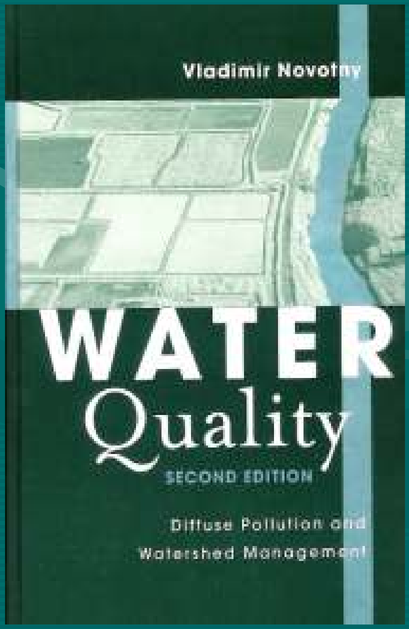
NUTRIENT IMPACT Including danger of cyanobacteria

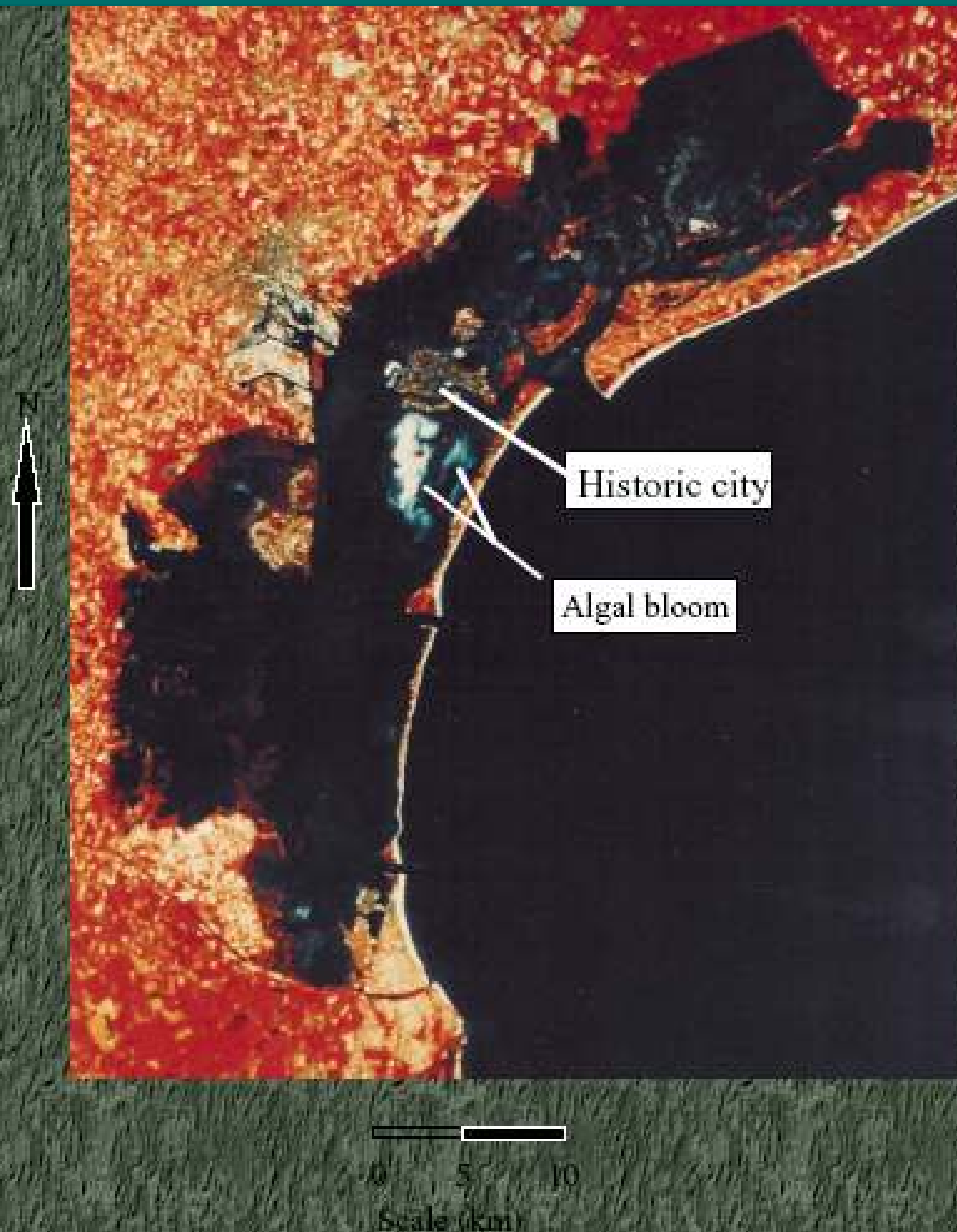


Supplement to Chapter 12

Definition

- Nutrients are primarily nitrogen and phosphorus that stimulate the growth of algae
- Algae and plants generally can use nitrogen in a form of ammonium and nitrate. Some algae (obnoxious blue greens) and plants (legumes) can fix atmospheric nitrogen

Algal Bloom of *Ulva* in the Lagoon of Venice



NUTRIENT IMPACT

- Photosynthesis is the driving process
  - $6CO_2 + 6H_2O \longrightarrow 6O_2 + C_6H_{12}O_6$
- Photosynthesis occurs in the water layer where light can penetrate (euphotic zone)
- In the layer with insufficient light, on cloudy days and during night algae respire and impose oxygen demand (the equation is reversed)

Algae In Venice (Lagoon) and Milwaukee River

Algae in Venice and in Mexico

Ulva in Venice

Water hyacinths in Mexico

Water Hyacinth at Lake Victoria in Africa

EUTROPHICATION

Macronutrients CO_2 (alkalinity)
N, P
Micronutrinets Mn, Cu, Zn, etc.

Stimulate production of organic matter

$$6CO_2 + 6H_2O \rightleftarrows C_6H_{12}O_6 + 6O_2$$

Nutrients ↗ ↖ Energy

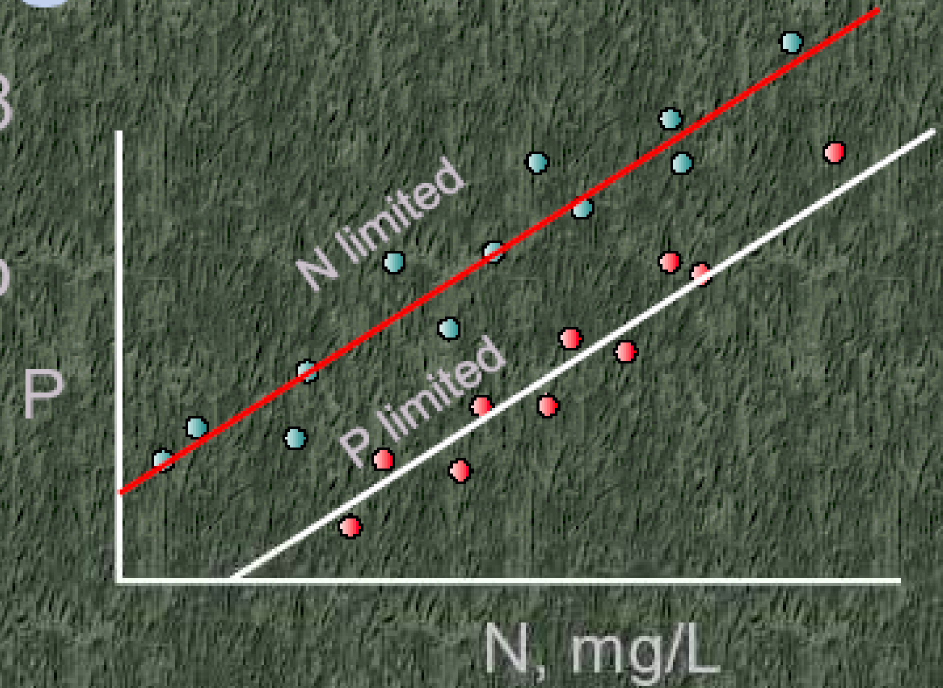
Primary productivity = organic matter produced from CO_2 (alkalinity - HCO_3^-) and nutrients

$$CO_2 + H_2O \rightleftarrows HCO_3^- + H^+$$

Limiting Nutrient

N/P ratio for algae ≈8

* if N/P of water >8 to 15, phosphorus is limiting
* if N/P < 5 to 8, N is limiting



Typically, for inland lakes P is limiting
For marine waters N is limiting
Rivers both can be limiting

What is eutrophication?

