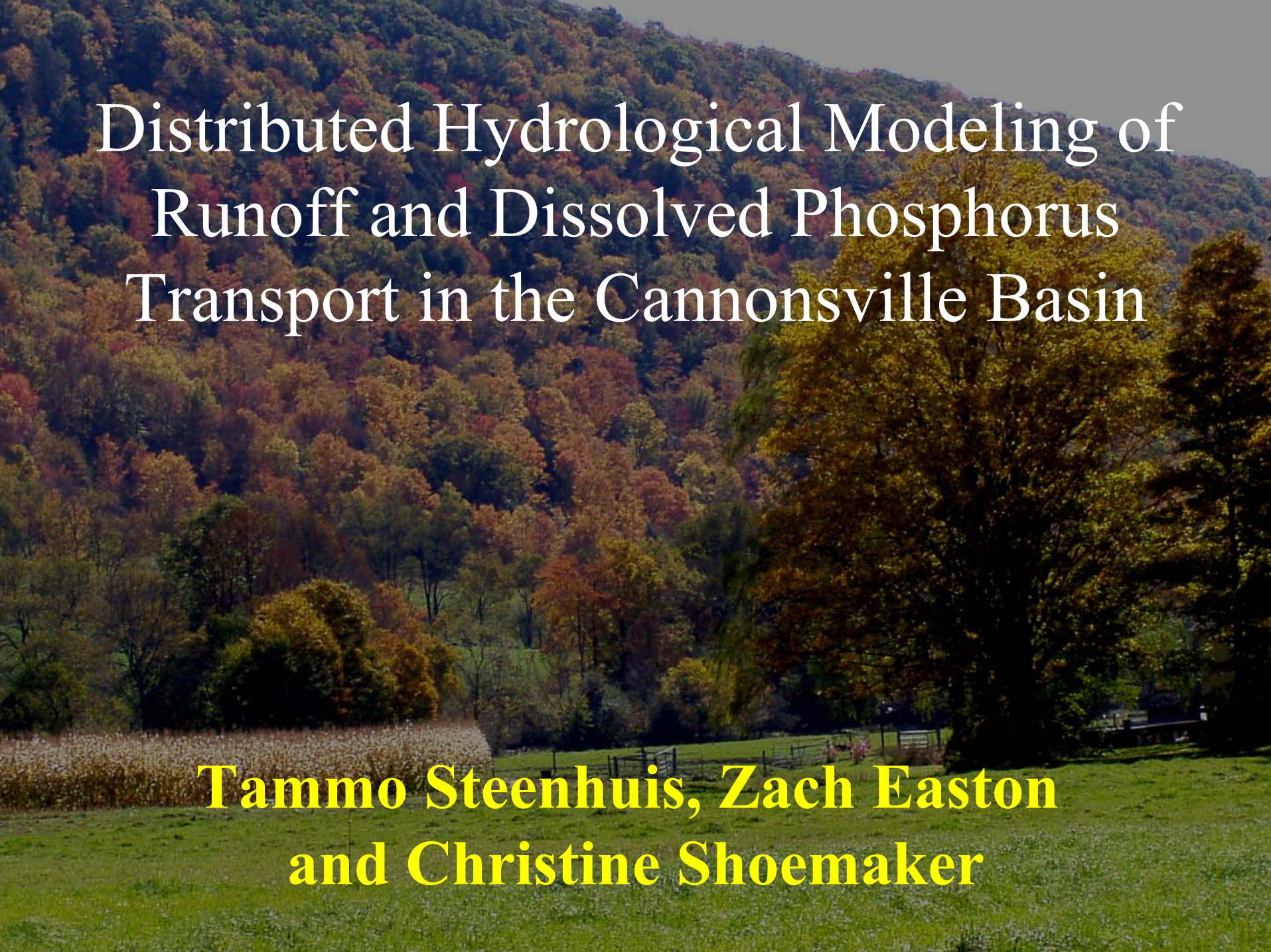


Distributed Hydrological Modeling of Runoff and Dissolved Phosphorus Transport in the Cannonsville Basin

Tammo Steenhuis, Zach Easton and Christine Shoemaker

Distributed Hydrological Modeling

- Rationale
- Curve Number and VSA hydrology
- Proof of Concept: SWAT meets SWAT-VSA
- Conclusions

