Eutrophication:
Reversible Problem or One-way Trip?

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Millennium Ecosystem Assessment
http://www.MAweb.org

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RESILIENCE ALLIANCE
http://www.resalliance.org

Main Points

1. Eutrophication is a global problem.

2. Eutrophication is an environmental trap.

3. Escaping the trap requires new approaches.

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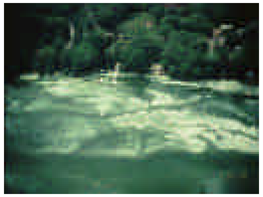
Eutrophication

Consequences:

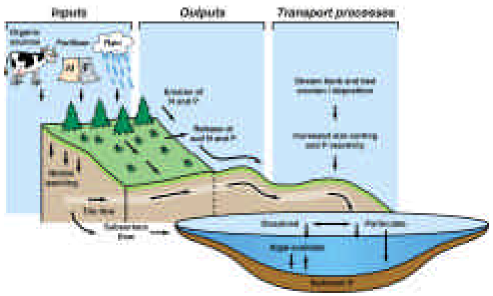
Blooms of noxious (often toxic) algae
Anoxic events
Fish kills
Susceptibility to invasion
Increased costs of water treatment for human use
Loss of ecosystem services of freshwater



Eutrophication

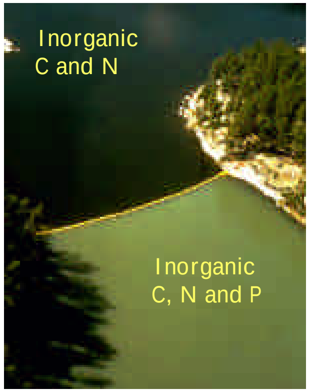
Key Factors:

Inputs and recycling of phosphorus
Inputs of other nutrients such as nitrogen
Food-web change



Role of Phosphorus

Experimental Impact



source: ELA

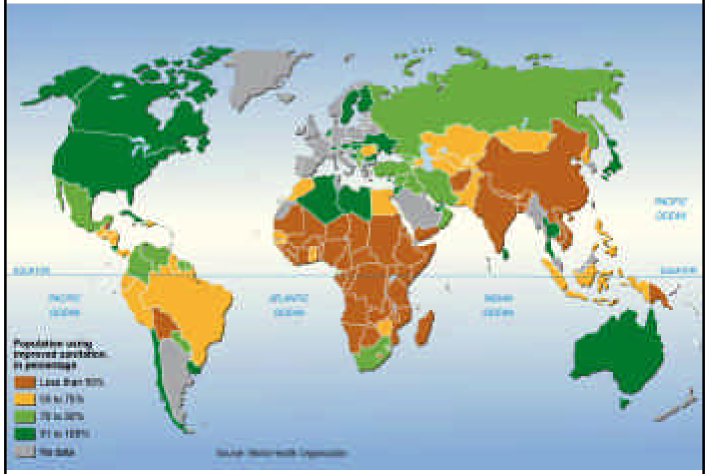
Ecosystem Memory

*slow cycle (turnover time in soil and sediment is centuries or more)

