2014 Wisconsin Lakes PreConvention Workshop

Lake Eutrophication Modeling and WiLMS

Paul McGinley & Nancy Turyk

Center for Watershed Science & Education

UW-Stevens Point

Center for Watershed Science and Education

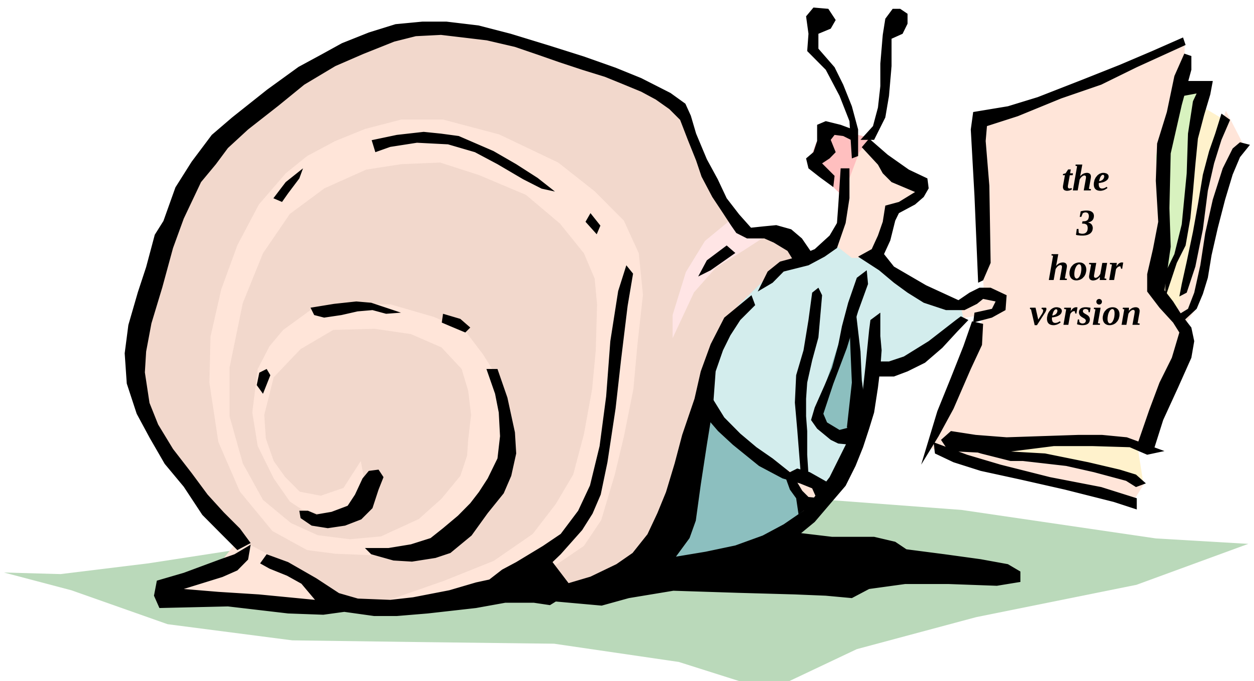
UW Extension

Tentative Outline/Approach

- ***Overview – Eutrophication & Modeling***
- **Introductions**
- ***First Model– back_of_the_envelope***
- **Introduce & discuss details as we work through a few examples**
- ***Other Models***
- **Time for your projects**

- ***Please question / interrupt / stop us!***
- ***Break at 2:40 (but feel free to move around!)***

- <u>This is only a few hours...and a new workshop</u>
- *We aren't discussing everything...*
- Some background /Use WiLMS
- *Context with respect to other models*
- Learn more about your needs / suggestions for developing this course



Eutrophication

- "Process of an ecosystem becoming more productive by nutrient enrichment stimulating primary producers"
  – Walter Dodds, *Freshwater Ecology*

- Cultural eutrophication- nutrient input increased by humans

Trophic State

- Level of ecosystem productivity

- Oligotrophic - “few” “foods”
- Eutrophic – “many” “foods”

Implications of Trophic State

- Biomass quantity
- Types of organisms
- Light penetration
- Dissolved oxygen
- Algal toxins

Measures of Trophic State

- Fish Biomass
- Algal Concentration
- Nutrient Concentrations
  - Phosphorus

Note Units mg/m^3 = µg/liter

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

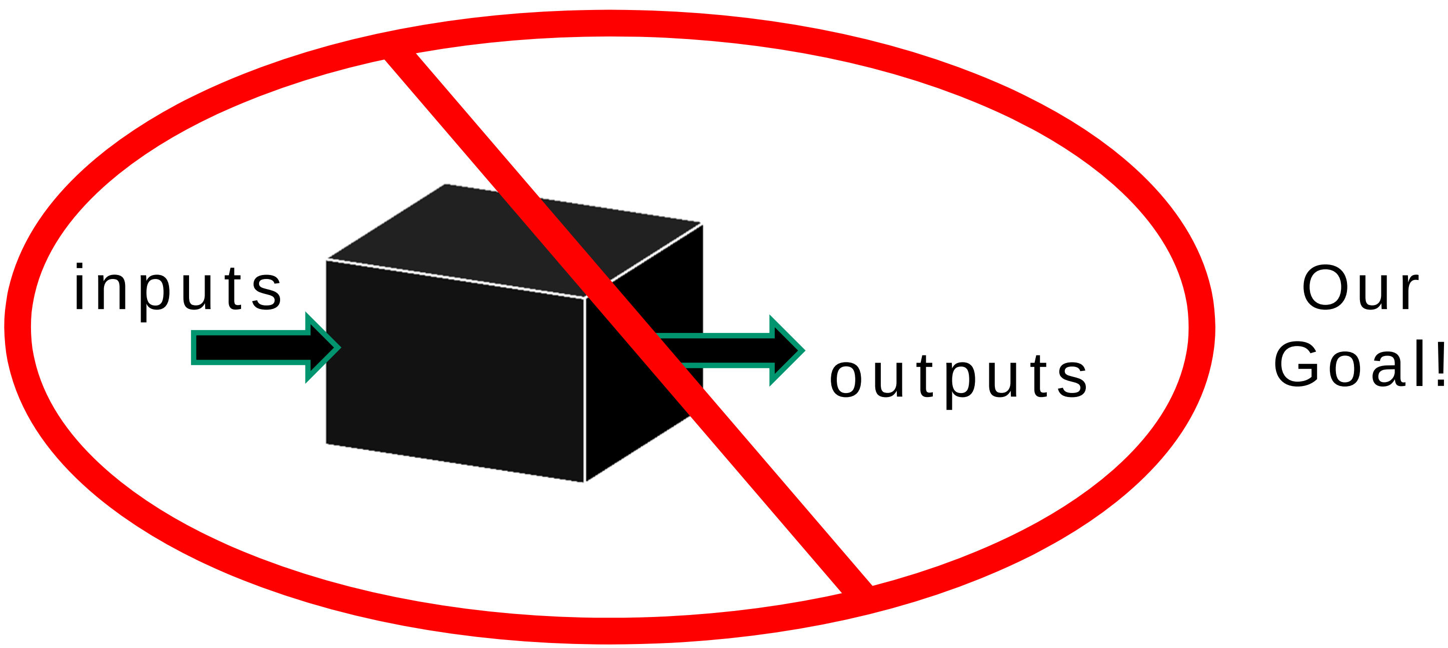
http://www.secchidipin.org/trophic_state.htm

Models

- A mathematical description to help visualize something

- “All models are wrong but some are useful” -- George Box

Models

- A mathematical description to help visualize something
- 

Introductions

- What do you hope to get out of the next few hours?
- How might / do you use eutrophication modeling?
- *Name / County / Lake(s) / Affiliation*

Our First Model

- Goal– predict the P concentration

Given

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

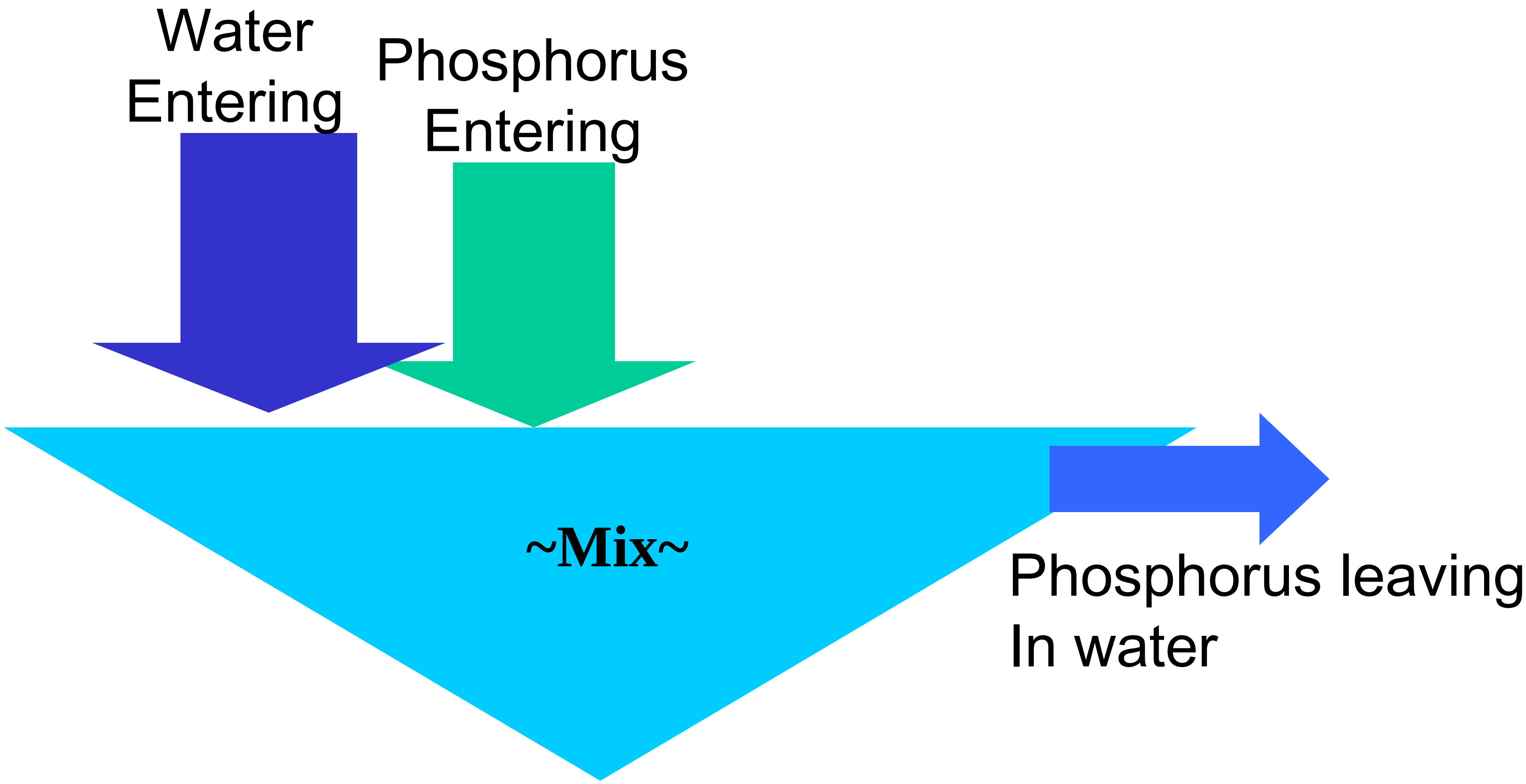
Our First Model

- Goal– predict the P concentration

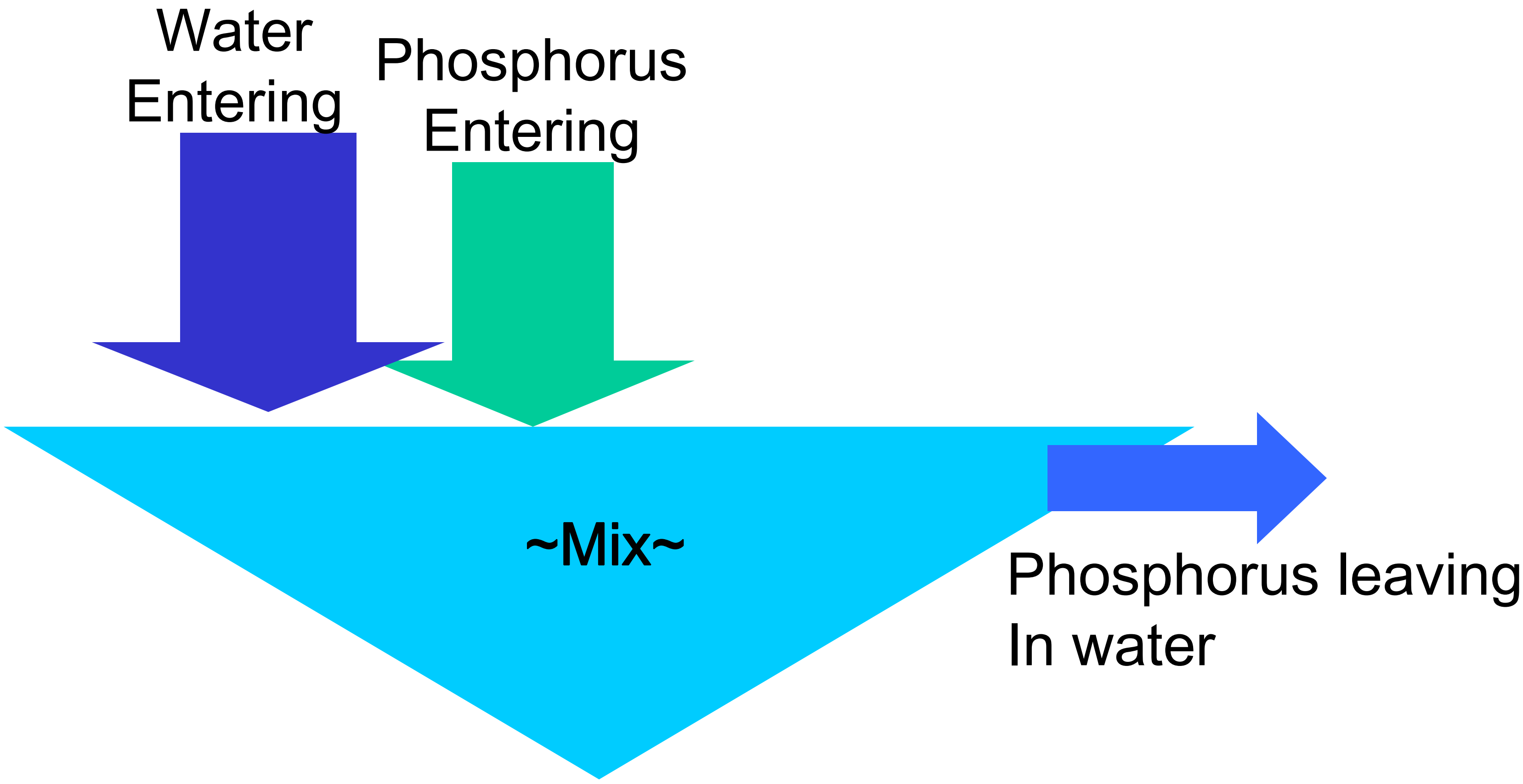
Given

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

Drawing


Water
Entering
Phosphorus
Entering
~Mix~
Phosphorus leaving
In water

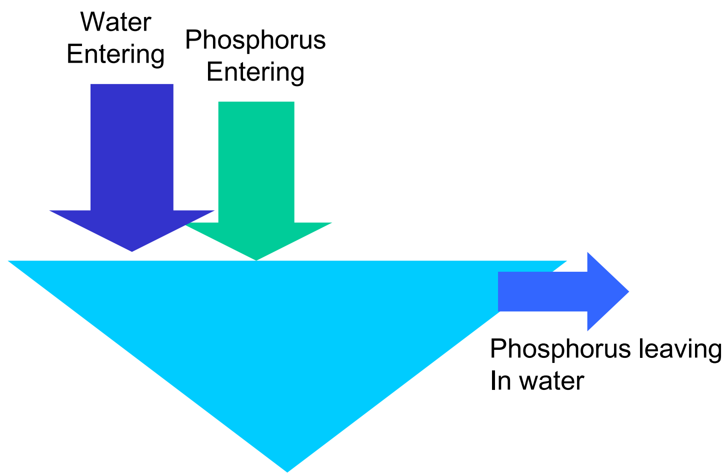
How does this calculate concentration?



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



Assume (more on this later)

- 34,000 kg/year P
- 150,000,000 m3/year water

“Simple Model”

- Concentration of P
- C_P = Mass of P / Volume of Water
- C_P = 34,000 kg P/yr/ 150,000,000 m3/yr

“Simple Model”

- Concentration of P
- C_P = Mass of P / Volume of Water
- C_P = 34,000 kg P/yr/ 150,000,000 m3/yr
- C_P = 34,000,000,000mgP/y/ 150,000,000m3/y

“Simple Model”

- Concentration of P

- C_P = Mass of P / Volume of Water

- C_P = 34,000 kg P/yr/ 150,000,000 m3/yr
- C_P = 34,000,000,000mg P/yr/ 150,000,000m3/yr

- C_P = 222 mg/m3 = 222 ug/liter

...think about our assumptions

- Outflow conc. same as lake conc. (lake completely mixed)
- Uniform conditions (“steady-state”)

Review these

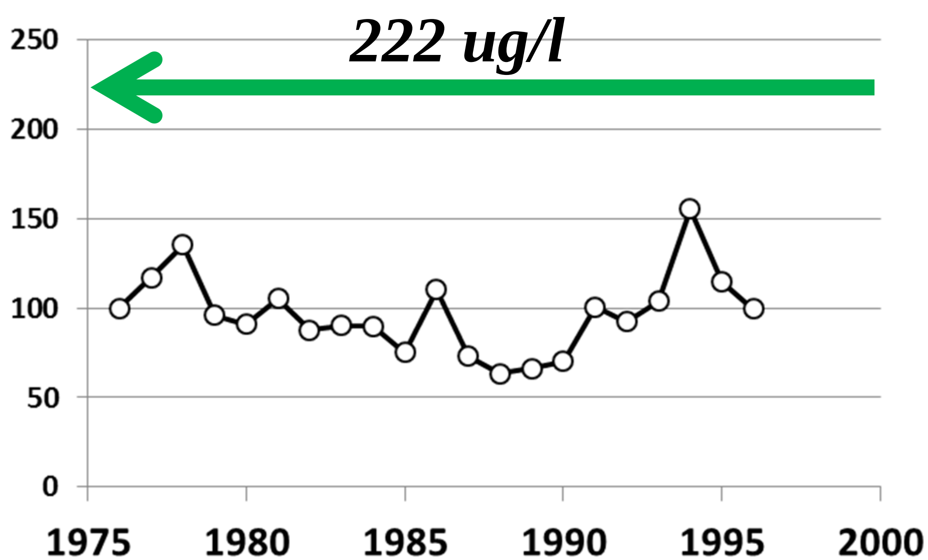
- **Steady Conditions**
  - The P concentration doesn't change with time
  - The amount of P in the lake is constant
  - ***What goes in must be equal to what goes out***

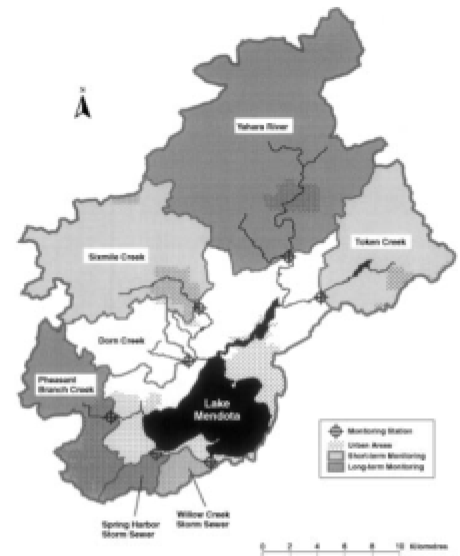
Review these

- **Steady 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

Take a look at some data





Lathrop and Panuska 1998

Not a very good model

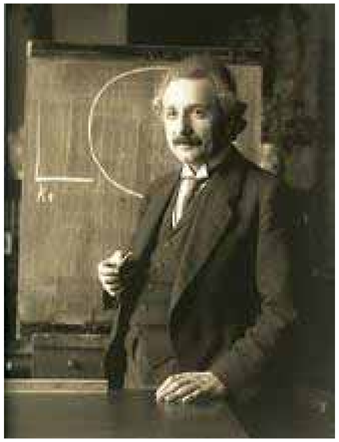
- Why?
- What happens to P in a lake?

Not a very good model

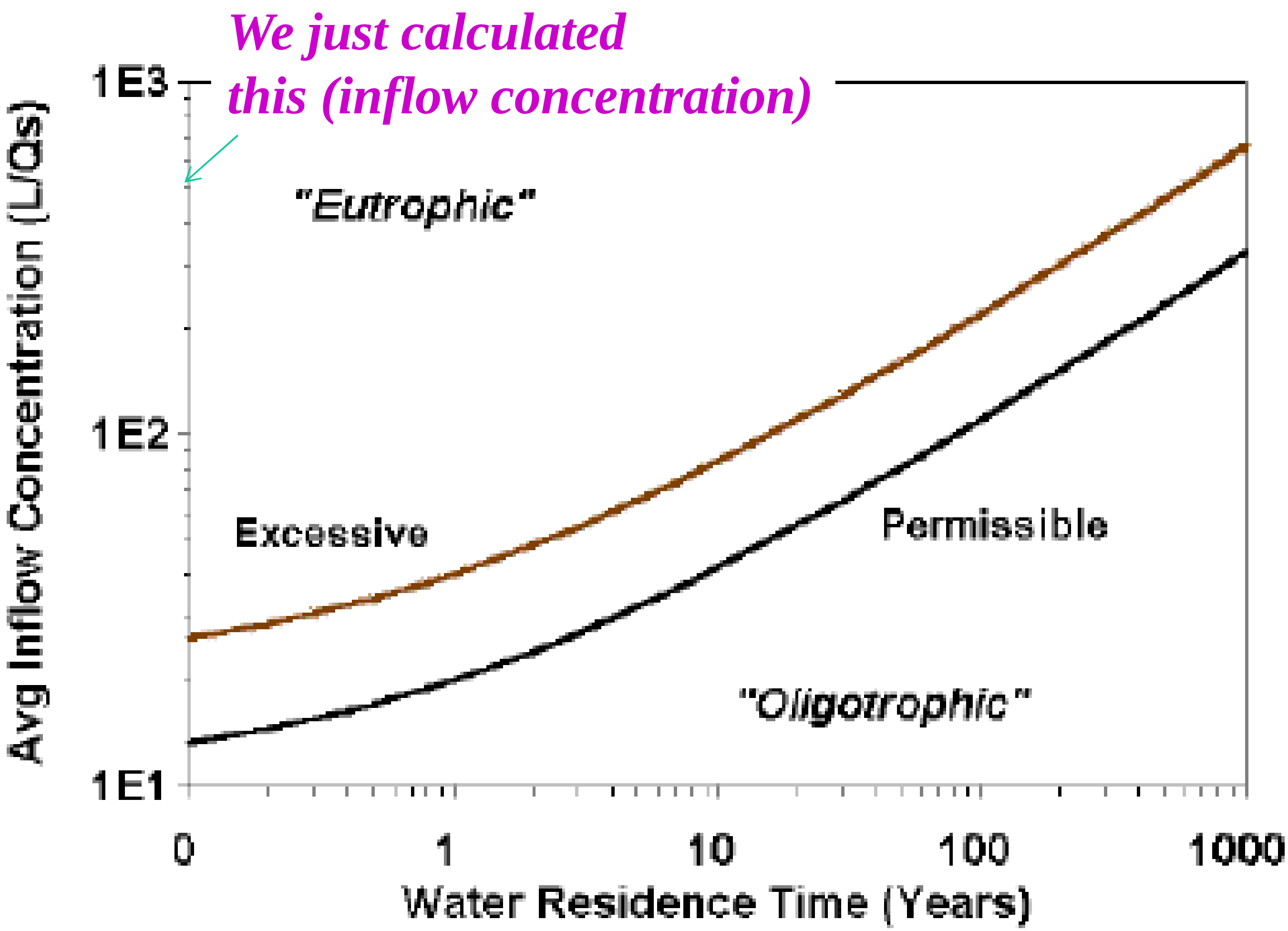
- Why?

- What happens to P in a lake?

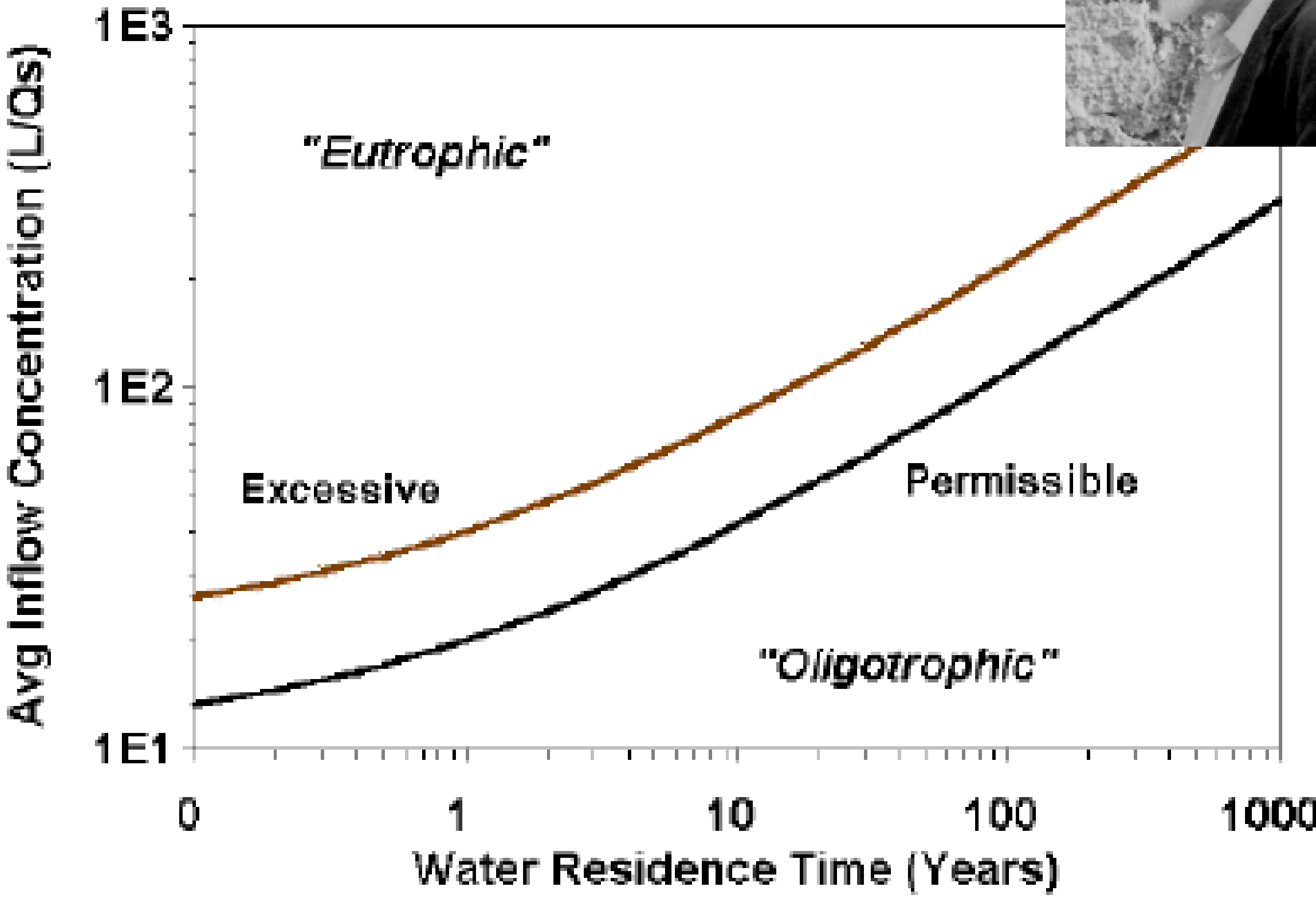
- Another observation on modeling
  - “Everything should be made as simple as possible, but no simpler”
    A. Einstein



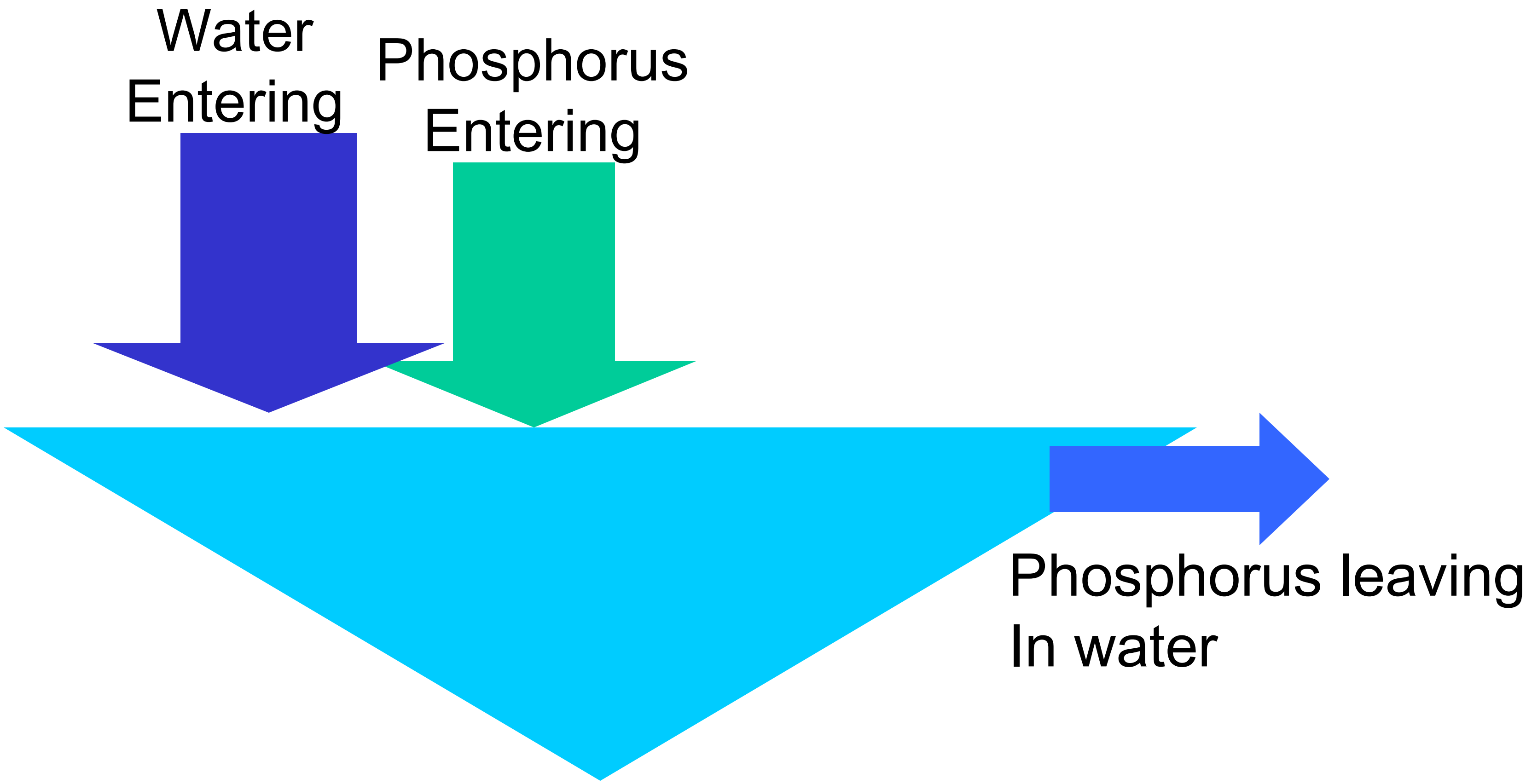
Historical Note– 1960s… higher "Inflow P Conc" OK if you have a longer residence time



"Vollenweider Plots"

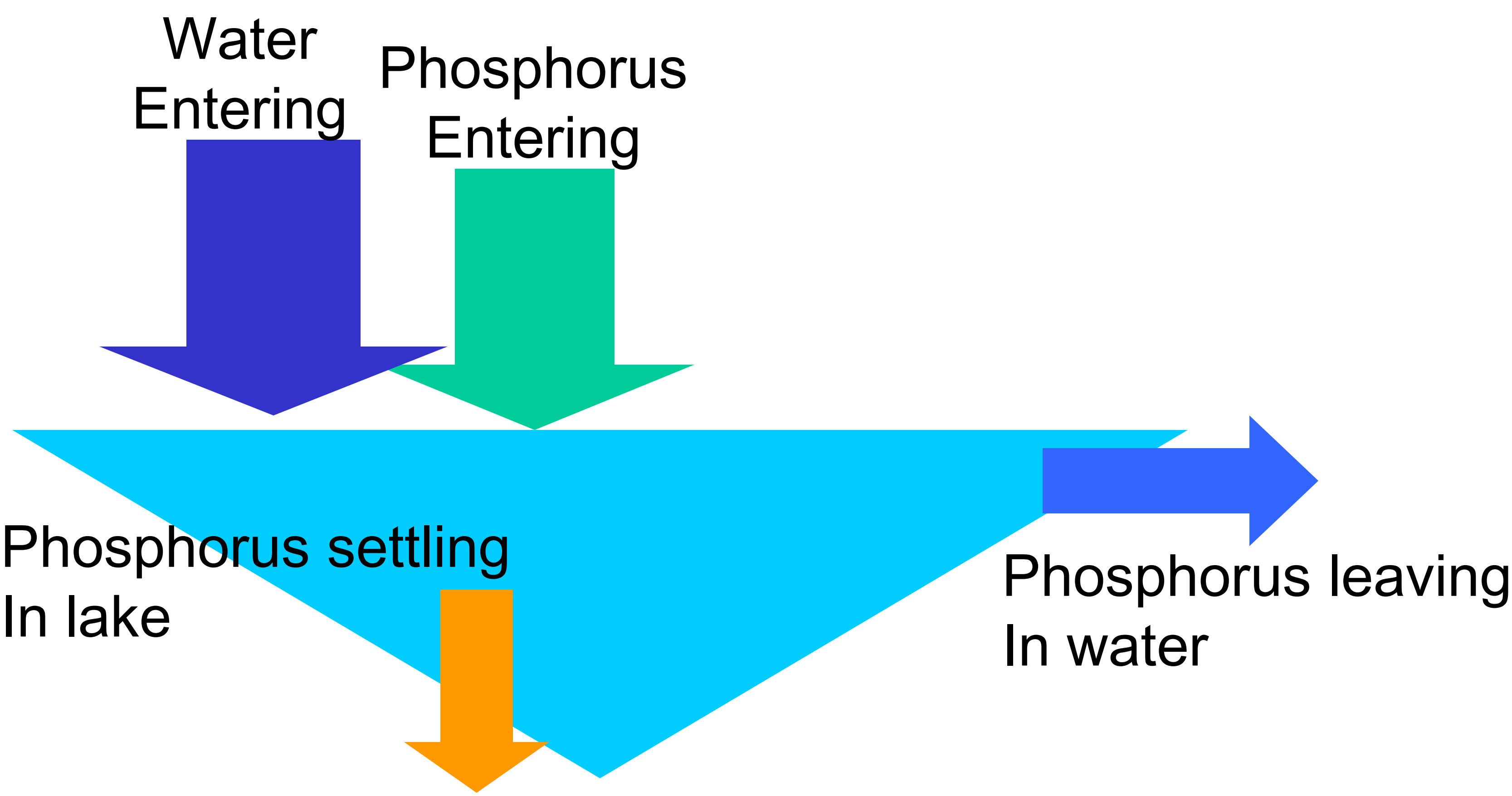


Second Model



"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)

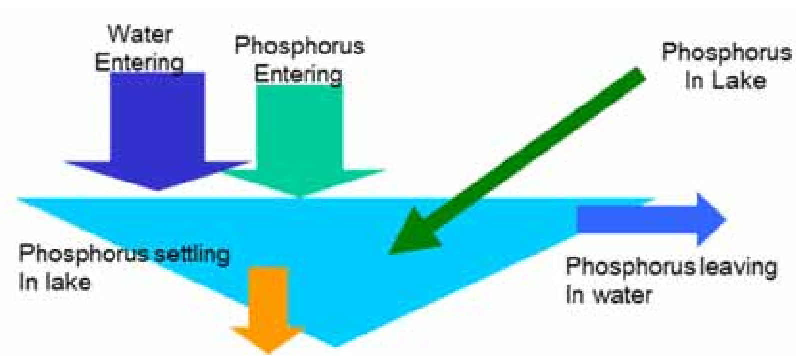
Second Model



"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)

…just make a few assumptions

- Lake completely mixed
- Outflow conc. same as lake conc.
- Uniform conditions ("steady-state")
- <u>Sedimentation proportional to lake conc.</u>



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

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

Note: Both Depend On P Conc

- **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***

$$M = QC_P + vAC_P$$

This looks a lot like our simple model...

Phosphorus Concentration in Lake

Mass of Phosphorus per year entering lake

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

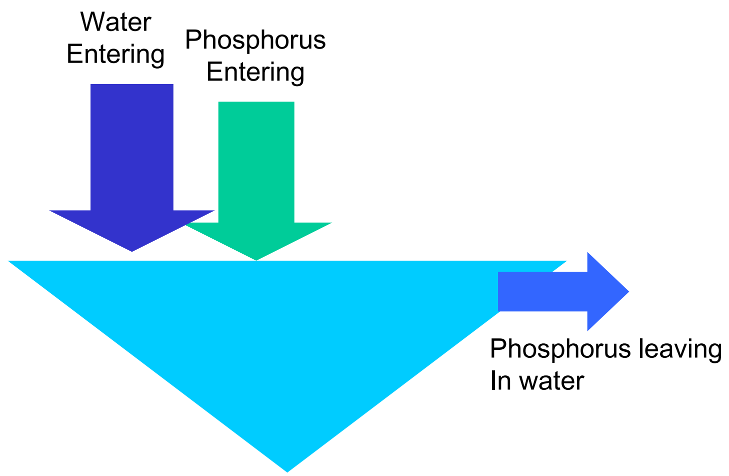
Amount of water Entering lake in a year

*Settling term (“settling velocity” * Area*

With this added

Let’s give this a try

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



Assume

- 34,000 kg/year P
- 150,000,000 m3/year water
- 40,500,000 m2 lake surface
- 10 meter/year settling velocity

Our "Less Simple Model"

- Concentration of P
- C_P = Mass of P/t / (Volume of Water/t+ Settling Velocity*Lake Area)
- C_P = 34,000,000,000mg P/yr / (150,000,000m3/yr + 405,000,000m3/yr)
- C_P = 62 ug/l (better?)

What does this have to do with WiLMS?

