Sediment Nutrient Release – It's Not Just for Eutrophic Lakes!

Implications for Surface Water Restoration

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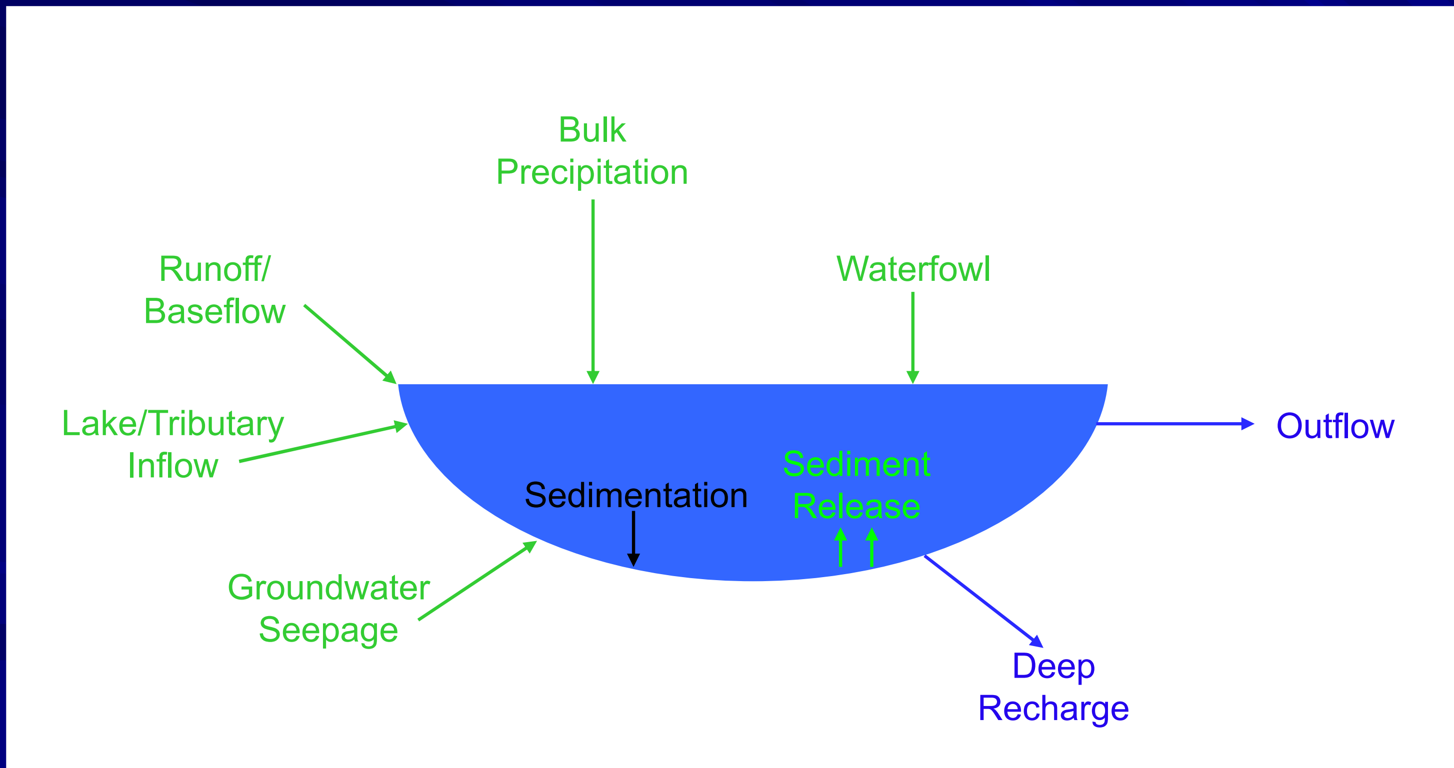
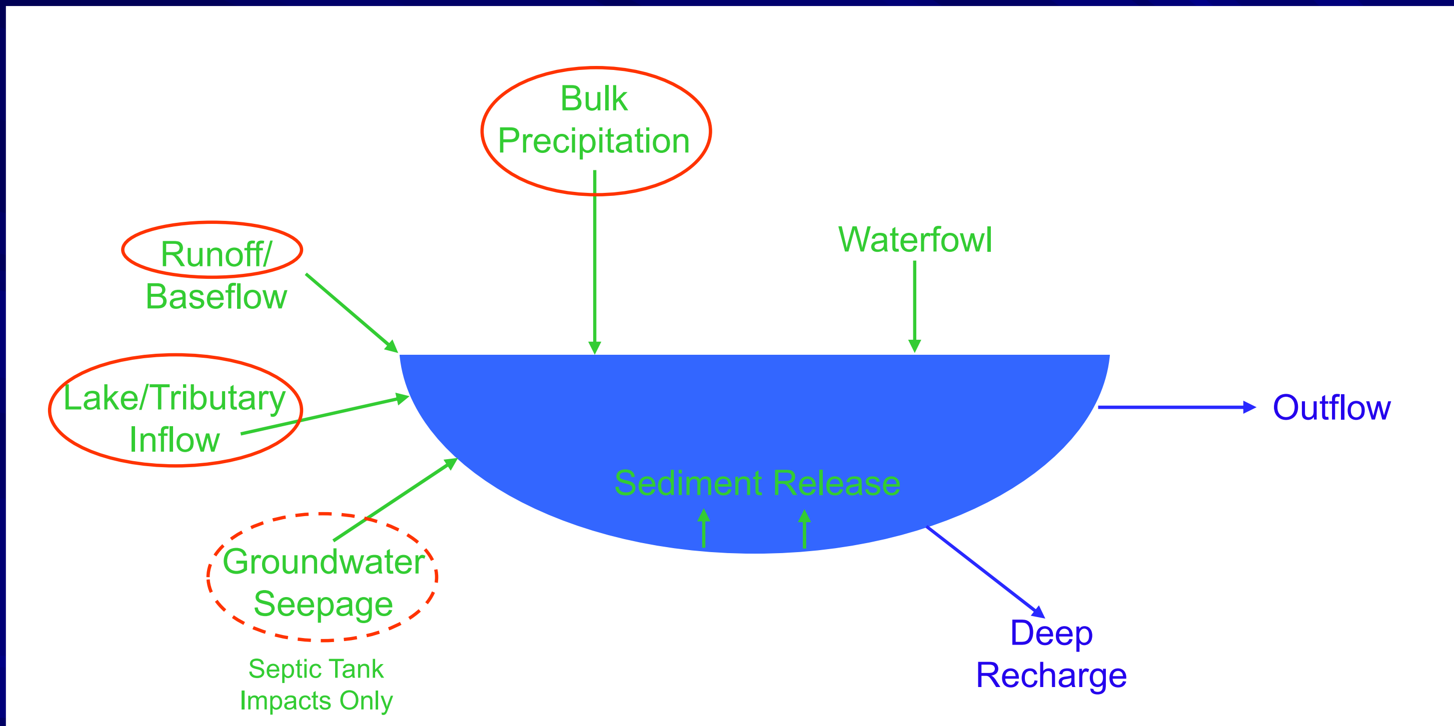
Typical Nutrient Inputs/Losses to Waterbodies



Typical Nutrient Inputs Included in Florida TMDL Evaluations

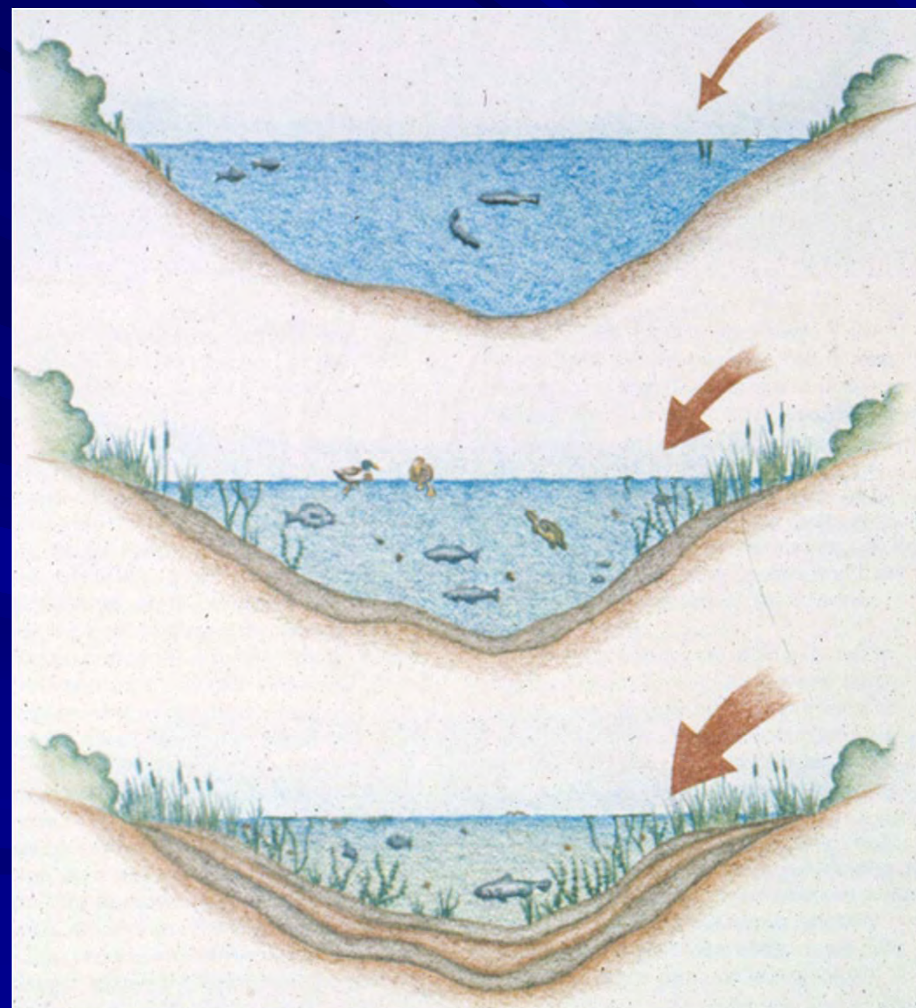


Stages in Lake Aging

Newly formed lake
- few nutrients
- low productivity
- little sediment

Middle aged lake
- increasing nutrients
- moderate prod.
- increasing sediment
- decreasing depth

Aging lake
- high nutrients
- high productivity
- deep sediments
- plant invasions
- algal blooms



