Lakes & Watersheds
Measurements & Modeling

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Lake Leaders 2018

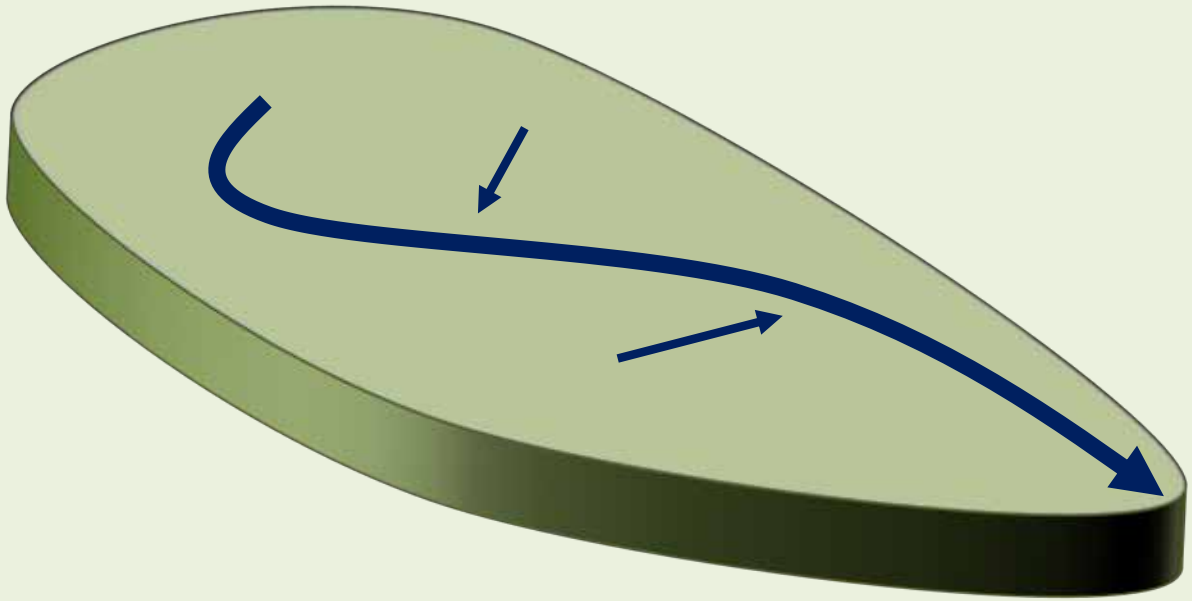
Today…. 1) Watersheds and 2) Lakes *& 3) Streams*

- **Functioning – big picture arm waving – & the development of "Conceptual" Models**
- **Modeling Approaches –**
  - **Fundamentals**
  - **Examples**

Goal- Understand & Apply several Models

(and most important… not make a potentially confusing topic more confusing…)

First, What's a Watershed?



Land area where the water drains to the outlet point of interest

Why is that important?

- Precipitation

__ Inches per Year +/-

↓

___ storms per year +/-

↓

___ hours of precipitation (>trace) per year +/-

- Precipitation

32 Inches per Year +/-

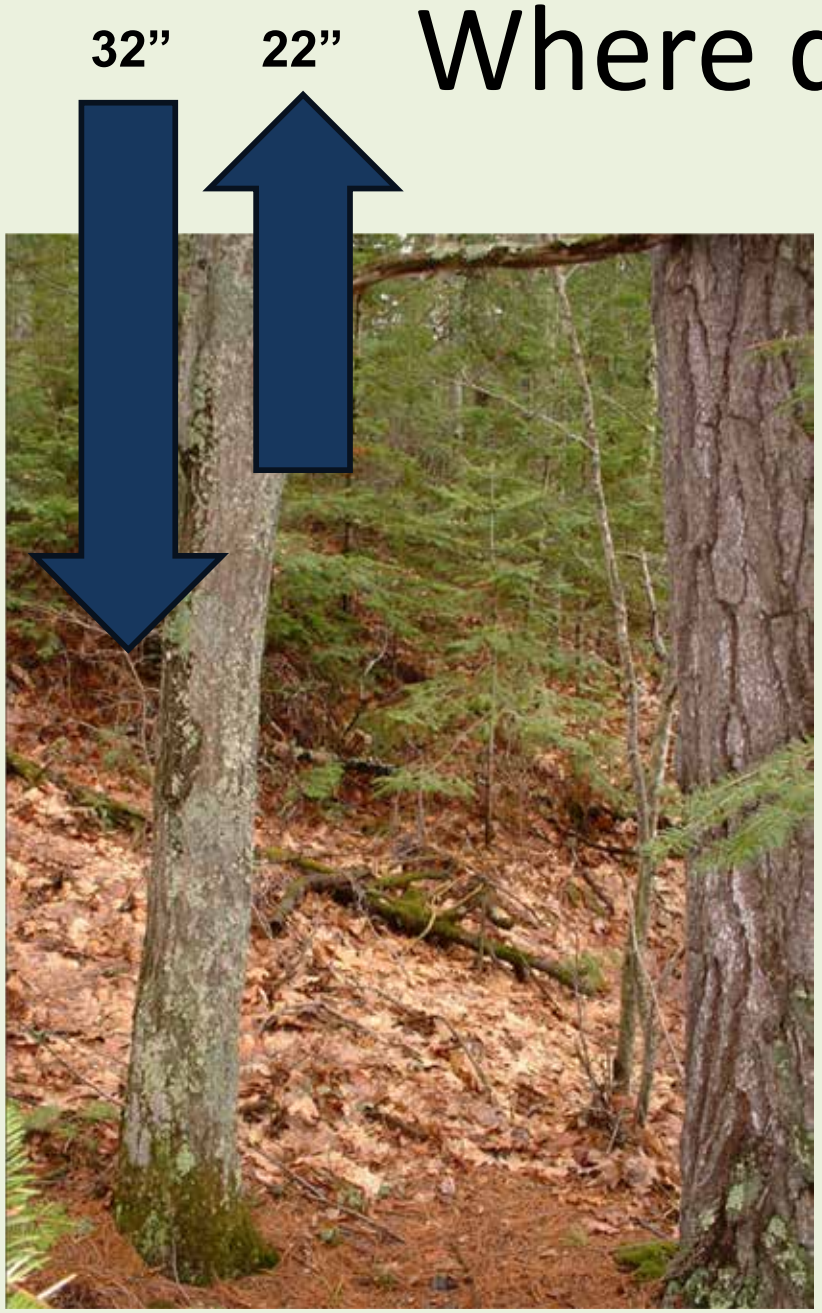
↓

100 storms per year +/-

↓

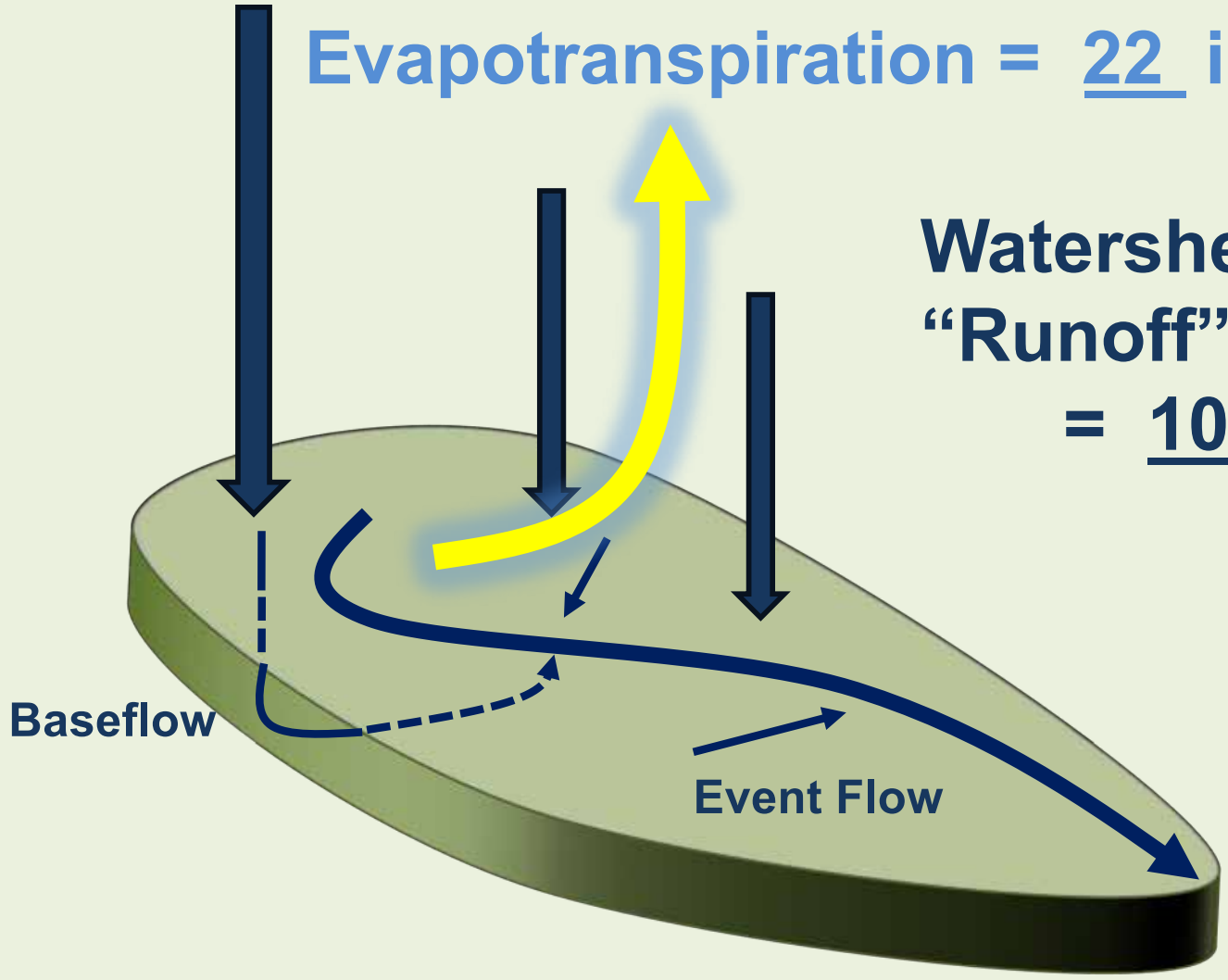
500 hours of precipitation (>trace) per year +/-

Where does it go?



