ATCAVE 2010
Water Supply Limnology

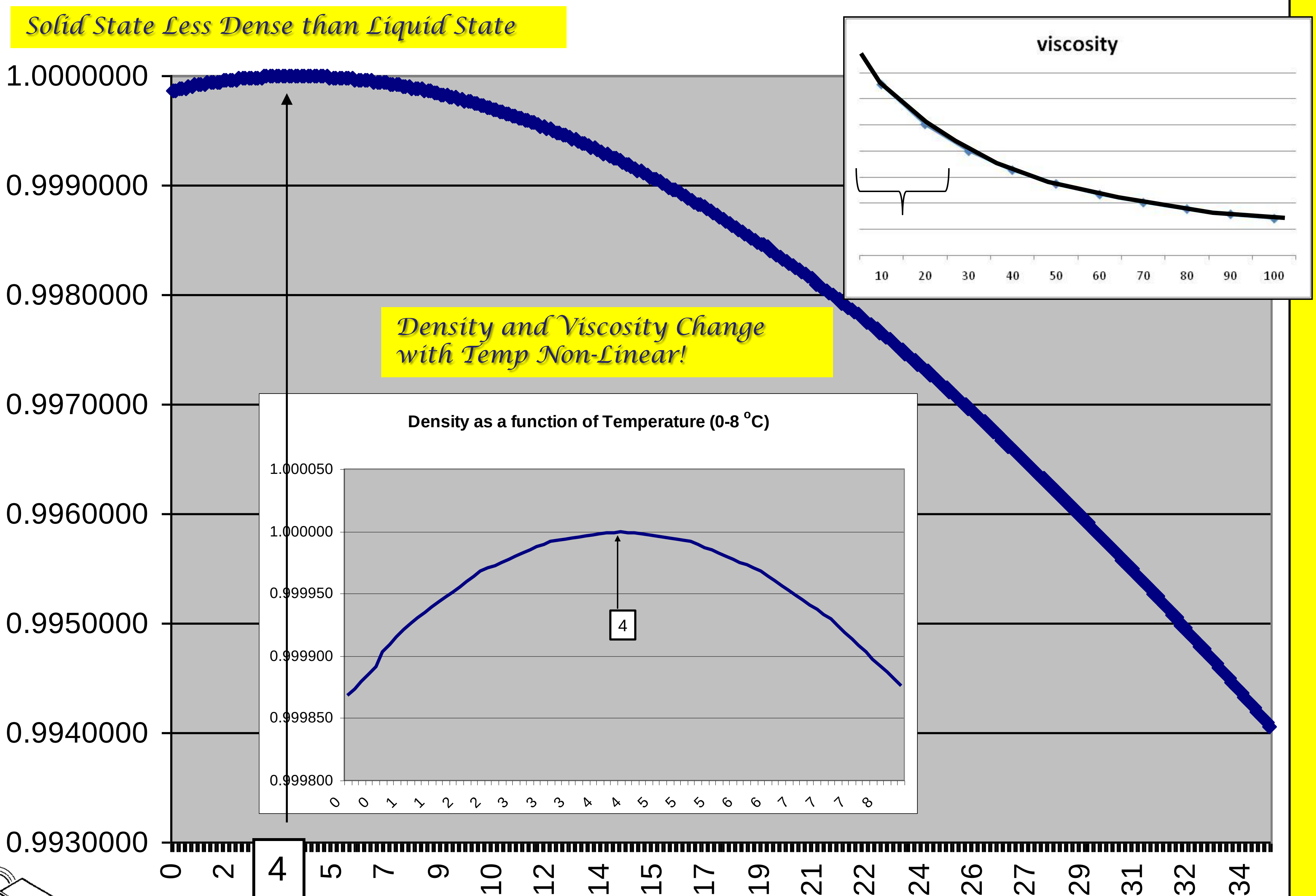
Properties of Water
Limnology of Supply Reservoirs
Management of Supply Reservoirs

Case Study Examples
Thank You Acknowledgements
Connecticut Water, Aquarion, NJ American, Groton Utilities, Ct MDC, Norfolk VA Utilities, Pennichuck Water Works, NJDWSC, Brick Utilities NJ,

Water - A Very Unique Substance!

Chemically reduced state of oxygen
Polar Molecule- Cohesive Forces
Universal Solvent
Density and Viscosity Change as a Function of Temperature
Phase Changes-Pressure Relationships
Specific Heat

Density as a function of Temperature (^oC)



RTRM

Relative Thermal Resistance to Mixing

$$\textbf{RTRM} = \frac{\text{Density of Upper Layer} - \text{Density of Lower Layer}}{\text{Density at } 5^{o}\text{ C} - \text{Density at } 4^{o}\text{ C}}$$

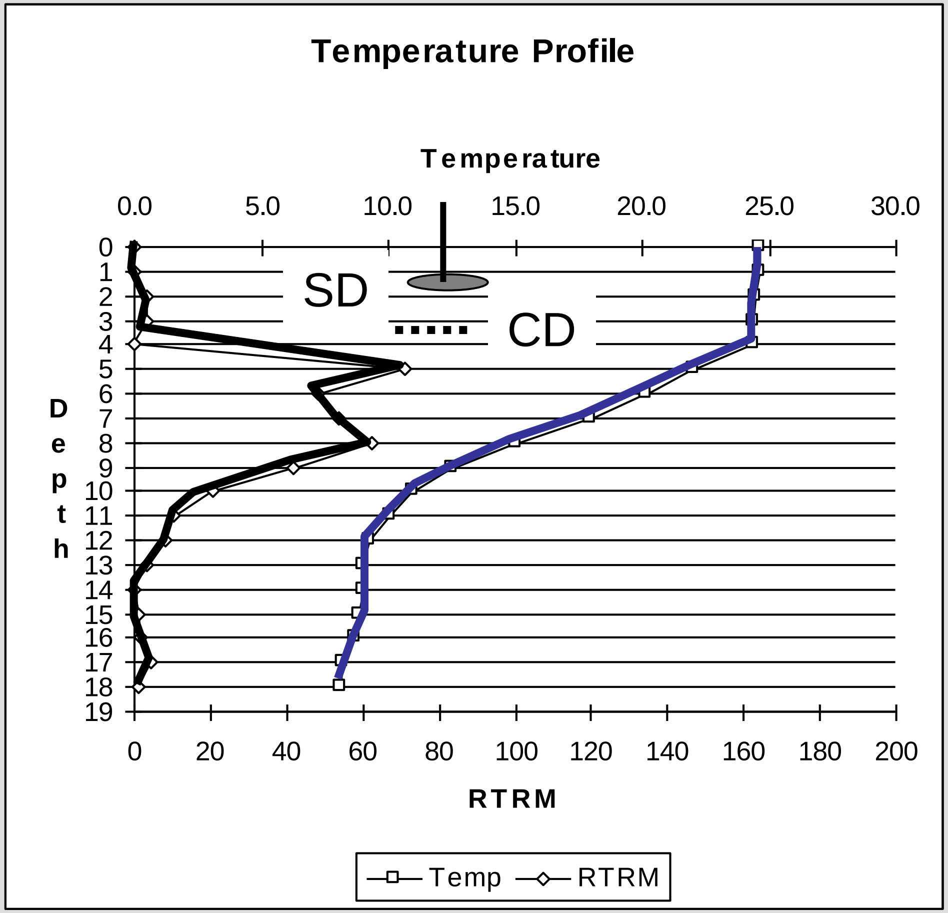
RTRM

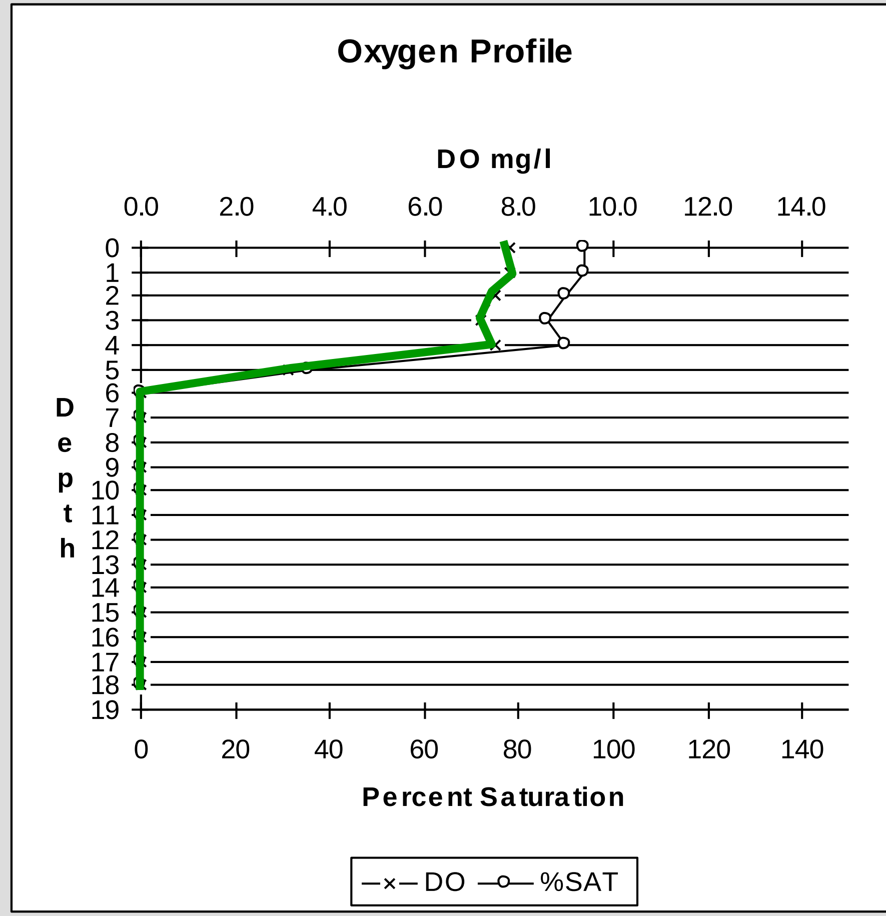
- …is a relative, non-dimensional, value which quantifies stratification as a function of temperature differential.
- …is independent of the units of depth used.
- …is additive (RTRMsum indicates total stratification intensity).
- …the Peak RTRM identifies the location and intensity of the thermocline (steepest density gradient).

Excel Spreadsheet for computation and vertical profiling available at www.ecosystemconsulting.com (Free)

SD= Secchi Disk Depth

CD= Compensation Depth (Photosynthetic Oxygen Production Balances Respiratory Consumption)





"Typical Stratification"

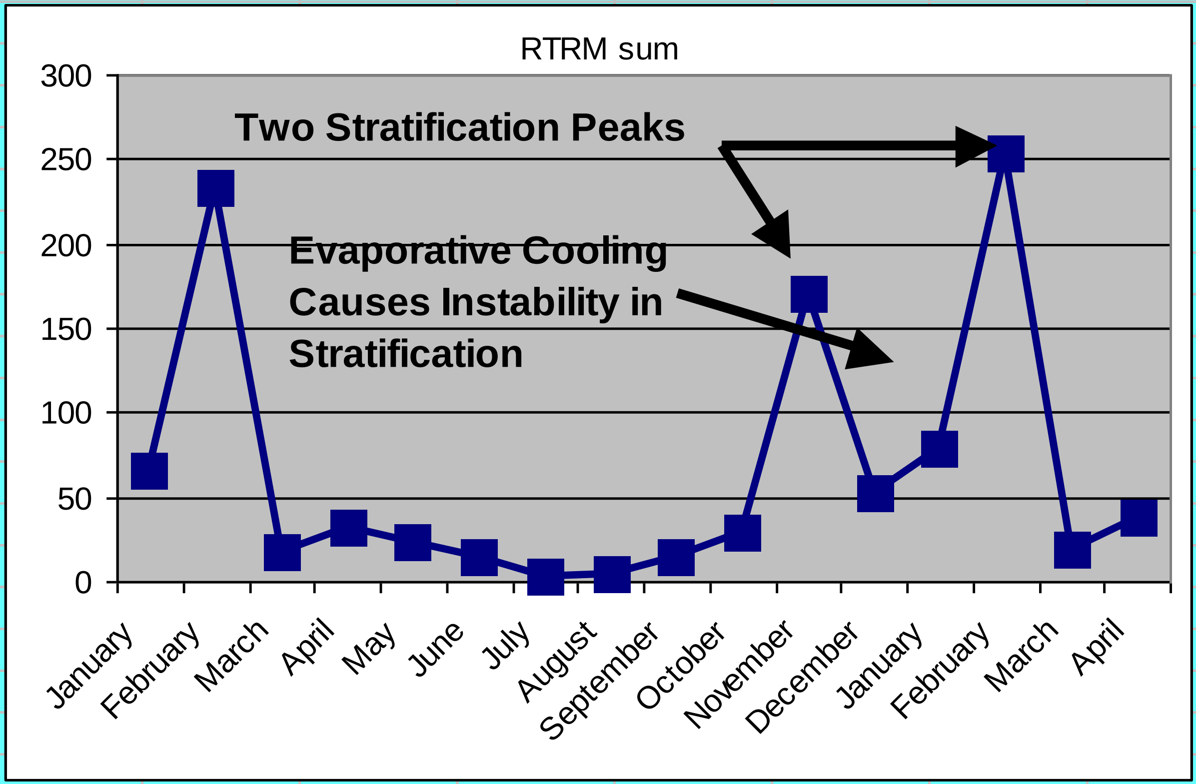
Often portrayed in textbooks…rarely seen in Nature!

The warmer the Temperature – the greater the density difference per Degree

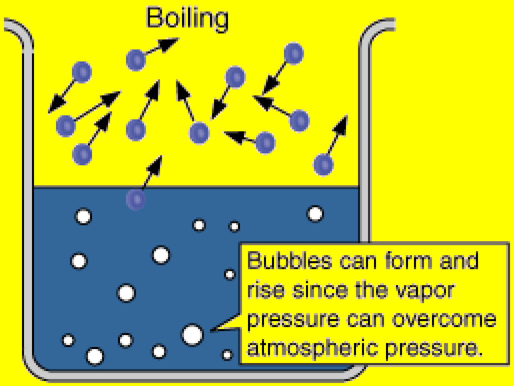
Stratification in a Warm Reservoir can be VERY STRONG…**AND** UNSTABLE!

(Think about that one for a moment)

	RTRM sum
January	65
February	233
March	17
April	32
May	23
June	15
July	3
August	5
September	15
October	29
November	171
December	53
January	79
February	253
March	19
April	38



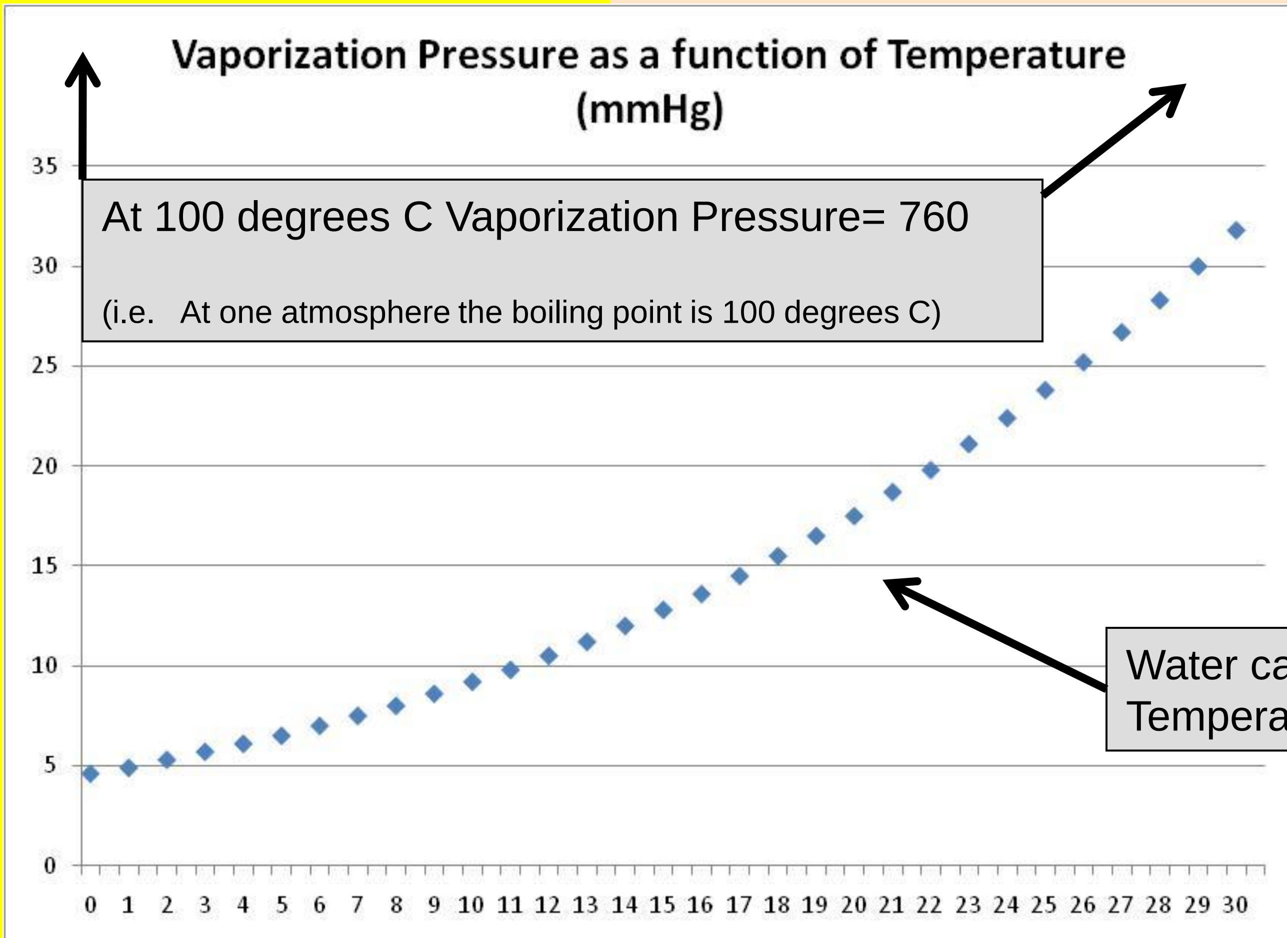
Guarapiranga Reservoir, Sao Paulo, Brazil



Boiling Point

The boiling point is defined as the temperature at which the saturated vapor pressure of a liquid is equal to the surrounding atmospheric pressure. For water, the vapor pressure reaches the standard sea level atmospheric pressure of 760 mmHg at 100°C. Since the vapor pressure increases with temperature, it follows that for pressure greater than 760 mmHg (e.g., in a pressure cooker), the boiling point is above 100°C and for pressure less than 760 mmHg (e.g., at altitudes above sea level), the boiling point will be lower than 100°C. As long as a vessel of water is boiling at 760 mmHg, it will remain at 100°C until the phase change is complete. Rapidly boiling water is not at a higher temperature than slowly boiling water. The stability of the boiling point makes it a convenient calibration temperature for temperature scales.

At the boiling point, saturated vapor pressure equals atmospheric pressure.

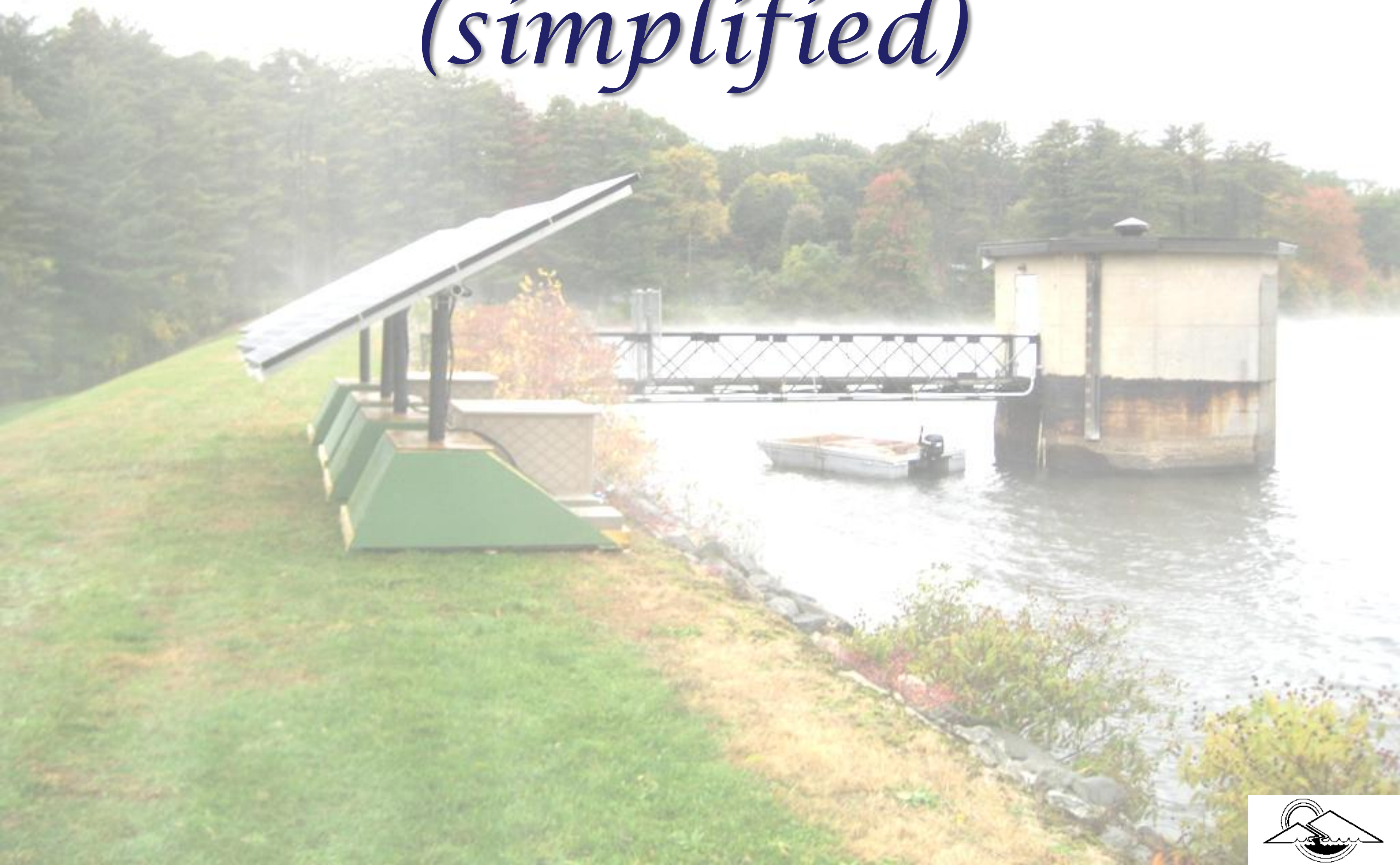


At 100 degrees C Vaporization Pressure= 760

(i.e. At one atmosphere the boiling point is 100 degrees C)

Water can be boiled at a low Temperature by reducing pressure.

Eco-Biochemistry of Life (simplified)



"*Eutrophication*" means there is more of this (because there is more organic fuel produced in, *or washed into*, the lake).

$$(CH_2O)_n \longrightarrow CO_2$$

If it lives…it performs respiration!

All living organisms "combust" organic fuel to carbon dioxide. We often measure the rate of oxygen loss in a lake hypolimnion. That measures *aerobic respiration*. We rarely measure the rate of increase in dissolved inorganic carbon (CO_2) which would account for *all respiration* of *all living organisms*.

Autochthonous *and* Allochthonous

Large Reservoir: Small Watershed **Large Watershed:Small Reservoir:**

Synthesis $CO_2 \longrightarrow CH_2O$

Photosynthesis
Chemosynthesis

Respiration $CO_2 \longleftarrow CH_2O$

Aerobic Respiration
Anaerobic Respiration
Fermentation

Photosynthesis Happens in the Watershed too.

(ALLOCHTHONOUS LOADING)

Photosynthesis

$CO_2 \longrightarrow (CH_2O)_n$

e^-

$H_2O \longrightarrow O_2$

Water is the electron donor, it is oxidized to oxygen

Aerobic Respiration

$(CH_2O)_n \longrightarrow CO_2$

e^-

$O_2 \longrightarrow H_2O$

Oxygen is the electron acceptor, it is reduced to water

In Order

(ATEAs)

$(CH_2O)_n \longrightarrow CO_2$

e^-

$NO_3 \longrightarrow N_2$

$\boxed{Fe{+}3\text{-}PO_4} \longrightarrow Fe{+}2 + PO_4$

React to cause a loss of "Functional Iron" and decreased P-Binding

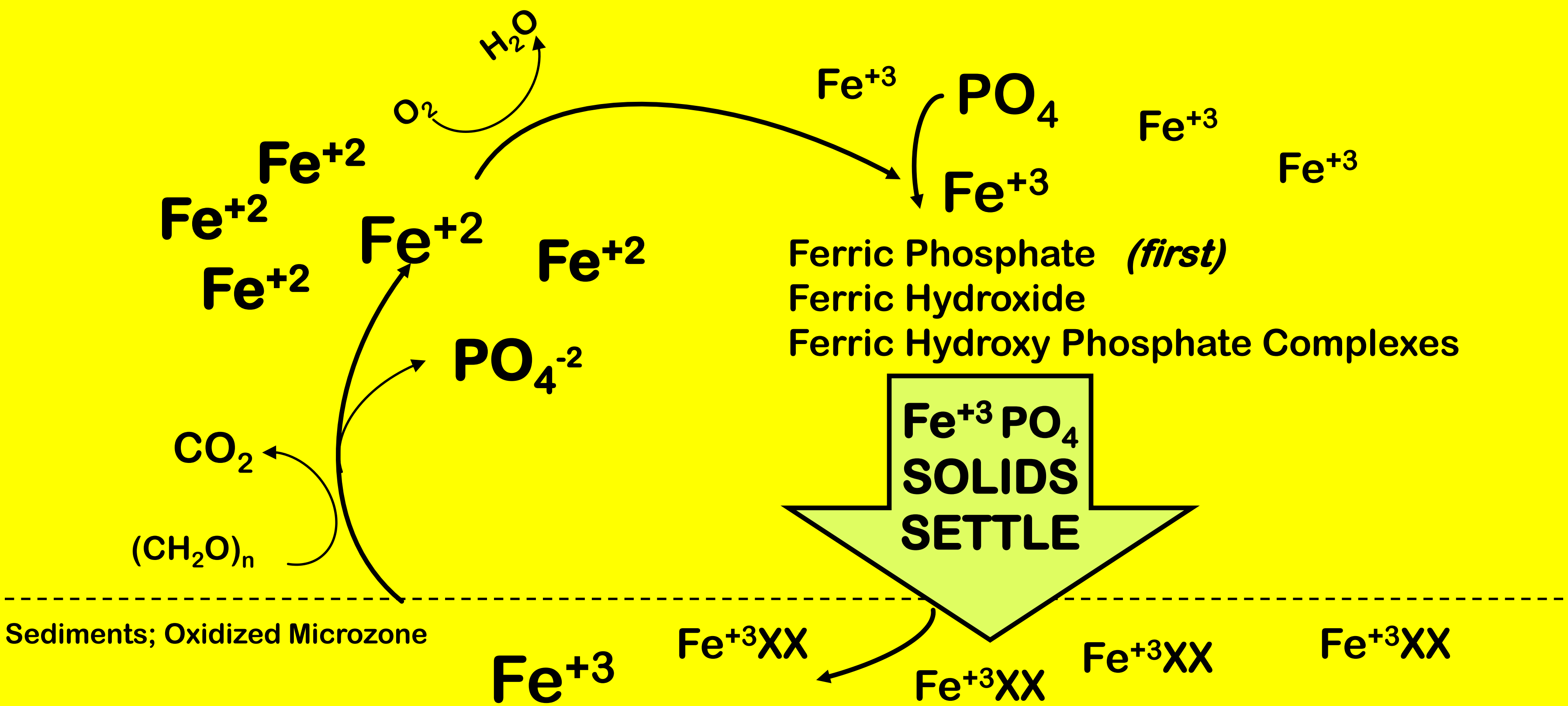
$S^o \longrightarrow H_2S^=$

And Mn reduction, Sulfur Rotten Egg Odor, Oxidant Demand…

Respiration using an Alternate to Oxygen as the electron acceptor

Anaerobic Respiration

- *Ferrous Iron is typically in excess compared to phosphorus.*
- *Iron is precipitated as phosphate before hydroxide is formed.*