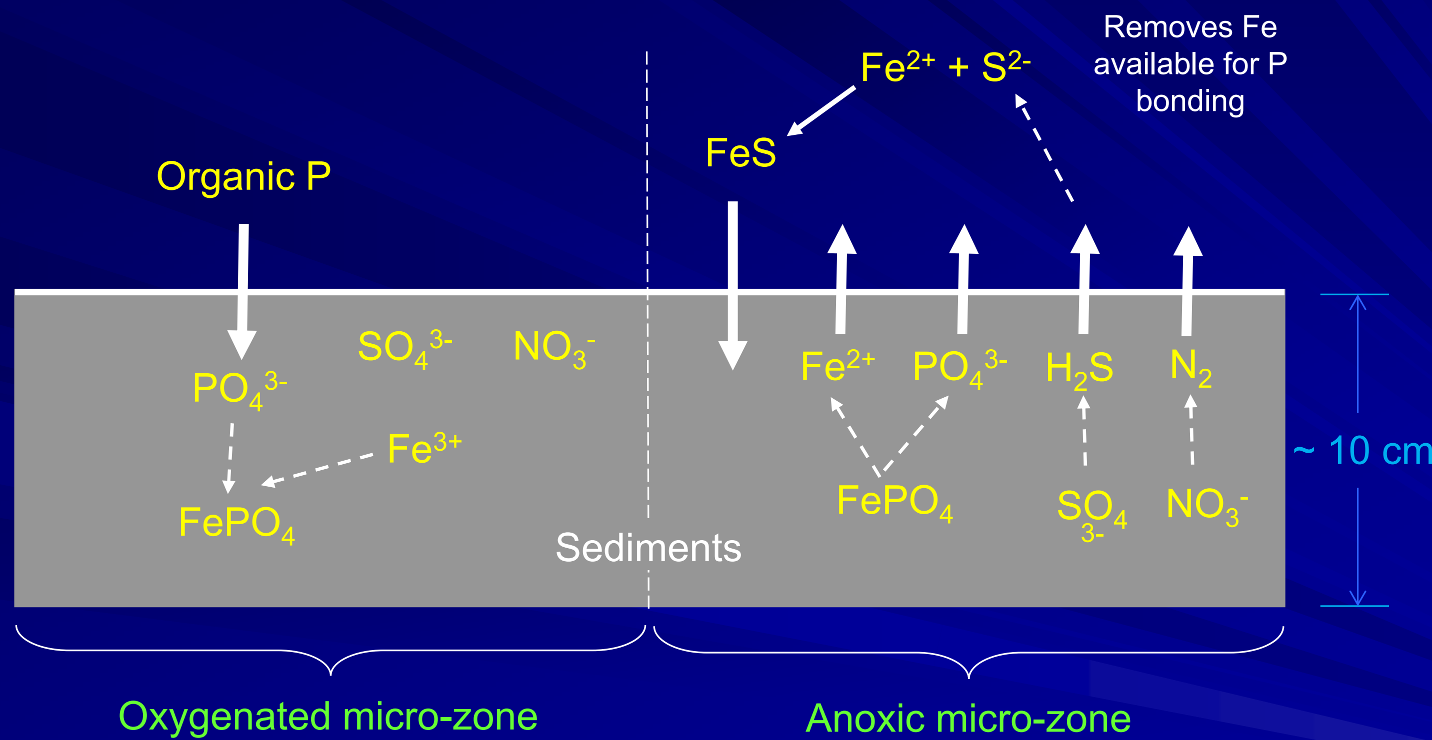
Sedimentation in Lakes

- Deposition and accumulation of organic and inorganic matter
  - Internal sources
  - Rainfall deposition
  - Watershed inflows
  - Biological
    - Plants
    - Aquatic organisms
- Lake sediments are an important, integral part of the lake ecosystem
- Sediments reflect changes in land-use and lake characteristics
  - Can be used as an historical archive
  - Affect the structure and function of lake ecosystem
- Organic matter is decomposed by micro-organisms
  - Process consumes oxygen, often creating anoxic conditions
  - Releases N and P stored in organic matter
  - Nutrients enter sediment pore water in soluble form

Phosphorus Bonding in Sediments

- Released soluble P is present as both inorganic and organic ions
- P in lake sediments is generally bound in associations with one of the following:
  - Iron and manganese
    - Inorganic precipitates
    - Adsorption onto metal oxides
    - Stability depends on redox potential
  - Calcium
    - Inorganic precipitates – pH > 10
  - Aluminum
    - Inorganic precipitates
    - Adsorption onto metal oxides
  - Organic matter
    - Fresh matter – decomposes relatively quickly
    - Recalcitrant matter – resistant to further decomposition
- Significance of an association depends on geology of the watershed and lake

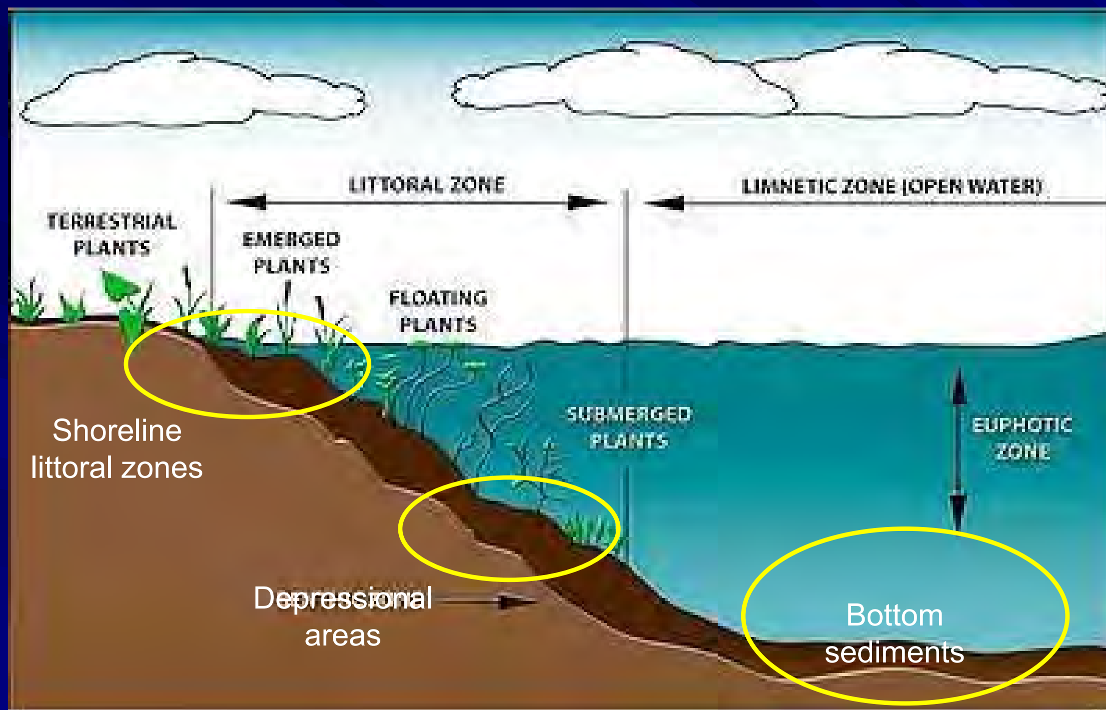
Significant Reactions at the Water-Sediment Interface



Whether or not an oxygenated micro-zone is maintained depends on:

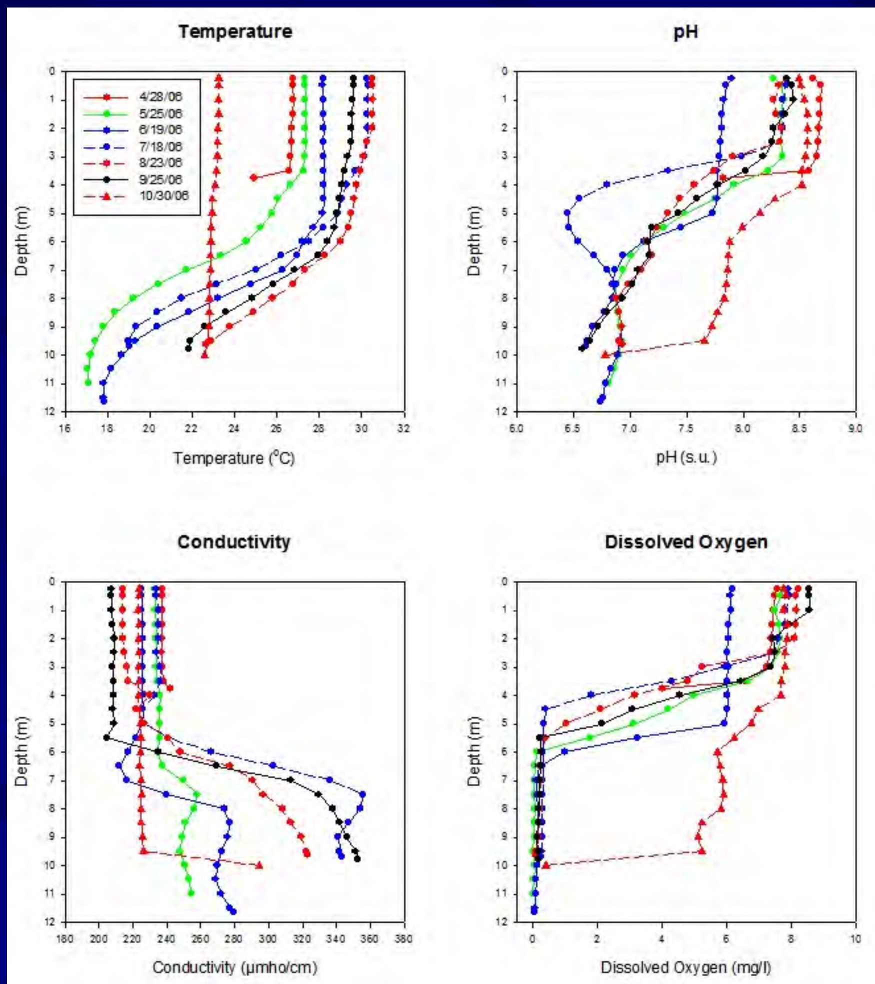
- rate of oxygen supply to the sediments
- turbulent mixing of surficial sediments
- oxygen demand of the sediments

Anoxic Areas in Lakes



- Anoxic zones occur in multiple areas of a lake

Vertical Field Profiles
in Lake Pineloch from April – October 2006

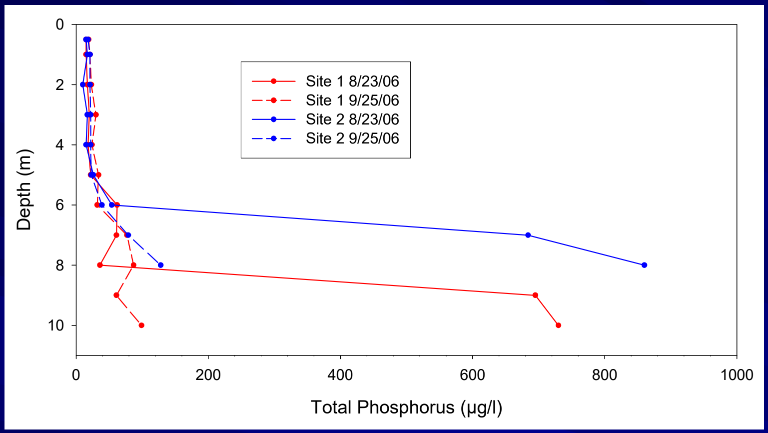


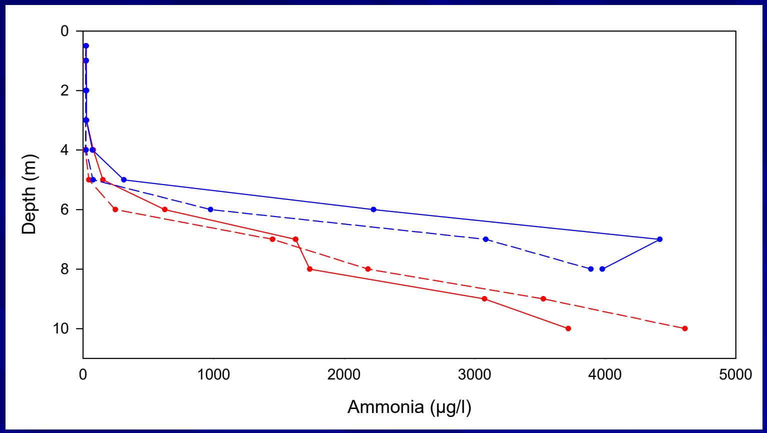
Eutrophic Lake

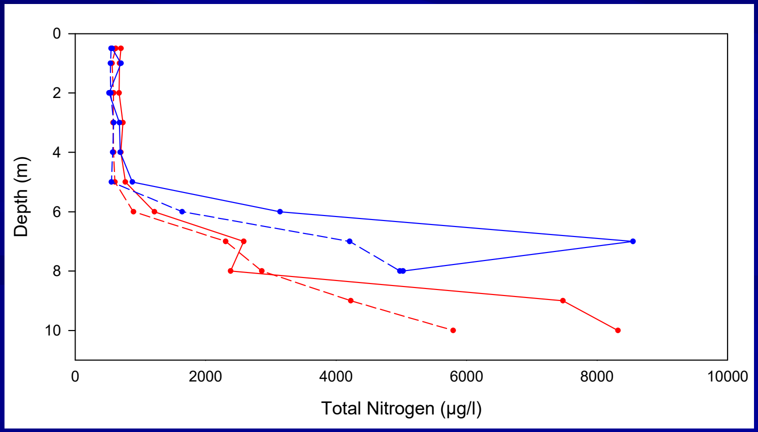
-Exhibits classic symptoms of a lake with high potential for internal recycling