- WiLMS uses “empirical models”

- “Empirical Models” based fitting a group of lakes with different equations

- Most started similar to the simple steady-state mass balance method... then fit with some adjustment factors

- For example, our second model is similar to:

$$C_P = \frac{L}{q_s + v_s}$$

- Reckhow Natural Lake Model

$$C_P = \frac{L}{1.2q_s + 11.6}$$

These are not perfect fits…

Prediction of Total Phosphorus Concentrations, Chlorophyll *a*, and Secchi Depths in Natural and Artificial Lakes[1]

DANIEL E. CANFIELD JR.,[2] AND ROGER W. BACHMANN

Department of Animal Ecology, Iowa State University, Ames, IA 50011, USA

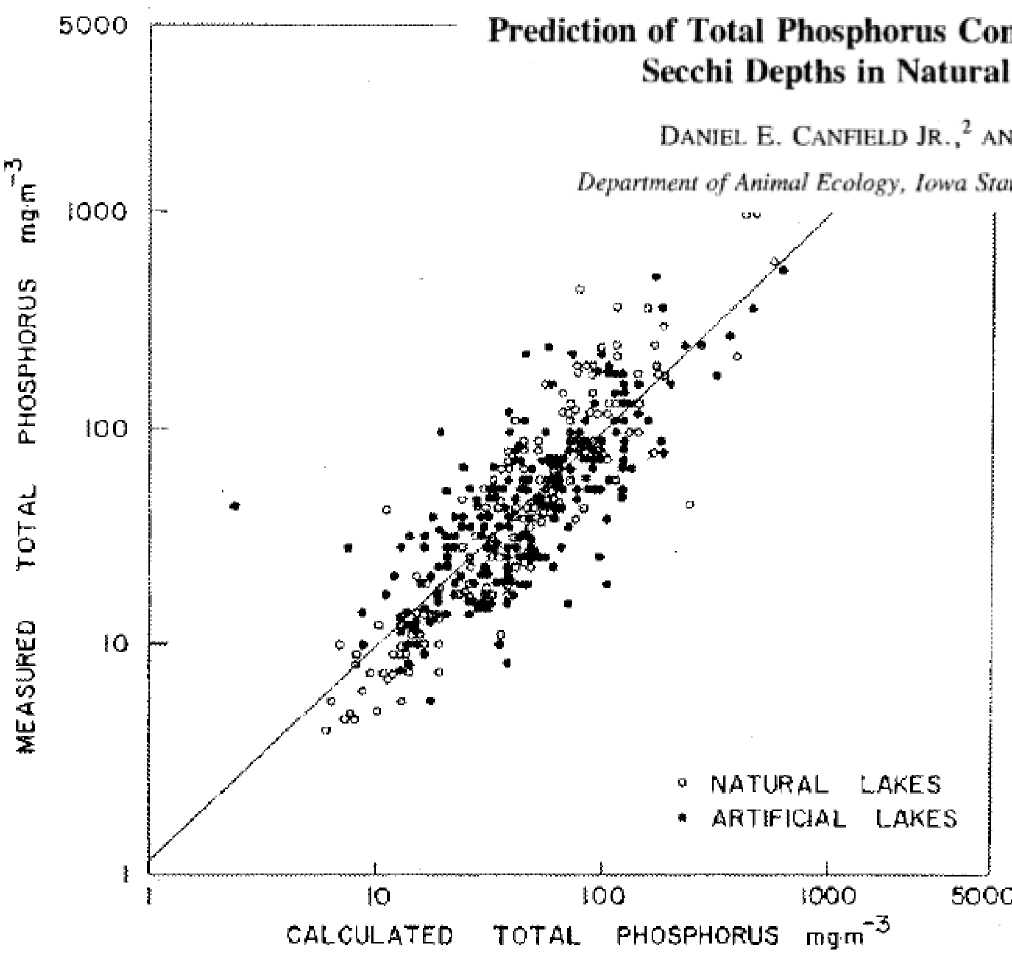


FIG. 2. Relationship between measured total phosphorus and total phosphorus calculated with equations 1, 5, and 6 of this study. The best-fit linear regression line is shown.

These are not perfect fits...

Prediction of Total Phosphorus Concentrations, Chlorophyll *a*, and Secchi Depths in Natural and Artificial Lakes[1]

DANIEL E. CANFIELD JR.,[2] AND ROGER W. BACHMANN

Department of Animal Ecology, Iowa State University, Ames, IA 50011, USA

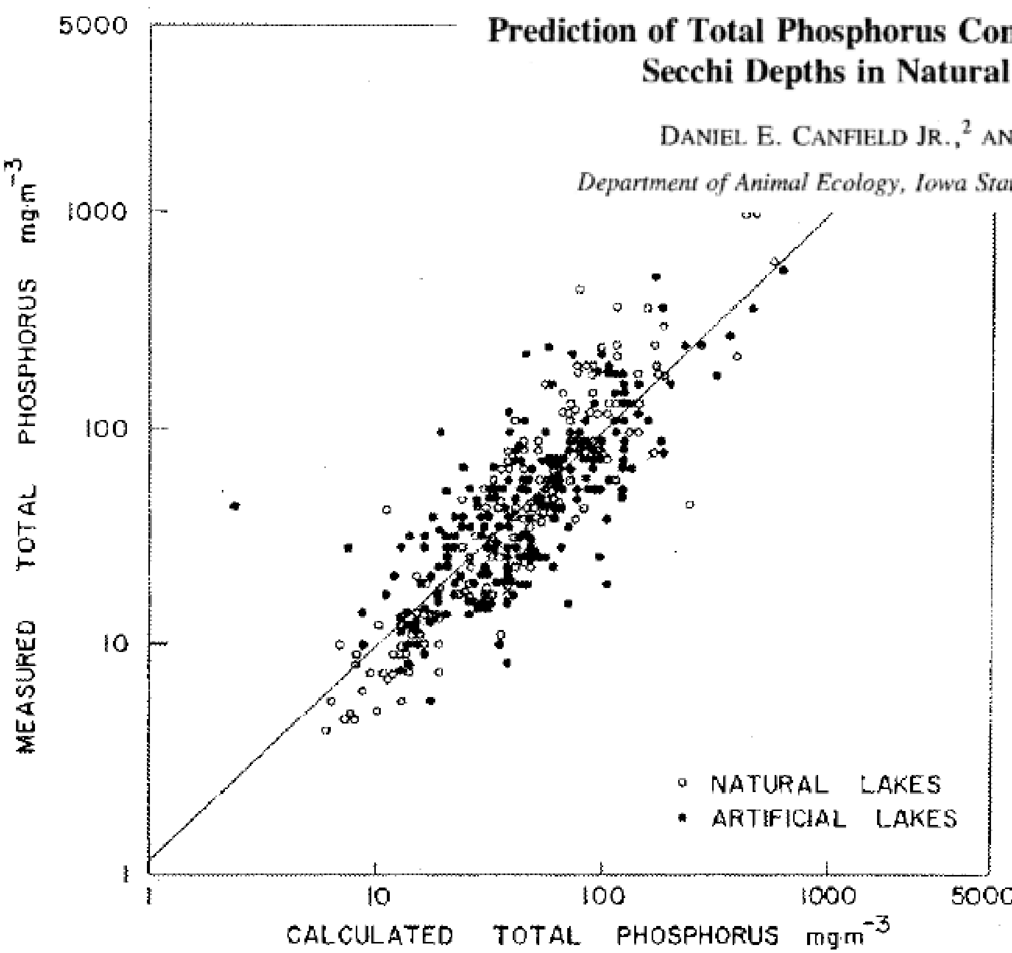


FIG. 2. Relationship between measured total phosphorus and total phosphorus calculated with equations 1, 5, and 6 of this study. The best-fit linear regression line is shown.

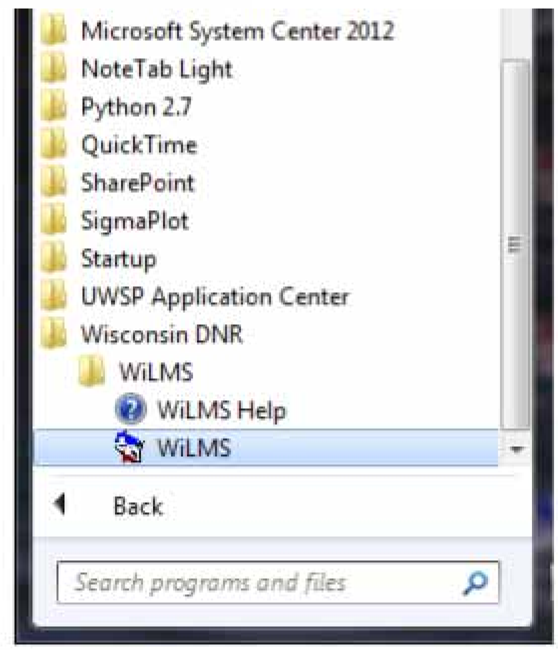
Note Units mg/m^3 = µg/liter

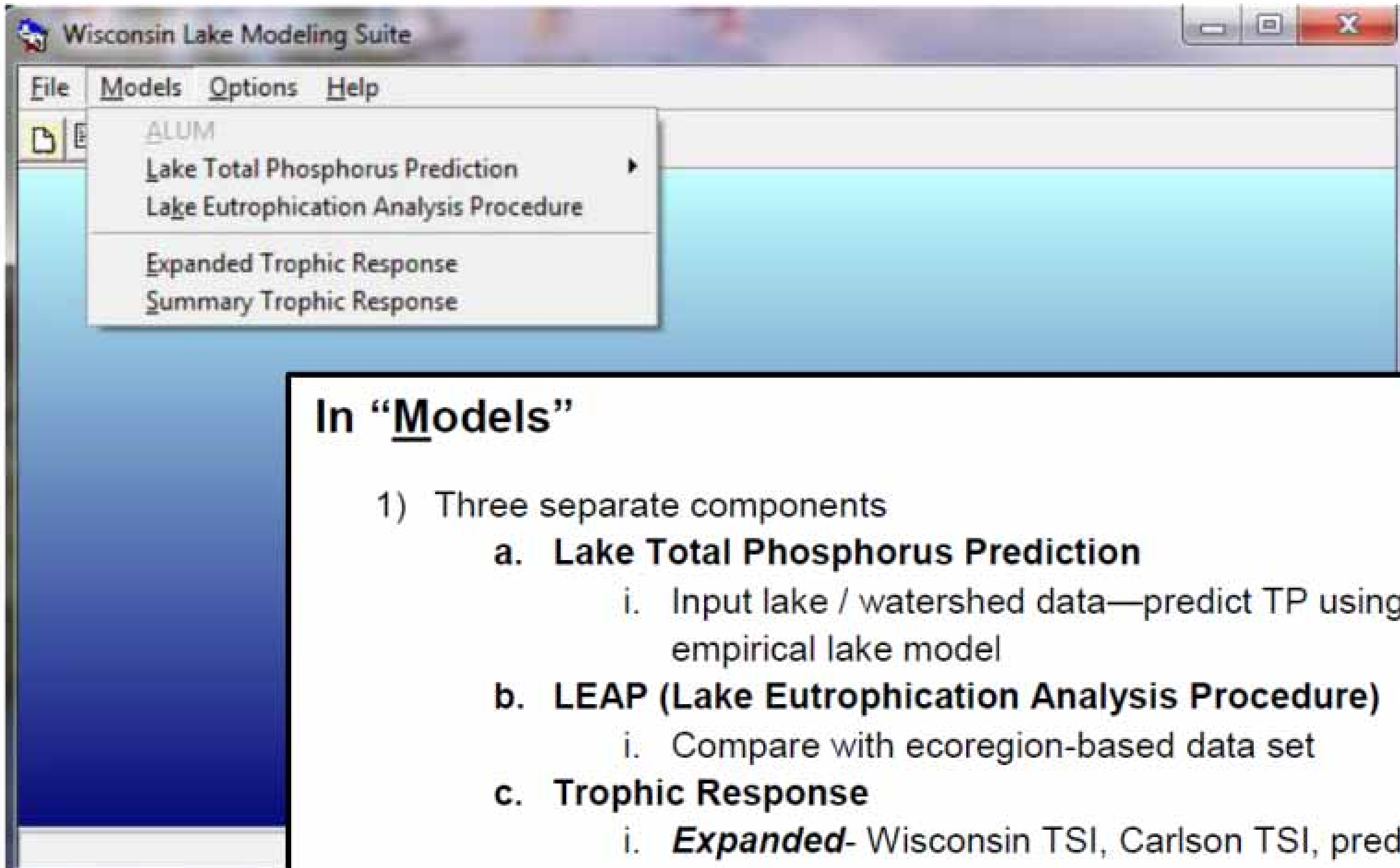
Brings us to WiLMS

- Combine **watershed export** model & **lake response** tool
- Estimate lake P concentration with knowledge of lake and P loading (external loads)
- Annual time-step

WiLMS

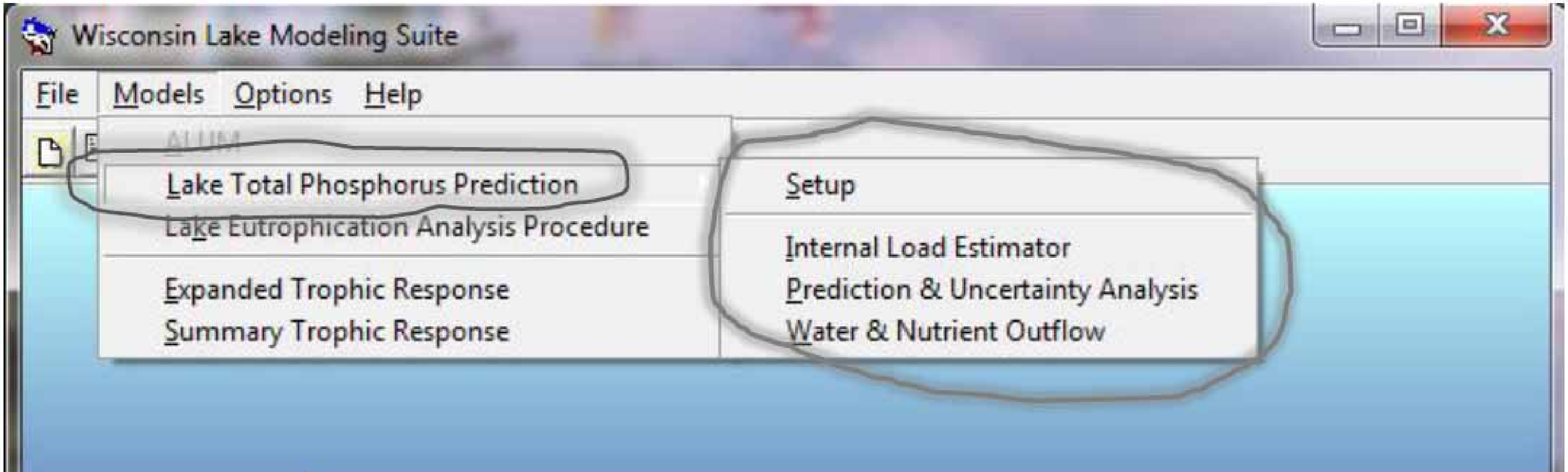
1. Download from WDNR **http://dnr.wi.gov/lakes/model/**
2. Installed – usually in
    a. "All Programs"
        i. "Wisconsin DNR"
            1. WiLMS





In "Models"

1) Three separate components
   a. **Lake Total Phosphorus Prediction**
      i. Input lake / watershed data—predict TP using empirical lake model
   b. **LEAP (Lake Eutrophication Analysis Procedure)**
      i. Compare with ecoregion-based data set
   c. **Trophic Response**
      i. ***Expanded***- Wisconsin TSI, Carlson TSI, predictive equations for Secchi and Chlorophyll
      ii. ***Summary*** – Wisconsin TSI and predictive



"Lake Total Phosphorus Prediction"

1) First—**Setup**
    a. Lake data
    b. Watershed / Point Sources / Other P Loads
    c. Get load summary
2) Second – **Prediction and Uncertainty Analysis**
    a. Estimate average phosphorus concentration
    b. Compare different estimation methods
3) Third –
    a. Explore sensitivity to load reductions
    b. Maybe use **Internal Load Estimator**
    c. Possibly use **Water & Nutrient Outflow**

WiLMS Example 1

Setup / General & Hydrologic/Morphometric Module

- Dane Co
- SPO: 110 mg/m3; GSM: 85 mg/m3
- 10,000 acre lake
- 420,000 acre feet lake volume
  - Check mean depth ~42 feet?
  - Check q_s... about 10 ft/year? *(what's that?)*
  - What is water residence time? *(what's that?)*
  - What is the lake flushing rate? *(what's that?)*

First time using WiLMS on your computer?

- Will need to locate the County hydrology data file
- Use browse button on the data file – should go to the right location– then select

Example 1

Phosphorus Module (NPS)

- Row Crop 90,000 acres
- Pasture Grass 30,000 acres
- MD Urban 30,000 acres
- *Note that lake surface is already entered*
- *Note loading in kg/ha-year “export rates”*

Example 1

Phosphorus Module (PS)

- Don’t enter anything here
  - *Point sources and septic tank stuff*

Example 1

(Total Loading)

- Nothing to enter here...
  - *Review*
    - *Total loading in lbs.... Around 100,000?*
    - *Should be all NPS... right?*
  - *Leave – save as something ("Dane1"?)*

Example 1

(Models – Lake Total Phosphorus Prediction – Prediction & Uncertainty Analysis)

- Look at Results

Phosphorus Predictions & Uncertainty Analysis

Observed spring overturn total phosphorus (SPO): 110.0 mg/m^3

Observed growing season mean phosphorus (GSM): 85.0 mg/m^3

Back calculation for SPO total phosphorus: 0.0 mg/m^3

Back calculation GSM phosphorus: 0.0 mg/m^3

Nurnberg Model Input - Est. Gross Int. Loading: 0 kg

% Confidence Range: 70

Lake Phosphorus Model	Low Total P (mg/m^3)	Most Likely Total P (mg/m^3)	High Total P (mg/m^3)	Predicted -Observed (mg/m^3)	% Dif.	Confidence Lower Bound	Confidence Upper Bound	Parameter Fit?	Back Calculation (kg/year)	Model Type
Walker, 1987 Reservoir	44	50	59	-35	-41	36	69	Tw	0	GSM
Canfield-Bachmann, 1981 Natural Lake	55	60	67	-25	-29	19	173	FIT	1	GSM
Canfield-Bachmann, 1981 Artificial Lake	46	49	53	-36	-42	15	141	FIT	1	GSM
Rechow, 1979 General	67	76	91	-9	-11	52	109	FIT	0	GSM
Rechow, 1977 Anoxic	181	205	244	120	141	149	277	FIT	0	GSM
Rechow, 1977 water load<50m/year	76	87	103	2	2	60	123	P Pin	0	GSM
Rechow, 1977 water load>50m/year	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Walker, 1977 General	129	146	174	36	33	87	233	FIT	0	SPO
Vollenweider, 1982 Combined OECD	73	81	93	-17	-17	45	136	FIT	0	ANN
Dillon-Rigler-Kirchner	88	100	119	-10	-9	72	136	P	0	SPO
Vollenweider, 1982 Shallow Lake/Res.	63	71	83	-27	-28	41	117	FIT	0	ANN
Larsen-Mercier, 1976	109	124	147	14	13	93	163	P Pin	0	SPO
Nurnberg, 1984 Oxic	96	109	129	24	28	68	167	P	0	ANN

Finished | Write Results | Display Parameter Values | Help

- *13 empirical equations*
- *TP Predictions*
- *Difference from observed– that was input in the "Setup" screen (note that if both GSM and SPO– the average will be used for ANN)*
- *Uncertainty bounds - set confidence range*
- *Parameter fit?– checks to see if the input fits within the model data set – if not it indicates where it differs (N/A means it didn't calculate) .... Page 18-21 in notes*

Phosphorus Predictions & Uncertainty Analysis

Observed spring overturn total phosphorus (SPO): 110.0 mg/m^3

Observed growing season mean phosphorus (GSM): 85.0 mg/m^3

Back calculation for SPO total phosphorus: 0.0 mg/m^3

Back calculation GSM phosphorus: 0.0 mg/m^3

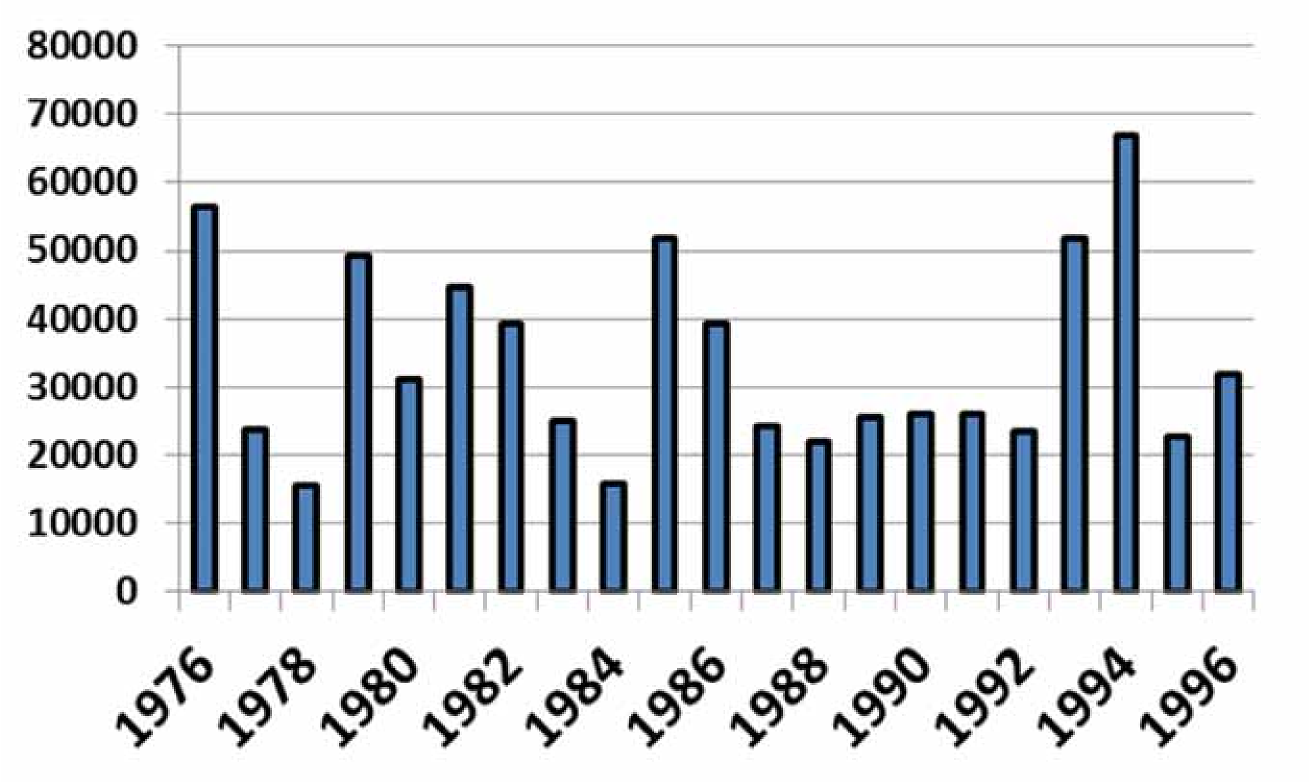
Nurnberg Model Input - Est. Gross Int. Loading: 0 kg

% Confidence Range: 70

Lake Phosphorus Model	Low Total P (mg/m^3)	Most Likely Total P (mg/m^3)	High Total P (mg/m^3)	Predicted -Observed (mg/m^3)	% Dif.	Confidence Lower Bound	Confidence Upper Bound	Parameter Fit?	Back Calculation (kg/year)	Model Type
Walker, 1987 Reservoir	44	50	59	-35	-41	36	69	Tw	0	GSM
Canfield-Bachmann, 1981 Natural Lake	55	60	67	-25	-29	19	173	FIT	1	GSM
Canfield-Bachmann, 1981 Artificial Lake	46	49	53	-36	-42	15	141	FIT	1	GSM
Rechow, 1979 General	67	76	91	-9	-11	52	109	FIT	0	GSM
Rechow, 1977 Anoxic	181	205	244	120	141	149	277	FIT	0	GSM
Rechow, 1977 water load<50m/year	76	87	103	2	2	60	123	P Pin	0	GSM
Rechow, 1977 water load>50m/year	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Walker, 1977 General	129	146	174	36	33	87	233	FIT	0	SPO
Vollenweider, 1982 Combined OECD	73	81	93	-17	-17	45	136	FIT	0	ANN
Dillon-Rigler-Kirchner	88	100	119	-10	-9	72	136	P	0	SPO
Vollenweider, 1982 Shallow Lake/Res.	63	71	83	-27	-28	41	117	FIT	0	ANN
Larsen-Mercier, 1976	109	124	147	14	13	93	163	P Pin	0	SPO
Nurnberg, 1984 Oxic	96	109	129	24	28	68	167	P	0	ANN

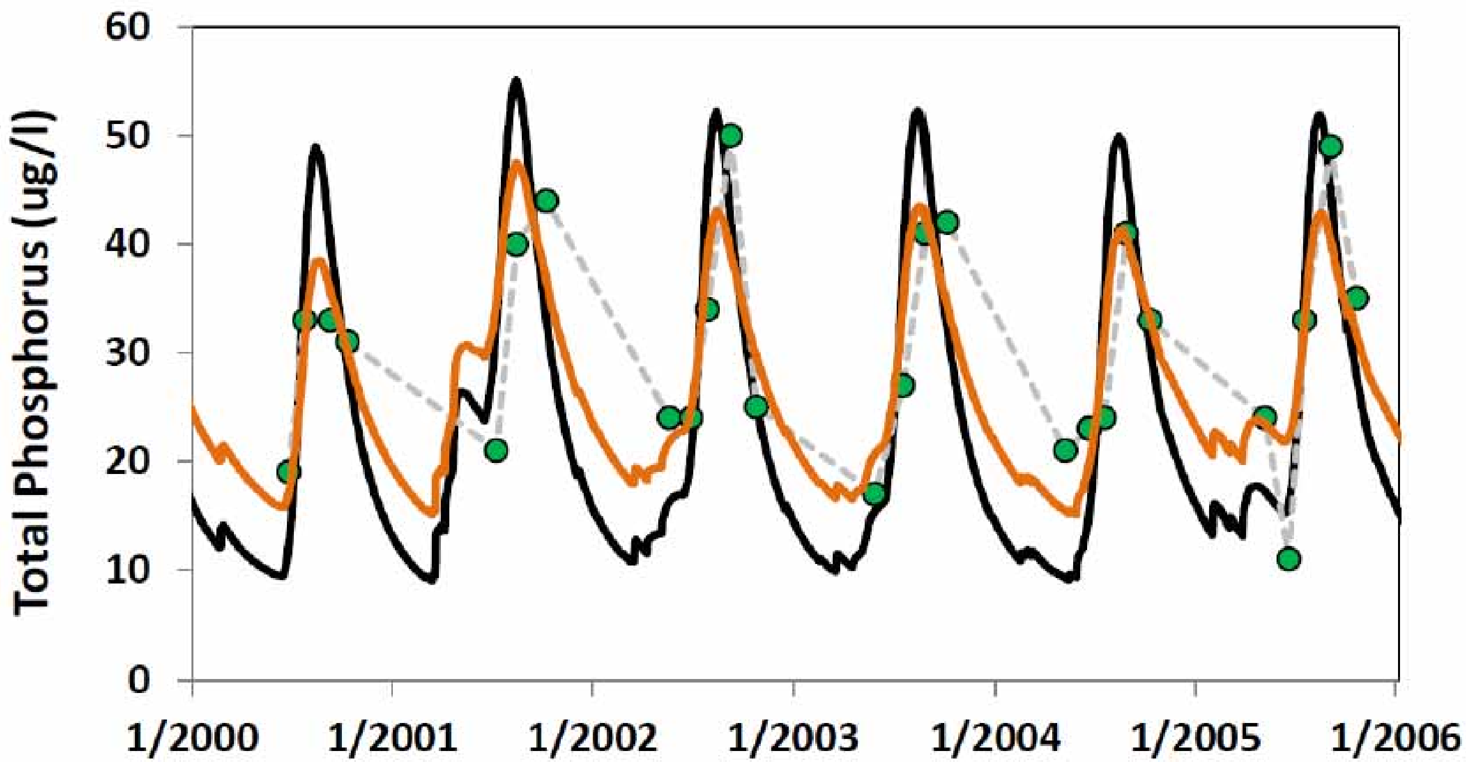
Finished | Write Results | Display Parameter Values | Help

Challenges: Annual Variations



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

Challenges: Variations during the year



There is a lot of terminology related to the P “settling”...

- Retention =fraction of the incoming P that is retained
  - » $R = 1 - (C_{out}/C_{in})$
  - » See page 58, 68, 100 of notes
  - » Therefore
  - » Can show that $R = v_s/(v_s+q_s)$ and...
  - » $C_P = (L/q_s)(1-R)$
- Volumetric Removal...

Or $kV_L = vA_s$

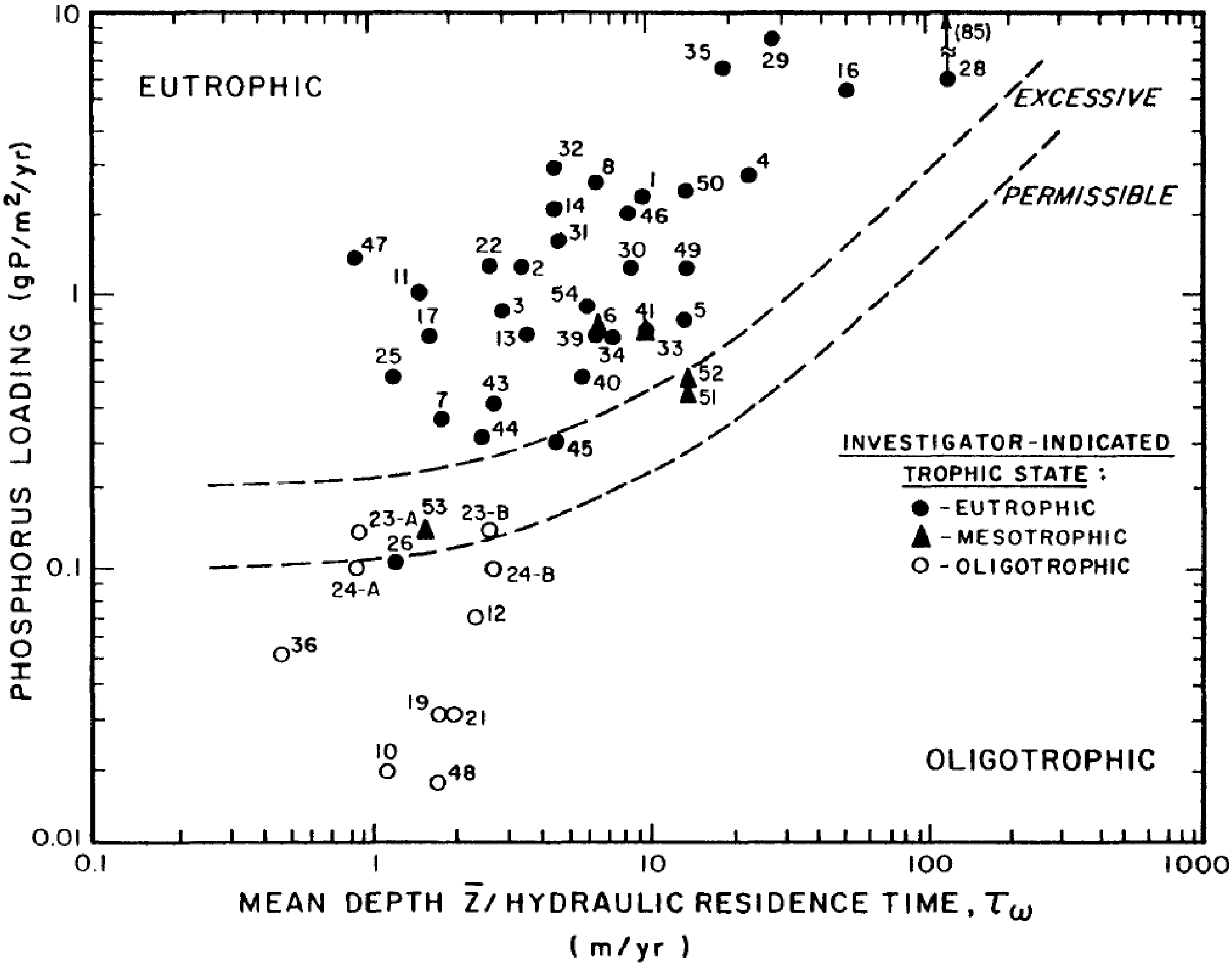
These are equivalent...

- For example... retention
  - Our example, 78% of the annual P is retained (is “stored”)
  - Our hydraulic loading is
    - 10 ft/year (that’s q_s)
  - Our P load could be expressed as
    - 1.12 g/(m^2 of lake surface – year) (that’s L)
  - Then could use $Cp = (L/q_s)(1-R) = 82$ ug/l

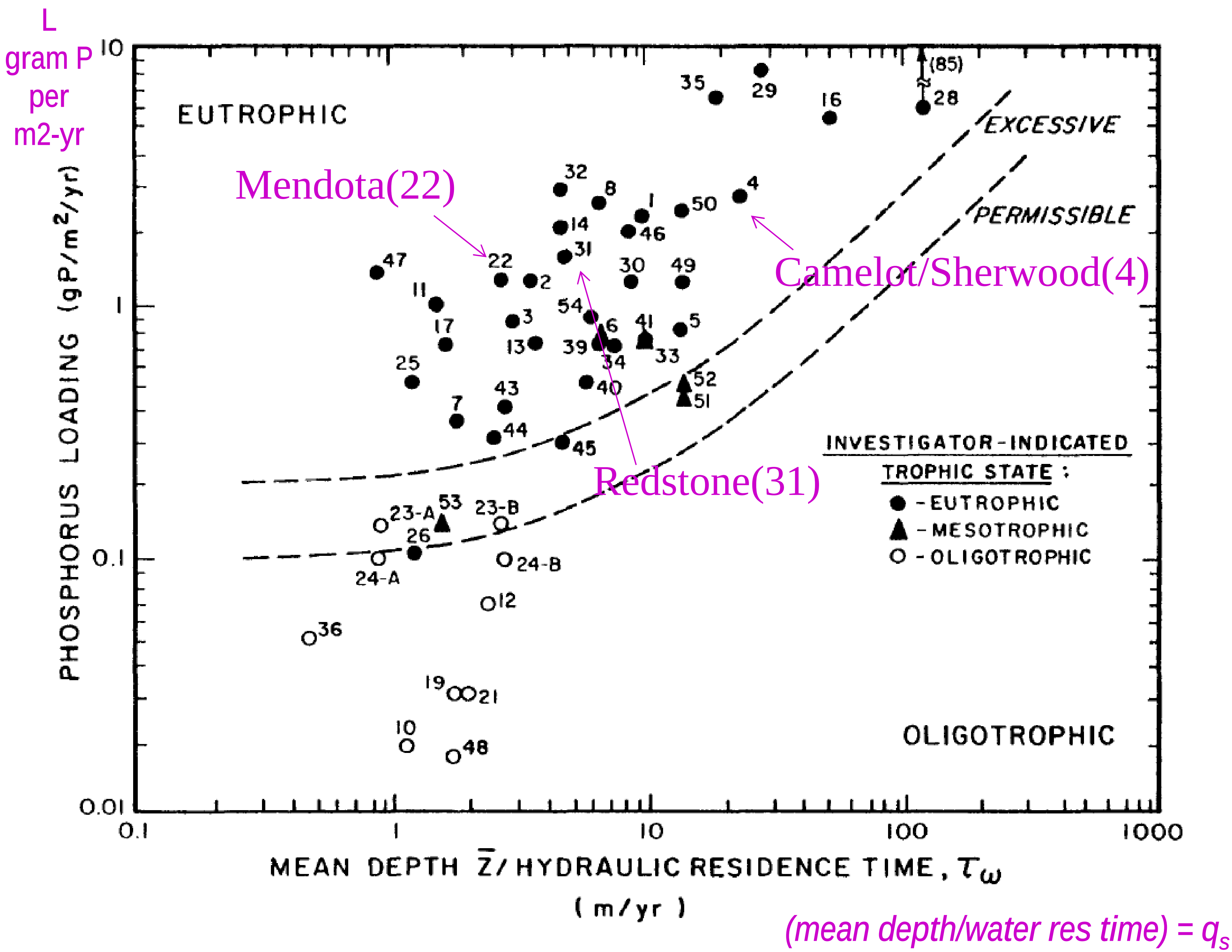
You want more of this… check out Reckhow and Chapra Book pages

Historical Note

- 1960s/70s eutrophication / phosphorus
- OECD (Organization for Economic Cooperation and Development) Eutrophication Study (1970s)
  - 18 countries involved, in some, field studies were initiated
  - US used small grants to encourage reports on existing studies
  - Summarized in 1978 Report (Rast and Lee)



EUTROPHIC
OLIGOTROPHIC
EXCESSIVE
PERMISSIBLE
INVESTIGATOR-INDICATED TROPHIC STATE :
● - EUTROPHIC
▲ - MESOTROPHIC
○ - OLIGOTROPHIC
(85)
PHOSPHORUS LOADING (gP/m²/yr)
MEAN DEPTH Z̄/ HYDRAULIC RESIDENCE TIME, τω (m/yr)
10
1
0.1
0.01
0.1
1
10
100
1000



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

Now Let's Talk about Those Inputs

- Water Budget
  - Annual estimate for WiLMS
  - Need the total quantity of water entering the lake
  - What happens to precip on land & water?
- Phosphorus Loading

Watershed - *Water Budget*

- Hydrology
  - Precipitation = ET + "Runoff"
  - "Runoff" = baseflow + event flow
  - "Baseflow" = percolation to saturated zone (groundwater)
  - "Event flow" = surface runoff, saturation excess flow

