Problems *(and Solutions)* in Applying SWAT in the Upper Midwest USA

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And members of
SMAUG:
SWAT Midwest America Users Group

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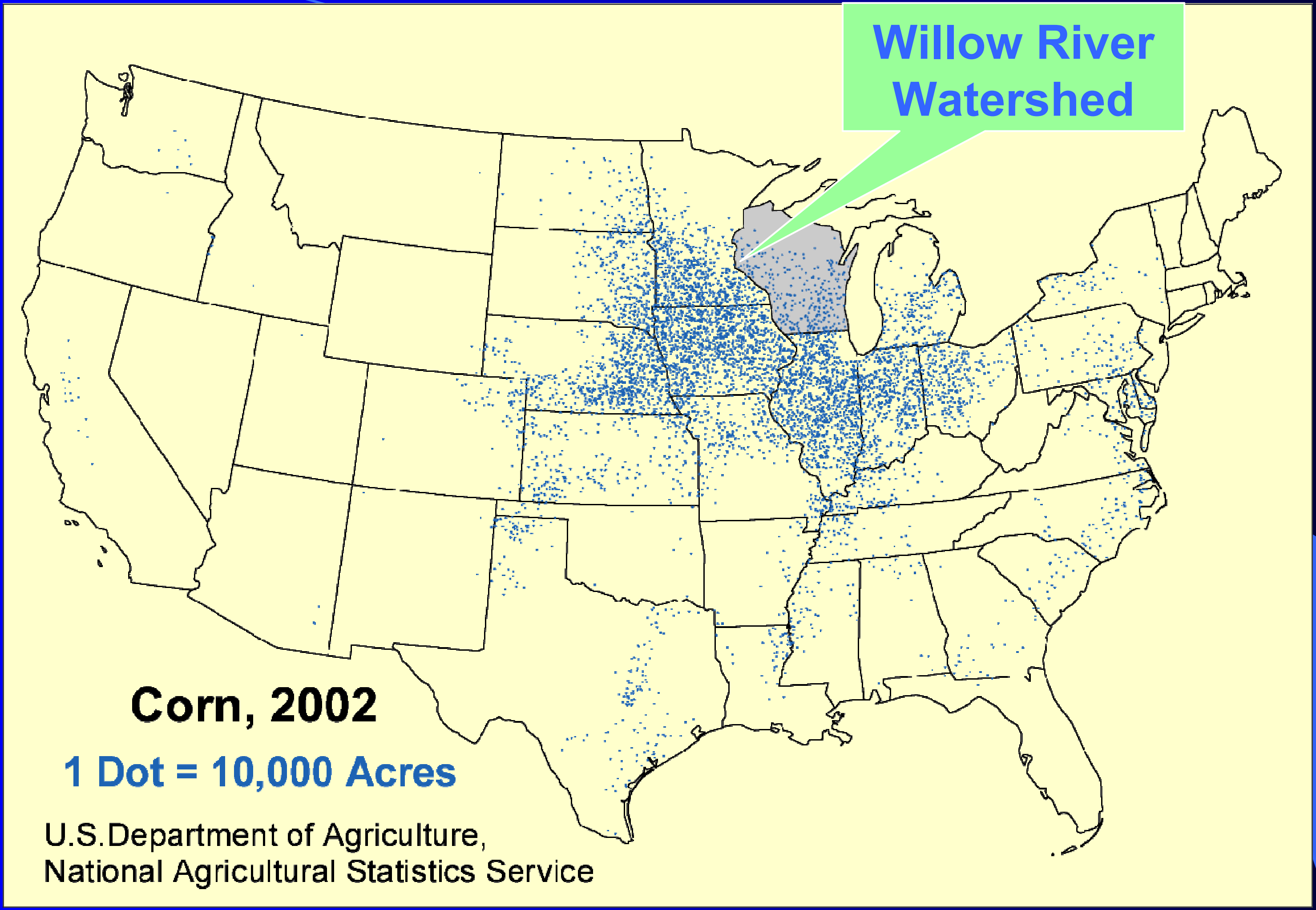
SWAT problems and solutions:

- Background
  - Environmental issues in Upper Midwest USA
  - Study site: Willow River
  - Calibrated SWAT model
- SWAT problems, and solutions
  - **Persistent alfalfa**
  - **Loss of infiltrated water**
  - **Extraneous phosphorus loads**
  - Excessive denitrification
  - Large sediment yields
  - Alternate calibrations
- Summary & Conclusions

Background



- Upper Midwest USA has intensive row-crop agriculture

Background

- Corn typifies row-crop agriculture

Zea mays L.

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Background

- Soybeans often grown the next year

Glycine max L.

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Background

- Alfalfa is grown for dairy cattle

Perennial crop, grown continuous for 3-4 years

Medicago sativa L.

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- Corn & soybean production with conventional tillage can cause excessive loads of:

Sediment

Phosphorus

Nitrogen

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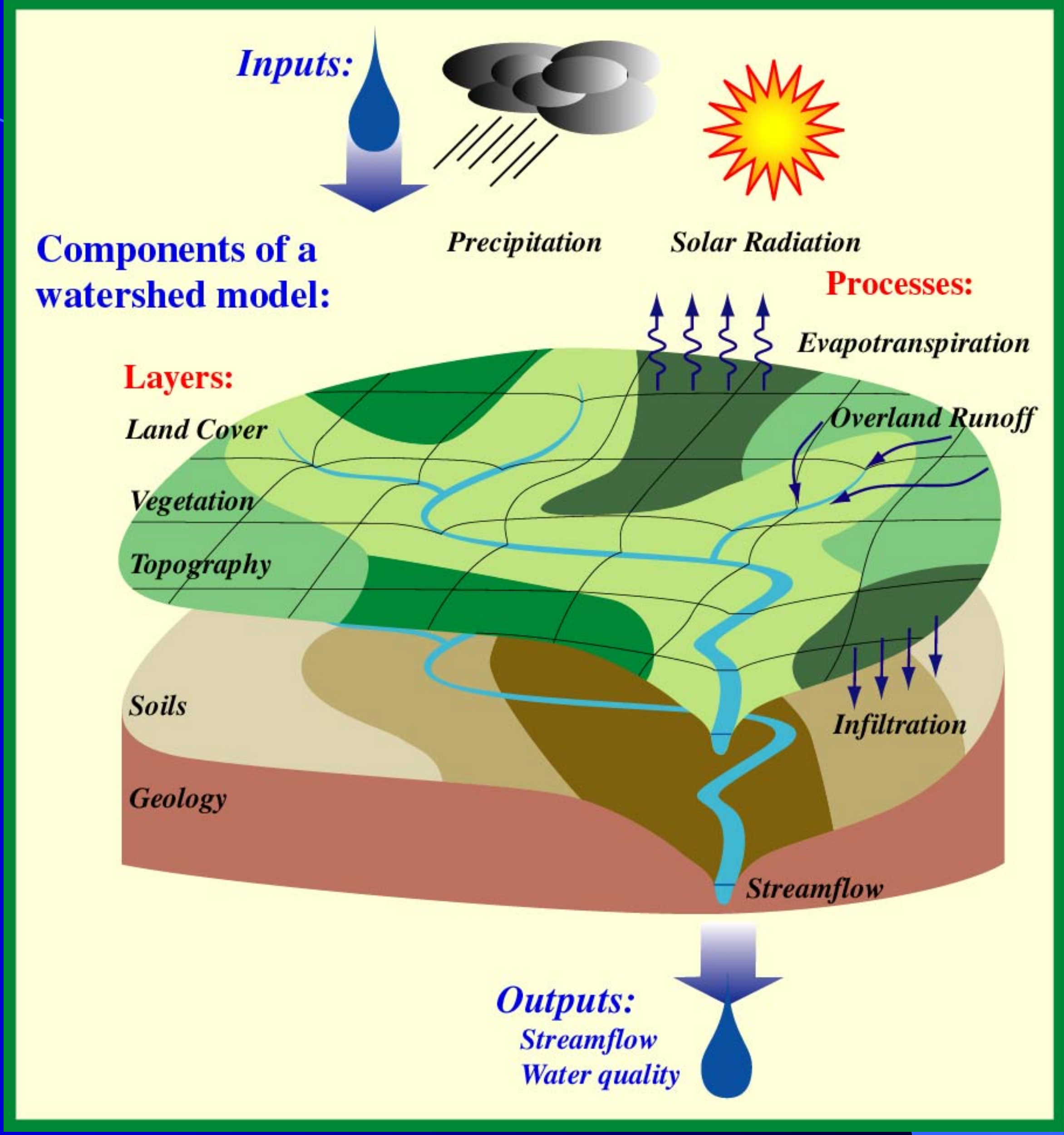
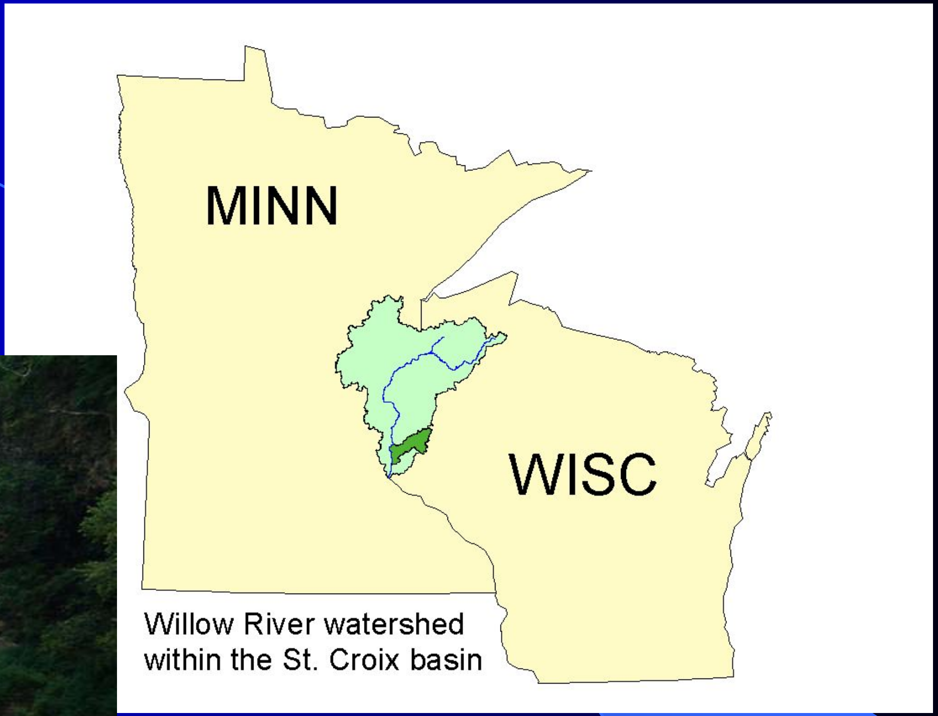
- SWAT is useful for evaluating these nonpoint-source pollution problems
  - What factors are most responsible for the problem?
  - What can be done to fix the problem?



