Effects of Sediment on Water Quality / Quantifying WQ Benefits

Florida Stormwater Association
2020 Fall Seminar

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ERD
Water Quality Engineering

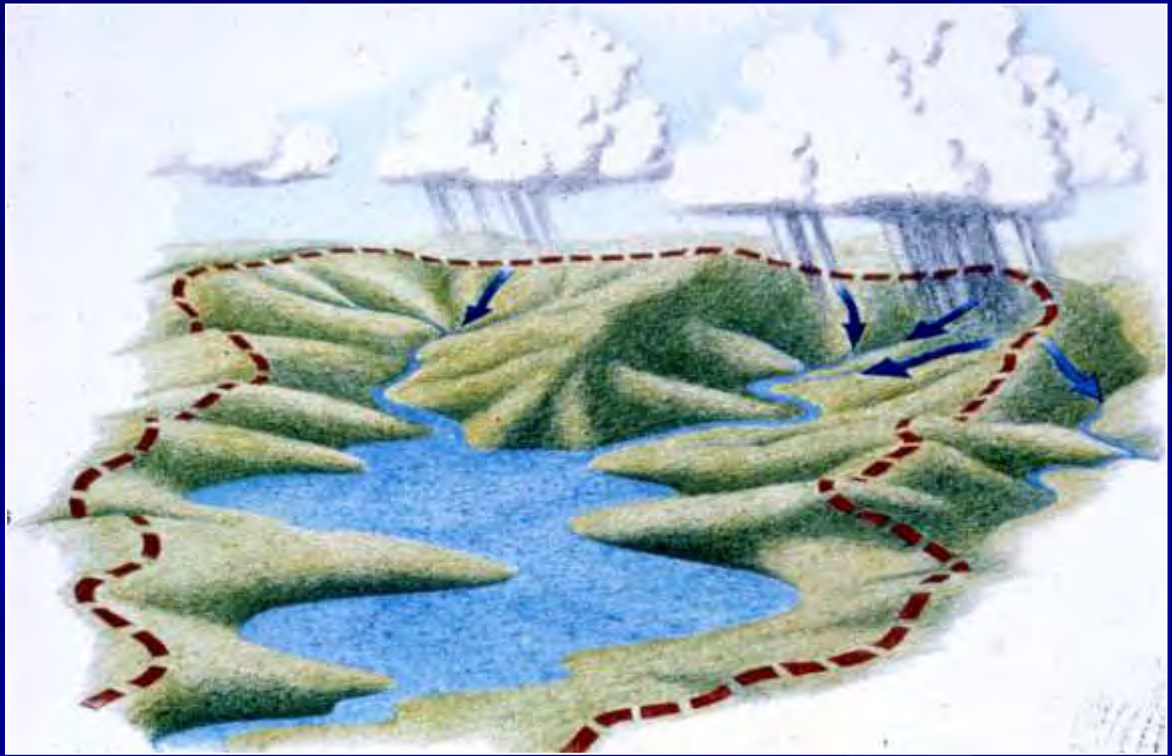
Topics

1. Introduction
2. Sediment sources
3. Sediment characteristics
4. Sediment impacts
5. Reducing sediment loadings
6. Sediment nutrient release
7. Reducing sediment impacts
8. Quantifying load reductions/credits

1. Introduction

Stormwater is Generated within a Watershed

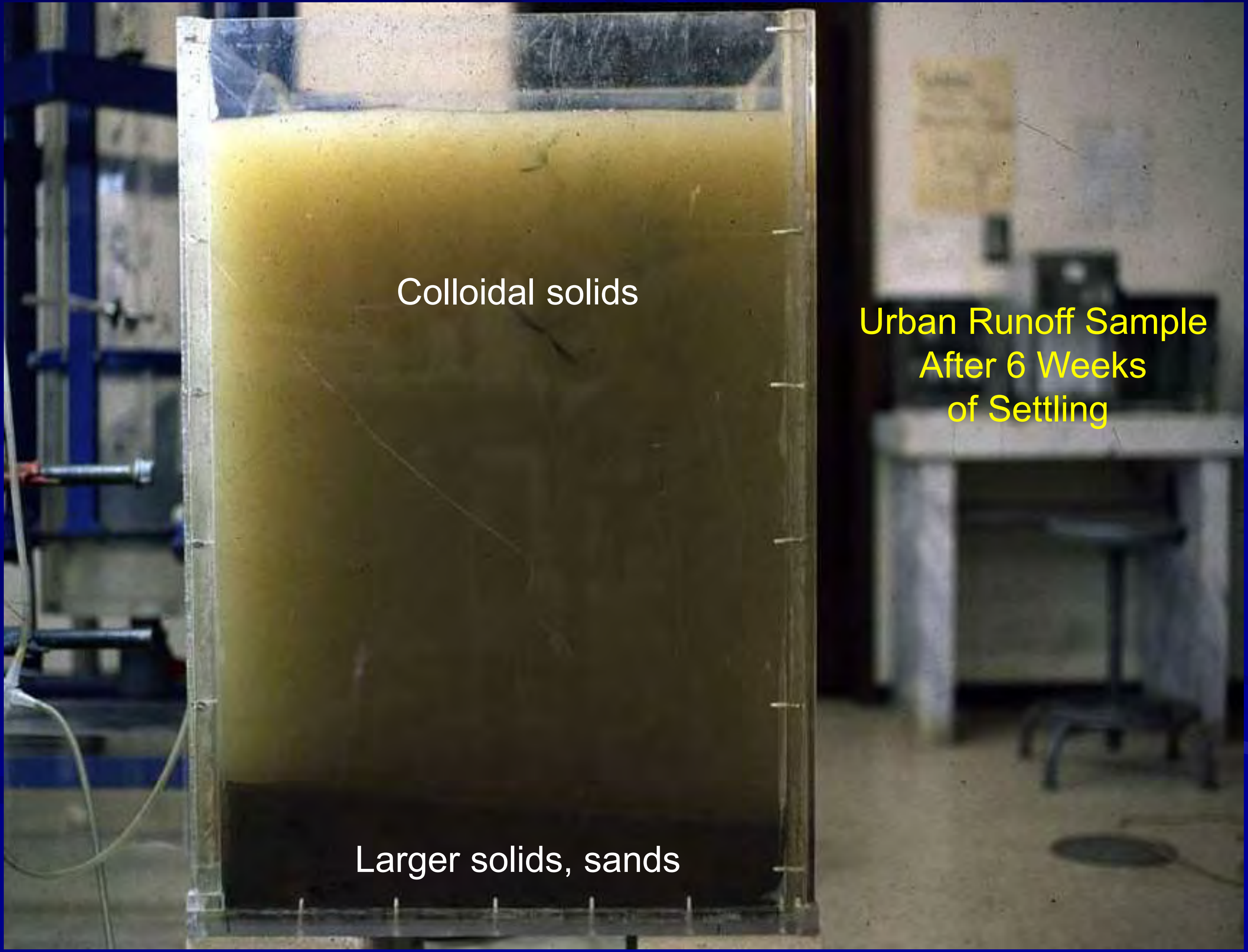
- Characteristics of runoff are a function of:
  - Land cover
  - Slope
  - Soil characteristics
  - Land use
  - Precipitation characteristics



Runoff Entering an Urban Lake

Suspended Solids in an Urban Runoff Sample

- Solids in runoff are present in many different forms
- Type of solids affects:
  - Removal mechanisms
  - BMP selection
  - Nutrient content
  - Environmental impacts
- Nutrients, metals, and organics are often attached to solids



2. Sediment Sources

a. External

b. Internal

Sediment Sources

a. External

Agriculture

Silviculture

Construction/erosion

Industry

Urban areas

Erosion of Roadway Surfaces

- Pavement surfaces generate larger size inert particles
- Pavement surface erosion rates
  - ~ 1 mm/year or 1-inch in 25 years

Sediment Sources

b. Internal

- The largest source of sediments to most lakes is deposition of organic matter from biologically generated organic matter

- Biological matter generates deposition of ~ 1 cm/year in productive urban lakes
- A portion of the organic matter decomposes
- Organics difficult to break down accumulate and become organic muck

3. Sediment Characteristics

Solids Collected from Urban Gross Pollutant Separators

- The characteristics of runoff solids are determined by the contributing watershed
  - Land use
  - Topography
  - Soil types
    - Sand
    - Clay
  - Vegetation
  - Type of drainage system

a. Mixture of sand and organic matter

b. Fine to medium sand

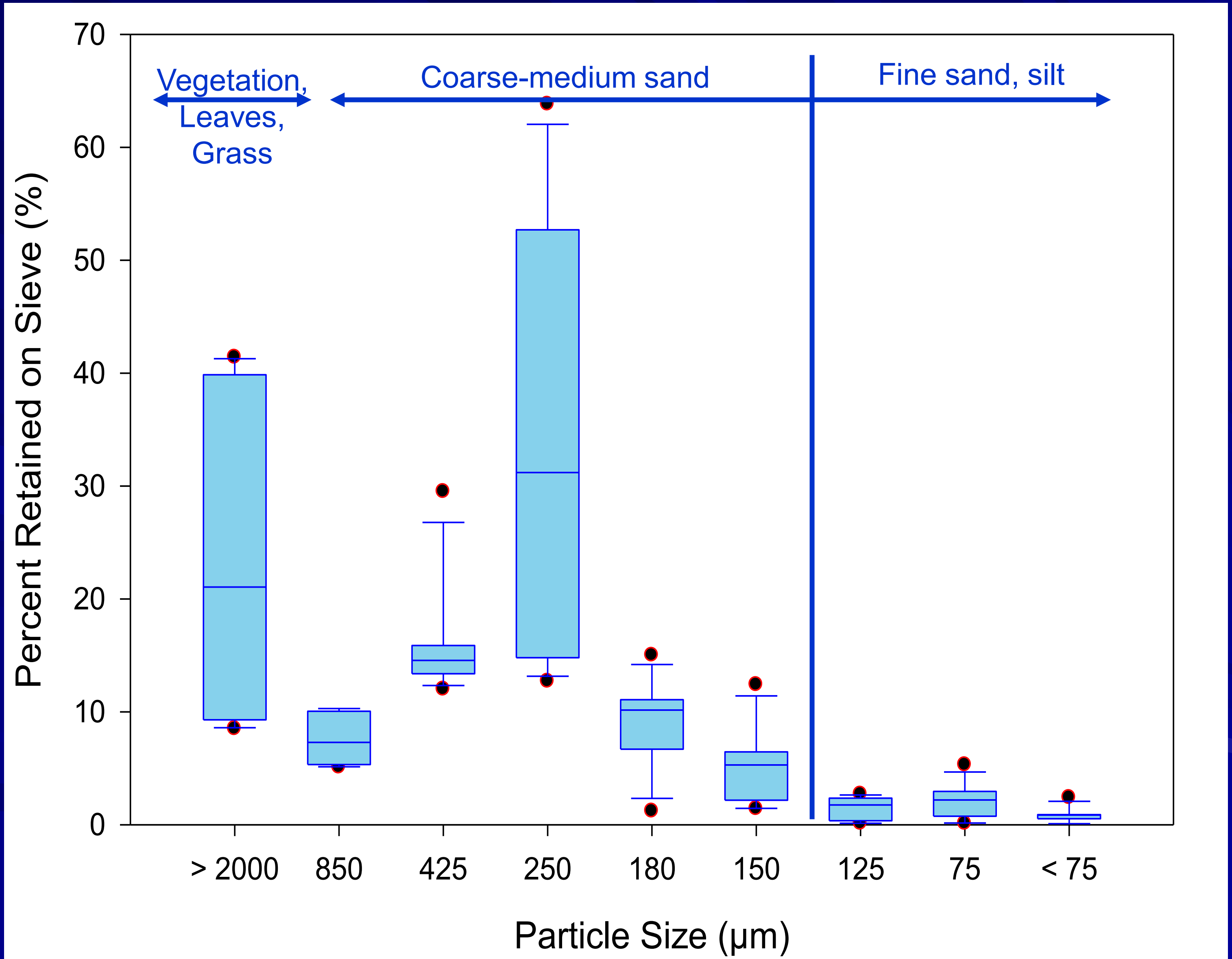
c. Mixture of sand and organic matter

d. Mostly organic matter

Street Sweeping!

Distribution of Particle Sizes in Residential Roadway Solids

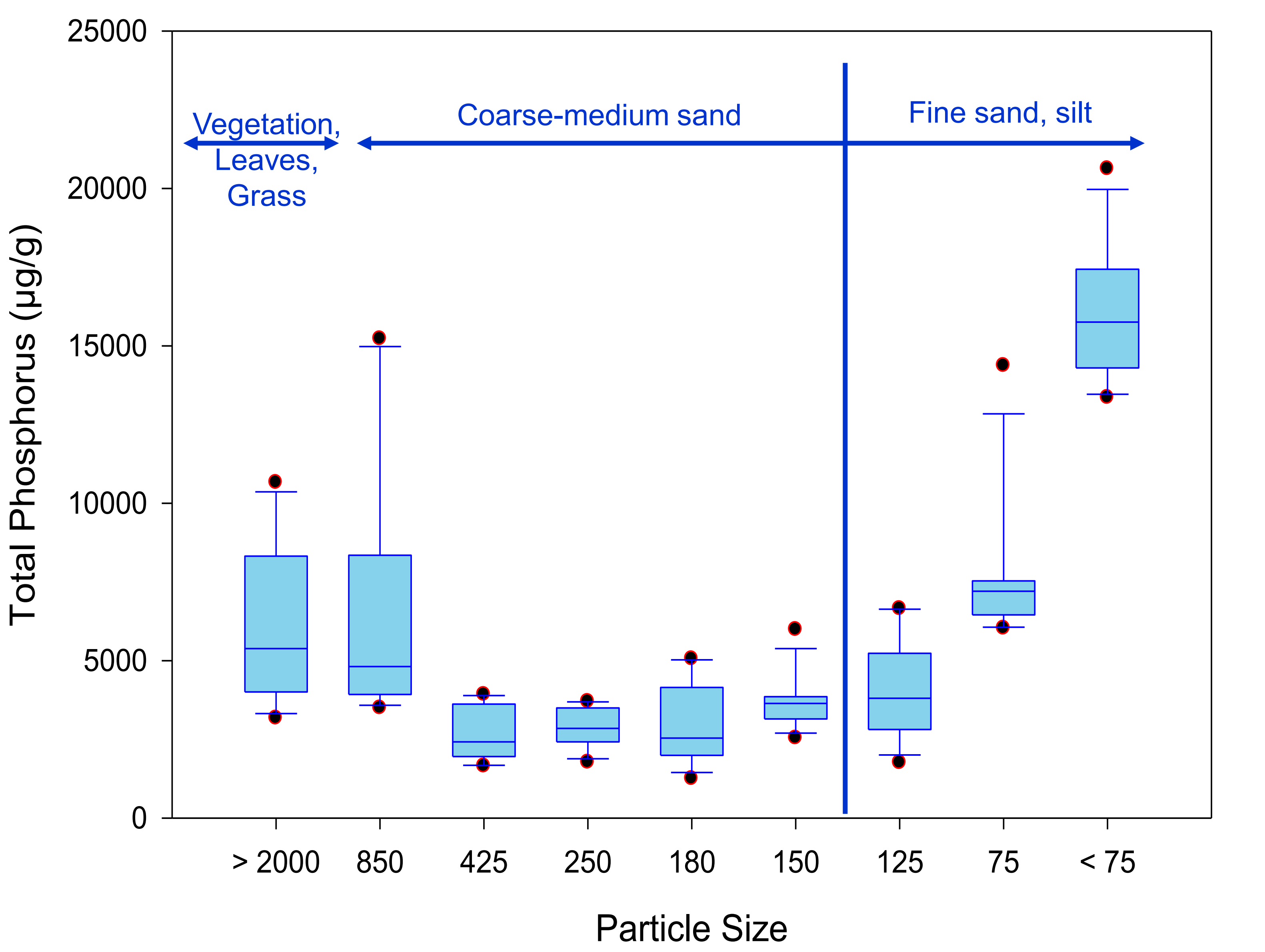
1. Majority of roadway solids consist of coarse to medium sand
2. Second largest source by mass is vegetation, grass, etc.
3. Smallest contribution is from fine sand and silt