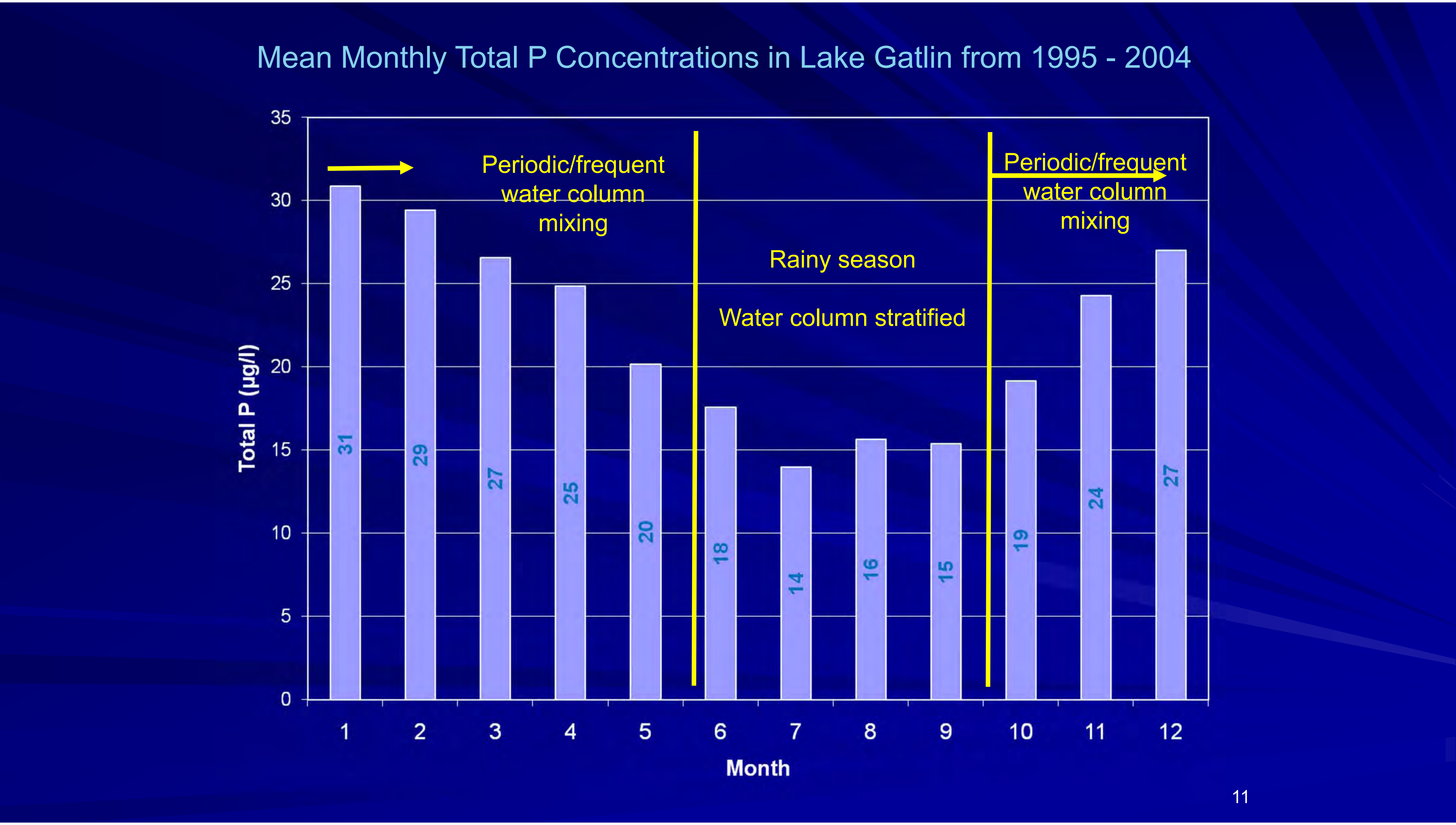
-significant thermal stratification
-high pH at surface with sub neutral pH near bottom
-anoxic hypolimnion
-conductivity increase in hypolimnion suggest internal recycling

Vertical Variability in Water Quality in Lake Pineloch





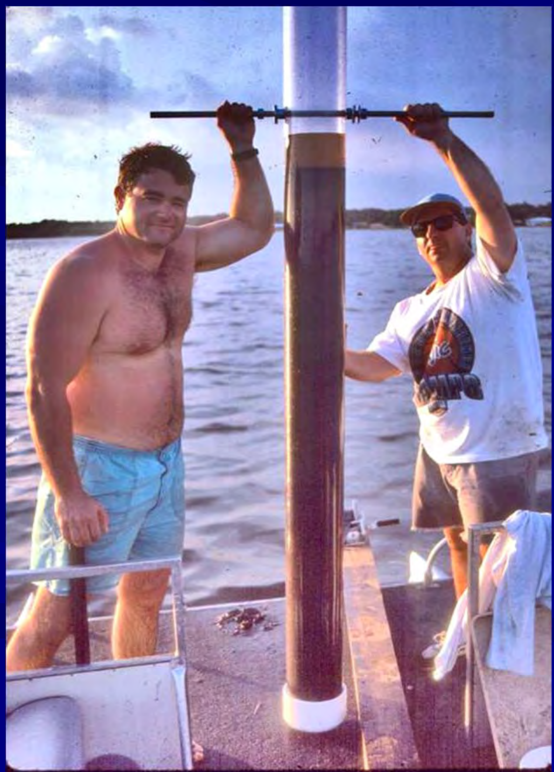




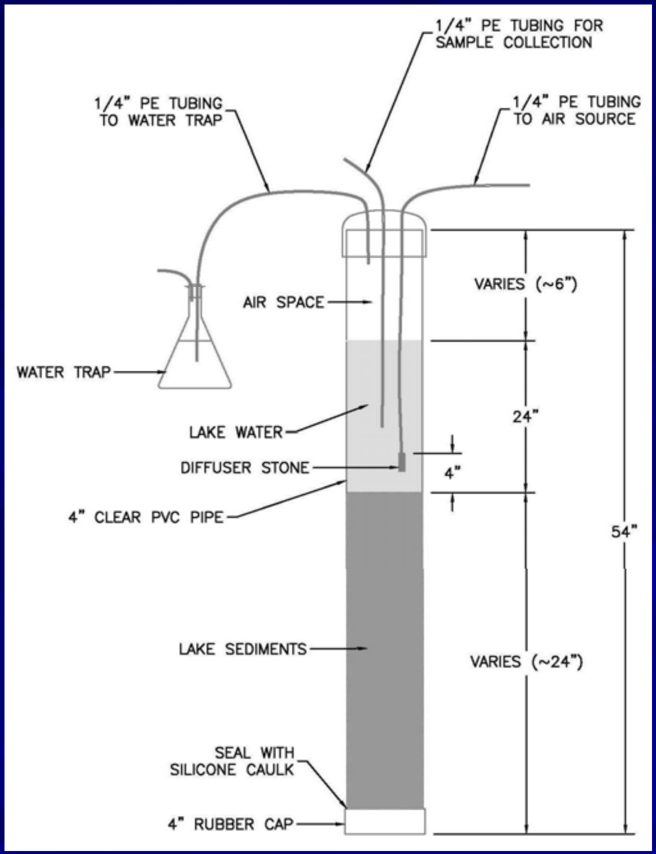
Mean Monthly Total P Concentrations in Lake Gatlin from 1995 - 2004
Periodic/frequent water column mixing
Rainy season
Water column stratified
Periodic/frequent water column mixing
Total P (µg/l)
Month
0
5
10
15
20
25
30
35
1
2
3
4
5
6
7
8
9
10
11
12
31
29
27
25
20
18
14
16
15
19
24
27

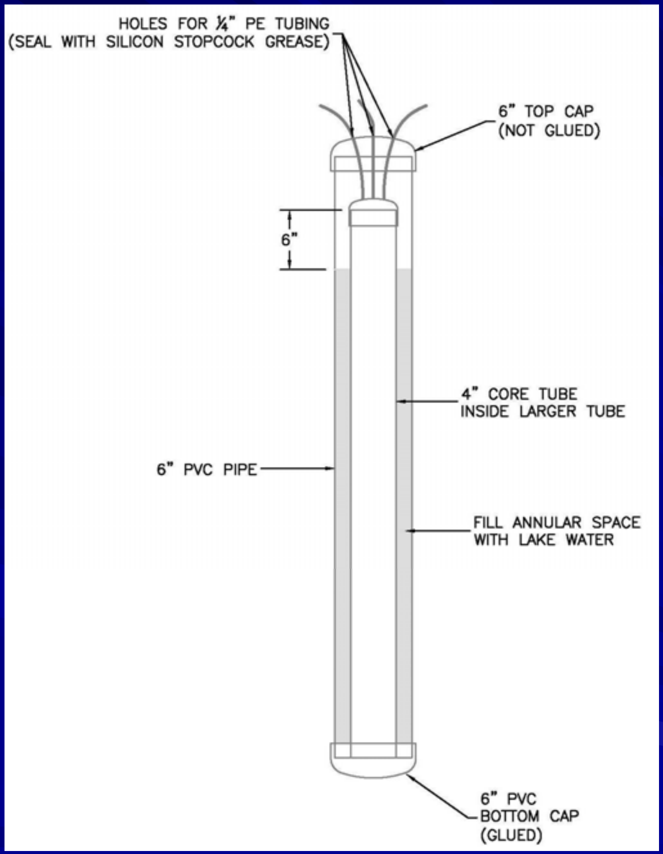
Quantification of Internal P Recycling

- Large diameter core samples collected at multiple locations
- Core samples incubated under aerobic and anoxic conditions
- Samples collected periodically and analyzed for P



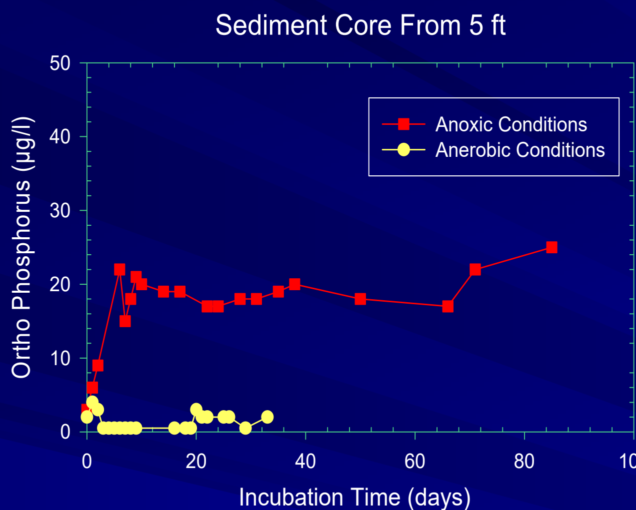
Schematic of Sediment Incubation Apparatus