Background

- Willow River
  - in western Wisconsin
  - sediment & phosphorus problems
  - tributary to St. Croix River, a federally protected river

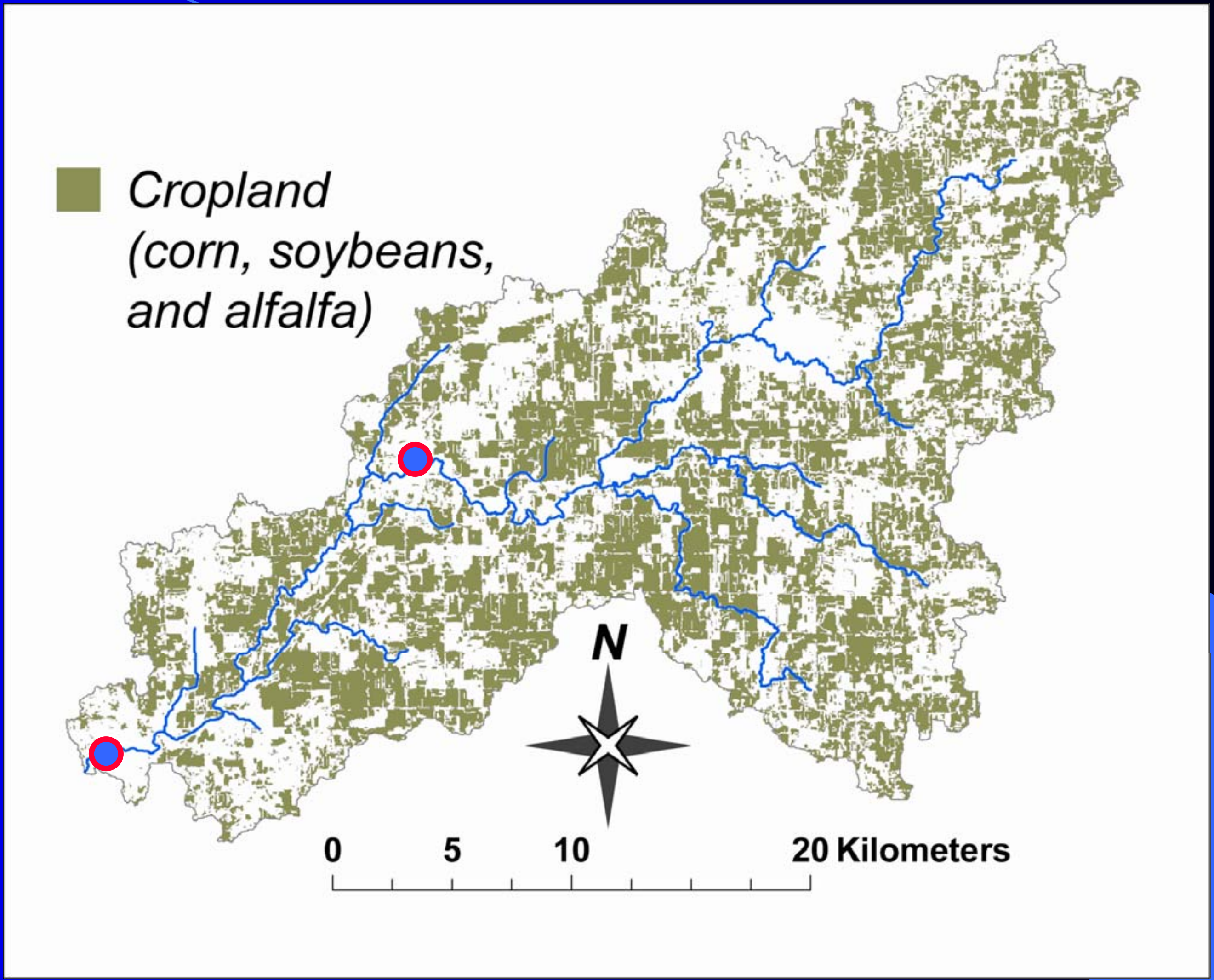


Willow River

St. Croix River

Background

- Land use
  - 40% agriculture
  - corn, soybeans, and alfalfa
  - dairy farming common
- Reservoirs
  - Upper
  - Lower



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- Representative crop rotations:

YEAR 1 YEAR 2 YEAR 3 YEAR 4 YEAR 5 YEAR 6 YEAR 7

C2A3:


CORN


CORN


ALFALFA

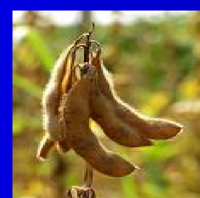

ALFALFA


ALFALFA

C3S1A3:


CORN


CORN


SOYBEANS


CORN

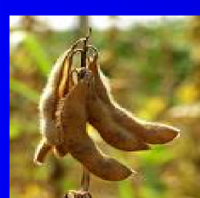

ALFALFA


ALFALFA


ALFALFA

C1S1:


