Coupled Biogeochemical Cycling of Macro-elements

K. Ramesh Reddy
Wetland Biogeochemistry Laboratory
Soil and Water Sciences Department
University of Florida-IFAS

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	15 P 31	16 S 32

Outline

- ✓ Introduction
- ✓ Watershed landuse
- ✓ Nutrient loads
- ✓ Coupled biogeochemical cycles
- ✓ Biogeochemical processes - Nitrogen
- ✓ Biogeochemical processes – Phosphorus
- ✓ Legacy nutrients – water quality

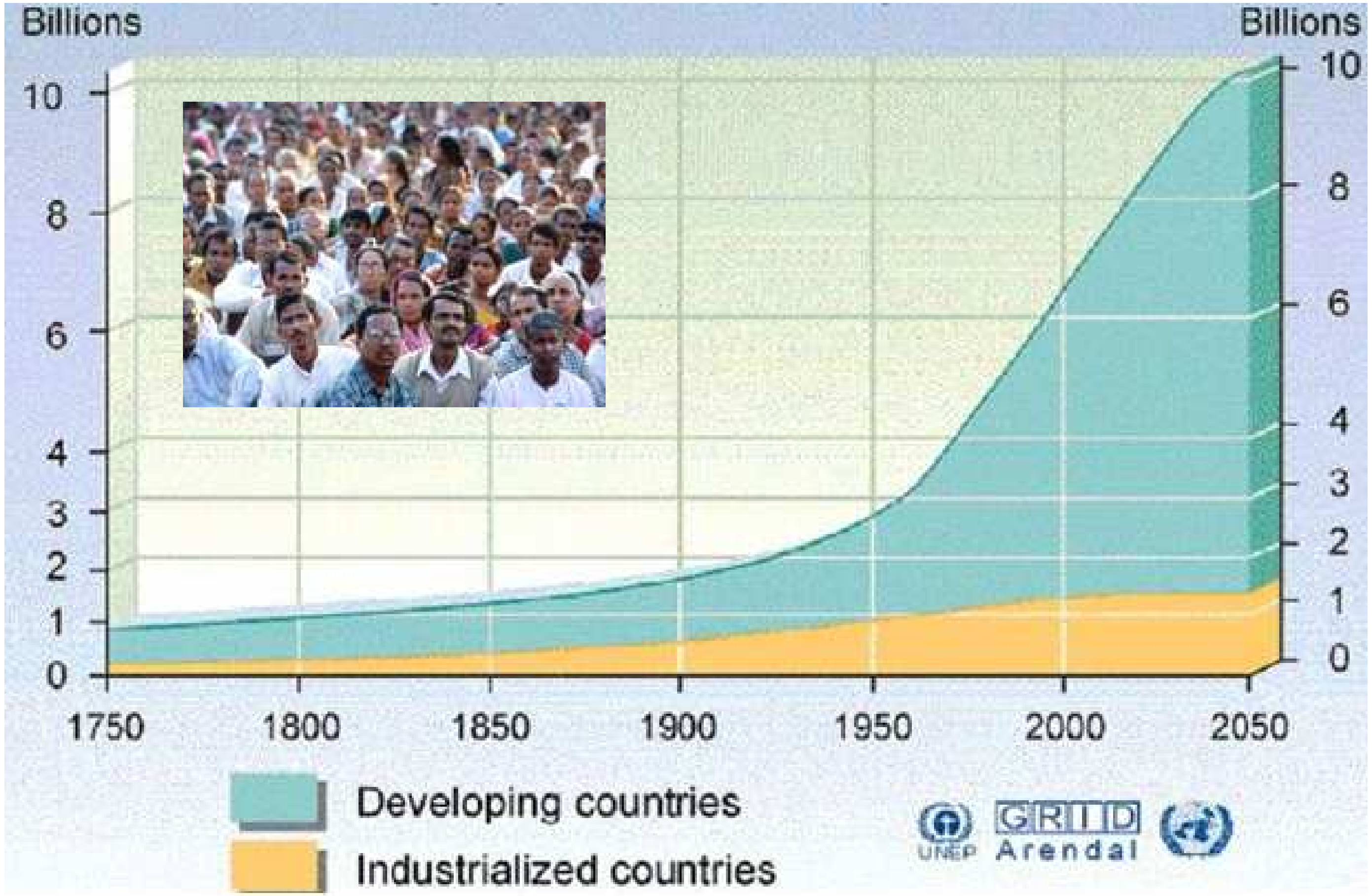
C. Nelleman and E. Corcoran, 2010 United Nations Environment Programme (UNEP)

Dead Planet, Living Planet

"Ecosystems, from forests and freshwater to coral reefs and soils, deliver essential services to humankind estimated to be worth over US $ 72 trillion a year – comparable to World Gross National Income. Yet in 2010, nearly two-thirds of the globe's ecosystems are considered degraded as a result of damage, mismanagement and a failure to invest and reinvest in their productivity, health and sustainability". ***Achim Steiner,*** *UN Under-Secretary General and UNEP Executive Director*

C. Nelleman and E. Corcoran, 2010 United Nations Environment Programme (UNEP)

Global Population



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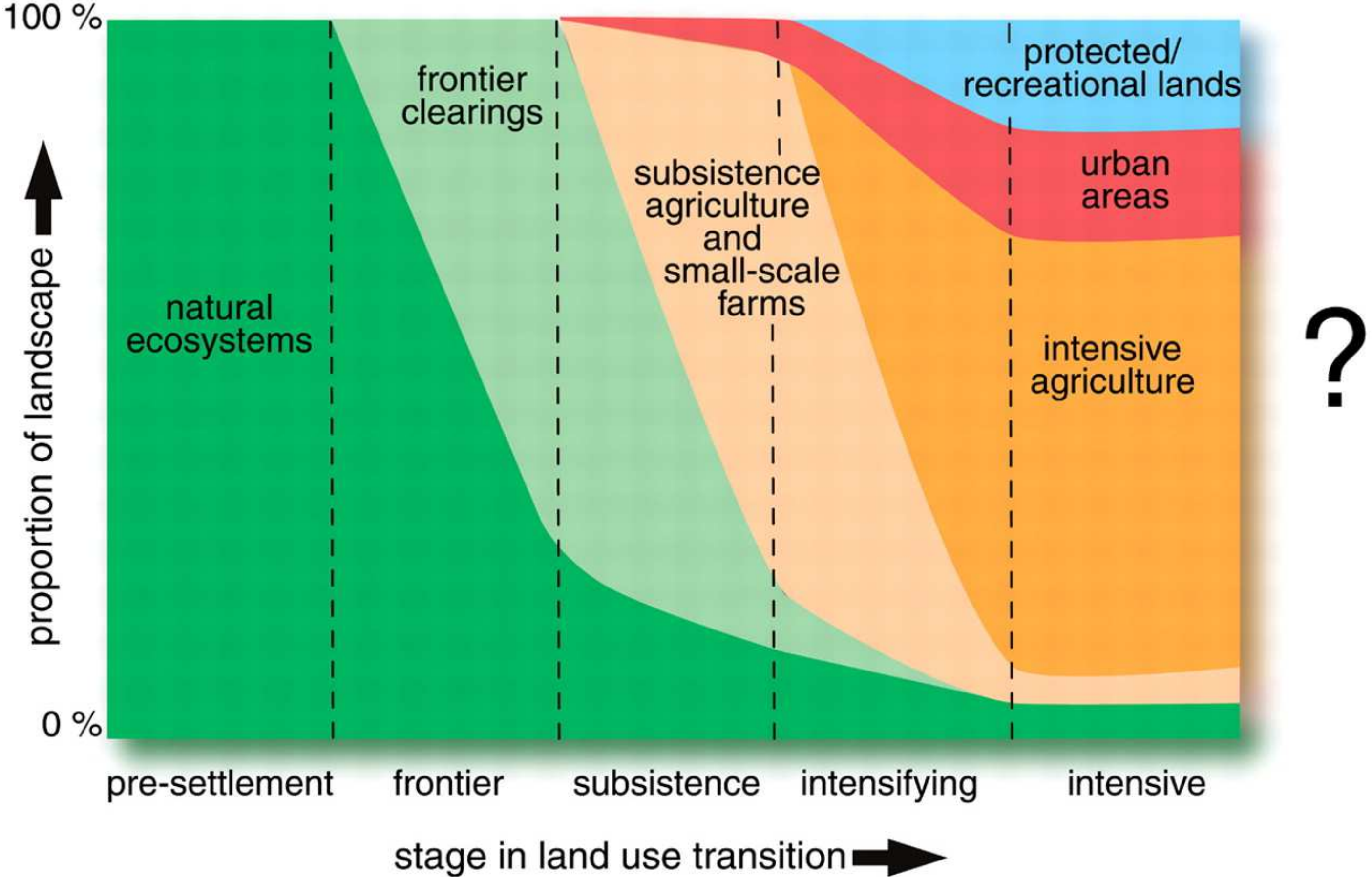
Land and Water – Natural Resources

- Are the landuse practices compatible with sustaining the quality of natural resources?
- Are the landuse practices adequate to meet current demands and future needs to sustain the quality of our natural resources?

Land and Water – Natural Resources

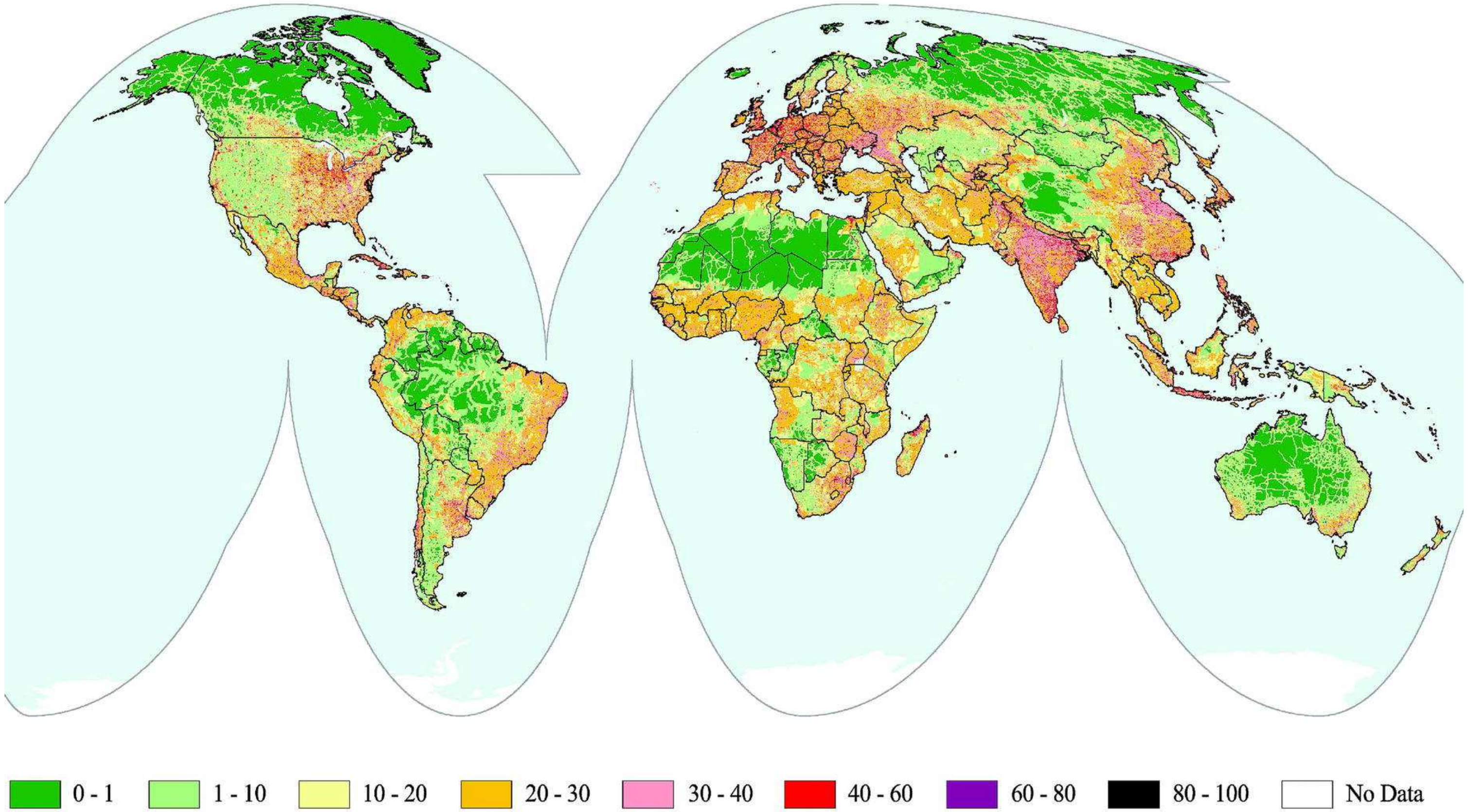
- Current practices are compatible (?) but are not adequate with sustaining the quality of natural resources
- The future of global sustainability depends on:
  - Meeting the food and fiber needs of a world population projected to exceed 10 billion by 2050
  - Protecting the quality of natural resources for future generations
- Sustainable development is needed for an optimized economic growth & natural resource protection.
- Challenge is to develop new practices that are efficient and compatible with current needs and future demands

Land-use transitions.



Jonathan A. Foley et al. Science 2005;309:570-574

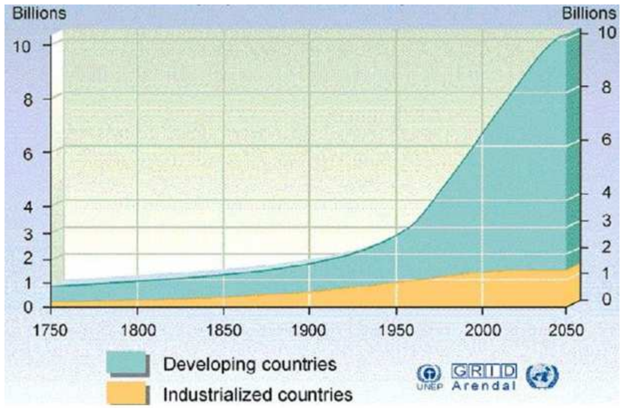
Land Surface and Human Impact



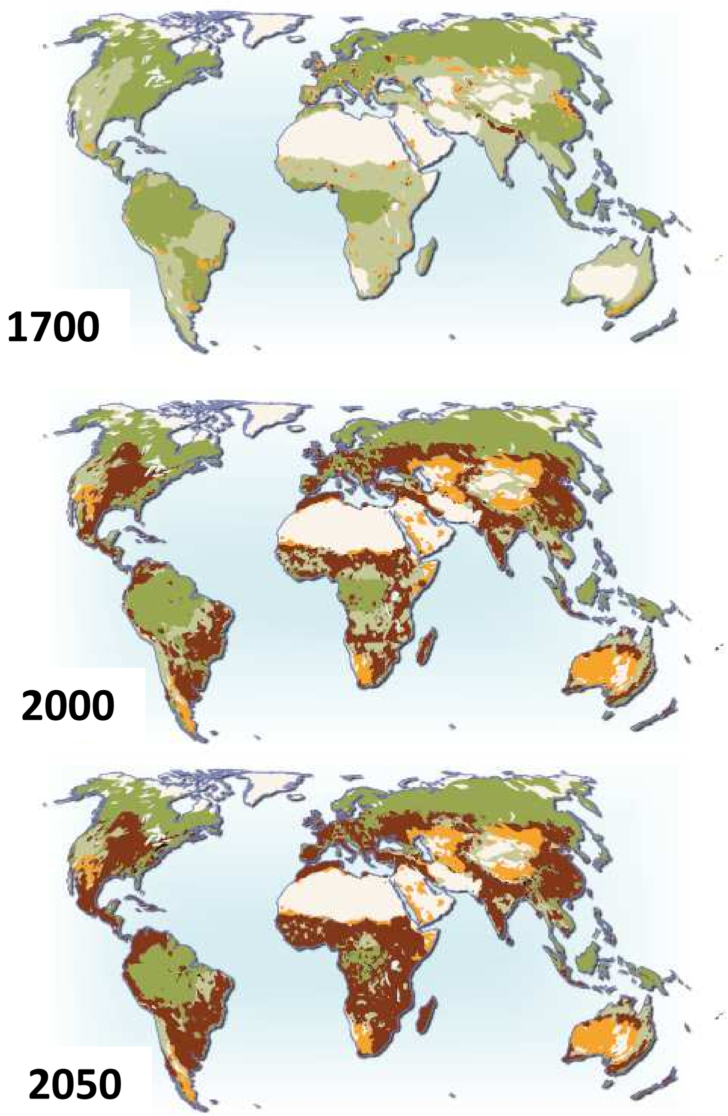
Index developed integrates human population density, land transformation, human access, and electrical power infrastructure. This study suggests that over 80% of the land surface is impacted by human activity

Sanderson etal. 2002. BioScience 52(10):891-904

Global Landuse & Agriculture



Landuse and agriculture
- Agricultural land
- Extensive grasslands (incl pasture)
- Regrowth after use
- Forests
- Grasslands
- Non-productive land



