Modeling … What's the Use?

Paul McGinley
Center for Watershed Science & Education
UW Stevens Point

UW Extension

Center for Watershed Science and Education
College of Natural Resources
University of Wisconsin-Stevens Point

Lake Leaders 2014

What's a model

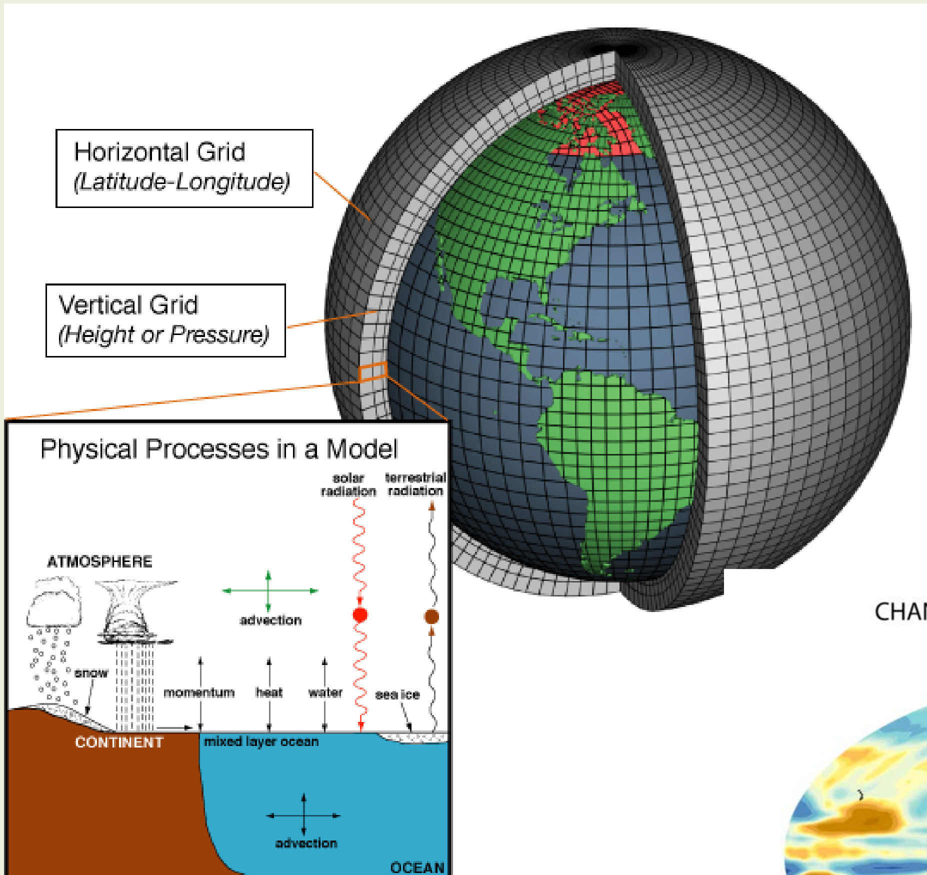
One definition:

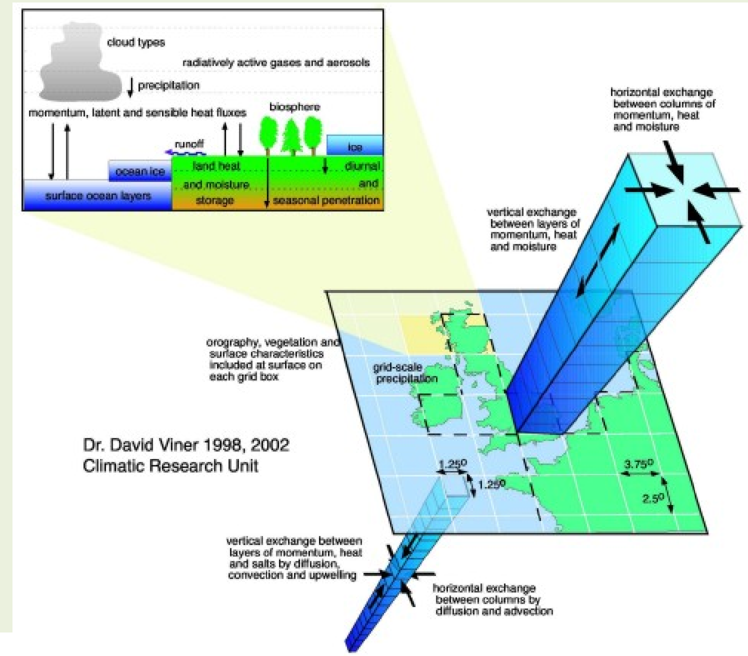
A mathematical description to help visualize something

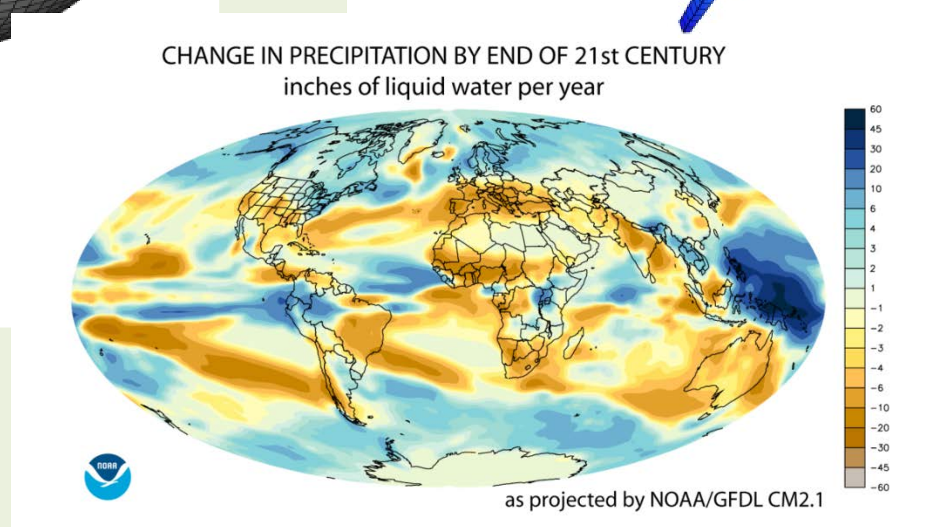
Model airplane

Very large computer

Example– General Circulation Model







http://celebrating200years.noaa.gov/breakthroughs/climate_model/AtmosphericModelSchematic.png

What’s a model

One definition: A mathematical description to help visualize something

Can this help us “visualize” how past actions have led to a current condition

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

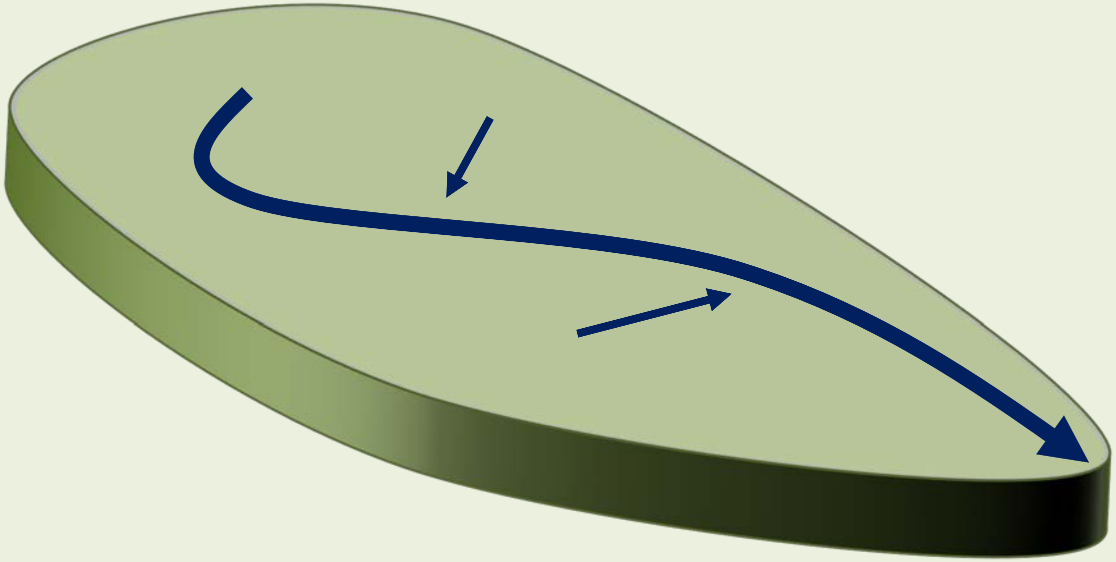
Today…. 1) Watersheds and 2) Lakes *& 3) Streams*

- **Functioning – big picture arm waving – & the development of "Conceptual" Models**
- **Modeling Approaches –**
  - **Fundamentals**
  - **Examples (simple & not so simple)**
  - **Compare & contrast**

Goal- Understand if these might be useful & what is an appropriate model

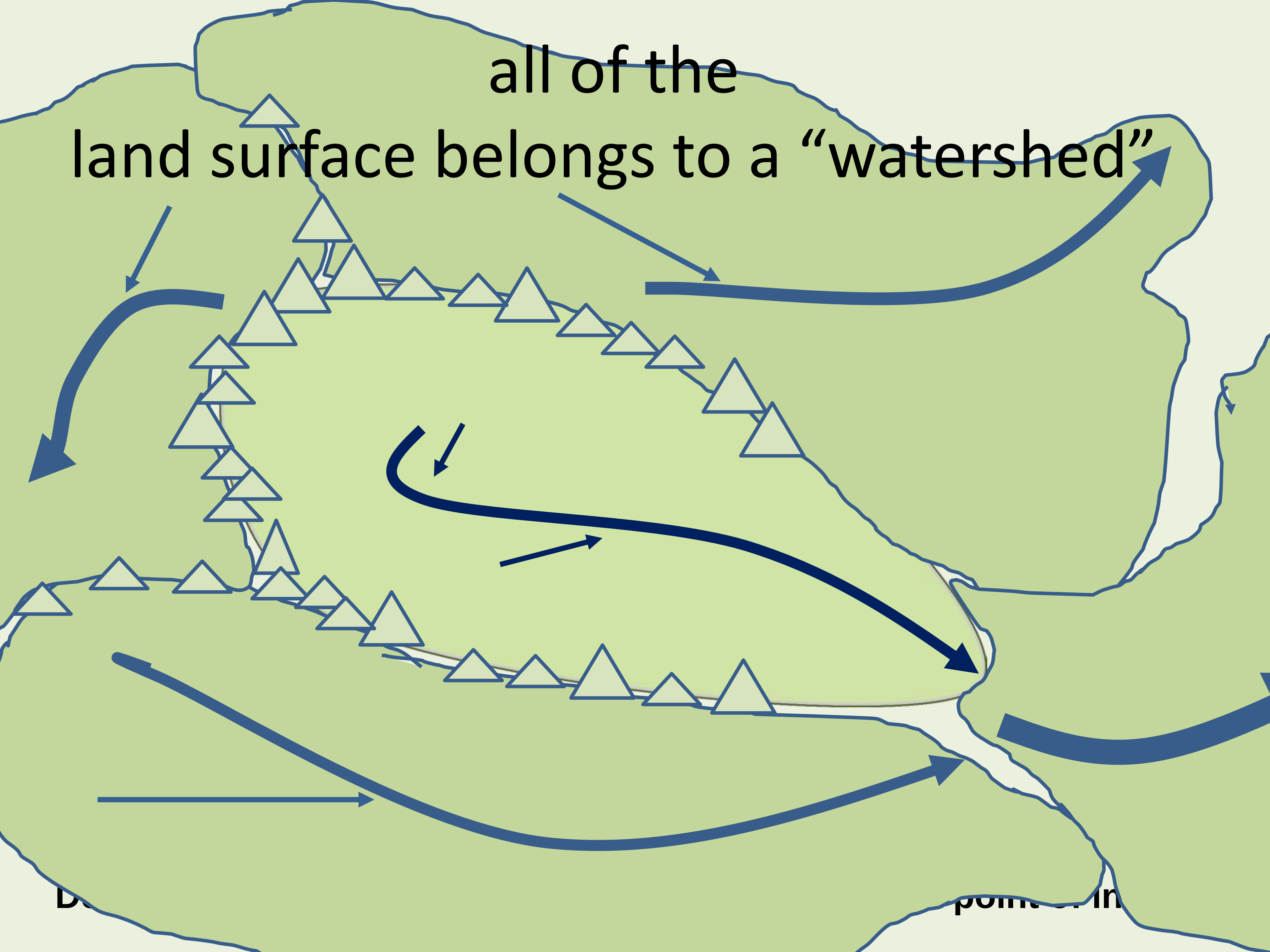
(and most important… not make a potentially confusing topic more confusing…)

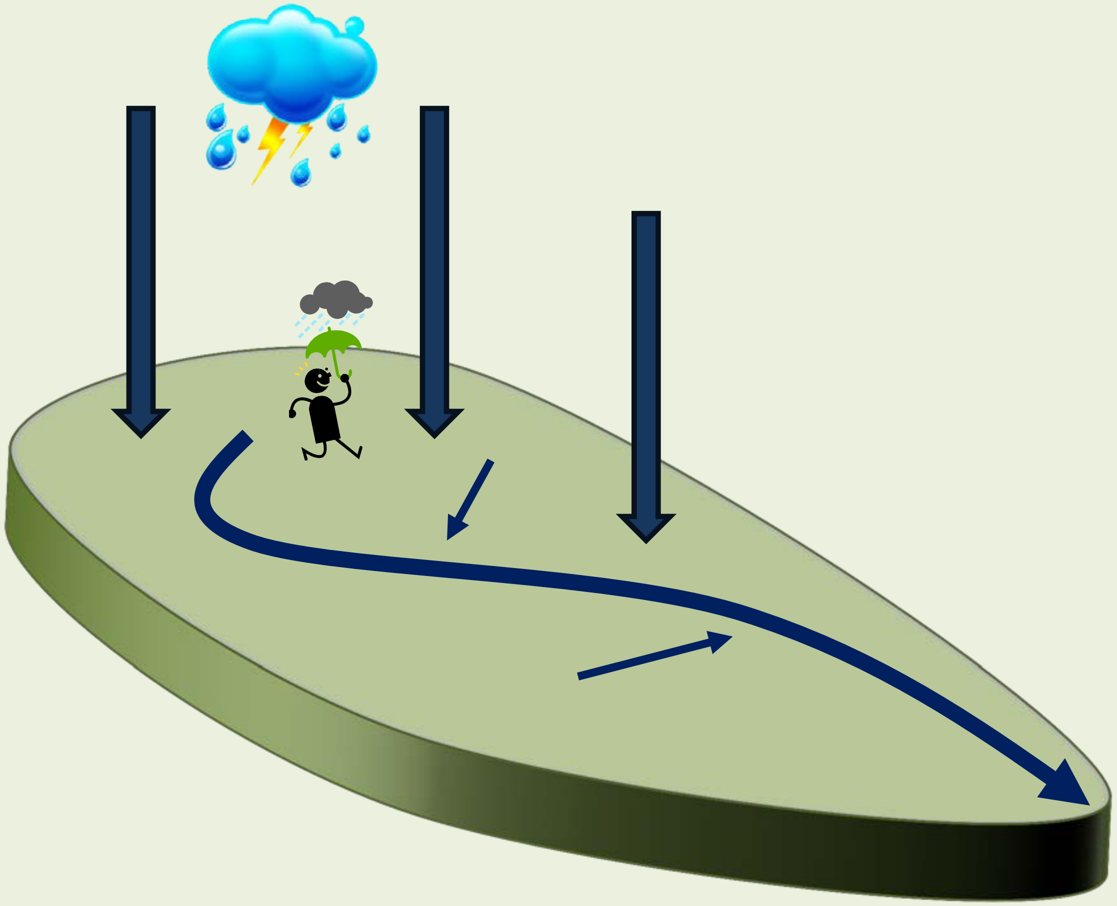
Part 1 – Watersheds



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

all of the land surface belongs to a “watershed”