CORN


SOYBEANS

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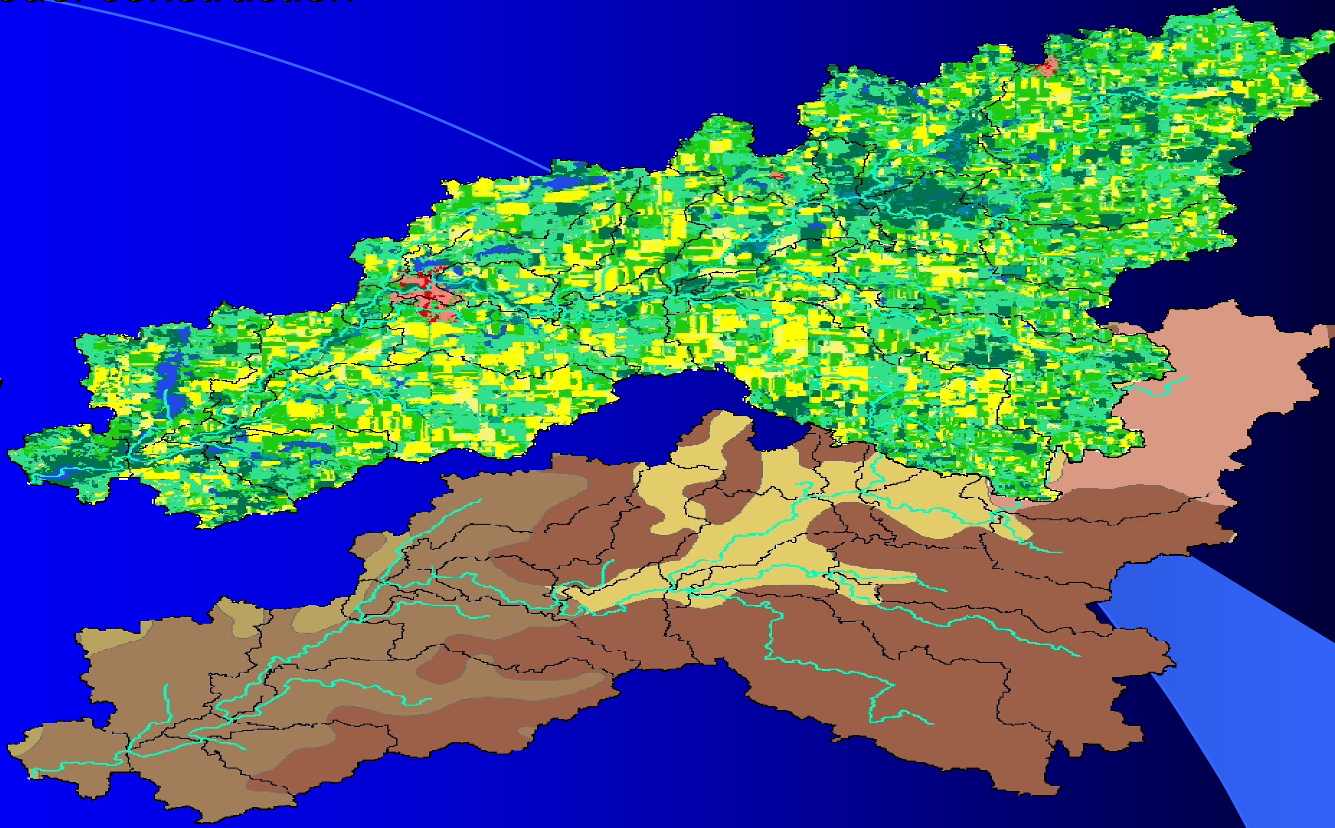
Background – Model construction



Land Cover

Soil Type

Hydrologic Response Units (HRUs)

-- All parcels with the same vegetation & soils are lumped (aggregated) within each subbasin into a single homogeneous HRU

-- Each HRU has distinct rainfall-runoff response

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Background -- Model calibration philosophy

Uplands/Fields
(HRUs in subbasins)

Channels
(Reaches and Floodplains)

- ***Make the model realistic:*** **Check reasonable loads of water, sediment, and phosphorus for each of the arrows (transport pathways) –** ***even though we really had hard data from the outlet, for only 1 year.***

- ***Make the model internally consistent:*** **Check mass balance: outputs from uplands must equal inputs to channels; outputs from channels must equal inputs to reservoirs; outputs from lower reservoir must equal measured loads**

Reservoirs

Outlet

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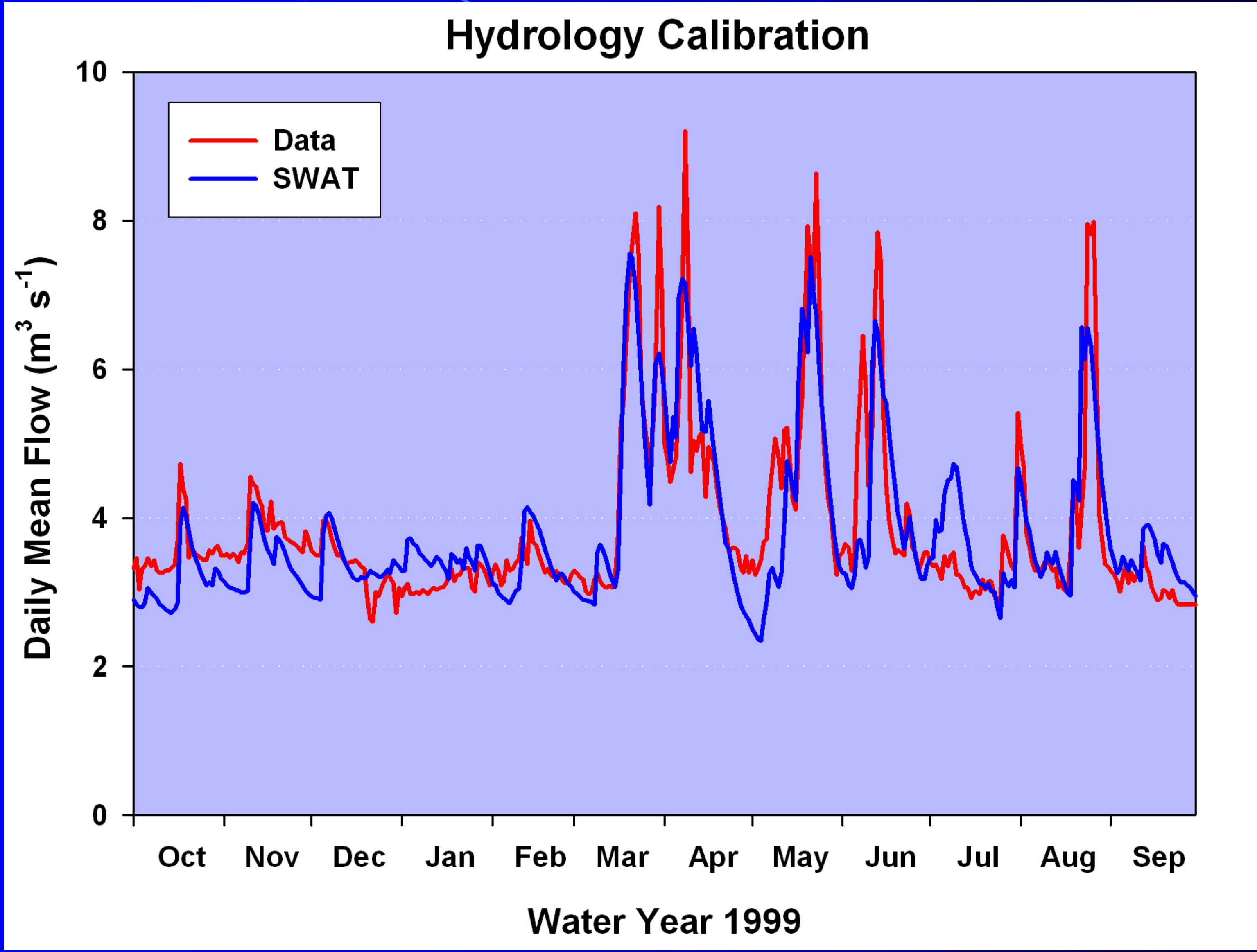
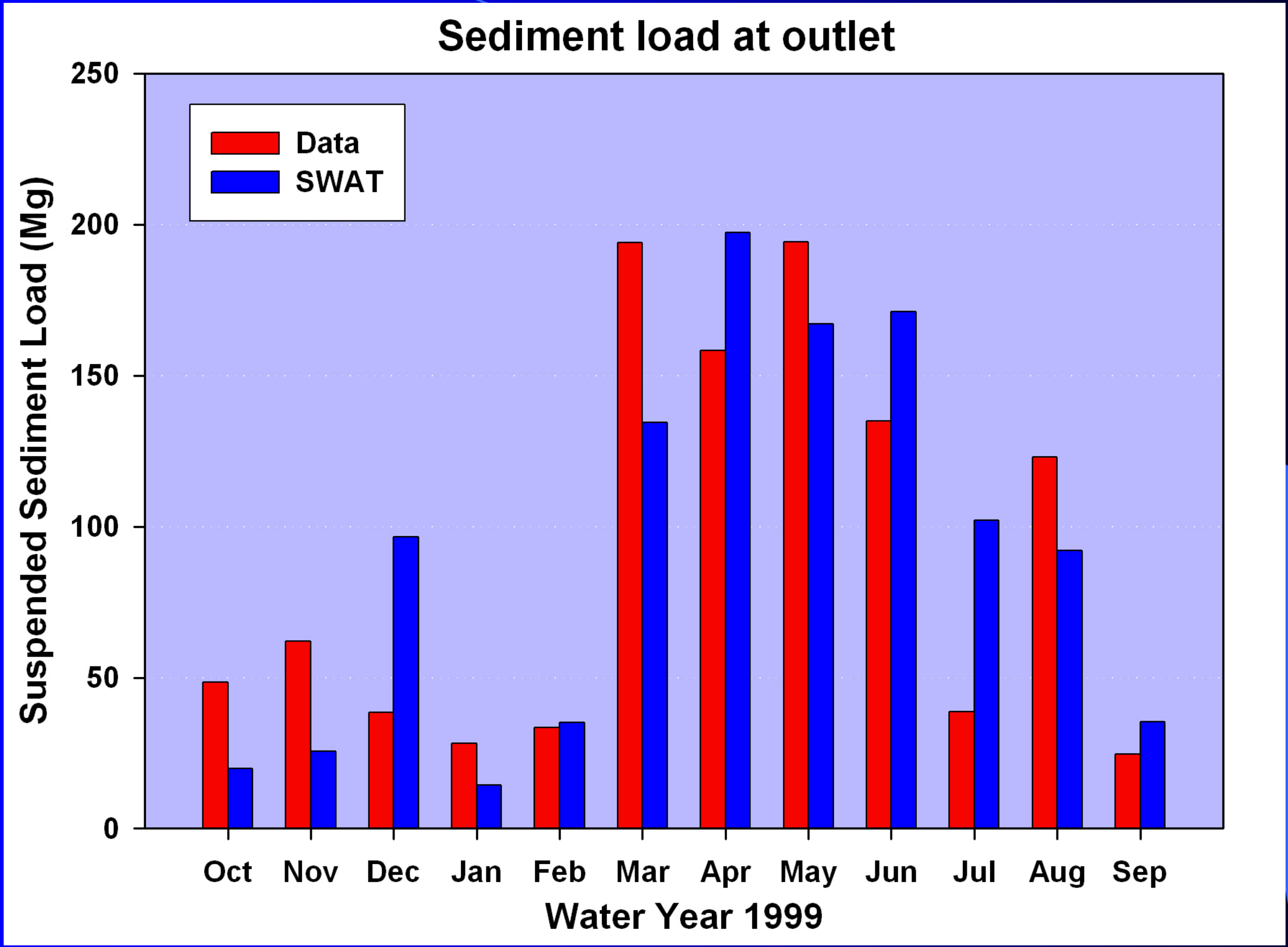
Background – Model calibration