Precipitation = 32 inches/yr

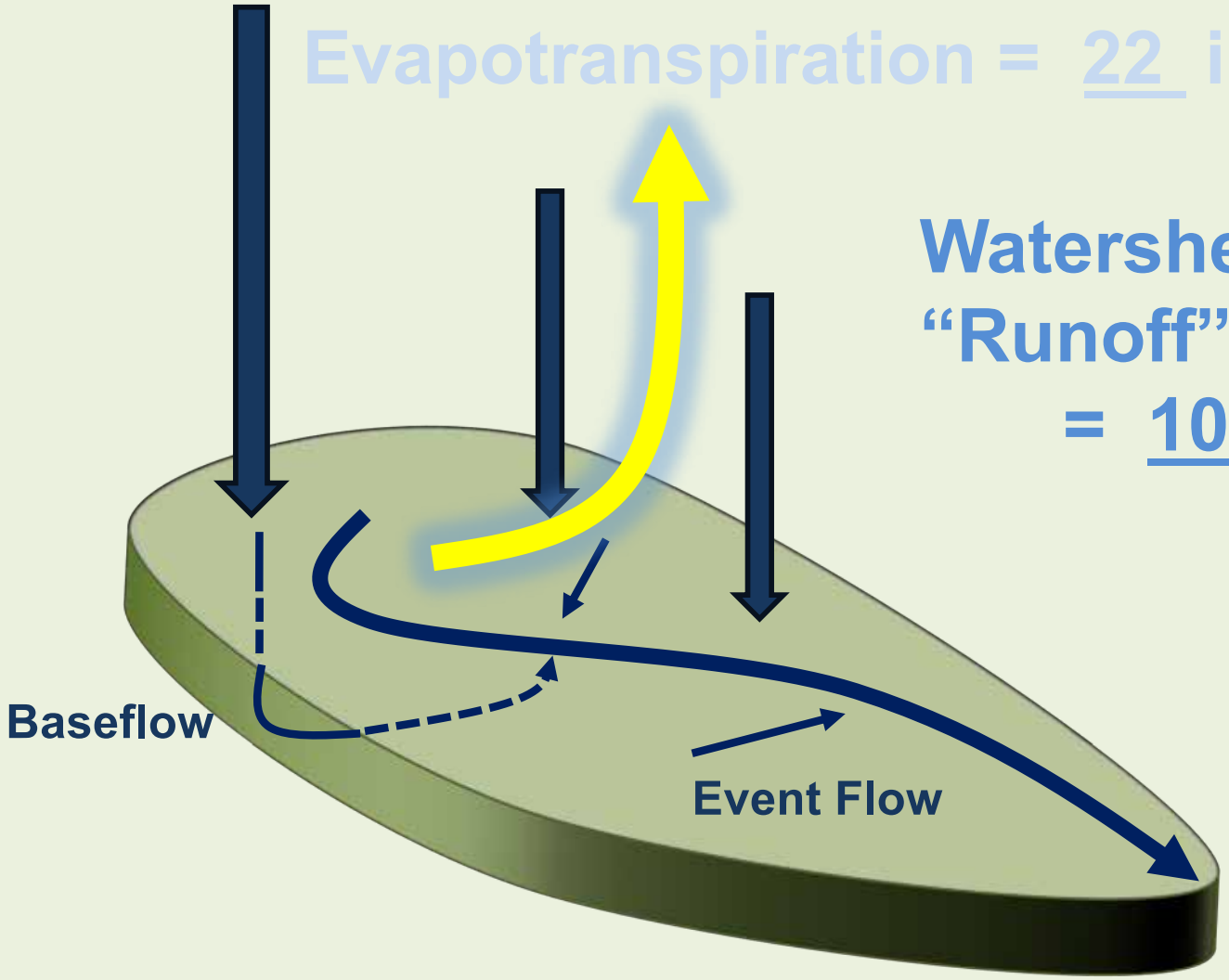
Evapotranspiration = 22 inches/yr



Watershed
"Runoff"
= 10 inches/yr

Precipitation = 32 inches/yr

Evapotranspiration = 22 inches/yr



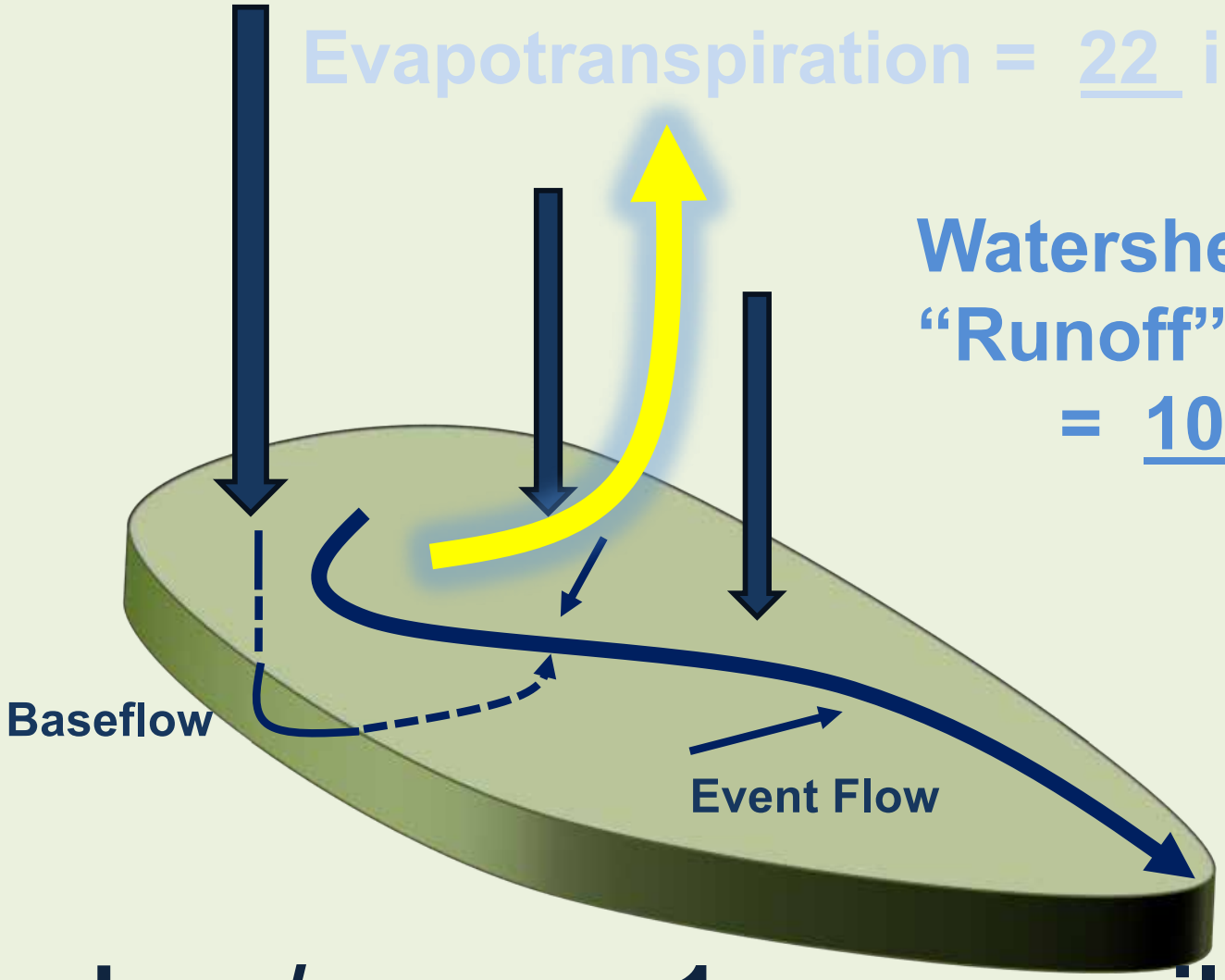
Watershed "Runoff" = 10 inches/yr

10 inches /year on 1 square mile…

= 23,000,000 cubic feet /year!

Precipitation = 32 inches/yr

Evapotranspiration = 22 inches/yr



Watershed
"Runoff"
= 10 inches/yr

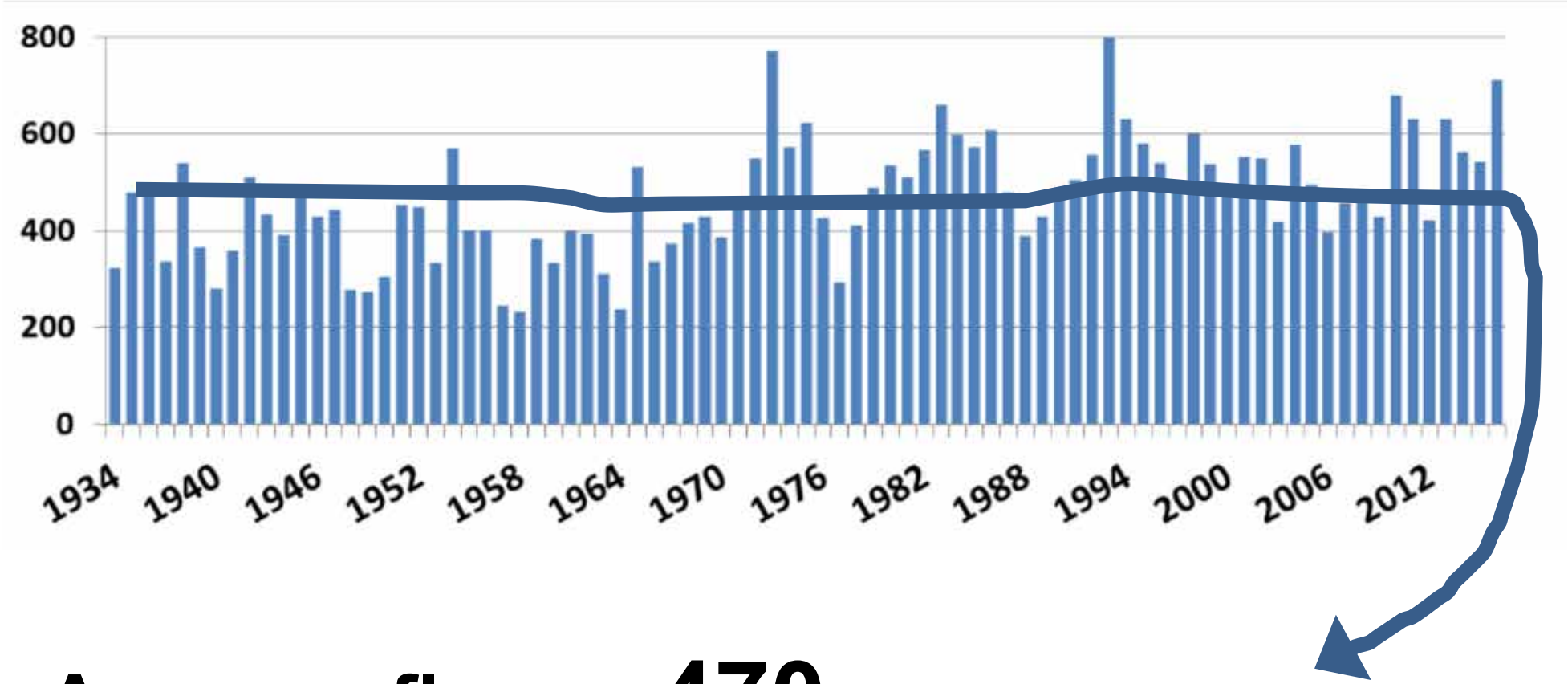
10 inches /year on 1 square mile…

= 23,000,000 cubic feet /year!

= 0.7 cubic foot every second!

Really?

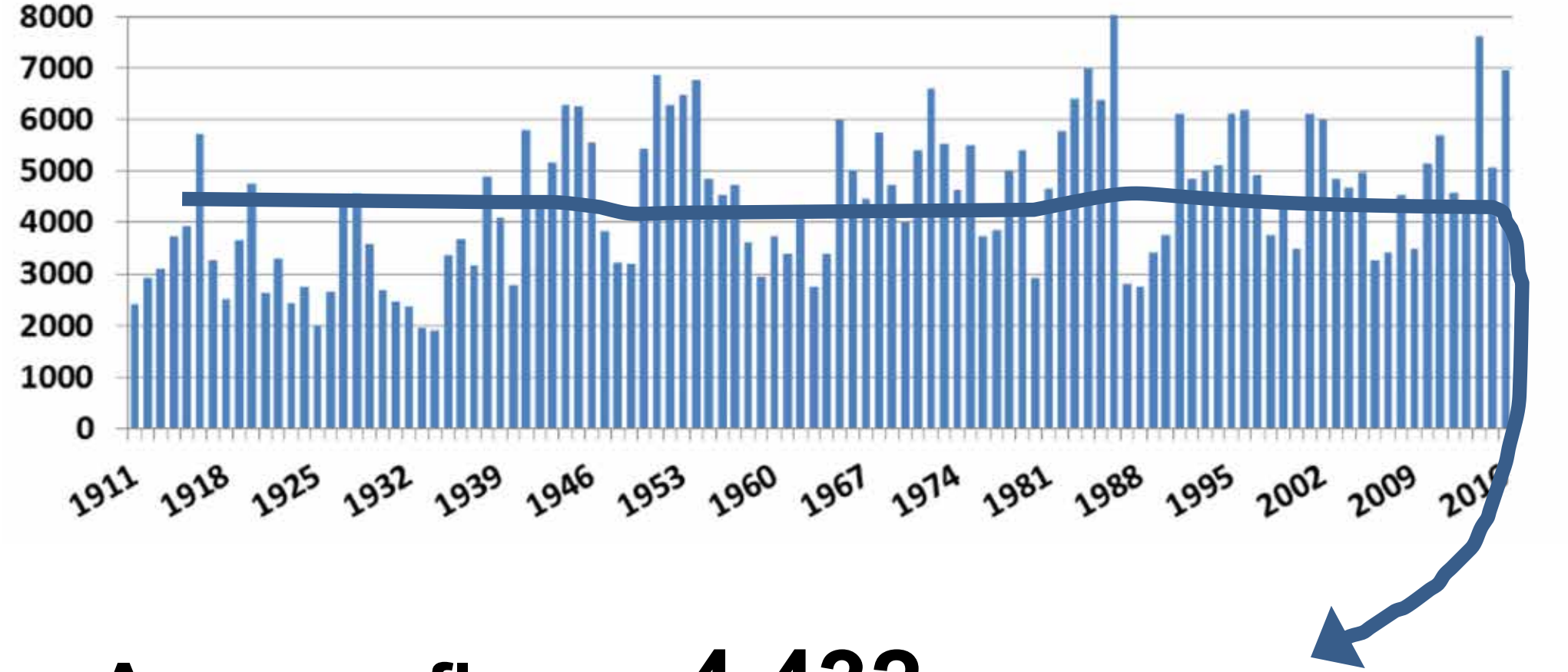
- **USGS 05379500 TREMPEALEAU RIVER AT DODGE, WI**
- **DRAINAGE AREA**.--643 square miles.



