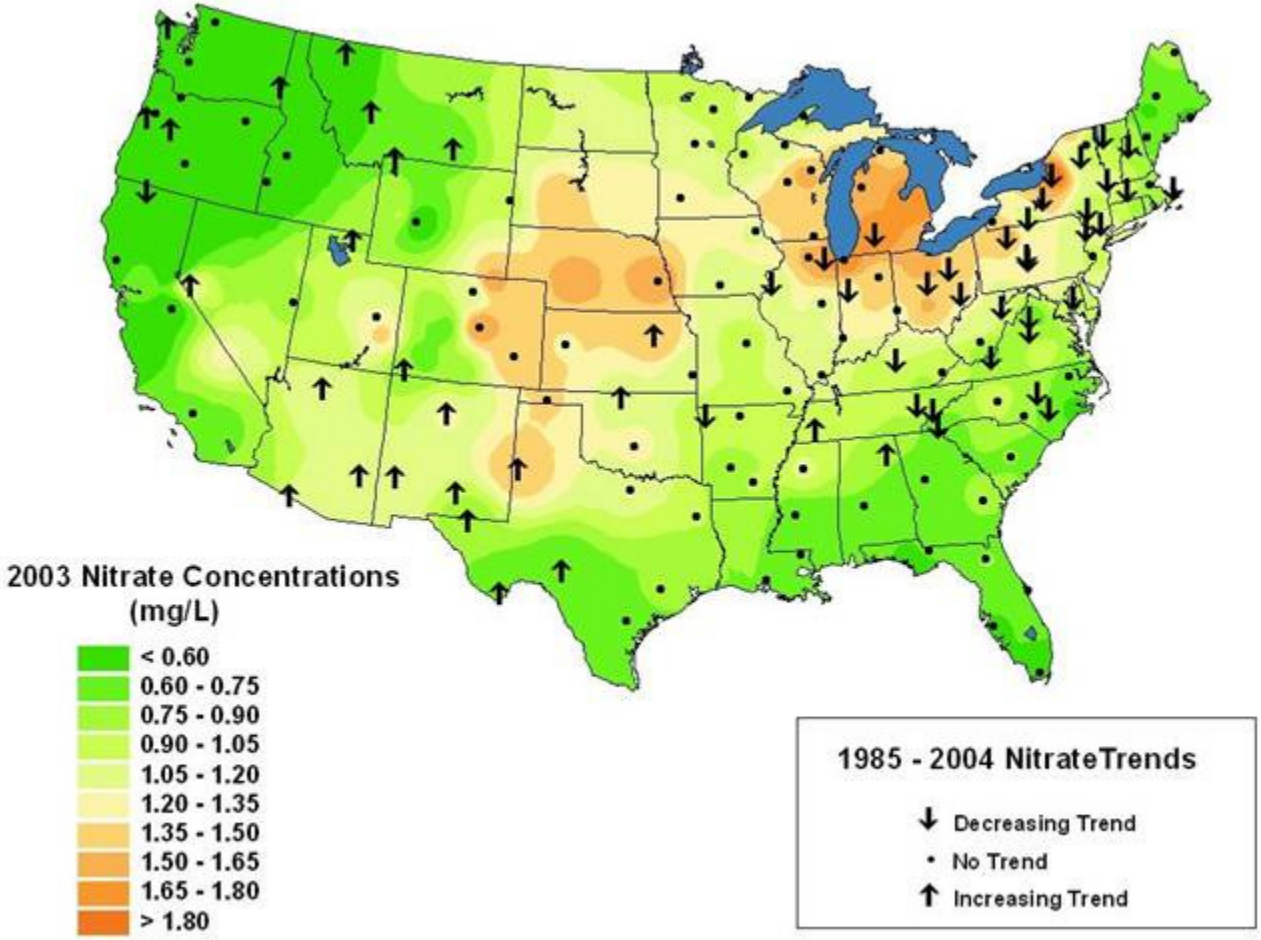
Nitrate Precipitation Declining in East and Increasing in West



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Due to NOx controls in the east, nitrate deposition has been decreasing; however, we are seeing increases in the west, which may be affecting nitrogen sensitive ecosystems

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Terrestrial Effects: Agricultural Ecosystems

- Haber-Bosch has facilitated agricultural intensification.
- 40% of world's population is alive because of it.
- An additional 3 billion people by 2050 will be sustained by it.
- Most N that enters agroecosystems is released to the environment.
- Picture source: NRCS/USDA photogallery

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Agriculture: A significant source

- Reactive N released from
  - Heavy use of N fertilizer,
  - planting of high yield crop varieties,
  - and increasing planting of corn.
- Curtailing or even eliminating fertilizer N use may not necessarily eliminate release of reactive nitrogen into the environment.
- Major source of nitrous oxide.
- Growing global demand for fertilizer
  - 92 MMT/yr in 2007, increasing at 1% per year (FAO)

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It is essential to add additional reactive N to the soil beyond what is provided naturally from lightening or nitrogen fixing legumes (soybeans) in order to maintain the high yields of current crop hybrids. Without N fertilizer or heavy applications of manure or compost, soils will be mined for their nitrogen (as they were until the modern era of chemical fertilizers).

Agricultural Soils

- Reservoir and also a long-term sink for reactive nitrogen.
- Soil management determines if soils add to the reactive nitrogen problem or help solve it.
- In the US, some of the reactive nitrogen not taken up by crops is immobilized in soil.
  - Depends upon location and soil type
- Highly organic soils (muck or peat soils) are source of reactive nitrogen into the environment.