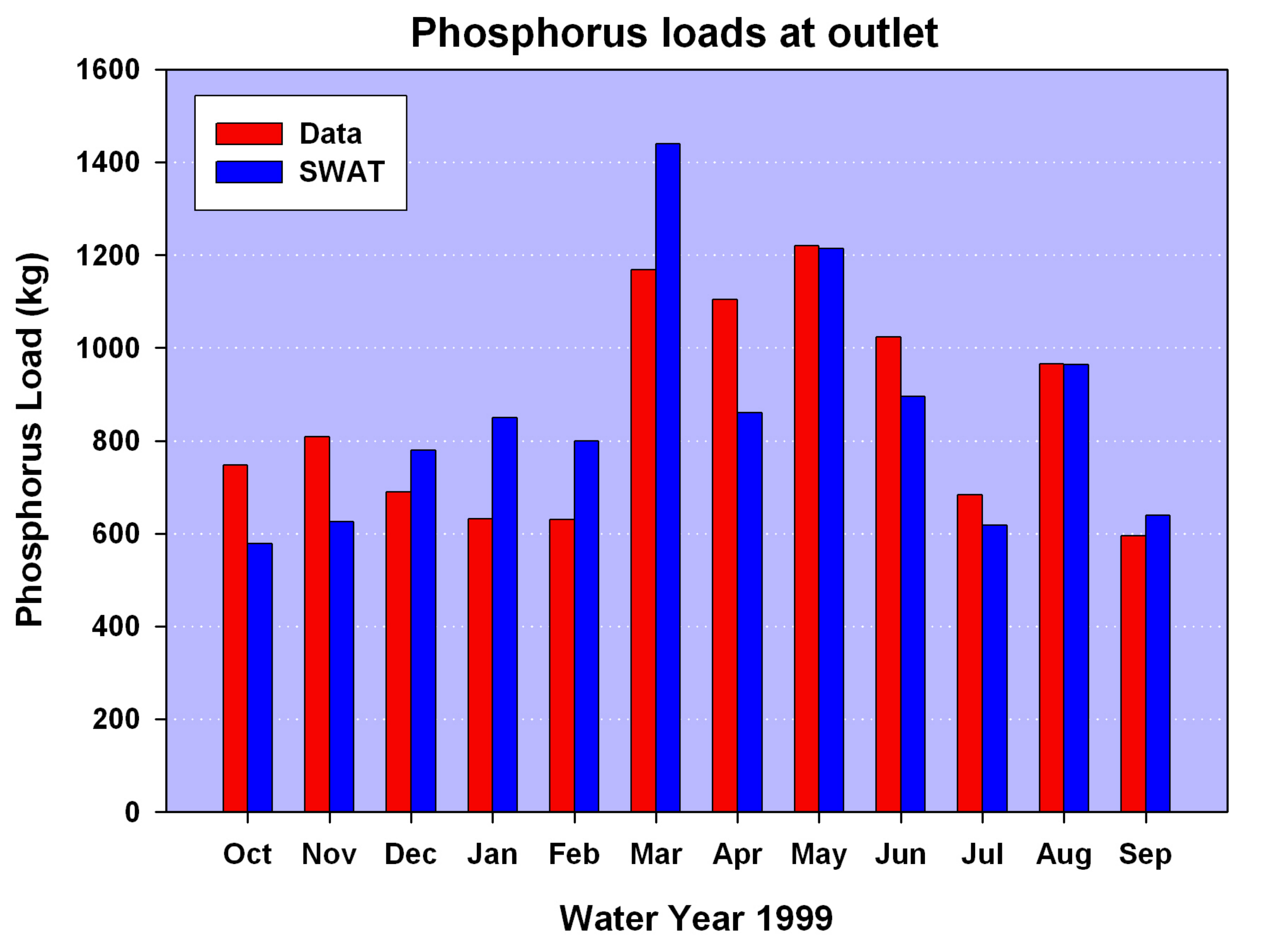
- *Nash-Sutcliffe CoE = 0.70*

Background – Model calibration



- *Nash-Sutcliffe CoE = 0.63*

Background – Model calibration



- *Nash-Sutcliffe CoE = 0.47*

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- Background
  - Environmental issues in Upper Midwest USA
  - Study site: Willow River
  - Calibrated SWAT model
- SWAT2000 problems, and solutions
  - **(1) Persistent alfalfa**
  - **(2) Loss of infiltrated water**
  - **(3) Extraneous phosphorus loads**
  - (4) Excessive denitrification
  - (5) Large sediment yields
  - (6) Alternate calibrations
- Summary & Conclusions

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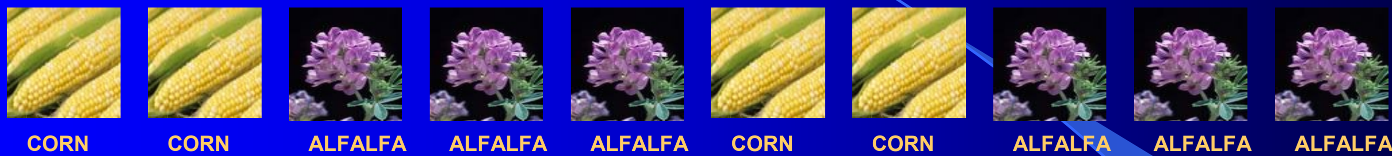
- Once planted, alfalfa cannot be killed