- Natural and anthropogenic process of enrichment of water bodies by organic particulates stimulated by nutrient inputs and recycling
- Eutrophication progresses over the historic times in various stages
  - Oligotrophic
  - Mesotrophic
  - Eutrophic
- A hyper-trophic water body classification was added about twenty – thirty years ago which is characterized by massive algal blooms (10^4 to 10^6 algae/ml)
- End of the process is disappearance of the water body and its conversion into a wetland and ultimately dry land

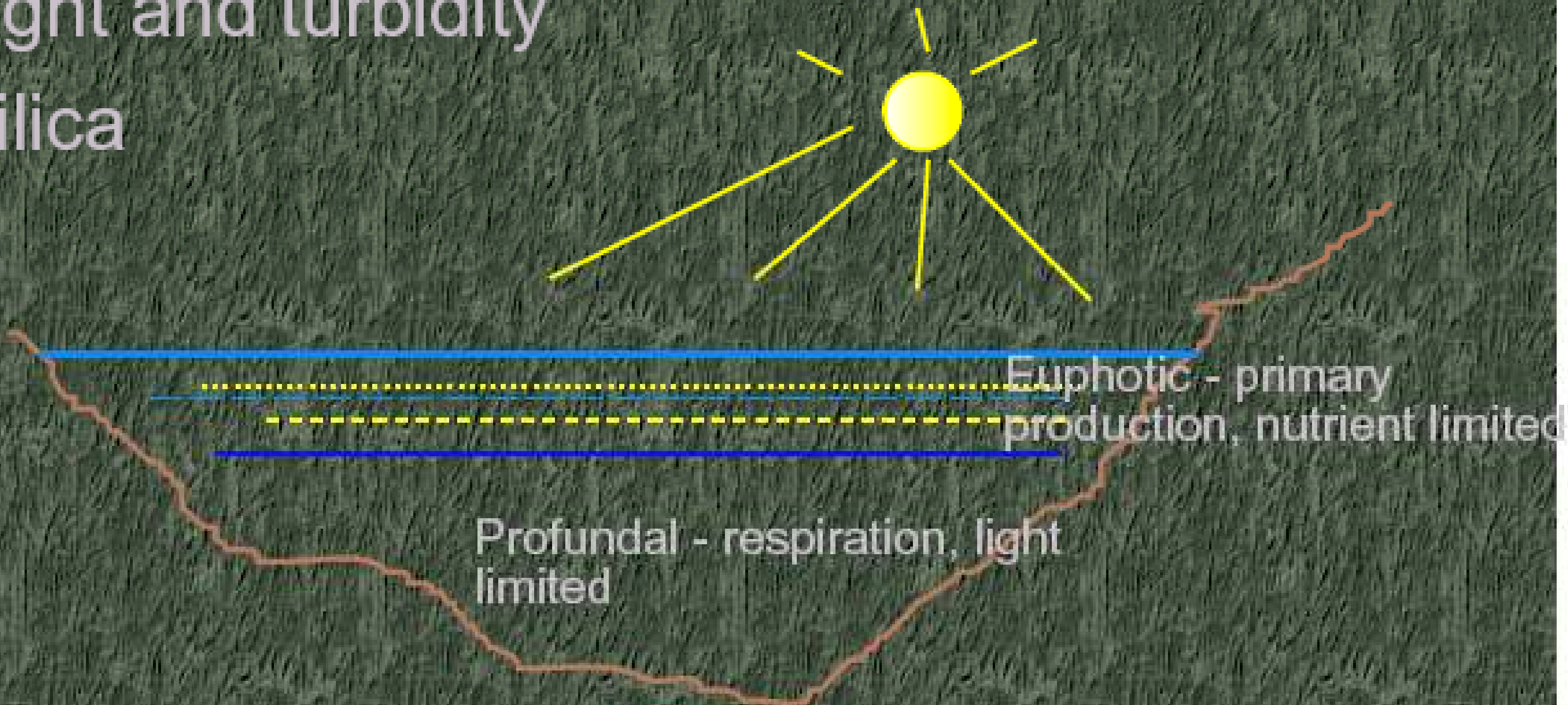
Eutrophication Characteristics

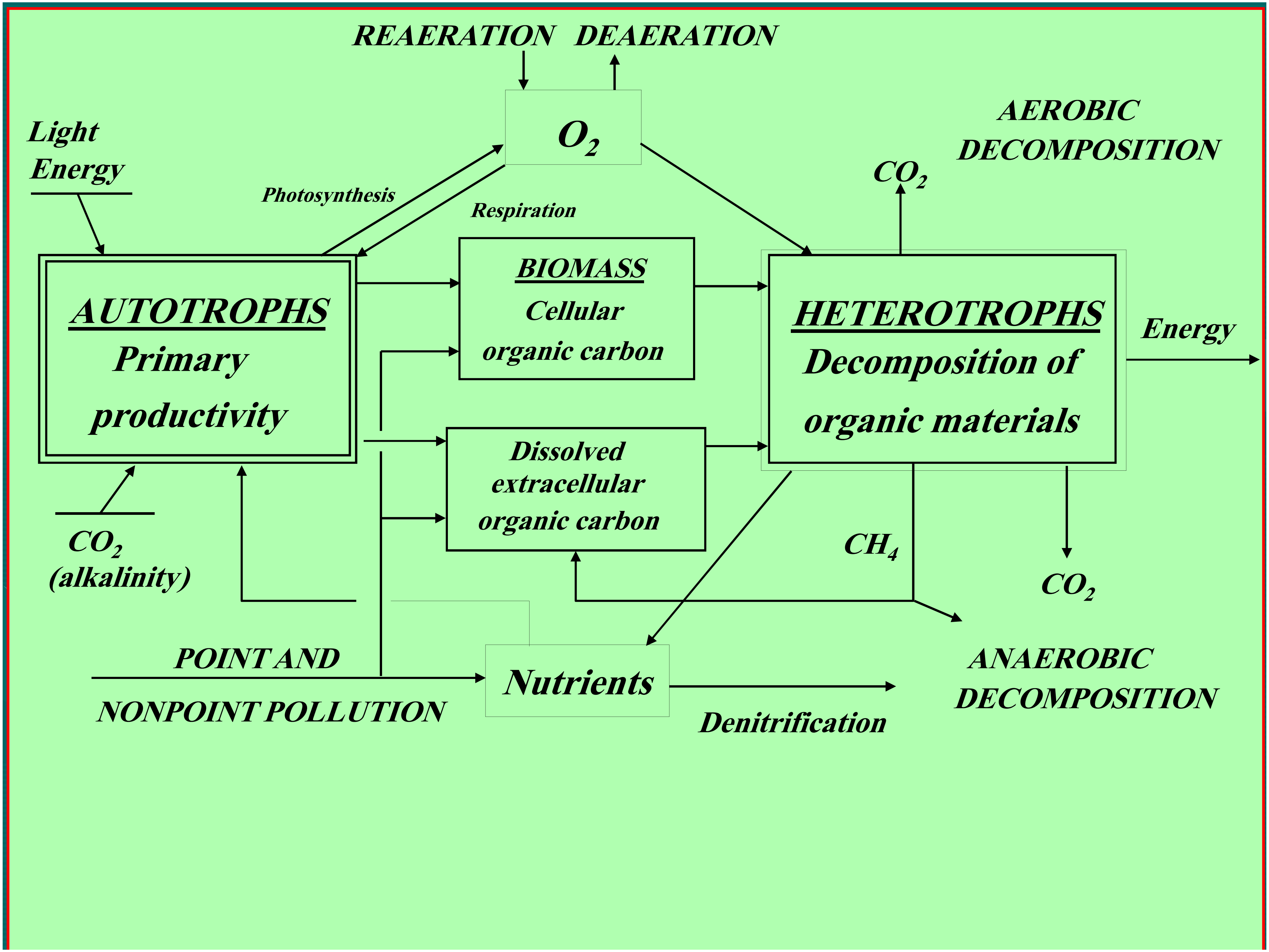
Quality Water	Oligotrophic	Mesotrophic	Eutrophic	Hyper-eutrophic*
Total P (µg/L)	<10	10-20	>20	> 50
Chlorophyll - *a*	<4	4-10	>10	>20
Secchi disc transparency depth (m)	>4	2-4	<2	<1
Hypolimnetic oxygen (% saturation)	>80	10-80	<10	0

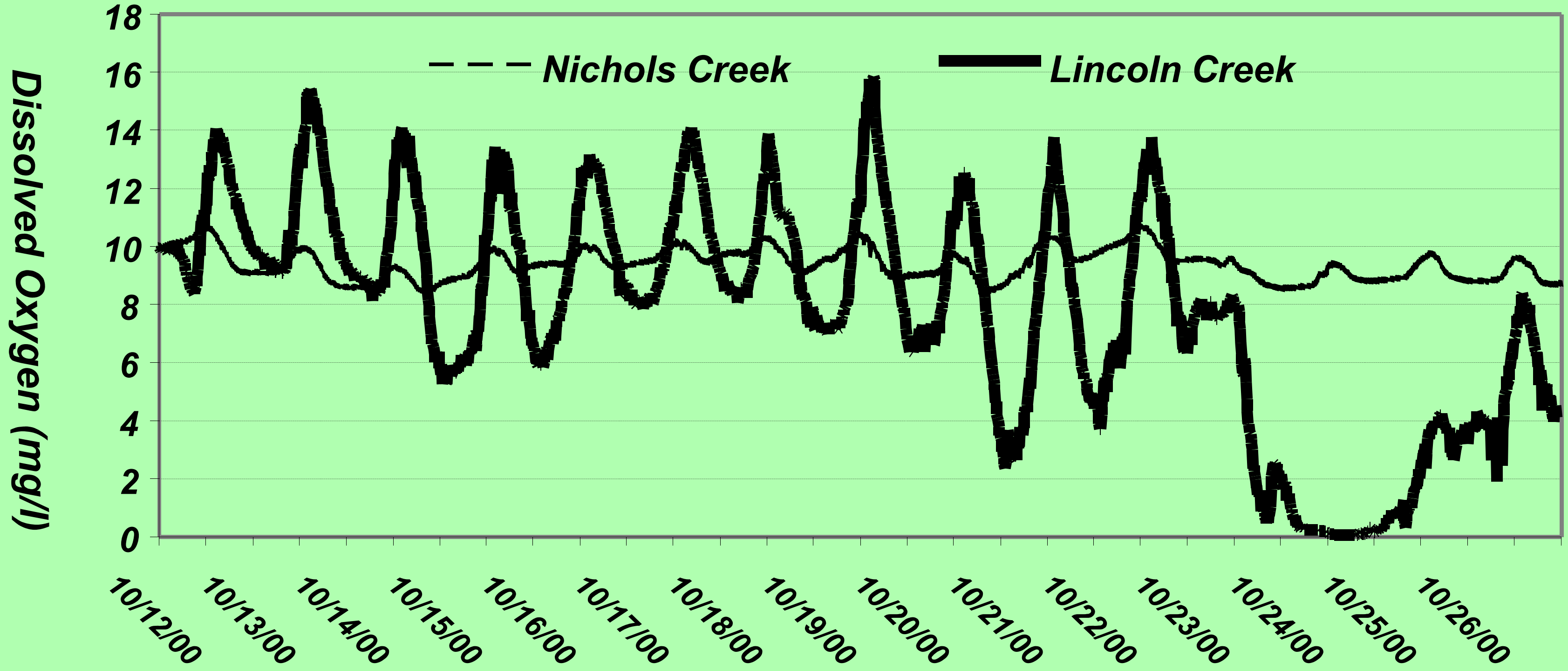
World Health Organization nitrogen standard of 10 mg nitrate N/L protects infants from blue baby disease but does nothing to controlling eutrophication and hypertrophy