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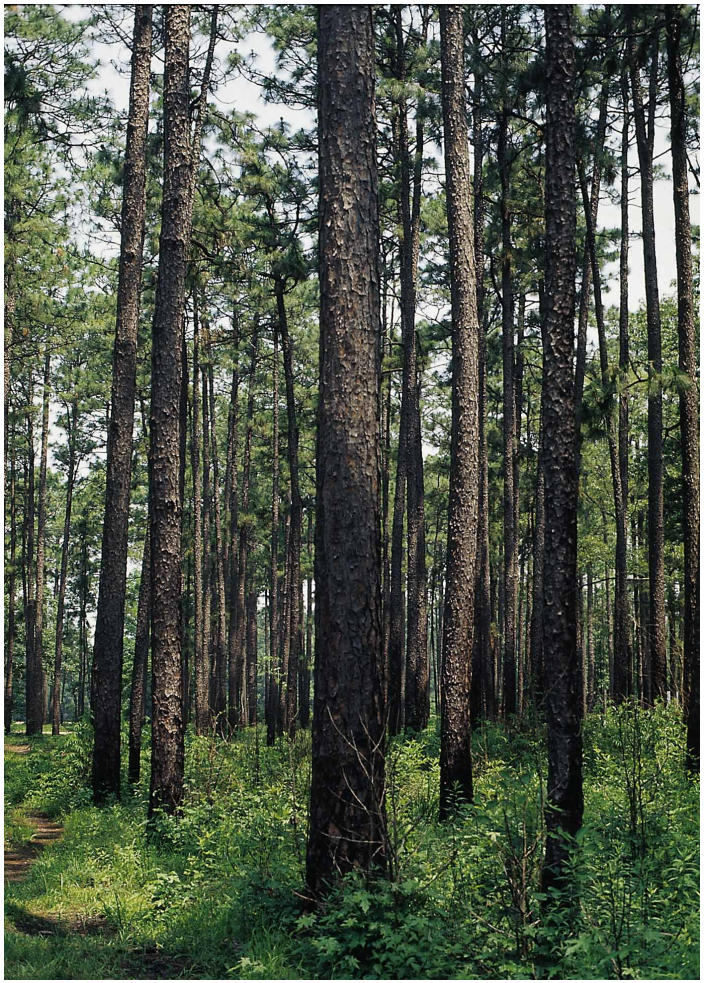
Forest and Grassland Ecosystems



- N is the **limiting nutrient** in most temperate and arctic ecosystems.
- Nr deposition increases and then **decreases** forest and grassland **productivity**.
- Nr additions probably **decrease biodiversity** across the entire range of deposition.
- Picture source: NRCS/USDA photogallery

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Changes in Ecosystem Processes

- Species alterations
  - Dominant species changes to competitive advantages
  - Invasive opportunistic species
- Nitrogen saturation and acidification
  - Soil mineral depletion
  - Toxic metal leaching
- Changing fire regimes
  - Nitrogen can increase pine needles
  - Ozone can cause more needle dropping

- New research collaborations between EPA and the Forest Service, including GIS layering of emissions, deposition, invasive species damage.