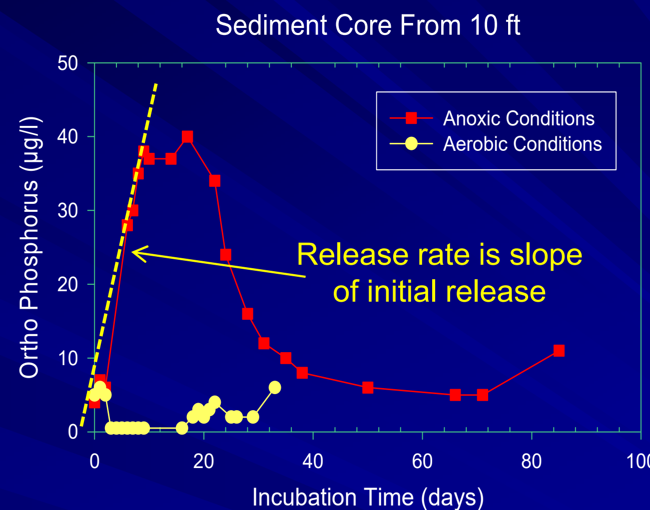


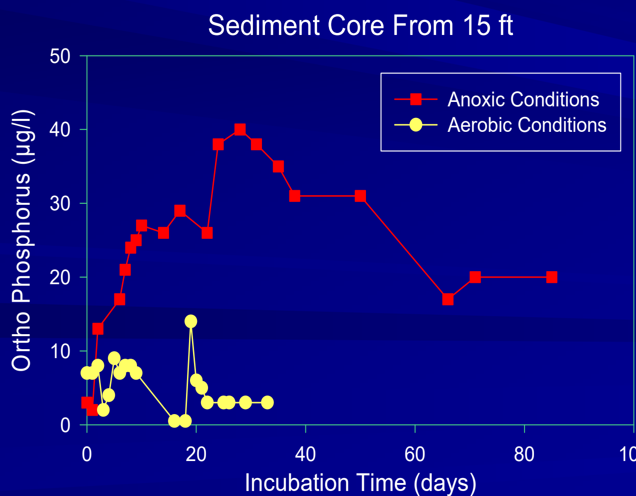


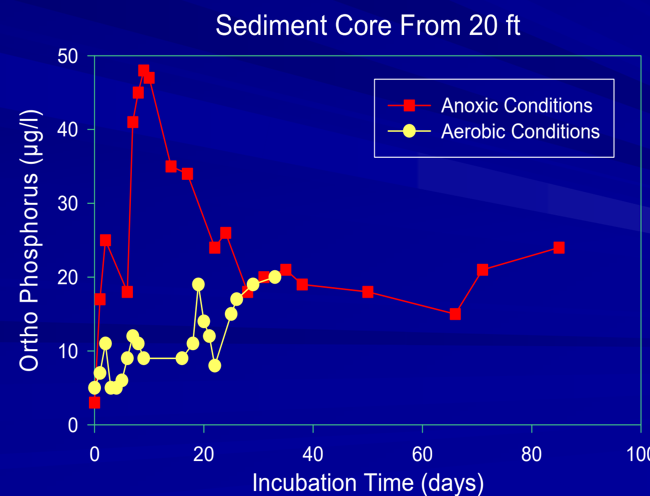
- ERD has conducted measurements of sediment benthic release rates in more than 50 Florida lakes

LAKE MAITLAND ISOLATION EXPERIMENT
ORTHO PHOSPHORUS CONCENTRATIONS

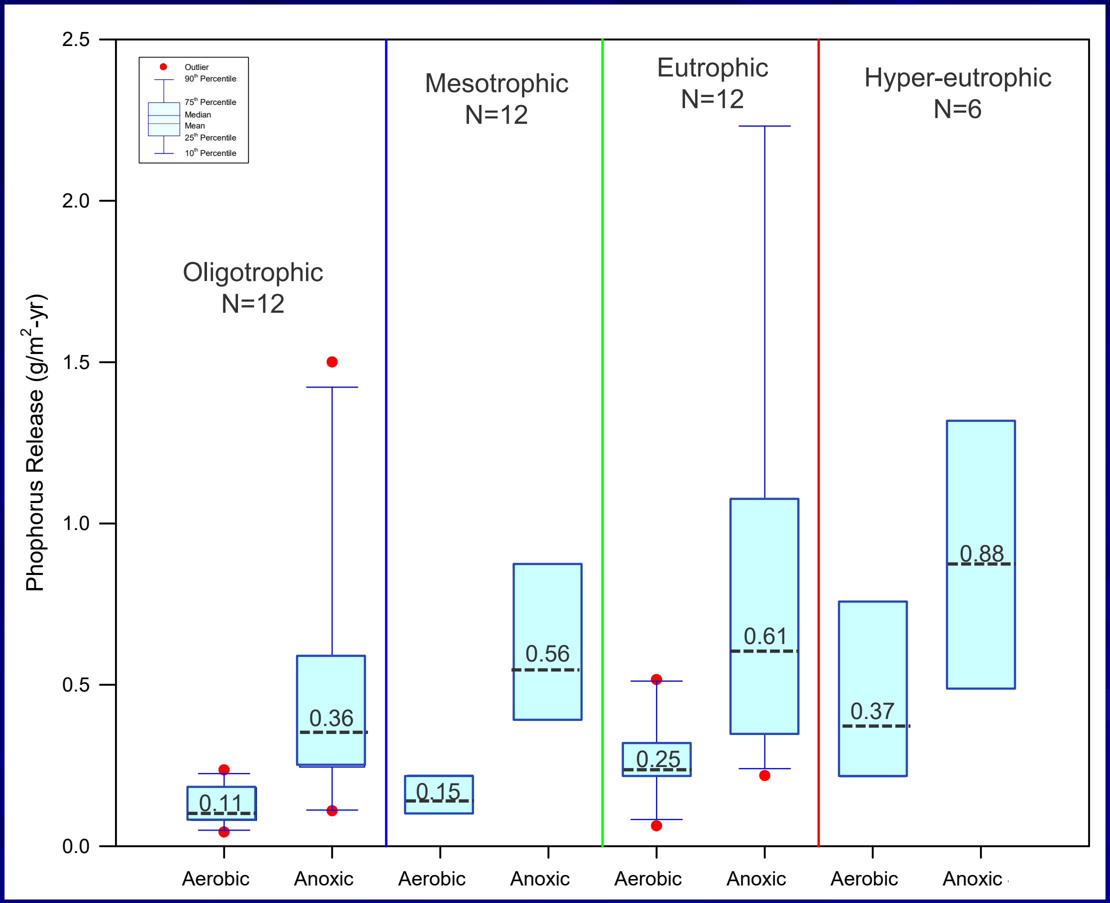






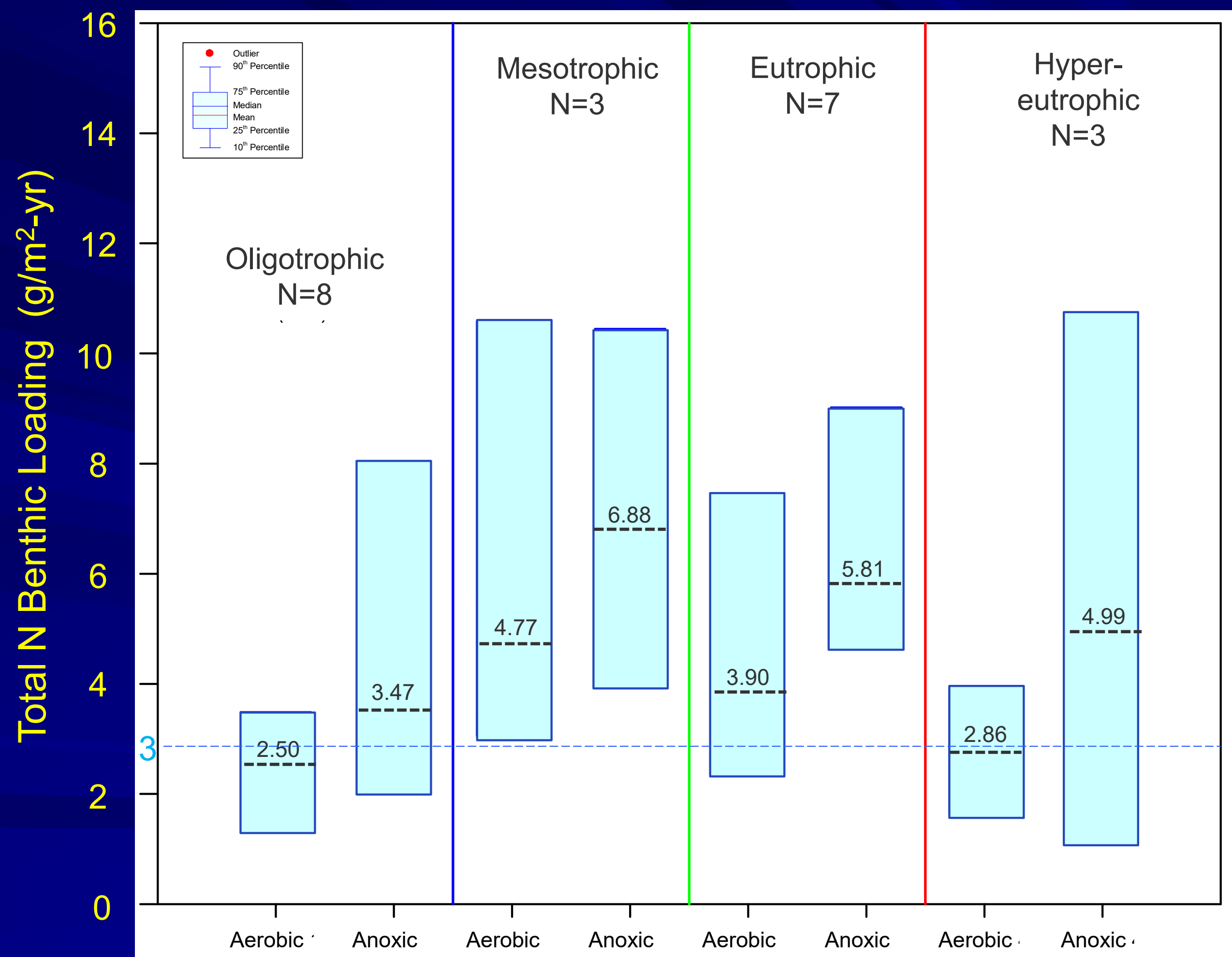


TP Benthic Release by Trophic Status
(42 lakes)