Other limitations

- Alkalinity (Inorganic carbon) Alk , 25 mg/l
- Light and turbidity
- Silica




REAERATION
DEAERATION
O_2
Light Energy
Photosynthesis
Respiration
AEROBIC DECOMPOSITION
CO_2
AUTOTROPHS
Primary productivity
BIOMASS
Cellular organic carbon
HETEROTROPHS
Decomposition of organic materials
Energy
Dissolved extracellular organic carbon
CO_2 (alkalinity)
CH_4
CO_2
POINT AND NONPOINT POLLUTION
Nutrients
Denitrification
ANAEROBIC DECOMPOSITION



Dissolved Oxygen (mg/l)
18
16
14
12
10
8
6
4
2
0
Nichols Creek
Lincoln Creek
10/12/00
10/13/00
10/14/00
10/15/00
10/16/00
10/17/00
10/18/00
10/19/00
10/20/00
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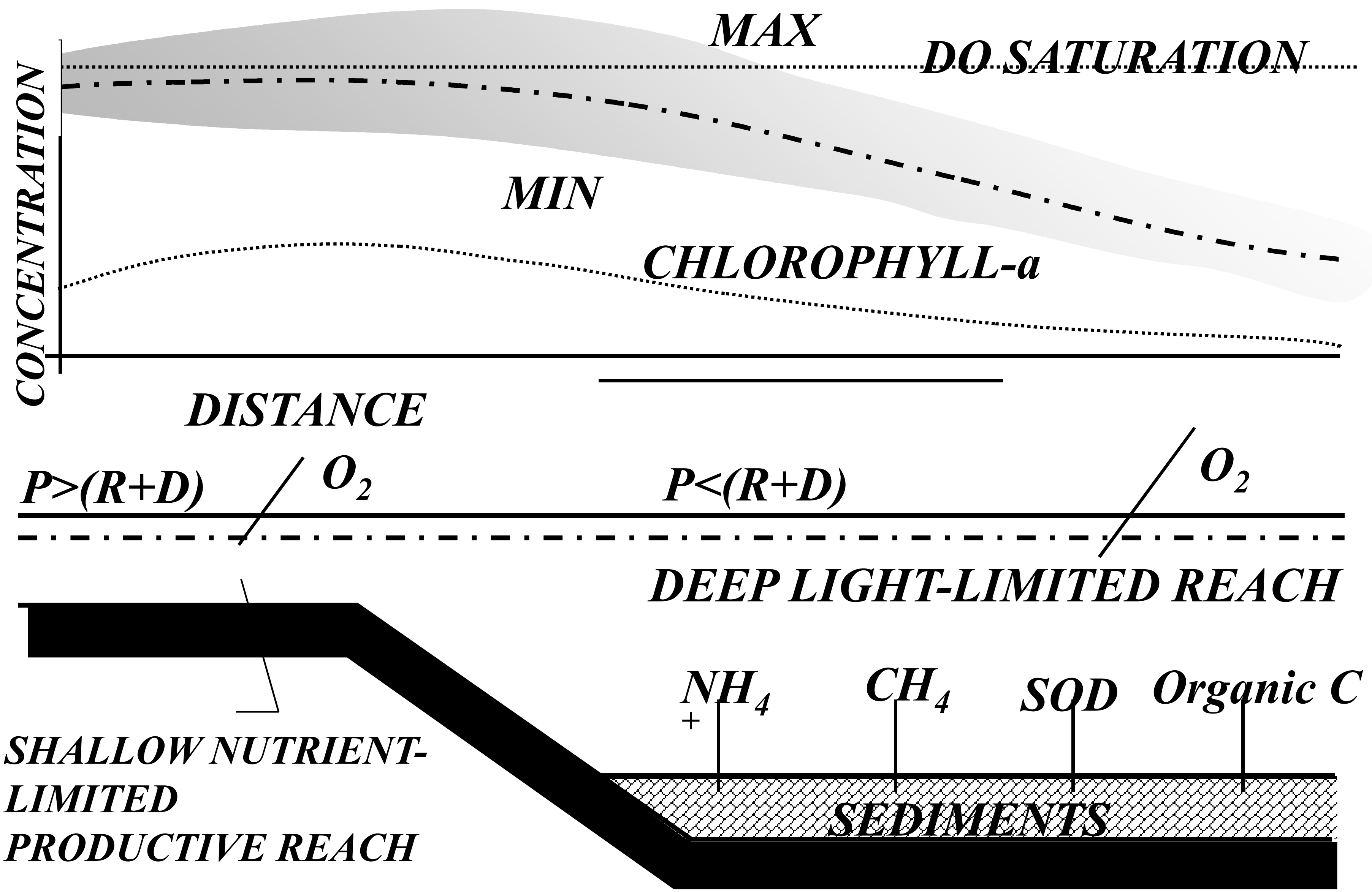
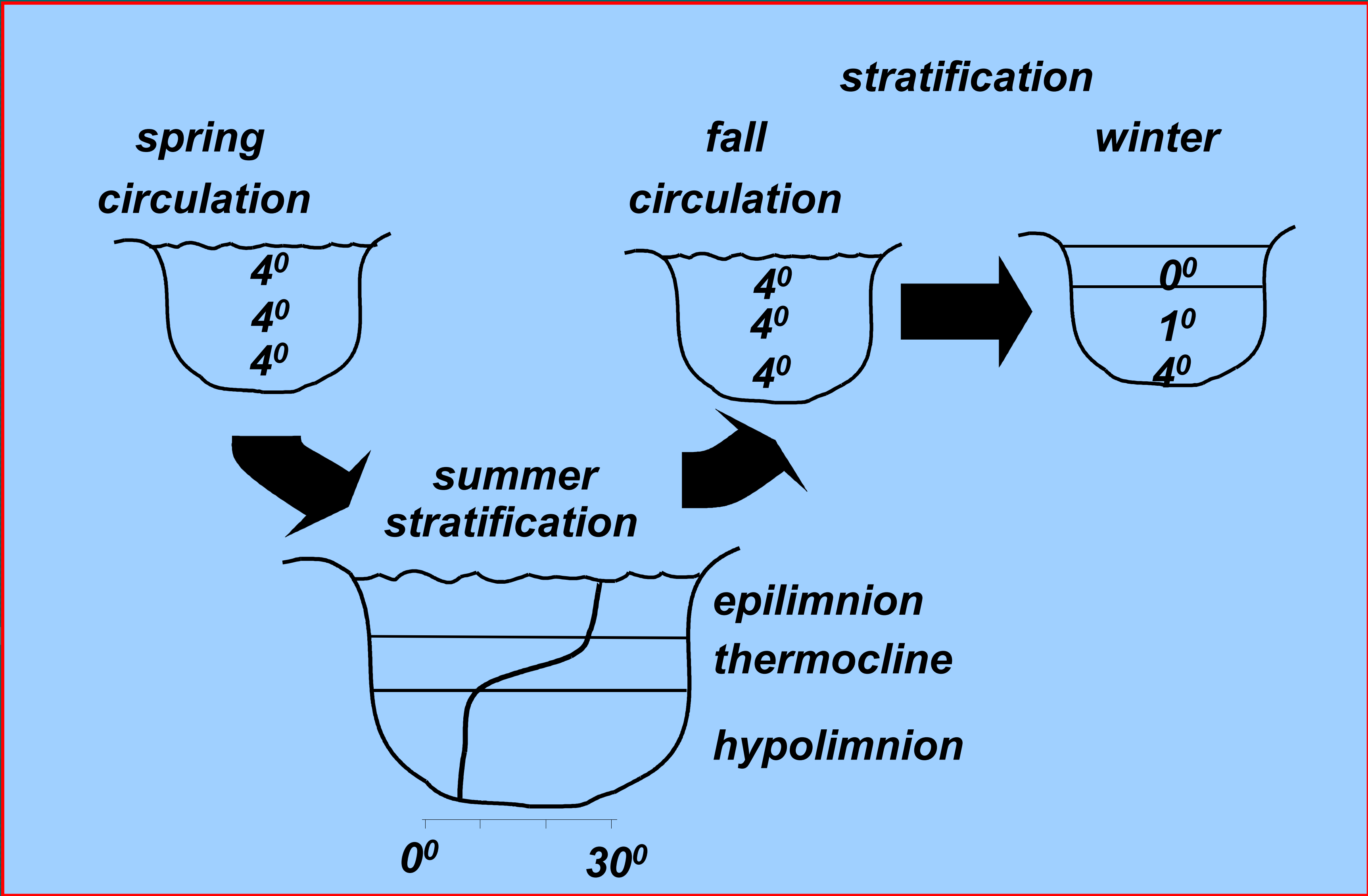
10/23/00
10/24/00
10/25/00
10/26/00