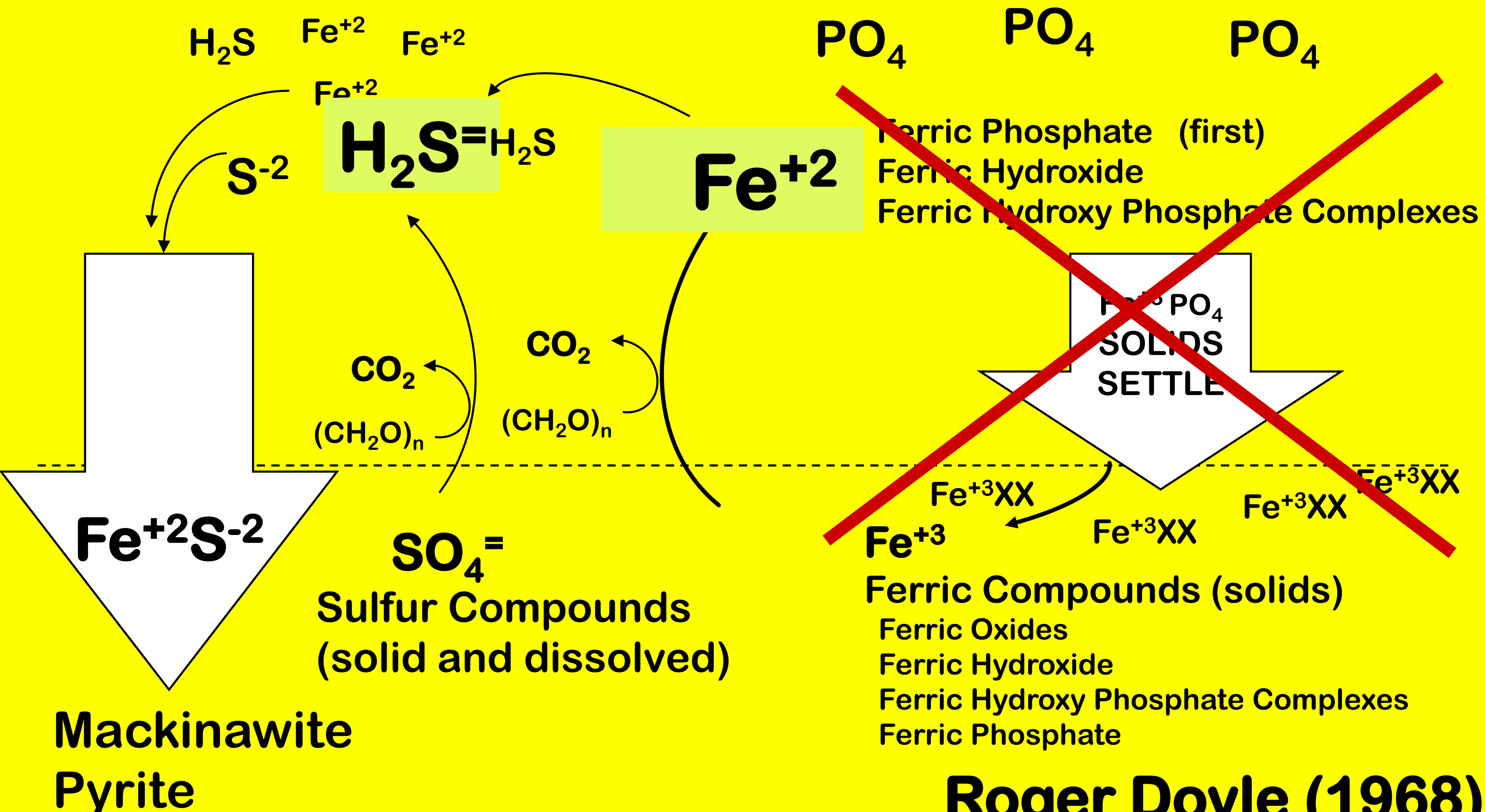
Ferric Compounds (solids)

- Ferric Oxides
- Ferric Hydroxide
- Ferric Hydroxy Phosphate Complexes
- Ferric Phosphate

Einsele (1936,1938)
Hutchinson (1941)

- *Ferric Iron gives sediments a "Phosphorus Binding Capacity".*

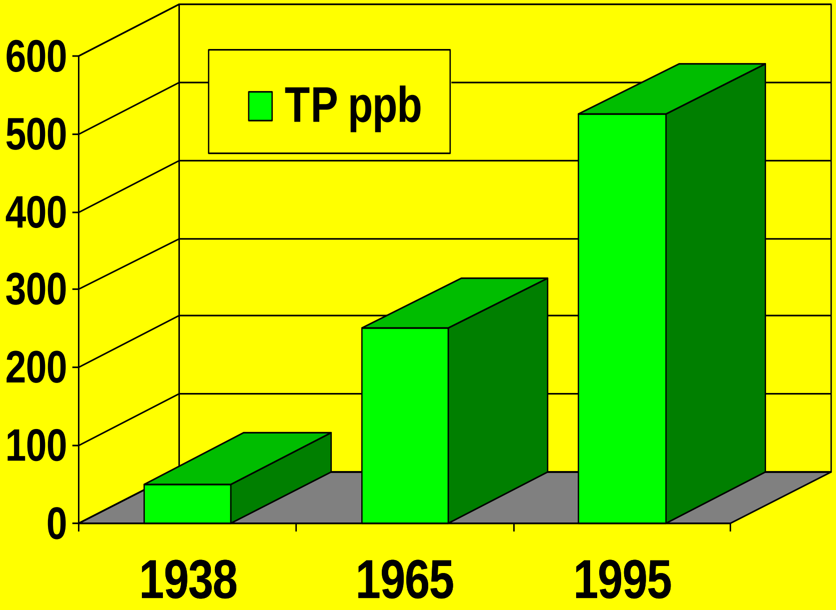
- *Iron no longer participates in anaerobic respiration (it is permanently deposited as ferrous sulfide).*
- *Iron no longer cycles between the sediments and the water column.*
- *Iron no longer removes phosphorus from the water column, (phosphorus is left behind in the water).*
- *More Hydrogen Sulfide production occurs to replace the respiration role previously filled by iron.*



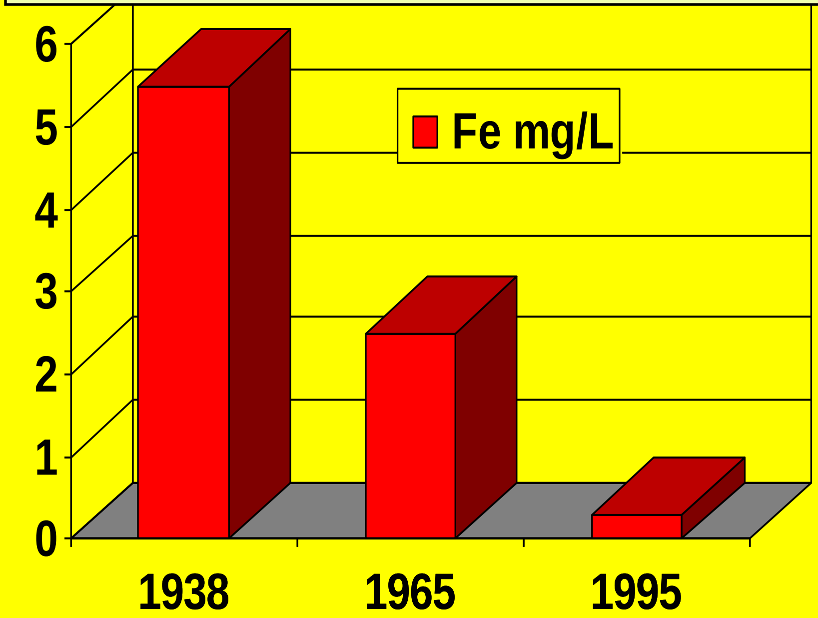
Roger Doyle (1968)

- *The Phosphorus Binding Capacity of sediments is lost.*
- *$AlSO_4$ = ALUM, Might the sulfate load have an adverse impact?*

Linsley Pond 13m Fe TP Concentrations



Sulfur Cycle Became Dominant

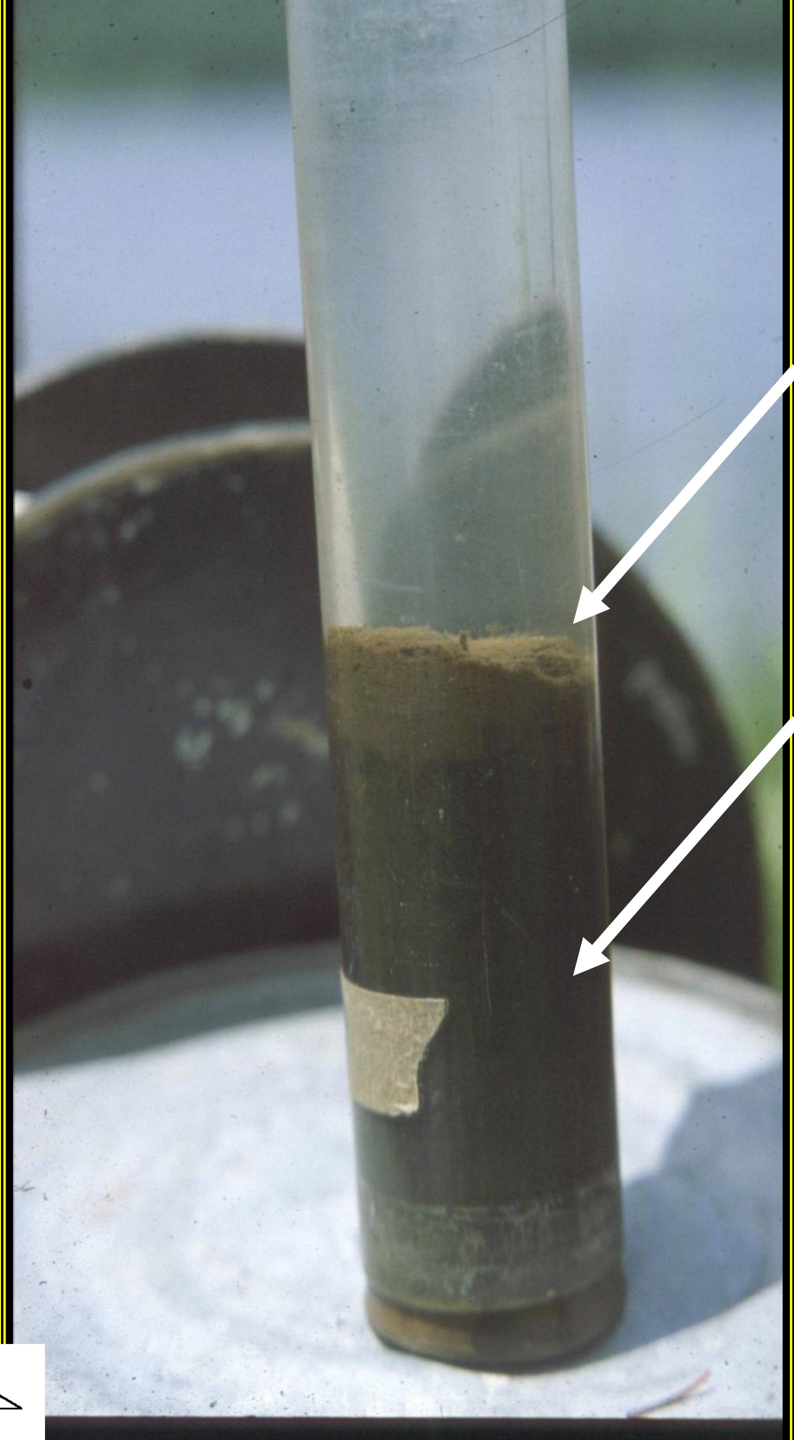


Increasing Eutrophication,
Increasing Organic Supply (Autoth. And Allochth.),
Increasing Carbonaceous Oxygen Demand
Increasing demand for ATEAs…more S= production which permanently removes Fe.

It is "*iron*ic" that this was observed at Roger Doyle's study lake.

Loss of a "Functional Iron Cycle" is a *consequence of Eutrophication*, *and leads to more intense eutrophic conditions.*

In Fe-dominated systems:

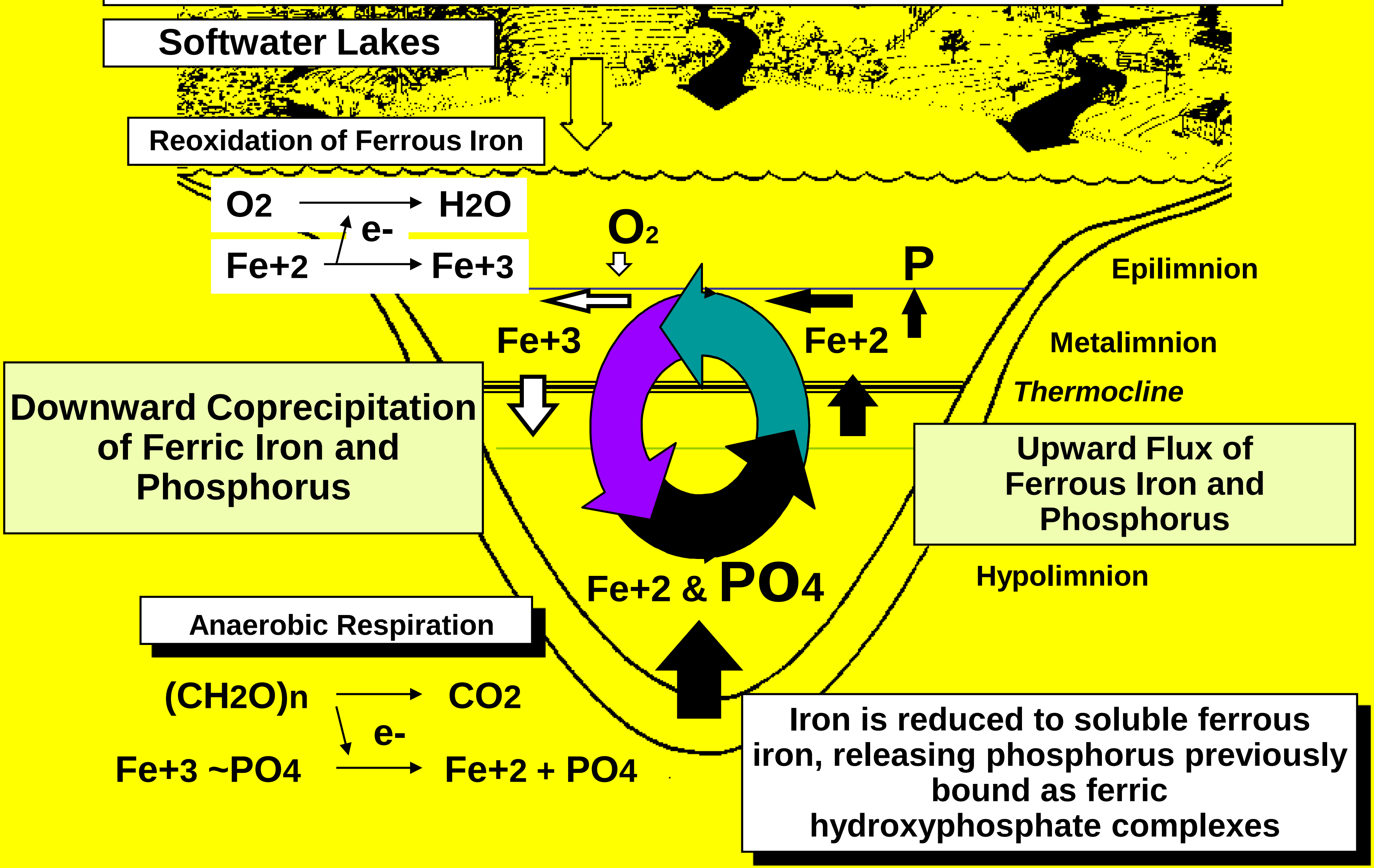


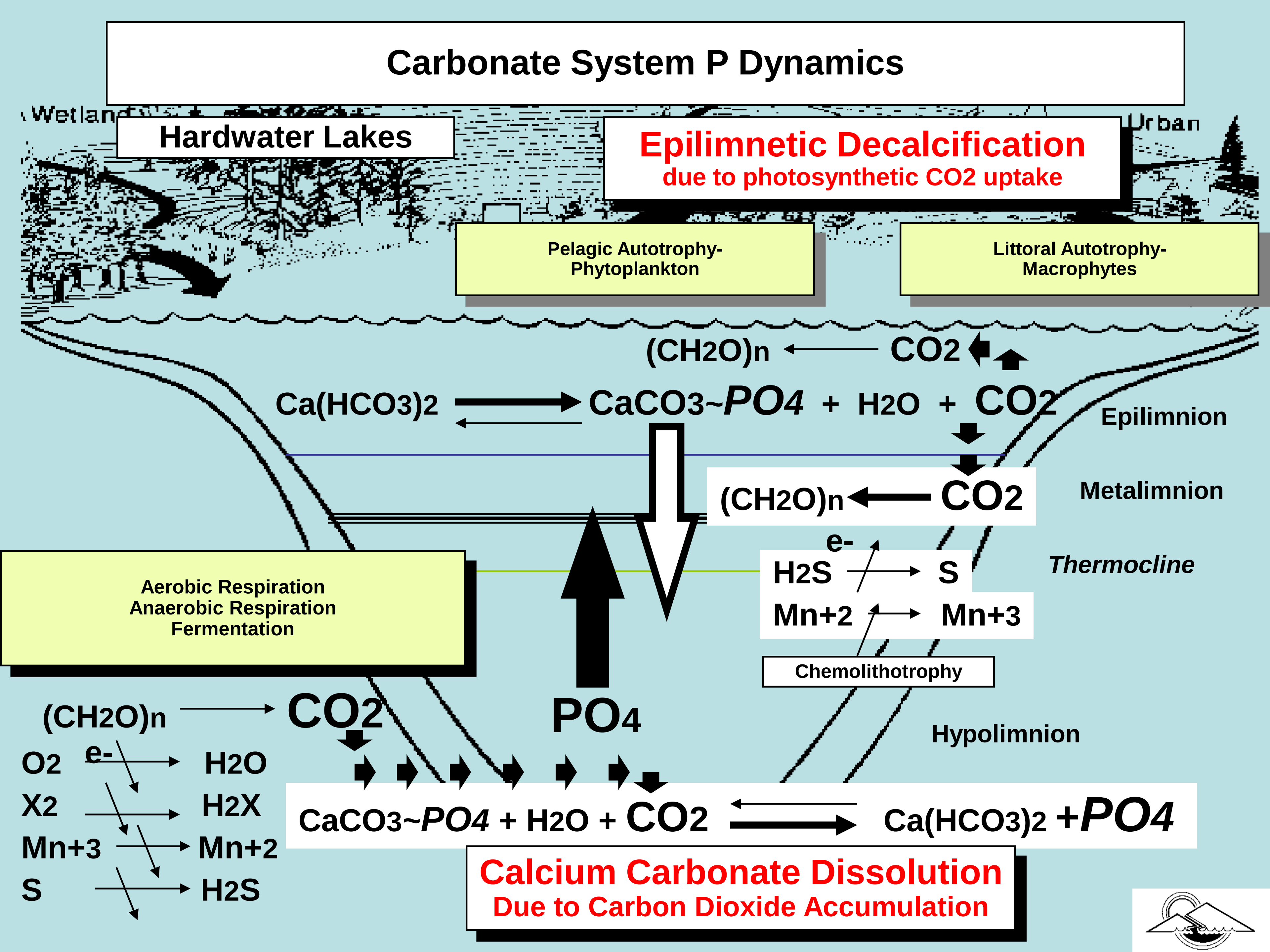
Oxidized Microzone
Ferric Iron Complexes
(*<u>Some</u>* of the Fe binds P)

Deep Anaerobic Sediments
(with Ferr***ous*** Sulf***ide*** solids;
Note: both the iron and
sulfur are chemically
reduced and do not
participate in biotic redox or
P-binding any longer!)

(Re: Roger Doyle, 1968)

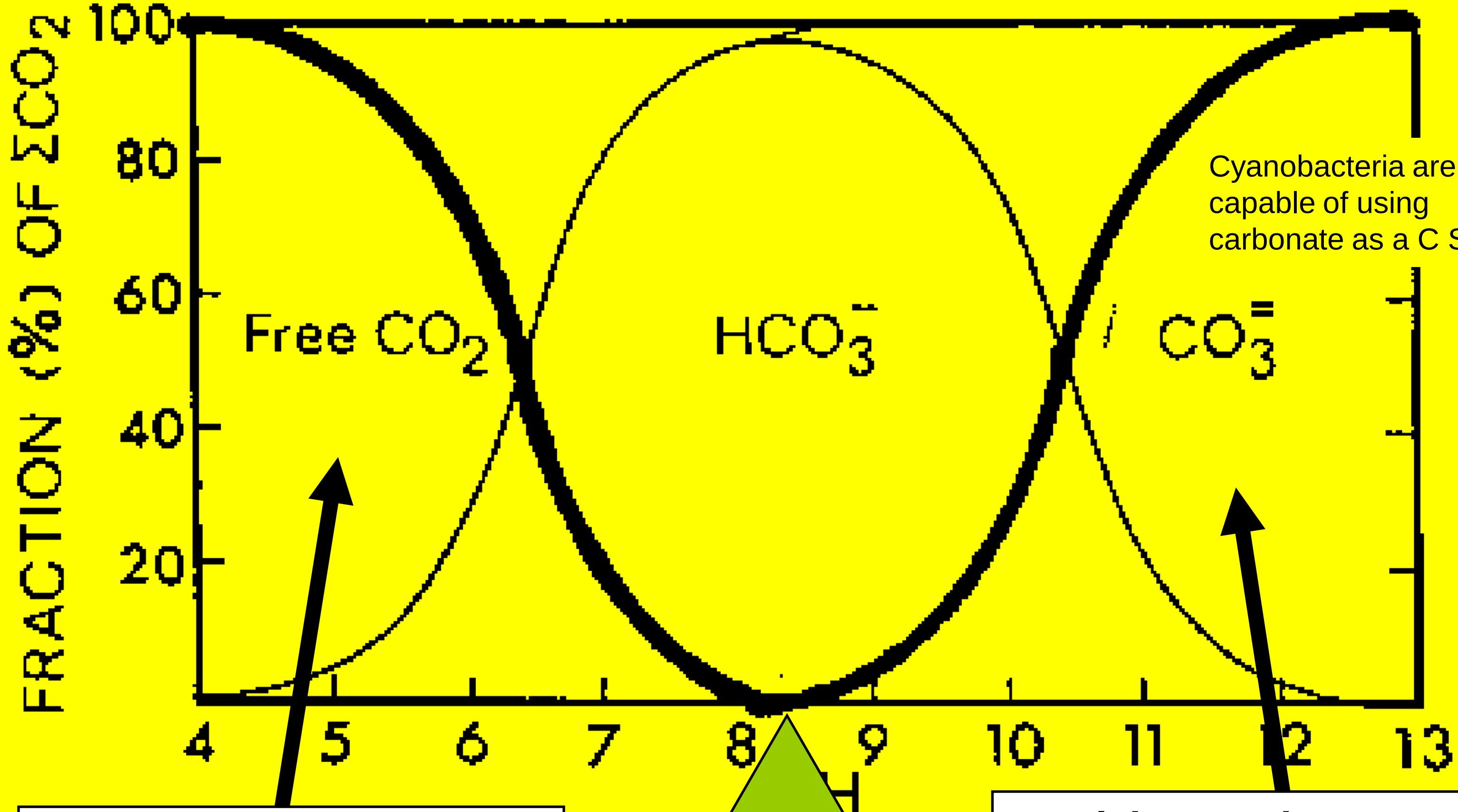
The Ferrous Wheel




Carbonate System P Dynamics
Wetland
Hardwater Lakes
Urban
Epilimnetic Decalcification
due to photosynthetic CO2 uptake
Pelagic Autotrophy-
Phytoplankton
Littoral Autotrophy-
Macrophytes
(CH2O)n
CO2
Ca(HCO3)2
CaCO3~PO4 + H2O + CO2
Epilimnion
(CH2O)n
CO2
Metalimnion
e-
H2S
S
Thermocline
Mn+2
Mn+3
Chemolithotrophy
Aerobic Respiration
Anaerobic Respiration
Fermentation
(CH2O)n
CO2
PO4
Hypolimnion
O2
e-
H2O
X2
H2X
Mn+3
Mn+2
S
H2S
CaCO3~PO4 + H2O + CO2
Ca(HCO3)2 +PO4
Calcium Carbonate Dissolution
Due to Carbon Dioxide Accumulation

DECALCIFICATION PHOSPHORUS REMOVAL

Hardwater Lakes



Photosynthesis Removes Free Carbon Dioxide
(pH increases at surface)

> pH 8.3

Calcium Carbonate Precipitates to Re-establish Equilibrium

Respiration releases CO2 (carbonic acid- decreases pH at bottom)- dissolves Carbonate- releases P

Biological Populations, Communities, Ecosystems.

Cyanobacteria will be emphasized…but they are not the only critters of concern!

BLUEGREEN ALGAE = CYANOBACTERIA

Phytoplanktonic and Benthic Mats

Taste & Odor: Geosmin and MIB (22^{o}C)

Toxins: Microcystin, Anatoxin, among others…

Cyanobacteria Have Evolved Many Competitive Strategies over several Billion Years!

N:P Ratio Organic-N Organic-P

SiO_2 : P Ratio

pH, CO_2, Bicarb. Buffer System (DIC Source)

Light Penetration, Cellular Buoyancy

Zooplanktivory and Grazing Rate

Mixing Depth D_e

Bluegreen Algae (Cyanobacteria, prokaryotic cells)

Nature is our foremost teacher! The task of technology is not to correct Nature…but to imitate it!

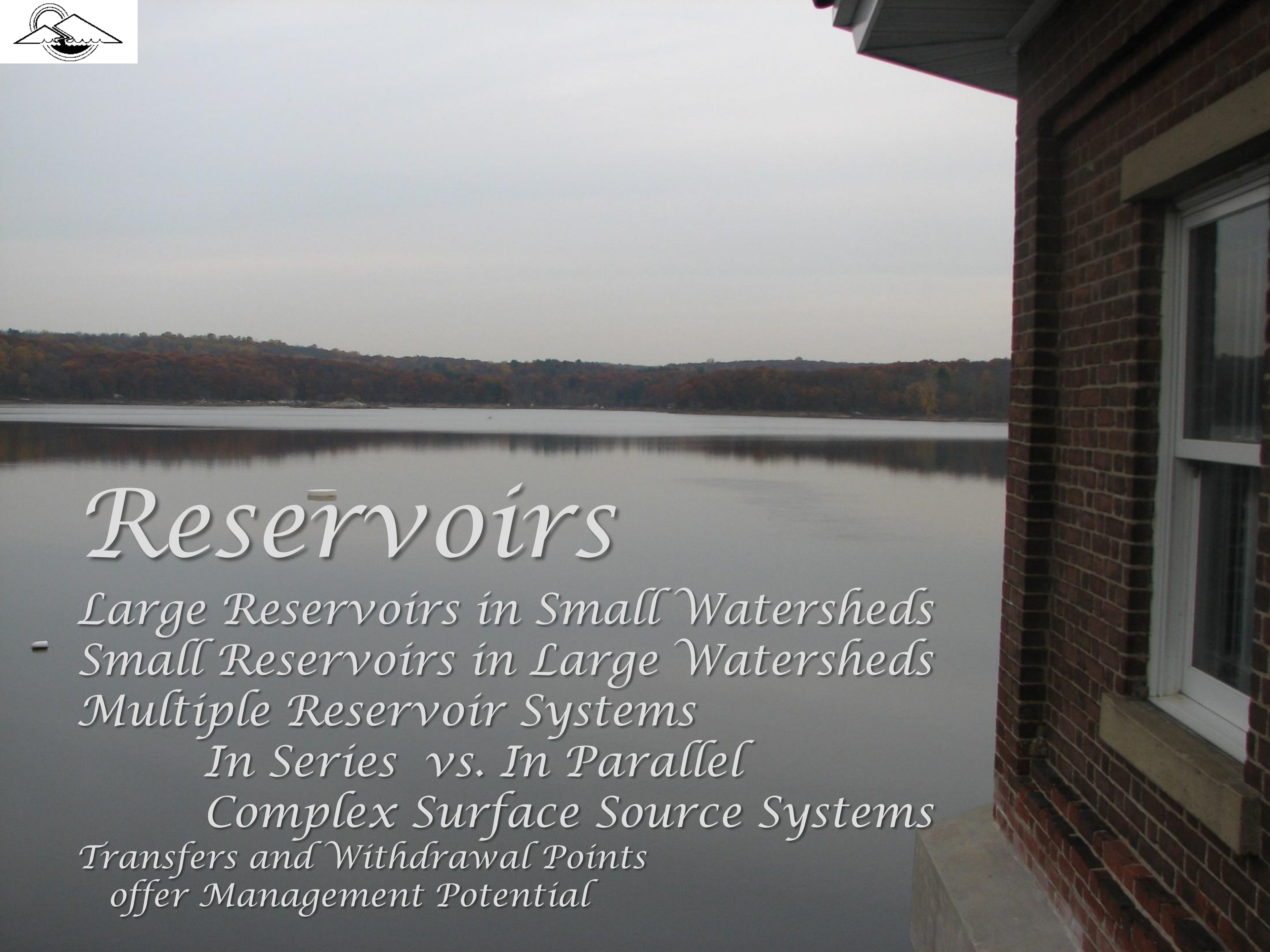
To avoid Cyanobacteria Blooms…

….prevent the conditions which provide them a competitive advantage!

Prevent their Dominance…

Avoid Them by Withdrawal Strategies.