RATIONELE

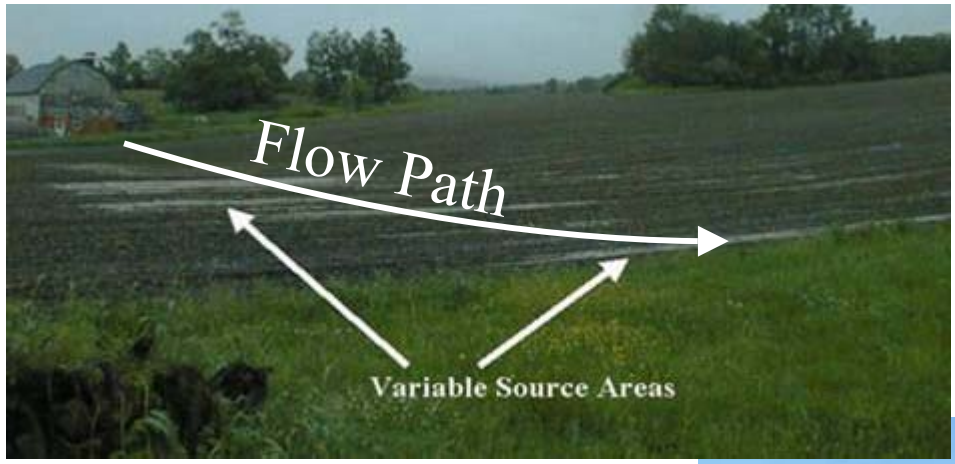
BMP's should be installed where runoff is generated

Obviously

Finding Runoff Location

- Ask land owner
  - Not consistent from one farm to the next
- Sit in office and use models
  - Models usually validated on discharge
  - No guarantee that runoff location is correct
    - Hence BMP effectiveness not guaranteed

Runoff location



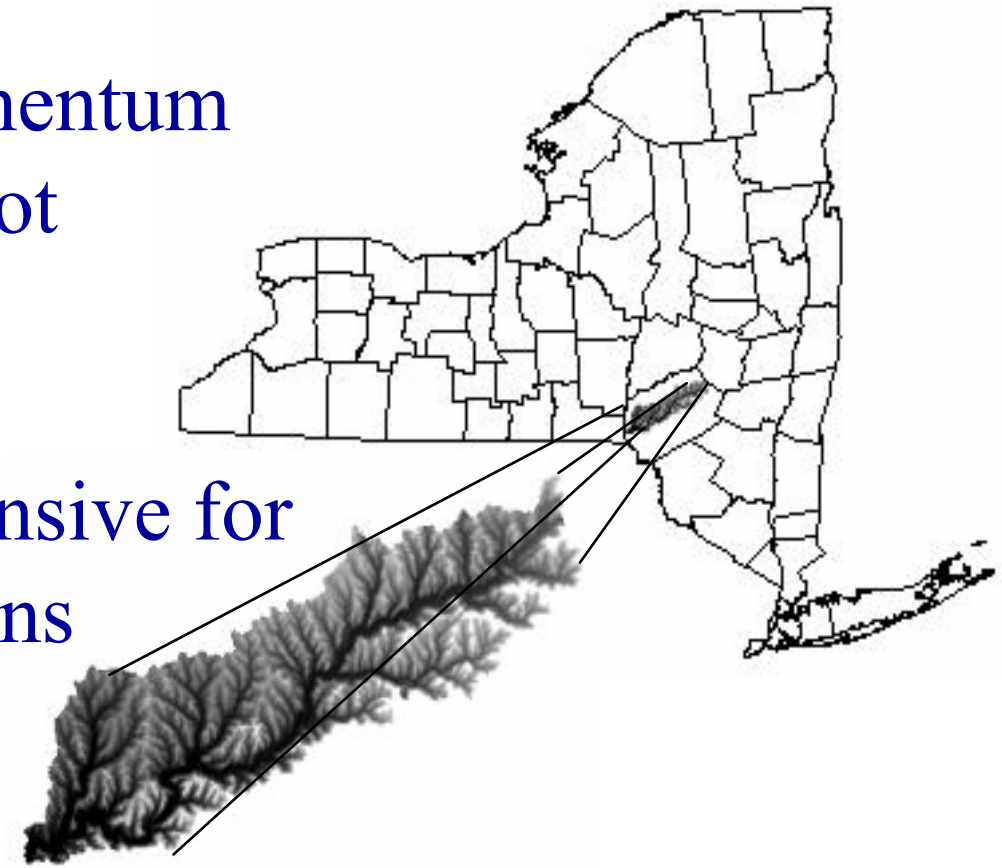
Variable Source Areas (VSA)