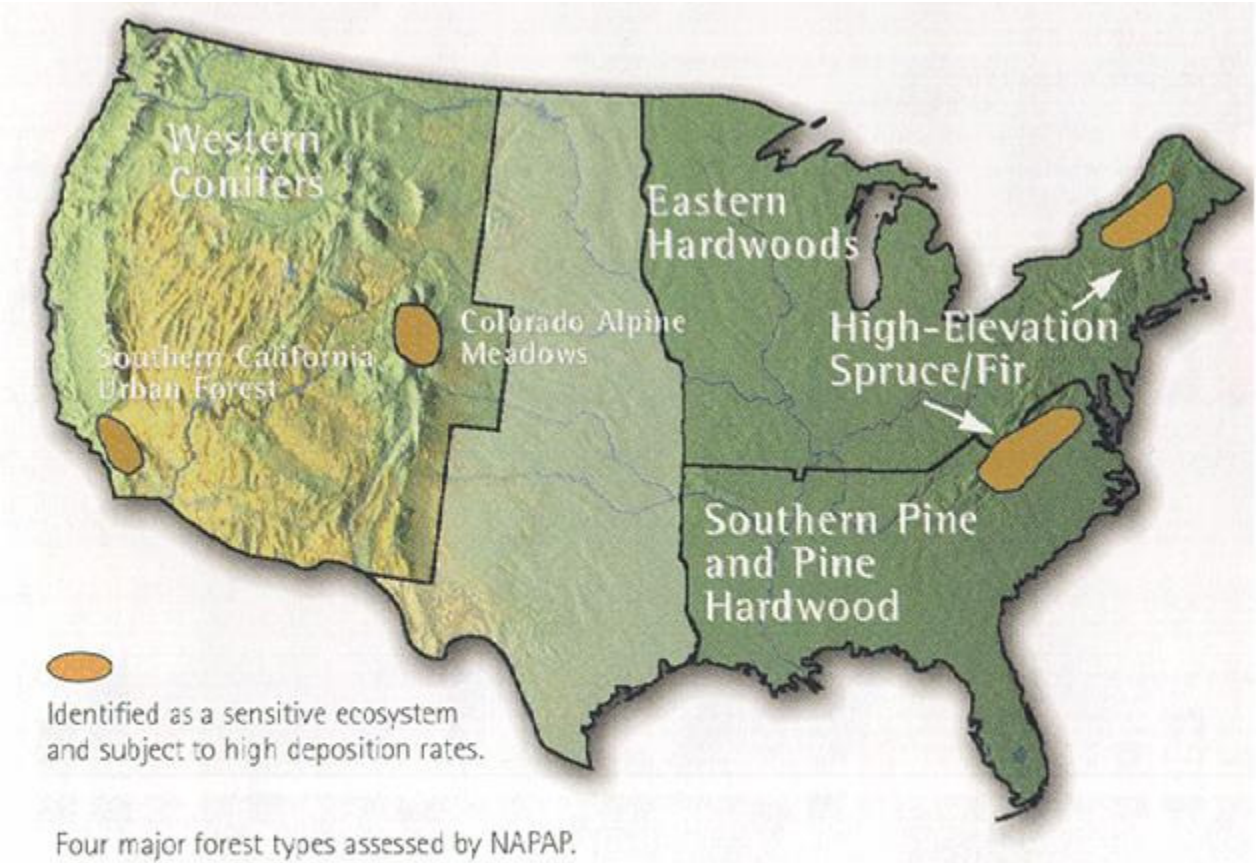
- See also

  – http://www.fort.usgs.gov/resources/spotlight/EcoForecasting/EF_projects.asp -cheatgrass picture in West (invasive)

  – **science.howstuffworks.com/acid-rain1.htm** - forest pic

  – http://www.ces.ncsu.edu/depts/pp/notes/Ornamental/odin19/od19.htm – ozone damage to pines

Forests Affected by Acid Deposition



Four major forest types assessed by NAPAP.

Source: NAPAP. 1996. *NAPAP Biennial Report to Congress: An Integrated Assessment*, National Science and Technology Council Committee on Environment and Natural Resources.

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Effects of Acid Rain - Forests

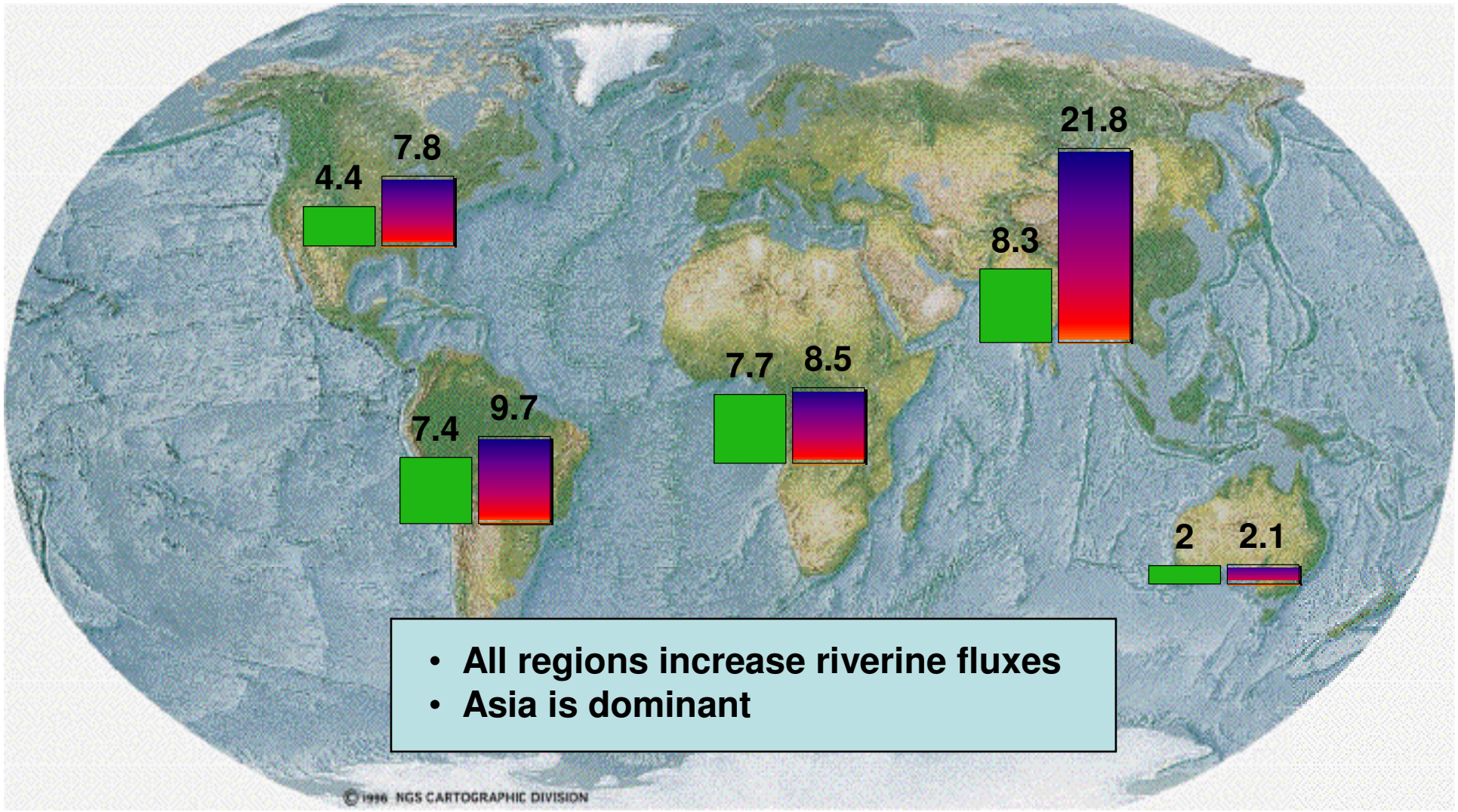
Source: http://www.epa.gov/acidrain/effects/forests.html

- slowed growth of some forests.
- Leaves and needles turn brown and fall off when they should be green and healthy. In extreme cases, individual trees or entire areas of the forest simply die off without an obvious reason.
- -Places in the mountainous northeast, like New York's Adirondack and Catskill Mountains, have thin soils with low buffering capacity.
- -Acid rain weakens trees by damaging their leaves, limiting the nutrients available to them, or exposing them to toxic substances slowly released from the soil.
- Scientists know that acidic water dissolves the nutrients and helpful minerals in the soil and then washes them away before trees and other plants can use them to grow. At the same time, acid rain causes the release of substances that are toxic to trees and plants, such as aluminum, into the soil.
- Forests in high mountain regions often are exposed to greater amounts of acid than other forests because they tend to be surrounded by acidic clouds and fog that are more acidic than rainfall. Scientists believe that when leaves are frequently bathed in this acid fog, essential nutrients in their leaves and needles are stripped away. This loss of nutrients in their foliage makes trees more susceptible to damage by other environmental factors, particularly cold winter weather.

