Use of SWAT to Scale Sediment Delivery from Field to Watershed in an Agricultural Landscape with Depressions

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Outline:

- Problem
  - Landscape depressions impact sediment yield
  - Sediment Delivery Ratio (SDR) exemplifies this effect
- Solution (partial)
  - SWAT pond & wetland functions can help
  - Applied to two watersheds in north-central USA
- Spatial scales of sediment yield
  - Plot > Field > Upland > Pre-Riverine > Riverine > Watershed
- Conclusion
  - Extrapolation of plot-scale parameters to the watershed scale requires caution

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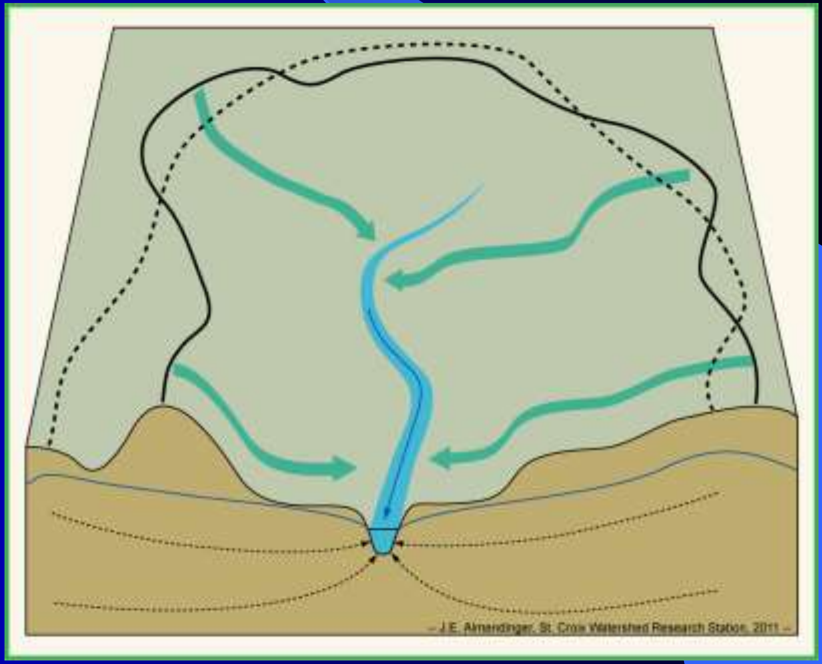
Importance:

- **Nonpoint-source pollution (NPS)** is the main cause of water pollution in the USA today
- **Landscape depressions** – especially noncontributing basins – *must* have a significant impact on watershed hydrology and transport of NPS (sediment and nutrients)
- Yet the impact of such depressions is **under-reported** in the literature, especially in the modeling literature.
  - The research group at Kiel University is an exception
- For sediment transport, landscape depressions contribute to the problem of a **scale mis-match**
  - between *mechanism at the plot scale*, and
  - *impacts at the watershed scale*
  - because depressions are at a scale intermediate between plots and watersheds.

The Problem:

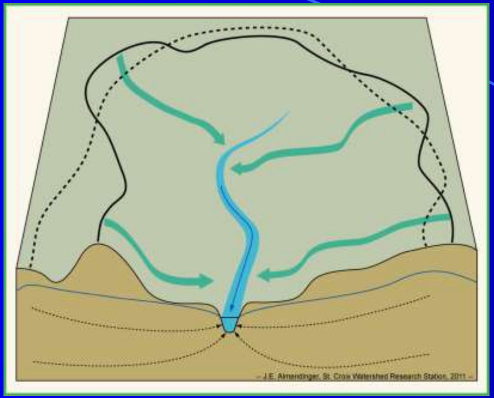
Plot-scale yields (t km^{-2} yr^{-1}) ***often*** **>** **Watershed-scale yields (t km^{-2} yr^{-1})**



...and the difference can be LARGE

Sediment delivery ratio (SDR):

(for yields in t km^{-2} yr^{-1})

SDR = 

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$$\text{SDR} = \frac{\text{Watershed sediment yield}}{\text{USLE sediment yield (area wtd)}}$$

almost always **<< 1** ***(or 100%)***

SDR is scale-dependent:
The larger the watershed, the smaller the SDR.

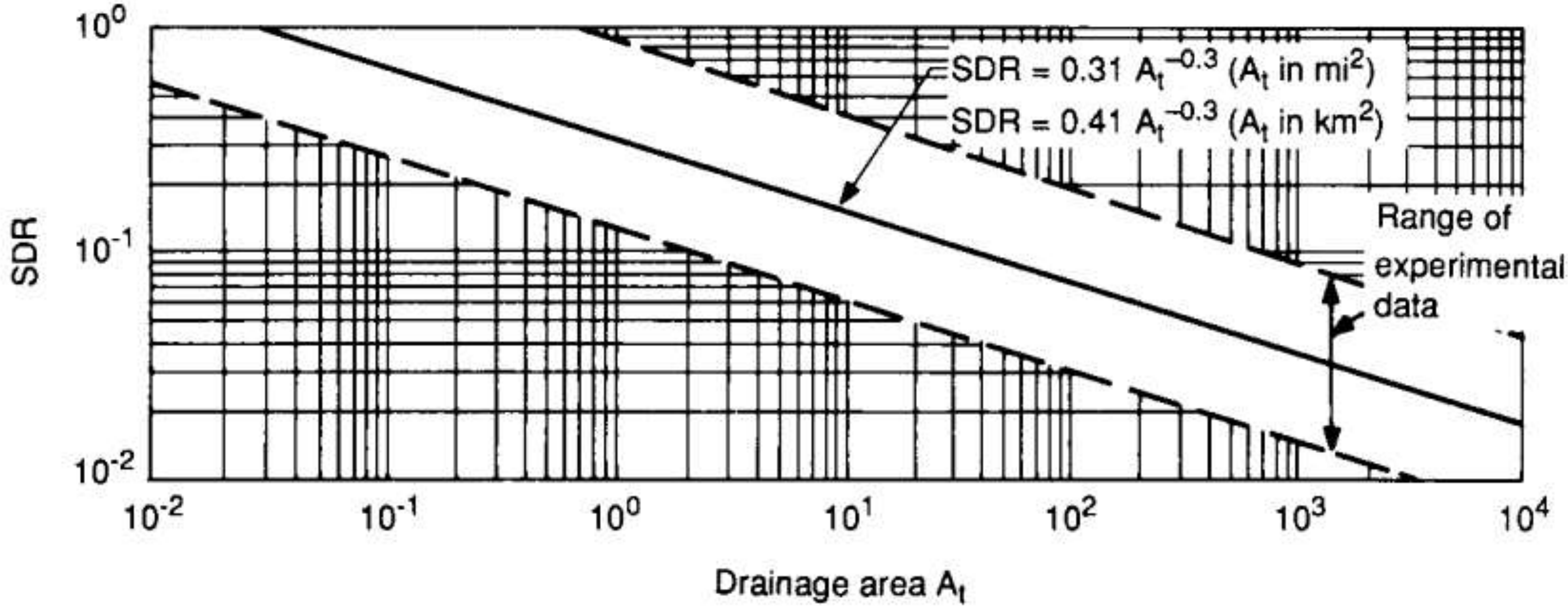

FIGURE 12.10.4 Sediment-delivery ratio (SDR) vs. drainage area.

Maidment, D.R., ed. 1993. Handbook of Hydrology, McGraw Hill, p. 12.53

For 700 km^2 watershed, SDR = 6%

So 94% of the sediment gets trapped between the field and watershed outlet. Where does it go??

The modeler must make a decision about this…

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Where does the missing sediment go?

It is halted in short-term and long-term traps between the point of generation and the watershed outlet.

FIELD

In-field potholes

Grass waterways

Edge of field

Ponds

Wetlands

Floodplains

Reservoirs

WATERSHED OUTLET

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How does SWAT handle the problem?

SWAT uses the modified USLE = MUSLE

- **Modified Universal Soil Loss Equation**
  - **Williams, 1975**
  - **Replaces the USLE rainfall factor with a runoff factor:**
  - $11.8*(Q_{vol}*q_{peak})^{0.56}$

These two parameters were determined by fitting the MUSLE to sediment yield data from 18 study watersheds in southern USA.

- ***To the degree that these 18 watersheds represent the topographic sediment traps of your watershed, the MUSLE eliminates the need for a sediment delivery ratio.***
- ***Watersheds with more internal sediment traps will require more processing than MUSLE alone.***

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Glaciated landscapes can have "deranged hydrology" with many closed depressions

Extent of ice advance at the last glacial maximum, ca. 20 ka, covering Canada and northern USA

(after Dyke et al. 2003)