- TP benthic release increases with trophic status

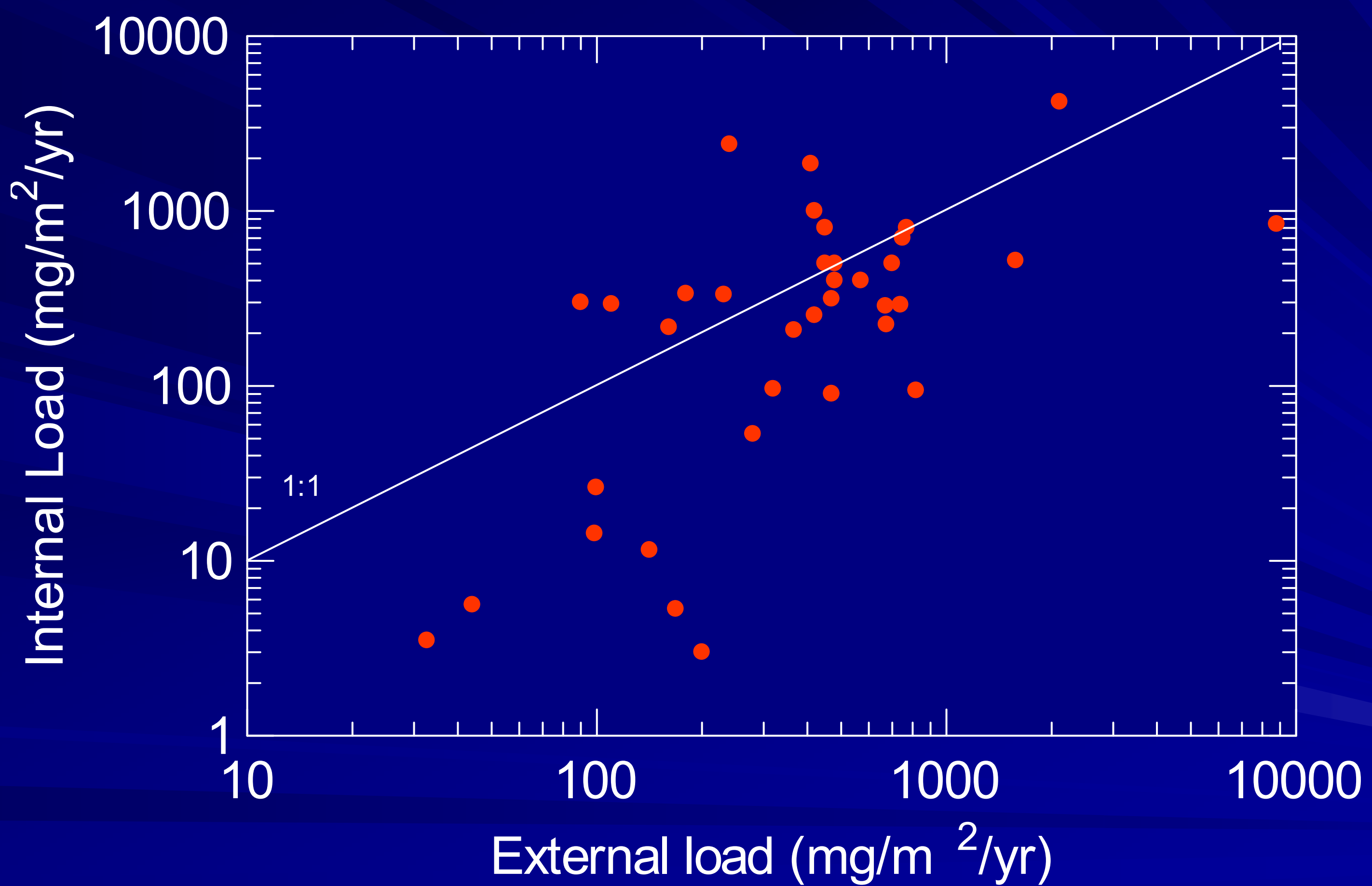
TN Benthic Release by Trophic Status



Geometric Mean Nutrient Recycling Rates by Trophic Status

Trophic Status	Recycling Rate (g/m^2/yr)			
	Total P		Total N	
	Aerobic	Anoxic	Aerobic	Anoxic
Oligotrophic	0.11	0.36	2.50	3.57
Mesotrophic	0.15	0.56	4.77	6.88
Eutrophic	0.25	0.61	3.90	5.81
Hyper	0.37	0.88	2.86	4.99

Internal Versus External P Load

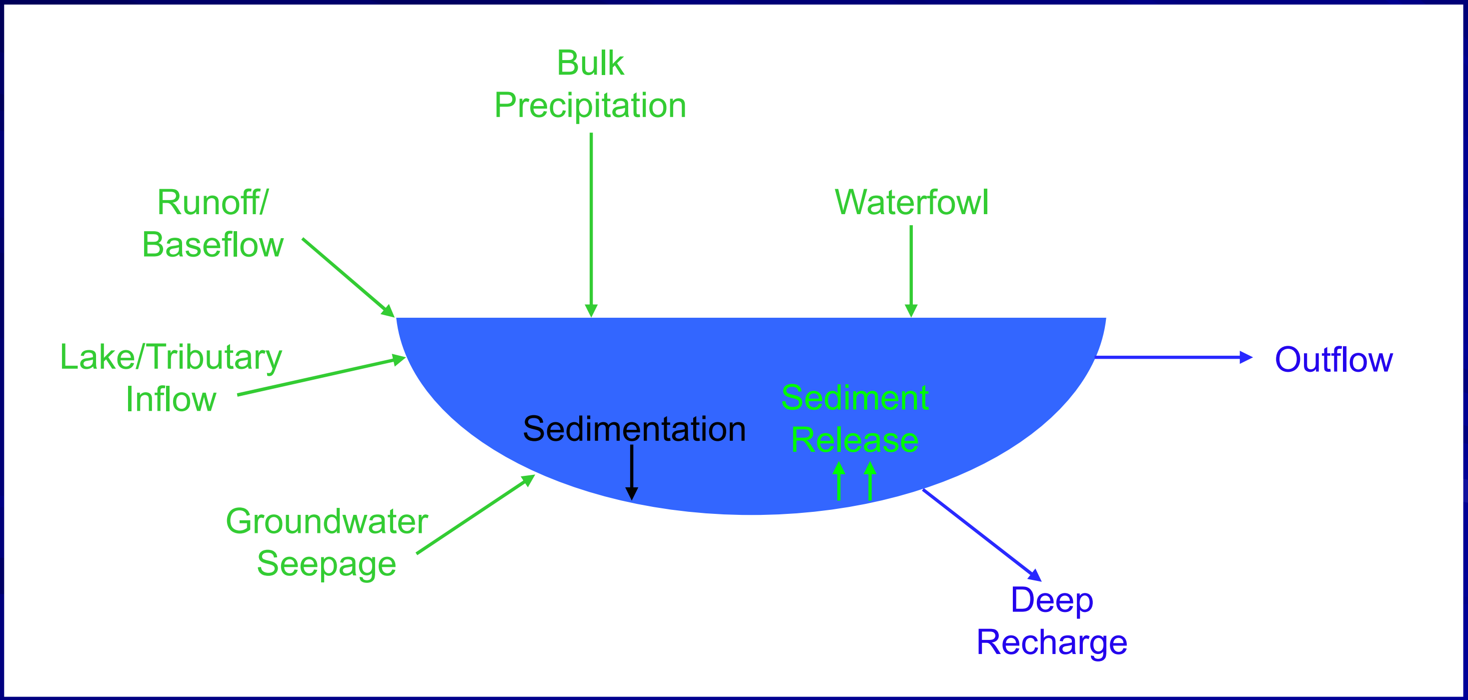


Nürnberg & LaZerte 2001

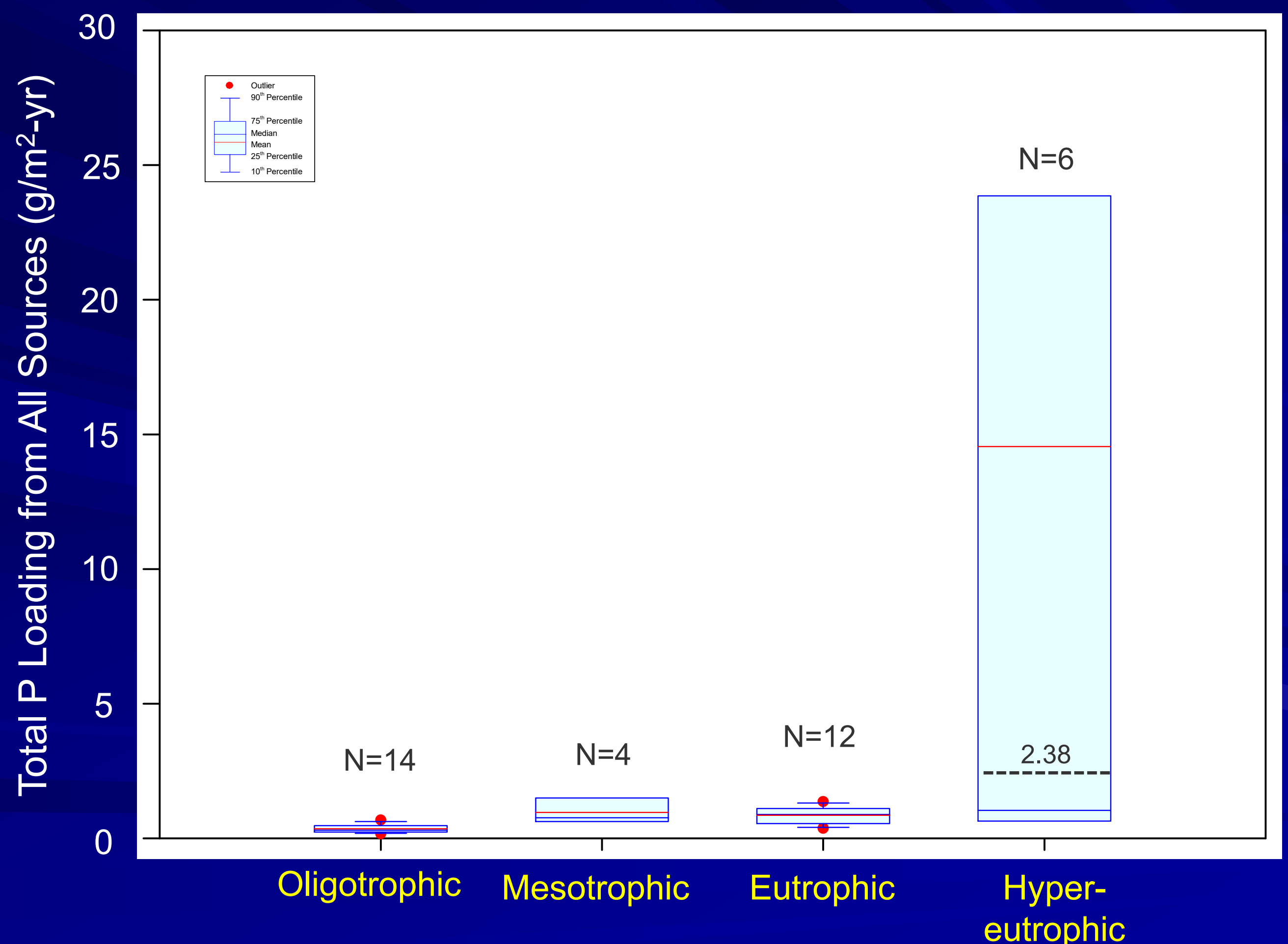
If a lake has high external loading, then it also has a high internal loading

Evaluating Nutrient Inputs/Losses

- ERD has conducted hydrologic/nutrient budgets on more than 50 Florida lakes
- All studies have included the sources listed below

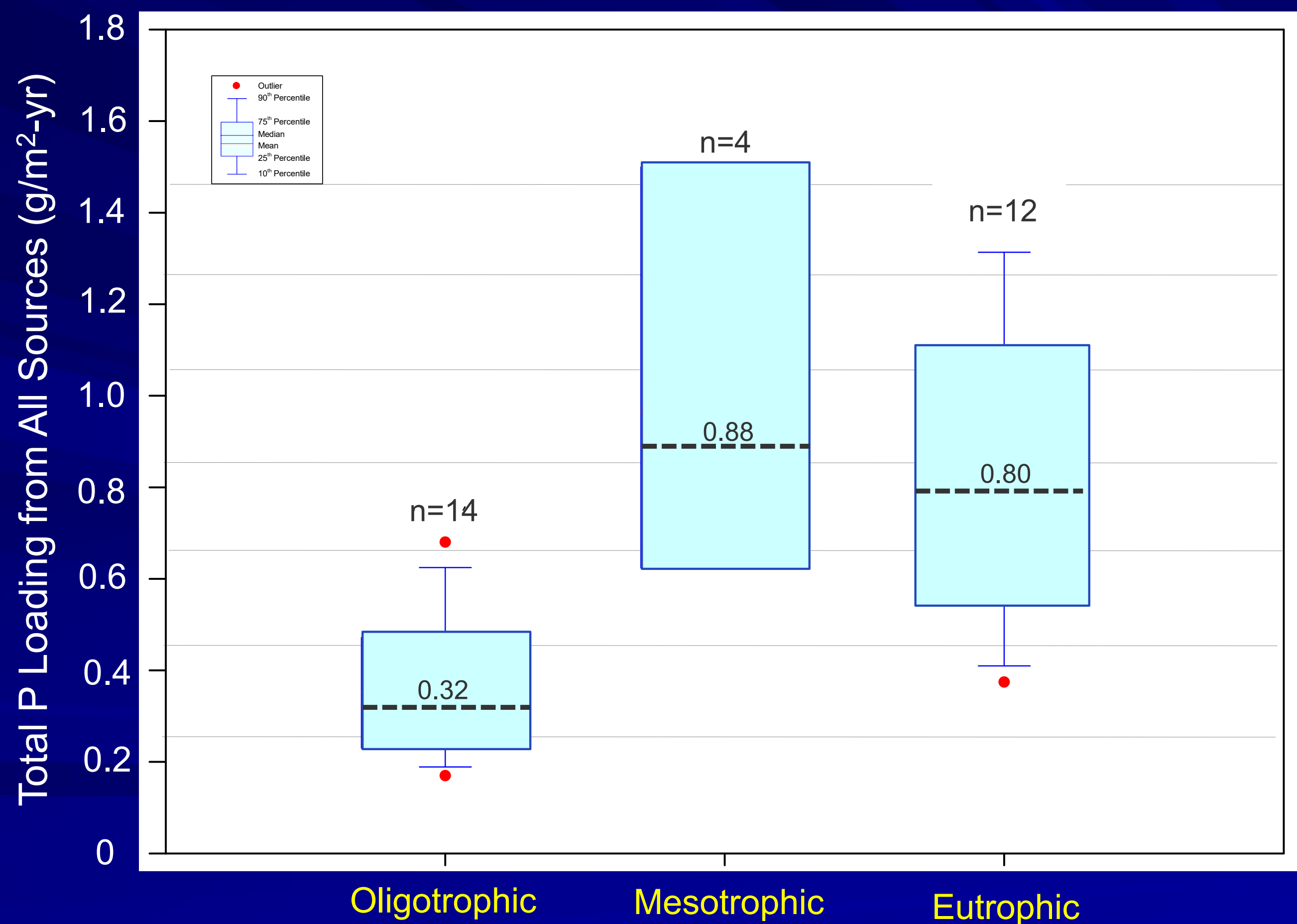


Overall Total P Loading by Trophic Status
(36 lakes)

