Soft-Data Considerations in Modeling Watershed-Scale Phosphorus Loads in the St. Croix Basin, Minnesota and Wisconsin, USA

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With help from Srini and associates from Texas A&M:
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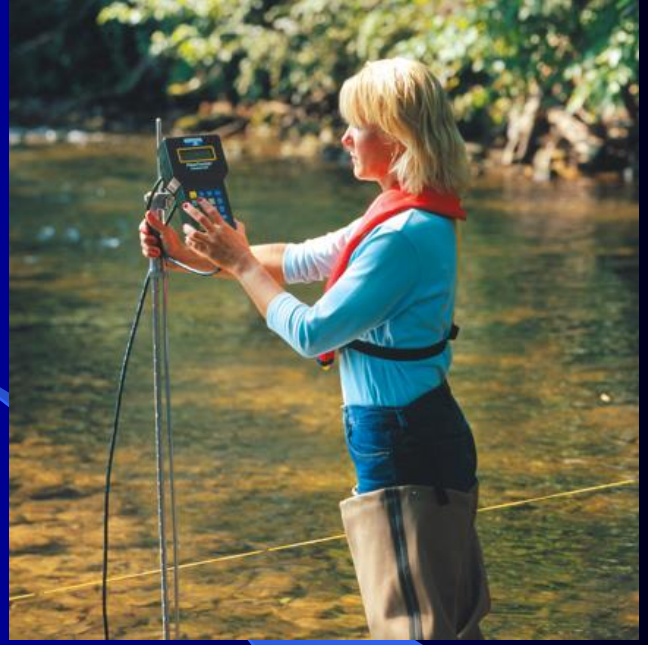
Funding and data provided by:

- **Hard data = data observed in your watershed**
  - Flows
  - Sediment loads
  - Total phosphorus loads
  - Total nitrogen or nitrate loads



- **Soft data = representative data from the literature**
  - What are common trapping efficiencies by lakes for:
    - Sediment
    - Total phosphorus

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- **The perils of over-parameterization: too many options during calibration!**
  - Hard data: 1-2 points with flows, and maybe loads
  - Parameters: dozens of parameters that could be adjusted
  - Result = many non-unique calibration parameter sets
- **Goal: constrain your options with soft data to make your calibration as reasonable and unique as possible**
  - SWAT_CHECK does a good job in assessing reasonableness

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Study Area

St. Croix River basin

- St. Croix River is a national scenic and recreational riverway

- A unit of the National Park Service, *America's best idea*

Study Area

St. Croix River basin

- 20,000 km^2 basin
- Intersection of lake-rich landscape and corn belt
- Lake St. Croix is 40-km long lake at basin terminus

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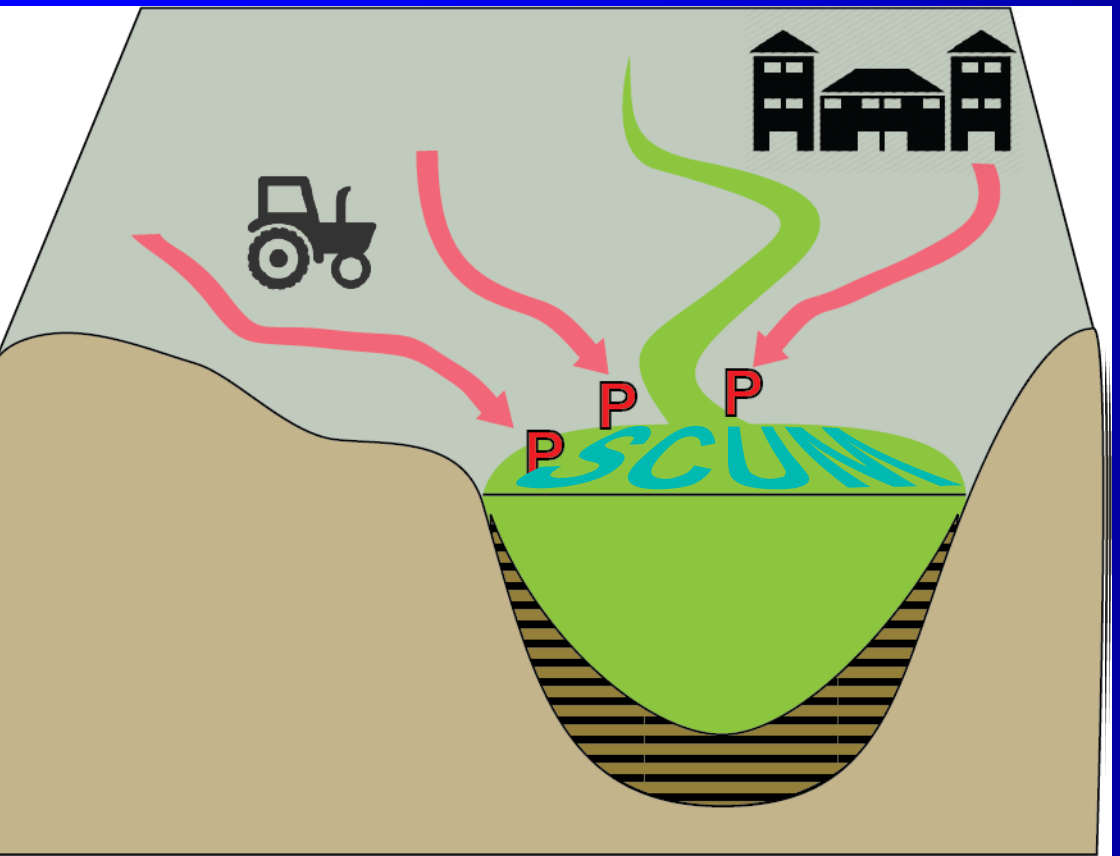
Ecological Issue of Concern:

- Excess P loads from the watershed cause eutrophication = excessive algal growth in lakes and rivers.



Lake St. Croix -- impaired by eutrophication from excess phosphorus

Purpose of SWAT model:

- **To help understand P source and transport:**
  - **Source factors**
    - **How much P from which land uses**
    - **Where they are located**
  - **Transport factors**
    - **How is the P routed through the watershed**
  - ***= Model calibration process***
- To use SWAT to estimate the reduction in ***phosphorus loads*** in our study watershed by applying best management practices (BMPs)

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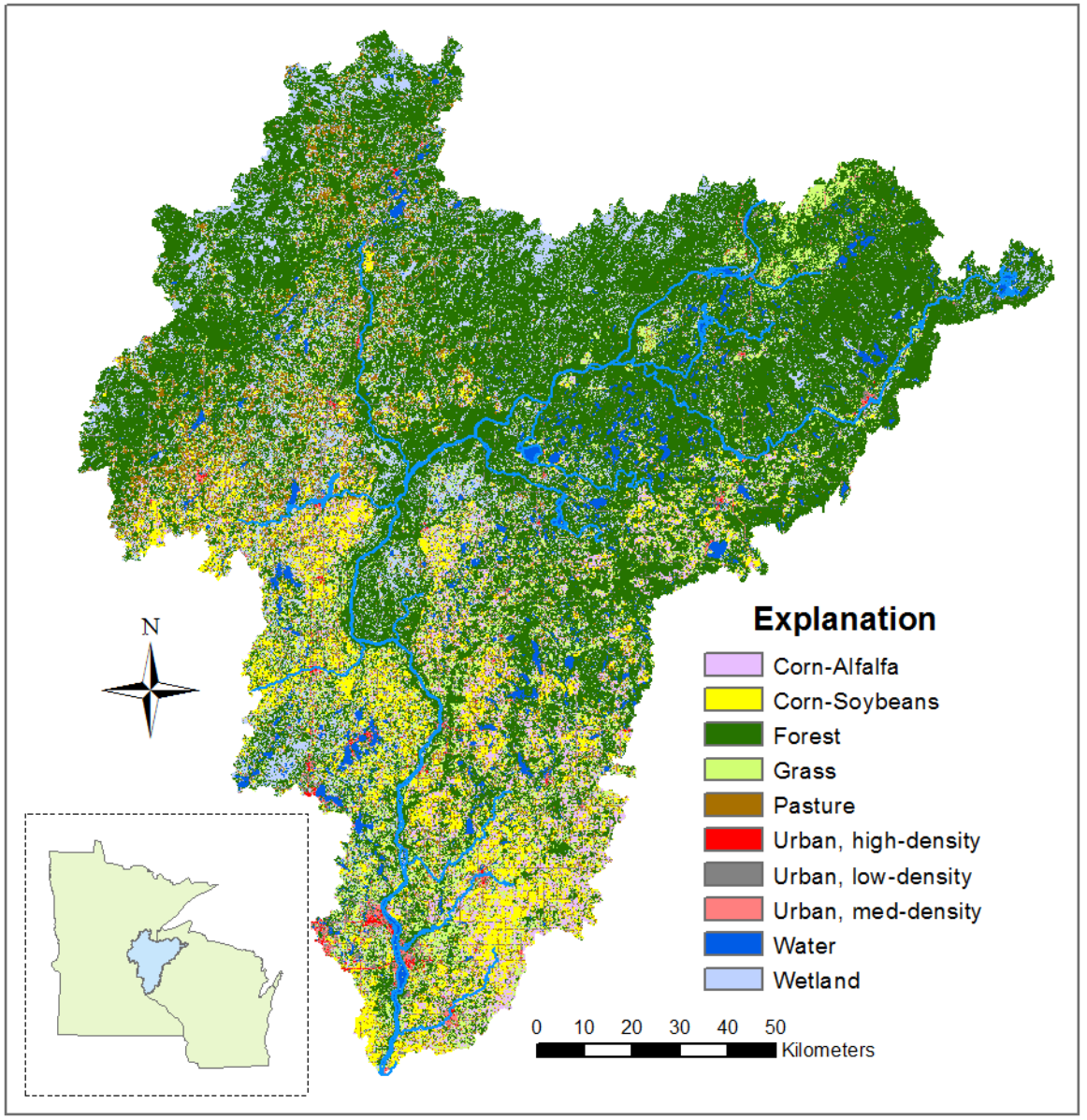
Background: Model Construction – basic inputs

- Land Use
  - Multiple overlays of USDA Crop Data Layers allowed identification of rotations to the pixel.