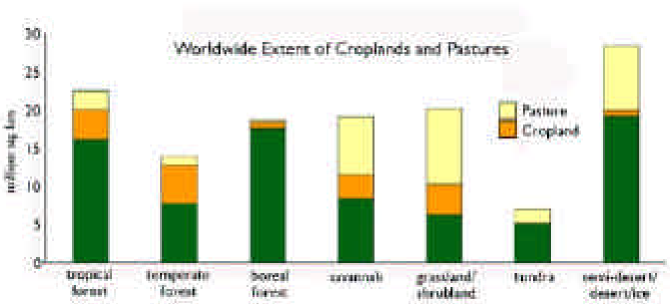
*low mobility on landscapes

*P sets long-term trends, other factors affect fluctuations around those trends

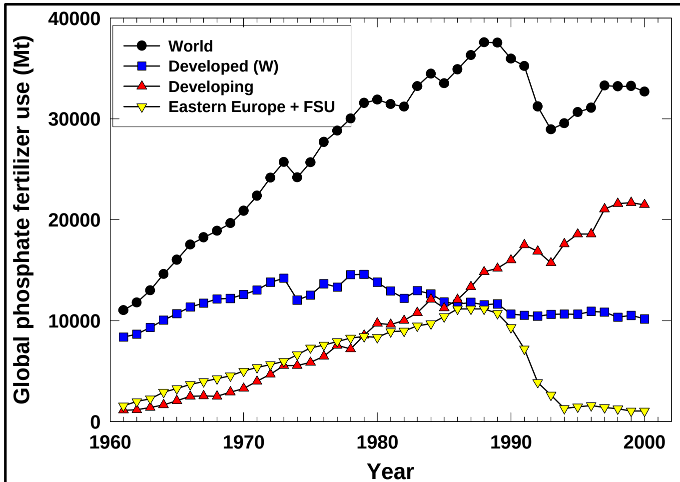
Global Access to Sanitation



Source: World Health Organization & Millennium Ecosystem Assessment (http://www.MAweb.org)



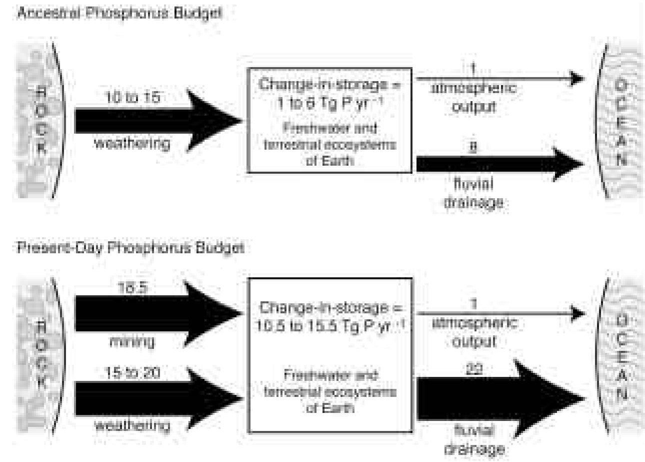
Foley et al., 2005, Science 309: 570-574.

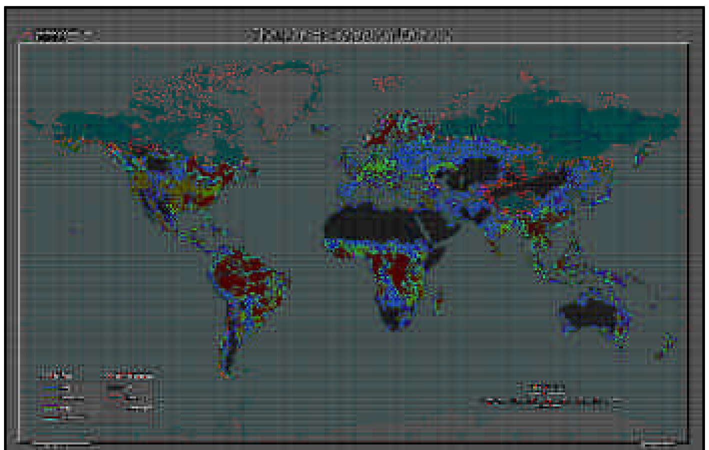


Millennium Ecosystem Assessment, http://www.MAweb.org

Changes in Earth's Phosphorus Budget

Bennett, Carpenter & Caraco, 2001, BioScience 51: 227-234





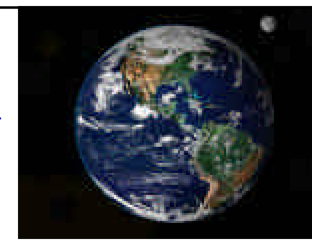
Source: USDA

The Global Picture:

About a third of people lack access to adequate fresh water

About a quarter of people are impoverished

Population will grow 40% - 60% by 2050. Demand for water and food will rise even more, if poverty is reduced.



Millennium Ecosystem Assessment
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Increases in agricultural production often cause decreases in water supply, water quality, and other aquatic resources.

How will food vs. water conflicts be resolved?