R. Alkemade et al. 2009.
Ecosystems 12:374-390

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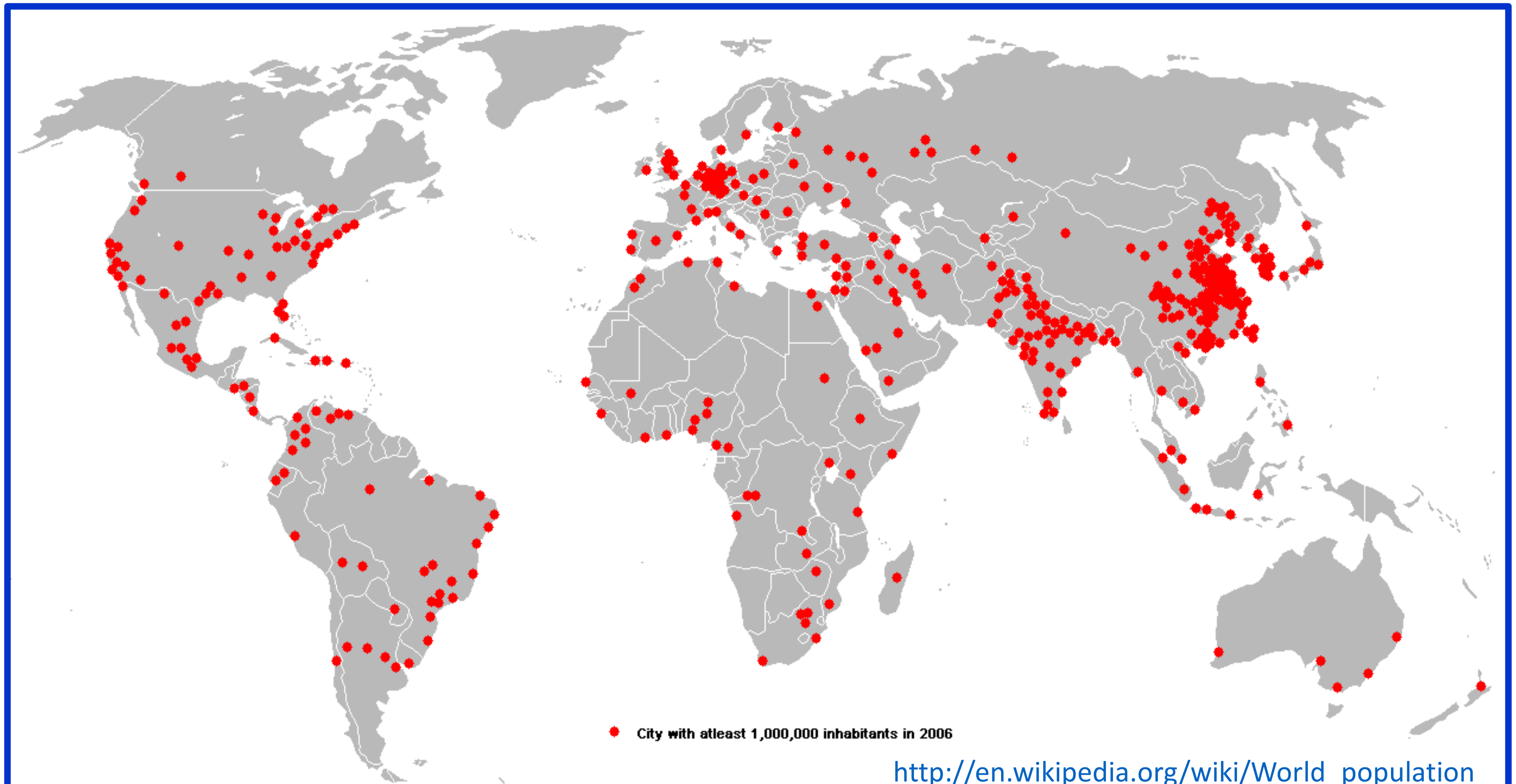
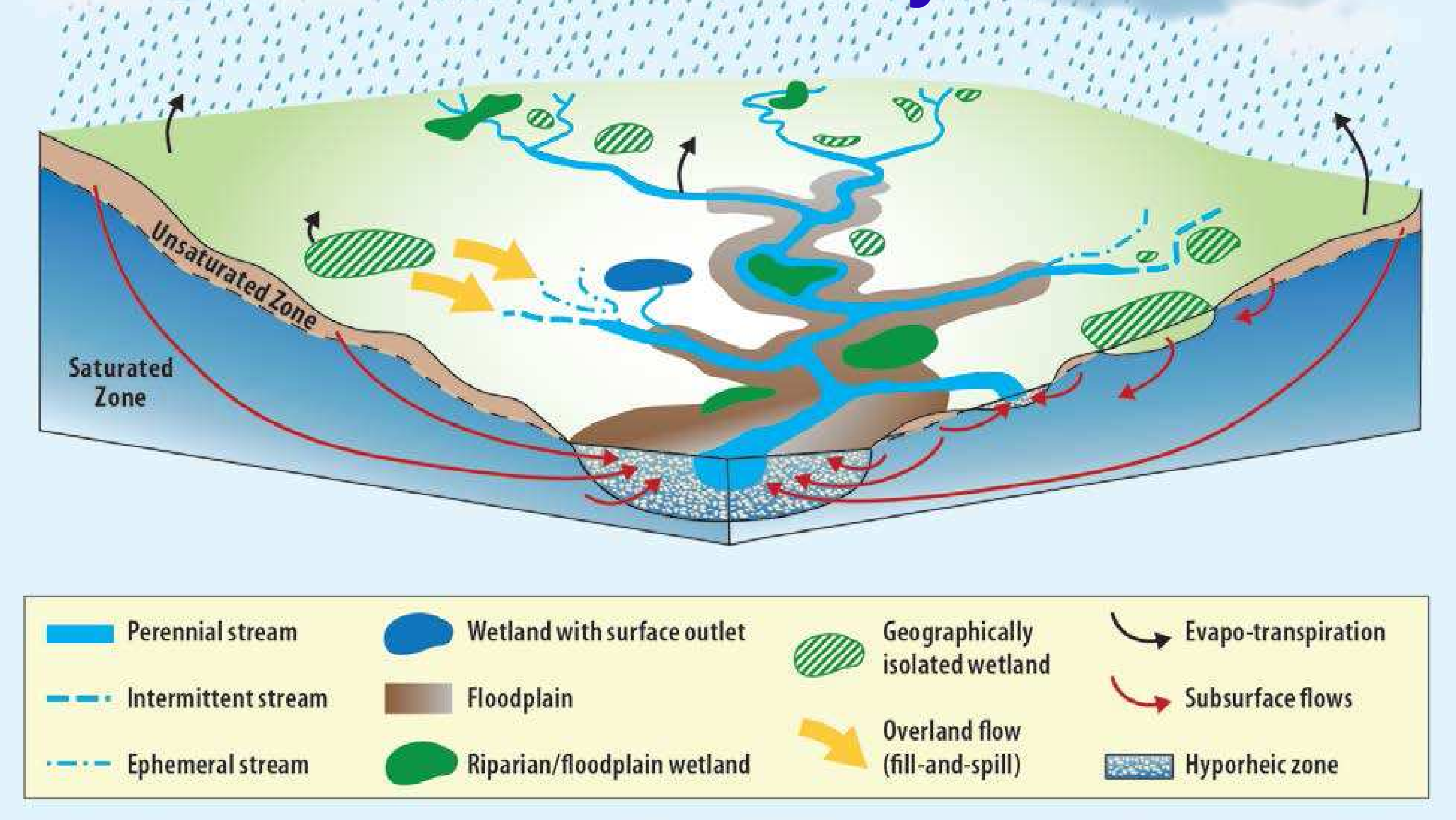
Soil & Water SCIENCE

Urban Areas – One Million Inhabitants in 2006



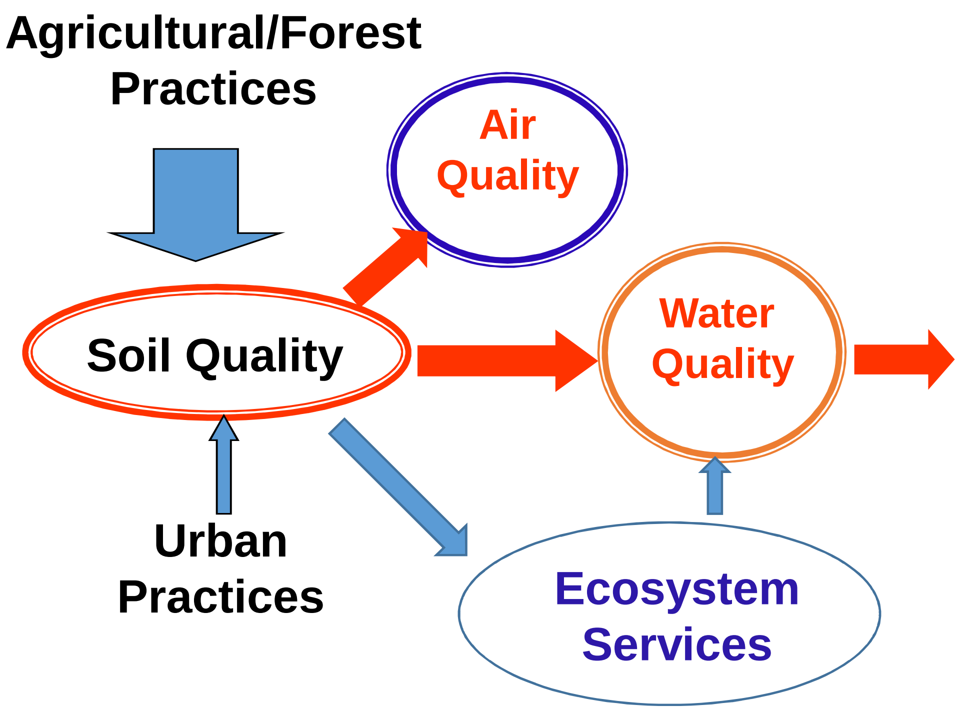
http://en.wikipedia.org/wiki/World_population

Watershed Hydrologic Connectivity



USEPA

Landuse and Natural Resources



Natural Resources
- -Wildlands
- -Wetlands
- -Streams/Rivers
- -Lakes
- -Estuaries

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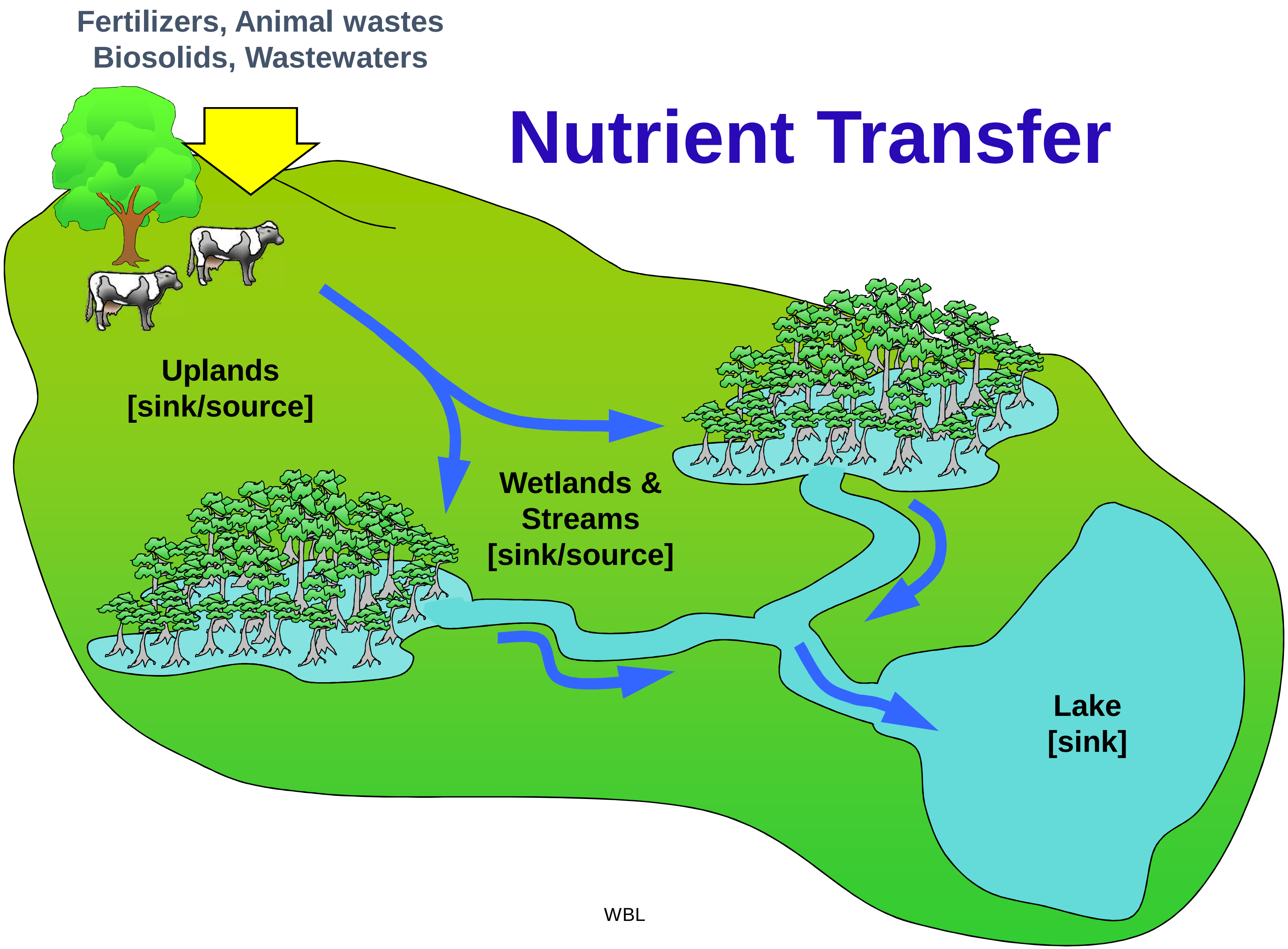
Nutrient Transfer



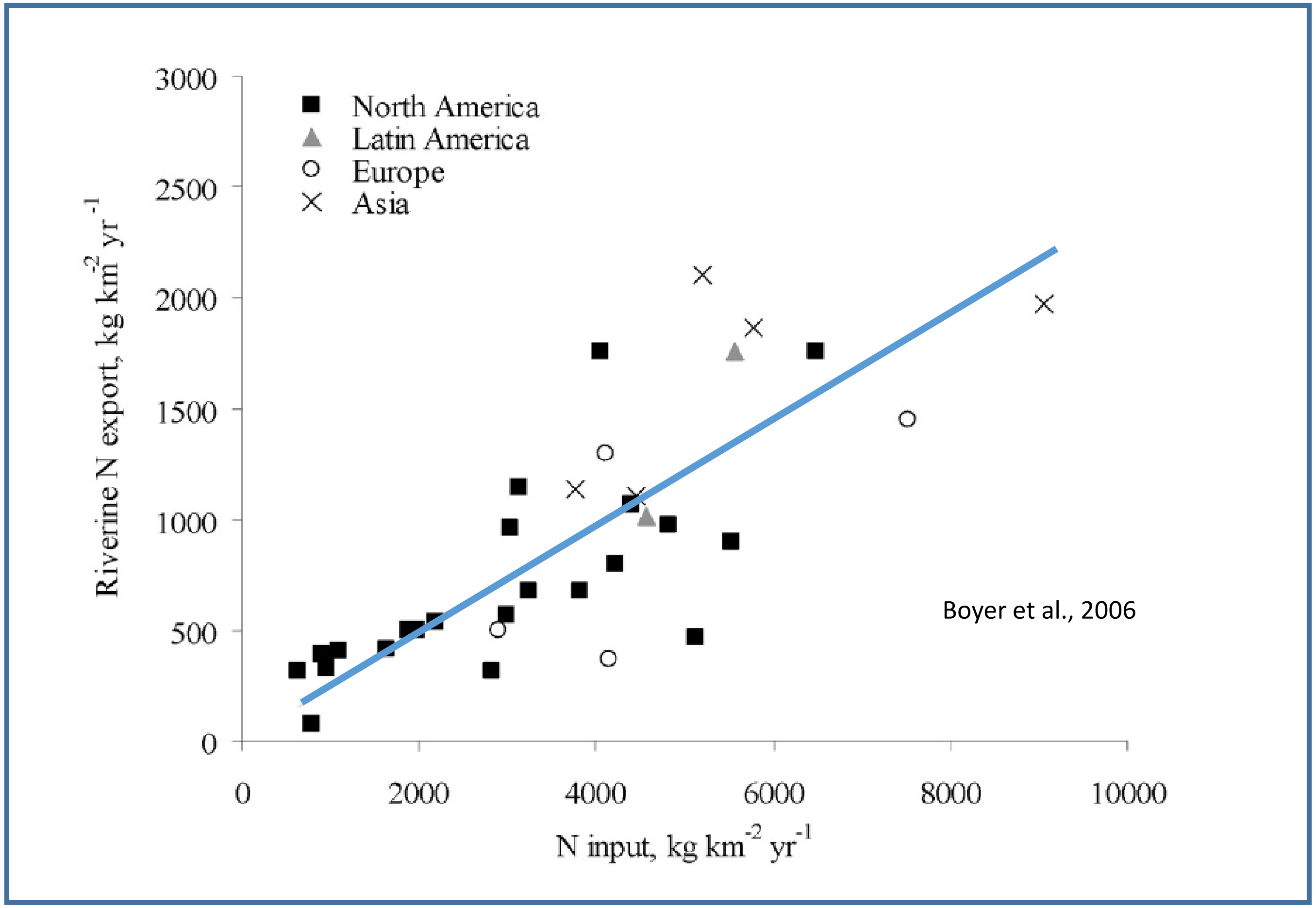
Fertilizers and Manures

- **The World** [Mullins et al., 2005]
  - Fertilizer use - N/P ratio = 5.8
  - Manure production - N/P ratio = 1.9
  - Collectable manure nutrients - N/P ratio = 0.9
- **North America** [Mullins et al., 2005]
  - Fertilizer use - N/P ratio = 6.2
  - Manure production - N/P ratio = 1.7
  - Collectable manure nutrients - N/P ratio = 0.8
- **Florida**
  - Fertilizer use – N/P ratio = 6.8

