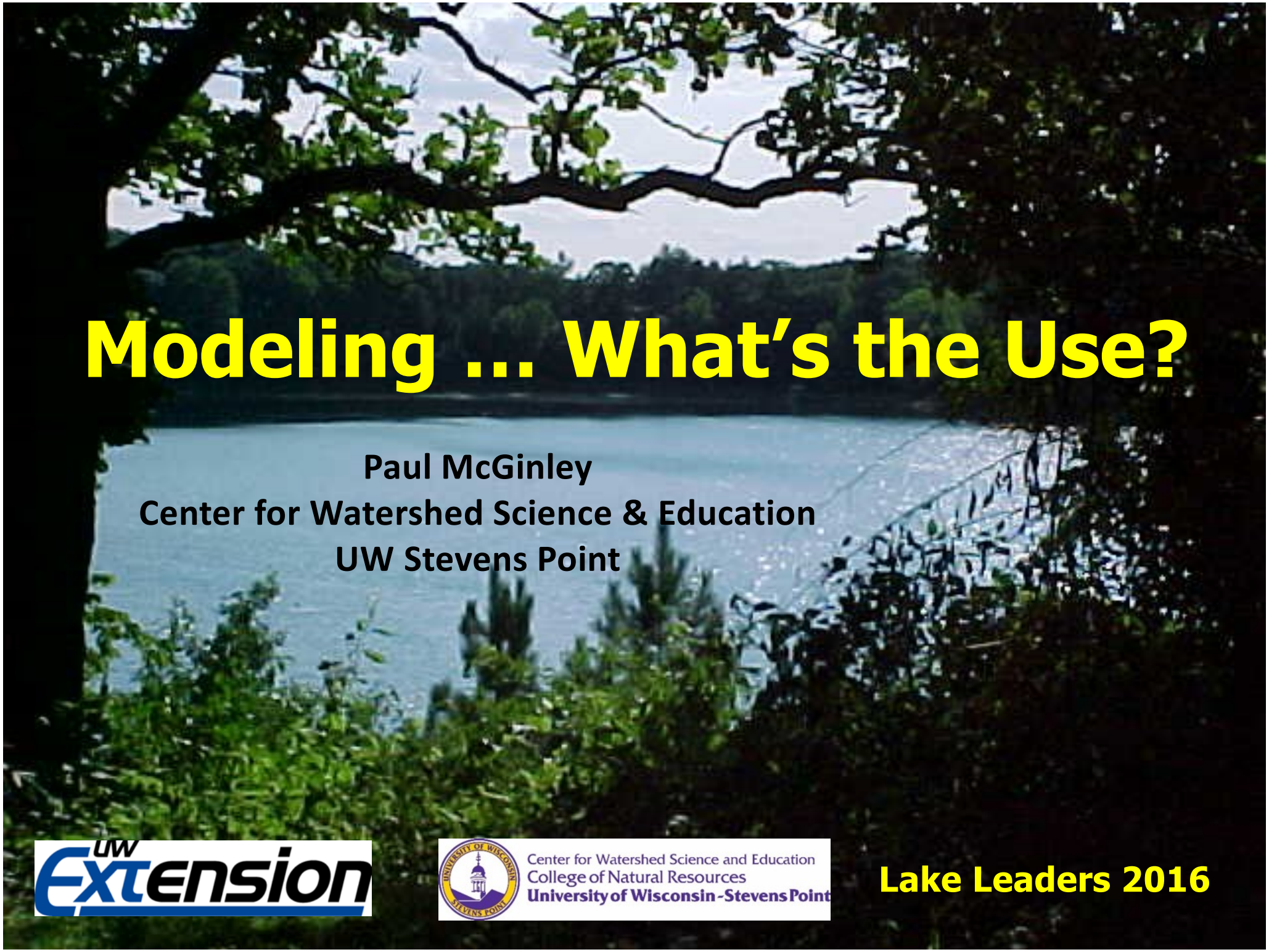

Modeling … What's the Use?

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Lake Leaders 2016

What's a model

One definition: A mathematical description to help visualize something

help us "visualize" a current condition to better understand it

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?

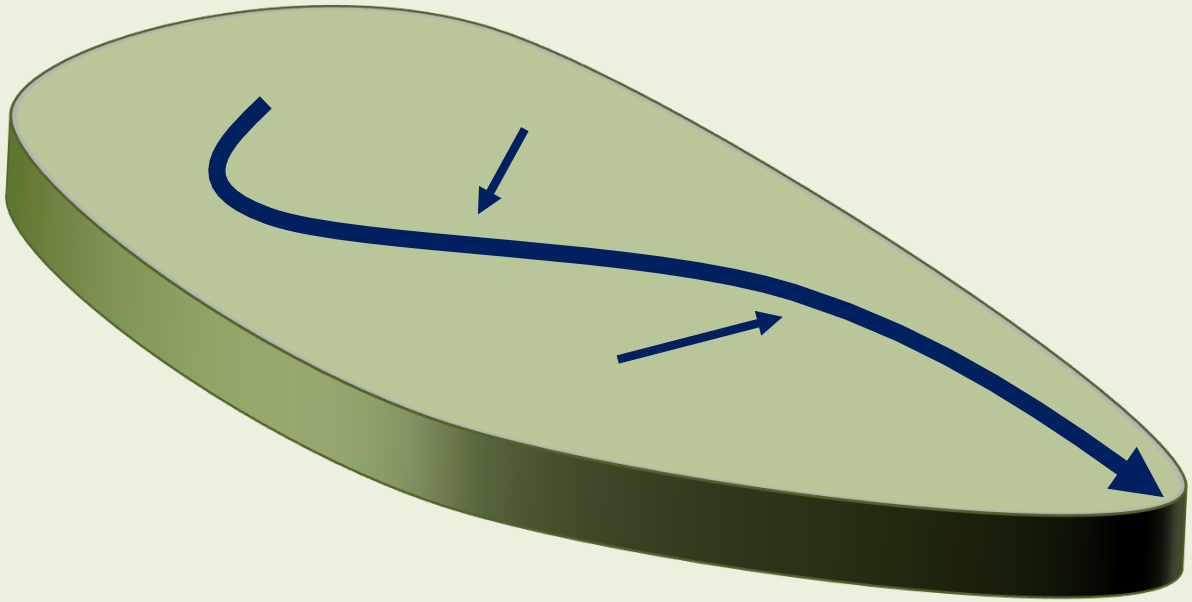
Today…. 1) Watersheds and 2) Lakes *& 3) Streams*

- **Functioning – big picture arm waving – & the development of "Conceptual" Models**
- **Take us through a couple examples**
- **End with brief discussion of other models**

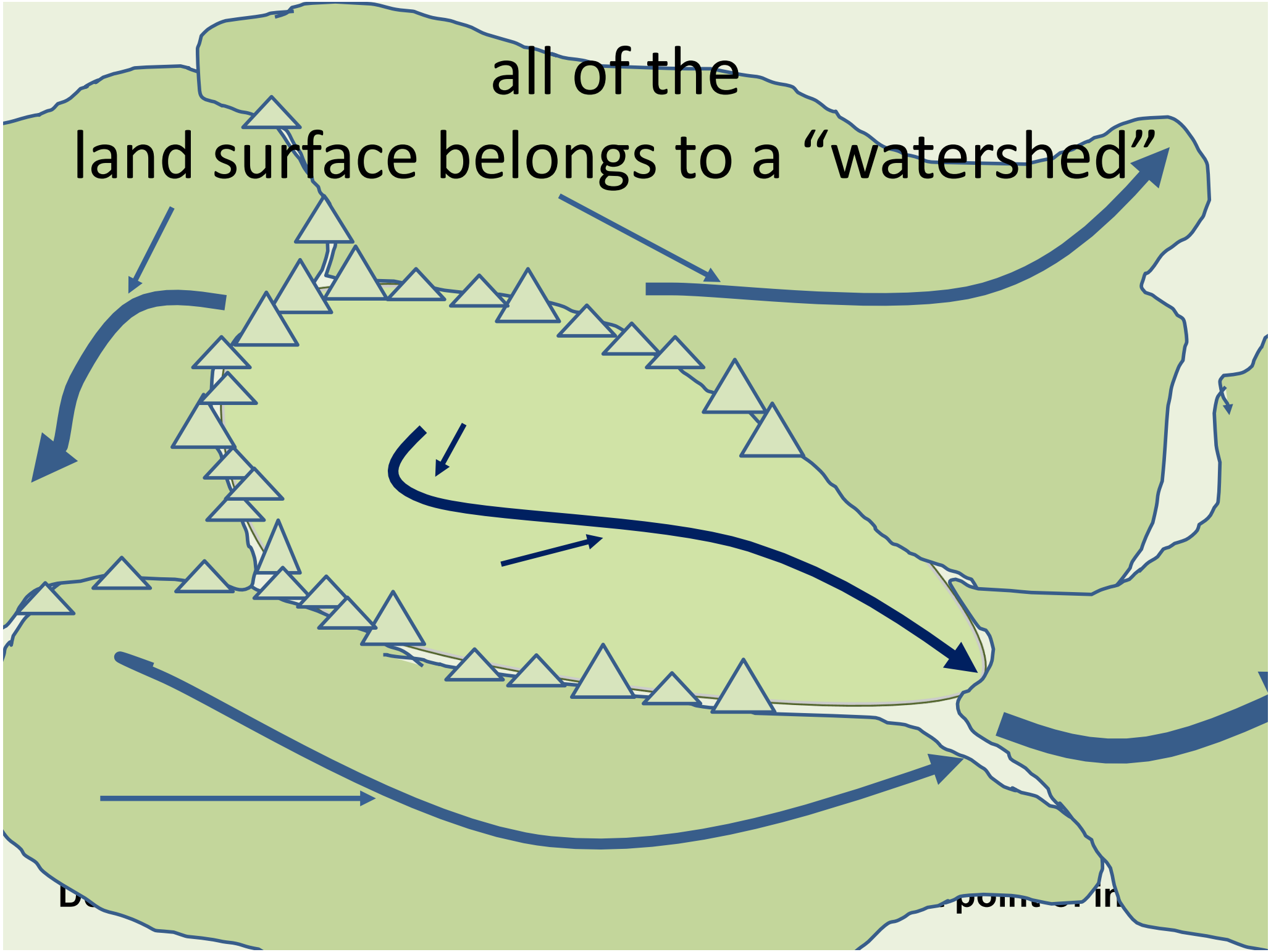
Goal- Understand & Apply several Models

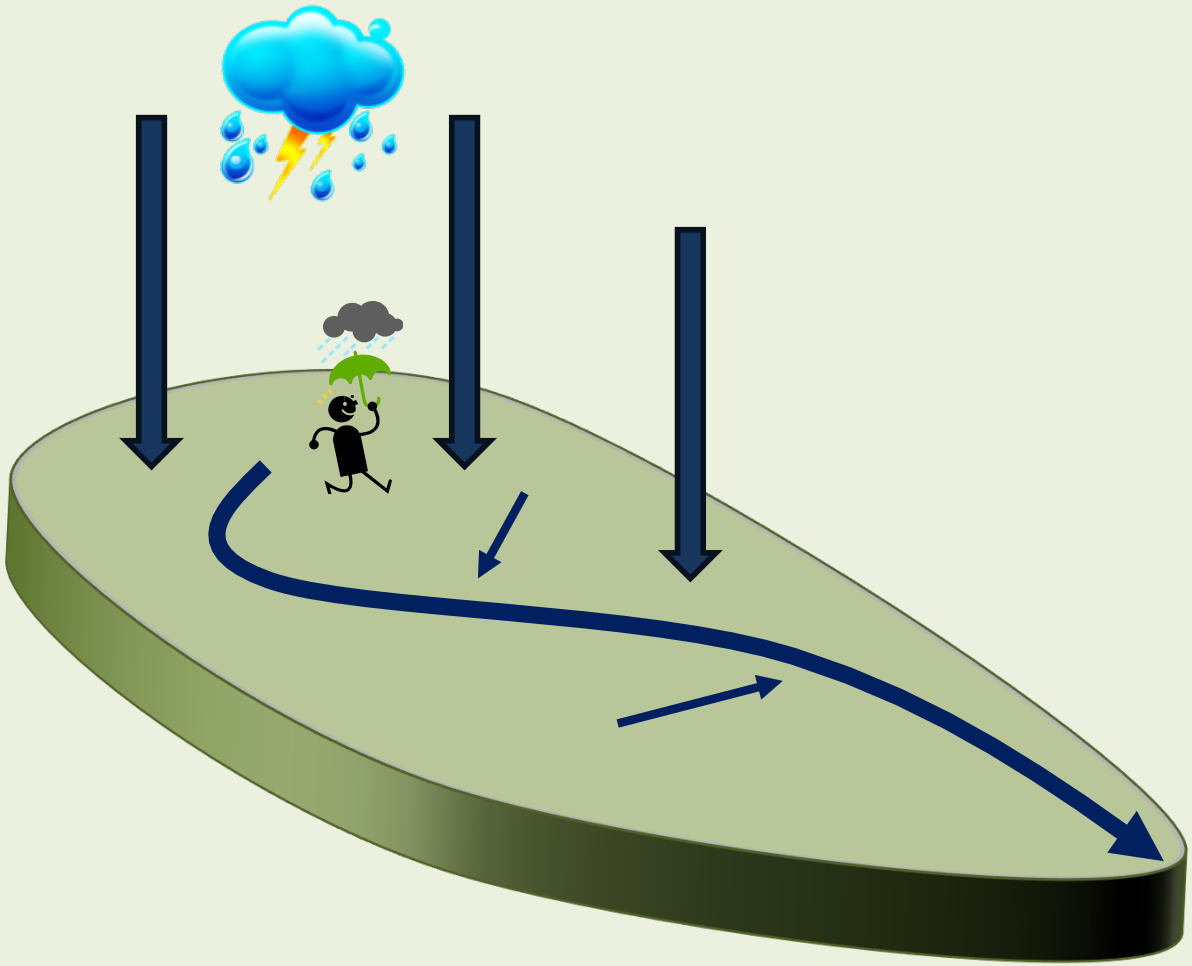
(and most important… not make a potentially confusing topic more confusing…)

First– Watersheds



Define- that area where the water drains to the outlet point of interest


all of the
land surface belongs to a “watershed”