DOUGHERTY ET AL.: A REVIEW OF PHOSPHORUS TRANSFER IN SURFACE RUNOFF

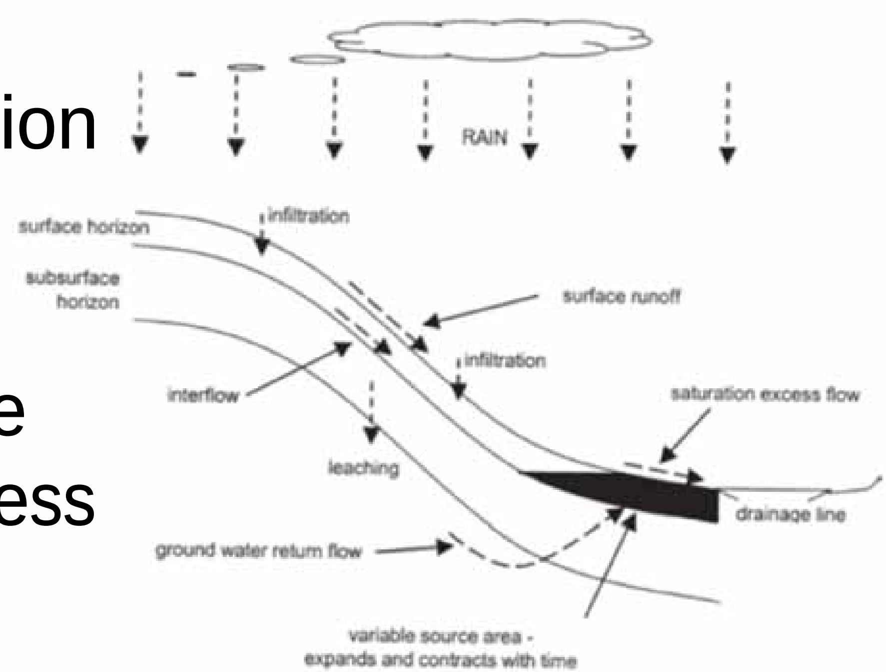
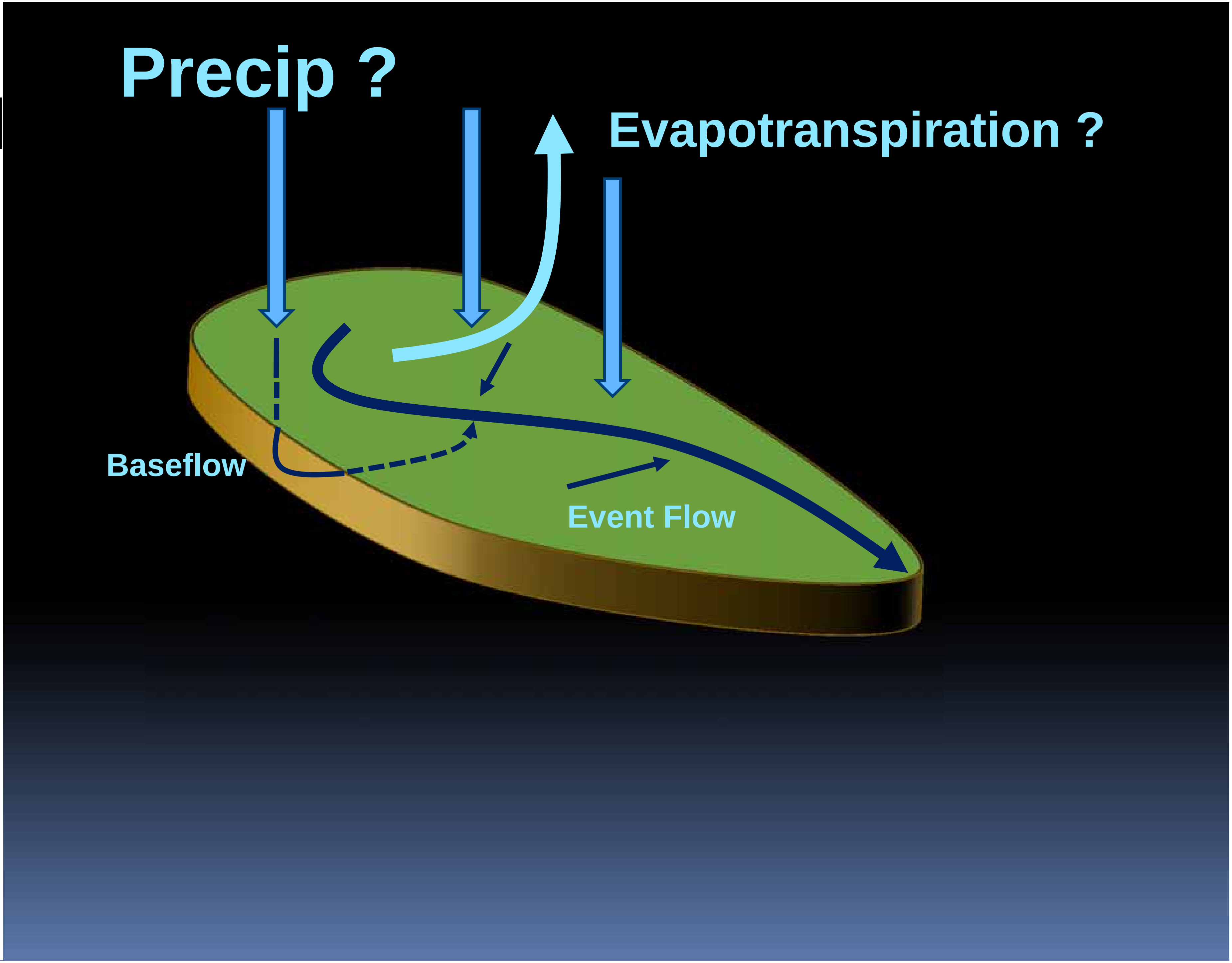
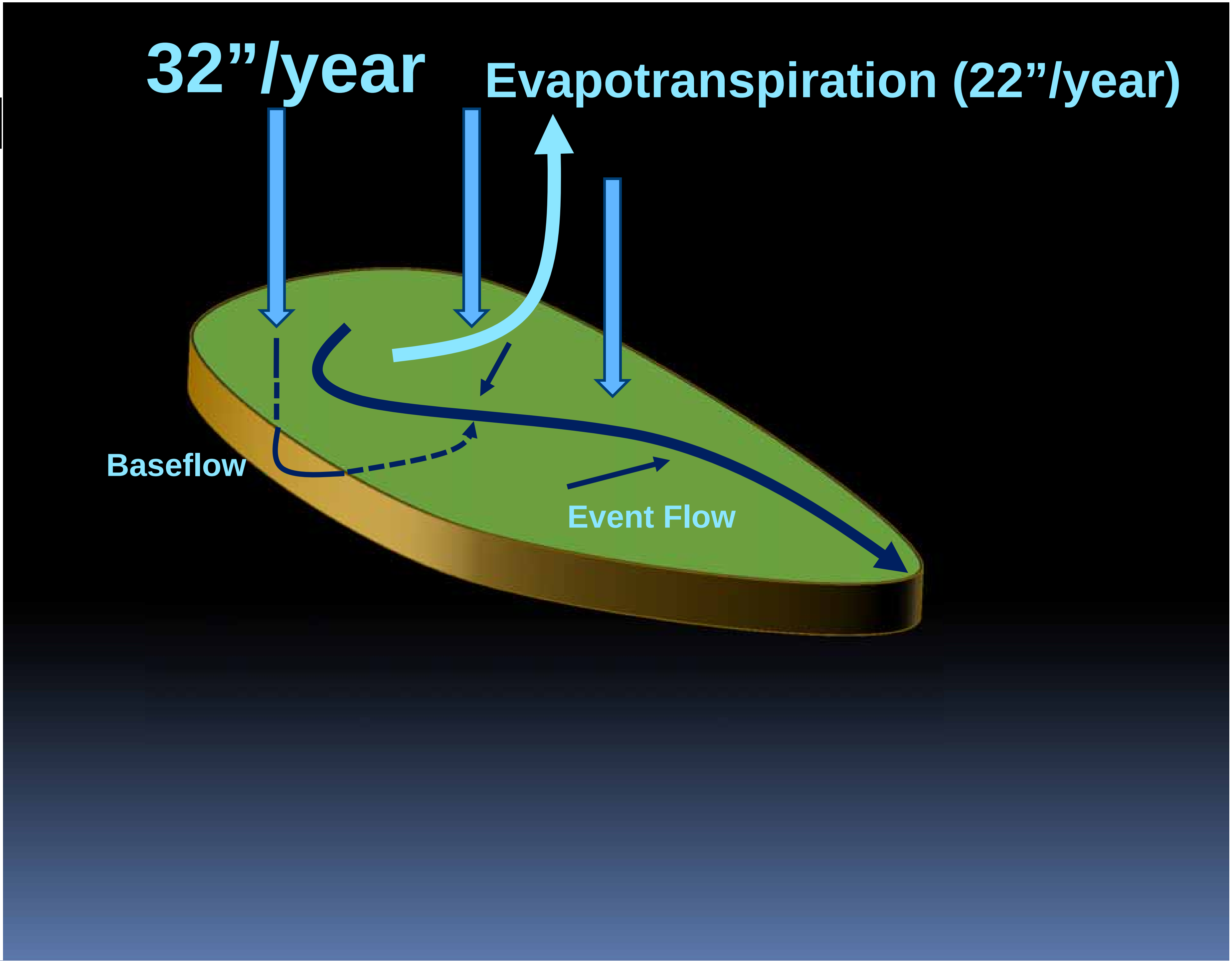
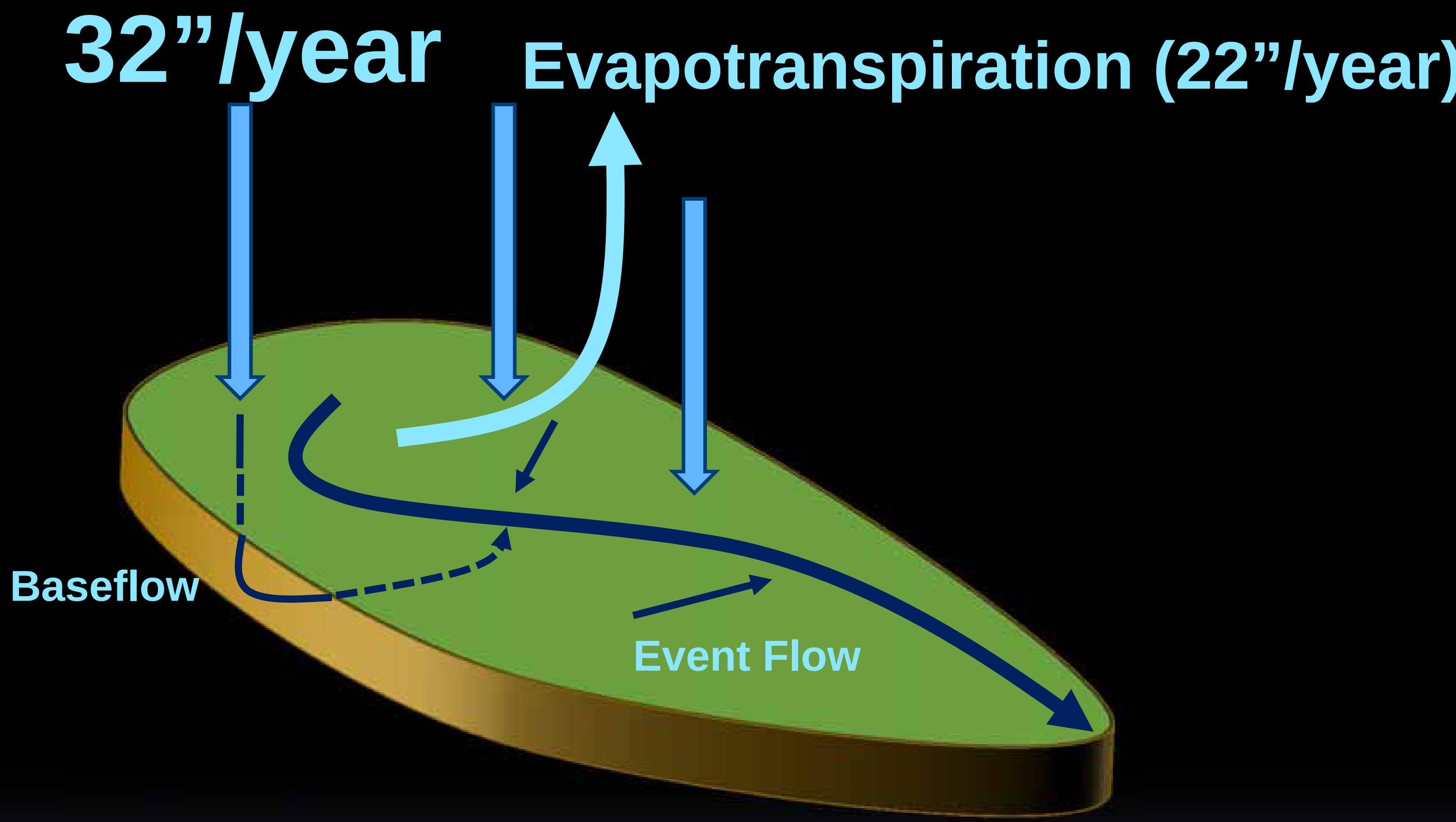


Fig. 4. Basic components of hillslope hydrology.


Precip ?
Evapotranspiration ?
Baseflow
Event Flow

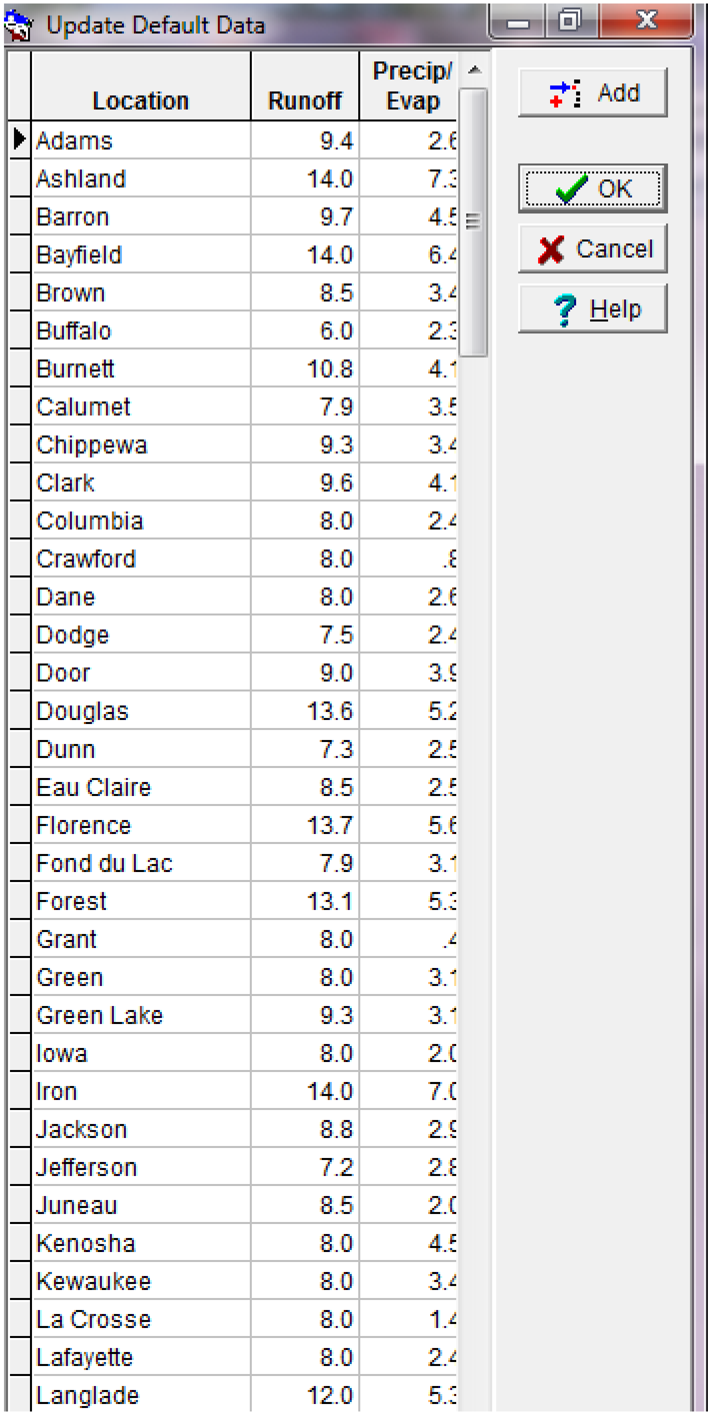

32”/year
Evapotranspiration (22”/year)
Baseflow
Event Flow



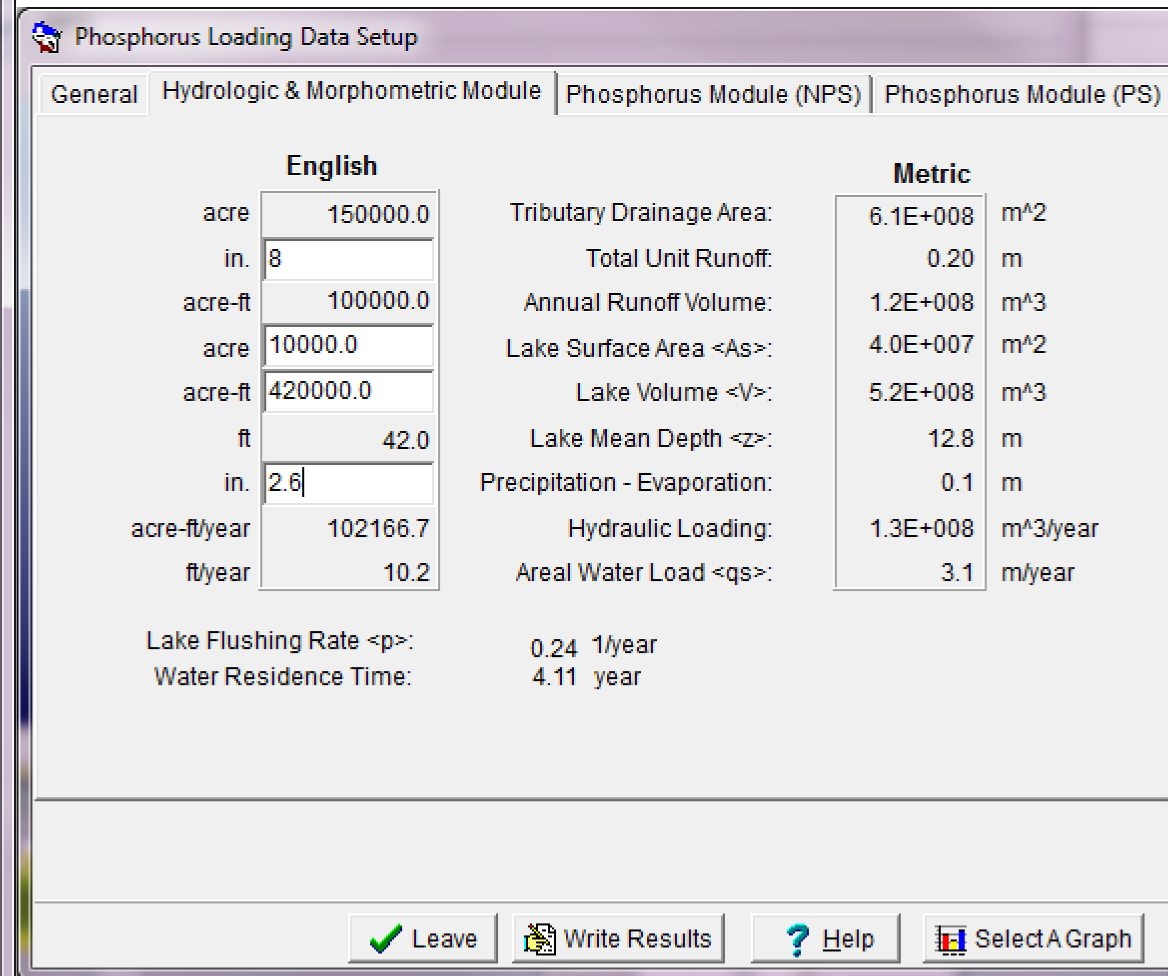
10 inches /year on 1 square mile…

= 23,000,000 cubic feet /year

= 0.7 cubic foot every second



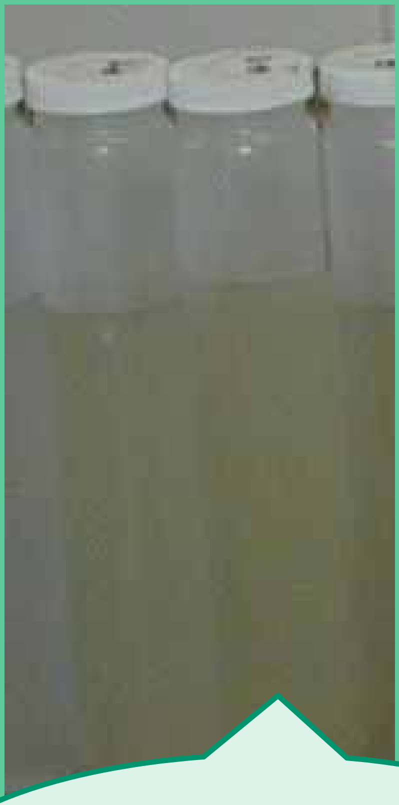
Location	Runoff	Precip/ Evap
Adams	9.4	2.6
Ashland	14.0	7.3
Barron	9.7	4.5
Bayfield	14.0	6.4
Brown	8.5	3.4
Buffalo	6.0	2.3
Burnett	10.8	4.1
Calumet	7.9	3.5
Chippewa	9.3	3.4
Clark	9.6	4.1
Columbia	8.0	2.4
Crawford	8.0	.8
Dane	8.0	2.6
Dodge	7.5	2.4
Door	9.0	3.9
Douglas	13.6	5.2
Dunn	7.3	2.5
Eau Claire	8.5	2.5
Florence	13.7	5.6
Fond du Lac	7.9	3.1
Forest	13.1	5.3
Grant	8.0	.4
Green	8.0	3.1
Green Lake	9.3	3.1
Iowa	8.0	2.0
Iron	14.0	7.0
Jackson	8.8	2.9
Jefferson	7.2	2.8
Juneau	8.5	2.0
Kenosha	8.0	4.5
Kewaukee	8.0	3.4
La Crosse	8.0	1.4
Lafayette	8.0	2.4
Langlade	12.0	5.3



Now Let's Talk about Those Inputs

- Water Budget
- Phosphorus Loading
  - Sources include
    - Event flow
    - Baseflow
    - Atmospheric Deposition
    - Internal (eg sediments)
- Land is a concentrated sediment & nutrient source

Total Suspended Solids...



0.01 gram/l

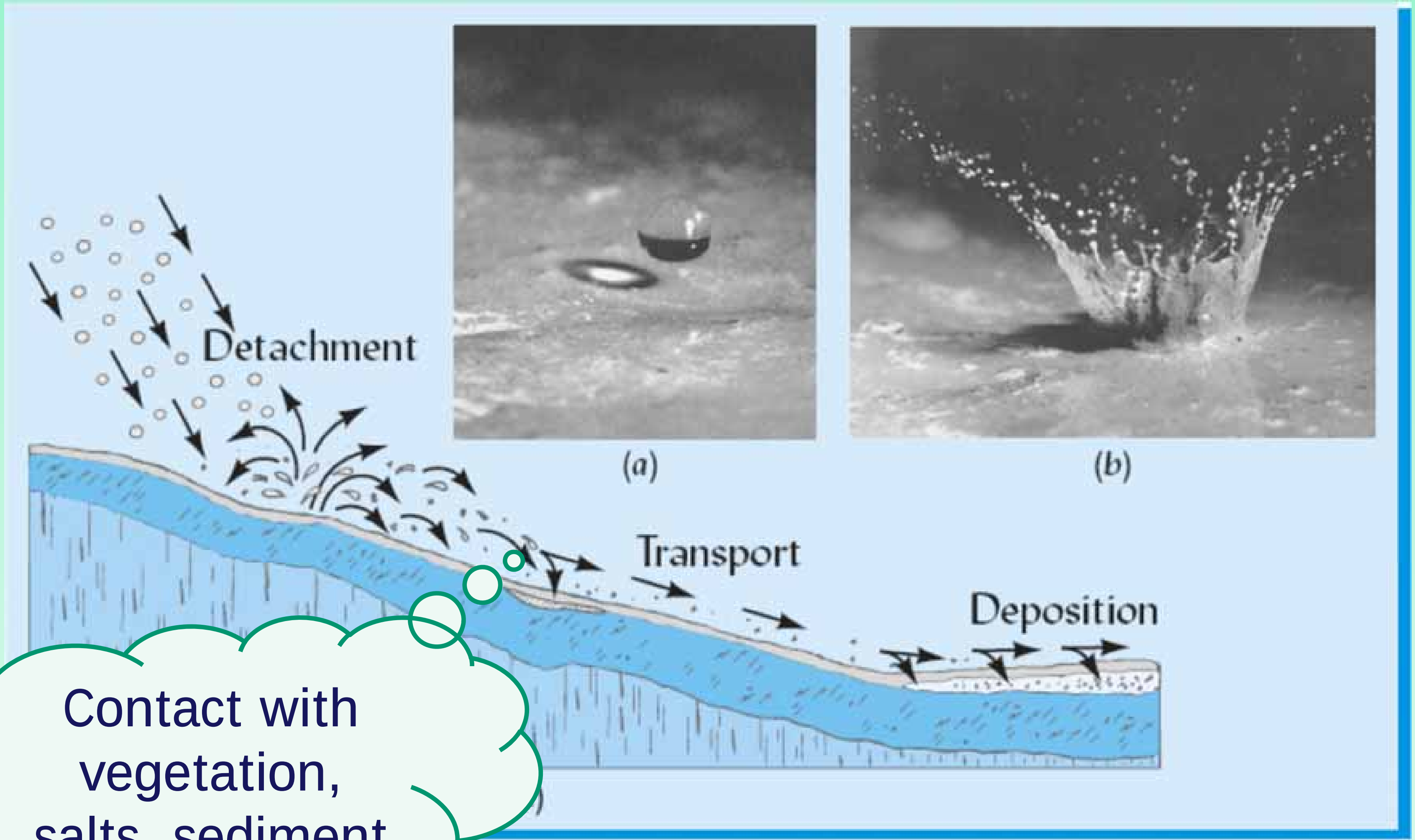
1,500 gram/l

Phosphorus

300,000 microgram P / liter

40 microgram P / liter

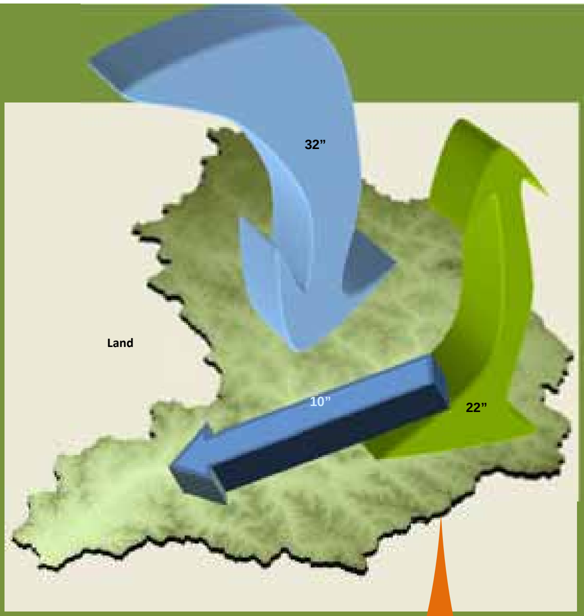
Add Energy & Opportunity



Contact with vegetation, salts, sediment

Nyle Brady and Raymond Weil 3/e

Modeling the Land?



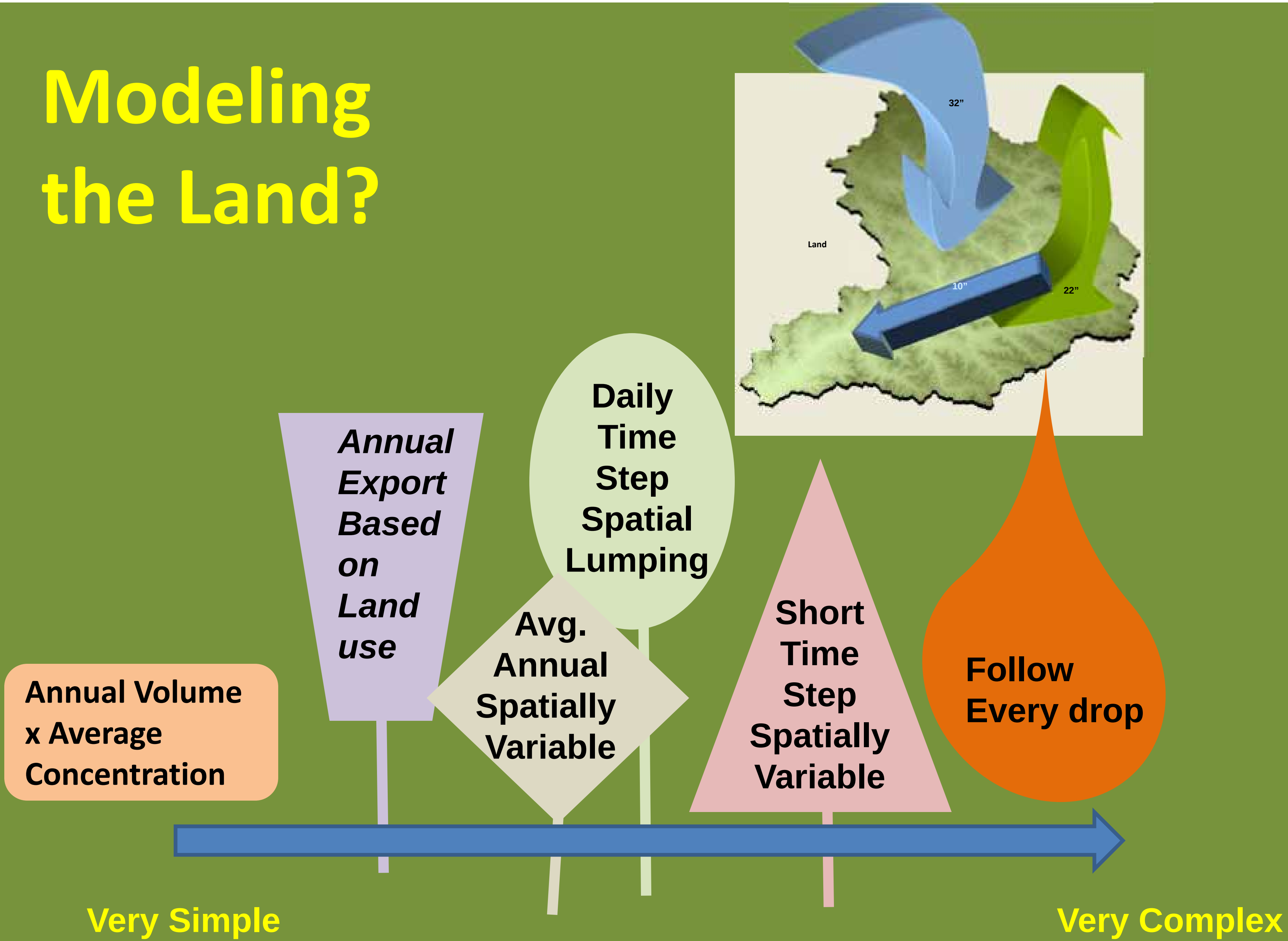
Follow Every drop

Annual Volume x Average Concentration

Very Simple

Very Complex

Modeling the Land?



WiLMS Watershed Inputs

- "Export"
  - Pounds/acre-yr
  - Kg/hectare-yr
  - Pounds/square mile-yr

- Comment on unit conversions
  - Is pound/acre-yr the same as kilogram/ha-yr?

- Watershed loading combines sources and transport
  - Quantity, availability
  - Interaction with water & transport

Phosphorus Export Coefficients

- Panuska and Lillie (p 29)
- Corsi et al. (p 37)
- Summary from PRESTO (p 41)
- Sparrow
- Hubbard Brook (p 52)
- Ontario LCM (p 119)

WiLMS Example 2

Input this...

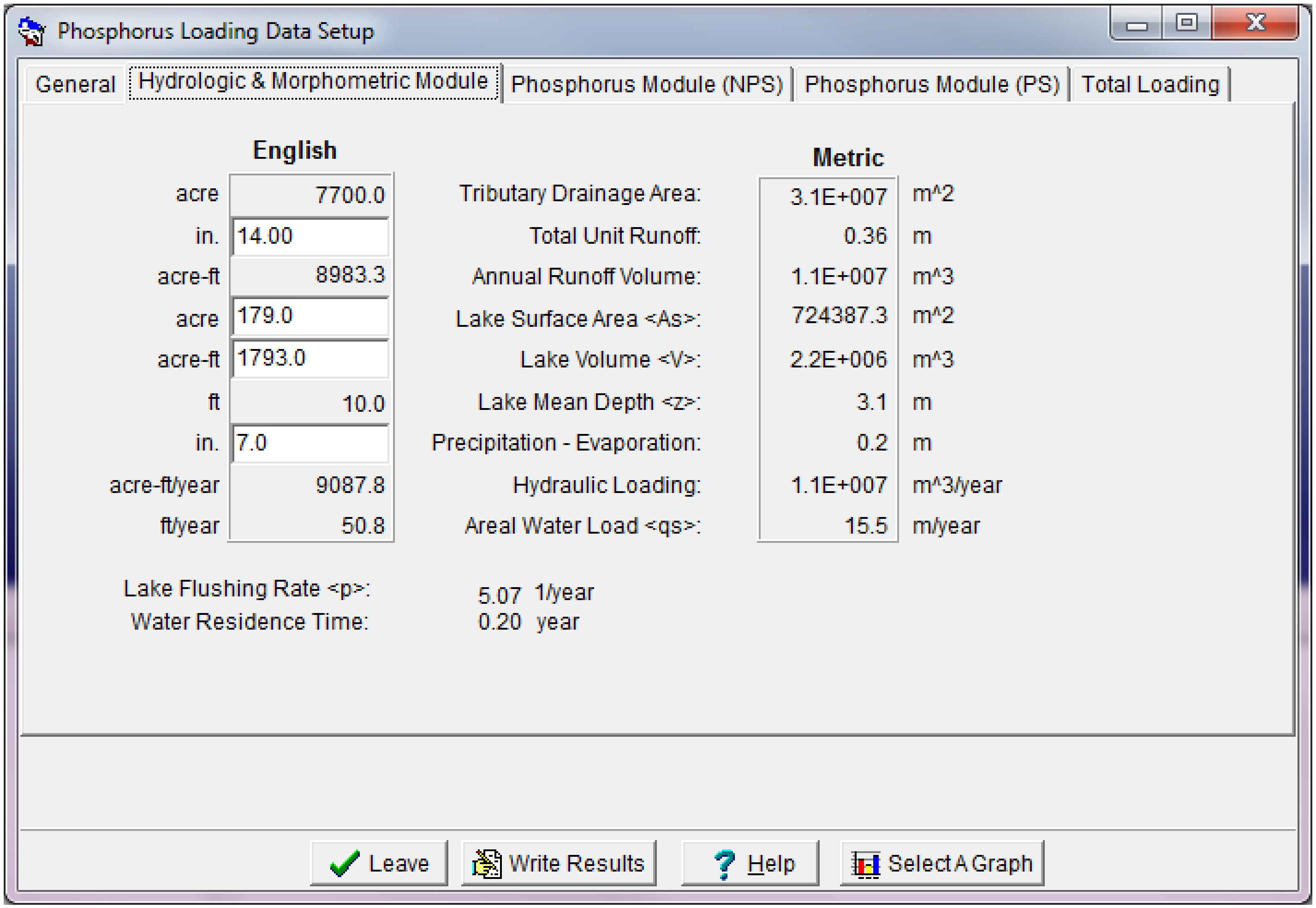
- Mercer Lake, Iron Co
- Area = 179 acres
- Volume = 1793 acre-feet
- P GSM=20 ug/l

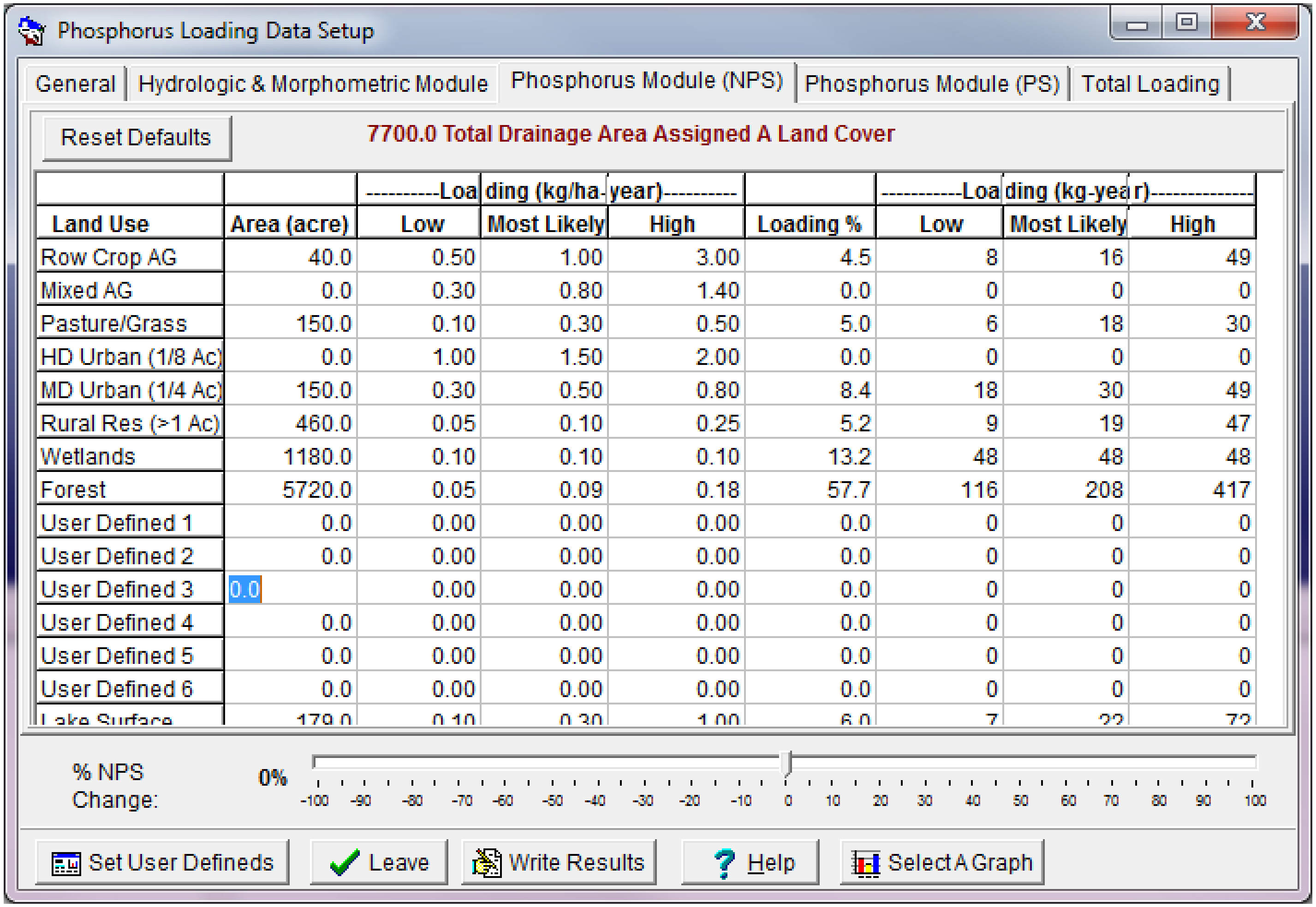
- Watershed

Land Use	Acres
Agriculture	40
Low Den Residential	460
Med Den Residential	150
Grassland	150
Water/Wetlands	1180
Forest	5720

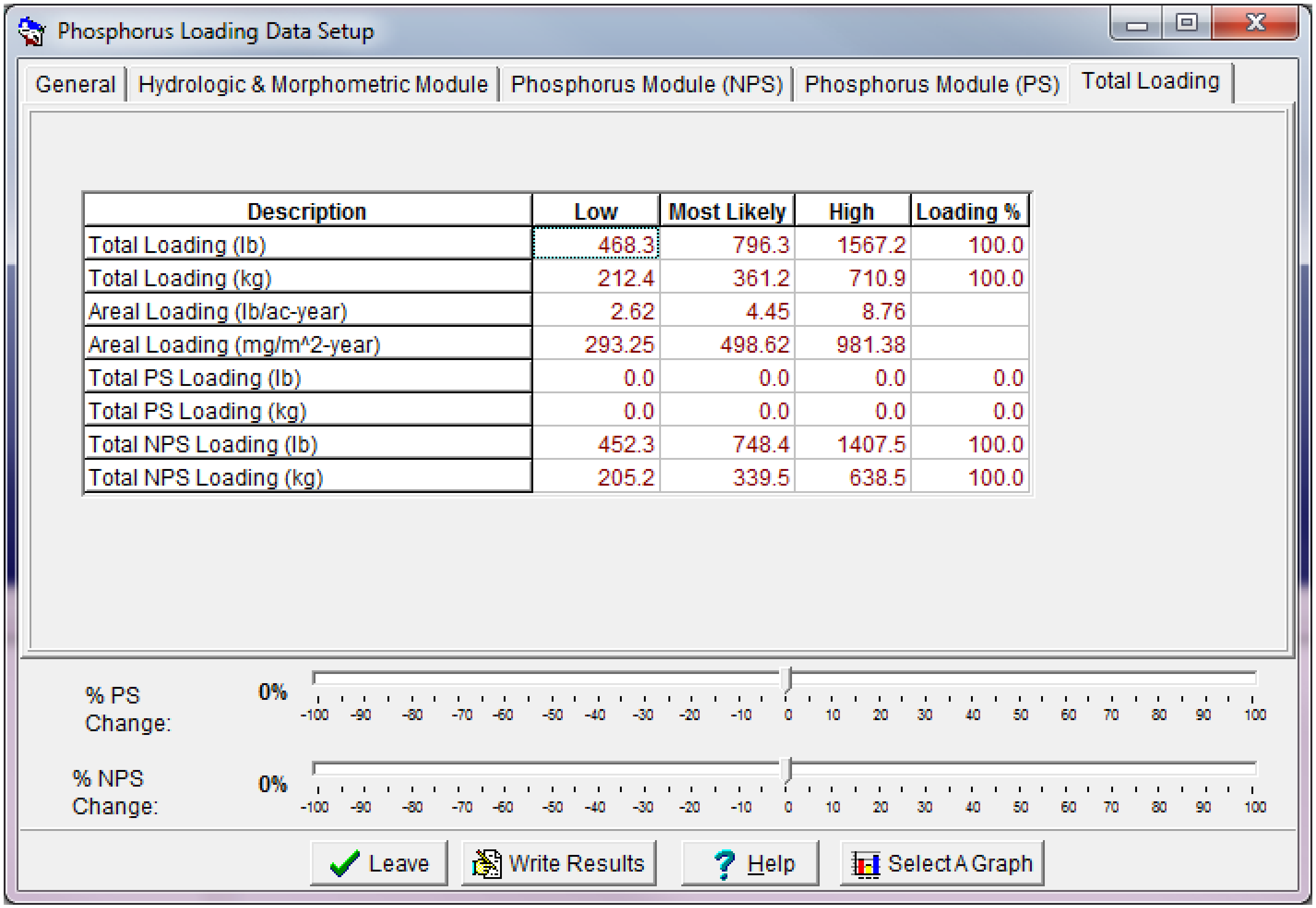
Find this...