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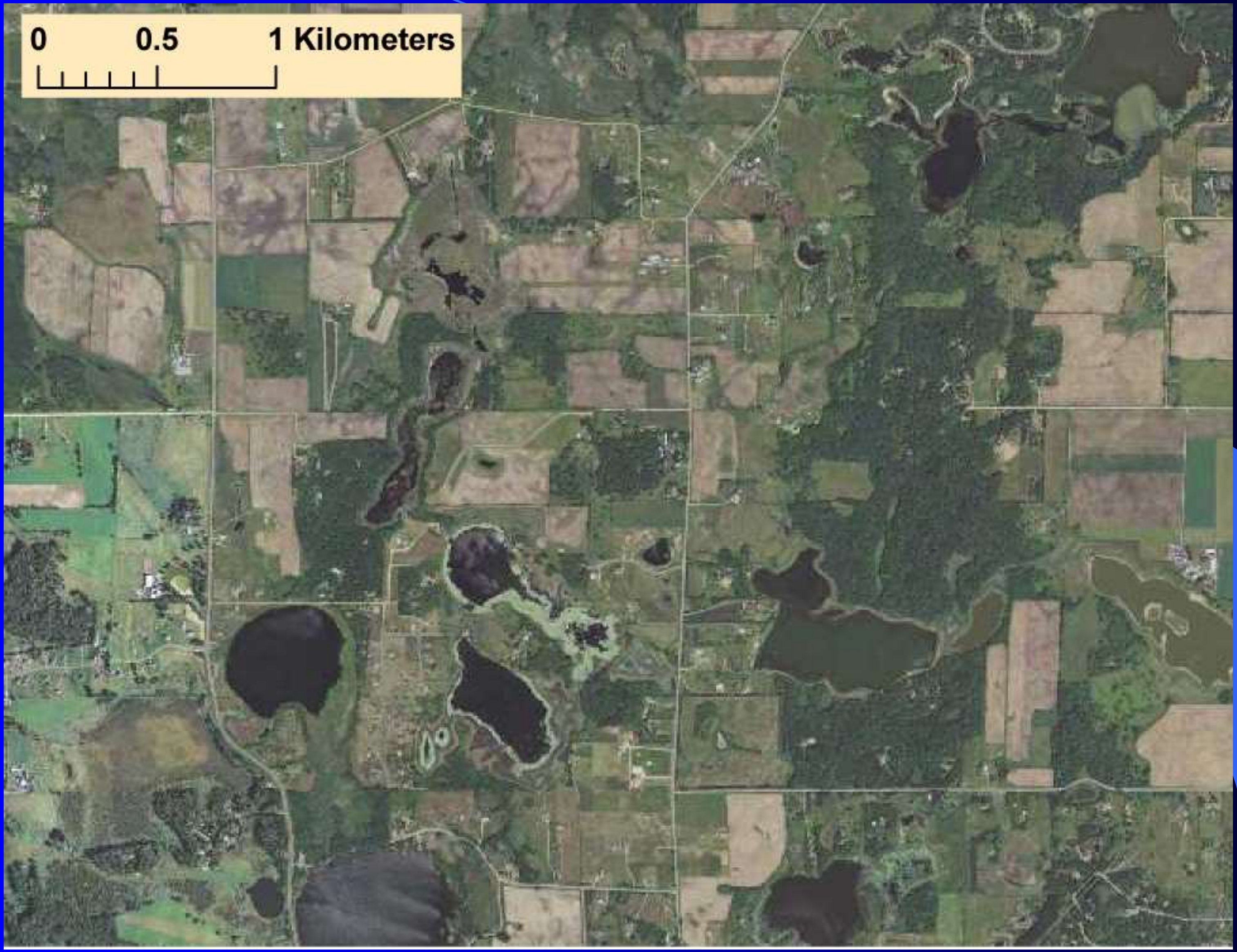
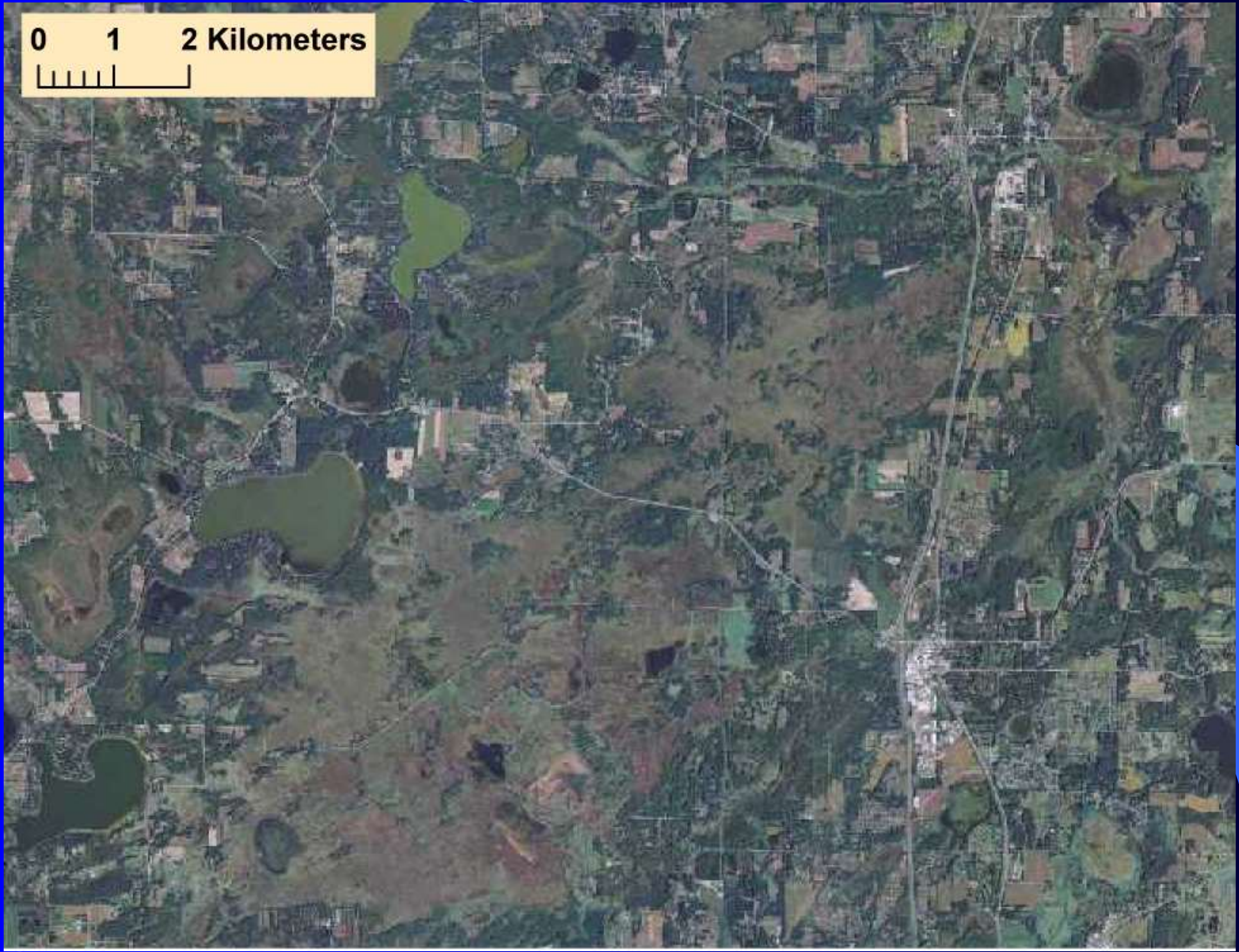
Glaciated landscape depressions

Kettle lakes and wetlands on moraines



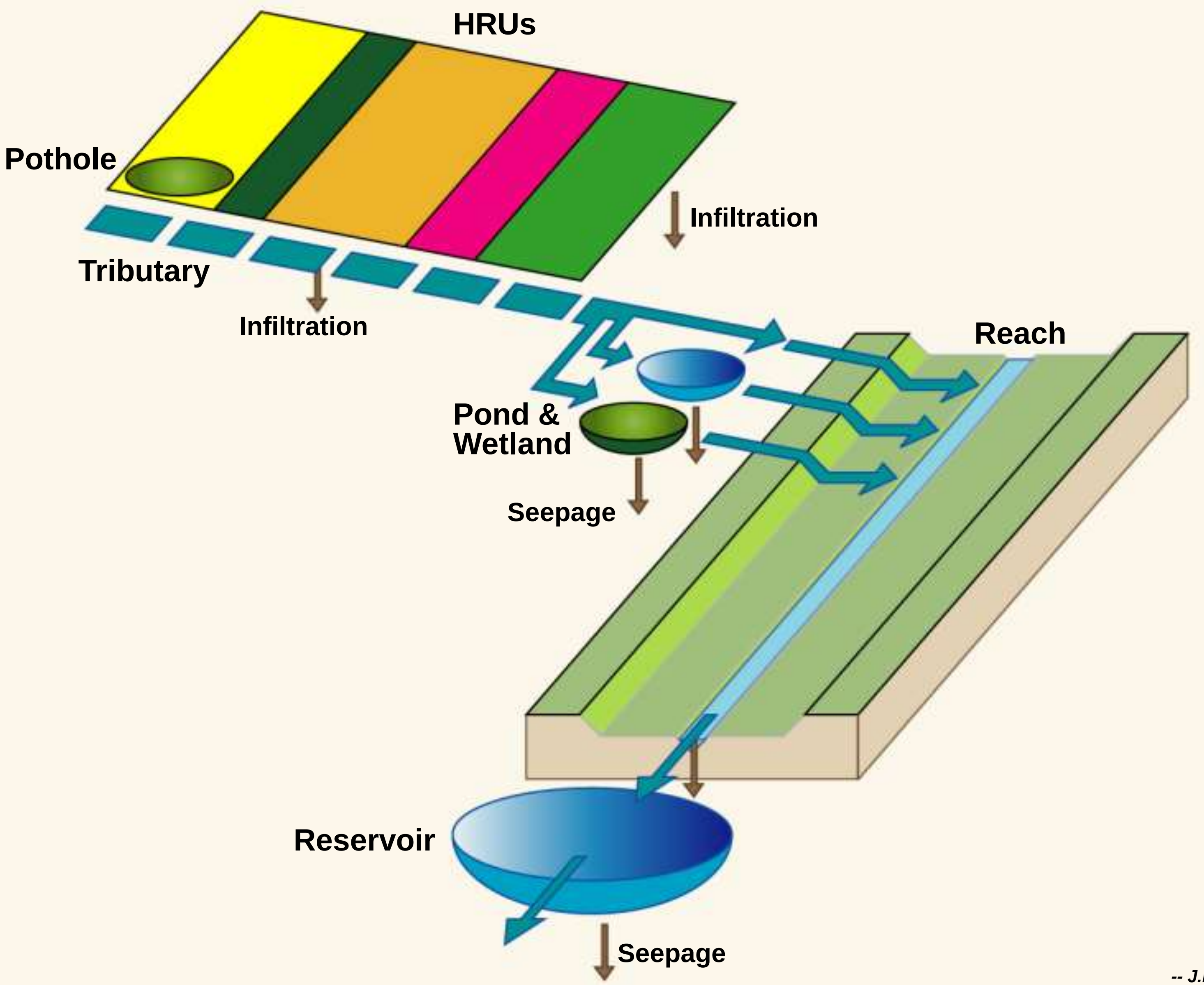
SE part of Sunrise River watershed, Minnesota

Expansive marshes on sandplains



Central part of Sunrise River watershed, Minnesota

SWAT can simulate the effect of landscape depressions with its Pothole, Pond, and Wetland functions:



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

If SWAT's impoundments do not reduce sediment yield enough, what more can you do?

The MUSLE equation:

$$sed = 11.8*(Q_{vol}*q_{peak})^{0.56}*K_{USLE}*C_{USLE}*P_{USLE}*LS_{USLE}*CFRG$$

All factors are determined by ArcSWAT from your input data (K, C, LS, and CFRG), or by SWAT during each model run (Q and q),

EXCEPT for P_{USLE}

P_{USLE}:

= Support Practice Factor, intended to account for contour tillage practices, e.g.

-- Defaults to 1

-- Can be used simply as a scaling parameter to further reduce sediment yields as needed: $0 < P_{USLE} < 1$

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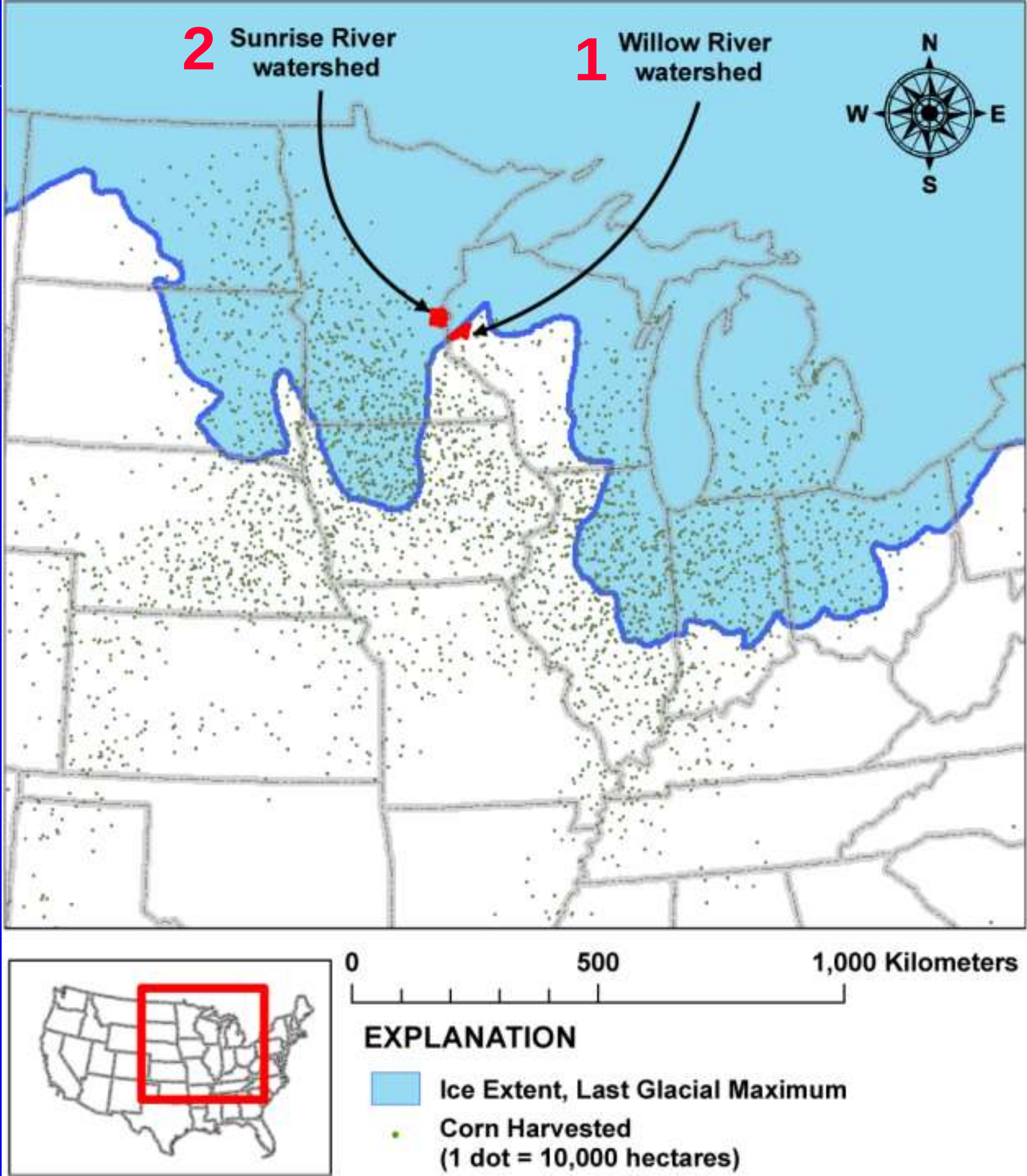
Willow River, western Wisconsin, USA