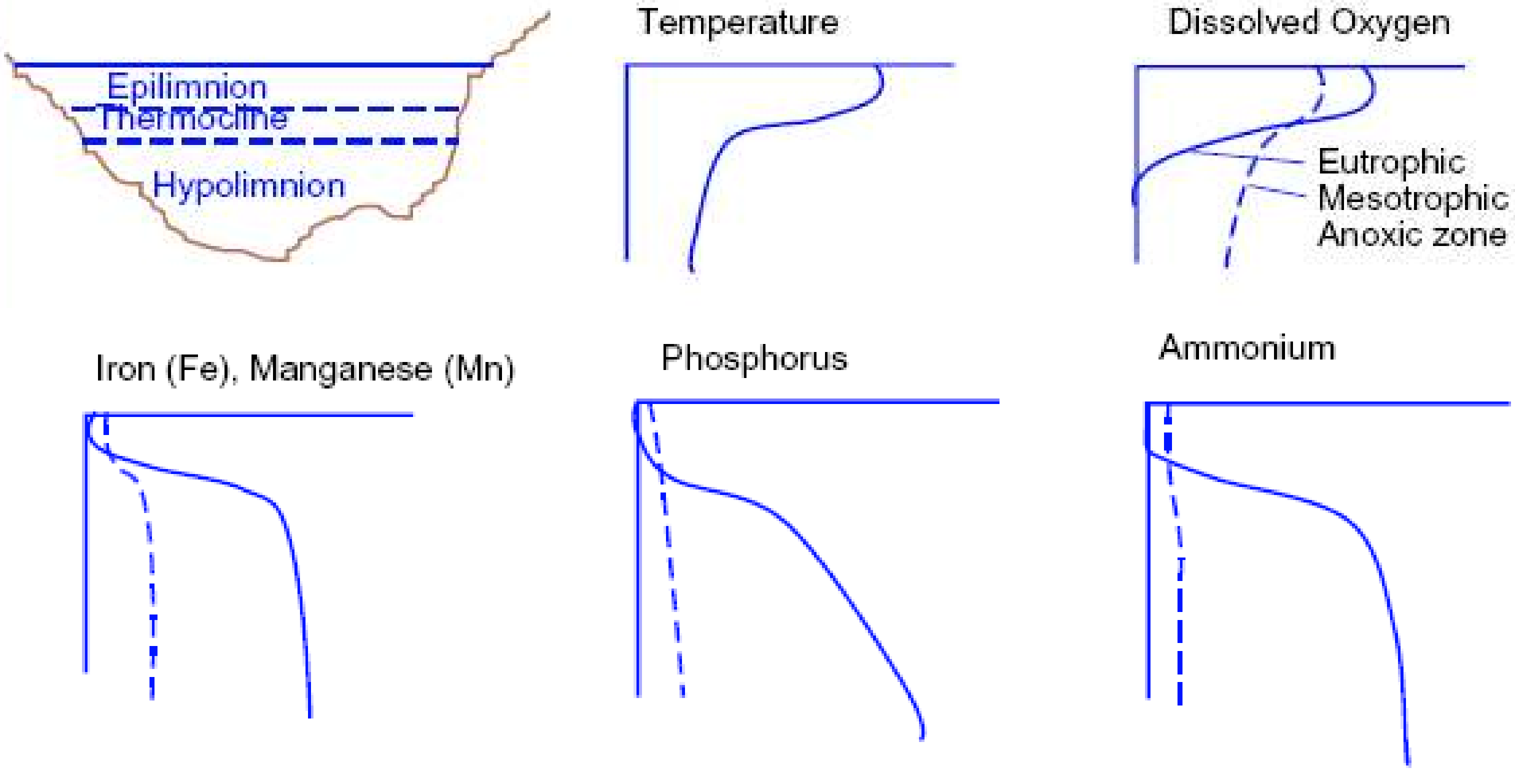
P - *photosynthesis*

(R+D) - *respiration, death and grazing*



stratification
spring
circulation
4⁰
4⁰
4⁰
fall
circulation
4⁰
4⁰
4⁰
winter
0⁰
1⁰
4⁰
summer
stratification
epilimnion
thermocline
hypolimnion
0⁰
30⁰

Pollutant concentrations during stratification

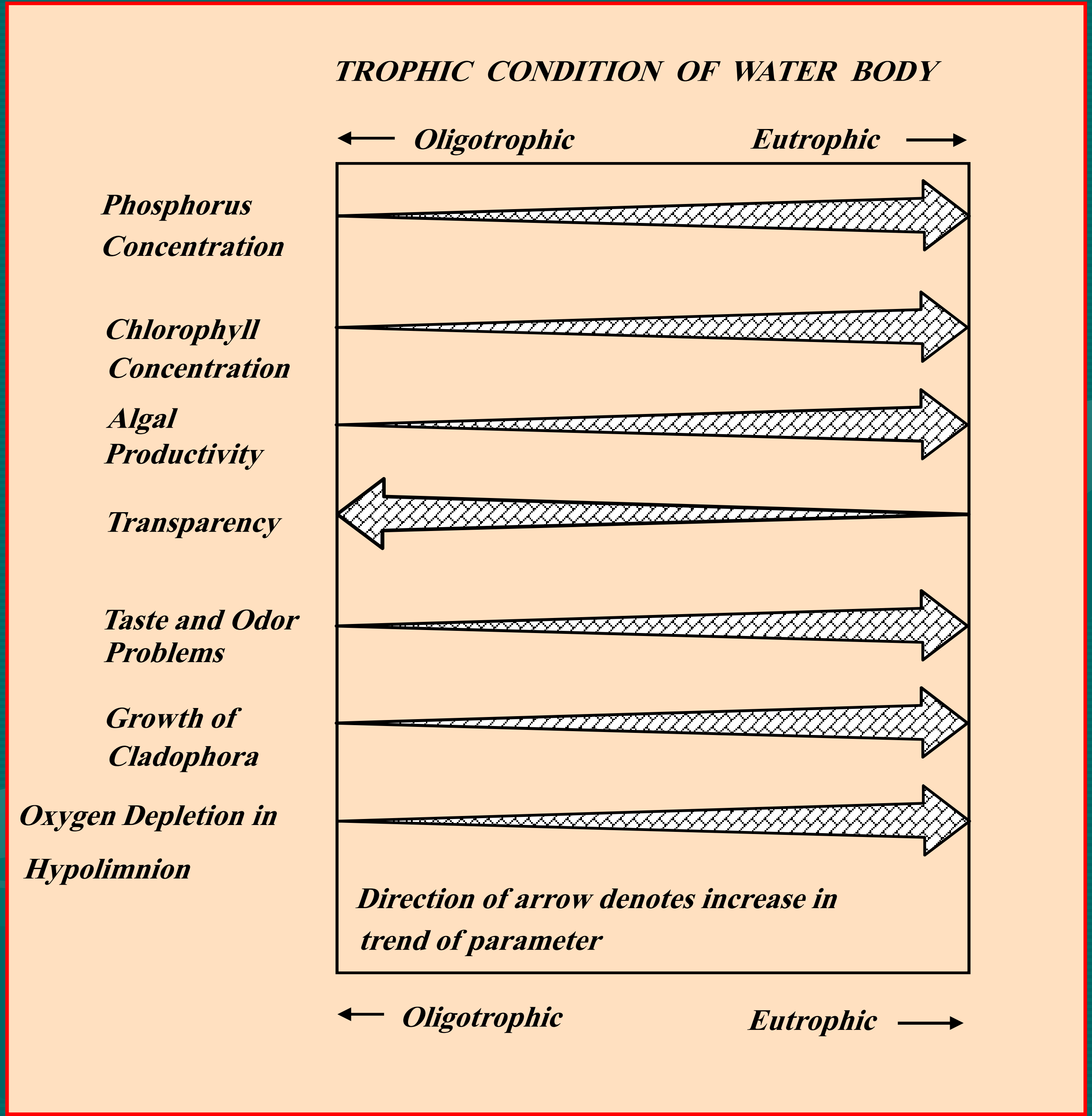


Reason - anoxic hypolimnium

NUTRIENT IMPACT

- Photosynthesis is the driving process
- Photosynthesis occurs in the water layer where light can penetrate (euphotic zone)
- In the layer with insufficient light, on cloudy days and during night algae respire and impose oxygen demand (the equation is reversed)
- Other limmiting factors are light (shading), hydraulics and alkalinity

Cyanobacteria in Lake Mendota (Madison, WI) in 1970s


TROPHIC CONDITION OF WATER BODY
Oligotrophic
Eutrophic
Phosphorus Concentration
Chlorophyll Concentration
Algal Productivity
Transparency
Taste and Odor Problems
Growth of Cladophora
Oxygen Depletion in Hypolimnion
Direction of arrow denotes increase in trend of parameter
Oligotrophic
Eutrophic