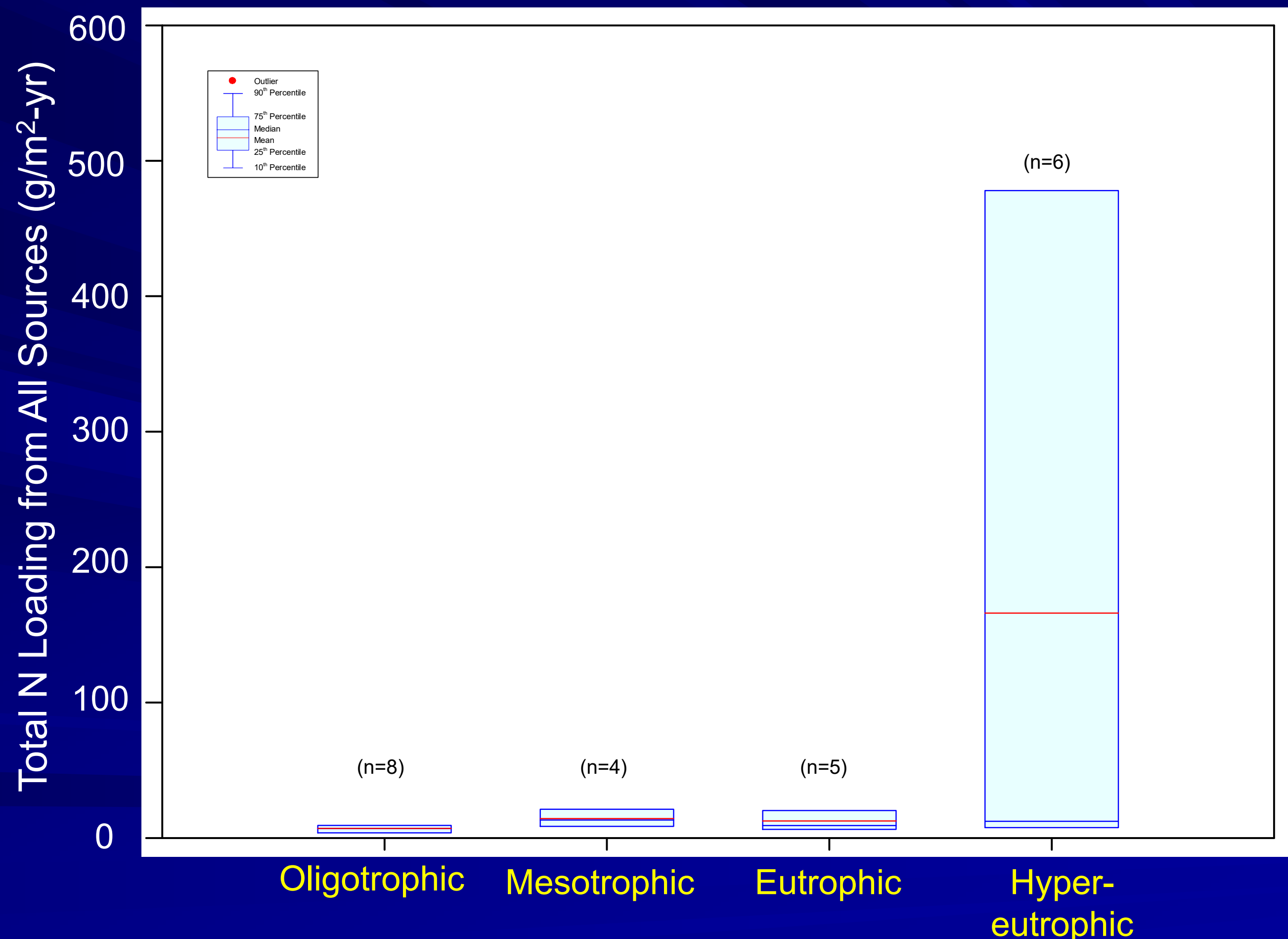


Overall Total P Loading by Trophic Status

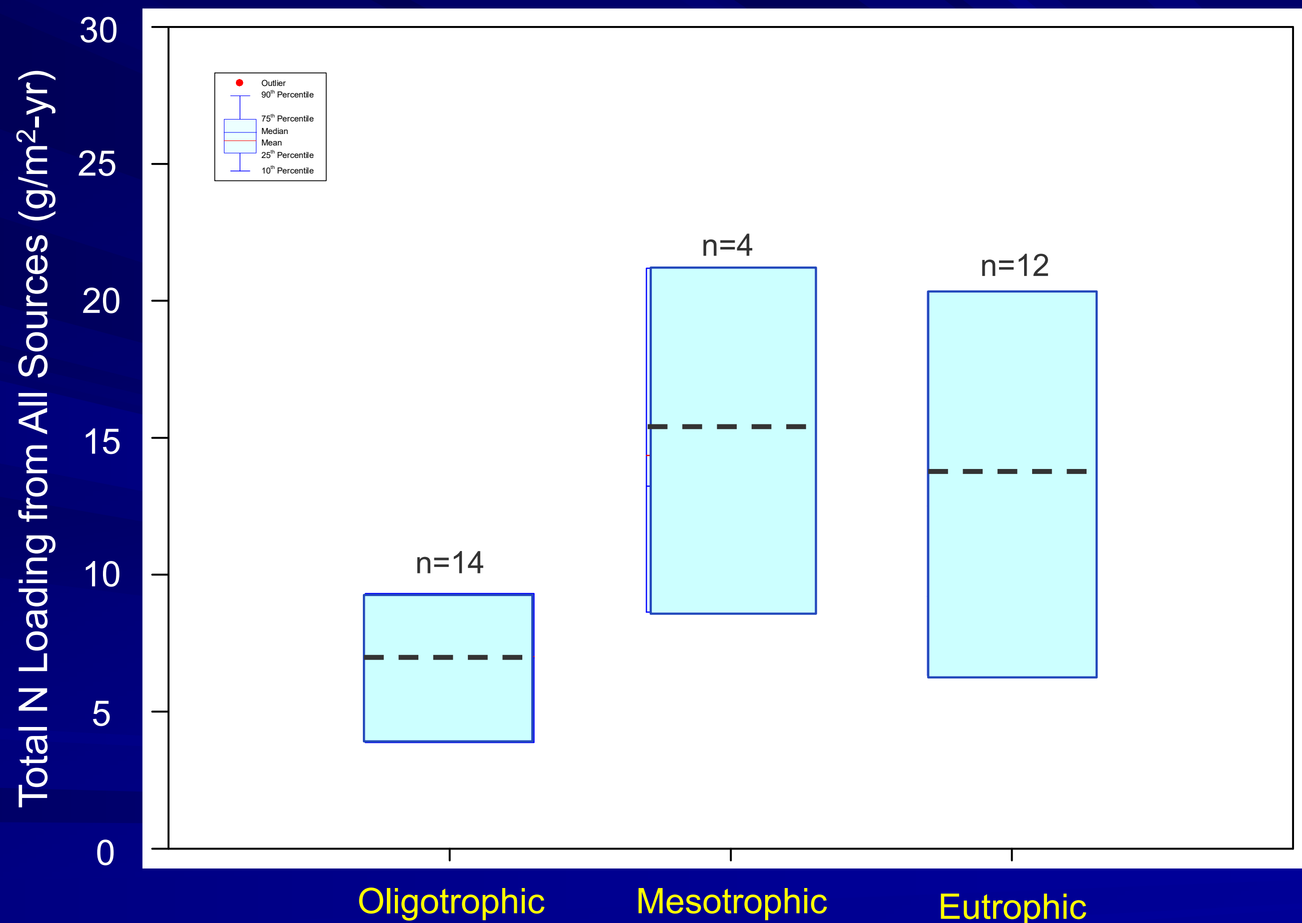
(All Sources)



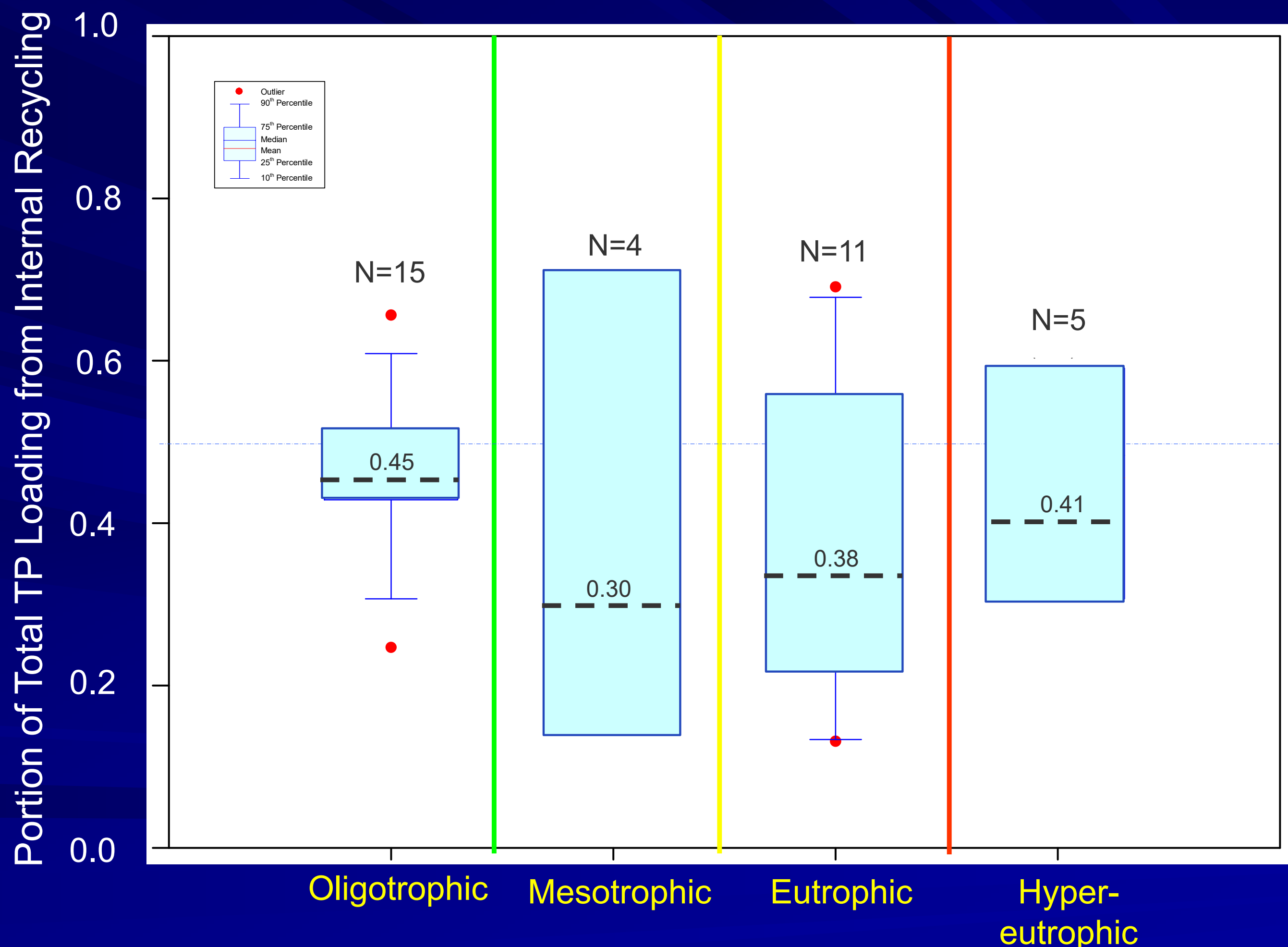
Overall Total N Loading by Trophic Status