Aquatic Ecosystem Effects

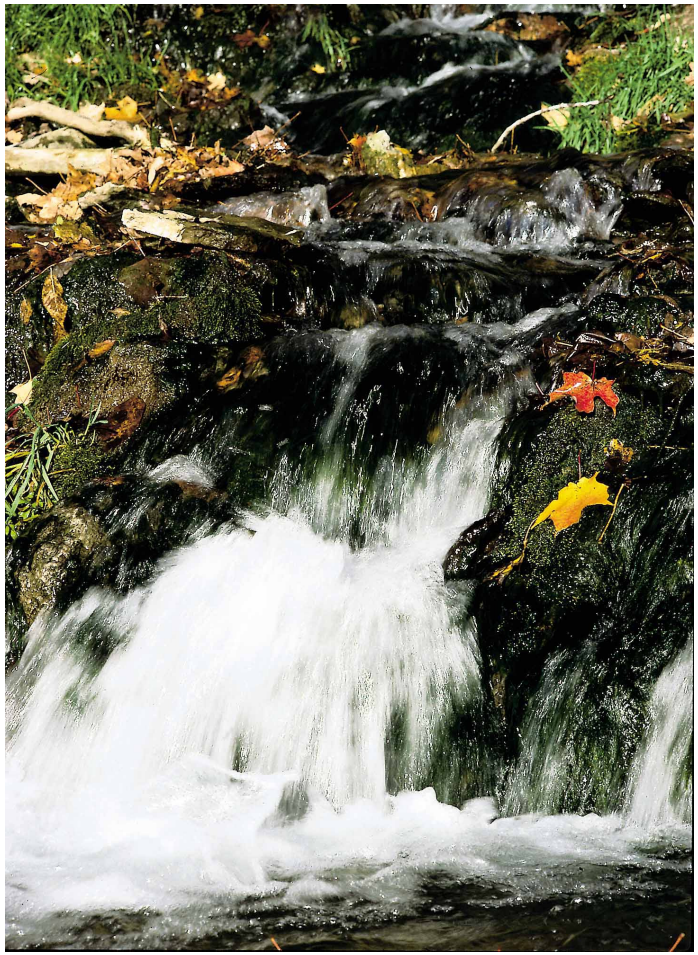
- Species alterations
- Acidification
- Ammonia toxicity
- Groundwater contamination
- Eutrophication
  - Algal blooms
  - Fish kills
  - Low dissolved oxygen
  - Toxic algal species blooms
  - Changes to food webs in estuaries

Nr Riverine Fluxes (Tg N/yr) 1860 (left) and 1990 (right)



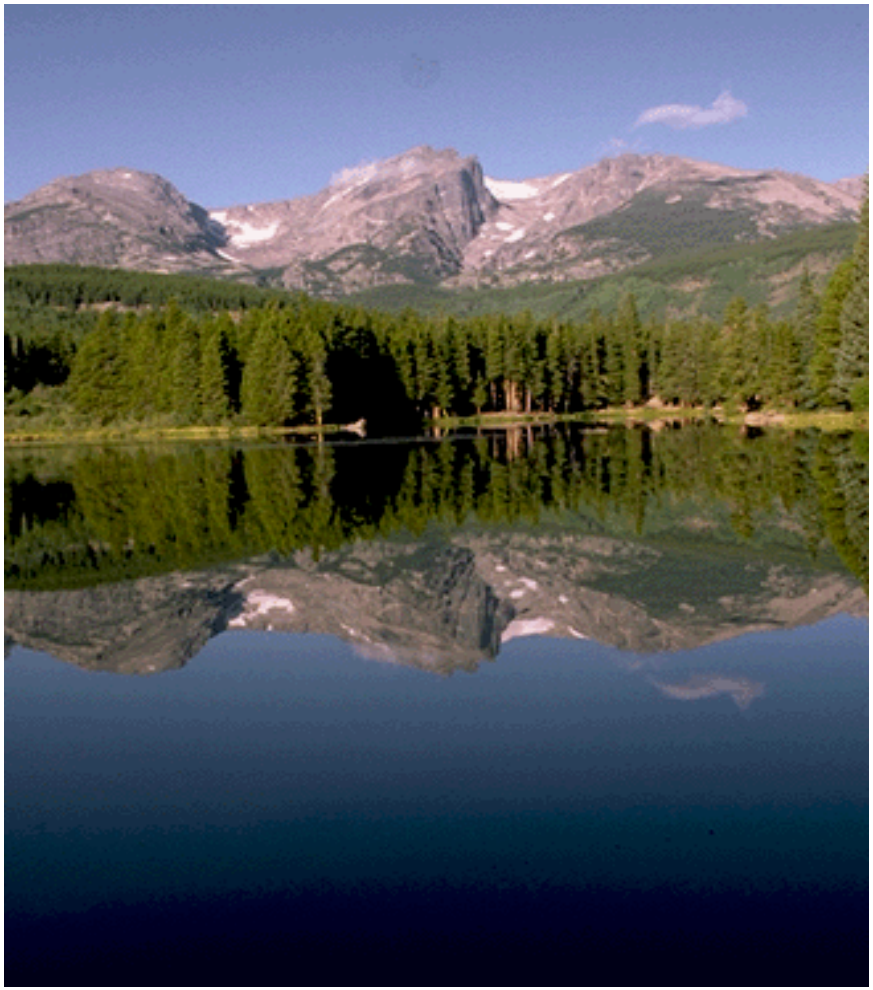
- All regions increase riverine fluxes
- Asia is dominant