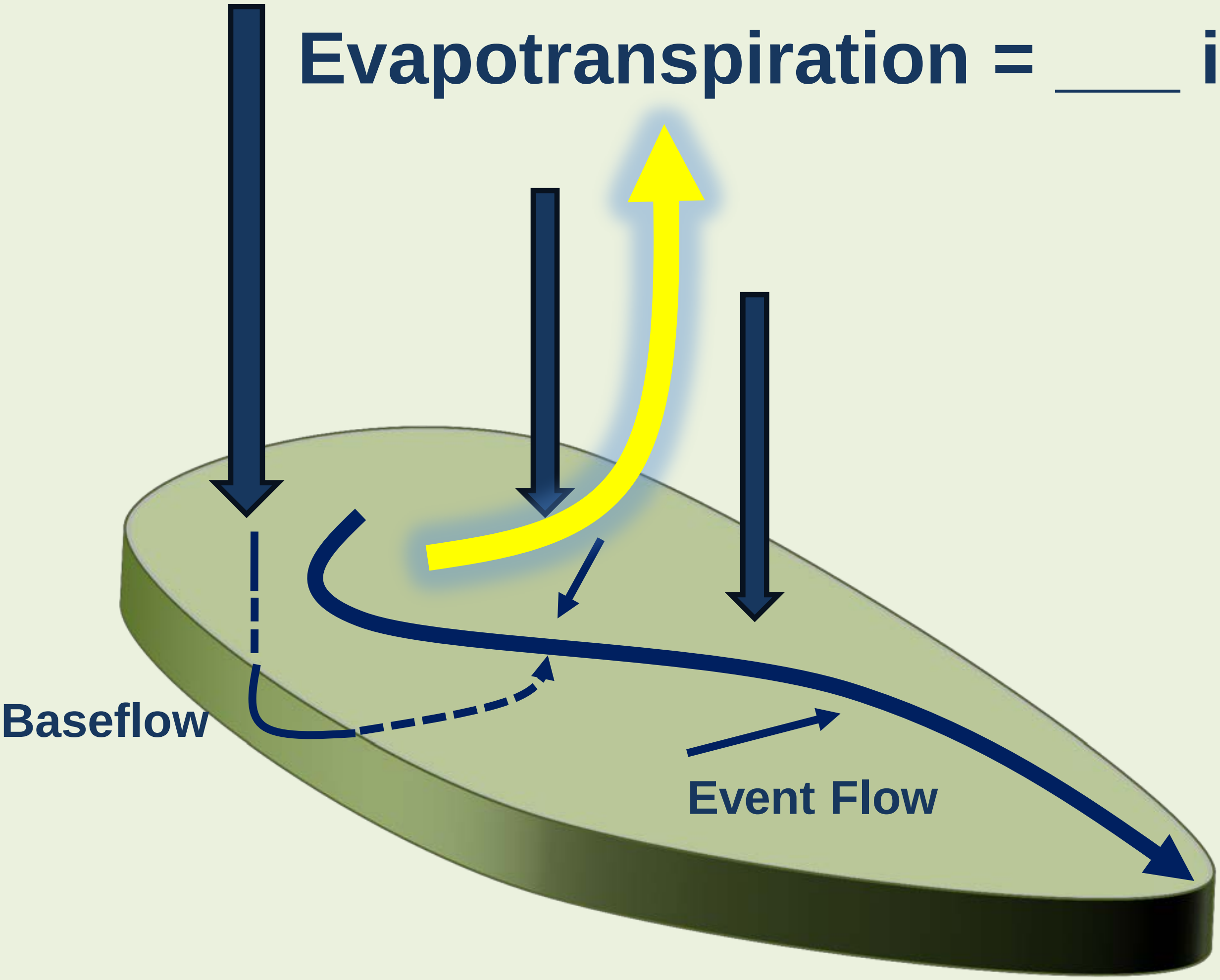


Our Watershed Interest This Morning

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

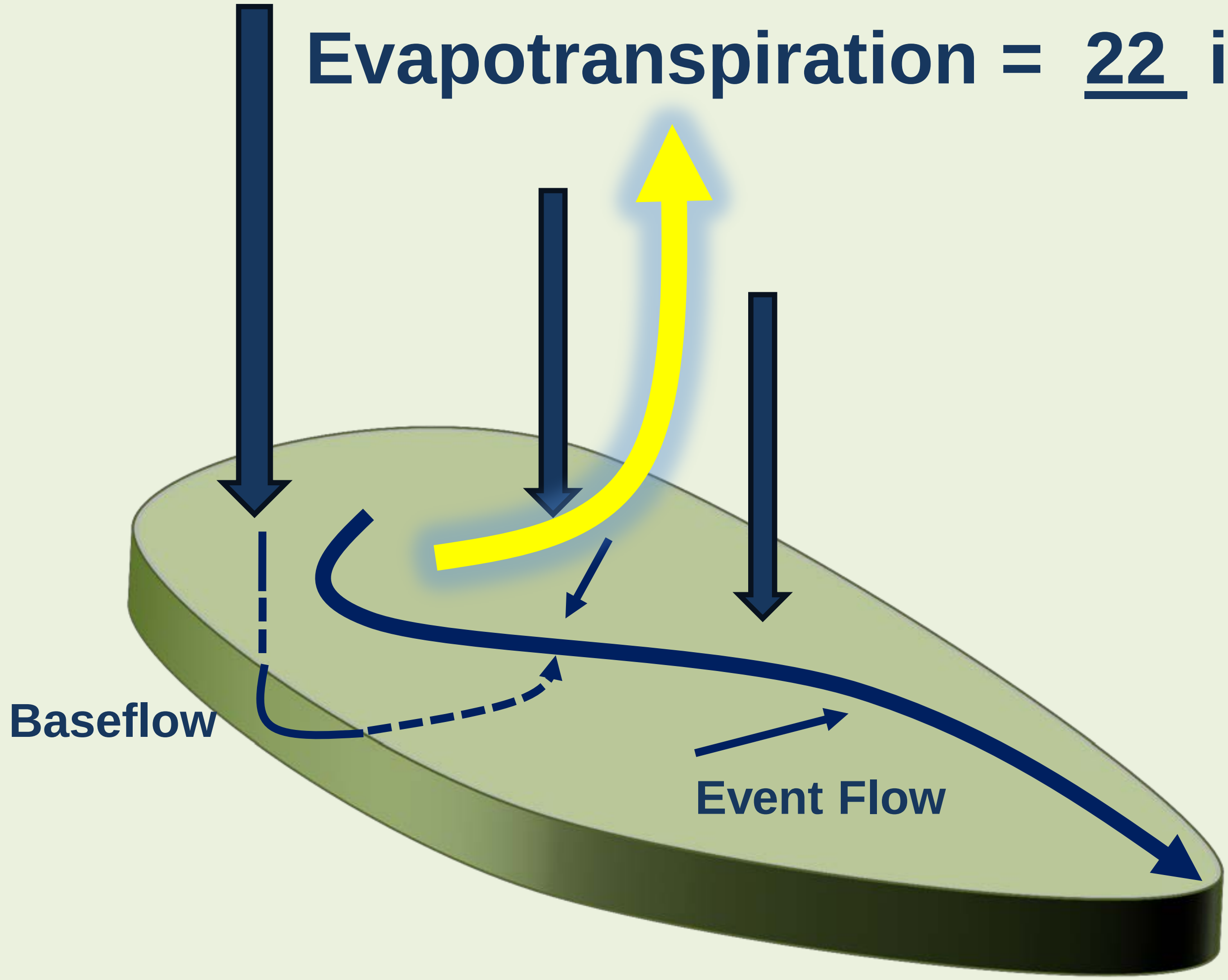
Precipitation = ___ inches/yr

Evapotranspiration = ___ inches/yr



Precipitation = 32 inches/yr

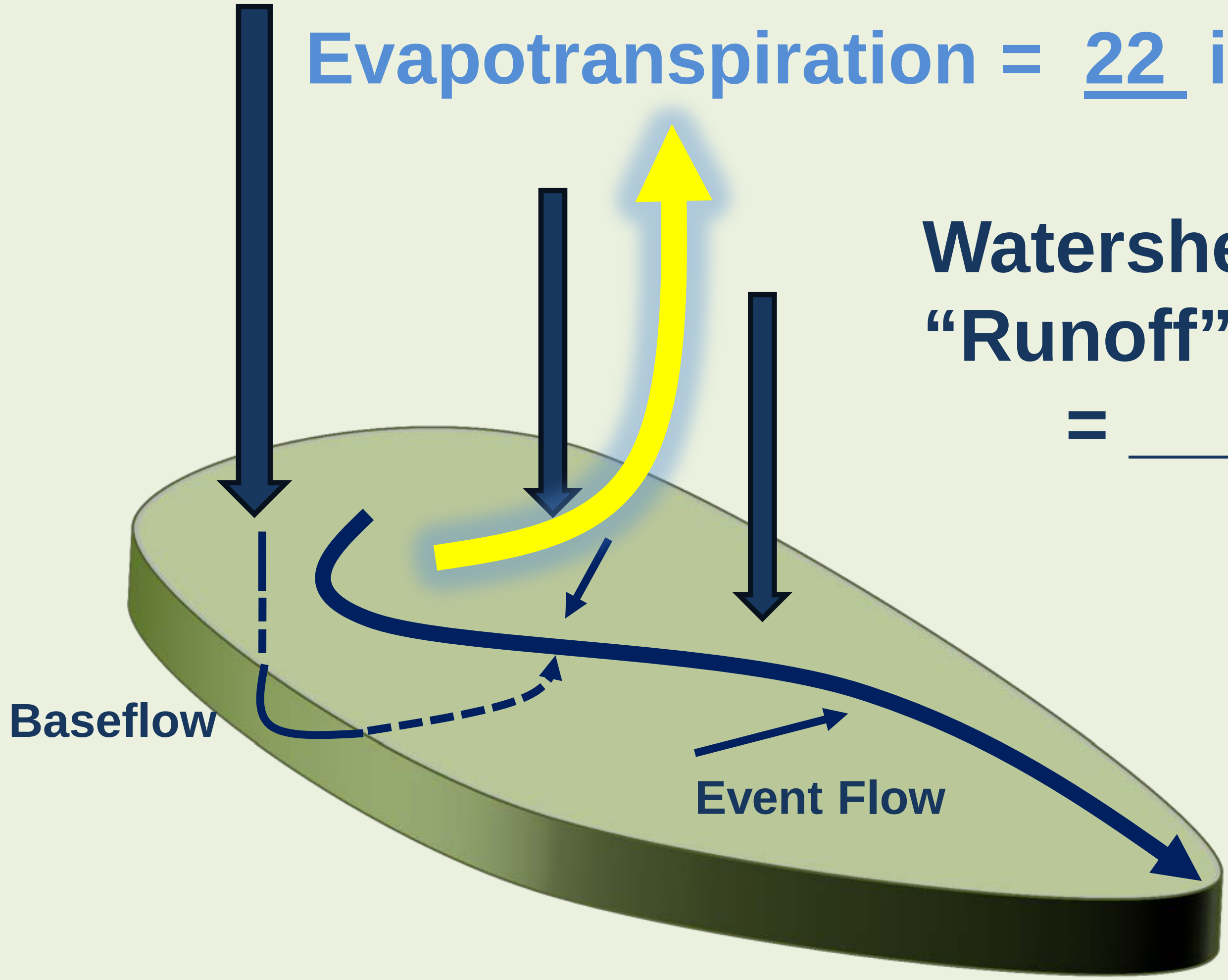
Evapotranspiration = 22 inches/yr



Precipitation = 32 inches/yr

Evapotranspiration = 22 inches/yr

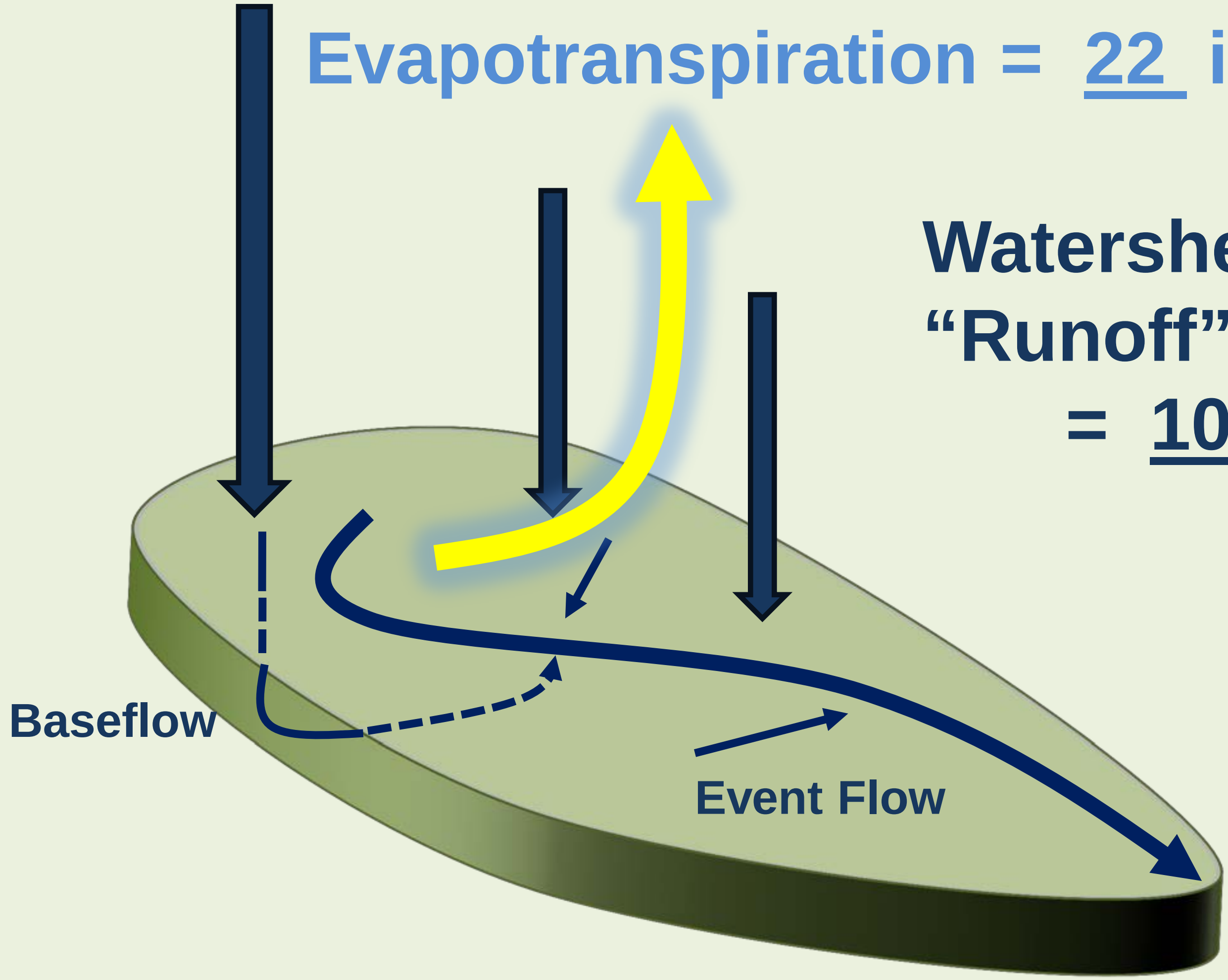
Watershed "Runoff" = ___ inches/yr



Precipitation = 32 inches/yr

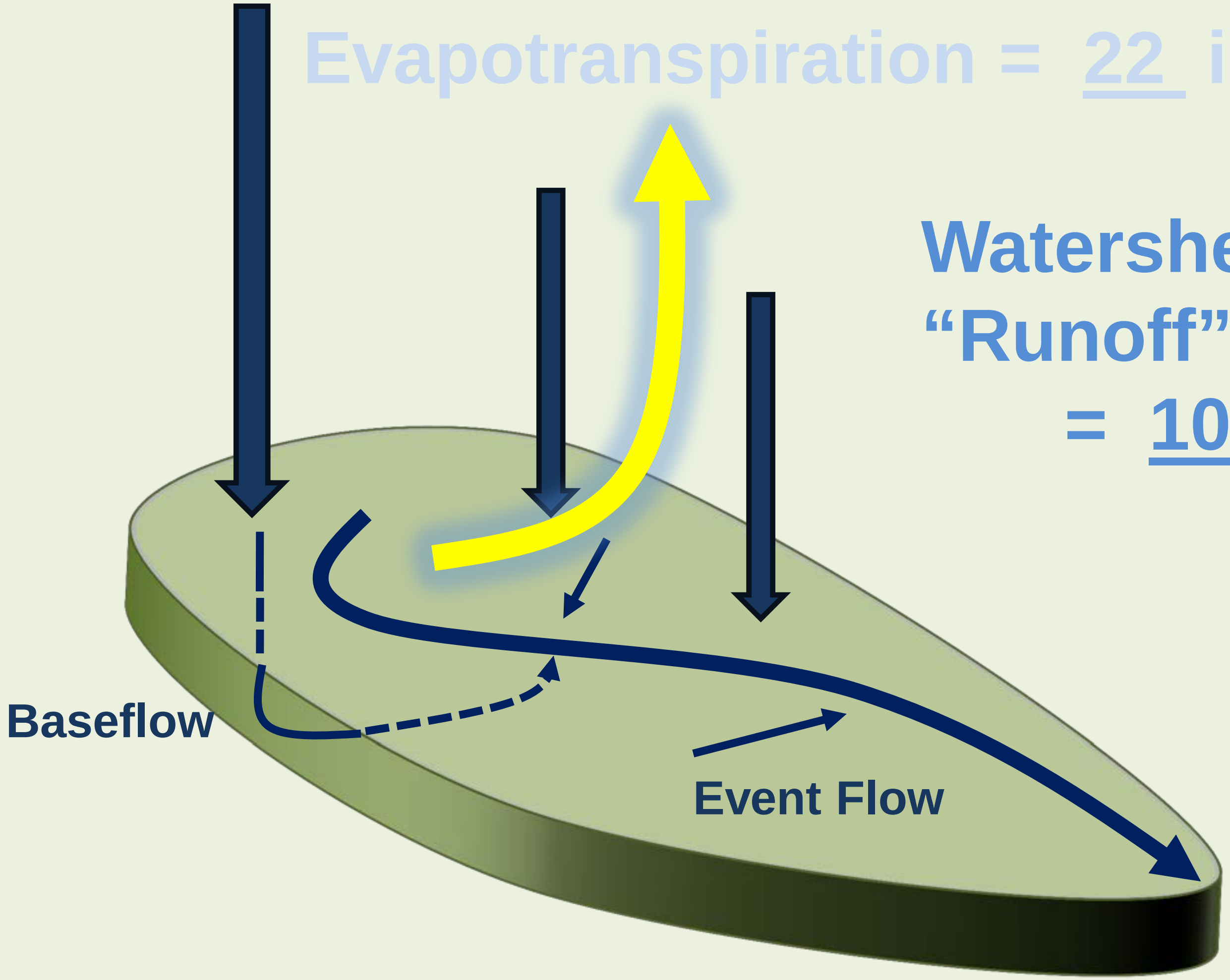
Evapotranspiration = 22 inches/yr

Watershed "Runoff" = 10 inches/yr



Precipitation = 32 inches/yr

Evapotranspiration = 22 inches/yr



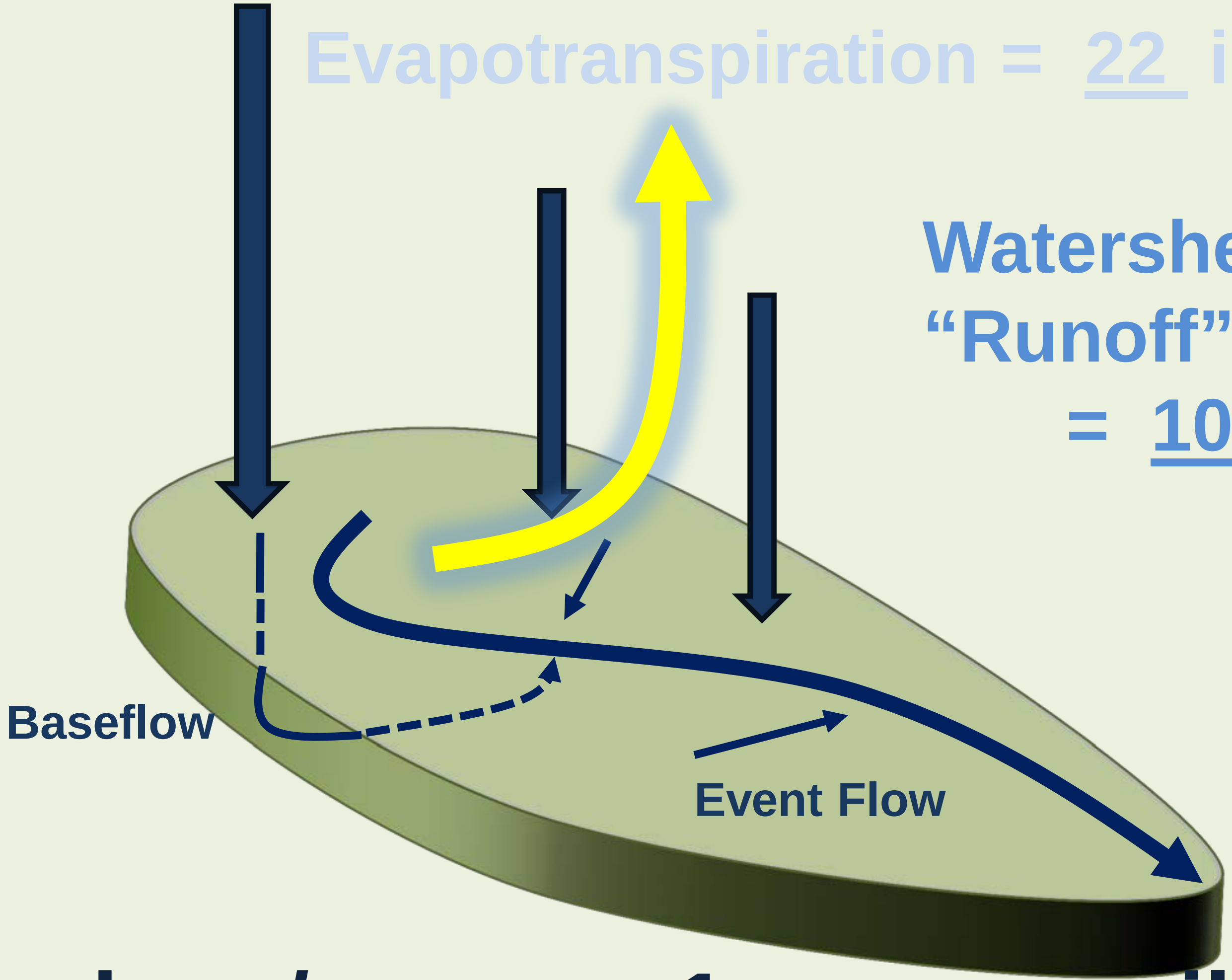
Watershed
"Runoff"
= 10 inches/yr

10 inches /year on 1 square mile…
= 23,000,000 cubic feet /year!

Precipitation = 32 inches/yr

Evapotranspiration = 22 inches/yr

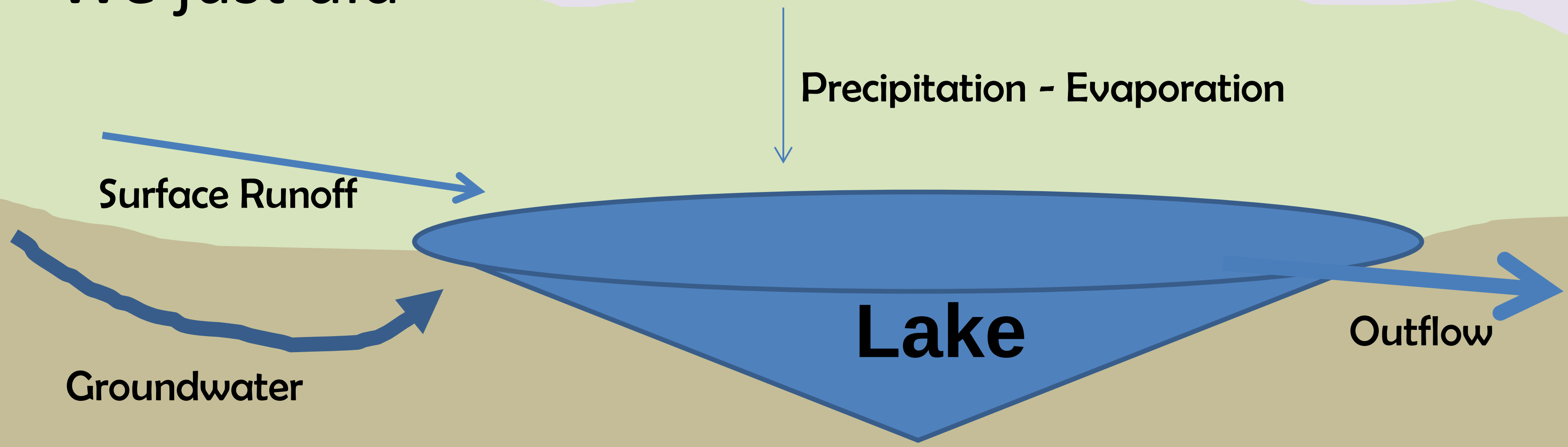
Watershed
“Runoff”
= 10 inches/yr



10 inches /year on 1 square mile…
= 23,000,000 cubic feet /year!
= 0.7 cubic foot every second!

Let's Model That for a lake at the outlet!

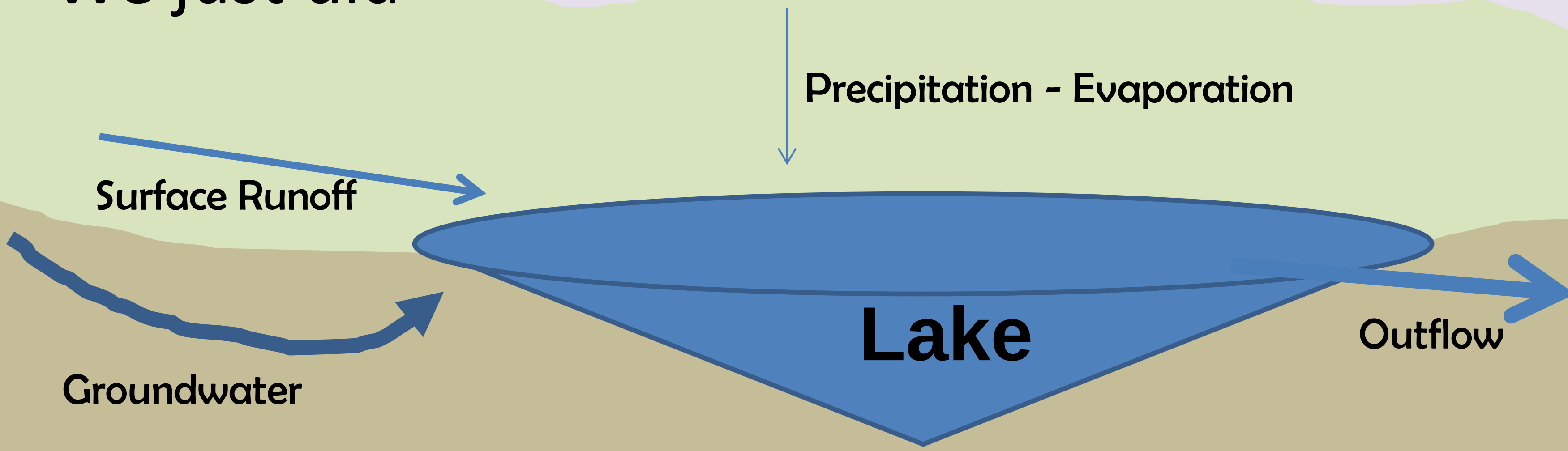
- We just did



- Water Budget

Let's Model That!

- We just did



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

Rule #1

“All models are wrong but some are useful”

George Box

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

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

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

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

$$= 3.2 \text{ years}$$

Limitations

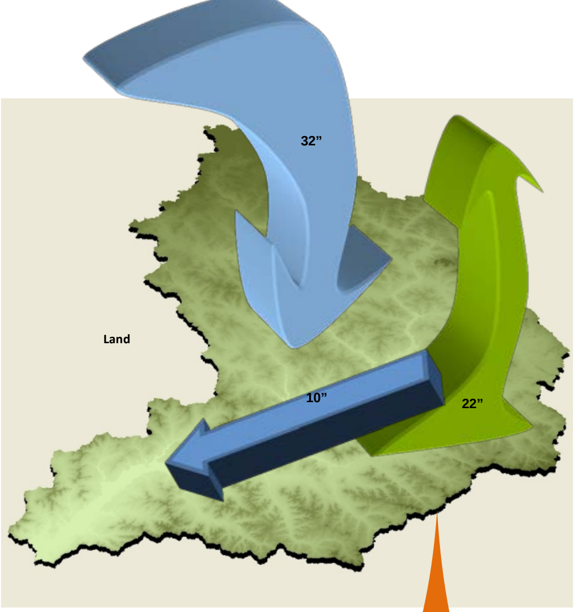
- Year-to-Year Variations?
- Different parts of the watershed have different response
  - Impervious surfaces
  - Compacted soil / raindrop impact

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?



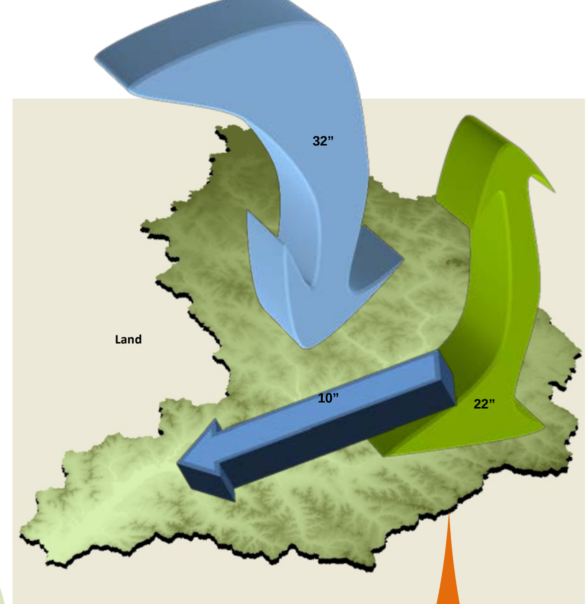
Annual Volume

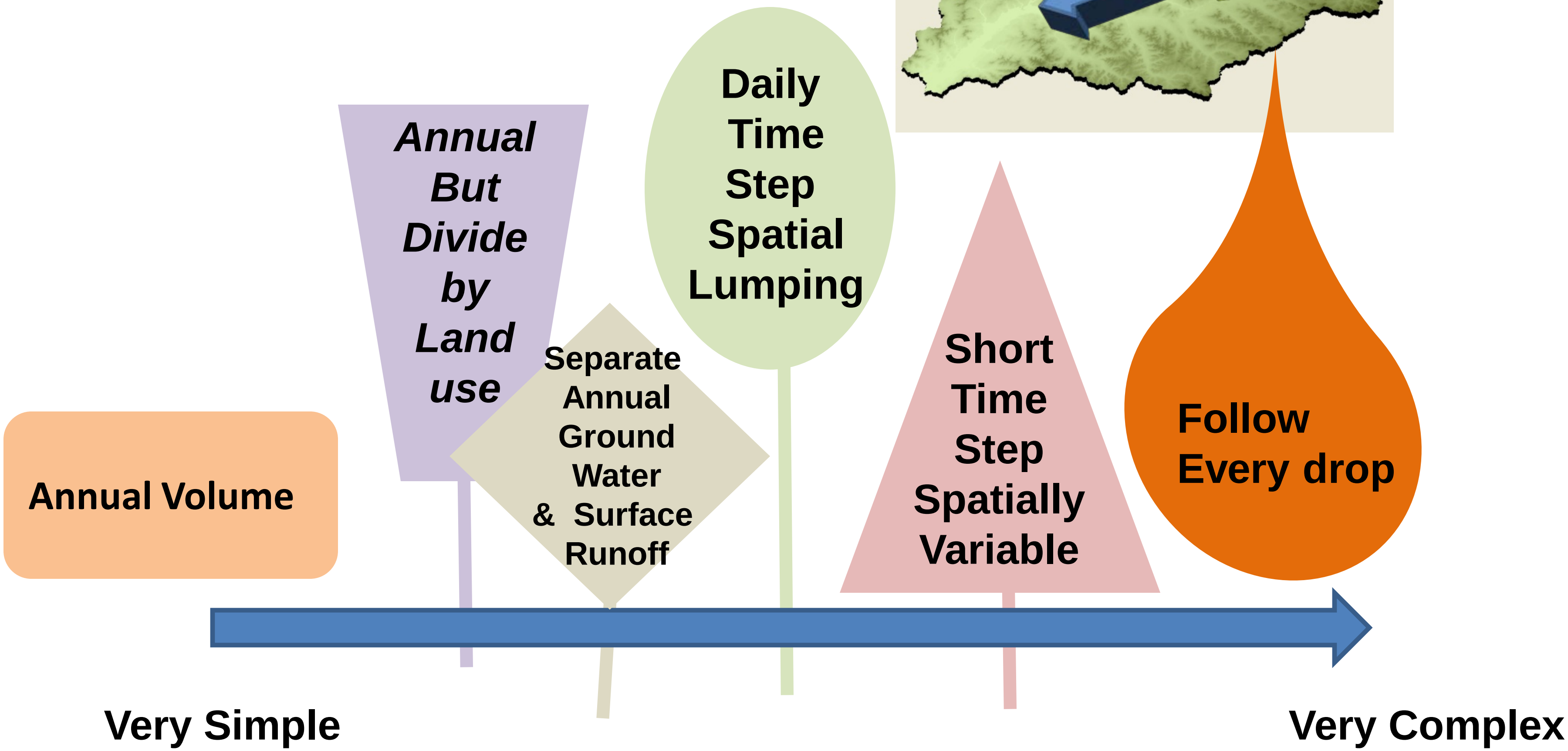
Follow
Every drop

Very Simple

Very Complex

Modeling the Water on Land?





Closely Related…**Nutrient Movement**

- Just talked about <u>water movement on land</u>

- Next… **<u>Nutrients Loss from Land</u>**
  - then **<u>Lakes & Streams</u>**

Let's look at Phosphorus Movement

- <u>Important Implications </u>for Lakes & Streams
- Oligotrophic - "few" "foods"
- Eutrophic – "many" "foods"

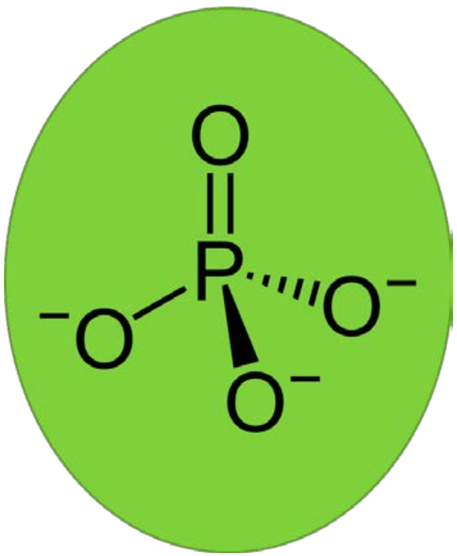
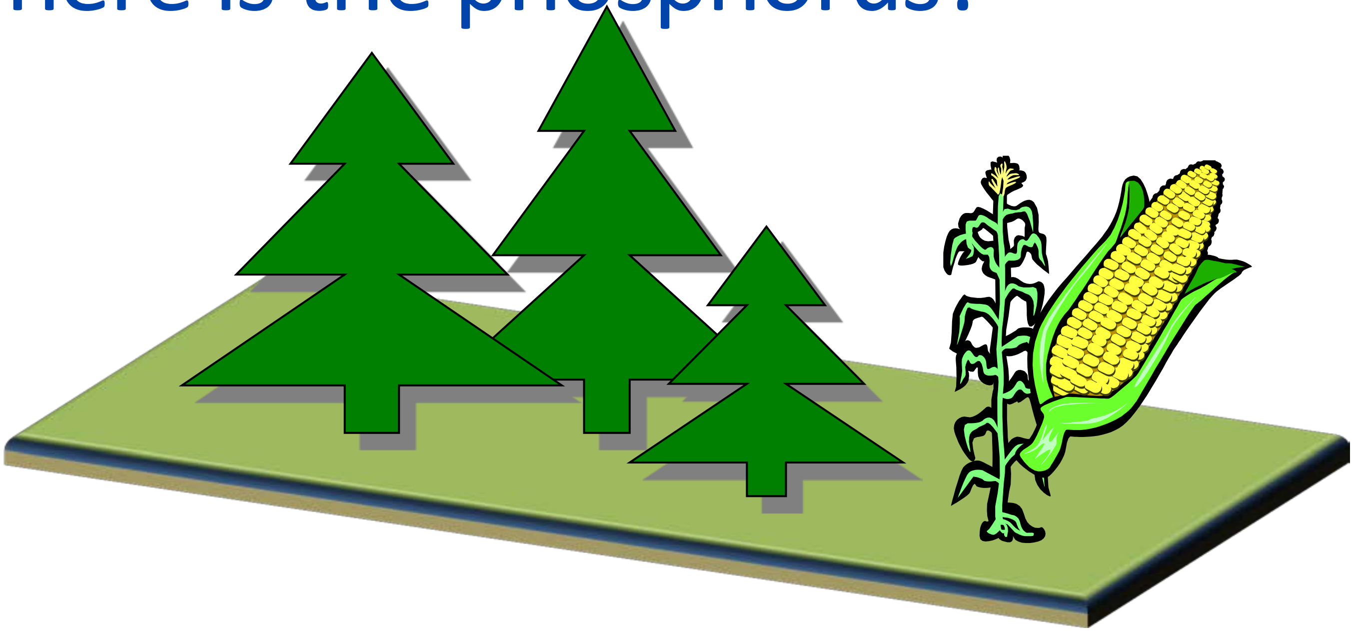


Table 1. Completed trophic state index and its associated parameters.

TSI	Secchi disk (m)	Surface phosphorus (mg/m3)	Surface chlorophyll (mg/m3)
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

Phosphorus

300,000 microgram P /"liter"

40 microgram P /liter

- Water Across Land = Phosphorus in the Water

Interesting Modeling Challenge

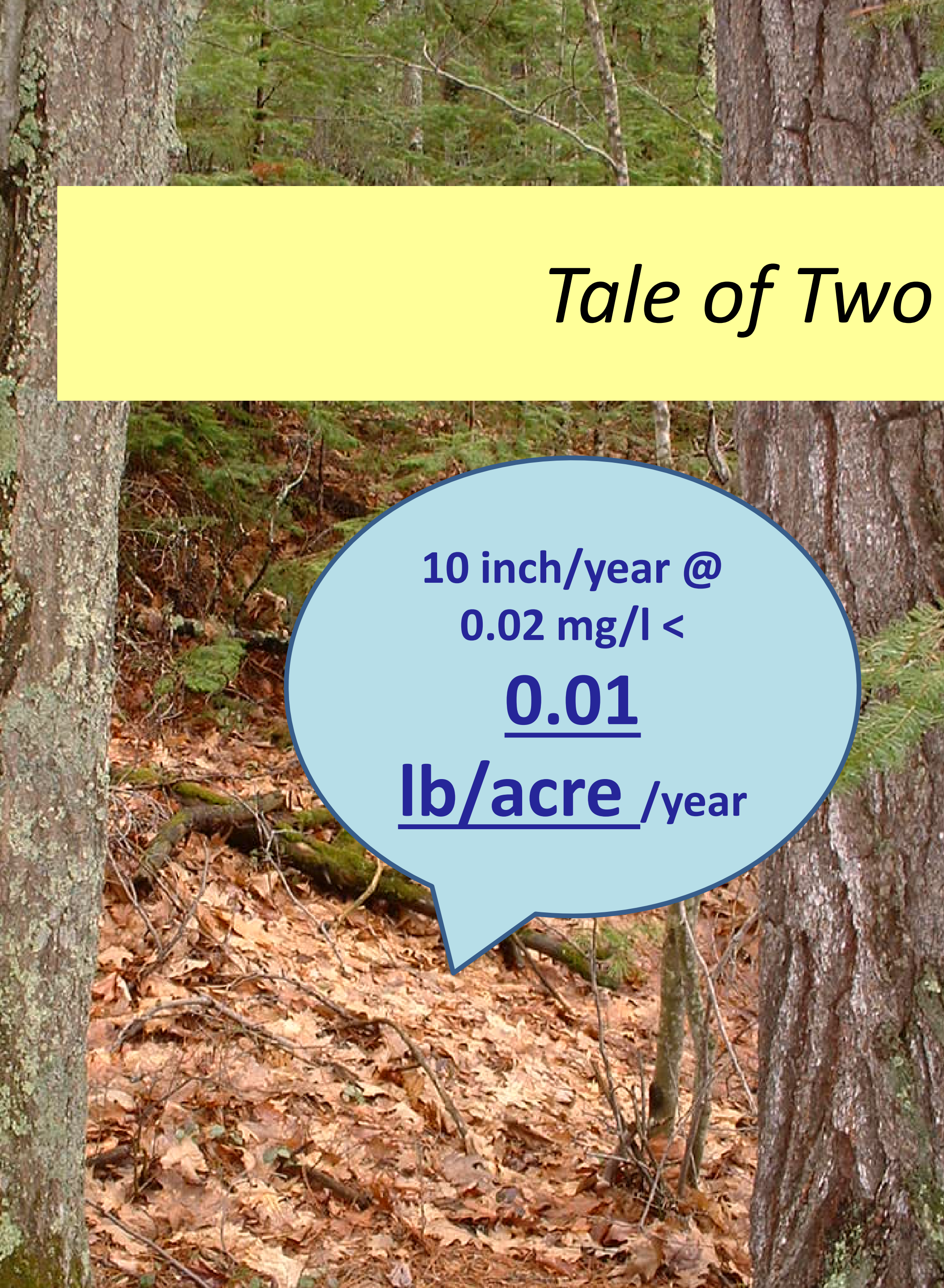
- **Pathway that the water takes is important**
- **The soil & vegetation it contacts is important**