SCREENING MODELS

Trophic index by Carlson

$TSI(SD) = 60 - 14.43 \ln(SD)$

$TSI(Chl) = 30.56 - 9.81 \ln(CHL)$

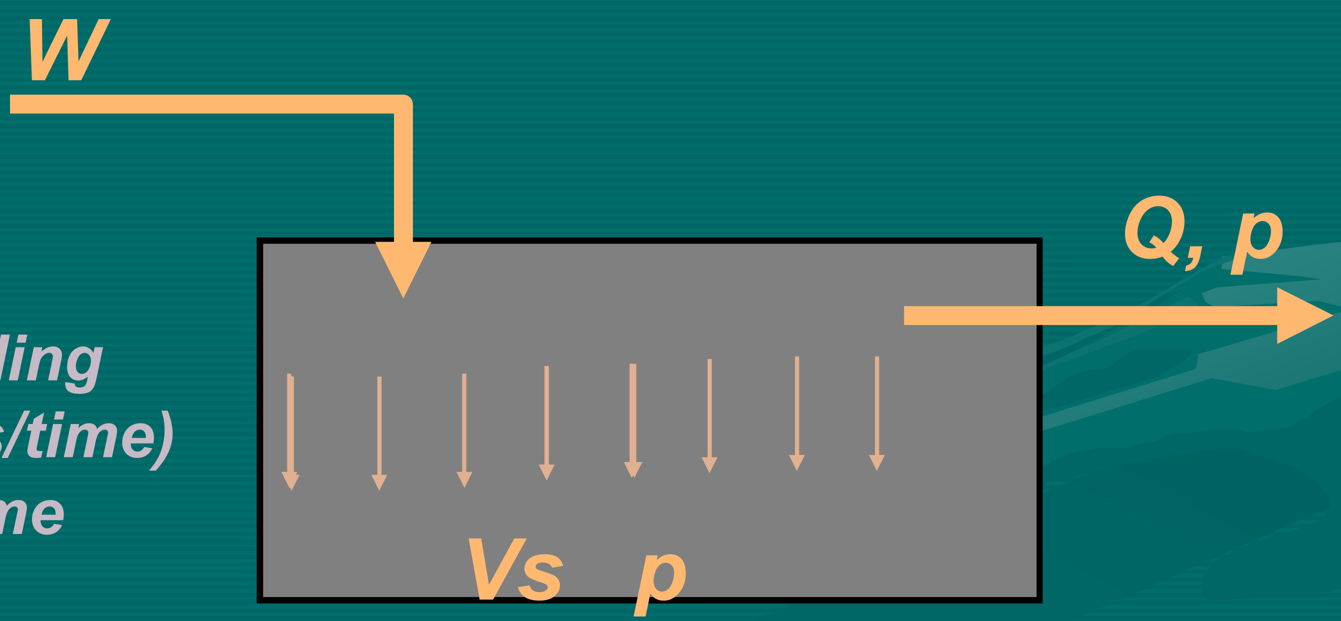
$TSI(TP) = 4.14 + 14.43 \ln(TP)$

where SD = Secchi disc depth in meters

Chl = Chlorophyll concentration in µg/L

TP = Total phosphorus concentration in µg/L

VOLLENWEIDER=s COMPLETELY MIXED LAKE SCHEMATIC



W= loading (Mass/time)
V=volume
Q=flow
p=concentration
V_s = settling velocity
A_s= surface area

$$V\frac{dp}{dt} = W - V_s A_s p - Qp$$

SIMPLE STEADY STATE SOLUTION

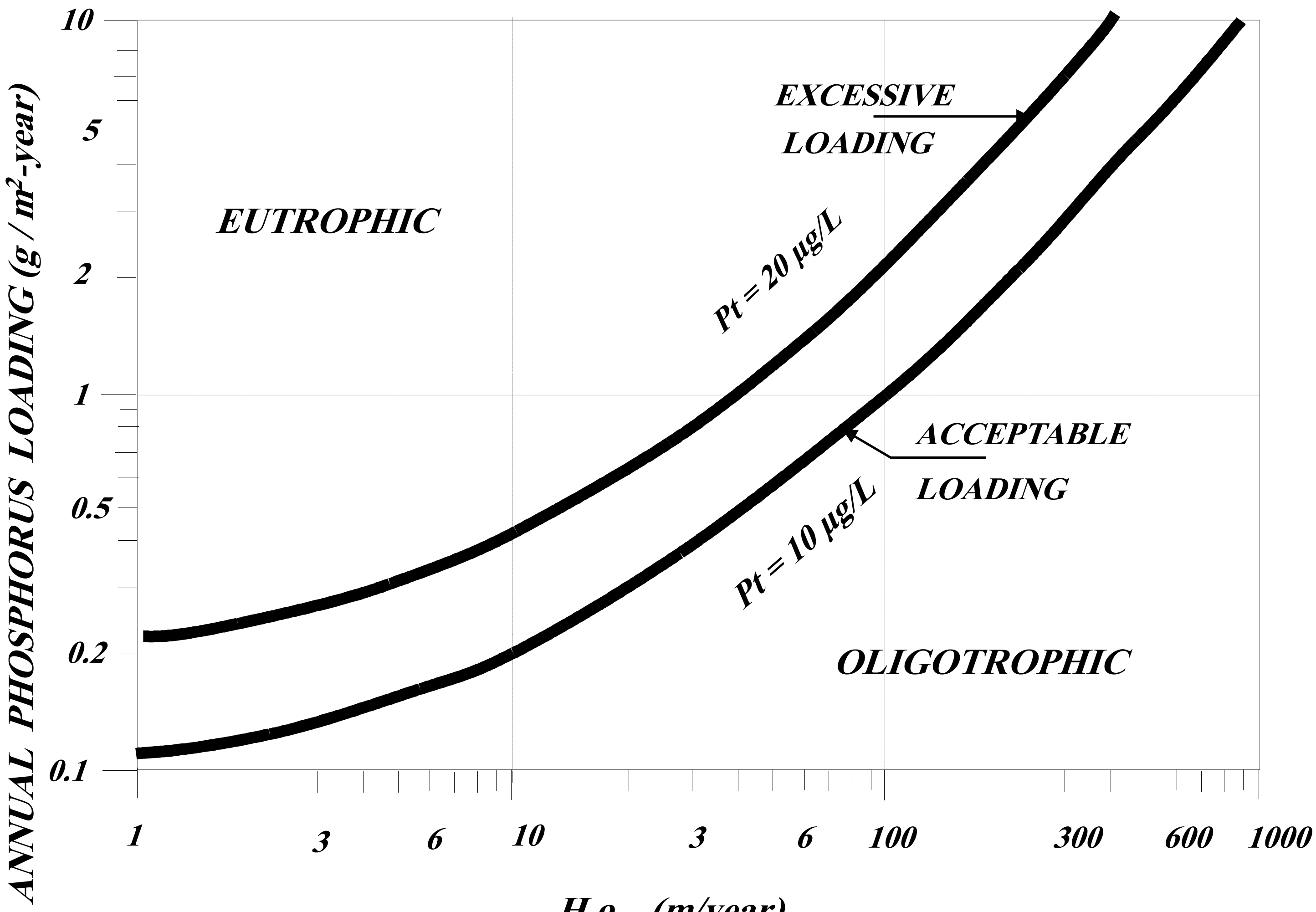
$$p = \frac{W'}{H\rho(1+\sqrt{1/\rho})}$$