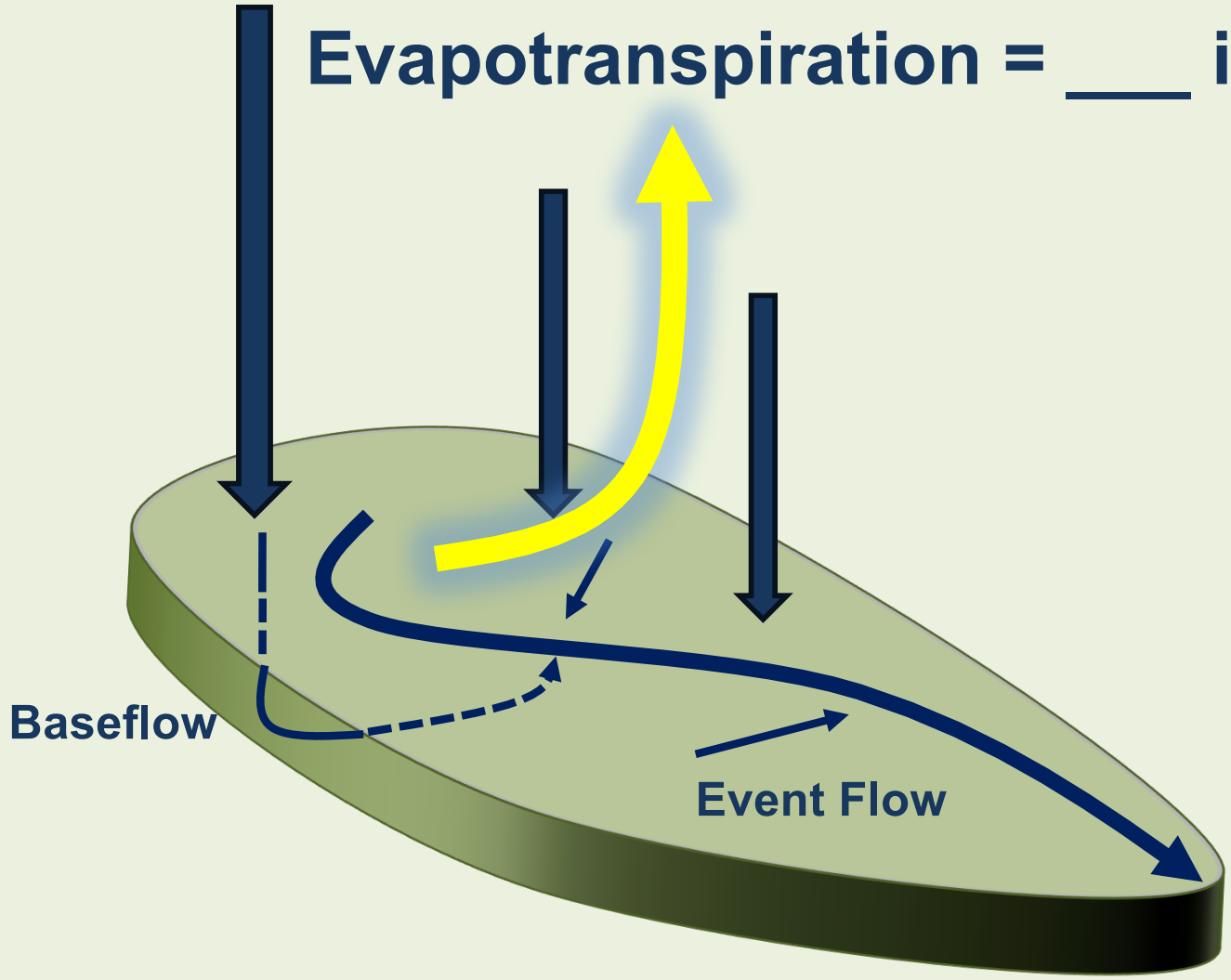


Our Watershed interests might be…

--- Water, Sediment & Nutrients (could be others)