Total Phosphorus Content by Particle Size in Residential Roadway Solids

1. Highest P content is in fine sand and silt, followed by vegetation, leaves, and grass

2. Lowest P content is in coarse to medium sand



Rate of Settling of Particles at 10ºC

1. Particle size and settling velocity dictate the type of BMP necessary for removal

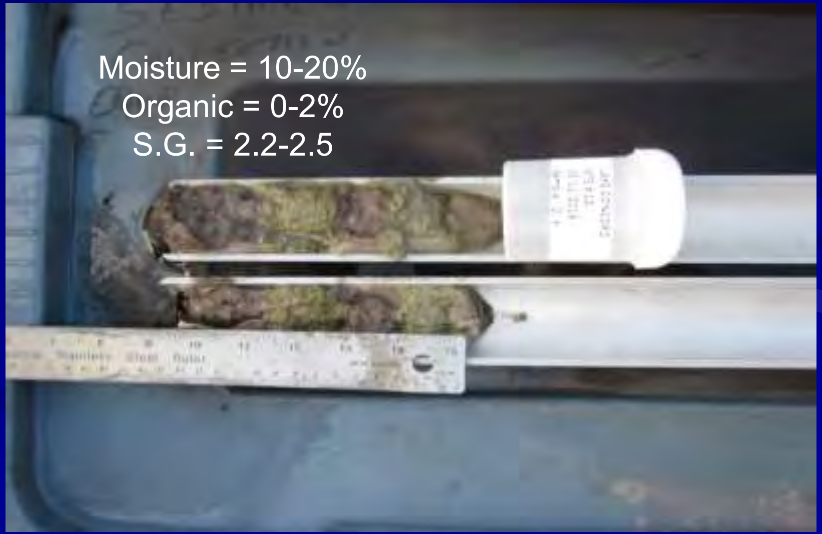
Material	Diameter		Settling Velocity (mm/sec)	Time to Settle 1 ft.
	mm	microns		
Gravel	10	10,000	1000	0.3 sec
Coarse sand	1.0	1,000	100	3 sec
Fine sand	0.1	100	8	38 sec
Silt	0.01	10	0.154	33 min
Bacteria	0.001	1	0.00154	55 hr
Clay	0.0001	0.1	0.0000154	230 days
Small colloids	0.00001	0.01	0.000000154	63 yrs

Typical Urban Waterbody Sediments

a. Sand layer over organic layer

b. Organic muck

c. Organic muck



d. Sand with benthic algae

4. Sediment Impacts

a. Physical

b. Water Quality

Sedimentation in Waterbodies

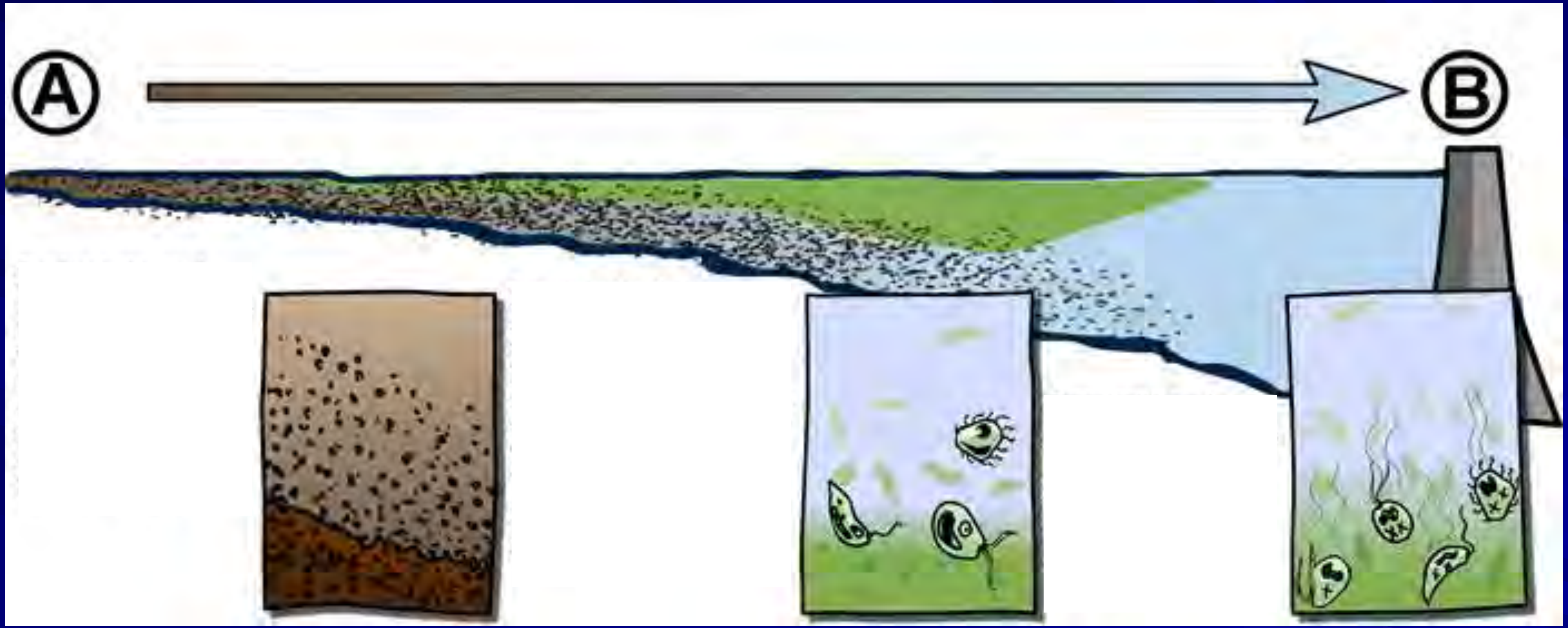
- Deposition and accumulation of organic and inorganic matter occur from a variety of sources

- Sediments are an important, integral part of the aquatic ecosystem

- Sediments reflect changes in land-use over time
  - 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

Fate of Solids in Receiving Waters



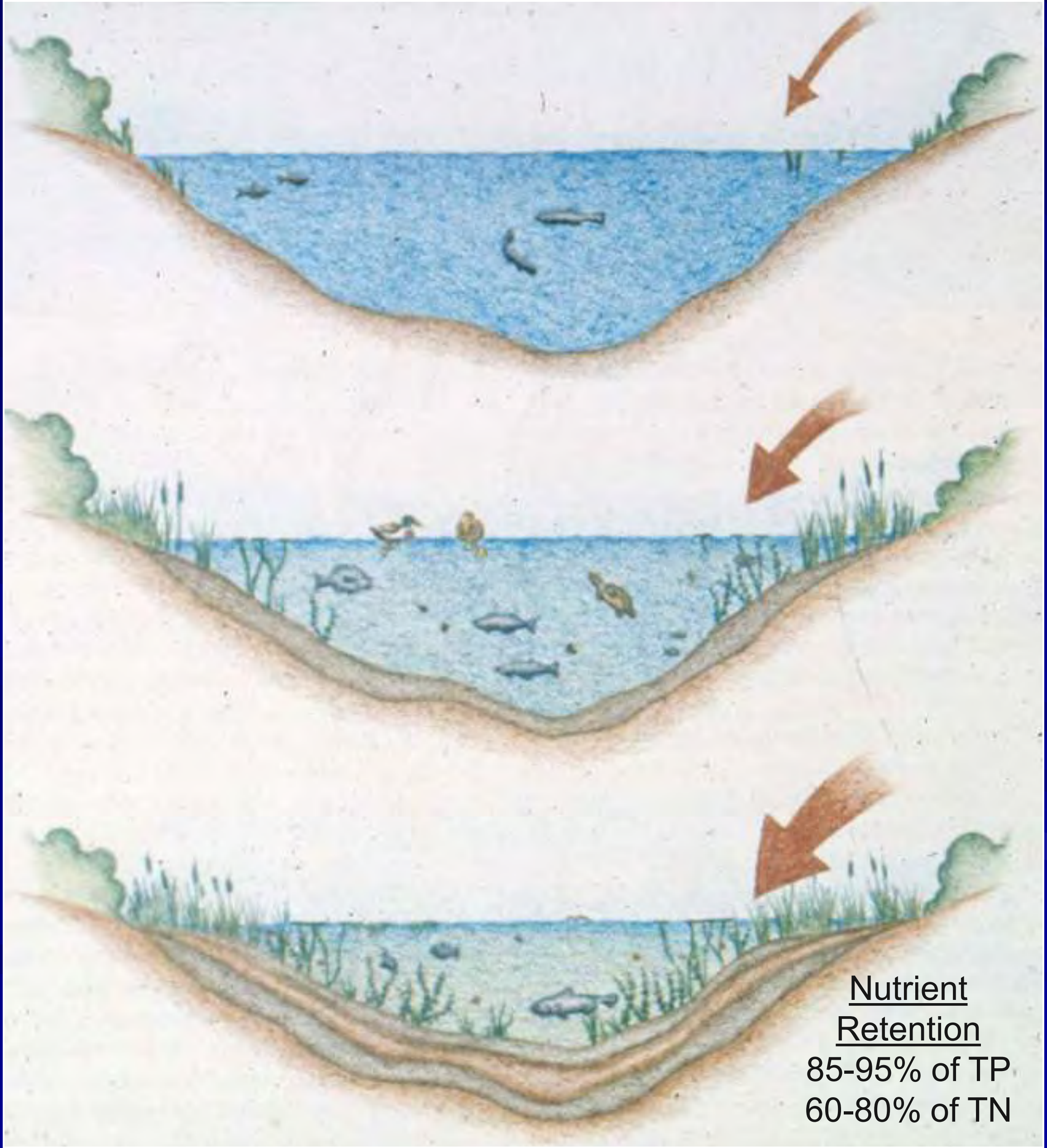
Inputs of solids have both physical and chemical impacts

Excessive Nutrient Additions Can Accelerate 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



a. Physical Impacts

Accumulated Solids in Lake Ella Exposed During Drawdown

a. Physical Impacts

How much sediment is too much?

1. Deposition and shoaling impact boating and navigation

2. Normal boating causes direct sediment re-suspension
   a. Increases turbidity
   b. Nutrient release
   c. Propeller or boat damage
   d. Safety issues

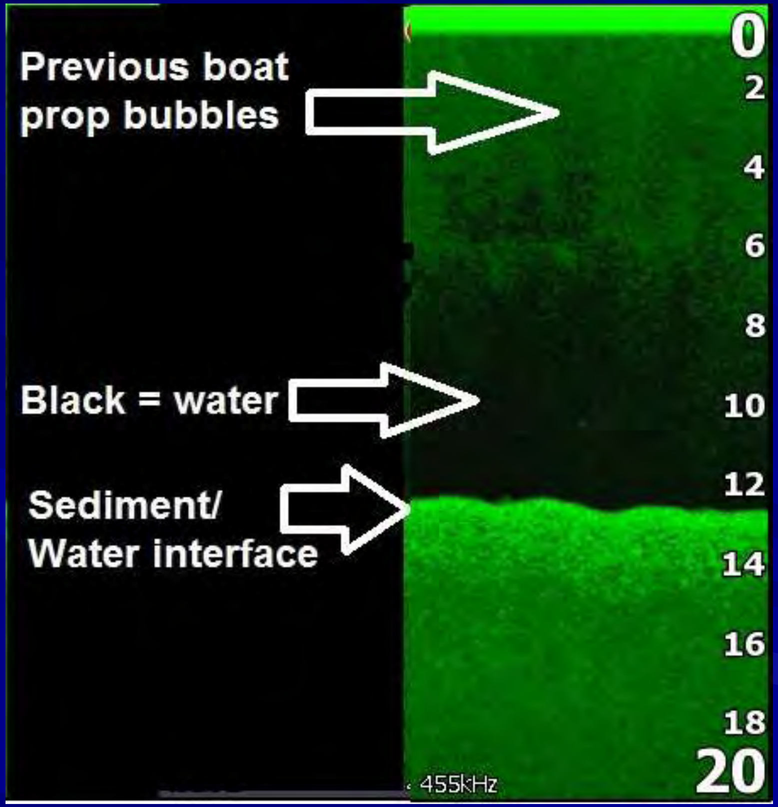
Sediment re-suspension from boating

a. Physical Impacts – con't.

Boating can cause sediment impacts well below the surface

Typical Recreational/Ski Boat

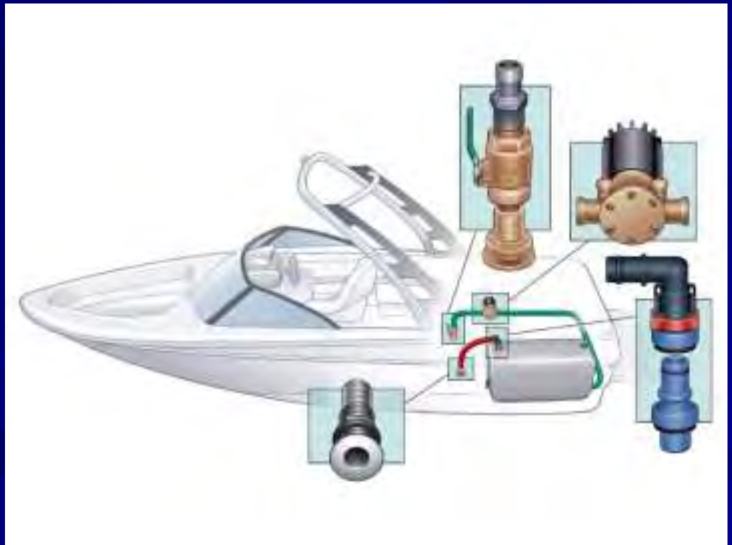
- When on plane, the boat rises up, lifting the motor and reducing prop depth
- Generates moderate wake



- Water disturbance limited to top 10 ft.

a. Physical Impacts – con't.

Enhanced Wake Watercraft

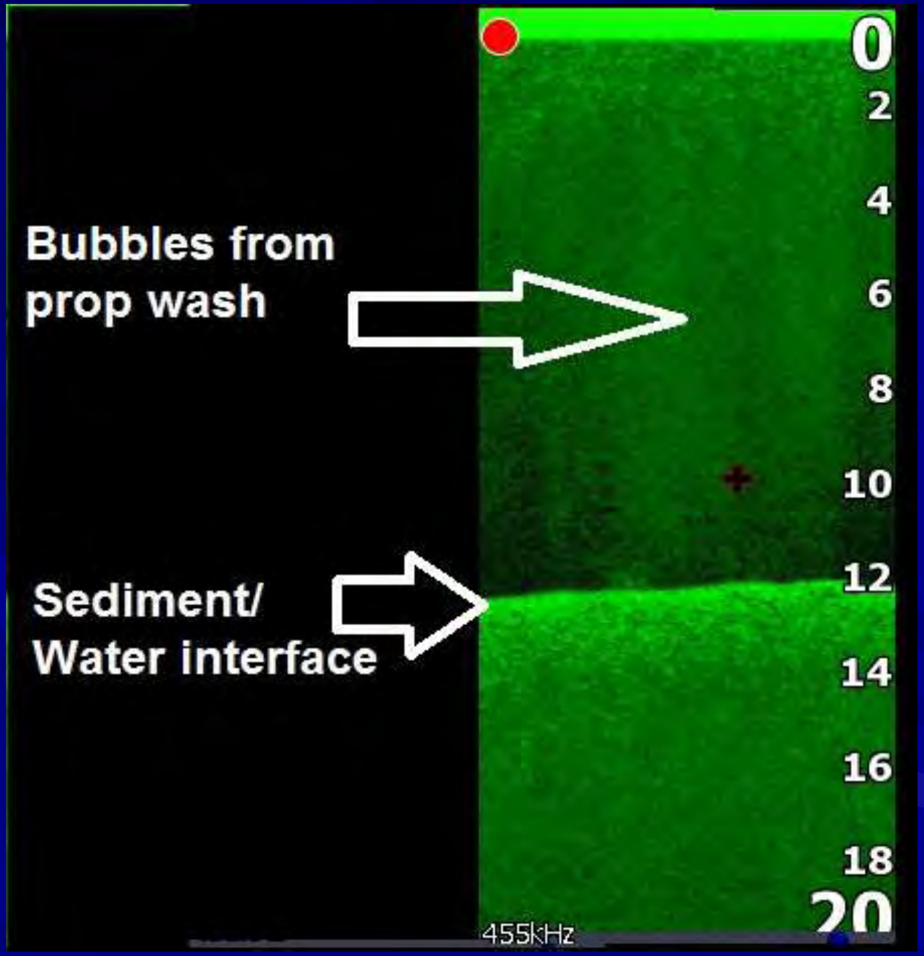


- Use water ballast to push rear of boat into the water which lowers the prop
    - Propulsion drives rear of boat farther into the water
        - Generates extreme wake

a. Physical Impacts – con't.