Acidification in Freshwater Ecosystems



- Tens of thousands of lakes and streams
- Significant biodiversity losses
- Negative feedbacks to forested ecosystems
- Picture source: NRCS/USDA photogallery

Effects on High Mountain Lakes



- One long term study of high alpine lakes in the Colorado Rockies showed increased lake algal growth over time due to N deposition.
- Similar trends seen in Rocky Mountain National Park.
- 70% of Colorado lakes are sensitive to acidification.
- 15% are extremely sensitive to acidification.
- Photo: National Park Service, http://www.nps.gov/romo/index.htm (from their photo gallery page/lakes)

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- Study source:
- http://www.colorado.edu/news/releases/2002/279.html http://cat.inist.fr/?aModele=afficheN&cpsidt=16391920

- **Colorado Alpine Lakes Show Troubling Changes**
  May 28, 2002
- A high alpine lake in the Colorado Rockies is showing increased algal growth thought to be caused by atmospheric nitrogen deposition from auto emissions and agricultural activity on the heavily populated Front Range, including Denver.

  Diane McKnight of the University of Colorado at Boulder said the study showed that since about 1940, changes in Green Lake 4 associated with nitrogen enrichment and climatic changes have increased algal growth, the accumulation of organic sediment and shifts in the dominant algal species. McKnight and her associates have studied algal species distribution in water samples, a sediment trap and a small sediment core in the lake on a weekly to biweekly summer basis since 1998.

  "Over the past 20 years, nitrogen deposition has increased in the Green Lakes Valley watershed and the lake ice cover has become progressively thinner," said McKnight, a fellow at CU's Institute for Arctic and Alpine Research. The five lakes in Green Lakes Valley - including Green Lake 4 at 11,500 feet, account for about 40 percent of Boulder's water supply.

  "The city of Boulder owns the watershed and makes a substantial effort to protect the water quality of the lakes, including a ban on hikers," she said. "But there are no means for the city to protect the watershed from atmospheric inputs that can cause increased algal growth and potentially have some influence on water quality."

  Similar trends have been observed in alpine lakes in Rocky Mountain National Park about 20 miles to the north, McKnight said. The Green Lakes study is part of the National Science Foundation's Long-Term Ecological Research effort, which administers about 20 sites in North American ecosystems where researchers document ecological and climate changes over decades and centuries.

  McKnight gave a paper on the subject at the Spring American Geophysical Union Meeting held in Washington, D.C., May 28 to May 31. Co-authors included CU graduate student Summer Waters, CU undergraduates Sean Sundermann and Meghann O'Brien, Alex Wolfe of the University of Alberta in Edmonton and Rolf Vinebrook of the University of Regina in Saskatchewan.

  According to McKnight, the ice has become about 12 inches to 14 inches thinner in late March since 1982, possibly due to warming winter temperatures or more accumulation of snow on the frozen lake, insulating the ice.

  One species of diatom -- algae that have microscopic shells made of silica -- has grown faster under higher nitrogen conditions and become more abundant in the lake than other diatom species in the past 60 years, she said. The increased algae growth causes more algal pigments like chlorophyll and fucoxanthin, as well as organic carbon from algae, to accumulate in the lake sediments.

  "In addition to light, algae need two main nutrients, nitrogen and phosphorus, to grow," she said. "We think the nitrogen deposition in Green Lake 4 stimulated the growth of algae on the lake bottom because there is a supply of phosphorus from the lake sediments."

  On a regional scale, there are now proposed levels of maximum nitrogen deposition that may become part of air quality regulations, said McKnight. "These levels have been determined based on avoiding acidification of the water by nitrate in spring snowmelt."

  The results of the study indicate that more algal growth in the lake can occur at lower nitrogen levels than those that could cause acidification, she said. They also suggest lower standards than those proposed may be needed to protect water quality in alpine lakes on the Front Range, many of which are sources of water for Front Range communities in Colorado.

  Undergraduates O'Brien and Sundermann were supported by CU-Boulder's Undergraduate Research Opportunities Program, which allows undergraduates to receive stipends to work with faculty on research projects. They also were supported by the NSF's Research Experience for Undergraduates program.

http://cat.inist.fr/?aModele=afficheN&cpsidt=16391920

- High elevation alpine and subalpine Rocky Mountain lakes in Colorado and south-eastern Wyoming were examined to determine regional variability in water chemistry and their sensitivity to atmospheric deposition. Acid neutralizing capacity, pH, conductivity and concentrations of major anions and cations were compared. Regional differences in water chemistry are evident. The south-eastern most lakes have significantly higher pH, conductivity, ANC, and sums of acid and base concentrations than lakes in the other regions of the state. In contrast the north-western most lakes are significantly more dilute than those from other regions. Despite these two regional differences, most regions are similar in having a wide range of variability in potential sensitivity of their lakes to acidification and nitrogen export. Many wilderness areas in western and eastern regions contains lakes that are extremely sensitive and other lakes not susceptible to deposition. Overall, 70% of the Colorado lakes are sensitive to acidification and 15% are extremely sensitive to acidification. All of the regions had lakes that are classified as susceptible or sensitive to acidification, with 12 of the 17 areas having all of their sampled lakes susceptible or sensitive. Generally NO[3][1-] concentration in surface waters decreased from mid-season to late season; yet a large number of the lakes export NO[3][1-] late in the season, suggesting nitrogen saturation. The results confirm the sensitivity of high elevation wilderness aquatic ecosystems in all regions of Colorado to acidification and nitrogen deposition.