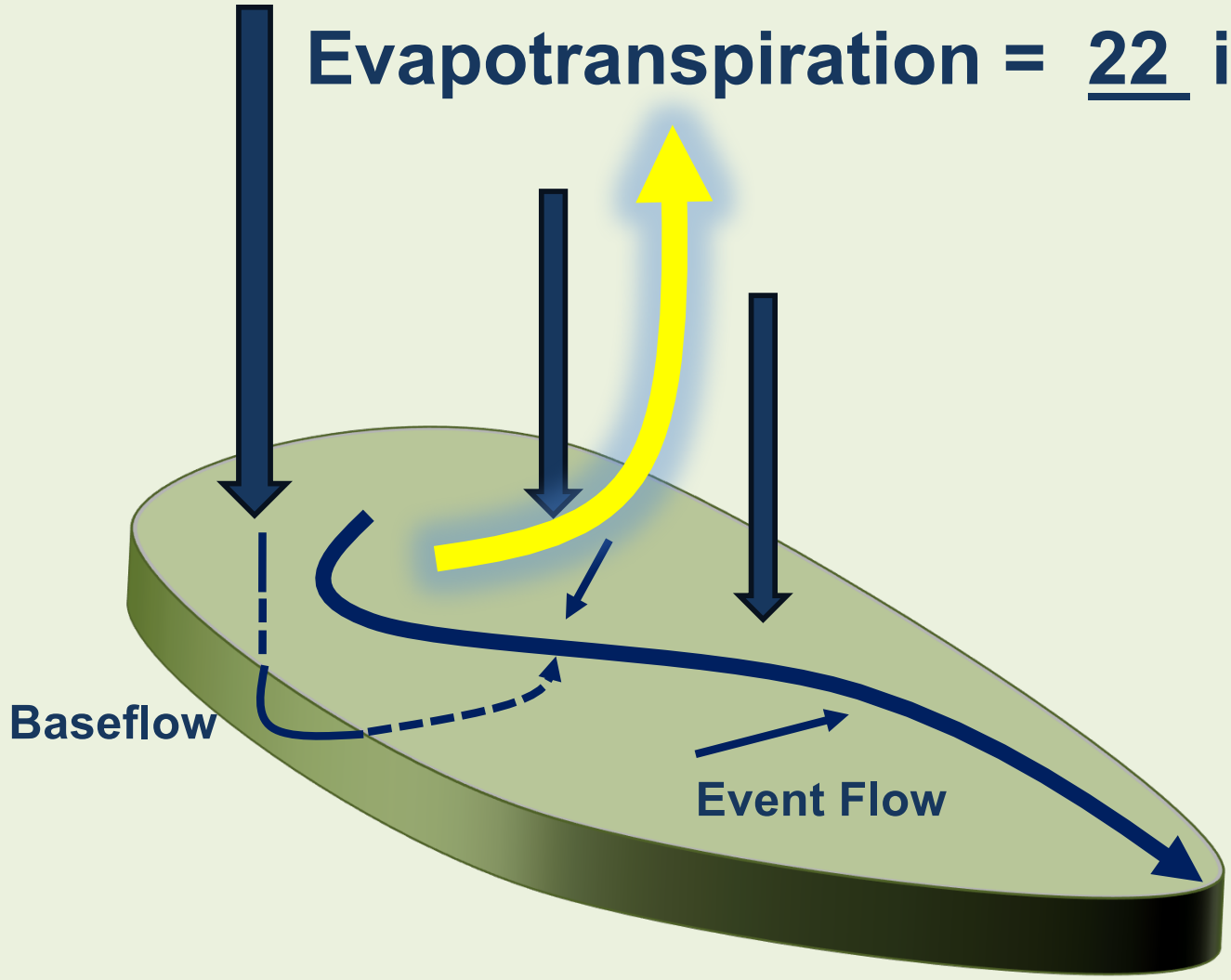
Precipitation = ___ inches/yr

Evapotranspiration = ___ inches/yr



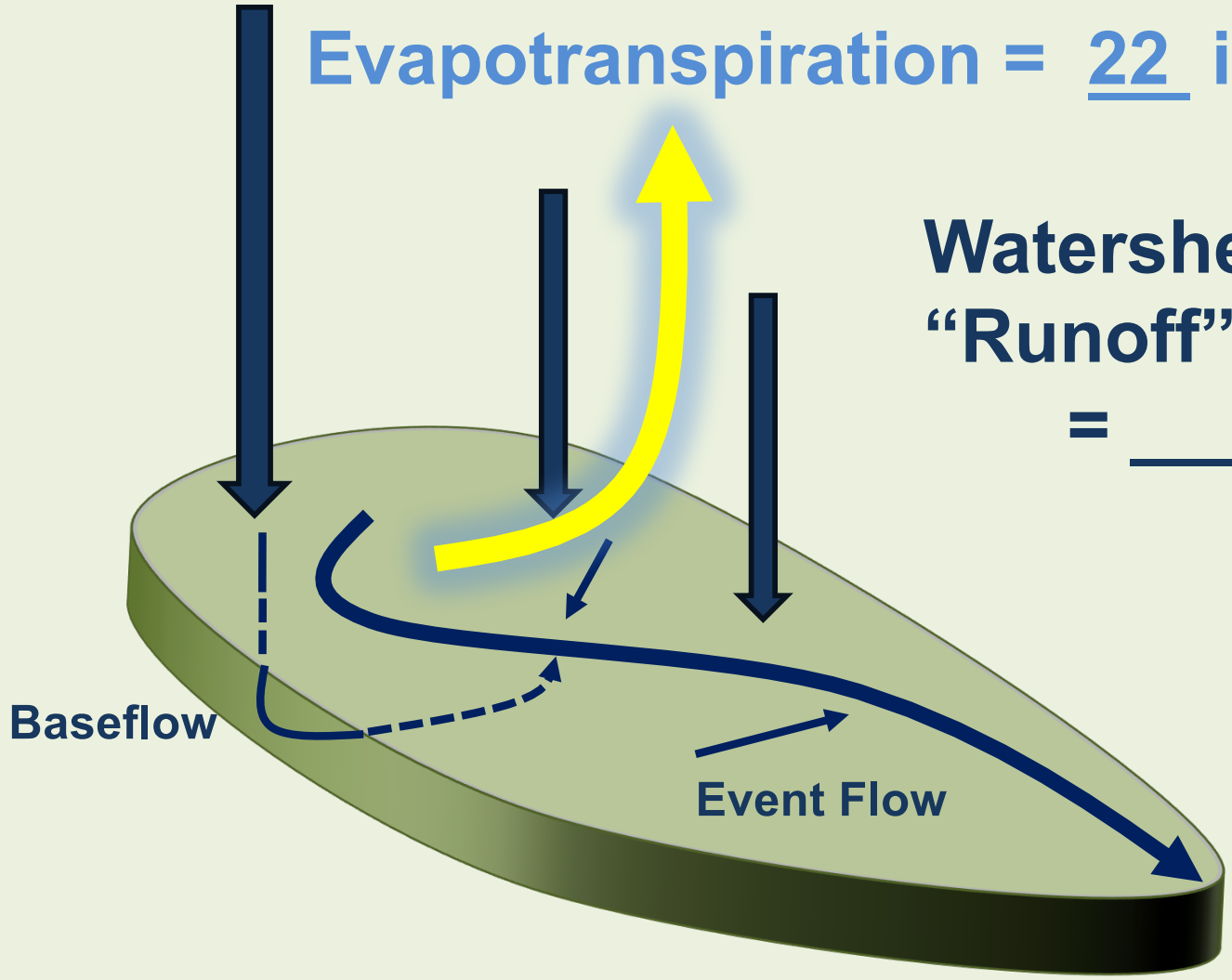
Precipitation = 32 inches/yr

Evapotranspiration = 22 inches/yr



Precipitation = 32 inches/yr

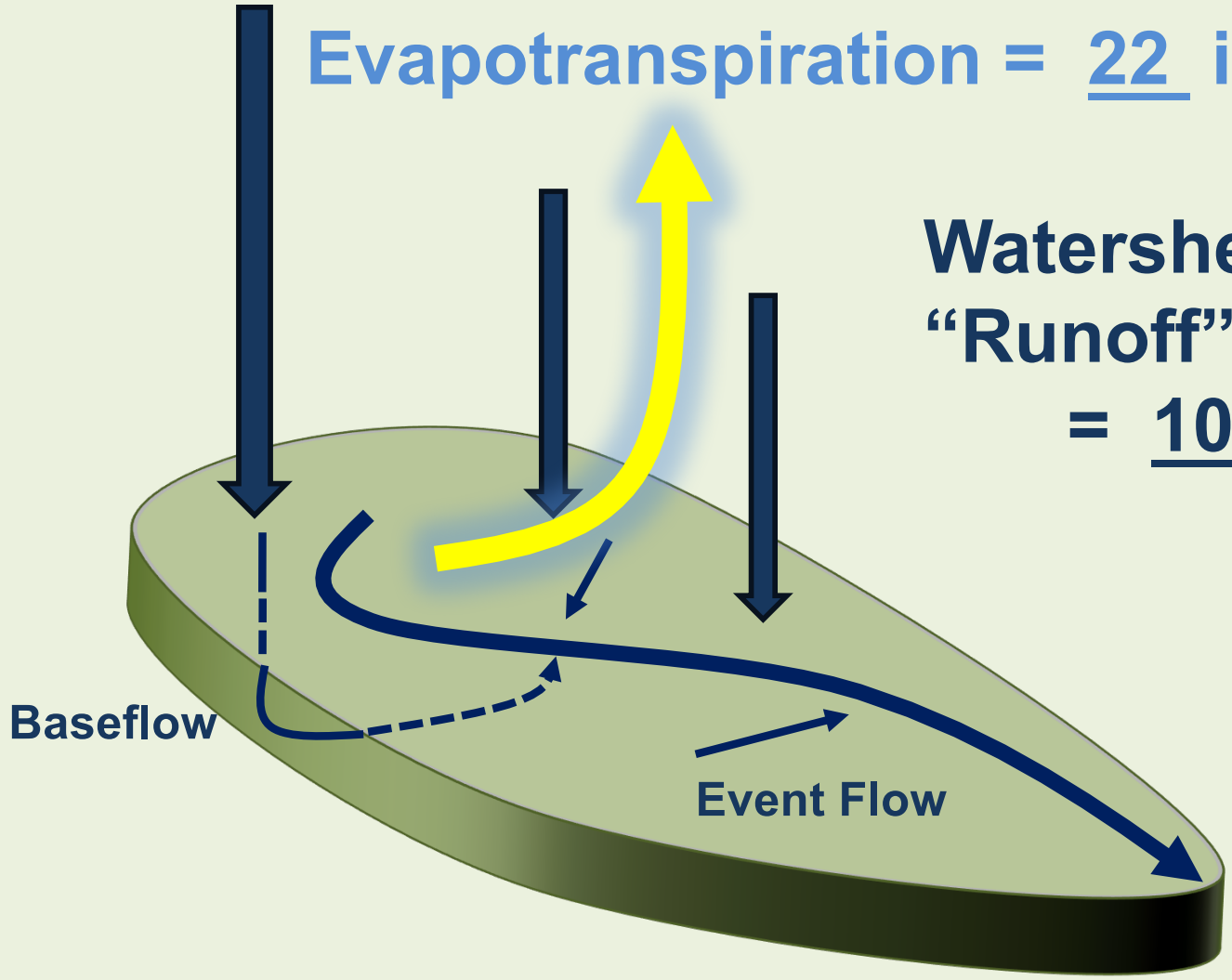
Evapotranspiration = 22 inches/yr



Watershed
"Runoff"
= ___ inches/yr

Precipitation = 32 inches/yr

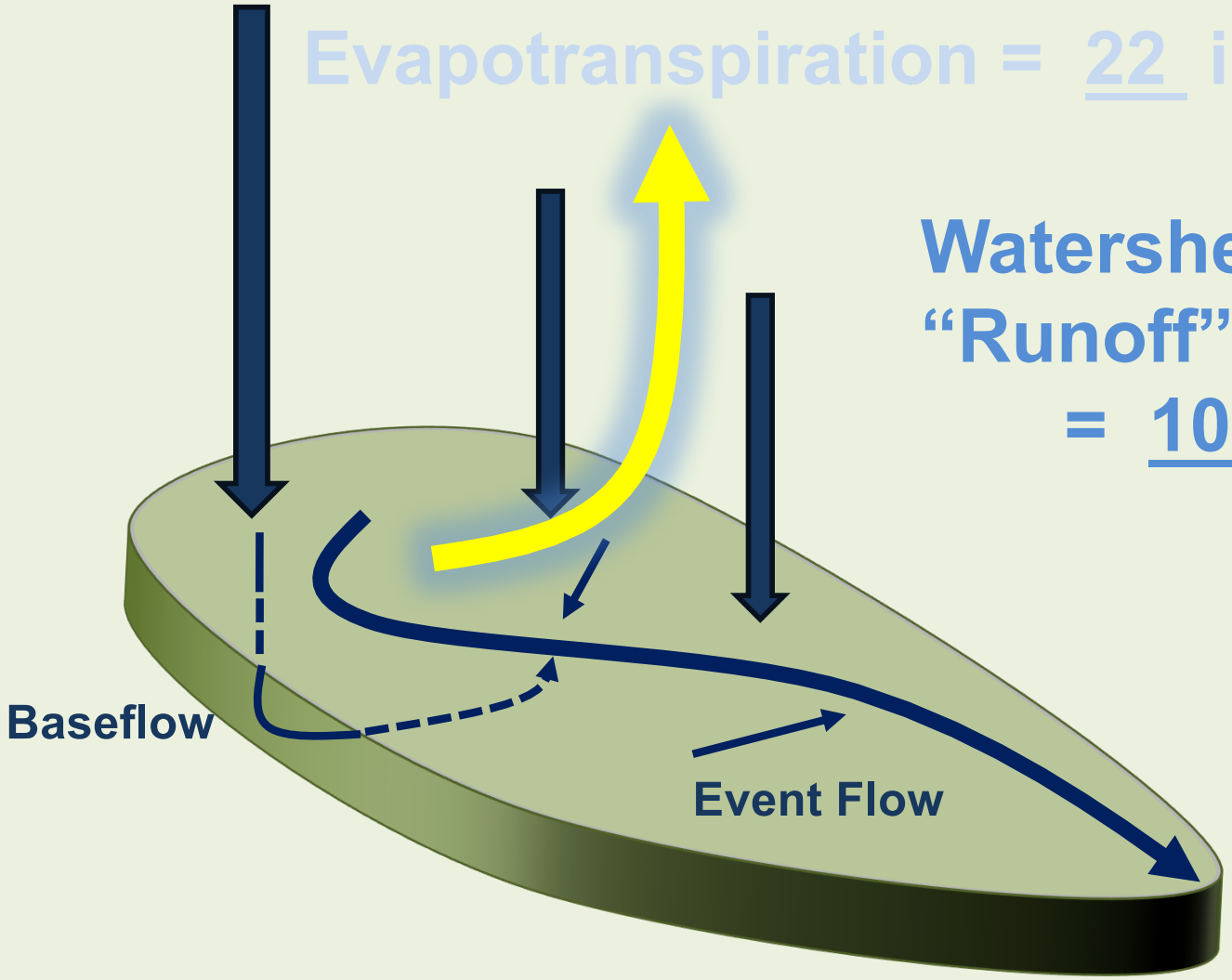
Evapotranspiration = 22 inches/yr



Watershed
"Runoff"
= 10 inches/yr

Precipitation = 32 inches/yr

Evapotranspiration = 22 inches/yr



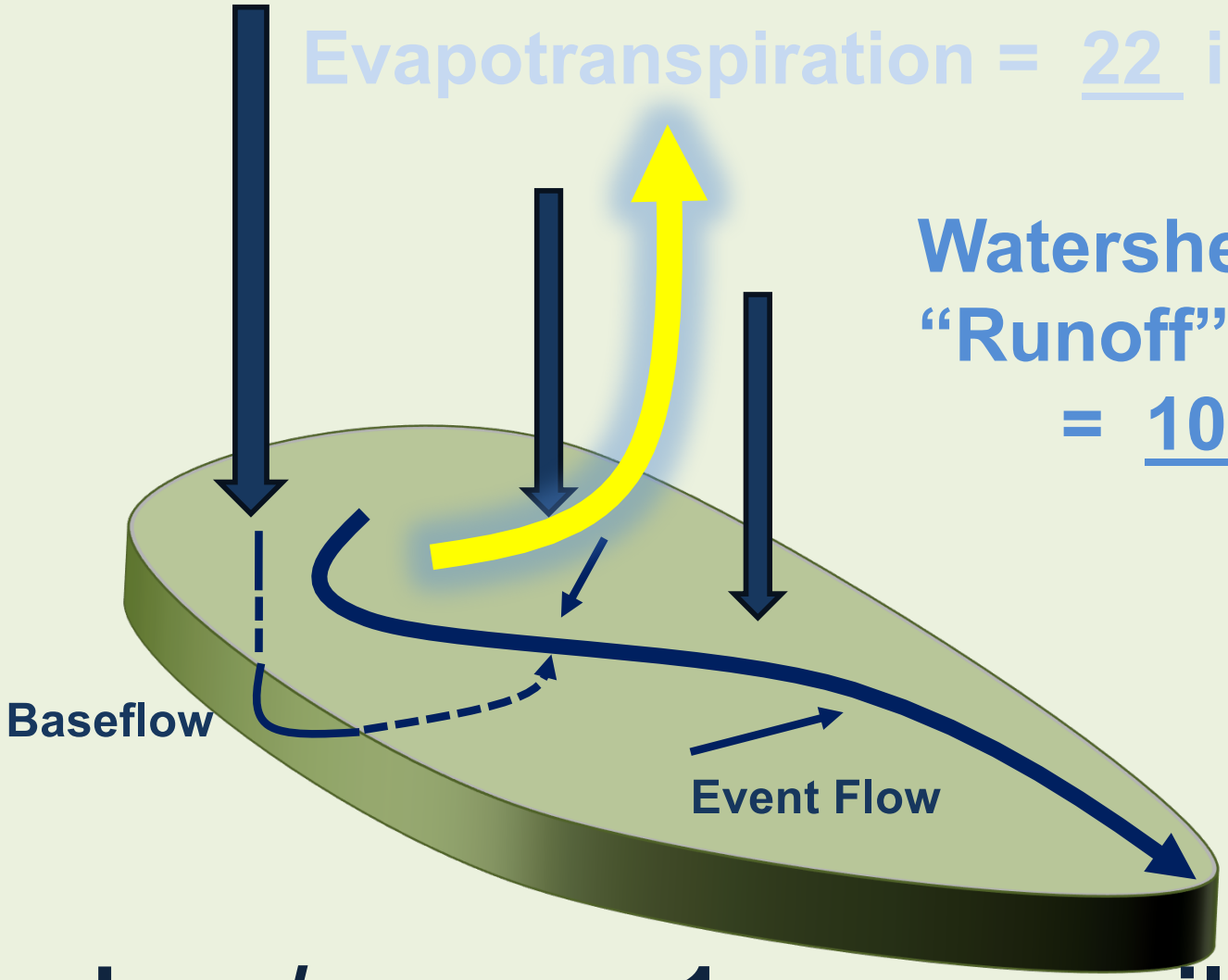
Watershed "Runoff" = 10 inches/yr

10 inches /year on 1 square mile…

= 23,000,000 cubic feet /year!

Precipitation = 32 inches/yr

Evapotranspiration = 22 inches/yr



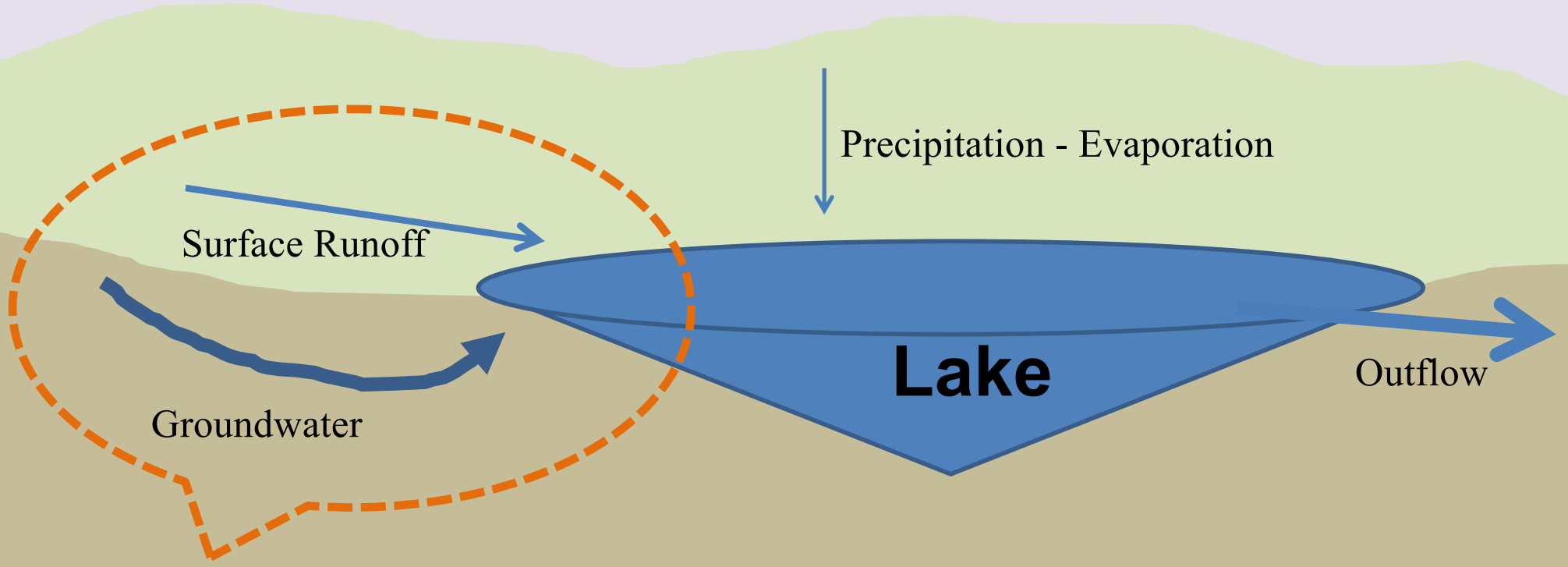
Watershed "Runoff" = 10 inches/yr

10 inches /year on 1 square mile…

= 23,000,000 cubic feet /year!

= 0.7 cubic foot every second!

This is a watershed model !



- Water Budget

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

Rule #1

“All models are wrong but some are useful”

George Box

Wrong

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

- **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 =**

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

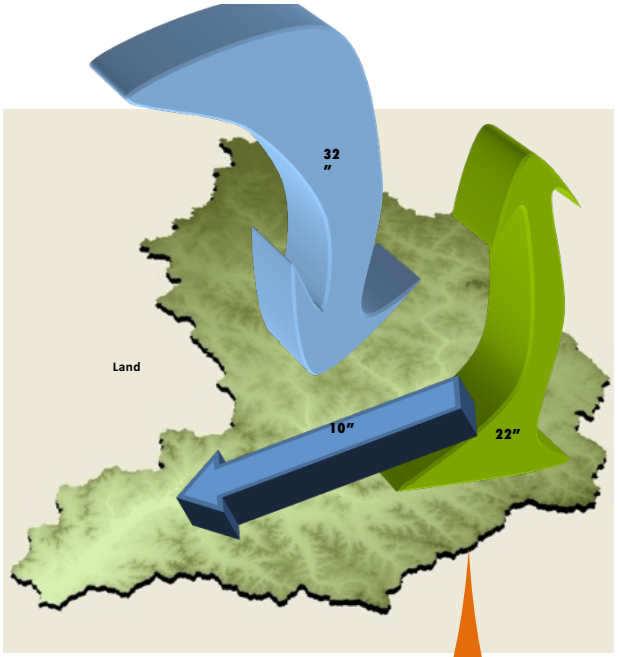
$$= 3.2 \text{ years}$$

How can we improve this model?

- Refine for different areas
- Look at storm intensity, patterns, soil moisture
- Simulate each year… or each day…

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

Modeling the Land?