Average flow ~470 cubic feet per second

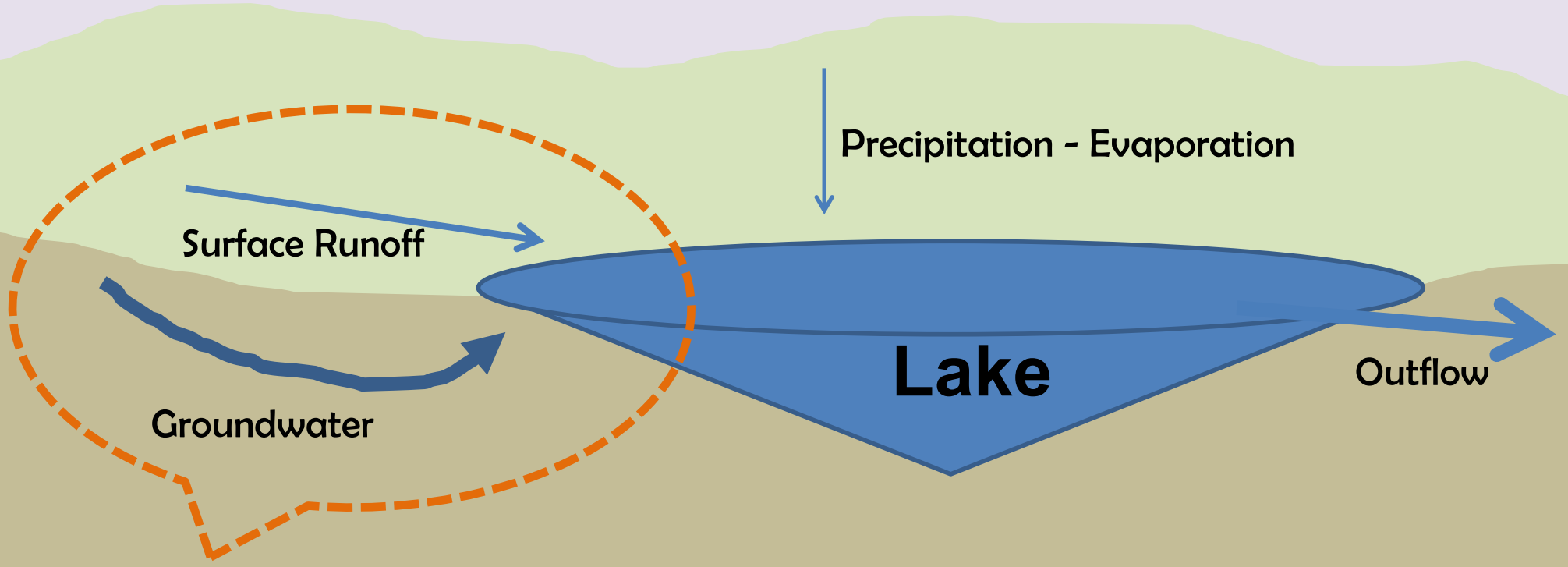
Really?

- **USGS 05340500 ST. CROIX RIVER AT ST. CROIX FALLS, WI**
- **DRAINAGE AREA**.—6,240 square miles.



Average flow ~4,432 cubic feet per second

This is a watershed model !



- Water Budget

Water Entering the Lake Each Year = **(10 in/year)*(Watershed Area)**

What's a model

One definition: A mathematical description to help visualize something

help us "visualize" how a current condition

or help us "visualize" how future actions could alter the current condition

- Examples
  - How long does water spend in my lake?
  - If a wooded area is converted to row crops, what might that do to the phosphorus concentration in the lake?

- **Useful?**
  - **Residence time =**

$$= \frac{\text{Amount of Water in Lake}}{\text{Rate Which Water Leaves Lake}}$$

- **Useful?**
  - **Say 10,000 acre lake, mean depth of 40 feet with a 150,000 acre watershed**
  - **Residence time estimate =**

$$= \frac{(10{,}000 \text{ acre})(40 \text{ feet mean depth})}{(150{,}000 \text{ acre})(0.83 \text{ ft/yr})}$$

$$= 3.2 \text{ years}$$

Rule #1

“All models are wrong but some are useful”

George Box

Limitations

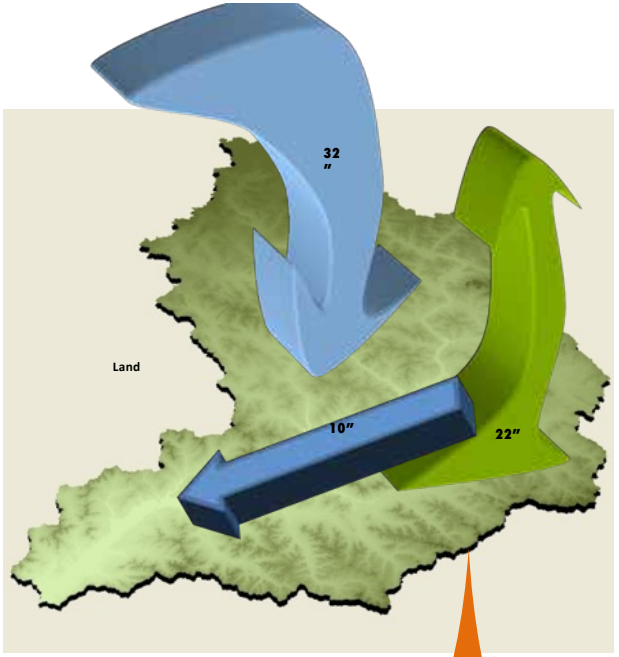
- Year-to-Year Variations?
- Different parts of the watershed have different response
  - Impervious surfaces
  - Compacted soil / raindrop impact

How can we improve this model?

- Spatial Variability
- Temporal Variability

- Of course this comes at a cost… is it necessary? Is it worth it?

Modeling the Land?



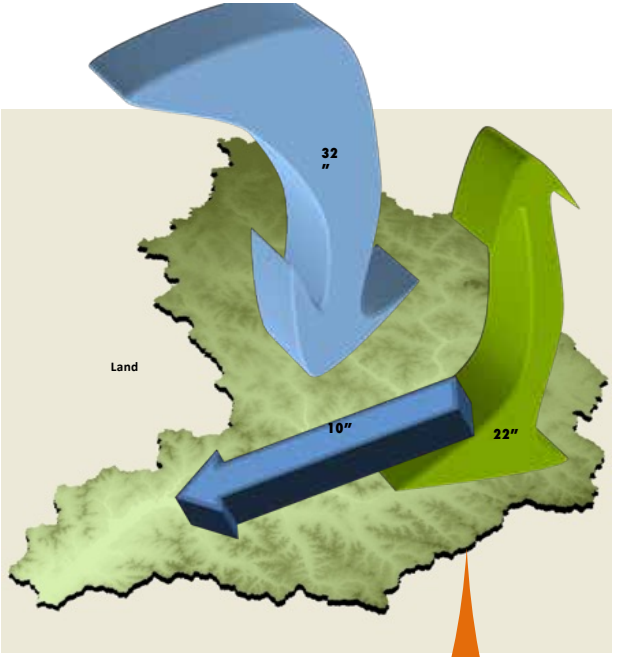
Follow
Every drop

Annual Volume

Very Simple

Very Complex

Modeling the Water on Land?



Annual Volume

Annual But Divide by Land use

Separate Annual Ground Water & Surface Runoff

Daily Time Step Spatial Lumping

Short Time Step Spatially Variable

Follow Every drop

Very Simple

Very Complex

Closely Related…**Nutrient Movement**

- Just talked about water movement on land

- Next… **Nutrients Loss from Land**
  –then **Lakes & Streams**

Let's look at Phosphorus Movement

- Important Implications for Lakes & Streams
  - Oligotrophic - "few" "foods"
  - Eutrophic – "many" "foods"

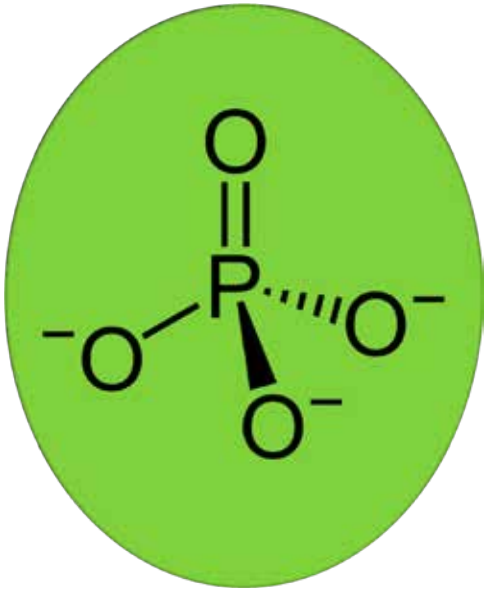
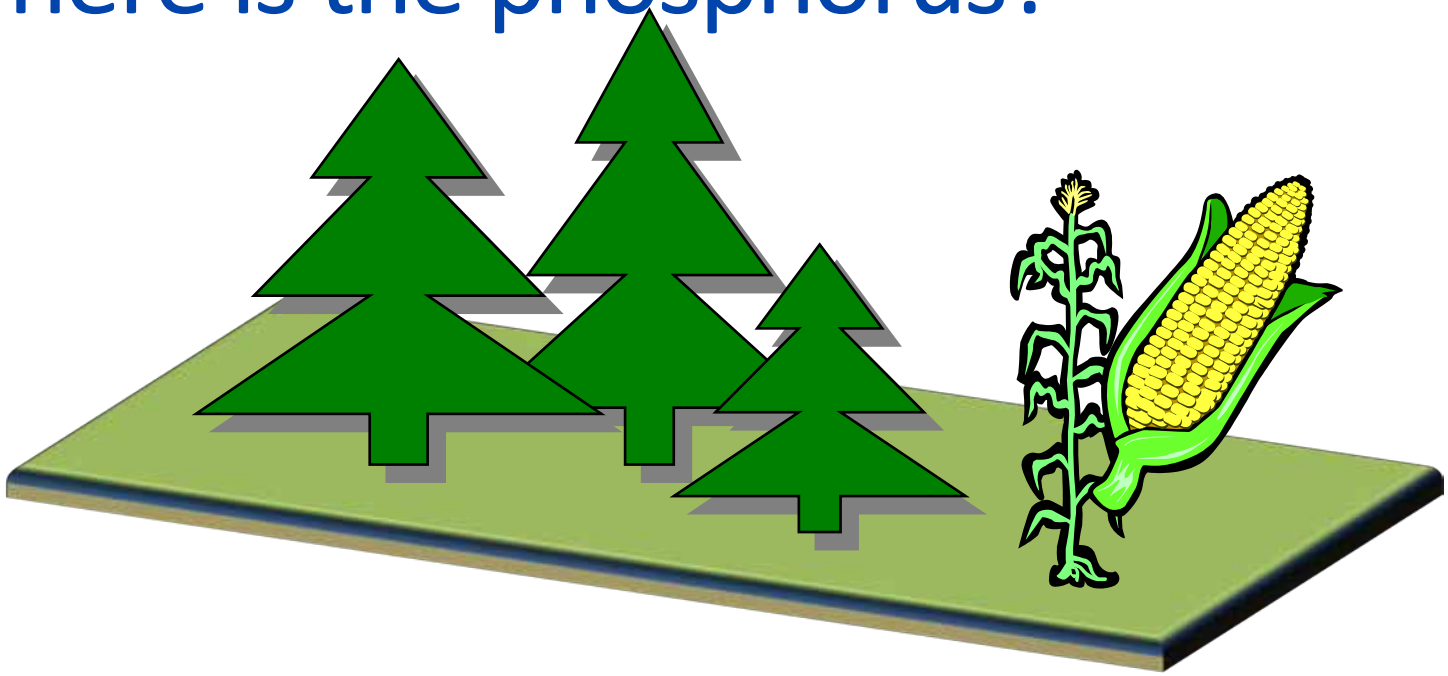


Table 1. Completed trophic state index and its associated parameters.

TSI	Secchi disk (m)	Surface phosphorus (mg/m^3)	Surface chlorophyll (mg/m^3)
0	64	0.75	0.04
10	32	1.5	0.12
20	16	3	0.34
30	8	6	0.94
40	4	12	2.6
50	2	24	6.4
60	1	48	20
70	0.5	96	56
80	0.25	192	154
90	0.12	384	427
100	0.062	768	1183

http://www.secchidipin.org/trophic_state.htm

Where is the phosphorus?