- What is water loading rate (feet/year)?
- What is water residence time (years)?
- What is your “most likely” P loading?
- What is P loading in mg/m2-year of lake surface?
- Compare your lake P prediction with the observed


Phosphorus Loading Data Setup
General
Hydrologic & Morphometric Module
Phosphorus Module (NPS)
Phosphorus Module (PS)
Total Loading
English
Metric
acre 7700.0 Tributary Drainage Area: 3.1E+007 m^2
in. 14.00 Total Unit Runoff: 0.36 m
acre-ft 8983.3 Annual Runoff Volume: 1.1E+007 m^3
acre 179.0 Lake Surface Area <As>: 724387.3 m^2
acre-ft 1793.0 Lake Volume <V>: 2.2E+006 m^3
ft 10.0 Lake Mean Depth <z>: 3.1 m
in. 7.0 Precipitation - Evaporation: 0.2 m
acre-ft/year 9087.8 Hydraulic Loading: 1.1E+007 m^3/year
ft/year 50.8 Areal Water Load <qs>: 15.5 m/year
Lake Flushing Rate <p>: 5.07 1/year
Water Residence Time: 0.20 year
Leave
Write Results
Help
Select A Graph



		----------Loading (kg/ha-year)----------				----------Loading (kg-year)-------------		
Land Use	Area (acre)	Low	Most Likely	High	Loading %	Low	Most Likely	High
Row Crop AG	40.0	0.50	1.00	3.00	4.5	8	16	49
Mixed AG	0.0	0.30	0.80	1.40	0.0	0	0	0
Pasture/Grass	150.0	0.10	0.30	0.50	5.0	6	18	30
HD Urban (1/8 Ac)	0.0	1.00	1.50	2.00	0.0	0	0	0
MD Urban (1/4 Ac)	150.0	0.30	0.50	0.80	8.4	18	30	49
Rural Res (>1 Ac)	460.0	0.05	0.10	0.25	5.2	9	19	47
Wetlands	1180.0	0.10	0.10	0.10	13.2	48	48	48
Forest	5720.0	0.05	0.09	0.18	57.7	116	208	417
User Defined 1	0.0	0.00	0.00	0.00	0.0	0	0	0
User Defined 2	0.0	0.00	0.00	0.00	0.0	0	0	0
User Defined 3	0.0	0.00	0.00	0.00	0.0	0	0	0
User Defined 4	0.0	0.00	0.00	0.00	0.0	0	0	0
User Defined 5	0.0	0.00	0.00	0.00	0.0	0	0	0
User Defined 6	0.0	0.00	0.00	0.00	0.0	0	0	0
Lake Surface	179.0	0.10	0.30	1.00	6.0	7	22	72


Phosphorus Loading Data Setup
General
Hydrologic & Morphometric Module
Phosphorus Module (NPS)
Phosphorus Module (PS)
Total Loading
Description | Low | Most Likely | High | Loading %
Total Loading (lb) | 468.3 | 796.3 | 1567.2 | 100.0
Total Loading (kg) | 212.4 | 361.2 | 710.9 | 100.0
Areal Loading (lb/ac-year) | 2.62 | 4.45 | 8.76
Areal Loading (mg/m^2-year) | 293.25 | 498.62 | 981.38
Total PS Loading (lb) | 0.0 | 0.0 | 0.0 | 0.0
Total PS Loading (kg) | 0.0 | 0.0 | 0.0 | 0.0
Total NPS Loading (lb) | 452.3 | 748.4 | 1407.5 | 100.0
Total NPS Loading (kg) | 205.2 | 339.5 | 638.5 | 100.0
% PS Change:
0%
-100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100
% NPS Change:
0%
-100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100
Leave
Write Results
Help
Select A Graph

Phosphorus Predictions & Uncertainty Analysis

Observed spring overturn total phosphorus (SPO): 0.0 mg/m^3

Observed growing season mean phosphorus (GSM): 20.0 mg/m^3

Back calculation for SPO total phosphorus: 0.0 mg/m^3

Back calculation GSM phosphorus: 0.0 mg/m^3

Nurnberg Model Input - Est. Gross Int. Loading: 0 kg

% Confidence Range: 70

Lake Phosphorus Model	Low Total P (mg/m^3)	Most Likely Total P (mg/m^3)	High Total P (mg/m^3)	Predicted -Observed (mg/m^3)	% Dif.	Confidence Lower Bound	Confidence Upper Bound	Parameter Fit?	Back Calculation (kg/year)	Model Type
Walker, 1987 Reservoir	13	23	45	3	15	14	39	FIT	0	GSM
Canfield-Bachmann, 1981 Natural Lake	15	24	44	4	20	7	69	FIT	1	GSM
Canfield-Bachmann, 1981 Artificial Lake	14	22	38	2	10	7	63	FIT	1	GSM
Rechow, 1979 General	10	17	33	-3	-15	10	29	FIT	0	GSM
Rechow, 1977 Anoxic	16	28	55	8	40	18	47	FIT	0	GSM
Rechow, 1977 water load<50m/year	12	21	41	1	5	13	36	FIT	0	GSM
Rechow, 1977 water load>50m/year	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Walker, 1977 General	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Vollenweider, 1982 Combined OECD	13	20	34	10	100	10	36	FIT	0	ANN
Dillon-Rigler-Kirchner	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Vollenweider, 1982 Shallow Lake/Res.	10	16	28	6	60	8	29	FIT	0	ANN
Larsen-Mercier, 1976	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Nurnberg, 1984 Oxic	10	18	35	-2	-10	10	32	FIT	0	ANN

Finished | Write Results | Display Parameter Values | Help

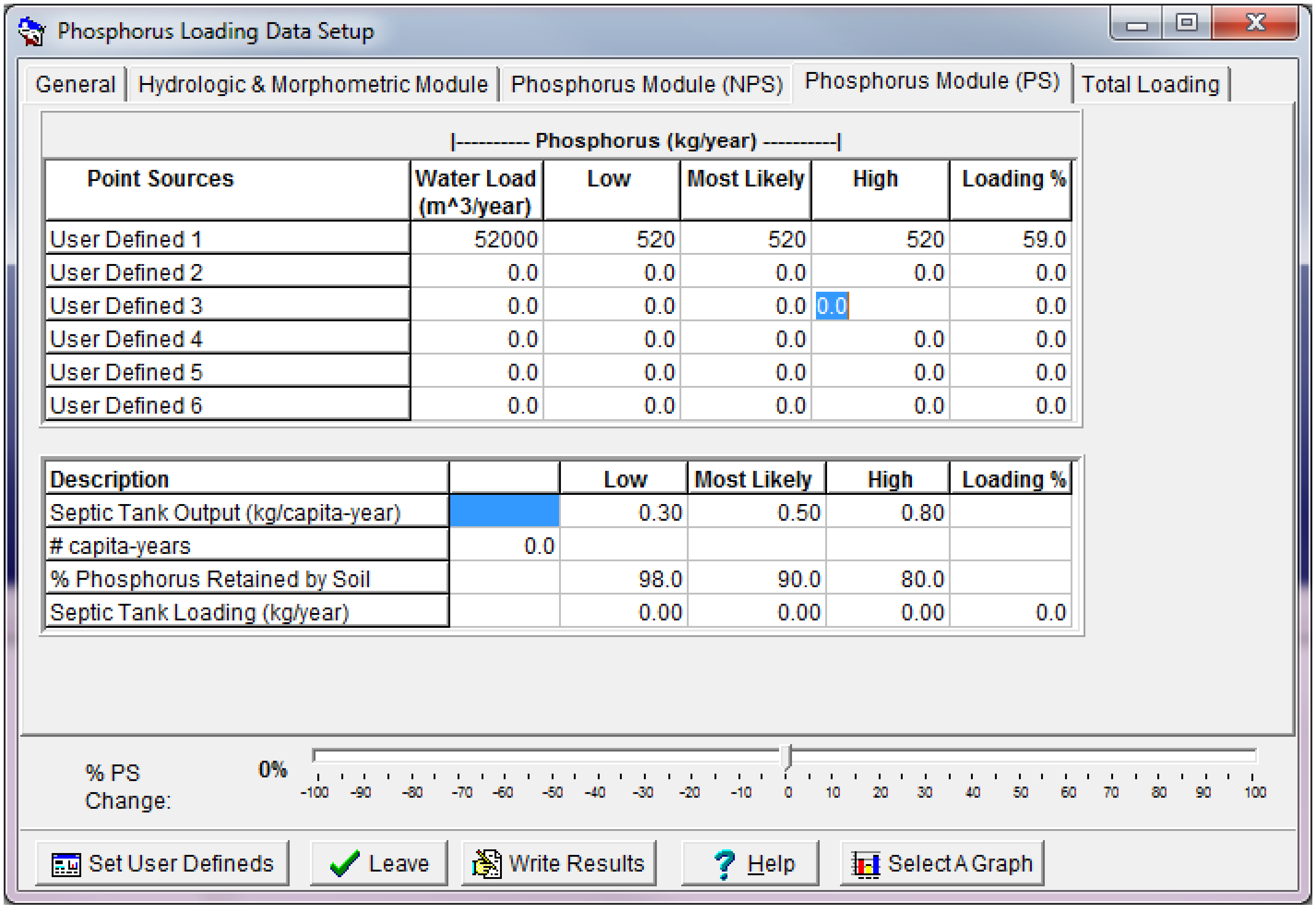
Water Quality, Hydrology, and Simulated Response to Changes in Phosphorus Loading of Mercer Lake, Iron County, Wisconsin, with Special Emphasis on the Effects of Wastewater Discharges

By Dale M. Robertson, Herbert S. Garn, William J. Rose, Paul F. Juckem, and Paul C. Reneau

Point Sources

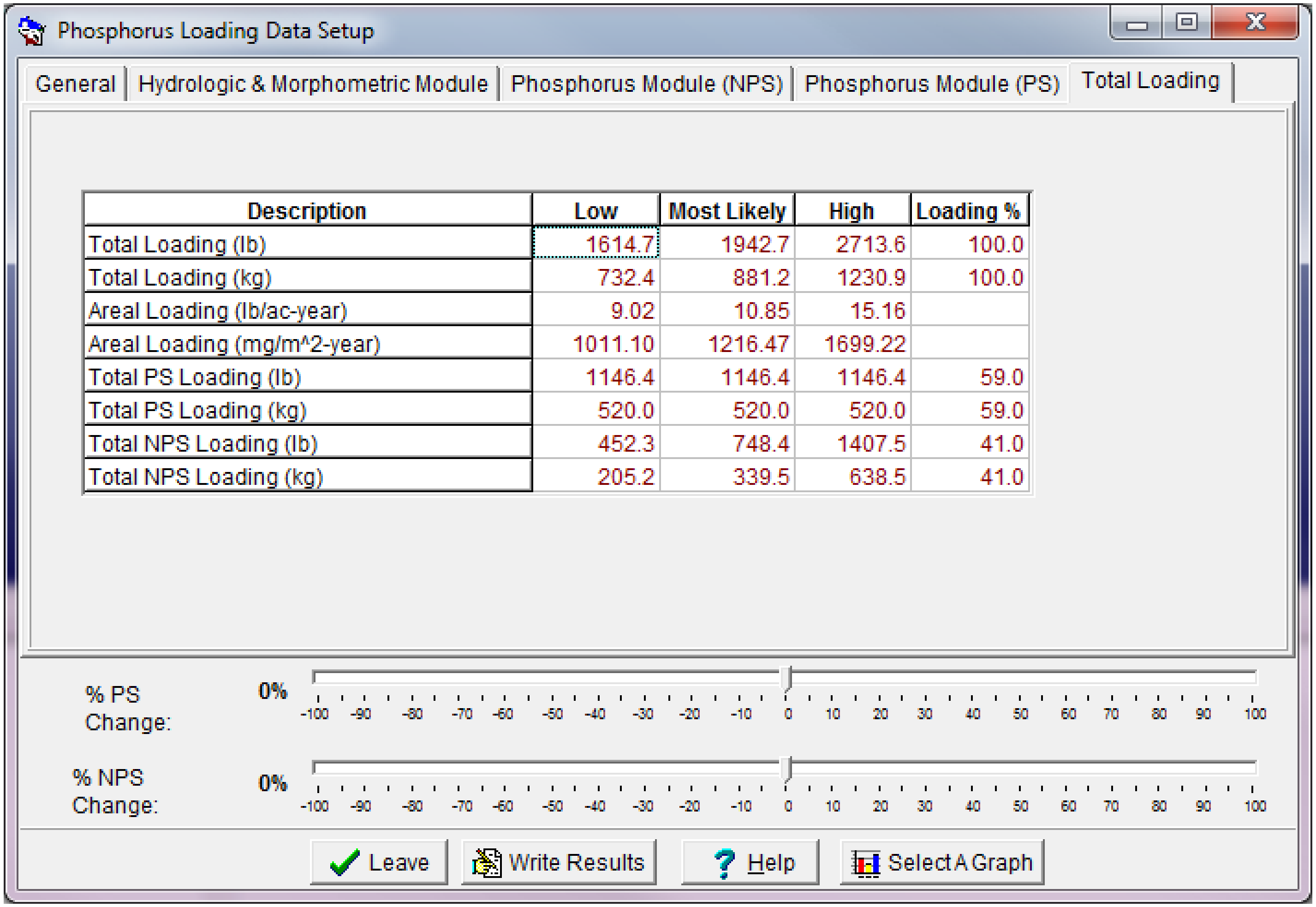
- Let's assume this lake had a WWTP discharge
  - 37,400 gallon/day
  - 10 mg/l P

- We'll need to do some math...
  - That's (37,400 gal/d)(365 d/yr)(1m3/264 gal)
  - <u>Or = 52,000 m3/year</u>
  - And, (52,000 m3/yr)(1000 liter/m3)(10mg/l)(1kg/1000000mg)
  - <u>Or = 520 kg/year</u>



Point Sources	Water Load (m^3/year)	Low	Most Likely	High	Loading %
User Defined 1	52000	520	520	520	59.0
User Defined 2	0.0	0.0	0.0	0.0	0.0
User Defined 3	0.0	0.0	0.0	0.0	0.0
User Defined 4	0.0	0.0	0.0	0.0	0.0
User Defined 5	0.0	0.0	0.0	0.0	0.0
User Defined 6	0.0	0.0	0.0	0.0	0.0

Description		Low	Most Likely	High	Loading %
Septic Tank Output (kg/capita-year)		0.30	0.50	0.80	
# capita-years	0.0				
% Phosphorus Retained by Soil		98.0	90.0	80.0	
Septic Tank Loading (kg/year)		0.00	0.00	0.00	0.0



Description	Low	Most Likely	High	Loading %
Total Loading (lb)	1614.7	1942.7	2713.6	100.0
Total Loading (kg)	732.4	881.2	1230.9	100.0
Areal Loading (lb/ac-year)	9.02	10.85	15.16	
Areal Loading (mg/m^2-year)	1011.10	1216.47	1699.22	
Total PS Loading (lb)	1146.4	1146.4	1146.4	59.0
Total PS Loading (kg)	520.0	520.0	520.0	59.0
Total NPS Loading (lb)	452.3	748.4	1407.5	41.0
Total NPS Loading (kg)	205.2	339.5	638.5	41.0

Phosphorus Predictions & Uncertainty Analysis

Observed spring overturn total phosphorus (SPO): 0.0 mg/m^3

Observed growing season mean phosphorus (GSM): 20.0 mg/m^3

Back calculation for SPO total phosphorus: 0.0 mg/m^3

Back calculation GSM phosphorus: 0.0 mg/m^3

Nurnberg Model Input - Est. Gross Int. Loading: 0 kg

% Confidence Range: 70

Lake Phosphorus Model	Low Total P (mg/m^3)	Most Likely Total P (mg/m^3)	High Total P (mg/m^3)	Predicted -Observed (mg/m^3)	% Dif.	Confidence Lower Bound
Walker, 1987 Reservoir	36	44	61	24	120	31
Canfield-Bachmann, 1981 Natural Lake	45	52	69	32	160	16
Canfield-Bachmann, 1981 Artificial Lake	39	44	57	24	120	14
Rechow, 1979 General	33	40	56	20	100	27
Rechow, 1977 Anoxic	56	67	94	47	235	48
Rechow, 1977 water load<50m/year	42	51	71	31	155	35
Rechow, 1977 water load>50m/year	N/A	N/A	N/A	N/A	N/A	N/A
Walker, 1977 General	N/A	N/A	N/A	N/A	N/A	N/A
Vollenweider, 1982 Combined OECD	35	41	54	31	310	23
Dillon-Rigler-Kirchner	N/A	N/A	N/A	N/A	N/A	N/A
Vollenweider, 1982 Shallow Lake/Res.	29	34	46	24	240	19
Larsen-Mercier, 1976	N/A	N/A	N/A	N/A	N/A	N/A
Nurnberg, 1984 Oxic	36	43	60	23	115	27

Finished | Write Results | Display Parameter Values | Help

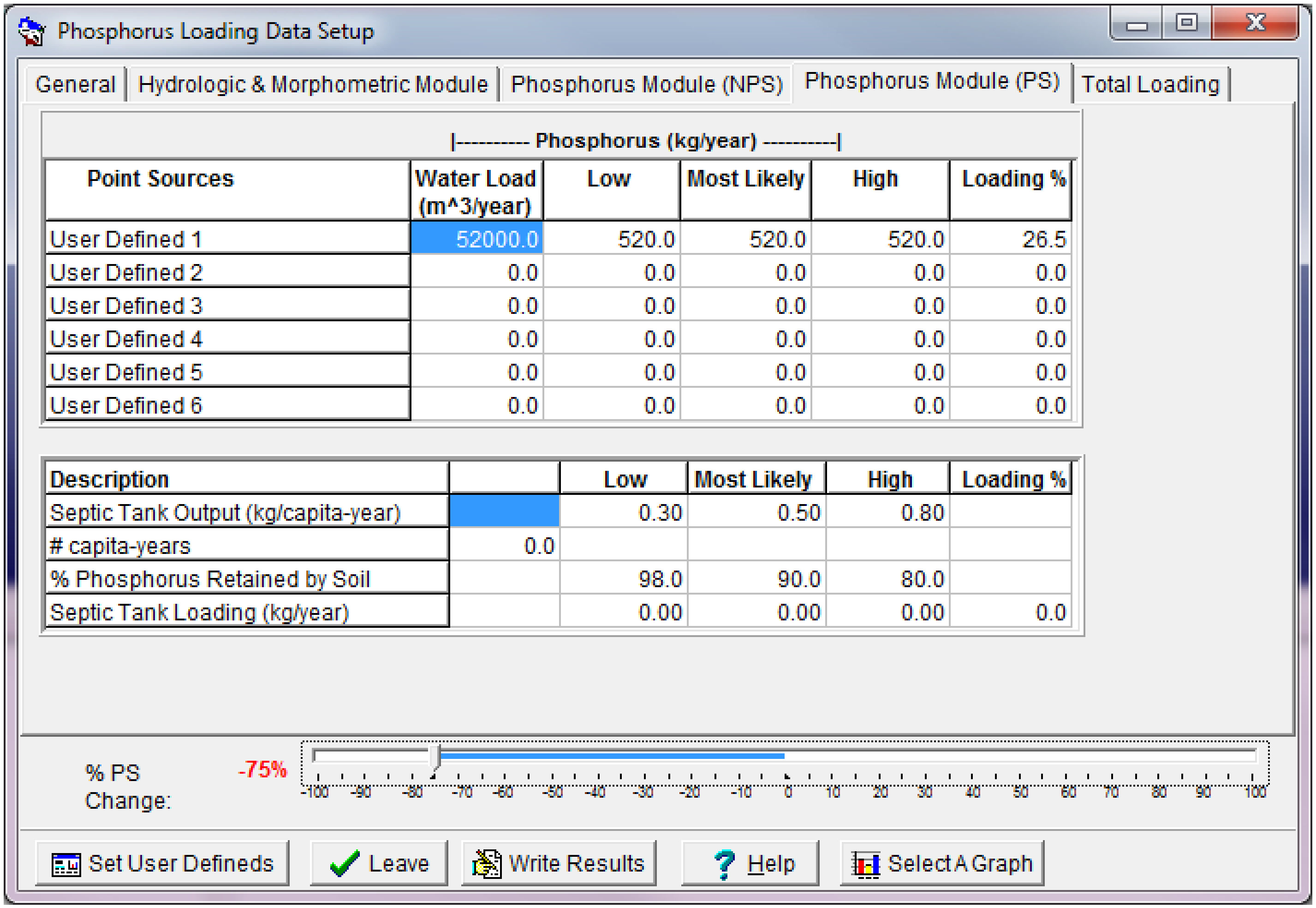
Table 5. Near-surface, summer-aw based on data from the East Basin c

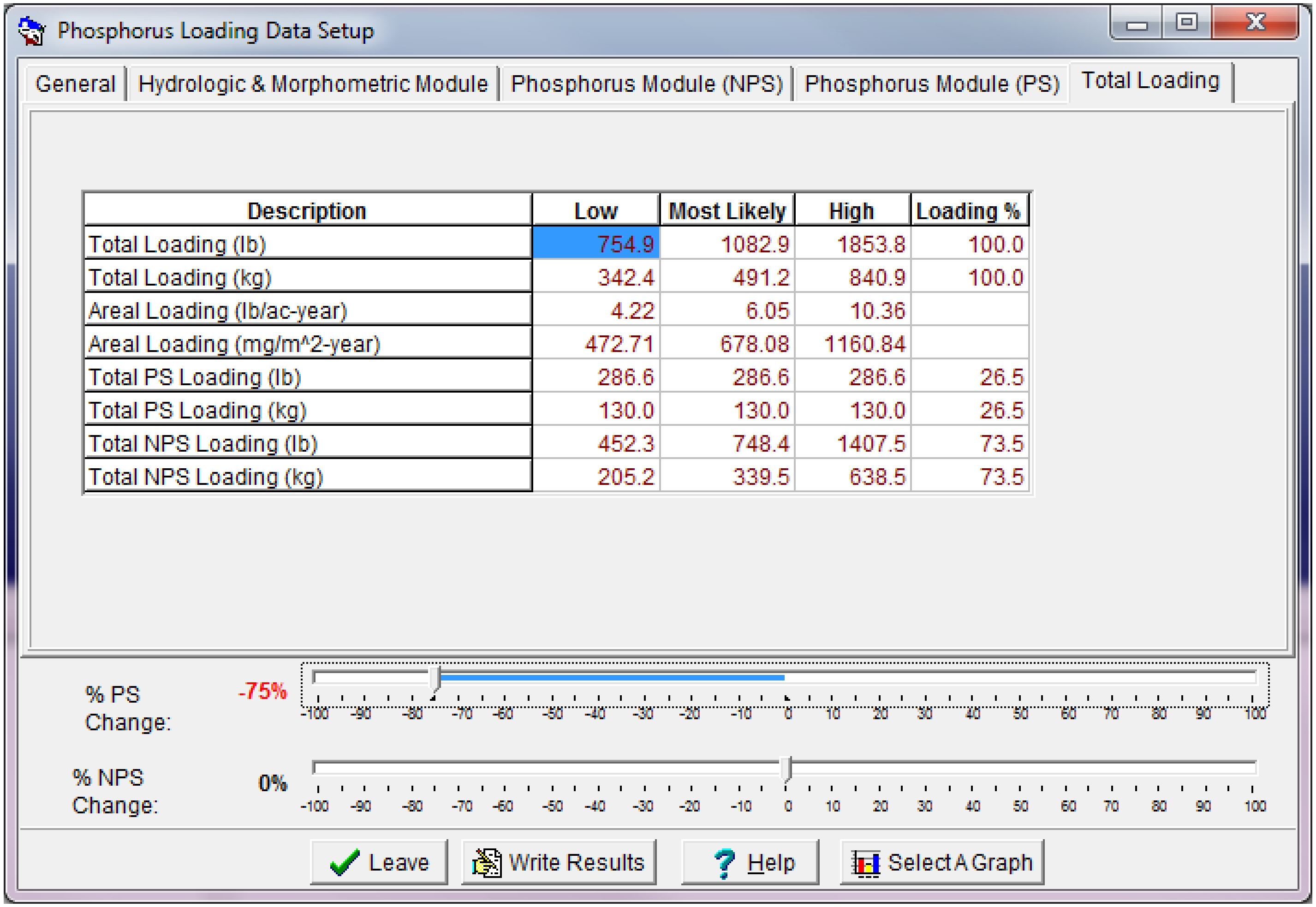
[mg/L, milligrams per liter; µg/L, microgr:

Year	Total phosphorus (mg/L)
1973	0.040
1974	0.030
1975	0.020
1976	0.030
1979	0.027
2000	0.015
2001	—
2002	0.018
2004	—
2005	—
2006	0.017
2007	0.017
2008	0.022
2009	0.024
2010	0.018
2011	0.019
Average 2006–10	0.019
Average	0.023

Slider Bar on Point Sources

- Return to Setup
- PS Tab (Phosphorus Module (PS))
- Do 75% reduction in point sources
- Then look at P prediction


Phosphorus Loading Data Setup
General
Hydrologic & Morphometric Module
Phosphorus Module (NPS)
Phosphorus Module (PS)
Total Loading
|---------- Phosphorus (kg/year) ----------|
Point Sources
Water Load (m^3/year)
Low
Most Likely
High
Loading %
User Defined 1 52000.0 520.0 520.0 520.0 26.5
User Defined 2 0.0 0.0 0.0 0.0 0.0
User Defined 3 0.0 0.0 0.0 0.0 0.0
User Defined 4 0.0 0.0 0.0 0.0 0.0
User Defined 5 0.0 0.0 0.0 0.0 0.0
User Defined 6 0.0 0.0 0.0 0.0 0.0
Description
Low
Most Likely
High
Loading %
Septic Tank Output (kg/capita-year) 0.30 0.50 0.80
capita-years 0.0
% Phosphorus Retained by Soil 98.0 90.0 80.0
Septic Tank Loading (kg/year) 0.00 0.00 0.00 0.0
% PS Change:
-75%
-100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100
Set User Defineds
Leave
Write Results
Help
Select A Graph



Description	Low	Most Likely	High	Loading %
Total Loading (lb)	754.9	1082.9	1853.8	100.0
Total Loading (kg)	342.4	491.2	840.9	100.0
Areal Loading (lb/ac-year)	4.22	6.05	10.36	
Areal Loading (mg/m^2-year)	472.71	678.08	1160.84	
Total PS Loading (lb)	286.6	286.6	286.6	26.5
Total PS Loading (kg)	130.0	130.0	130.0	26.5
Total NPS Loading (lb)	452.3	748.4	1407.5	73.5
Total NPS Loading (kg)	205.2	339.5	638.5	73.5

Phosphorus Predictions & Uncertainty Analysis

Observed spring overturn total phosphorus (SPO): 0.0 mg/m^3

Observed growing season mean phosphorus (GSM): 20.0 mg/m^3

Back calculation for SPO total phosphorus: 0.0 mg/m^3

Back calculation GSM phosphorus: 0.0 mg/m^3

Nurnberg Model Input - Est. Gross Int. Loading: 0 kg

% Confidence Range: 70

Lake Phosphorus Model	Low Total P (mg/m^3)	Most Likely Total P (mg/m^3)	High Total P (mg/m^3)	Predicted -Observed (mg/m^3)	% Dif.	Confidence Lower Bound
Walker, 1987 Reservoir	20	29	49	9	45	19
Canfield-Bachmann, 1981 Natural Lake	23	32	50	12	60	10
Canfield-Bachmann, 1981 Artificial Lake	21	28	43	8	40	9
Rechow, 1979 General	16	22	38	2	10	14
Rechow, 1977 Anoxic	26	37	64	17	85	25
Rechow, 1977 water load<50m/year	20	28	49	8	40	18
Rechow, 1977 water load>50m/year	N/A	N/A	N/A	N/A	N/A	N/A
Walker, 1977 General	N/A	N/A	N/A	N/A	N/A	N/A
Vollenweider, 1982 Combined OECD	19	25	39	15	150	14
Dillon-Rigler-Kirchner	N/A	N/A	N/A	N/A	N/A	N/A
Vollenweider, 1982 Shallow Lake/Res.	15	20	33	10	100	11
Larsen-Mercier, 1976	N/A	N/A	N/A	N/A	N/A	N/A
Nurnberg, 1984 Oxic	17	24	41	4	20	14

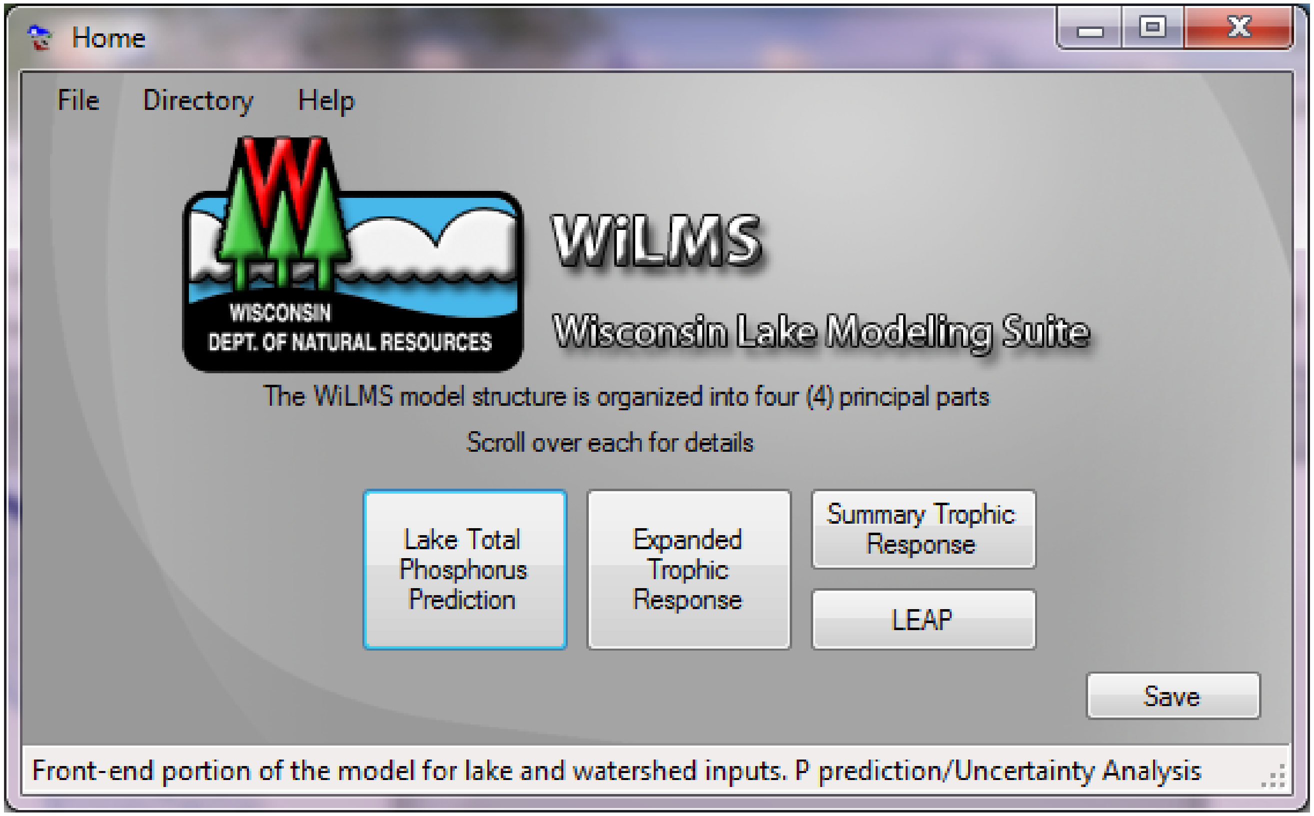
Finished | Write Results | Display Parameter Values | Help

Table 5. Near-surface, summer-aw
based on data from the East Basin c

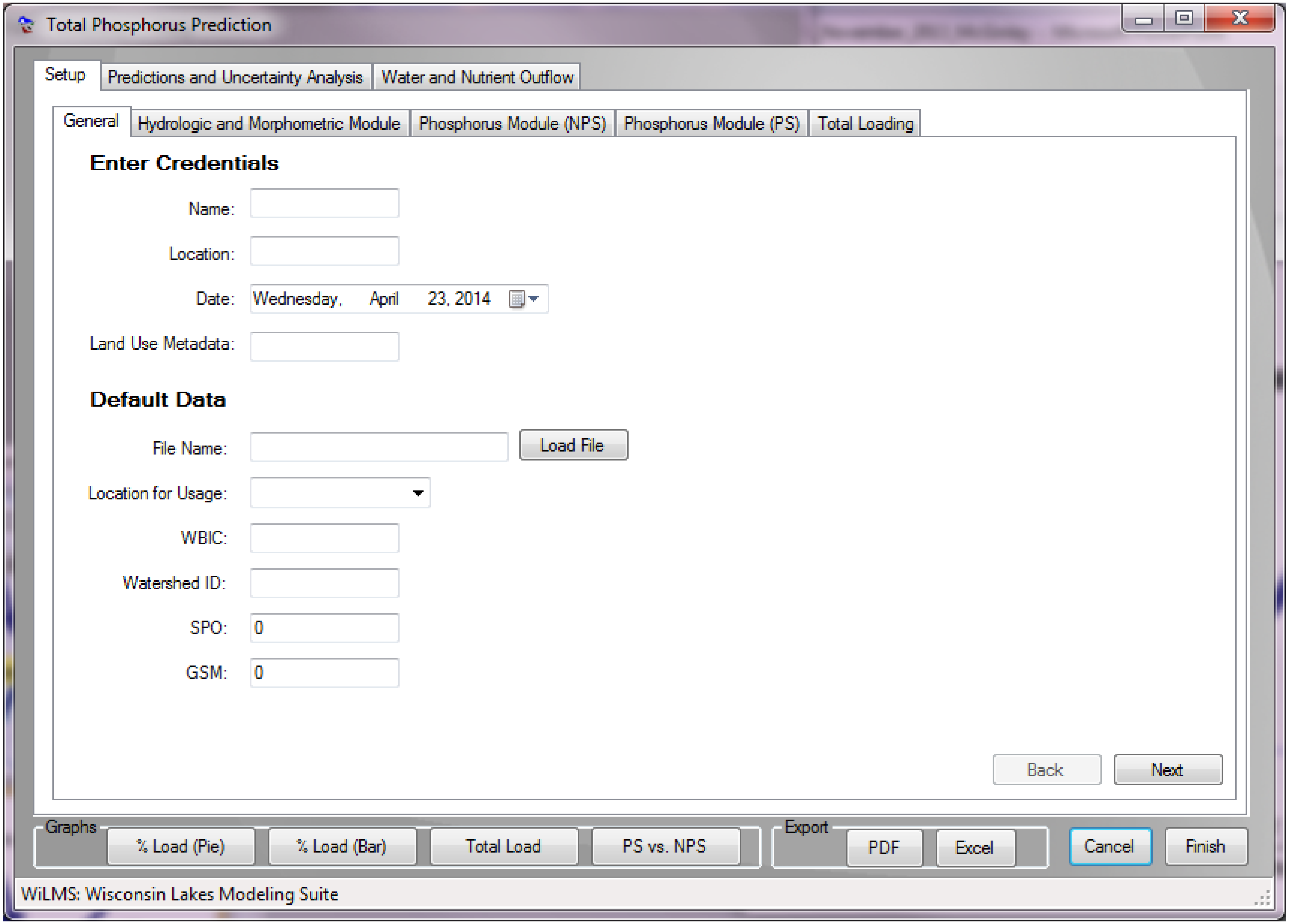
[mg/L, milligrams per liter; µg/L, microgr

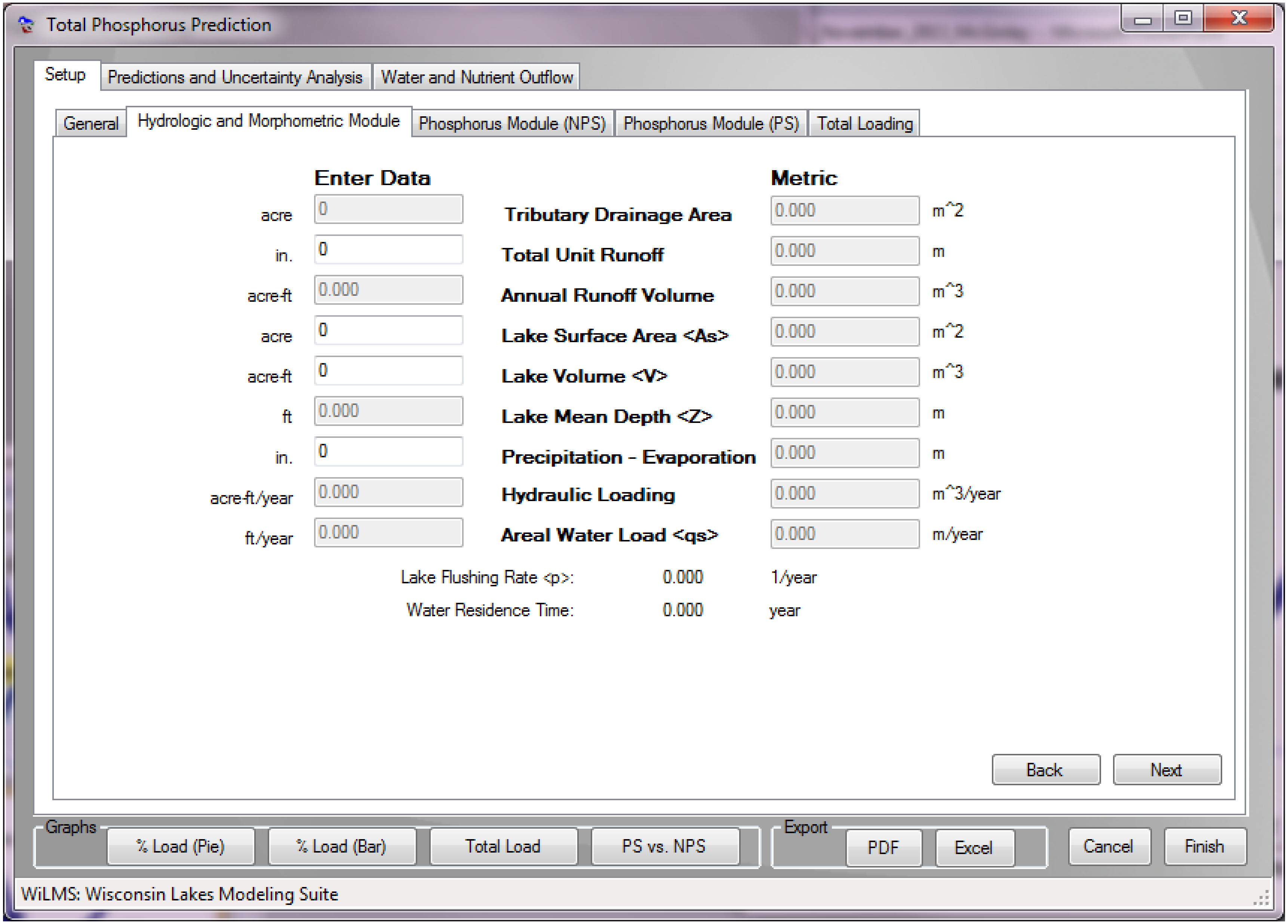
Year	Total phosphorus (mg/L)
1973	0.040
1974	0.030
1975	0.020
1976	0.030
1979	0.027
2000	0.015
2001	—
2002	0.018
2004	—
2005	—
2006	0.017
2007	0.017
2008	0.022
2009	0.024
2010	0.018
2011	0.019
Average 2006–10	0.019
Average 2008–09	0.023

- WiLMS History
  - 1990s– Spreadsheet
  - 2005 – Current Version
  - 2015 – Updated Version



Similar Look




Total Phosphorus Prediction
Setup
Predictions and Uncertainty Analysis
Water and Nutrient Outflow
General
Hydrologic and Morphometric Module
Phosphorus Module (NPS)
Phosphorus Module (PS)
Total Loading
Enter Data
Metric
acre
0
Tributary Drainage Area
0.000
m^2
in.
0
Total Unit Runoff
0.000
m
acre-ft
0.000
Annual Runoff Volume
0.000
m^3
acre
0
Lake Surface Area <As>
0.000
m^2
acre-ft
0
Lake Volume <V>
0.000
m^3
ft
0.000
Lake Mean Depth <Z>
0.000
m
in.
0
Precipitation - Evaporation
0.000
m
acre-ft/year
0.000
Hydraulic Loading
0.000
m^3/year
ft/year
0.000
Areal Water Load <qs>
0.000
m/year
Lake Flushing Rate <p>:
0.000
1/year
Water Residence Time:
0.000
year
Back
Next
Graphs
% Load (Pie)
% Load (Bar)
Total Load
PS vs. NPS
Export
PDF
Excel
Cancel
Finish
WiLMS: Wisconsin Lakes Modeling Suite

Groundwater & Septic Systems

- General Ideas
  - – Groundwater contributing area may not be the same as the surface watershed
    - Treat as a point source, or
    - Treat as another land use
  - – Conventional septic systems release phosphorus... even functioning as designed
    - The phosphorus can be retained in the soil profile and the groundwater aquifer
    - The question is... how much "retention" and what's the best way to describe it?