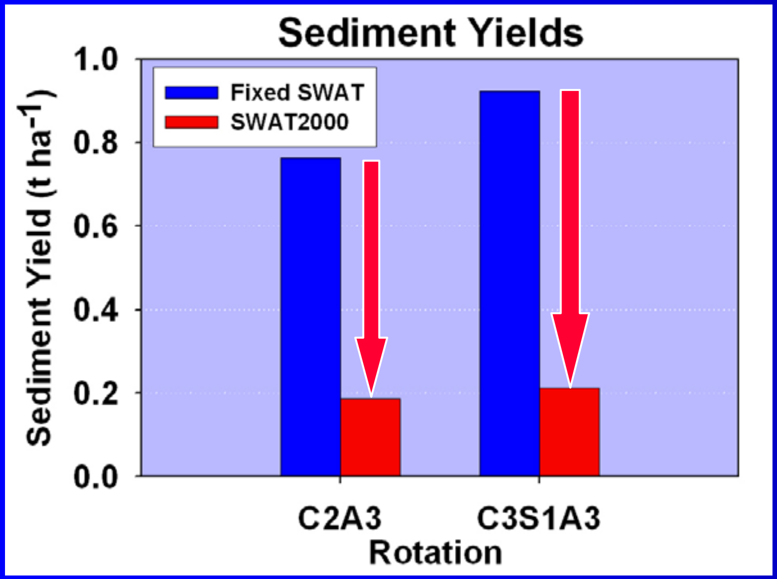
C2A3: what we want

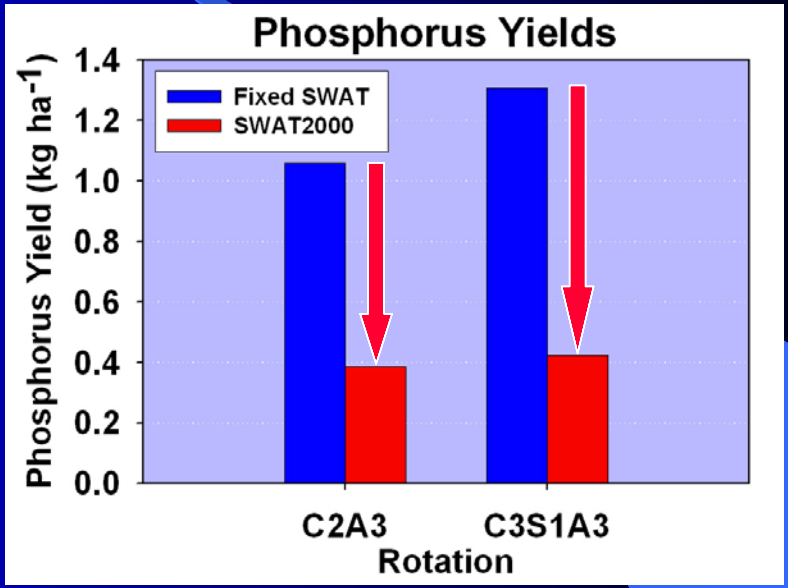


C2A∞: what the model does

- Why is this a problem?
  - Perennial alfalfa gives much lower sediment and phosphorus yields than corn
  - The model greatly underestimates sediment and phosphorus yields

- How big is the problem?
  - Sediment underpredicted by 75-77%
  - Phosphorus underpredicted by 63-68%





- What is the solution?
  - FORTRAN code modification by Paul Baumgart, UW-Green Bay

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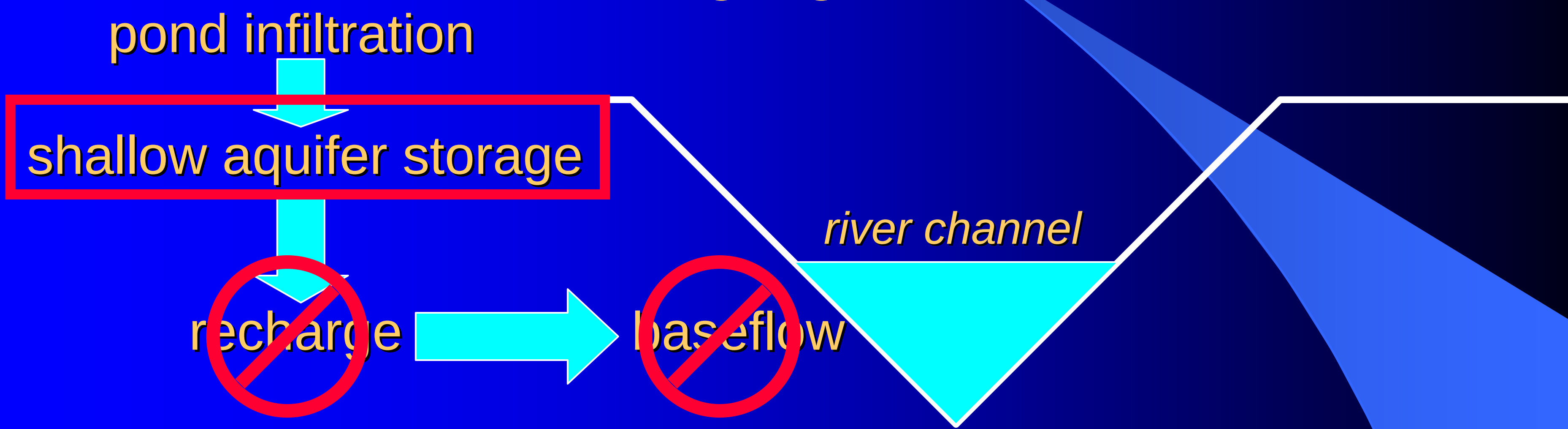
Problems & Solutions – (2) Loss of infiltrated water

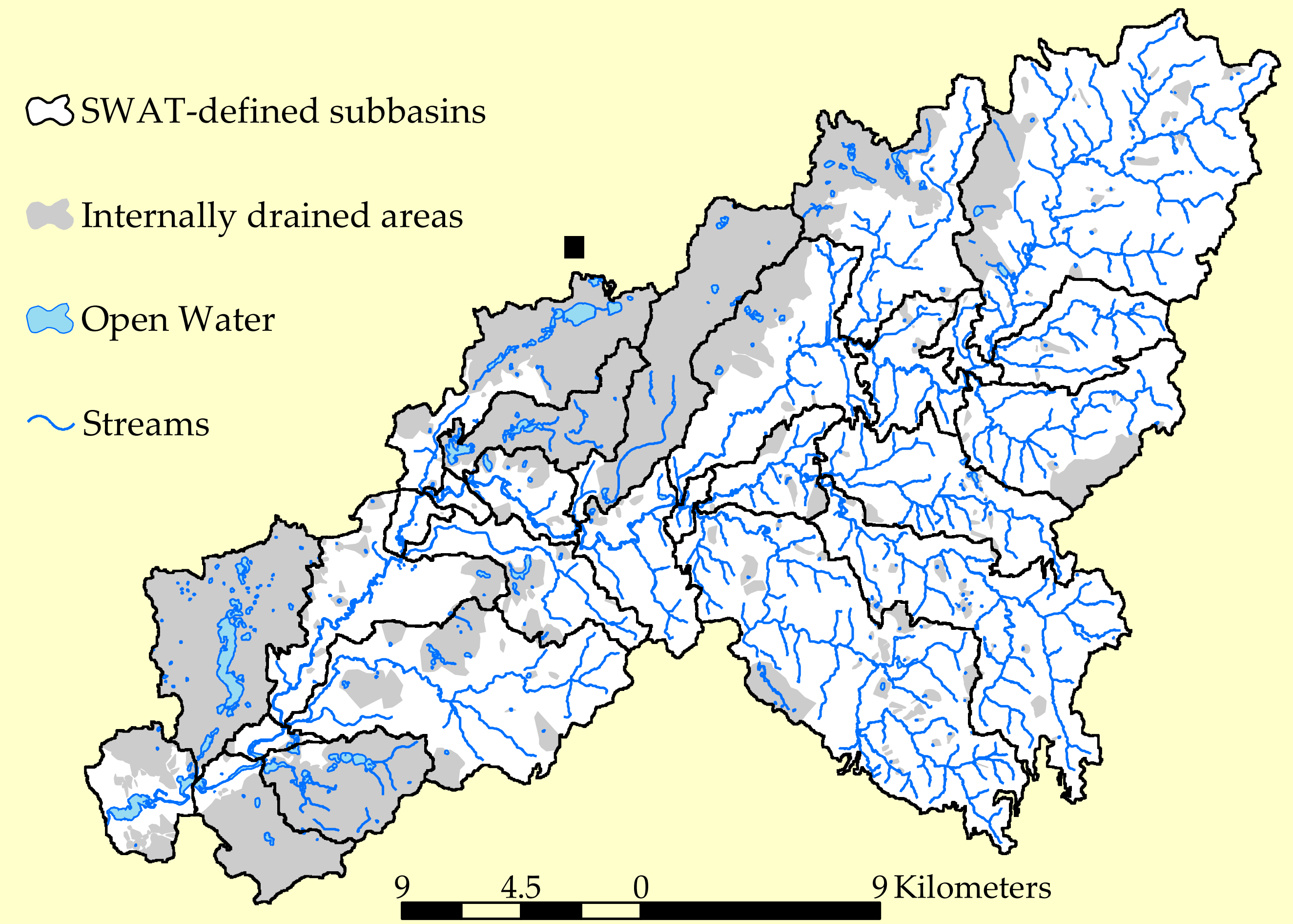
- Water infiltrating from surface-water bodies (e.g., Ponds) gets trapped and does not recharge groundwater