Health Effects via Groundwater

- Health Impacts of levels above standard of 10 ppm nitrate (10mg/L)
  - Methemoglobinemia in infants (short term exposure)
  - diuresis, increased starchy deposits and hemorrhaging of the spleen with high lifetime exposure
- Similar impacts from nitrate in surface water.

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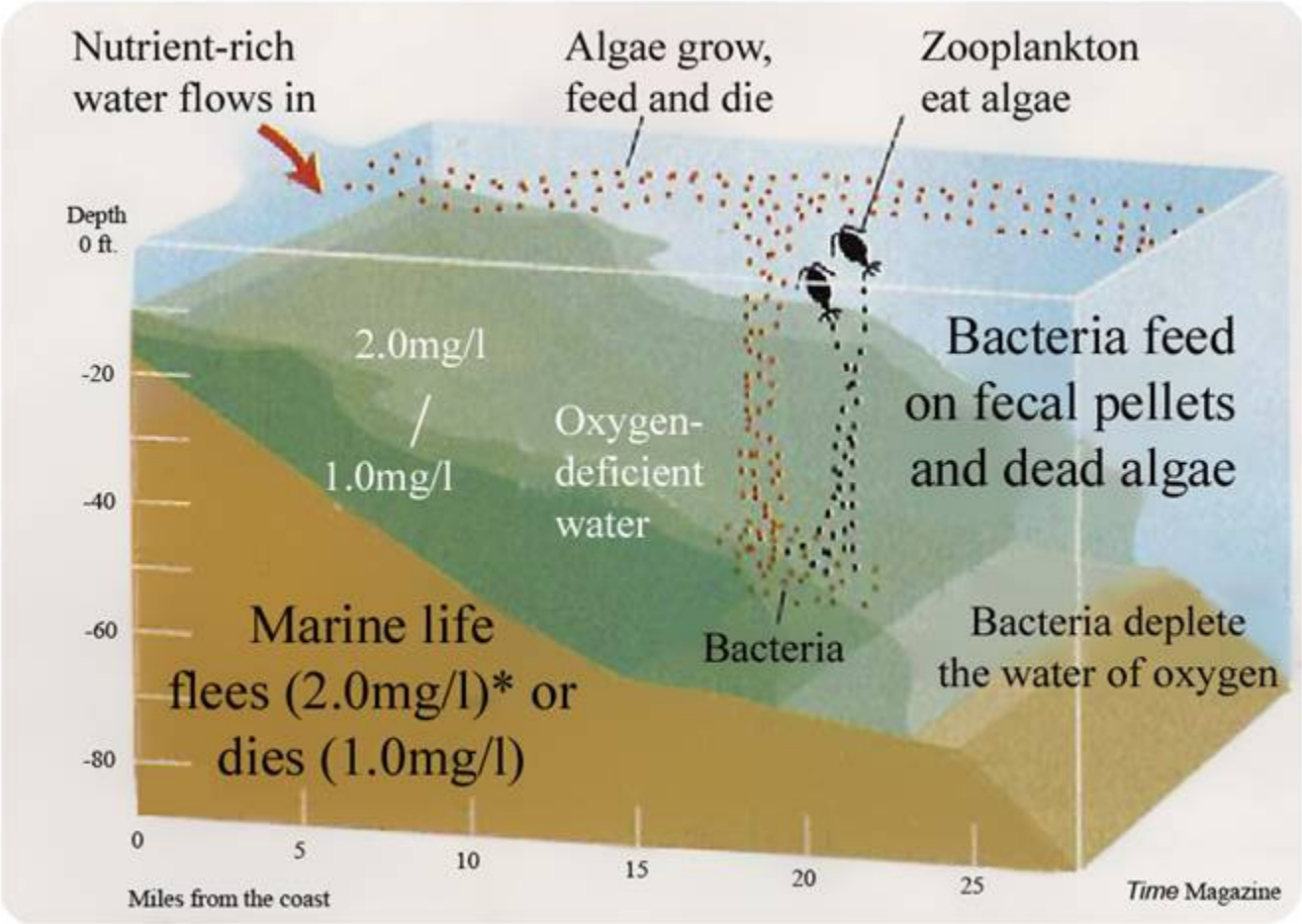
Coastal Ecosystem Effects

- Riverine and atmospheric deposition are significant Nr sources to coastal systems
- Nr inputs into coastal regions result in eutrophication, biodiversity losses, emissions of N_2O to the atmosphere.
- Most coastal regions are impacted.

The Eutrophication Process



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Nitrogen Deposition Impacts Coastal Ecosystems