Groundwater

- For WiLMS need two things
  - Flow rate of water
  - Mass of phosphorus
- For a landuse– that's already included in the
  - Area & the "runoff"
  - Export rate (kg/ha-yr)

Groundwater

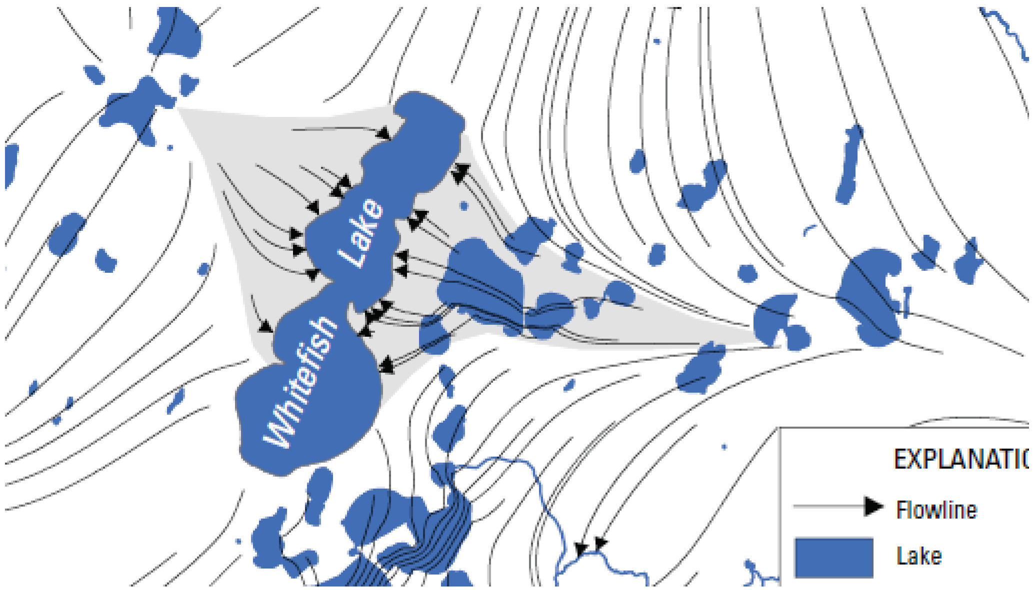
- Let’s look at an acre of land, assume 14” of groundwater “produced’’/yr and a groundwater P concentration of 0.015 mg/l.
  - Point Source Approach **(need a flow and mass/year)**
    - That 14”/year is about 1,440 m3/year for each acre
    - At 0.015 mg/l, that is about 0.02 kg/yr for every acre
  - Other Land Use Approach **(enter as area, export rate)**
    - At 14” and 0.015 mg/, that is about 0.05 kg/ha-yr
    - (...why is that about the same as a forested land use?)
  - Most important thing... don’t double count!

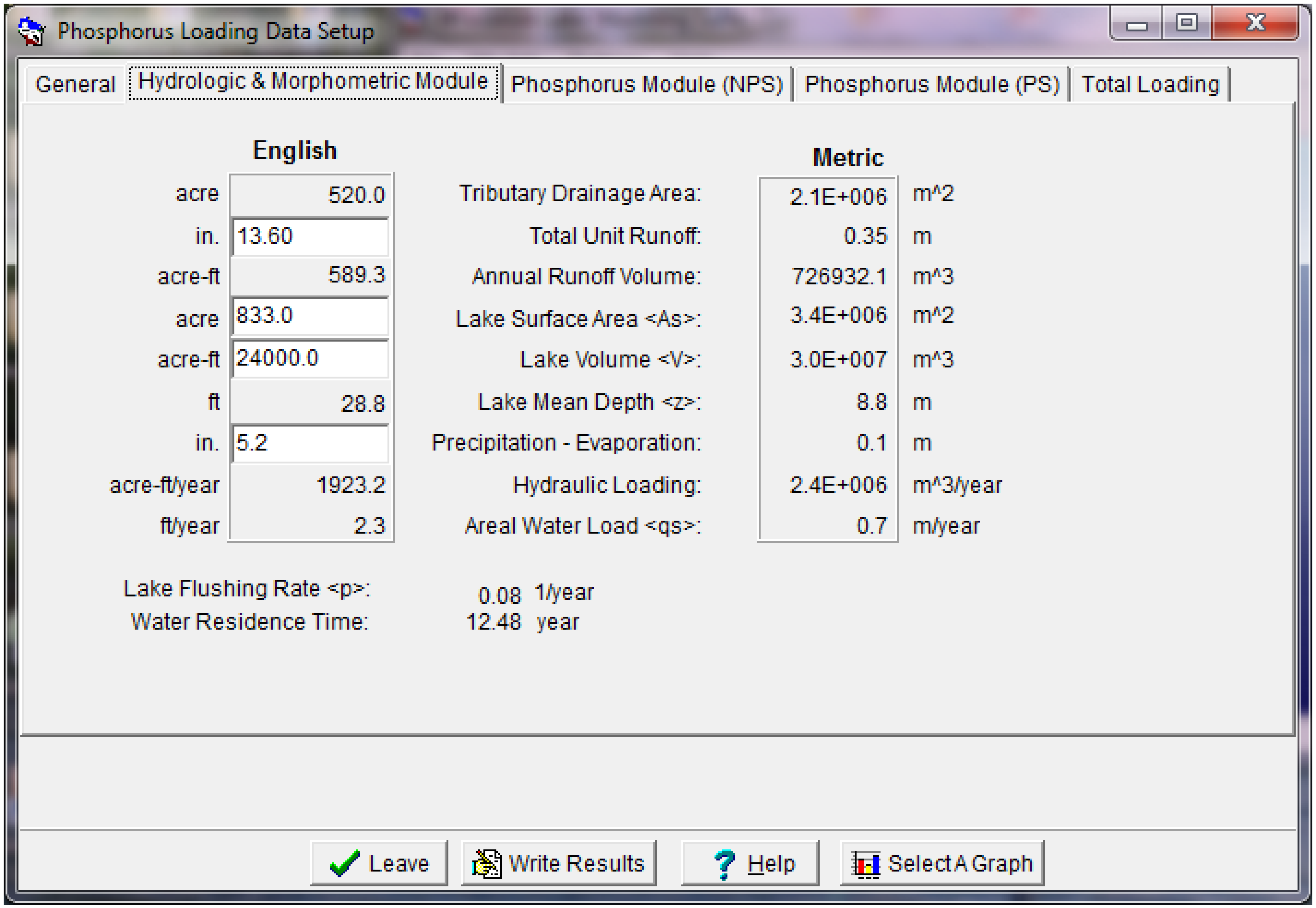
Septic Systems

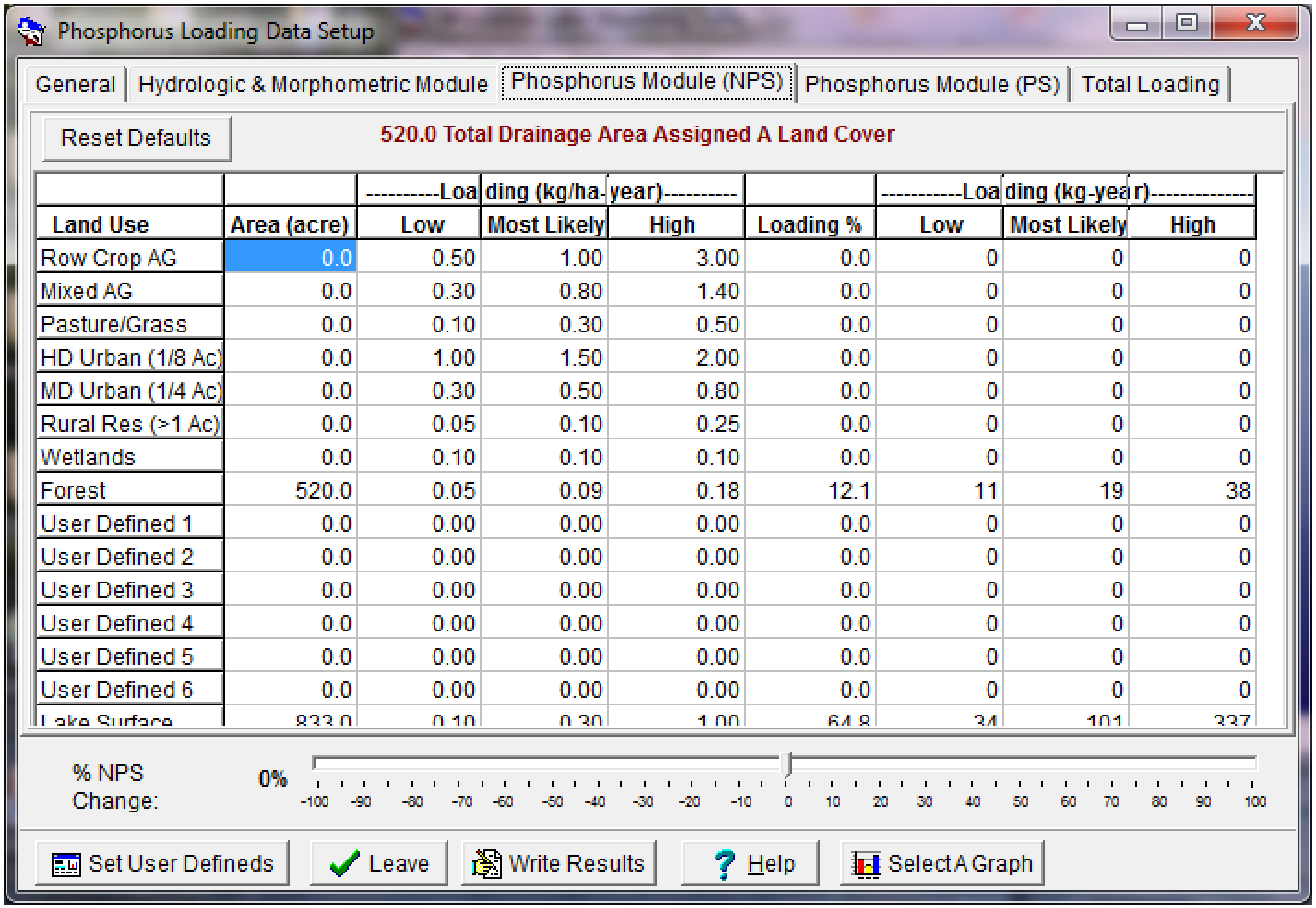
- WilMS Approach
  - Assume a number of **people-years**
    - Sum of (# of people)*(fraction of year they use lake)
  - Assume a **kilogram of P/person-year**
    - Usually something like 0.5 kg (range 0.3 to 0.8)
  - Assume a **fraction of the P retained**
    - Will depend on soil– more surface area– more retention
    - Also effect of iron– more iron– more retention
    - Some evidence that more basic soils– less retention
    - But high calcium could tie up some P
    - Probably some complex function of pH / redox /other
    - Assume 70% (range from 50% to 90%)

Example 3

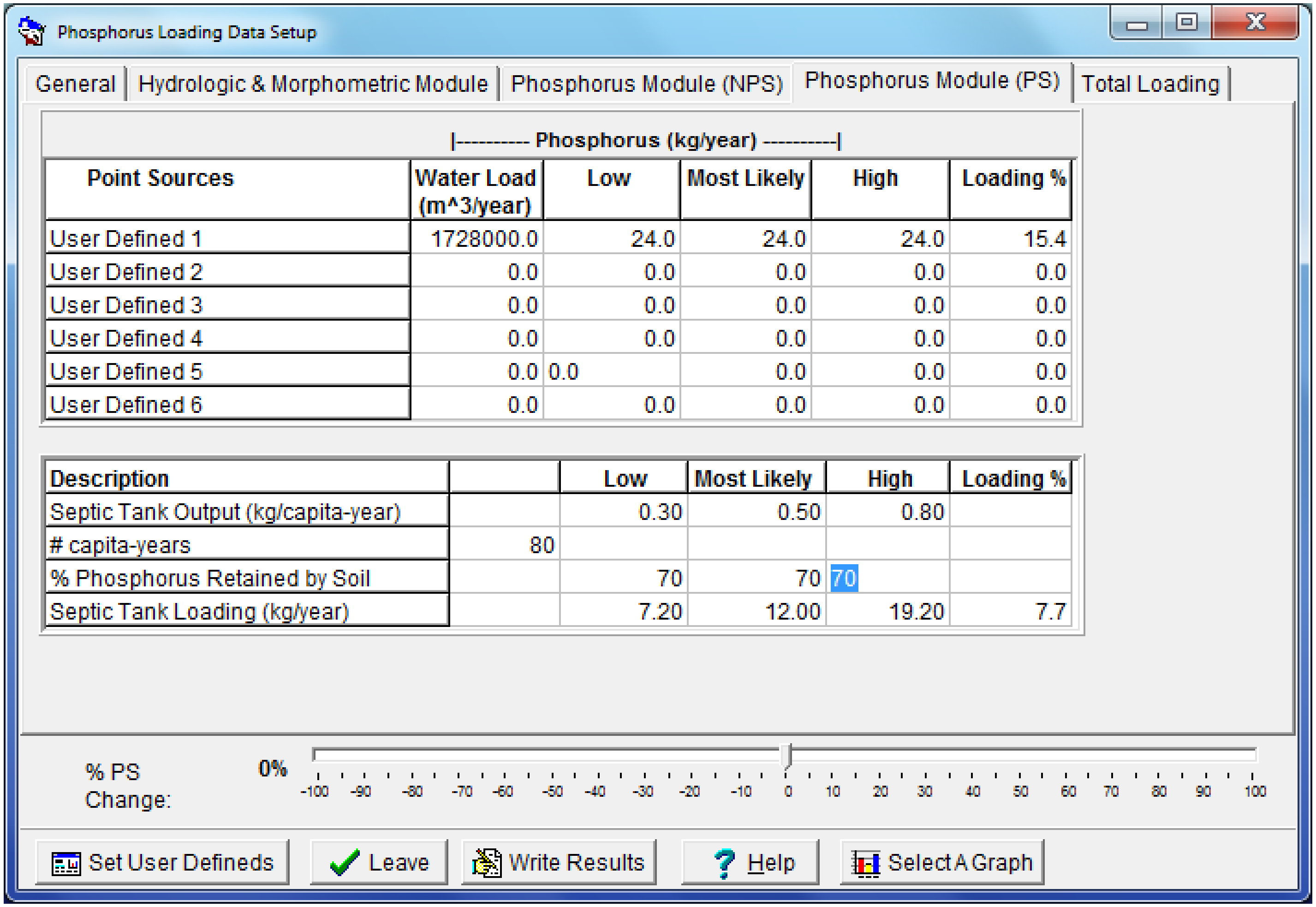
- 833 acre lake, Douglas County
- Mean depth of 29 feet
- Measured TP 0.007 mg/l (GSM & SPO)
- 520 acre watershed
  - Assume all forest
- Extra 1200 acres of groundwater contributing area
  - Try point source
  - 1440 m3/yr-acre (14 inch/yr)
  - 0.02 kg/yr-acre (0.015 mg/l)
- Septic Systems
  - 80 capita-years
  - 70% retention
  - (range 90% to 50%)




Phosphorus Loading Data Setup
General
Hydrologic & Morphometric Module
Phosphorus Module (NPS)
Phosphorus Module (PS)
Total Loading
English
Metric
acre 520.0 Tributary Drainage Area: 2.1E+006 m^2
in. 13.60 Total Unit Runoff: 0.35 m
acre-ft 589.3 Annual Runoff Volume: 726932.1 m^3
acre 833.0 Lake Surface Area <As>: 3.4E+006 m^2
acre-ft 24000.0 Lake Volume <V>: 3.0E+007 m^3
ft 28.8 Lake Mean Depth <z>: 8.8 m
in. 5.2 Precipitation - Evaporation: 0.1 m
acre-ft/year 1923.2 Hydraulic Loading: 2.4E+006 m^3/year
ft/year 2.3 Areal Water Load <qs>: 0.7 m/year
Lake Flushing Rate <p>: 0.08 1/year
Water Residence Time: 12.48 year
Leave
Write Results
Help
Select A Graph



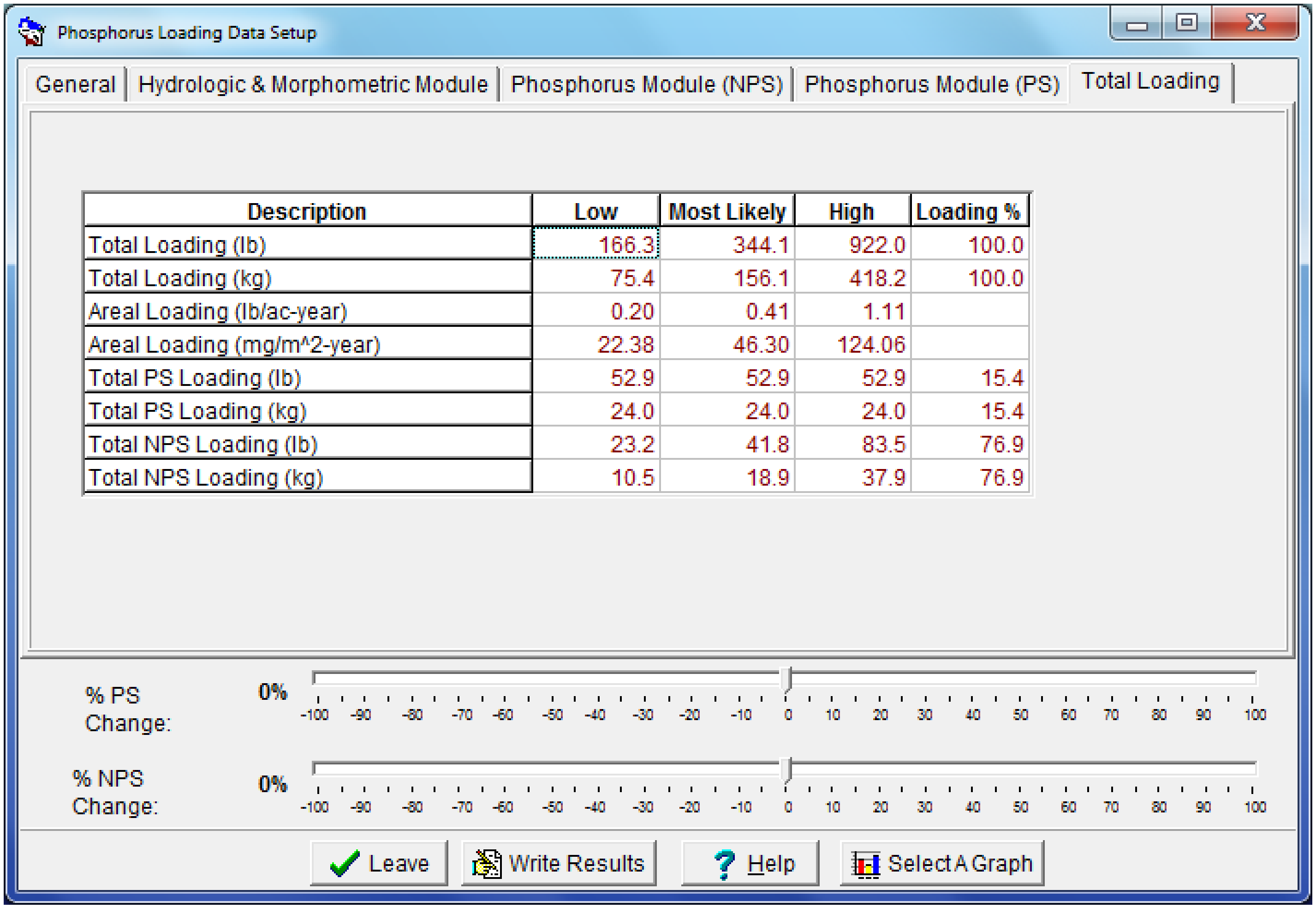
		----------Loading (kg/ha-year)----------				----------Loading (kg-year)----------		
Land Use	Area (acre)	Low	Most Likely	High	Loading %	Low	Most Likely	High
Row Crop AG	0.0	0.50	1.00	3.00	0.0	0	0	0
Mixed AG	0.0	0.30	0.80	1.40	0.0	0	0	0
Pasture/Grass	0.0	0.10	0.30	0.50	0.0	0	0	0
HD Urban (1/8 Ac)	0.0	1.00	1.50	2.00	0.0	0	0	0
MD Urban (1/4 Ac)	0.0	0.30	0.50	0.80	0.0	0	0	0
Rural Res (>1 Ac)	0.0	0.05	0.10	0.25	0.0	0	0	0
Wetlands	0.0	0.10	0.10	0.10	0.0	0	0	0
Forest	520.0	0.05	0.09	0.18	12.1	11	19	38
User Defined 1	0.0	0.00	0.00	0.00	0.0	0	0	0
User Defined 2	0.0	0.00	0.00	0.00	0.0	0	0	0
User Defined 3	0.0	0.00	0.00	0.00	0.0	0	0	0
User Defined 4	0.0	0.00	0.00	0.00	0.0	0	0	0
User Defined 5	0.0	0.00	0.00	0.00	0.0	0	0	0
User Defined 6	0.0	0.00	0.00	0.00	0.0	0	0	0
Lake Surface	833.0	0.10	0.30	1.00	64.8	34	101	337



|---------- Phosphorus (kg/year) ----------|

Point Sources	Water Load (m^3/year)	Low	Most Likely	High	Loading %
User Defined 1	1728000.0	24.0	24.0	24.0	15.4
User Defined 2	0.0	0.0	0.0	0.0	0.0
User Defined 3	0.0	0.0	0.0	0.0	0.0
User Defined 4	0.0	0.0	0.0	0.0	0.0
User Defined 5	0.0	0.0	0.0	0.0	0.0
User Defined 6	0.0	0.0	0.0	0.0	0.0

Description		Low	Most Likely	High	Loading %
Septic Tank Output (kg/capita-year)		0.30	0.50	0.80	
# capita-years	80				
% Phosphorus Retained by Soil		70	70	70	
Septic Tank Loading (kg/year)		7.20	12.00	19.20	7.7



Description	Low	Most Likely	High	Loading %
Total Loading (lb)	166.3	344.1	922.0	100.0
Total Loading (kg)	75.4	156.1	418.2	100.0
Areal Loading (lb/ac-year)	0.20	0.41	1.11	
Areal Loading (mg/m^2-year)	22.38	46.30	124.06	
Total PS Loading (lb)	52.9	52.9	52.9	15.4
Total PS Loading (kg)	24.0	24.0	24.0	15.4
Total NPS Loading (lb)	23.2	41.8	83.5	76.9
Total NPS Loading (kg)	10.5	18.9	37.9	76.9

Phosphorus Predictions & Uncertainty Analysis

Observed spring overturn total phosphorus (SPO): 7.0 mg/m^3

Observed growing season mean phosphorus (GSM): 7.0 mg/m^3

Back calculation for SPO total phosphorus: 0.0 mg/m^3

Back calculation GSM phosphorus: 0.0 mg/m^3

Nurnberg Model Input - Est. Gross Int. Loading: 0 kg

% Confidence Range: 70

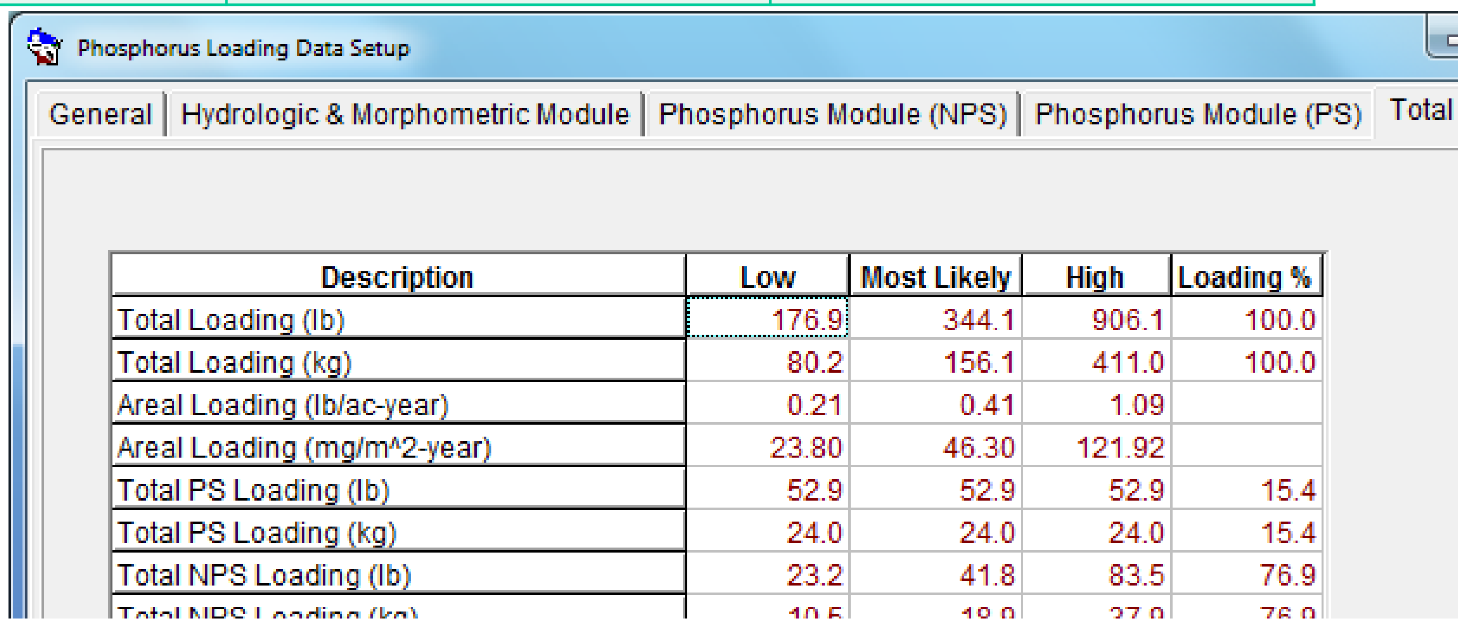
Lake Phosphorus Model	Low Total P (mg/m^3)	Most Likely Total P (mg/m^3)	High Total P (mg/m^3)	Predicted -Observed (mg/m^3)	% Dif.	Confidence Lower Bound	Confidence Upper Bound	Parameter Fit?	Back Calculation (kg/year)	Model Type
Walker, 1987 Reservoir	9	18	49	11	157	11	38	Tw	0	GSM
Canfield-Bachmann, 1981 Natural Lake	7	12	22	5	71	4	35	FIT	1	GSM
Canfield-Bachmann, 1981 Artificial Lake	9	13	22	6	86	4	37	FIT	1	GSM
Rechow, 1979 General	2	4	10	-3	-43	2	8	L	0	GSM
Rechow, 1977 Anoxic	9	19	50	12	171	11	39	FIT	0	GSM
Rechow, 1977 water load<50m/year	2	5	13	-2	-29	3	10	FIT	0	GSM
Rechow, 1977 water load>50m/year	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Walker, 1977 General	8	16	43	9	129	8	35	FIT	0	SPO
Vollenweider, 1982 Combined OECD	7	13	28	6	86	6	26	FIT	0	ANN
Dillon-Rigler-Kirchner	6	13	34	6	86	7	27	L qs p	0	SPO
Vollenweider, 1982 Shallow Lake/Res.	5	10	23	3	43	5	20	FIT	0	ANN
Larsen-Mercier, 1976	6	13	34	6	86	8	26	Pin	0	SPO
Nurnberg, 1984 Oxic	5	11	30	4	57	6	24	FIT	0	ANN

Finished | Write Results | Display Parameter Values | Help

Recap

Source	Low kg/year	Most Likely kg/year
Surface watershed	11	19
Atmospheric (lake surface)	34	101
Additional groundwater	24	24
Septic systems	12	12
Total –kilograms/year	81	156
Total—pounds/year	177	344

Note that the septic P doesn't show up in the point source total but it is in the total loading


Phosphorus Loading Data Setup

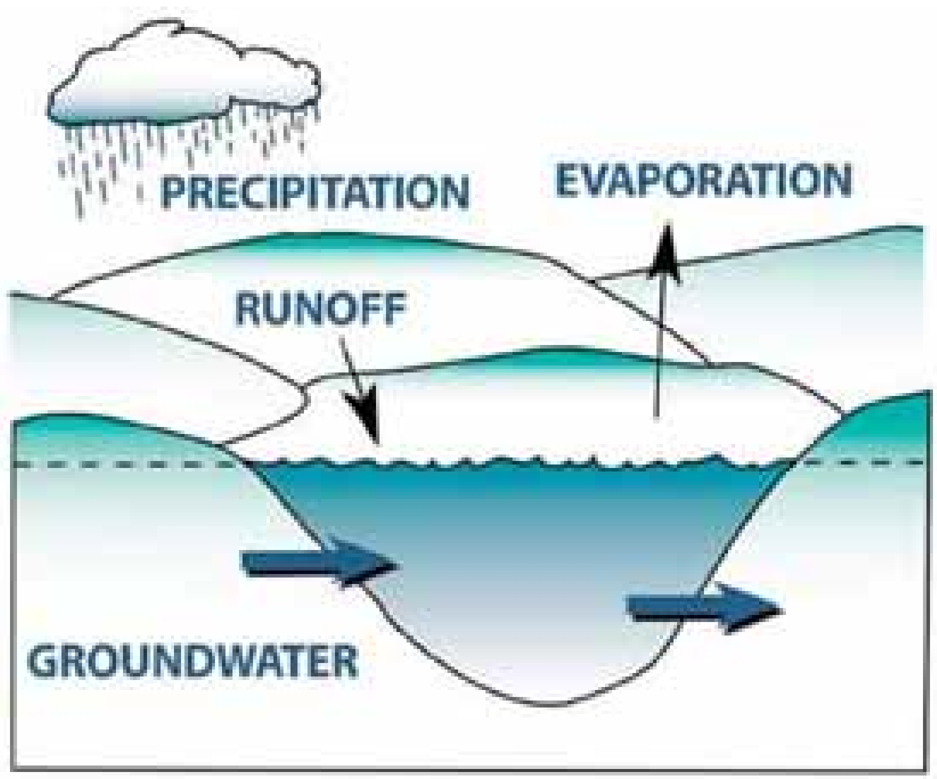
General | Hydrologic & Morphometric Module | Phosphorus Module (NPS) | Phosphorus Module (PS) | Total

Description	Low	Most Likely	High	Loading %
Total Loading (lb)	176.9	344.1	906.1	100.0
Total Loading (kg)	80.2	156.1	411.0	100.0
Areal Loading (lb/ac-year)	0.21	0.41	1.09	
Areal Loading (mg/m^2-year)	23.80	46.30	121.92	
Total PS Loading (lb)	52.9	52.9	52.9	15.4
Total PS Loading (kg)	24.0	24.0	24.0	15.4
Total NPS Loading (lb)	23.2	41.8	83.5	76.9
Total NPS Loading (kg)	10.5	19.0	37.9	76.9

We do have some things we can discuss….

- This is a seepage lake
- Let’s take a close look at atmospheric deposition
- Does groundwater actually enter the lake?
- What should the groundwater P concentration be?
- Take another look at steady-state in shallow lakes
- How about riparian runoff?
- Other?