- Why is this a problem?
  - Reduces baseflow component
  - Underestimates total water yield from basin

- How big is the problem?
  - Can be large problem in Upper Midwest USA because of closed drainages modeled as Ponds

29% of the Willow watershed drains to closed depressions – which we modeled as Ponds in SWAT



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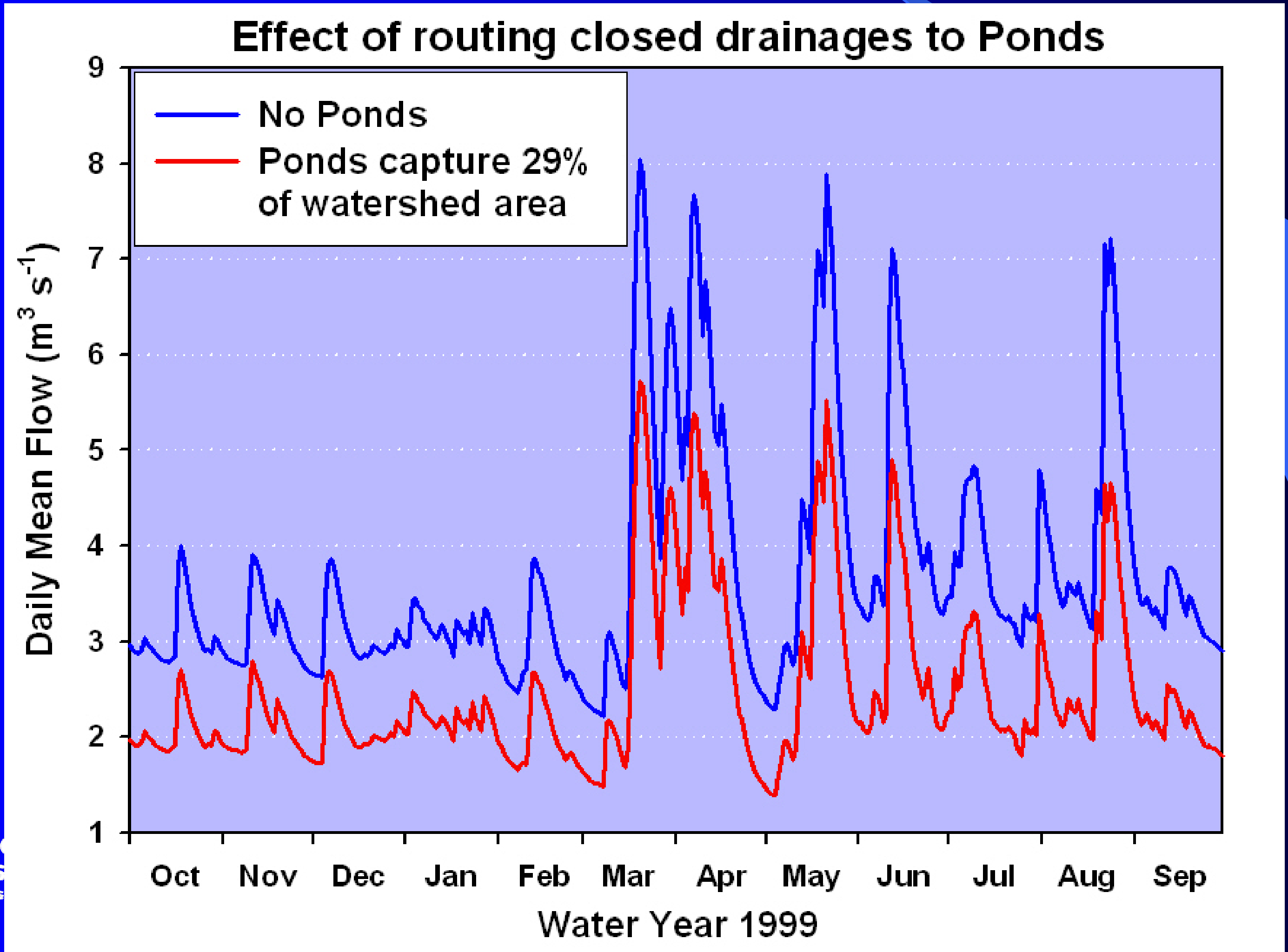
- When Ponds were added, annual runoff volume dropped 29%
  - Also lost about 30% of sediment and phosphorus yields, as expected
  - But the water should NOT have been trapped