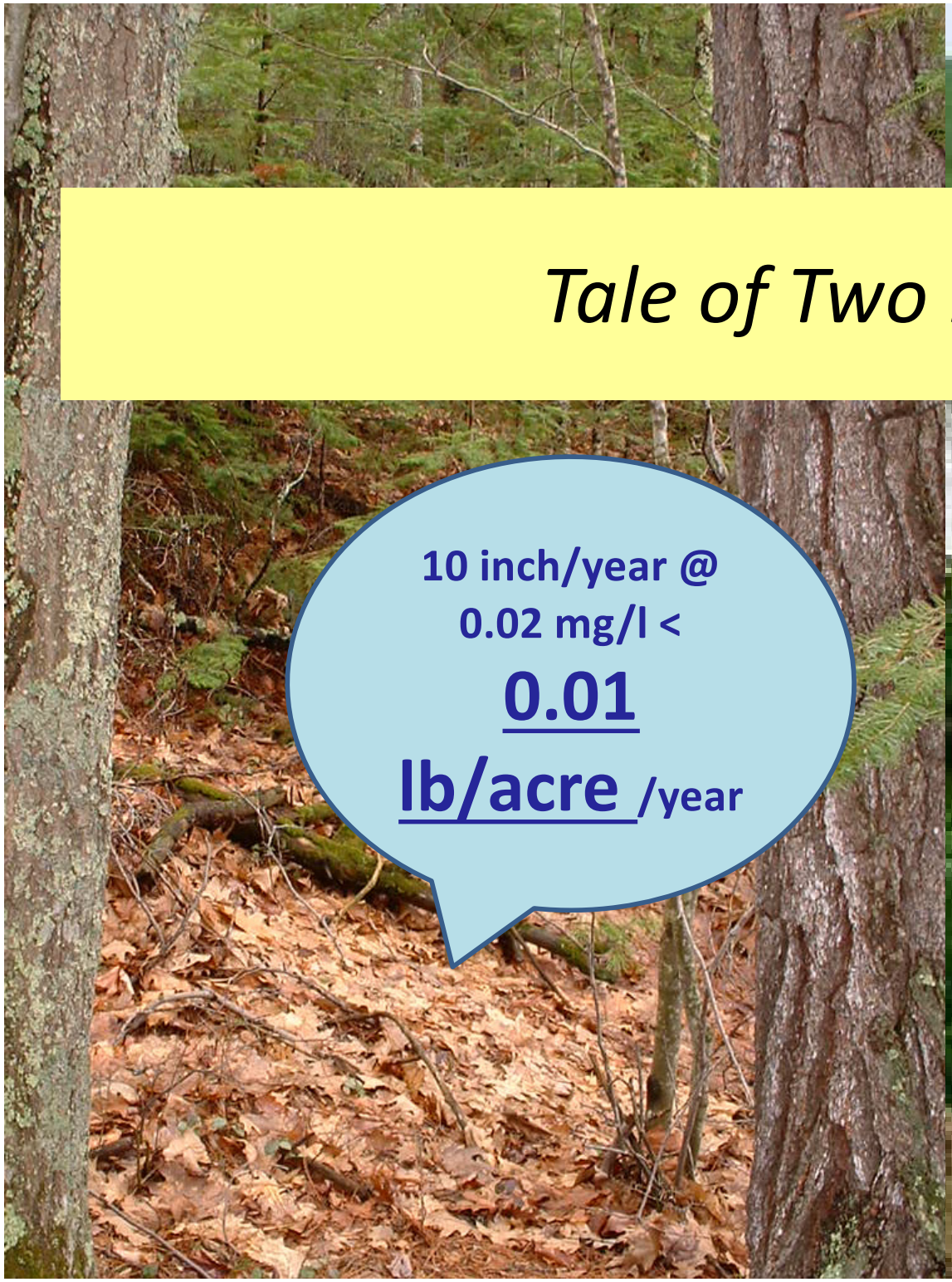
45,000 lb plant P
50,000 lb organic matter P
250,000 lbs soil P (top 6”)

350,000 lb P /sq mile

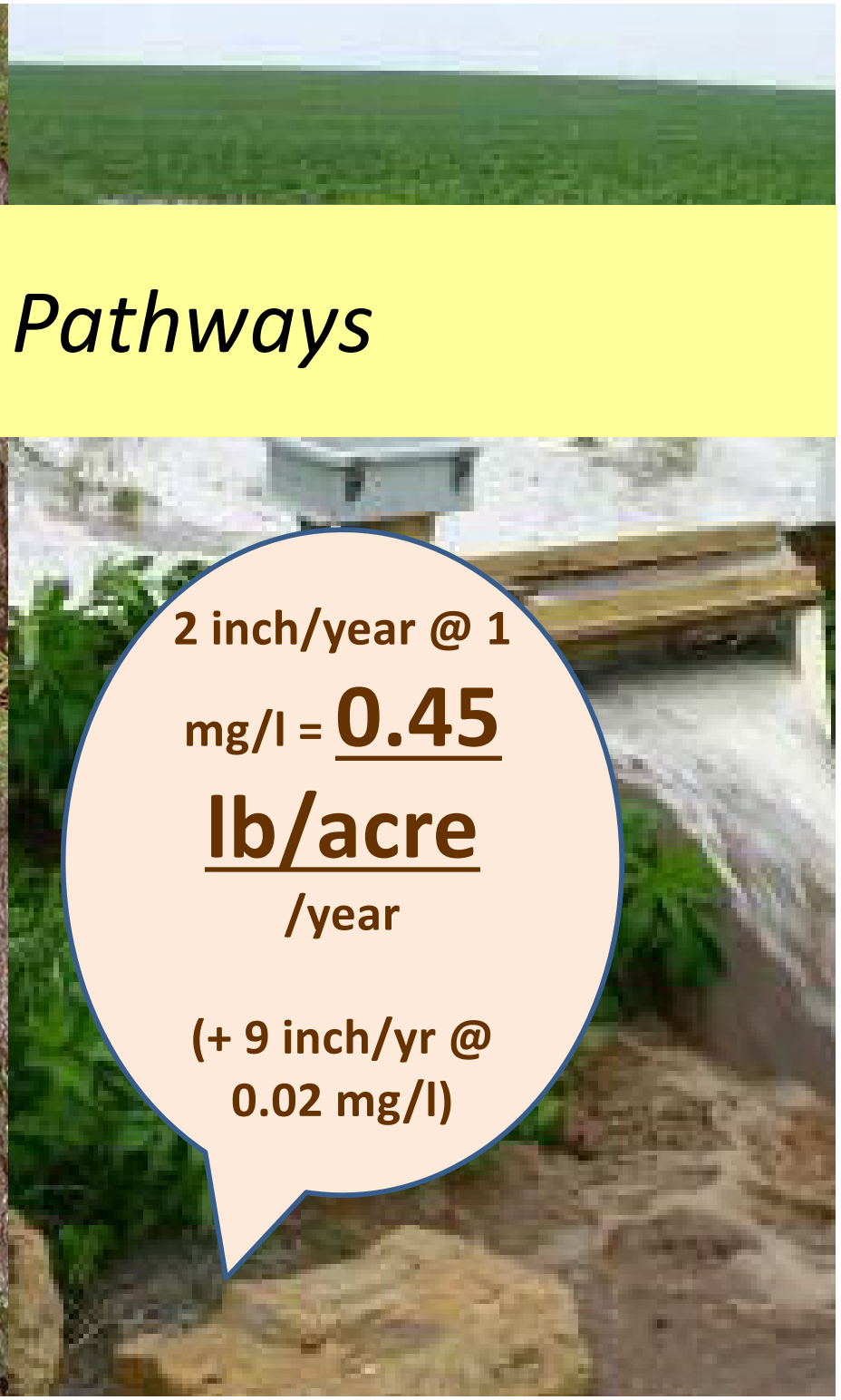
Adapted from Yanai, R.D., 1992. Phosphorus Budget of a 70-year-old northern hardwood forest Biogeochemistry 17:1-22

- Water Across Land = Phosphorus in the Water

Tale of Two Pathways



10 inch/year @ 0.02 mg/l < **0.01** **lb/acre** /year



2 inch/year @ 1 mg/l = **0.45** **lb/acre** /year

(+ 9 inch/yr @ 0.02 mg/l)

“Phosphorus Export Coefficients” (pounds/acre-year)

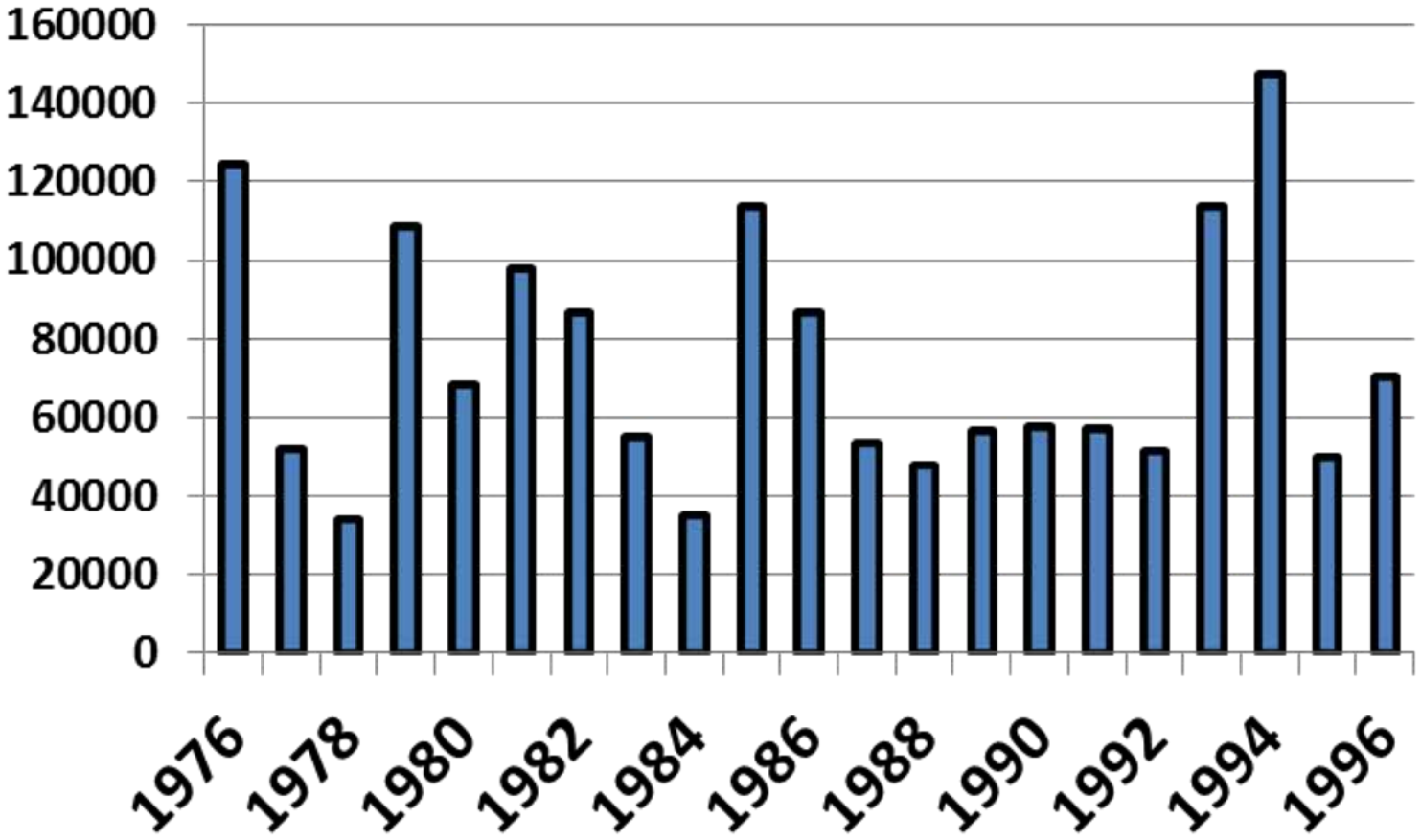
	Low	Most Likely	High
Agriculture (Mixed)	**0.3**	**0.8**	**1.4**
Med Density Urban	**0.3**	**0.5**	**0.8**
Pasture	**0.1**	**0.3**	**0.5**
Forest	**0.05**	**0.09**	**0.18**
Atmospheric (lake surface)	**0.1**	**0.3**	**0.5**

Adapted from WiLMS, Wisconsin Lake Modeling Suite
http://dnr.wi.gov/lakes/model/

Useful?