Seepage Lake

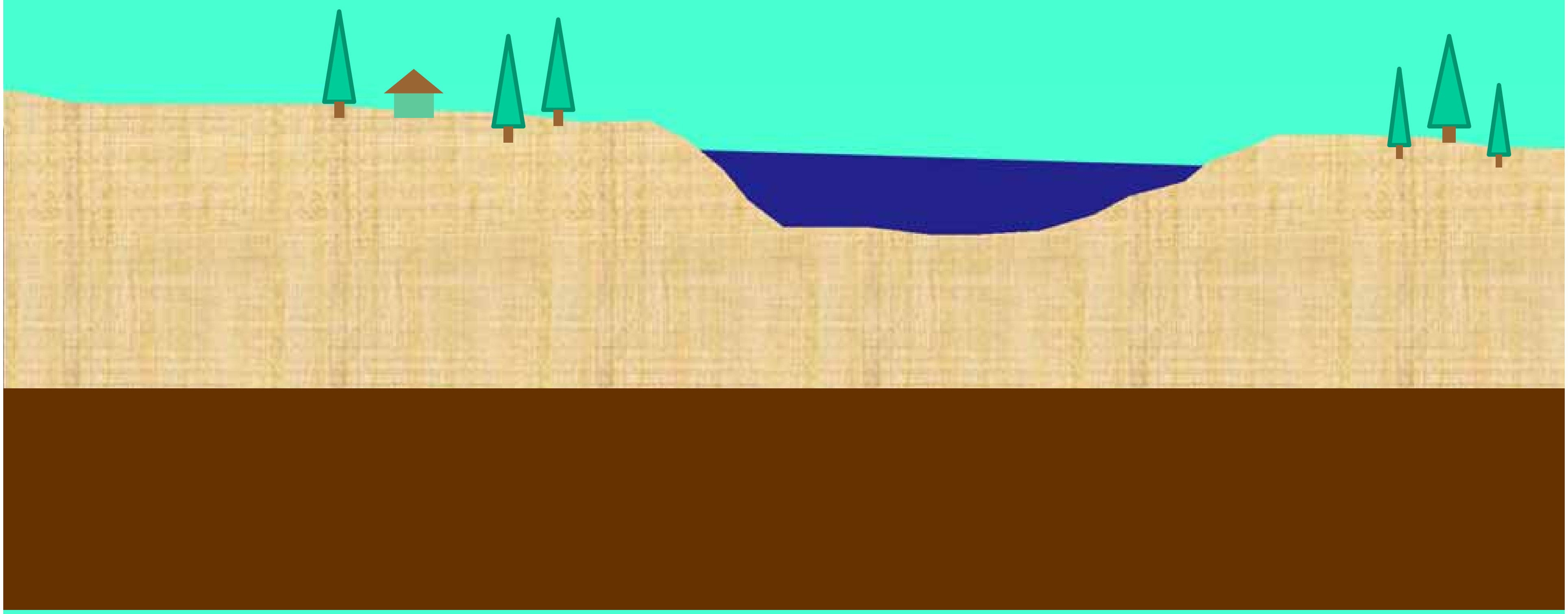


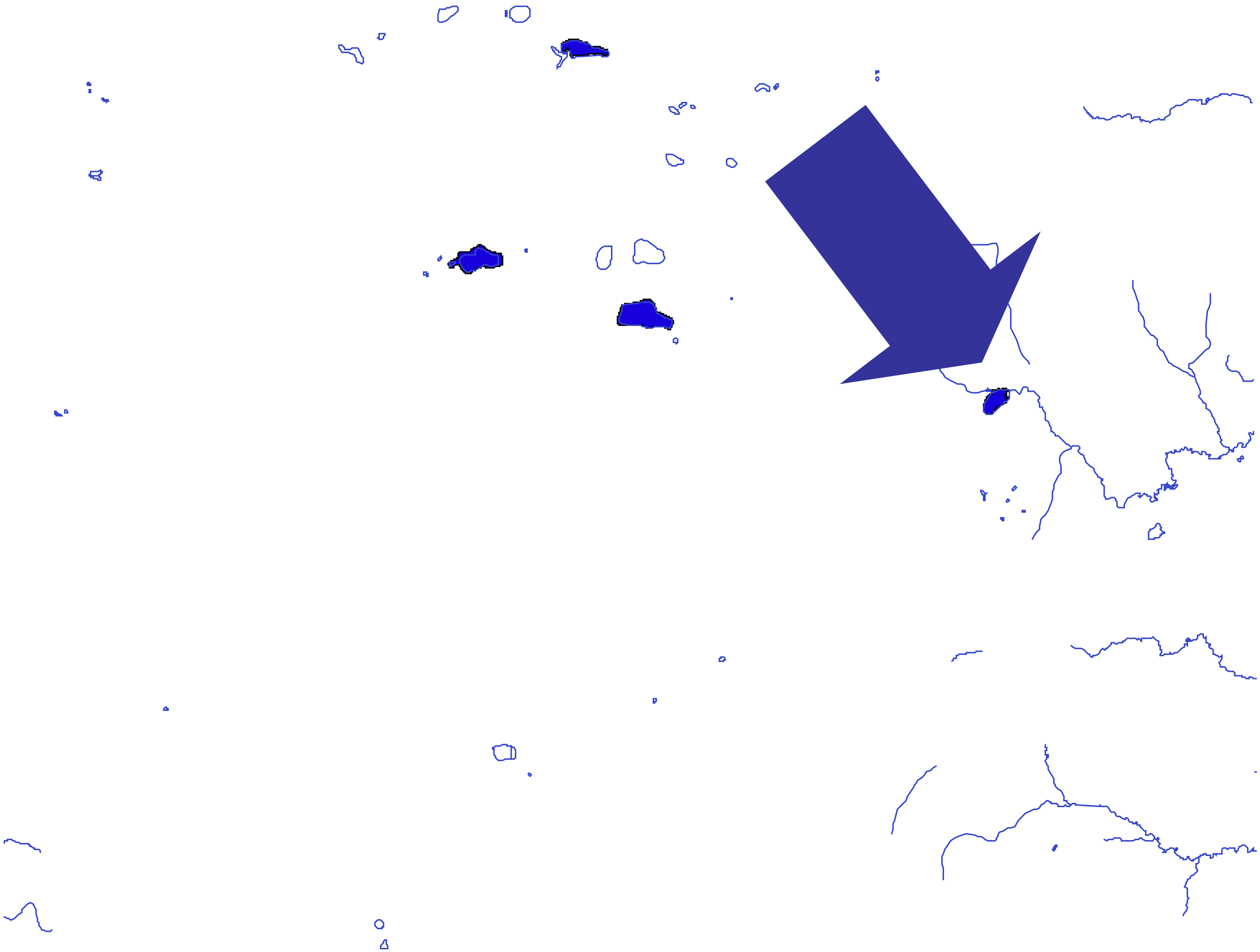
Atmospheric Deposition

- **“Lake Surface”**
- **WiLMS Default**
  - **“Most likely” estimate 0.3 kg/ha-yr (similar to Reckhow and Simpson p 81 in notes w/ range 0.15 to 0.5 in that paper)**
- **Other Values**
  - **0.06 kg/ha-yr: N WI (Rose, W.J., 1993 Balsam Lake 1987-89: USGS WRI 91-4125)**
  - **0.16 kg/ha-yr: (Field and Duerk, 1988 Delavan Lake USGS WRI 87-4168)**
  - **0.17 kg/ha-yr (Ontario LCM modified in 2006, p 118 in notes)**
  - **Robertson (Whitefish Lake Study) used**
    - **Dry deposition**
      - **0.12 kg/ha-yr for small lake, conifers**
      - **0.07 for large lake, conifers**
    - **Wet deposition**
      - **0.13 kg/ha-yr (0.016 mg/l assumed)**

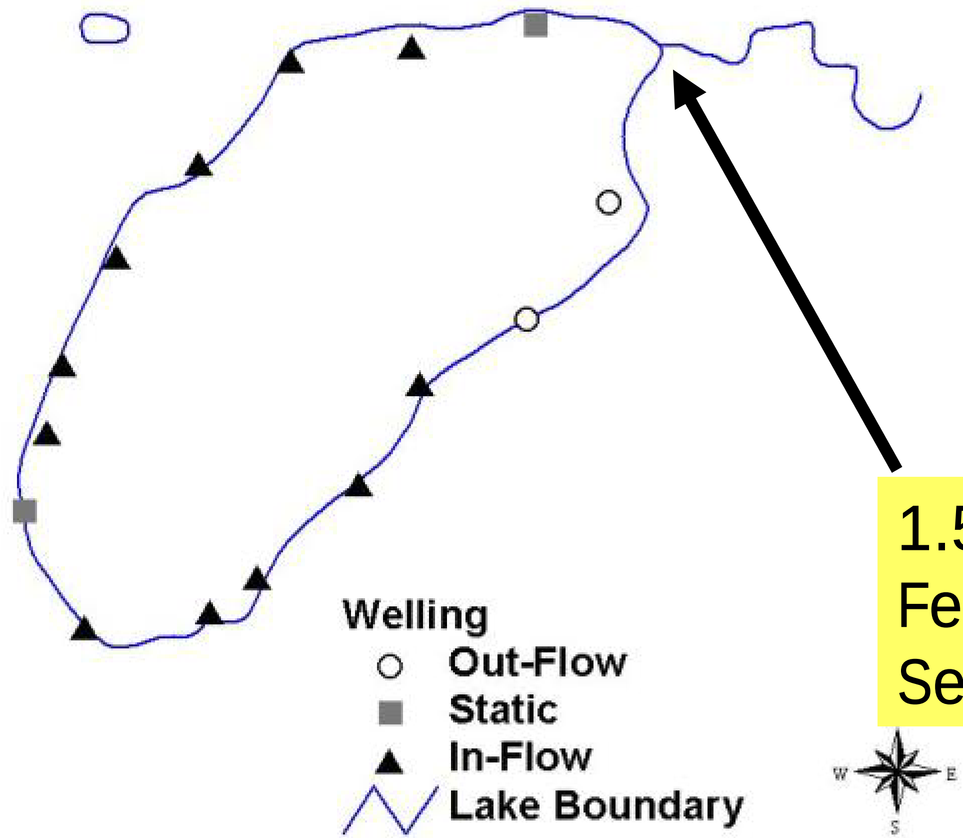
Used ~0.19 kg/ha-yr
Or ~ 60 kg total for
833 acre lake

Lakes are connected to groundwater…

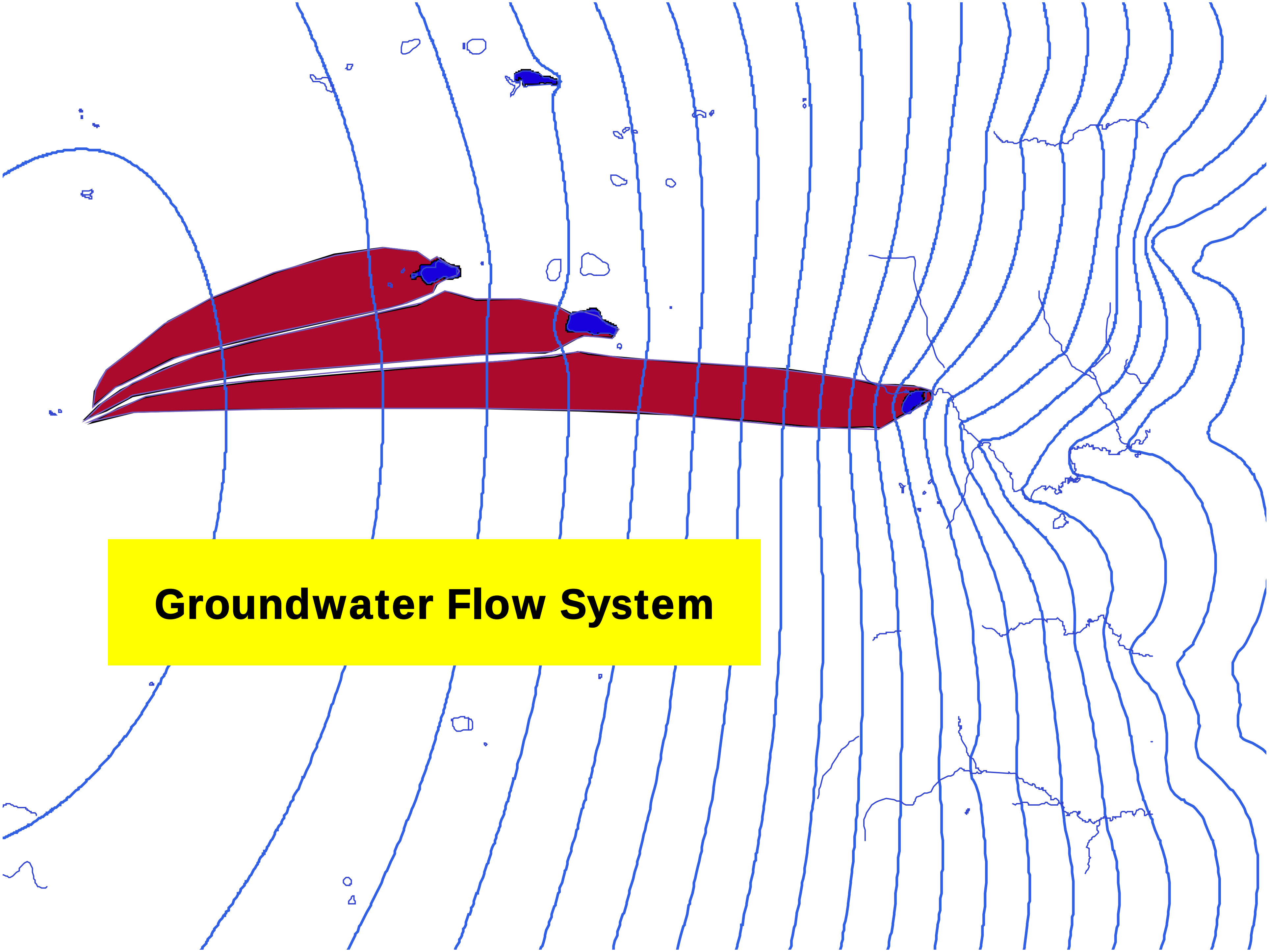




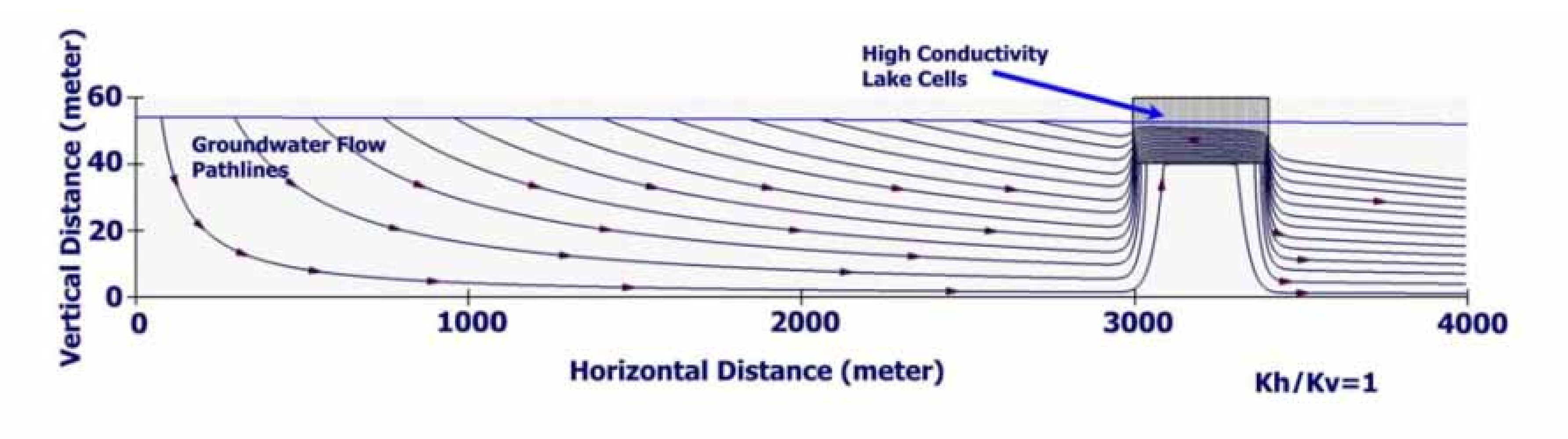
Fountain Lake



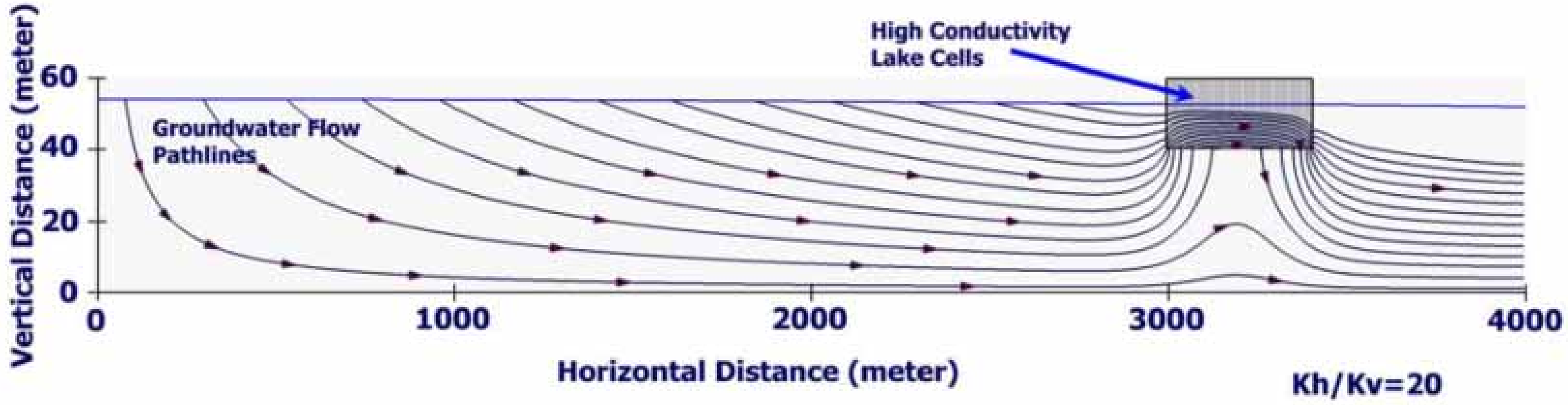
1.5 Cubic Feet Per Second


Groundwater Flow System

Does groundwater flow under lakes?



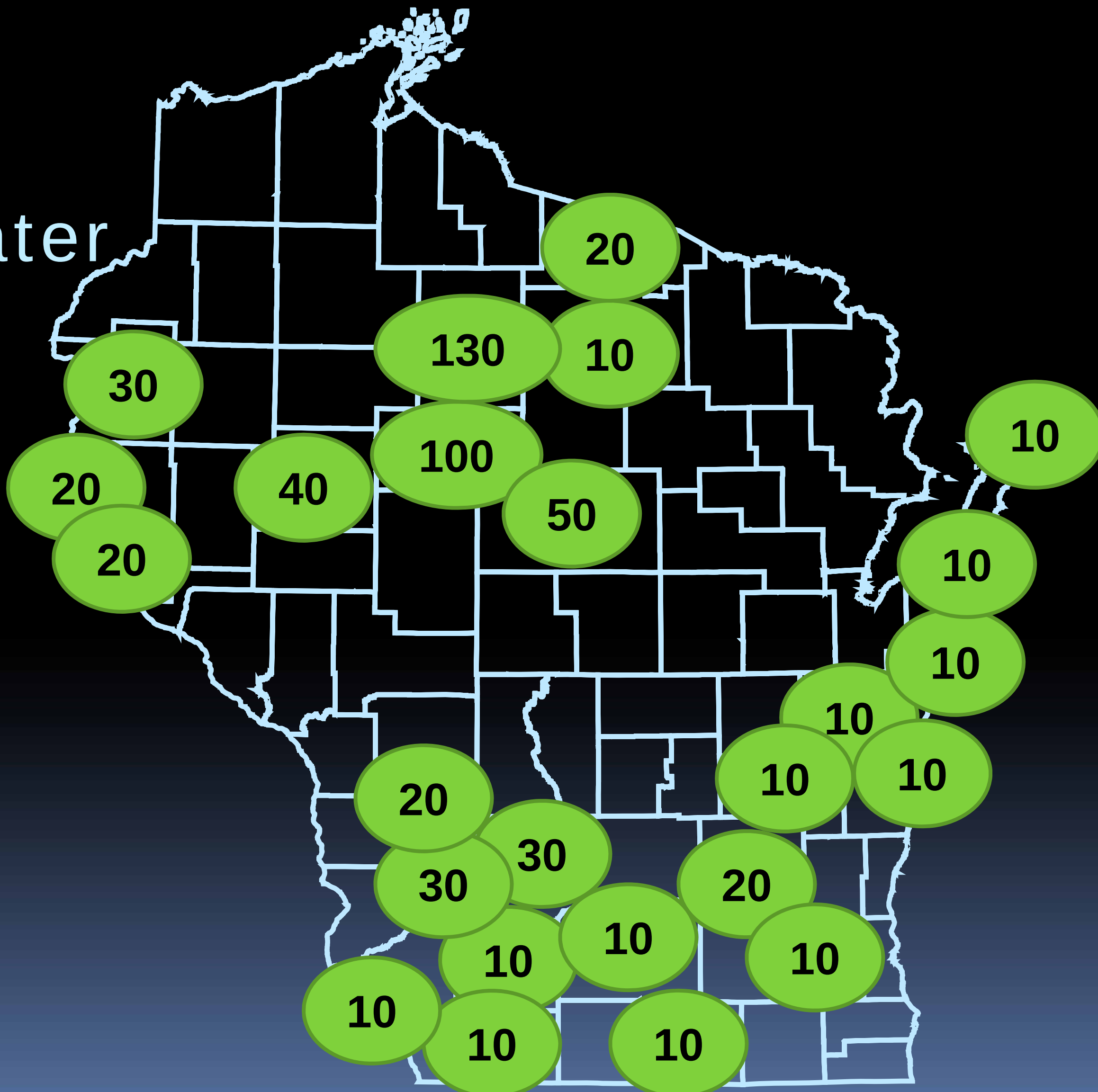
Does groundwater flow under lakes?



Groundwater P Conc?

Groundwater Median P µg/l

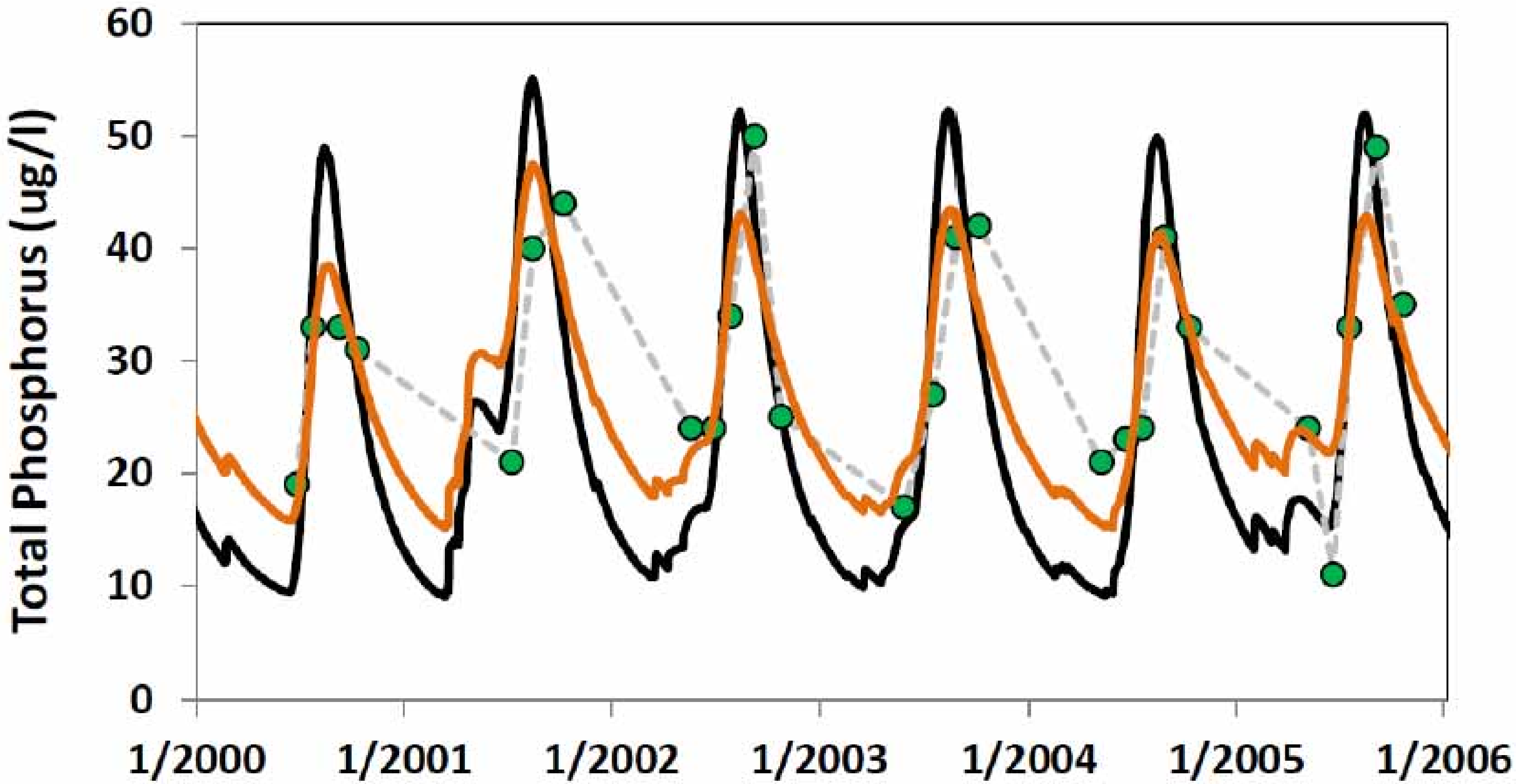
UWSP Drinking Water Program Data



What about Steady-State?

- Is that an important assumption?
- What about concentrations that vary during the growing season

Is this steady-state?




Do we have time to discuss
RIPARIAN RUNOFF MODELS?

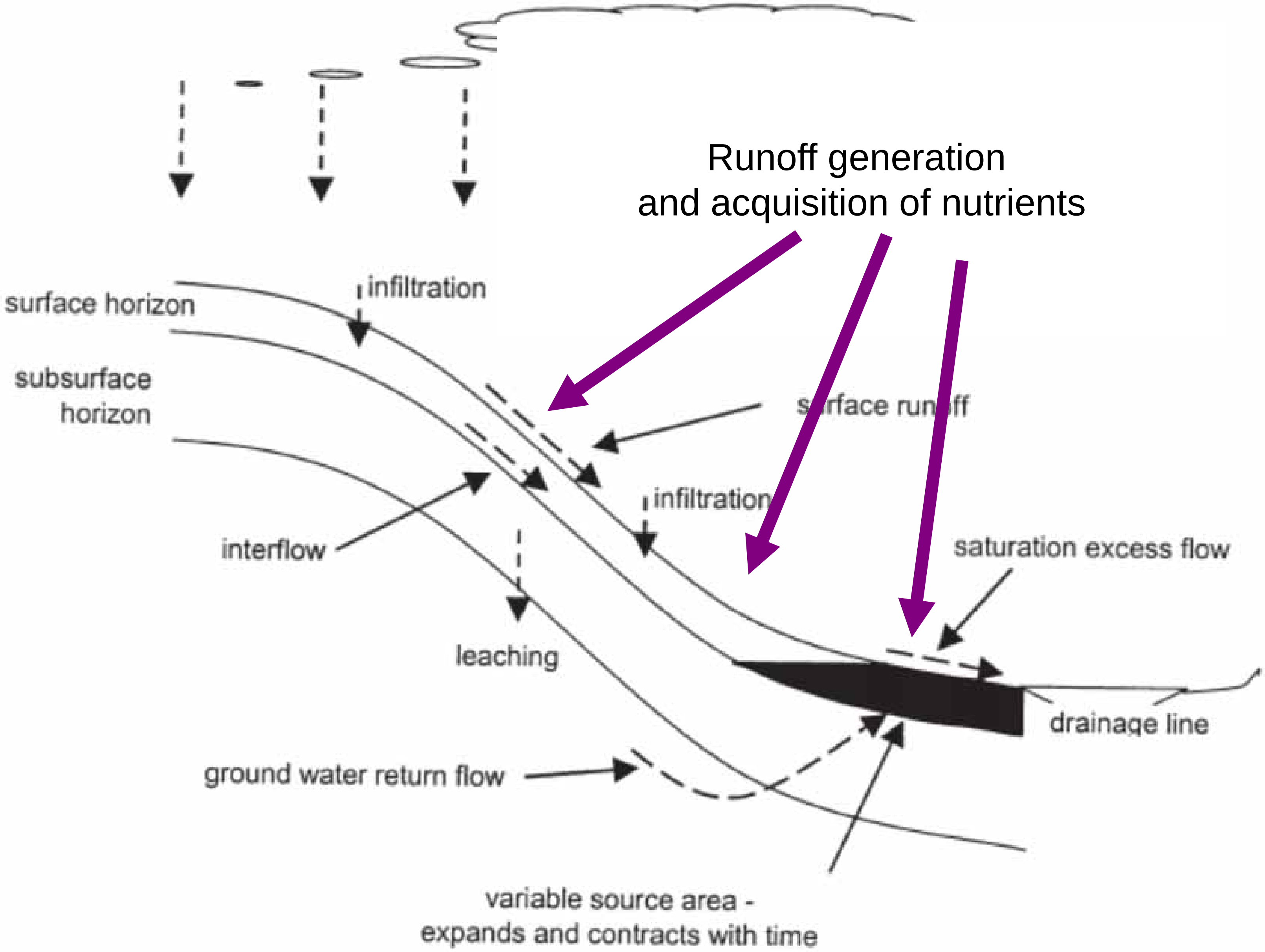


Fig. 4. Basic components of hillslope hydrology.

Changes to phosphorus movement because of development?

- 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

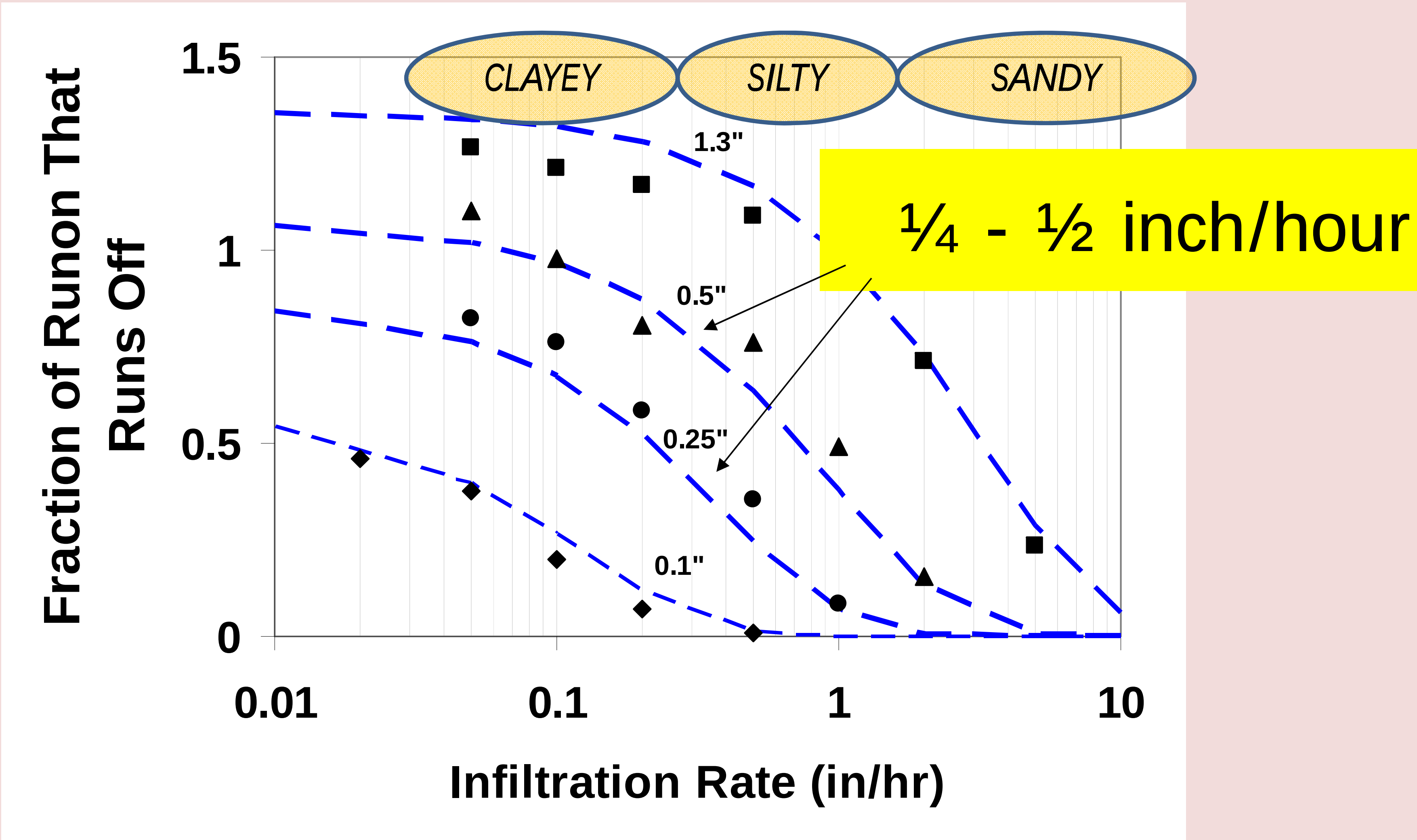
Observations (WDNR N WI Study)

- Concentrations of P in runoff may be similar in woods and lawn
  - Both reflect movement of water across high P surfaces
- Runoff volume differences likely the biggest contributor to differences in export
  - 10x, 50x, 100x differences in runoff volume between developed/undeveloped
- Export = (volume)*(concentration)

Ideas?

- Delivery? Connectivity?
- What is the quality of the runoff?
  - Runoff that originates from a roof and is conveyed across vegetation can have a very different concentration
- Controls – Infiltration?

What controls the infiltration rate?

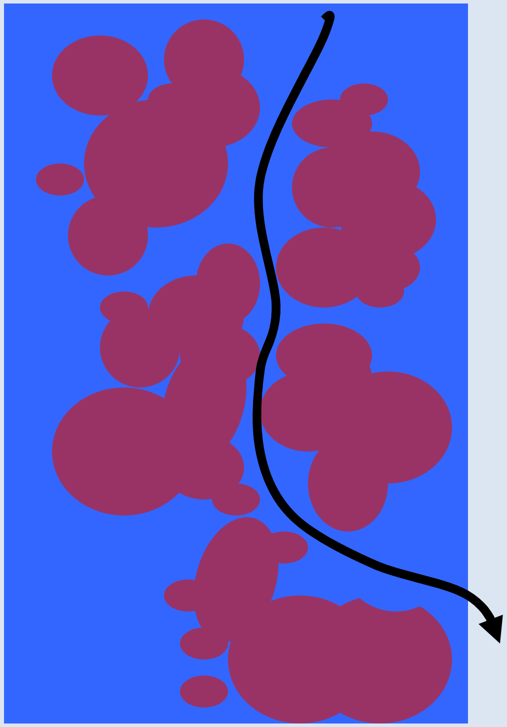


Runon Ratio
500 / 5(w) x 40 (L)

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.

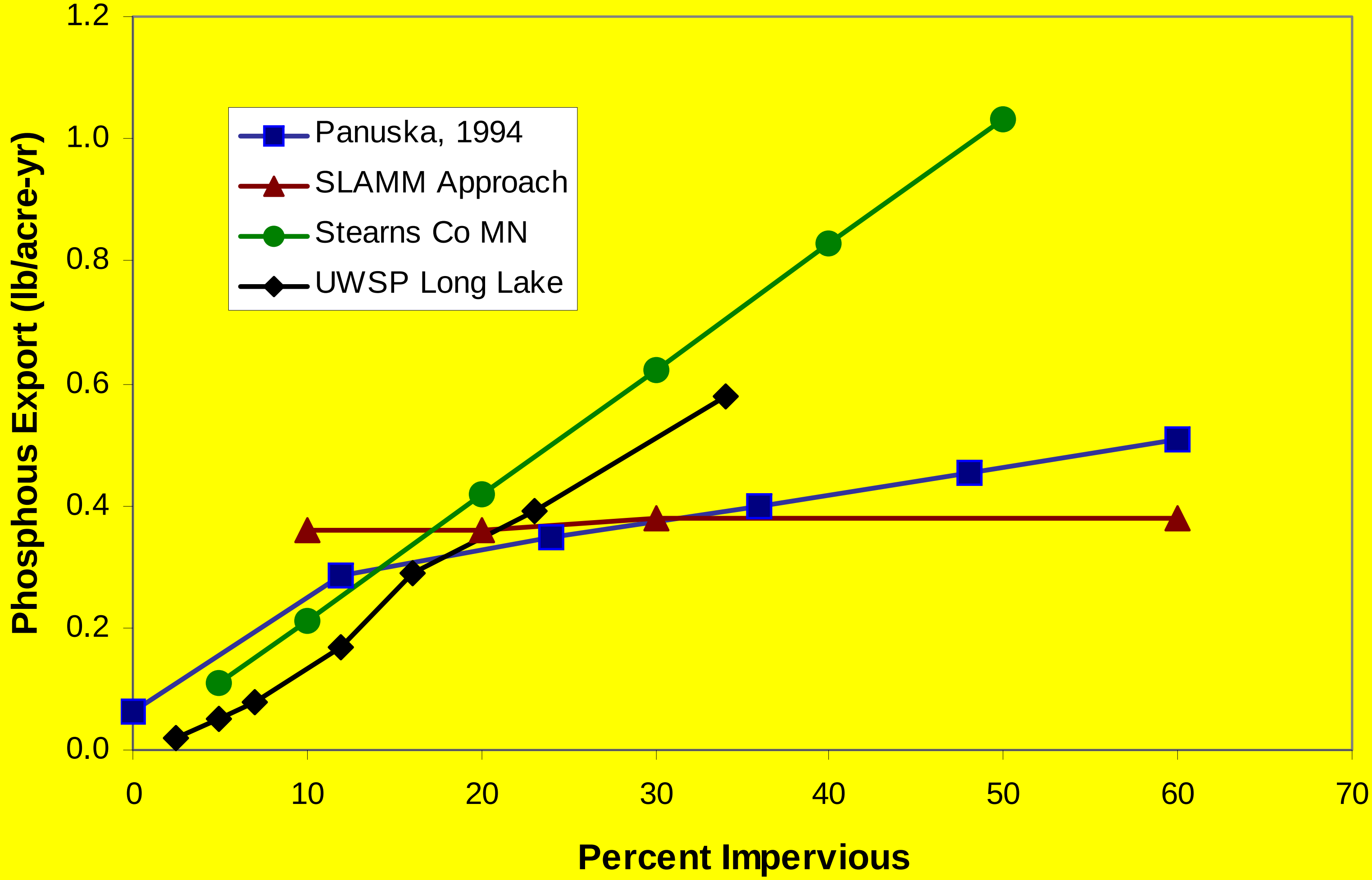
What about compaction?

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.

SOME EXAMPLES FROM MODELS
RIPARIAN MODEL OUTPUT EXAMPLE
4% to 5% slope/Silt Loam or Silty



Before we end…Last Piece Discuss Other Models

- Watershed
  - Simulate storms
  - Results by day / month
- Lake
  - Simulate algae, fish...

Quick Modeling Overview

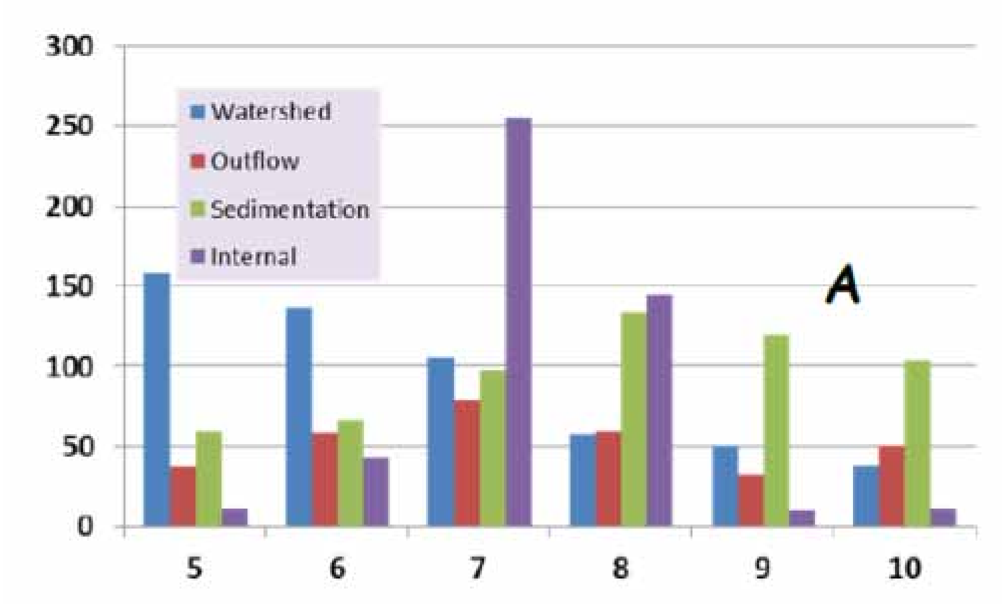
General Categories of Models --------- Examples	
Single Event Rainfall / Runoff	TR-55, Rational Method
Continuous Hydrologic	HEC-1
Hydraulic	SWMM, HEC-RAS, HydroCAD
Steady-State Nutrient Export	WILMS, BATHTUB
Continuous Hydrologic w/ Nutrient & Sediment Export	Urban – P8, WinSLAMM Mixed Watershed – SWAT, HSPF
Steady-State Water Response Continuous Water Response	WILMS, BATHTUB AQUATOX, WASP, QUAL2E
NOTE– Increasingly these models overlap in capability	

Quick Modeling Overview

General Categories of Models --------- Examples	
Single Event Rainfall / Runoff	TR-55, Rational Method
Continuous Hydrologic	HEC-1
Hydraulic	SWMM, HEC-RAS, HydroCAD
Steady-State Nutrient Export	WILMS, BATHTUB
Continuous Hydrologic w/ Nutrient & Sediment Export	Urban – P8, WinSLAMM Mixed Watershed – SWAT, HSPF
Steady-State Water Response Continuous Water Response	WILMS, BATHTUB AQUATOX, WASP, QUAL2E
NOTE– Increasingly these models overlap in capability	

Usefulness of shorter time-step?

- Partition seasonal loads?
  - Here looking at the monthly P (in kilograms) for watershed loading (blue)



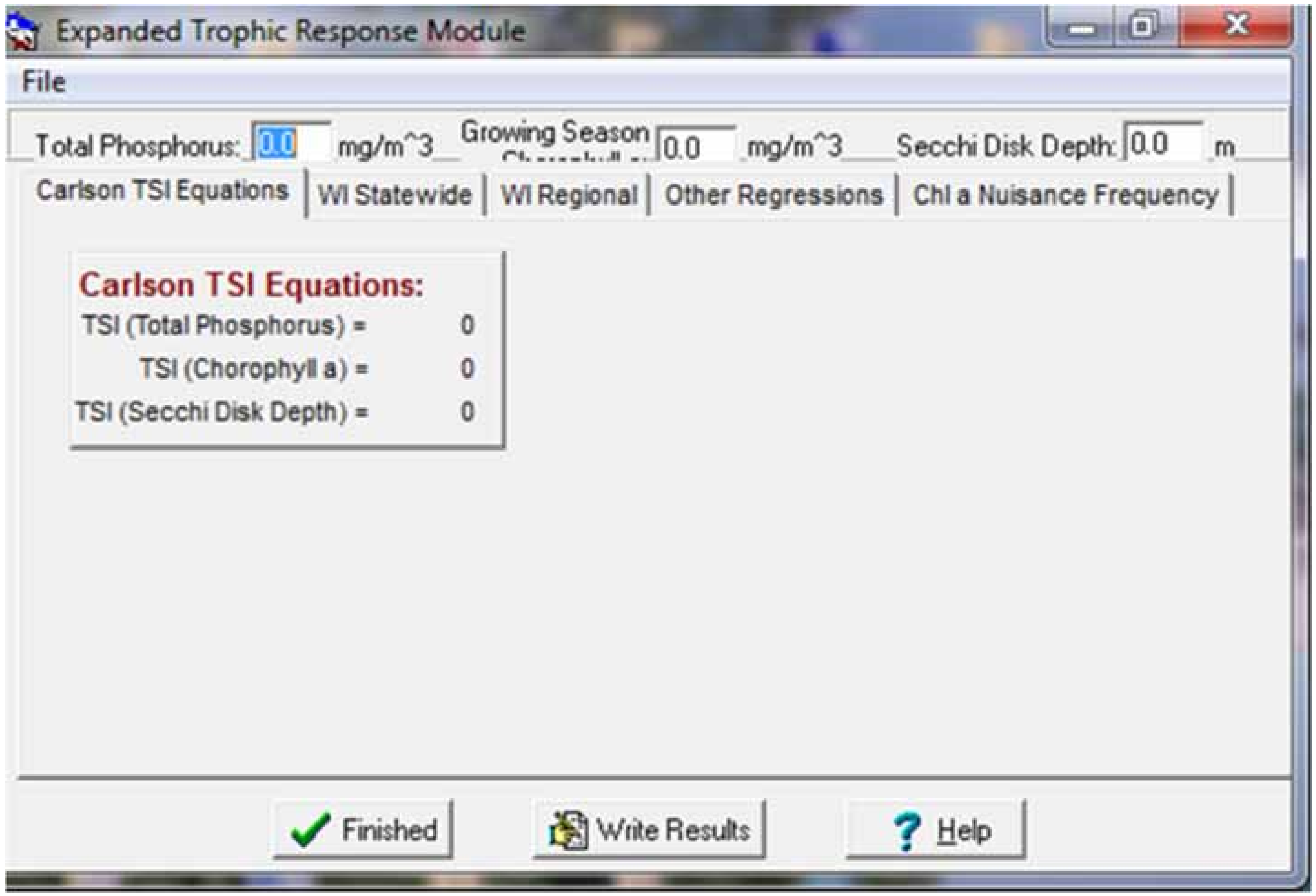
For more information

- Notepack (pdf file)
  - Includes many of the original articles
- Questions
  - Paul McGinley pmcginle@uwsp.edu
  - Nancy Turyk nturyk@uwsp.edu


QUESTIONS & TIME FOR YOUR PROJECTS

Extra Stuff

- Trophic Response Model Discussion?