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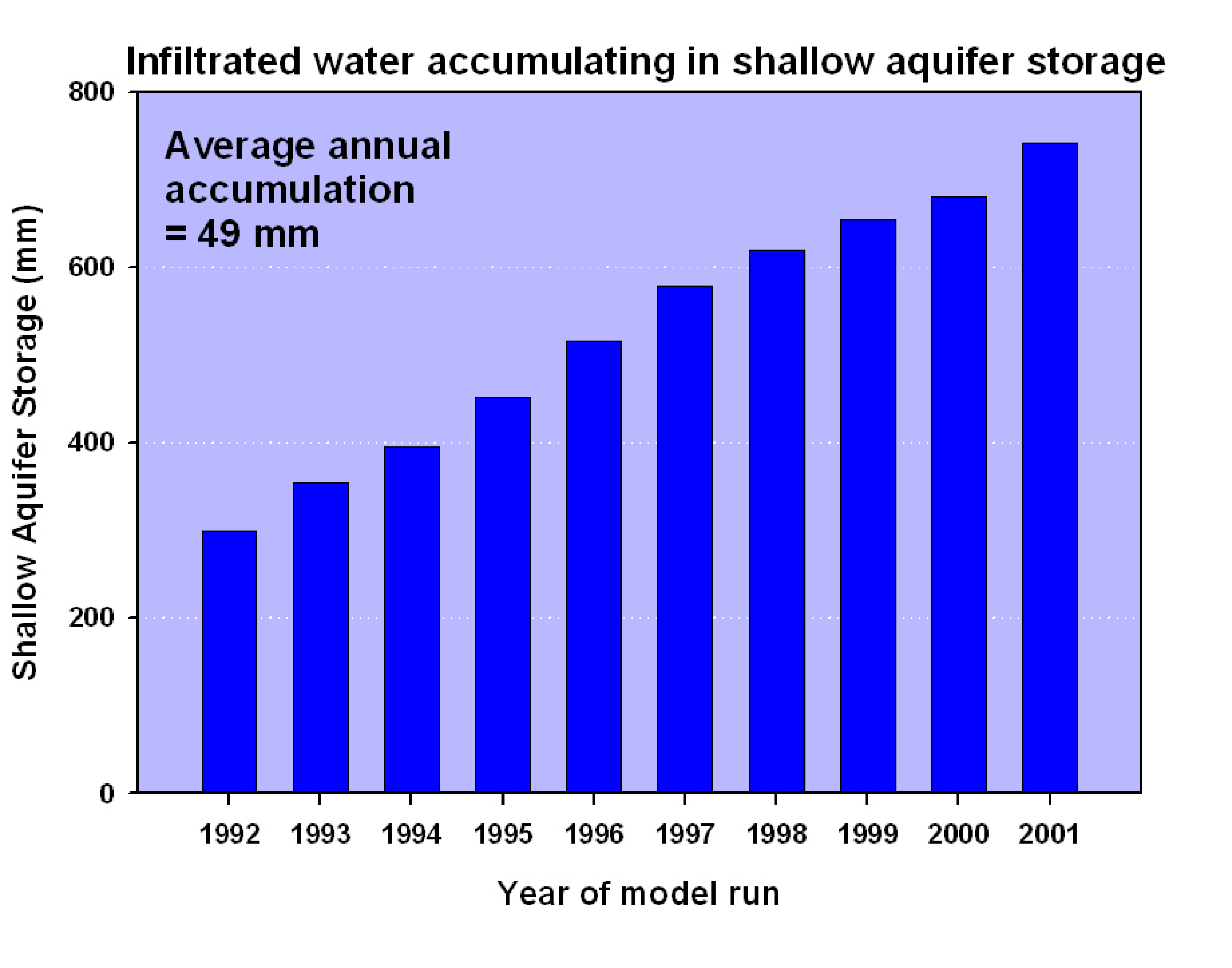
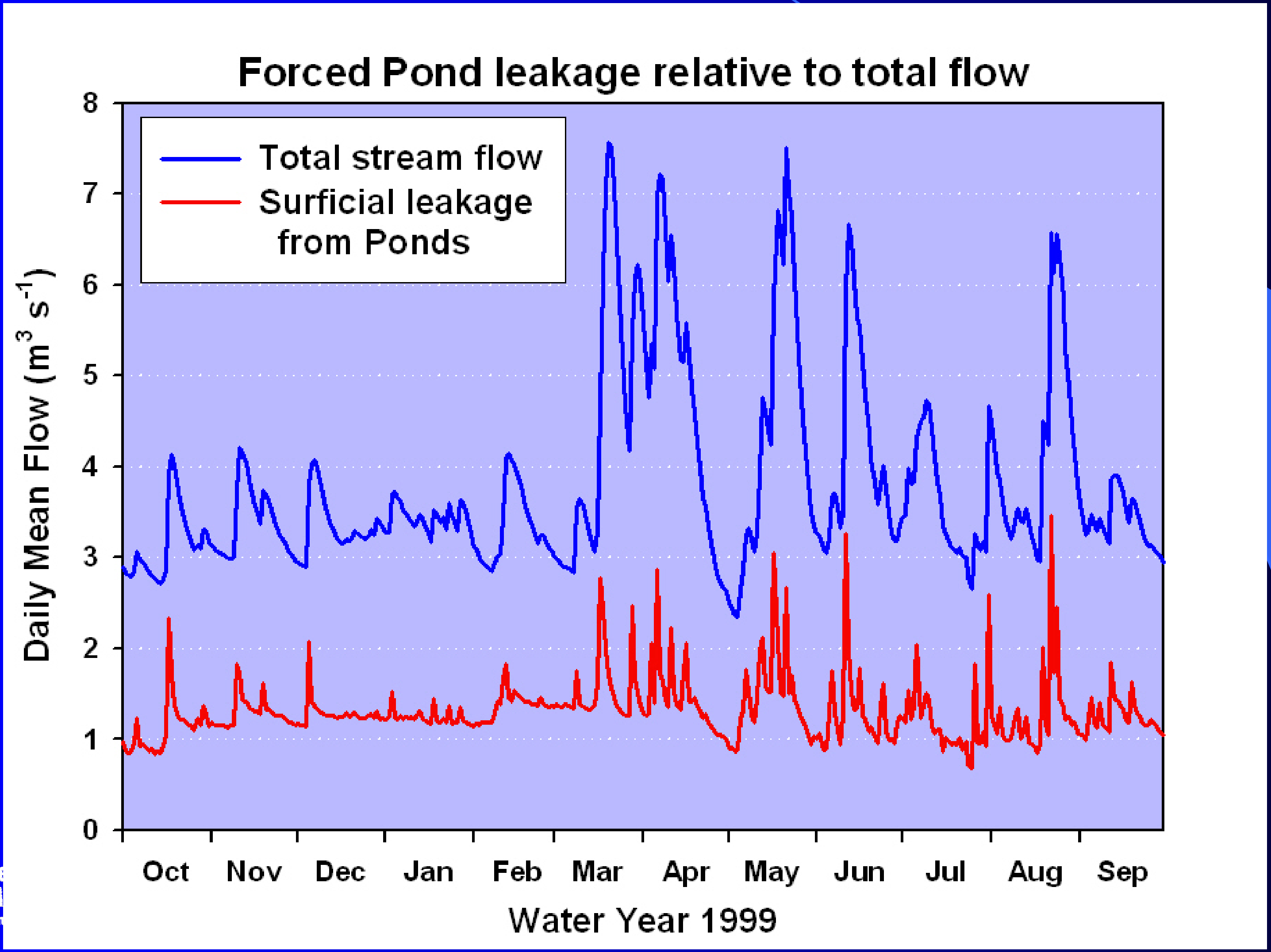
- Where did the water go?
  - Trapped in shallow aquifer storage



- What is the solution?
  - Best is to revise the FORTRAN code
  - Work-around is to stop Pond seepage and force slow surficial leakage (set pond K = 0 and NDTARG = 500 or so)



Problems & Solutions – (3) Extraneous phosphorus from subbasin chlorophyll

- SWAT delivers a chlorophyll load from subbasins to the channel – and then QUAL2E converts that chlorophyll to phosphorus

Uplands/Fields
(HRUs in subbasins)

Delivered to reaches:
-- Phosphorus (as ORGP, SEDP, SOLP, and P_GW)
-- Chlorophyll (acc. to Cluis et al. 1988)

Channel Reaches

Without QUAL2E:
-- Phosphorus output = input
-- Chlorophyll output = input

With QUAL2E:
-- Phosphorus output > input
-- Chlorophyll output < input

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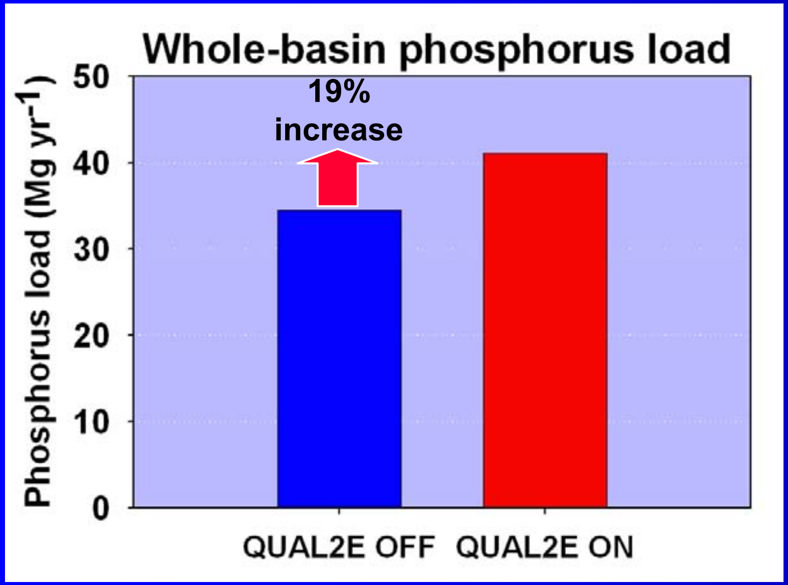
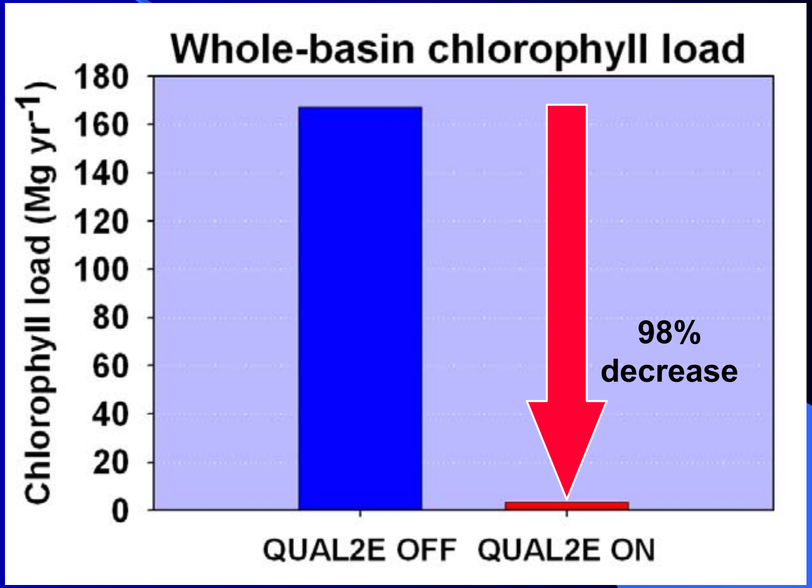
- Why is this a problem?
  - Adds extraneous (unreal) phosphorus, causing SWAT to overestimate phosphorus loads