Sunrise River, eastern Minnesota, USA

Located near southern edge of glaciated landscape and northern edge of "corn belt" (area of intensive row-crop agriculture in USA)



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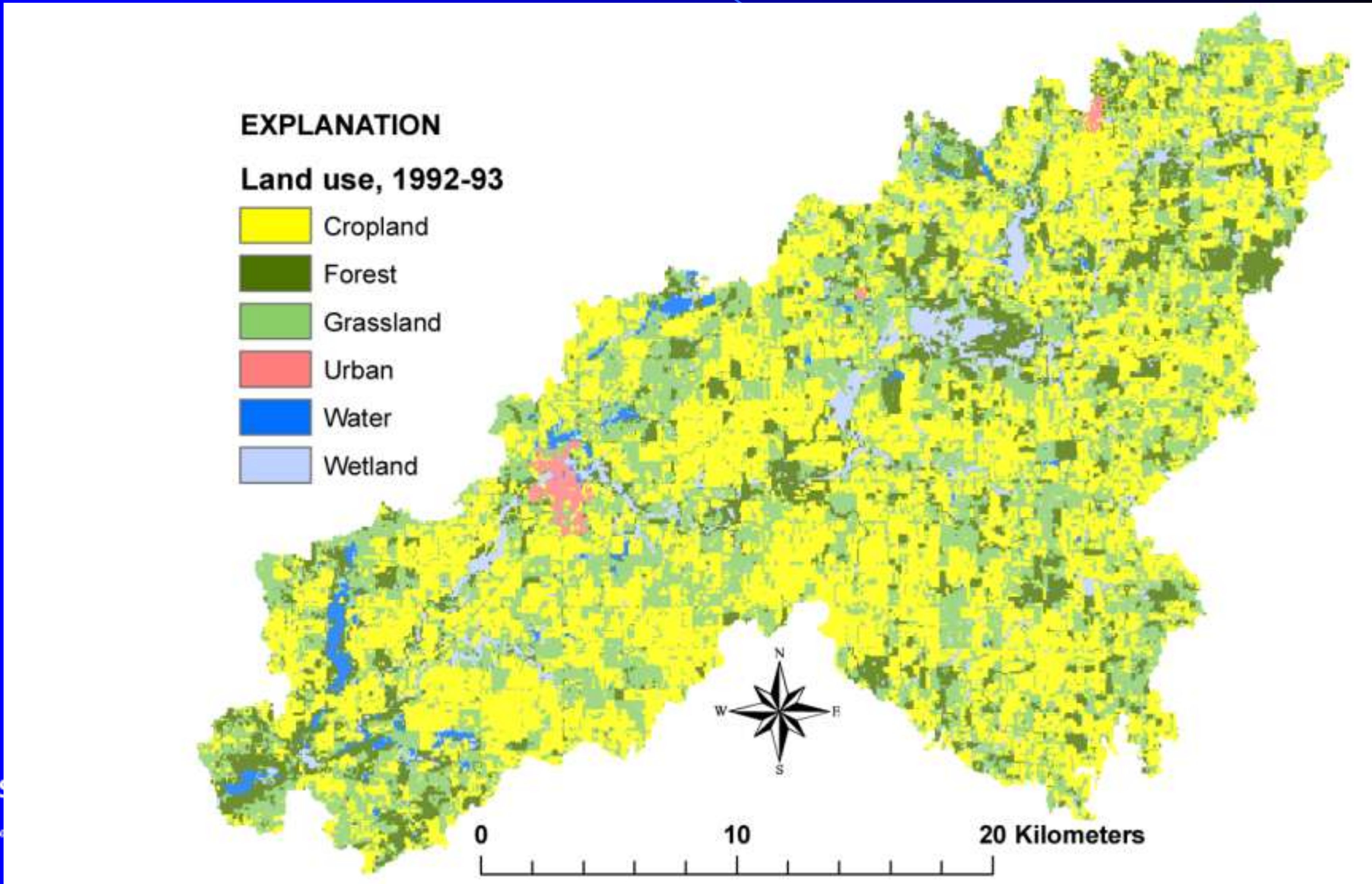
Land Cover – Willow River watershed, western Wisconsin

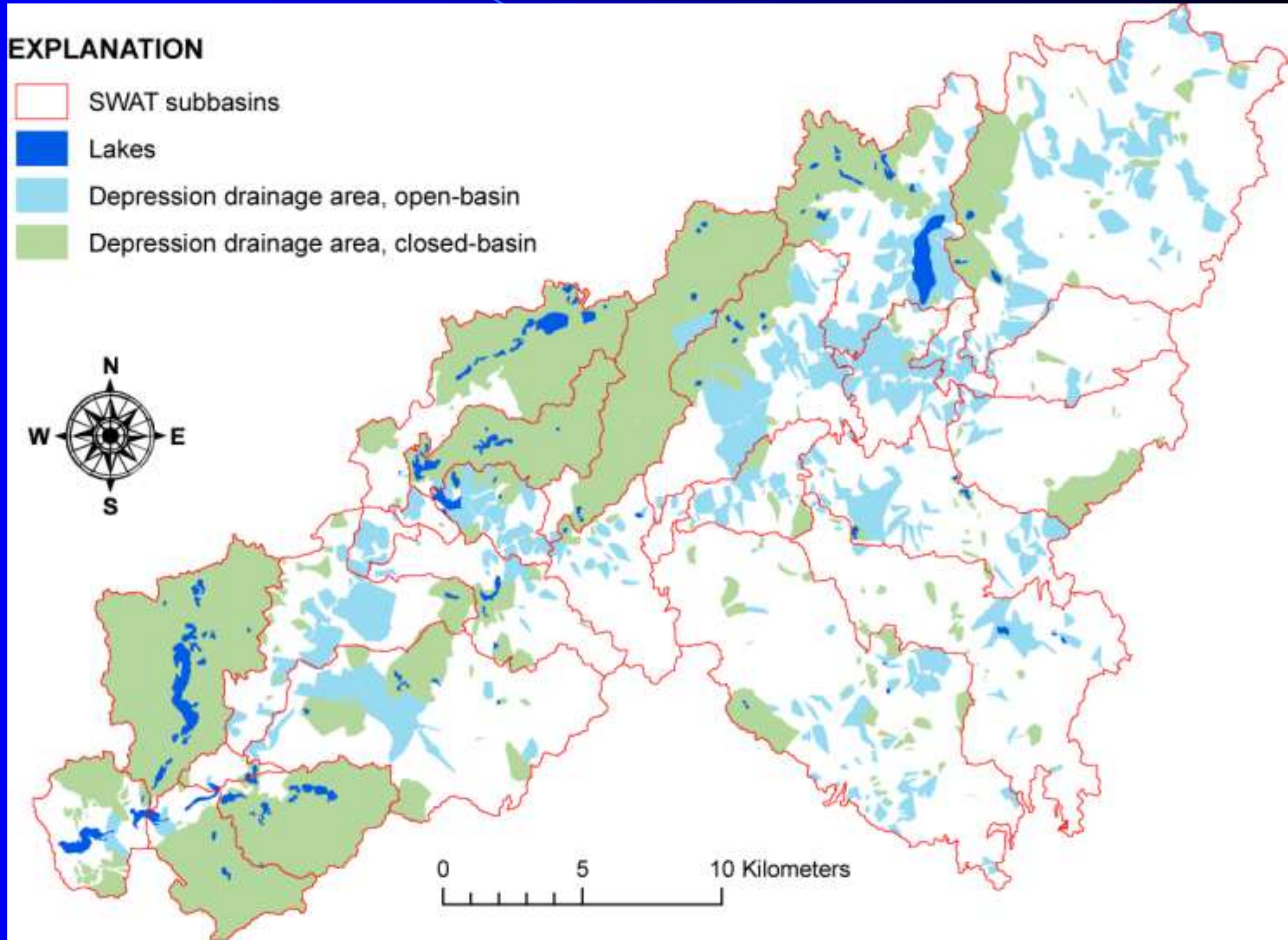
- *-- Many small lakes in northern half of watershed, on moraine*
- *-- Large wetlands along river*
- *-- Built model using SWAT2000:*
  - *-- 27 subbasins, 532 HRUs*



Drainage areas to depressions – Willow River watershed

-- Drainage areas determined by hand, from topographic maps

-- 13% of watershed drained to open-basin depressions
-- 29% of watershed drained to closed-basin depressions
-- Total = 42%



Drainage areas to open-basin (riparian) and closed-basin depressions in the Willow River watershed.