Main Points

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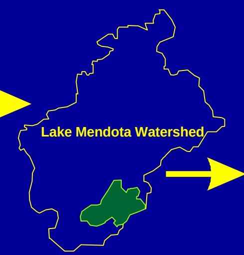
WATERSHED PHOSPHORUS BUDGET

P inputs

- Fertilizer for agricultural crops, including:
  - corn
  - soybeans
  - wheat
  - oats
  - peas and beans
  - barley
- Feed supplements for dairy cattle
- Fertilizer for urban lawn
- Dry and wet deposition

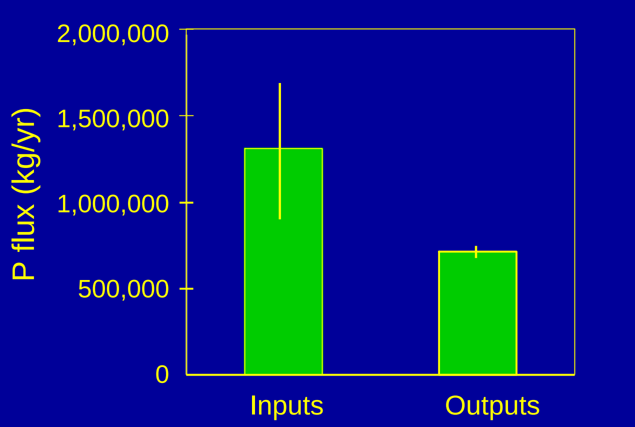


P outputs

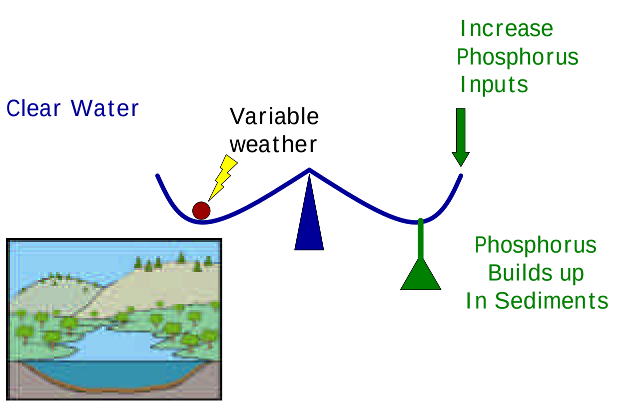
- Crops harvested, including:
  - corn
  - soybeans
  - wheat
  - oats
  - peas and beans
  - barley
  - forage
- Animal products, including:
  - cattle
  - hogs/pigs
  - milk and dairy
  - eggs
- Hydrologic exports to Lake Mendota

INPUTS - OUTPUTS = CHANGE IN STORAGE

Source: Bennett et al., 1998, *Ecosystems*

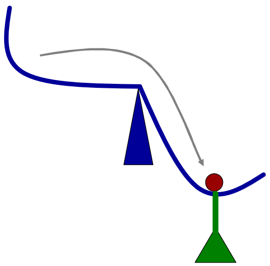


Source: Bennett et al., 1998, *Ecosystems*

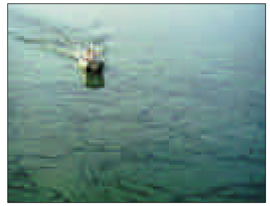


Source: Carpenter, Ludwig and Brock, *Ecological Applications* 9: 751-771

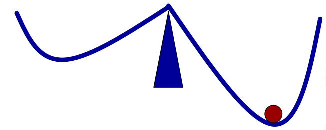
Buildup of Phosphorus in sediments, plus ongoing input, shifts the lake to the turbid state:



Turbid Water



Phosphorus buildup in soil and sediments stabilizes the turbid state



Analysis of P Thresholds in Lake Mendota
(Carpenter, Lathrop and others, in preparation)

*Goal: analyze P budget data for Lake Mendota to estimate thresholds and probabilities of crossing them

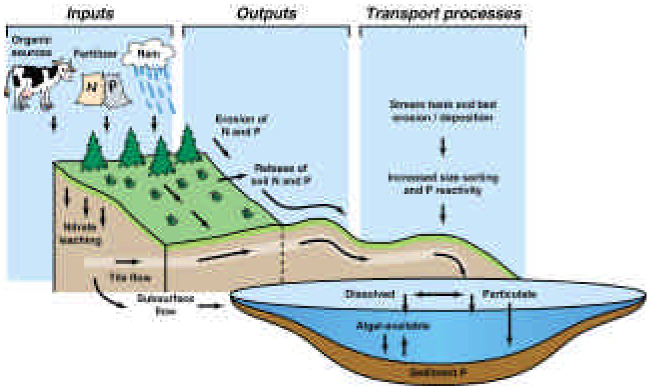
*Based (so far) on 1976-1996 data

*To be continued with data from 1997-present

Analysis of P Thresholds in Lake Mendota
(Carpenter, Lathrop and others, in preparation)