Enhanced Wake Watercraft – cont.

- Water disturbance extends well into the water column
- Energy waves extend to 10 – 15 ft. or more
- Capable of disturbing sediments and releasing pore water



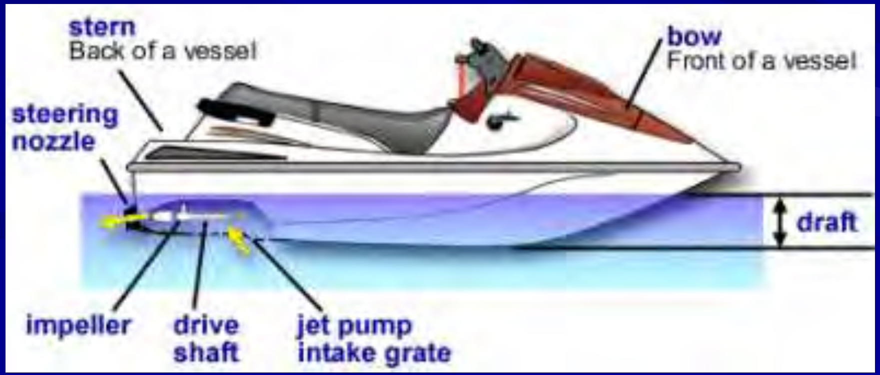
a. Physical Impacts – con't

Personal Watercraft

- Propulsion jet exits close to the water surface in focused stream

- Maximum energy input occurs within top 1-2 ft of water column

- Generates minimum wake

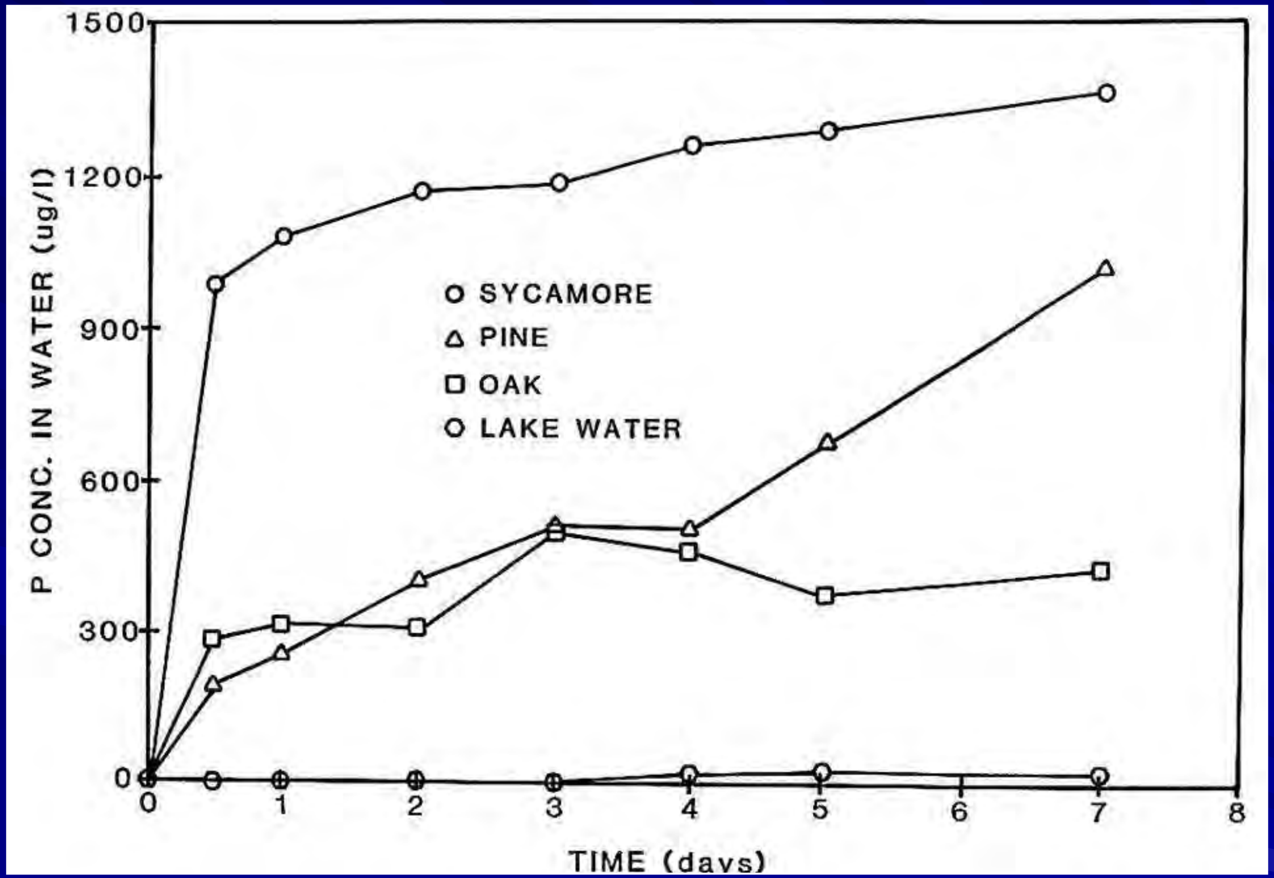


b. Water Quality Impacts

- Decreases transmission of light through water
- May effect respiration and digestion in aquatic species
- Decreases survival rates of fish eggs and population sizes
- Increases thermal stratification and decreases oxygen concentrations
- Decreases value for recreational and commercial purposes
- Increases treatment costs for surface drinking water supplies
- Stimulates algal growth and eutrophication
- Toxic algal blooms may cause health impacts in sensitive individuals

b. Water Quality Impacts – con't.

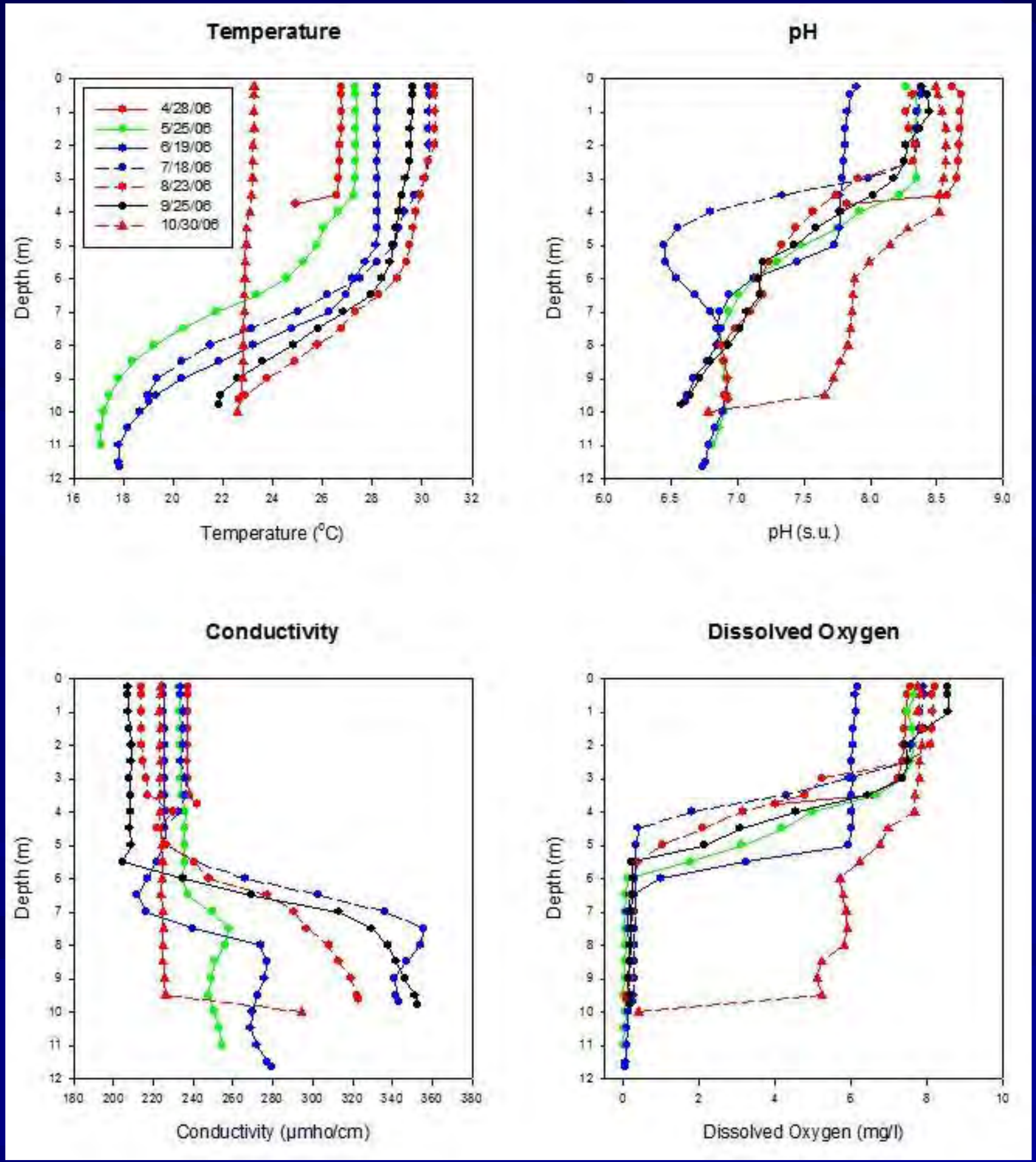
Release of Phosphorus from Saturated Leaves



- After entering water, leaves exhibit a rapid nutrient release
- Frequent maintenance and removal is essential
- Nutrient release is much less when the solids are stored in a dry condition

b. Water Quality Impacts – con't.

Vertical Field Profiles in Lake Pineloch from April – October 2006



<u>Eutrophic Lake</u>

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

- significant thermal stratification

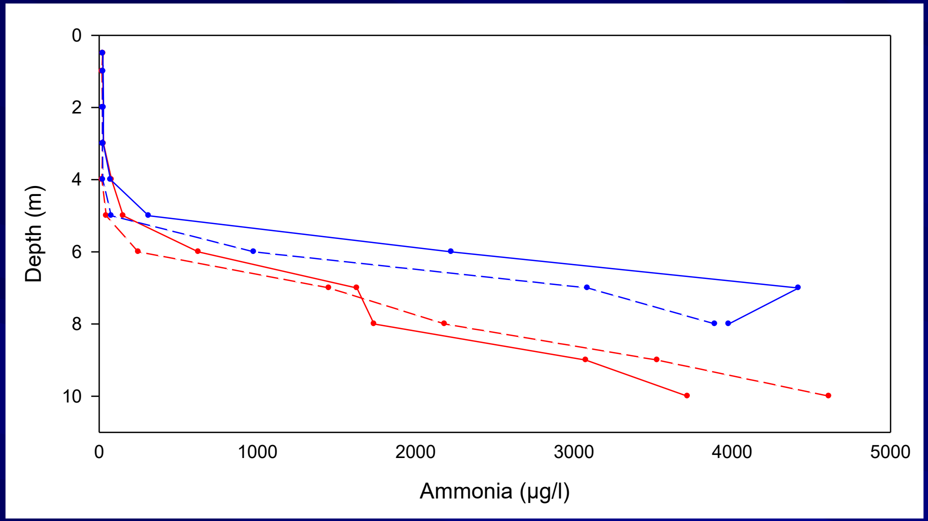
-high pH at surface with sub neutral pH near bottom

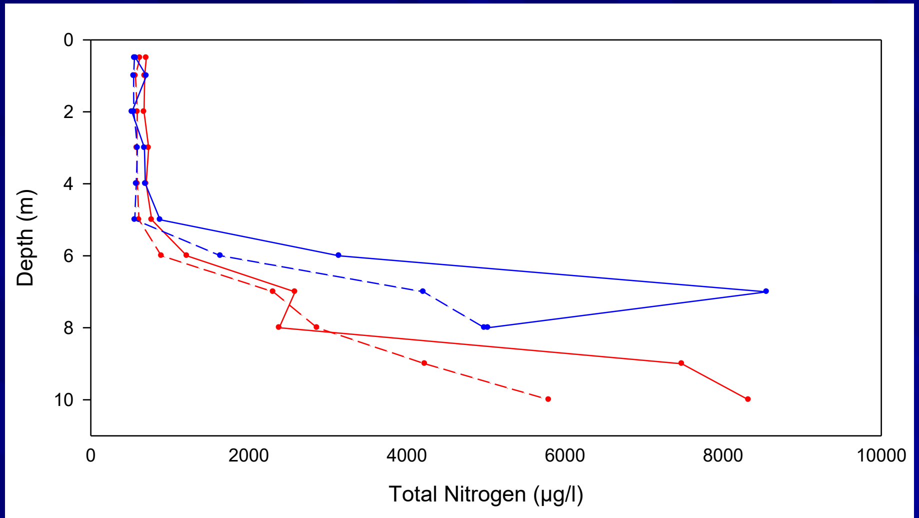
-anoxic hypolimnion

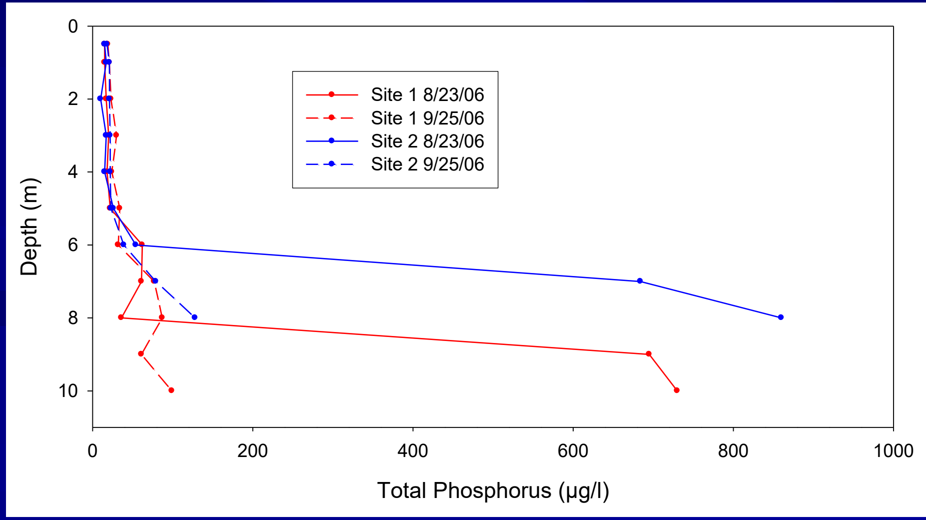
-conductivity increase in hypolimnion suggest internal recycling

b. Water Quality Impacts – con't.