Nitrate, Nitrification Enhancement
Epilimnetic Mixing Depth
Prolonged Diatom Maximum
Carbonate Buffer System…pH
Light Penetration



Reservoirs

Large Reservoirs in Small Watersheds

Small Reservoirs in Large Watersheds

Multiple Reservoir Systems

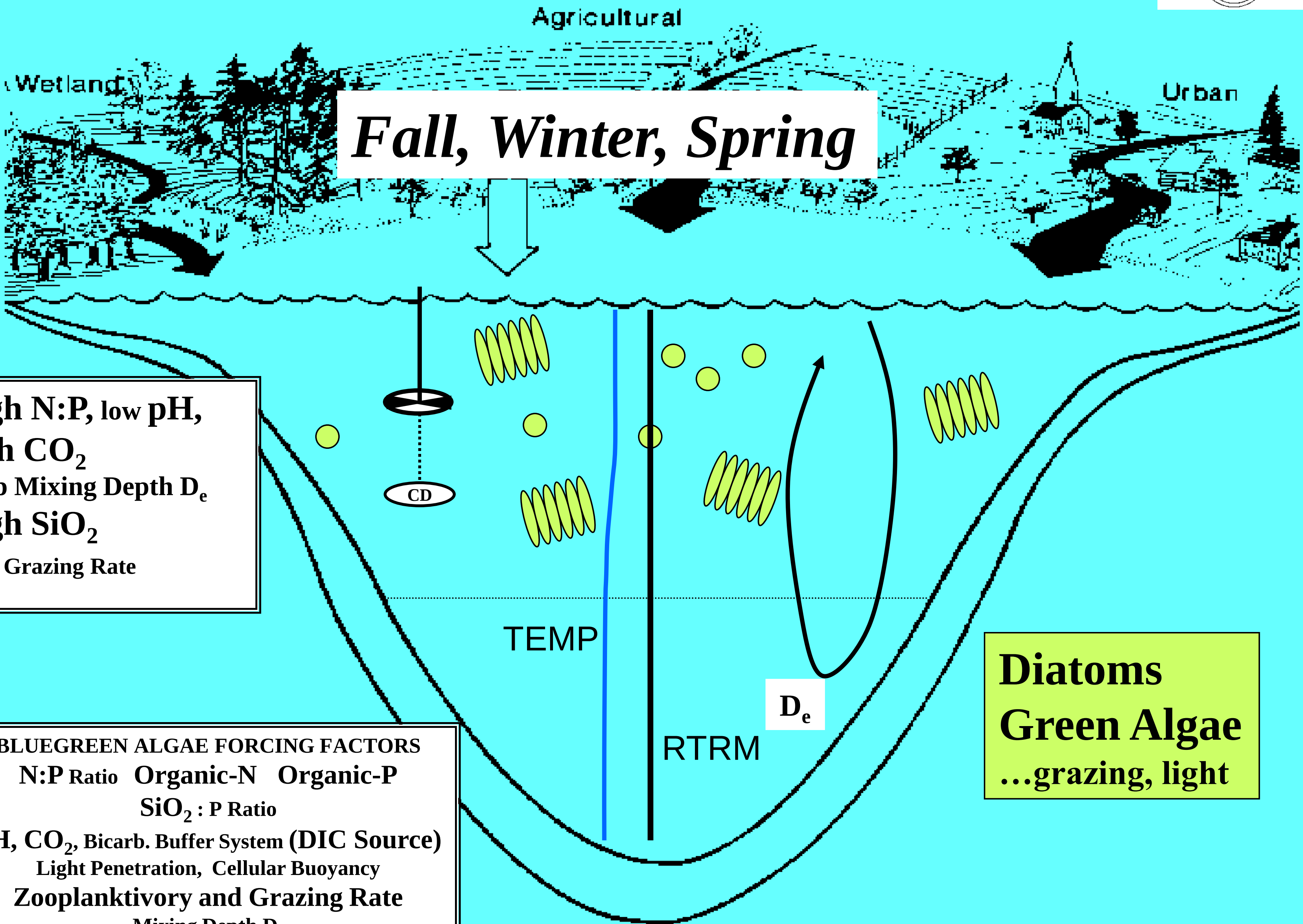
In Series vs. In Parallel

Complex Surface Source Systems

Transfers and Withdrawal Points offer Management Potential

“Tis the Season”

Fall, Winter, Spring

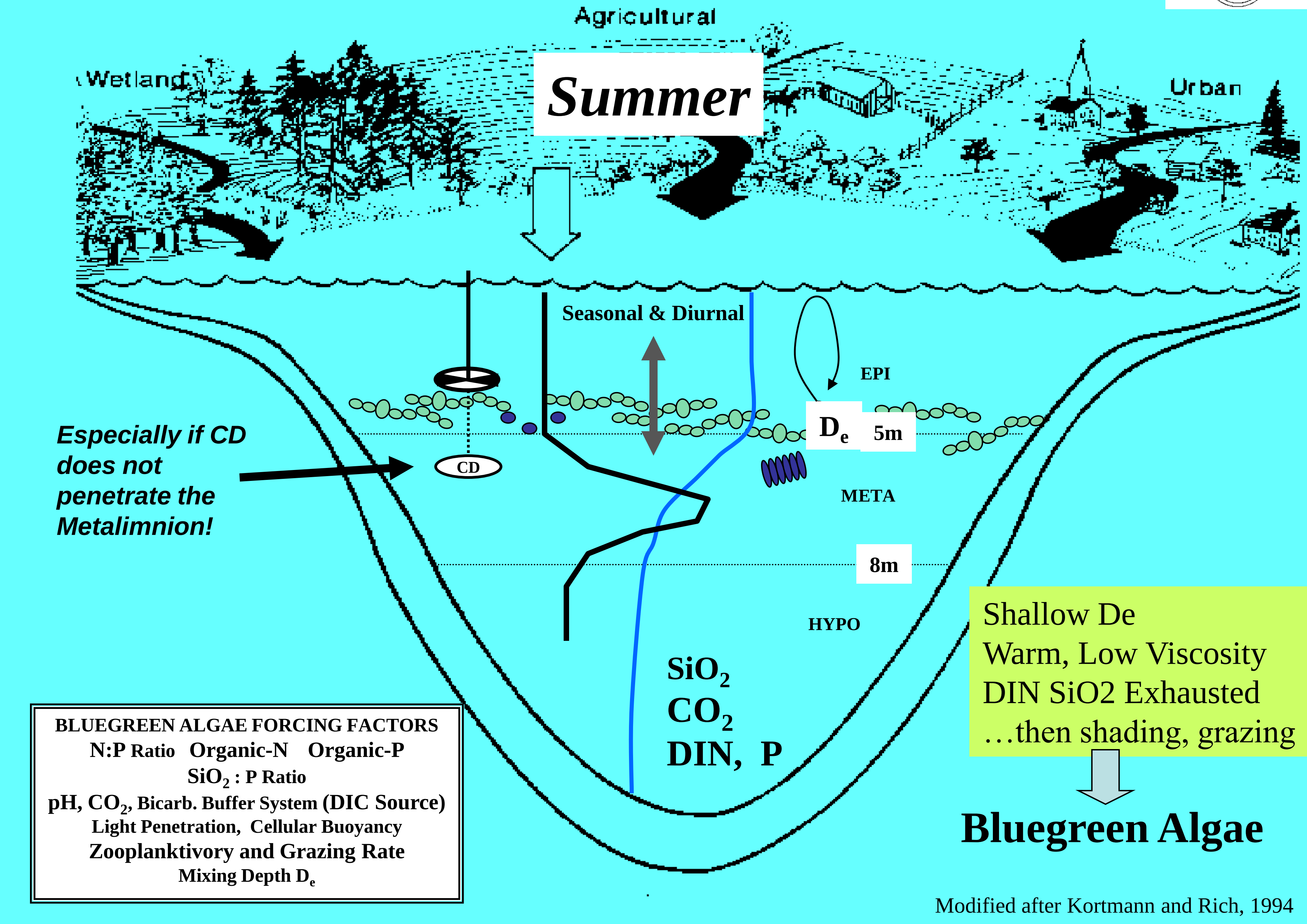


High N:P, low pH,
high CO_2
Deep Mixing Depth D_e
High SiO_2
High Grazing Rate

Diatoms
Green Algae
…grazing, light

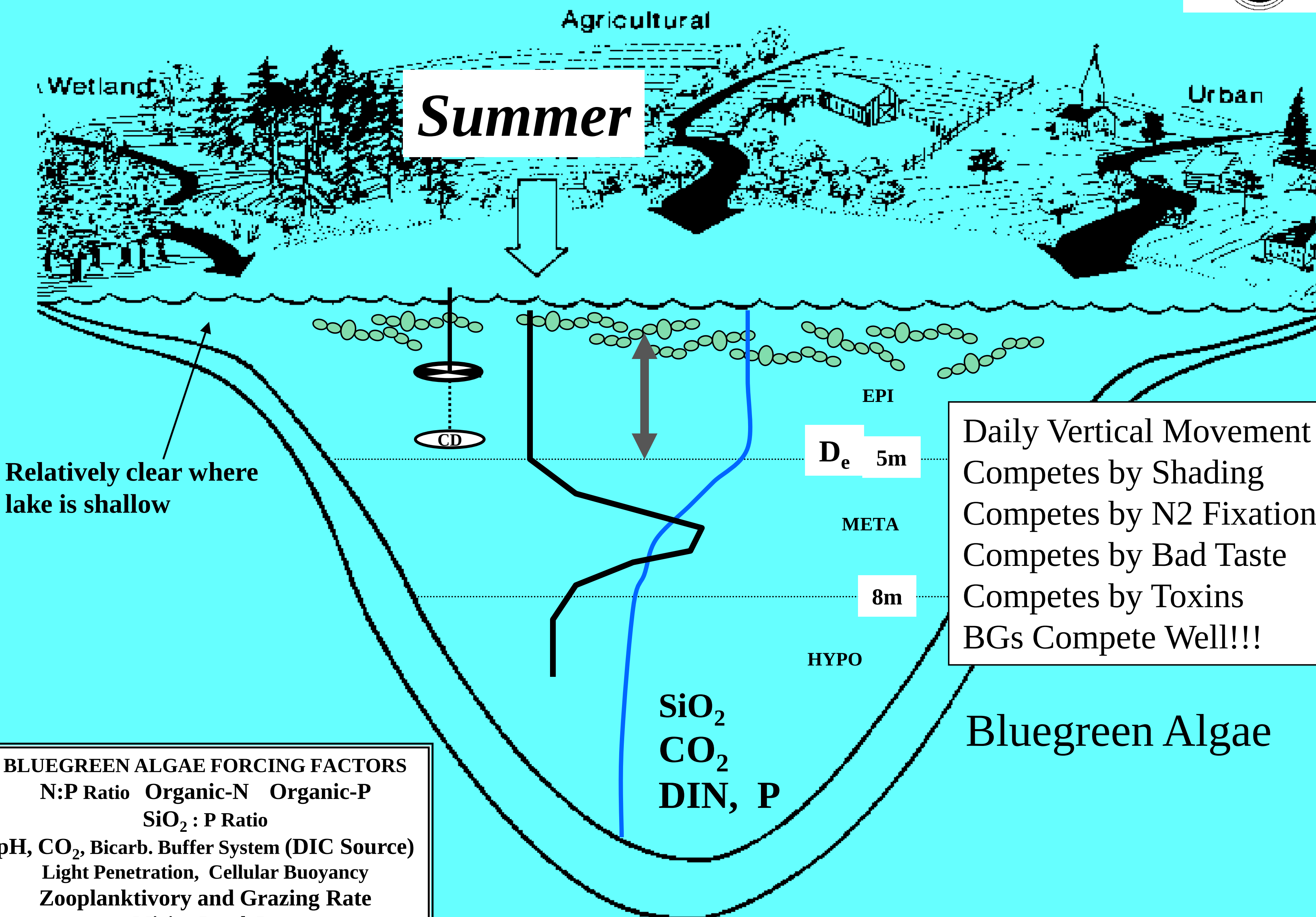
BLUEGREEN ALGAE FORCING FACTORS
N:P Ratio Organic-N Organic-P
SiO_2 : P Ratio
pH, CO_2, Bicarb. Buffer System (DIC Source)
Light Penetration, Cellular Buoyancy
Zooplanktivory and Grazing Rate
Mixing Depth D_e

Modified after Kortmann and Rich, 1994



Agricultural
Wetland
Summer
Urban
Seasonal & Diurnal
EPI
D_e
5m
CD
META
8m
HYPO
Especially if CD does not penetrate the Metalimnion!
SiO_2
CO_2
DIN, P
Shallow De
Warm, Low Viscosity
DIN SiO2 Exhausted
…then shading, grazing
Bluegreen Algae
BLUEGREEN ALGAE FORCING FACTORS
N:P Ratio Organic-N Organic-P
SiO_2 : P Ratio
pH, CO_2, Bicarb. Buffer System (DIC Source)
Light Penetration, Cellular Buoyancy
Zooplanktivory and Grazing Rate
Mixing Depth D_e
Modified after Kortmann and Rich, 1994

Summer

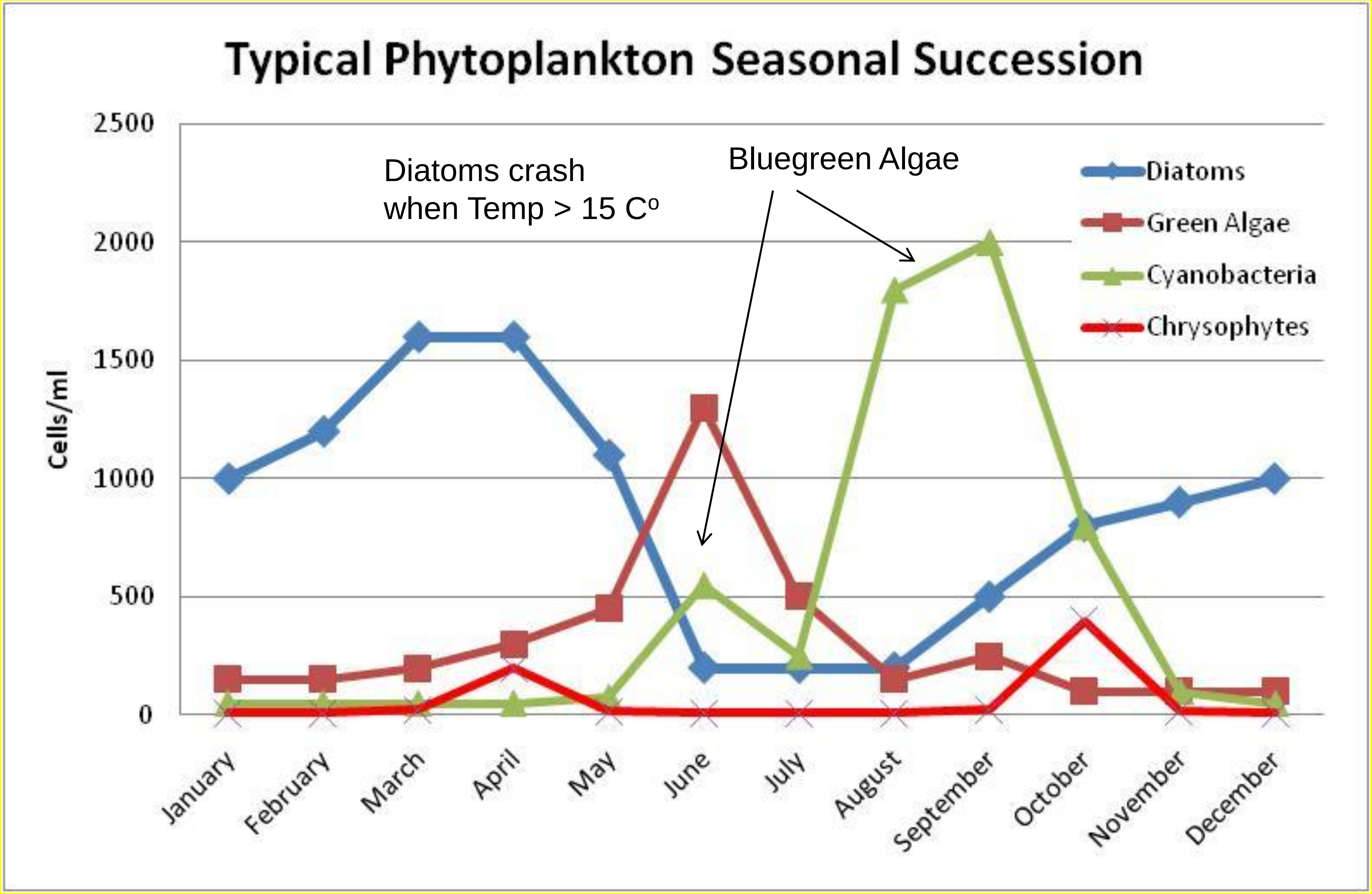


Daily Vertical Movement
Competes by Shading
Competes by N2 Fixation
Competes by Bad Taste
Competes by Toxins
BGs Compete Well!!!

Bluegreen Algae

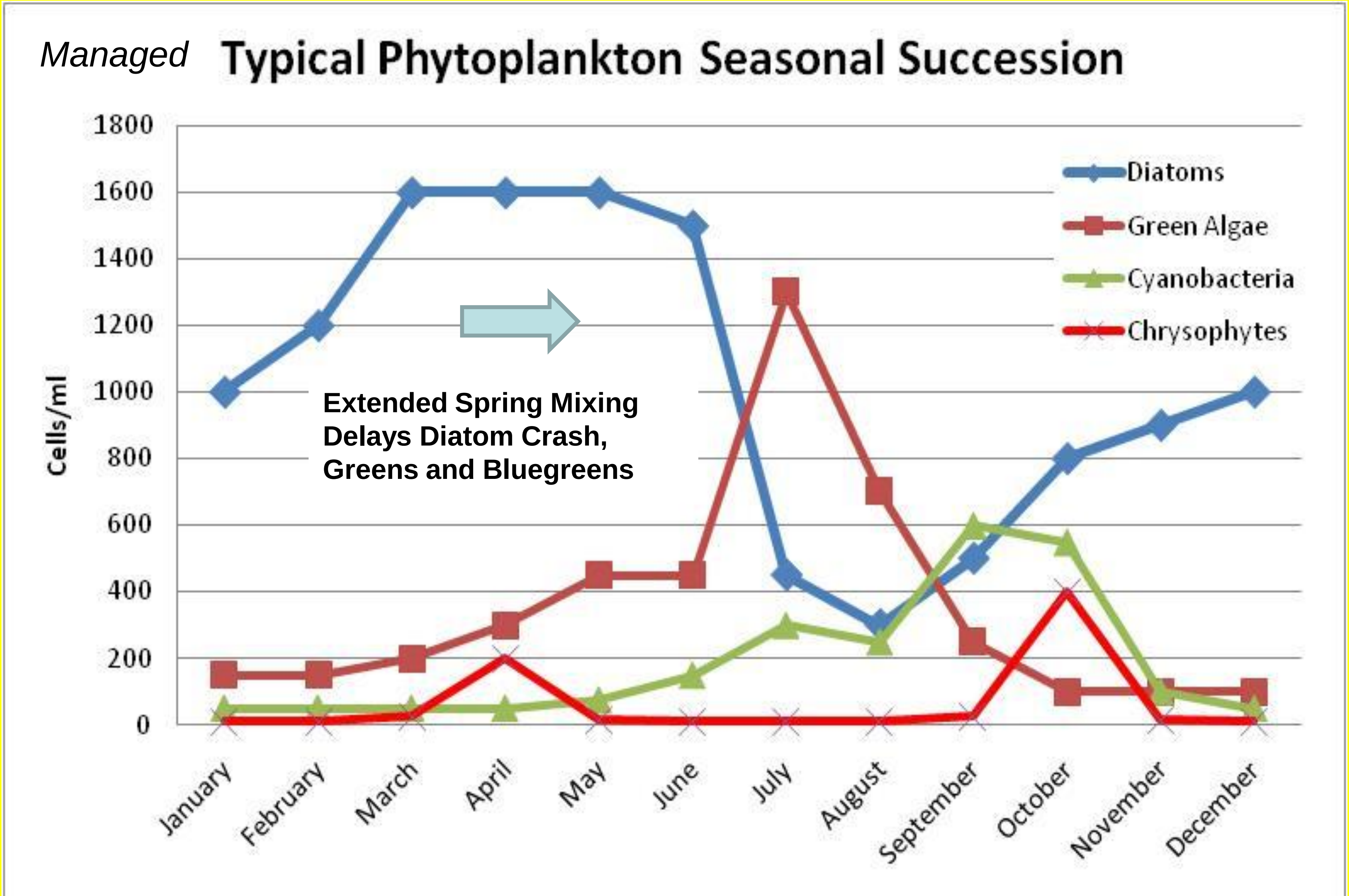
BLUEGREEN ALGAE FORCING FACTORS
N:P Ratio Organic-N Organic-P
SiO_2 : P Ratio
pH, CO_2, Bicarb. Buffer System (DIC Source)
Light Penetration, Cellular Buoyancy
Zooplanktivory and Grazing Rate
Mixing Depth D_e

Modified after Kortmann and Rich, 1994



DIATOMS → GREENS → BLUEGREENS → DIATOMS

Managed



DIATOMS → GREENS → BLUEGREENS → DIATOMS

Managing Reservoir Systems-
The first step in water treatment

Critical Natural Features of Reservoir-Watershed Ecosystems

Operational Management Approaches
Reservoir Management Systems and Treatments

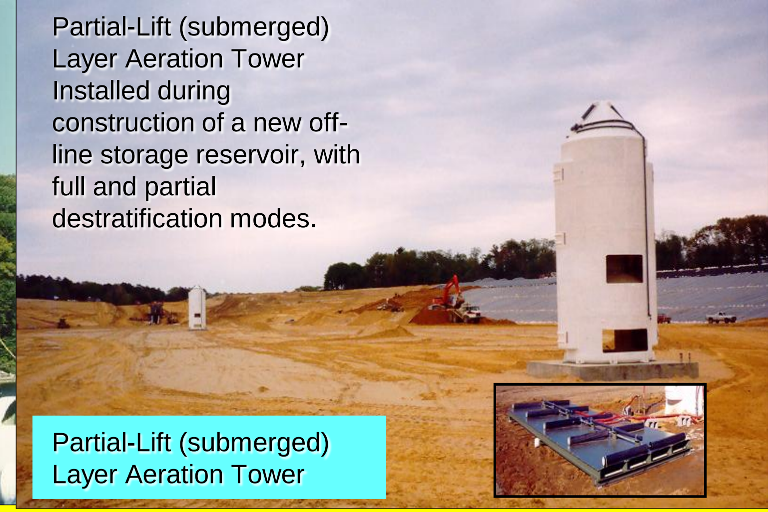
Now for a "closer look" …
… with diagnostic and management implications.

Synthesis – Respiration: Anaerobic Pathways
Physical Limnology: Managing the Heat Budget and Stratification Dynamics
Food Web Dynamics: Productivity vs. Biomass

Raw Water Quality Relationships:

Anaerobic Respiration Products- Fe, Mn, S=; NTU, Filter Runs
Alkalinity, Buffering Capacity
Relates to Coagulation Flocculation/Dosing, Enhanced Coag.
Temperature Swings- Disruption of settling Processes
Disinfection Byproducts and Precursors- THMs and HAAs
Where to place the first Disinfection Step
Taste and Odor- Geosmin and MIB – Phytoplankton vs Epibenthic Algae
Emerging Issue….Cyanotoxins (we don't know much yet)
"Nutrient" Source Management – Internal vs. External

Full-Lift Hypolimnetic Aeration Towers



Partial-Lift (submerged) Layer Aeration Tower Installed during construction of a new off-line storage reservoir, with full and partial destratification modes.

Partial-Lift (submerged) Layer Aeration Tower

Solar-Powered

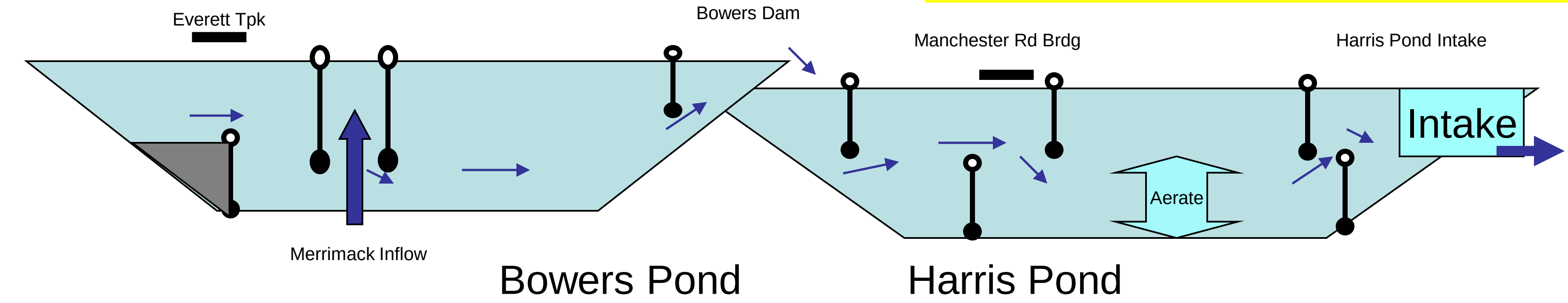
"AERATION"

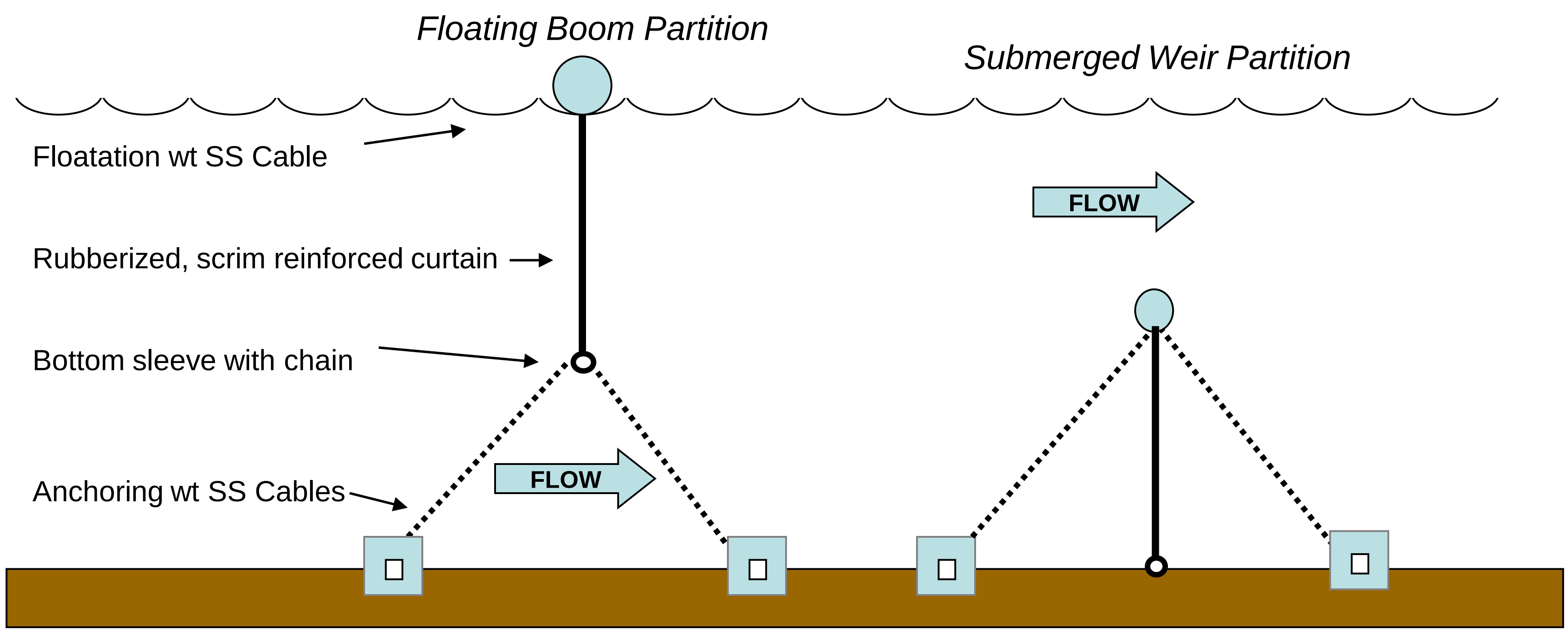
(and management of stratification/heat distribution)

- **Winter / Spring Seasonal Artificial Circulation**
- **Fall Controlled "Turnover"**
- **Summer Epilimnetic Expansion, Layer Aeration, Hypolimnetic Aeration**
- **Destratification – Good for shallow intermittent stratification systems**
  - **NOT for deeper reservoirs with total RTRM>100**
  - ***CERTAINLY NOT* just in front of the Dam & Intakes!!!!!**
    - **Mechanical, Downward Flow, Solar ("SolarBee")**
    - **Diffused Air**

FLOW ROUTING / RESERVOIR PARTITIONING

Manage how water enters, flows through, and leaves a reservoir.