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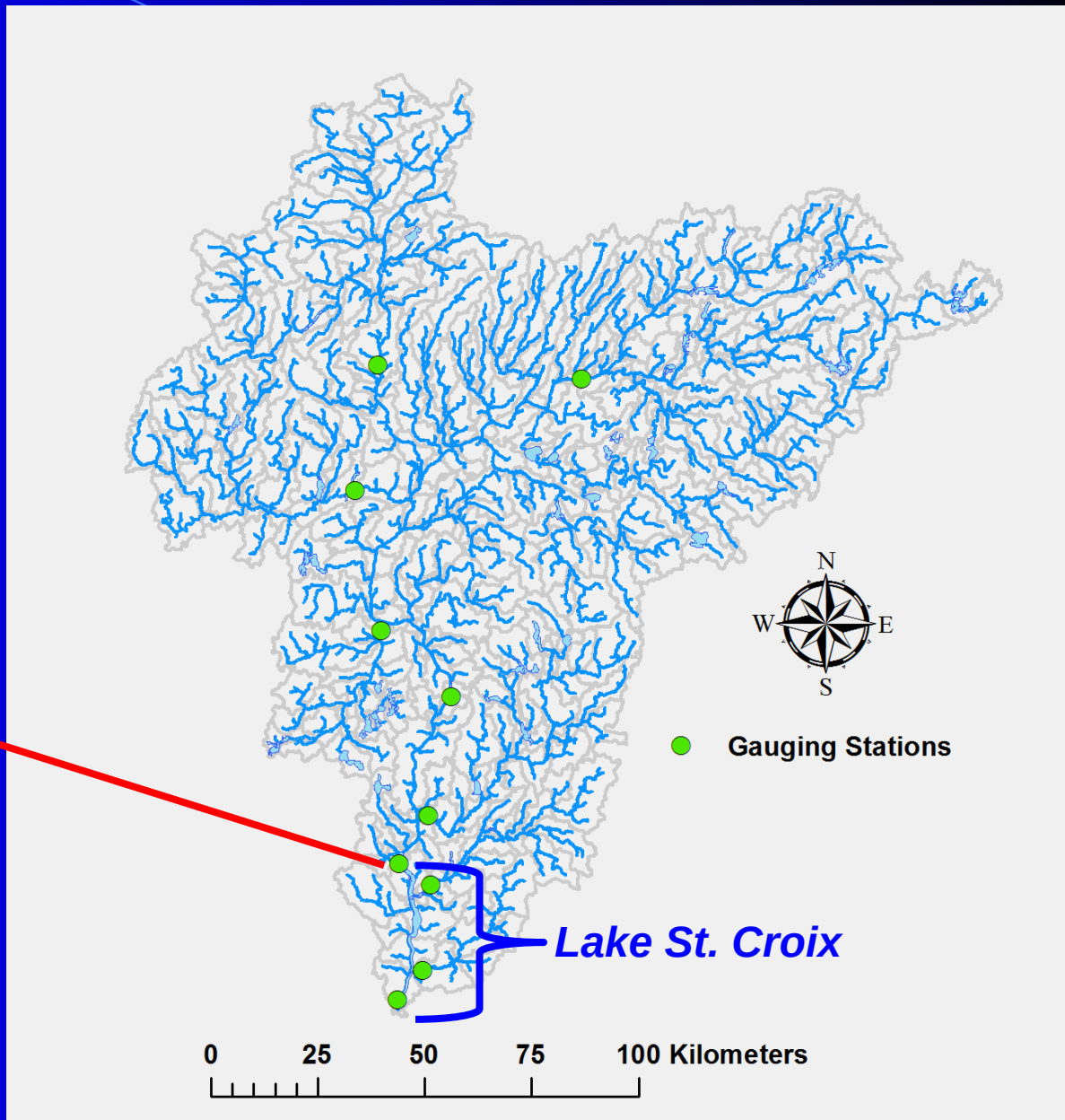
Background: Model Construction – basic inputs

- Subbasin discretization
  - 419 subbasins
    - ~48 km^2 each
    - ~18 mi^2 each
  - 39 lakes
    - >200 ha

St. Croix River at Stillwater:



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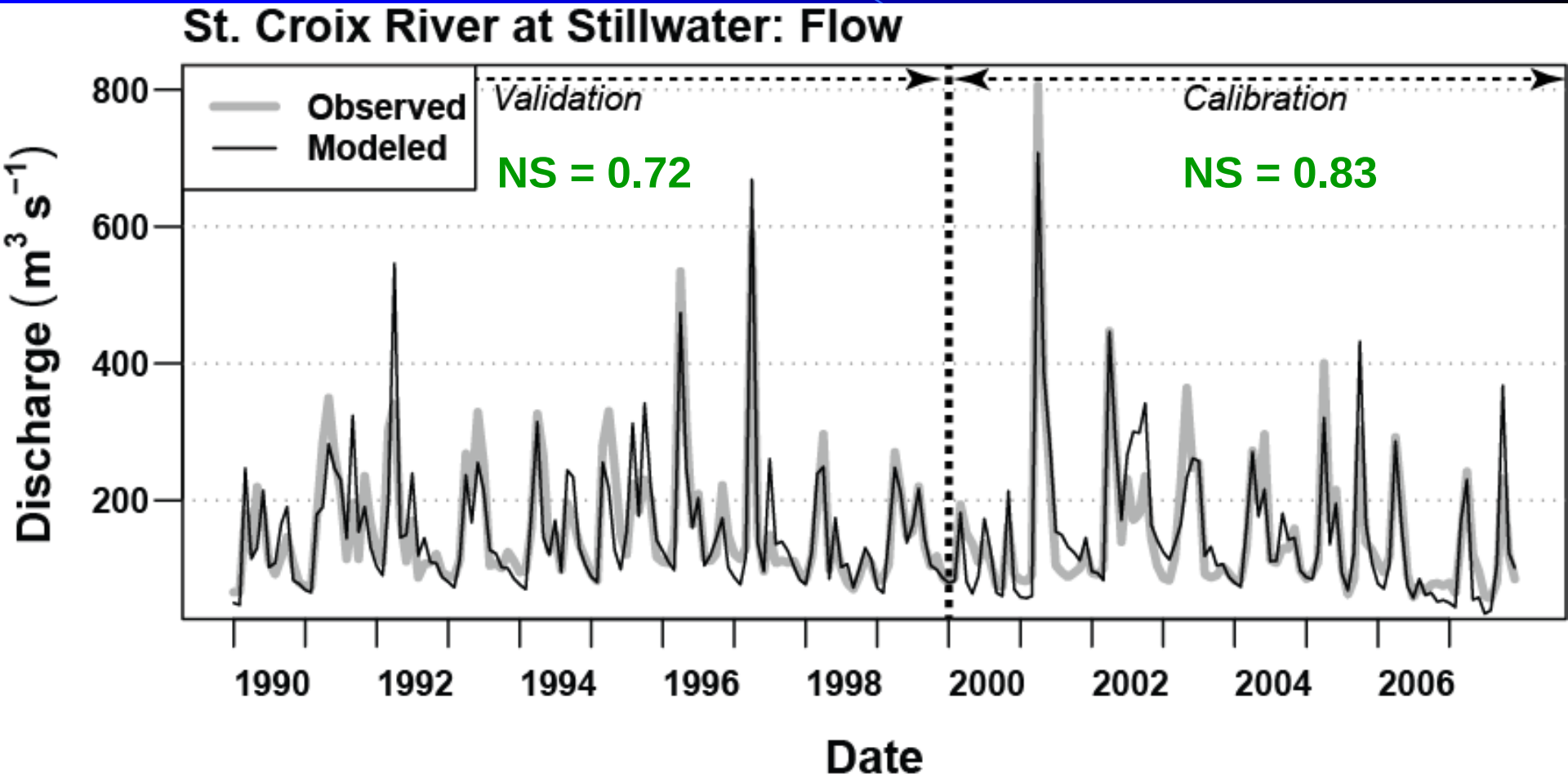
Model calibration: Hydrology (hard data)