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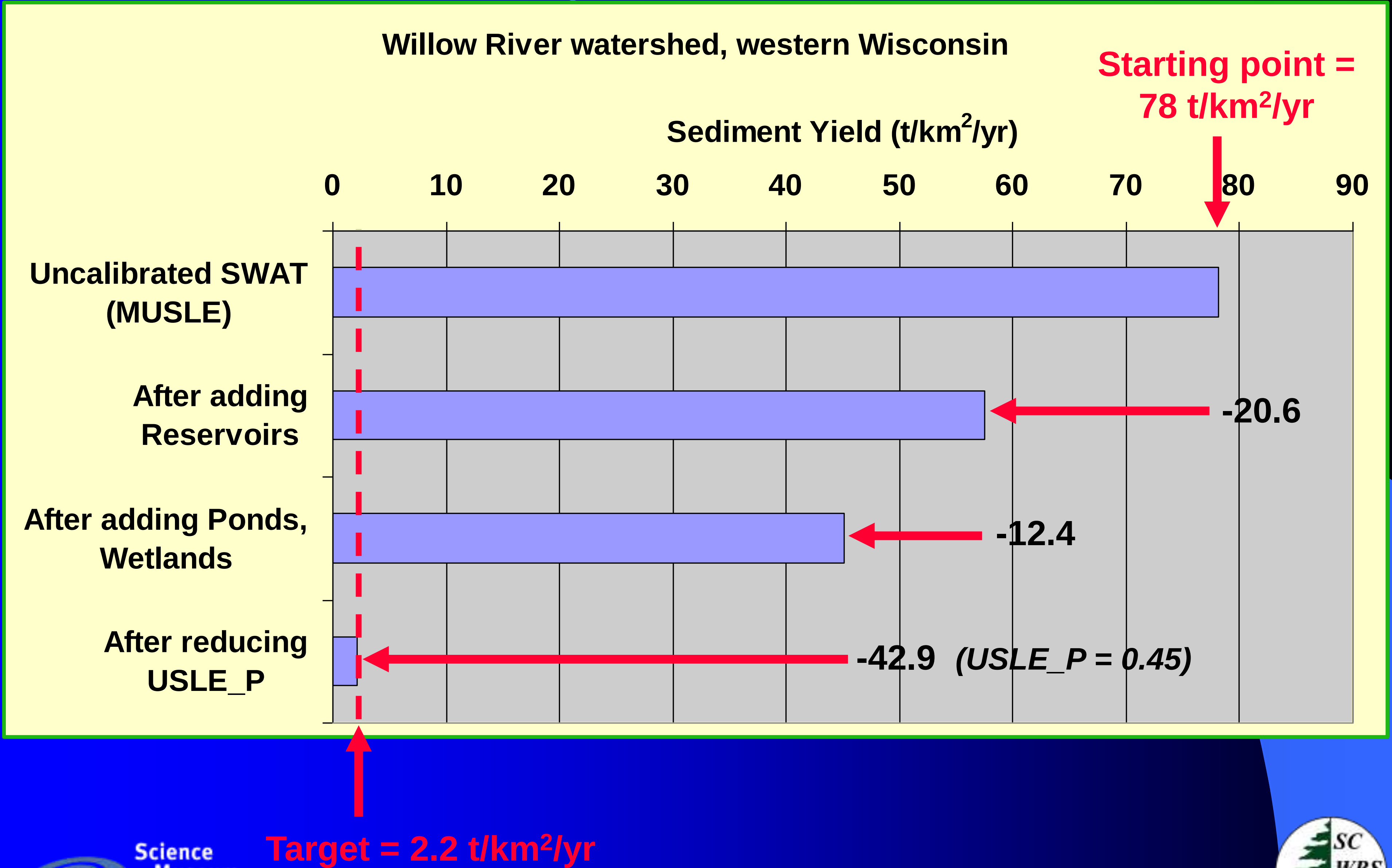
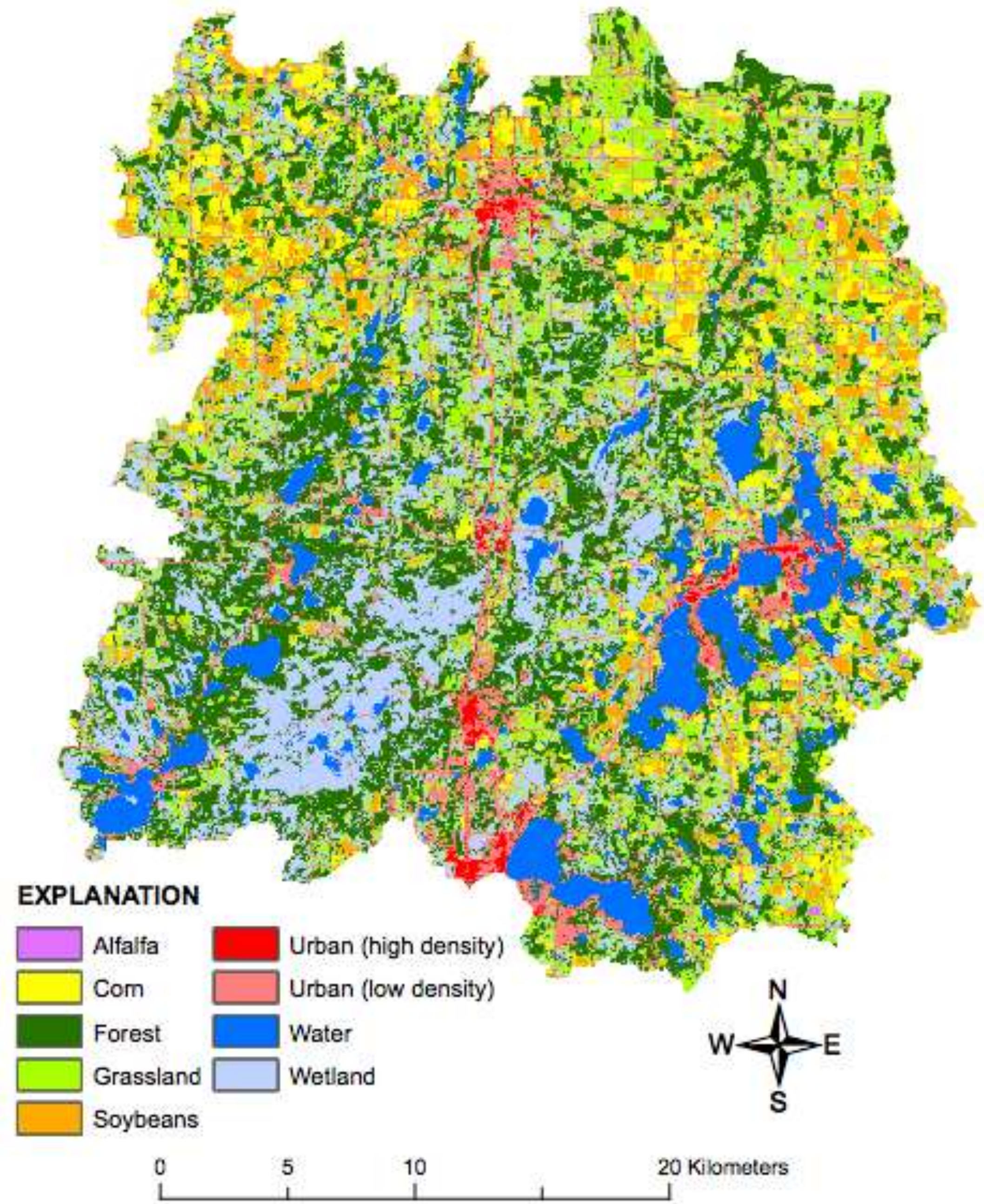
Willow River: Calibration sequence for sediment yield



Land Cover – Sunrise River watershed, eastern Minnesota

-- Many kettle lakes on moraine
-- Large marshes along river, especially on sandplain
-- Built model using SWAT2005
  -- 142 subbasins
  -- 1642 HRUs



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Drainage areas to depressions – Sunrise River watershed

-- Drainage areas determined by using ArcHydro Tools

ArcHydro depression analysis:

-- Ignored depressions (a) with drainage areas < 1 ha, or (b) runoff-fill depths of < 1 cm (= depression volume / drainage area)

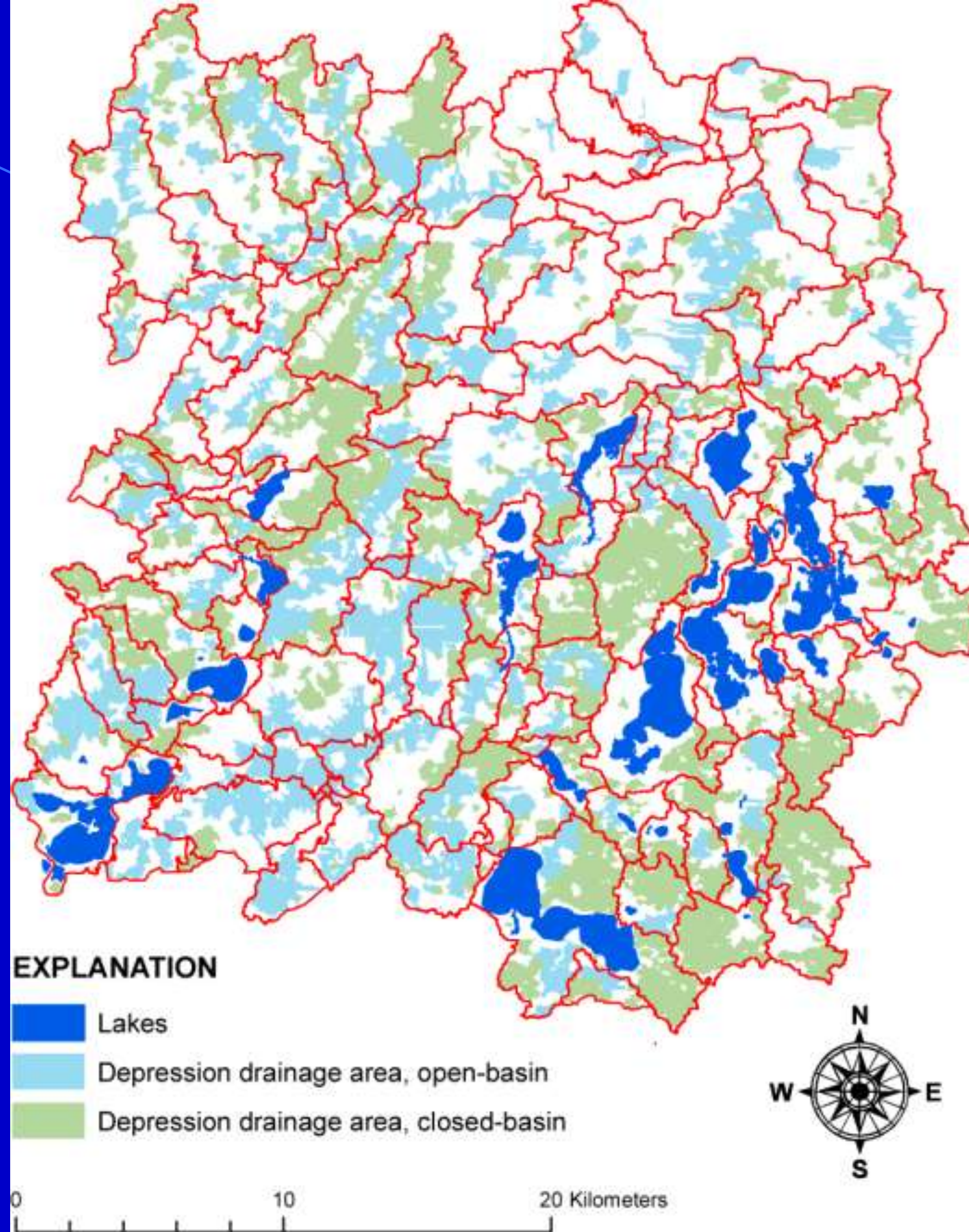
-- Drainage areas intersecting channel network (with 50-m buffer) and wetland land use = open-basin

-- Remaining drainage areas = closed-basin

-- 16% of watershed drained to open-basin depressions

-- 25% of watershed drained to closed-basin depressions

-- Total = 41%



Drainage areas to open-basin and closed-basin depressions in the Sunrise River watershed.

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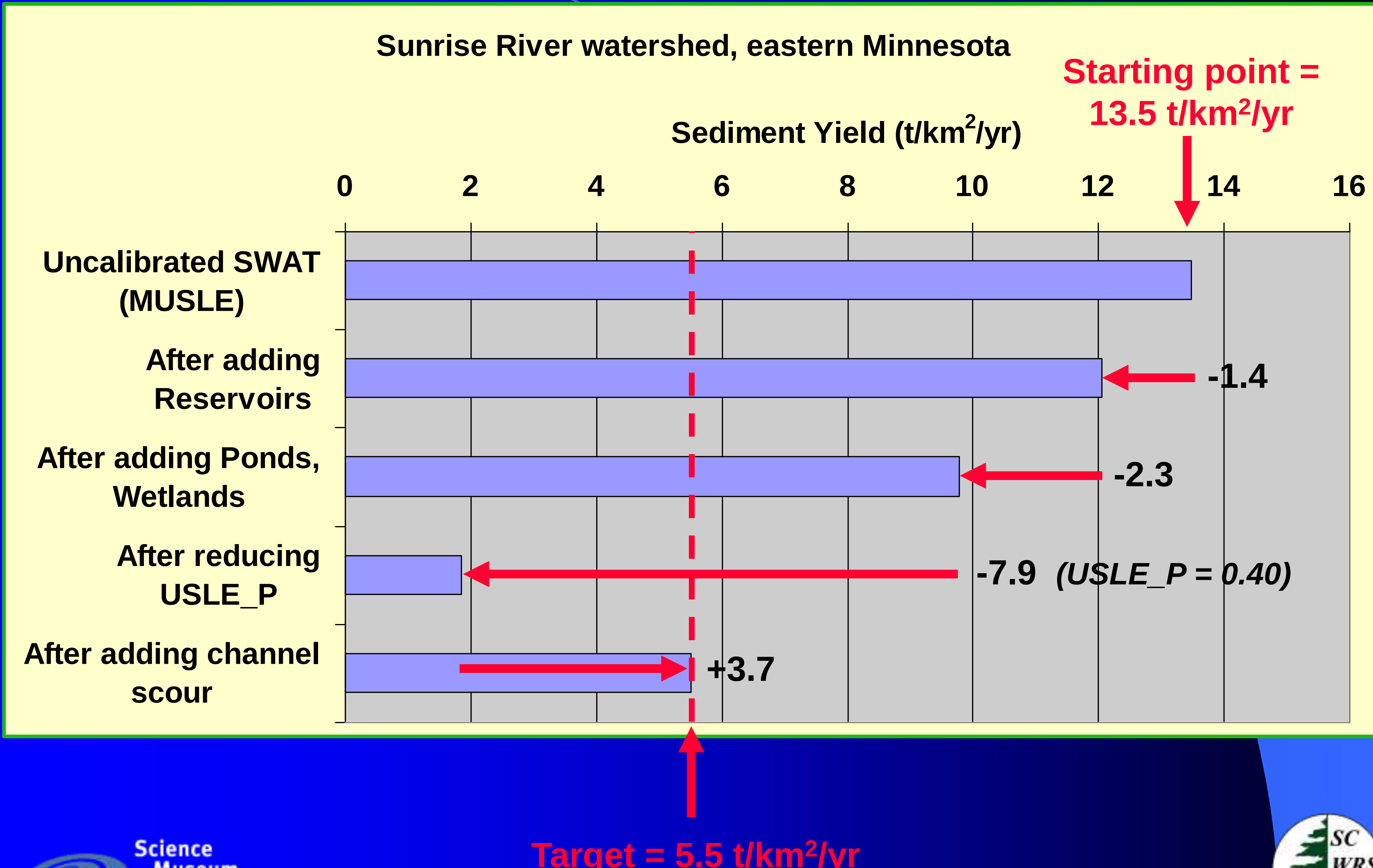
Sunrise River: Calibration sequence for sediment yield