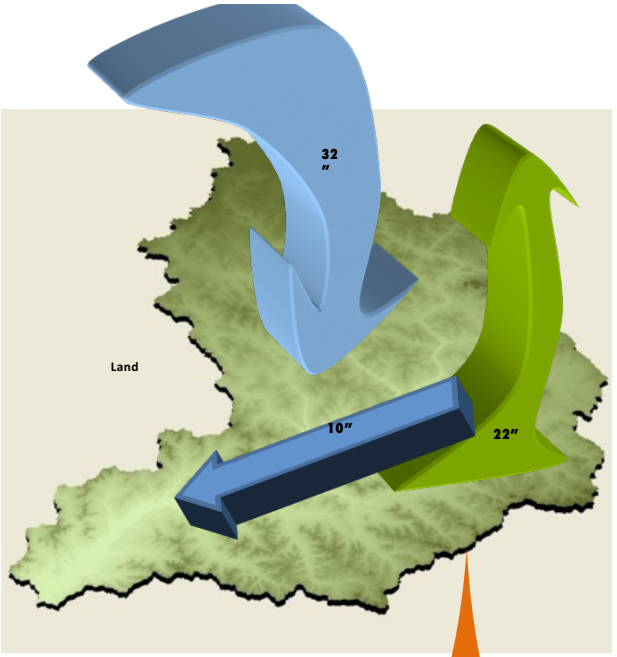
Follow
Every drop

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

Hourly Rainfall Vary By Area

Follow Every drop

Very Simple

Very Complex

Closely Related…**Nutrient Movement**

- Just talked about water movement on land

- Next… **Nutrient Loss from Land**

Let's look at Phosphorus Movement

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

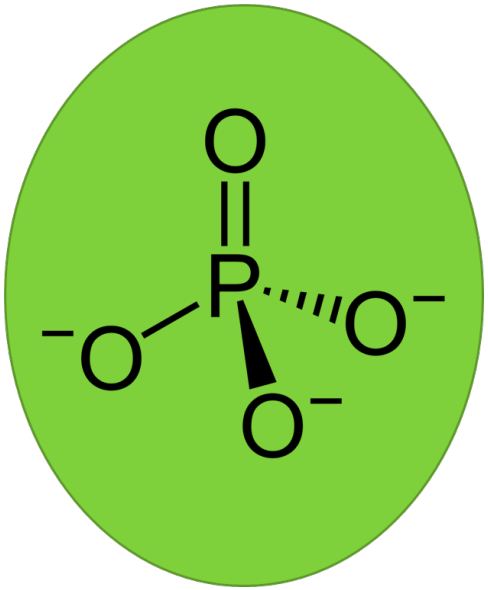
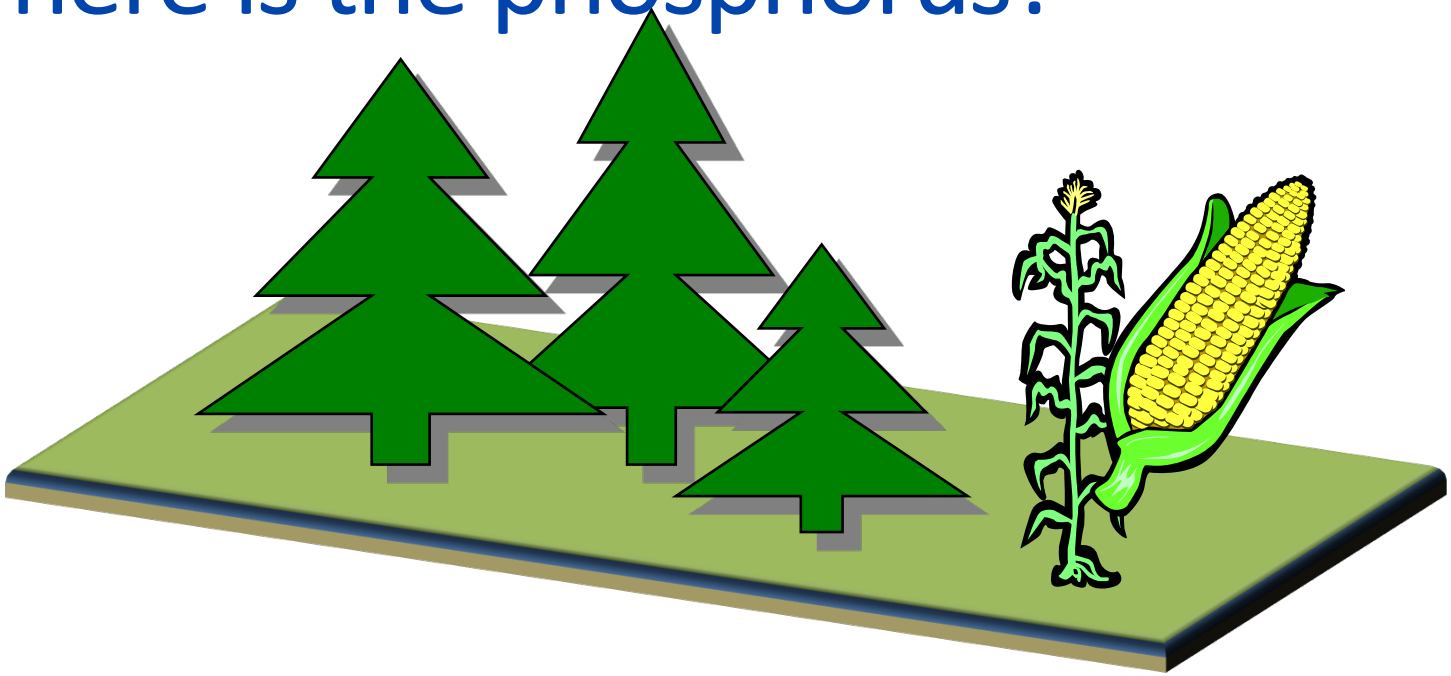


Table 1. Completed trophic state index and its associated parameters.

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

A Tale of Two Pathways

(and, how we go from rainfall to runoff volume w/ phosphorus concentration to lbs/acre-year)

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)

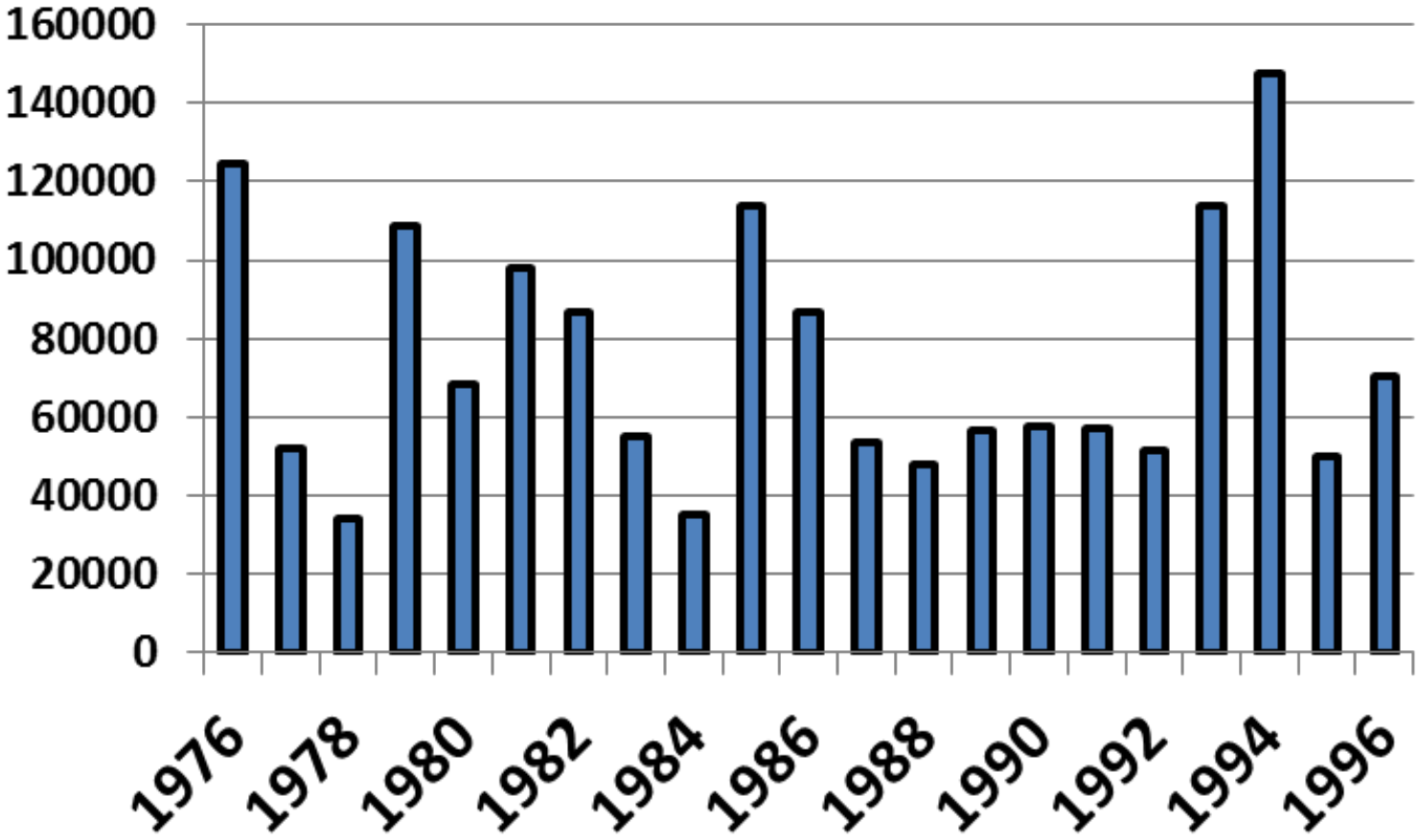
	Low	Most Likely	High
Agriculture (Mixed)	**0.3**	**0.8**	**1.4**
Med Density Urban	**0.3**	**0.5**	**0.8**
Pasture	**0.1**	**0.3**	**0.5**
Forest	**0.05**	**0.09**	**0.18**
Atmospheric (lake surface)	**0.1**	**0.3**	**0.5**

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

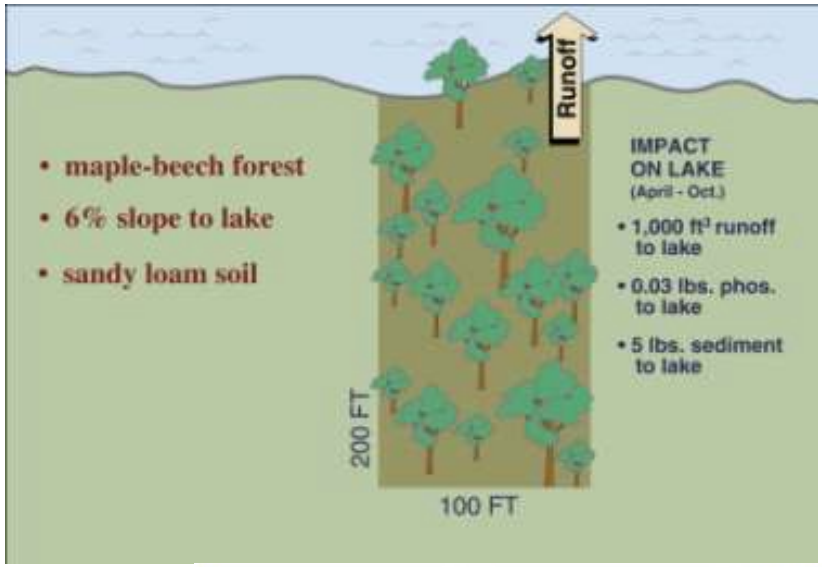
Useful... back to our 150,000 acre watershed

- 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
  - USEFUL?

Of course, this is a simplification: Annual Variations in P to Lake!

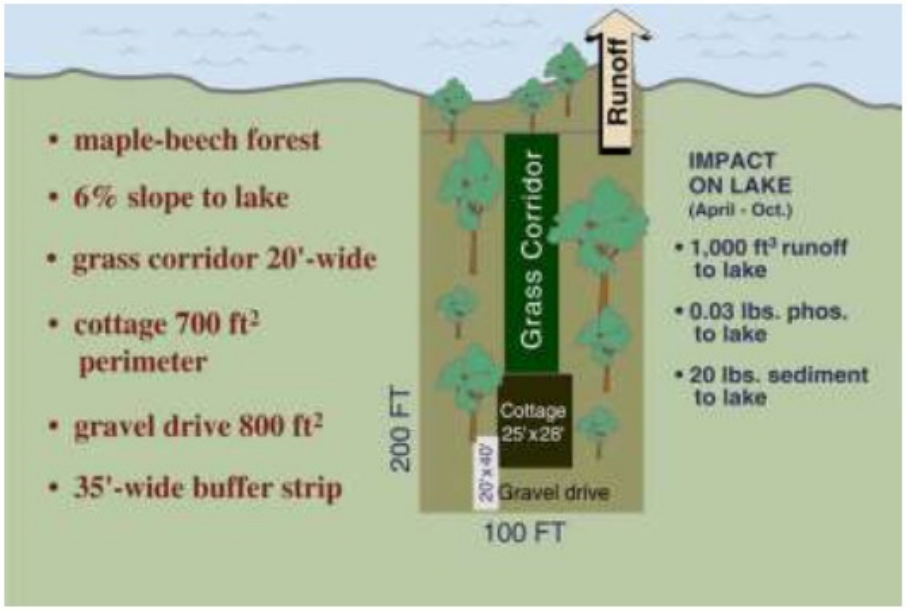


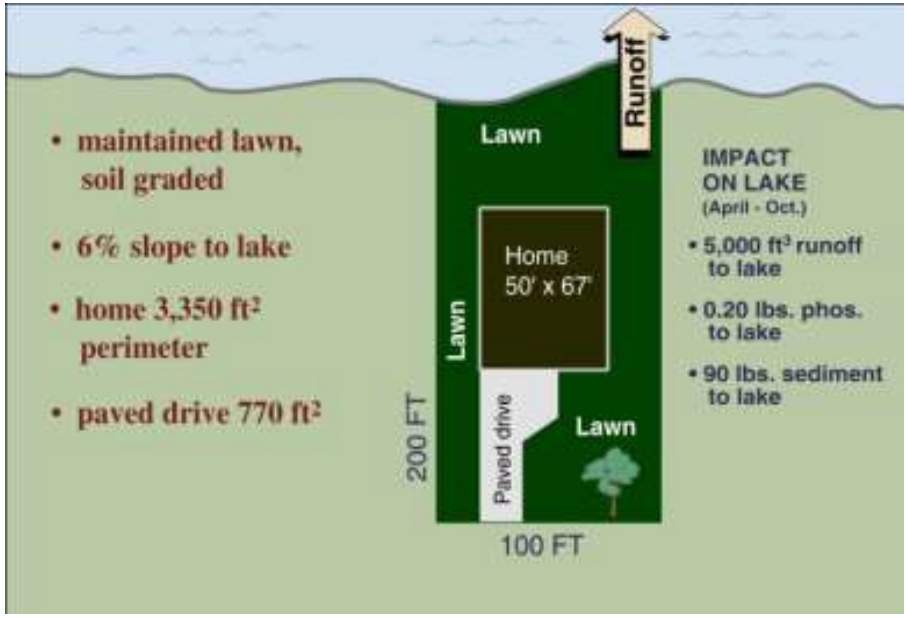
- P Load (lb) to Lake (Lathrop and Panuska)

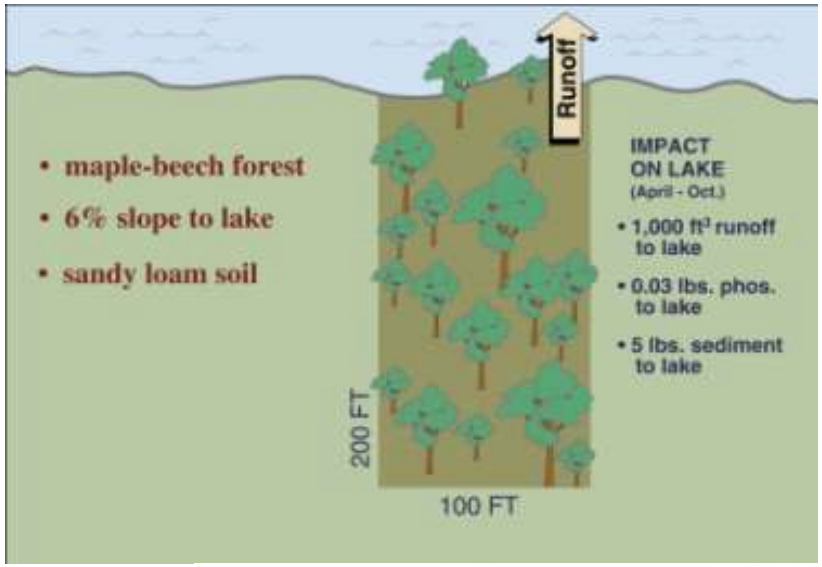


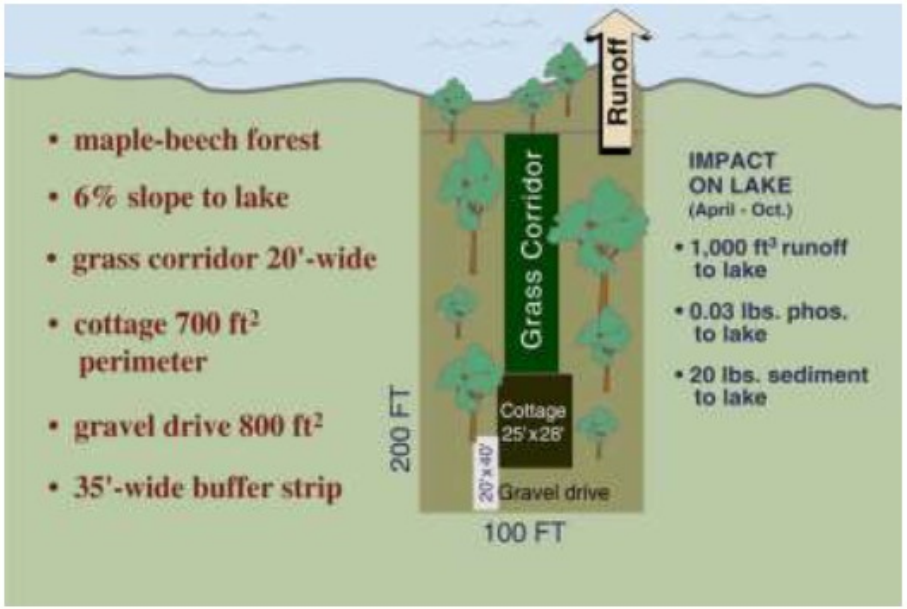
How about another important land modification….