St. Croix River at Stillwater, MN

+ Nine auxiliary sites



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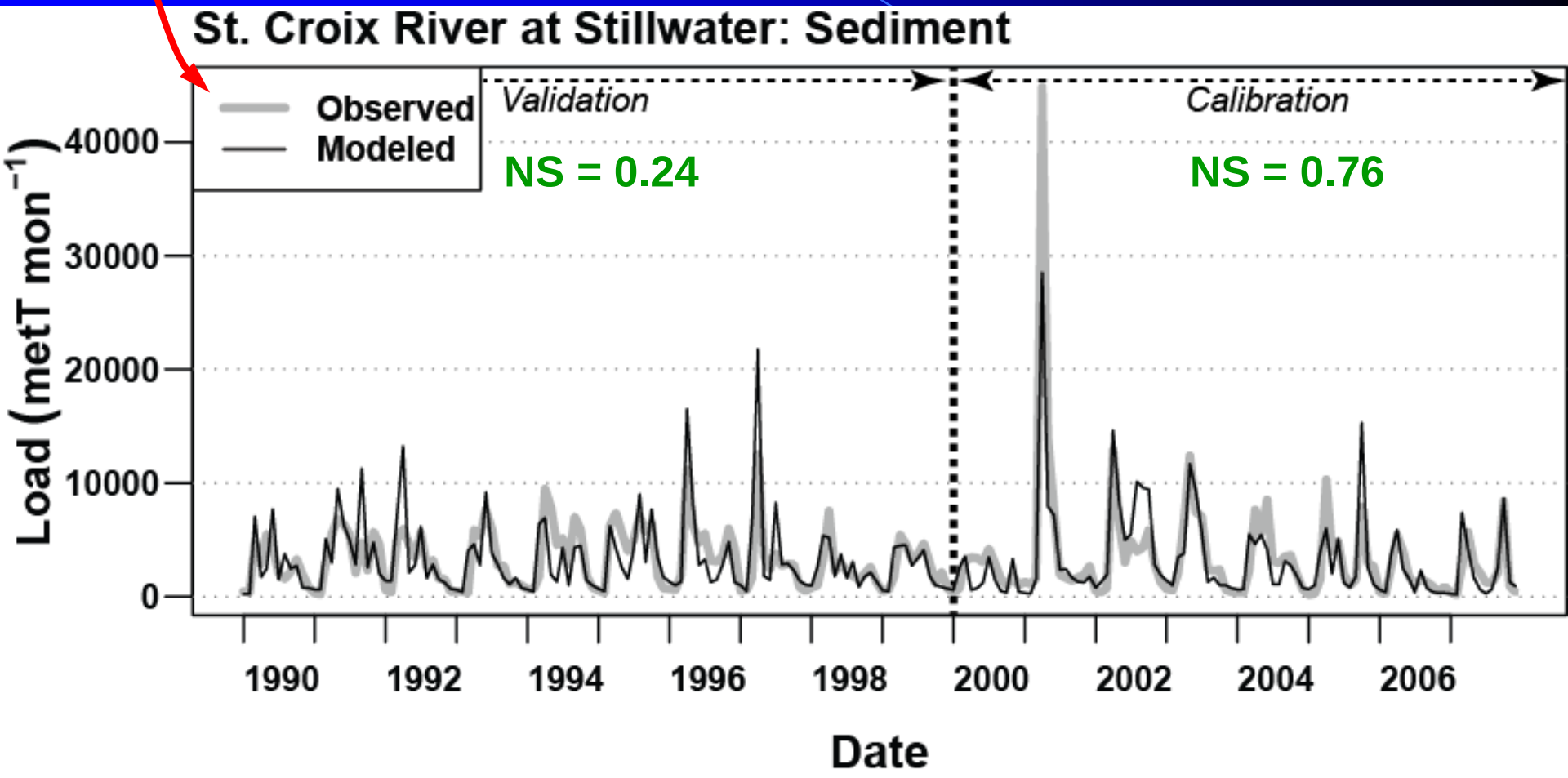
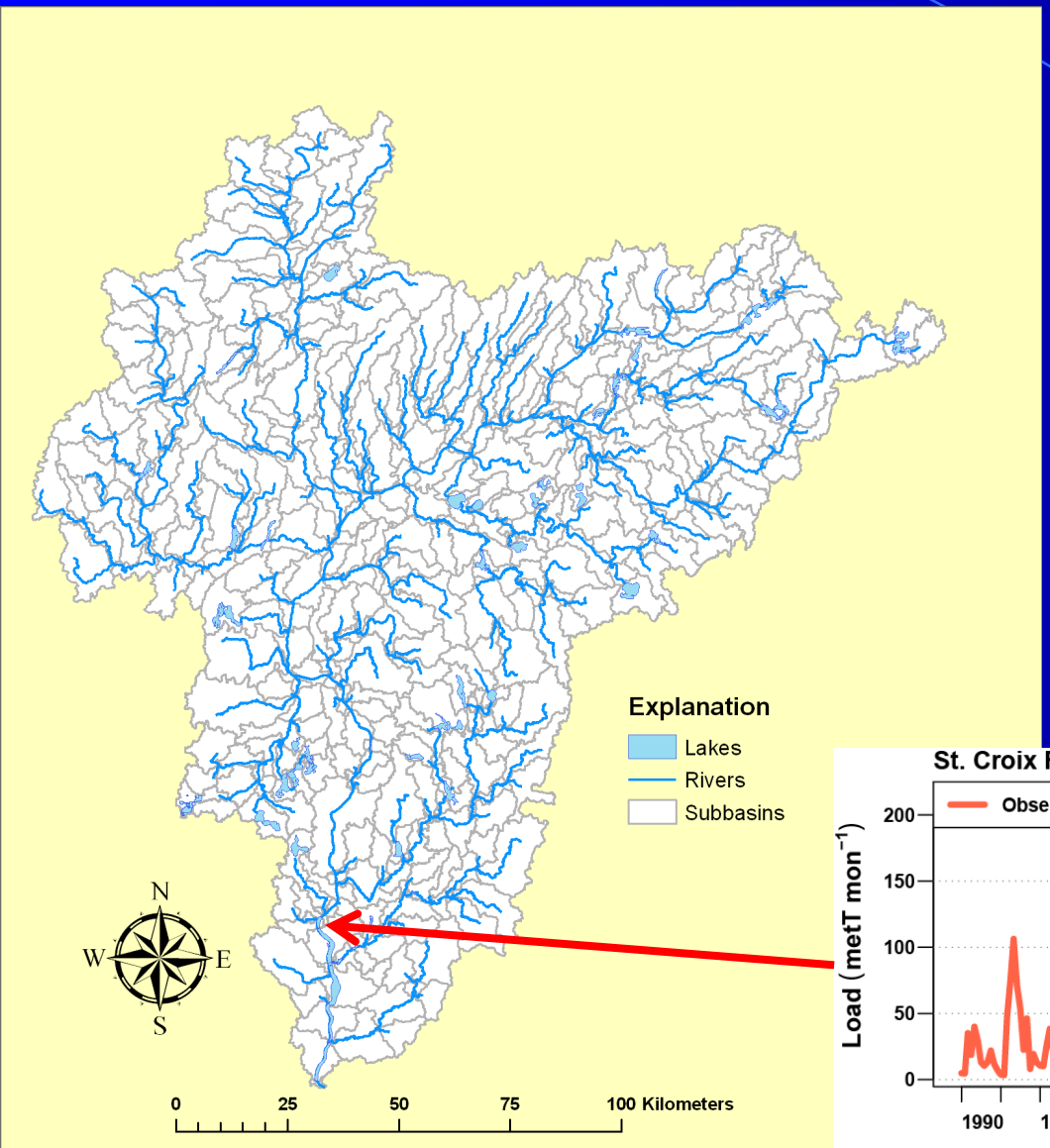
Model calibration: Sediment (hard data)

Observed loads are considered "hard data" here...

(...even though loads are estimated and not really observed)

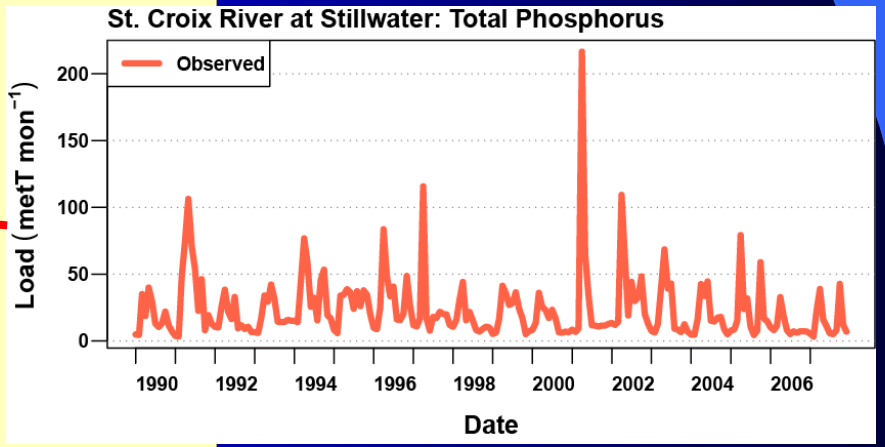


Model TP calibration target (hard data):