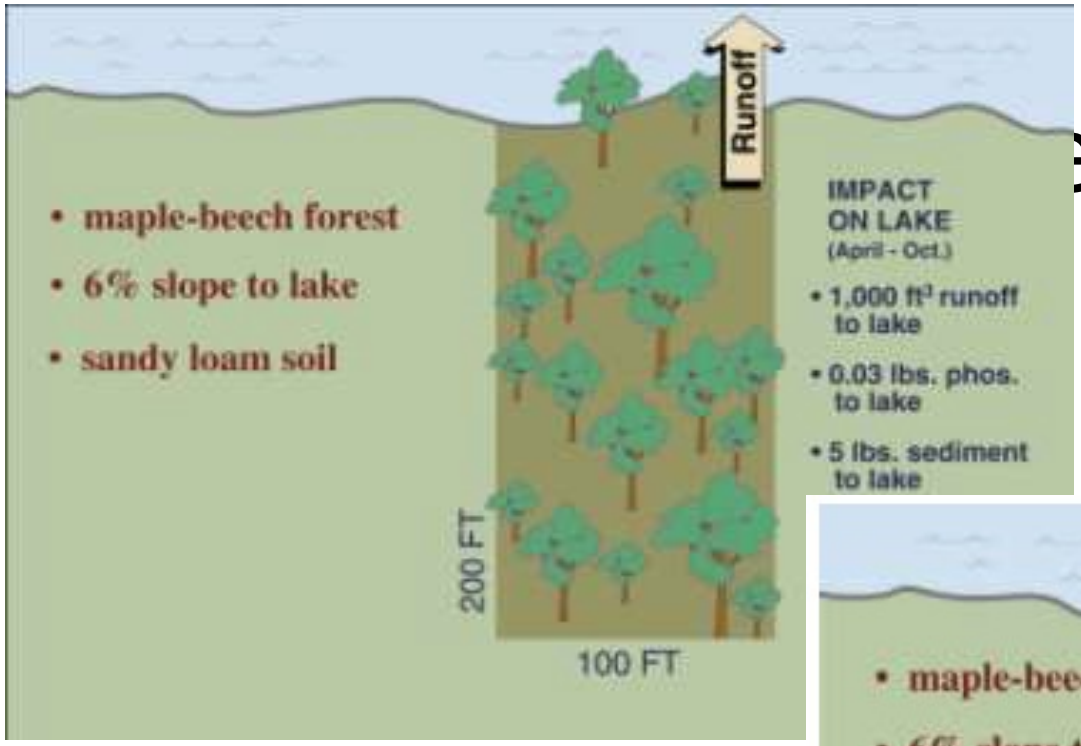
- Estimate the long term average P transfer from a watershed to the lake
  - 90,000 acres Row Crop
    - 90,000 ac*0.8 lb/ac-year = 72,000 lbs/year
  - 30,000 acres Pasture/Grass
    - 30,000 ac*0.3 lb/ac-year = 9,000 lbs/year
  - 30,000 acres Med Den Urban
    - 30,000 ac*0.5 lb/ac-year = 15,000 lbs/year
  - TOTAL = 96,000 lbs/year

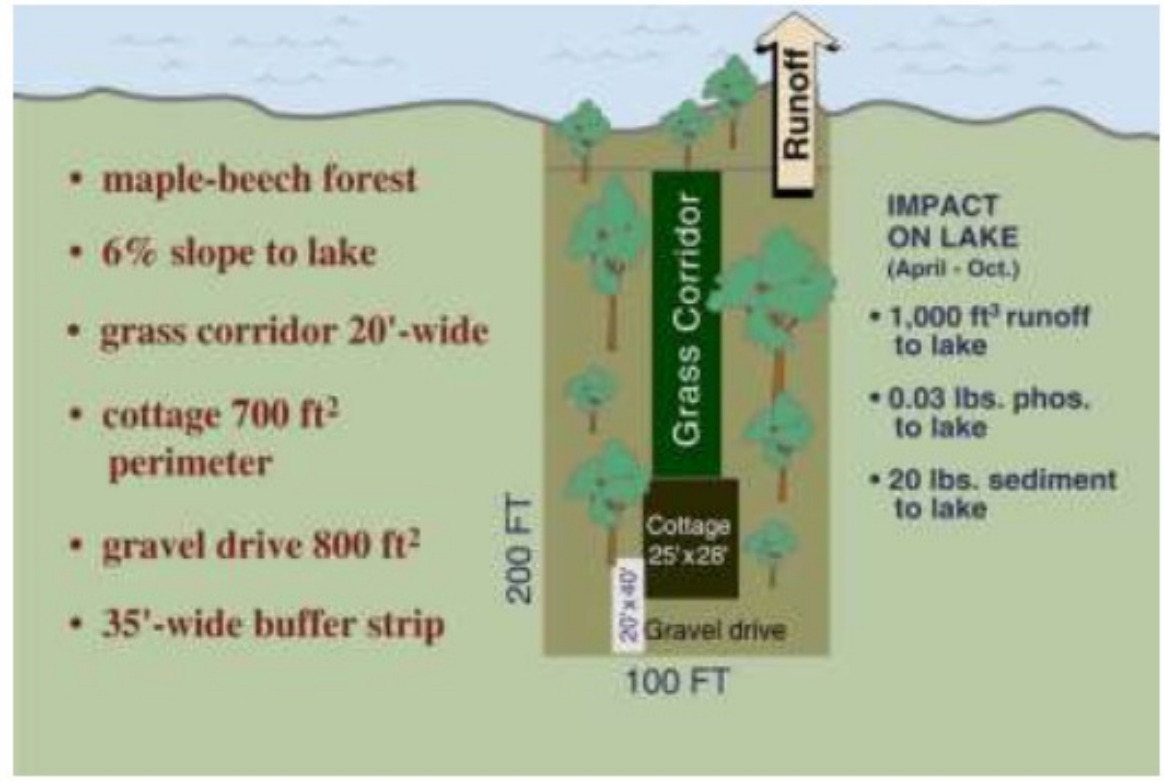
Challenges: Annual Variations in P to Lake!



- P Load (lb) to Lake (Lathrop and Panuska)

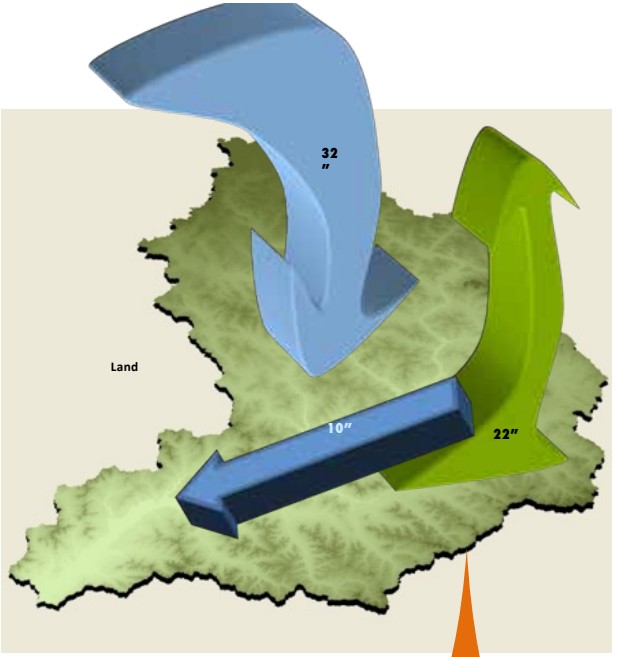
elopment


Runoff
• maple-beech forest
• 6% slope to lake
• sandy loam soil
IMPACT ON LAKE
(April - Oct.)
• 1,000 ft³ runoff to lake
• 0.03 lbs. phos. to lake
• 5 lbs. sediment to lake
200 FT
100 FT


Runoff
• maple-beech forest
• 6% slope to lake
• grass corridor 20'-wide
• cottage 700 ft² perimeter
• gravel drive 800 ft²
• 35'-wide buffer strip
Grass Corridor
Cottage 25' x 28'
20' x 40'
Gravel drive
200 FT
100 FT
IMPACT ON LAKE
(April - Oct.)
• 1,000 ft³ runoff to lake
• 0.03 lbs. phos. to lake
• 20 lbs. sediment to lake


Runoff
• maintained lawn, soil graded
• 6% slope to lake
• home 3,350 ft² perimeter
• paved drive 770 ft²
Lawn
Home 50' x 67'
Lawn
drive
Lawn
• 0.20 lbs. phos. to lake
• 90 lbs. sediment to lake

Modeling the Land?



Annual Volume x Average Concentration

Annual Export Based on Land use

Avg. Annual Spatially Variable

Daily Time Step Spatial Lumping

Short Time Step Spatially Variable

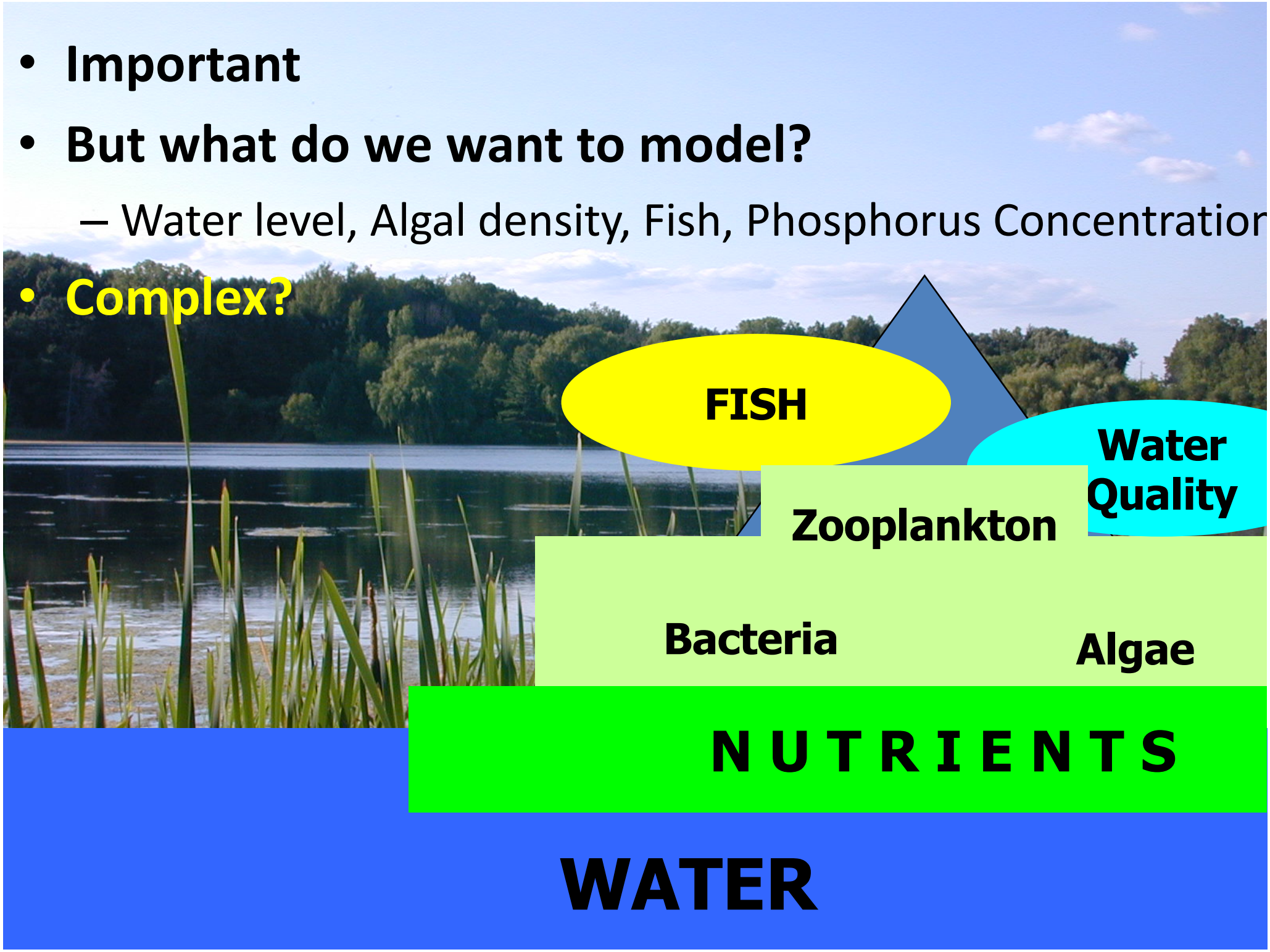
Follow Every drop

Very Simple

Very Complex

Part 2 - LAKES

- **Important**
- **But what do we want to model?**
  - Water level, Algal density, Fish, Phosphorus Concentration
- **Complex?**