Overall Total N Loading by Trophic Status



Fraction of Total TP Loading Contributed by Recycling



Significance of Runoff vs. Recycling Loadings Evaluation Assumptions
(Watersheds with Little Treatment)

- Calculations were conducted to compare TP loadings from runoff and recycling

Runoff Assumptions

Parameter	Units	Value
Lake Area	acres	100
Watershed C Value	-	0.25
Rainfall	in/yr	50
Runoff TP Conc.	mg/L	0.250

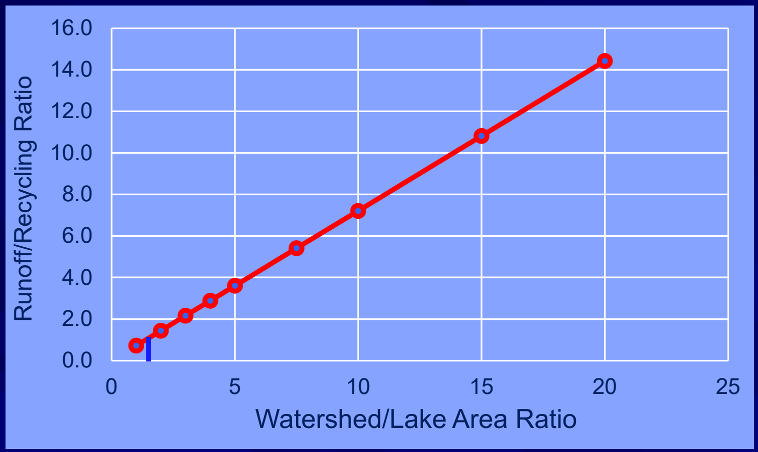
Geometric Mean Nutrient Recycling Rates by Trophic Status

Trophic Status	Recycling Rate (g/m^2/yr)					
	Total P			Total N		
	Aerobic	Anoxic	Mean	Aerobic	Anoxic	Mean
Oligotrophic	0.11	0.36	0.11	2.50	3.57	2.5
Mesotrophic	0.15	0.56	0.29	4.77	6.88	5.5
Eutrophic	0.25	0.61	0.49	3.90	5.81	5.2
Hyper	0.37	0.88	0.88	2.86	4.99	5.0

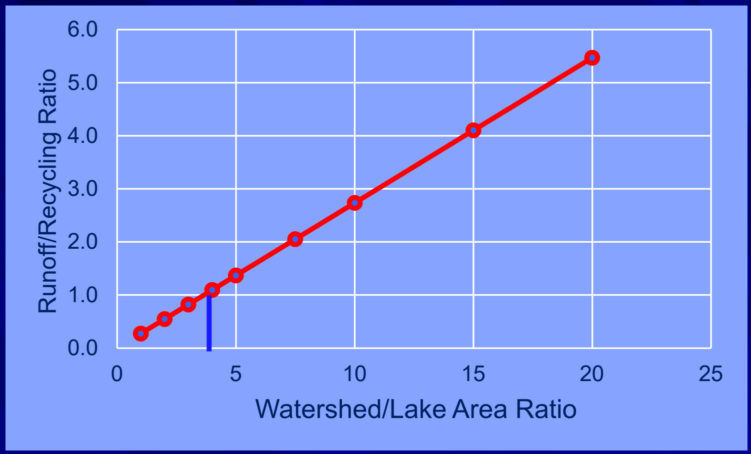
Assumptions

- Oligotrophic sediments – 100% aerobic
- Mesotrophic sediments – 75% aerobic, 25% anoxic
- Eutrophic sediments – 25% aerobic, 75% anoxic
- Hyper-eutrophic sediments – 100% anoxic

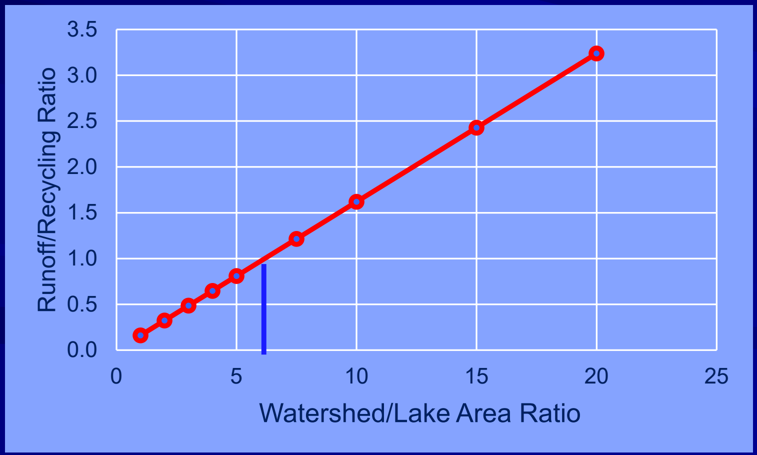
Significance of Runoff vs. Recycling Loadings



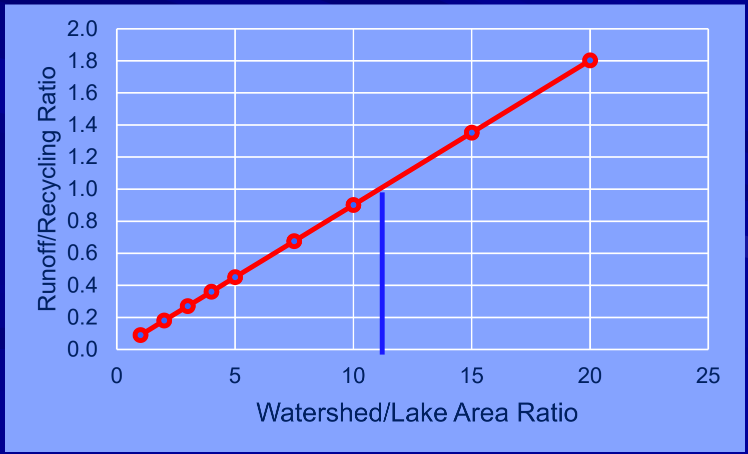
Oligotrophic Lakes



Mesotrophic Lakes



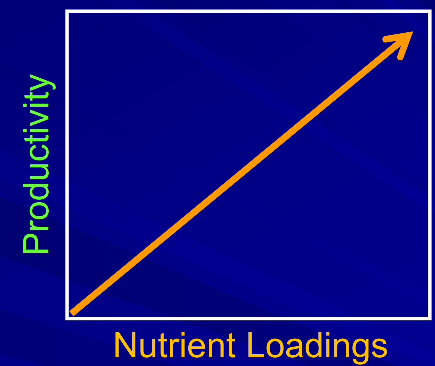
Eutrophic



Hyper-eutrophic

TMDL Approach

- The current TMDL process ignores many significant sources of nutrient loadings to waterbodies
  - Internal recycling
  - Groundwater seepage
  - Baseflow



- Water quality model is developed which assumes a relationship between nutrient loadings and productivity

- Over-emphasizes the significance of runoff loadings
  - Many models overestimate runoff loadings
  - Models are often calibrated by increasing runoff to account for missing components

Stormwater Management as a Cure-All

- Managing and treating stormwater has become institutionalized and a large stormwater industry has developed
- Since stormwater caused the problems, then the approach assumes that runoff must be treated to restore waters
  - Virtually every TMDL in Florida is based on reducing runoff loadings
- In most eutrophic lakes, runoff is not the most significant loading source
- Narrow focus on reducing runoff loadings
  - Almost a punitive approach
- Stormwater management has become a large industry
- Focus more on accounting and numbers than water quality goals

Management of Internal Recycling
(Sediment Removal)

- Sediment removal is a technique used when sediments:
  - Negatively impact water quality
  - Impact navigation or recreational activities
- Multiple methods of sediment removal
  - Drawdown and mechanical removal
  - Mechanical dredging
  - Hydraulic dredging
    - Hydraulic dredge with rotating cutterhead sucks up sediments and generates a water-sediment slurry
    - Slurry is pumped to a dewatering area
    - Expensive - $2500 – 5000/kg TP



Management of Internal Recycling
(Alum Sediment Inactivation)

-Clear, light green to yellow solution, depending on Fe content

-Liquid is 48.5% solid aluminum sulfate

-Specific gravity = 1.34

-11.1 lbs/gallon

-Freezing point = -15° C

-Delivered in tanker loads of 4500 gallons each

Floc Settling in a Shallow Lake

- Alum floc initially settles onto the top of the loose surficial layer

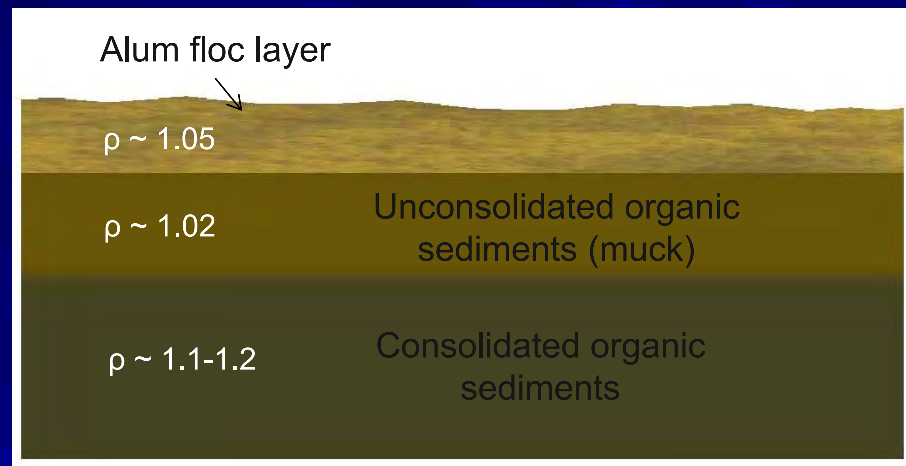
- Floc migrates downward over time into unconsolidated sediment layer

- If the alum treated sediment re-suspends as a result of wind or boating activities, then it will quickly settle back

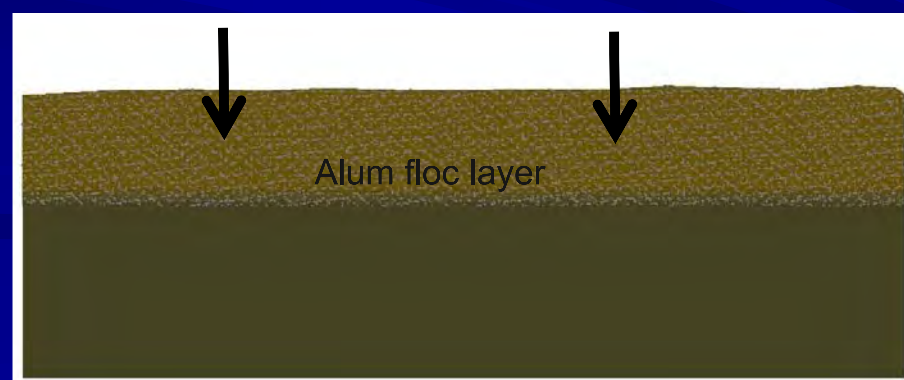
- This will have no impact on the effectiveness since the sediment P will be adsorbed onto the floc

- Since the alum floc still maintains effectiveness, floc re-suspension may adsorb and remove additional P from the water column