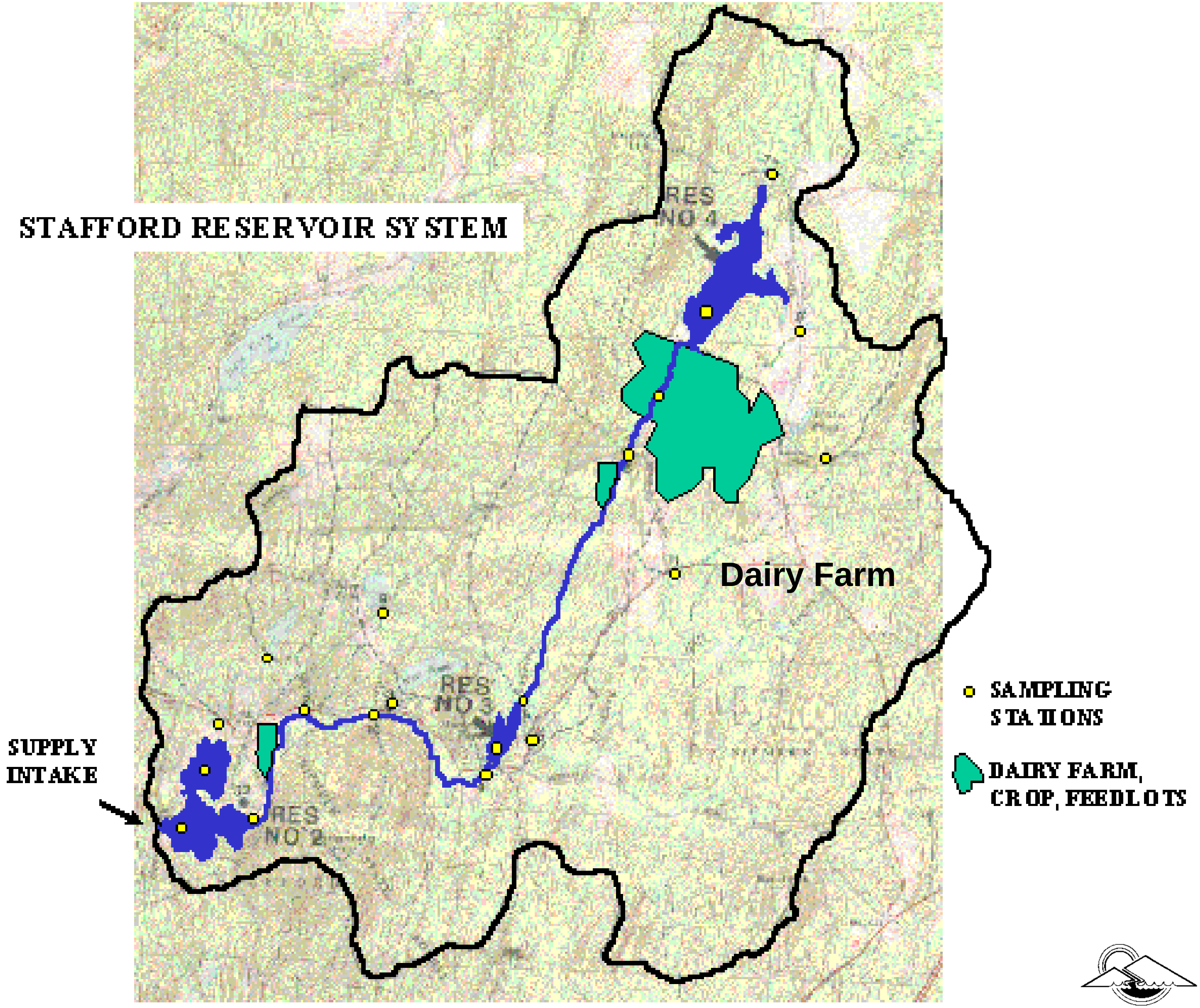




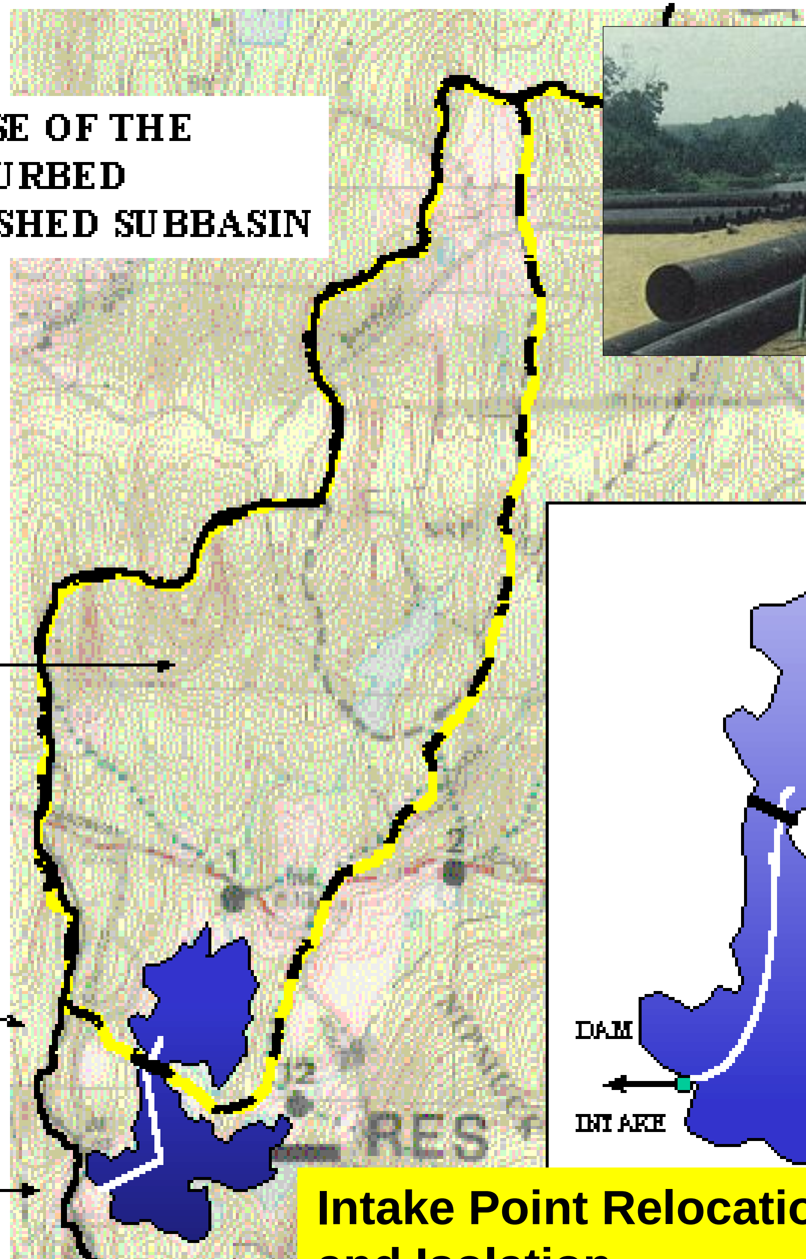
Function/Purpose: Contains the surface water layer upstream of the baffle; minimizes horizontal mixing above the bottom of the partition. These baffle partitions induce flow downstream in deeper, cooler layers. These surface baffles also contain floatable materials.

Function/Purpose: Contains the deep layer upstream of the baffle; minimizes horizontal mixing below the top of the partition.

STAFFORD RESERVOIR SYSTEM



MAXIMIZE THE USE OF THE TOTALLY UNDISTURBED WOODED WATERSHED SUBBASIN

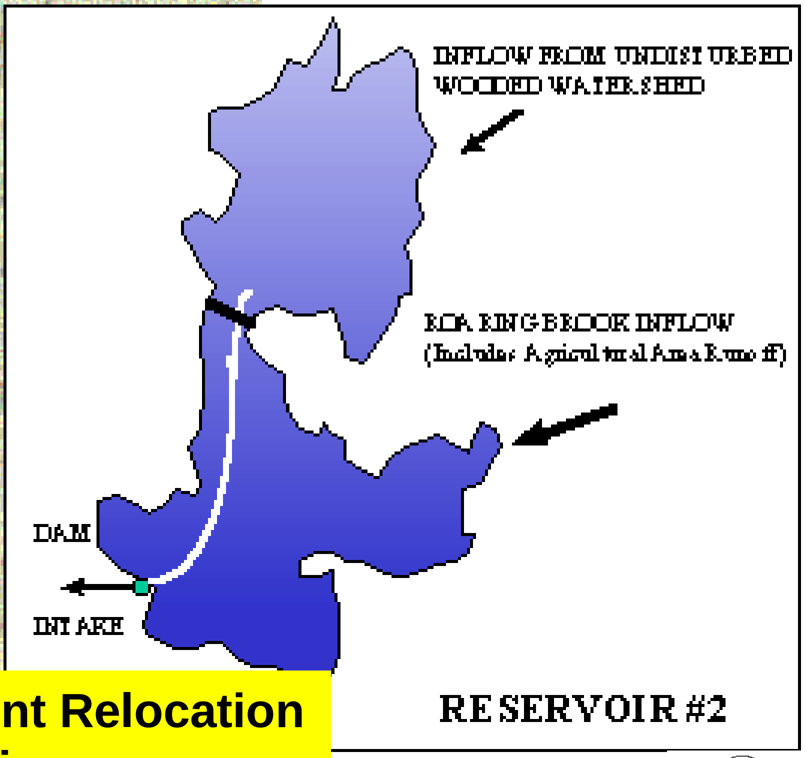


Watershed Area Draining Directly to the Northern Bay of the Reservoir

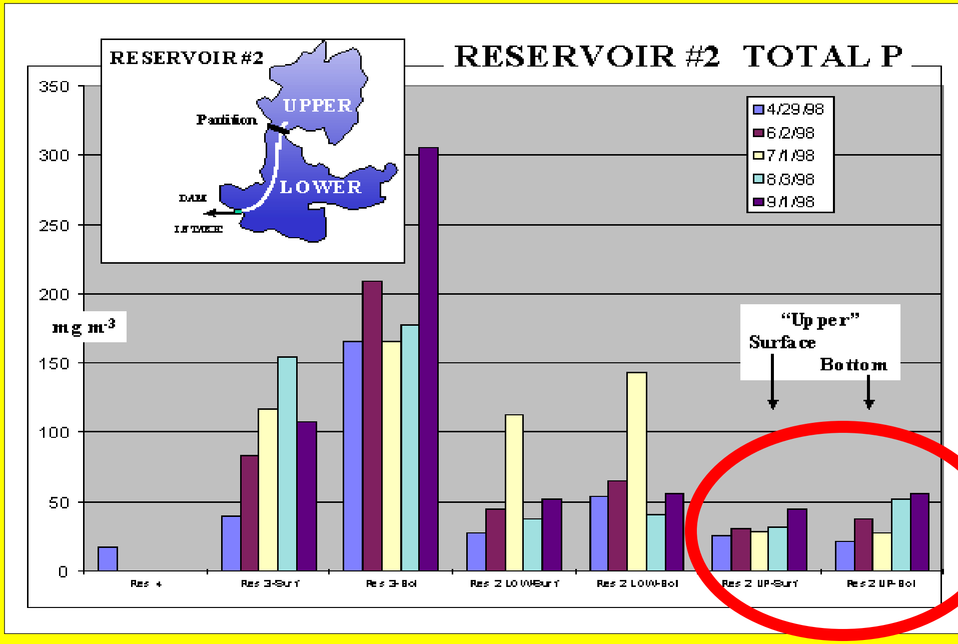
"PARTITION CURTAIN"

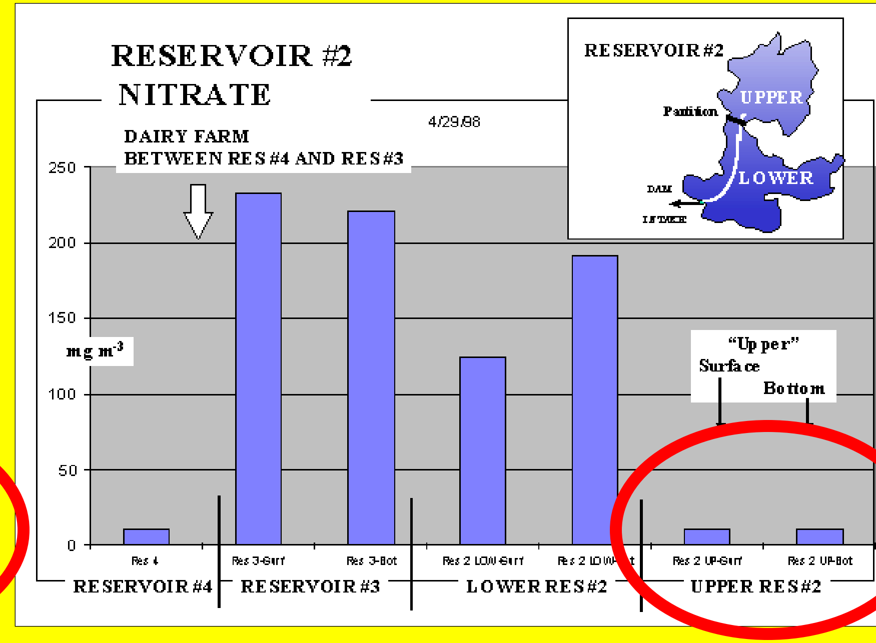
INTAKE EXTENSION

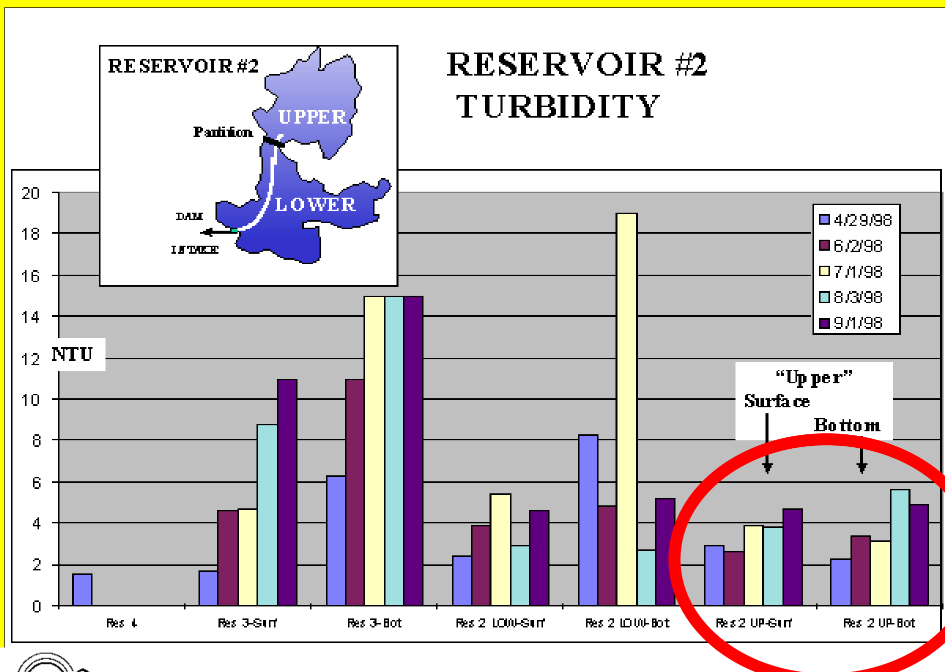
RESERVOIR PARTITIONING INTAKE ISOLATION

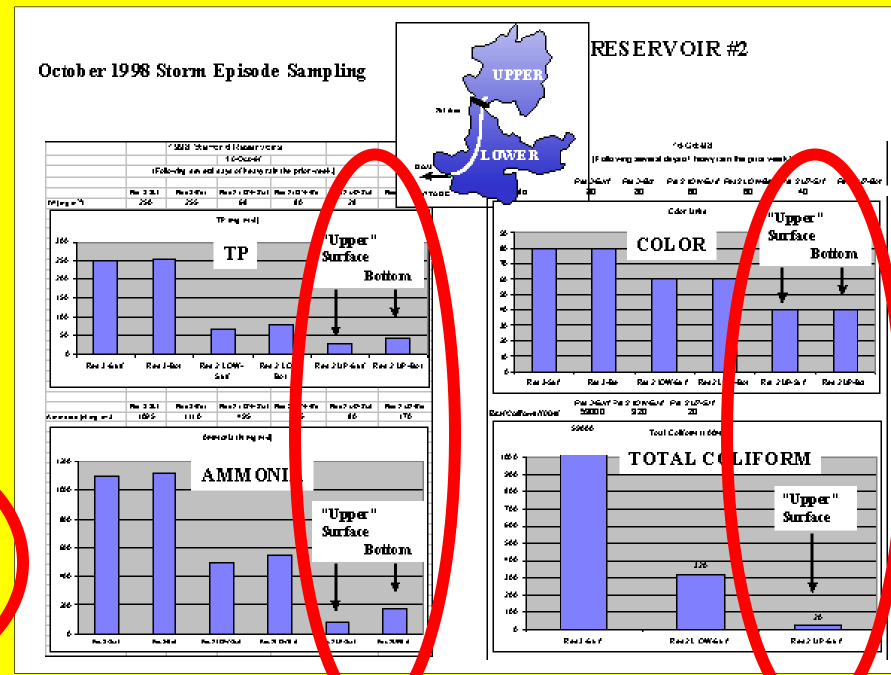


Intake Point Relocation and Isolation


RESERVOIR #2 TOTAL P
RESERVOIR #2
UPPER
Partition
LOWER
DAM
INTAKE
mg m-3
350
300
250
200
150
100
50
0
4/29/98
6/2/98
7/1/98
8/3/98
9/1/98
"Upper"
Surface
Bottom
Res 4
Res 3-Surf
Res 3-Bot
Res 2 LOW-Surf
Res 2 LOW-Bot
Res 2 UP-Surf
Res 2 UP-Bot

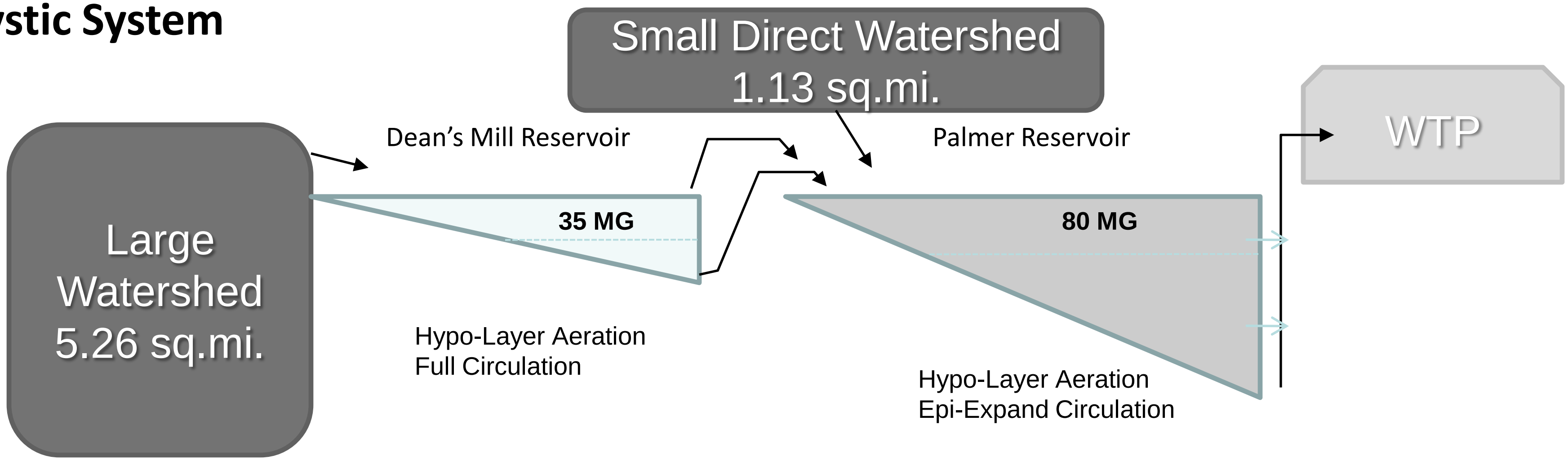

RESERVOIR #2
NITRATE
4/29/98
DAIRY FARM
BETWEEN RES #4 AND RES #3
RESERVOIR #2
UPPER
Partition
LOWER
DAM
INTAKE
mg m-3
250
200
150
100
50
0
"Upper"
Surface
Bottom
Res 4
Res 3-Surf
Res 3-Bot
Res 2 LOW-Surf
Res 2 UP-Surf
Res 2 UP-Bot
RESERVOIR #4
RESERVOIR #3
LOWER RES #2
UPPER RES #2


RESERVOIR #2
TURBIDITY
RESERVOIR #2
UPPER
Partition
LOWER
DAM
INTAKE
NTU
20
18
16
14
12
10
8
6
4
2
0
4/29/98
6/2/98
7/1/98
8/3/98
9/1/98
"Upper"
Surface
Bottom
Res 4
Res 3-Surf
Res 3-Bot
Res 2 LOW-Surf
Res 2 LOW-Bot
Res 2 UP-Surf
Res 2 UP-Bot


October 1998 Storm Episode Sampling
RESERVOIR #2
UPPER
LOWER
TP
"Upper"
Surface
Bottom
AMMONIA
COLOR
TOTAL COLIFORM


Reservoir 2 Upper Basin
Reservoir 2 Lower Basin
Intake
September 21, 2009

Mystic System



Critical Natural Features:

Small Storage Reservoirs in Very Large Watershed

Dependant on regular rainfall-runoff events

High Flushing Rate when significant storms occur

Significant TOC, Color, DBP Precursor influence from watershed after leaf fall

Low Alkalinity, Humic Coloration- low buffering capacity soft-water system

Thermal Stratification is strong despite relatively shallow depths- Impacts managed by Aeration

1%-5% Light reaches much of the bottom- Benthic Algae Habitat

"Issues"/Mgmt Options:

T&O from Benthic Mats- SCUBA Survey & Depth-Selective Cu Treatment

T&O from Phytoplankton (+Actinomycetes)- Monitor & Depth-Selective Cu Treatment

Fe, Mn, NTU, TP from Anaerobic Respiration Products – Aeration System

TOC, Color, DBP Precursors- On-Going Effort (Storage Flow Routing / Sequencing?)

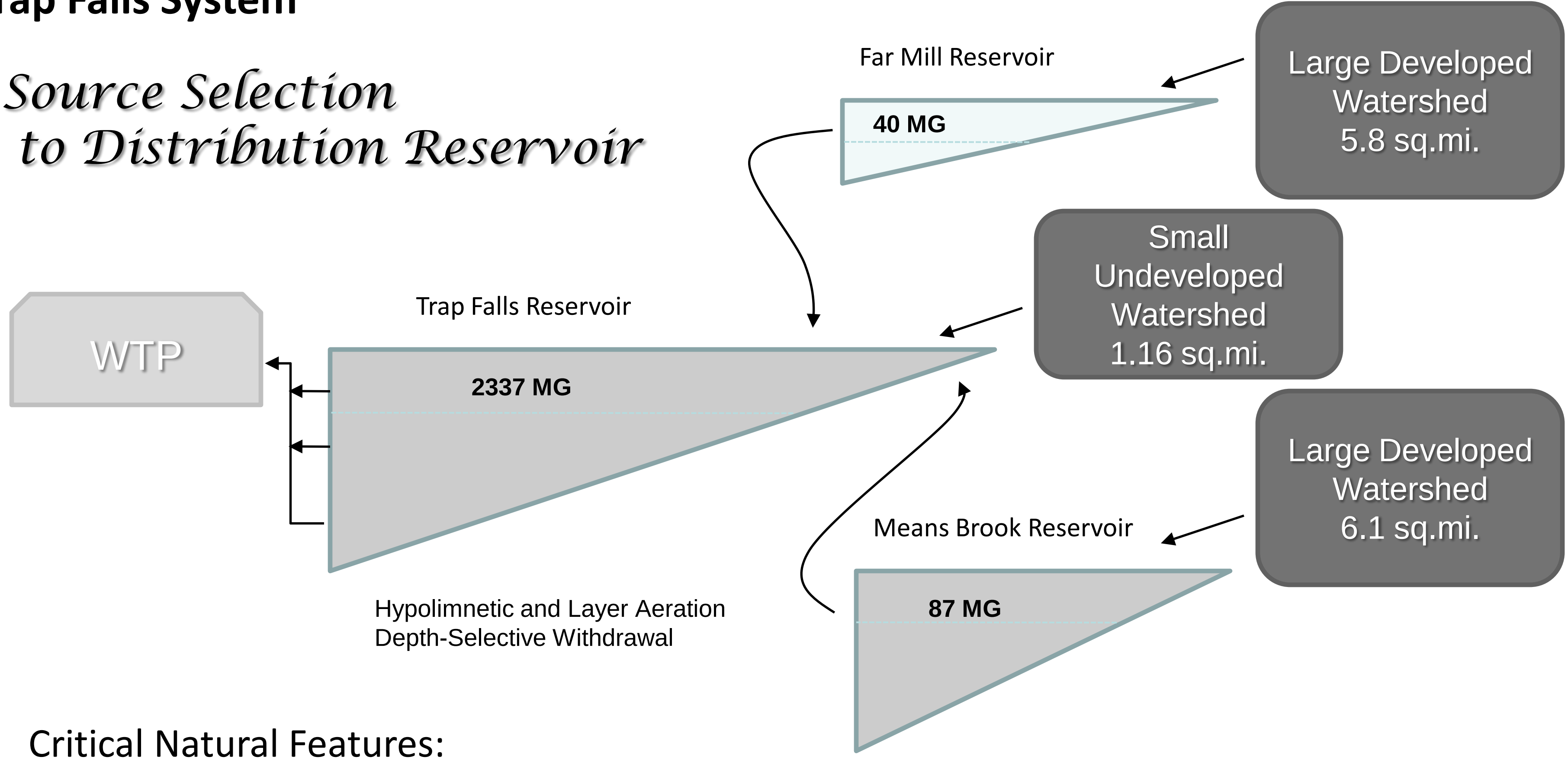
THM precursors appear more related to "productivity in-reservoir"

HAA precursors appear more related to Allochthonous Organics and Respiration Products

Small Reservoir in a Large Watershed

Trap Falls System

Source Selection to Distribution Reservoir



Critical Natural Features:

Large Storage Reservoir (TF) in Very Small Direct Watershed

Dependant on transfers from Means Brook and Far Mill Reservoirs

Far Mill: High Flushing Rate when significant storms occur (Relatively small and shallow compared to watershed)

Means Brook: Larger and deeper; strong stratification, anoxia, and resulting poor water quality

Thermal Stratification is strong - Impacts managed by Layer and Hypolimnetic Aeration

1%-5% Light reaches a large bottom area- Benthic Algae Habitat

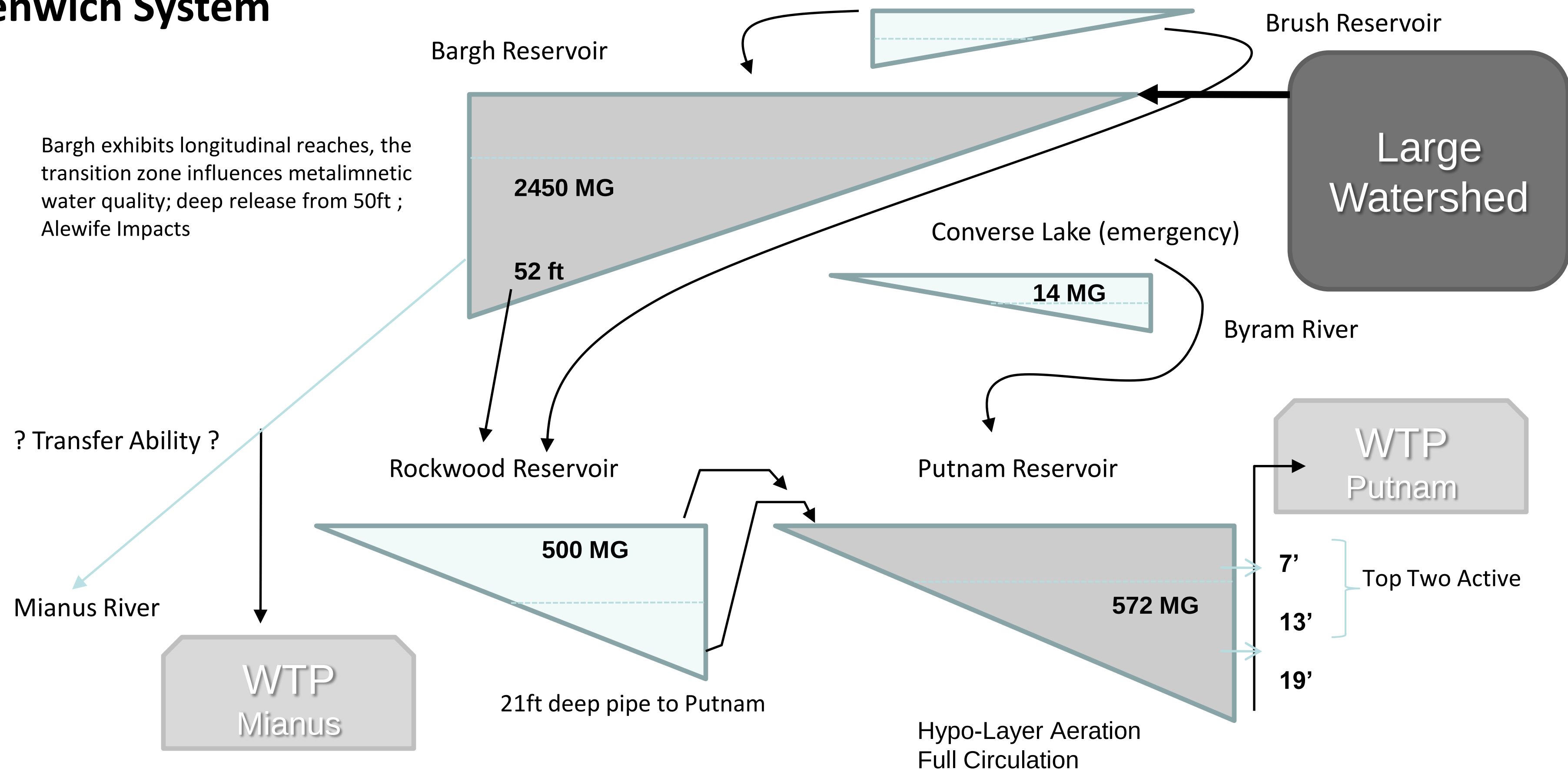
"Issues"/Mgmt Options:

T&O from Benthic Mats- SCUBA Survey & Depth-Selective Cu Treatment

T&O from Phytoplankton (+Actinomycetes)- Monitor & Depth-Selective Cu Treatment

Fe, Mn, NTU, TP from Anaerobic Respiration Products – Aeration System

Greenwich System



"Issues"/Mgmt Options:

T&O from Benthic Mats- SCUBA Survey & Depth-Selective Cu Treatment

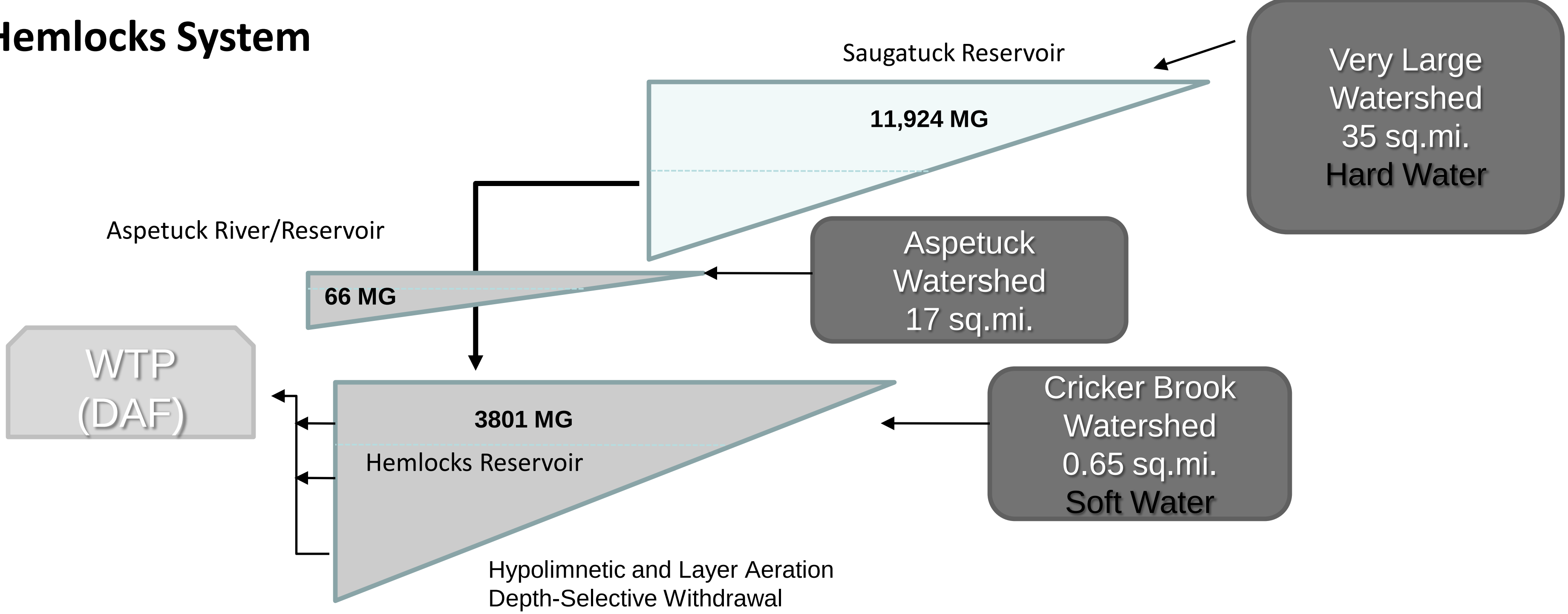
T&O from Phytoplankton (+Actinomycetes)- Monitor & Depth-Selective Cu Treatment

Fe, Mn, NTU, TP from Anaerobic Respiration Products – Aeration System

TOC, Color, DBP Precursors- On-Going Effort (Storage Flow Routing / Sequencing?)