Riparian Development





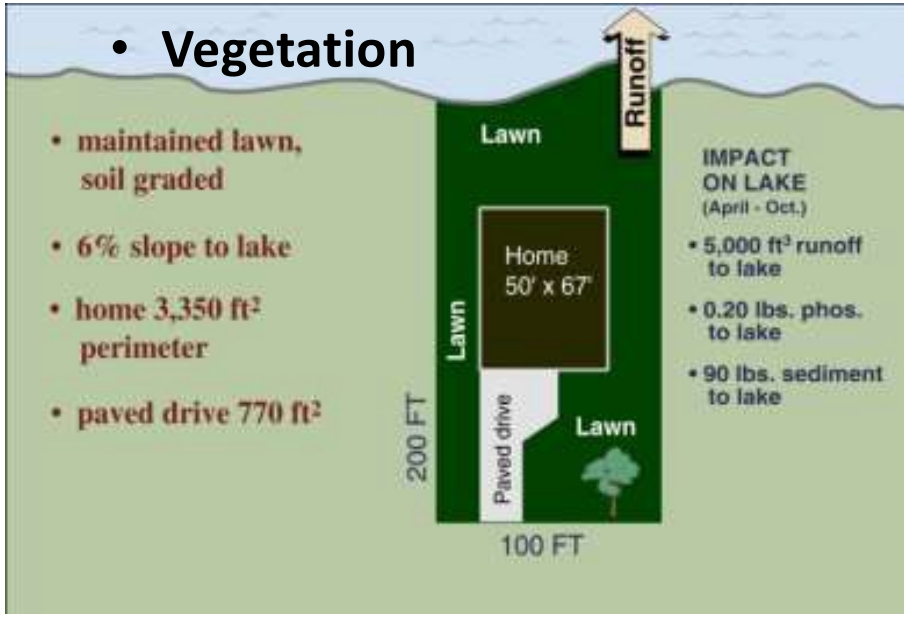




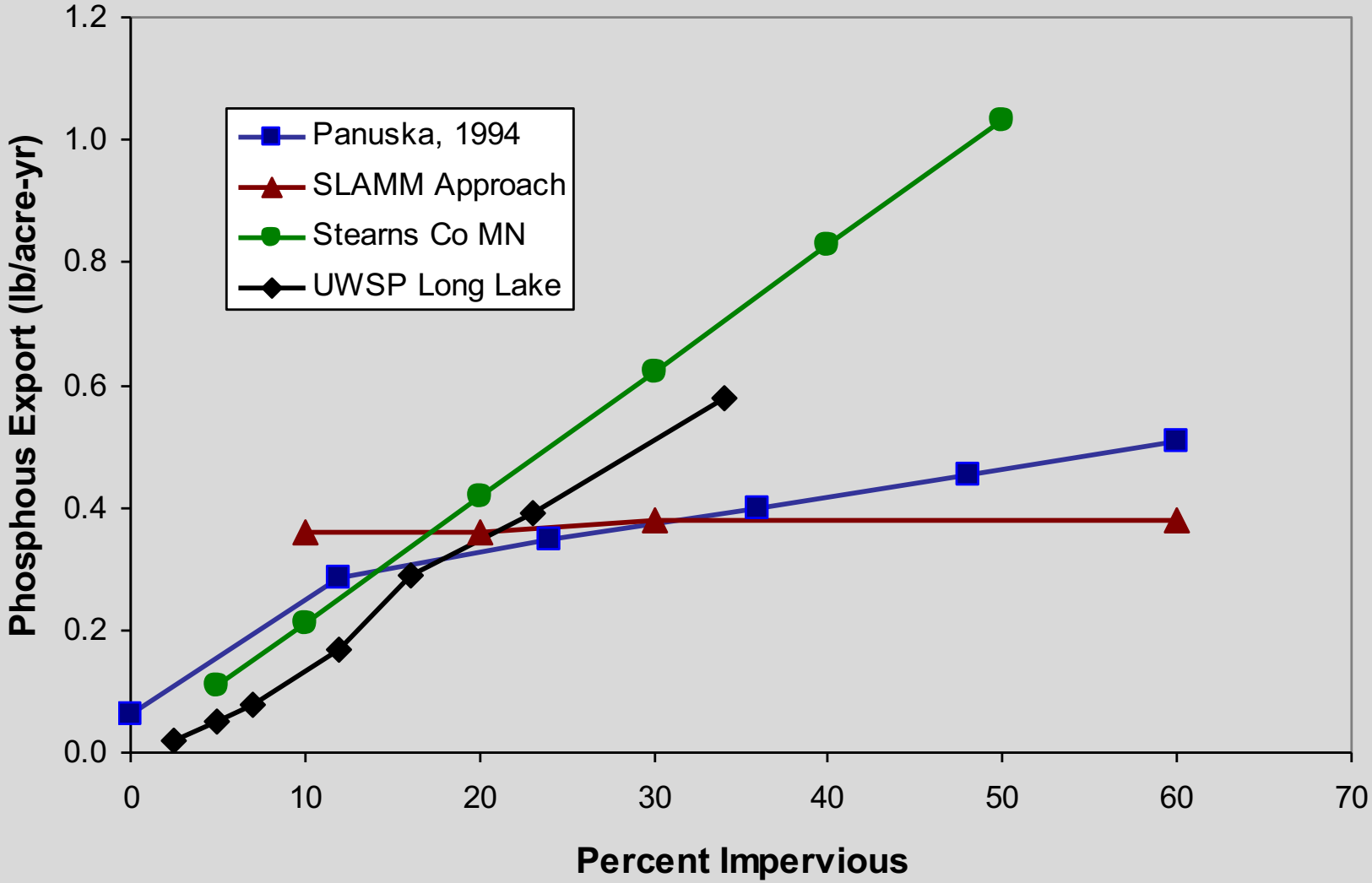
Riparian Development

Changes to phosphorus movement?

- **Changes in vegetation**
  - **Interception**
  - **Evapo-transpiration**
- **Changes in infiltration**
  - **Compaction**
- **Changes in runoff generation**
  - **Sources of runoff**
  - **Pathways it takes**
- **Changes in nutrient availability**
  - **Fertilizer**
  - **Vegetation**

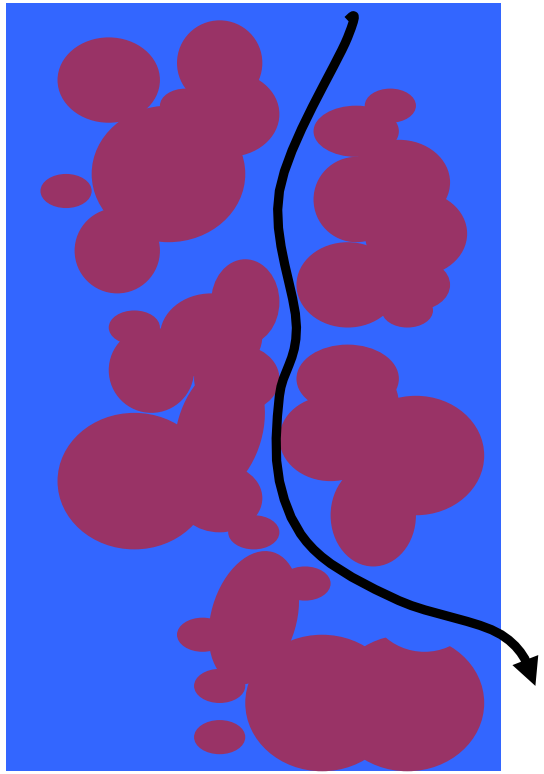


RIPARIAN MODEL OUTPUT EXAMPLE
4% to 5% slope/Silt Loam or Silty



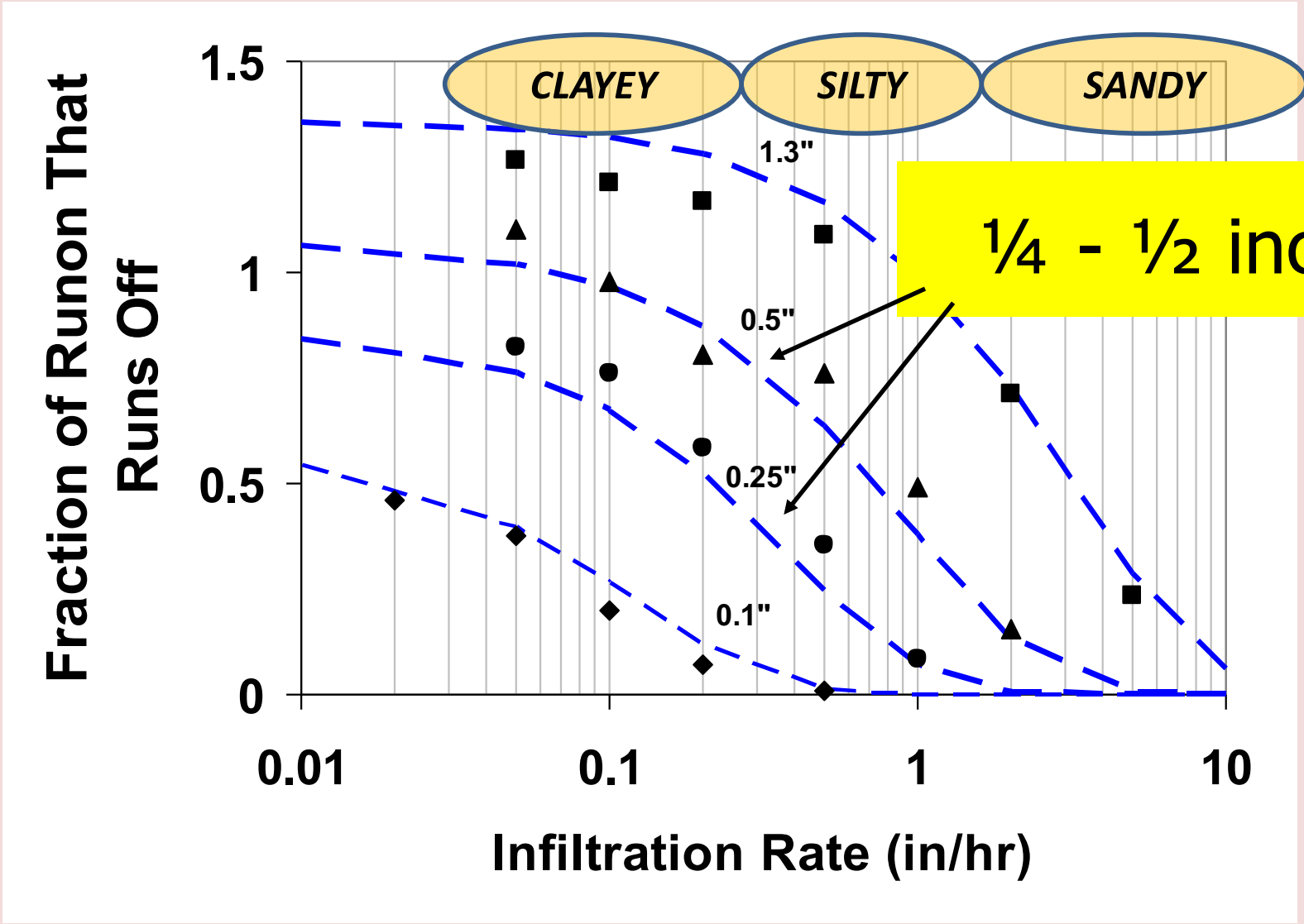
What about compaction?

Condition	Ponded Infiltration Rate (in/hr)
Vegetated	3.4
Open Soil	0.7
Traffic	0.1



Silt loam soil described by Vervoort, R.W., S.M. Dabney and M.J.M. Romkens. 2001. Tillage and Row Position Effects on Water and Solute Infiltration Characteristics, Soil Science Society of America Journal 65:1227-1234.

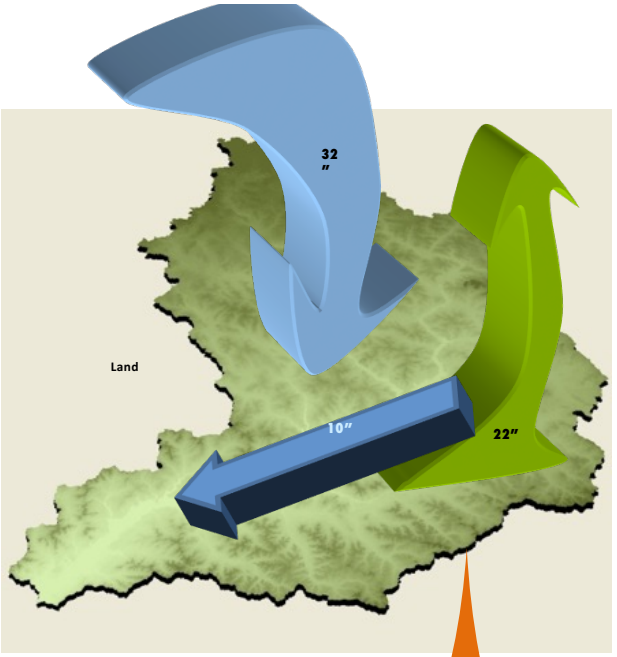
Another Model…. Runoff from an impervious area onto a pervious slope
Short time-step, rain, runoff, flow across infiltration surface!