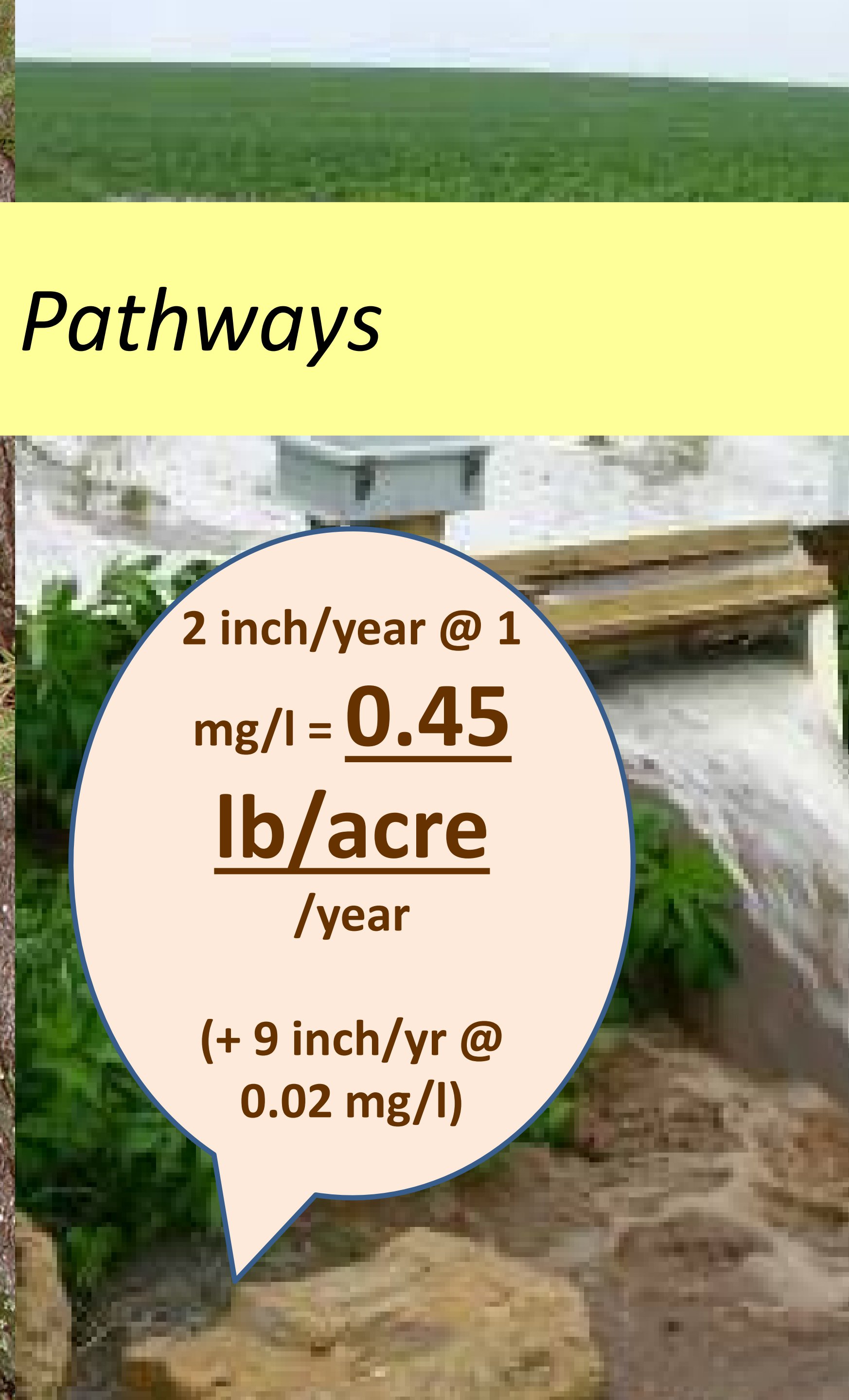
- **Higher Land Concentration--- More P**
- **More Surface Runoff Water – More P**

Modeling P Movement

- Let’s consider two approaches
  - 1) every year the same, some adjustment for land use
  - 2) try to track the daily runoff / some characteristics of the land

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

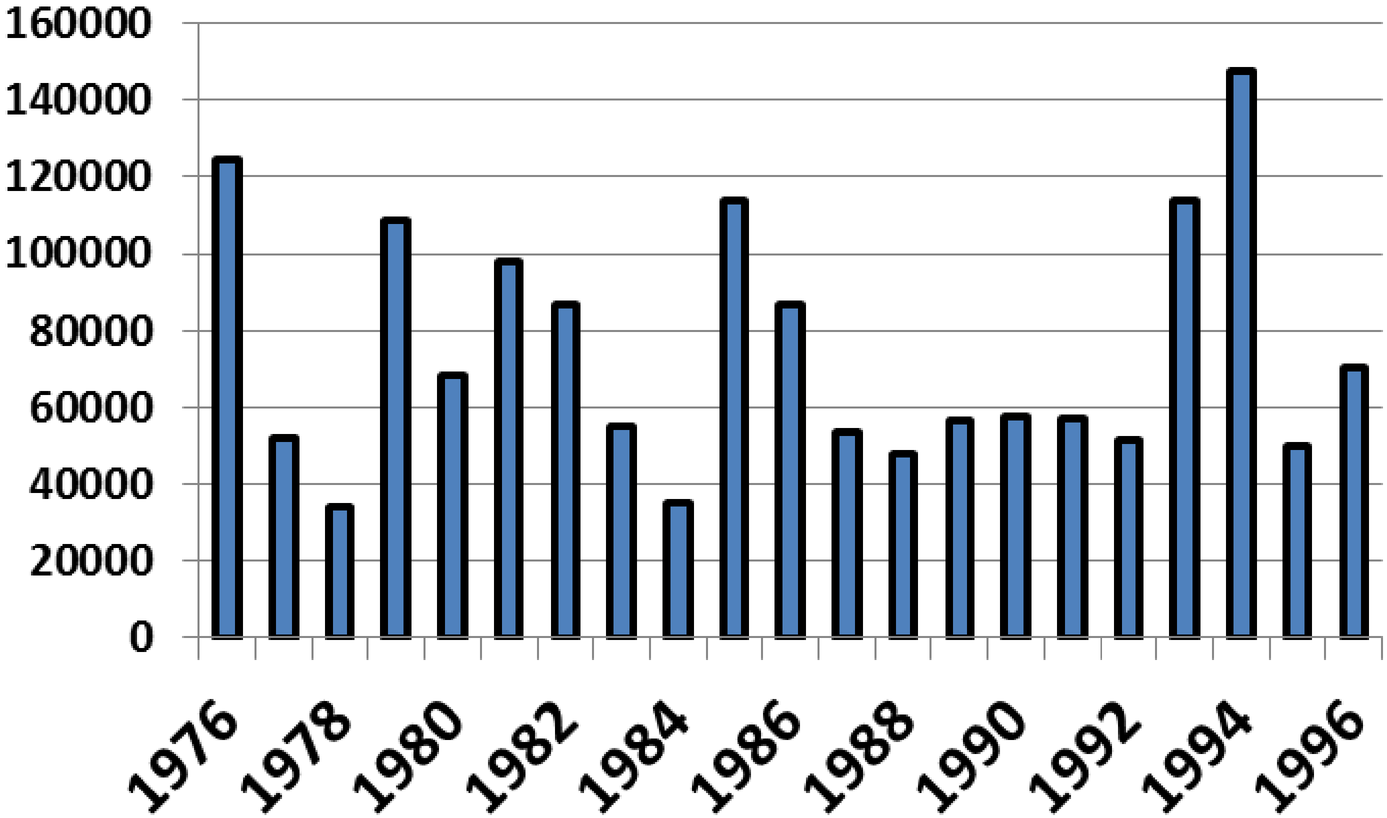
Adapted from WiLMS, Wisconsin Lake Modeling Suite
http://dnr.wi.gov/lakes/model/

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!

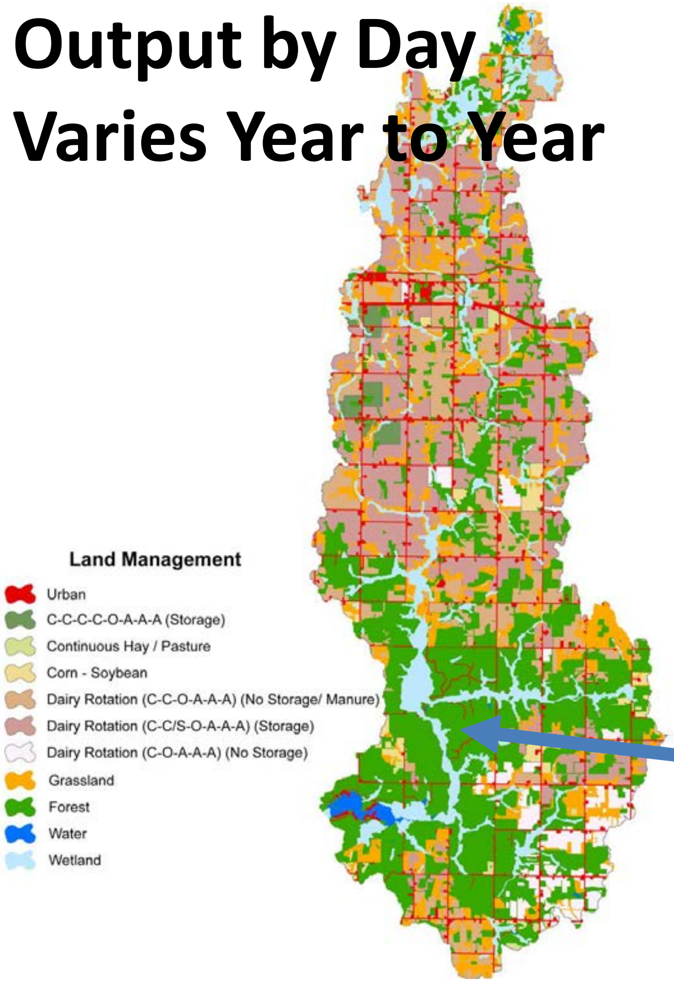


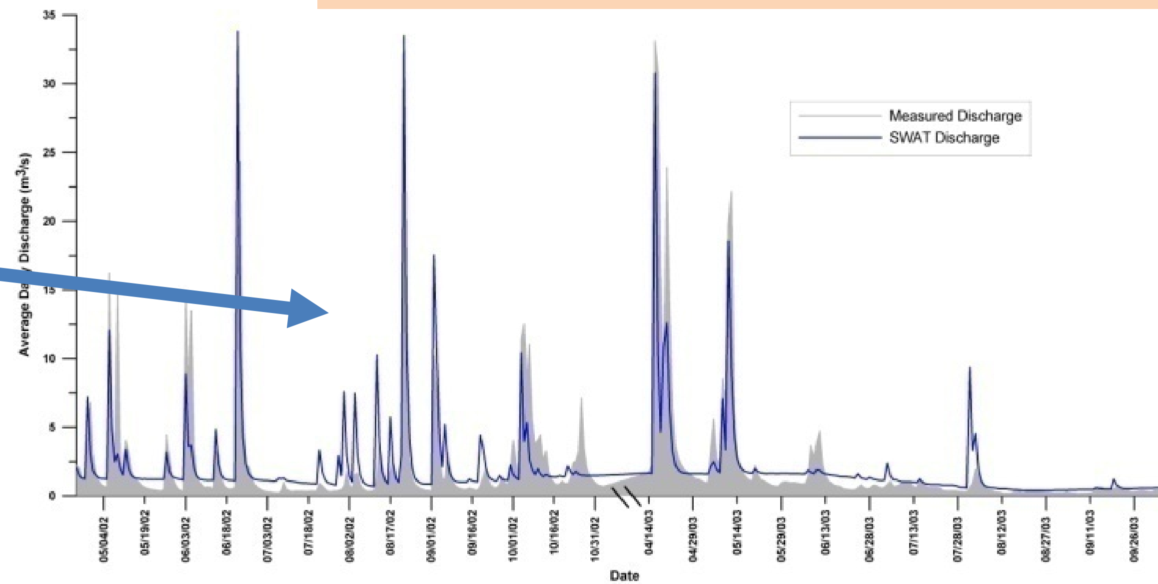
- P Load (lb) to Lake (Lathrop and Panuska)

More Complicated Model

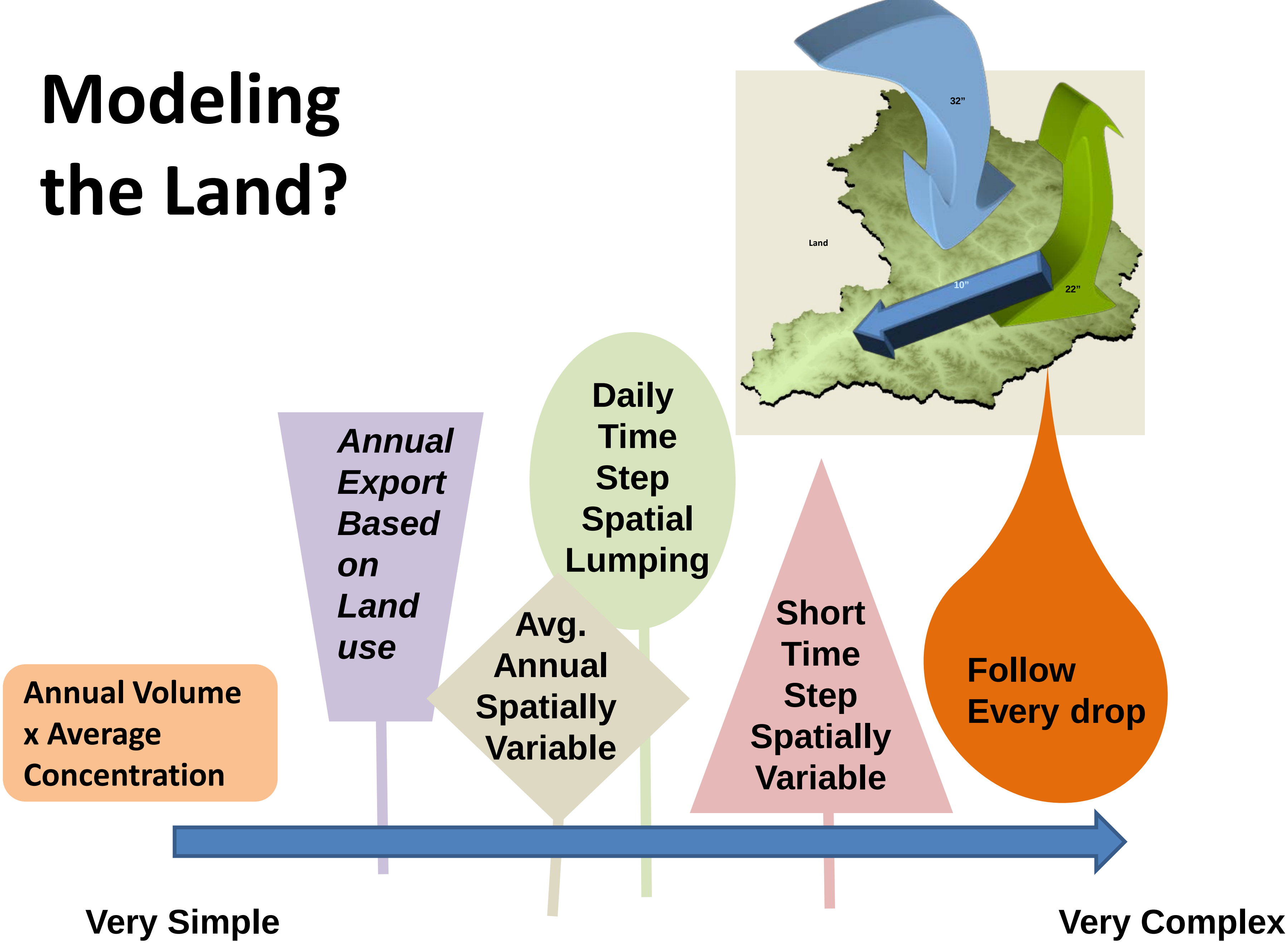
Spatial Variations
Daily Rainfall
Output by Day
Varies Year to Year

- Watershed
  - **250 km^2**
- SWAT Model
  - **10 subbasins**
  - **119 HRUs**
- Calibration
  - **2 years flow/ TSS / TP**
  - **Matched total w/ CN**
  - **Adjusting USLEP, Filterw**
  - **Tried to fit P fractions and P Content**



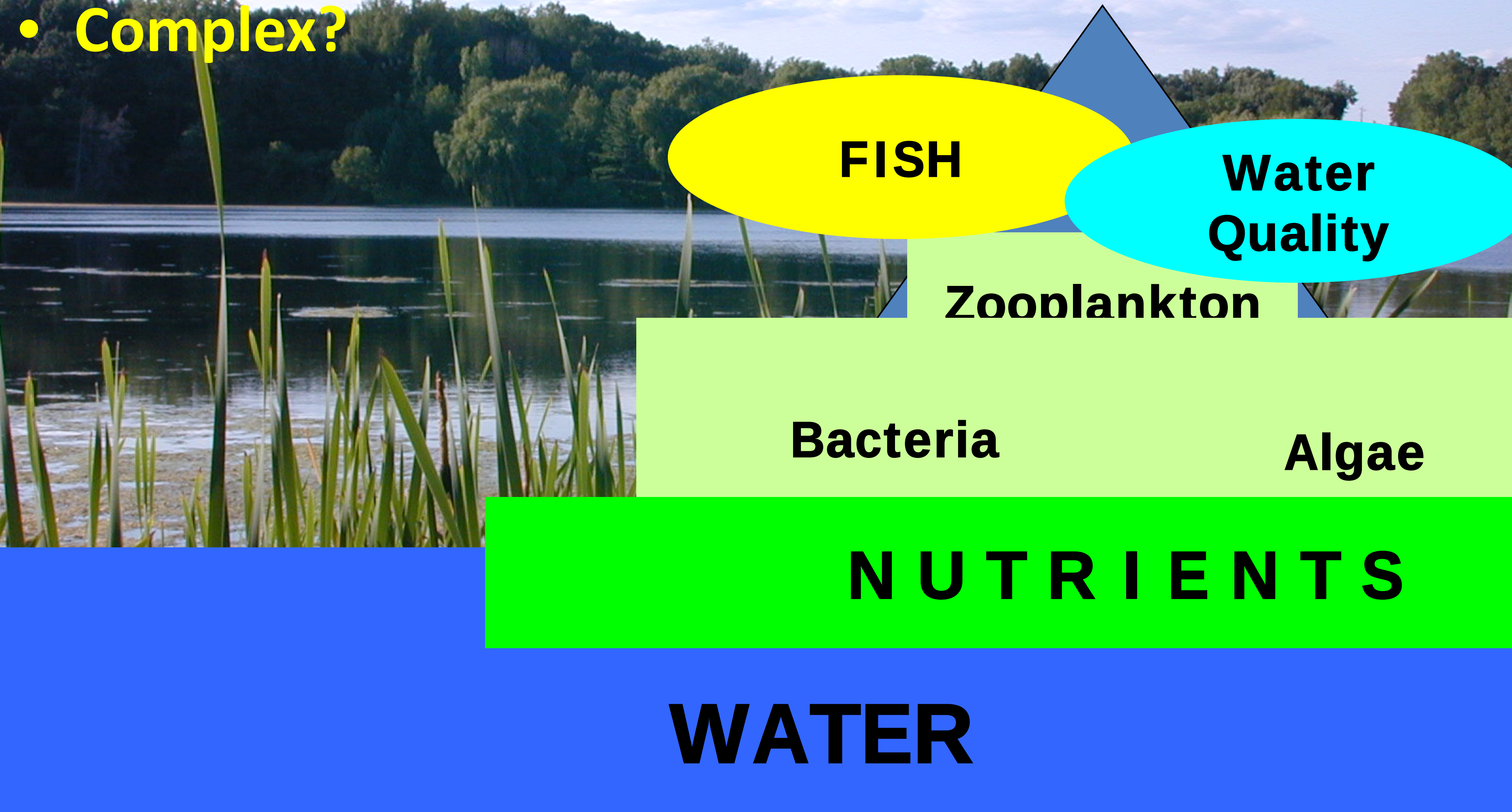


Modeling the Land?



Part 2 - LAKES

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

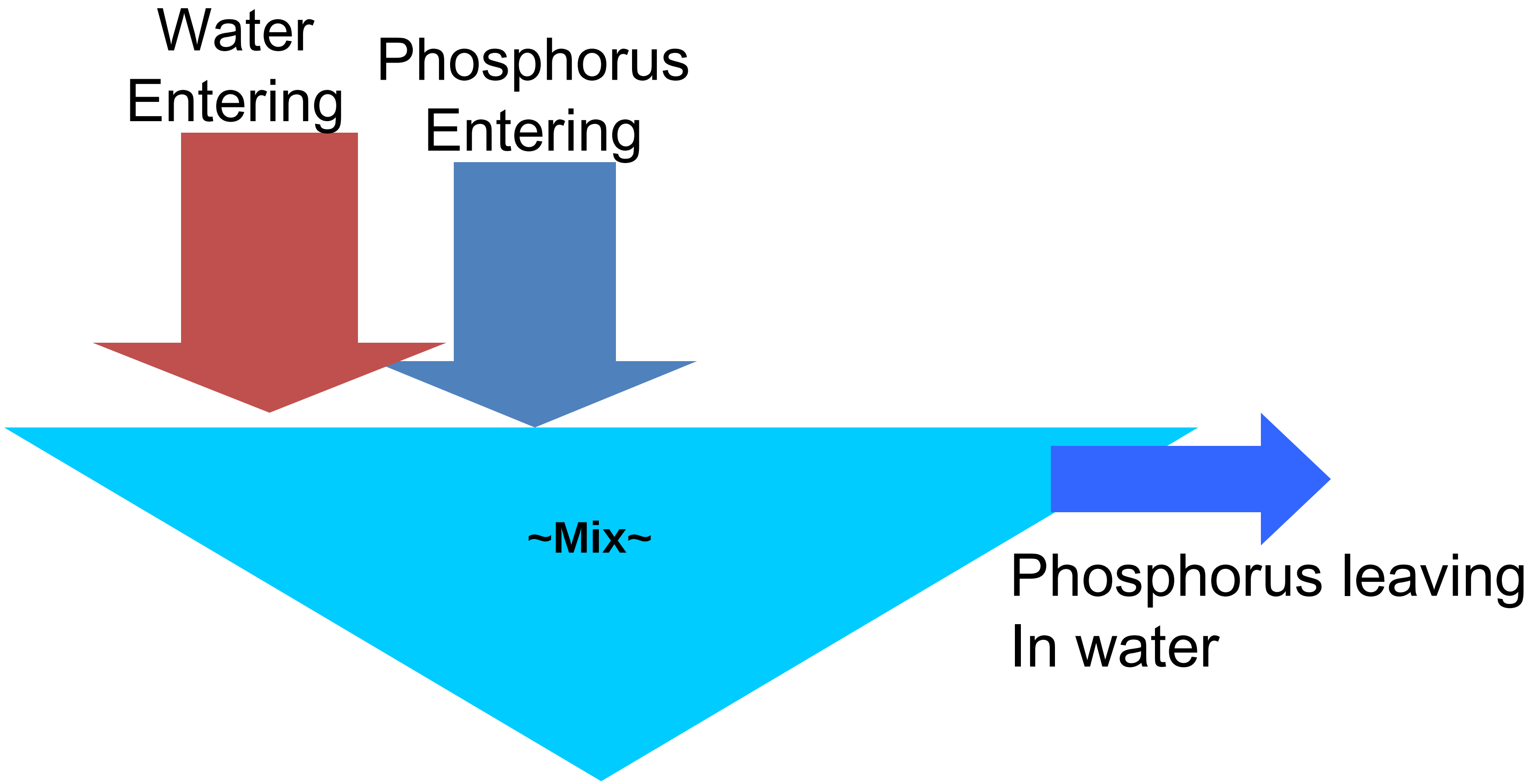


Our First Model

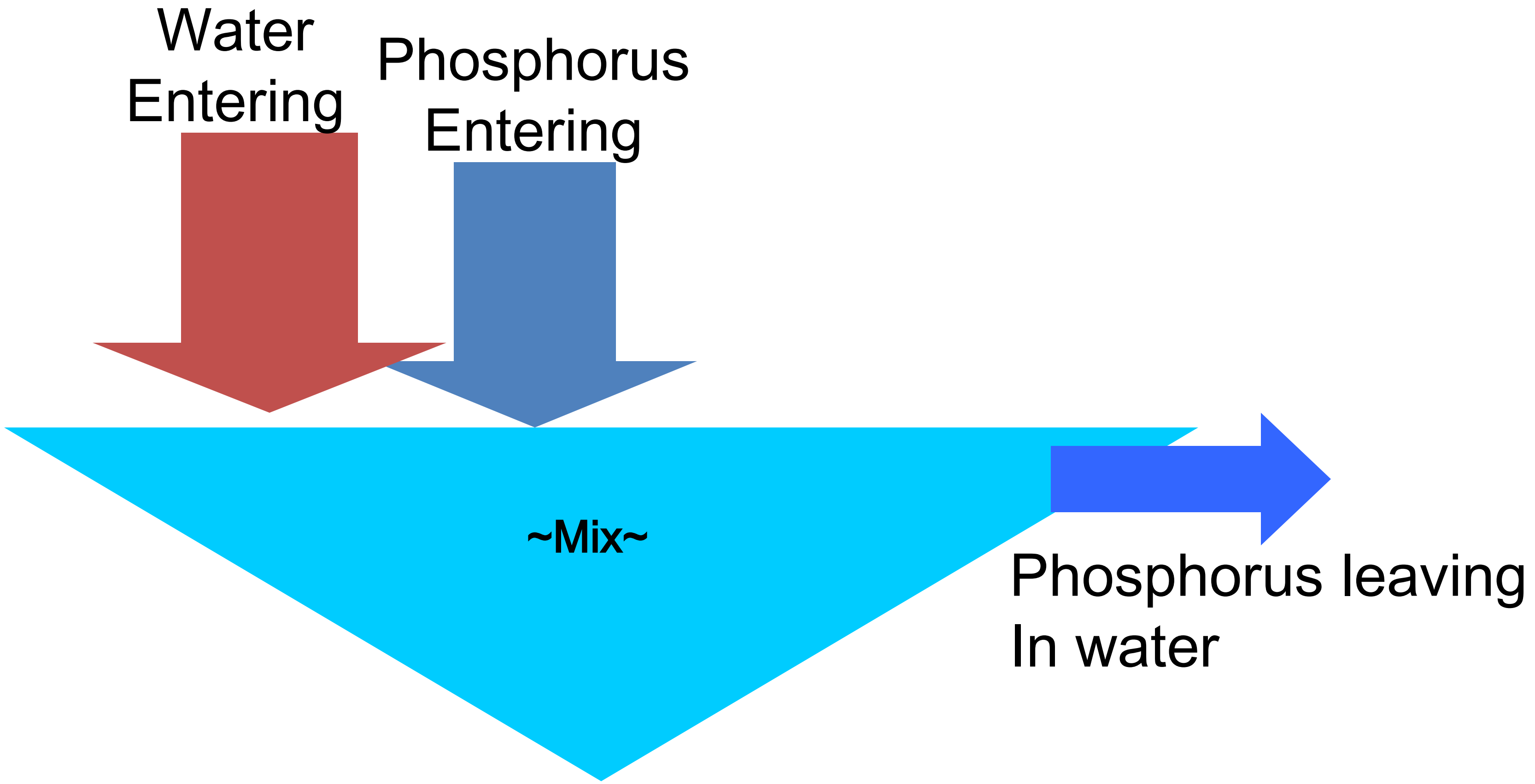
- Goal– predict the P concentration

Given

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


Water
Entering
Phosphorus
Entering
~Mix~
Phosphorus leaving
In water

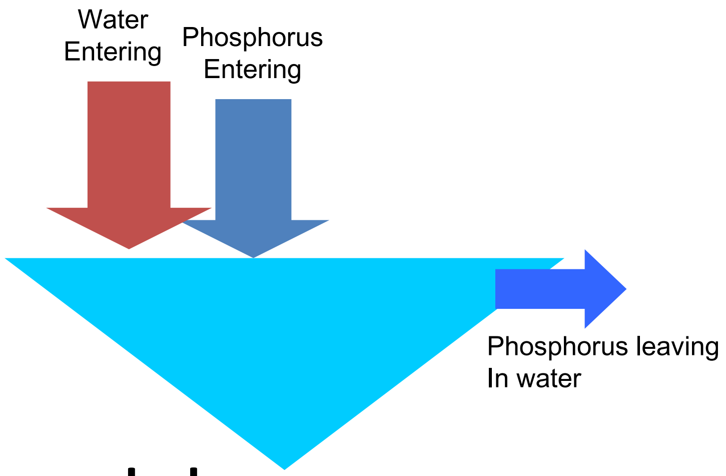
How does this calculate concentration?