Vertical Variability in Water Quality in Lake Pineloch

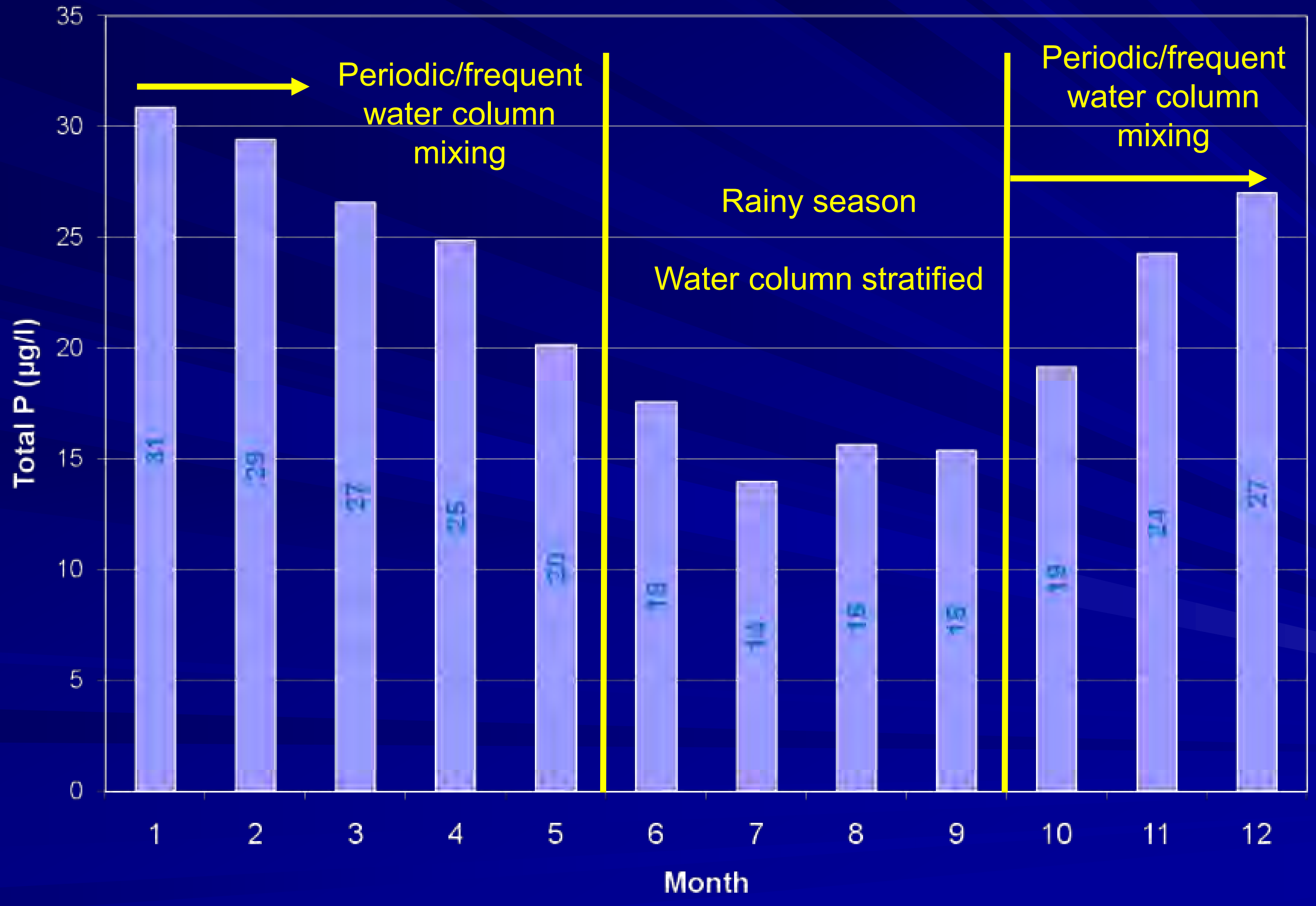






b. Water Quality Impacts – con't.

Mean Monthly Total P Concentrations in Lake Gatlin from 1995 - 2004



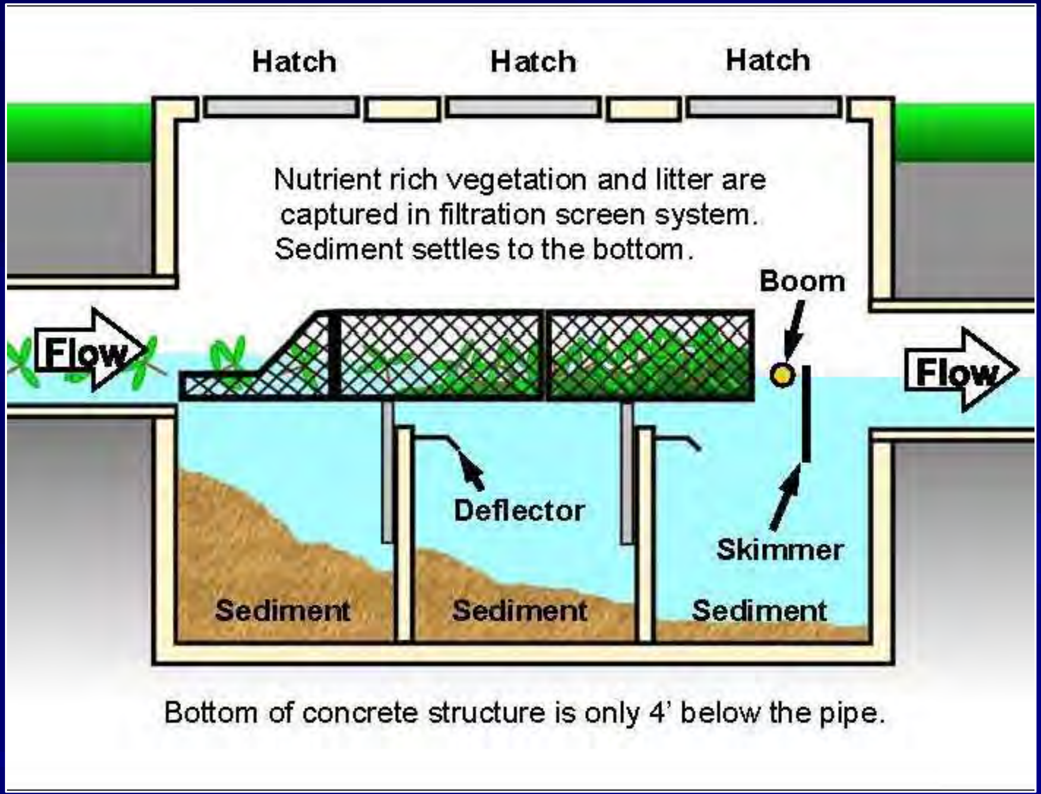
5. Reducing Sediment Loadings

a. Gross Pollutant Separators

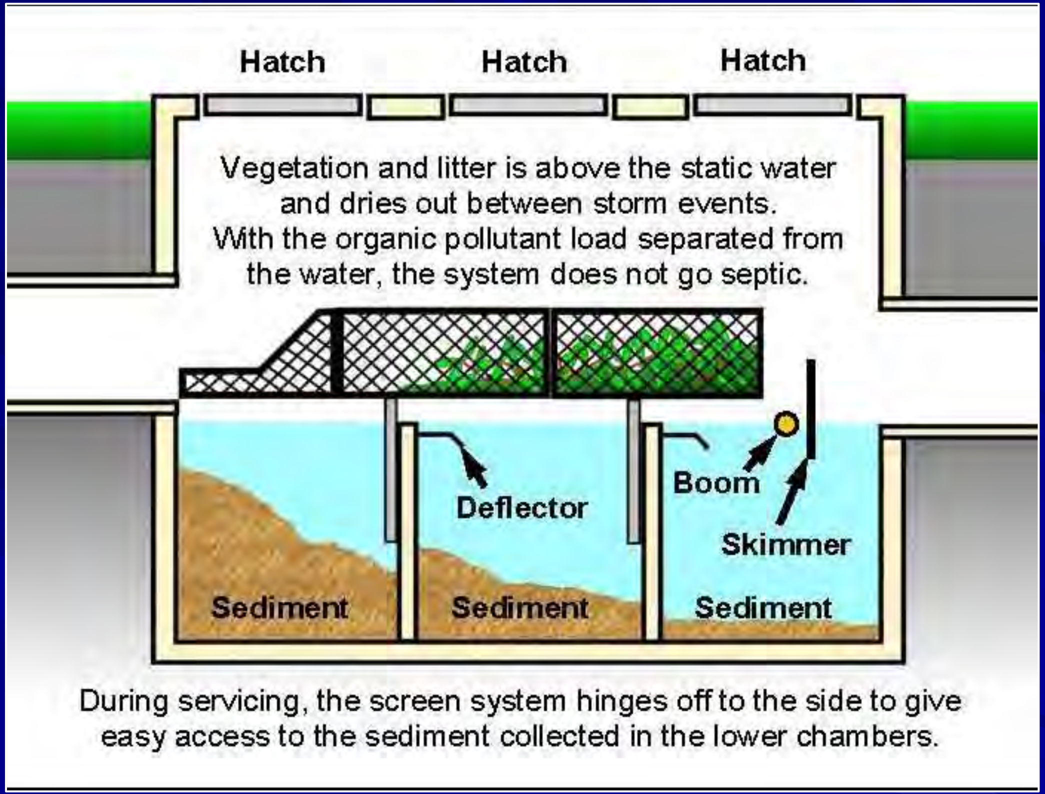
b. Street Sweeping

a. Gross Pollutant Separators

Suntree Nutrient Separating Baffle Box



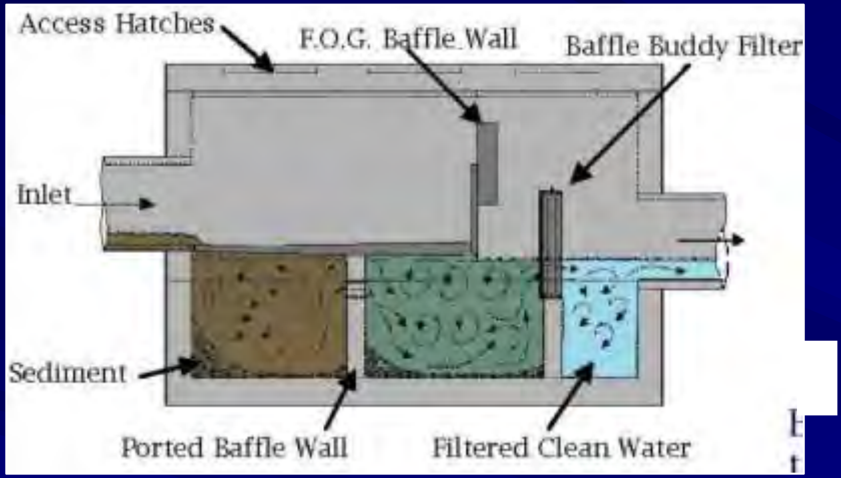
a. During storm event conditions



b. Following storm event

a. Gross Pollutant Separators

EcoVault Unit



a. Schematic flow patterns in the EcoVault Unit

b. Bottom solids screens

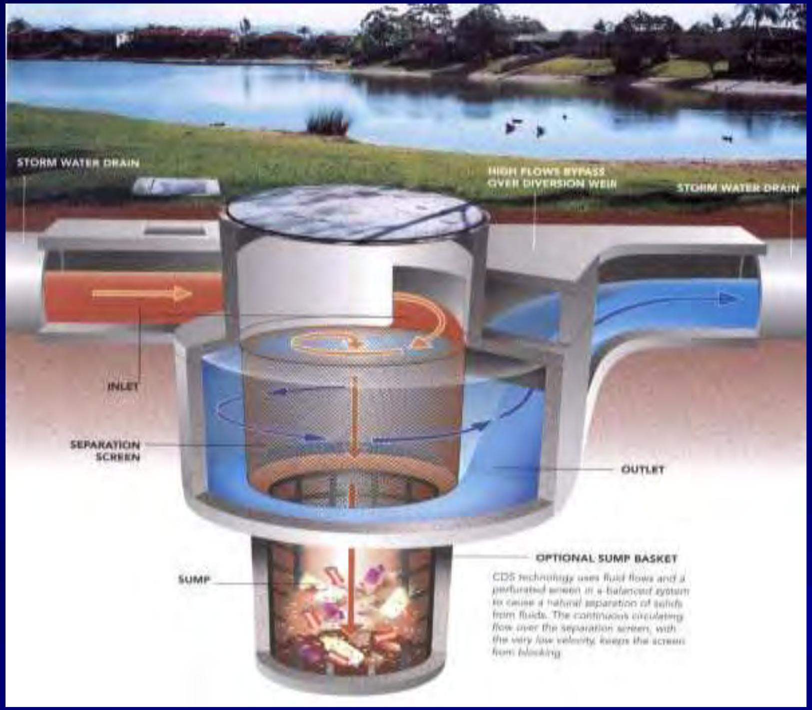
c. Vault-Ox equipment

d. Bottom screens opened for cleaning

e. Outlet filter containing aluminum silicate

a. Gross Pollutant Separators

Swirl Separators



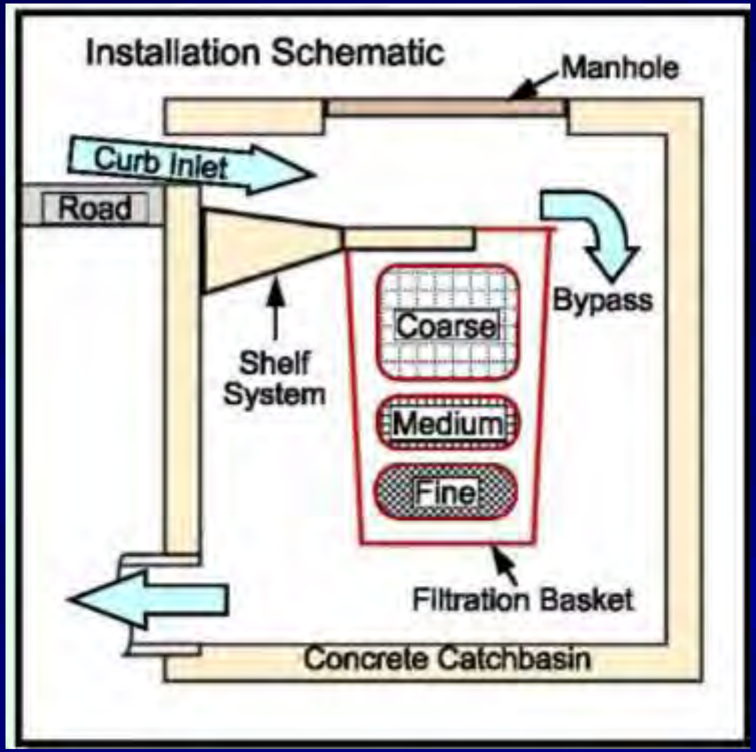
CDS Unit

Stormceptor

- Literature removals are based on inflows at the design capacity
- Swirling motion is required to remove and screen solids
- At lower flow rates the swirling is reduced

a. Gross Pollutant Separators

Inlet Baskets



a. Schematic of the Suntree high capacity curb inlet basket

b. Basket filled with collected solids

a. Gross Pollutant Separators

Evaluated Removals and Removal Costs

Site/Unit	Mass Removal (%)			Present Worth Removal Cost ($/kg) (20-yr, i = 2.5%)		
	Total N	Total P	TSS	Total N	Total P	TSS
Concord Suntree Baffle Box	2	7	73	6,110	15,928	11.20
San Pablo CDS Unit	5	12	94	5,699	23,252	43.32

a. Gross Pollutant Separators

Eco-Vault Removal Efficiencies and Costs

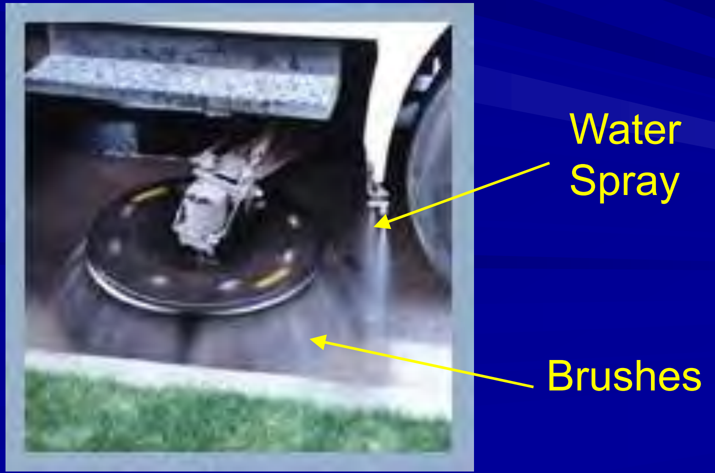
Site/Unit	Mass Removal (%)			Present Worth Removal Cost ($/kg) (20-yr, i = 2.5%)		
	Total N	Total P	TSS	Total N	Total P	TSS
Lake Hodge EcoVault	14	57	90	3,433	1,755	4.89
Gee Creek EcoVault	2	41	78	34,377	10,188	14.05
San Pablo EcoVault	14	11	89	3,393	25,582	14.49

b. Pavement Cleaning/Street Sweeping

Types of Street Sweepers

Mechanical Sweepers

- Most common type of sweeper – requires hard curb
- Uses rotating brooms to sweep solids onto a conveyor and into a hopper
- Water may be sprayed for dust control
- Mostly remove leaves, debris and larger solids
- May cause dust release



b. Pavement Cleaning/Street Sweeping – con't

Types of Street Sweepers

Mechanical Sweepers – cont.