Complex Reservoir System (start at the direct source)

Hemlocks System



Critical Natural Features:

Large Storage Saugatuck Reservoir in Very Large Watershed

- Saugatuck is Hard-Water, Other Sources are Soft-Water
- Saugatuck Water is released from 50 ft (upper Hypolimnion) – Cold- Must flow Through Aspetuck Reservoir to get into Hemlocks Reservoir
- During Summer Stratification and Low Flow in the Aspetuck River, Saugatuck Water flows through Aspetuck Reservoir and through the Mid-Depths of Hemlocks to the intakes "Intact".

Thermal Stratification is strong in Hemlocks- Impacts managed by Layer and Hypolimnetic Aeration

Benthic Algae was a problem in the early 1990's – not recently a problem (Winter Drawdown**).**

Alewife Impacts need to be watched.

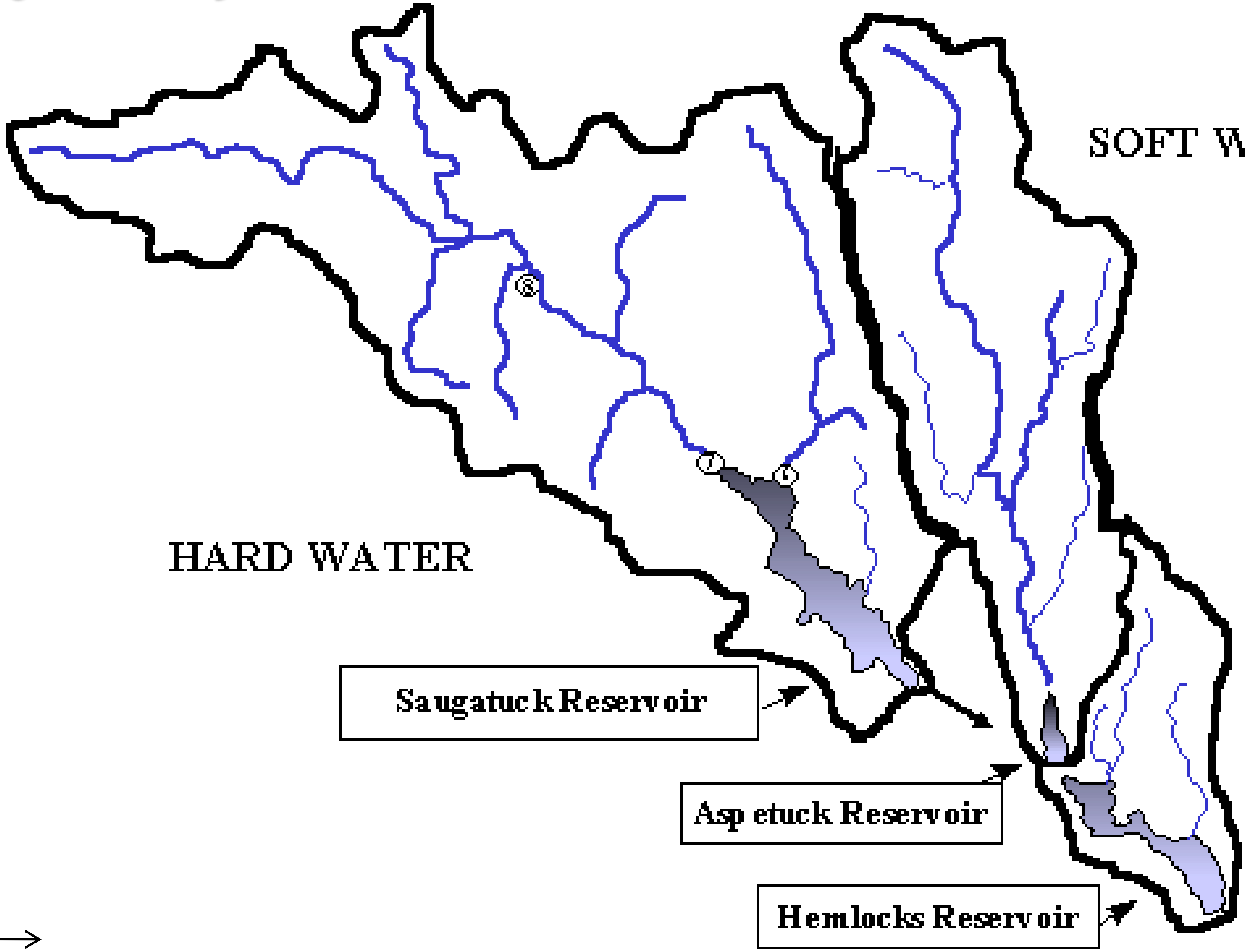
"Issues"/Mgmt Options:

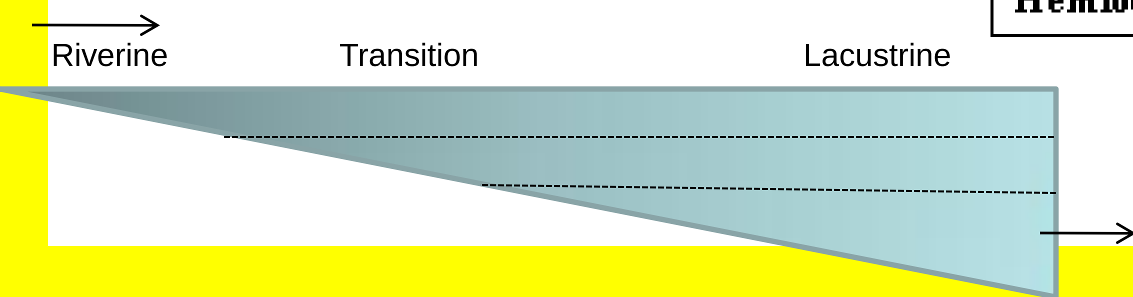
T&O from Benthic Mats- SCUBA Survey & Depth-Selective Cu Treatment

T&O from Phytoplankton (+Actinomycetes)- Monitor & Depth-Selective Cu Treatment

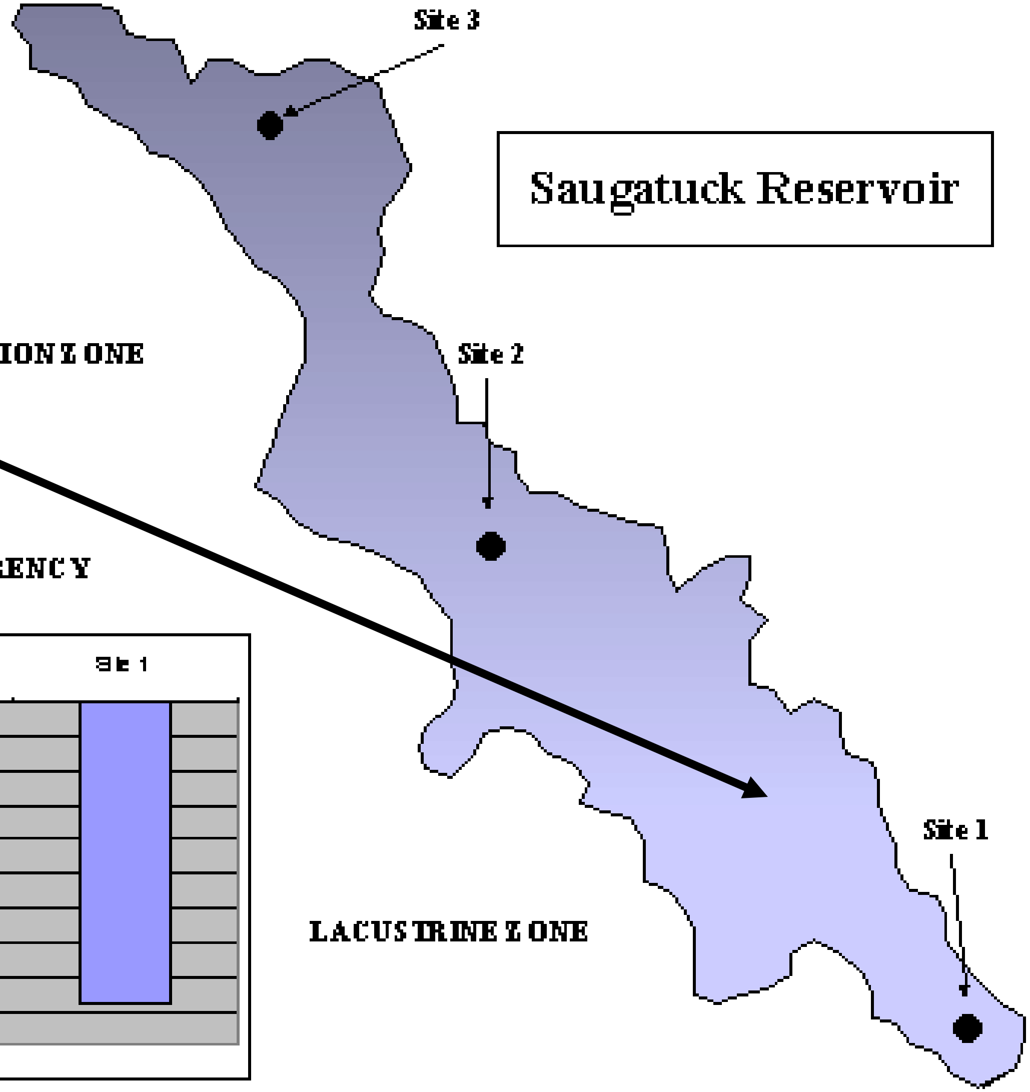
Fe, Mn, NTU, TP from Anaerobic Respiration Products – Aeration System

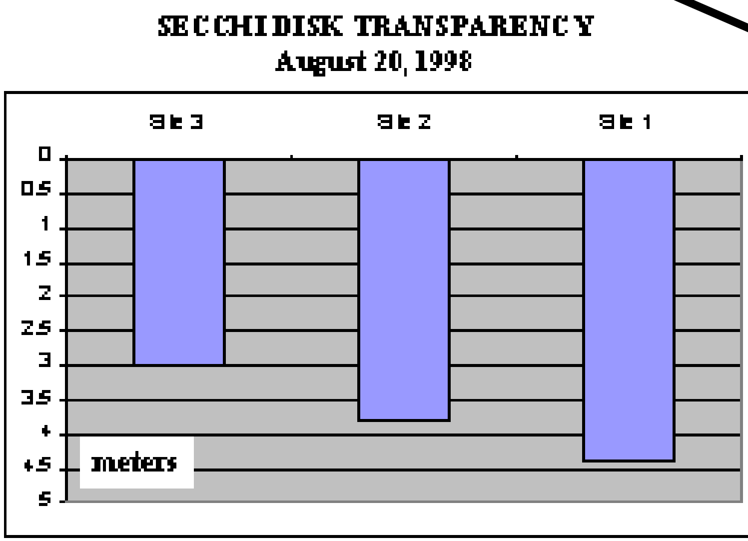
Large Run-of-River Reservoirs

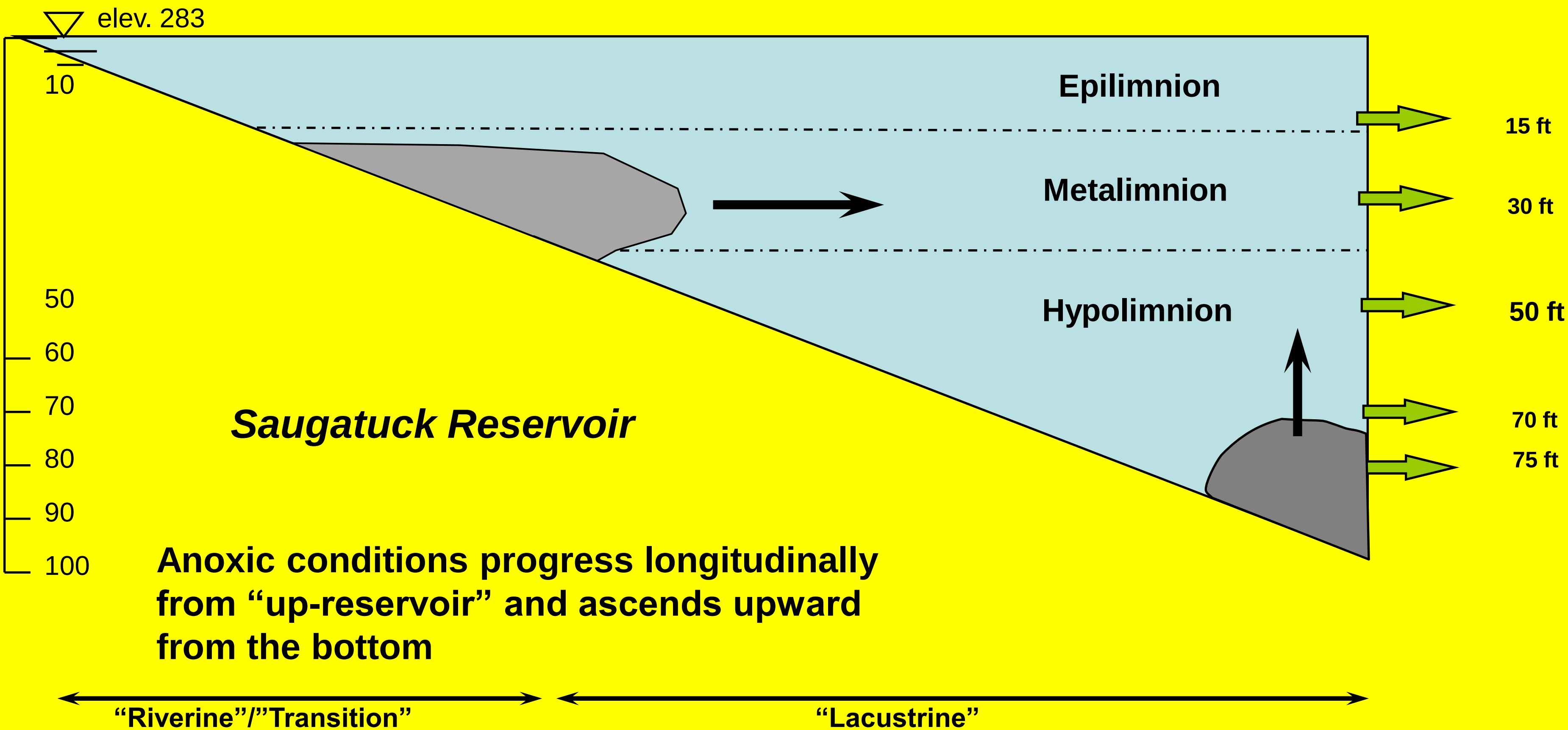




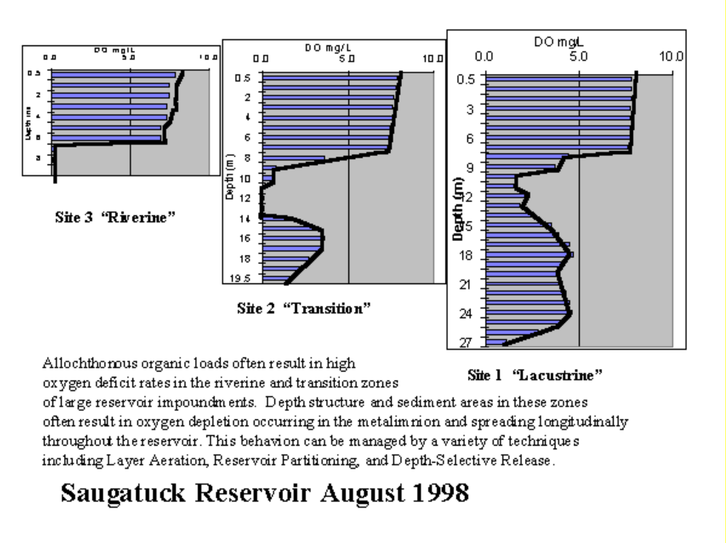
Water clarity improves in the large, deep, lacustrine zone.







Large Run-of-River Reservoir



Seasonal Source System Optimization – Hemlocks System (Based on Water Quality – Quantity needs balancing)

"Season 1" Winter

Approx. December 15 to March 15

- Use the Aspetuck River source to maintain/refill Hemlocks Reservoir;
- Winter Drawdown of Hemlocks for Milfoil Control (option)
- Winter Circulation for Alewife Control (option)
- Allow Refill of Saugatuck Reservoir Storage

Utilize Aspetuck River during Higher Flow/Water Quality Season (while refilling Saugatuck Storage Volume)

"Season 2" Spring

Approx. March 15 to May 15

- Close the Aspetuck Reservoir Gate;
- Consume Hemlocks Reservoir Storage;
- Allow Aspetuck Dam Overflow
- Allow Refill of Saugatuck Reservoir Storage

Minimize Spring Nutrient Input to Hemlocks Reservoir

"Season 3" Summer

Approx. May 15 to October 15

- Open the Aspetuck Reservoir Gate to Hemlocks Reservoir;
- Divert from Saugatuck Reservoir Storage at 50 ft;
- Layer Aeration and Interflow to/thru Hemlocks Reservoir

Maximize use of Saugatuck Reservoir Water

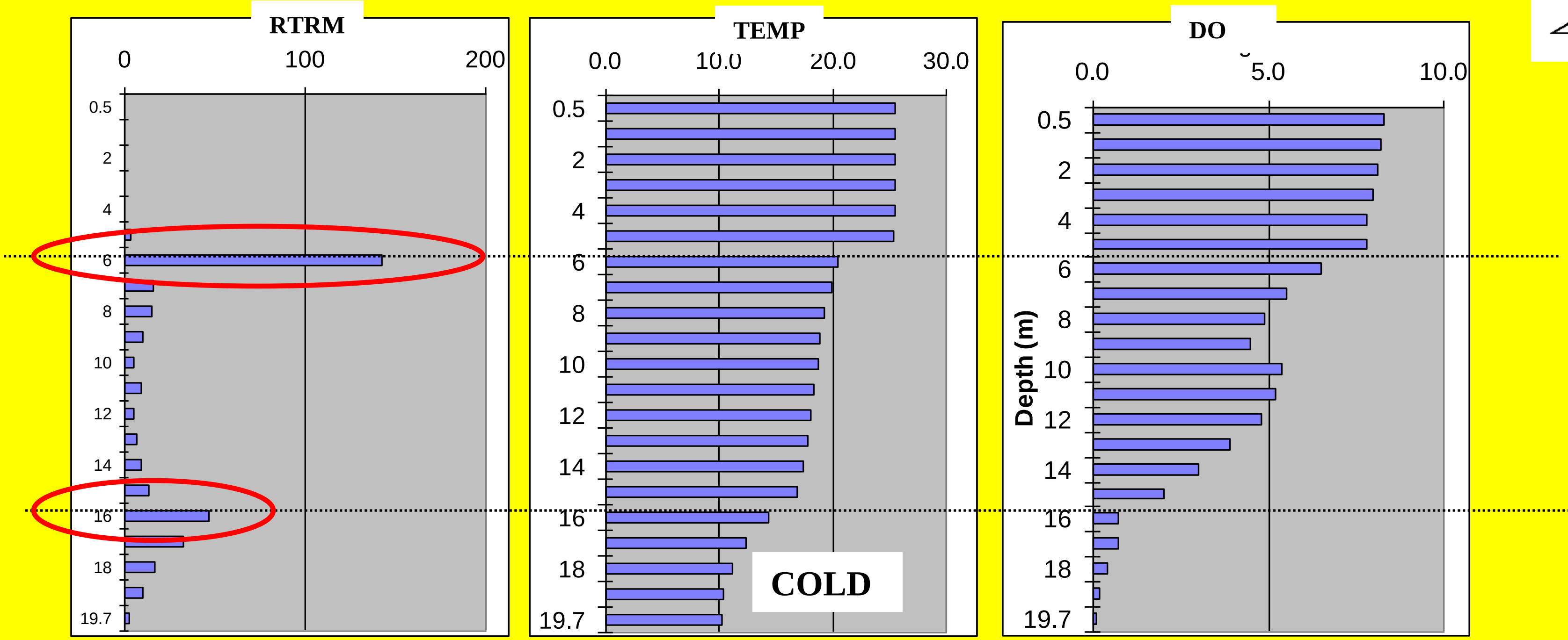
"Season 4" Autumn

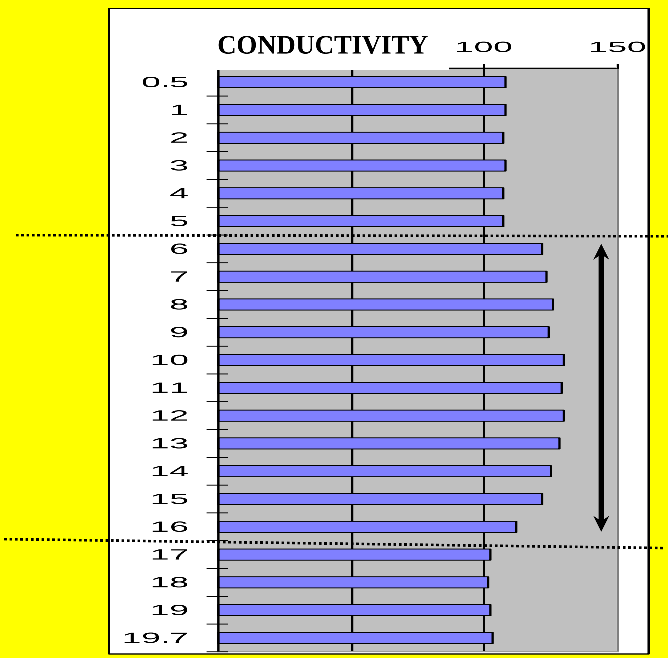
Approx. October 15 to December 15

(From the beginning of leaf-fall)

- Consume Hemlocks Storage
- Close the Aspetuck Reservoir Gate;
- Close the diversion from Saugatuck Reservoir;
- Allow refill of Saugatuck Storage

Avoid High Color, TOC/DOC, in Aspetuck River





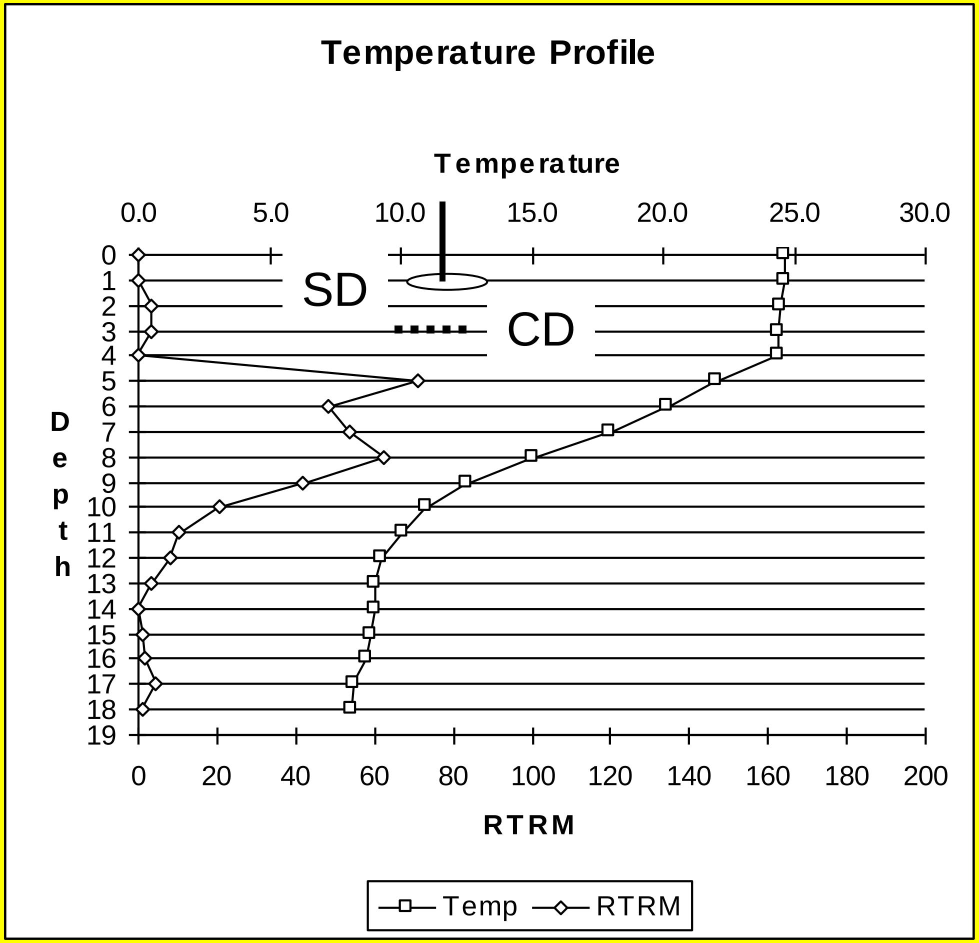
Hemlocks Reservoir August 19, 1998

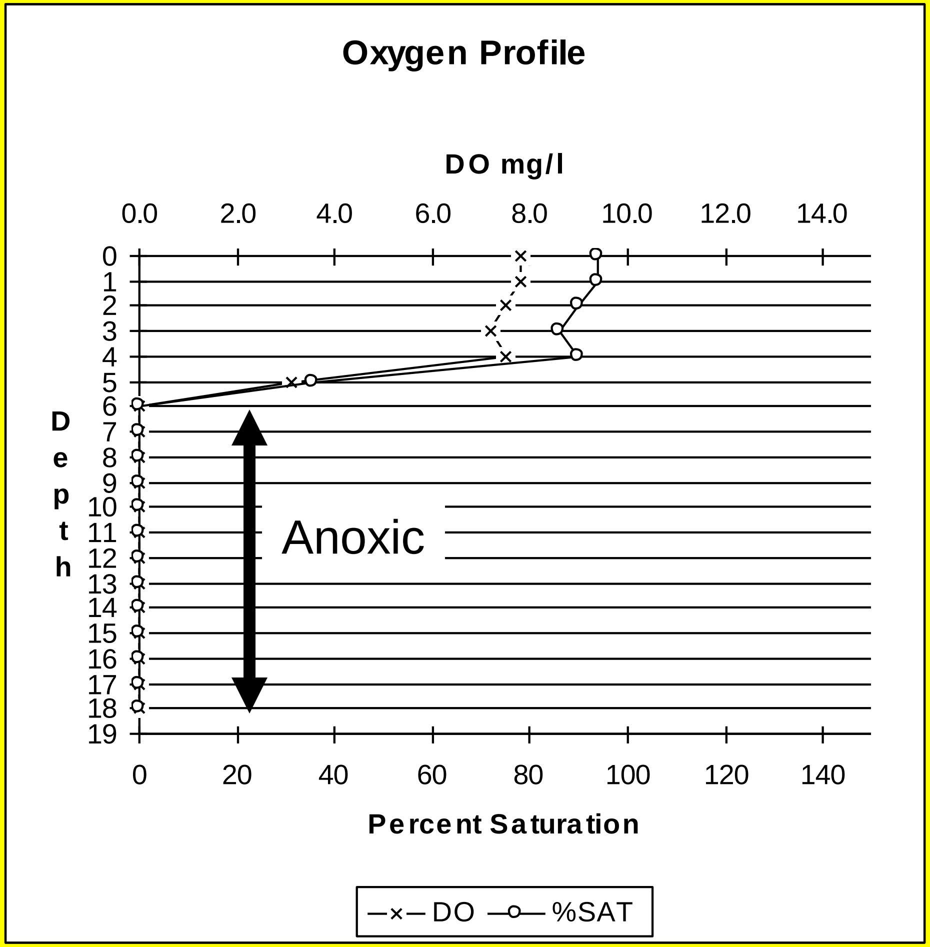
Saugatuck Reservoir water, released from about 50 feet deep, flows through Aspetuck Reservoir as an "Underflow", and then it flows through Hemlocks Reservoir as an "Interflow" between thermoclines at 6 and 16 meters deep.