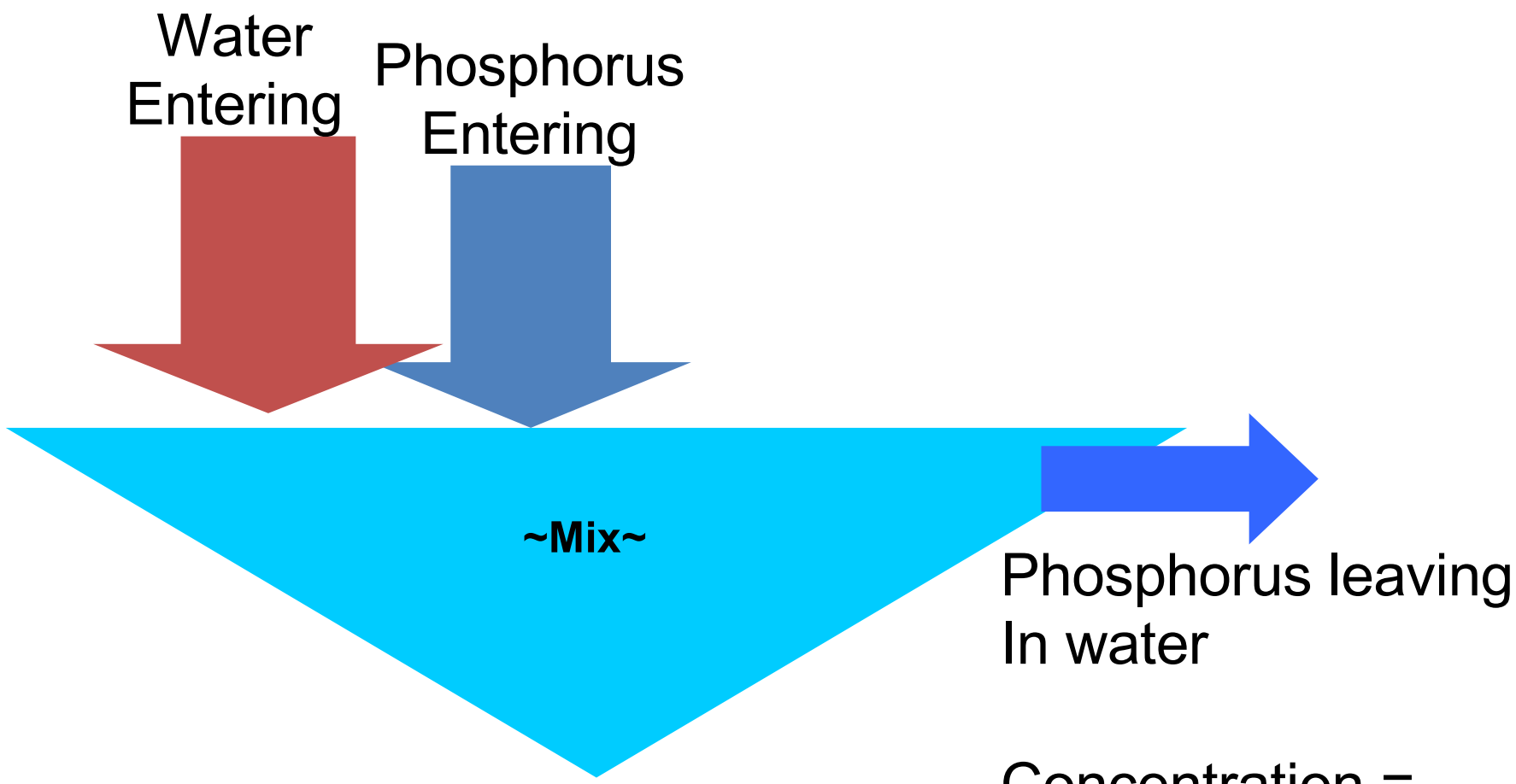


Our First Model

- Goal– predict the P concentration

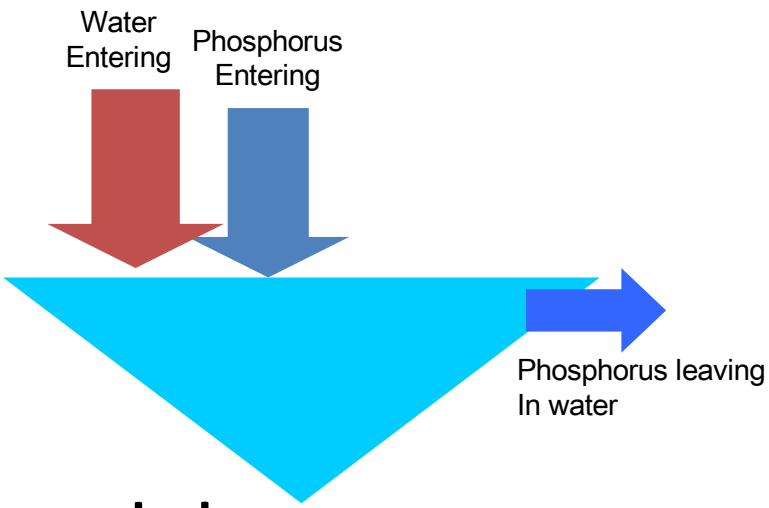
Given

- The amount of P entering the lake
- The amount of water entering the lake


Water
Entering
Phosphorus
Entering
~Mix~
Phosphorus leaving
In water
Concentration =
Phosphorus/Water

Let's give this a try

- 10,000 acre lake
- 150,000 acre watershed



Recall our simple watershed model…

- 96,000 lb/year P
- 125,000 acre-ft/year water

“Simple Model”
(annual P/annual water)

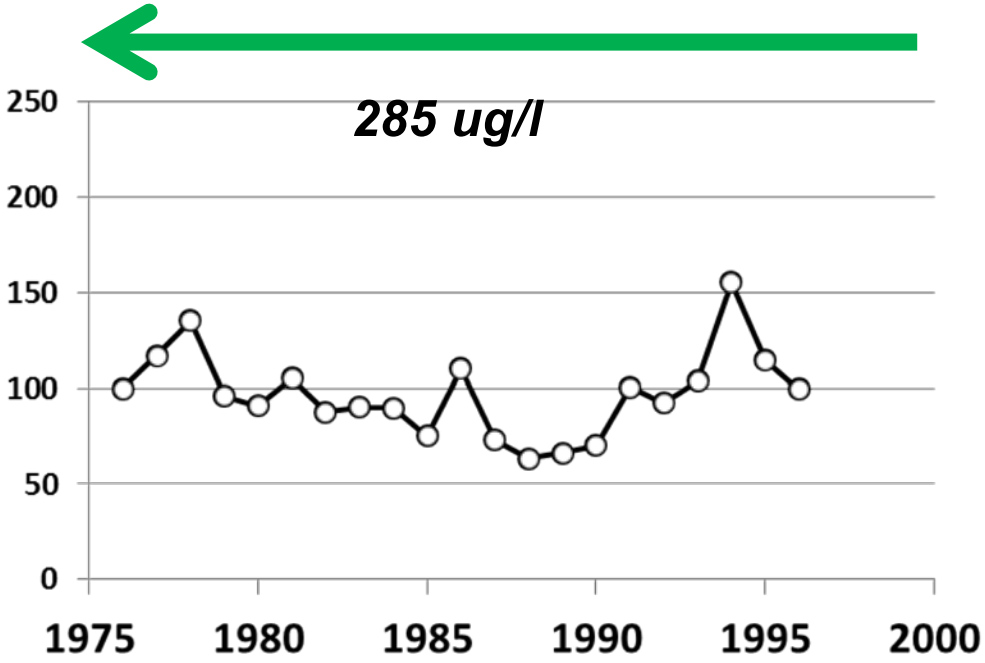
- ***Concentration of P***

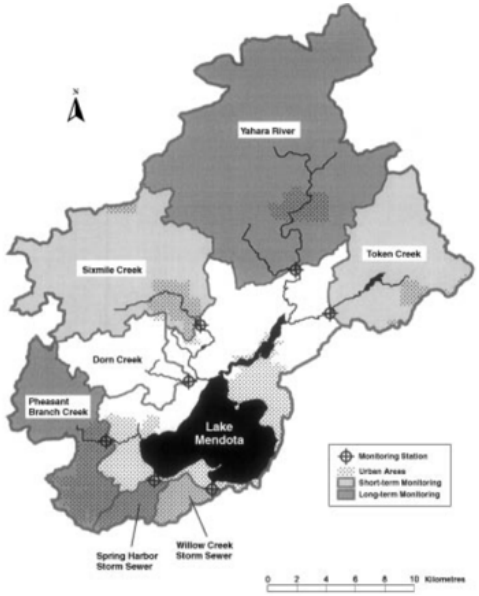
  = Mass of P / Volume of Water

  = 96,000 pounds / 23,000,000 cubic feet

  = 285 ug/l

Take a look at some data

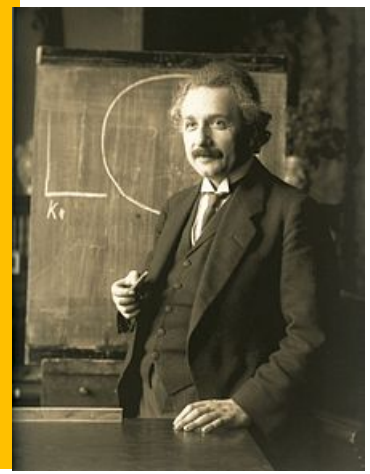




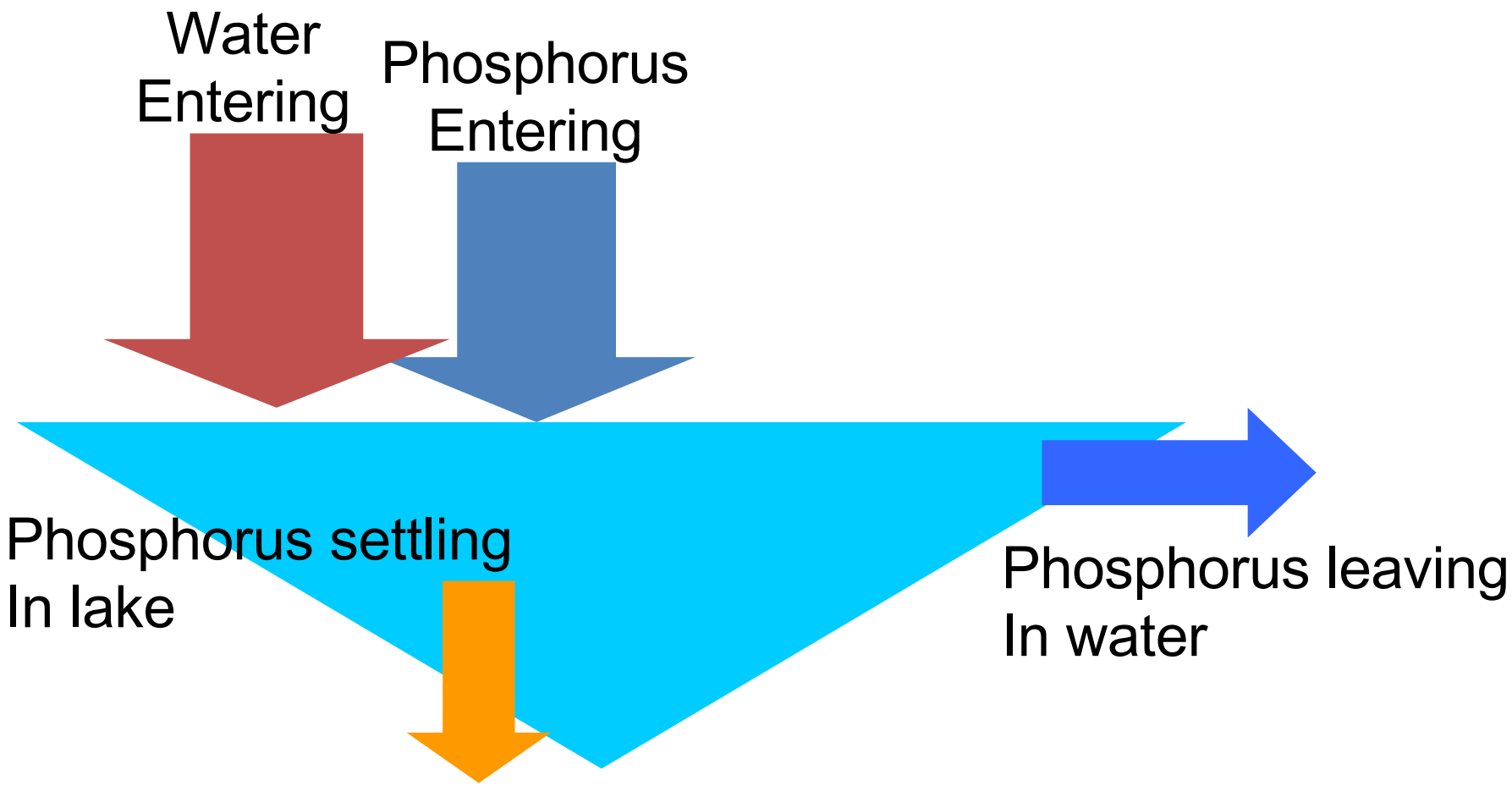
Lathrop and Panuska 1998

Not a very good model

- **Why?**
- **What happens to P in a lake?**
- **Another observation on modeling**
  - **"Everything should be made as simple as possible, but no simpler"** **A. Einstein**