Need include VSA in runoff models

Runoff Location

Current distributed models can predict runoff location but have shortcomings:

- No institutional momentum
- User interfaces are not typically intuitive
- Often these are too computationally intensive for large basin simulations



Re-conceptualizing Water Quality Models

- Rationale
- Curve Number and VSA hydrology
- Proof of Concept: SWAT meets SWAT-VSA
- Conclusions

USDA-NRCS Curve Number Model

That is a big problem

Infiltration capacity in excess of rainfall intensity!

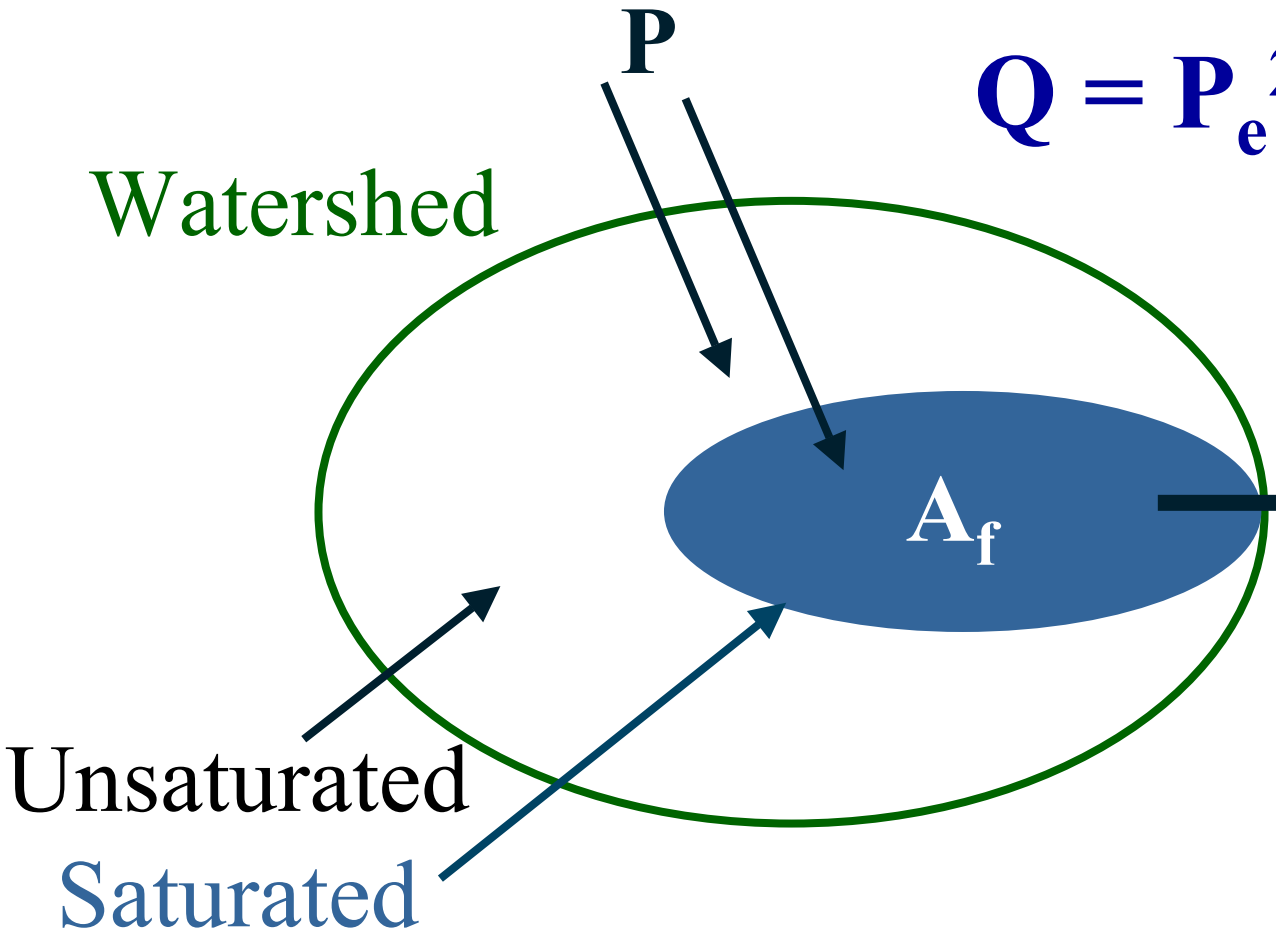
But there is hope…

$$\text{“Runoff”} = P_e^2/(P_e + S)$$

Victor Mockus justified his model largely “on grounds that it produces rainfall–runoff curves of a type found on natural watersheds”