Conductivity Signature of Saugatuck Water

Induced Deep Withdrawal (under a baffle curtain)

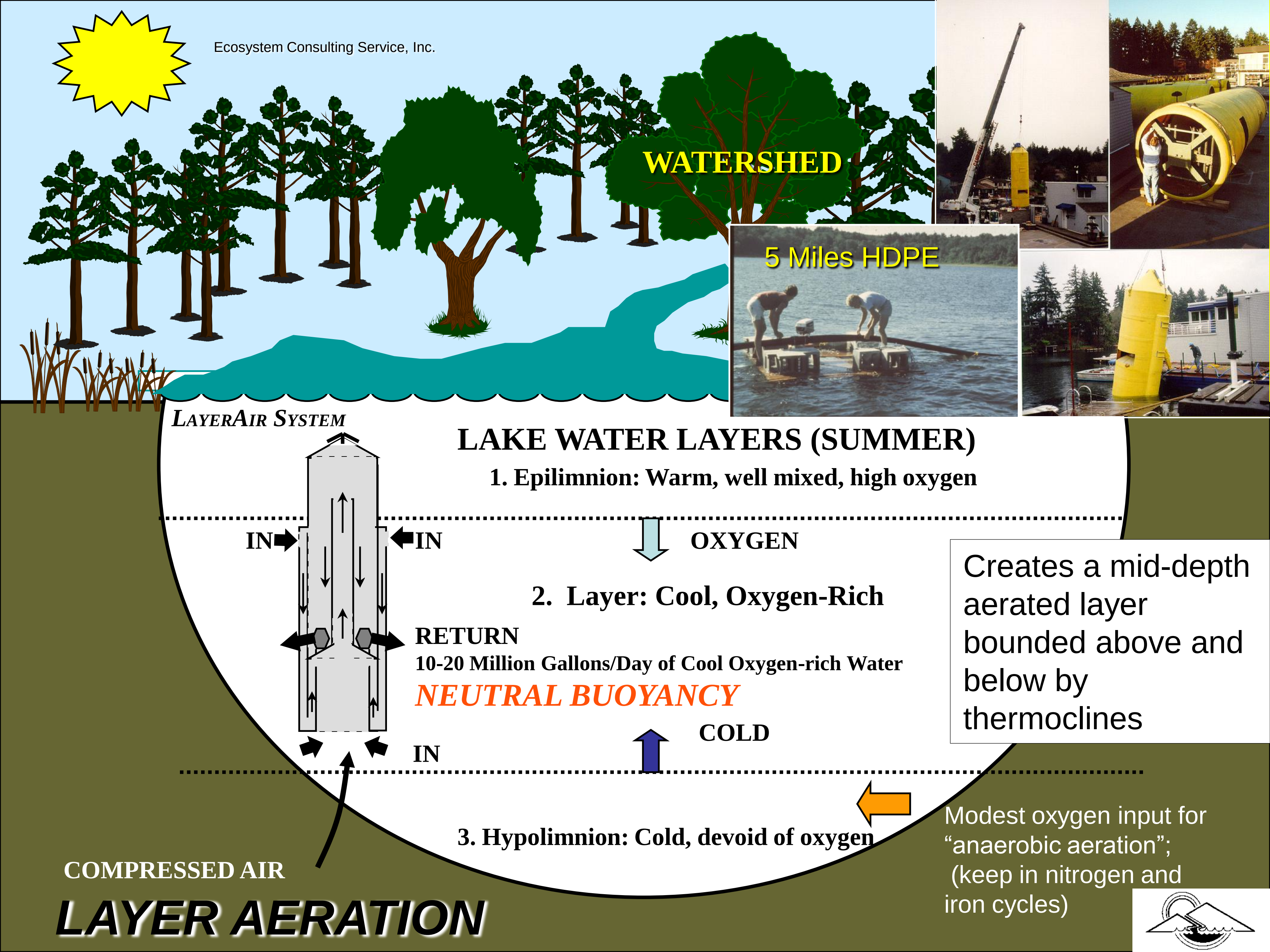
Induced Plunge of Cold Inflow



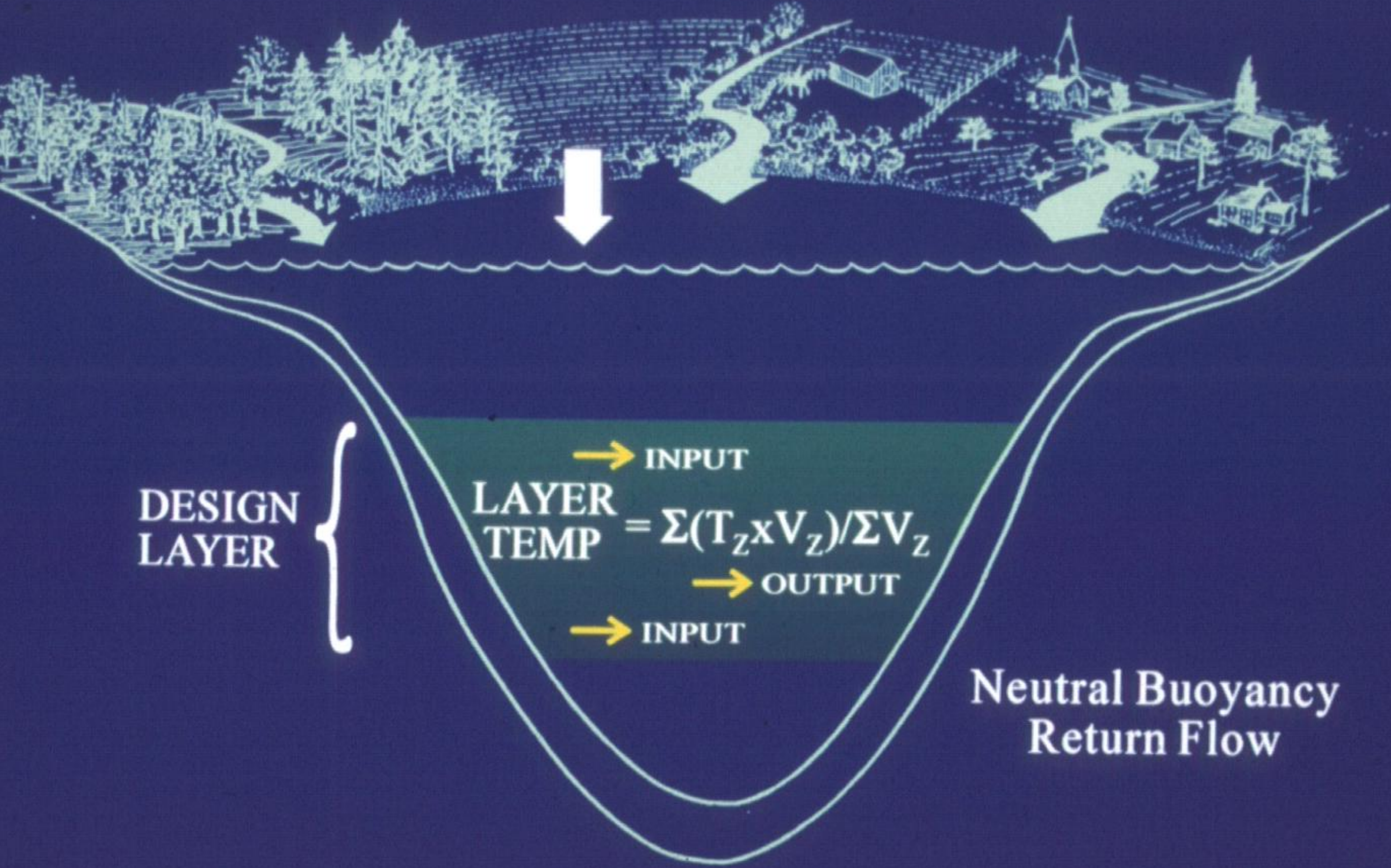


Lake Shenipsit 8/19/1985 (Before Multiple Layer Aeration)

SD= 1.5 m RTRMsum= 333 RTRM Units

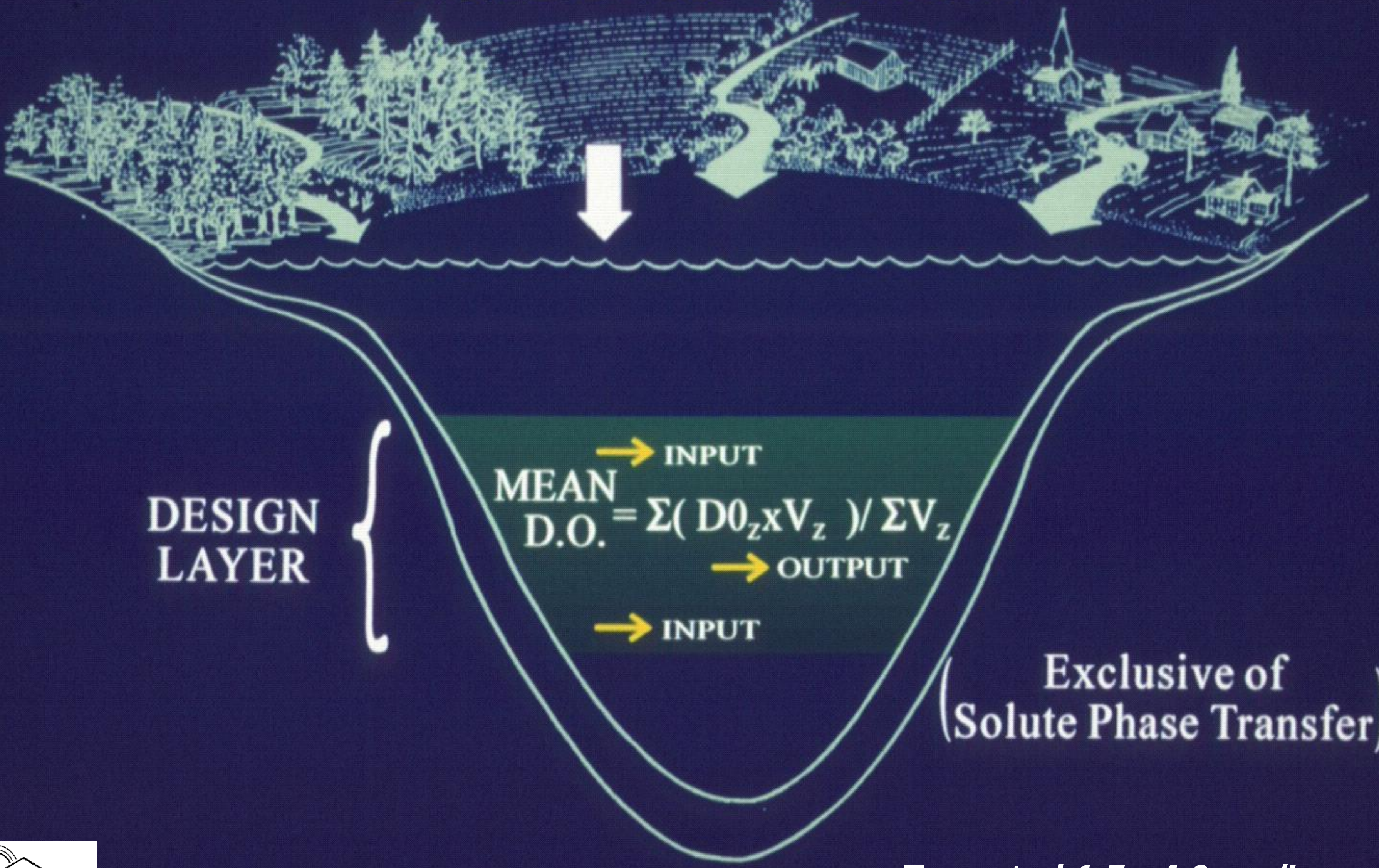

Ecosystem Consulting Service, Inc.
WATERSHED
5 Miles HDPE
LAYERAIR SYSTEM
LAKE WATER LAYERS (SUMMER)
1. Epilimnion: Warm, well mixed, high oxygen
IN
IN
OXYGEN
2. Layer: Cool, Oxygen-Rich
RETURN
10-20 Million Gallons/Day of Cool Oxygen-rich Water
NEUTRAL BUOYANCY
COLD
IN
3. Hypolimnion: Cold, devoid of oxygen
COMPRESSED AIR
LAYER AERATION
Creates a mid-depth aerated layer bounded above and below by thermoclines
Modest oxygen input for “anaerobic aeration”; (keep in nitrogen and iron cycles)

MEAN LAYER TEMPERATURE

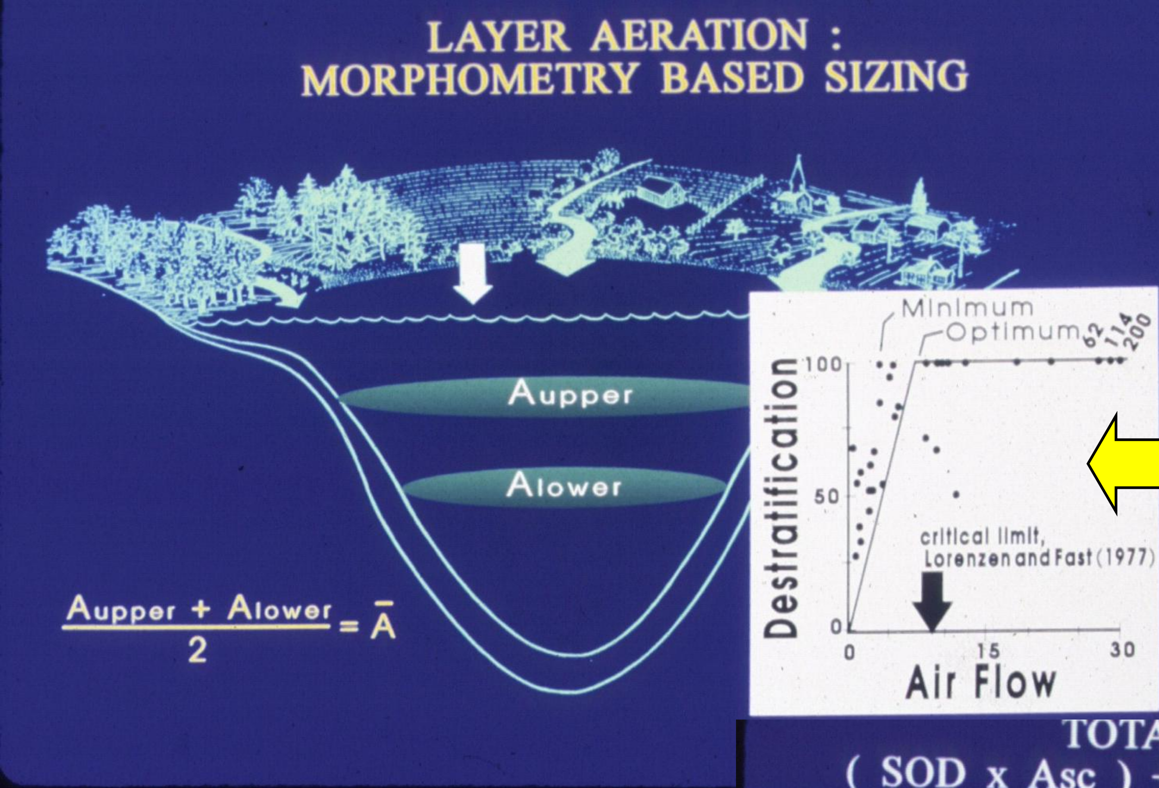


Expected 12-14°C

MEAN LAYER DISSOLVED OXYGEN



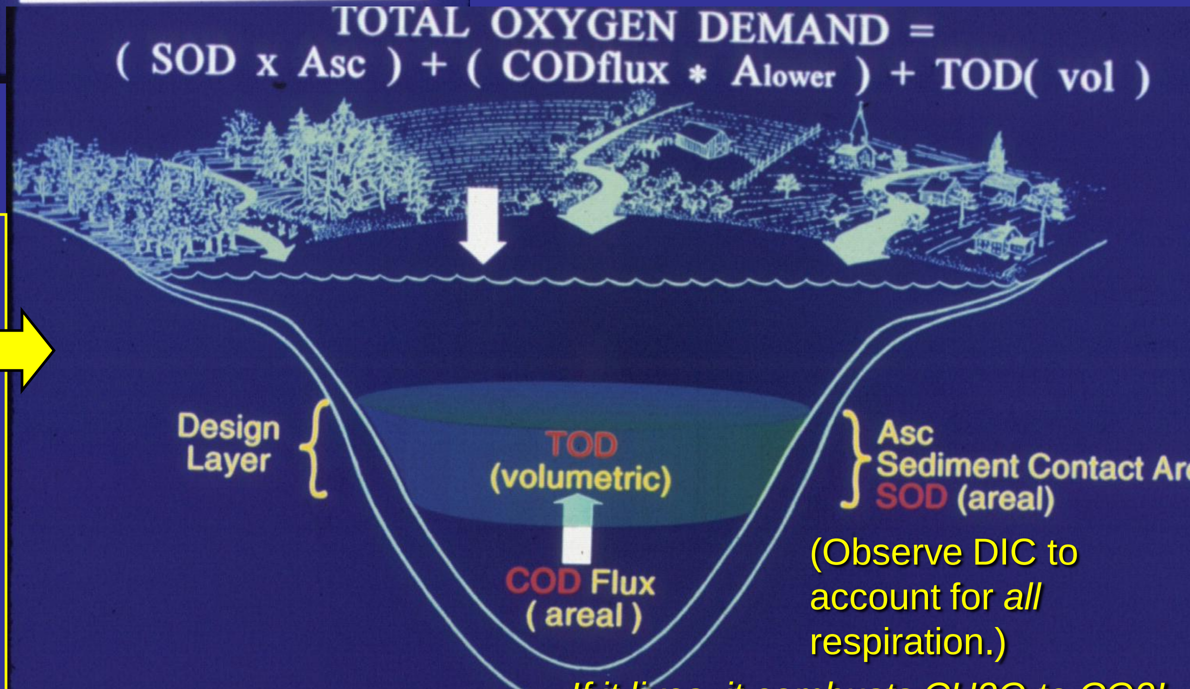
Expected 1.5 - 4.0 mg/L



Depth-Discrete Circulation Capacity estimated from empirical artificial circulation case results; using area of the layer.

How much more DO needs to enter solute phase?

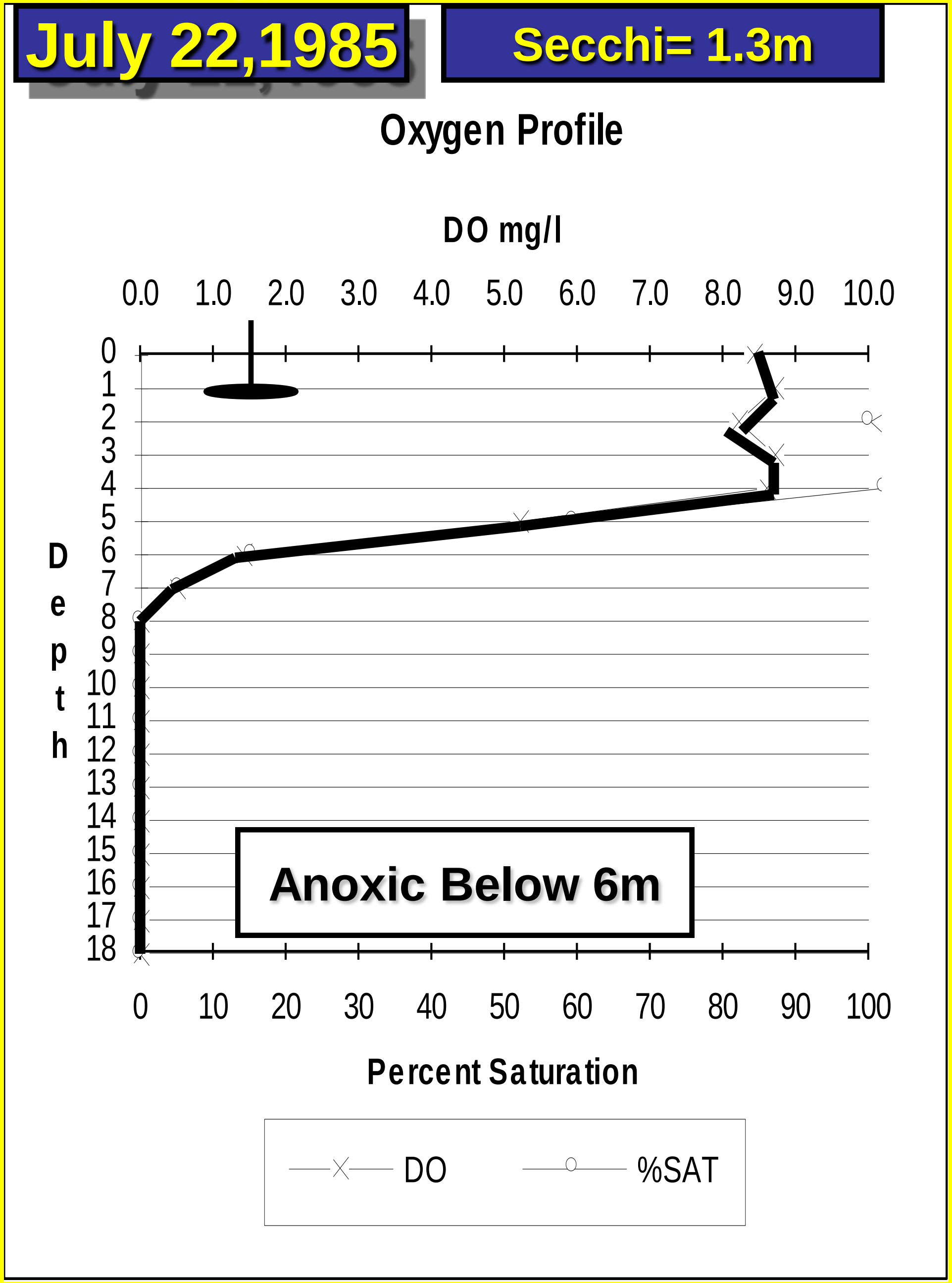
Volumetric Oxygen Demand
Sediment Oxygen Demand
COD Flux Rates
Nitrogenous Oxygen Demand

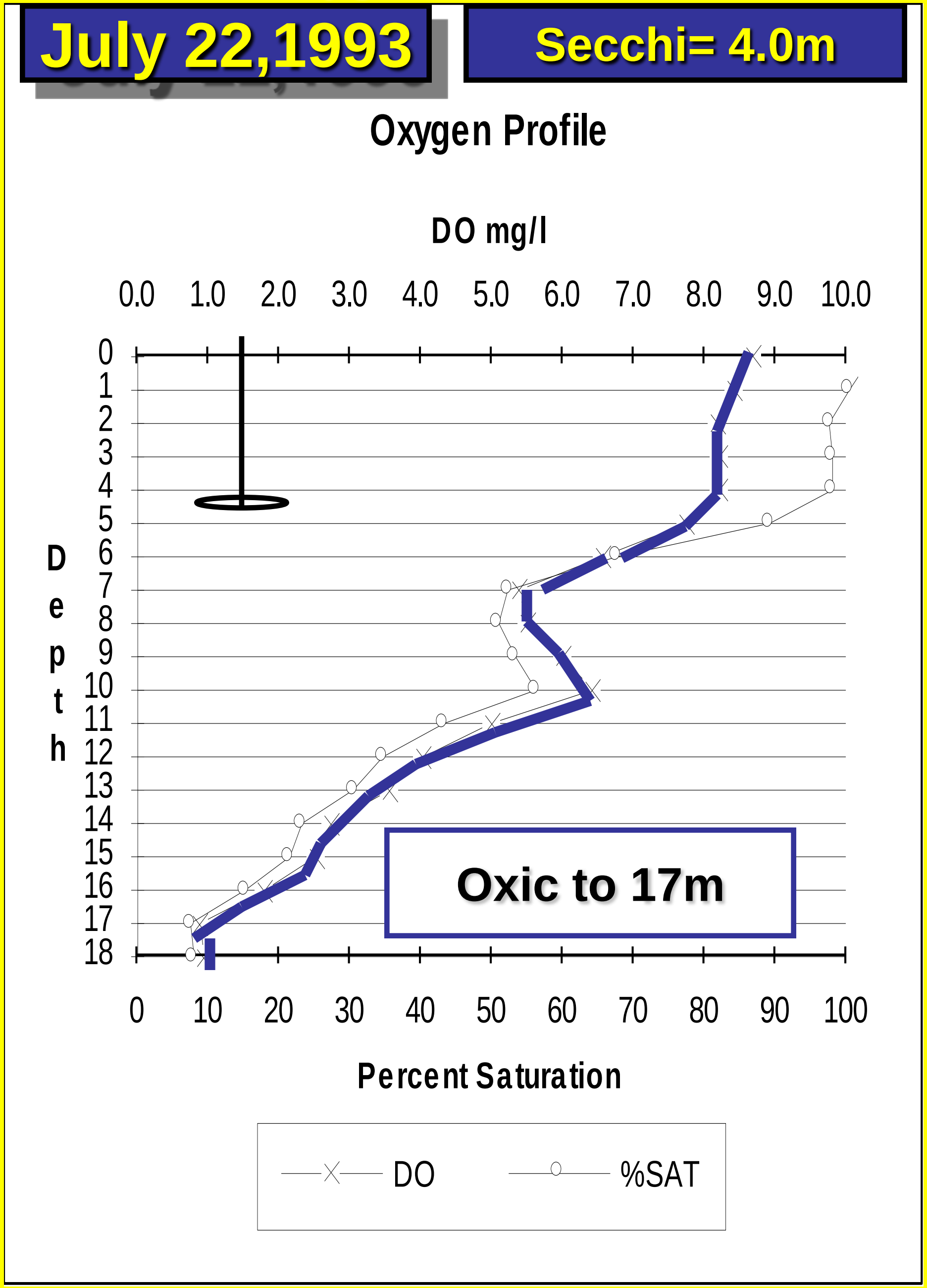


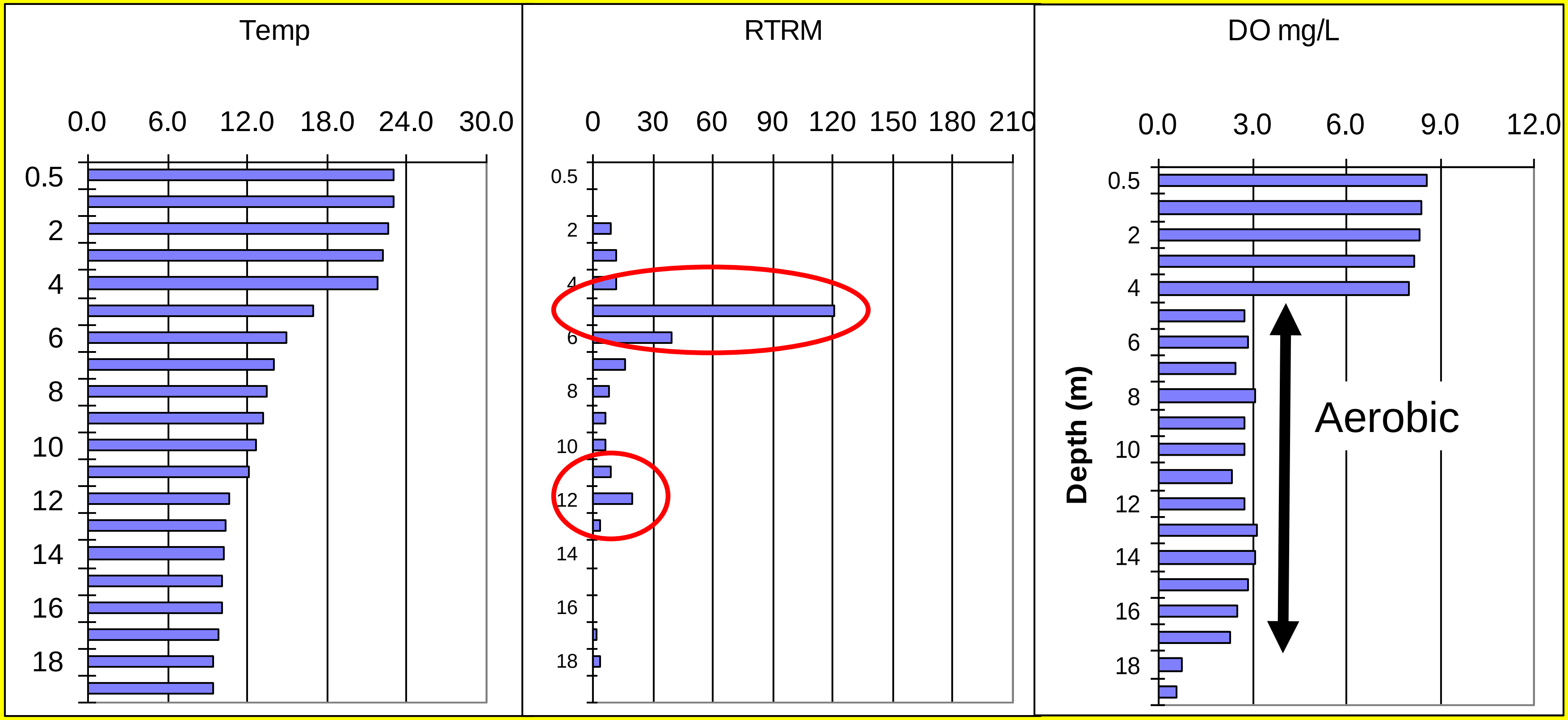
(Observe DIC to account for *all* respiration.)