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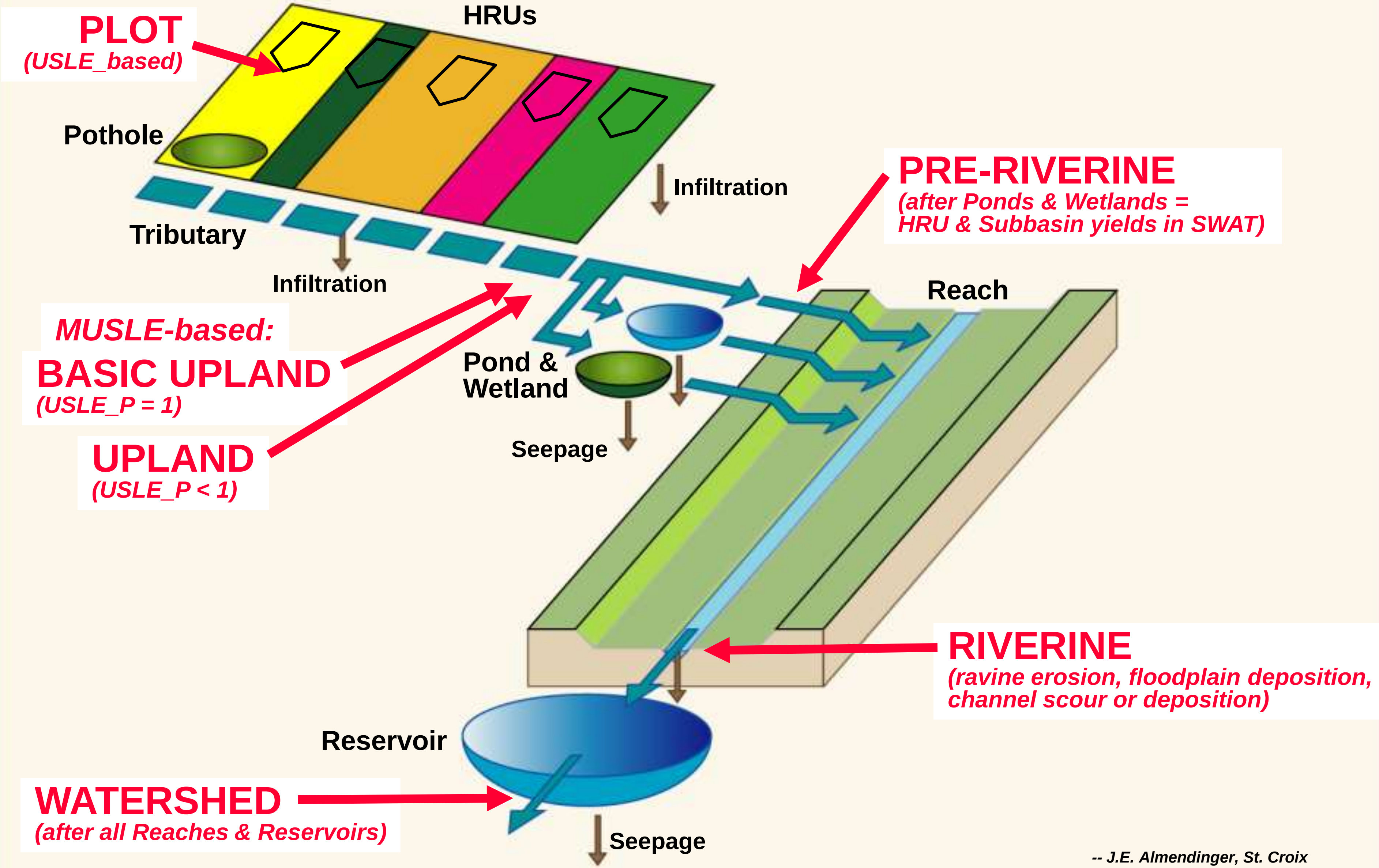
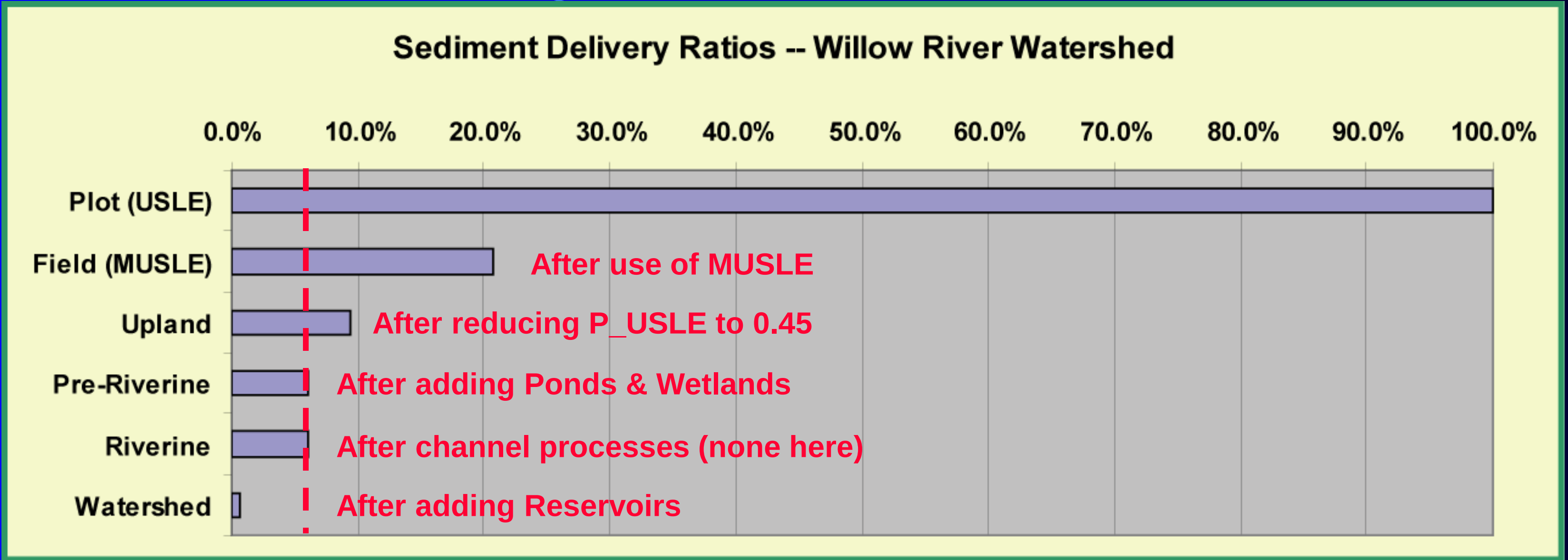
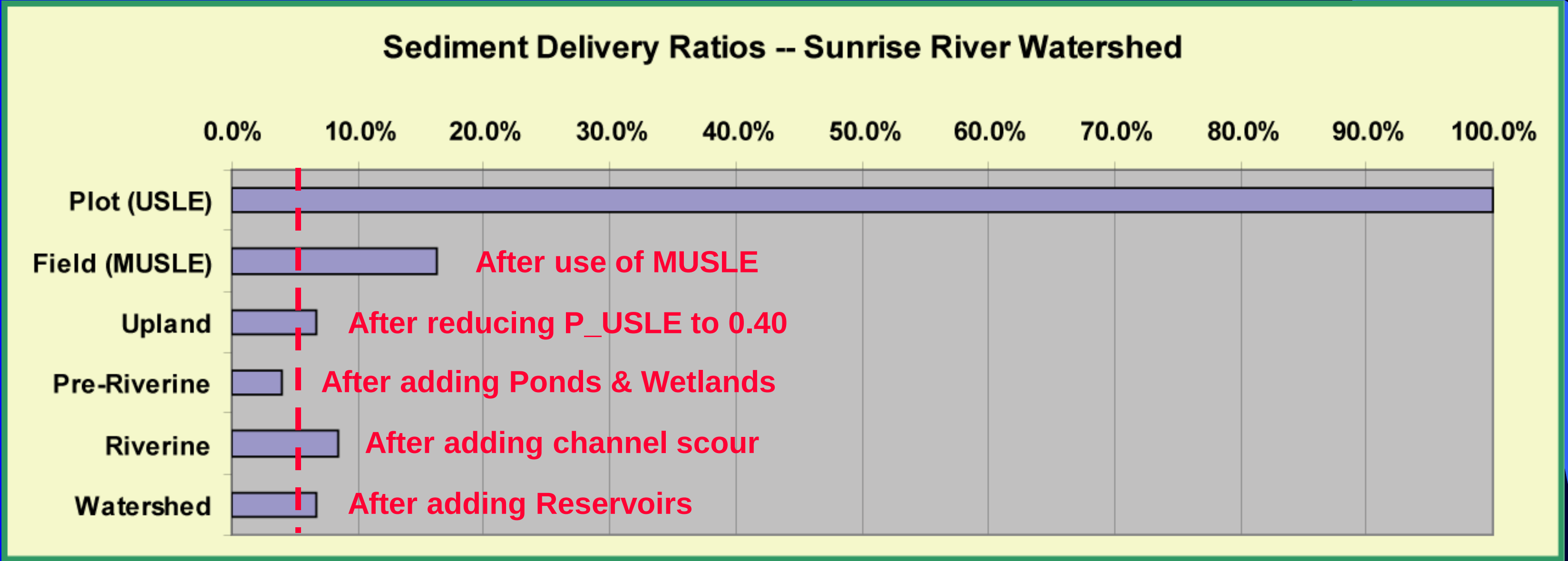
Conceptual scales of sediment yield



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

Apparent Sediment Delivery Ratios at nested conceptual spatial scales





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Red dashed line = SDR based on watershed area = $0.41 * A^{-0.3}$