W==Loading of pollutant per unit area, W/A$_s$

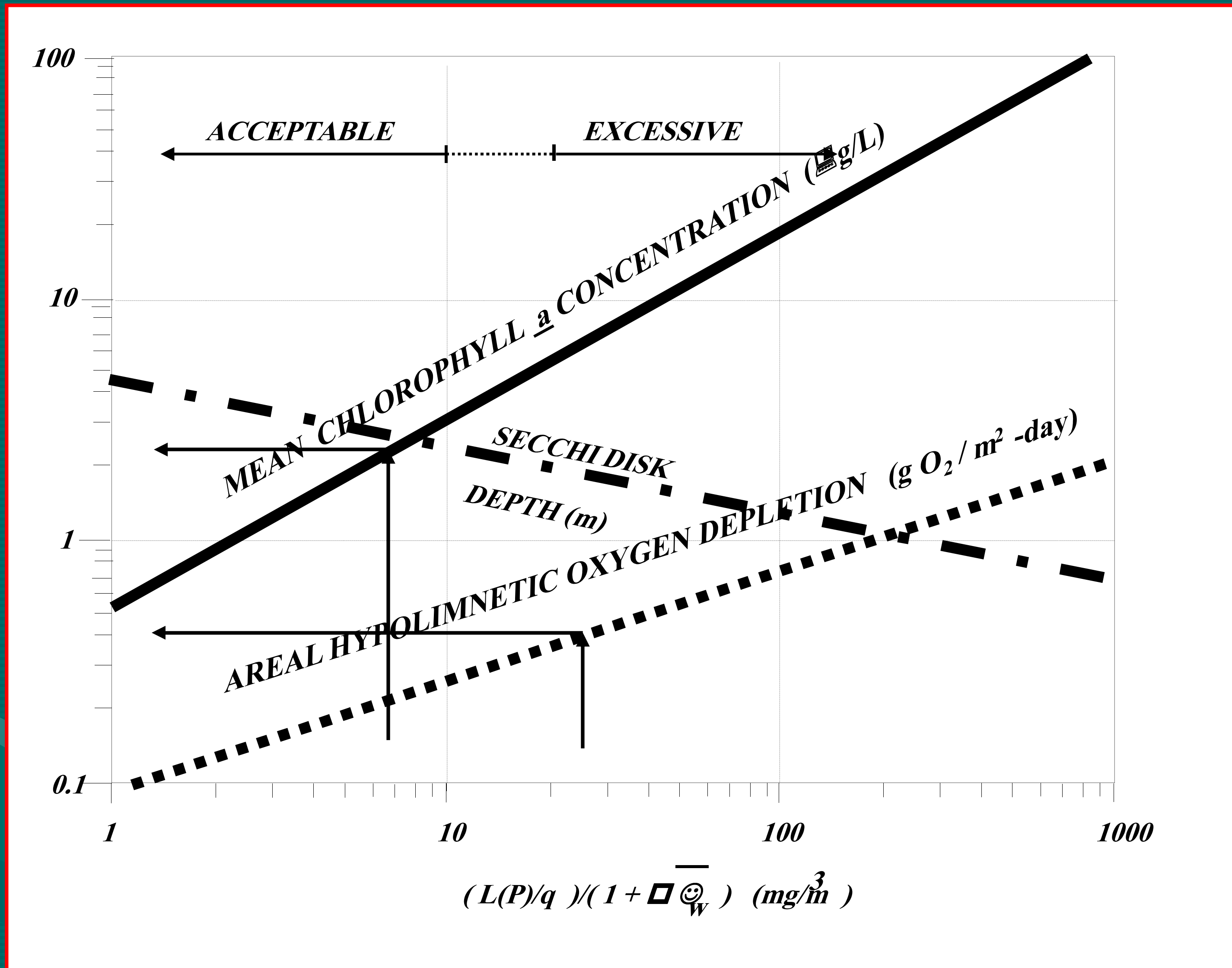
ρ= Q/V = flushing rate of the impoundment

H = average depth

Vollenweider Chart



Lee Chart



100
10
1
0.1
ACCEPTABLE
EXCESSIVE
MEAN CHLOROPHYLL a CONCENTRATION (g/L)
SECCHI DISK
DEPTH (m)
AREAL HYPOLIMNETIC OXYGEN DEPLETION (g O2 / m2 -day)
1
10
100
1000
(L(P)/q)/(1 + W) (mg/m3)

Cyanobacteria (Blue Green Algae)

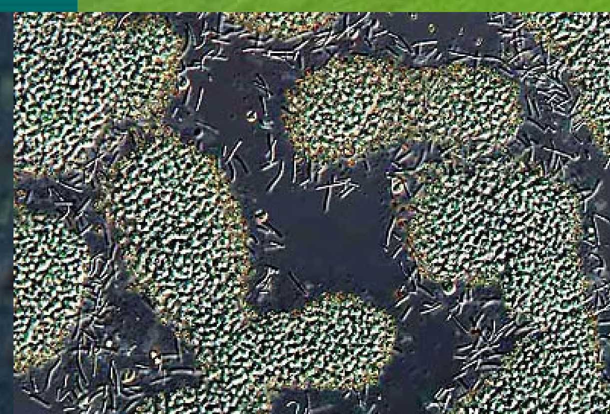
- Cyanobacteria have been around for more than 3 billion years
- These microorganisms are responsible for atmospheric dissolved oxygen
- Some species can assimilate atmospheric nitrogen
- They are ubiquitous to nature
- They prefer warmer water bodies
- They produce toxins and impair taste and odor

Blue – Greens in Czech Republic

Orlík

Sedlice

Anabaena



Microcystic

75% or reservoirs have been infected


Pea soup. Hans Paerl samples cyanobacteria in ailing Taihu Lake.

ECOLOGY

Doing Battle With the Green Monster of Taihu Lak

In attempting to subdue a vicious algal bloom, scientists aim to

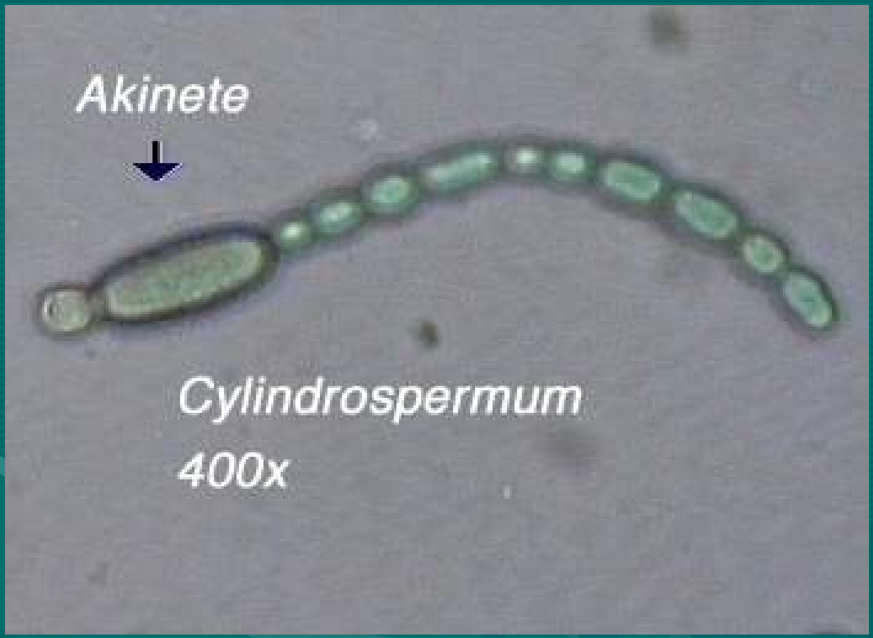
PEA SOUP IN CHINA

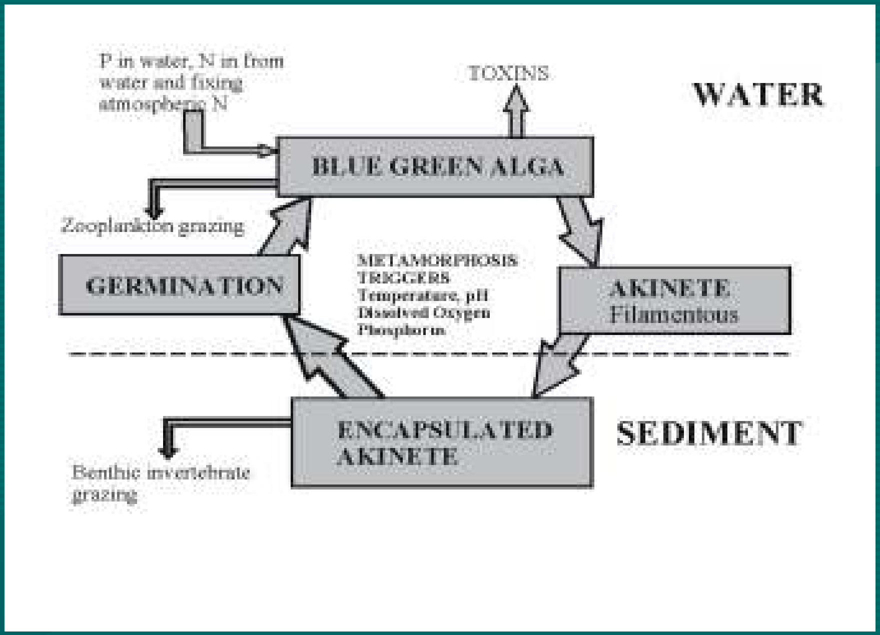
Conditions affecting cyanobacteria (Kravchuk, 2006)

- Temperature
- Phosphorus concentration
- Hydraulic conditions
- Light
- Grazing by zooplankton

Algal blooms occur suddenly even when nutrients controls have been implemented (Lake Delavan, Charles River). Once they occur they are extremely difficult and costly to control.