If it lives, it combusts CH2O to CO2!

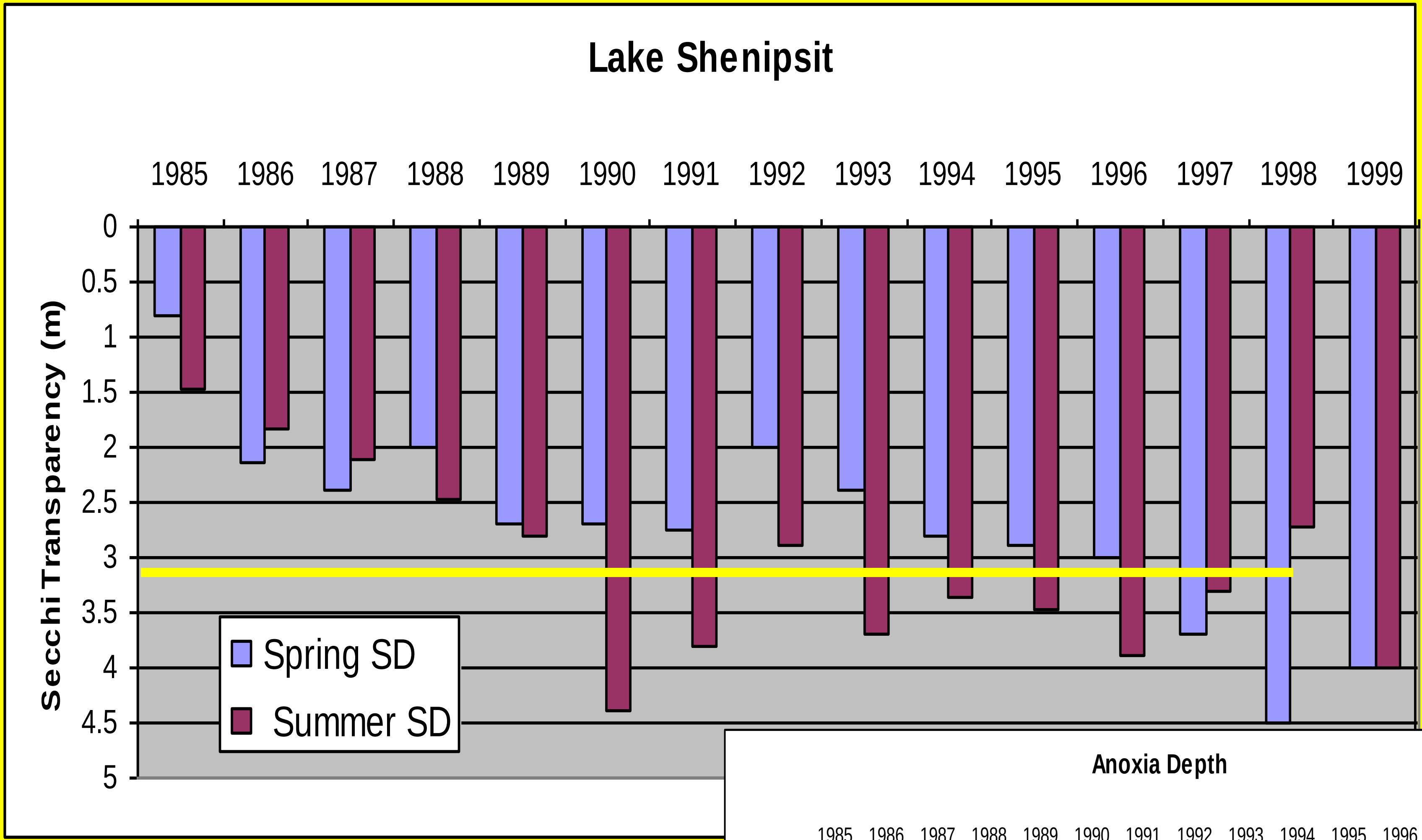
Layer / Hypolimnetic Aeration – Effect of Dissolved Oxygen Distribution



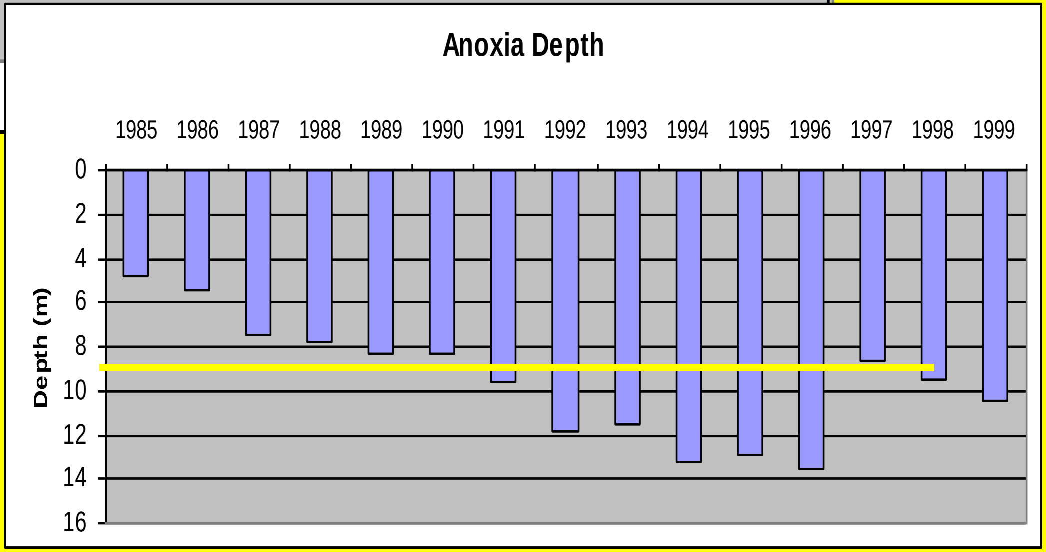




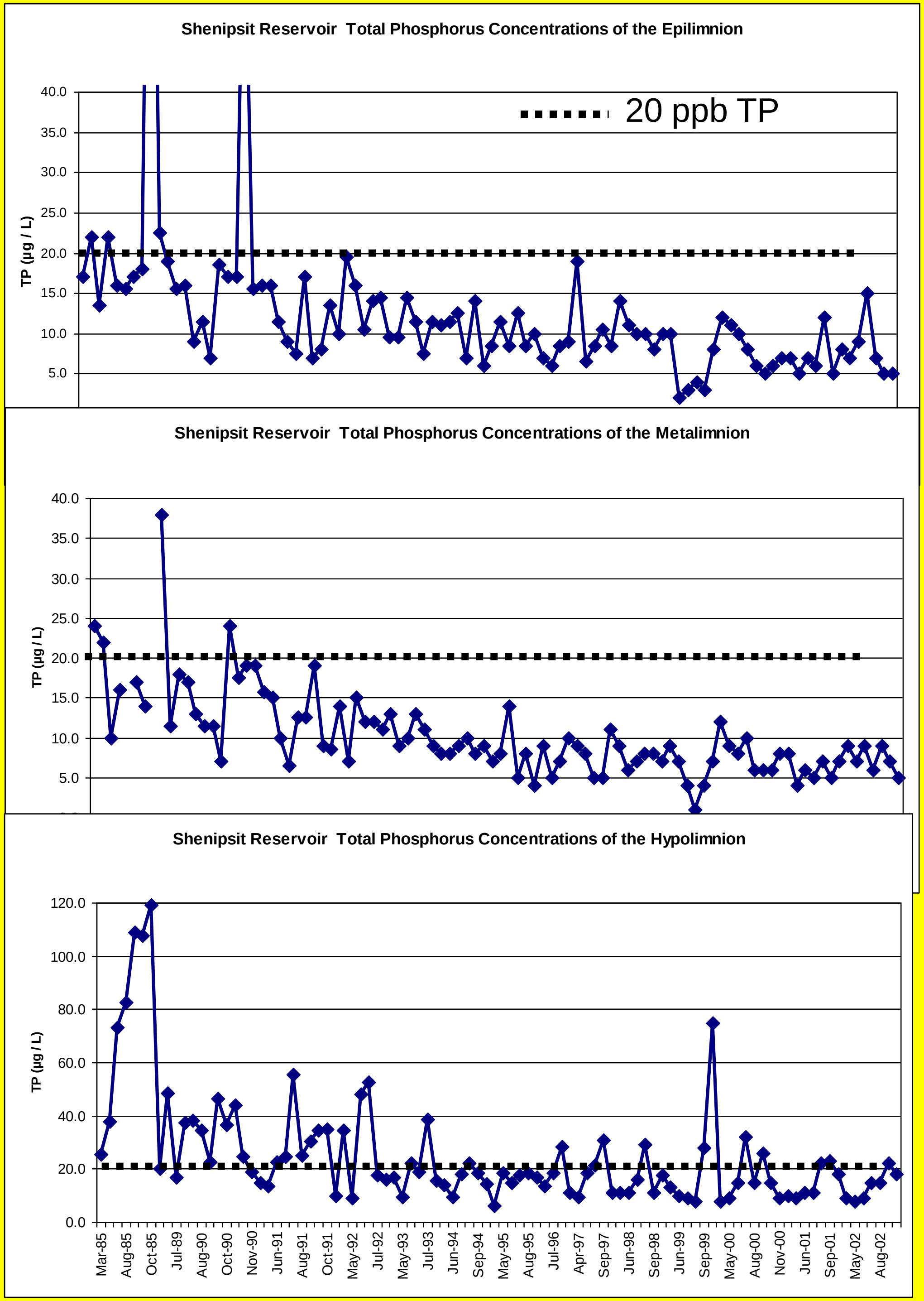
Lake Shenipsit 2000 (During Multiple Layer Aeration)



Lake Shenipsit
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Secchi Transparency (m)
Spring SD
Summer SD



Anoxia Depth
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
0
2
4
6
8
10
12
14
16
Depth (m)



TP Epilimnion

TP Metalimnion
(Aerated Layer)

TP Hypolimnion
("Anaerobic Aeration")

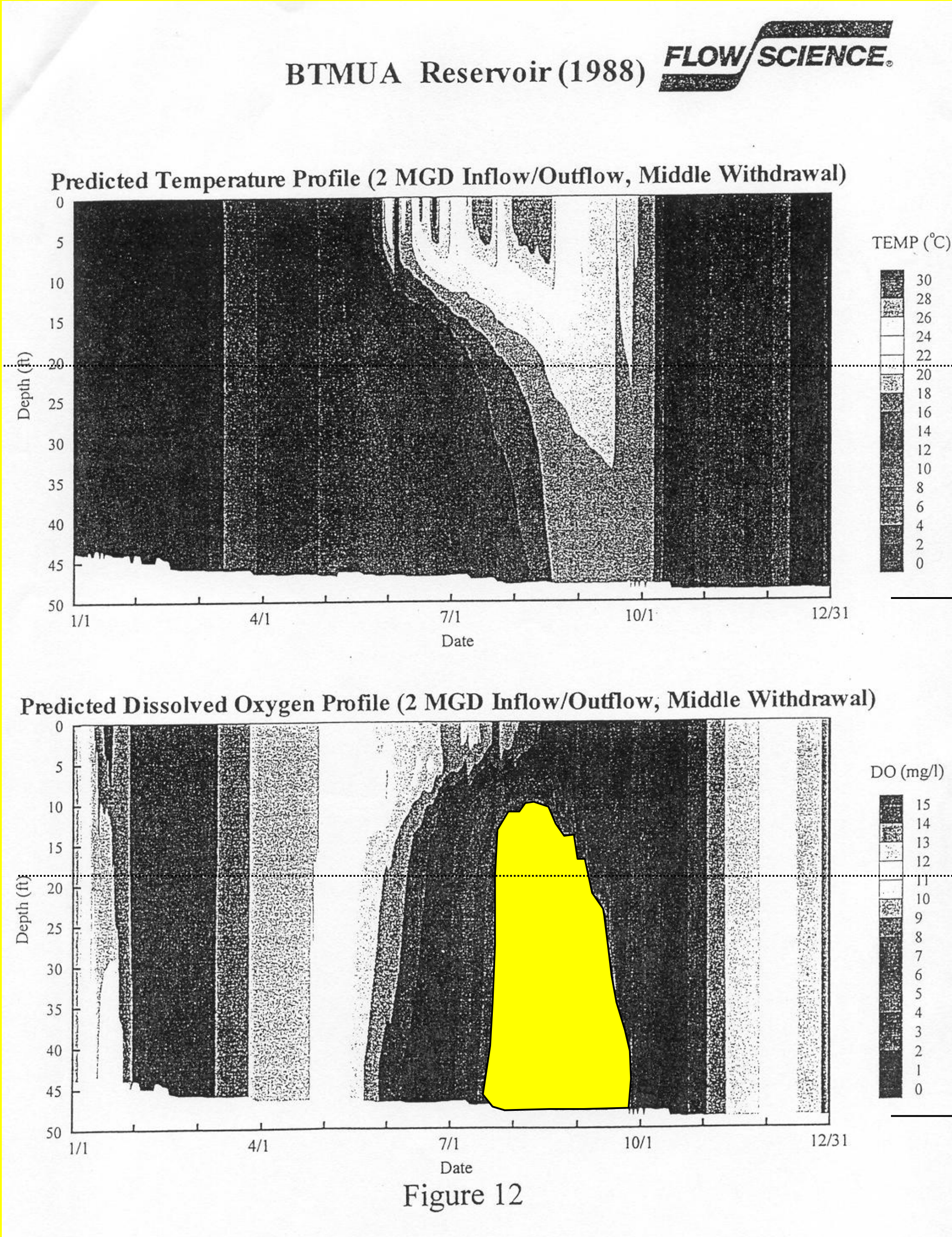
1985

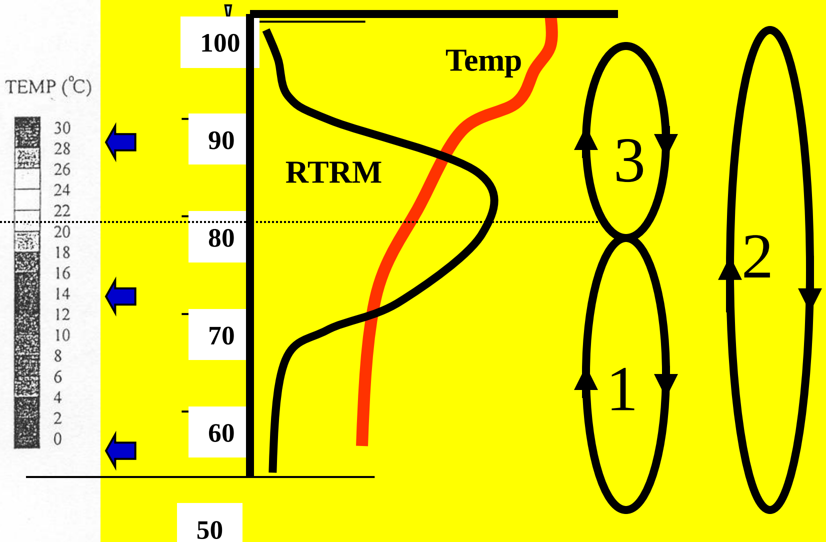
2002

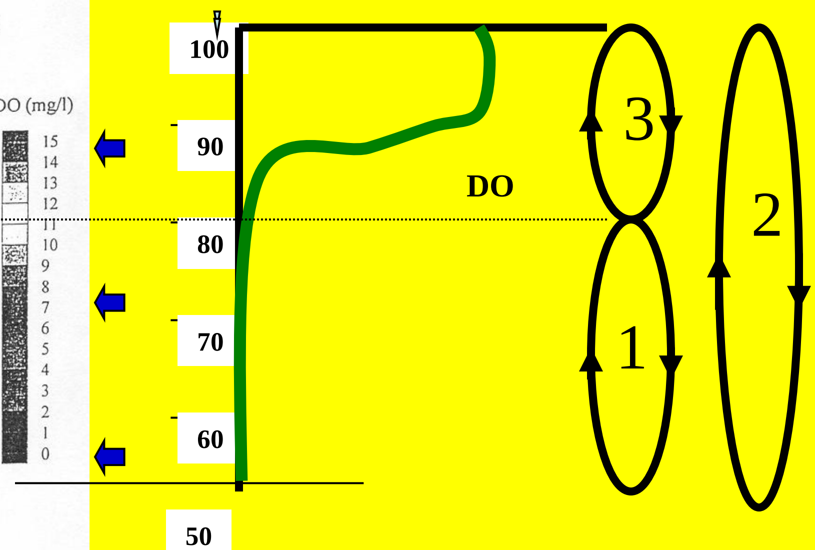
Lake Shenipsit: Additional Effects on Ecosystem Structure and Function:

- ***2000+ acre-ft of CW Habitat Restored***
    - ***Fish (piscivory, zooplanktivory)***
    - ***Herbivorous Zooplankton Refuge***
- ***Increased Nitrification***
    - ***(less Ammonia-N, more Nitrate for BG Avoidance and Denitrification)***
- ***Lower TOC, lower pH peaks***
- ***Deepened SD and CD***

Supply Intakes

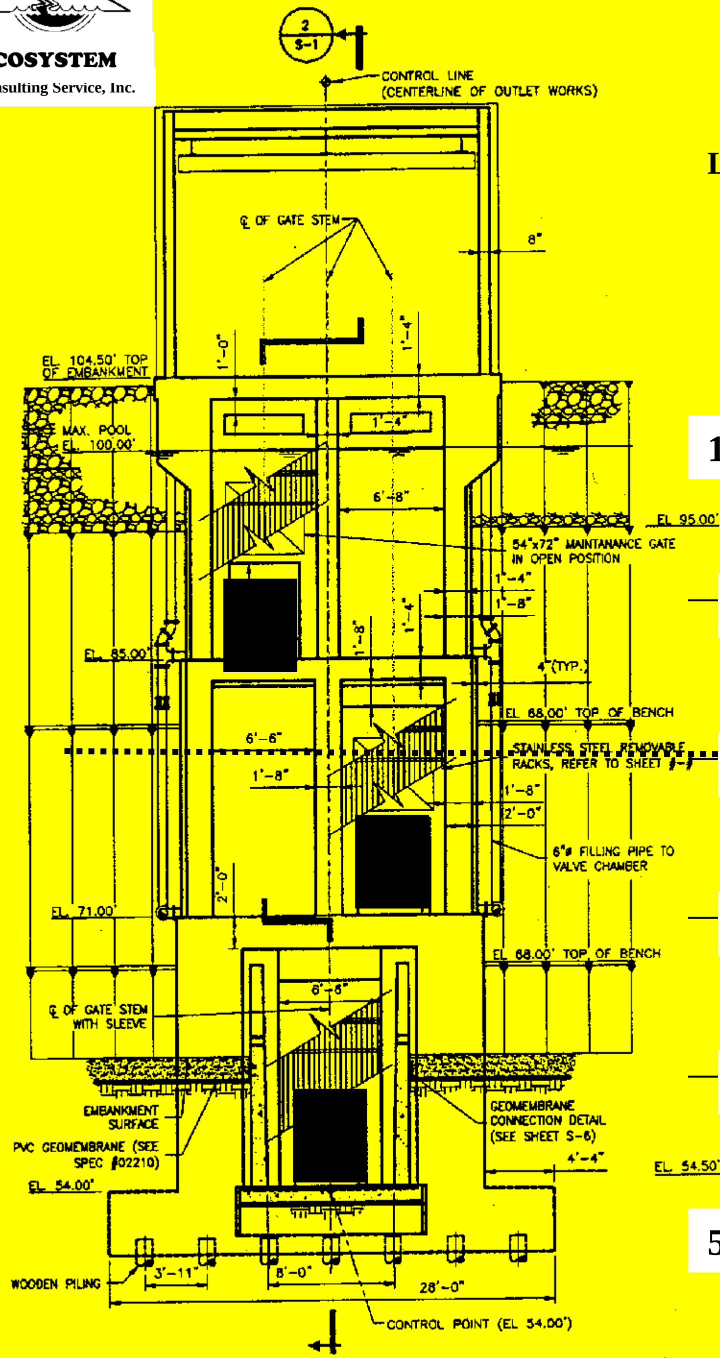






Process Schematic – BTMUA Storage Reservoir Management / Treatment System

ECOSYSTEM
Consulting Service, Inc.

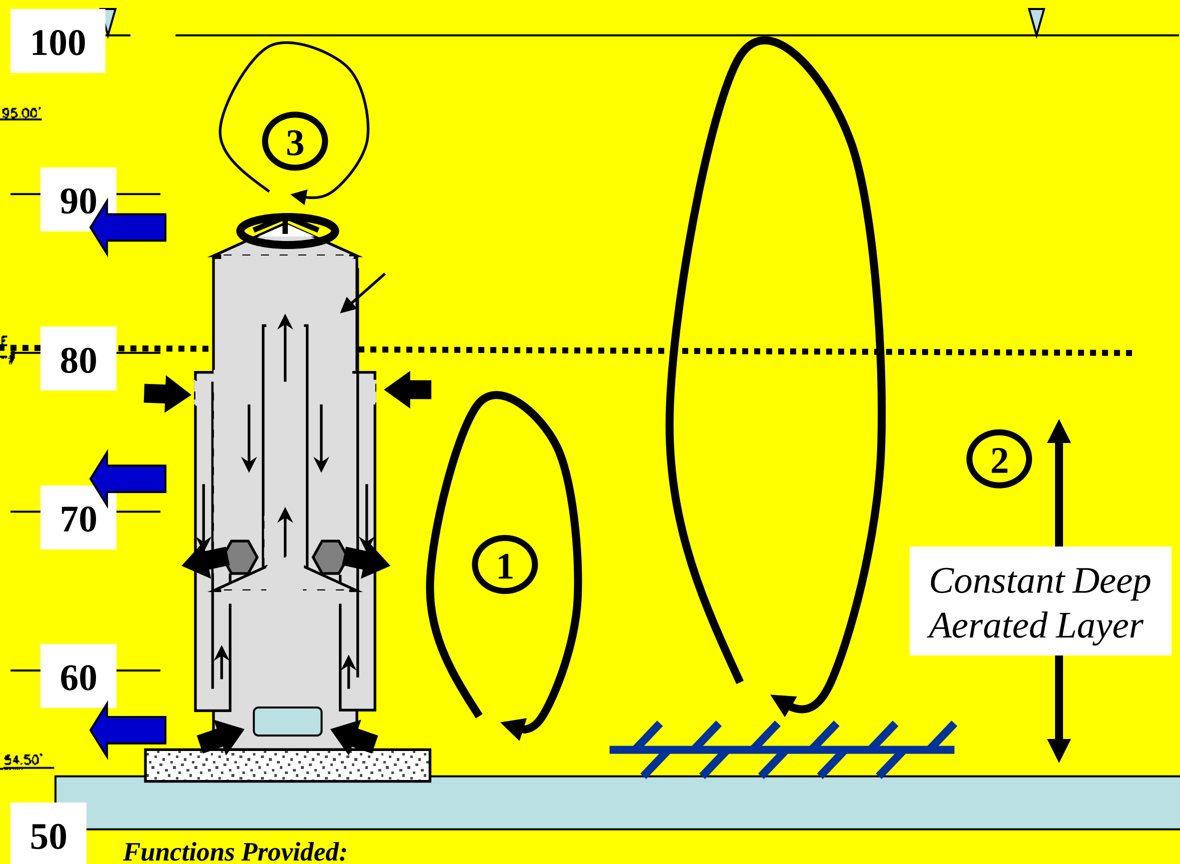


Layer Aeration (Partial Lift)

Add a ChemFeed Manifold to the diffused vent release

Artificial Circulation

Full Artificial Circulation Diffuser Module with Dual Chem Feed Installed at each Layer Aerator Slab

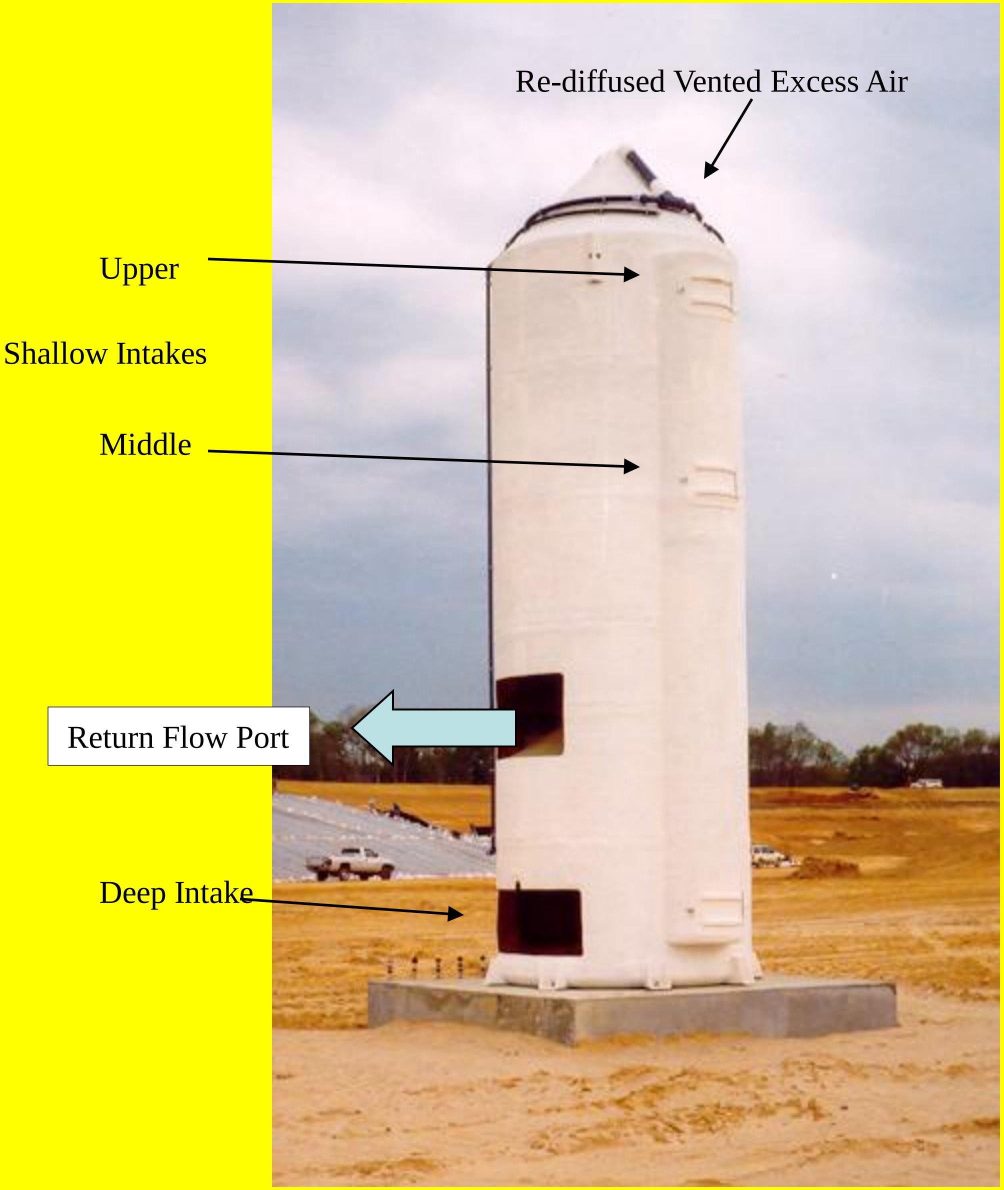


Functions Provided:

1. Layer Aeration below elev. 78ft with Dual ChemFeed
2. Complete Artificial Circulation down to elev. 50 ft with Dual Chem Feed
3. Enhanced Epilimnetic Circulation down to elev. 80ft (using vented air)

Ecosystem Consulting Service, Inc.