- Capable of removing only coarse particles (>400 μm)
- National Urban Runoff Program (NURP) studies indicated that mechanical sweeping is not a viable water quality management practice
- Bender and Terstriep (1984) evaluated mechanical sweeping in Champaign, Il.
    - Bi-weekly sweeping achieved 42% reduction of street solids
    - No removal of particles <10 μm
    - No significant difference between pre and post runoff nutrient concentrations

b. Pavement Cleaning/Street Sweeping – con't

Mechanical Sweepers

Mechanical sweepers grind up roadway solids and leave a homogenized "paste" on the roadway surface

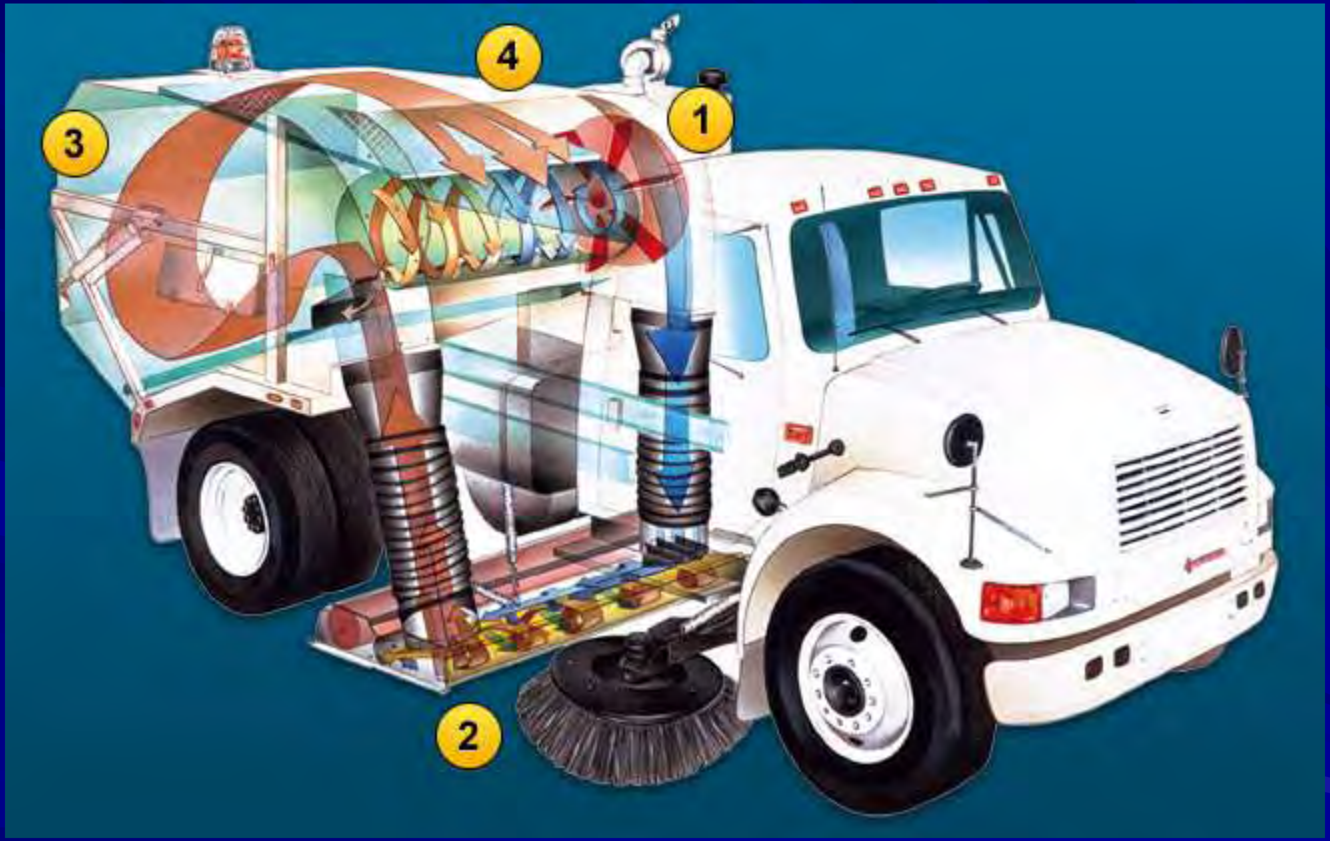
Mechanical sweepers perform poorly in areas with accumulated leaves

b. Pavement Cleaning/Street Sweeping – con't

Types of Street Sweepers

Regenerative Air

- Air is forced down onto the pavement, to suspend particles
- Particles are captured by a high-powered vacuum
- Air is filtered and recycled
- Large particles may not receive sufficient agitation to become air-entrained
- Efficiency ~ 30% for particles < 10 μm



b. Pavement Cleaning/Street Sweeping – con't

Types of Street Sweepers

<u>Vacuum Assisted</u>

- Provides air vacuum over entire path
- Does not require a hard curb
- May have mechanical brush assist
- May or may not use sprayed water
- Best removal of all street sweepers

b. Pavement Cleaning/Street Sweeping – con't

Relationships Between Particle Size and Sweeper Efficiency

(Mechanical Sweeper; Ref. USEPA)

Particle Size (microns)	Sweeper Efficiency (%)
>2000	76
840 – 2000	66
246 – 840	60
104 – 246	48
43 – 104	20
<43	15
Overall	50

b. Pavement Cleaning/Street Sweeping – con't

Estimated TSS Reduction from Street Sweeping (%)

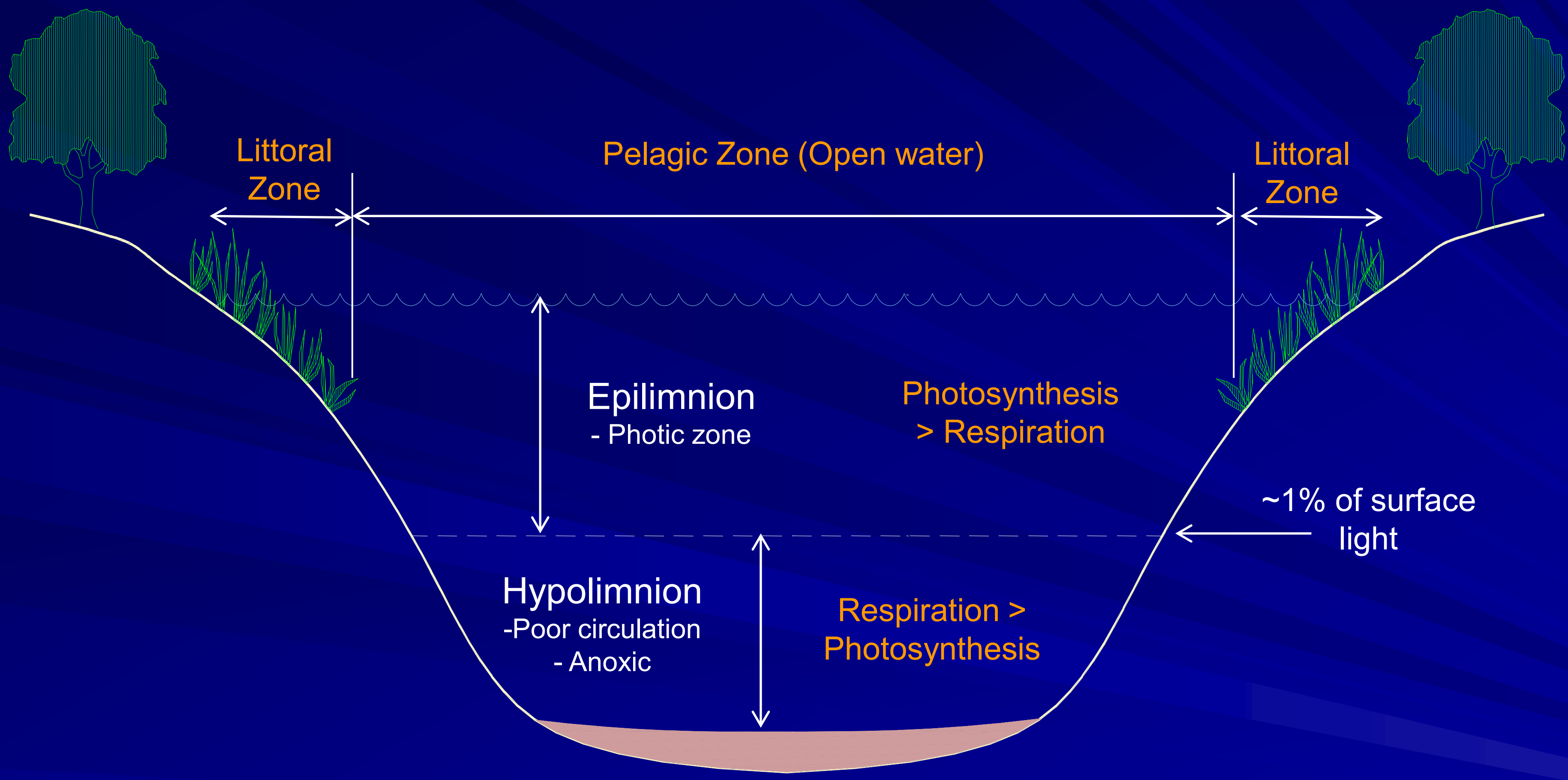
(Residential Area)

Sweeper Type	Frequency of Sweeping			
	Monthly	Twice Monthly	Weekly	Twice Weekly
New Type Vacuum	51	63	79	87
Regenerative Air	43	53	65	71
Mechanical Brush Type	17	23	29	33

Source: U.S. EPA

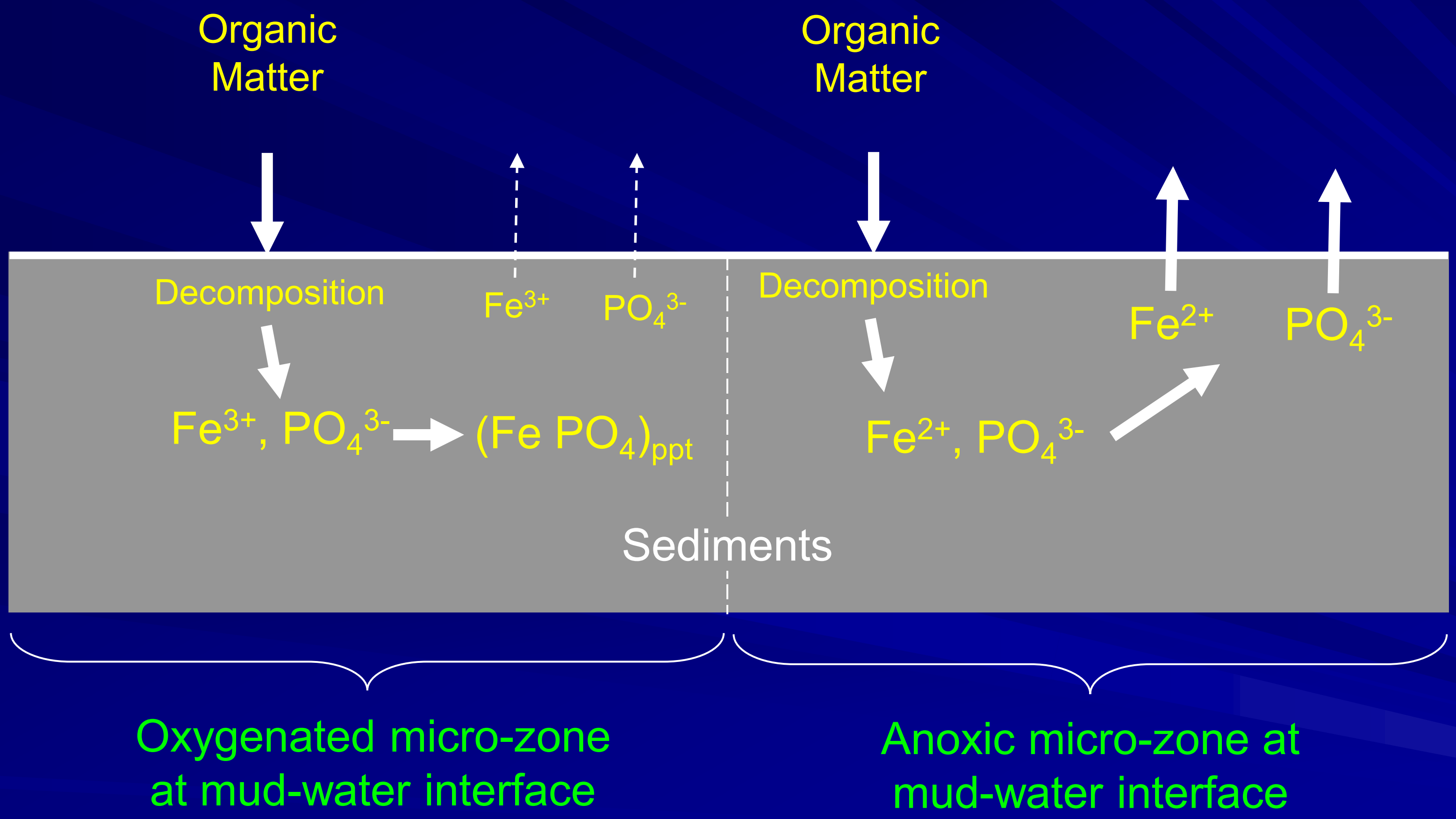
6. Sediment Nutrient Release

Typical Zonation in a Lake



- Lakes are sinks for nutrients
  - Organic matter accumulates in the bottom of lakes and undergoes decomposition
    - Nutrients are released during the decomposition
    - Anoxic sediments release P, Fe, Mn, ammonia and other ions

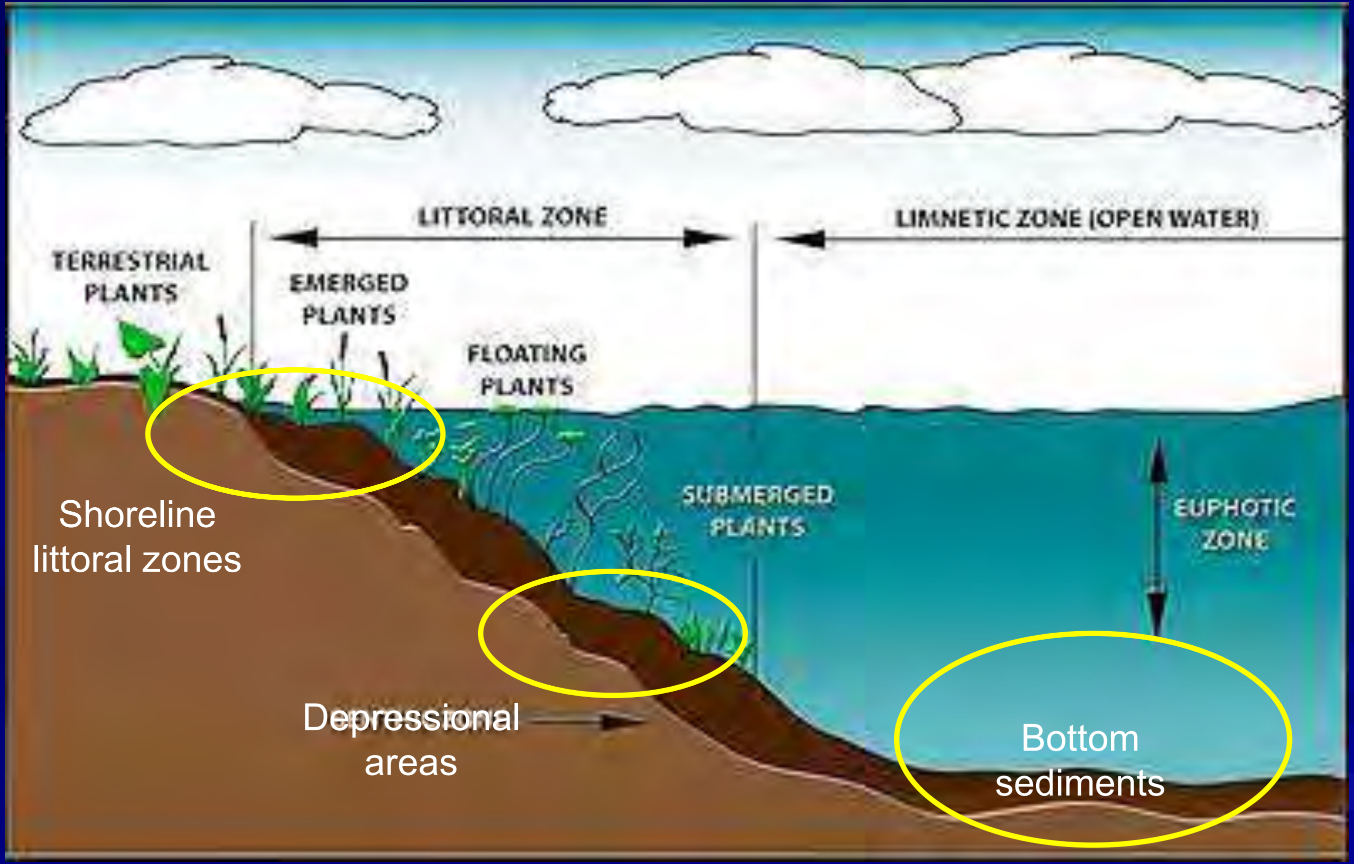
Significant Reactions at the Water-Sediment Interface