Runon Ratio
500 / 5(w) x 40 (L)

The fraction of runon to the secondary buffer that would infiltrate for different storm sizes and infiltration rates (assumes a 500 ft2 impervious area draining to a five foot wide channel, forty feet long and one hour storm of depth shown). Dashed lines show the fitted equation based on soil infiltration rate and storm depth.

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

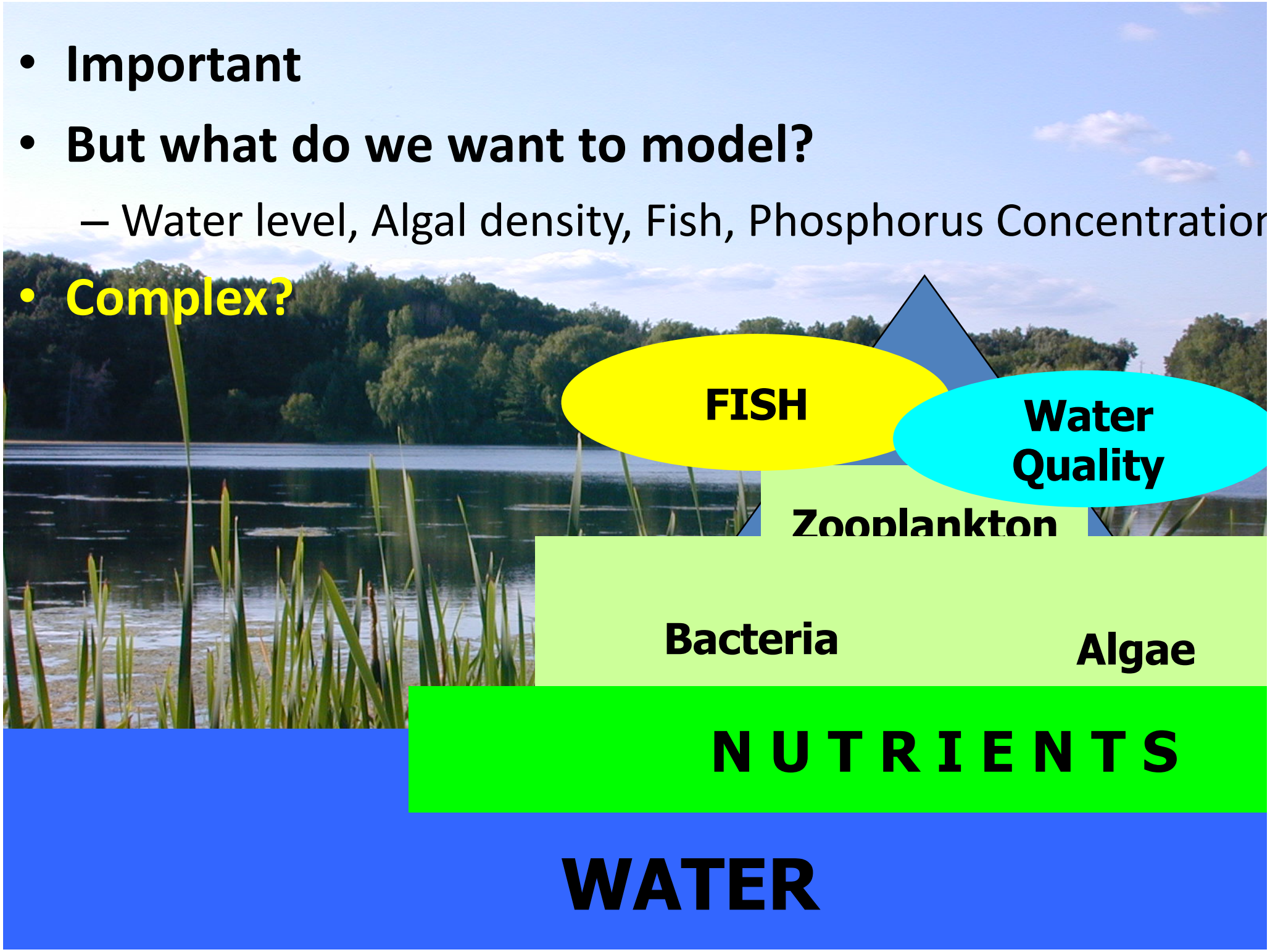
Follow Every drop

Very Simple

Very Complex

Part 2 - LAKES

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

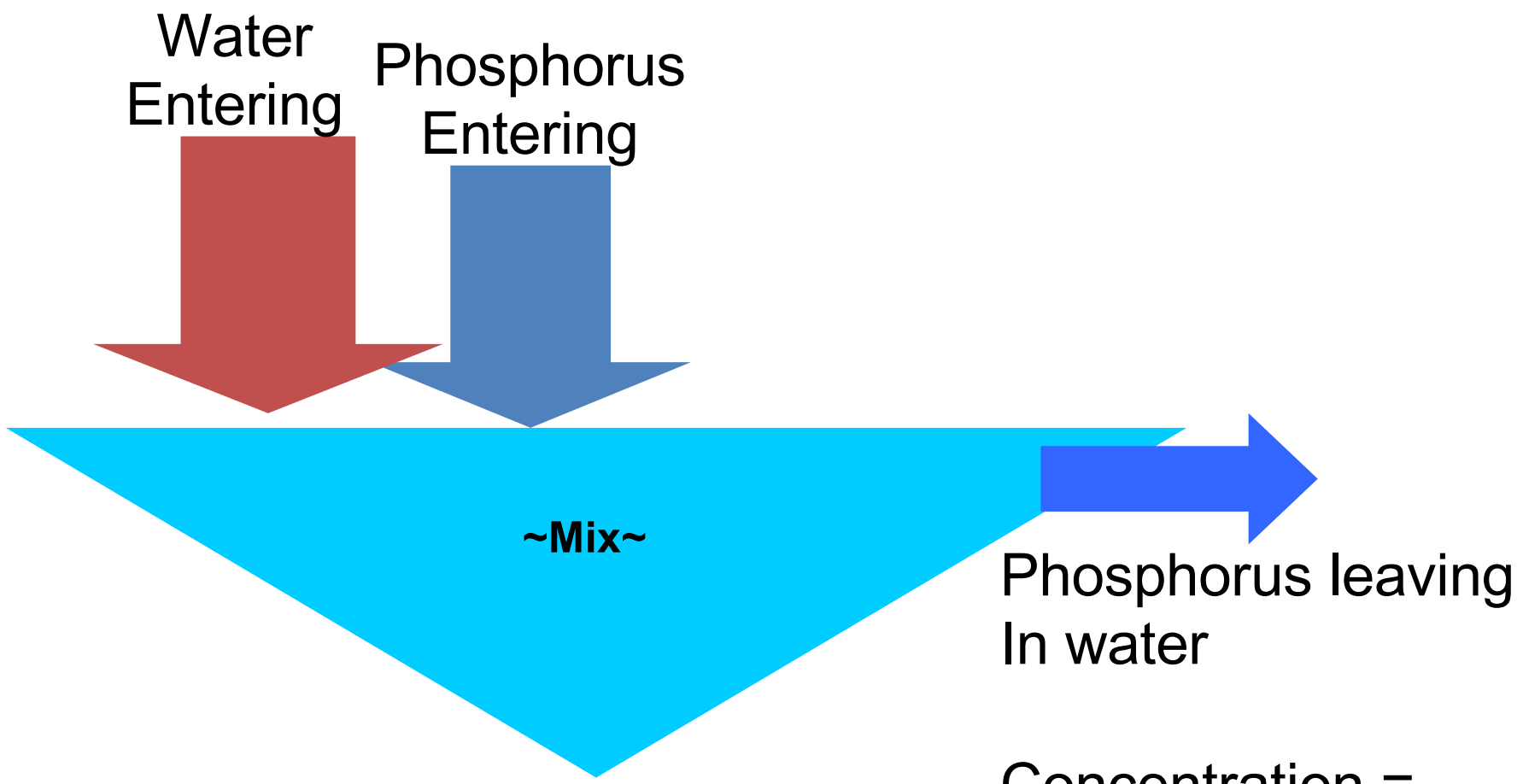


Our First Model

- Goal– predict the P concentration

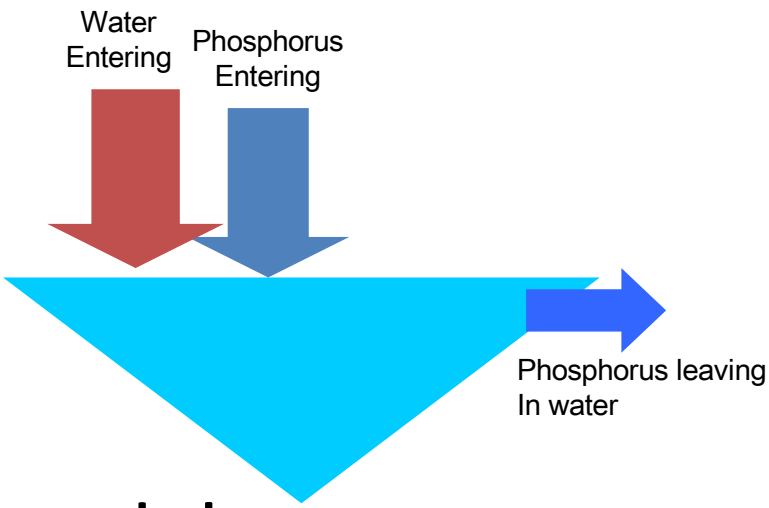
Given

- 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)