BTMUA Reservoir
Aeration Management System



LayerAir PIP8 Layer Aerator

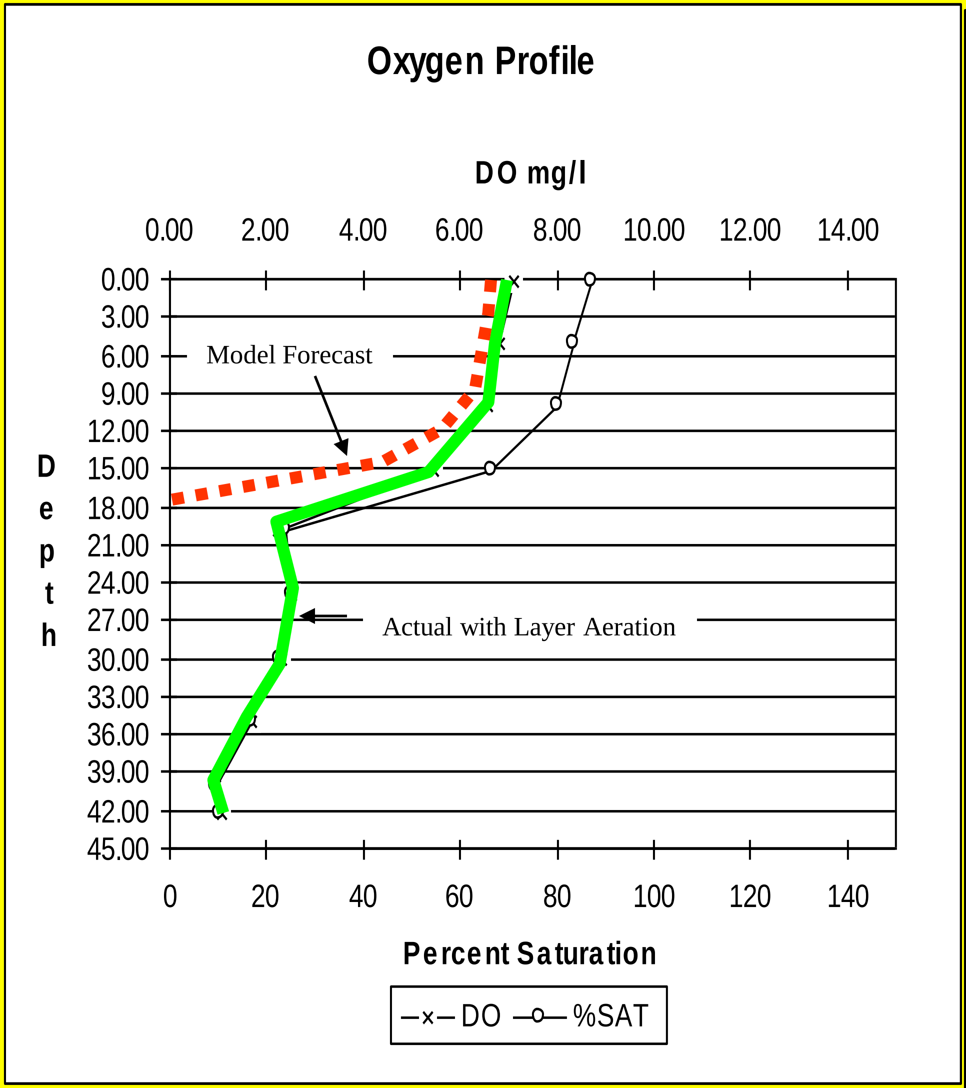
Three shallow intakes are available to establish the thickness of the aerated layer. The deep intake is always used. The initial set-up has the upper shallow intake port open (other two are closed). As lake data is collected, the upper intake could be closed and the middle intake opened which will focus aeration on a more narrow water layer. Opening only the lower shallow intake (or closing all three intakes) turns the aerator function into a "Hypolimnetic" mode of operation.

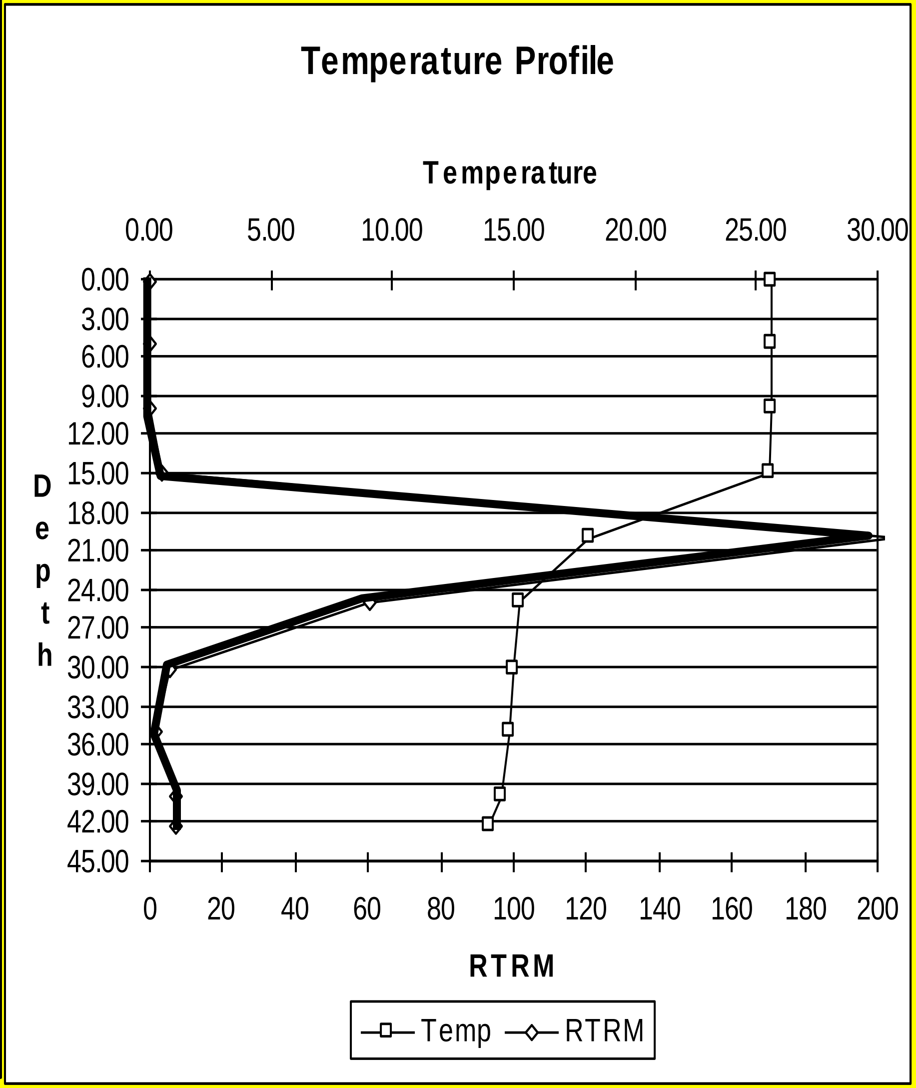
Chemical Feed Options

1. Into the Layer Aeration Tower (to treat the deep layer),
2. Into the re-diffused vent air plume (to treat the surface layer),
3. Into the Full Artificial Circulation Diffuser Module (to mix and treat the entire water column).

All operational modifications and treatments can be performed from the land-based compressor facility.

BTMUA Reservoir R-8 8/6/2004





Remained Aerobic; would have been anoxic below 21 ft without aeration.

Very Strong Thermocline @ 21 ft; Good circulation of surface and deep layers.

Where air feed piping needs to be very long, aerators can be “unitized” as pairs (double capacity per air feed pipe; reducing cost)

Watershed Management

EXAMPLE

Example
Watershed Management Plan

- Designation of Lake Protection Areas
- Septic System Mgmt Approaches
  1. Pump Out Reporting Ordinance
  2. Effluent Filters - “Consider for Use”
  3. P Removal Minimums for Sand Fill
  4. Leaching Field Geometry
  5. “Ban” Septic System Additives
  6. Innovative Septic Designs- P Removal
- “Ban” on High-P Fertilizers
- Standard Conditions/Policies PZC, IW
- Nutrient Allocation Evaluation
- Road / Drainage Maint. Schedule
- First Flush Stormwater Management

EXAMPLE

Nutrient Allocation - Land Use Worksheet

Watershed Areal P Export Allocation= 0.32 lb P $Acre^{-1}$ $Year^{-1}$

Base Loading Areal TP Allocations:

Undisturbed Woodlands=	*0.09*	lb P $Acre^{-1}$ $Year^{-1}$
Impervious Area=	*1.5*	lb P $Acre^{-1}$ $Year^{-1}$
Semi-Pervious Area=	*1.25*	lb P $Acre^{-1}$ $Year^{-1}$

Parcel Area=	67485 sq ft	1.549242 Acres	67485	Sq. Feet
Parcel Allocation=		**0.495758** lb P $Year^{-1}$		
		0.495758 lb P $Year^{-1}$		

Existing Single Family Residential Use: **No BMP Credits**

	sq ft	Est P Load (lb P / acre / yr)	LOAD
Roof	1860	1.5	0.06405
Driveway	1530	1.5	0.052686
Lawn	7000	1.25	0.200872
Woodland	43120	0.09	0.089091
Pond Surface	13975	0.75	0.240616
TOTAL	67485		**0.647315**

Compare:
Does not meet allocation.

Need to apply Best Management Practices to comply with the Total Phosphorus Allocation:
Reduce disturbed area, reduce impervious areas, increase retained woodland,
Rain Gardens, Roof Water Harvesting / Rain Barrels, "Simple" Infiltrators,

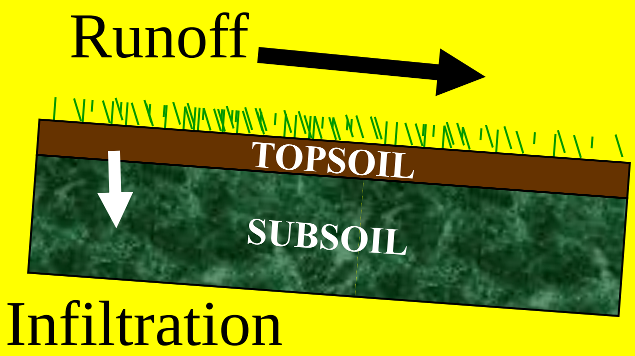
Do you want a Green Lawn?
Do you want a Clean Lake?

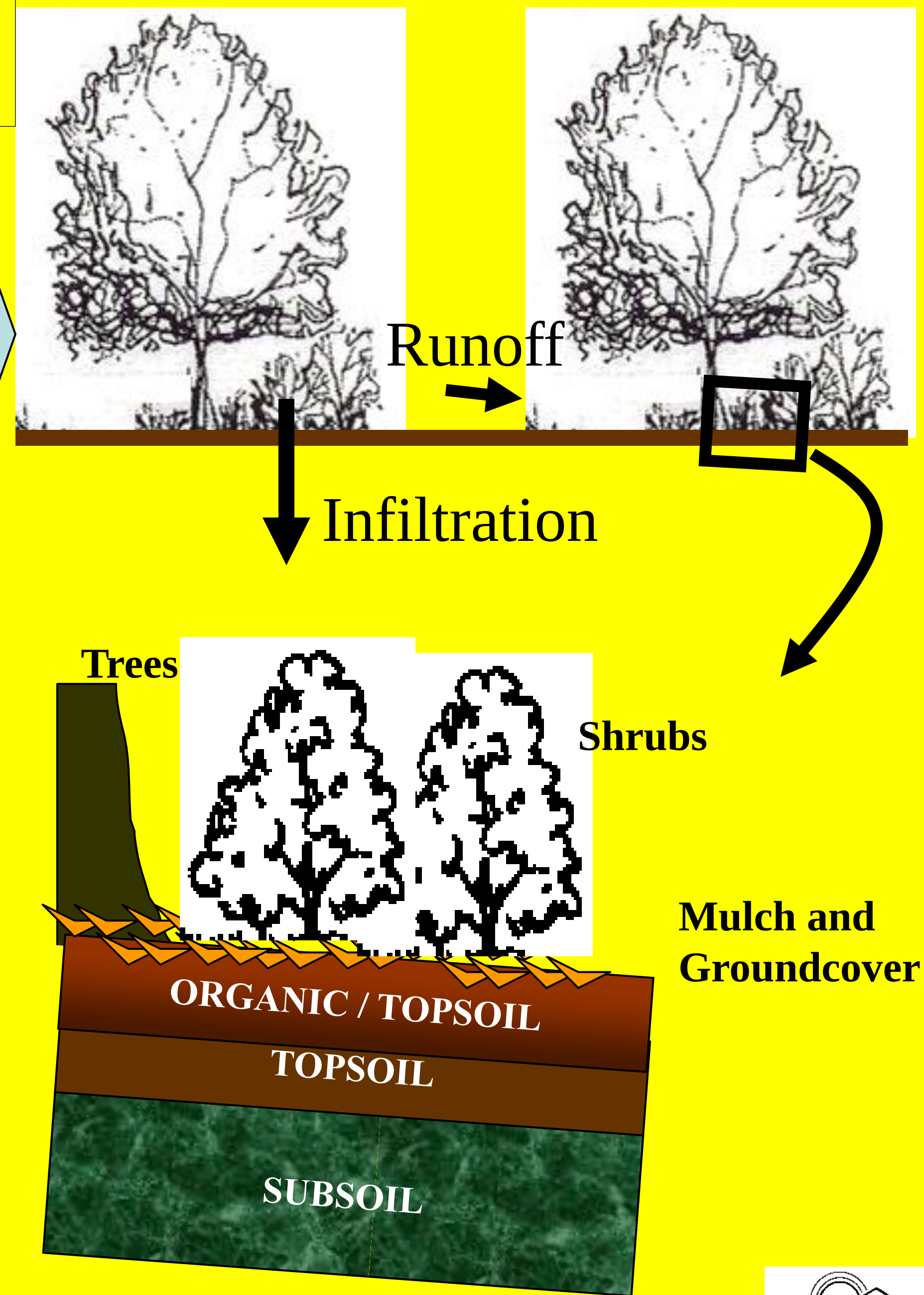
You can help to Have BOTH!
Zero Phosphorus Fertilizers

A full line of ZERO PHOSPHORUS fertilizer is available for lake communities!

Your lawn needs nitrogen…not phosphorus; and we need to minimize phosphorus in the lake to reduce algae blooms and weed abundance. You are a part of the lake ecosystem, and *you can help!*

0.20 lb
P / Acre / Year





Convert Semi-Pervious to "Simulated Woodland"

- **Mimic the Function of Woodlands**
- **Ornamental Landscaping**

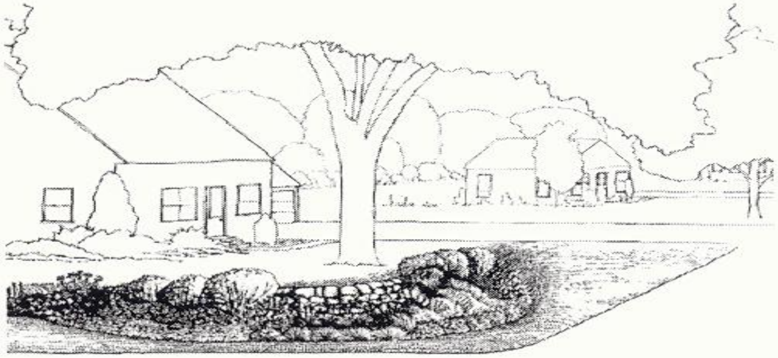
Example: Convert a Lawn

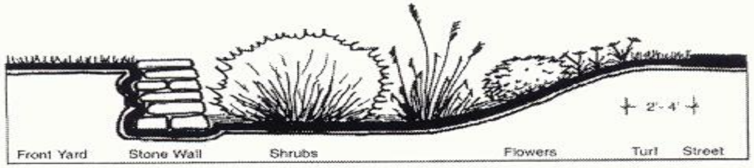
1. **Spread 3" of Peat Moss over the area**
2. **Rototill to > 6 inches**
3. **Cover with Mulch**
4. **Plant Groundcover**
5. **Plant Shrubs (50% cover when grown)**
6. **Plant Tree Saplings (> 1"DBH; 30' On-Center Spacing)**

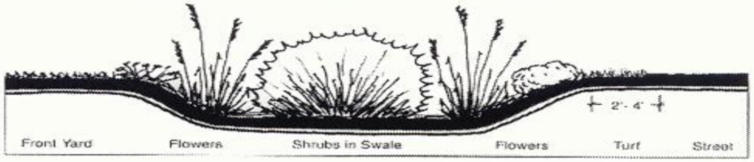
First ½ Inch
0.40 lb P / Acre / Year
First 1 Inch
0.20 lb P / Acre / Year

Figure 4-6. Residential Rain Gardens

Typical Residential Rain Garden (With and Without Masonry Wall)



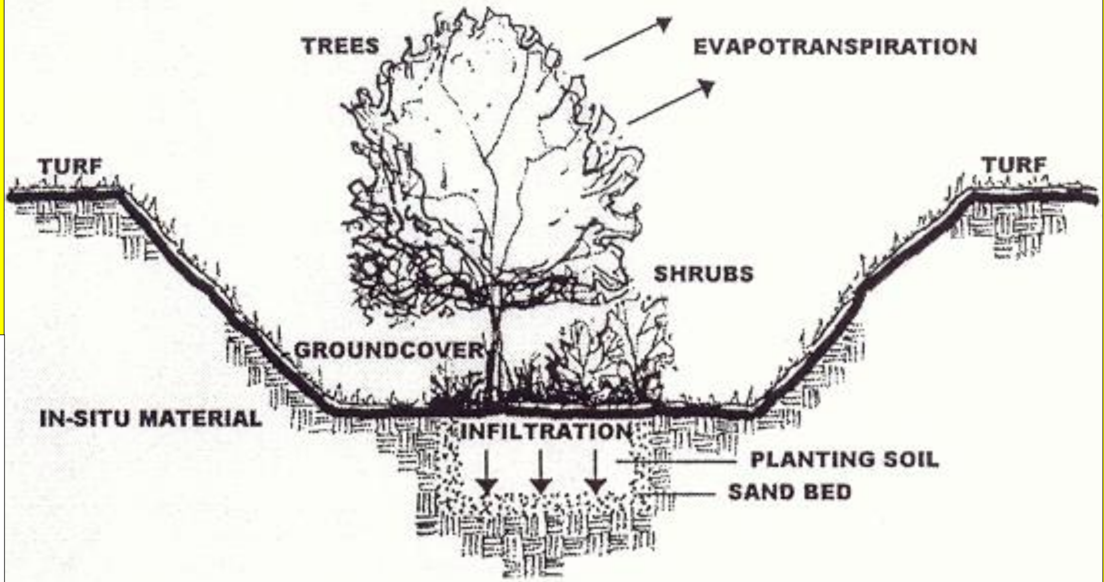




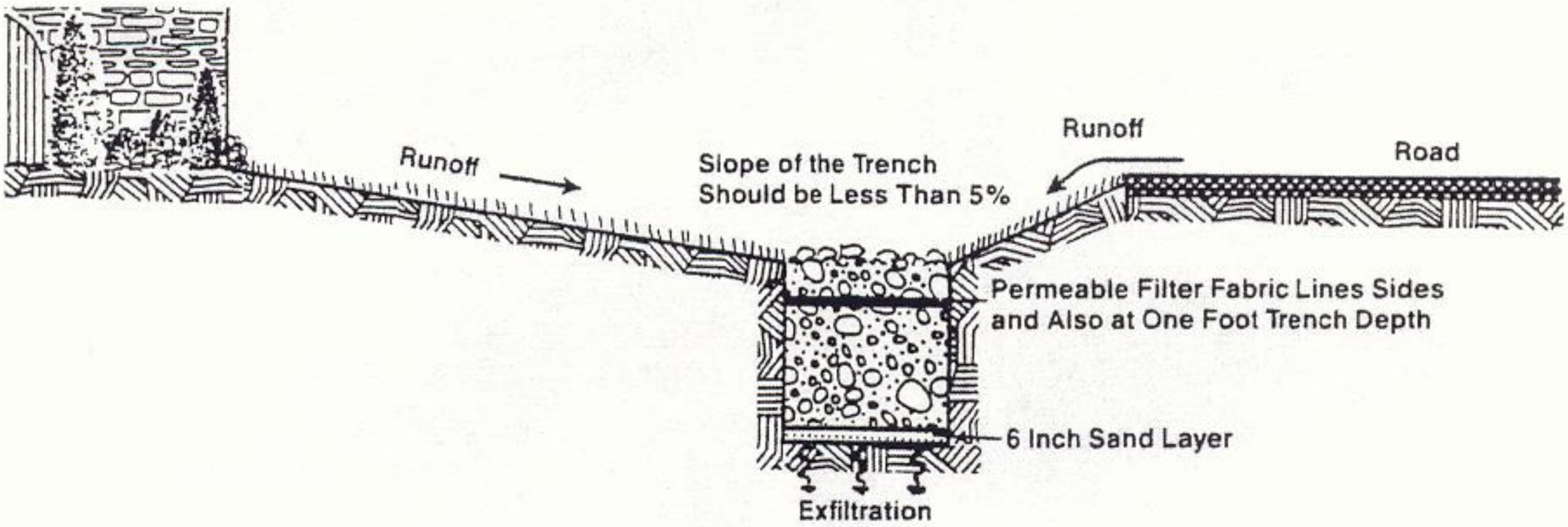
Examples of Residential Rain Gardens

Source: Metropolitan Council, 2001 (Adapted from Nassauer et al., 1997) and Low Impact Development Center (www.lowimpactdevelopment.org), 2001.

First ½ Inch
0.40 lb P / Acre / Year
First 1 Inch
0.20 lb P / Acre / Year



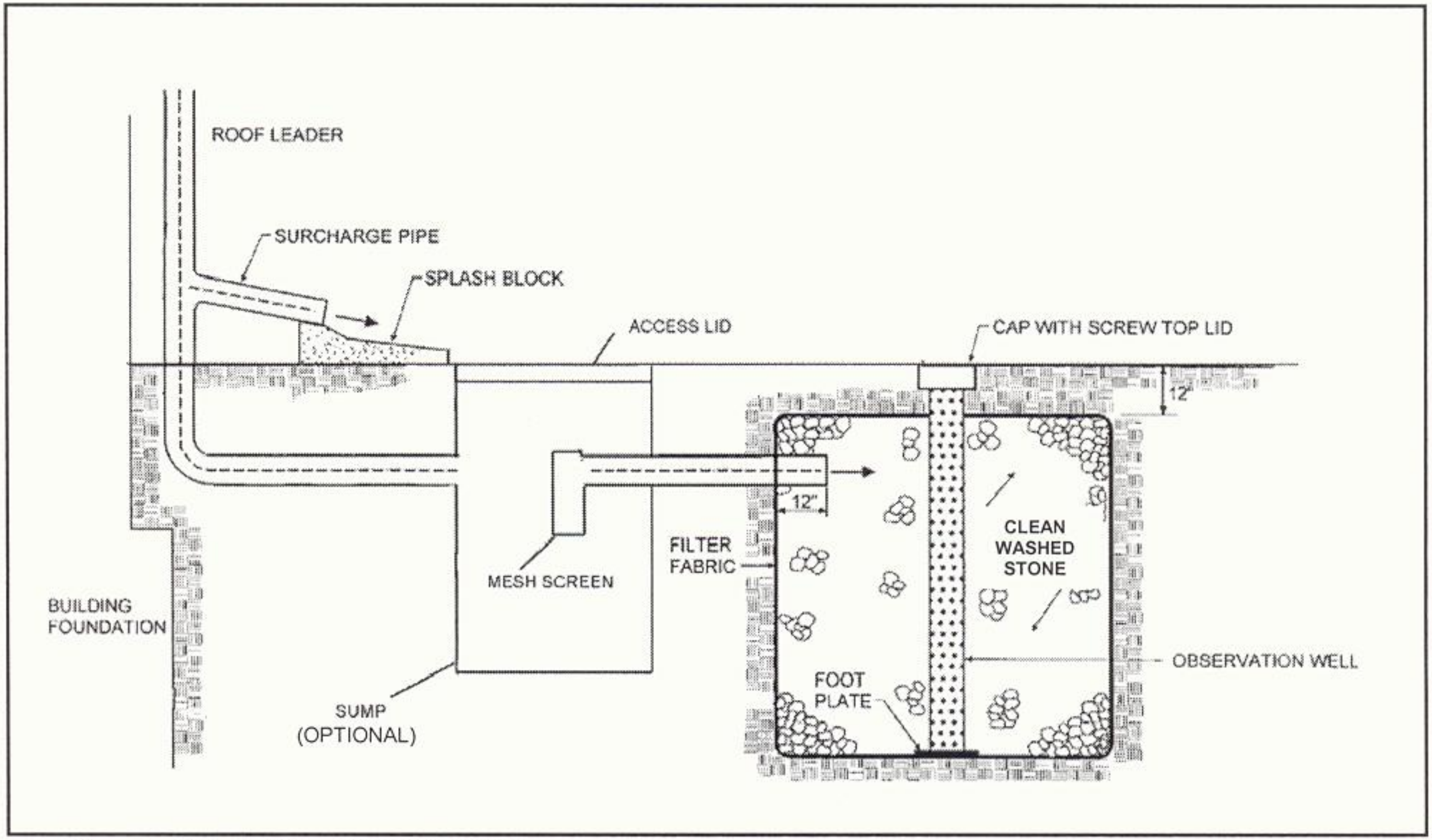
Bioretention Basin



Enhanced Swale

ADAPTED FROM SCHUELER

Figure 4-7. Schematic of Typical Dry Well

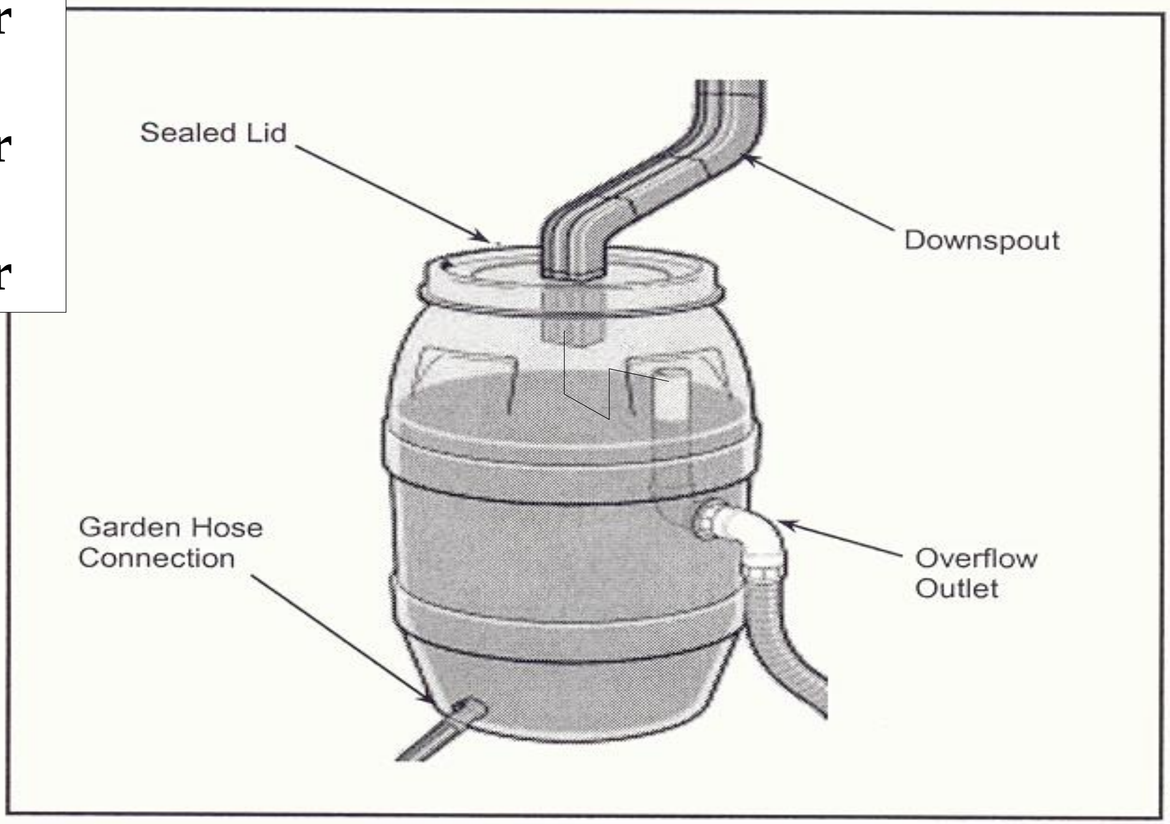


Source: Adapted from NYDEC, 2001.

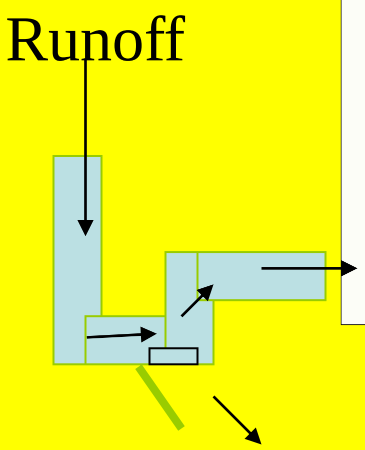
First ½ Inch
0.40 lb P / Acre / Year
First 1 Inch
0.20 lb P / Acre / Year

First ¼ Inch
0.60 lb P / Acre / Year
First ½ Inch
0.40 lb P / Acre / Year
First 1 Inch
0.20 lb P / Acre / Year

Figure 4-8. Typical Rain Barrel



Source: Adapted from urbangardencenter.com (D&P Industries, Inc., 2001).



Bypass After Full

First Flush Fills Barrel

An Adobe version of these slides is available at:
www.ecosystemconsulting.com

The End (finally!)

Questions?

Remember…you are what you…DRINK!