Concentration of P = C_P = Mass of Phosphorus /Volume of 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

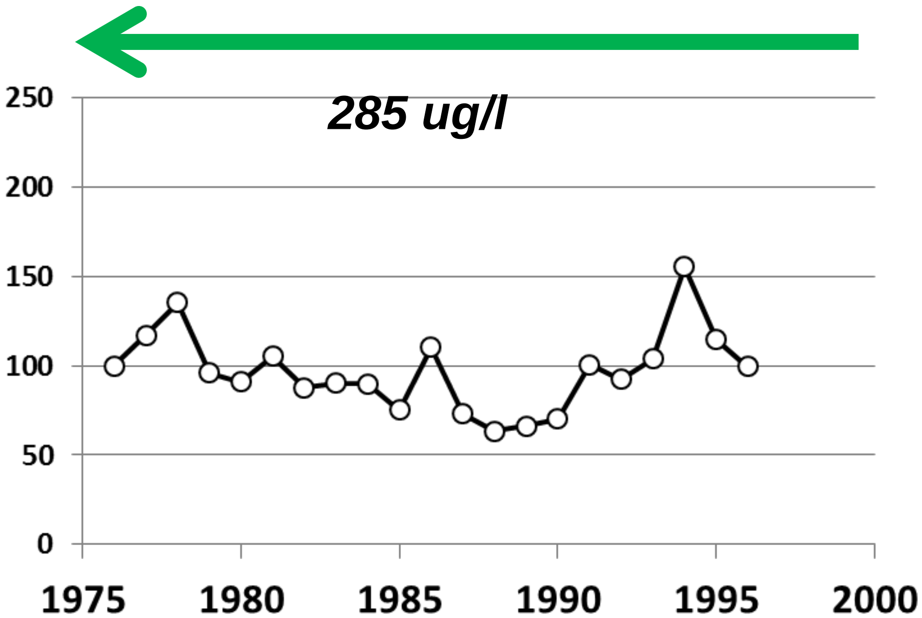
“Simple Model”

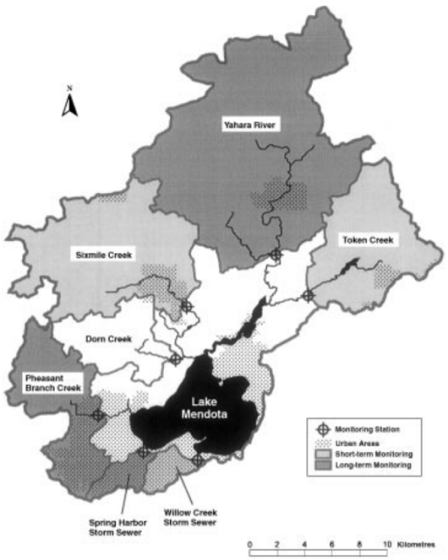
- ***Concentration of P***

  = Mass of P / Volume of Water

  = 285 ug/l

Take a look at some data

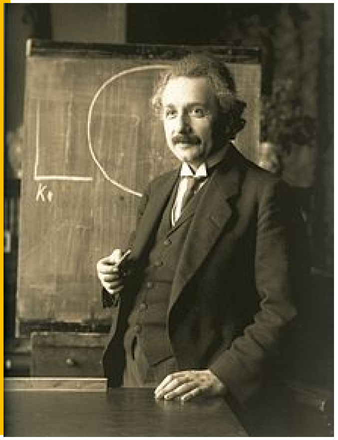




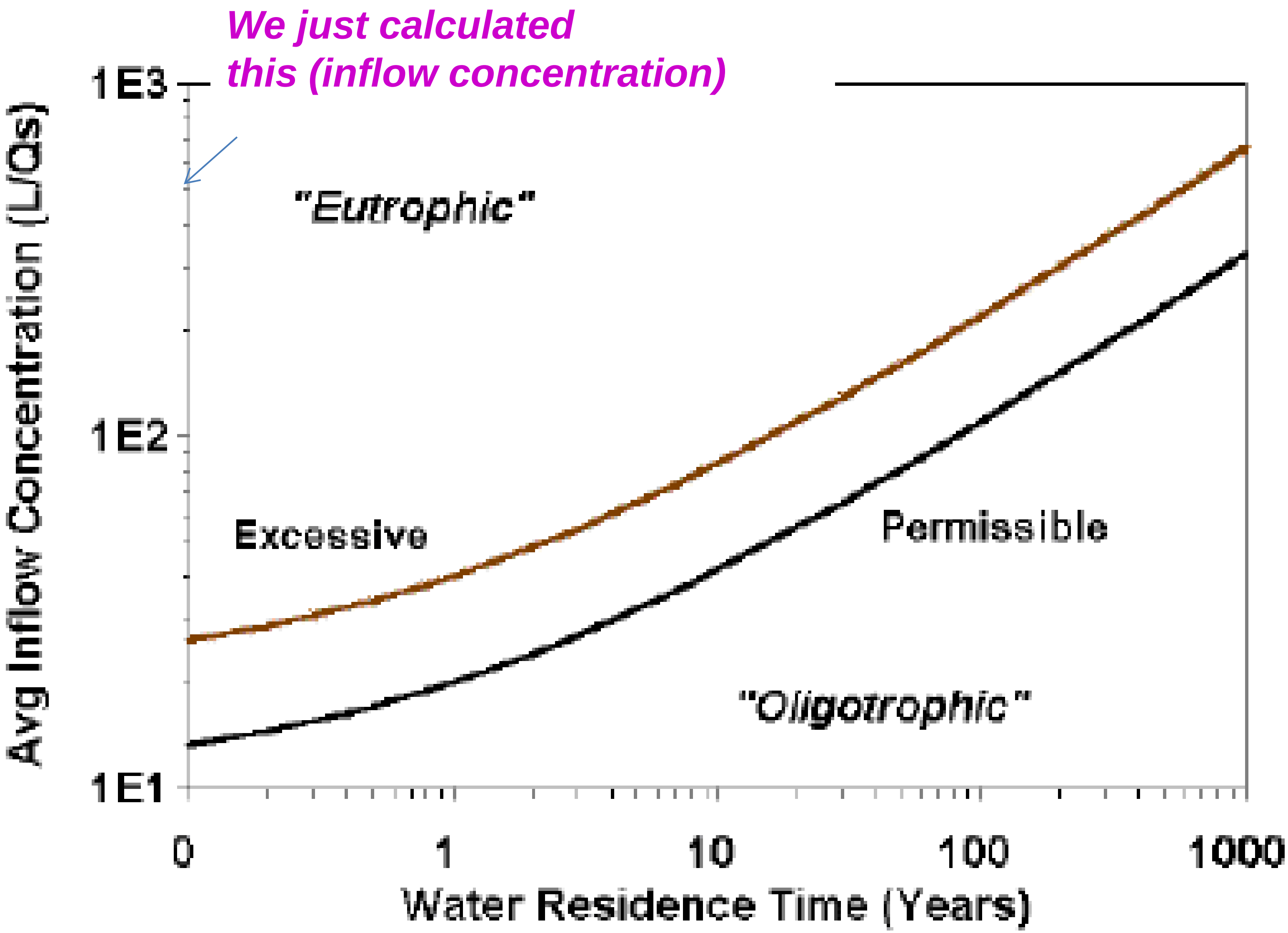
Lathrop and Panuska 1998

Not a very good model

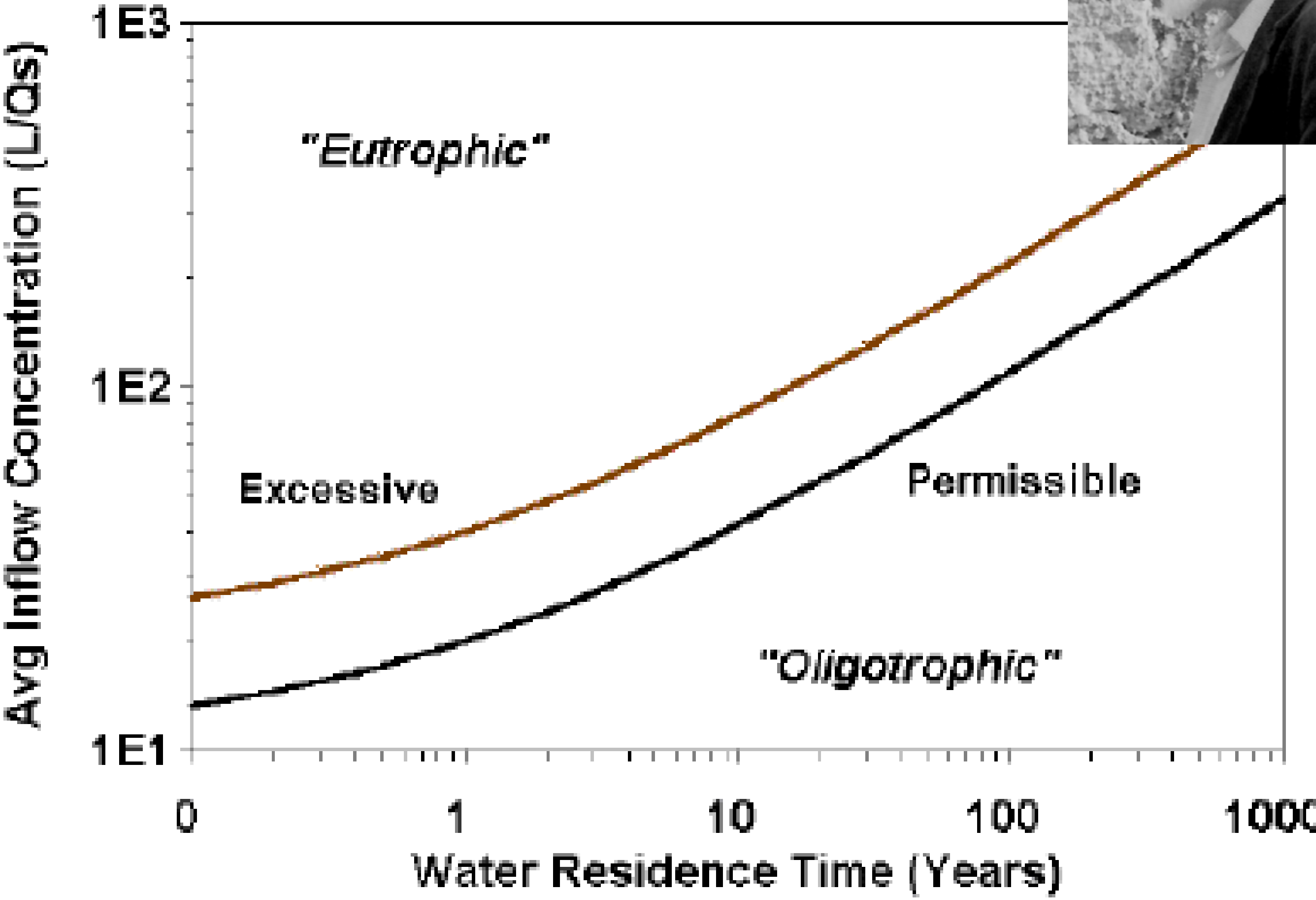
- Why?
- What happens to P in a lake?
- Another observation on modeling
  - "Everything should be made as simple as possible, but no simpler"   A. Einstein

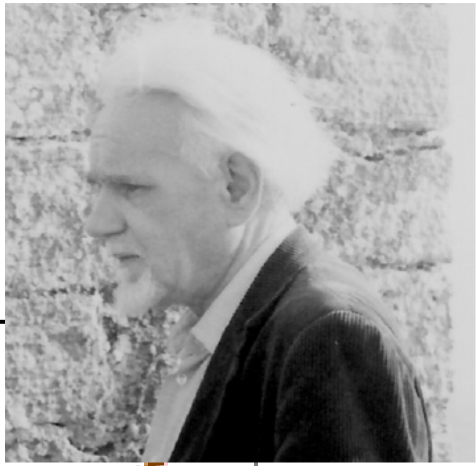


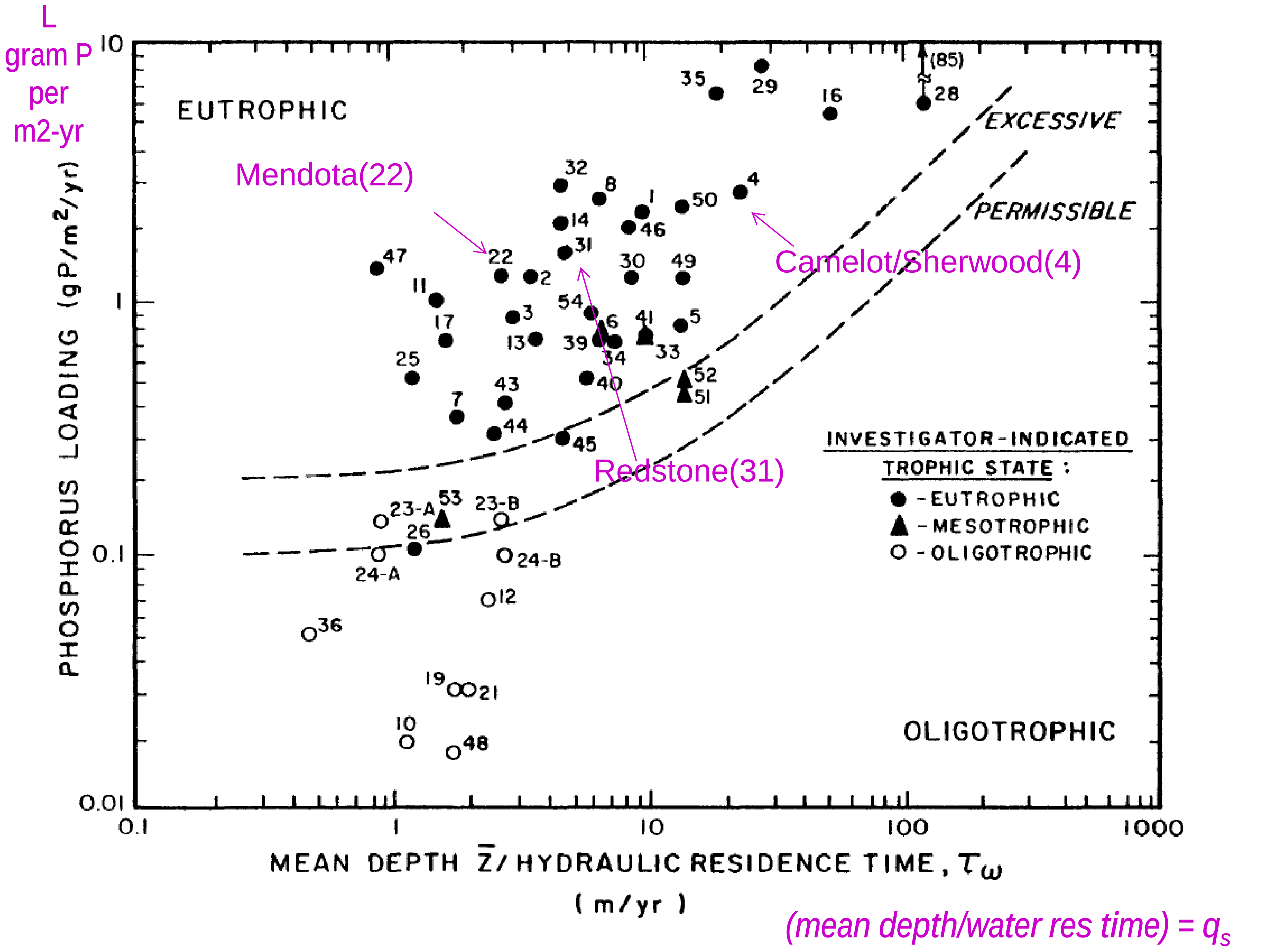
Historical Note– 1960s… higher "Inflow P Conc" OK if you have a longer residence time



“Vollenweider Plots”

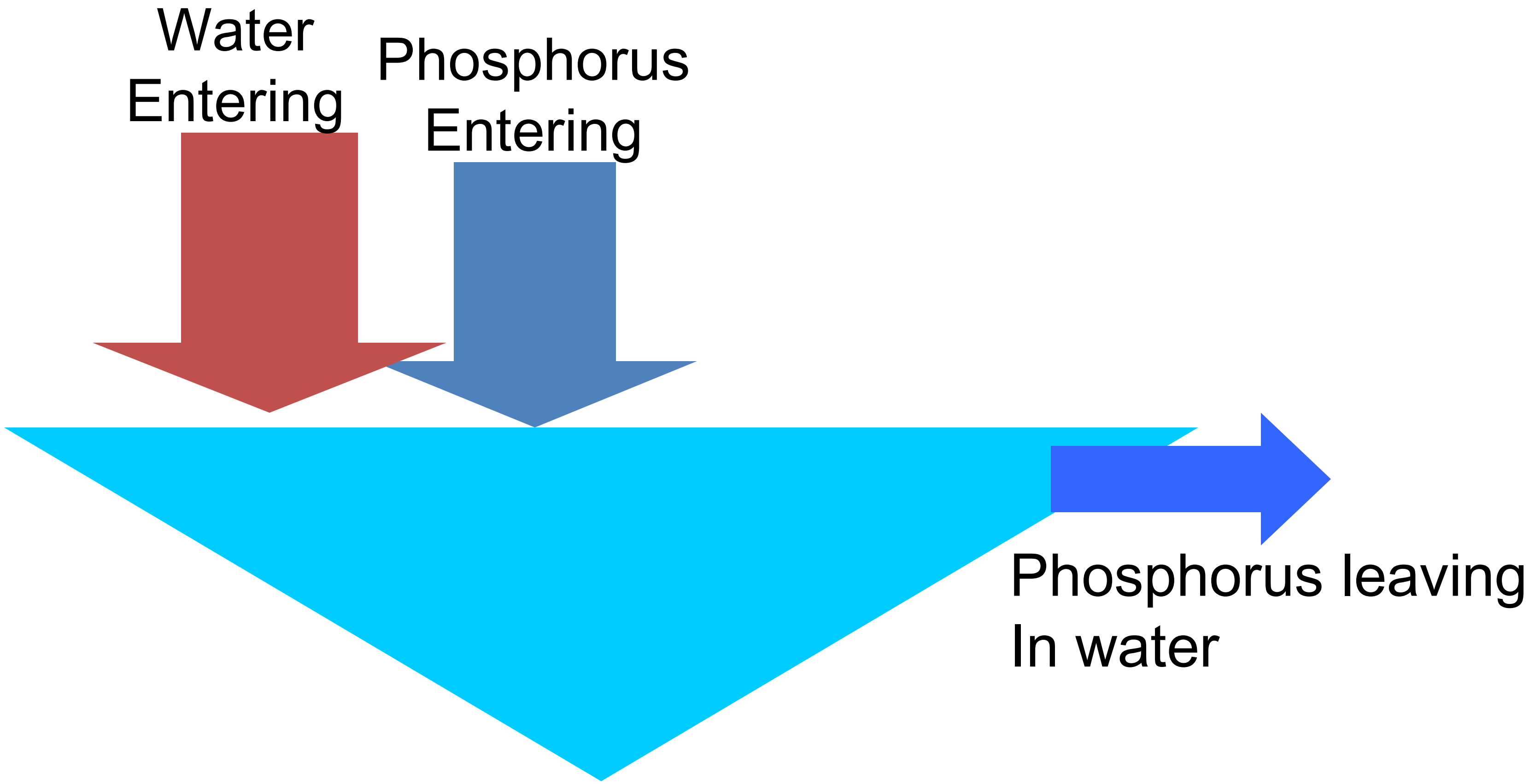






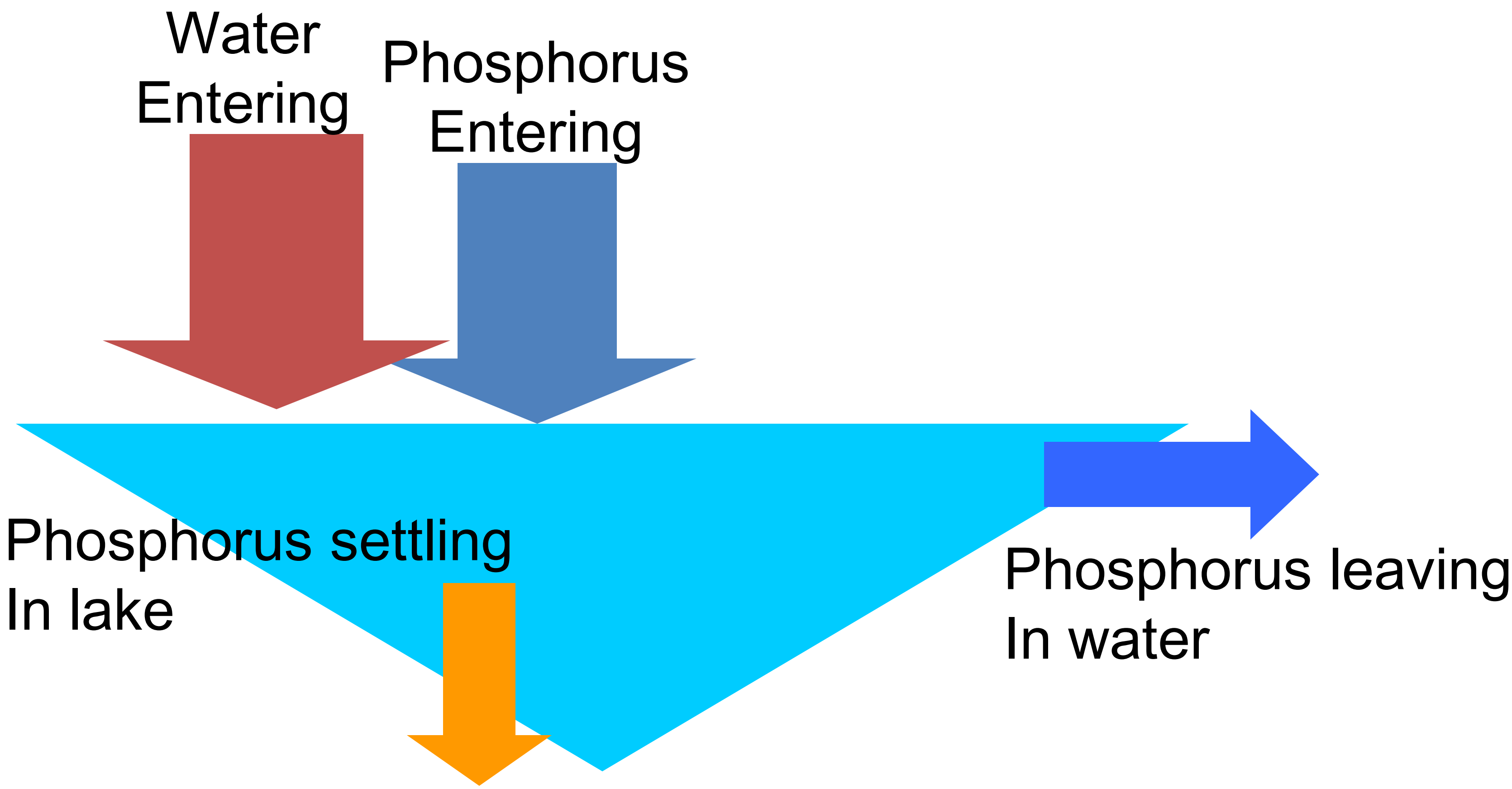
L
gram P per m2-yr
EUTROPHIC
Mendota(22)
Camelot/Sherwood(4)
Redstone(31)
EXCESSIVE
PERMISSIBLE
(85)
INVESTIGATOR-INDICATED TROPHIC STATE :
- EUTROPHIC
- MESOTROPHIC
- OLIGOTROPHIC
OLIGOTROPHIC
PHOSPHORUS LOADING (gP/m2/yr)
MEAN DEPTH Z̄/ HYDRAULIC RESIDENCE TIME, τω
(m/yr)
(mean depth/water res time) = qs

Second Model



"mean total P concentration is amount of phosphorus divided by volume of water and diminished by retention term as P apparently lost to sediments" (Nurnberg, 1984)

Second Model



“mean total P concentration is amount of phosphorus divided by volume of water and 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

  – ***What goes in must be equal to what goes out***

P Into Lake	=	P Flowing Out of Lake	+	P Lost To “Settling”

Uniform ("steady-state") Conditions

The P concentration doesn't change with time

The amount of P in the lake is constant

Phosphorus Concentration in Lake

Mass of Phosphorus per year entering lake

$$C_P = \frac{M}{Q + vA}$$

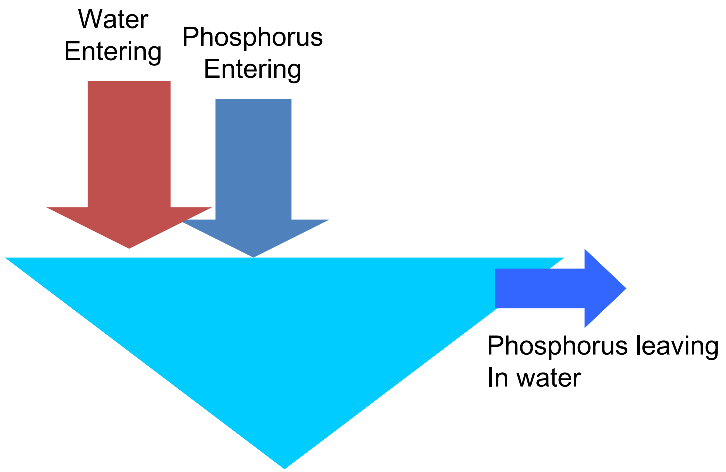
Amount of water Entering lake in a year

*Settling term ("settling velocity" * Area*

With this added

Let's give this a try

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



Assume

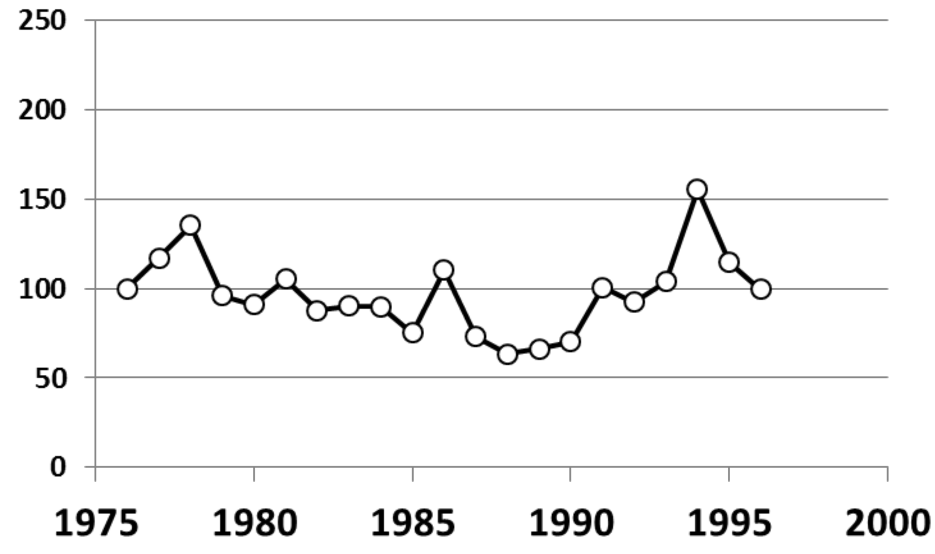
- 96,000 lb/year P
- 125,000 acre-feet water/year
- 40,500,000 m2 lake surface
- 10 meter/year settling velocity

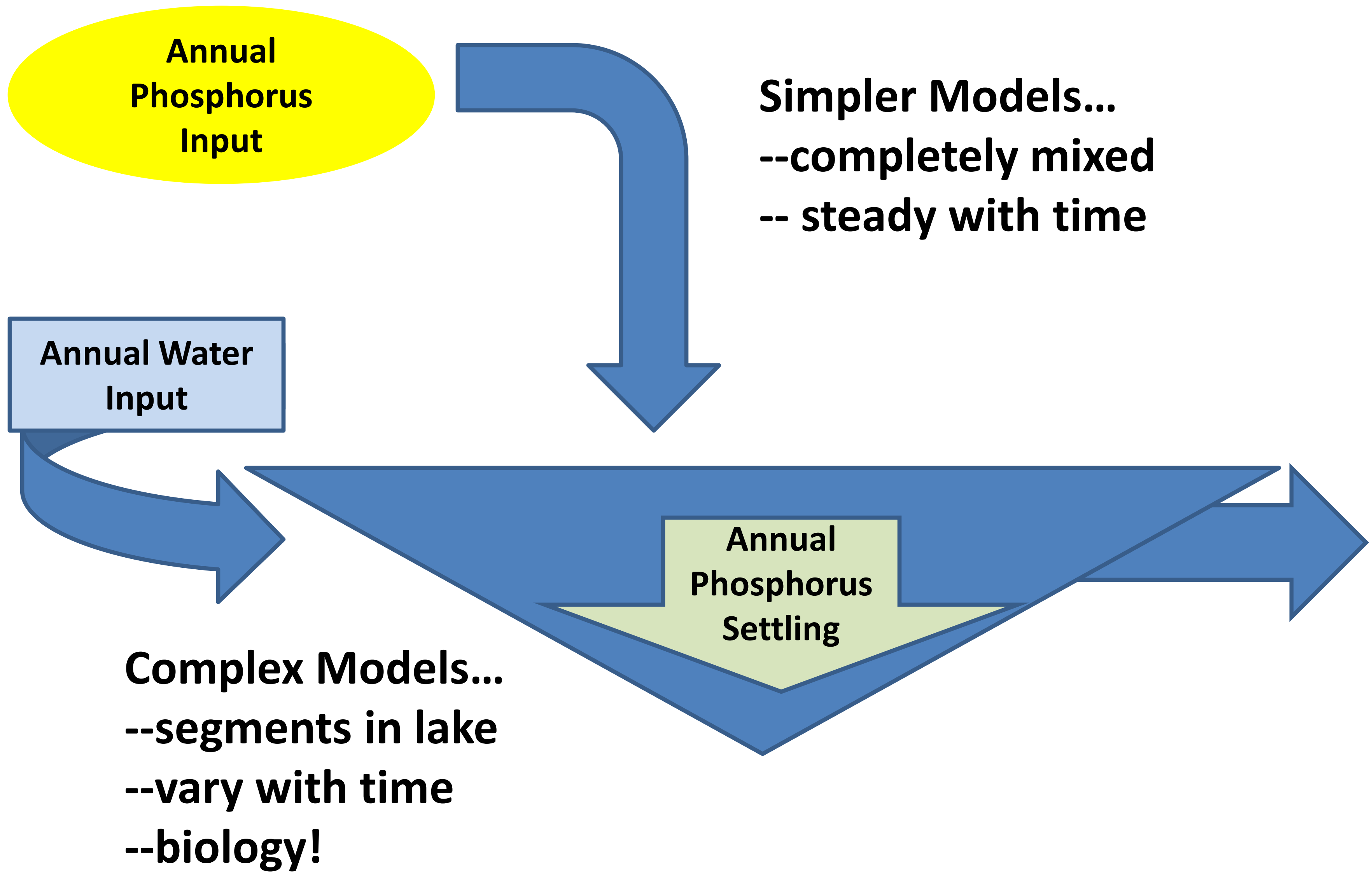
Our "Less Simple Model"

- **Concentration of P**

= 79 ug/l (better?)