Floc initially settles onto the surface of the sediments



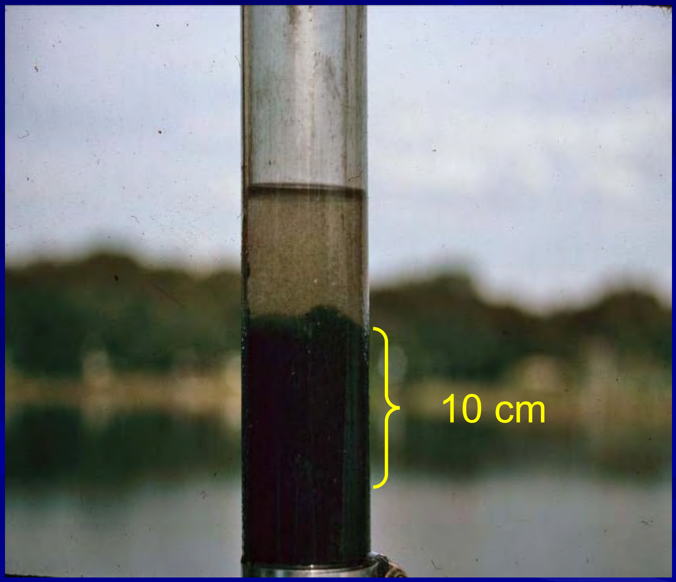
Floc migrates downward over time



Lake Davis ~ 1992 (No. 3)

Alum Dose Calculation

- A new approach for determining alum dose was developed for Lake Davis
- Based on available P in sediments
- Soil speciation scheme modified for sediments and used to determine the available P in sediment cores
- Diffusion of sediment P is limited to the top 10 cm of sediments
- The 0-10 cm layer of the sediments was sectioned off and speciated for available P
- Sufficient alum added to bind all available P in the top 10 cm
- Alum dose determined by:



Alum dose = total available sediment P x Al:P ratio

- Al:P ratio usually between 2-10 (Peterson et al, 1974)
- 20 sediment core samples collected in Lake David during April 1992 and speciated for sediment P bonding

P Fractionation of Sediments

- Saloid – soluble + easily exchangeable P
- Fe Bound – sediment P bound with Fe
- Al Bound – sediment P bound with Al
- Ca Bound – sediment P bound with Ca
- Organic Bound – P associated with organic matter

Available for release (Saloid, Fe Bound)

Unavailable for release (Al Bound, Ca Bound, Organic Bound)

All fractionation is conducted using wet sediments

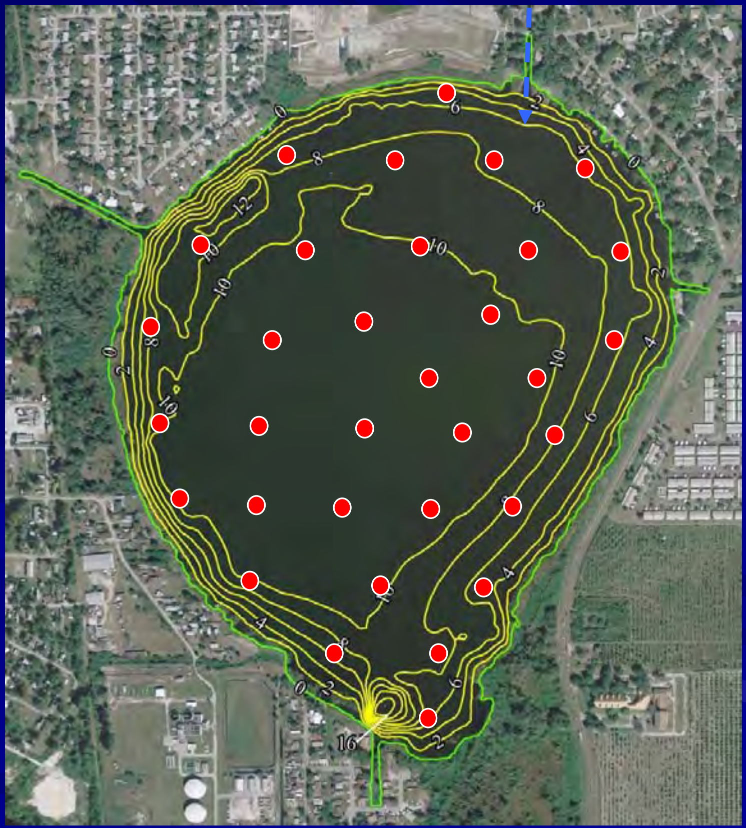
Concentrations expressed as µg/cm^3

Easy calculation for alum requirements

Alum Dose Determination – cont.

- Sediment core samples collected throughout lake
- Top 10 cm layer collected and speciated in lab for available sediment P
- Sediment P isopleth map developed and used as application guide

Typical sediment characteristics



Sediment Monitoring Sites
(Water Depth Contours, ft)

Lake Conine

Available P Contours
(µg P/cm³)

Application Map

- Each area contains the same amount of available P and receives equal amounts of alum

Lake Gatlin

Application Details

Area = 61.5 ac.

Mean Depth = 4.8 m

Alum Only

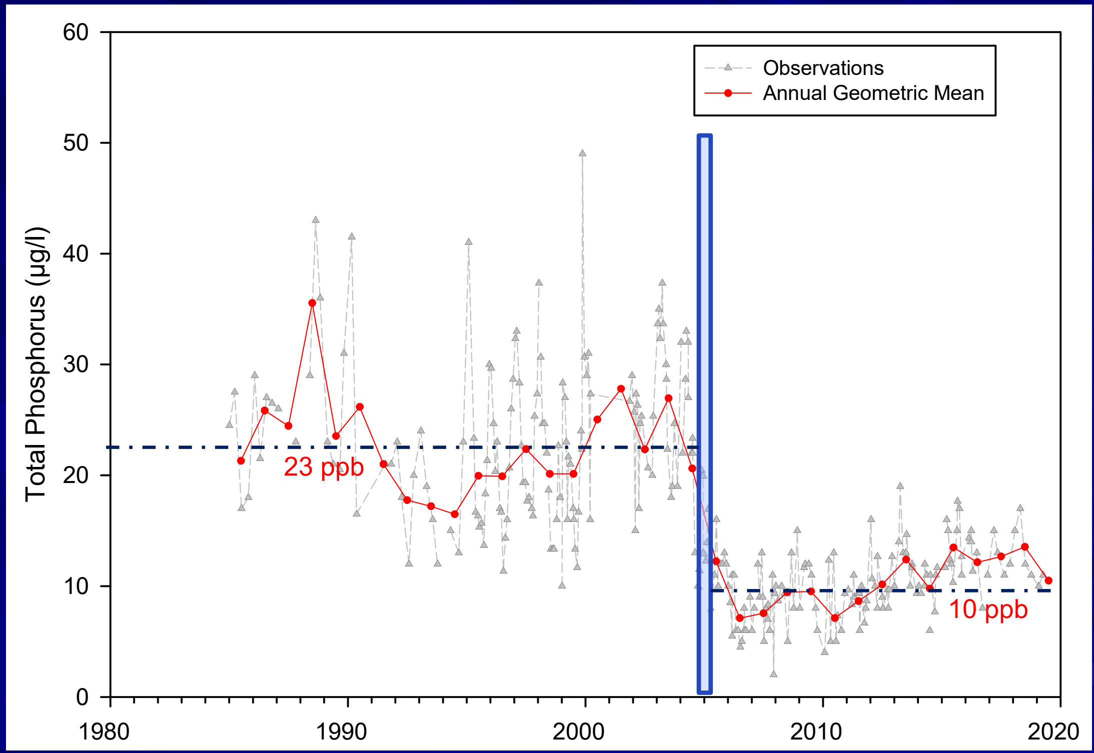
Al:P Ratio = 10:1

Water Column Dose = 5 mg Al/L

Areal Dose = 24 g Al/m^2

Effectiveness (%)

1 yr: 69
2 yr: 67
4 yr: 58
7 yr: 56
10 yr: 41
12 yr: 45
13 yr: 41



Lake Holden

Application Details

Area = 266 ac.

Mean Depth = 3.7 m

Alum Only

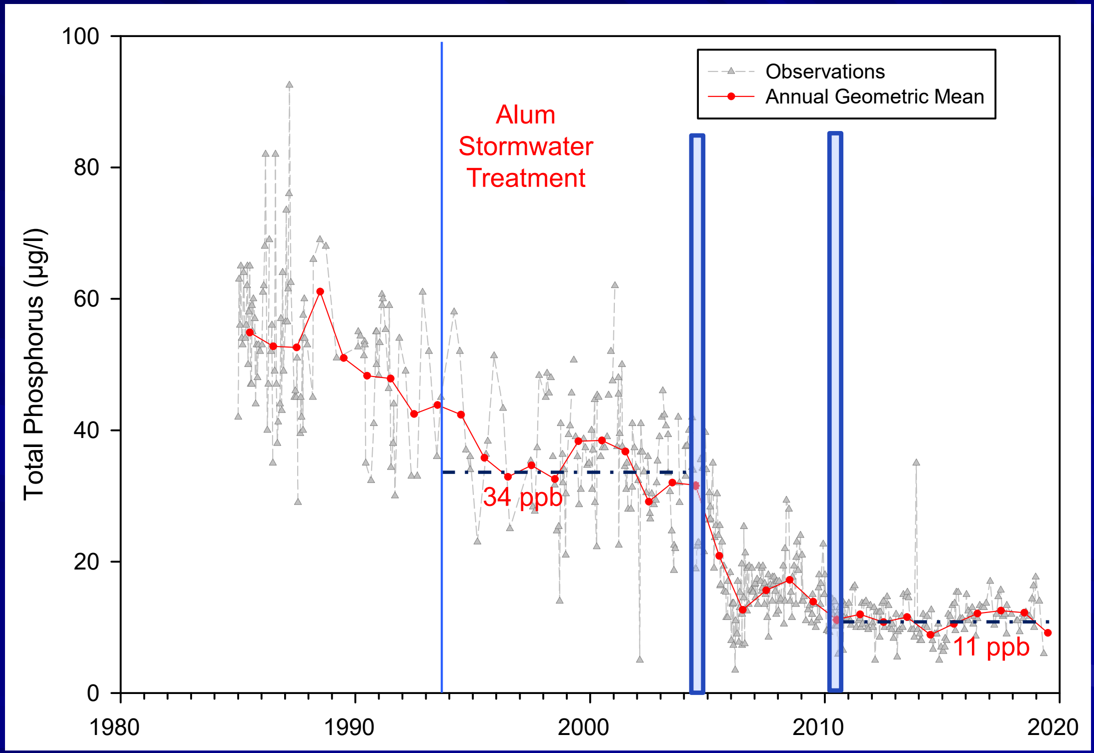
Al:P Ratio = 10:1

Water Column Dose = 16 mg Al/L

Areal Dose = 59 g Al/m^2

Effectiveness (%)

1 yr: 71
2 yr: 74
3 yr: 72
4 yr: 79
5 yr: 75
6 yr: 71
7 yr: 70



Photographs of the Alum/Lime Application Process

a. Application Equipment

b. Alum mixing into lake water

c. Visible floc in water column

d. Water following floc settling

Conclusions

- Internal recycling of nutrients is common in all lakes and all trophic states
- Recycling occurs under both aerobic and anoxic conditions
  - Phosphorus release is generally greater under anoxic conditions
- Internal recycling increases with trophic state and external loading
- Internal recycling contributes loadings of both nitrogen and phosphorus
- Omitted in TMDL assessments
- Many TMDL allocations can be met through internal recycling
  - Extremely low-cost method of removing P from lakes

Implications for Lake Management

- In many lakes internal recycling contributes 30-50% of the annual TP loading and often exceeds runoff loading
- Phosphorus removal costs (20-year, i=2.5%)
  - Stormwater treatment - $500-25,000/kg
  - Sediment inactivation - $75-200/kg
- Sediment inactivation is a low-cost method of removing P from a lake budget
  - Typical sediment load reduction of 80%
  - Average cost of $2,255/acre
- Many required TMDL load reductions can be achieved with sediment inactivation only

Questions?