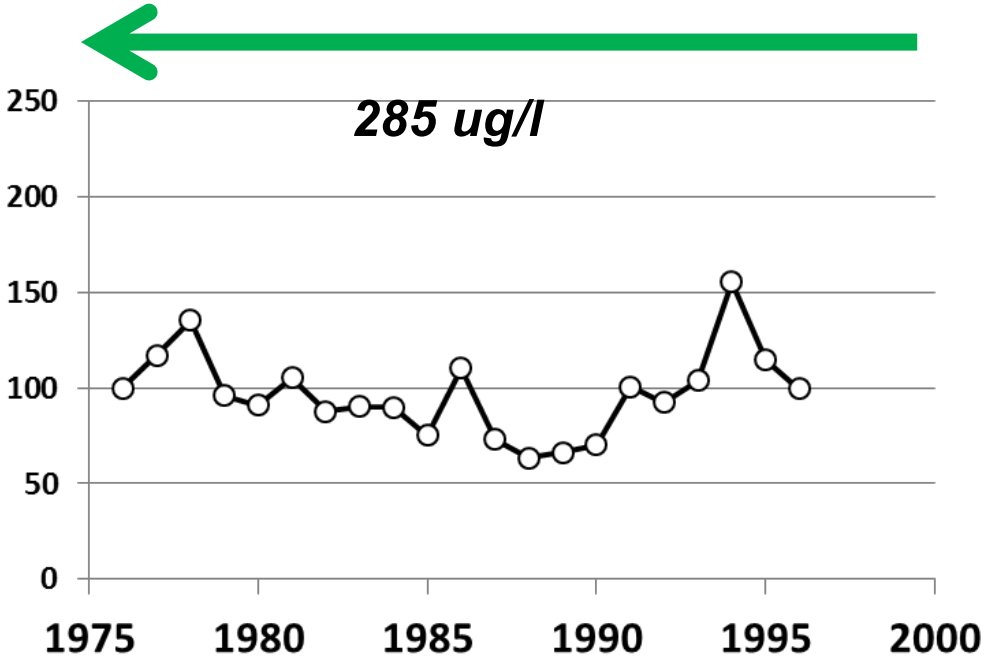
- ***Concentration of P***

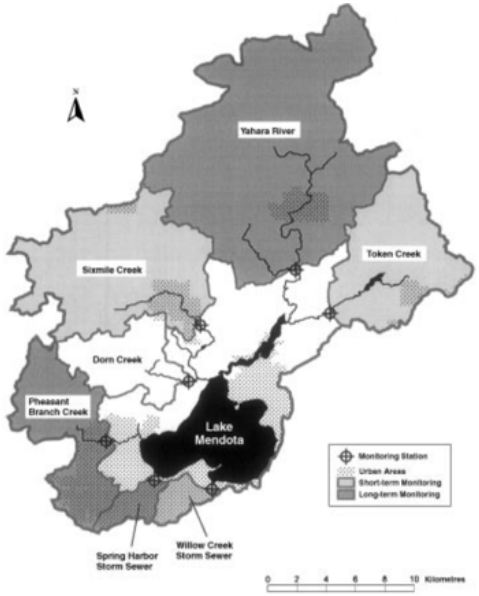
  = Mass of P / Volume of Water

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

  = 285 ug/l

Take a look at some data

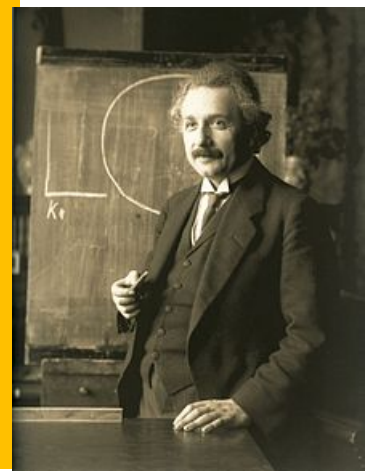




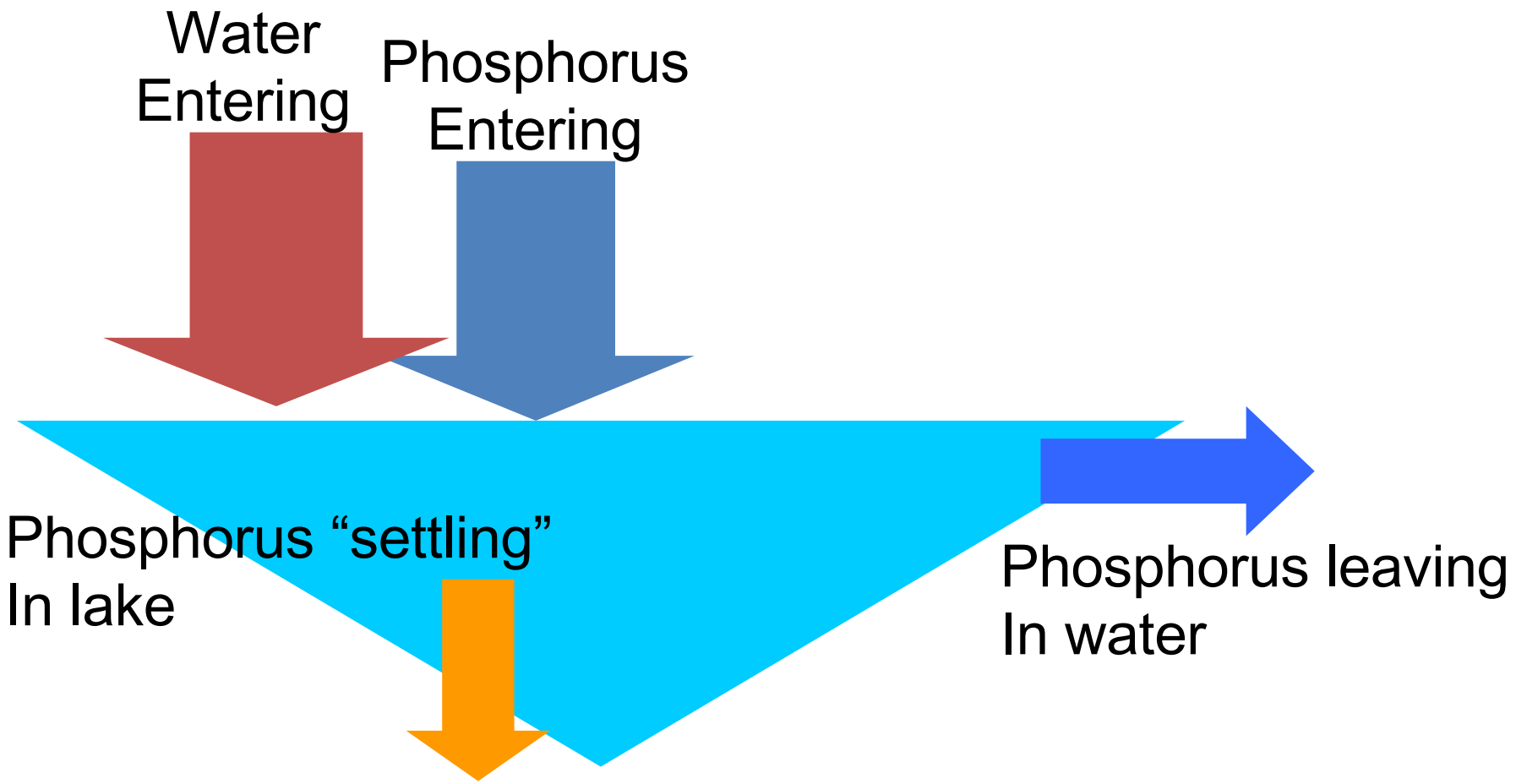
Lathrop and Panuska 1998

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

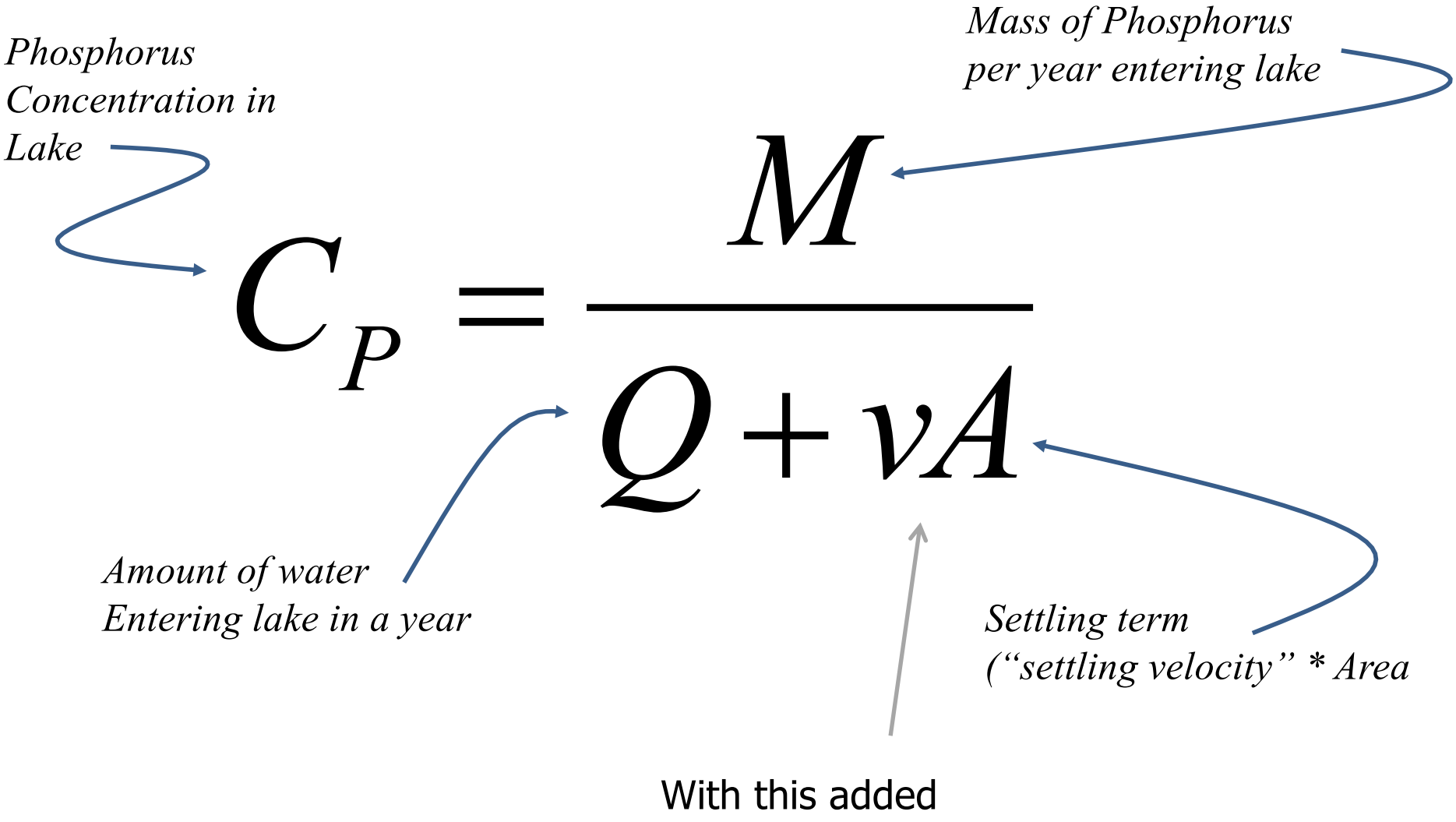


"diminished by retention term as P apparently lost to sediments" (Nurnberg, 1984)

Uniform ("steady-state") Conditions

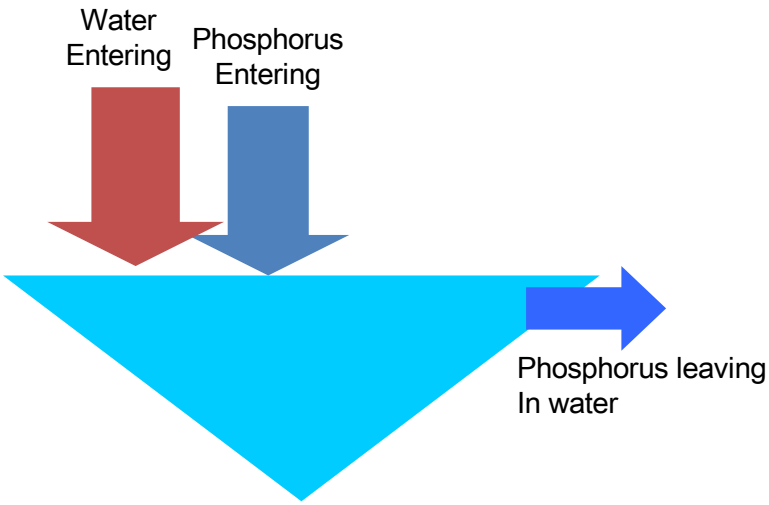
The P concentration doesn't change with time

The amount of P in the lake is constant



Let's give this a try

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



Assume

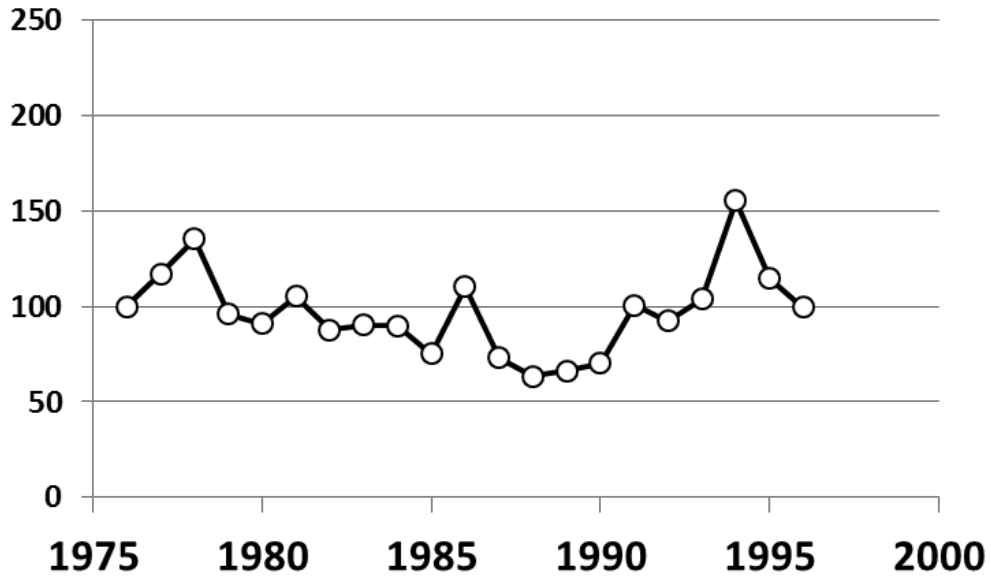
- 96,000 lb/year P
- 125,000 acre-feet water/year
- 40,500,000 m2 lake surface
- 10 meter/year settling velocity

Our “Less Simple Model”

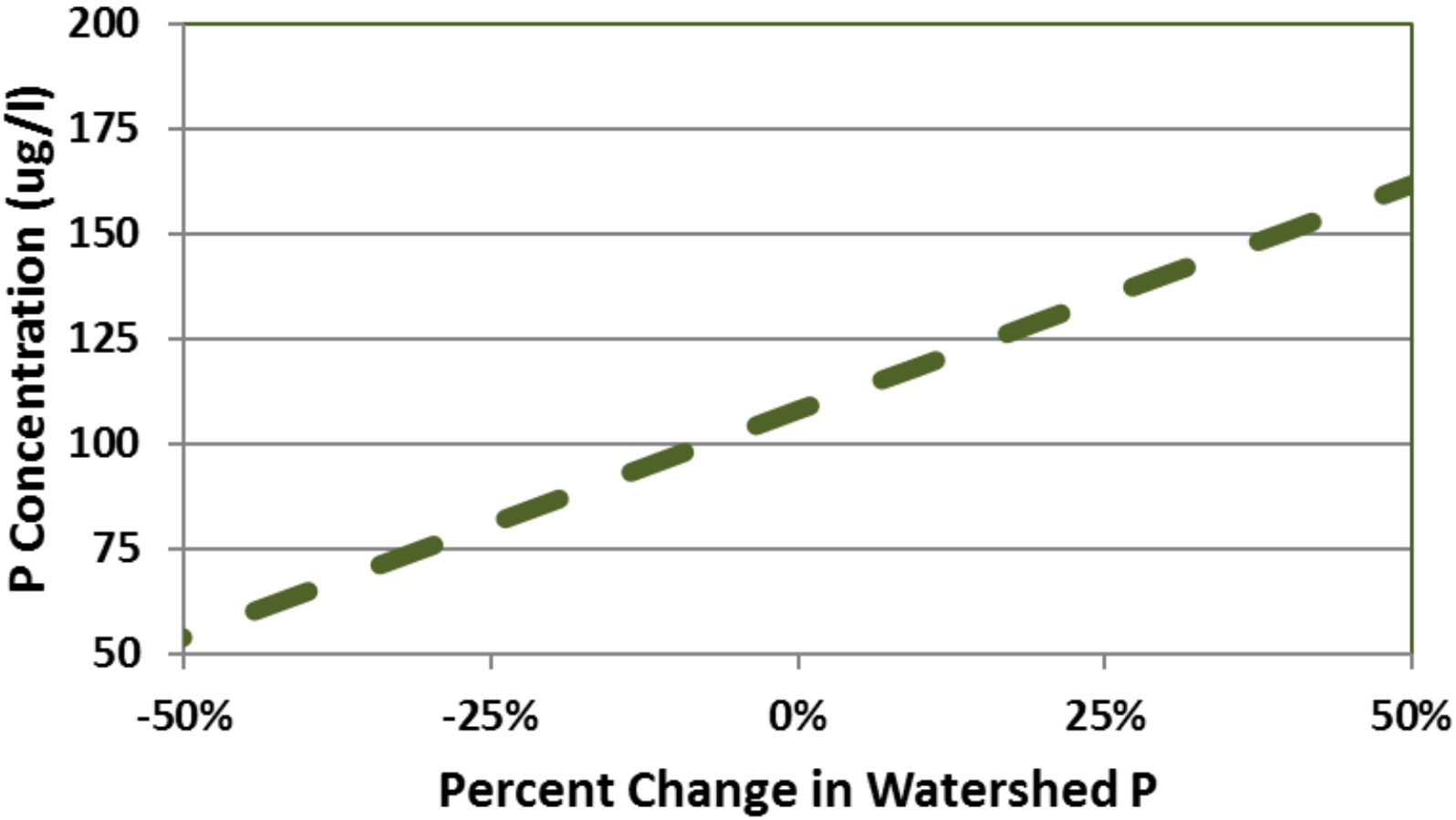
- **Concentration of P**

  = 108 ug/l (better?)

- **Useful?**



Useful?


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

Of course this is still a simple model…

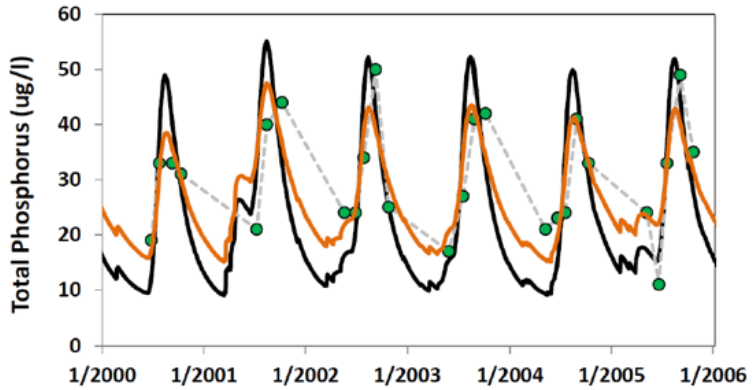
Annual Phosphorus Input

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

Annual Water Input

Annual Phosphorus Settling

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



Other Models

- Variations in movement of water
  - Stratified lake
  - Segmented lake
  - Groundwater flow models
  - Ice covered lake…warming--density!