- **Useful?**

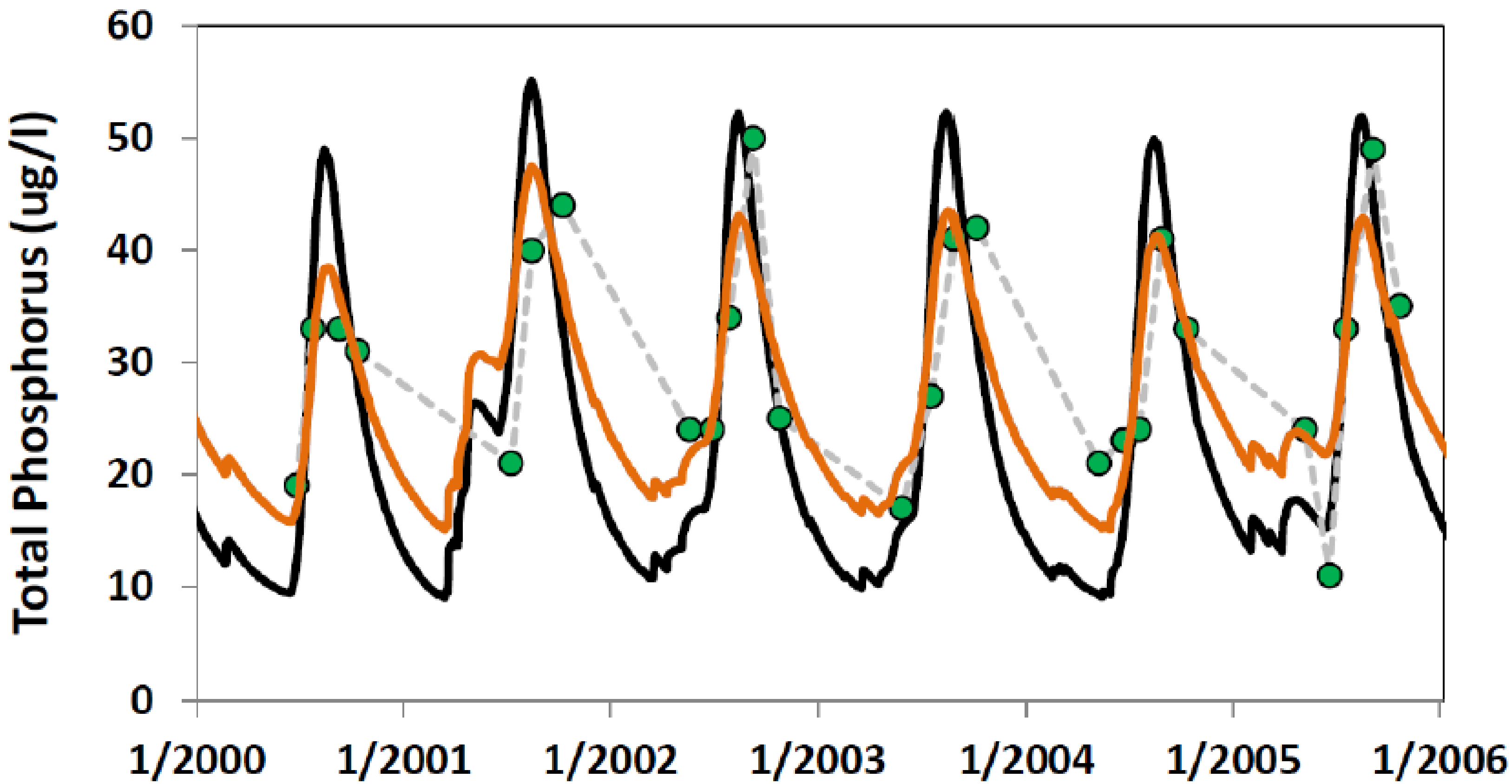



Annual Phosphorus Input
Simpler Models…
--completely mixed
-- steady with time
Annual Water Input
Annual Phosphorus Settling
Complex Models…
--segments in lake
--vary with time
--biology!

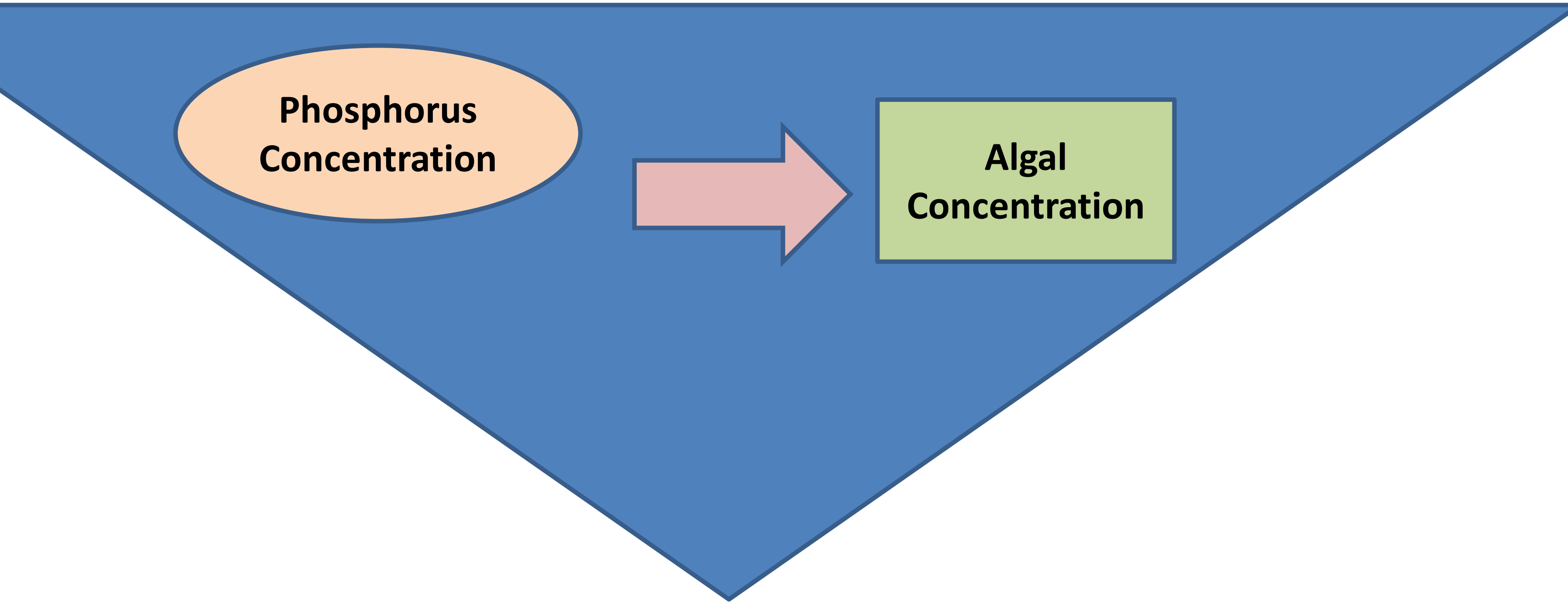
What about this Steady-State Assumption?

- Is that an important assumption?
- What about concentrations that vary during the growing season
- What about long-term trends or large year-to-year variations?

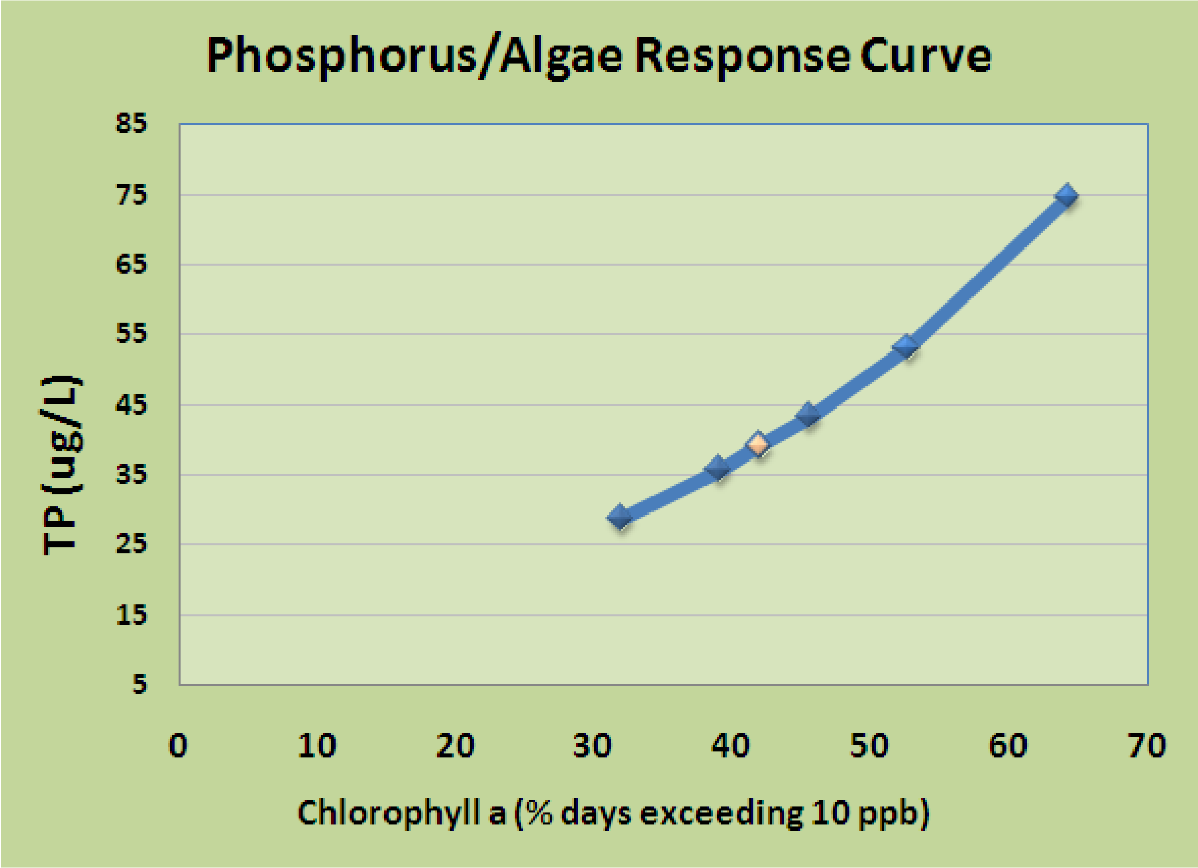
What about the P concentration in this lake?



Lake Response Model?

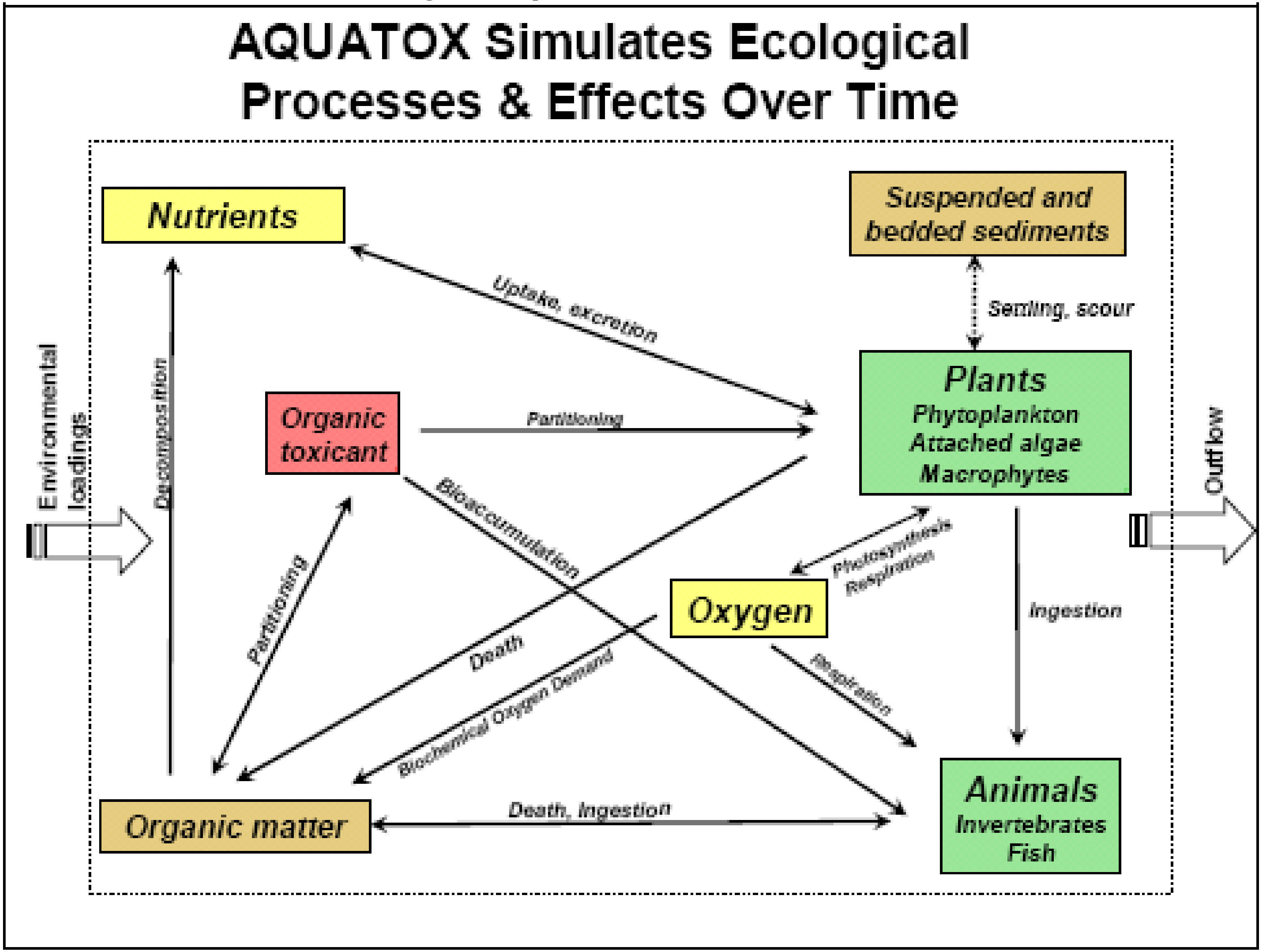


- Useful?

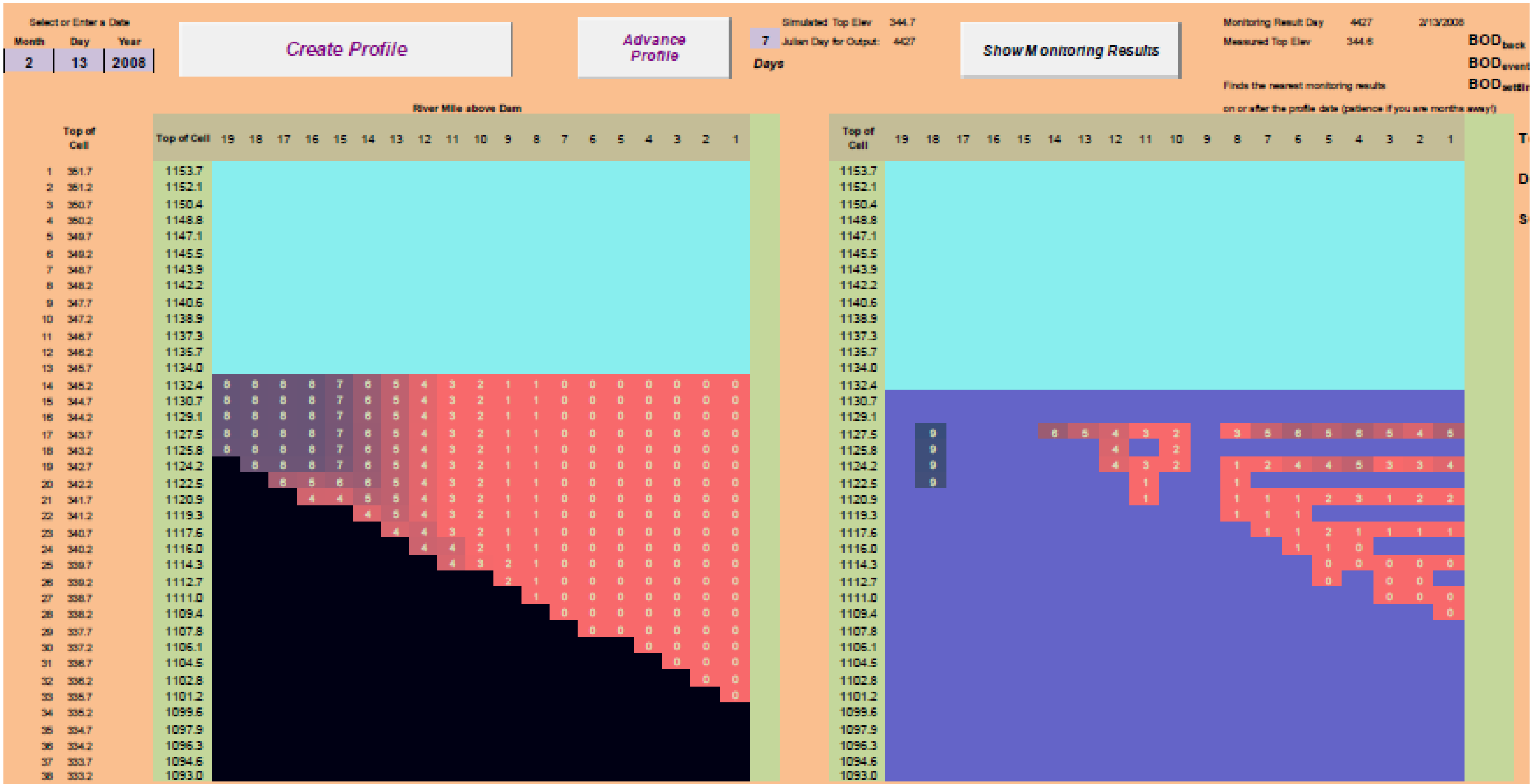


Phosphorus/Algae Response Curve
TP (ug/L)
85
75
65
55
45
35
25
15
5
0
10
20
30
40
50
60
70
Chlorophyll a (% days exceeding 10 ppb)

But we can make this very complex!



Lake Model with changing daily inputs and spatial variations within the lake…



Summary Discussion

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

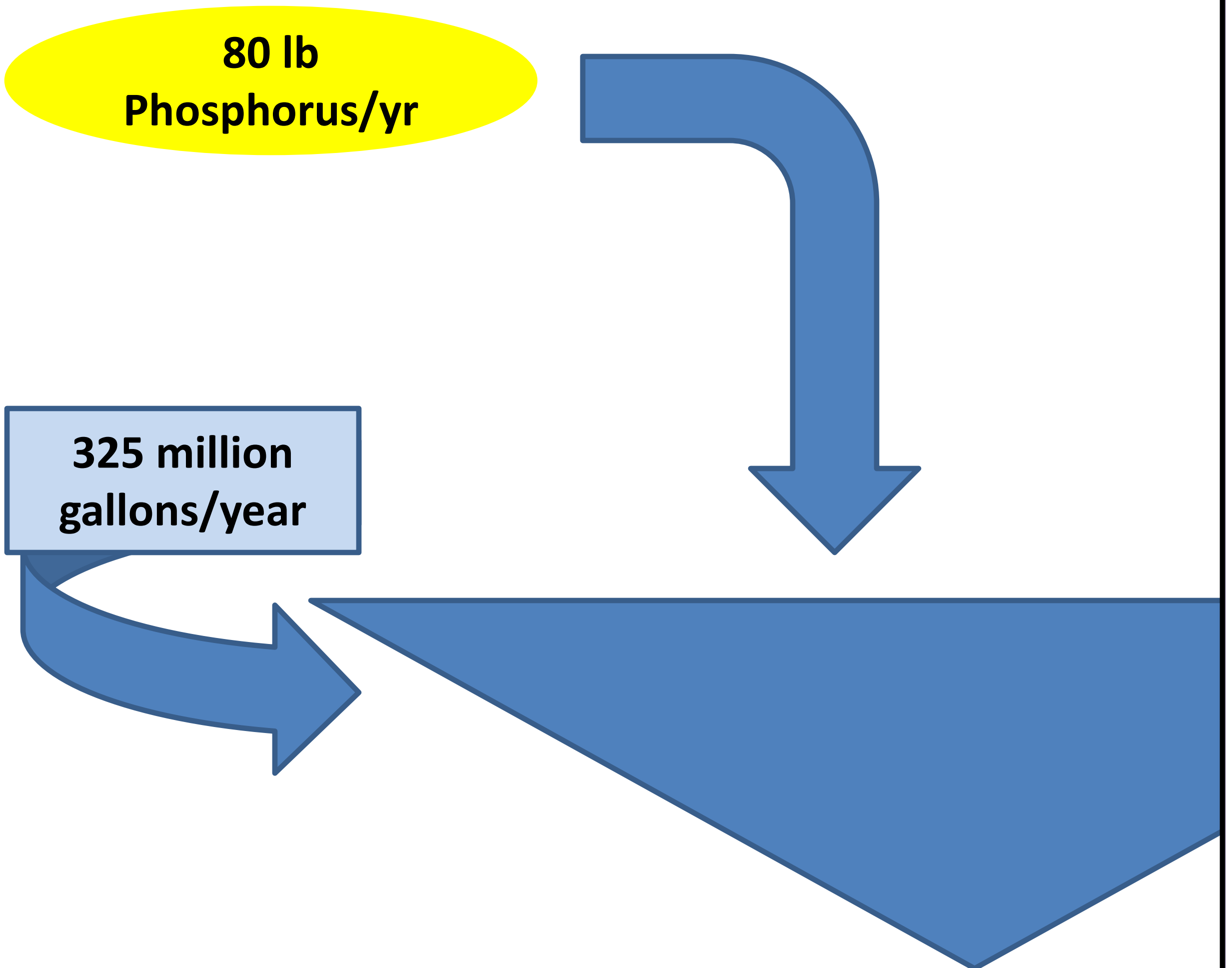
- Simple
  - Reduce Spatial Variations
  - Long Term Averages
- Complex
  - Time and Space Variations
  - Daily / Yearly Variations

Questions

Paul McGinley
UW-Stevens Point
pmcginle@uwsp.edu
(715) 346-4501

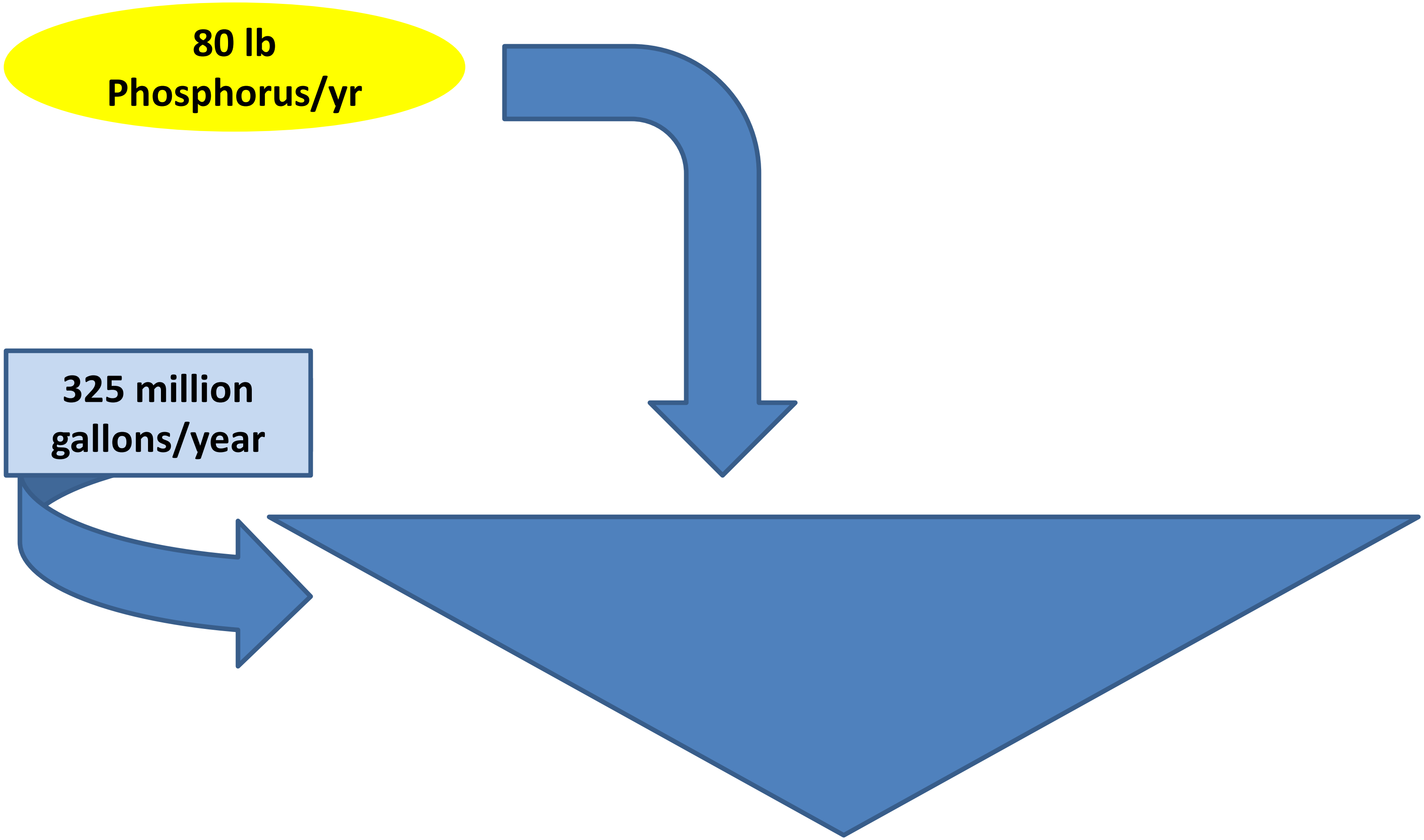
Center for Watershed Science and Education
College of Natural Resources
University of Wisconsin-Stevens Point

UW Extension

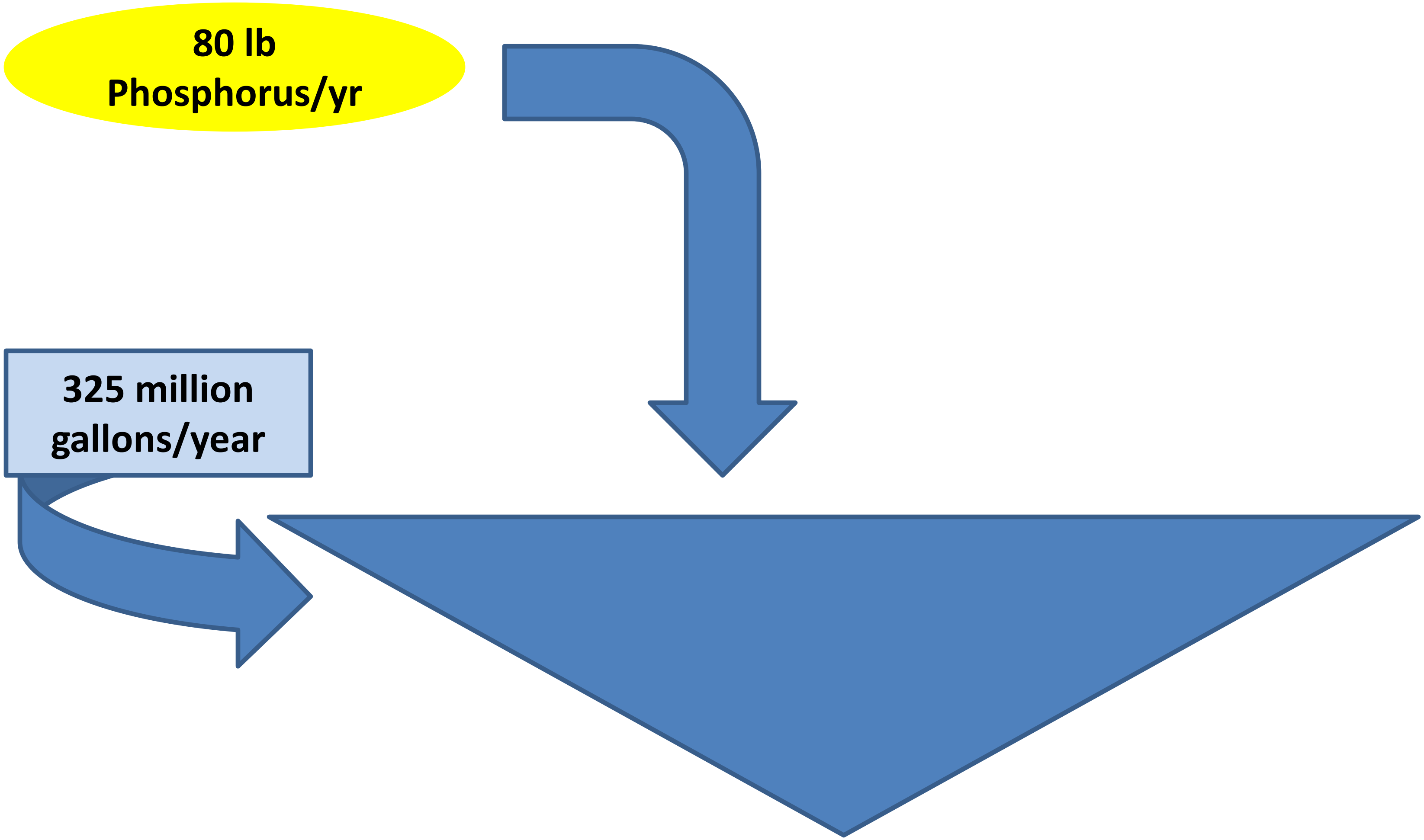


A model for the phosphorus concentration in a lake

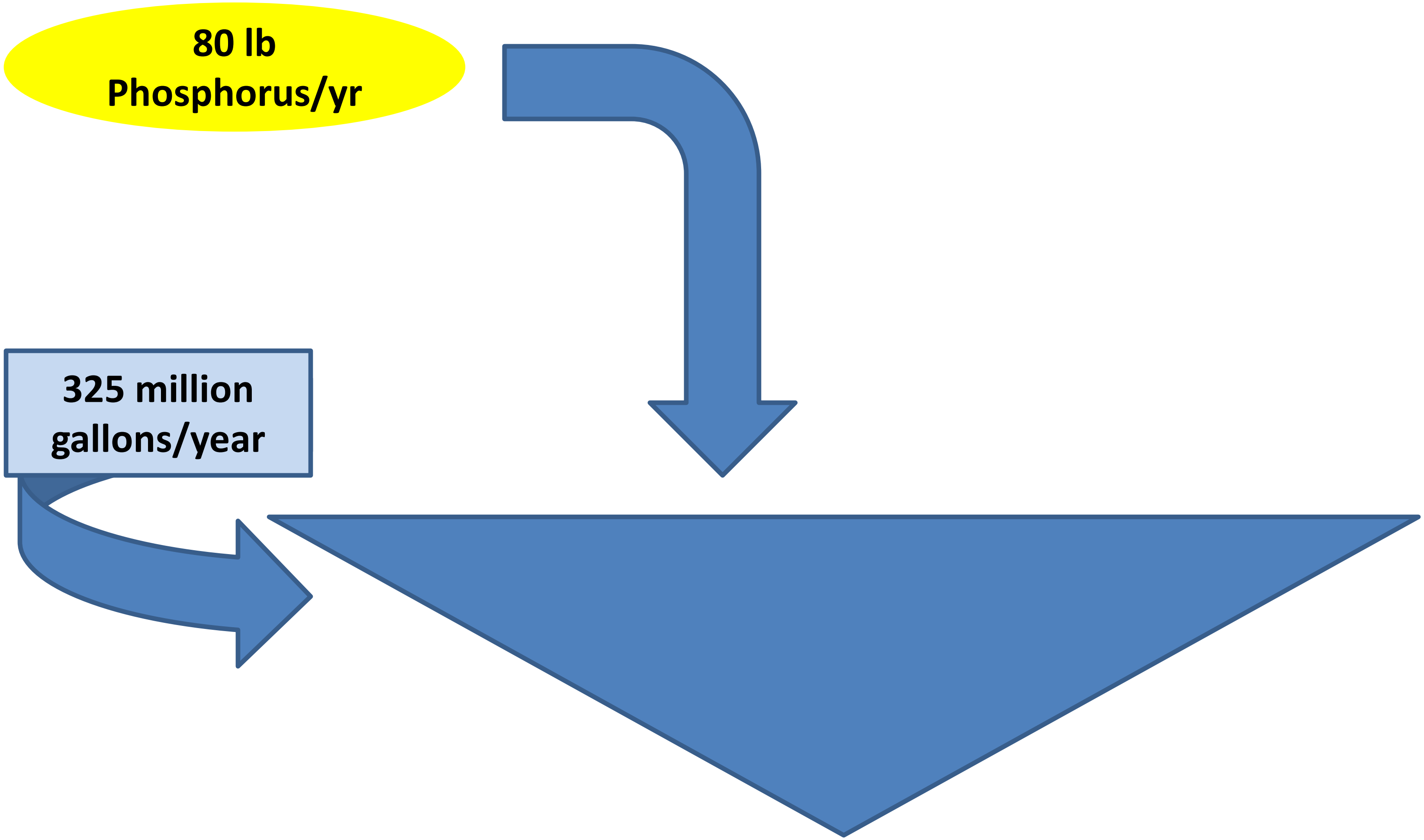
$$= \frac{\text{Amount of Phosphorus}}{\text{Amount of Water}}$$