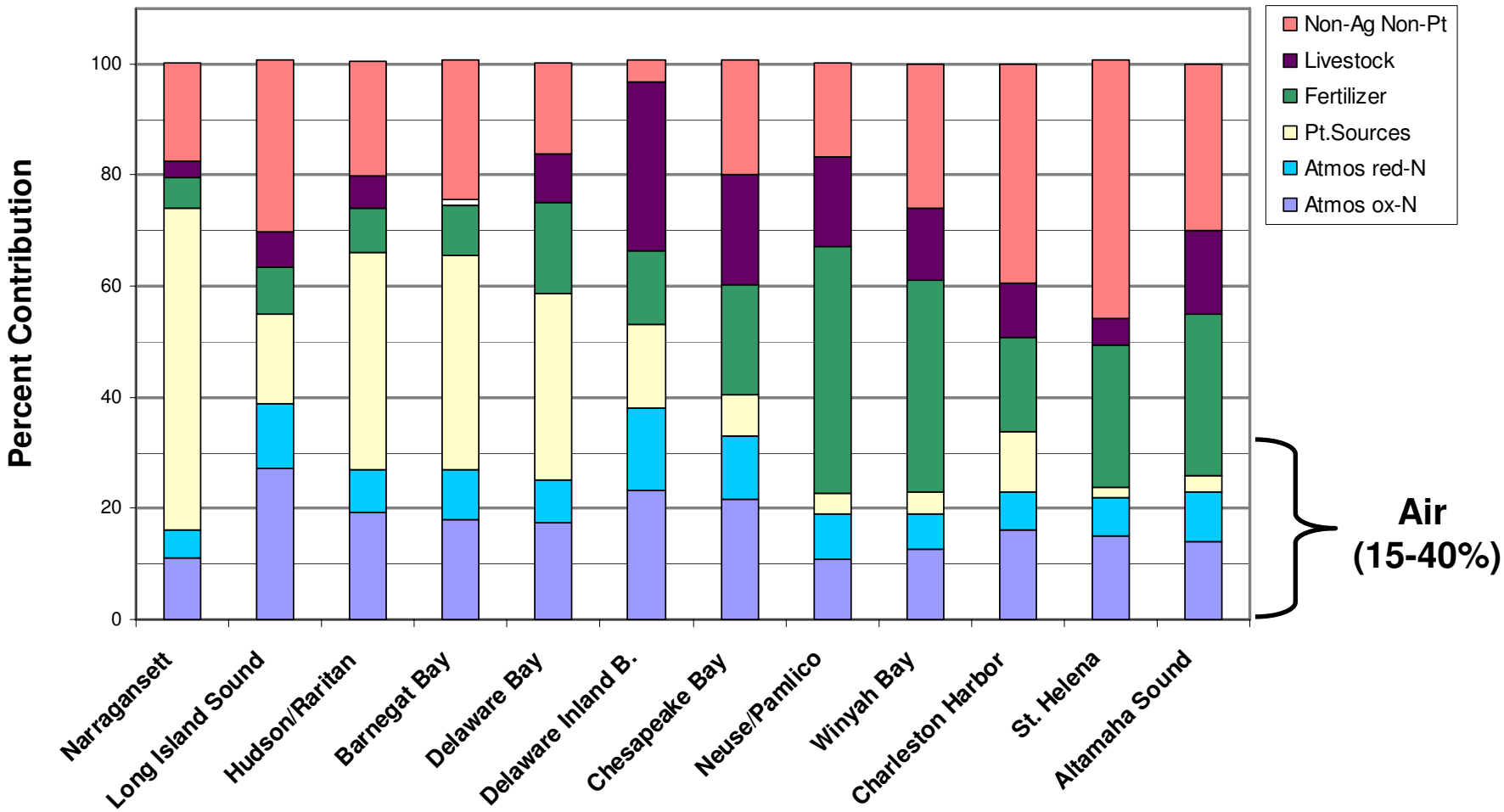
- 44 estuaries along all of the nation's coasts are highly eutrophic
- Estuaries in the Mid-Atlantic and Gulf of Mexico are particularly sensitive
- An additional 40 estuaries (not shown) have moderate levels of eutrophic conditions

Estuaries with Highly Eutrophic Conditions

- **Source: NOAA, National Estuarine Eutrophication Assessment 1999**

- Note: Conditions are not necessarily related in whole to human-related eutrophication; to various degrees natural causes and other human disturbances may also play a role. For instance, some estuaries in Maine are typified by natural occurrences of toxic algae, which drift in from the open ocean. Once in the estuary, however, these blooms may be sustained by human nutrient inputs.

Nitrogen Loading to Estuaries by Source Type



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Atmospheric deposition of N to coastal ocean is approximately equal to riverine input for mid-Atlantic & New England

Eutrophication and Algal Blooms

- Algal blooms: Blue-green (cyanobacteria), dinoflagell ates, and macroalgae
  - toxic to estuarine and marine mammals
  - losses to shellfish industry, aquaculture, recreational fishing and tourism industries
- Potential human health risks

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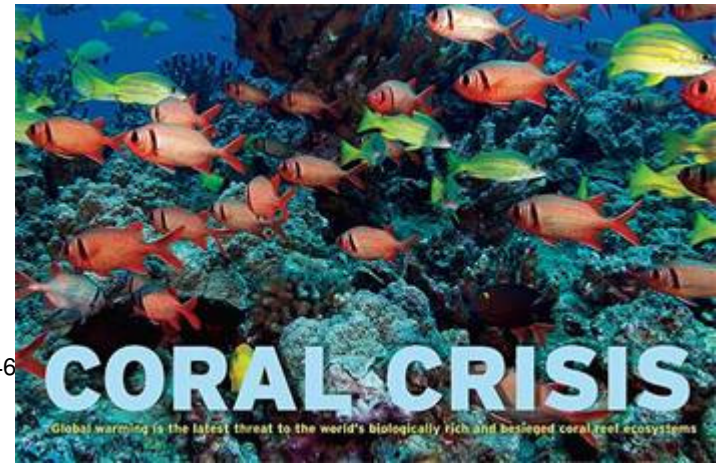
Changing Ocean pH Levels

- New research suggests N and S in atmosphere may be driving down pH more than expected in coastal waters.
- Potential impacts: dying coral reefs.
- Hardest hit are areas close to pollution source.