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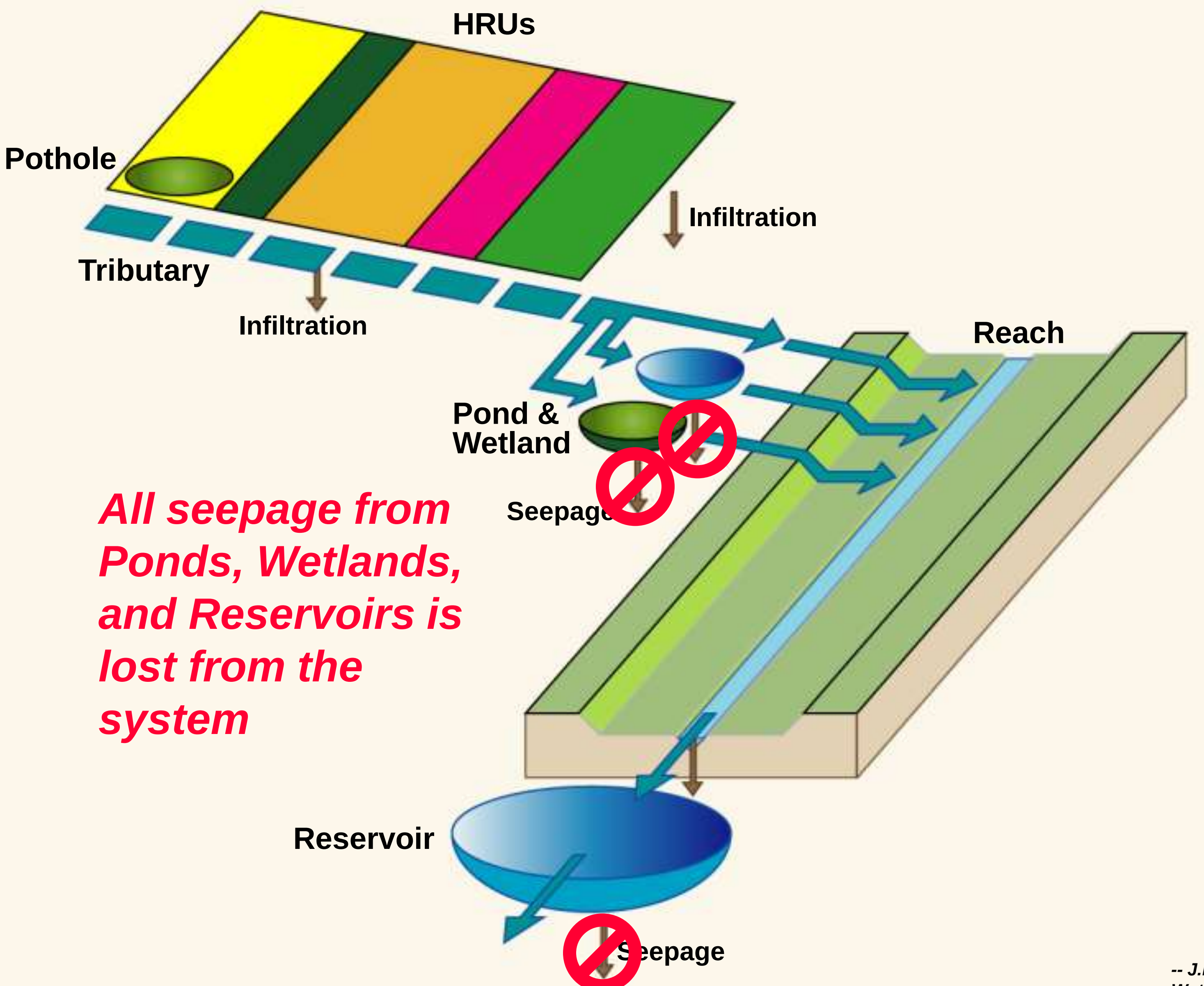
Current problem in SWAT model code: **Loss of seepage water**



All seepage from Ponds, Wetlands, and Reservoirs is lost from the system

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

Summary & Conclusions:

- **Landscape depressions can reduce watershed-scale sediment yields far below USLE yields, and even below MUSLE yields**
  - SWAT can simulate these depressions with its Pothole, Pond, Wetland, and Reservoir functions
  - These functions provide a pseudo-mechanistic way to simulate why SDR < 1
  - Erosion may need further reduction by setting P-USLE < 1
- **Sediment yield is impacted by many processes intermediate between the plot scale and watershed scale.**
  - Output from SWAT can be extracted at different scales, from Field > Upland > Pre-Riverine > Riverine > Watershed
  - Hence parameters derived from plot-scale measurements may not be applicable at the watershed scale

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Thank You – Questions?

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(extra slides follow)

Conceptual scales of sediment yields in watersheds

Conceptual Scale	Description	SWAT output
PLOT	Gross erosion	USLE or RUSLE
↓ *Sediment entrained by runoff minus loss to upland traps outside plot*		
FIELD (Basic Upland)	Modified Gross erosion	HRU or Subbasin output: MUSLE, $P_{USLE} = 1$ No Ponds and Wetlands
↓ *Sediment entrained by runoff minus loss to other upland traps*		
UPLAND	Sediment delivered from uplands to lowlands	HRU or Subbasin output: MUSLE, $P_{USLE} < 1$, as needed No Ponds and Wetlands
↓ *Loss to lowland traps (ponds, wetlands)*		
PRE-RIVERINE (Subbasin)	Sediment delivered from subbasins to floodplain & channel	HRU or Subbasin output: Ponds and Wetlands activated
↓ *Net gains & losses from floodplain & channel processes*		
RIVERINE	Sediment transported in channel	Reach output: Channel parameters activated (or not)
↓ *Losses to reservoirs (on-channel lakes)*		
WATERSHED	Sediment leaving the watershed	Reservoir output

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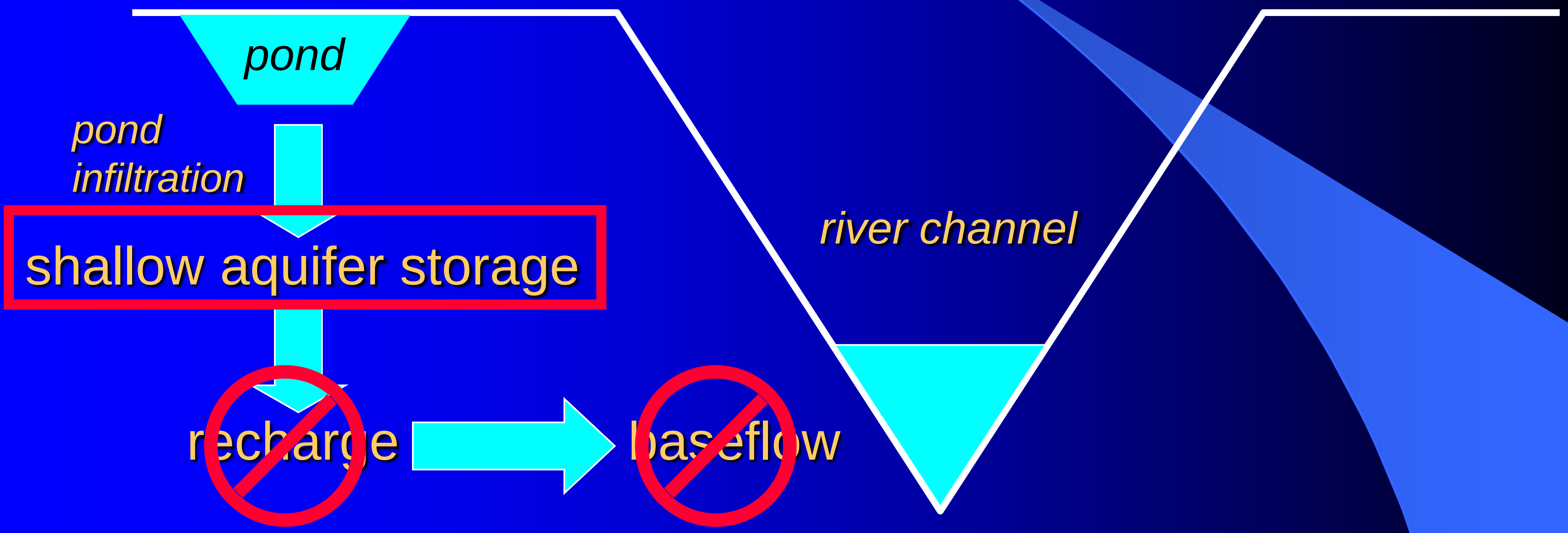
Problem: Loss of infiltrated water

- 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
  - *This problem still persists in SWAT2009*

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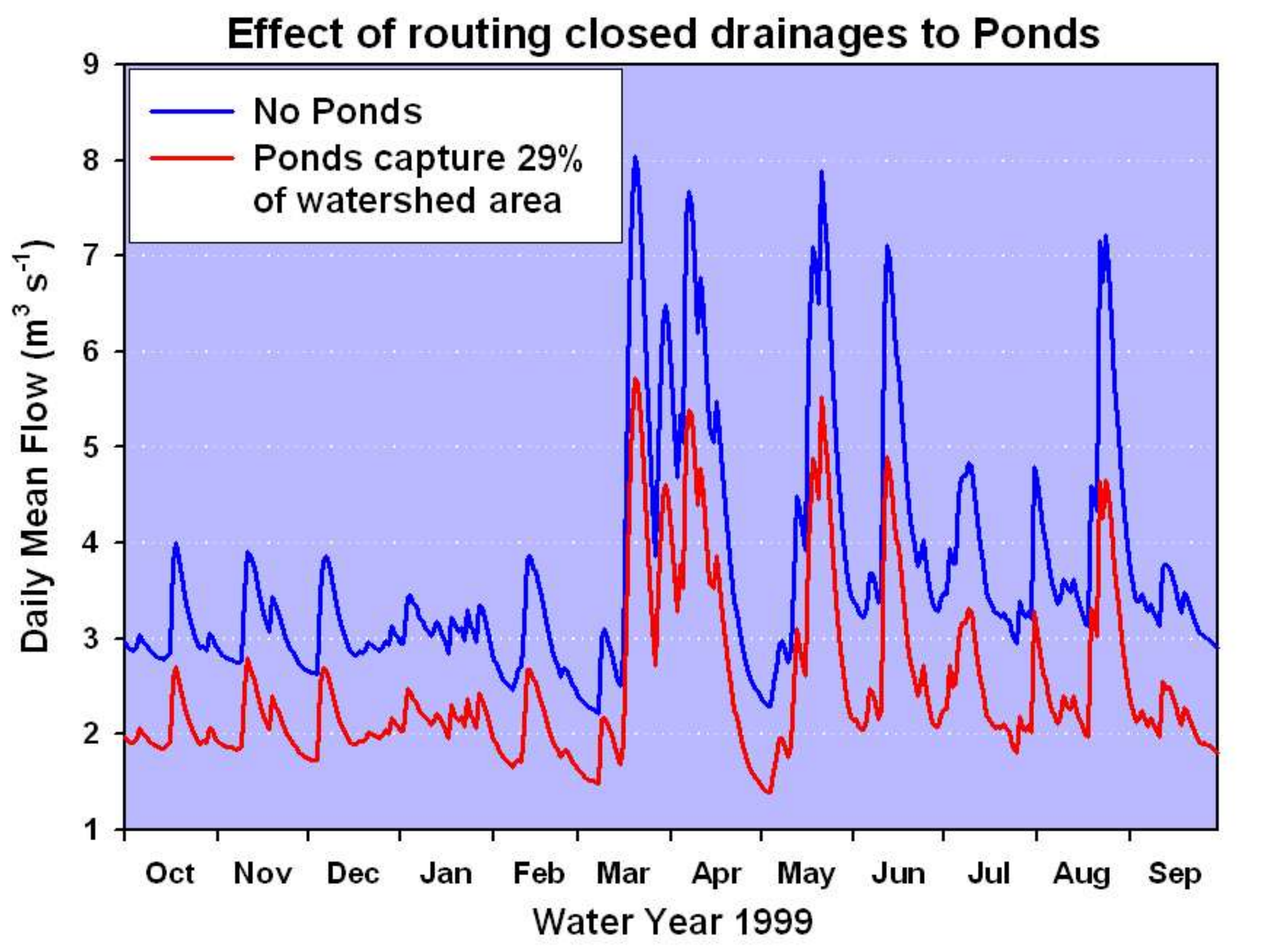
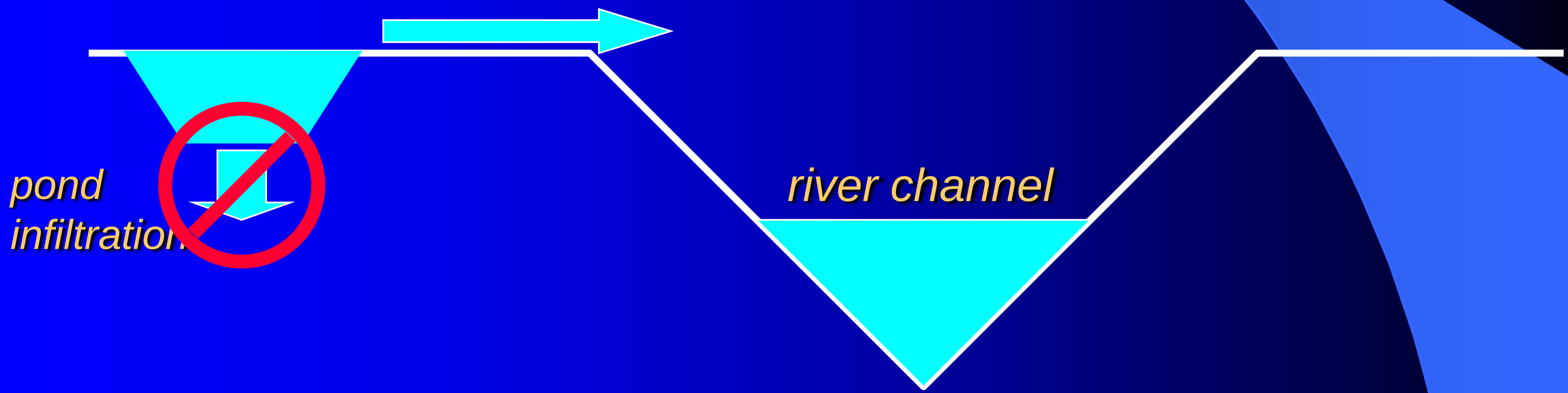
- When closed-depressions were added, annual runoff volume dropped 29%
  - All water infiltrated in closed depressions (Ponds) was lost from the system