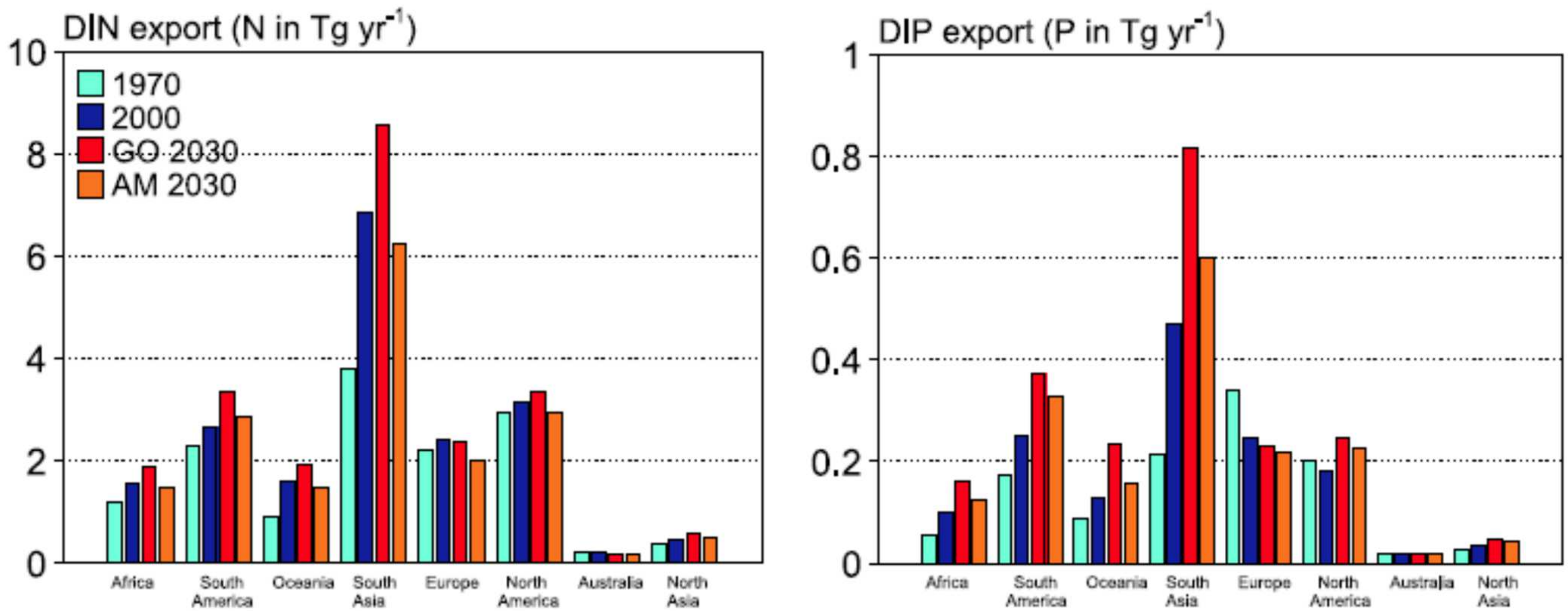
Lands used for Production Agriculture

- Long-term application of fertilizer P has resulted in substantial accumulation of P in soils
- Land application of manures and other organic wastes
  - Nitrogen basis…results in excess P load
  - Phosphorus basis… increases land area requirements
- In many areas response to added fertilizer P appears to be poor

Nitrogen Export from Rivers



Reactive Nitrogen and Phosphorus Export from Rivers



S. P. Seitzinger et al, 2010. GBC 24: GB0A08, doi:10.1029/2009GB003587,

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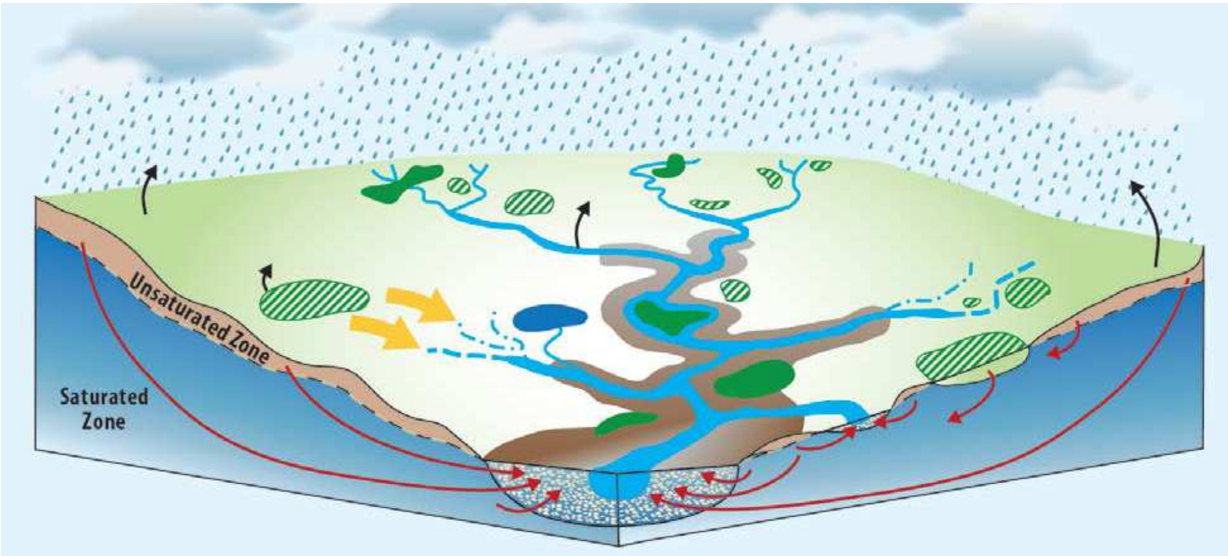
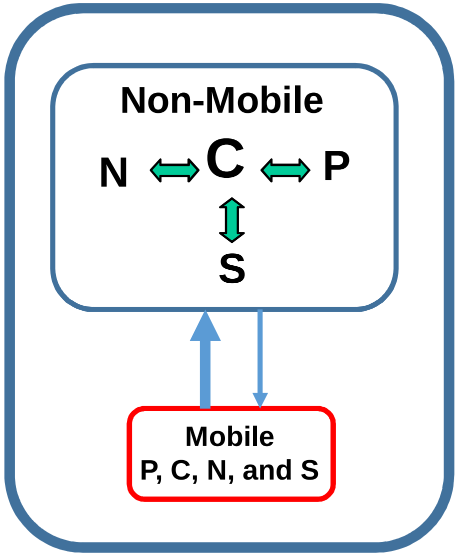
Coupled Biogeochemical Cycles

For a watershed input and output and relationships between them are known.. BUT

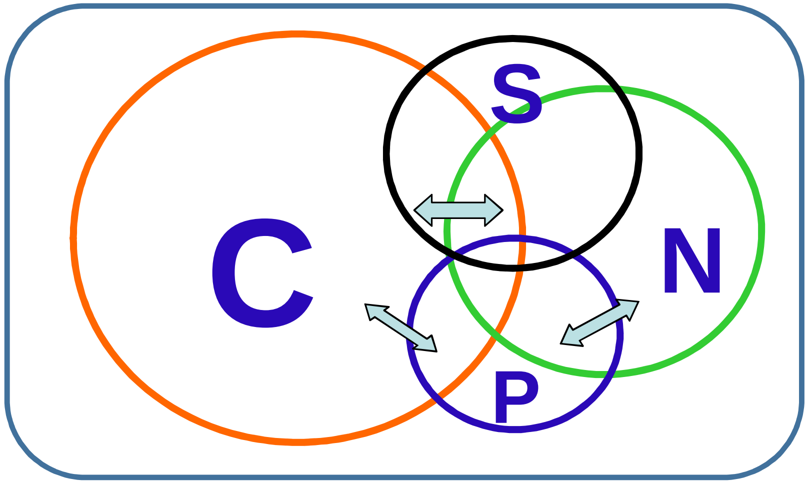




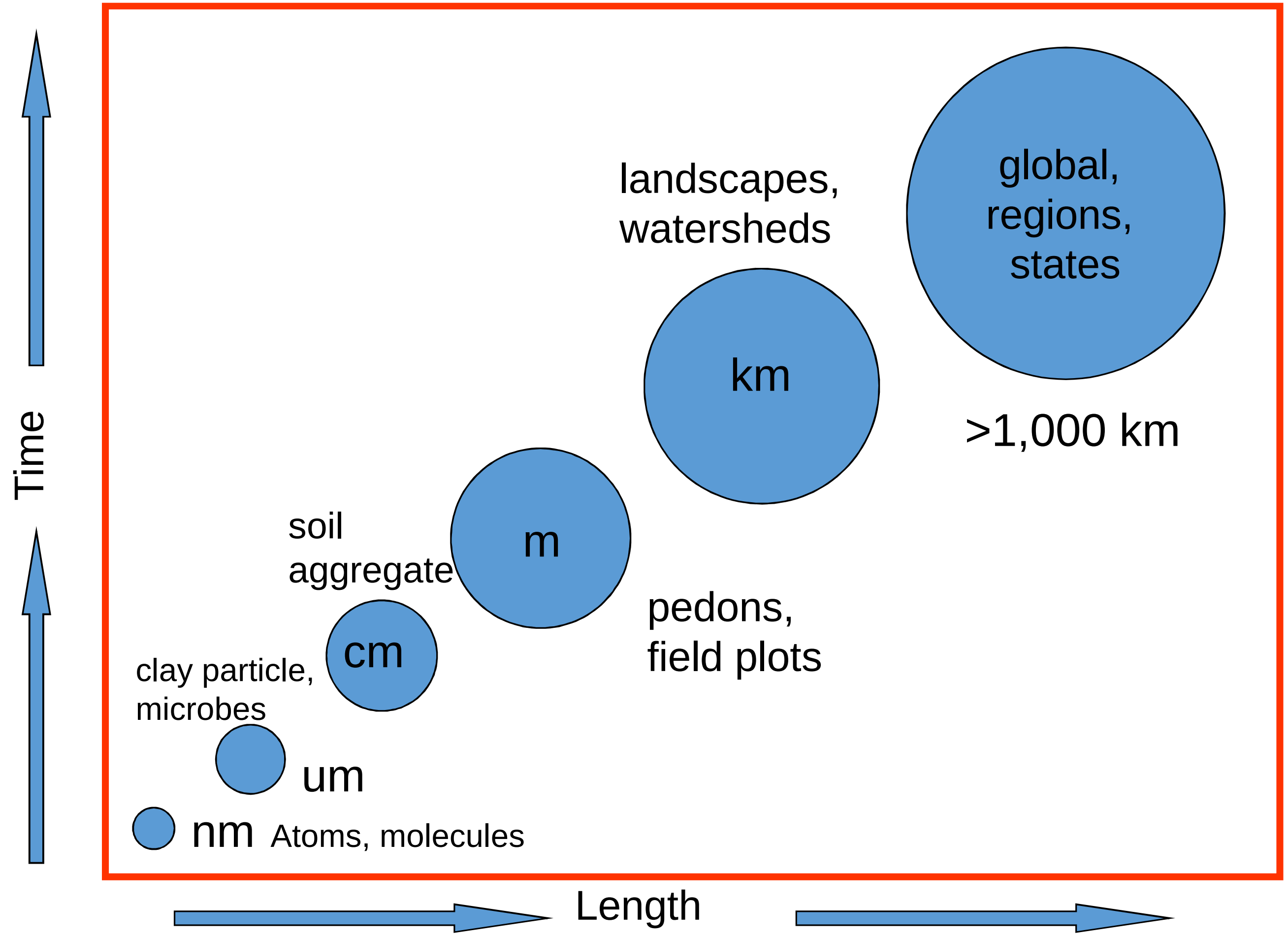
- Internal processes are not well understood
- Often considered complex and difficult to measure
- Often considered not important by managers and policy makers

Coupled Biogeochemical Cycles

- ✓Mutual dependency of one cycle over another (feedbacks and controls) or one organism over another (microbes, algae, and vegetation)
- ✓Linkages between biogeochemical processes and biotic communities (vegetation, algae, and microbes)
- ✓Cycles at different scales (molecular to landscape)
- ✓Cumulative effects of these cycles on nutrient removal or retention



Spatial and Temporal Scales



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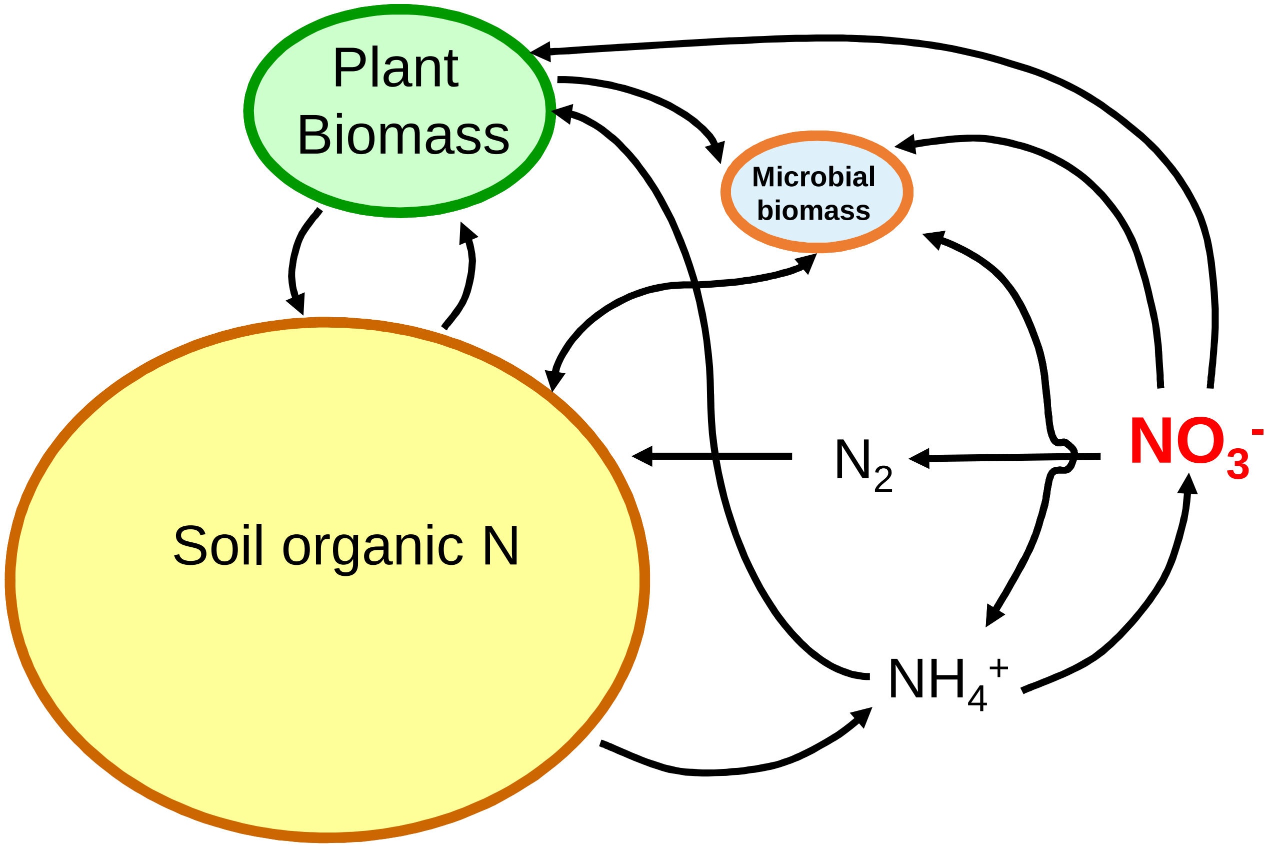
Nitrogen:

Also a pollutant when too much reactive N is released to the environment

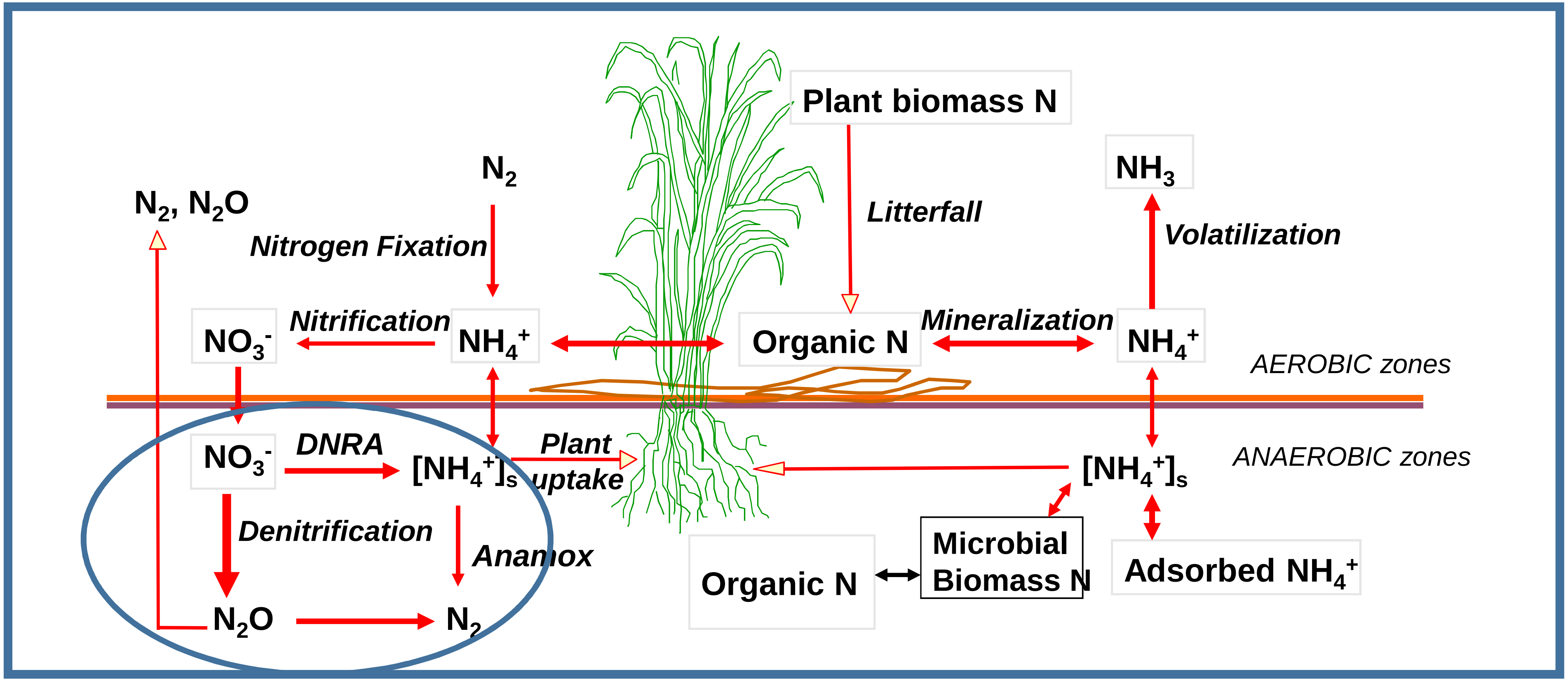
Non-reactive N: N_2 (78% of atmosphere)

Reactive N (Nr): All biologically, chemically, and radiatively active compounds (NH_3 , NH_4^+, NO_x , N_2O, NO_3^-, organic N)

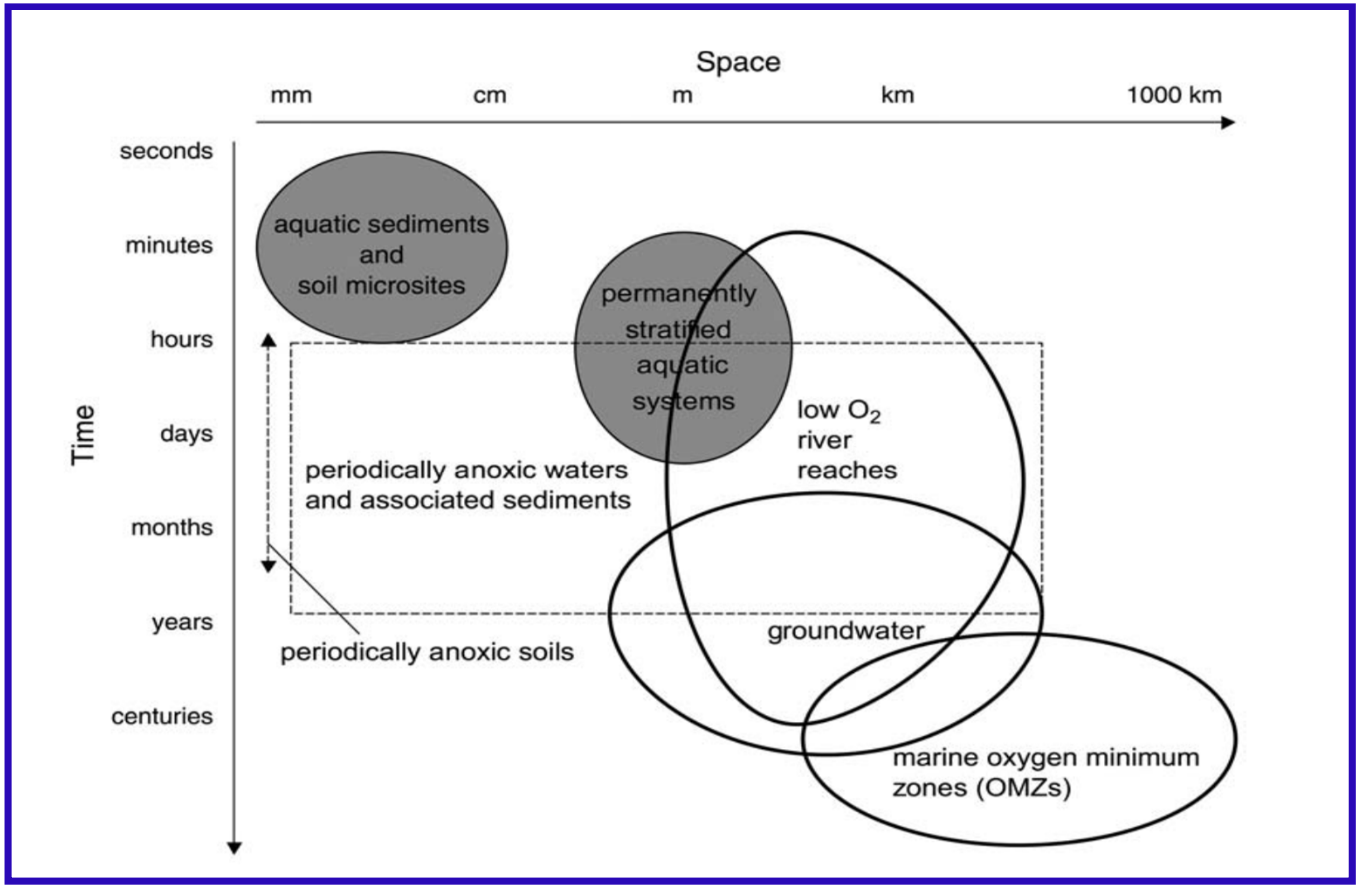
Nitrogen Cycle



Nitrogen Cycle



Nitrate Reduction



Seitzinger etal.2006. Ecological Applications. 16:2064-2090

Nitrate Reduction

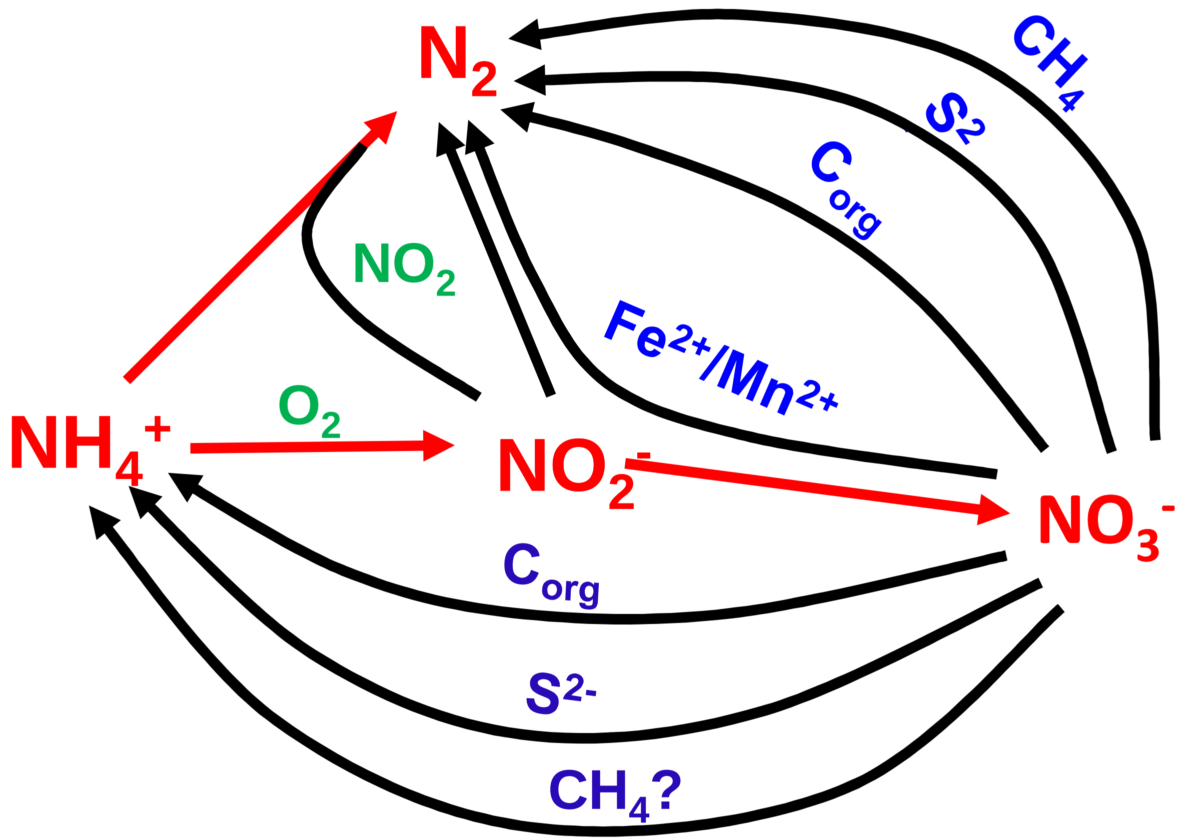
- Denitrification
  - $NO_3 \xrightarrow{5\ e^-} N_2$
- Dissimilatory nitrate reduction to ammonia (DNRA)
  - $NO_3^- \xrightarrow{8\ e^-} NH_4^+$
- Assimilatory nitrate reduction to ammonia
  - $NO_3^- \longrightarrow NH_4^+ \longrightarrow$ Proteins

Nitrate Reduction

Maquenne, 1882. ***Sur la reduction des nitrates dans la terre arable. Comptes rendus herbomadaires des seances de l'Acadenie des sciences. 95: 691-693***

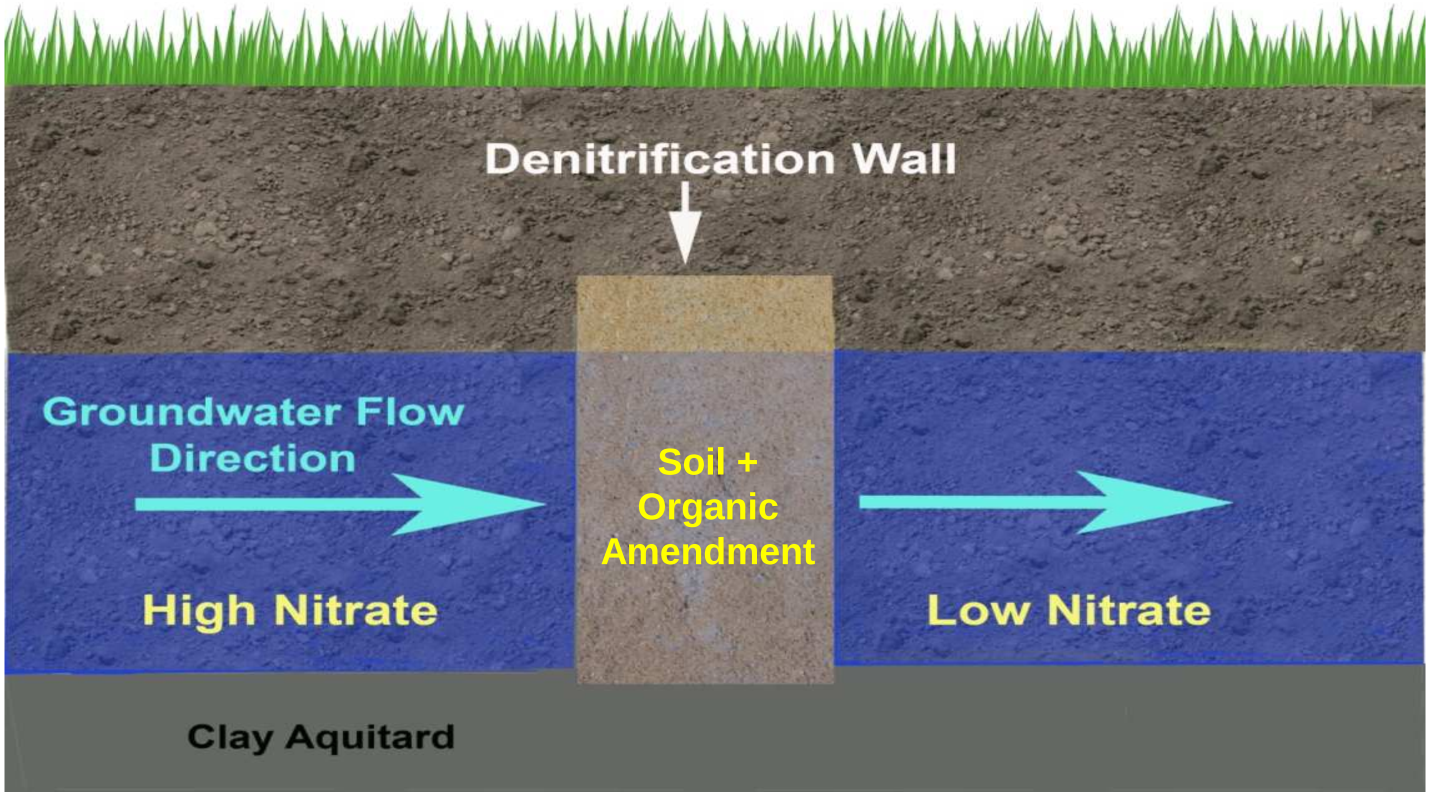
- ✓ In summary from my experience:
  - ✓ Nitrate is reduced under certain conditions in arable land releasing nitrogen gas
  - ✓ Nitrate reduction occurs in arable soil which contains a high organic matter
  - ✓ We have observed that this reduction occurs when the soil atmosphere is completely stripped of oxygen