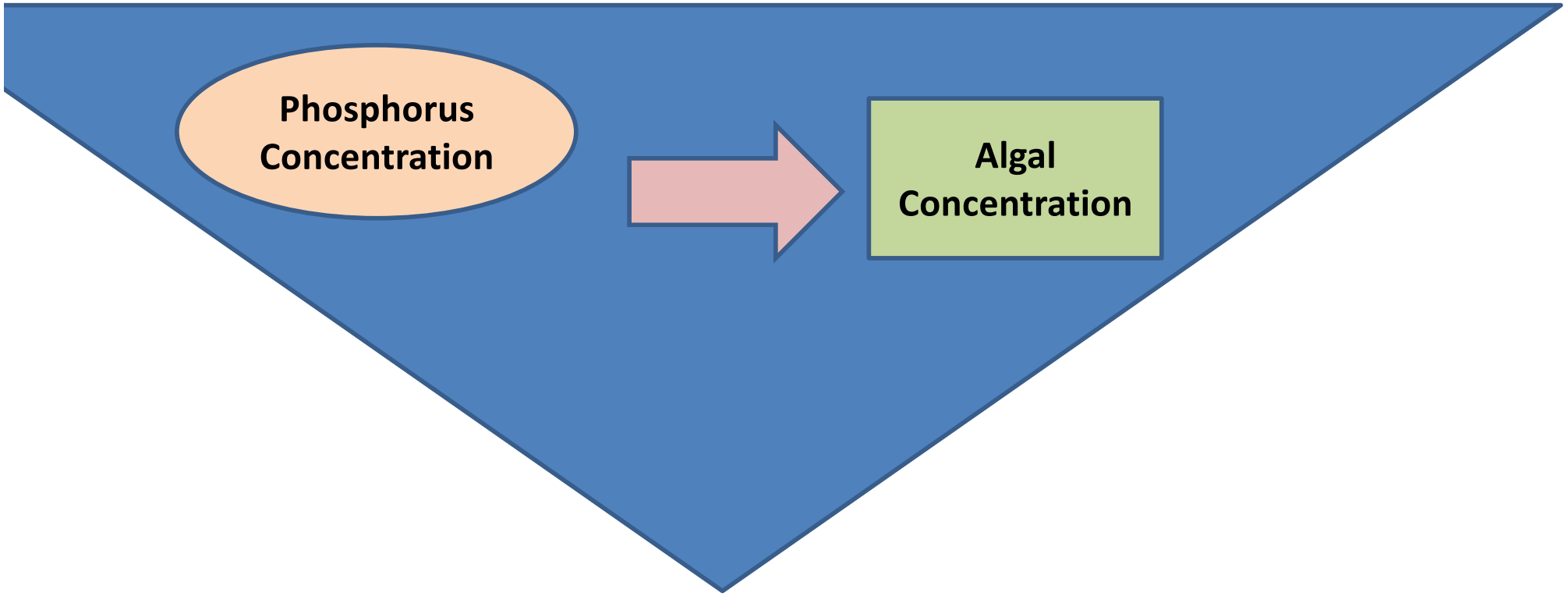
"Hydrodynamic Models"
"One-Dimensional, Two-D, Three-D"

Other Models

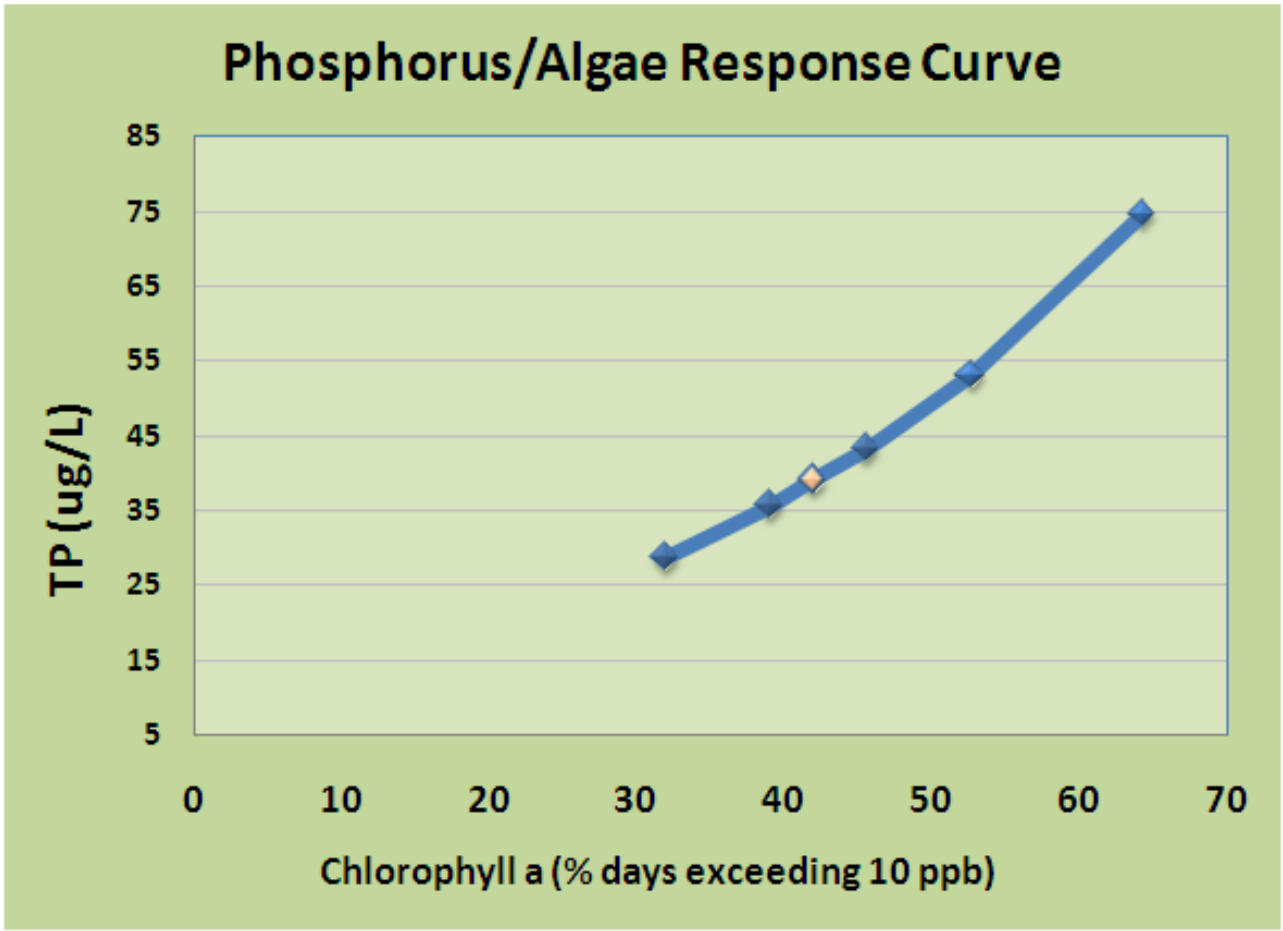
- Variations in Chemistry (P, other) over time /space
  - Daily or hourly models
  - Segmented lake models
  - Dissolved oxygen
  - Calcium carbonate formation (“Marl”)
  - Sediment release

“Transient Models”
“Spatially Variable Models”
“Chemical Models”

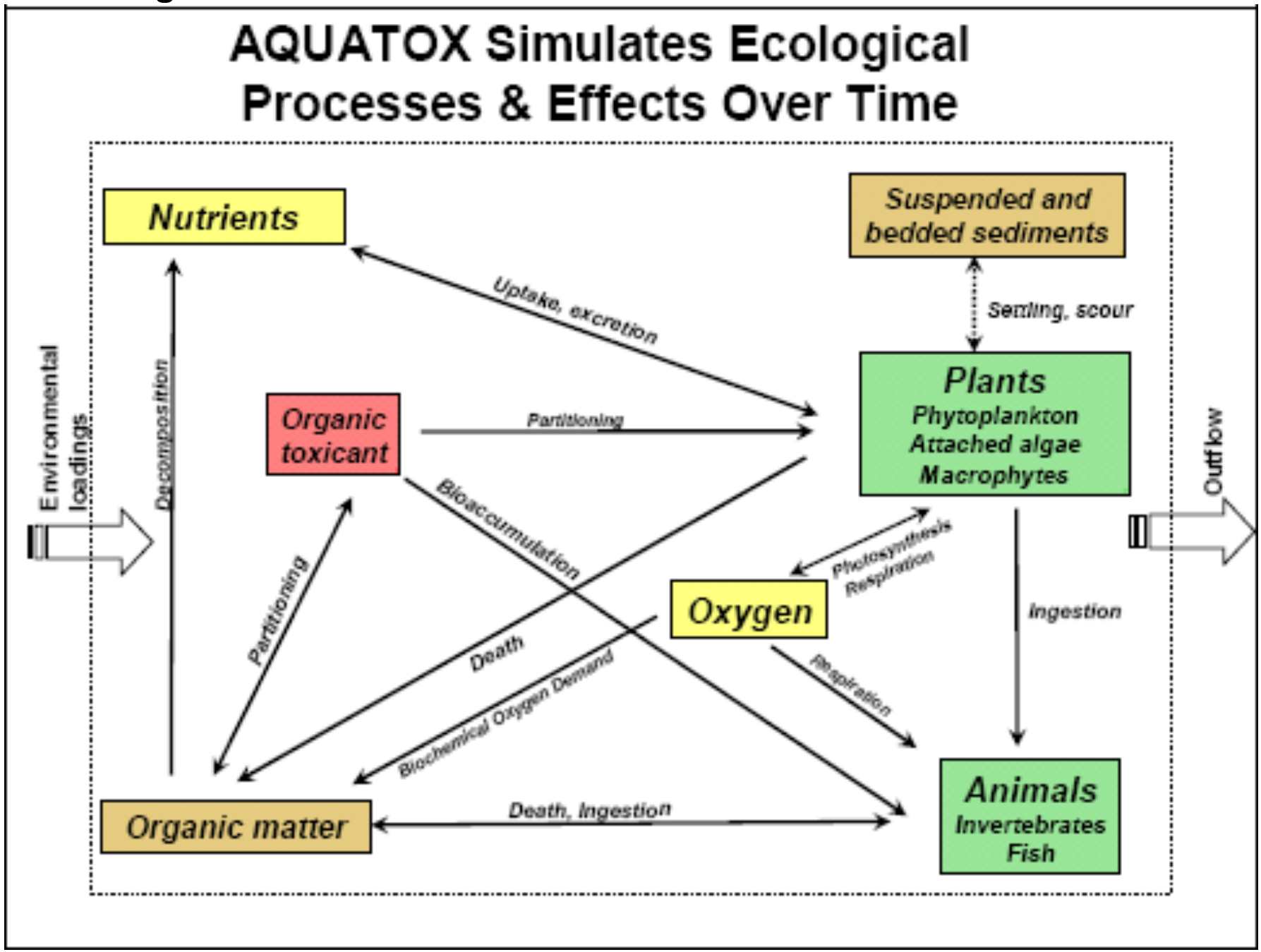
Lake Response Model?



- 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)

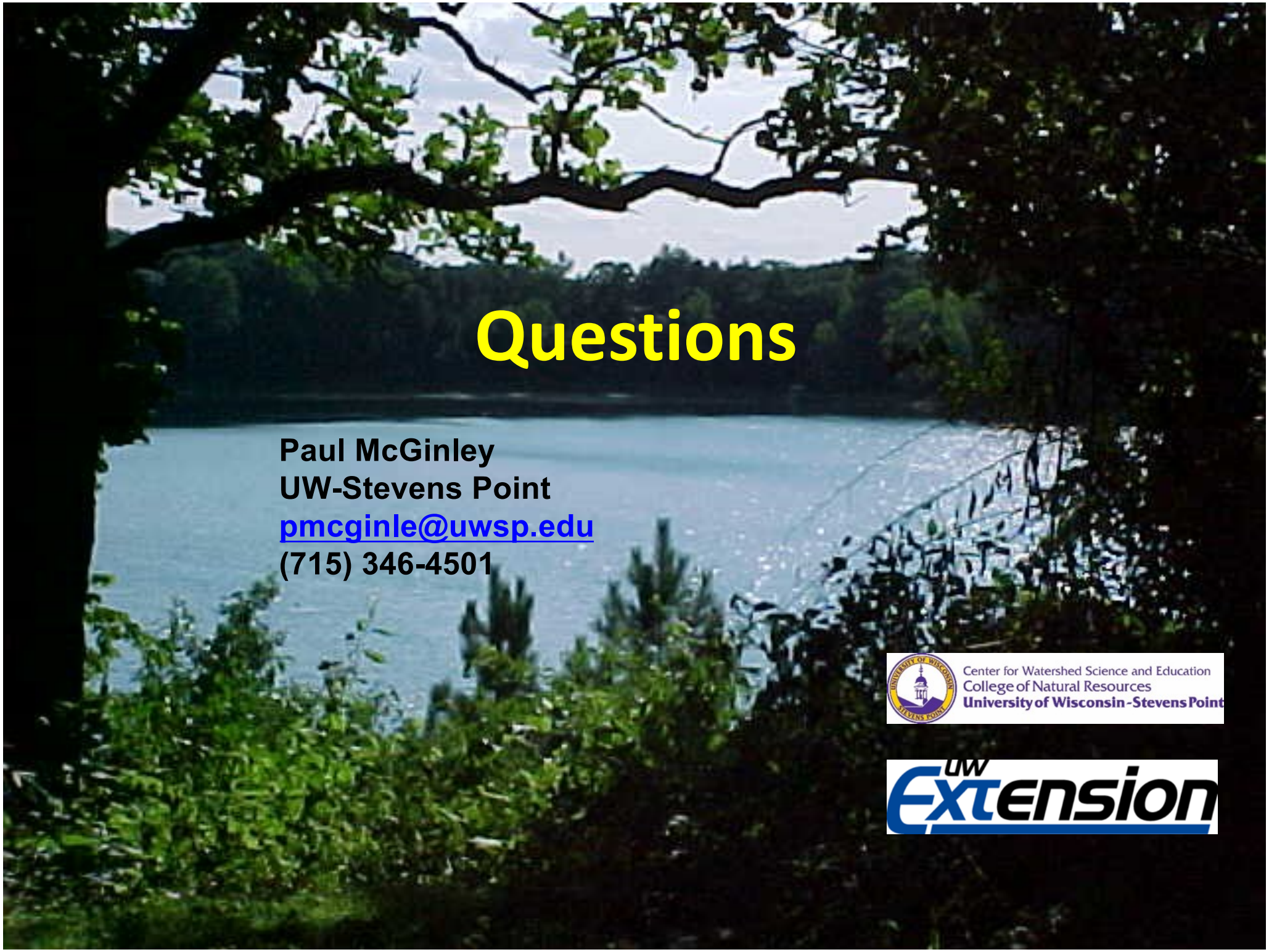
Increasing interest in food web models



Discussion

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

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


Questions
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