- Our work-around for SWAT2000 was to disallow Pond seepage and force surface outflow to be slow and steady to mimic groundwater discharge

Exaggerate storage capacity;

Slow rate of outflow



Problem: Loss of seepage from Ponds, Wetlands, and Reservoirs

For SWAT2005, we repaired the code ourselves

-- We spent the $ on the Intel FORTRAN compiler
-- Created recharge variables for Ponds, Wetlands, and Reservoirs in each subbasin
-- Released infiltrated water to baseflow at the rate determined by ALPHA_BF parameter

hrupond4ppt.txt - Notepad

File Edit Format View Help

```
      subroutine hrupond

!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this subroutine routes water and sediment through ponds in the HRUs

      use parm

      integer :: j
      real :: cnv, pndsa, xx, yy, totno3_conc, zz

      j = 0
      j = ihru

      if (pnd_fr(j) > 0.01) then
        cnv = 0.
        cnv = hru_ha(j) * 10.

        !! calculate area of HRU covered by pond
        pndsa = 0.
        pndsa = bp1(j) * pnd_vol(j) ** bp2(j)

        !! calculate water flowing into pond for day
        !!pndflwi = qdr_pnd(j) * 10. * hru_ha(j) * pnd_fr(j)
        !!ULRICH -- changed to conform to changes made to wetlan.f
        pndflwi = qdr_pnd(j) * 10. * (hru_ha(j) - pndsa)

        !! COMMENTED -- not needed
        !!qdr(j) = qdr(j) - qdr(j) * pnd_fr(j)
```

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Plot scale:

- **We are good at measuring processes at the plot scale**
  - **Our understanding of mechanism depends on plot-scale data, because we can control for many variables**
- **USLE was developed based on plot-scale data (72.6x60 ft^2 = 0.04 ha)**
- **Watershed models commonly use mechanisms determined at the plot scale**
  - ***With default parameters determined from plot-scale data***

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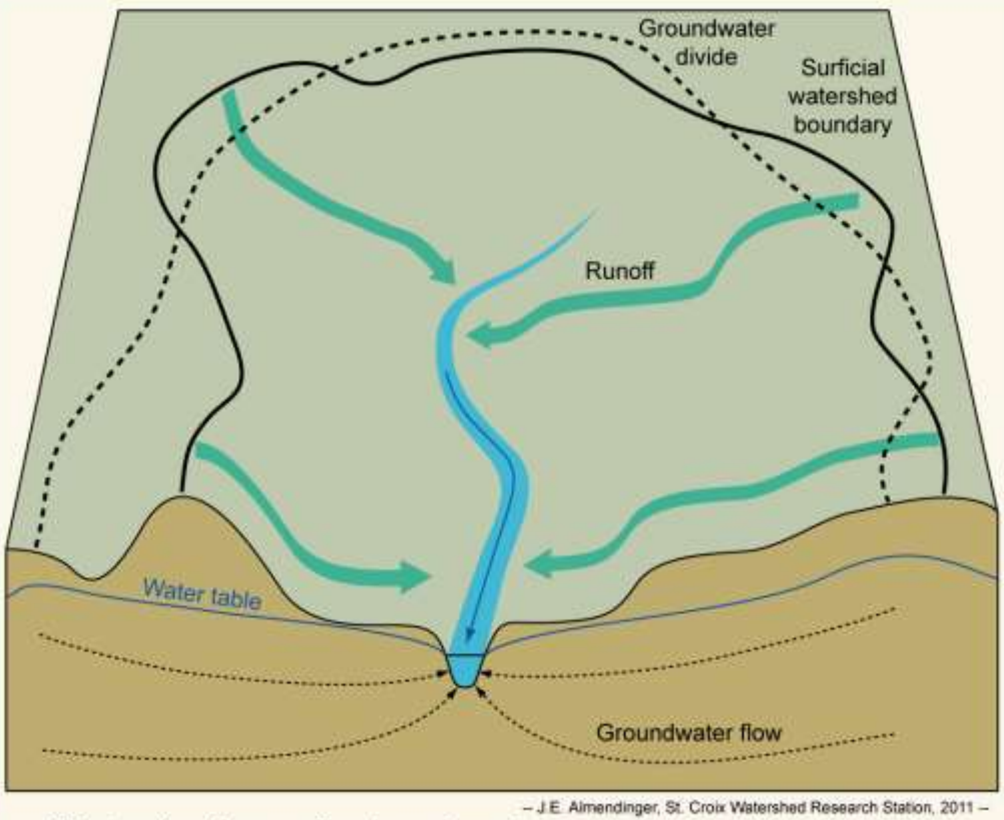
Watershed scale:

- **We are also good at collecting data at the watershed scale**
  - **About 1 to 100,000 km²**

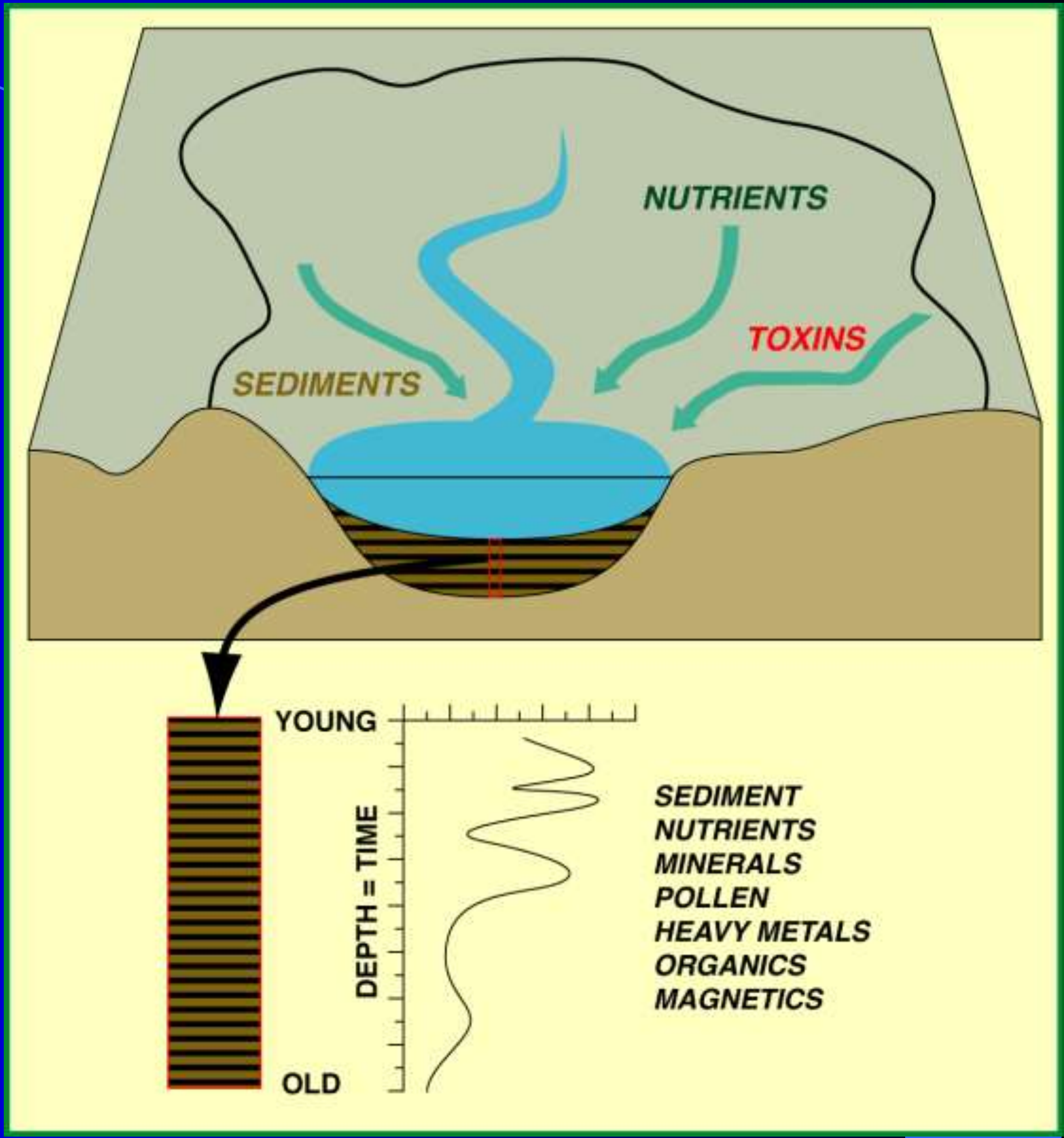
- **From stream-gauged sites**
  - **Time limitation = length of data-collection record**



Watershed as collector of surface and groundwater flows
All flow lines converge at mouth of watershed

Watershed scale:

- **From lake-sediment accumulation records**
  - **Time limitation = length of sediment core**
  - **Resolution of sediment chronology**