Nitrate Reduction – Ammonium Oxidation



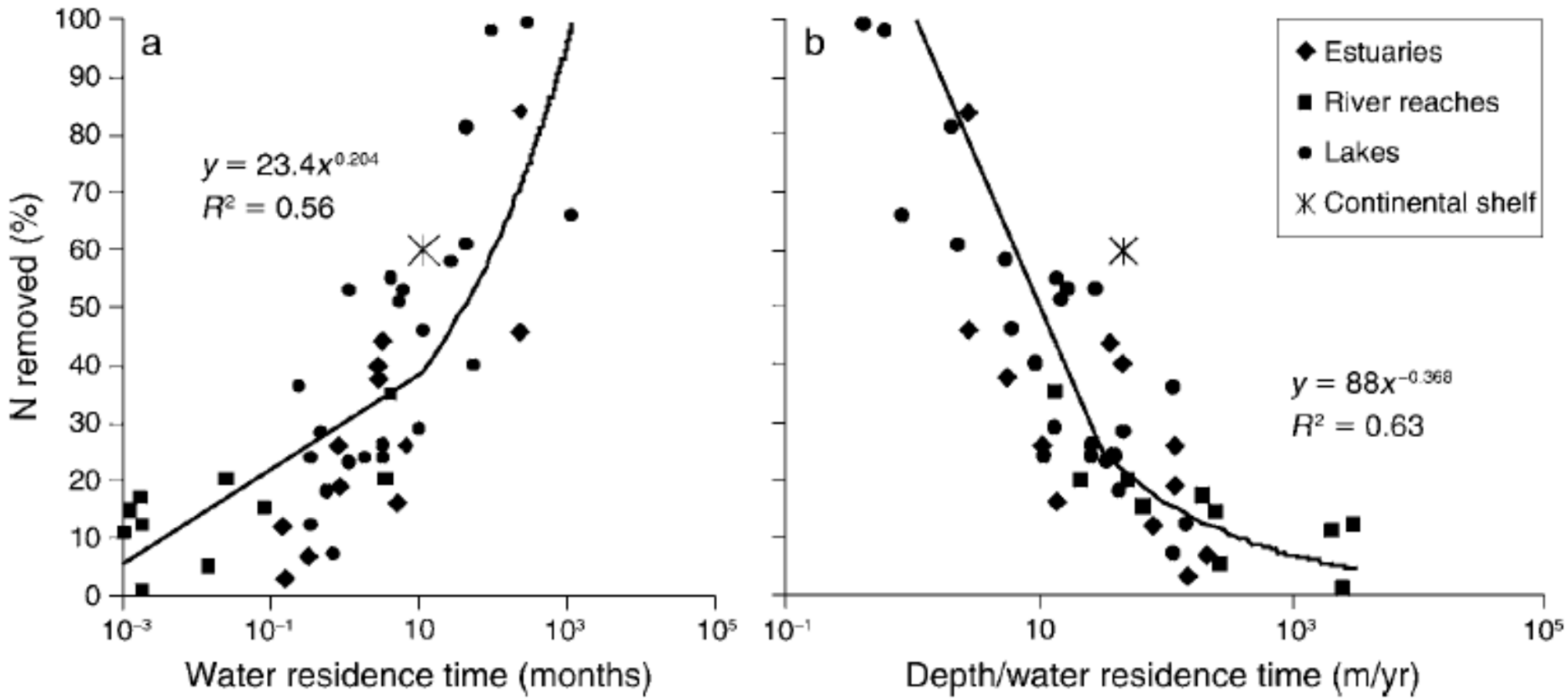
Denitrification Wall

Organic Carbon $_{\text{(electron donor)}}$ + $NO_{3\text{(electron acceptor)}}$ ➔ $N_2 + CO_2$



Schmidt and Clark, 2010

Nitrate Reduction



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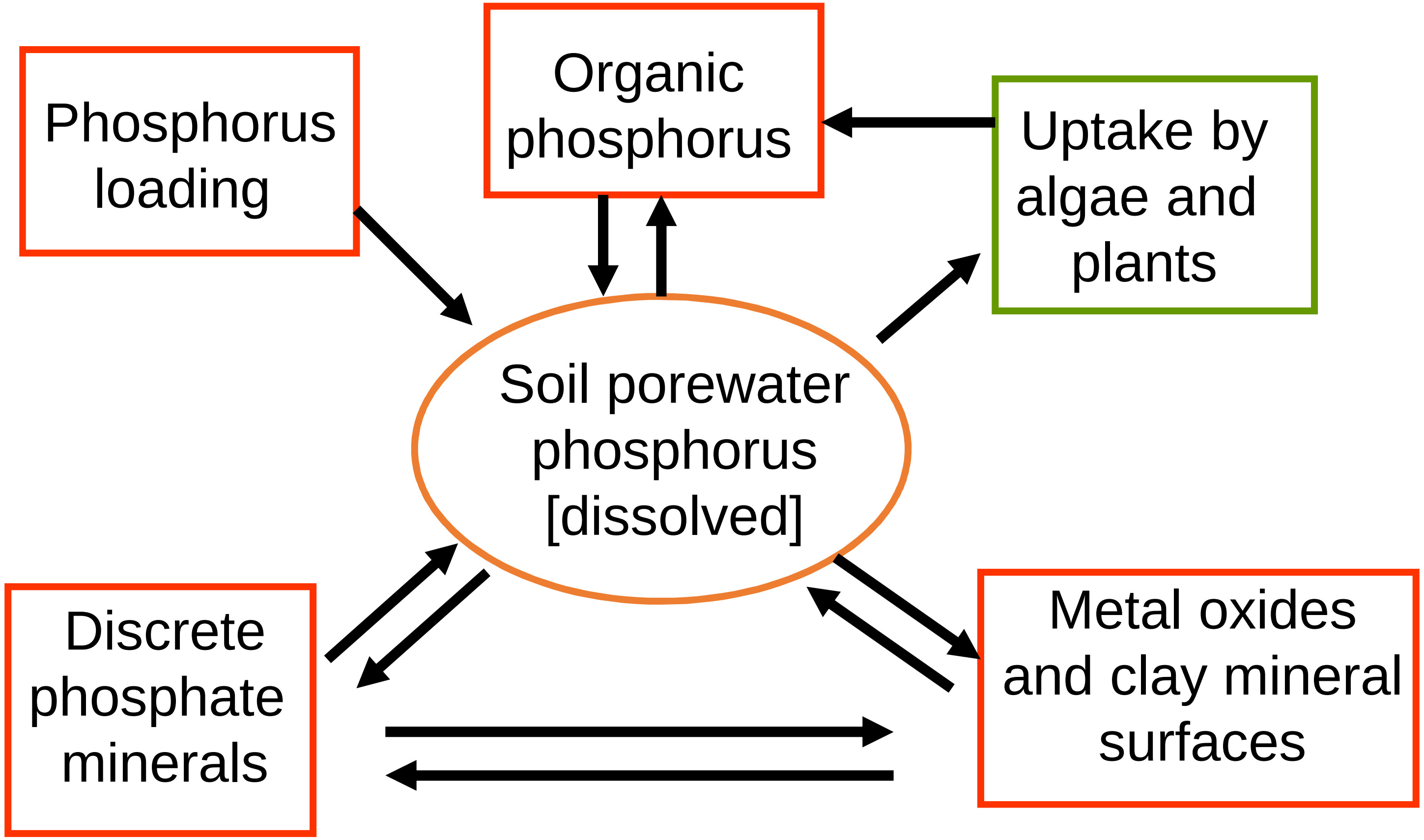
Phosphorus:

Also a pollutant when too much reactive P is released from uplands into aquatic systems

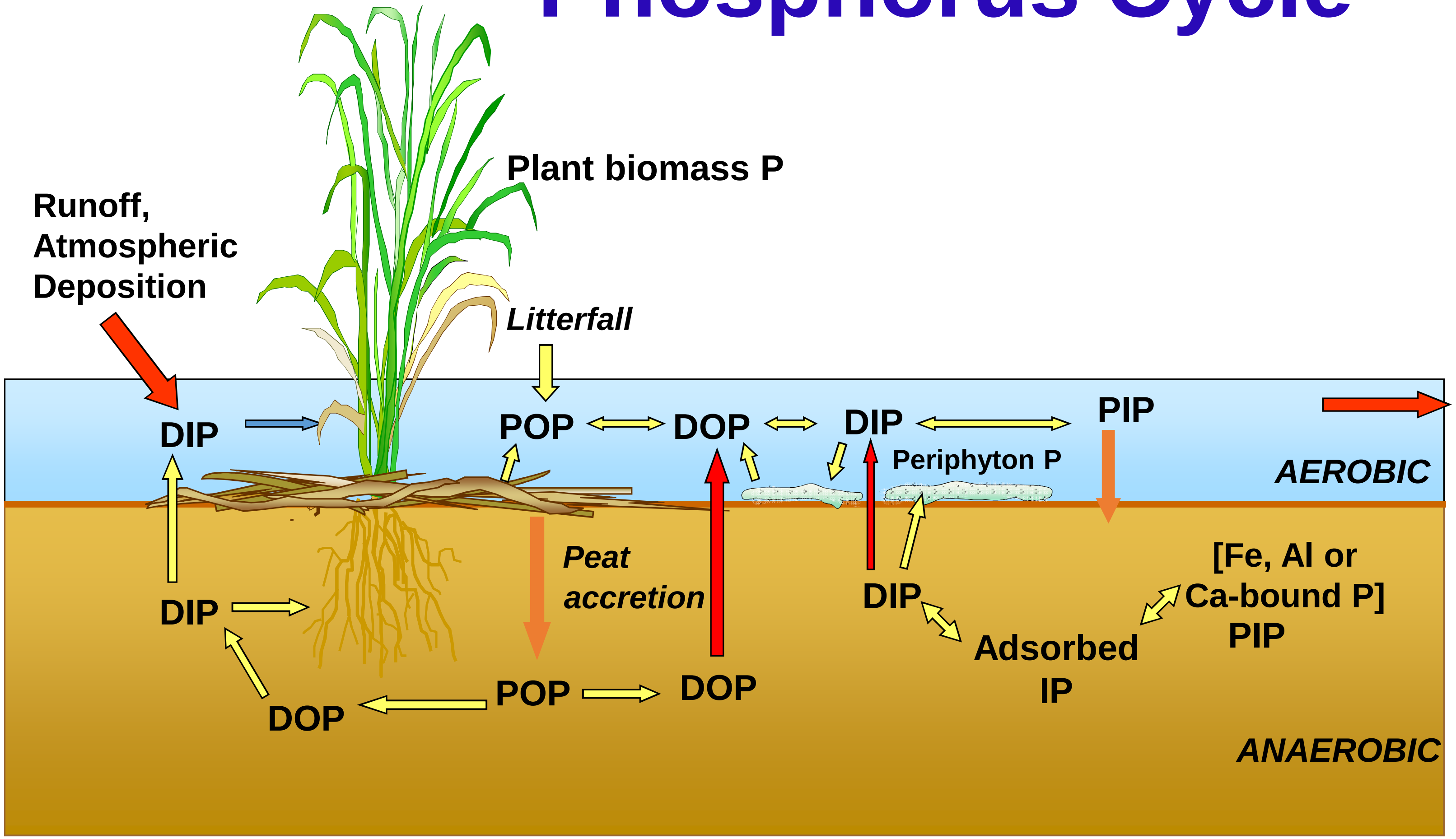
Reactive P(RP): All biologically and chemically active compounds (dissolved inorganic P, dissolved organic P, particulate inorganic P, and particulate organic P)

Non-reactive P (NRP): Biologically not available and permanently buried in soils and sediments

Phosphorus in Soils



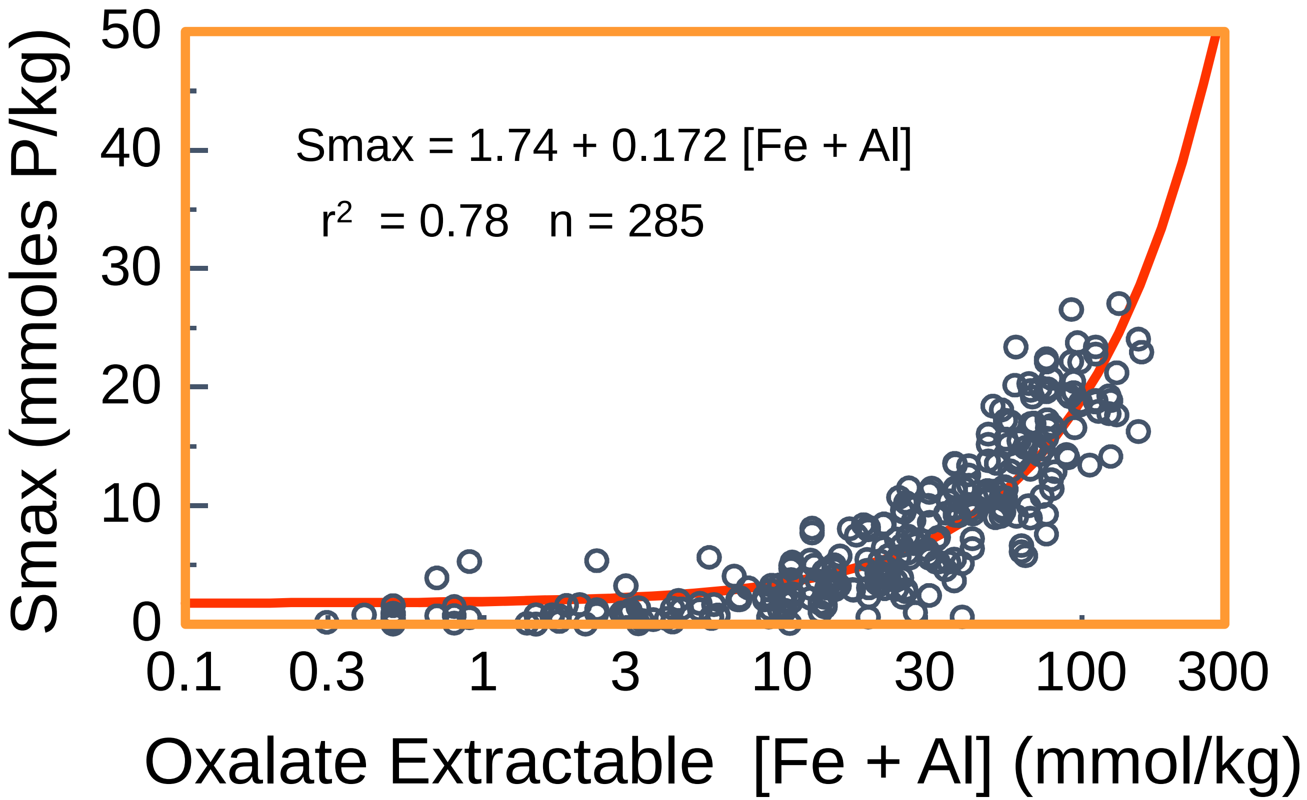
Phosphorus Cycle



Regulators of Inorganic Phosphorus Retention

- pH and Eh
- Phosphate concentration
- Clay content
- Iron and aluminum oxides
- Organic matter content
- Calcium carbonate content
- Time of reaction/aging
- Temperature

Phosphorus Retention Capacity
Mineral Soils – Okeechobee Basin



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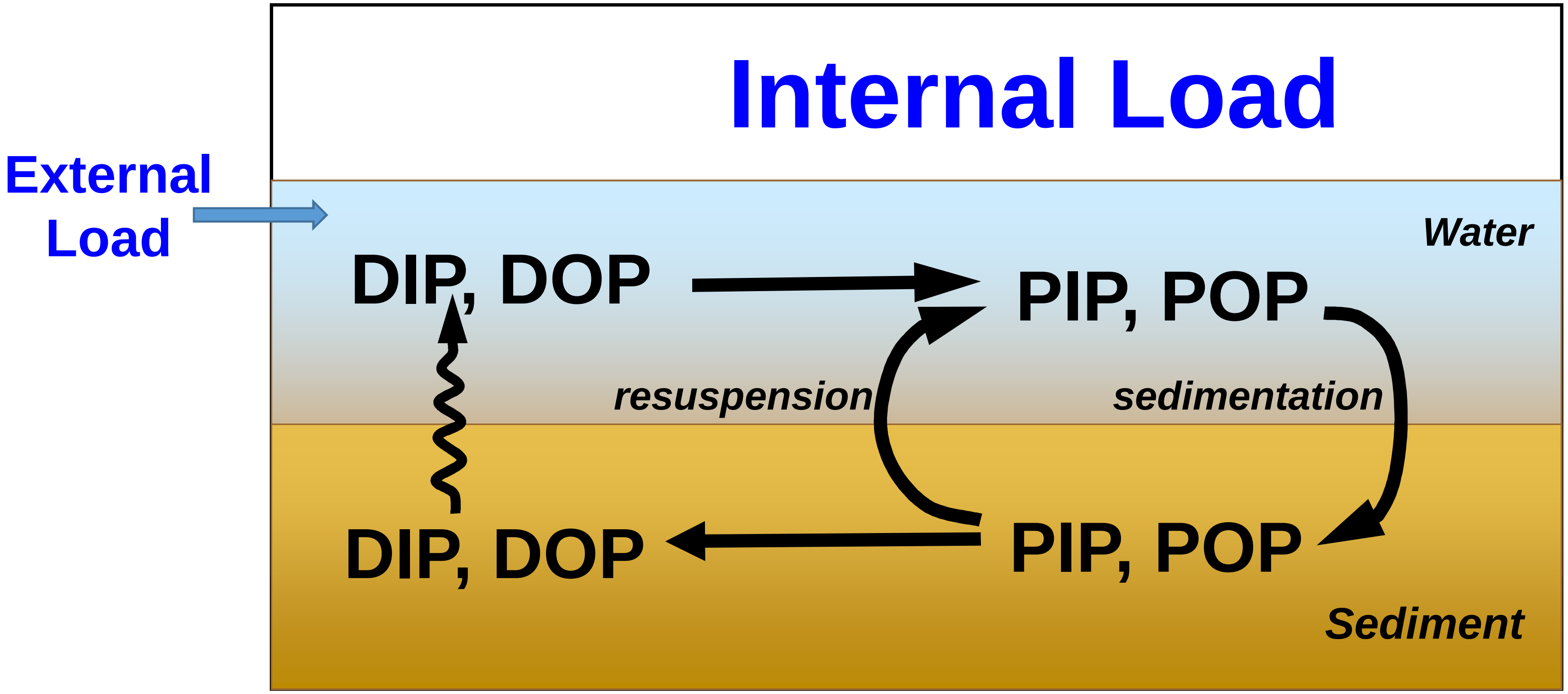
Phosphorus Loads from Uplands

- Uplands have been a steady source of P to aquatic systems
- Best management practices and other remedial measures can significantly reduce P loads from uplands to aquatic systems
- How will aquatic systems respond to external P load reduction and legacy P?
- How long P memory lasts in aquatic systems before they reach stable condition?