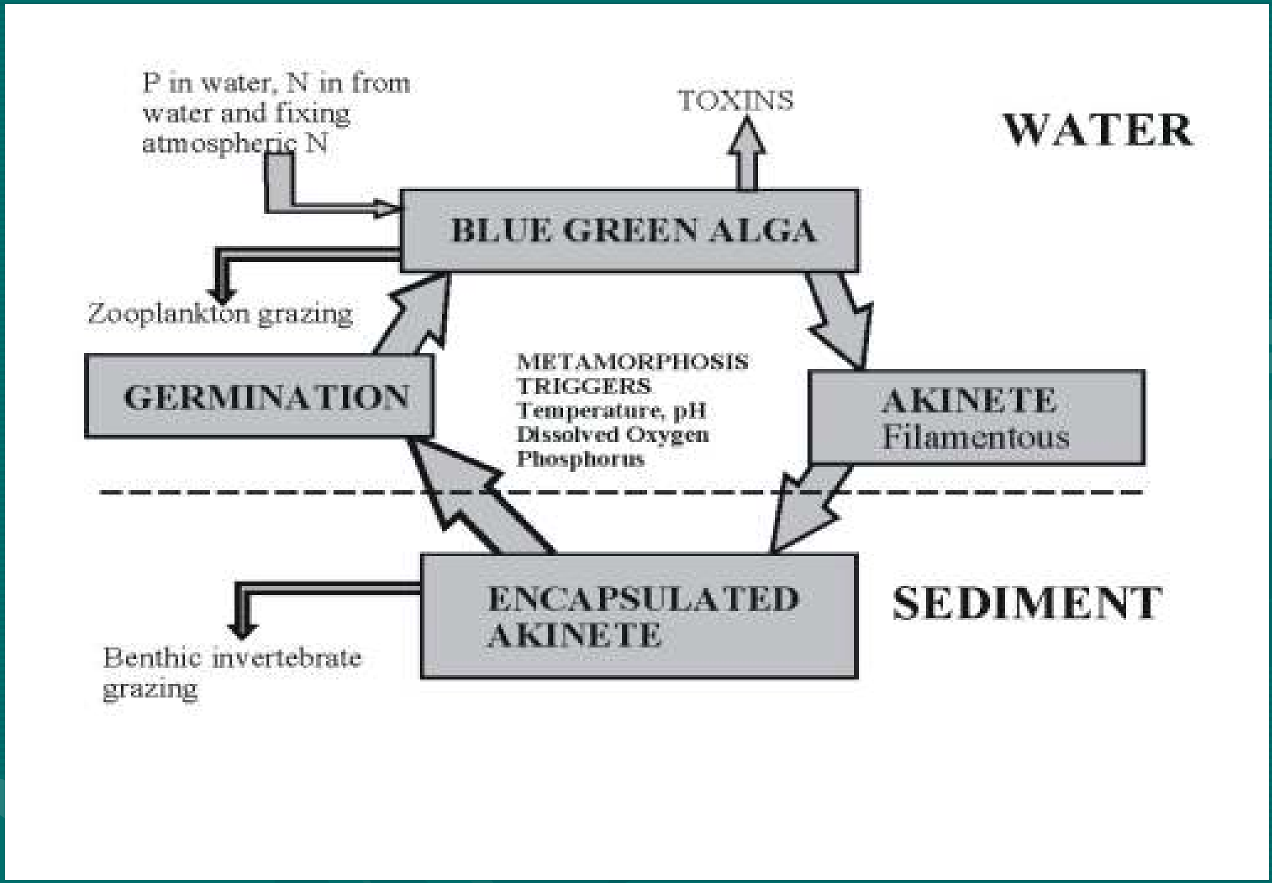
Some cyanobacteria fix atmospheric nitrogen and encapsulate into akinetes





Akinetes settle into sediments where they overwinter and can take up phosphorus. They can stay in the sediment for several years and rise into water when conditions are favorable. They have a preference for higher temperatures (impact of global warming)

Bluegreens have four lives



Vollenweider and other lake models do not work

Conditions affecting cyanobacteria (Kravchuk, 2006)

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- Phosphorus concentration
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Švihov Reservoir in Czech Republic provides most potable water to 1.2 million people in Prague

Landscape

- Varied shape

All forbays and upper reaches of the Švihov Reservoir are infested by cyanobacteria

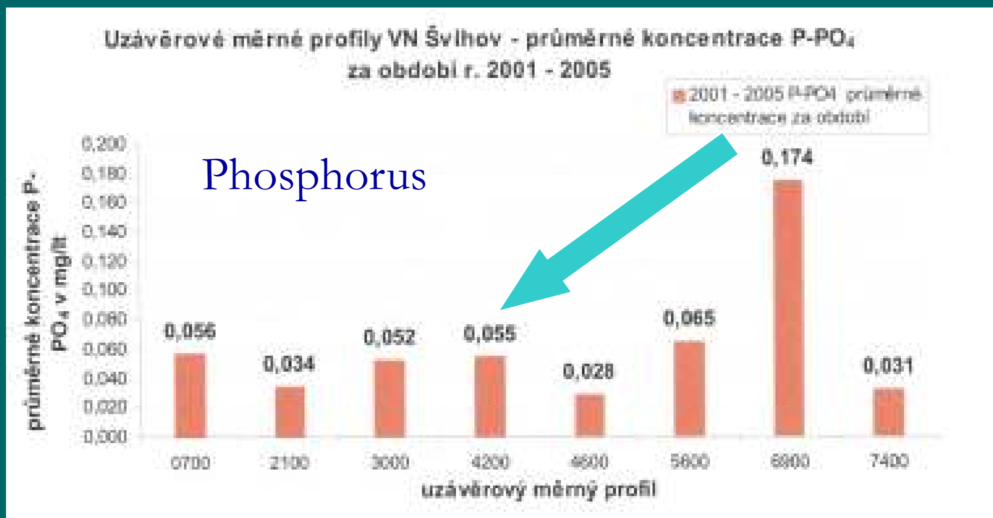
Forbay Sedlice

Upper reach of the main reservoir

Land use in the Watershed

	%
Arable land	47.8
Meadows and pastures	12.3
Forests	29.0
Urban (built)	1.2
Other	9.7

N & P in Švihov Reservoir Tributaries



CURRENT CONCENTRATIONS IN ŽELIVKA

N --- 6.37 mg/L

P --- 0.055 mg/L

Vulnerable - Hyper-eutrophication

DESIRABLE TO CONTROL EUTROPHICATION

N --- < 1 mg/L

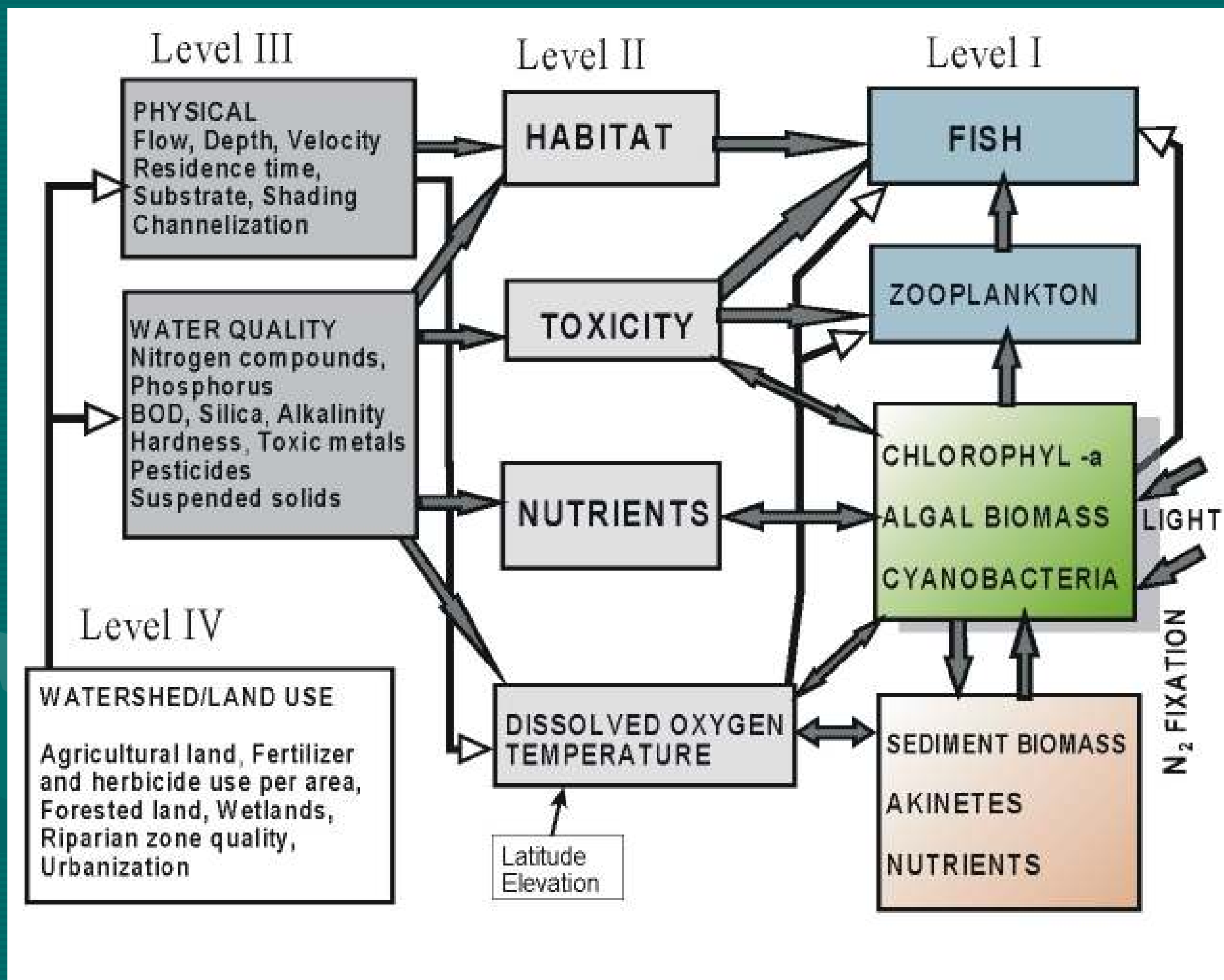
P --- < 0.015 ,g/L

__Average annual__ water quality characteristic throughout the Švihov reservoir. Data from the Vltava Watershed (Povodi) Agency by Hejzlar at al. (2006)

Parameteer	Profile and River Km (from the Sázava River)				
	Dam (0099) RKm. 4.7	Kralovice (0899) RKm. 15	Budeč (1699) RKm. 24.2	Zahrádka (2099) RKm 29.2	Vojslavice (2699) RKm 36.5
Transparency, meters	5.1	4.3	3.4	3.2	2.0
pH	8.1	8.1	8.1	8.4	8.2
Total P, µg/L	20	24	32	28	61
Chlorophyll *a*	8	7	10	21	15
Classification	MT	MT-E	MT-E	E	HT