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

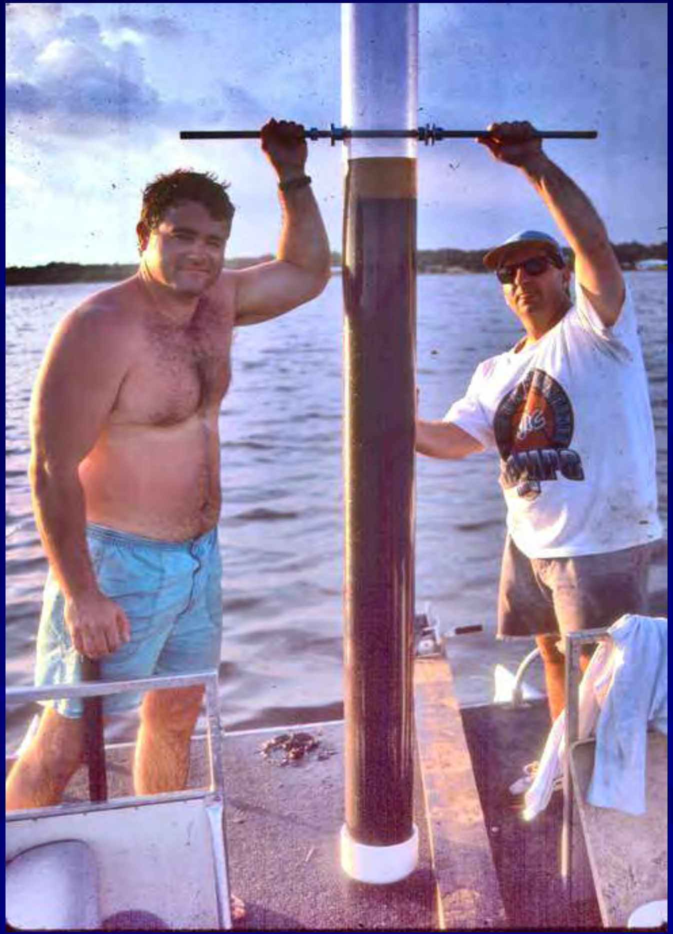
Anoxic Areas in Lakes

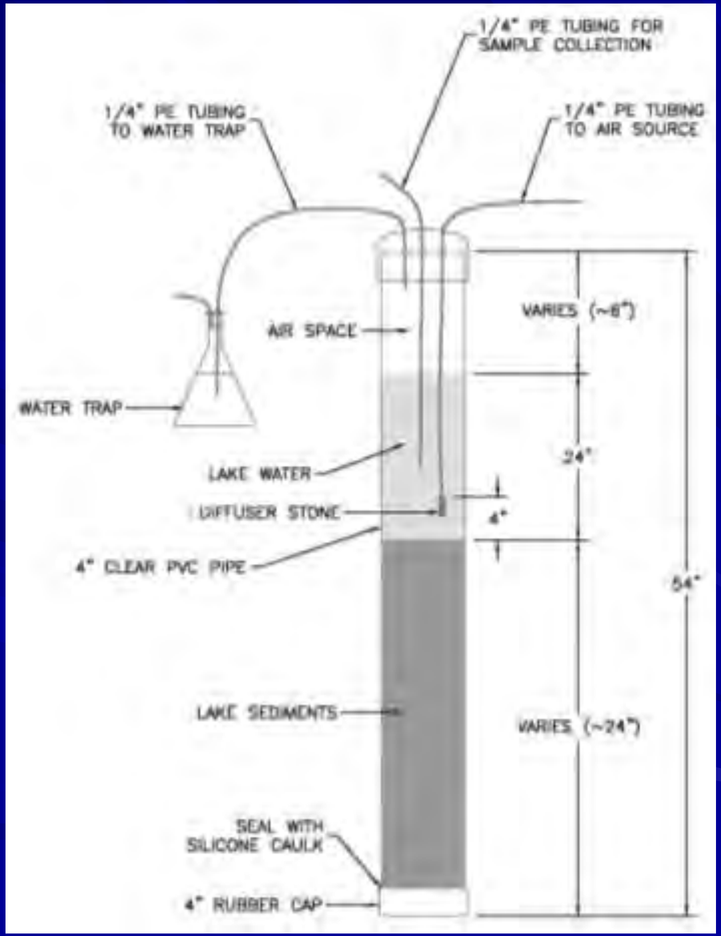


- Anoxic zones occur in multiple areas of a lake

Quantification of Internal P Recycling

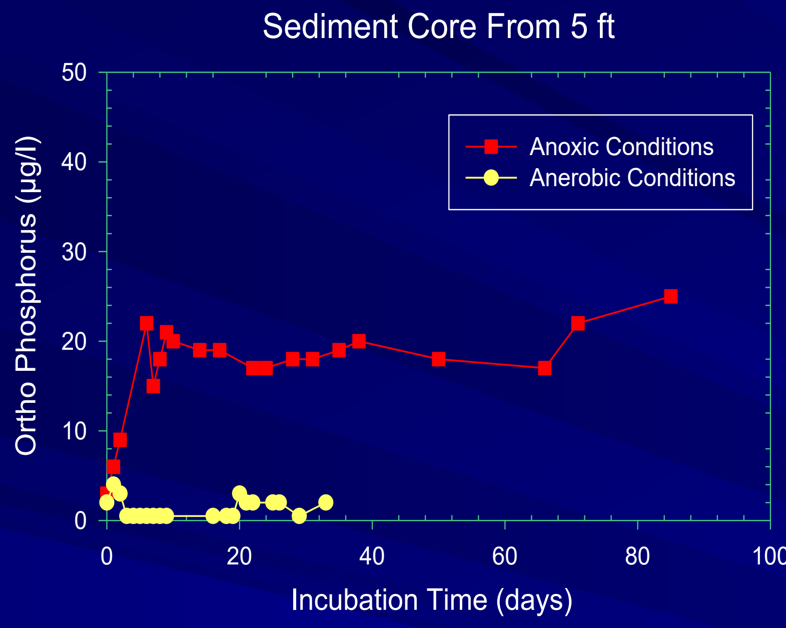
- Large diameter core samples collected at multiple locations
- Core samples incubated under aerobic and anoxic conditions
- Samples collected periodically and analyzed for P

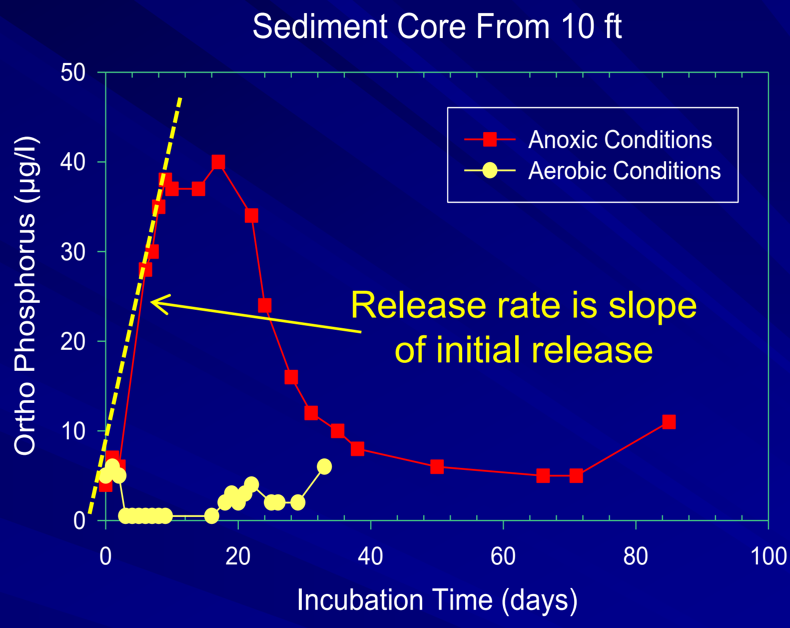


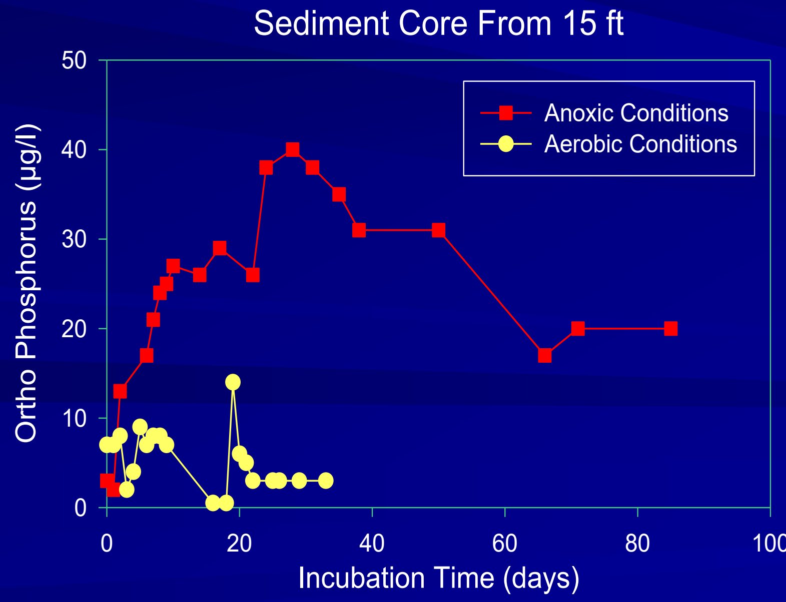


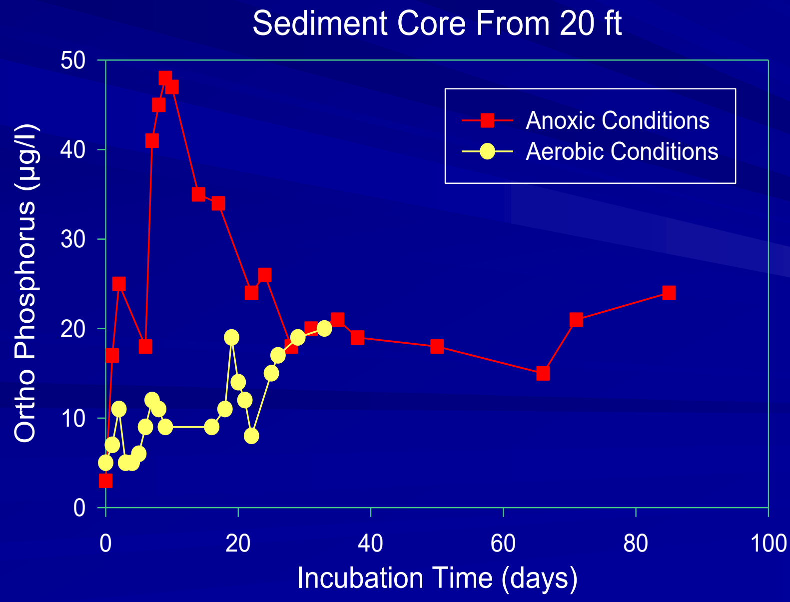
- ERD has conducted measurements of sediment benthic release rates in more than 50 Florida lakes

LAKE MAITLAND ISOLATION EXPERIMENT
ORTHO PHOSPHORUS CONCENTRATIONS



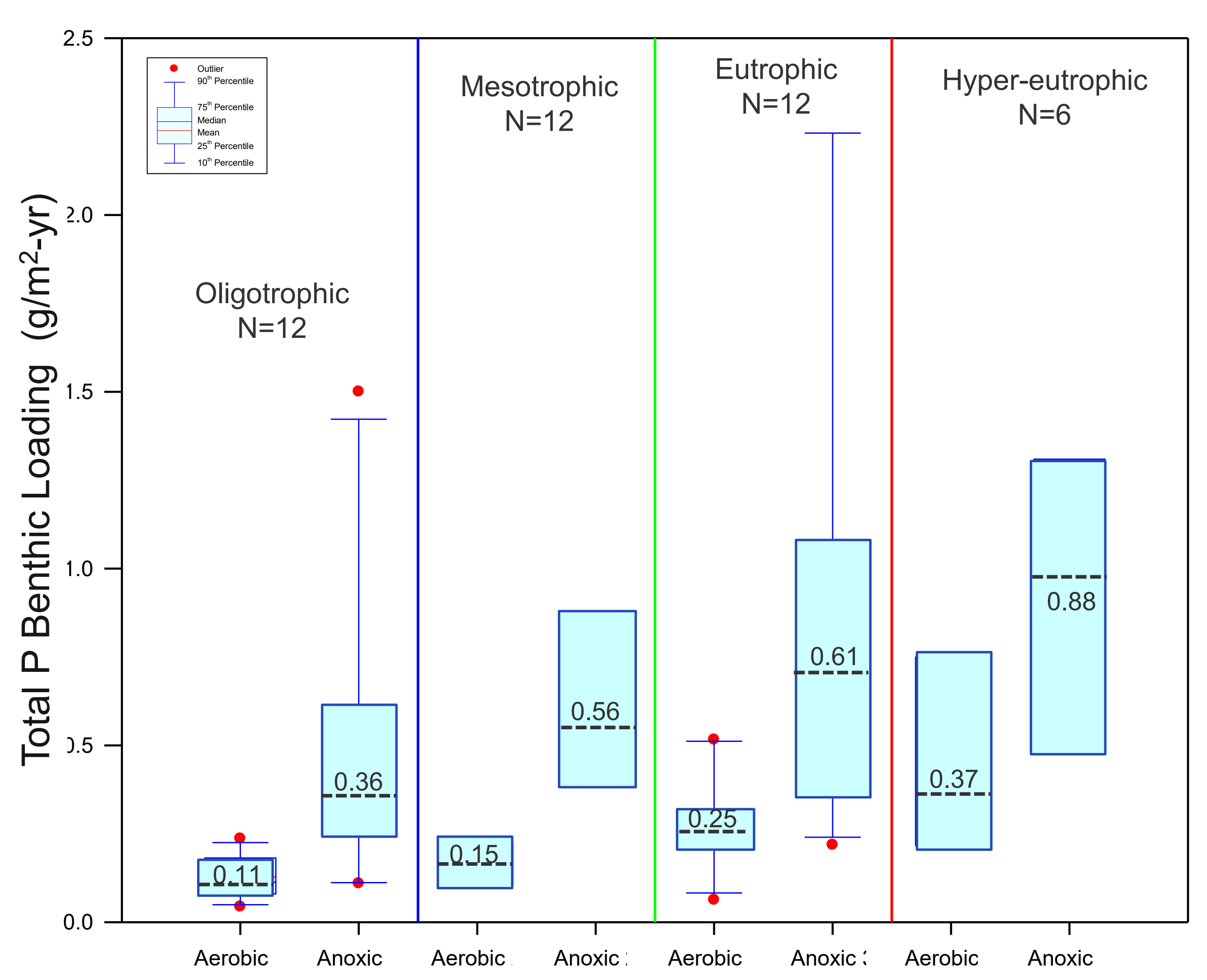






TP Benthic Release by Trophic Status

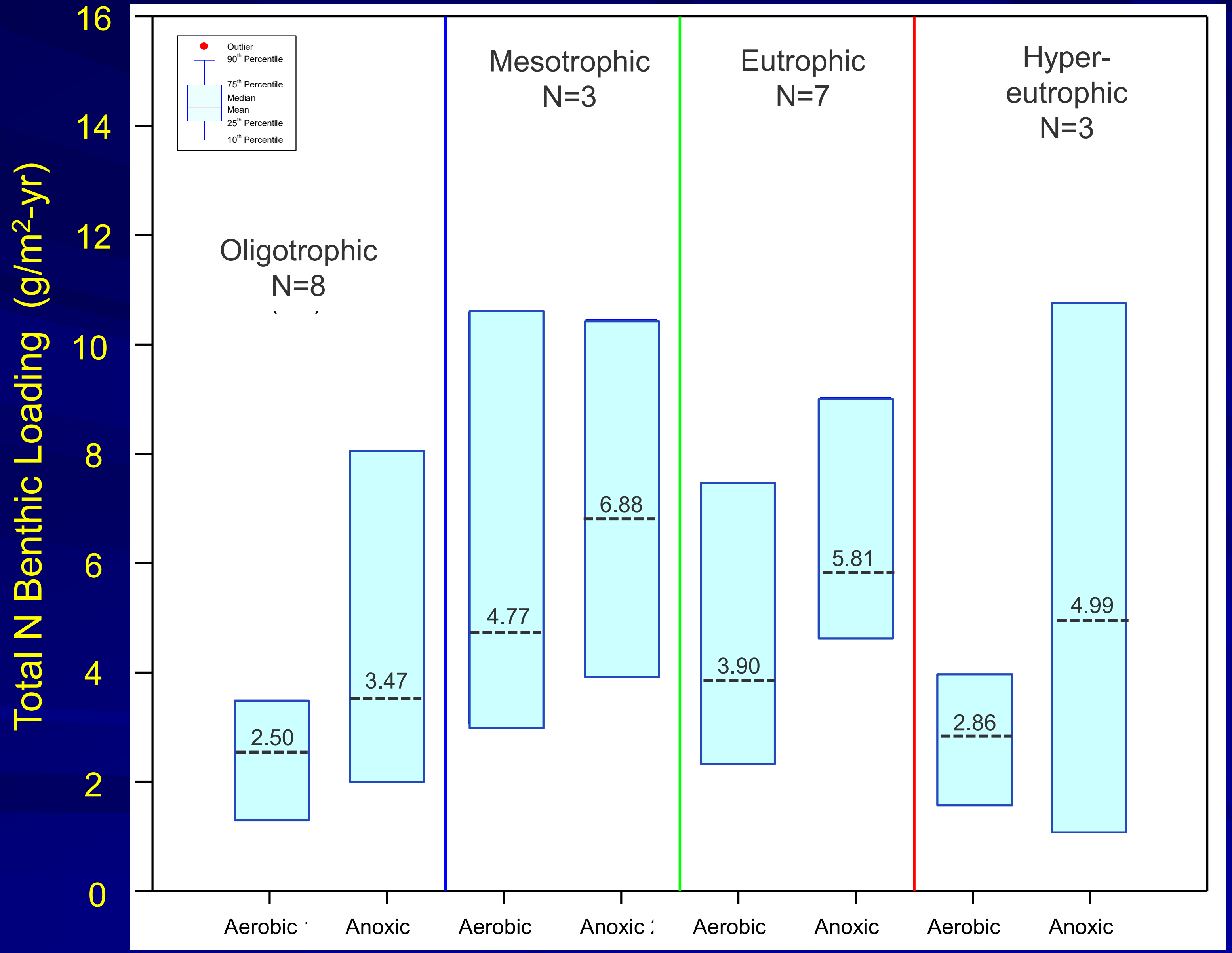
(42 lakes)