Phosphorus Exchange between Sediment and Water Column



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Legacy Nutrients

Nitrogen

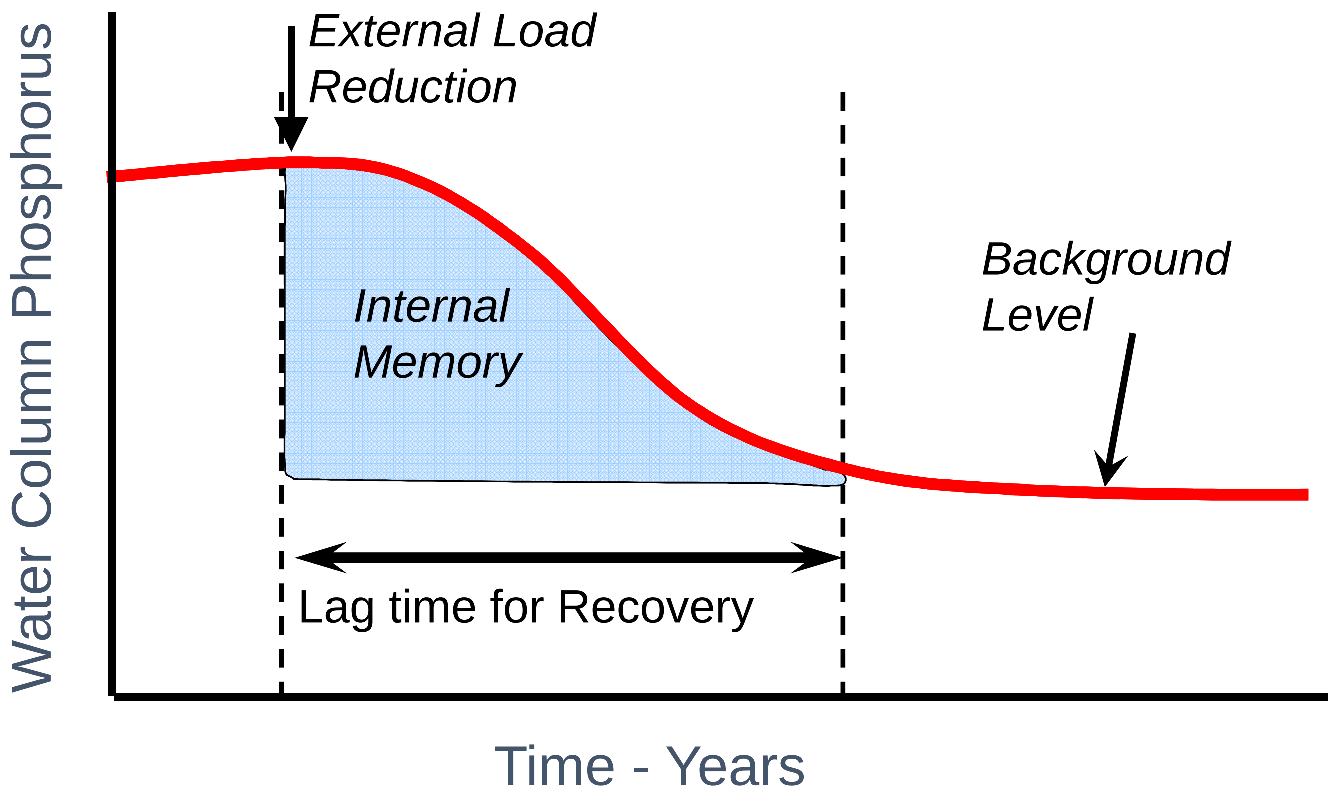
- Nitrogen is tightly coupled carbon
- Nitrogen accumulates as a part of soil organic matter
- Nitrogen is lost as gaseous forms
- Inorganic nitrogen is small part of total N
- Ammonium N is unstable in uplands
- Nitrate is highly soluble and its mobility is linked travel time of water
- Nitrogen is effectively removed in anaerobic patches of watershed
- A small of applied fertilizer N accumulates in soils

Legacy Nutrients

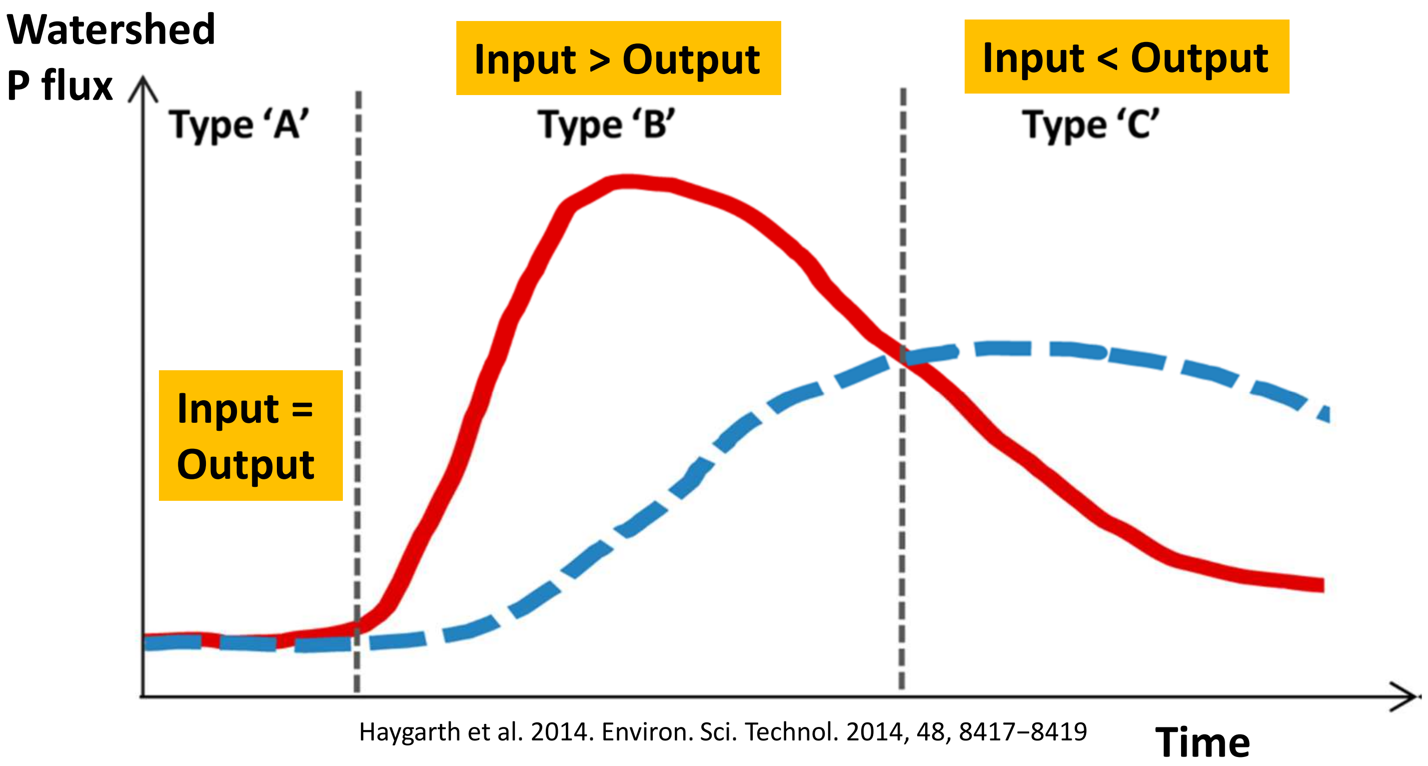
Phosphorus

- Phosphorus is not tightly coupled carbon
- Only organic P accumulates as a part of soil organic matter
- Inorganic P is large proportion of soil total P
- A large proportion of P accumulates in soils, because inorganic P strongly bound to metals
- Depending on soil types, only small portion of P in soluble form and its mobility is linked travel time of water
- Transport of P is directly liked to sediment transport
- Phosphorus requirement of crops is low as compared to N

Legacy Phosphorus Memory

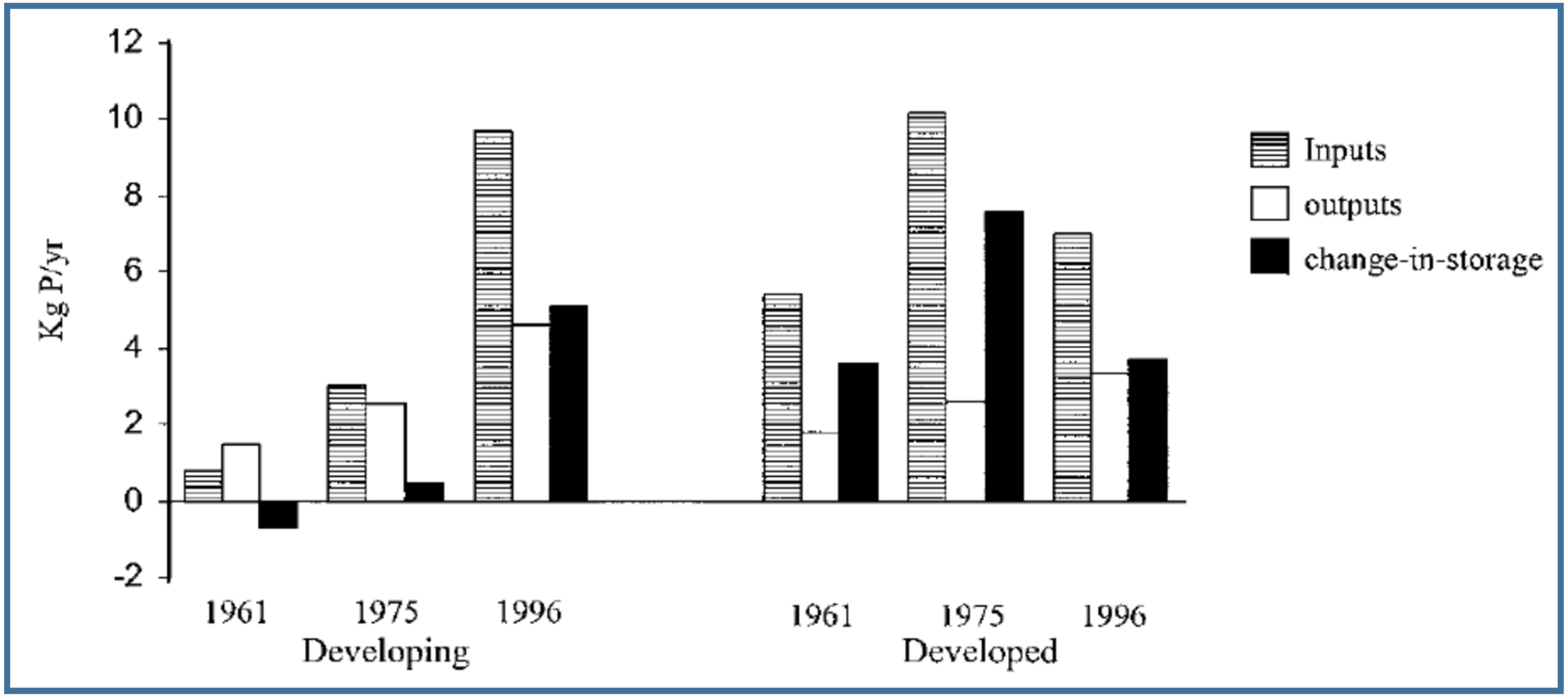


Legacy Phosphorus



Haygarth et al. 2014. Environ. Sci. Technol. 2014, 48, 8417−8419

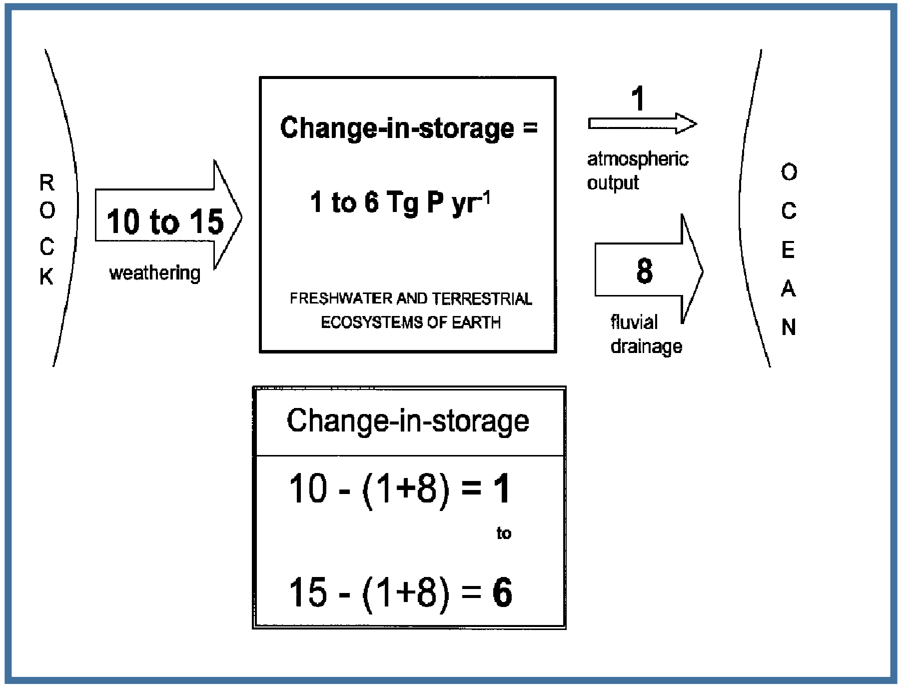
Phosphorus Storage in Agricultural Lands



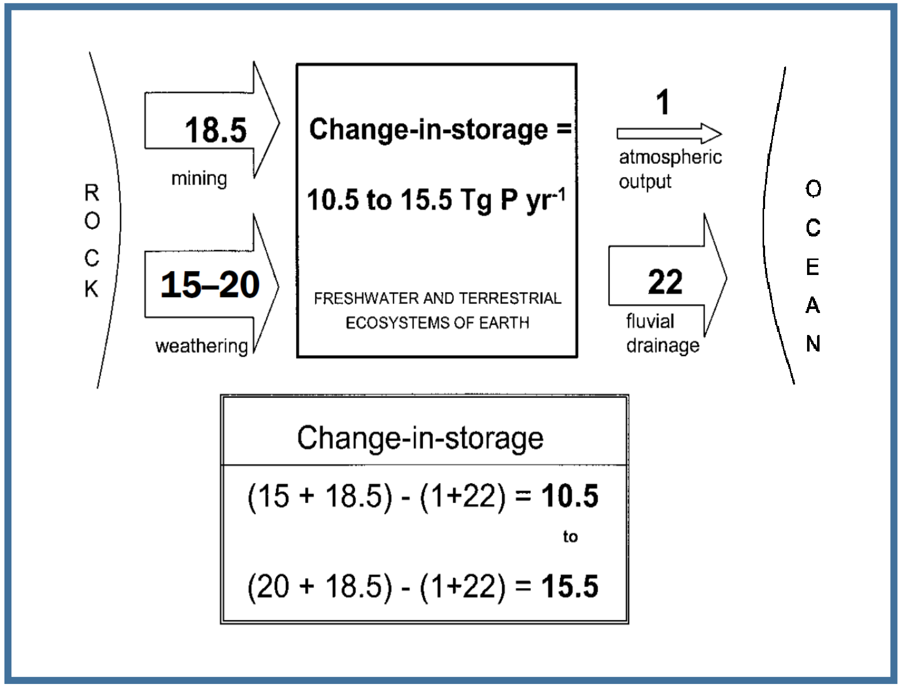
Bennett et al., 2001. BioScience, 51:227-234