- **The expanded trophic response menu in WiLMS** evaluates water body trophic response using total phosphorus, chlorophyll a and Secchi depth transparency. The purpose of this feature is to allow **stand-alone or model generated** trophic response conditions to be evaluated. This part of WiLMS consists of four evaluation components driven by total phosphorus, chlorophyll a and Secchi depth transparency inputs. The four evaluation components are:

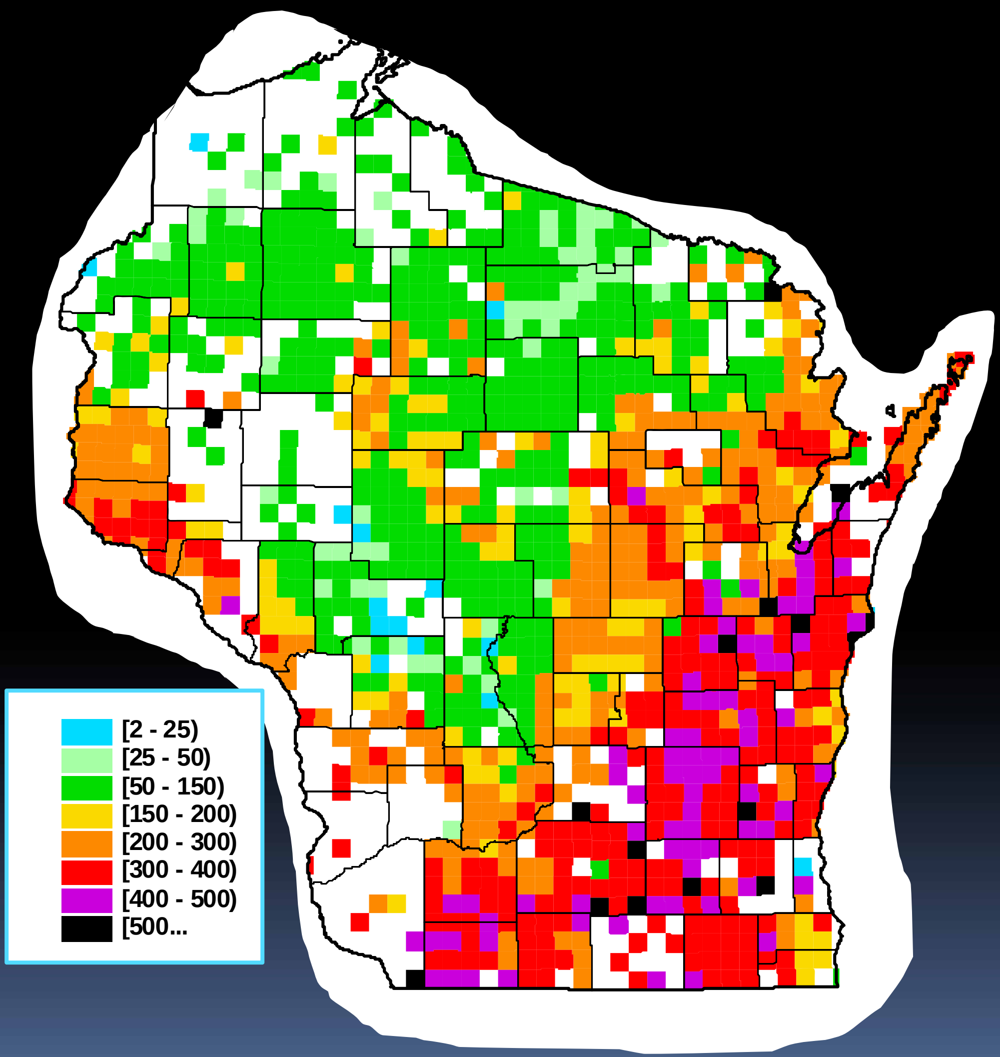
- *1. Carlson trophic state evaluation equations*

- *2. Wisconsin statewide predictive equations*

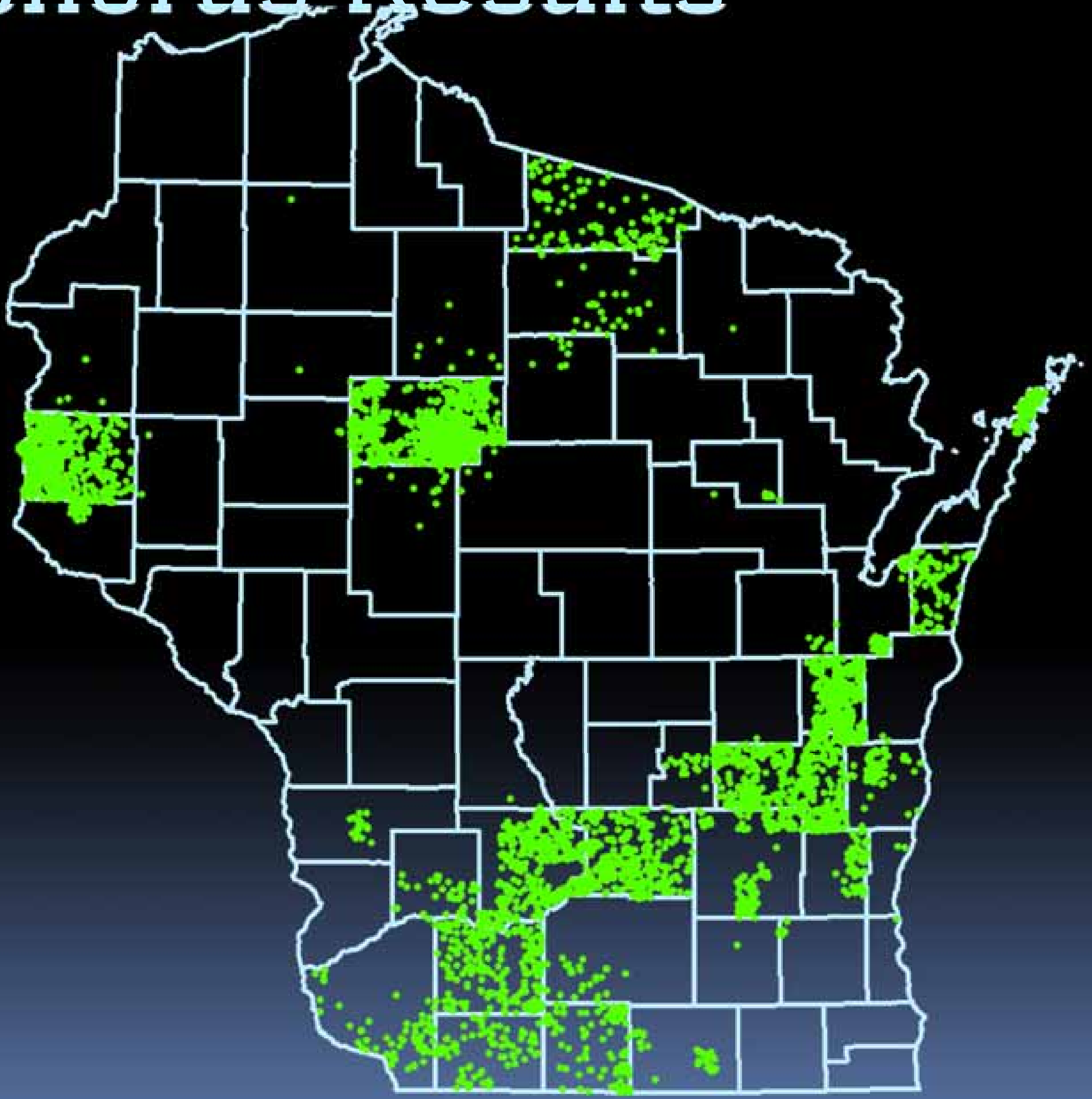
- *3. Wisconsin regions predictive equations*

- *4. Commonly used regressions including user defined.*

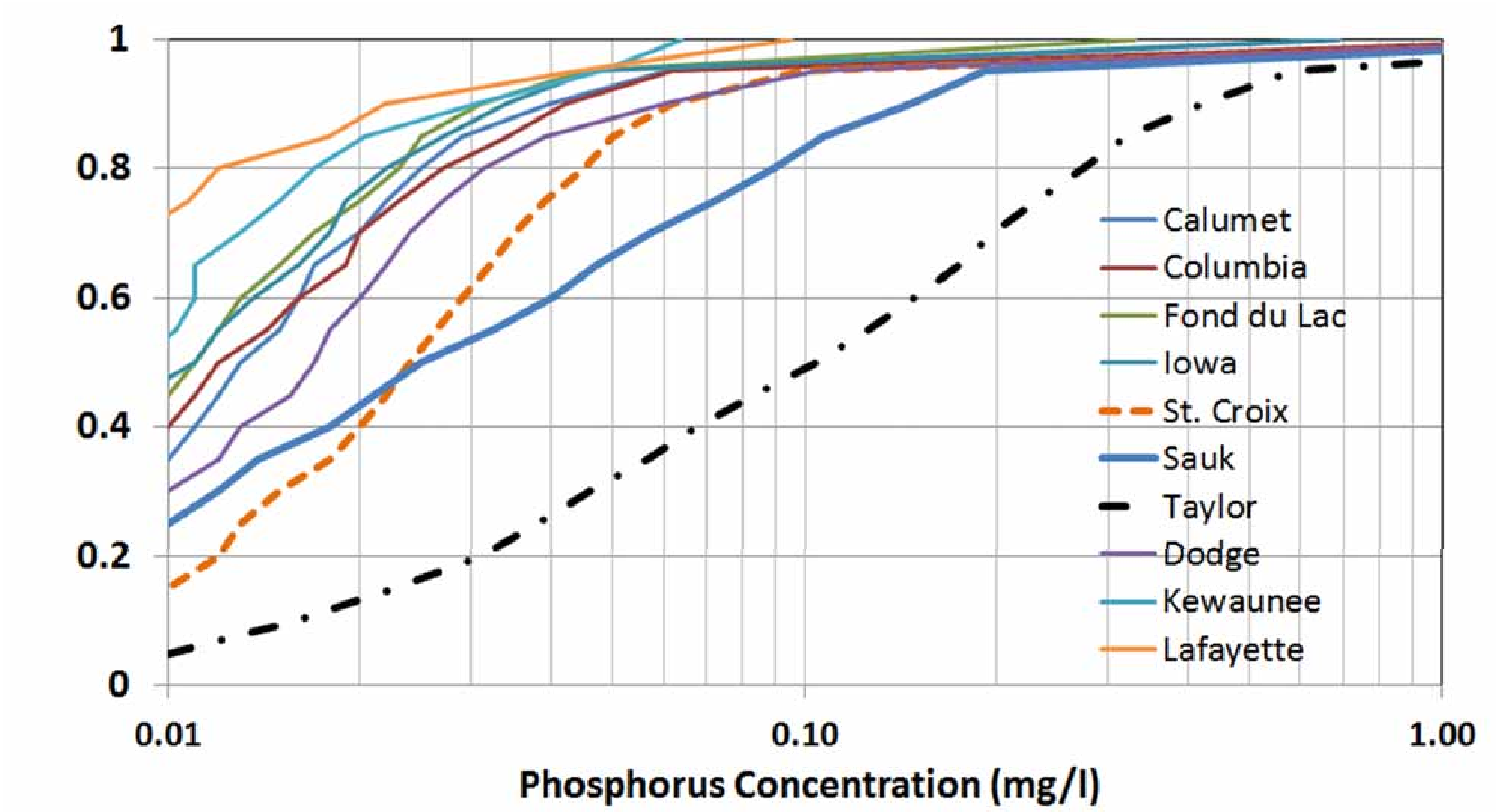
Wisconsin Private Well Data
Calcium & Magnesium (Hardness)



Phosphorus Results

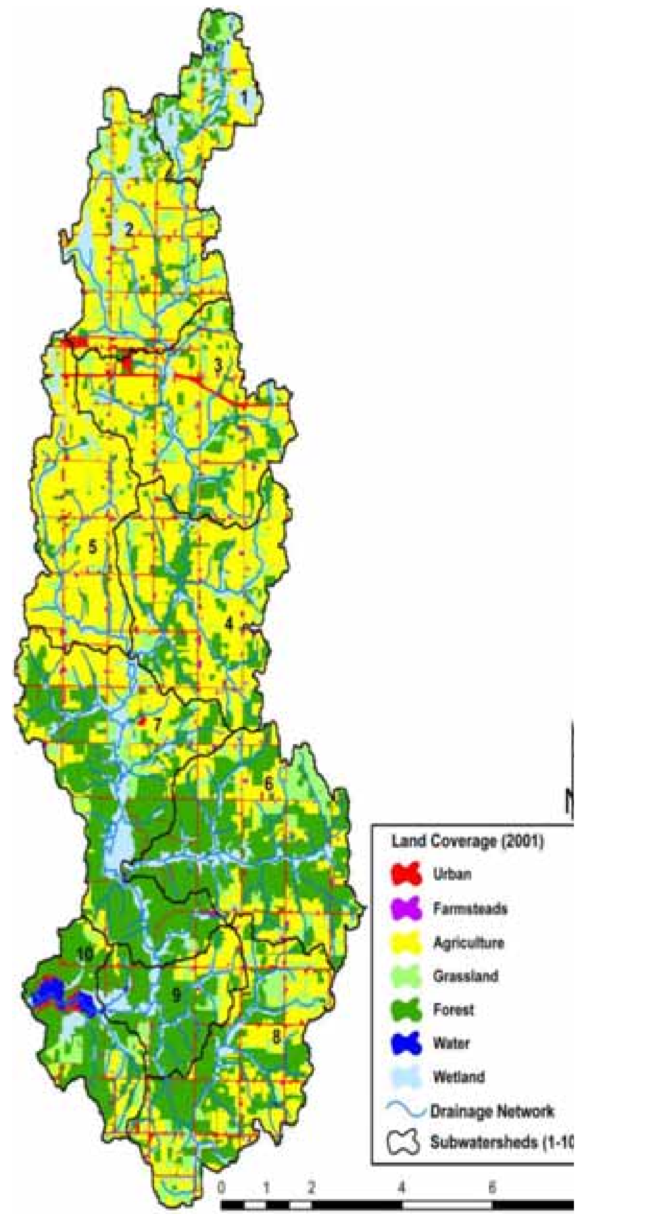


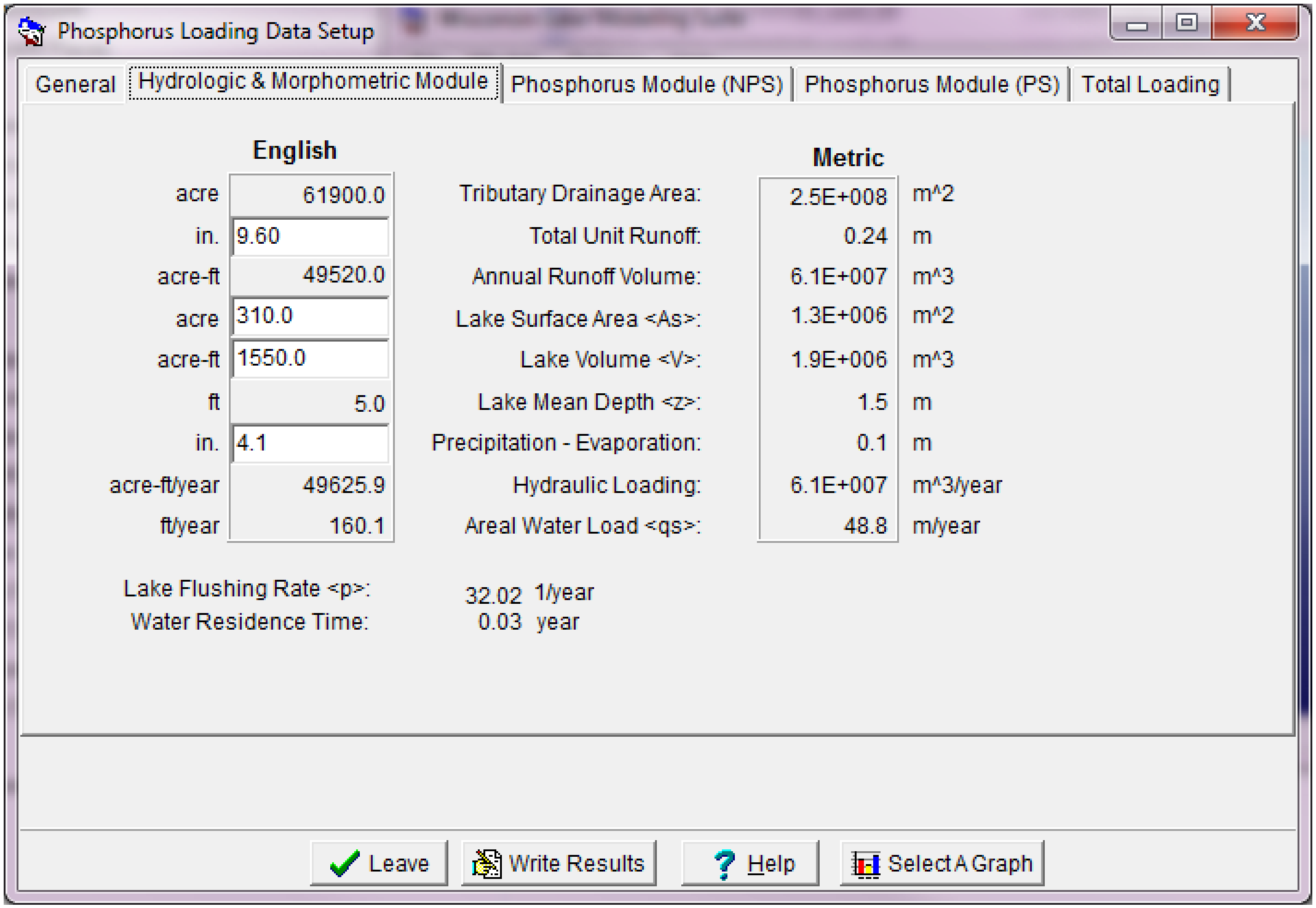
Phosphorus Distributions by County

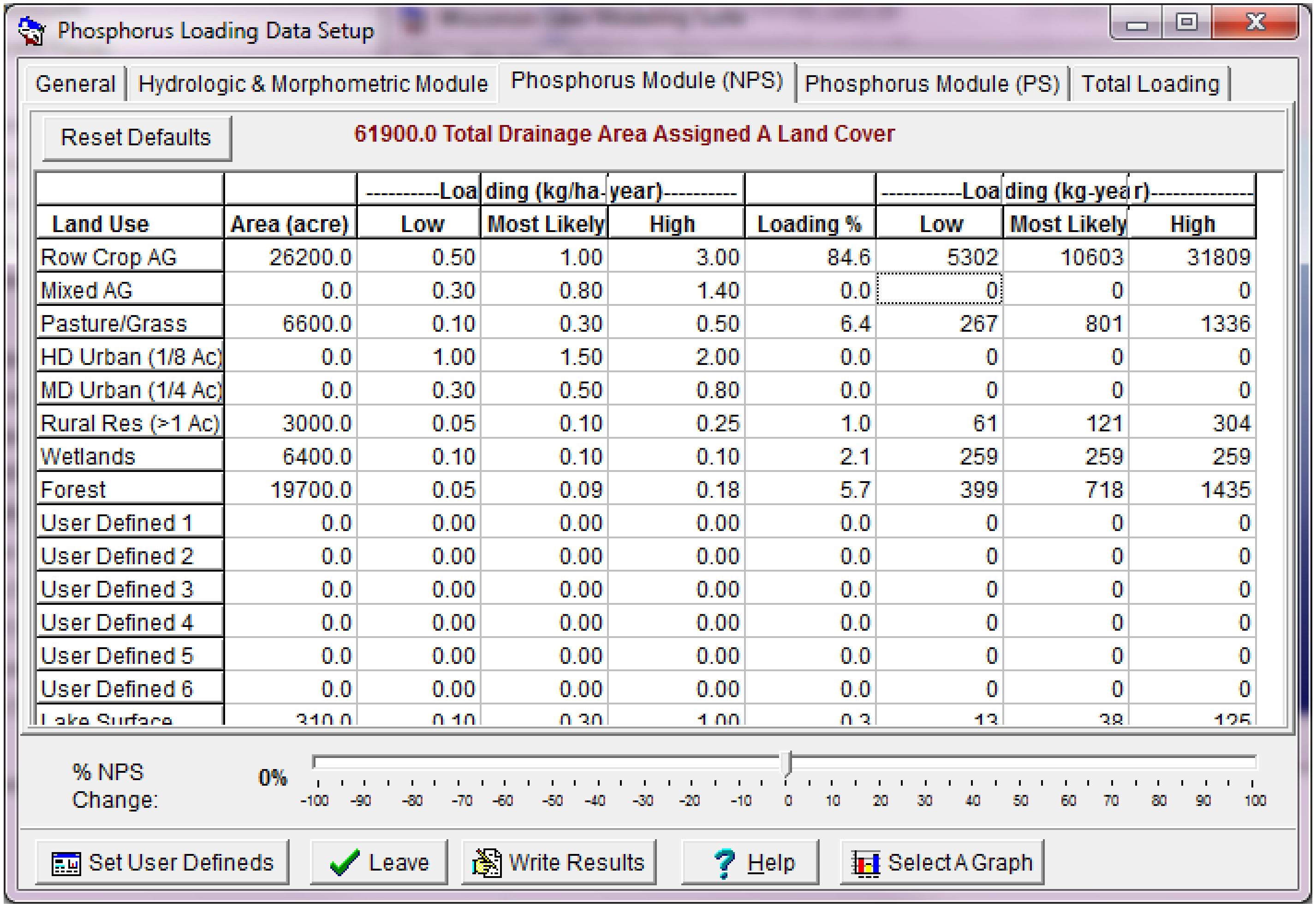


Extra Example

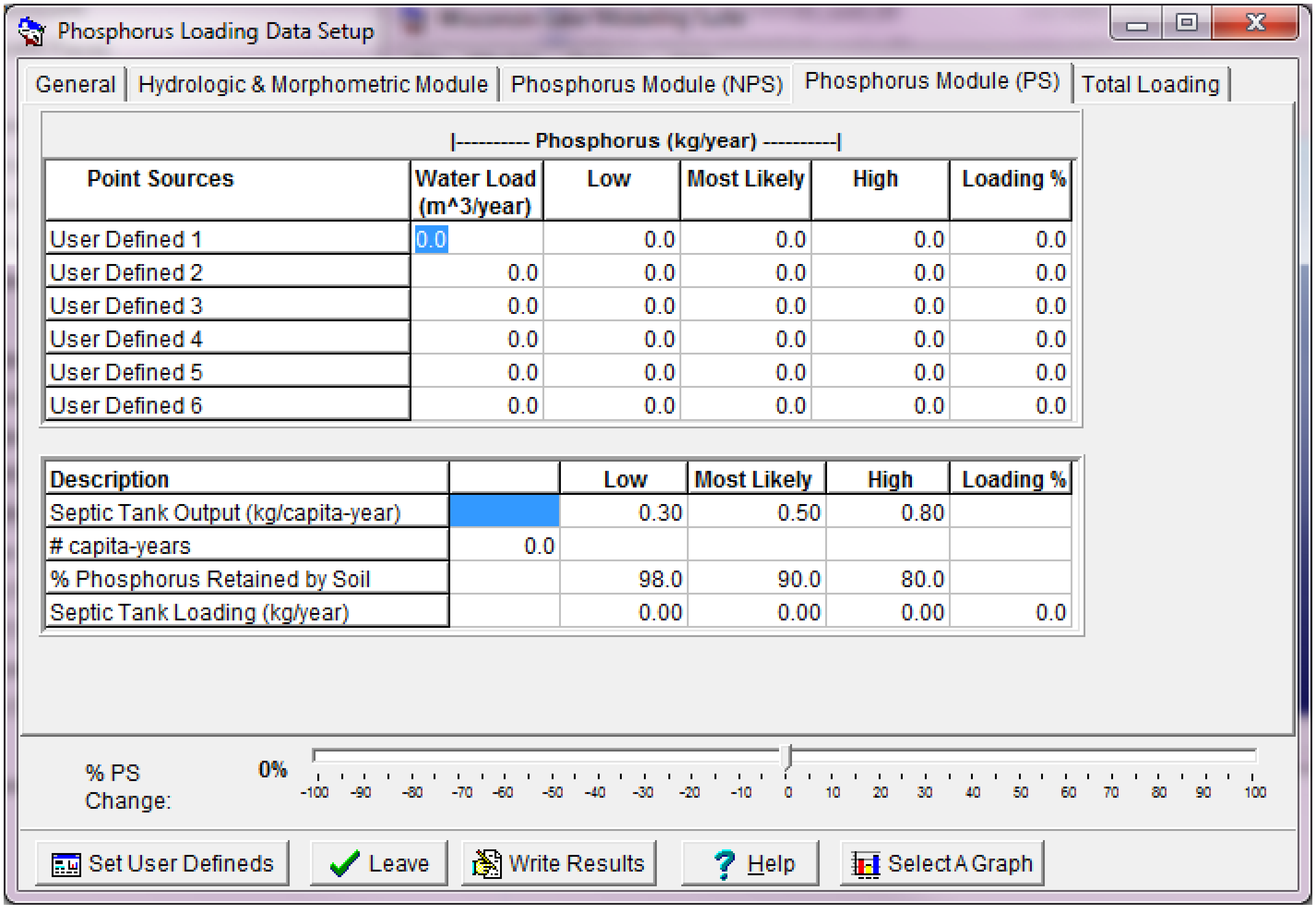
- 310 acre lake, Clark Co
- Mean depth 5 feet
- Average TP 110 ug/l (GSM/SPO)
- 61,900 acre watershed
  - Agriculture: 26,200
  - Grassland: 6,600
  - Forest: 19,700
  - Residential: 3,000
  - Water/Wetland: 6,400
- What is the areal water load?
- What is the water residence time?
- What is the predicted lake TP?




Phosphorus Loading Data Setup
General
Hydrologic & Morphometric Module
Phosphorus Module (NPS)
Phosphorus Module (PS)
Total Loading
English
Metric
acre 61900.0 Tributary Drainage Area: 2.5E+008 m^2
in. 9.60 Total Unit Runoff: 0.24 m
acre-ft 49520.0 Annual Runoff Volume: 6.1E+007 m^3
acre 310.0 Lake Surface Area <As>: 1.3E+006 m^2
acre-ft 1550.0 Lake Volume <V>: 1.9E+006 m^3
ft 5.0 Lake Mean Depth <z>: 1.5 m
in. 4.1 Precipitation - Evaporation: 0.1 m
acre-ft/year 49625.9 Hydraulic Loading: 6.1E+007 m^3/year
ft/year 160.1 Areal Water Load <qs>: 48.8 m/year
Lake Flushing Rate <p>: 32.02 1/year
Water Residence Time: 0.03 year
Leave
Write Results
Help
Select A Graph



		----------Loading (kg/ha-year)----------				----------Loading (kg-year)----------		
Land Use	Area (acre)	Low	Most Likely	High	Loading %	Low	Most Likely	High
Row Crop AG	26200.0	0.50	1.00	3.00	84.6	5302	10603	31809
Mixed AG	0.0	0.30	0.80	1.40	0.0	0	0	0
Pasture/Grass	6600.0	0.10	0.30	0.50	6.4	267	801	1336
HD Urban (1/8 Ac)	0.0	1.00	1.50	2.00	0.0	0	0	0
MD Urban (1/4 Ac)	0.0	0.30	0.50	0.80	0.0	0	0	0
Rural Res (>1 Ac)	3000.0	0.05	0.10	0.25	1.0	61	121	304
Wetlands	6400.0	0.10	0.10	0.10	2.1	259	259	259
Forest	19700.0	0.05	0.09	0.18	5.7	399	718	1435
User Defined 1	0.0	0.00	0.00	0.00	0.0	0	0	0
User Defined 2	0.0	0.00	0.00	0.00	0.0	0	0	0
User Defined 3	0.0	0.00	0.00	0.00	0.0	0	0	0
User Defined 4	0.0	0.00	0.00	0.00	0.0	0	0	0
User Defined 5	0.0	0.00	0.00	0.00	0.0	0	0	0
User Defined 6	0.0	0.00	0.00	0.00	0.0	0	0	0
Lake Surface	310.0	0.10	0.30	1.00	0.3	13	38	125



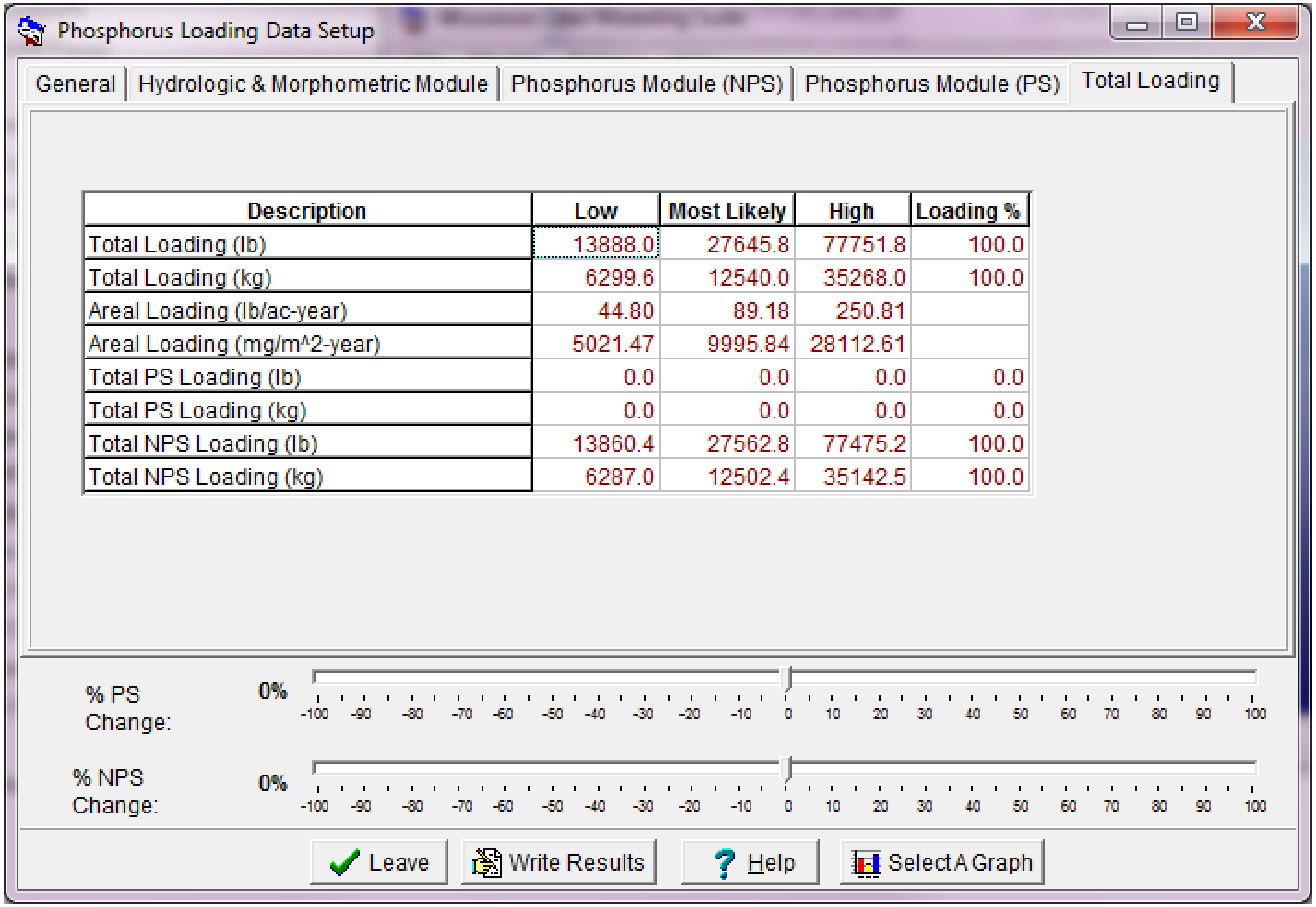
Phosphorus Loading Data Setup

General | Hydrologic & Morphometric Module | Phosphorus Module (NPS) | Phosphorus Module (PS) | Total Loading

|---------- Phosphorus (kg/year) ----------|

Point Sources	Water Load (m^3/year)	Low	Most Likely	High	Loading %
User Defined 1	0.0	0.0	0.0	0.0	0.0
User Defined 2	0.0	0.0	0.0	0.0	0.0
User Defined 3	0.0	0.0	0.0	0.0	0.0
User Defined 4	0.0	0.0	0.0	0.0	0.0
User Defined 5	0.0	0.0	0.0	0.0	0.0
User Defined 6	0.0	0.0	0.0	0.0	0.0

Description		Low	Most Likely	High	Loading %
Septic Tank Output (kg/capita-year)		0.30	0.50	0.80	
# capita-years	0.0				
% Phosphorus Retained by Soil		98.0	90.0	80.0	
Septic Tank Loading (kg/year)		0.00	0.00	0.00	0.0



Description	Low	Most Likely	High	Loading %
Total Loading (lb)	13888.0	27645.8	77751.8	100.0
Total Loading (kg)	6299.6	12540.0	35268.0	100.0
Areal Loading (lb/ac-year)	44.80	89.18	250.81	
Areal Loading (mg/m^2-year)	5021.47	9995.84	28112.61	
Total PS Loading (lb)	0.0	0.0	0.0	0.0
Total PS Loading (kg)	0.0	0.0	0.0	0.0
Total NPS Loading (lb)	13860.4	27562.8	77475.2	100.0
Total NPS Loading (kg)	6287.0	12502.4	35142.5	100.0

Phosphorus Predictions & Uncertainty Analysis

Observed spring overturn total phosphorus (SPO): 110.0 mg/m^3

Observed growing season mean phosphorus (GSM): 110.0 mg/m^3

Back calculation for SPO total phosphorus: 0.0 mg/m^3

Back calculation GSM phosphorus: 0.0 mg/m^3

Nurnberg Model Input - Est. Gross Int. Loading: 0 kg

% Confidence Range: 70

Lake Phosphorus Model	Low Total P (mg/m^3)	Most Likely Total P (mg/m^3)	High Total P (mg/m^3)	Predicted -Observed (mg/m^3)	% Dif.	Confidence Lower Bound	Confidence Upper Bound	Parameter Fit?	Back Calculation (kg/year)	Model Type
Walker, 1987 Reservoir	66	132	371	22	20	78	285	Tw	0	GSM
Canfield-Bachmann, 1981 Natural Lake	85	160	396	50	45	50	461	L	1	GSM
Canfield-Bachmann, 1981 Artificial Lake	72	126	267	16	15	39	363	FIT	1	GSM
Rechow, 1979 General	72	142	401	32	29	81	310	P	0	GSM
Rechow, 1977 Anoxic	91	180	507	70	64	108	388	FIT	0	GSM
Rechow, 1977 water load<50m/year	53	106	298	-4	-4	61	230	P	0	GSM
Rechow, 1977 water load>50m/year	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Walker, 1977 General	88	175	492	65	59	88	394	FIT	0	SPO
Vollenweider, 1982 Combined OECD	61	107	249	-3	-3	53	220	FIT	0	ANN
Dillon-Rigler-Kirchner	66	131	368	21	19	78	282	P L	0	SPO
Vollenweider, 1982 Shallow Lake/Res.	52	96	238	-14	-13	47	202	FIT	0	ANN
Larsen-Mercier, 1976	87	174	490	64	58	107	373	P Pin p	0	SPO
Nurnberg, 1984 Oxic	80	159	447	49	45	84	353	P L	0	ANN

Finished | Write Results | Display Parameter Values | Help

Internal Loading

- What is it?
- Importance

Internal Loading

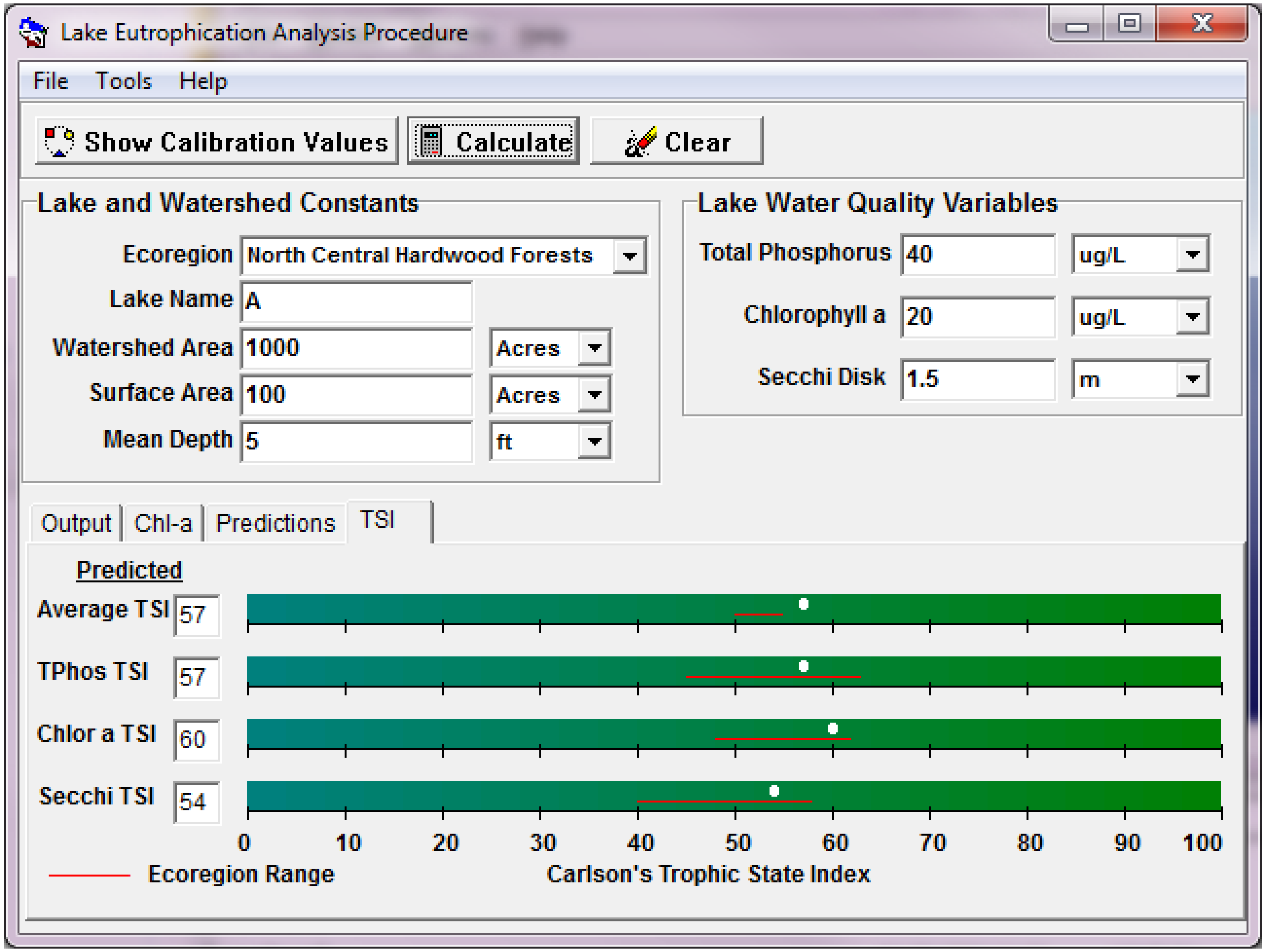
- Estimating
  - Internal Load Estimator
  - Iterate using Nurnberg loading

- Prediction Options
  - Using lake response model that includes internal load (net reduced retention)
  - Using Nurnberg Oxic + Internal Model

Discussion on LEAP

(Lake Eutrophication Analysis Procedure)

- Tools ... Ecoregion Setup
- Pick state
- Pick ecoregion
- Enter lake & watershed information
- Enter water quality information


Lake Eutrophication Analysis Procedure
File Tools Help
Show Calibration Values
Calculate
Clear
Lake and Watershed Constants
Ecoregion North Central Hardwood Forests
Lake Name A
Watershed Area 1000 Acres
Surface Area 100 Acres
Mean Depth 5 ft
Lake Water Quality Variables
Total Phosphorus 40 ug/L
Chlorophyll a 20 ug/L
Secchi Disk 1.5 m
Output
Chl-a
Predictions
TSI
Predicted
Average TSI 57
TPhos TSI 57
Chlor a TSI 60
Secchi TSI 54
0 10 20 30 40 50 60 70 80 90 100
Ecoregion Range
Carlson's Trophic State Index

LEAP

- Lake Eutrophication Analysis Procedure
- Reference- Wilson and Walker, 1989
  - MNLEAP
  - page 154

LEAP

- Inflow TP / Mean Depth / Residence Time
  - TP
    - Chl a
      - Secchi

Applications (S. Heiskary)

- How is a lake doing for its ecoregion and morphometry
- Quick estimates of water and nutrient budgets
- Flag lakes for additional study
- Compare TP / Chl-a / Secchi observed versus the reference lakes
- Estimate background P, Chl-a, Secchi
- Set goals? Along with other info

LEAP

- Average precip, evap, runoff
- Water Outflow = (runoff*wshed area) – (lake area*(precip-evap))
- P Loading = (lake area*atm dep) + (wshed area*runoff*regional stream P)
- Canfield & Bachmann (1981) P Model
- Some type of TP/Chl a/Secchi Model
  - State-wide set (MN)
  - WI?