Victor Mockus later concluded that *saturation excess* was probably the “likely runoff mechanism to be simulated by the method…”

Curve Number VSA hydrology



$$Q = P_e^2/(P_e+S)$$

$$\Delta Q = A_f \Delta P_e$$

$$dQ/dP_e = A_f$$

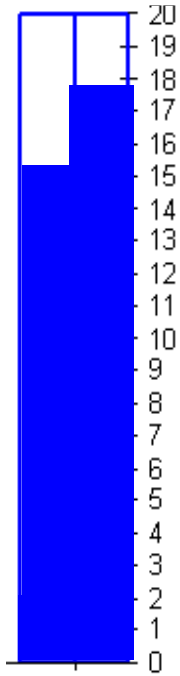
$$\text{Field Capacity} = f(S,A)$$

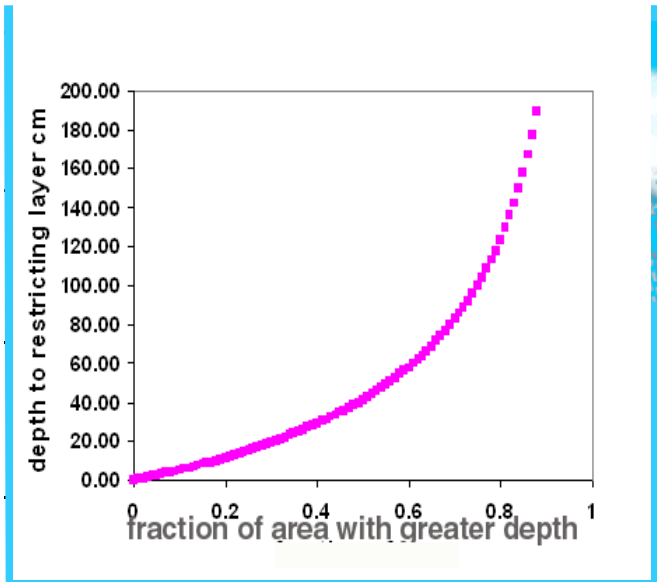
$$A_f = f(S,P_e)$$

Steenhuis et al. 1995. *ASCE Div Drain. & Irr.* 121:234-238

Rainfall

Effective Total



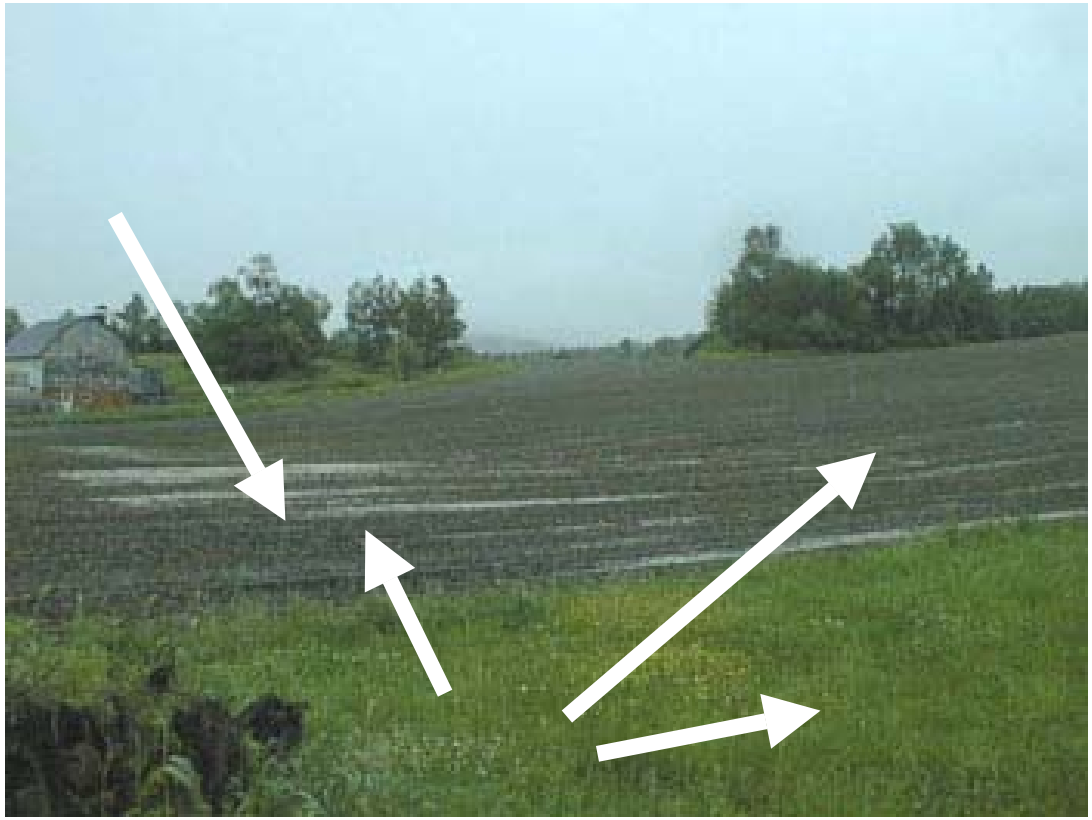


$A_f = \Delta Q / \Delta P_e$

0 0.2 0.4 0.6 0.8

relative distance

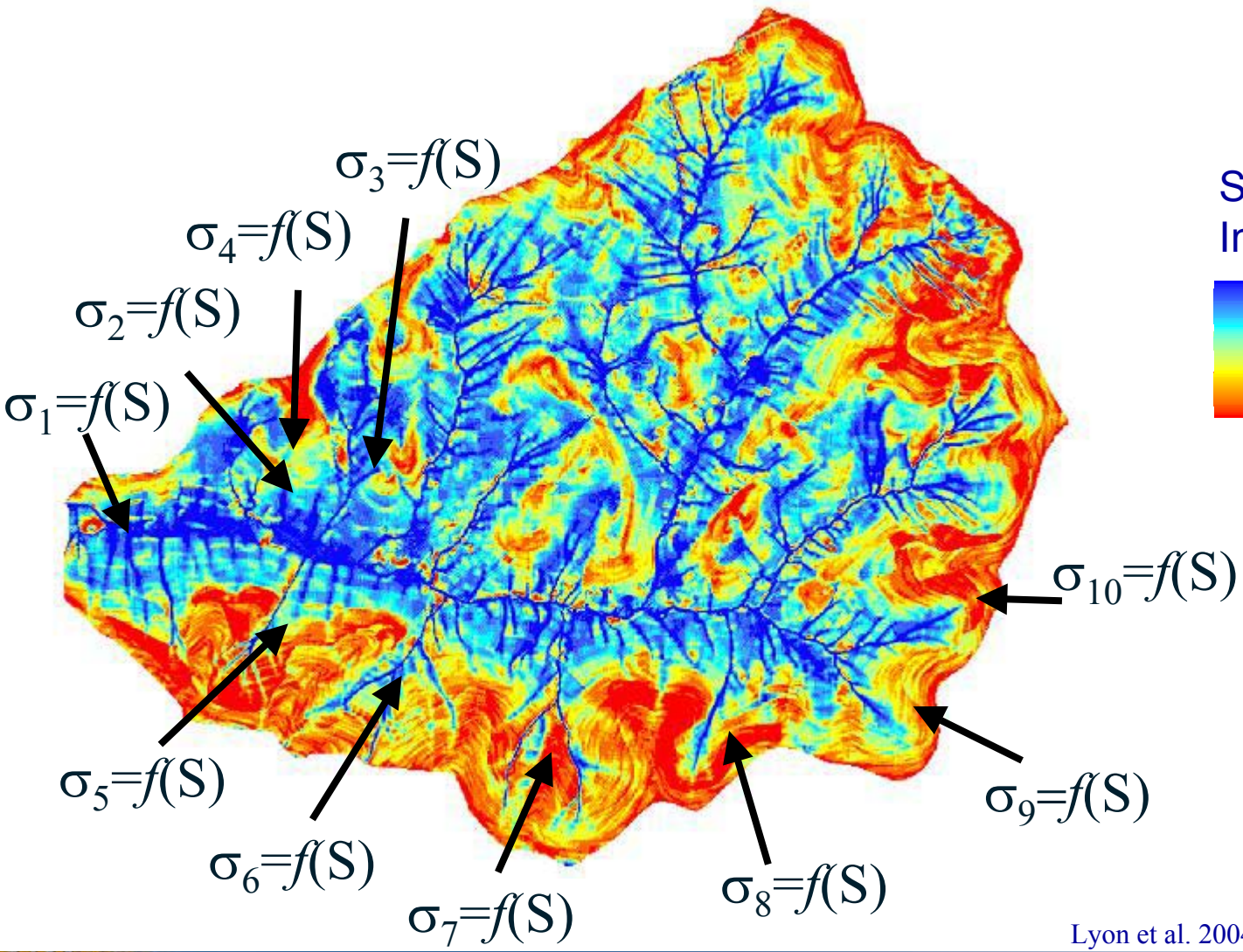
We know how much area is contributing…