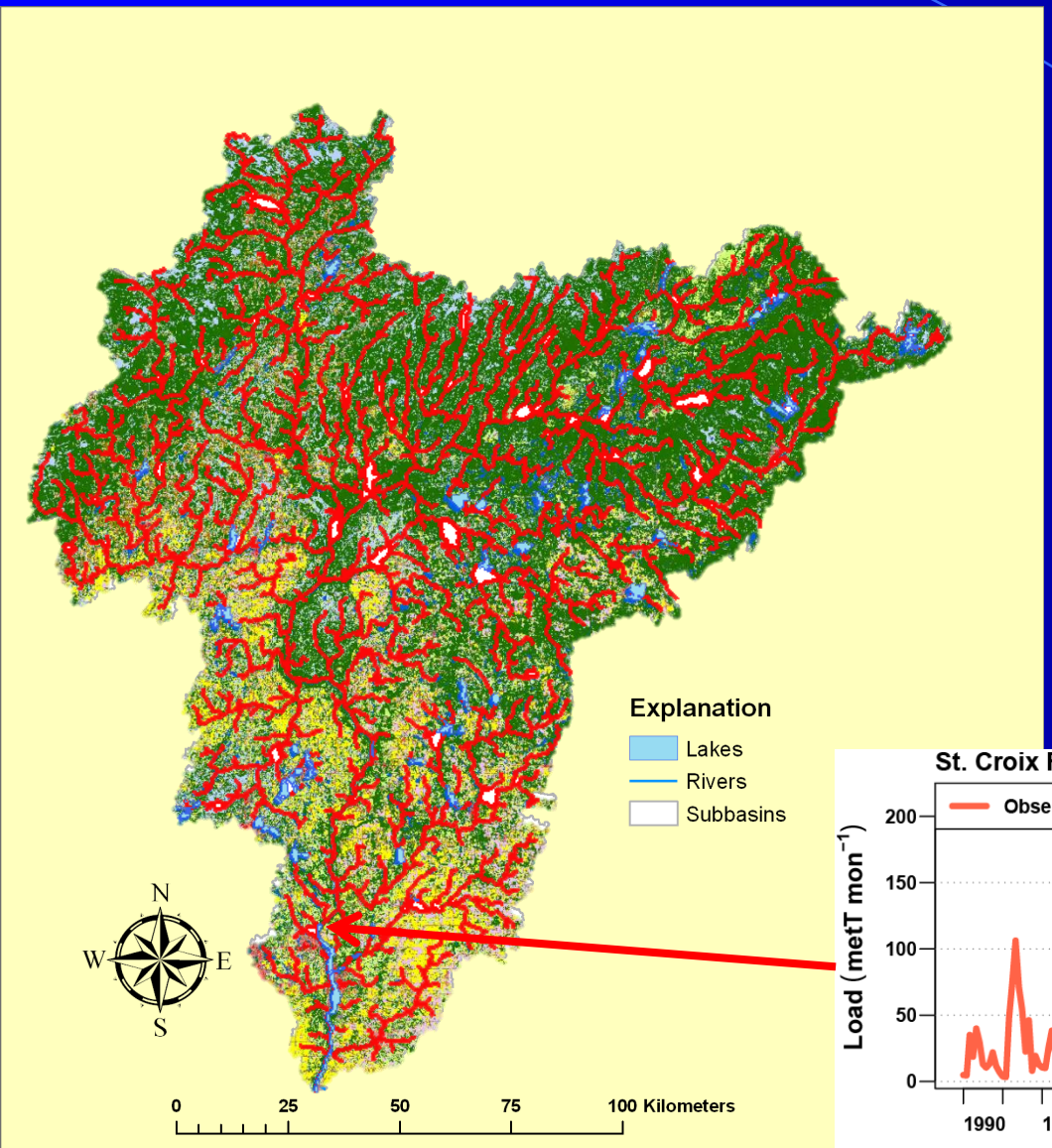
Loads of TP measured at inlet of Lake St. Croix

Considered "hard data" even though, as with sediment, loads are estimated and not actually observed



Model TP calibration target -- "soft data":

Source and Transport Factors



Source Factors (inputs):

Land use / land cover (HRUs)

Are TP yields reasonable?

Transport Factors (losses):

Overland runoff

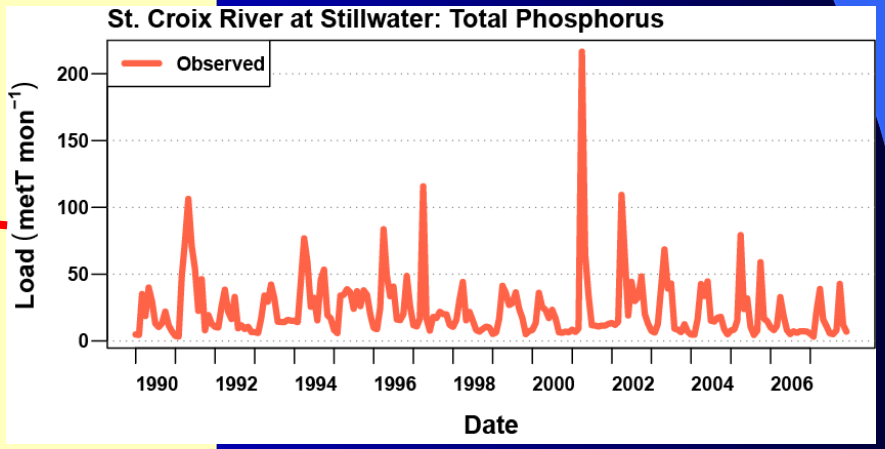
Ephemeral channels (tributaries)

Depressions (wetlands, ponds)

Reservoirs (lakes)

Channels & floodplains

Are TP losses reasonable?



Source and Transport Factor Schematic:

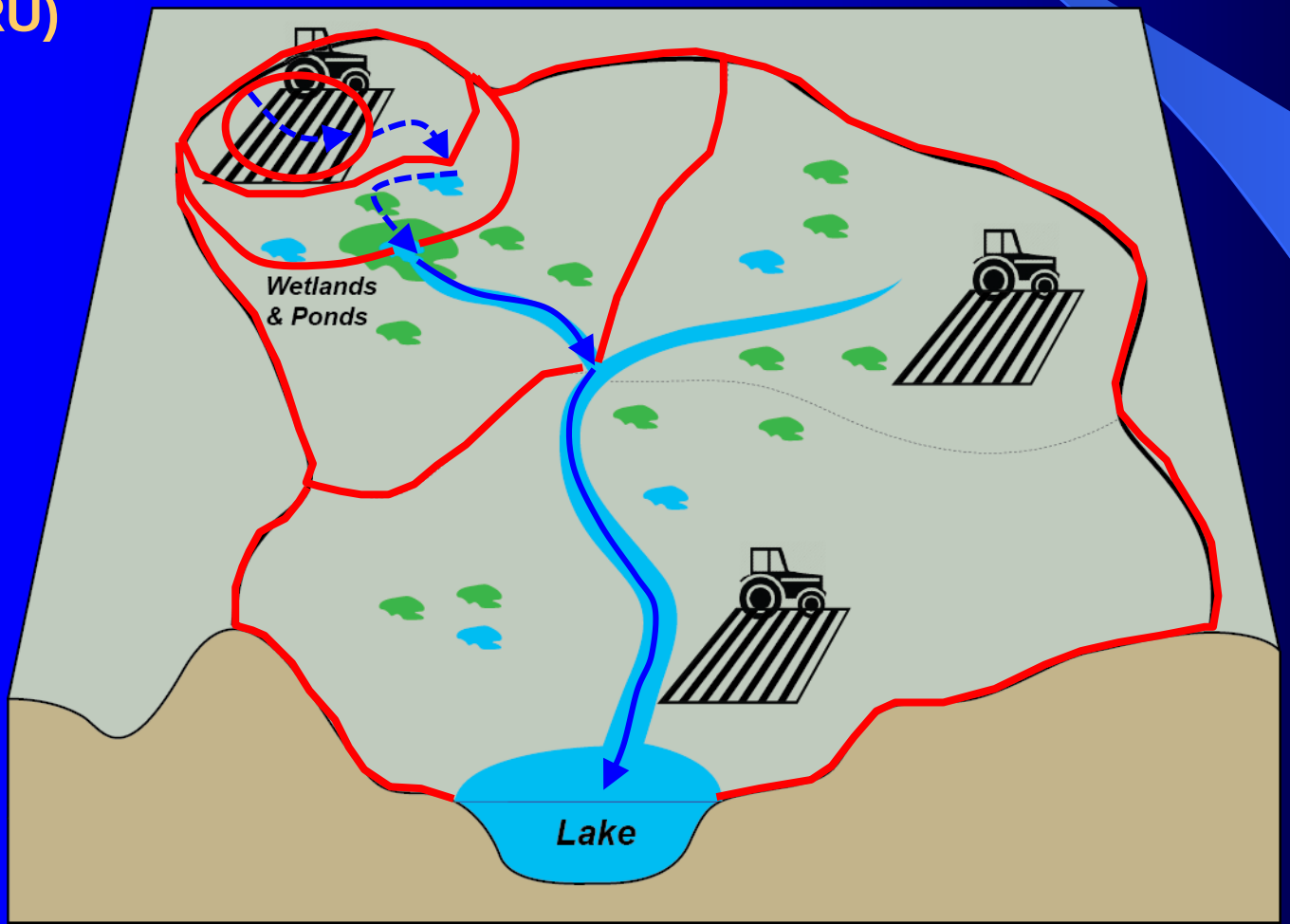
Source: Edge-of-field yields (kg/ha/yr) (HRU)

Transport: Overland flow (Tributary)