= 80 lb/ 325 million gallons =



= 80 lb/ 3 billion lbs water=

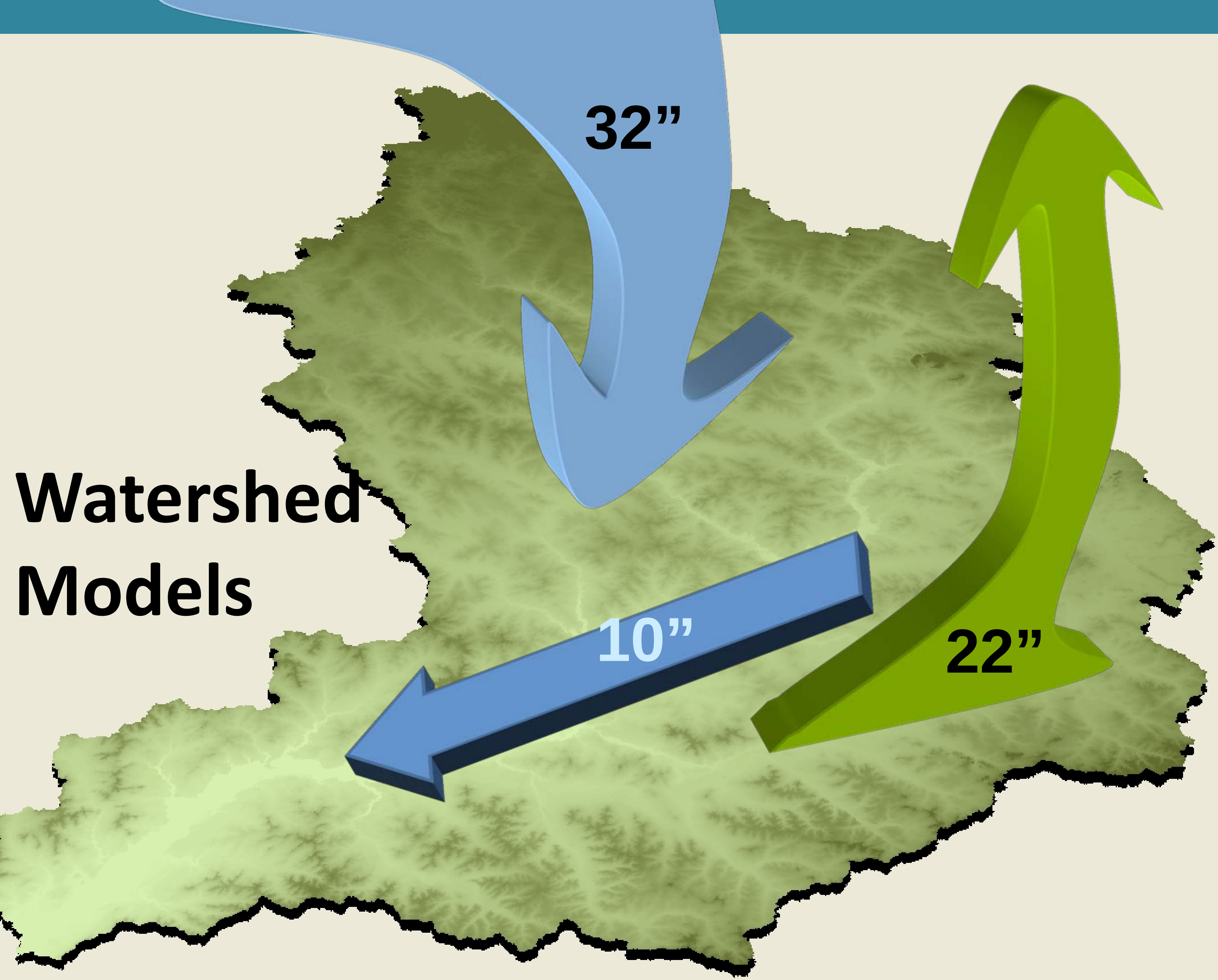


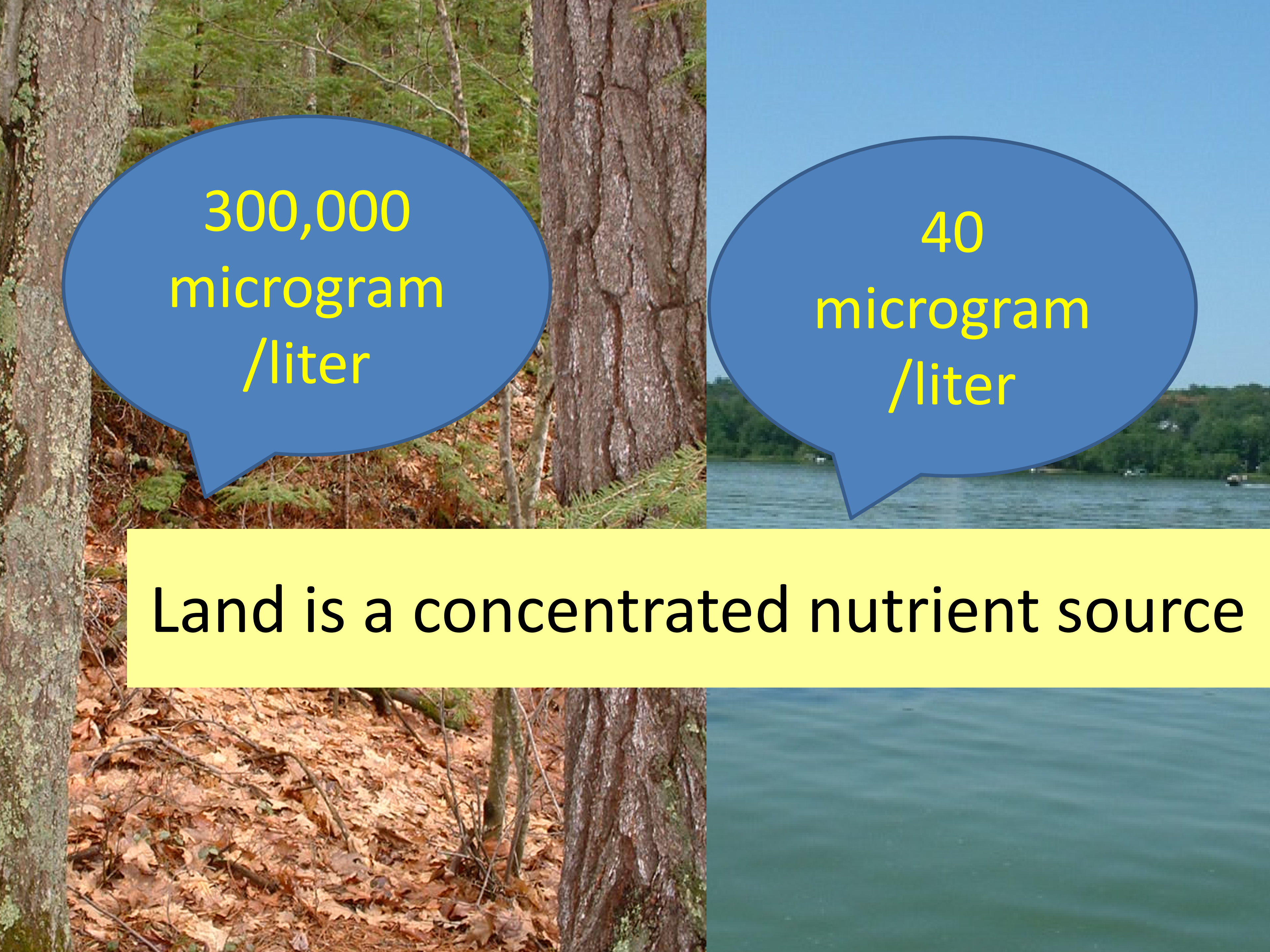
= 80 lb/ 3 billion lbs water= 27 ppb

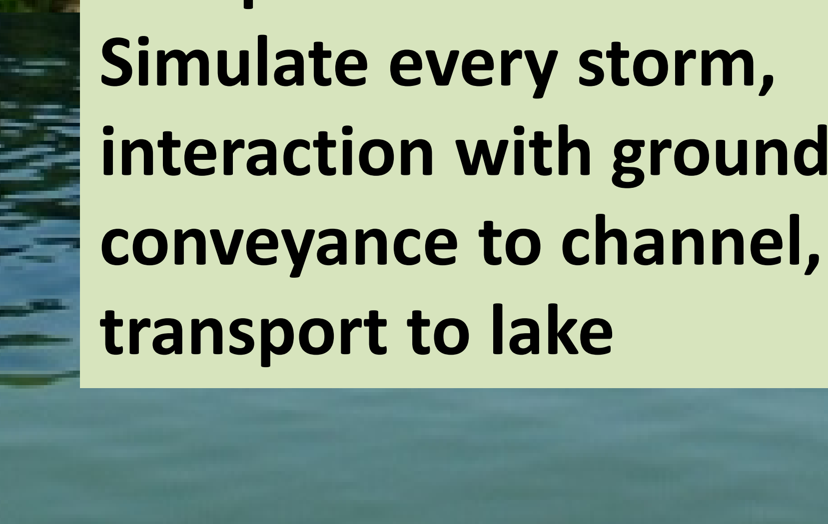
Why Model?

- Groundwater flow– where water is coming from?
- Lake concentration —what if we change the amount added?
- Watershed modeling– can watershed changes help and by how much?
- In-Lake Restoration – “experiment” with treatment, diversions etc.

Watershed Models




300,000 microgram /liter
40 microgram /liter
Land is a concentrated nutrient source

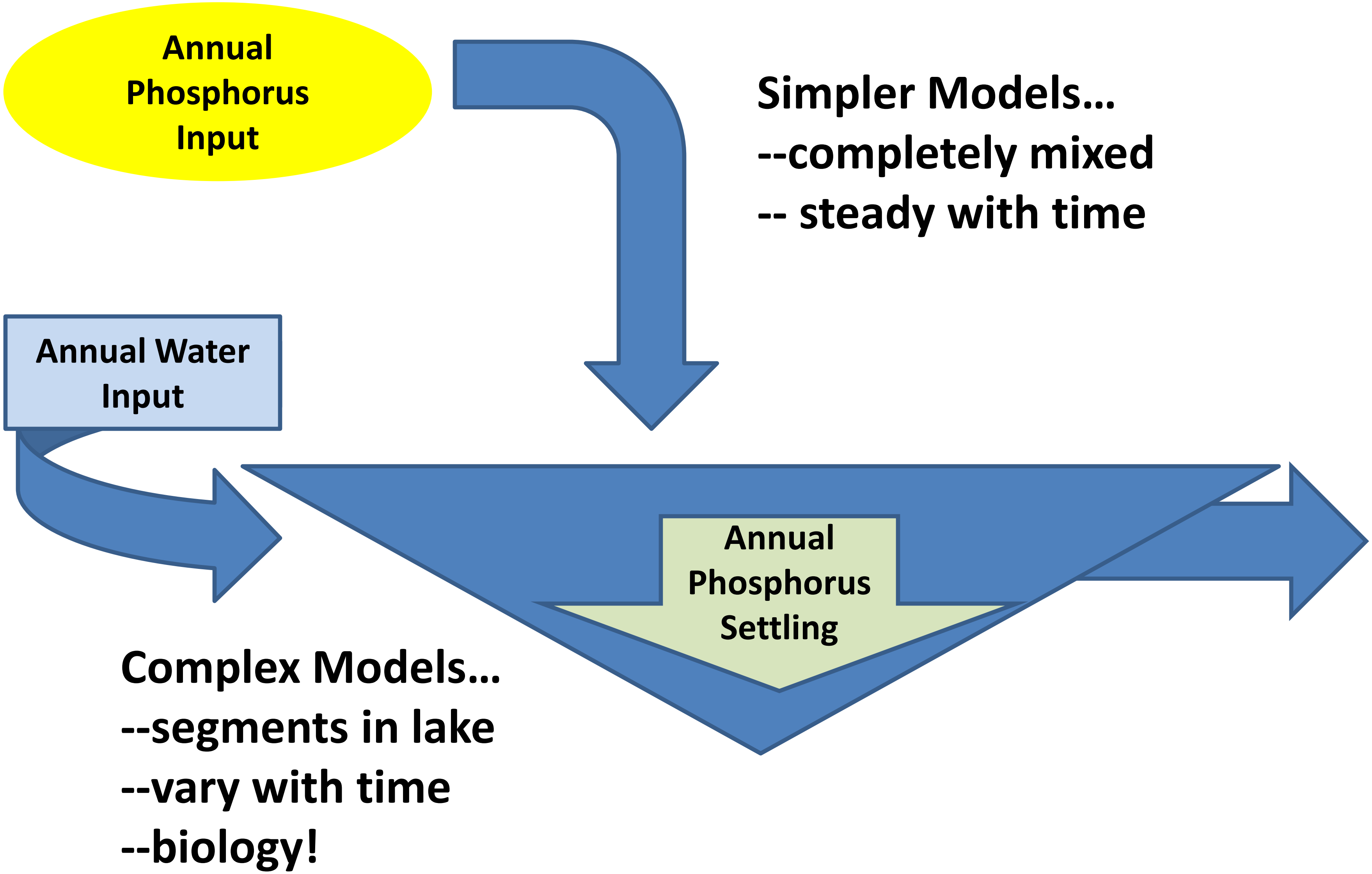


Simple Model:
Assign annual transfer rate to different land uses

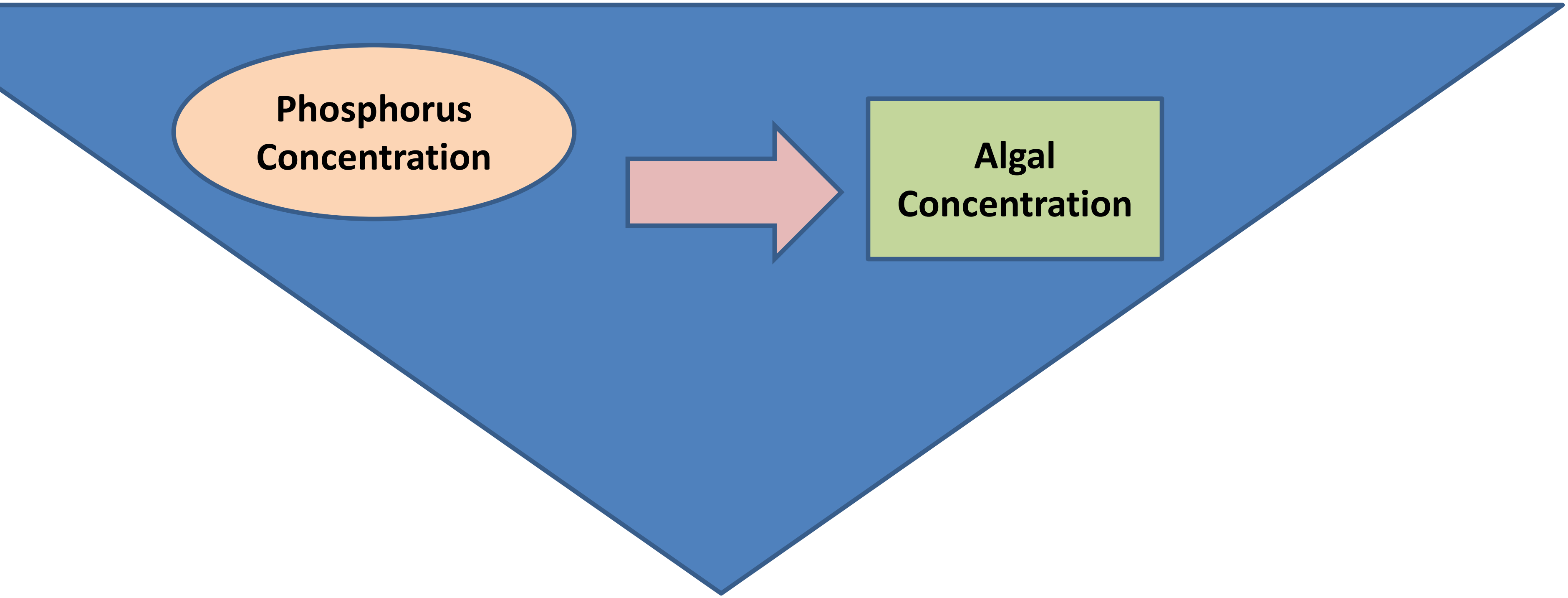
Complex Model:
Simulate every storm, interaction with ground, conveyance to channel, transport to lake

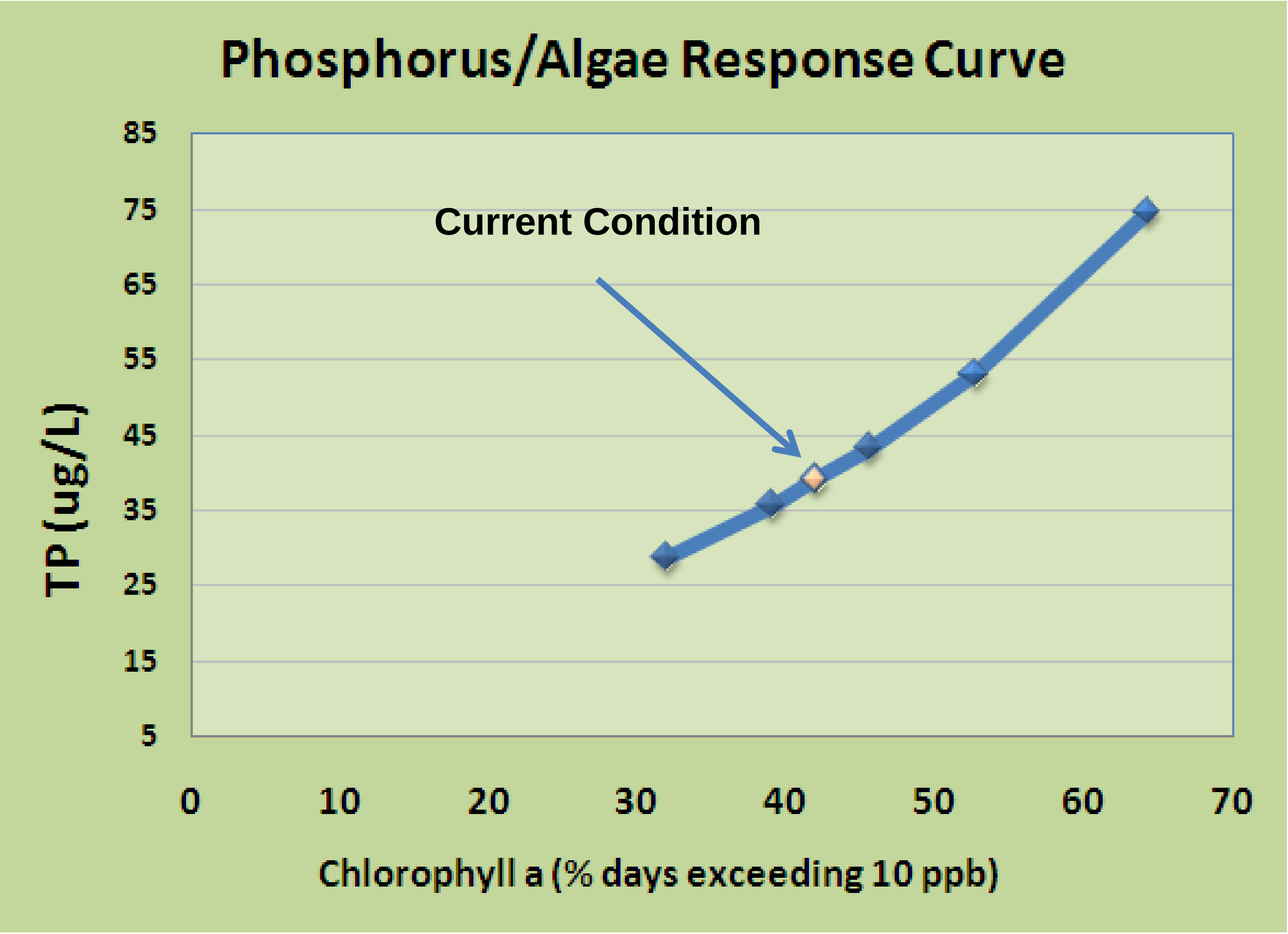
Lake Models

Phosphorus Concentration ($\mu g/l$)	Productivity
10	Low (Oligotrophic)
10-20	Medium (Mesotrophic)
Greater than 20	High (Eutrophic)


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!

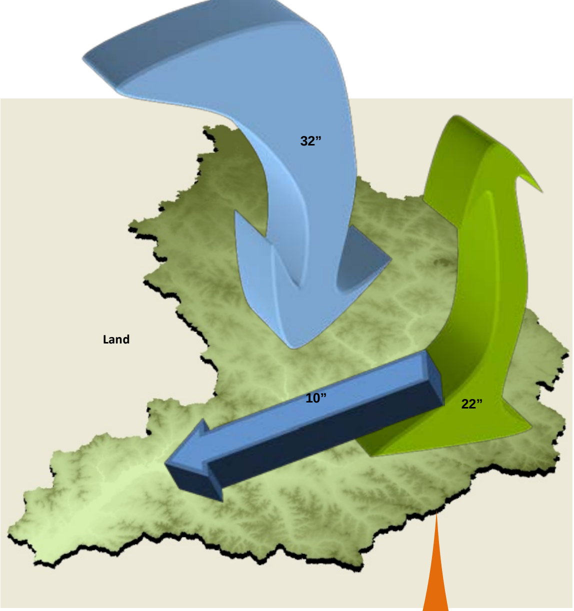
Lake Response Model?




Phosphorus/Algae Response Curve
Current Condition
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)

Application to Portage County

Modeling the Land?