…but from where in the landscape?

Soil Topographic Index

$$\lambda = \ln\left(\frac{a}{T \tan \beta}\right)$$



Soil Topographic Index

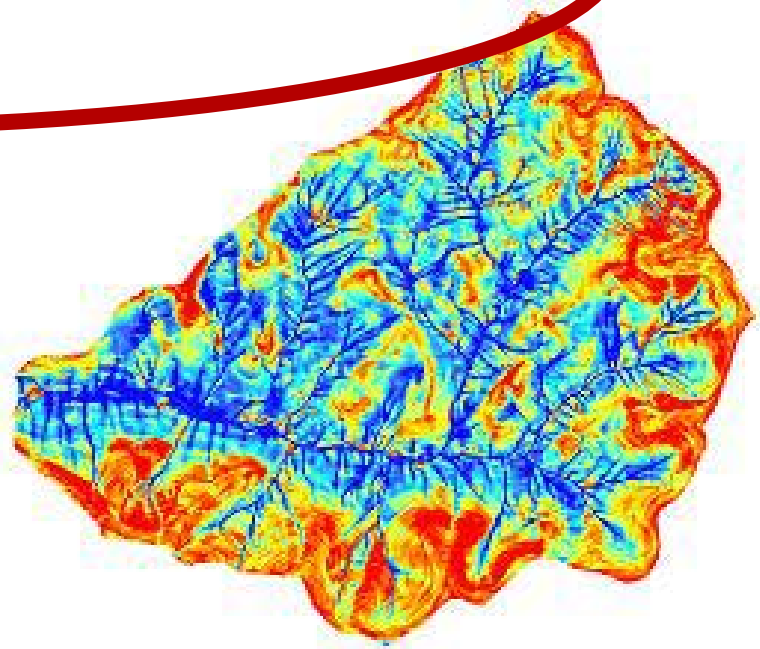
33.10

3.52

Lyon et al. 2004. *Hydrol. Proc.* 18(15): 2757-2771.
Schneiderman et al. 2006. *Hydrol. Proc.* (in press)