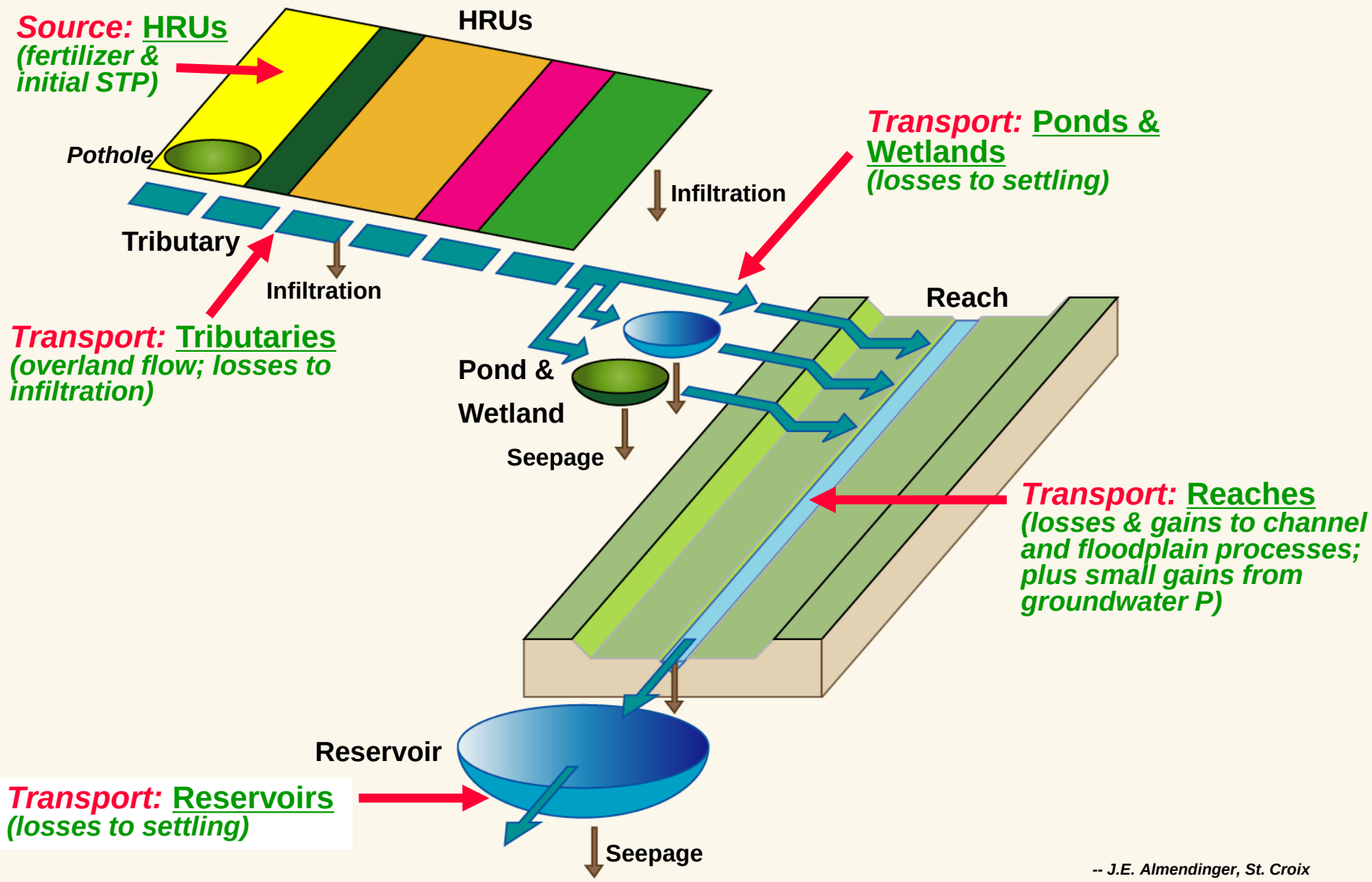
Transport: Lowland traps (Ponds)

Transport: Channel processes (Reaches)

Transport: Lake processes (Reservoirs)



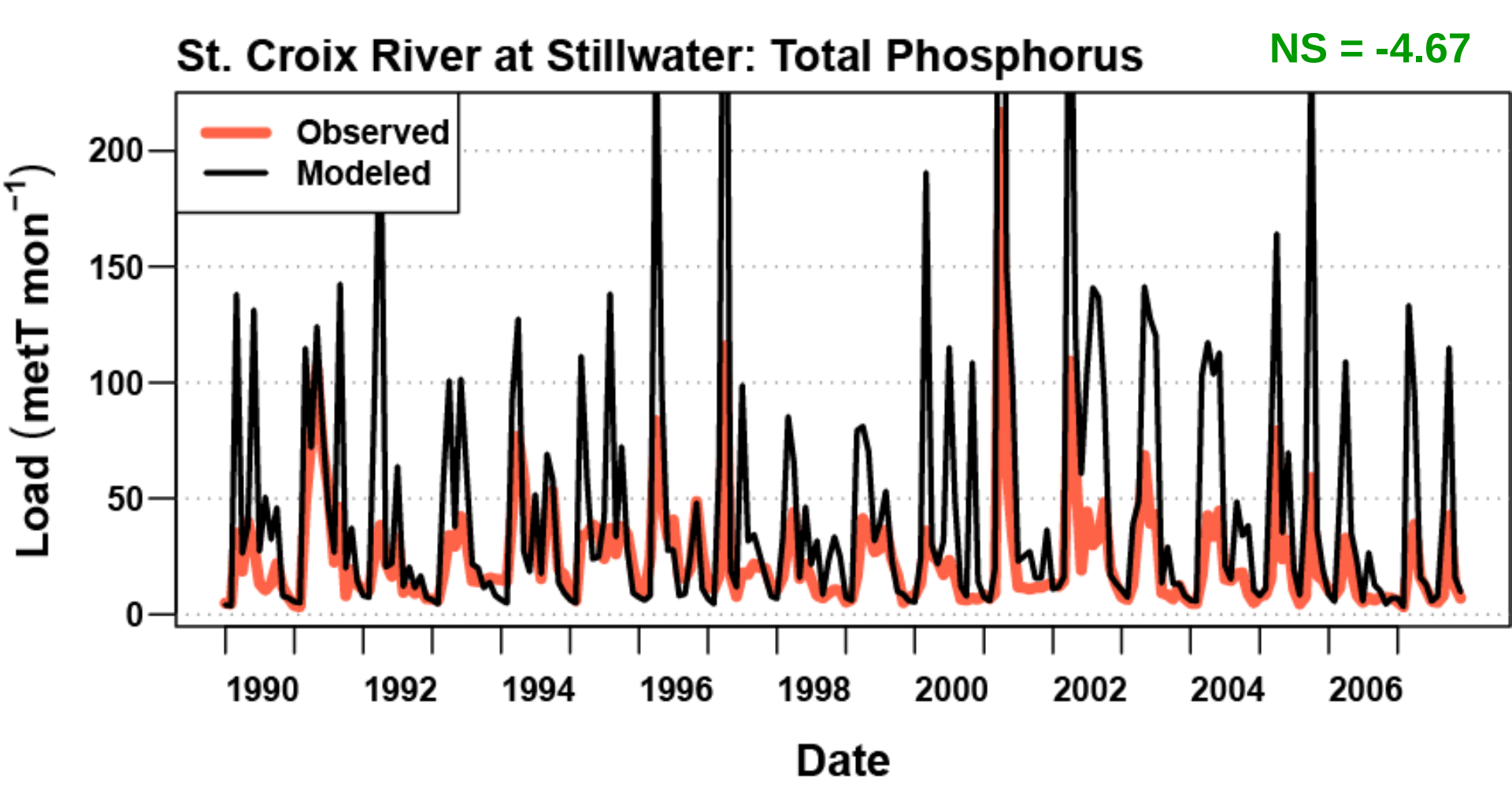
SWAT schematic view -- source and transport factors



-- J.E. Almendinger, St. Croix Watershed Research Station, 2011 --

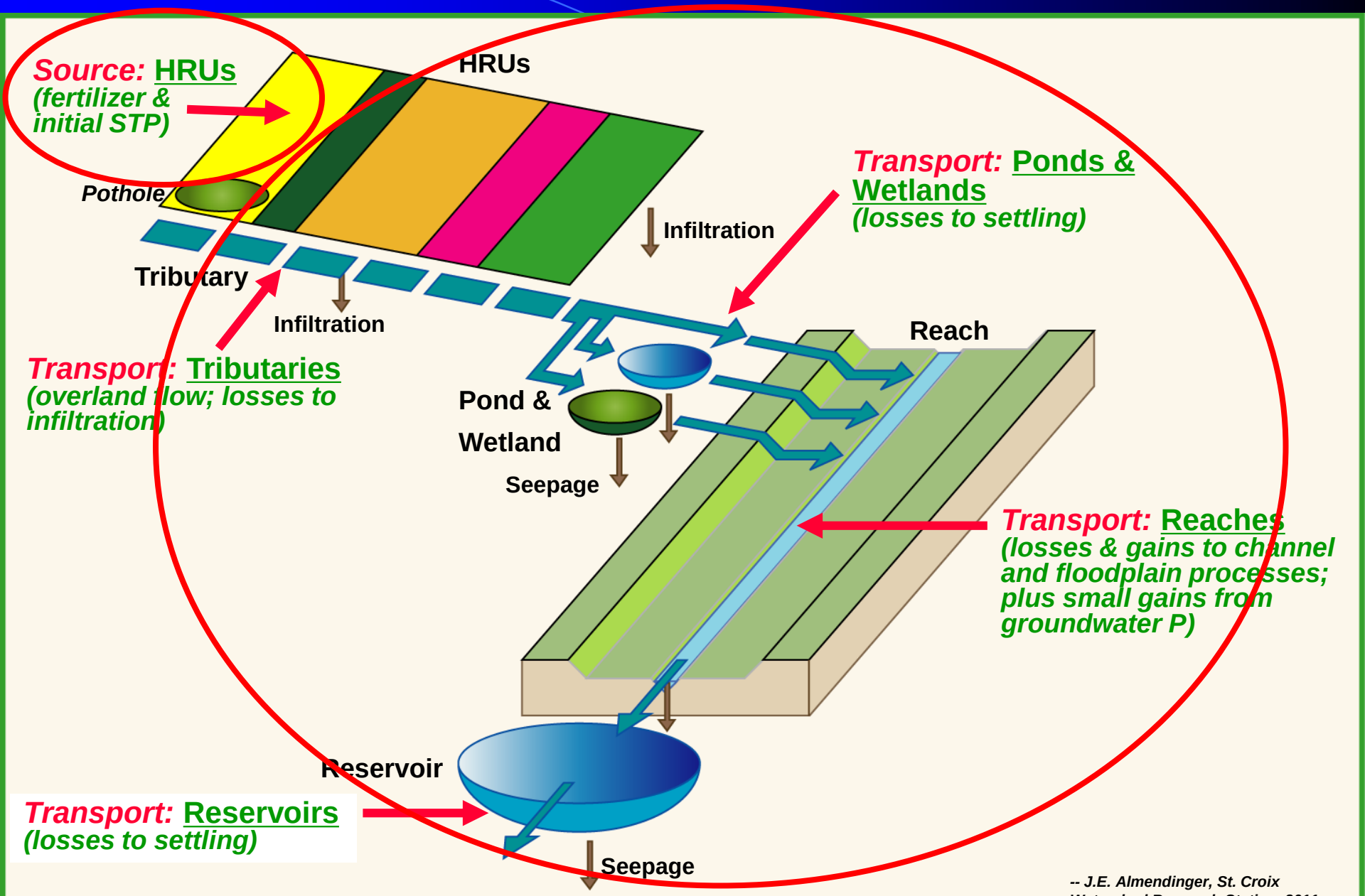
After hydrology & sediment calibrated

- Way too much TP at my gauge site -- %error in TP load = +110%
- How should I bring it down?
  - Reduce source strength?
  - Increase trapping along the way?
  - *Answer: a little bit of both, but how do you know how much of each??*



How much should I reduce this... ?