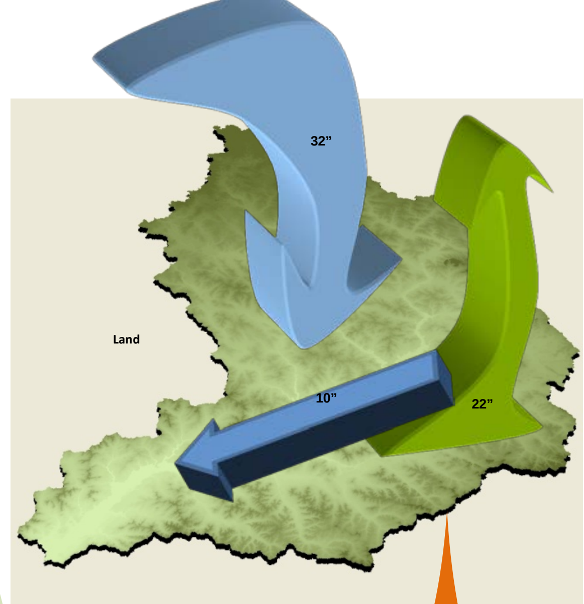
Annual Volume x Average Concentration

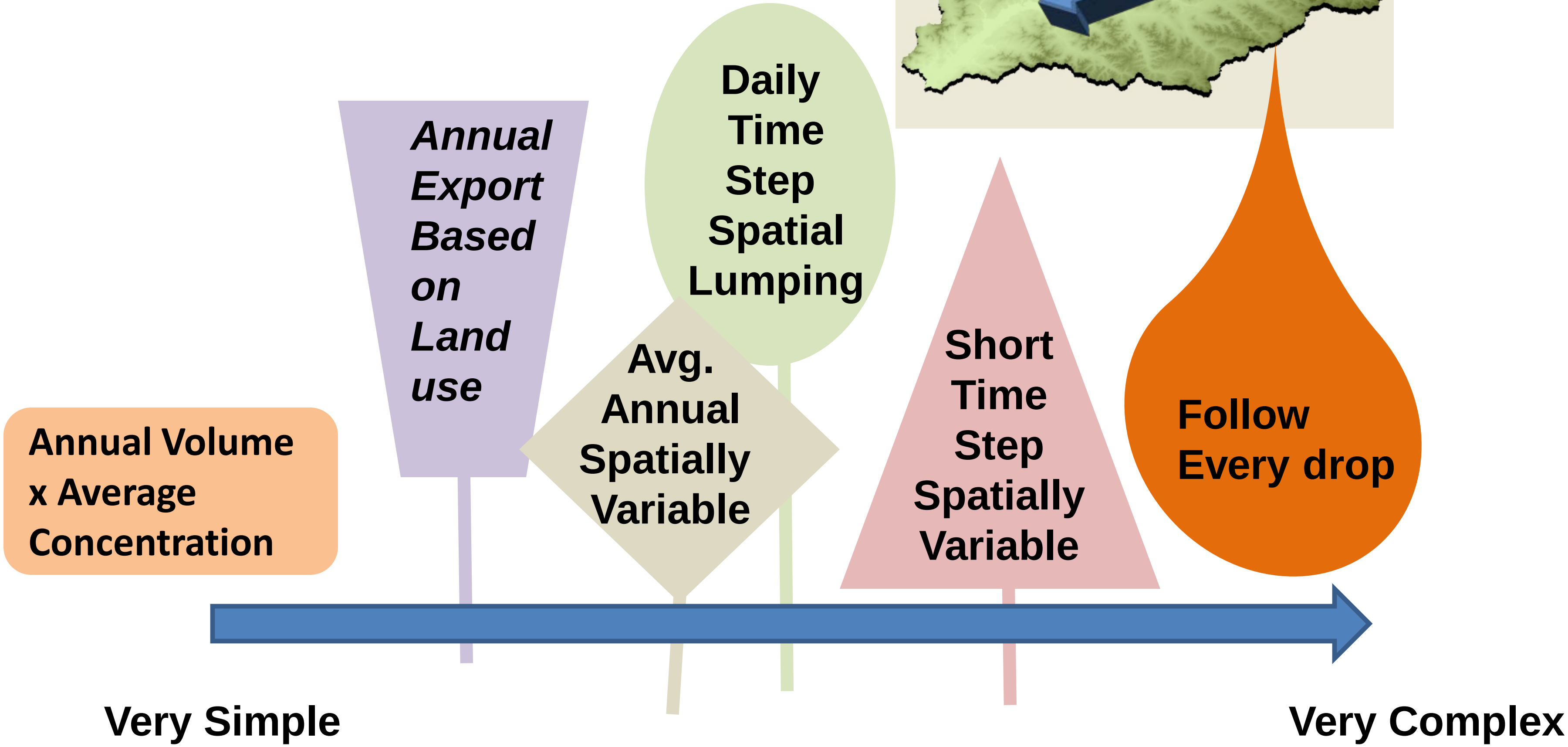
Follow Every drop

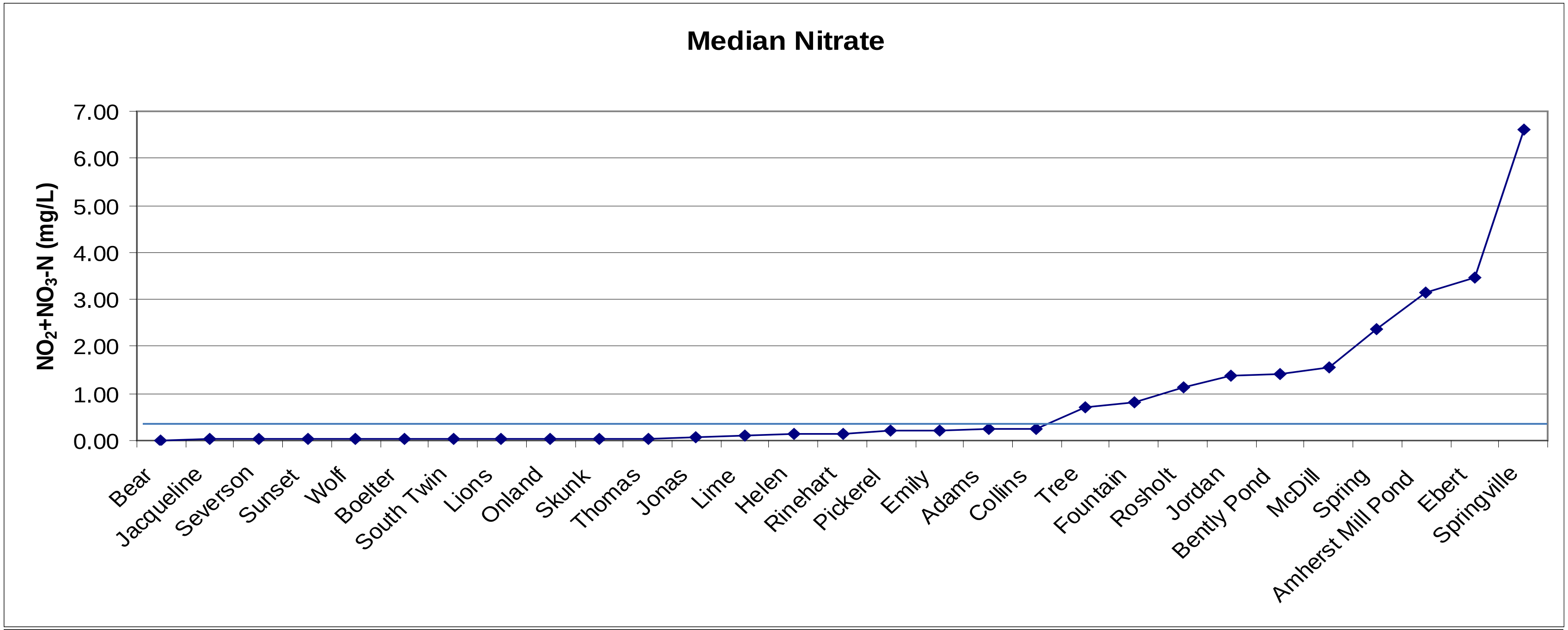
Very Simple

Very Complex

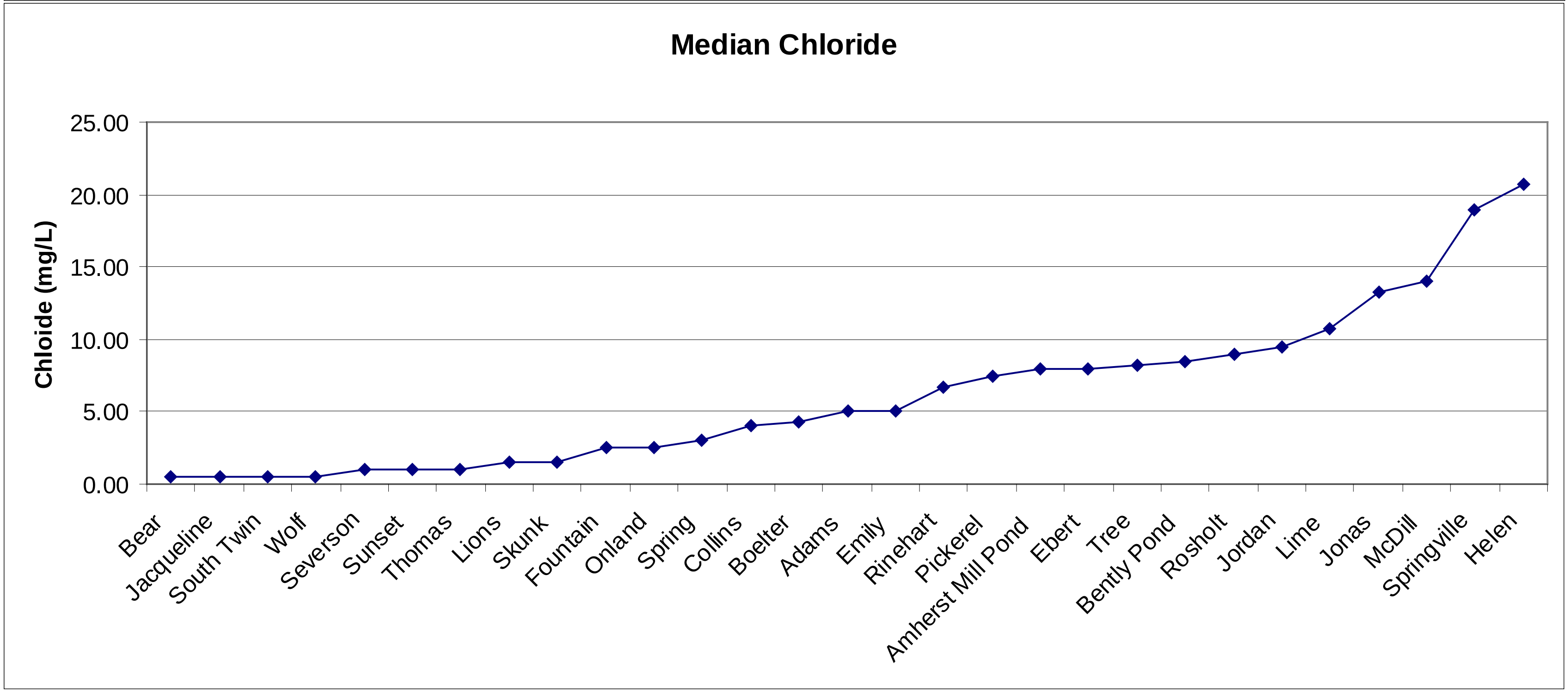
Modeling the Land?



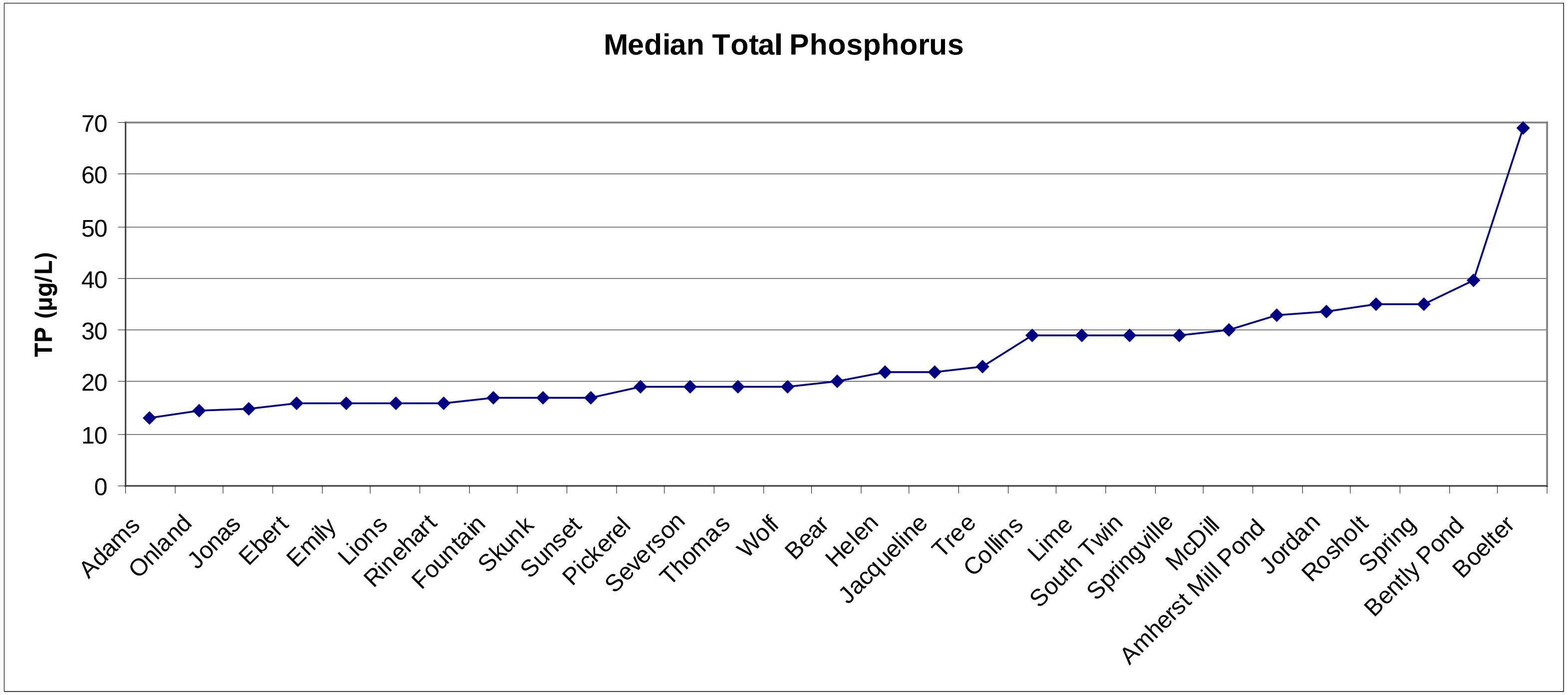


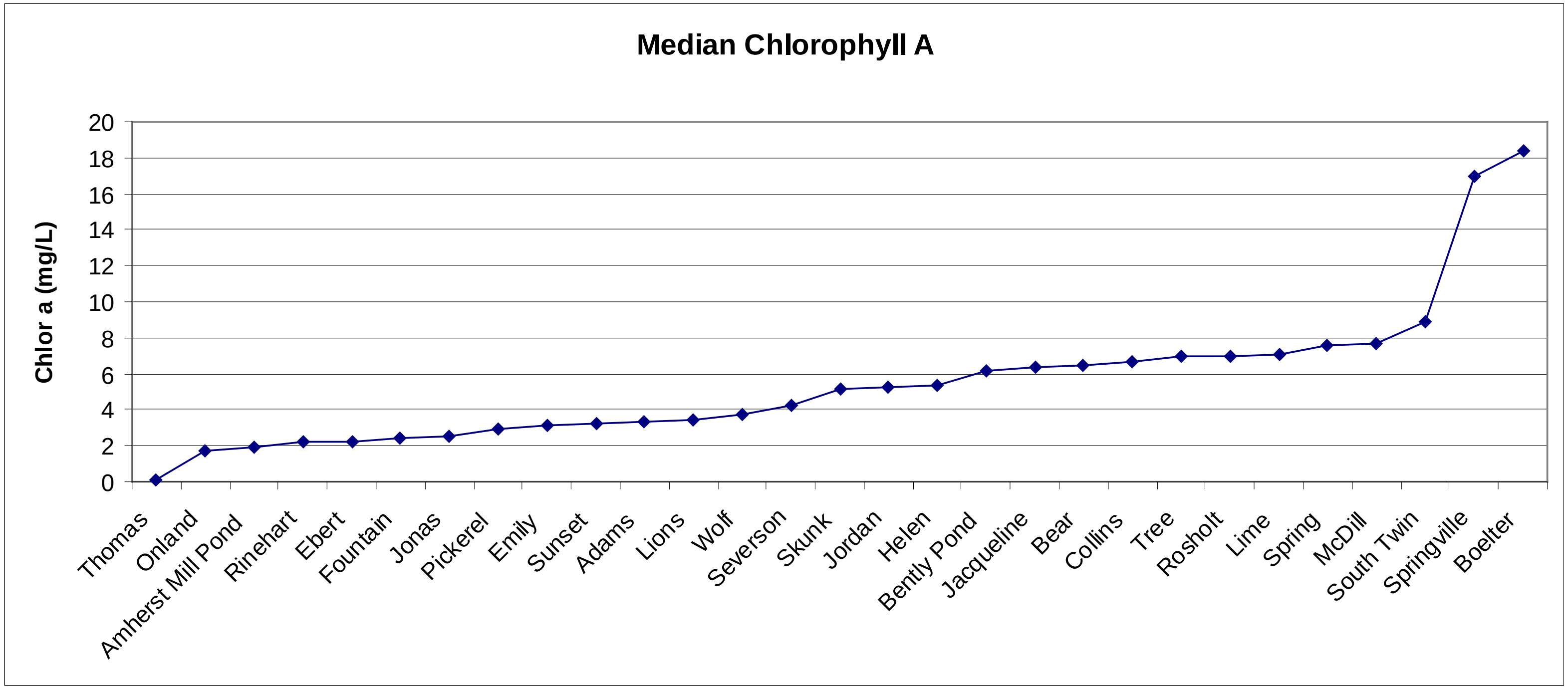


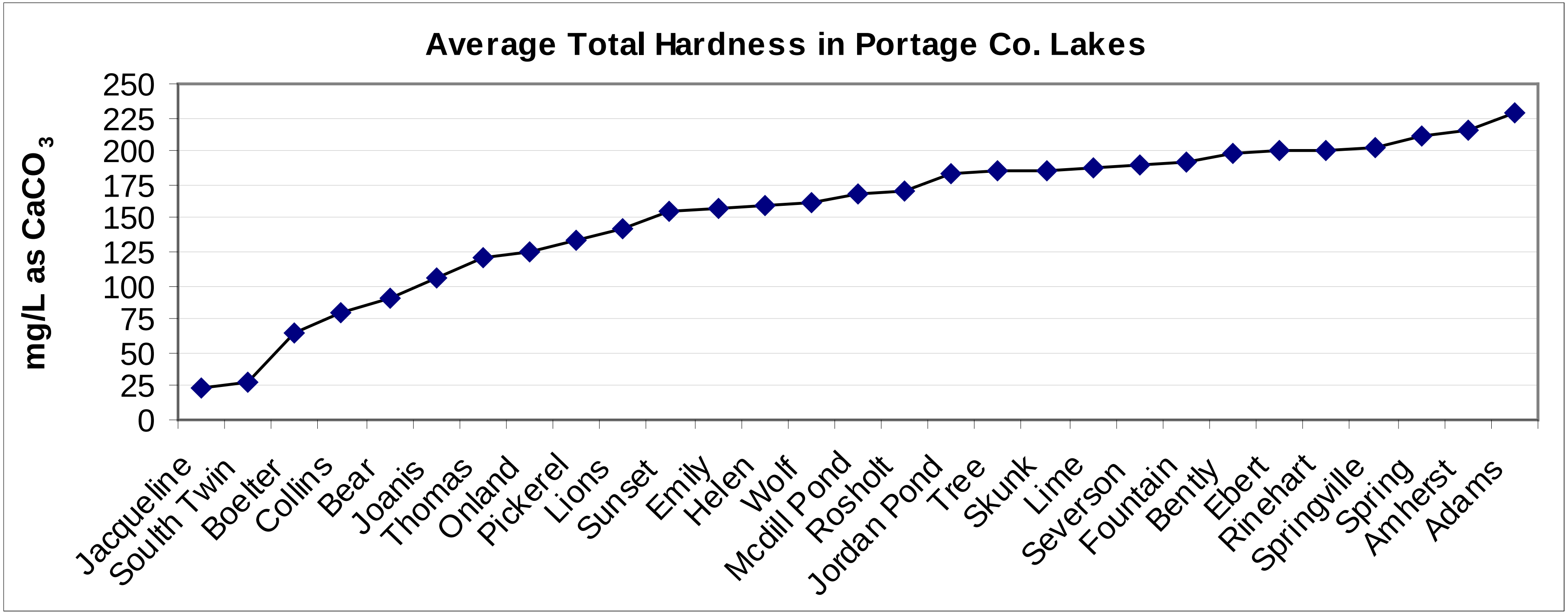
Median Nitrate
NO2+NO3-N (mg/L)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Bear
Jacqueline
Severson
Sunset
Wolf
Boelter
South Twin
Lions
Onland
Skunk
Thomas
Jonas
Lime
Helen
Rinehart
Pickerel
Emily
Adams
Collins
Tree
Fountain
Rosholt
Jordan
Bently Pond
McDill
Spring
Amherst Mill Pond
Ebert
Springville

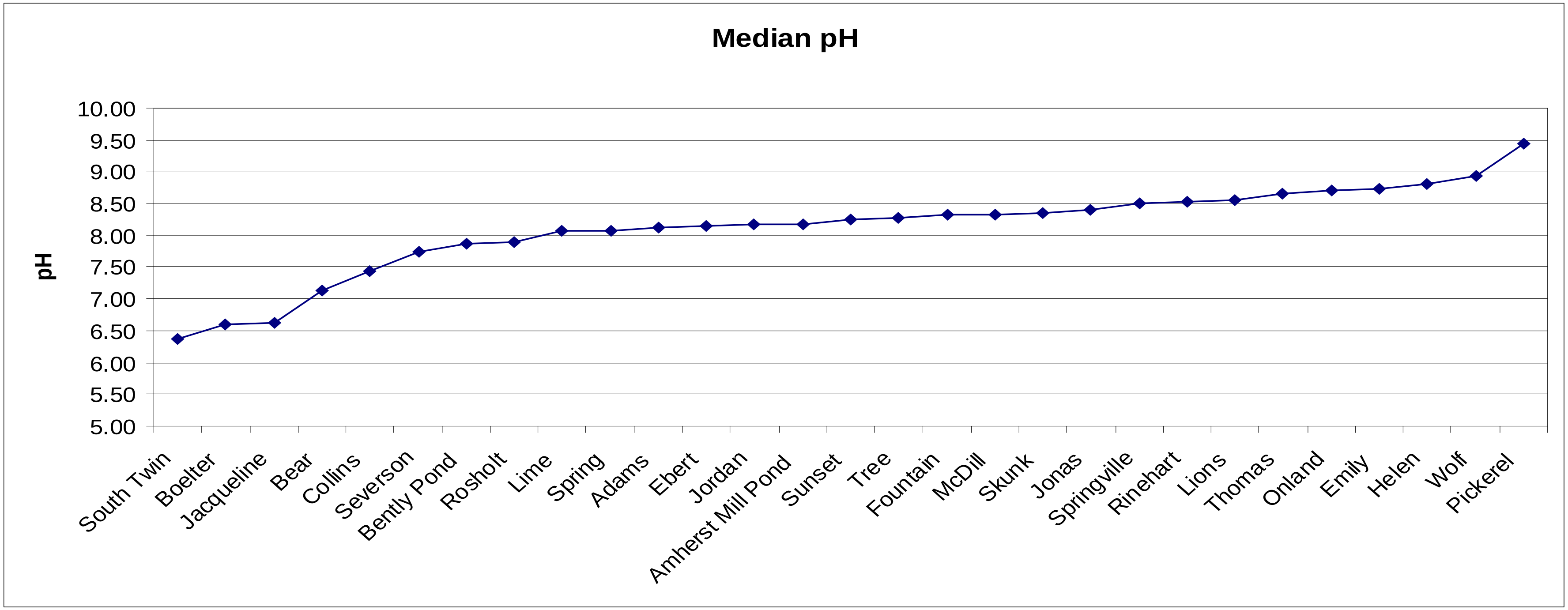


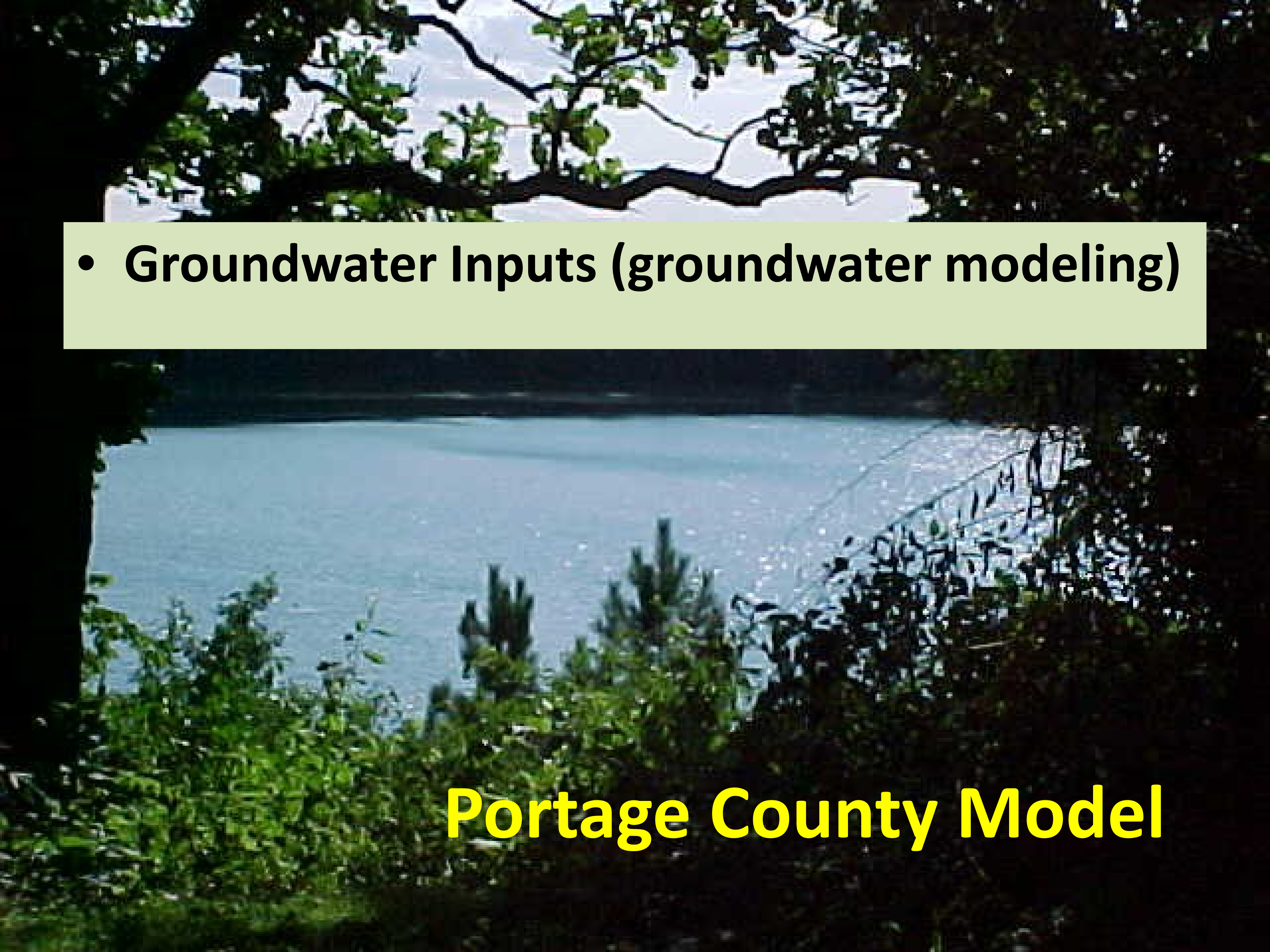
Median Chloride
Chloide (mg/L)
25.00
20.00
15.00
10.00
5.00
0.00
Bear
Jacqueline
South Twin
Wolf
Severson
Sunset
Thomas
Lions
Skunk
Fountain
Onland
Spring
Collins
Boelter
Adams
Emily
Rinehart
Pickerel
Amherst Mill Pond
Ebert
Tree
Bently Pond
Rosholt
Jordan
Lime
Jonas
McDill
Springville
Helen


Median Total Phosphorus
TP (µg/L)
0
10
20
30
40
50
60
70
Adams
Onland
Jonas
Ebert
Emily
Lions
Rinehart
Fountain
Skunk
Sunset
Pickerel
Severson
Thomas
Wolf
Bear
Helen
Jacqueline
Tree
Collins
Lime
South Twin
Springville
McDill
Amherst Mill Pond
Jordan
Rosholt
Spring
Bently Pond
Boelter


Median Chlorophyll A
Chlor a (mg/L)
0
2
4
6
8
10
12
14
16
18
20
Thomas
Onland
Amherst Mill Pond
Rinehart
Ebert
Fountain
Jonas
Pickerel
Emily
Sunset
Adams
Lions
Wolf
Severson
Skunk
Jordan
Helen
Bently Pond
Jacqueline
Bear
Collins
Tree
Rosholt
Lime
Spring
McDill
South Twin
Springville
Boelter

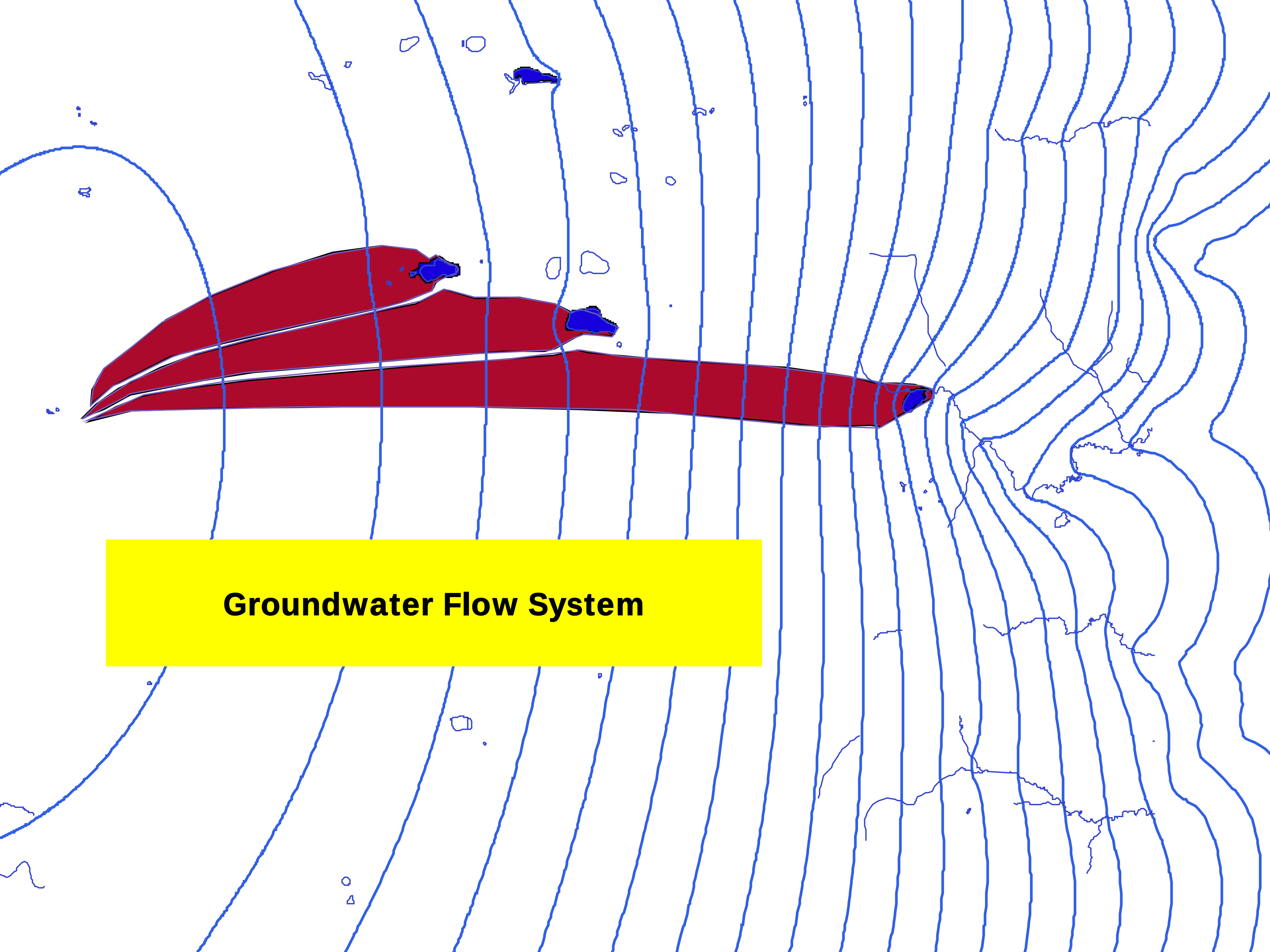

Average Total Hardness in Portage Co. Lakes
mg/L as $CaCO_3$
250
225
200
175
150
125
100
75
50
25
0
Jacqueline
Soulth Twin
Boelter
Collins
Bear
Joanis
Thomas
Onland
Pickerel
Lions
Sunset
Emily
Helen
Wolf
Mcdill Pond
Rosholt
Jordan Pond
Tree
Skunk
Lime
Severson
Fountain
Bently
Ebert
Rinehart
Springville
Spring
Amherst
Adams


Median pH
pH
10.00
9.50
9.00
8.50
8.00
7.50
7.00
6.50
6.00
5.50
5.00
South Twin
Boelter
Jacqueline
Bear
Collins
Severson
Bently Pond
Rosholt
Lime
Spring
Adams
Ebert
Jordan
Amherst Mill Pond
Sunset
Tree
Fountain
McDill
Skunk
Jonas
Springville
Rinehart
Lions
Thomas
Onland
Emily
Helen
Wolf
Pickerel



- Groundwater Inputs (groundwater modeling)