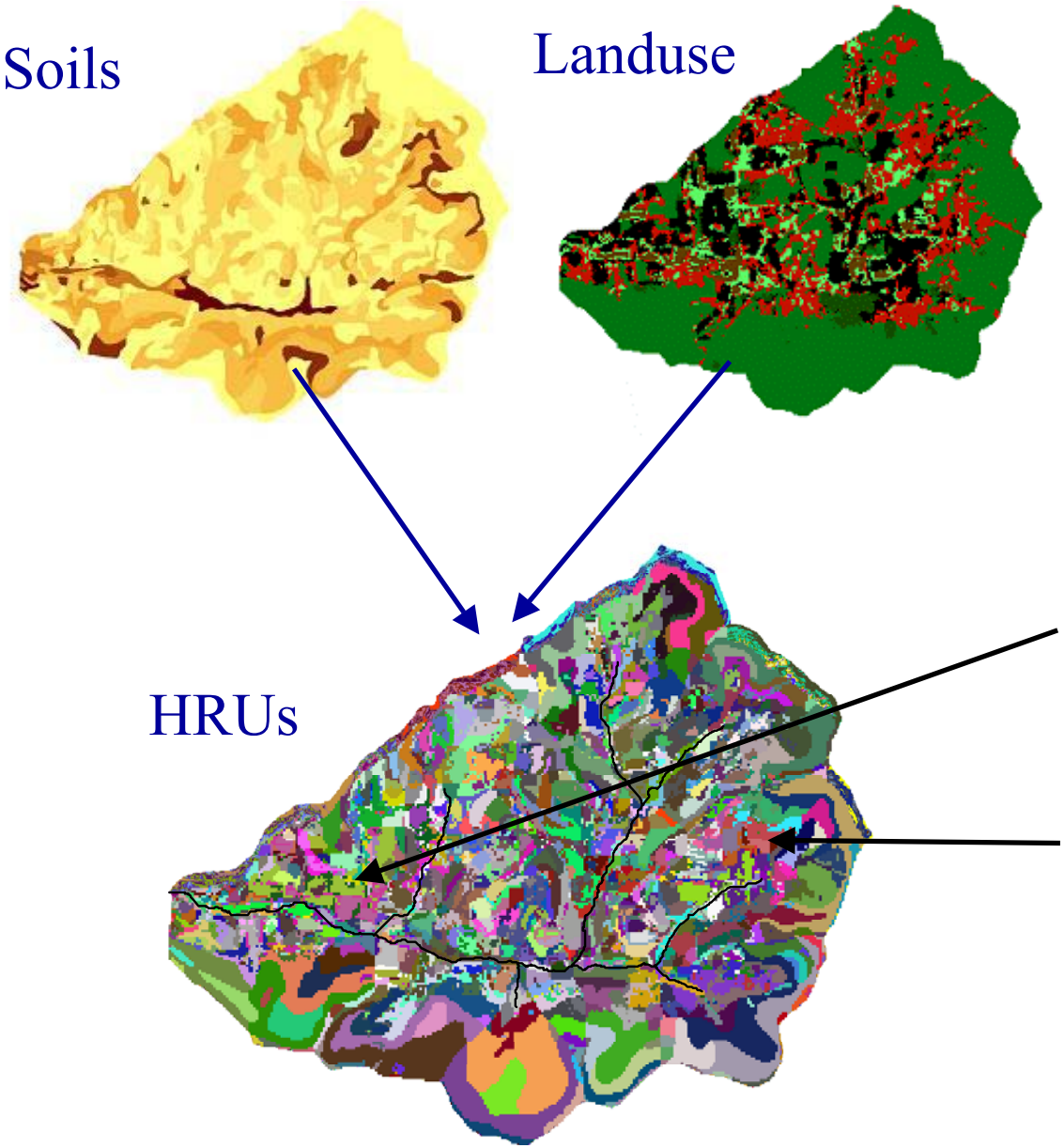
Re-conceptualizing Water Quality Models

- Rationale and Objectives
- Curve Numbering VSA hydrology
- Proof of Concept: SWAT meets SWAT-VSA
- Conclusions



Soil Water Assessment Tool (SWAT)

- Basin scale hydrological and water quality
  - 0.06 ha  continental
- Runs on easily available data
- Process based chemistry
  - vs export coefficient type models
- Does not require much calibration for hydrology
  - More for chemistry and sediment

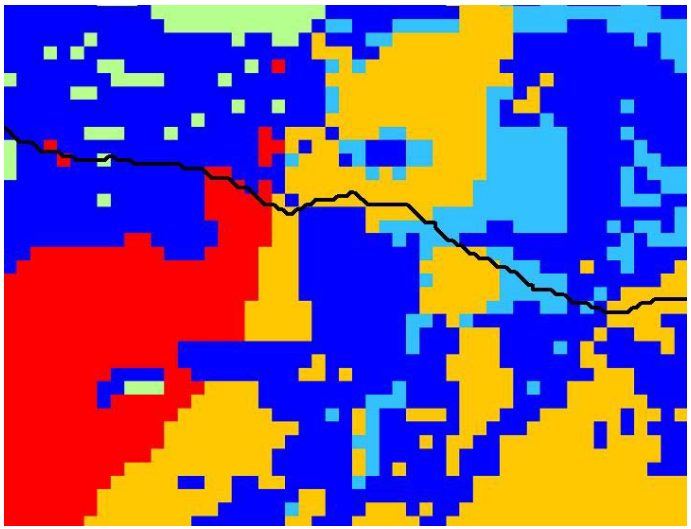


- SWAT defines HRUs as the coincidence of soil type and landuse
  - Hydrological/chemical properties are defined at the HRU