MT-mesotrophic, E-eutrophic, HT-hypertrophic

Finding relationship between many factors and loads is not easy but it can be done



Buffers and soil erosion control

Buffer strips Iowa

Erosion control in Wisconsin

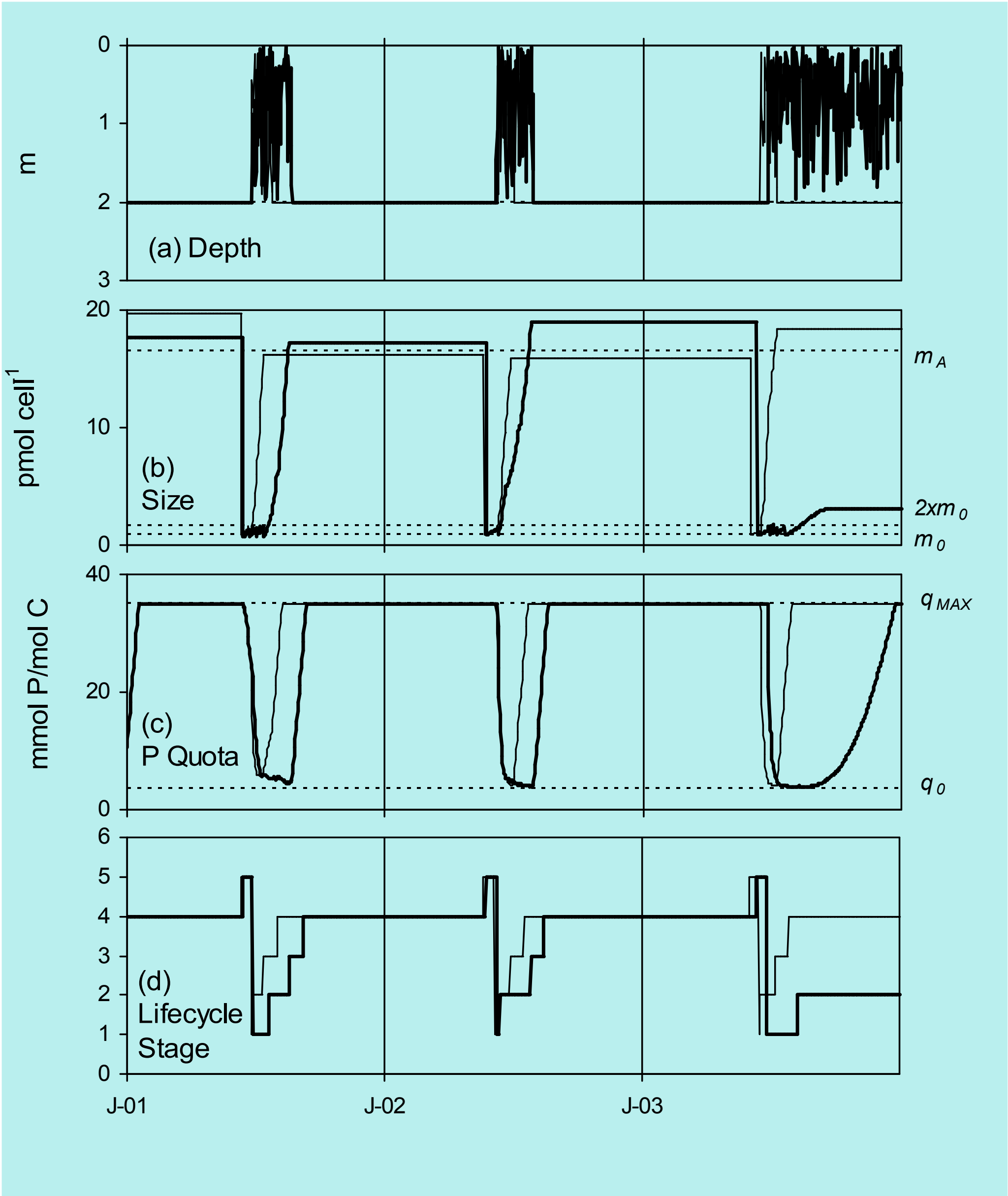
Wetlands are natural sinks of nutrients

Develop a plan – main proposed goals

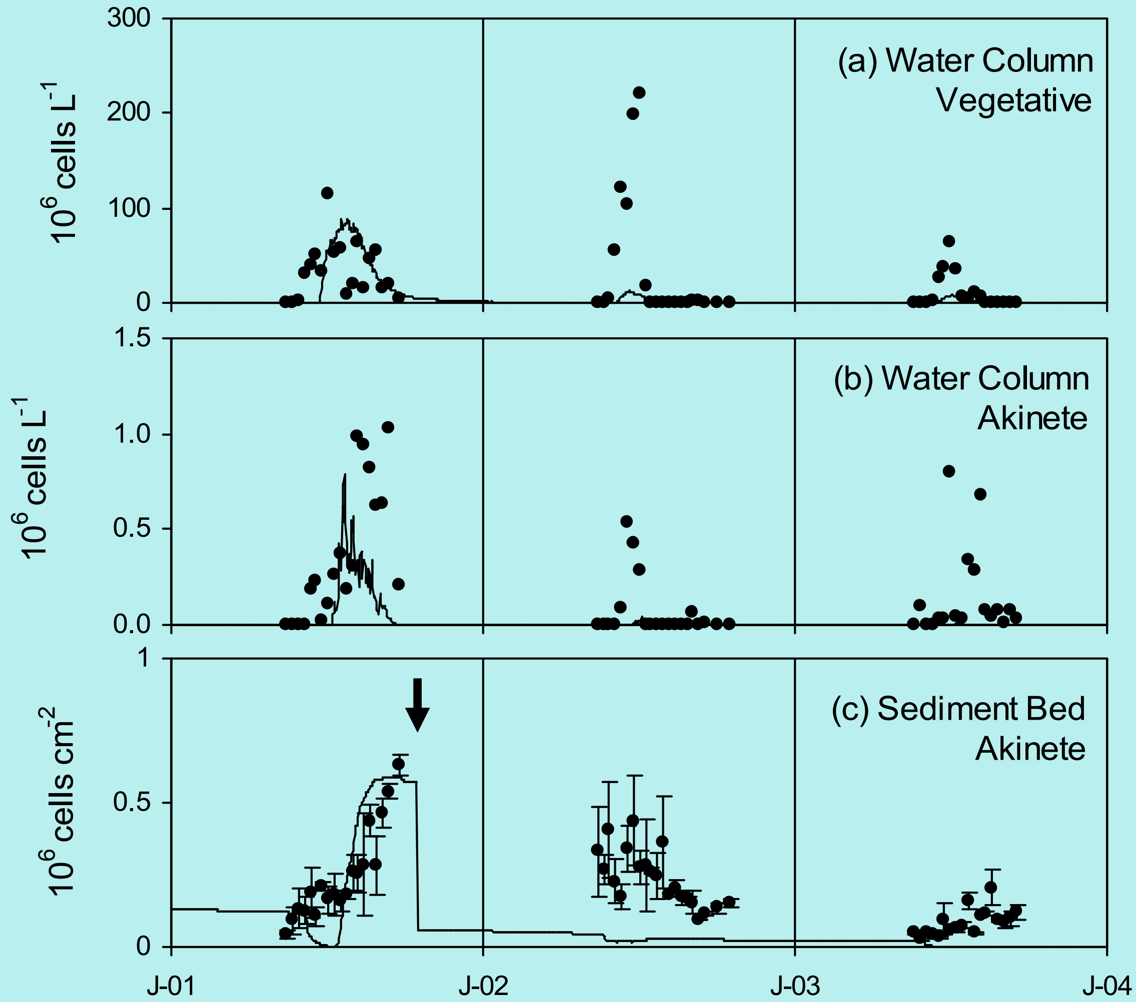
- Reversing the progress of hypertrophy
- Reduce point and diffuse source pollutant load
- Restoring the land ecology to provide barriers to pollution and buffering throughout the watershed
- Identify hazardous lands and buffer zones to be converted to a new sustainable use

Agent Based Modeling

- See Hellweger, Kravchuk, Novotny and Gladyshev (2008) Agent based modeling of the complex lifecycle of Cyanobacterium (Anabena) in a shallow lake, *Limnologia and Oceanographia* ***53***(4), 2008
- Agent base models follow a history of of thousands of "superagents" and behavior, life cycle and resting stages in water and sediment



History of two randomly-selected individual *Anabaena* cell lineages. (a) Depth (*z*), (b) size (*m*), (c) P quota (*qP*), and (d) lifecycle stage. Only one of two daughter cells is followed after division. Outflow and lysis loss is not permitted for the tracked cells.



Model simulation to investigate the effect of reducing the sediment akinete density. The sediment akinete density was reduced by 90% towards the end of year 1 (see arrow in panel c).

Conclusions

- Hypertrophy by cyanobacteria blooms is becoming ubiquitous in many countries as a result of excessive loads of nutrients from agriculture and urban areas.
- Protection of the Švihov reservoirs and Prague water supply from eutrophication (hypertrophy) requires a comprehensive watershed and water body management and protection
- Significant reductions of N and P loads must be achieved.
- The WHO N criterion is inappropriate
- Because of uncertainty the planning and management process must be adaptive and enforceable