Portage County Model


Groundwater Flow System

Relatively Simple Lake Model

Annual Phosphorus = P-Undeveloped + P-Developed

$$C = \frac{W}{A_S v_S + Q}$$

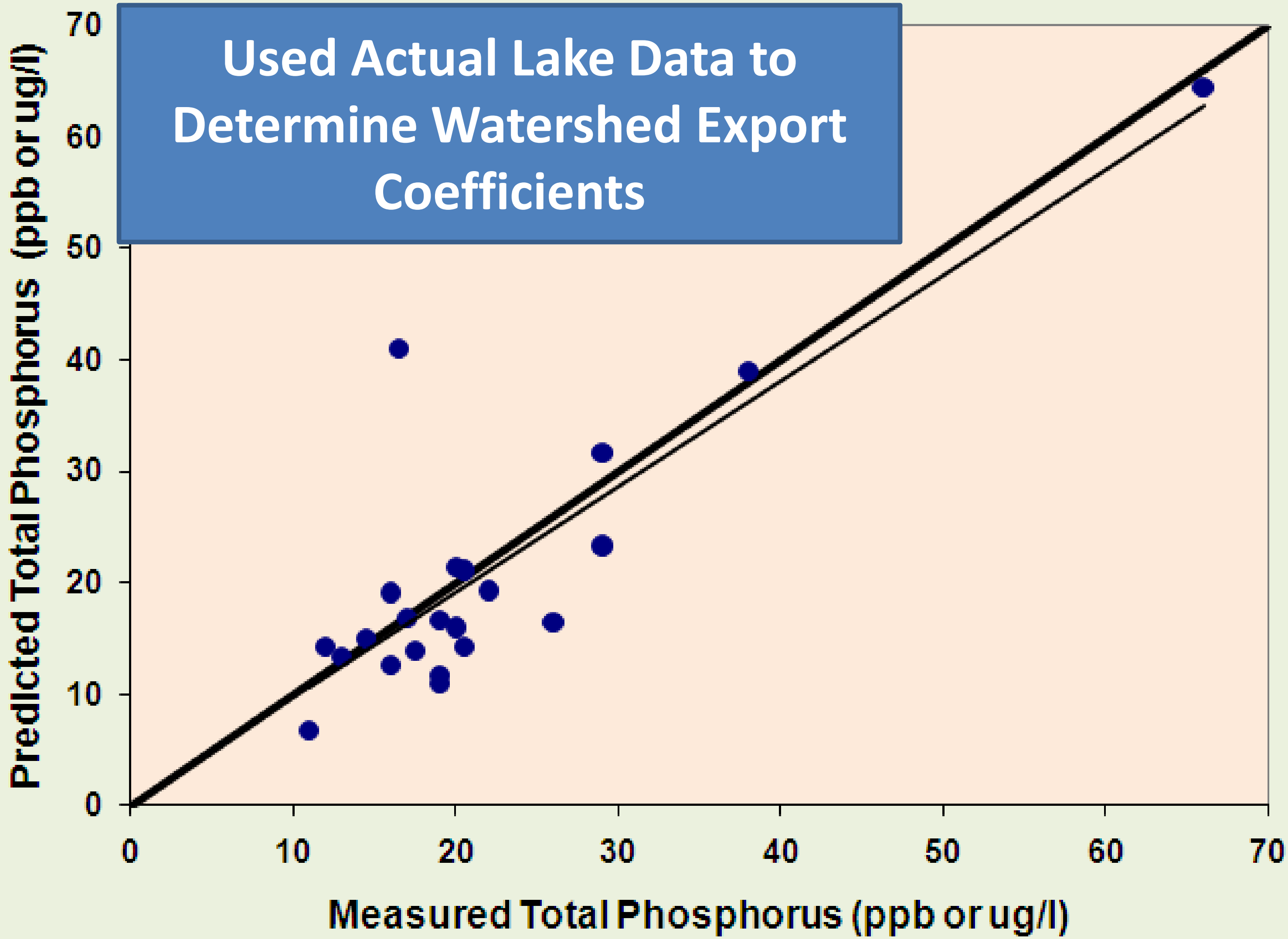
Amount of Water

"Settling Factor"

Portage County Model

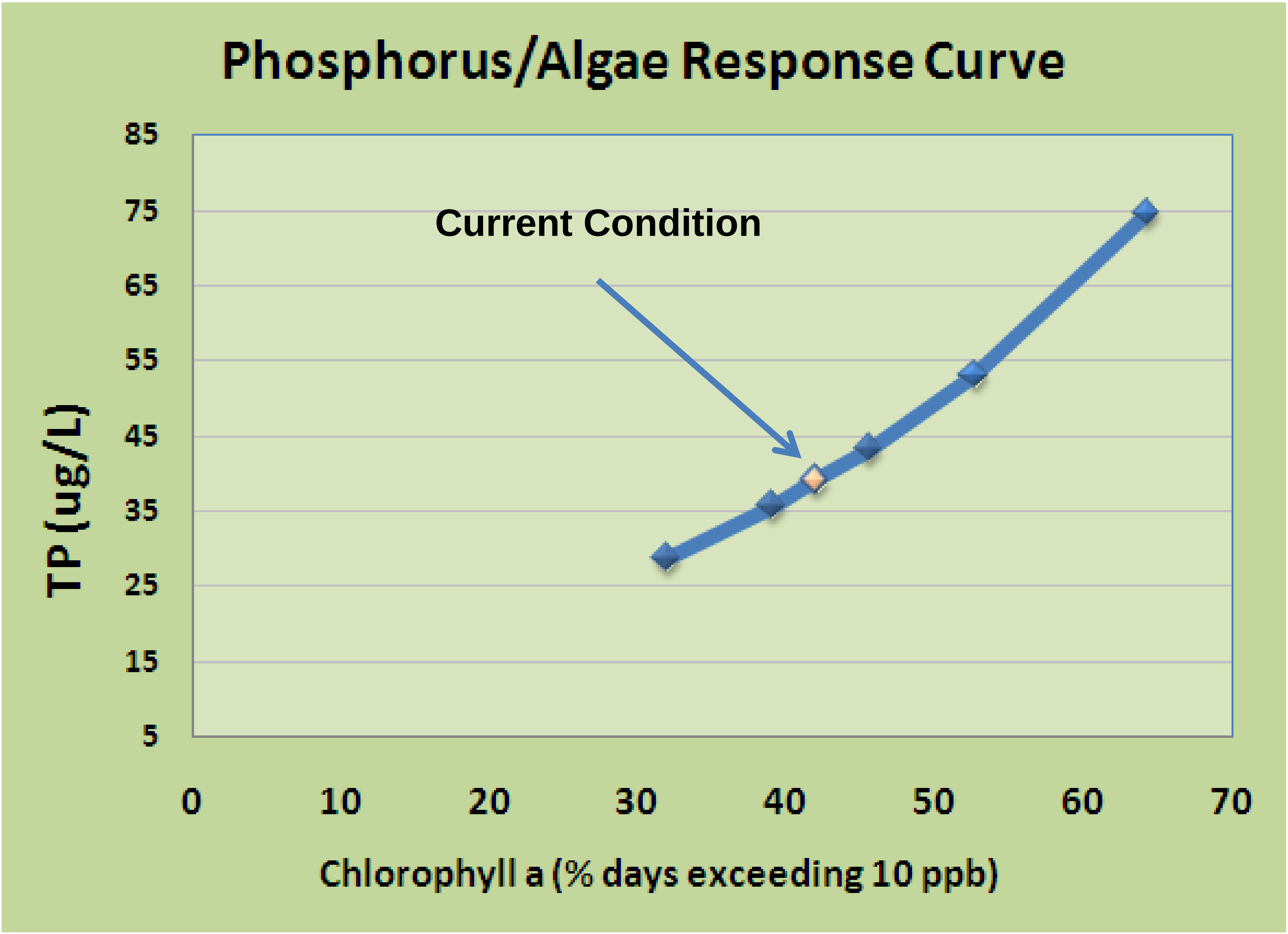
$$C = \frac{W}{A_S v_S + Q}$$

Used Actual Lake Data to Determine Watershed Export Coefficients



Use Lake Phosphorus to Predict Lake Chlorophyll

Portage County Model


Phosphorus/Algae Response Curve
Current Condition
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)

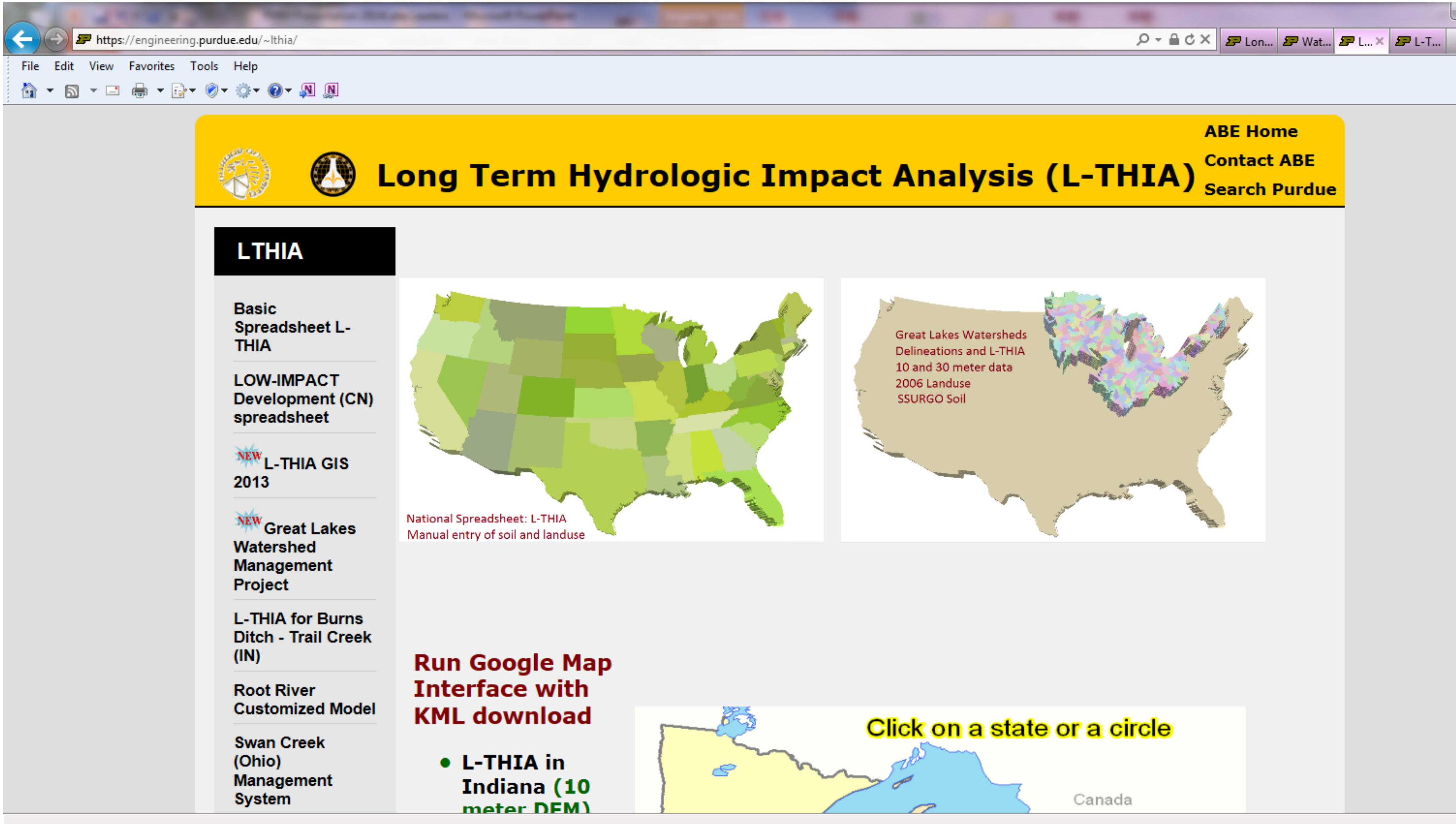

Questions

WATERSHED DELINEATION DISCUSSION

Watershed Delineation

- Topography
- Groundwater Complications
- Tools
  - WDNR Surface Water Data Viewer
  - New WDNR Tools (soon in PRESTO)

L-THIA


https://engineering.purdue.edu/~lthia/
File Edit View Favorites Tools Help
Long Term Hydrologic Impact Analysis (L-THIA)
ABE Home
Contact ABE
Search Purdue
LTHIA
Basic Spreadsheet L-THIA
LOW-IMPACT Development (CN) spreadsheet
NEW L-THIA GIS 2013
NEW Great Lakes Watershed Management Project
L-THIA for Burns Ditch - Trail Creek (IN)
Root River Customized Model
Swan Creek (Ohio) Management System
National Spreadsheet: L-THIA
Manual entry of soil and landuse
Great Lakes Watersheds
Delineations and L-THIA
10 and 30 meter data
2006 Landuse
SSURGO Soil
Run Google Map Interface with KML download
L-THIA in Indiana (10 meter DEM)
Click on a state or a circle
Canada

ing.purdue.edu/mapserve/LTHIAWD/wi/lthia2_wi.html?del=0&watershed=wdzt1572&statename=Wisconsin&countyname=Vernon&flowLengthFt=&xcoord=193882.61006086942&yc

Tools Help

Metadata

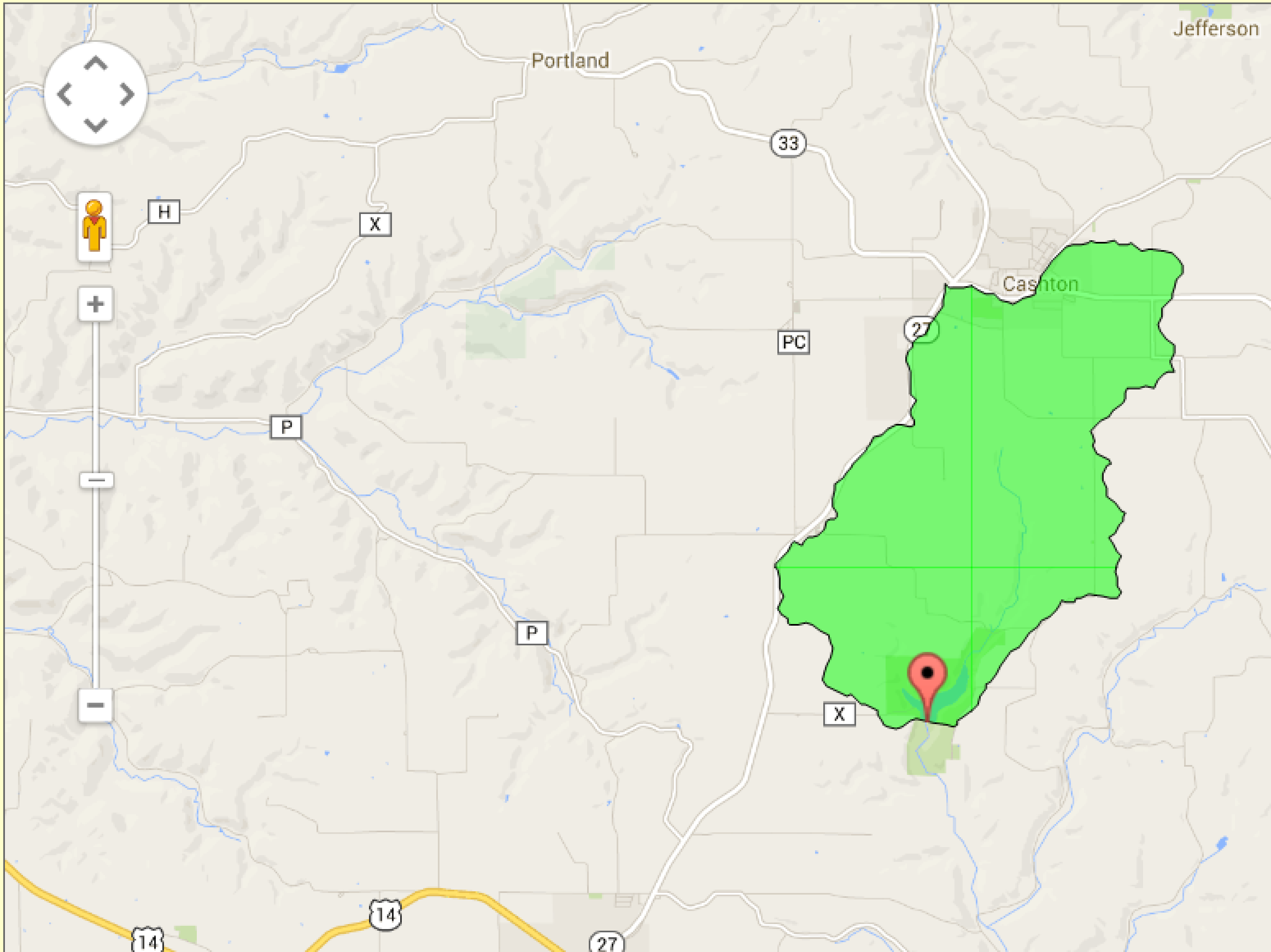
m-in to your area.

Search

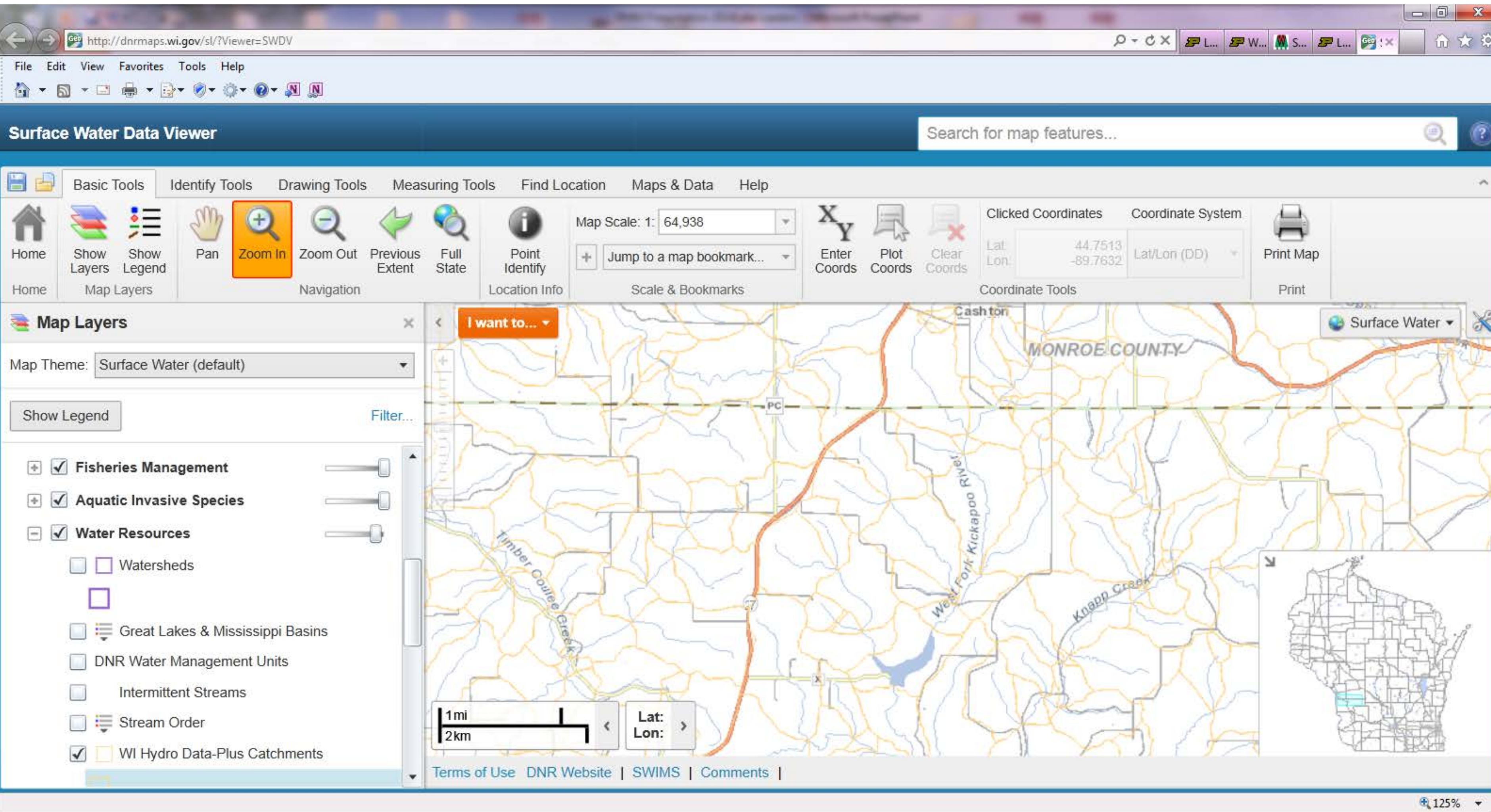
button and click on
watershed you
our location is sent
ine and the
point is calculated;
-THIA model on it

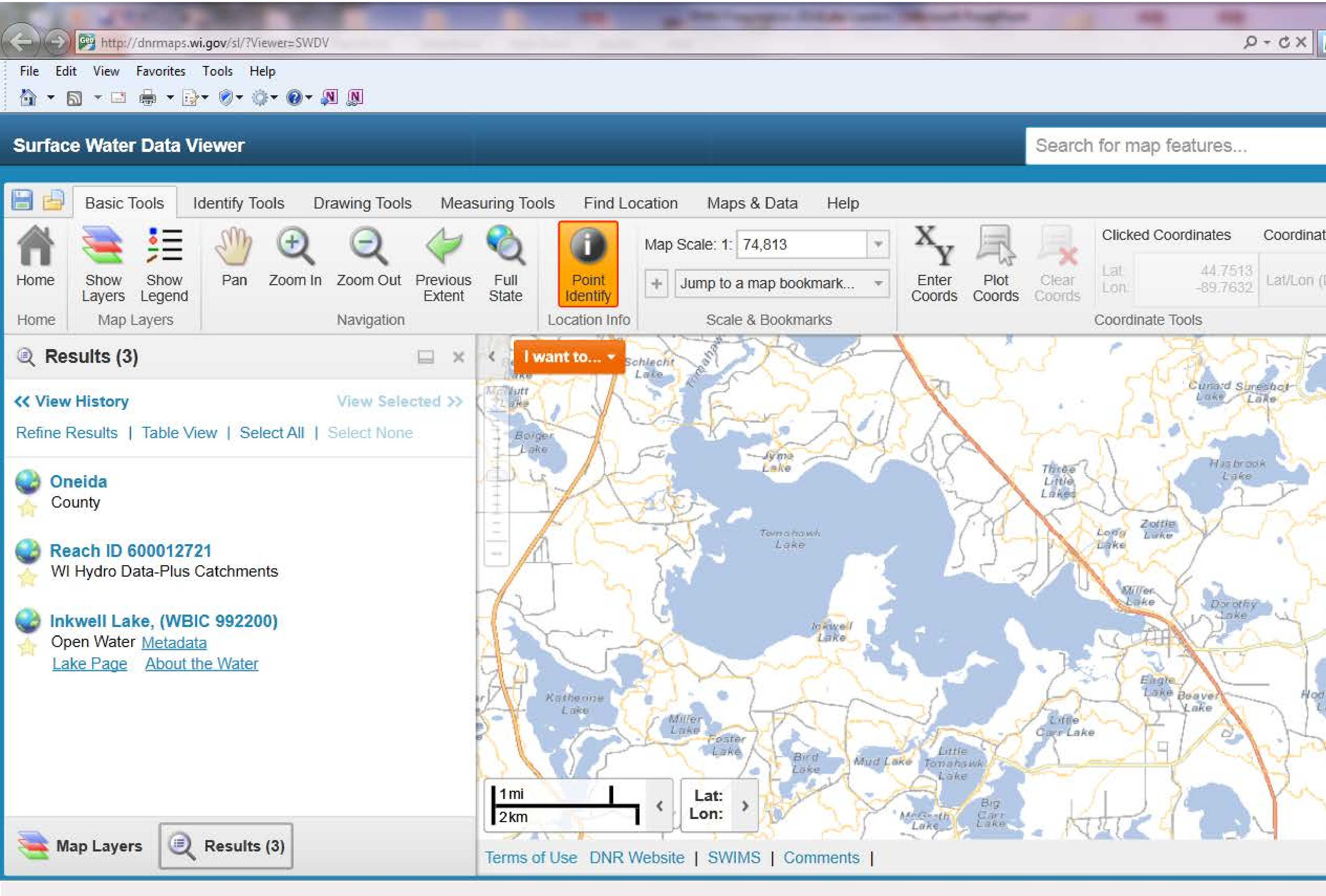
c latitude- longitude
utton below ,
us sign must be
o -87.00000 and
90000 to 42.00000

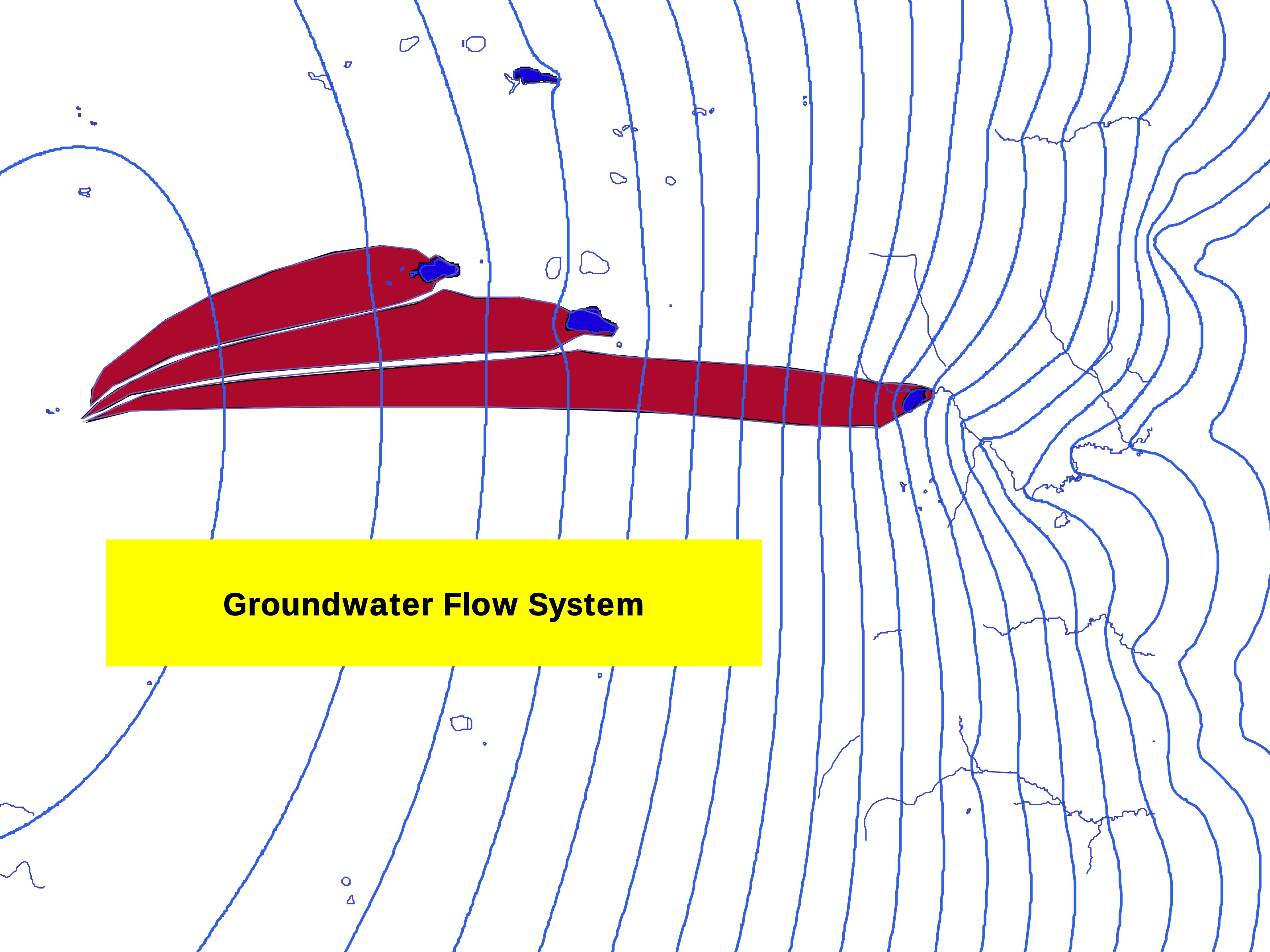
16 N coordinates in
X should be within
and Y within
000



WDNR SWDV (Surface Water Data Viewer)




http://dnrmaps.wi.gov/sl/?Viewer=SWDV
File Edit View Favorites Tools Help
Surface Water Data Viewer
Search for map features...
Basic Tools
Identify Tools
Drawing Tools
Measuring Tools
Find Location
Maps & Data
Help
Home
Show Layers
Show Legend
Pan
Zoom In
Zoom Out
Previous Extent
Full State
Point Identify
Map Scale: 1: 74,813
Jump to a map bookmark...
Enter Coords
Plot Coords
Clear Coords
Clicked Coordinates
Lat: 44.7513
Lon: -89.7632
Home
Map Layers
Navigation
Location Info
Scale & Bookmarks
Coordinate Tools
Results (3)
View History
View Selected
Refine Results | Table View | Select All | Select None
Oneida
County
Reach ID 600012721
WI Hydro Data-Plus Catchments
Inkwell Lake, (WBIC 992200)
Open Water Metadata
Lake Page About the Water
Map Layers
Results (3)
I want to...
Schlecht Lake
Borger Lake
Jyme Lake
Tomahawk Lake
Inkwell Lake
Three Little Lakes
Long Lake
Zottle Lake
Miller Lake
Dorothy Lake
Eagle Lake
Beaver Lake
Katherine Lake
Miller Lake
Foster Lake
Bird Lake
Mud Lake
Little Tomahawk Lake
Little Carr Lake
Big Carr Lake
Cunard Lake
Sureshot Lake
1 mi
2 km
Lat:
Lon:
Terms of Use DNR Website | SWIMS | Comments |


Groundwater Flow System