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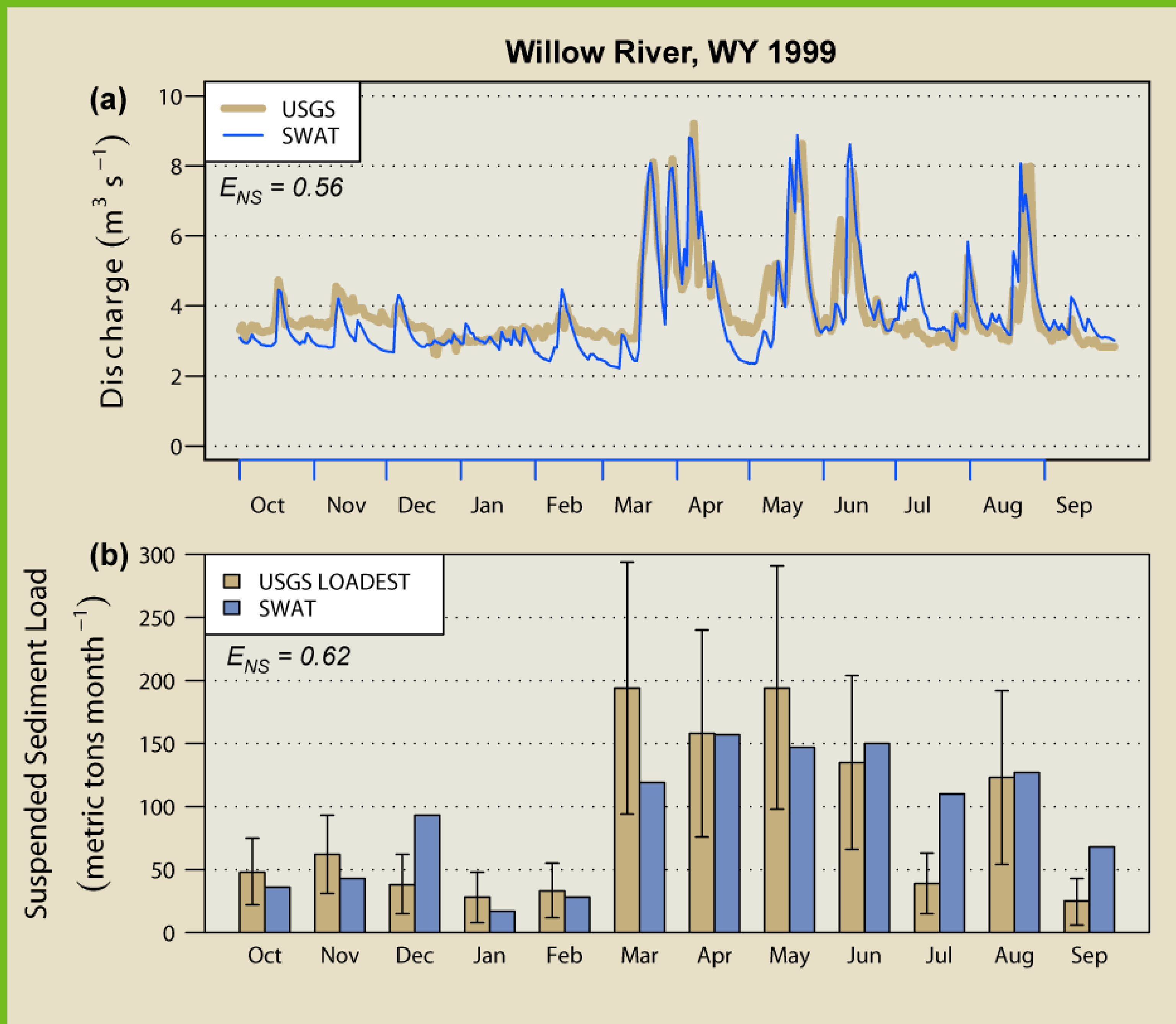
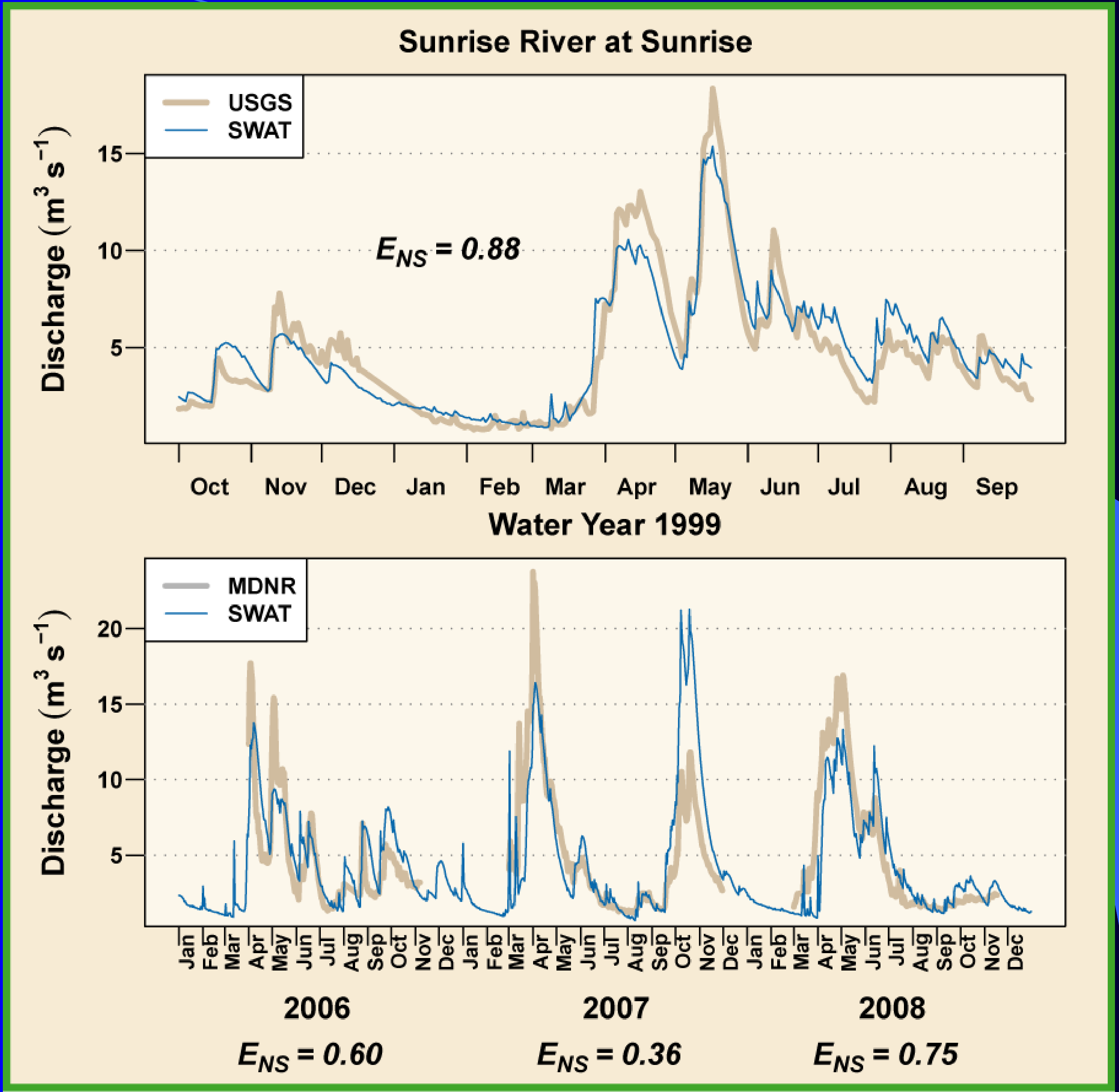
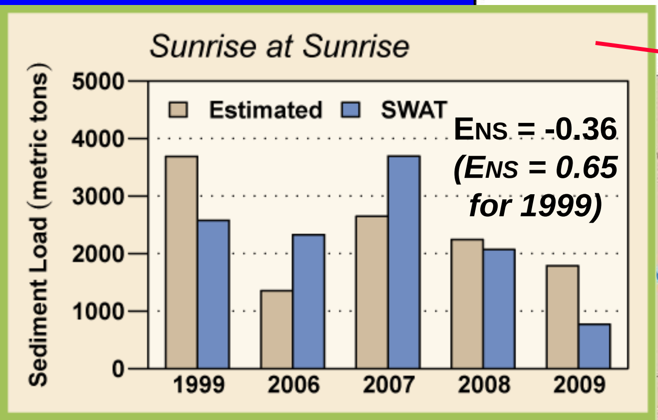
Model calibration: Willow River hydrology and sediment yield

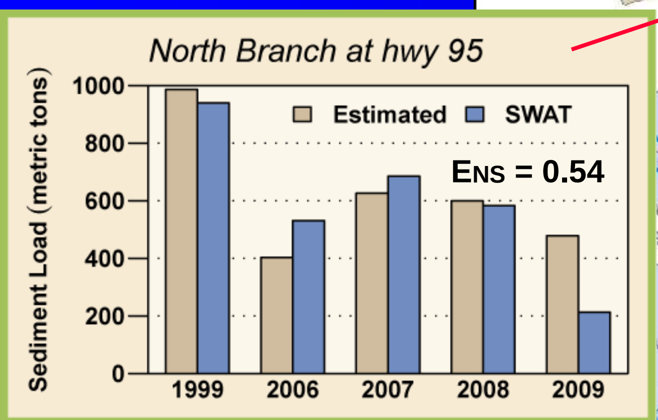


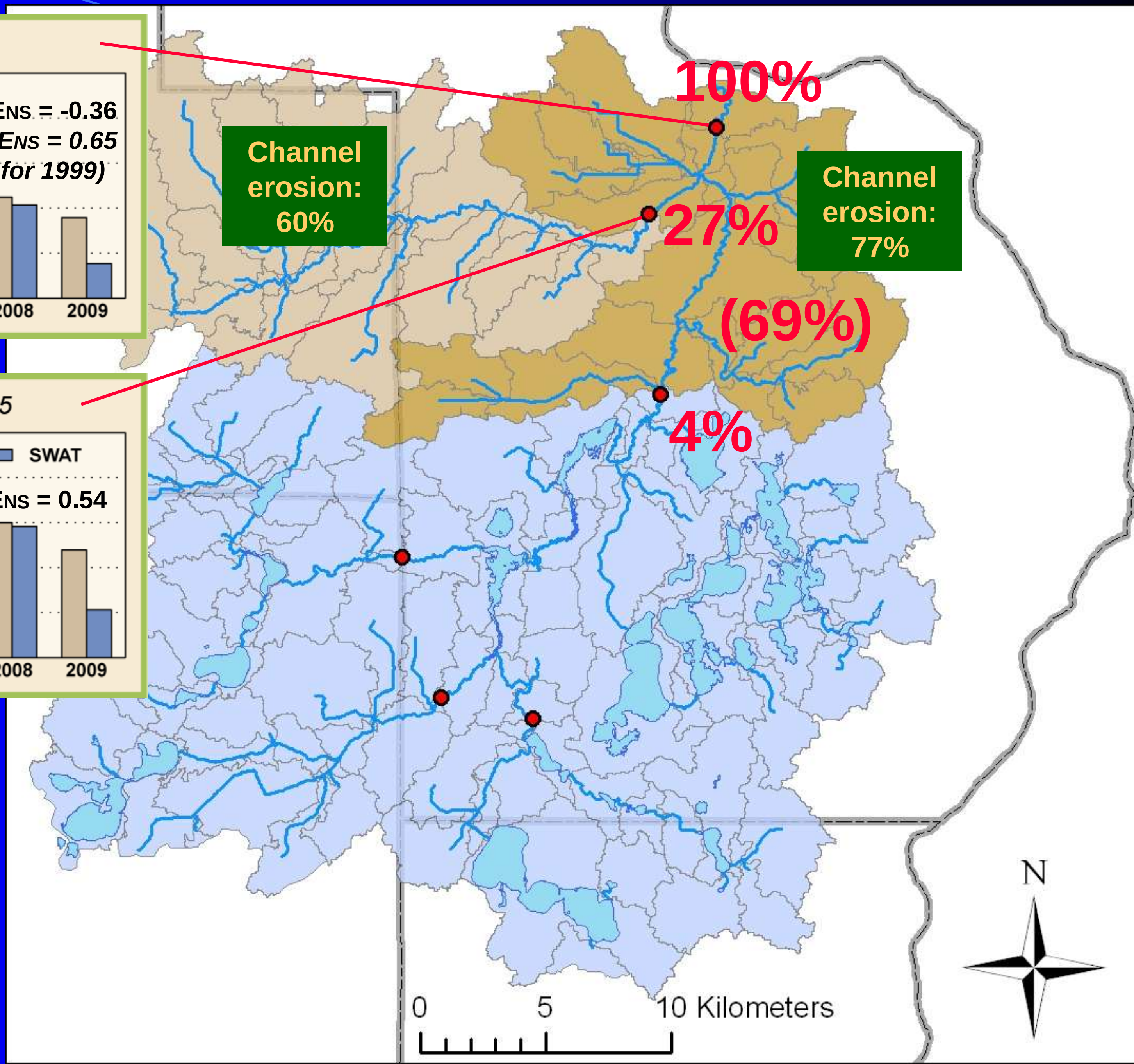
Model calibration & validation: Sunrise: Flow



Model calibration: Sediment







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