3 sept 2007, Nature, Heidi Ledford, author "Acid rain may hit coastal waters hard".
Picture from:http://www.nwf.org/nationalwildlife/printerFriendly.cfm?issueID=115&articleID=146

Linkages in the System

- There are significant effects of Nr accumulation within each reservoir.
- These effects are linked in the Nitrogen Cascade.

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Summary: Benefits of N

- Increased agricultural production worldwide
- Residential/urban landscape benefits (ornamental plants, residential gardens)
- Rebuilding of soil structure and productivity
- National defense (explosives)

Summary: Nitrogen's Negative Impacts

- **Human Health Effects**
  - Cancers, respiratory disease, toxic algae exposure
- **Effects on Aesthetics and Structures**
  - Reduced visibility, accelerated corrosion of buildings
- **Ecological Effects**
  - Acidification
  - Direct damage to vegetation
  - Eutrophication
  - Loss of biodiversity
  - Contributor to global warming

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The Big Picture

- Food and energy production results in creation of ~160 Tg of new Nr, most of which is released to the environment.
- We **know** where some of it goes and we generally know what it does when it gets there.
- We **do not know**:
  - *How much is stored in ecosystems vs. how much is incomplete denitrification leading to additional N_2O emissions (greenhouse gas).*
  - *How to feed and fuel the global population without exacerbating N pollution.*

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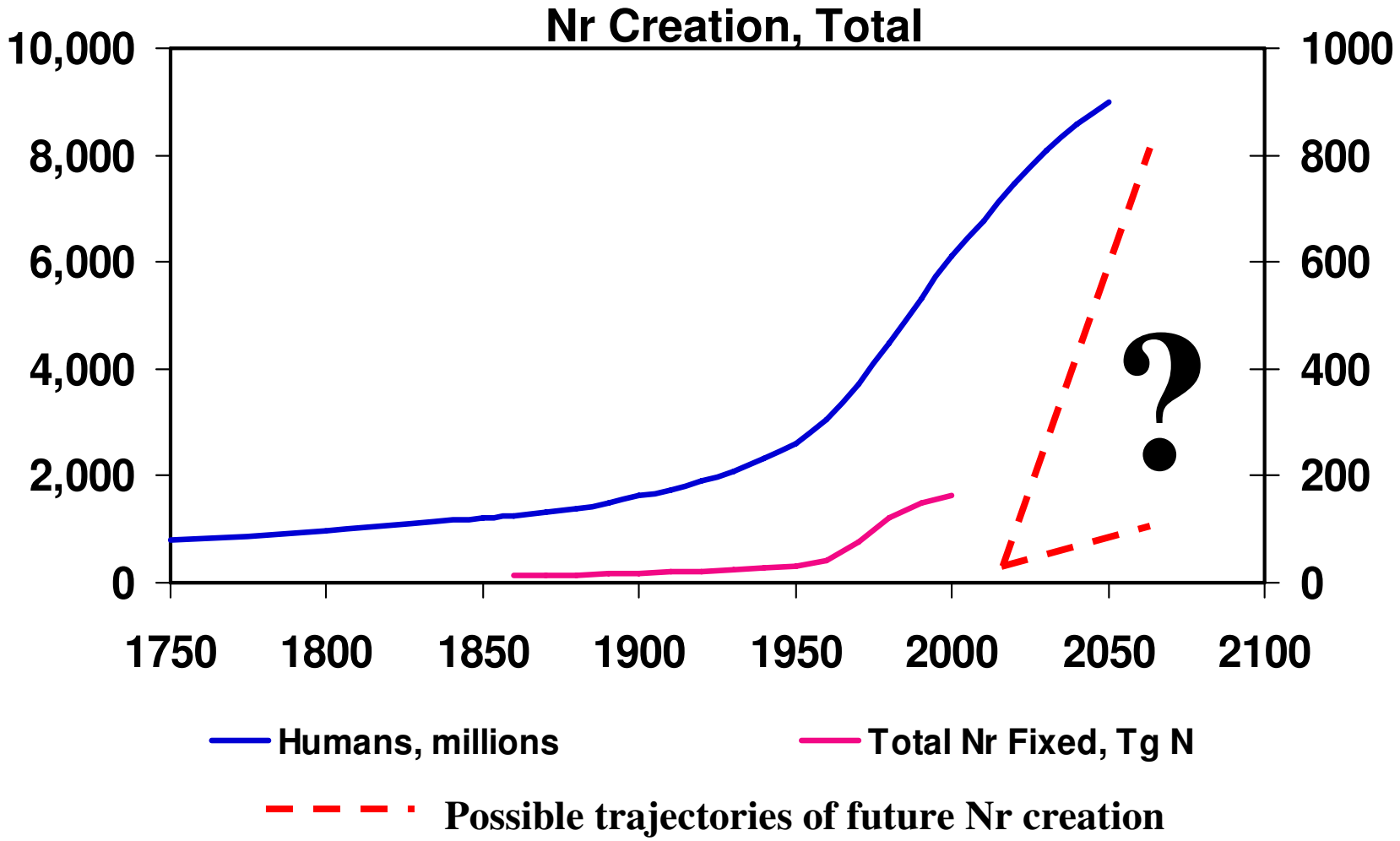
The Future of Nitrogen



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after Galloway and Cowling, 2002

Research Needs

- Understanding total benefits and costs of N pollution
  - Quantifying amounts of N from various sources
  - Increased and more frequent monitoring of loadings
  - Exposure information and tools to assess impairment
  - Quantifying effects on ecosystem services

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Take Home Points

- N releases have impacts on air, land, and water.
- Effects are diverse and interconnected.
- World population and economic growth will likely increase N impacts.
- Have to see this problem as A SYSTEM.
- Additional research will improve our understanding of the N Cascade.

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Acknowledgments

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