Terrestrial Phosphorus Budget

Preindustrial estimate- Tg/year



1996 estimate- Tg/year



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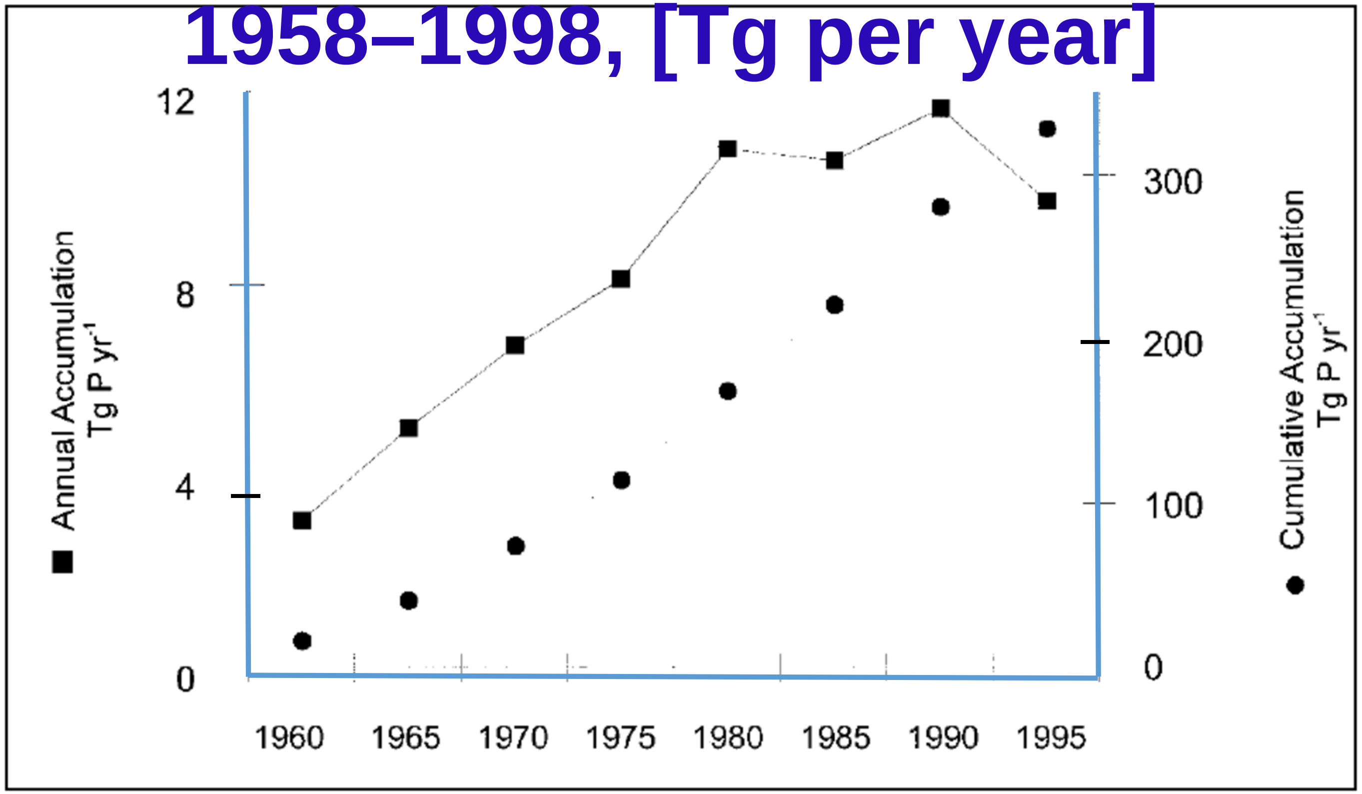
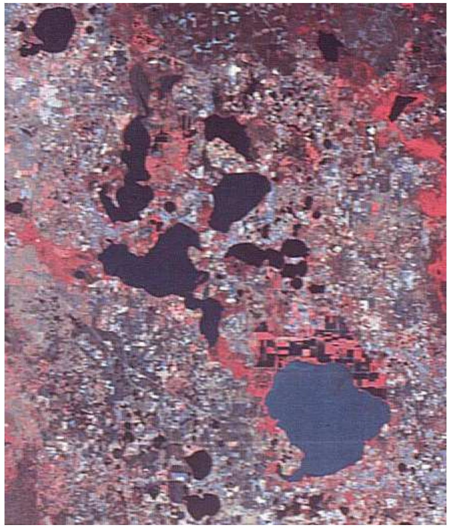
Global Phosphorus Accumulation in Agricultural Soils 1958–1998, [Tg per year]



Bennett et al., 2001. BioScience, 51:227-234

Lake Apopka

1989-96; 1997-2009



P

63 mt/ year

< 20 mt/year

1,490 metric tons P in top 30 cm sediments

SJRWMD

Phosphorus Forms

Surface Sediments: 0-10 cm

% of Total P

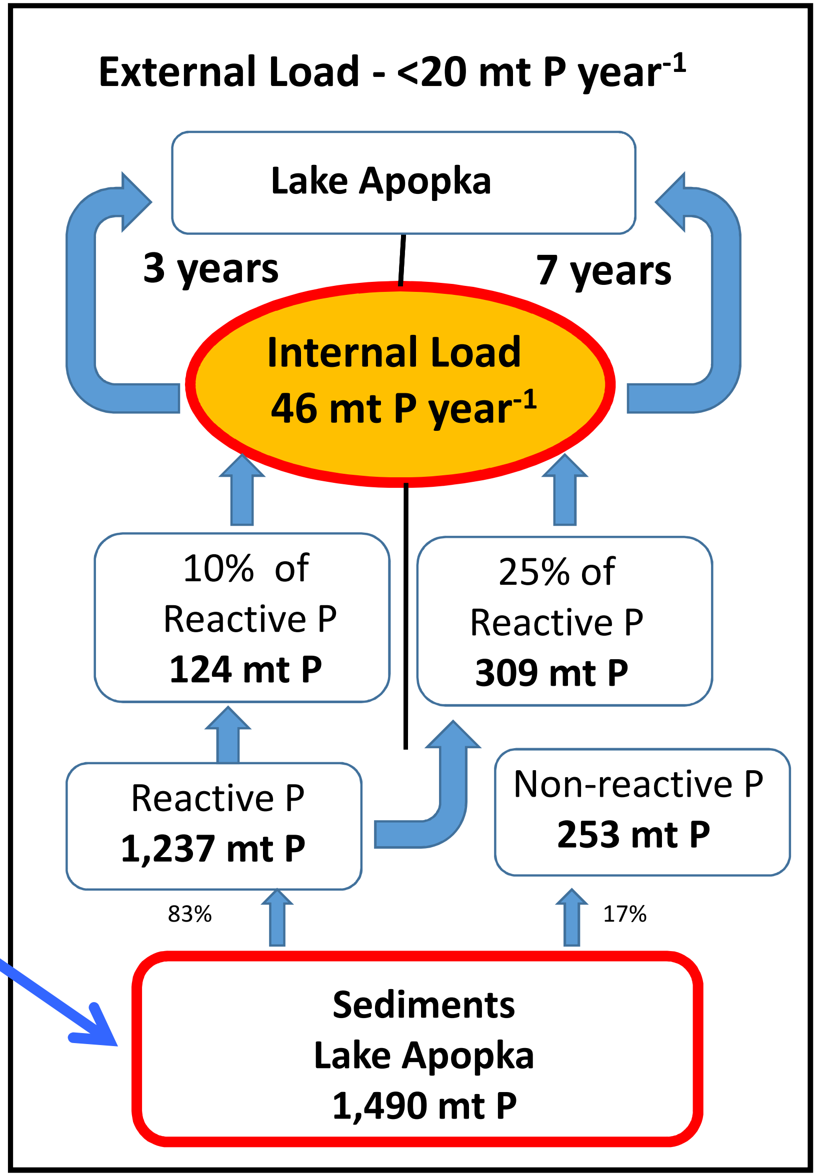
Reactive Phosphorus
- Inorganic P extracted with acid
- Organic P extracted with alkali

→ **83%**

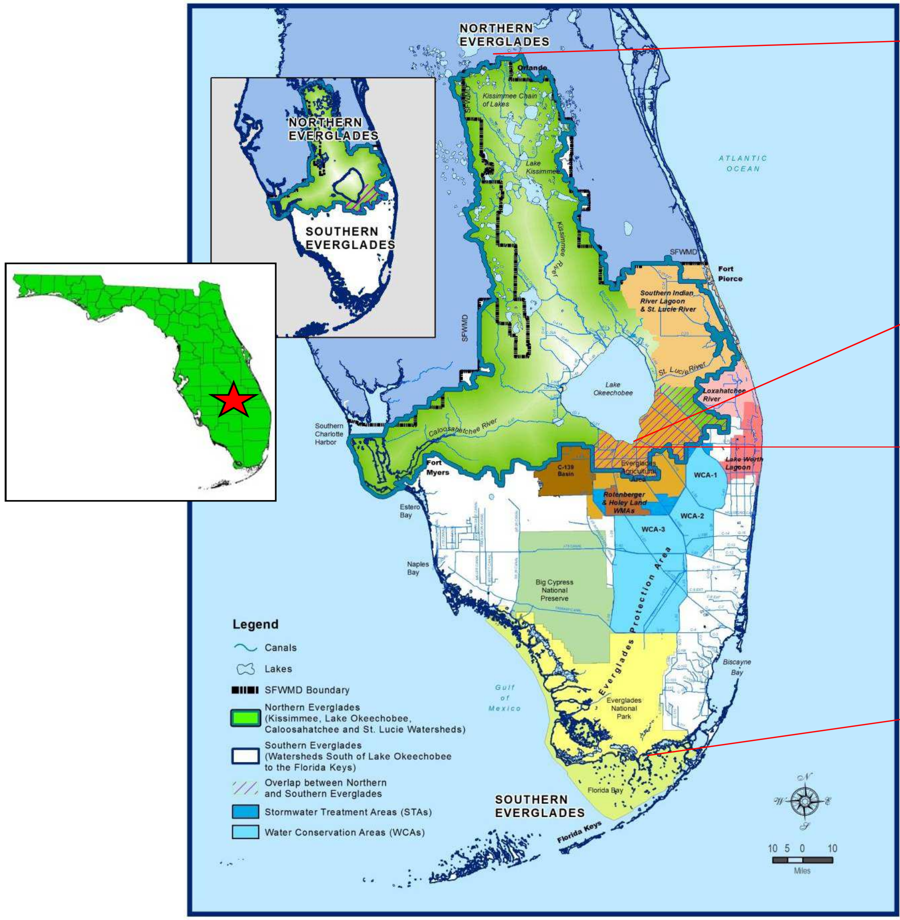
Non-reactive Phosphorus
- Total P – Reactive P

→ **17%**

Lake Apopka



External Load - <20 mt P year-1
Lake Apopka
3 years
7 years
Internal Load
46 mt P year-1
10% of
Reactive P
124 mt P
25% of
Reactive P
309 mt P
Reactive P
1,237 mt P
Non-reactive P
253 mt P
83%
17%
Sediments
Lake Apopka
1,490 mt P



1 Northern Everglades

2 Southern Everglades

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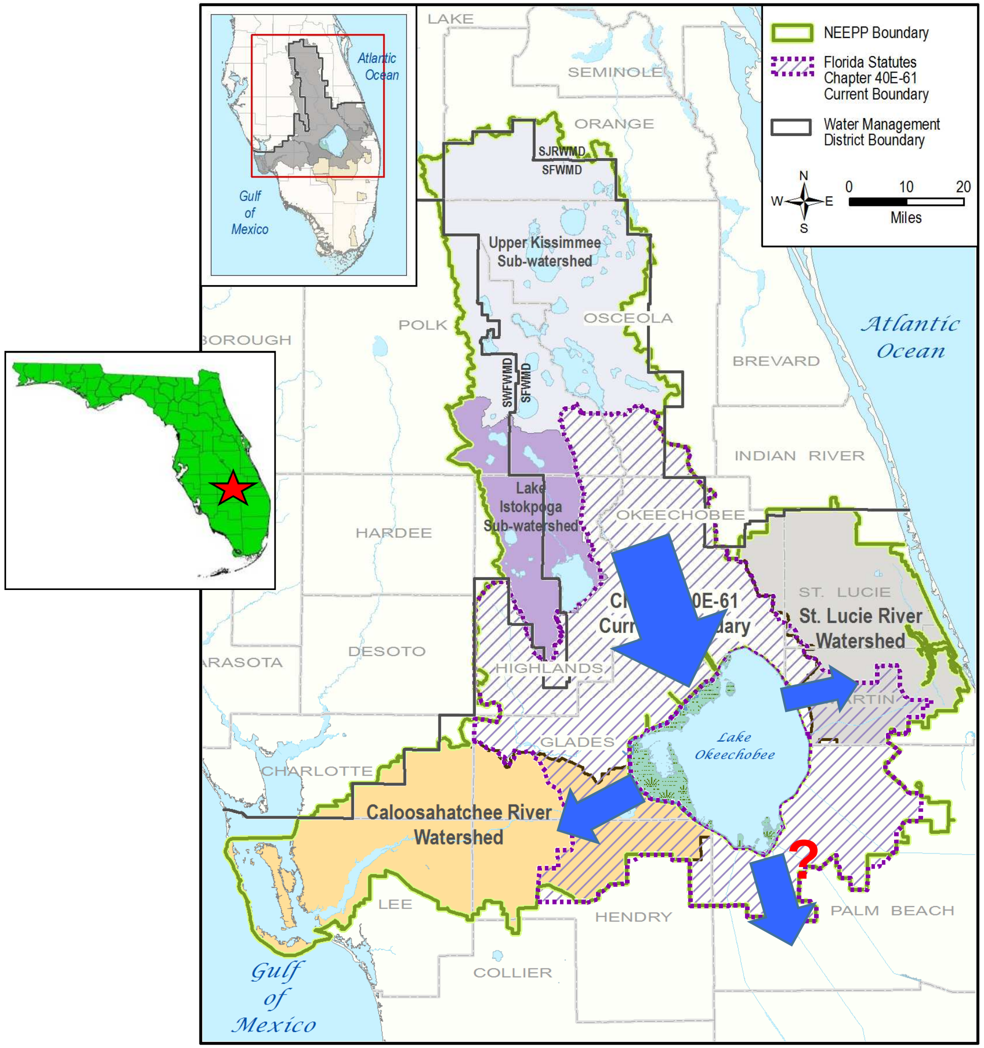
WBL

Northern Everglades



Phosphorus Forms

Surface Soils: 0-10 cm

% of Total P

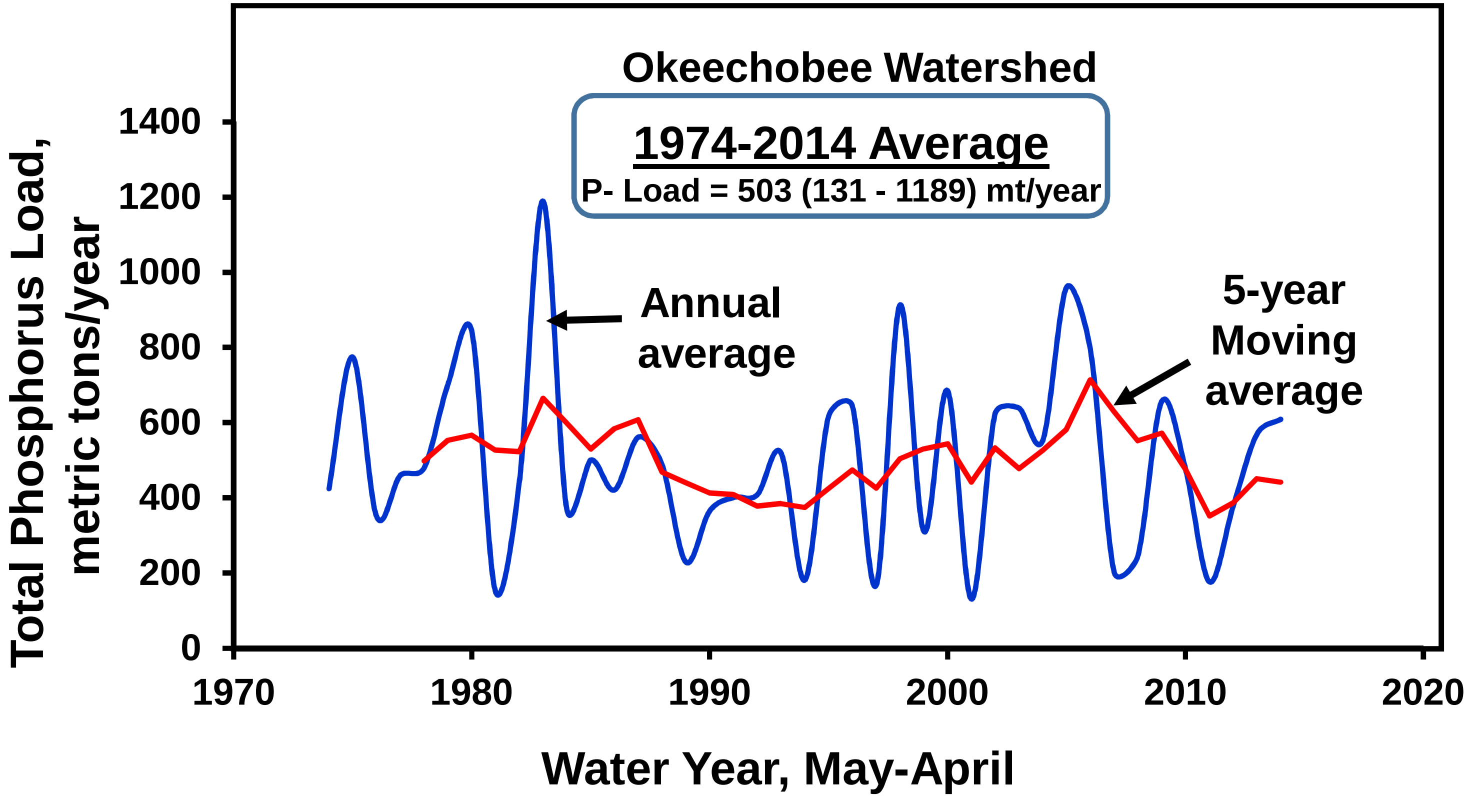
Reactive Phosphorus
- Inorganic P extracted with acid
- Organic P extracted with alkali