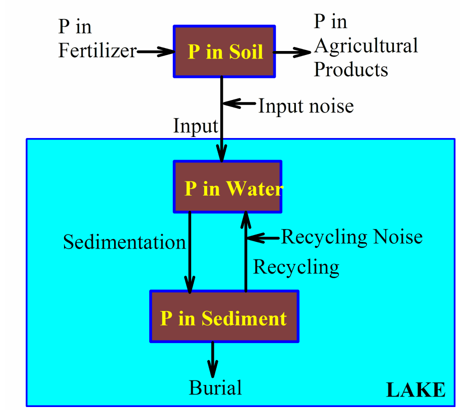
Expectations:	Outcome:
Lake Mendota has crossed the thresholds.	Lake Mendota has not crossed the thresholds, but the risk is high.
Water quality is as bad as it is going to get.	Water Quality could get worse, by 5X – 10X.
Management needs to cross the thresholds back to the clear-water condition.	Management needs to move the lake away from the thresholds.

Analysis of the full watershed and lake P cycle



Carpenter, 2005, PNAS 102: 10002-10005

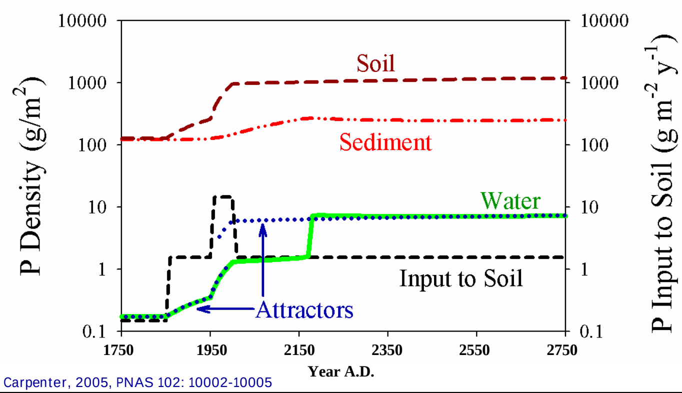
Watershed + Lake: Phosphorus Cycle



Carpenter, 2005, PNAS 102: 10002-10005

Mendota Scenario 1:

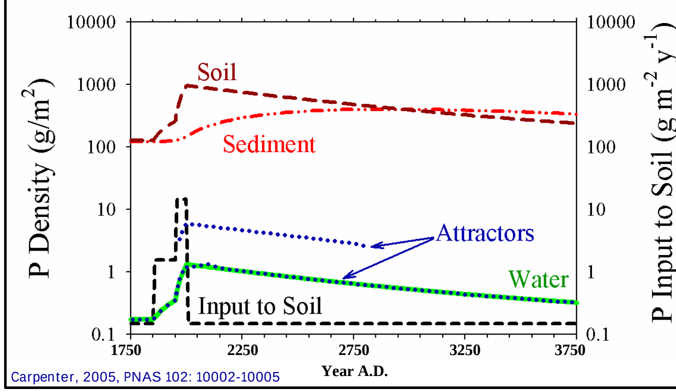
Balance the Watershed P Budget in year 2010 ⇨
Lake Switches to Permanent Eutrophy by year 2200



Carpenter, 2005, PNAS 102: 10002-10005

Mendota Scenario 2:

Return to Pre-Settlement P Input to Soil in Year 2010 ⇨
Gradual Recovery of Water Quality



Carpenter, 2005, PNAS 102: 10002-10005

Eutrophication is an Environmental Trap

Buildup of phosphorus in soils is gradual. It is not noticed until it is too late, and it is slow to reverse.

Buildup of phosphorus in sediments makes eutrophication more stable.

Policies and practices that got us into the problem will not get us out.