Trophic Status	Recycling Rate ($g\ P/m^2/yr$)	
	Aerobic	Anoxic
Oligotrophic	0.11	0.36
Mesotrophic	0.15	0.56
Eutrophic	0.25	0.61
Hyper	0.37	0.88

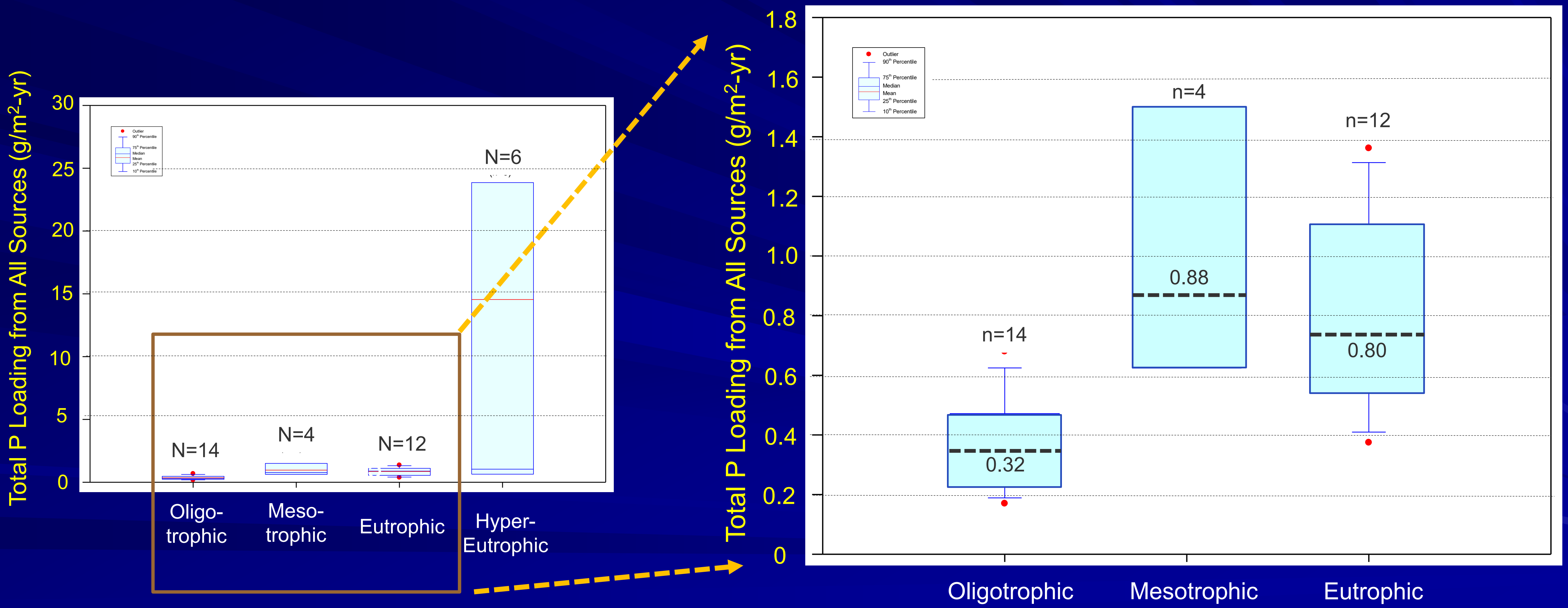
- TP benthic release increases with trophic status

TN Benthic Release by Trophic Status

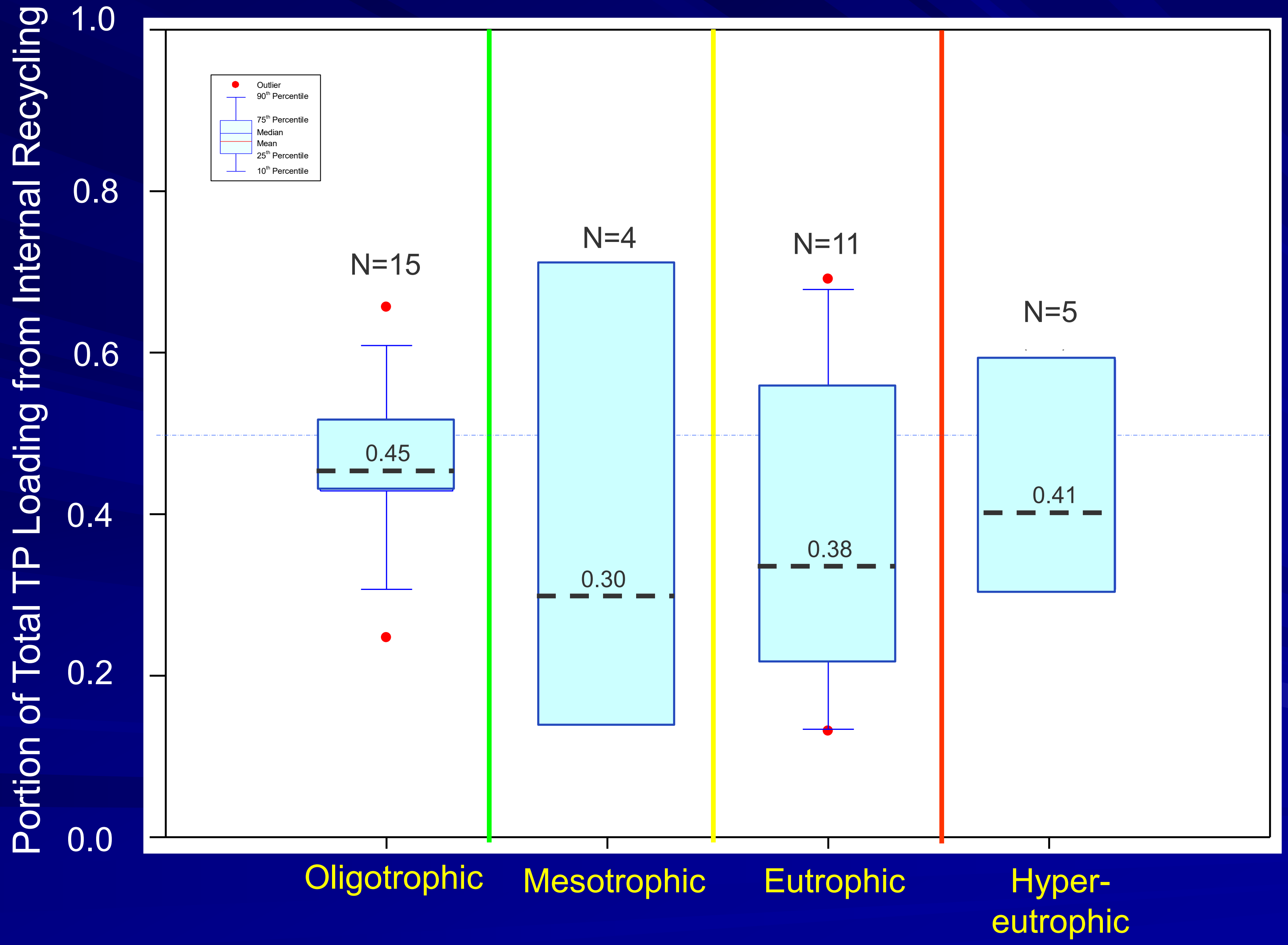


Trophic Status	Recycling Rate (g N/m²/yr)	
	Aerobic	Anoxic
Oligotrophic	2.50	3.57
Mesotrophic	4.77	6.88
Eutrophic	3.90	5.81
Hyper	2.86	4.99

Overall Total P Loading by Trophic Status
(36 lakes)



Fraction of Total TP Loading Contributed by Recycling



7. Reducing Sediment Impacts

a. Covering

b. Physical Removal

c. Chemical Sediment Inactivation

a. Sediment Covering

- An early method of mitigating sedimentation effects was physically covering the lake sediments
  - Sheeting material (plastic or rubber) has been used to seal the sediments at the bottom of a lake.
  - Particulate matter (clay or fly ash) is also used to seal the sediments
  -
- These methods stop the exchange of nutrients in the sediment with the overlying water
- Associated problems include
  - Ballooning of the sheeting material
  - Rupturing of a seal
  - Migration of gases generated within the sediments.

b. Physical Removal

- Sediment removal is a technique used when:
  - Sediments negatively impact water quality
  - Sediments impact navigation or recreational activities
  - To remove toxic materials
- Multiple methods of physical sediment removal
  - Drawdown and mechanical removal
    - Waterbody is drained and sediments allowed to dry
    - Sediments are then removed using earth-moving equipment
  - Mechanical dredging
    - Sediment removed using barge mounted dragline or long-arm scoop
    - Sediment transferred to floating barges or shore-based trucks
    - Creates significant turbidity and dissolved oxygen issues
  - Hydraulic dredging
    - Hydraulic dredge with rotating cutterhead sucks up sediments and generates a water-sediment slurry
    - Slurry is pumped to a dewatering area
    - Only feasible sediment removal technique for many waterbodies

b. Physical Removal – con't.

Hydraulic Dredging

Hydraulic Dredging Equipment

Sediment Spoils Area

Slurry pumped into bags

b. Physical Removal – con't.

Disadvantages of Sediment Removal

- Cost
- Sediment disturbance releases nutrients into water column
- Noise
- Potential for release of toxic materials from sediments
- Water loss and decrease in lake level
- Long process (multiple years)

b. Sediment Removal – con't.

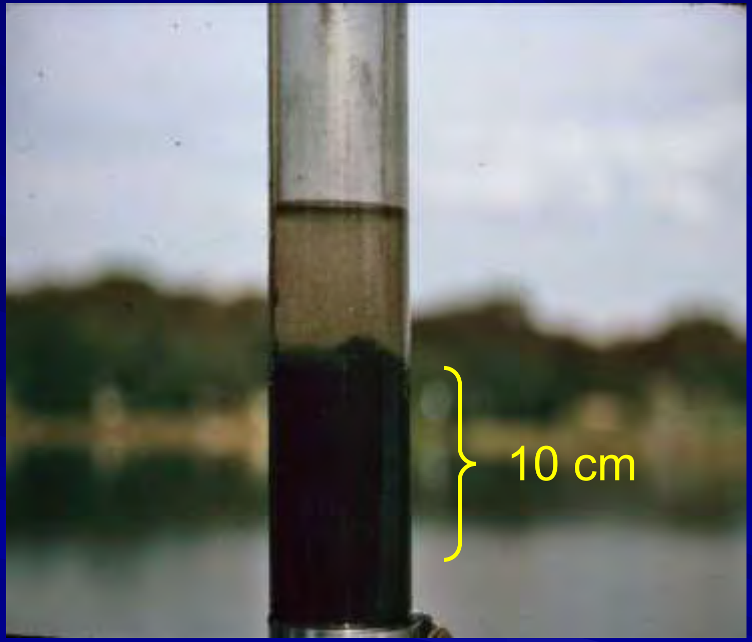
Sediment Removal Success

- Success depends on objectives
  - Navigation and boating
    - Generally effective in achieving objectives if dredging has good quality control
  - Water quality – sediment nutrient release
    - Sediment removal has a poor record of achieving water quality benefits
    - Hydraulic dredging is not 100% effective in removing organic sediments
    - Remaining sediments are redistributed over the lake bottom
    - Sediment nutrient release continues to occur

c. Chemical Inactivation

Phosphorus Bonding in Sediments

- 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 quickly
    - Recalcitrant matter – resistant to further decomposition

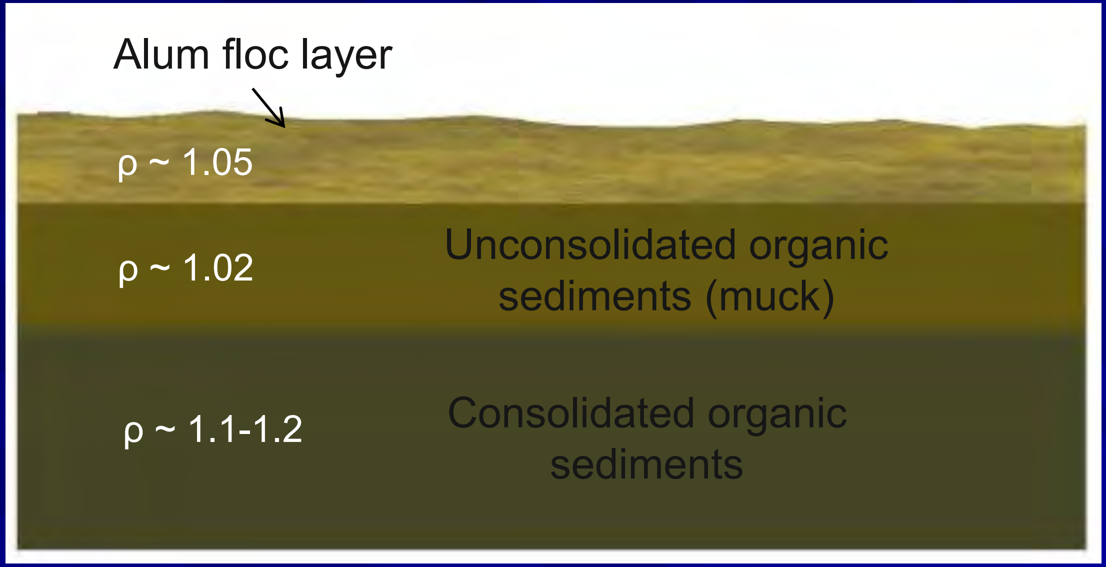


- Significance of an association depends on geology of the watershed and lake

c. Chemical Inactivation

Alum Floc Settling

Floc initially settles onto the surface of the sediments



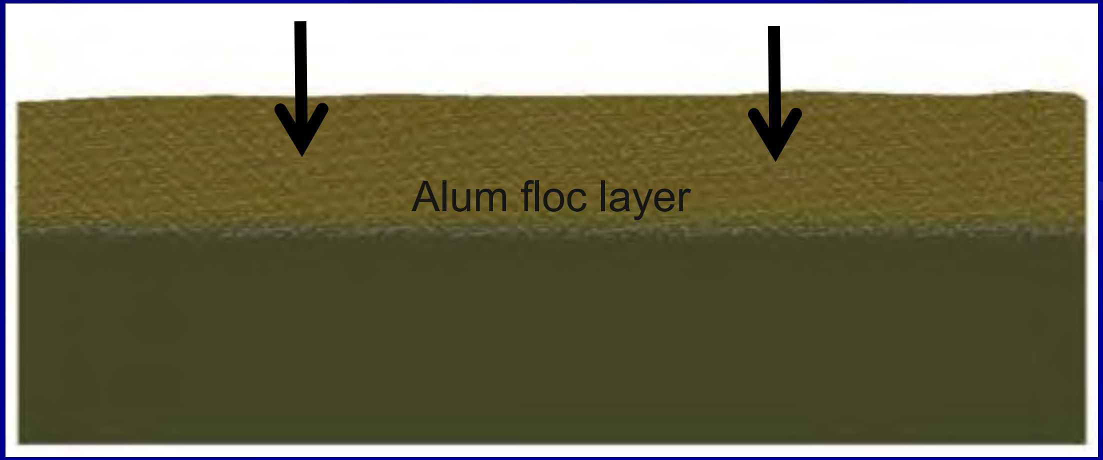
- Alum floc initially settles onto the top of the loose surficial layer