... or increase these?



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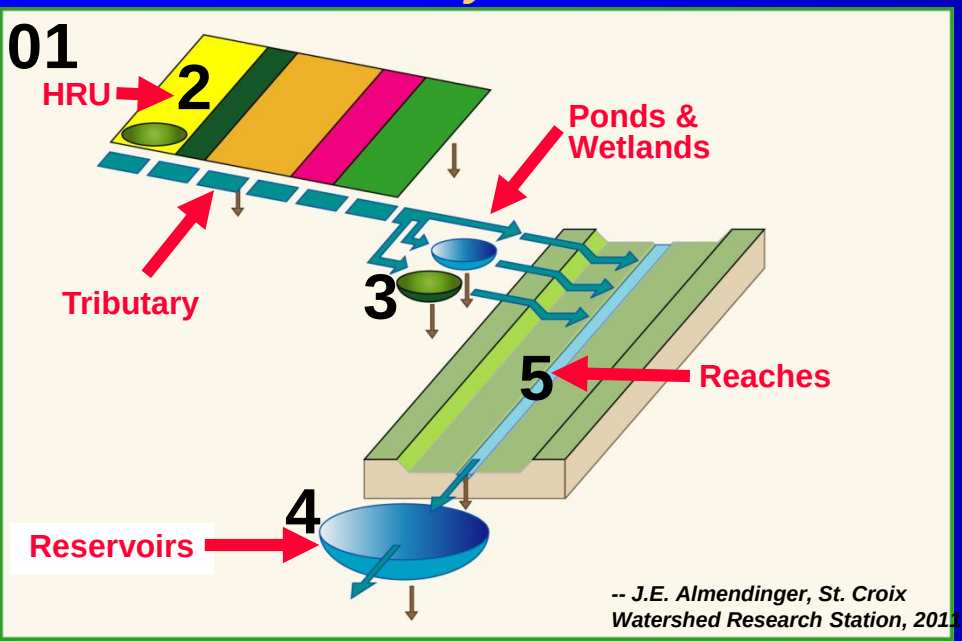
SWAT schematic view -- TP calibration steps

- (0) Build the model
  - Assign fertilizer rates
  - Assign STP (5-60 ppm)
  - Assign GW P (0.01-0.02 mg/L)
- (1) Calibrate hydrology & sediment
  - CN, ESCO, etc.
  - USLE_P (= 0.8 for St. Croix)
- (2) Adjust source: HRU TP yields
  - PSP, PHOSKD, etc.
  - SOL_LABP1 = coeff * STP
  - *Are HRU TP yields reasonable?*

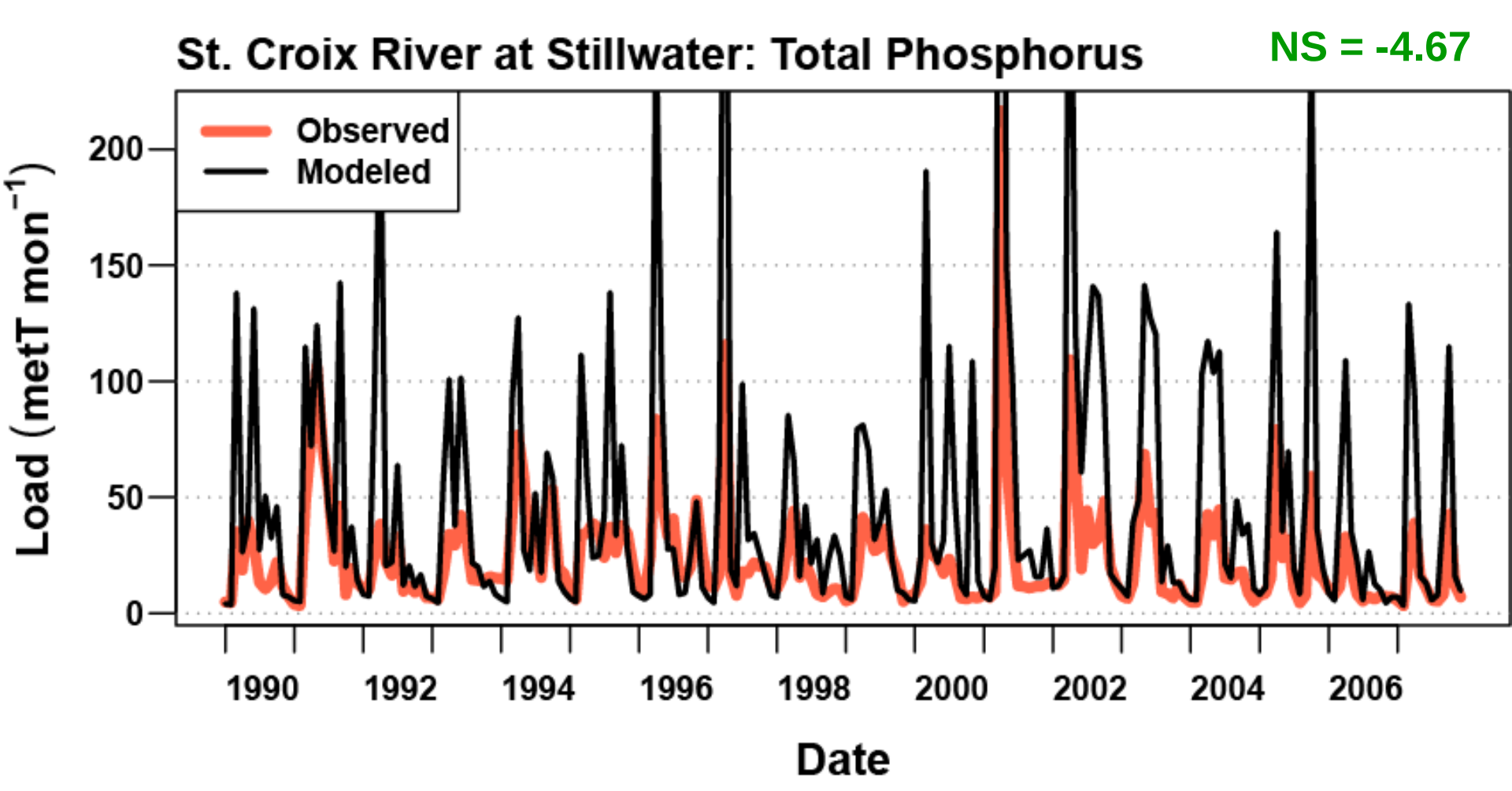


- (3) Adjust trapping by lowlands
  - Pond PSETLP1 & 2
  - Settling season Mar-Oct (3-10)
  - *Is Pond trapping reasonable?*
- (4) Adjust trapping by reservoirs
  - Reservoir PSETLR1 & 2
  - Settling season Mar-Oct (3-10)
  - *Is Reservoir trapping reasonable?*
  - *Is total load (PBIAS) reasonable?*
- (5) Adjust channel parameters
  - Activate QUAL2E to dampen TP signal
  - TP sedimentation + desorption
  - Floodplain & backwater storage & release?
  - *Is total load (PBIAS) still OK?*
  - *Is Nash-Sutcliffe fit OK?*

Step (1): Hydrology & sediment calibrated

- USLE_P = 0.8
- SOL_LABP1 = 0.4*STP
- No settling in Ponds or Reservoirs
- No Channel processes