Action Items

- ✓Stop importing phosphorus into the watershed
- ✓Reduce high soil P levels as rapidly as possible
- ✓Immobilize P in soils and sediments
- ✓Stop manure release
- ✓Stop erosion
- ✓Maintain food web with high levels of game fish and grazers

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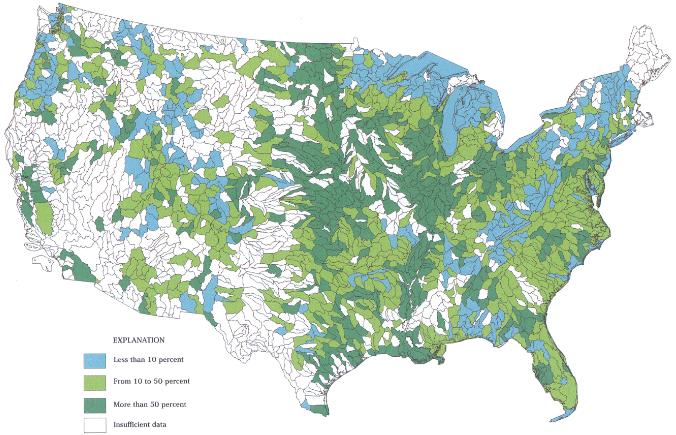


Figure 6. Percentage of total phosphorus concentrations that exceeded recommended limit of 0.1 milligram per liter, by hydrologic unit, 1990-95 [source of data: U.S. Environmental Protection Agency STORET data base].

Litke, DW, 1999, USGS Water Resource Investigations Report 99-4007

Uses of Surface Waters:

- Agriculture:
  - Irrigation
  - Pollution Dilution
  - Water for Livestock
- Carbon sequestration
- Industry:
  - Cooling
  - Industrial processes
  - Pollution Dilution
- Fish and Game Production
- Recreation
  - Boating
  - Fishing
  - Swimming
- Transportation
- Drinking water

Working Waters

Economic Valuations of Freshwater

Replacement cost, global, water only: 10% to 20% of global GDP

Benefit of achieving swimmable water quality for all US surface waters: $58B (1992 dollars)

Benefit of reducing P load to Lake Mendota by 50%: $52M (1998 dollars)

Benefit to housing market of increasing Secchi disk transparency by 1 foot: 7% increase in housing value

Source: Wilson and Carpenter, 1999, Ecological Applications 9: 772-783

What kinds of institutions work for ecosystem management?

Reactive Ecosystem Management

Maintain business as usual until there is a crisis.

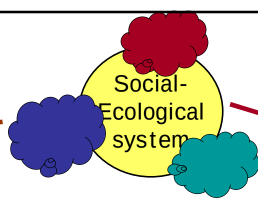
Address the crisis with quick fixes that meet short-term needs and placate the public. Do not address fundamental causes or long-term solutions.

Repeat as needed.

Proactive Ecosystem Management . . .

. . . is more varied; there is no simple recipe or even a single target.

Old Perception / New Perception



Old Perception

simple cause-effect

↓

Predictable
Controllable

↓

Focus on:
- Optimal plan
- Top-down central organization
- Technocratic solution
- Efficiency

New Perception

complex adaptive system

↓

Hard to predict
Control is limited

↓

Focus on:
- Learn by doing
- Distributed organization
- Knowledge diversity
- Assimilate change

What Does it Mean in Practice?

Key characteristics of regions that successfully manage ecosystems:

- Adaptive governance
- Networks
- Innovation
- Leadership

*From a global comparison of regions in transition by the Resilience Alliance (http://www.resalliance.org)

Principles of Adaptive Governance for Natural Resources:

Define the social-ecological system and the ecosystem services

Devise rules that fit local conditions and long-term goals

Involve all interested and informed parties in discussion of the rules

Use clear environmental accounting

Apply graduated sanctions for violations

Establish low-cost mechanisms for conflict resolution

Source: Dietz et al., 2003, *Science* 302: 1907-1912

Networks: effective networks

* connected key groups that affected, and were affected by, the resource

* brought in diverse forms of knowledge – scientific, traditional, experiences of local people

* provided arenas for open exploration of ideas outside of a formal decision-making process

* existed outside of government, but usually included government officials

Innovation:

Better monitoring: what is really changing? And how?

Faster response to emerging problems

Technological advances, for example better techniques to:

Immobilize soil or sediment phosphorus
Prevent erosion
Restore riparian ecosystems and wetlands

Market-based incentives for high-quality lakes

Leadership:

Key leaders were “embedded” -- they were locals

Effective leaders formed bridges among existing networks

Effective leaders promoted adaptive governance

Emergence of leadership was unpredictable but essential

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Limnophilia
Ecosystem services from lakes
Economic values of lake ecosystem services
Institutions for transformation:
- Adaptive Governance
- Networks
- Innovation
- Leaders

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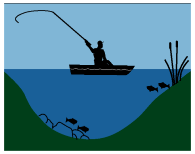

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