→ 65%

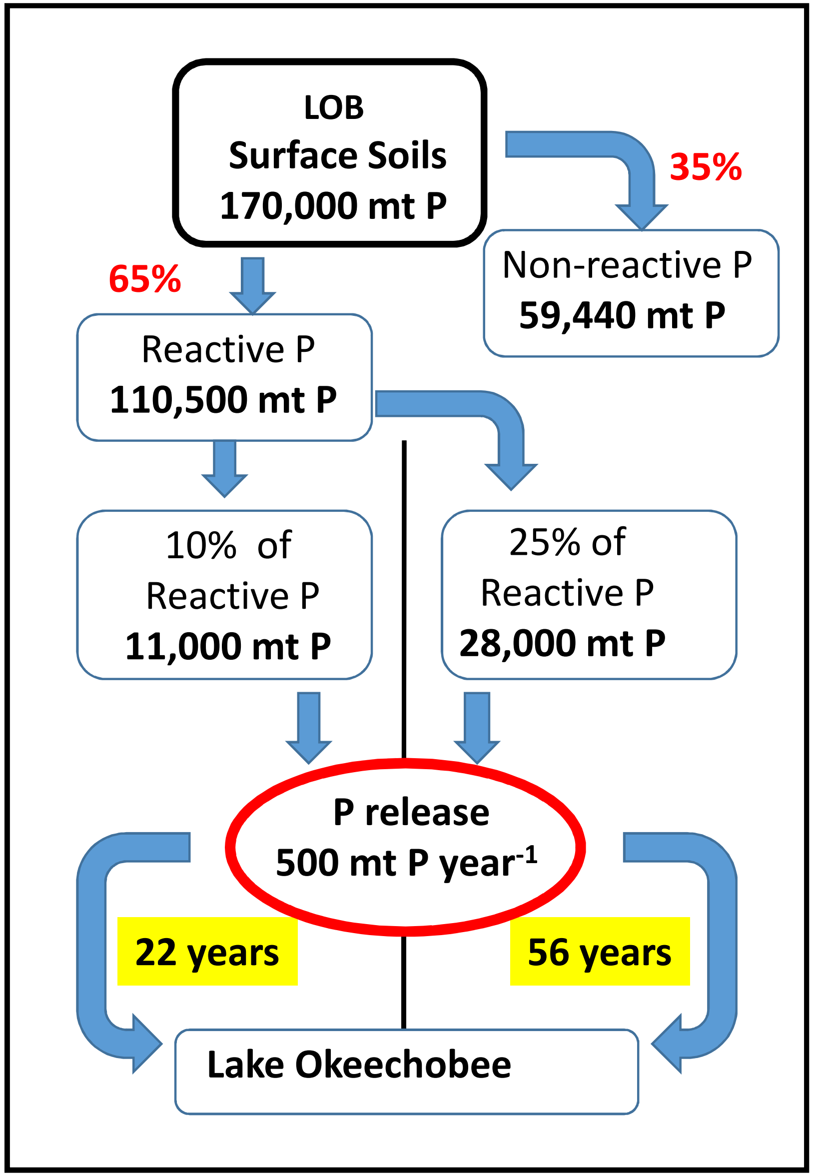
Non-reactive Phosphorus
- Total P – Reactive P

→ 35%

Northern Everglades

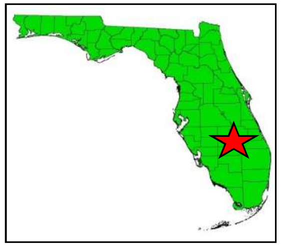


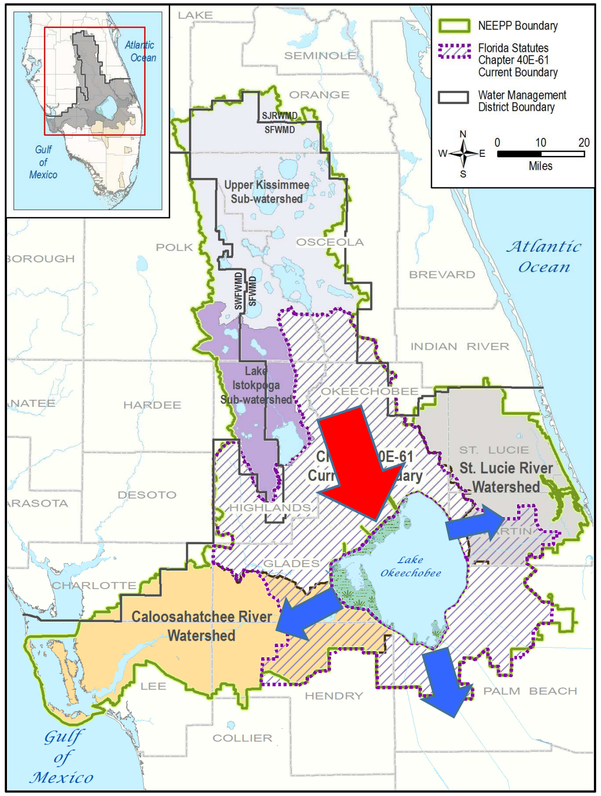
Phosphorus Loads to Lake Okeechobee -
500 metric tons per year [1974-2014]



Northern Everglades

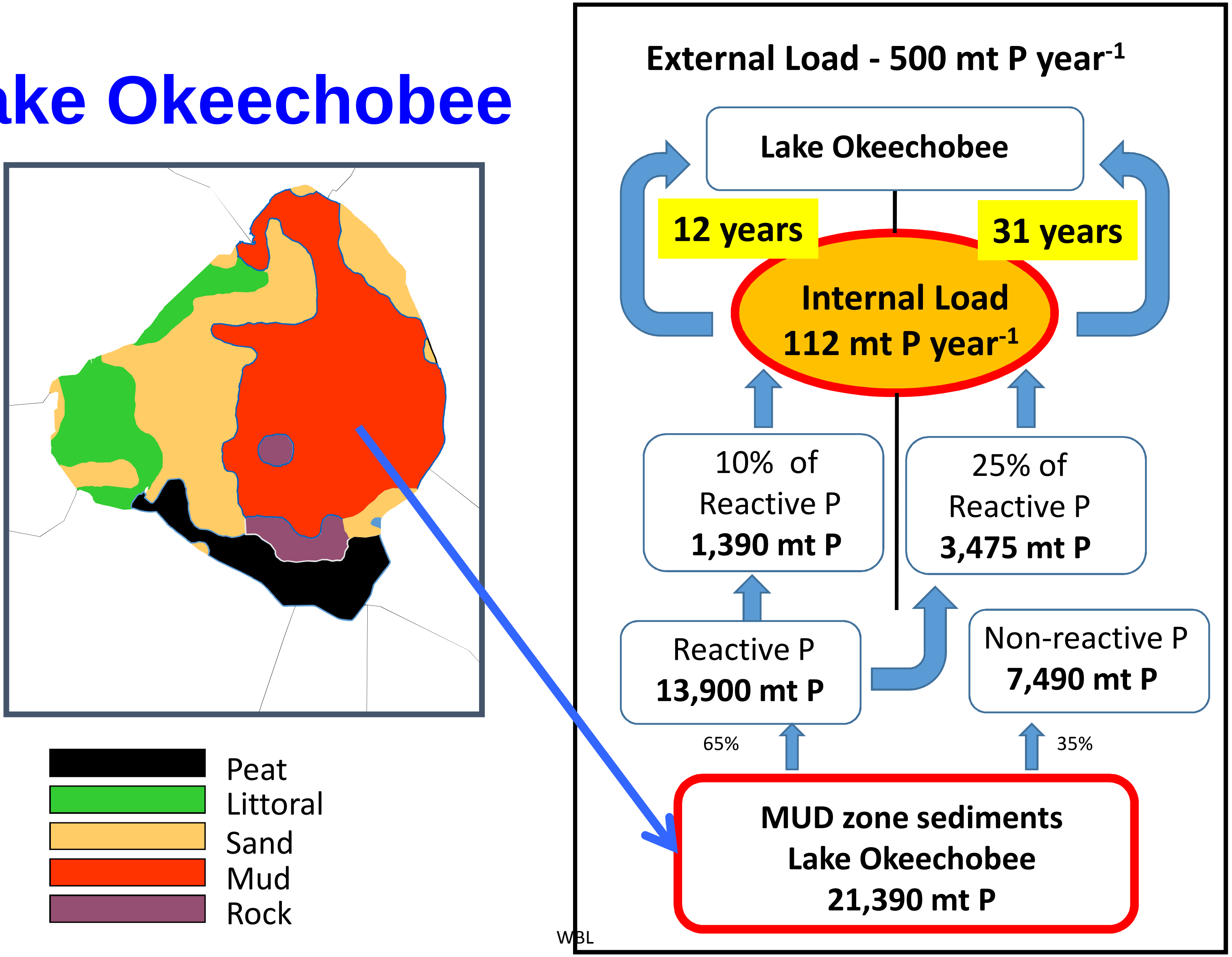
Legacy Phosphorus





WBL

Lake Okeechobee

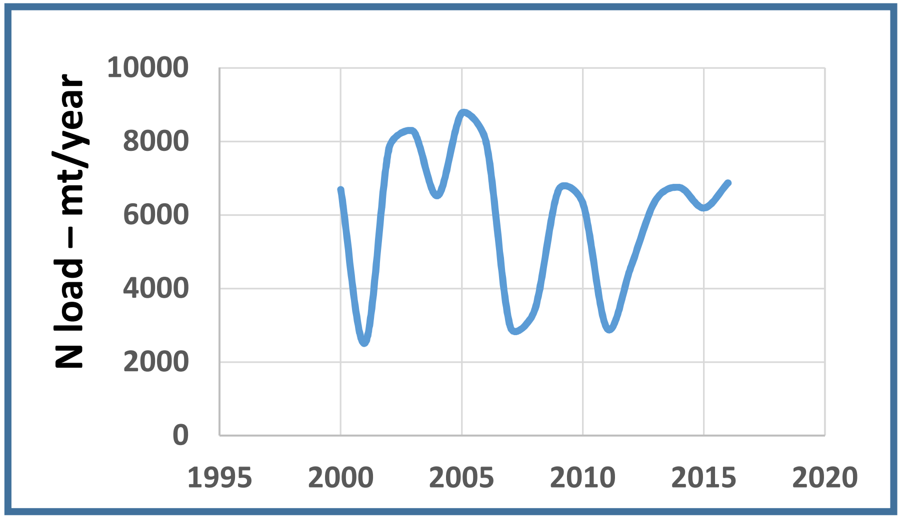


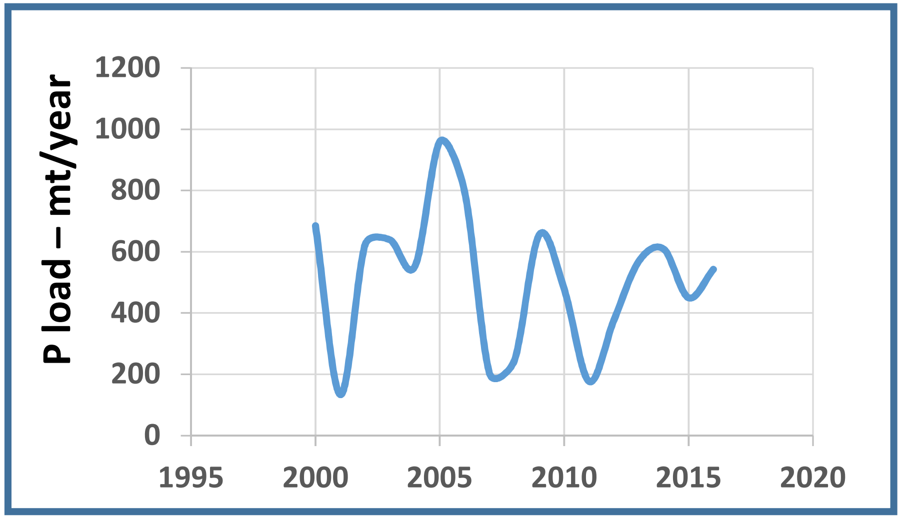
WBL

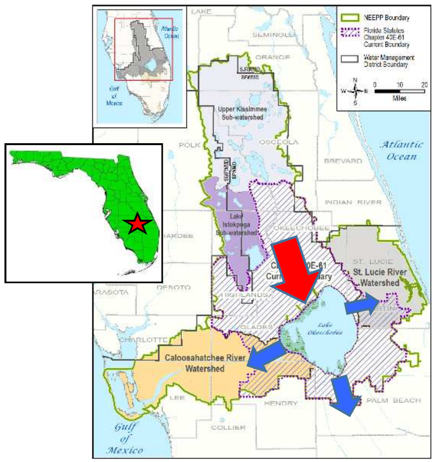
Annual Process Rates	External Inputs (watershed, groundwater, atmosphere)		
	$N:P \geq 23$	$23 > N:P > 9$	$N:P \leq 9$
Annual Net N_2 Flux in/out of Reactive N Pool	Annual average phytoplankton nutrient limit status		
$N_2 \rightleftarrows N_R$	1 N+P limited growth	2 N+P limited growth	3 Strongly N-limited growth
$N_2 \rightleftarrows N_R$	4 P-limited growth	5 N+P limited growth	6 N- or N+P-limited growth
$N_2 \rightleftarrows N_R$	7 Strongly P-limited growth	8 N+P limited growth	9 N+P limited growth

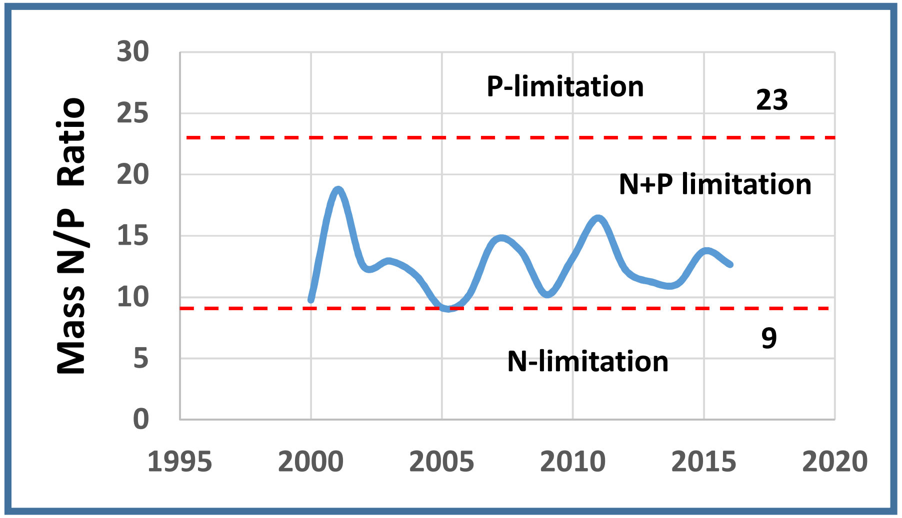
H. Pearl et al., 2016. Environ. Sci. Technol. 50: 10805-10813. DOI: 10.1021/acs.est.6b02575

Northern Everglades – Nitrogen & Phosphorus Loads









Restoration Implications

- ❖ Watershed legacy nutrients can increase the lag time for recovery… can extend for several decades
- ❖ In-situ remediation technologies are needed to reduce nutrient loads
- ❖ Constructed wetlands and riparian buffers are effective in reducing nutrient loads, but they must managed for long-term sustainability
- ❖ Nitrogen and P reactivity and mobility is linked to other associated elements

Sustainable Watershed Nutrient Management

- Long-term goals of watershed management should include conservation and enhancement of soil, water, air quality
- Policies to reduce nutrient loads from watersheds should seek to improve soil quality as a first step to improve water quality
- Integrated holistic approach is needed to manage watershed nutrients

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Soil & Water SCIENCES

Sustainable Watershed Nutrient Management

- Develop of watershed nutrient management practices that are compatible with extreme climatic change events
- Estimate economic values of watershed ecosystem services and tradeoffs associated with changes in landuse and nutrient management practices
- Protecting soil quality, like protecting air and water quality, should be a fundamental goal of national environmental policy

"The nation that destroys its soil, destroys itself." - Franklin Delano Roosevelt


http://soils.ifas.ufl.edu
E-mail: krr@ufl.edu