According to SH

- Maybe best for dimictic lakes in less impacted regions
- Probably most difficult to use for polymictic lakes with significant internal load, turbid lakes, seepage lakes

Example Problem

- 112 ha lake (275 acre)
- 750 ha watershed (1800 acre)
  - 50% Forested
  - 50% Row Crop Agriculture
- Overturn P of 30 ug/l
- Growing Season Mean 27 ug/l

A little discussion on other watershed models...SWAT

Briefly… Soil and Water Assessment Tool (brc.tamus.edu/swat)

Daily Time Step

HRU – Subbasin - Reach

Hydrology – NRCS CN

Sediment – Modified USLE

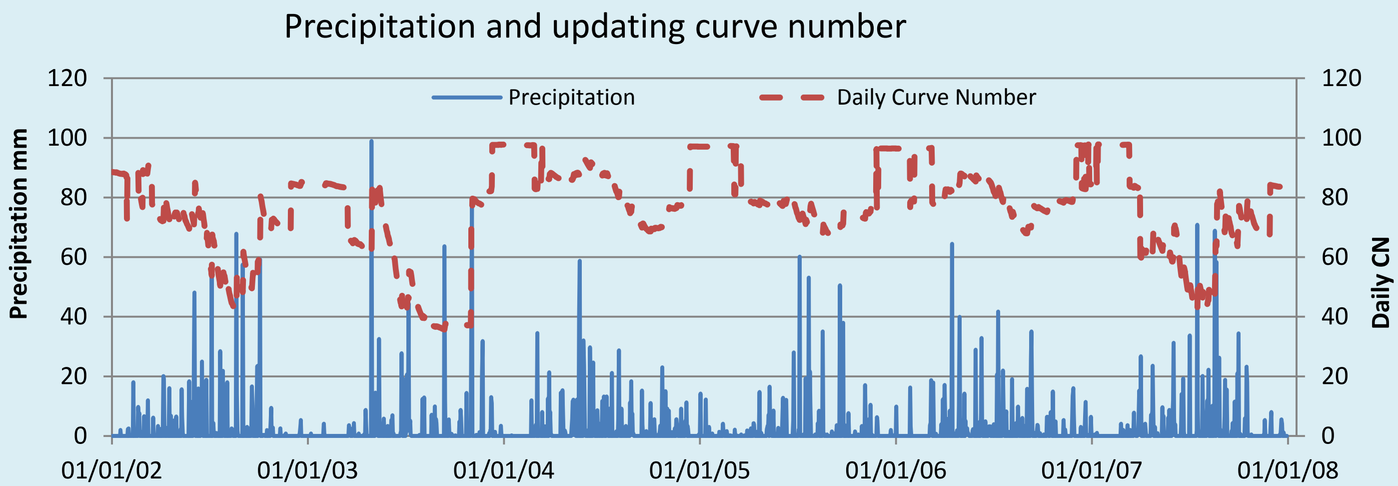
Phosphorus – Link Runoff and Sediment to P "pools"

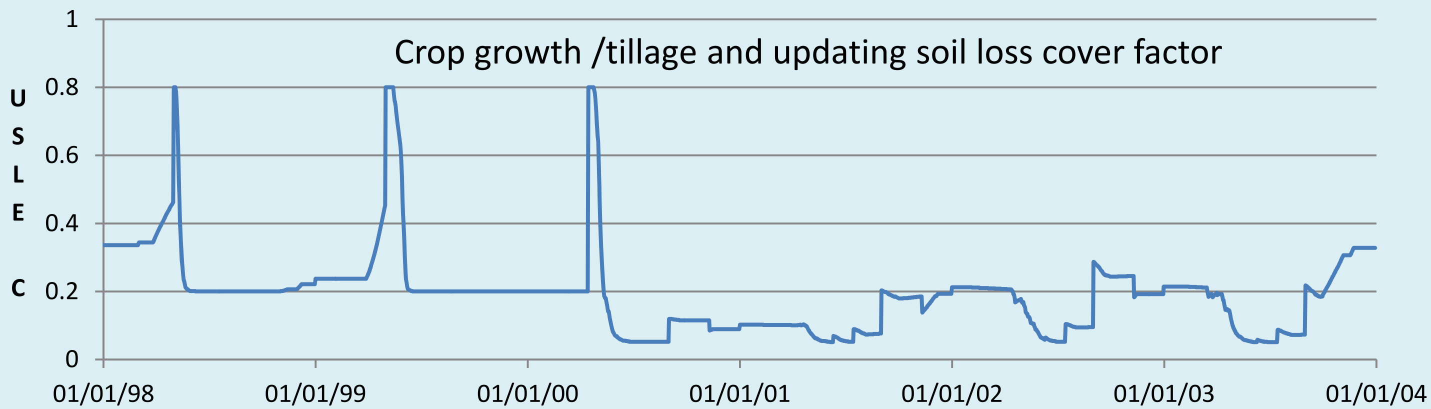
SWAT2000 (w/ revisions)

SWAT2005

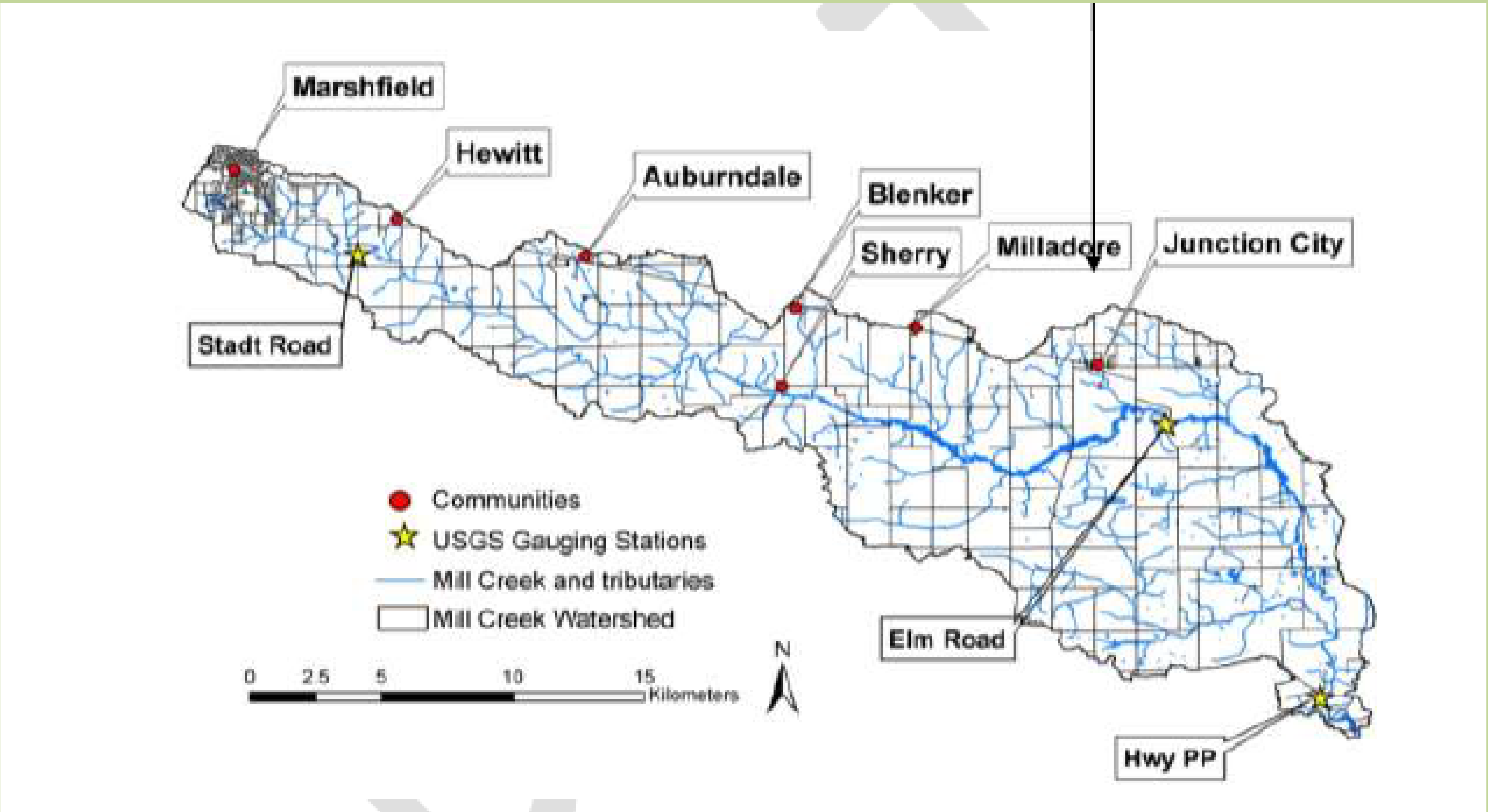
Primarily use in DOS

Excel VB for pre & post-processing

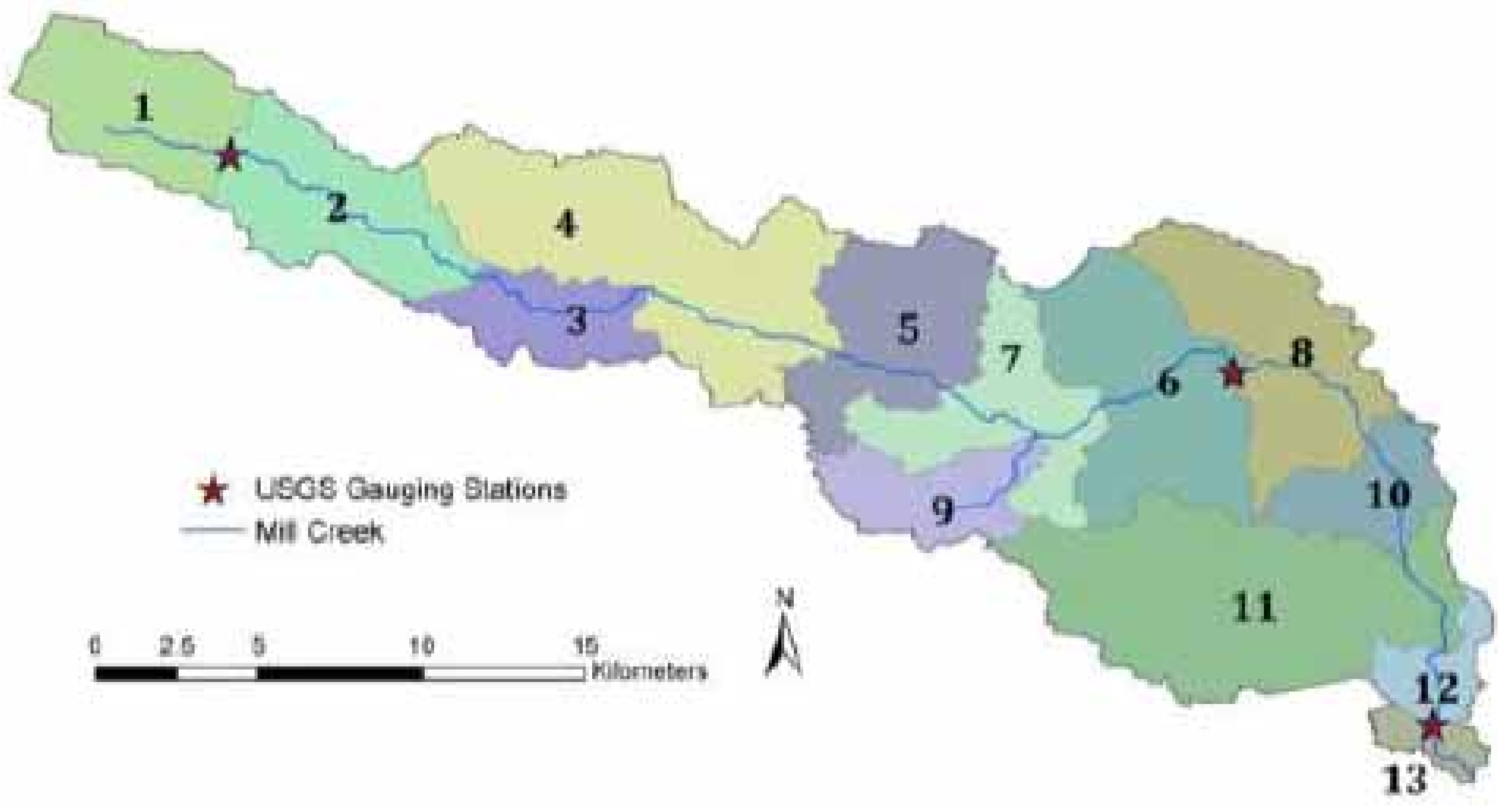




Mill Creek


Marshfield
Hewitt
Auburndale
Blenker
Sherry
Milladore
Junction City
Stadt Road
Elm Road
Hwy PP
Communities
USGS Gauging Stations
Mill Creek and tributaries
Mill Creek Watershed
0 2.5 5 10 15 Kilometers
N

Divide into “subbasins”



Divide into "hydrologic response units" (land mgt & soils)

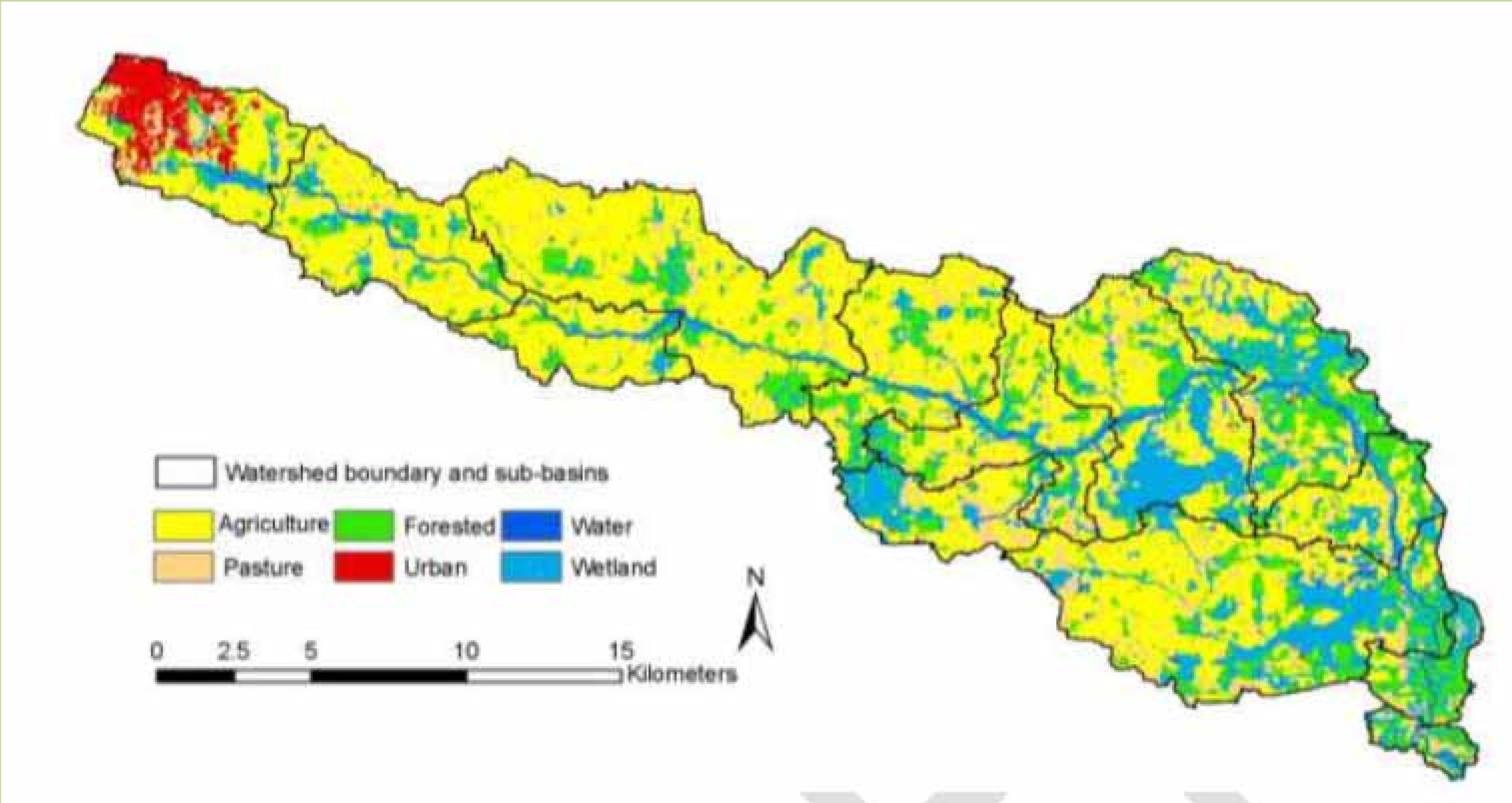


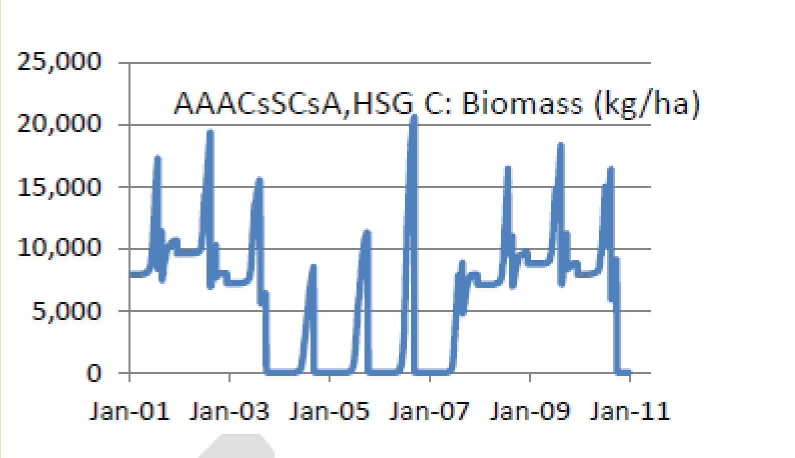
Figure out what's going on in the watershed… create model inputs

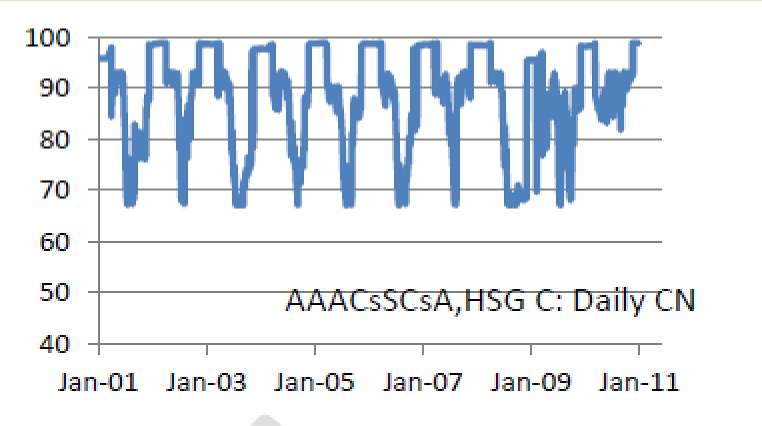
Table 3 Four rotation schedules used in the Mill Creek simulation

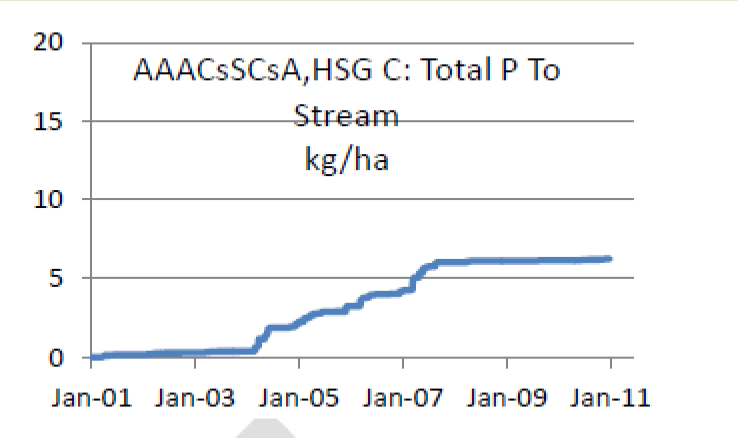
	Rotation A			Rotation B			Rotation C			Rotation D		
Year	**Crop**	**Operation[1]**	**Date**	**Crop**	**Operation[1]**	**Date**	**Crop**	**Operation[1]**	**Date**	**Crop**	**Operation[1]**	**Date**
1	Cs	MS	Jan-May	A	Harvest	6/8	C	Spread	5/1	A	Till-Chisel	4/20
		Till-MB	5/3		Harvest	7/1		Till-Chisel	5/3		Spread	5/1
		Plant	5/7		Harvest	8/1		Plant	5/7		Plant	5/15
		Harvest/kill	9/15		Harvest	9/1		Cultivate	6/10		Harvest	7/1
		MS	Oct - Dec					Harvest/kill	10/15		Harvest	8/1
								Spread	10/18		Harvest	9/1
2	C	Spread	5/1	A	Harvest	6/8	C	MS	Jan-May	A	Harvest	6/8
		Till-Chisel	5/3		Harvest	7/10		Till-MB	5/3		Harvest	7/10
		Plant	5/7		Harvest	8/20		Plant	5/7		Harvest	8/20
		Cultivate	6/10		Harvest	10/1		Cultivate	6/10			
		Harvest/kill	9/15					Harvest/kill	10/15			
		Spread	10/1					MS	Oct - Dec			
3	Cs	Spread	5/1	A	Harvest	6/8	S	Spread	5/1	A	MS	Jan- May
		Till-Chisel	5/3		Harvest	7/10		Till -Disk	5/2		Harvest	6/8
		Plant	5/7		Harvest	8/20		Plant	5/20		Harvest	7/10
		Cultivate	6/10		Harvest/kill	10/1		Harvest/kill	10/15		Spread	7/11
		Harvest/kill	10/15					Spread	10/18		Harvest	8/20
		Spread	10/18					Till-Chisel	10/20		Till-Chisel	10/3
											MS	Oct-Dec

Then add water– combine daily rainfall and land management

- simulate – crop growth, runoff etc…

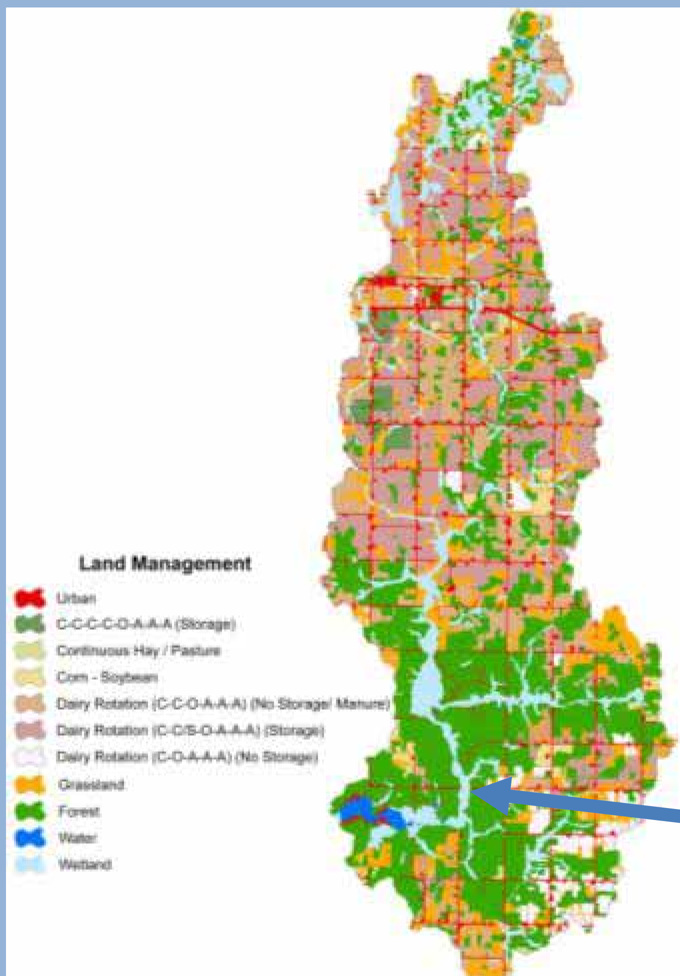


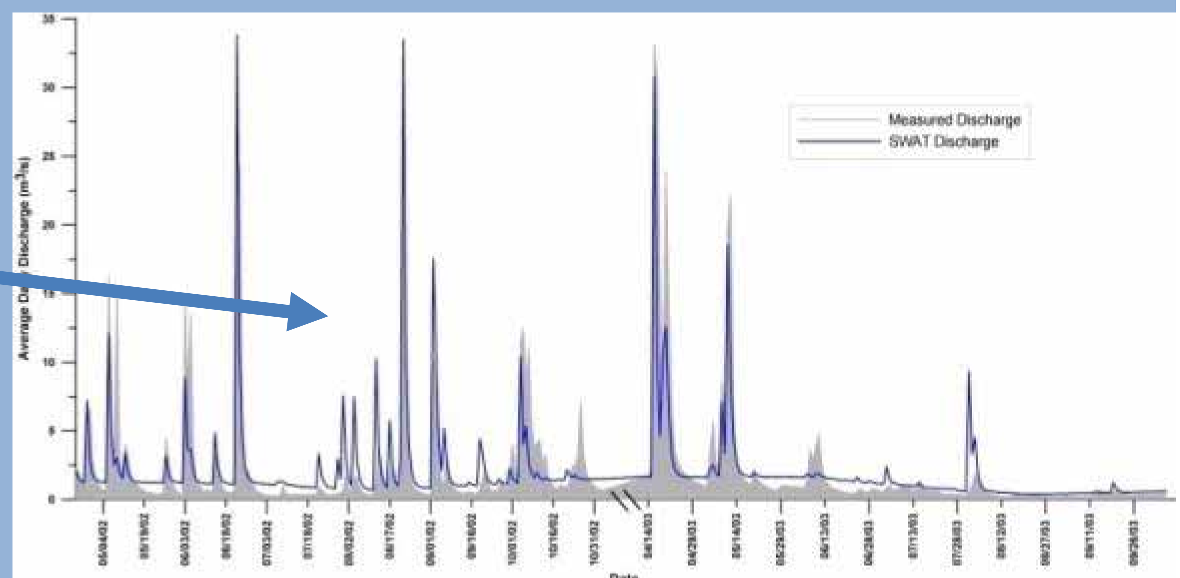




Example- Mead Lake

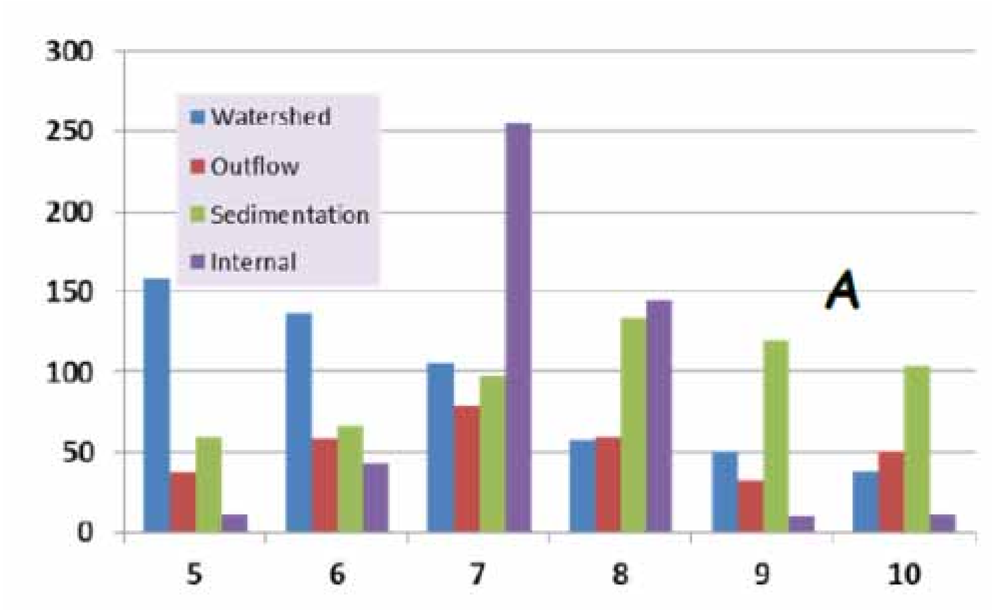
- Watershed
  - **250 km²**
- SWAT Model
  - **10 subbasins**
  - **119 HRUs**
- Calibration
  - **2 years flow/ TSS / TP**
  - **Matched total w/ CN**
  - **Adjusting USLEP, Filterw**
  - **Tried to fit P fractions and P Content**



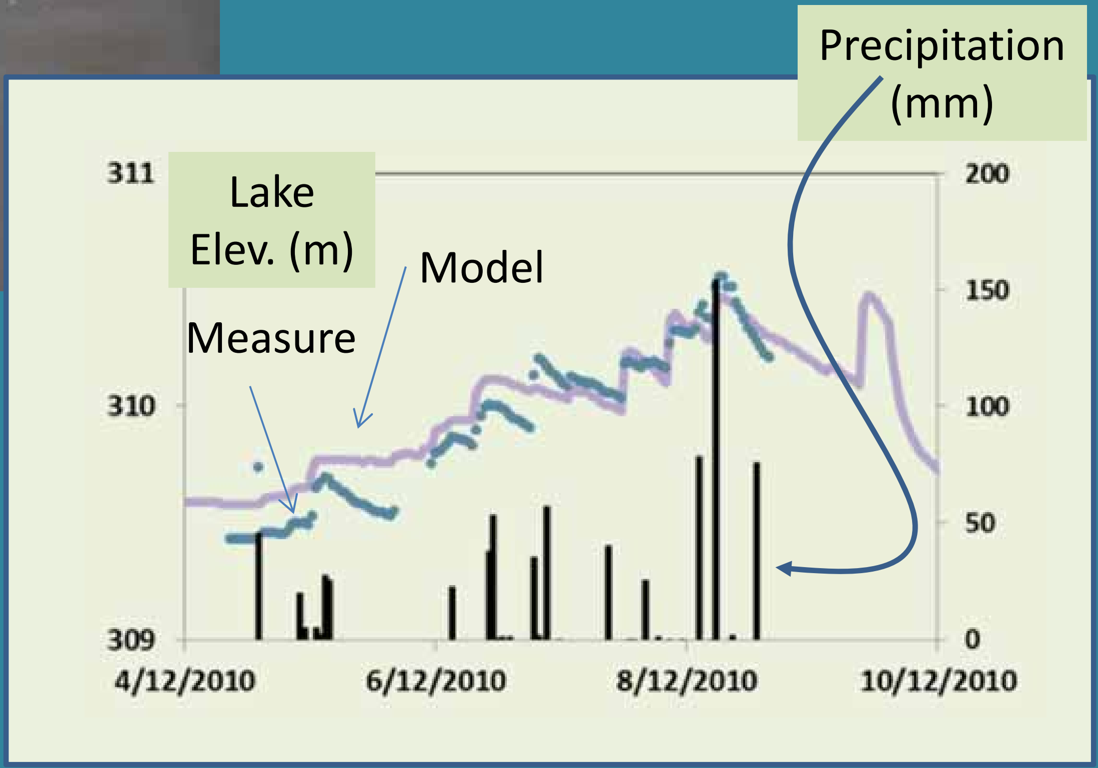


Usefulness of shorter time-step?

- Partition seasonal loads?
  - Here looking at the monthly P (in kilograms) for watershed loading (blue)



Daily Tracking– Lake Volume/Depth

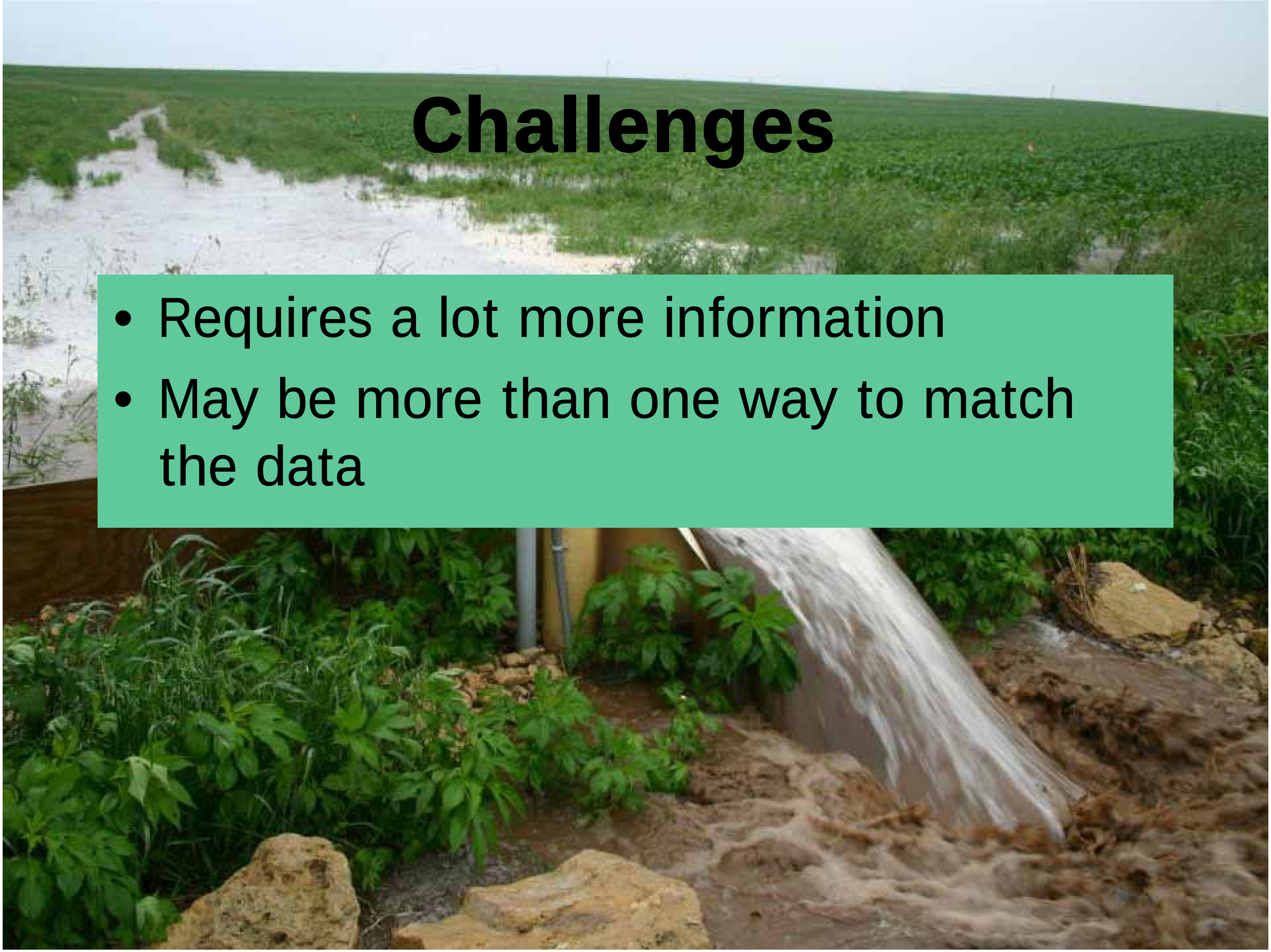


Why more detail on the model?

- Comparing effect of land management on P export.

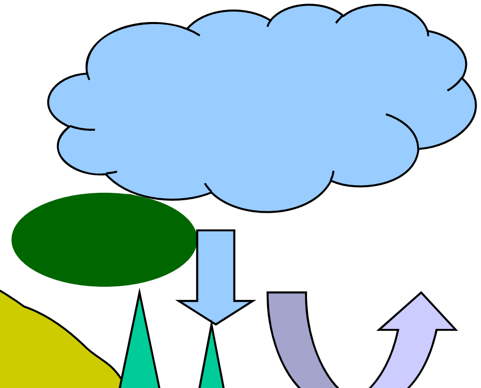
Table 3. Simulated Phosphorus Export Under Different Management Scenarios[1]

Scenario	Total Phosphorus kg/May-Sept / (lb/May-Sept) / Reduction %
Baseline	1703 / (3743)
Reducing Soil P (25 ppm)	1470 / (3231) / 14%
Reducing Soil Erosion (50% reduction in USLE P)	1465 / (3220) / 14%



Challenges

- Requires a lot more information
- May be more than one way to match the data



SURFACE RUNOFF

Study	Surface Runoff Total P (mg/l)
Graczyk et al., 2003	0.3-1.1
Garn, 2002	1.8-4.0
Stuntebeck, 2002	1.1-1.3
Bannerman, 1996	0.3
Waschbusch et al,	1.0-1.5

Combine some runoff measurements

- Graczyk, Greb– Woods / Lawn
- Pioneer Farm – Corn/Alfalfa