- Over full 18-year record:
  - NS = - 4.67
  - % Error in load = +110%



Step (2): Adjust source -- HRU yields

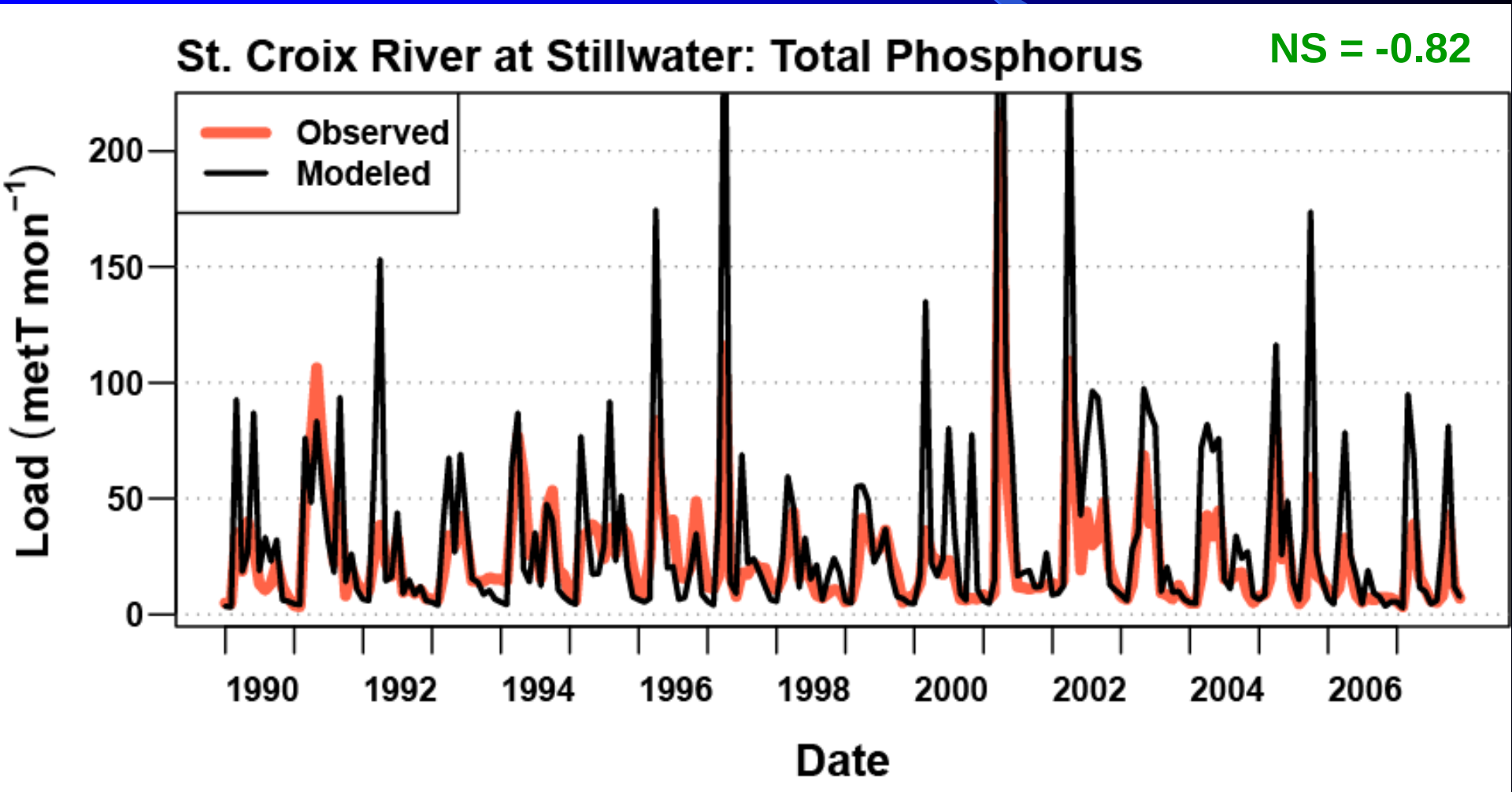
- SOL_LABP1 = 0.15*STP
- Over full 18-year record:
  - NS = - 0.82
  - % Error in load = +47%

Reasonable cropland HRU TP yields:

CORN = 1.86 kg/ha CSIL = 1.83 kg/ha

SOYB = 2.23 kg/ha ALFA = 0.44 kg/ha

(SDs = ~ 1-2 X means)



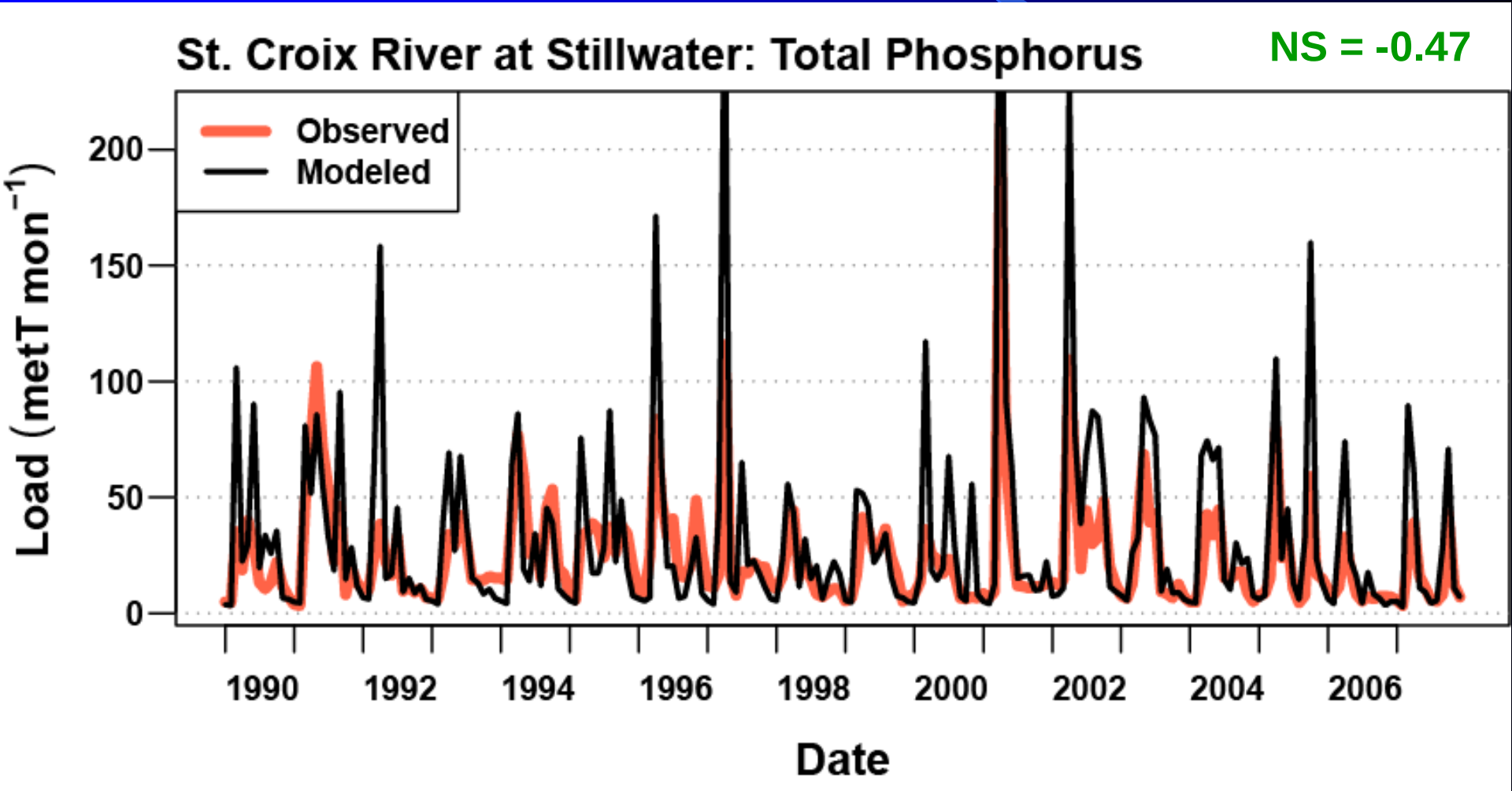
Step (3): Adjust trapping by lowlands (Ponds &/or Wetlands)

- PSETLP1&2 = 100 m/yr
- March-October settling season
- Over full 18-year record:
  - NS = - 0.47
  - % Error in load = +40%

Reasonable TP trapping (?):