- 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

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

Floc migrates downward over time

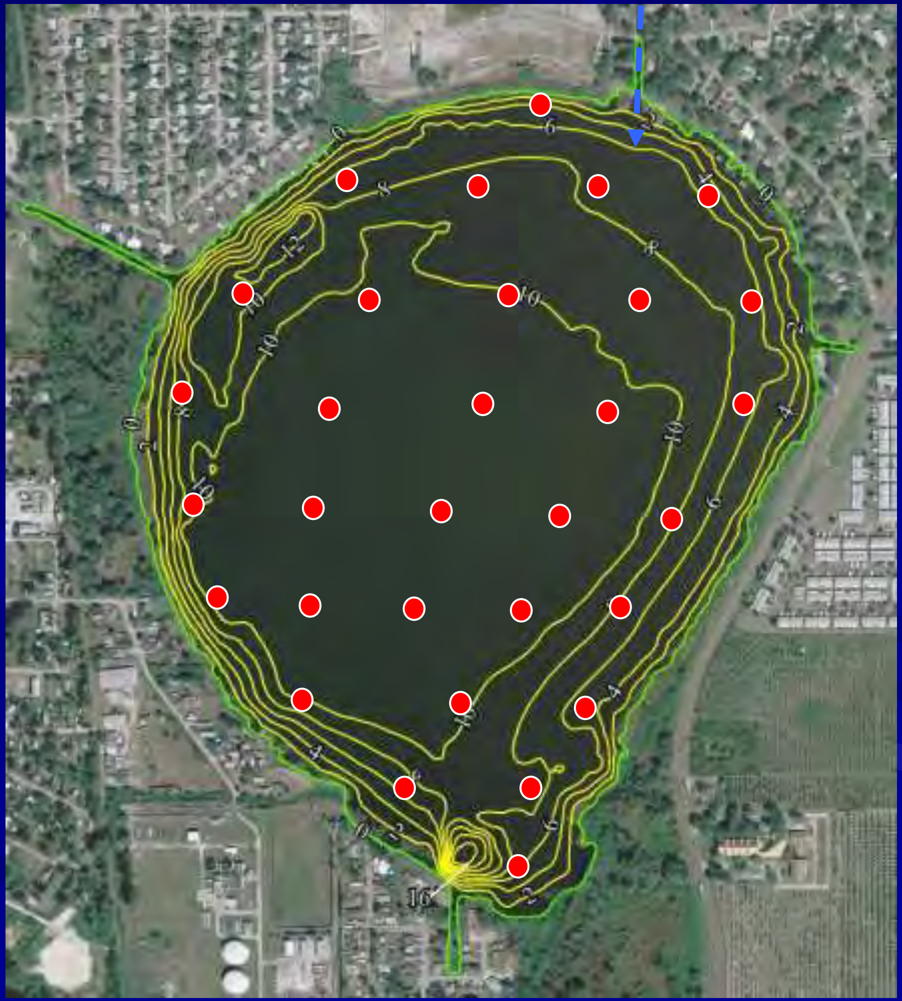


c. Chemical Inactivation

Sediment Inactivation Dose Determination

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

Typical sediment characteristics



Water Depth Contours (ft)

c. Chemical Inactivation

Sediment Inactivation Dose Determination

Available P Contours
(µg P/cm^3)

Application Map

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

c. Chemical Inactivation

Alum/Lime Application Process

- ERD has conducted ~50 alum or alum/lime applications in Florida
  - Treated lake area = 6,500 acres
  - Treated lake volume = 49,184 ac-ft
- Projects have applied:
  - > 3.2 million gallons alum
  - >130,000 gallons sodium aluminate
  - >125,000 gallons lime slurry

a. Application Equipment

b. Mixing alum into lake water

c. Visible floc in water column

d. Water following floc settling

c. Chemical Inactivation

Lake Gatlin

<u>Application Details</u>

Area = 61.5 ac.

Mean Depth = 4.8 m

Alum Only

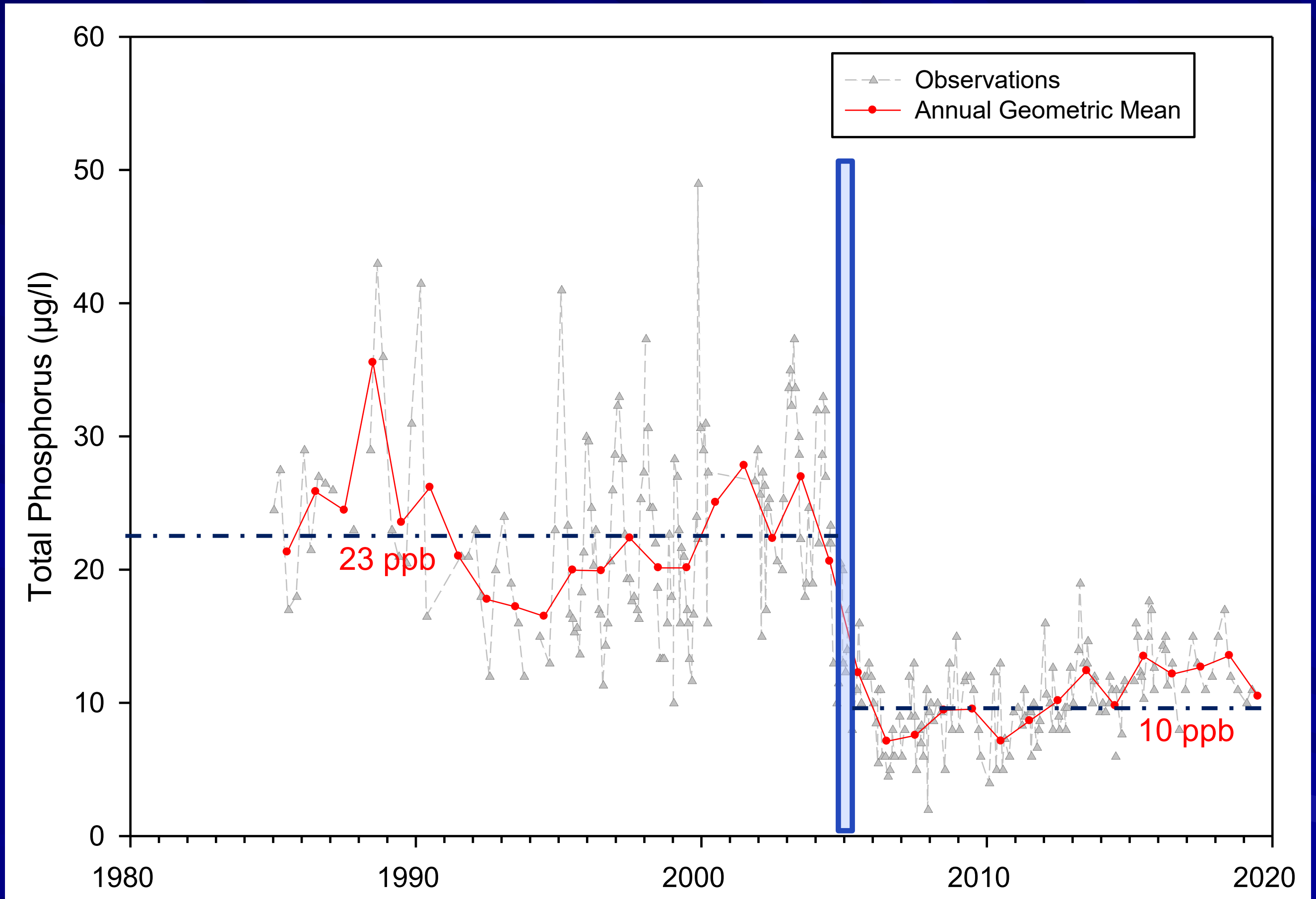
Al:P Ratio = 10:1

Water Column Dose =
5 mg Al/L

Areal Dose =
24 g Al/m^2

<u>Effectiveness (%)</u>

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



c. Chemical Inactivation
Lake Holden

<u>Application Details</u>

Area = 266 ac.

Mean Depth = 3.7 m

Alum Only

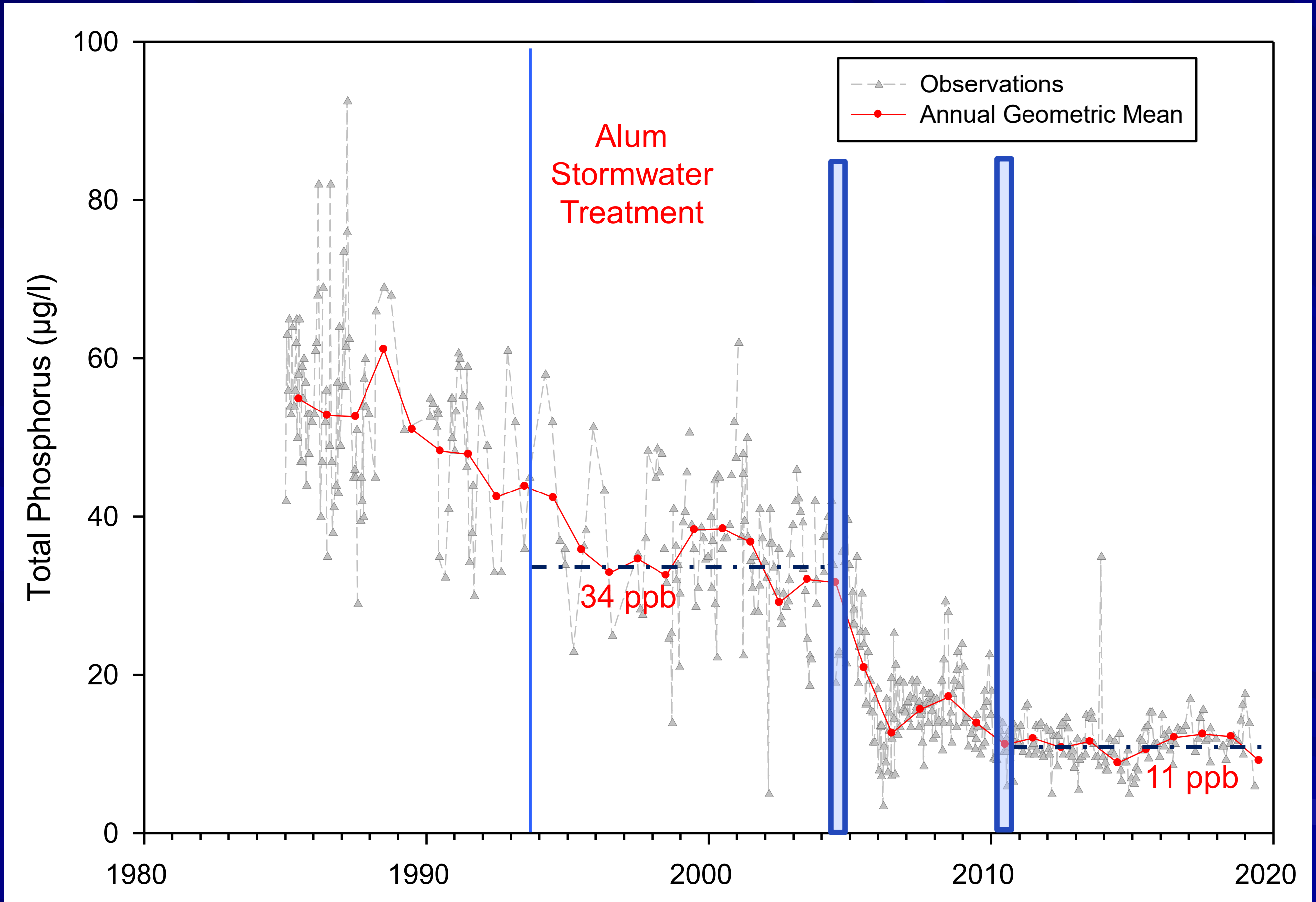
Al:P Ratio = 10:1

Water Column Dose =
16 mg Al/L

Areal Dose =
59 g Al/m^2

<u>Effectiveness (%)</u>

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



c. Chemical Inactivation

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

8. Quantifying Load Reductions/Credits

a. FDEP Nutrient Credits for Muck Removal

- Removal Guidelines
  - Muck must be a minimum average depth of 30 cm
  - Must be removed to natural substrate
  - Removed muck must be stored where it cannot be washed back into the waterbody
- Credit for sediment removal
  - Based on difference between nutrient flux rate of the muck and natural substrates
  - Multiply area dredged x Δ nutrient flux = credit
- Monitoring requirements
  - Measure post-project muck deposition rates every 5 years
  - Report data to FDEP
- Credit duration
  - Muck removal credit assigned for up to 10 years

b. FSA Load Reduction Assessment Tool

- Provides quantified values of the mass fraction of TN and TP associated with solids typically accumulated in BMPs, catch basins, and those solids collected by street sweepers
- Provides a standard methodology for calculating nutrient load reductions from removal of solids
- Tool is based on the 2011 study by Sansalone, John J.; Raje, Saurabh; Berretta, Christian, Quantifying Nutrient Loads Associated with Urban Particulate Matter (PM), and Biogenic/Litter Recovery Through Current MS4 Source Control and Maintenance Practices, University of Florida College of Engineering. Final Report to the Florida Stormwater Association.

Activity	TP (mg/kg)	TN (mg/kg)
Street Sweeping	332	610
Catch Basin	378	785
BMP	328	1054

b. FSA Load Reduction Assessment Tool – con't.

Enter Volume of Solids[1] Removed - Calculate Equivalent Dry Weight (FSA 2019)				
	For Wet or Dry Solids by Volume[2]			Calculated Equivalent Dry Weight Collected (kg)
Category of Maintenance Activity	Enter Volume of Collected Solids (ft^3)	Enter Dry Bulk Density Solids ($lbs./ft^3$)	Calculated Weight of Dry Solids (lbs)	
Street Sweepings	0	85	0	0
Catch Basin Cleanout	0	85	0	0
BMP Cleanout	0	85	0	0

###	GREEN Denotes Cells for DATA ENTRY
###	BLUE Denotes Calculation Results

NOTES:

1. "Particulate Matter" from the FSA Final Report is defined as "Solids" for use in this spreadsheet.
2. For measurements of volume, include approximate dry bulk density; use the default bulk density of 1.36 or 84.9 pounds per cubic foot until confirmed by sampling

b. FSA Load Reduction Assessment Tool – con't.

Calculated Nutrient Load Reductions from MS4 Maintenance Practices					
FSA 2019					
Total Phosphorus				Subtotal TP Removed (Kg)	Subtotal TP Removed (Pounds)
Street Sweepings	Dry Mass Collected (Kg)	0			
	TN Removed (Kg)	0		0	0
Catch Basins	Dry Mass Collected (Kg)	0			
	TN Removed (Kg)	0		0	0
BMPs	Dry Mass Collected (Kg)	0			
	TN Removed (Kg)	0		0	0
		Grand Total P Removed =		**0**	0

Total Nitrogen				Subtotal TN Removed (Kg)	Subtotal TN Removed (Pounds)
Street Sweepings	Dry Mass Collected (Kg)	0			
	TN Removed (Kg)	0		0	0
Catch Basins	Dry Mass Collected (Kg)	0			
	TN Removed (Kg)	0		0	0
BMPs	Dry Mass Collected (Kg)	0			
	TN Removed (Kg)	0		0	0
		Grand Total P Removed =		**0**	**0**

###	TAN Denotes Calculations for this Table
###	BLUE Denotes Calculations from Previous Table

Questions?