- Phosphorus
  - With QUAL2E on, basin-wide phosphorus loads increased 19%
  - Subbasins increased from 3% to 148%
- Chlorophyll
  - With QUAL2E on, basin-wide chlorophyll loads decreased 98%
  - QUAL2E was converting chlorophyll to phosphorus

- What is the solution?
  - (1) Avoid using QUAL2E within SWAT
  - (2) Make fraction of algae that is phosphorus (parameter AI2) negligibly small (0.001, from default of 0.015)
  - (3) Revise FORTRAN code to alter or remove algorithm from Cluis et al. 1988

Problems & Solutions – (4) Excessive denitrification

- SWAT2000 denitrified about 75% of nitrogen fertilizer applied to corn
  - Expected denitrification was about 15%
- Why is this a problem?
  - Corn yields underestimated due to false N stress
  - Residue decomposition altered
- What is the solution?
  - Alter FORTRAN code to allow access to denitrification parameters
    - We used code from Paul Baumgart, UW-Green Bay
    - SWAT2005 already has this improvement

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Problems & Solutions – (5) Excessive sediment yield & (6) alternate calibrations

Sediment Delivery from Field to Outlet:

Uplands/Fields
(HRUs in subbasins)

(1) Gross field erosion ~OK

Channels
(Reaches and Floodplains)

Here?

or Here?

(3) So where should we trap this excess sediment??
Important to know, because choice could impact the modeled effectiveness of BMPs

(4) We didn't know the best solution – so we did it both ways…+/-

(2) Reasonable estimate of sediment delivered to reservoirs and outlet –

but this is much smaller than gross erosion rates

Reservoirs and Outlet

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Sediment Delivery from Field to Outlet:

Uplands/Fields
(HRUs in subbasins)

Here

Excess sediment all trapped in the uplands

(primarily by reducing USLE P factor from 1.0 to 0.7)

Channels
(Reaches and Floodplains)

All channel processes are "turned off" – no deposition or erosion in channel

Reservoirs and Outlet

Model version (1): "Passive channel"

Sediment Delivery from Field to Outlet:

Uplands/Fields
(HRUs in subbasins)

Channels
(Reaches and Floodplains)

Much more sediment released from uplands than in passive-channel model

(by raising USLE P factor from 0.7 to default 1.0)

Here

Channel processes are "turned on", and the excess sediment delivered from uplands is trapped in channel (with no channel erosion allowed)

Model version (2): "Active channel"

Reservoirs and Outlet

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- SWAT calibrations can be non-unique
  - Both the “passive channel” and “active channel” versions of the Willow model are valid calibrated models
- Why is this a problem?
  - Because choice of calibration can change conclusions from running model scenarios under different conditions (changed management or climate, for example)
- What is the solution?
  - Run scenarios on a range of calibrated models…
  - Something we all know already:
    - ***Interpret model results cautiously***

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- Summary
  - SWAT2000 had significant problems with
    - (1) persistent alfalfa that could not be killed
    - (2) loss of infiltrated water from Ponds used to simulate closed depressions
    - (3) extraneous phosphorus loads originating as chlorophyll loads from subbasins to the channel
  - Other considerations
    - (4) beware of excessive denitrification
    - (5) beware that default sediment yields can be too high
    - (6) beware of implications of alternate calibrations

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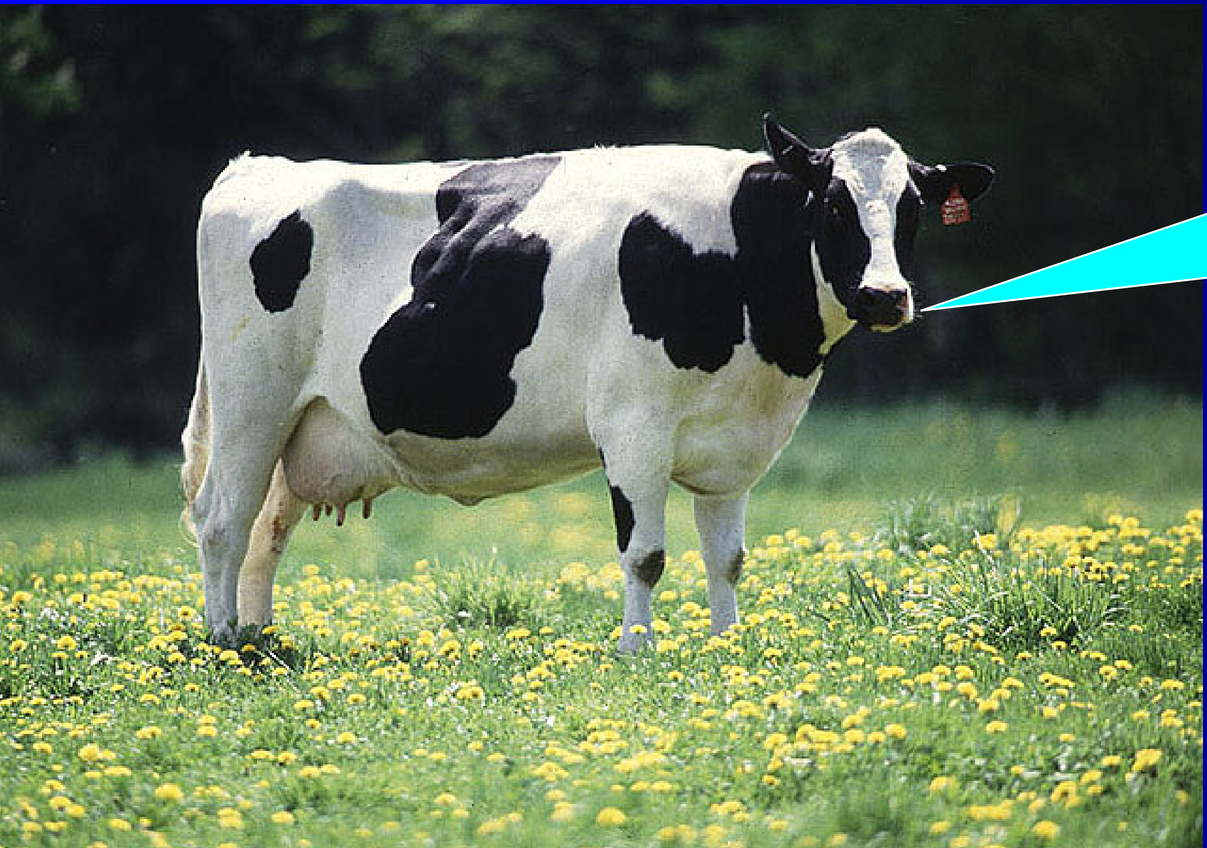
- Conclusions
  - No model is better than the weakest link in its chain
  - SWAT will continue to improve as bugs are fixed and algorithms are re-examined
  - **"All models are wrong; some models are useful."**



Kiss me –
I'm Dutch!!
(from Friesland)

- Corn & soybean production with conventional tillage can cause excessive loads of:

Sediment

Phosphorus

Nitrogen