Second Model

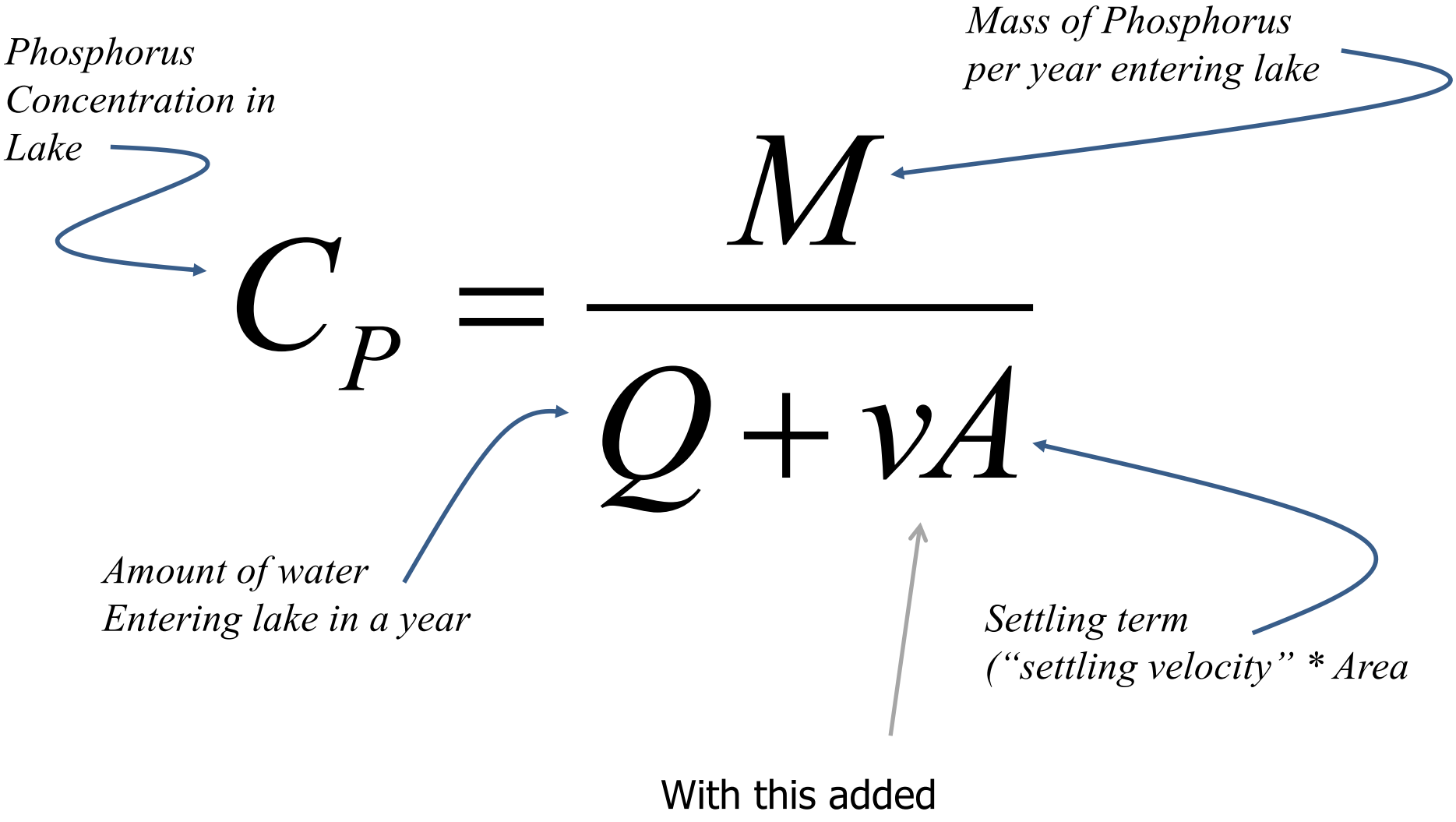


"diminished by retention term as P apparently lost to sediments" (Nurnberg, 1984)

Uniform ("steady-state") Conditions

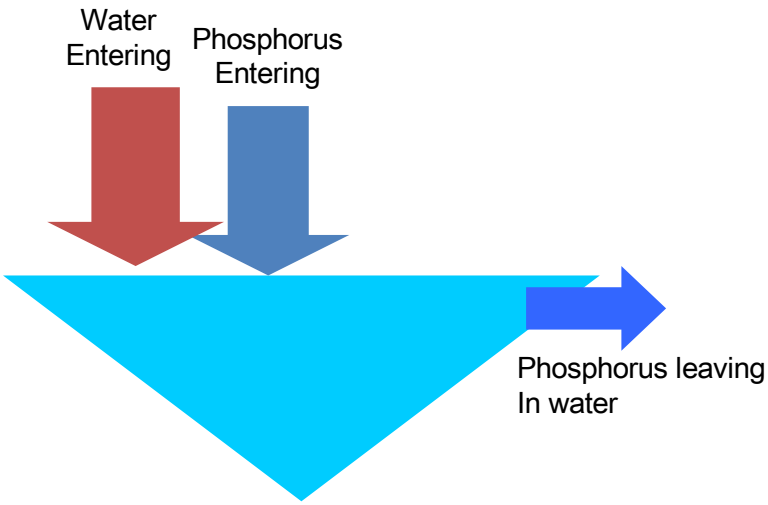
The P concentration doesn't change with time

The amount of P in the lake is constant



Let's give this a try

- 10,000 acre lake
- 150,000 acre watershed



Assume

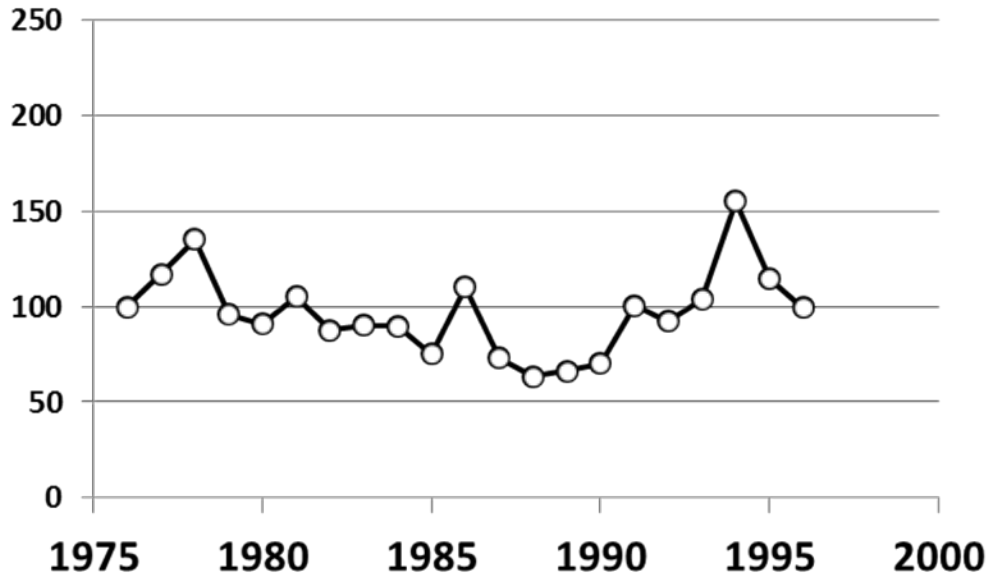
- 96,000 lb/year P
- 125,000 acre-feet water/year
- 40,500,000 m2 lake surface
- 10 meter/year settling velocity

Our “Less Simple Model”

- **Concentration of P**

  = 108 ug/l (better?)

- **Useful?**



Of course this is still a simple model…

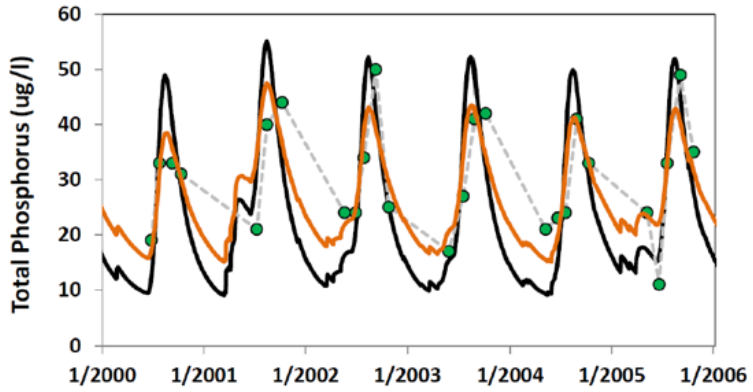
Annual Phosphorus Input

Simpler Models…
--completely mixed
-- steady with time

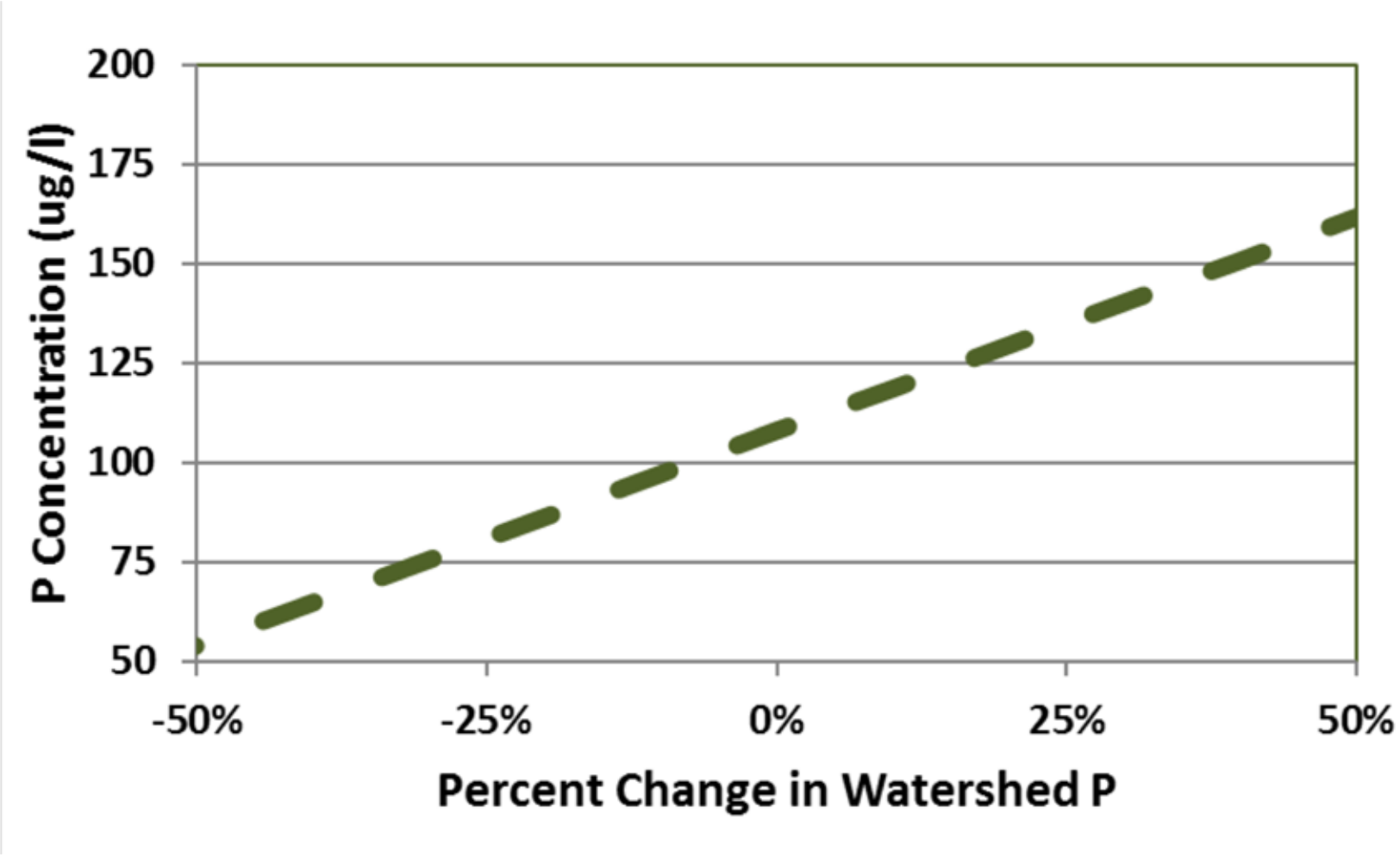
Annual Water Input

Annual Phosphorus Settling

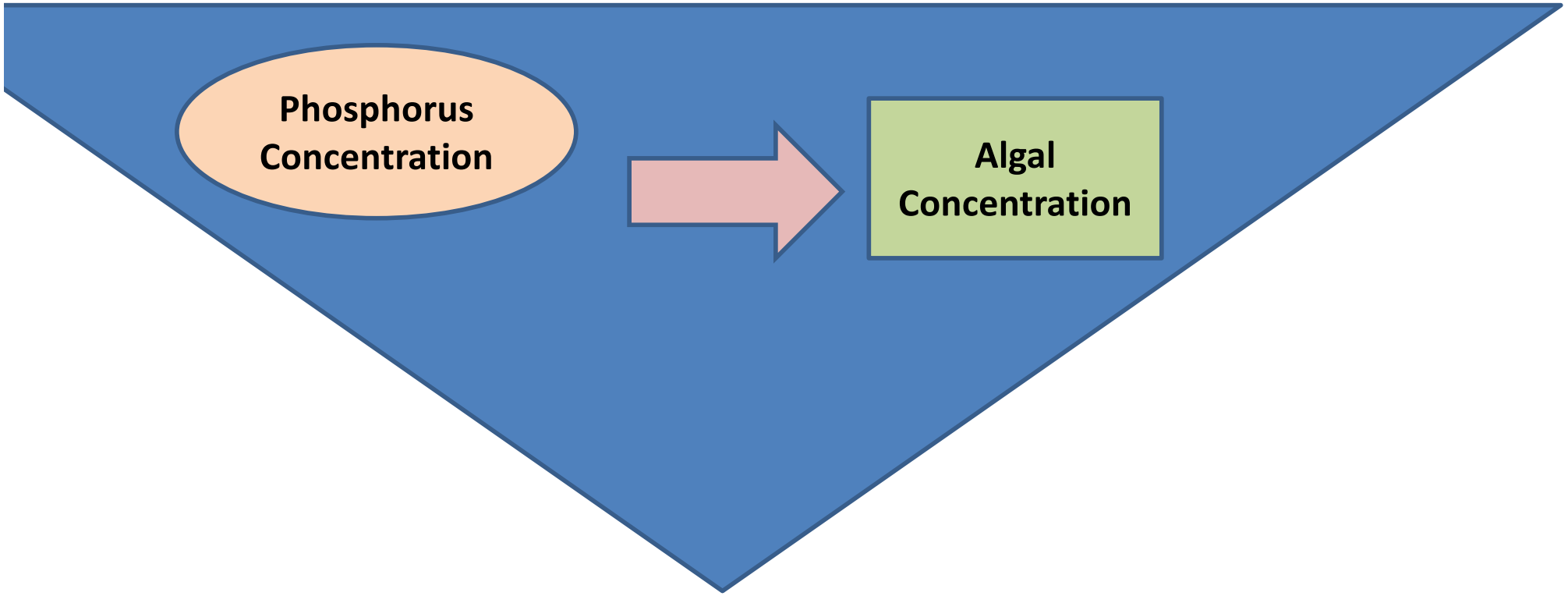
Complex Models…
--segments in lake
--vary with time
--biology!