-- About 45% of basin drains to lowlands

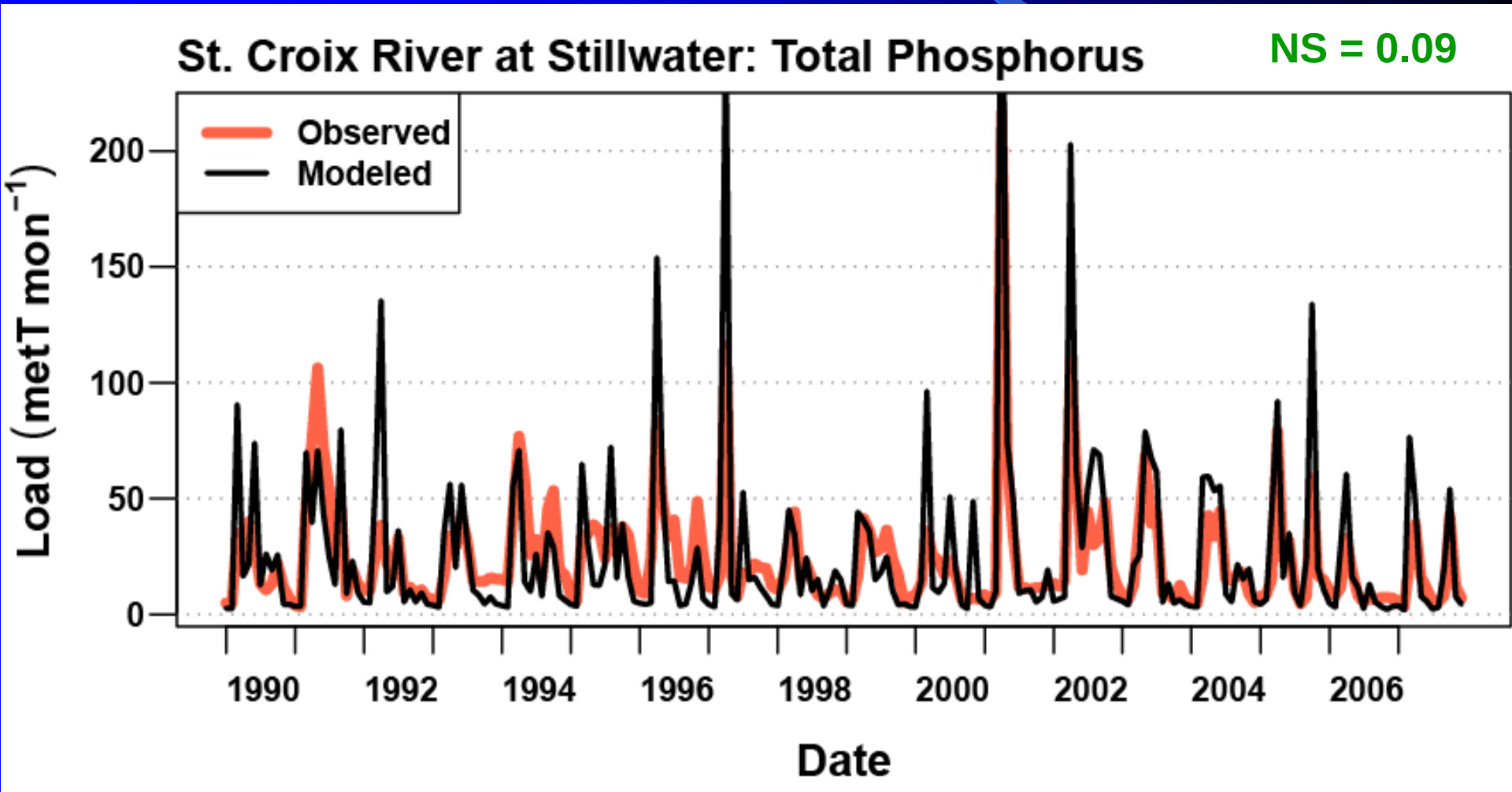
-- Trapping efficiency = ~15%



Step (4): Adjust trapping by lakes (Reservoirs)

- PSETLR1&2 = 5-224 m/yr (43 avg)
- March-October settling season
- Over full 18-year record:
  - NS = 0.09
  - % Error in load = +12%

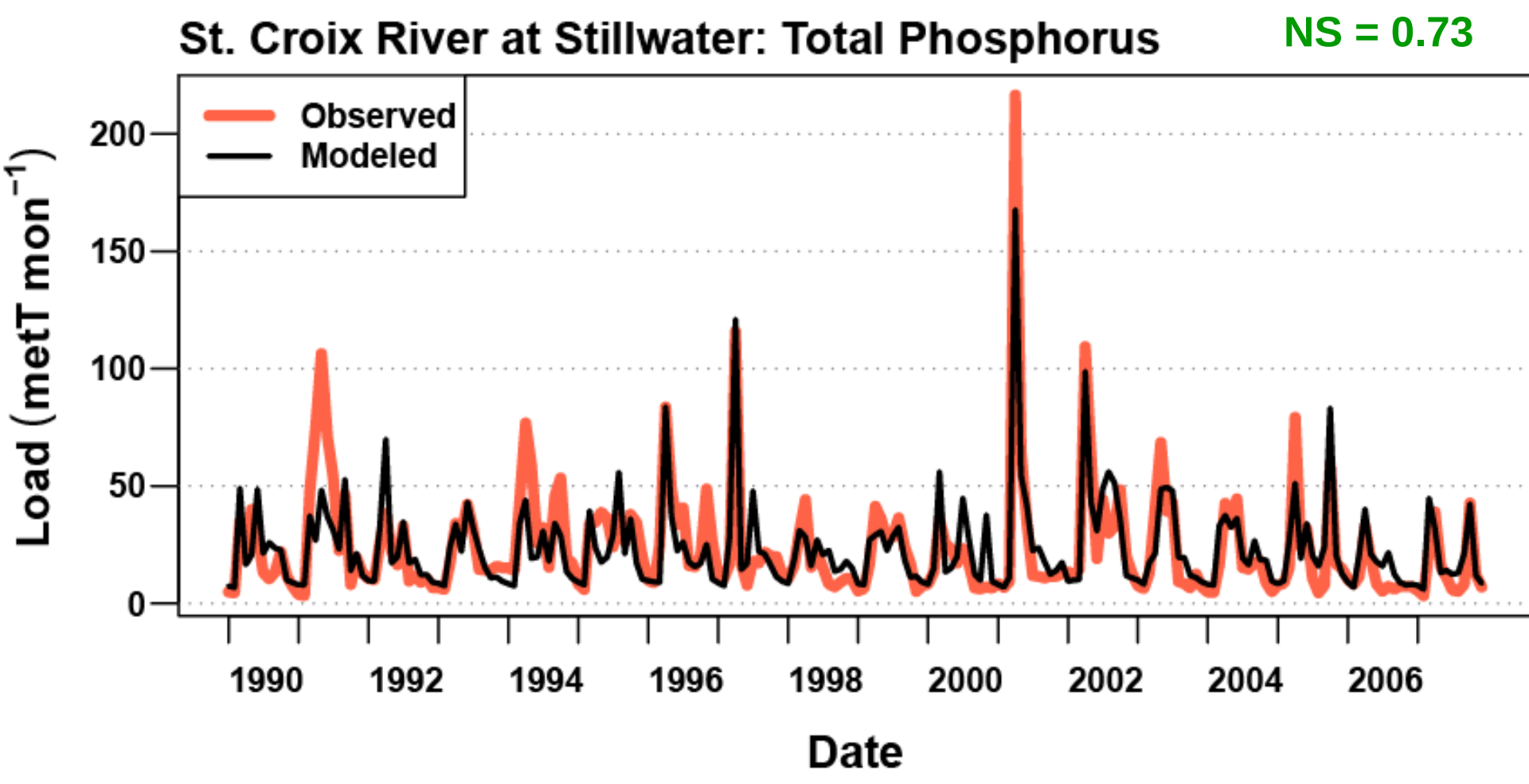
Reasonable TP trapping (?):
-- Trapping efficiency = ~48% (10 to 76%).
-- Within 2% of TP trapping in Lake St. Croix during 1990s
-- PSETLR = 50*D/Tr^0.5



Step (5): Activate channel processes (QUAL2E)

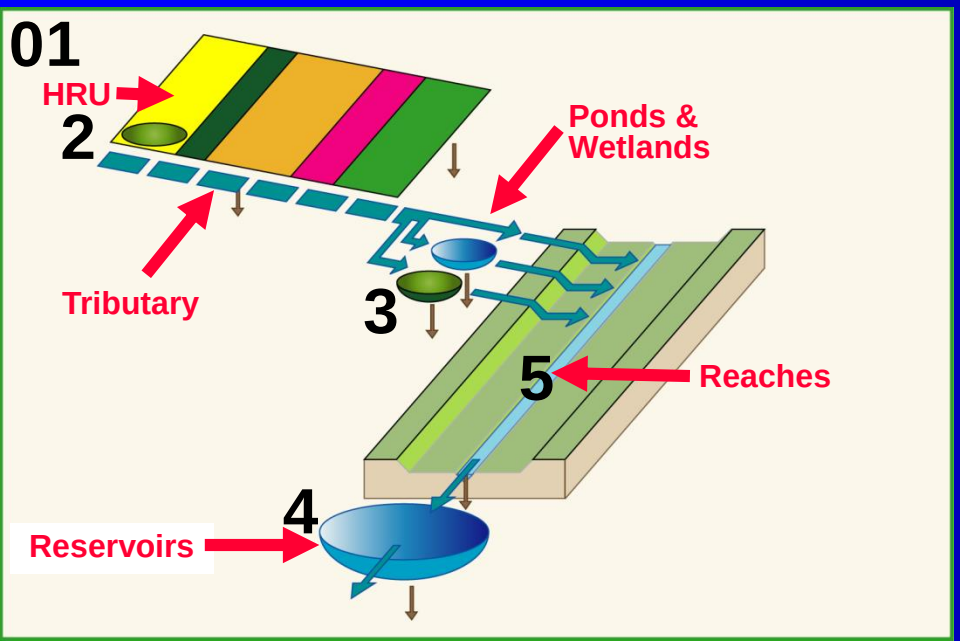
- P desorption RS2 = 15
- P settling RS5 = 1.4
- Over full 18-year record:
  - NS = 0.73
  - % Error in load < 1%

Reasonable TP processing (?):
-- Calibrated values ~ 10X defaults; not likely the same mechanism expected by QUAL2E.
-- Perhaps backwater storage & release?



SUMMARY -- TP calibration steps

- (0) Build the model
  - Assign fertilizer rates
  - Assign STP (5-60 ppm)
  - Assign GW P (0.01-0.02 mg/L)
- (1) Calibrate hydrology & sediment
  - USLE_P (= 0.8 for St. Croix)
- (2) Adjust source -- HRU yields
  - SOL_LABP1 = a * STP
  - *CORN & CSIL = 1.8 kg/ha*
  - *SOYB = 2.2 kg/ha*



- (3) Adjust trapping by lowlands
  - Pond PSETLP1&2 = 100 m/d
  - Settling season Mar-Oct (3-10)
  - *Pond TP trap efficiency ~15%*
- (4) Adjust trapping by reservoirs
  - Res PSETLR1&2 = 5-224 m/d
  - Settling season Mar-Oct (3-10)
  - *Res TP trap efficiency = 48%*
- (5) Adjust channel parameters
  - Activate QUAL2E to dampen TP signal
  - TP sedimentation + desorption
  - Floodplain & backwater storage & release?
  - *Channel traps ~12% TP load*
  - *18-yr Nash-Sutcliffe = 0.73*

-- J.E. Almendinger, St. Croix Watershed Research Station, 2011 --

Questions?

I envy this kid... He really, really knows the right answer!

When was the last time that you really, really knew the right answer?

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