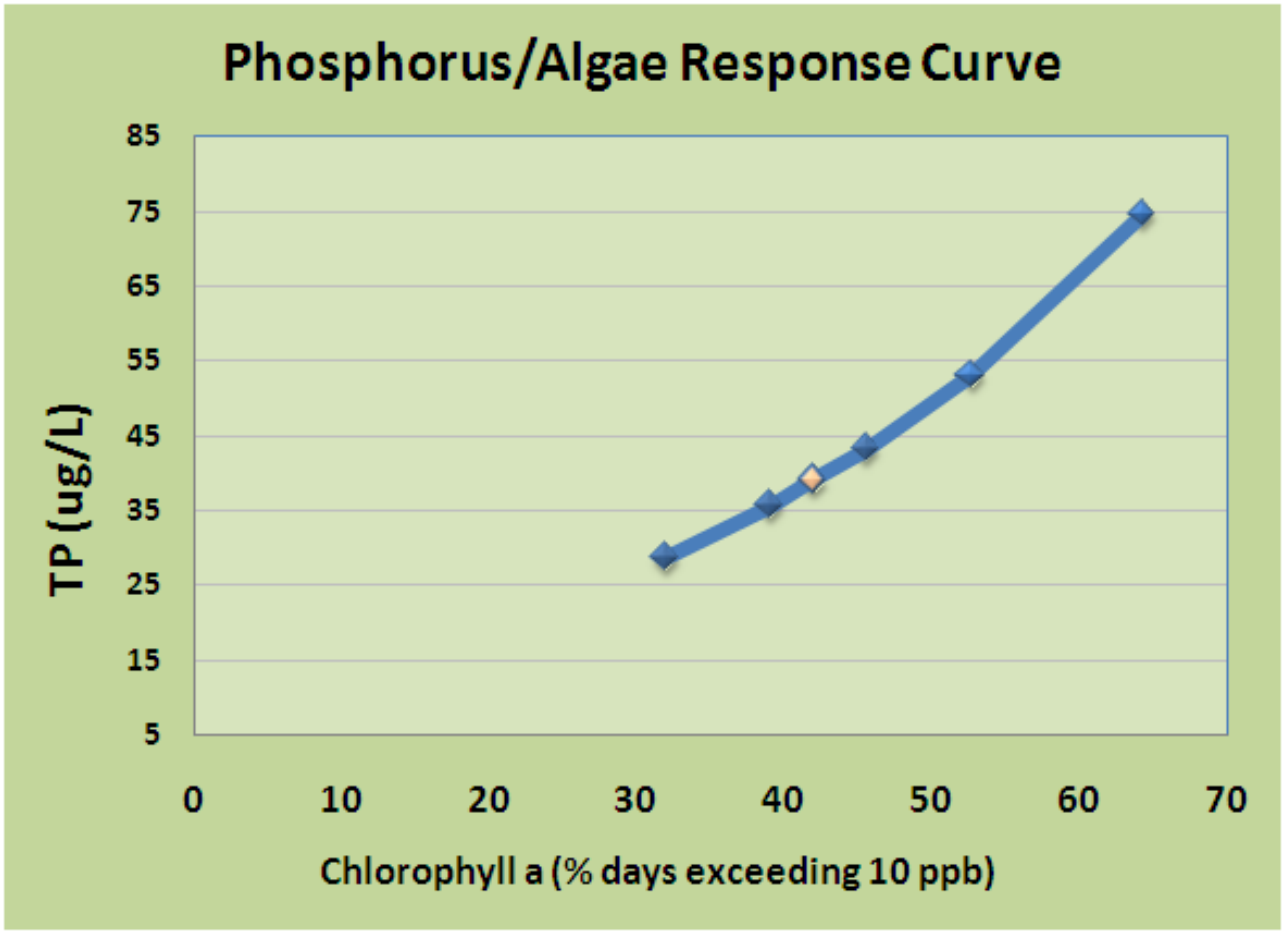
Useful?


200
175
150
125
100
75
50
P Concentration (ug/l)
-50%
-25%
0%
25%
50%
Percent Change in Watershed P

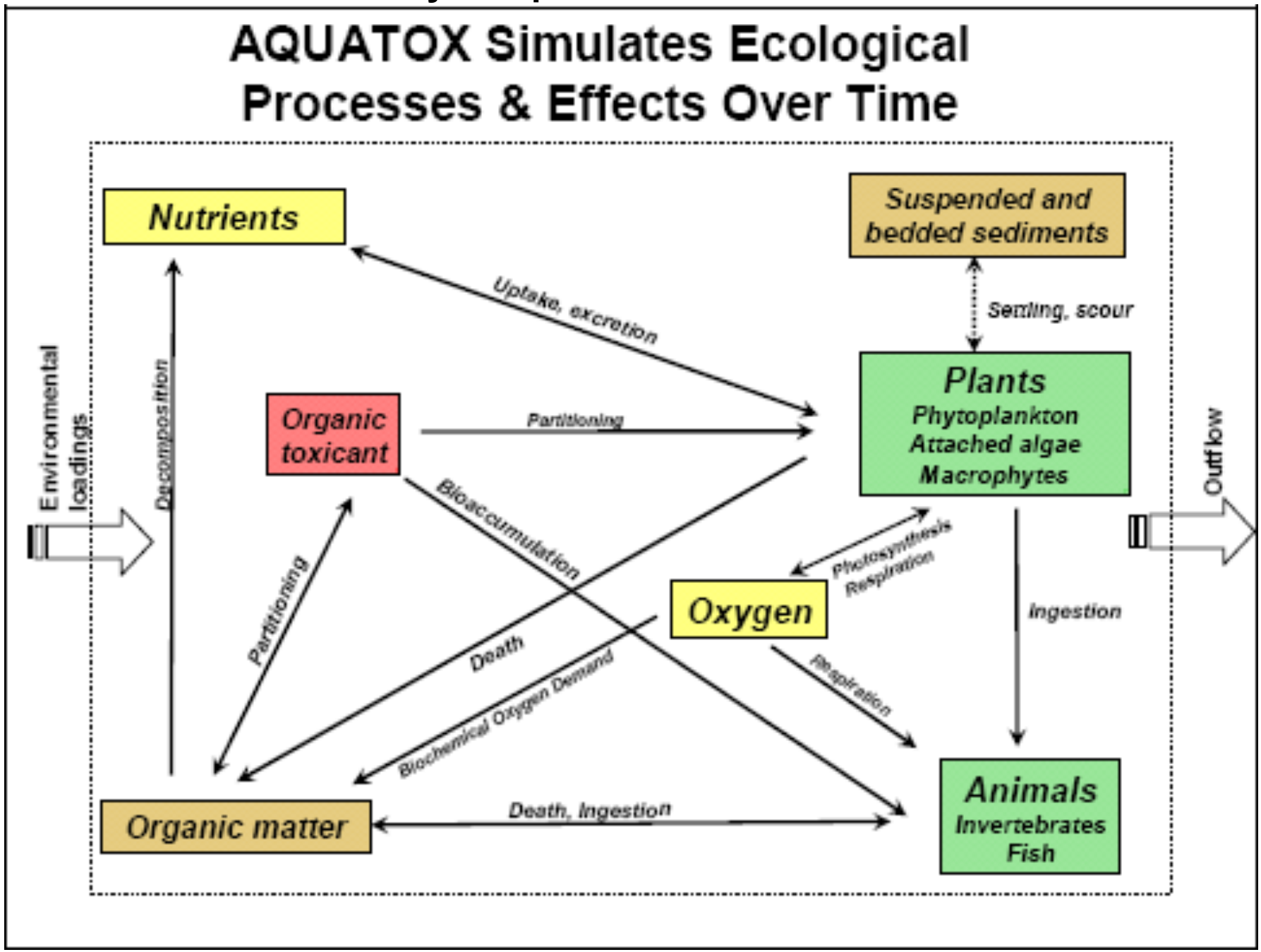
Lake Response Model?



- Useful?


Phosphorus/Algae Response Curve
TP (ug/L)
85
75
65
55
45
35
25
15
5
0
10
20
30
40
50
60
70
Chlorophyll a (% days exceeding 10 ppb)

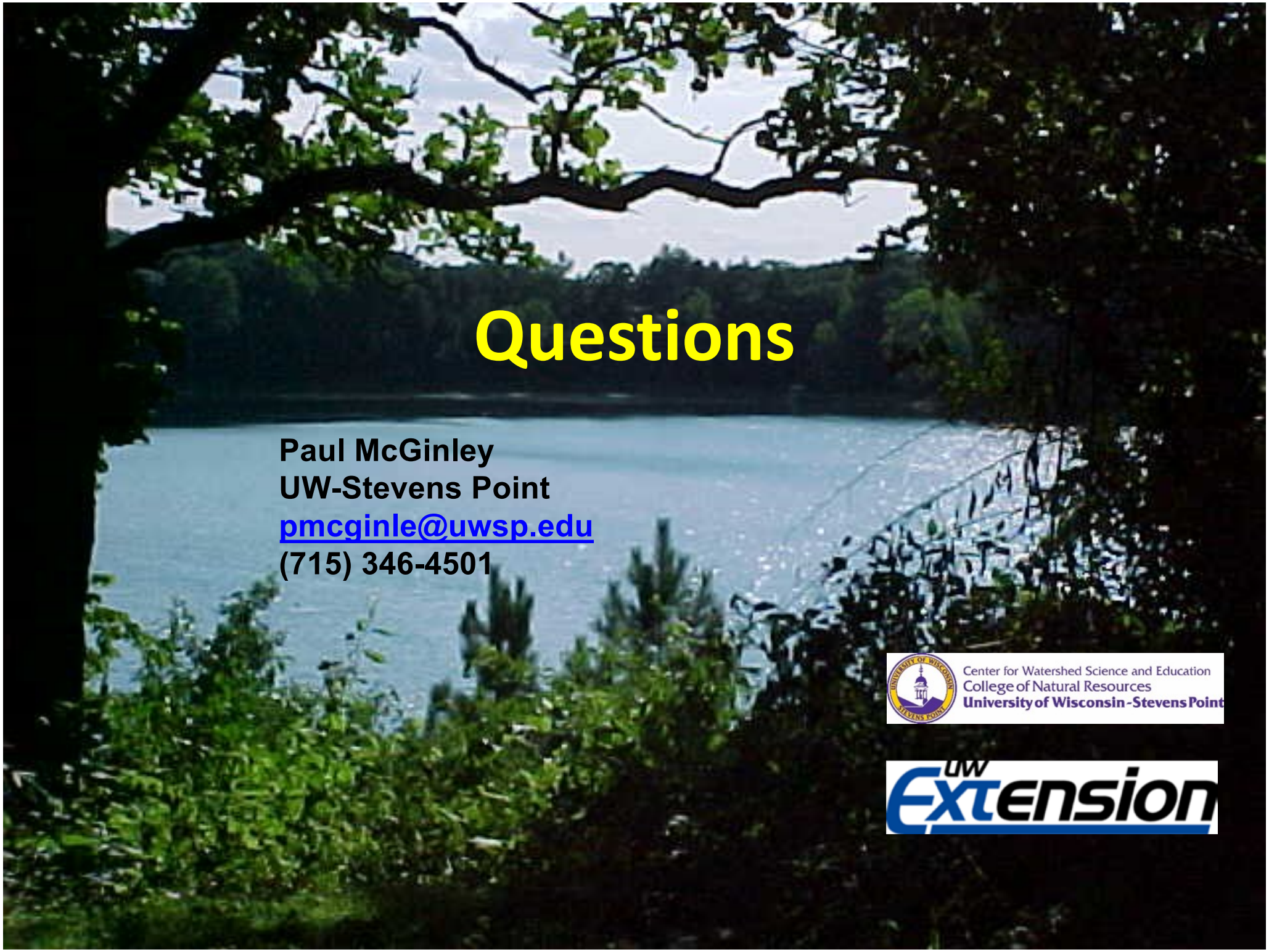
But we can make this very complex!



Summary Discussion

- Watershed
  - Water Budget
  - Phosphorus Budget
- Lake
  - Concentrations
  - Response

- Simple
  - Reduce Spatial Variations
  - Long Term Averages
- Complex
  - Time and Space Variations
  - Daily / Yearly Variations


Questions
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