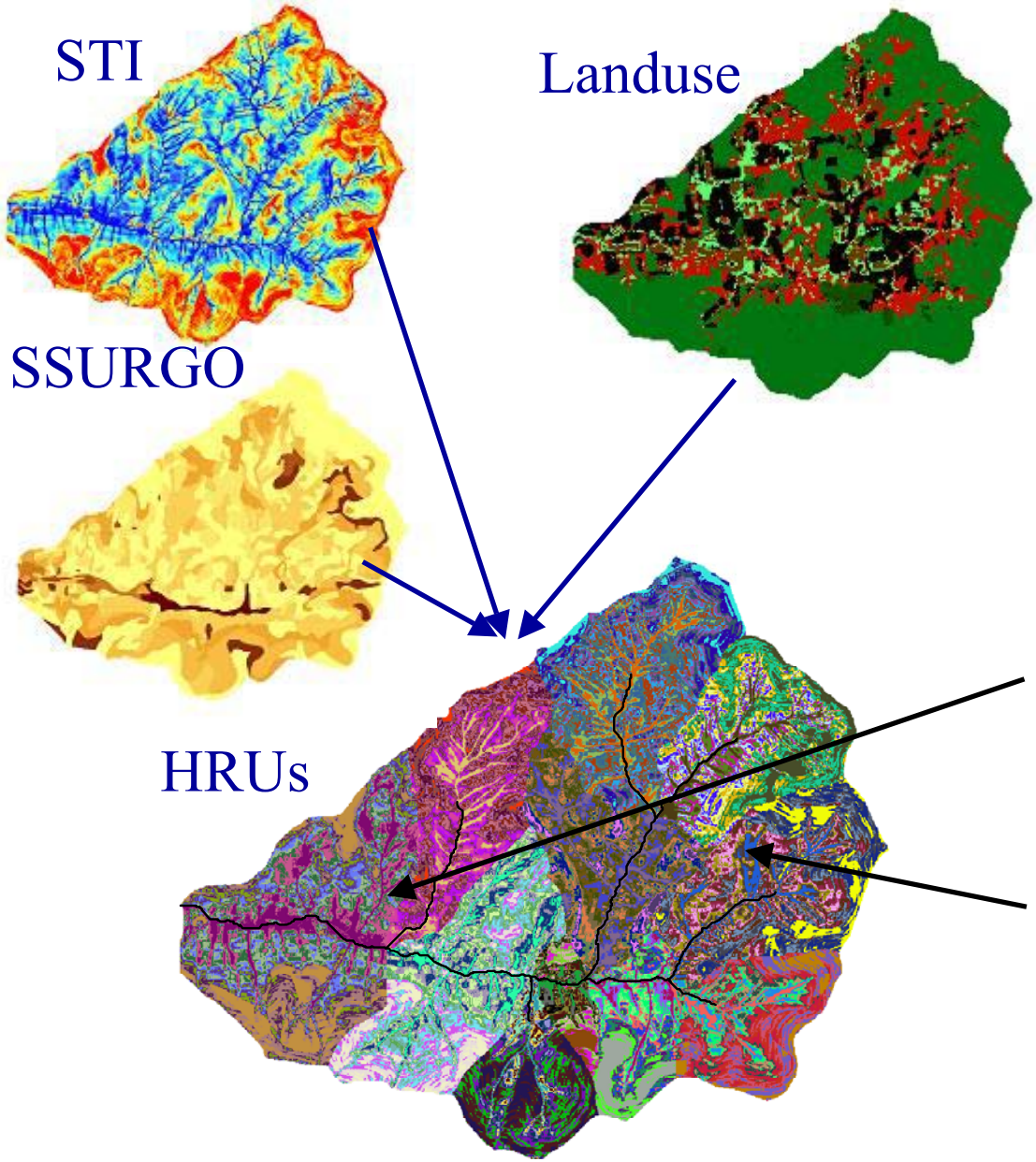
- So runoff/P loss is the same here (lowland pasture)
- As here (upland pasture)
- We know this is not the case

SWAT Issues

- Lumped model (i.e., no flow among HRUs)
  - Only spatial reference is at the subbasin level
    - Therefore, no capability to determine different landscapes source areas (VSAs)



- Spatially referencing attributes at the HRU level would require tremendous computing power and data storage needs
- So we need a way to identify occurrences at the HRU level without referencing them

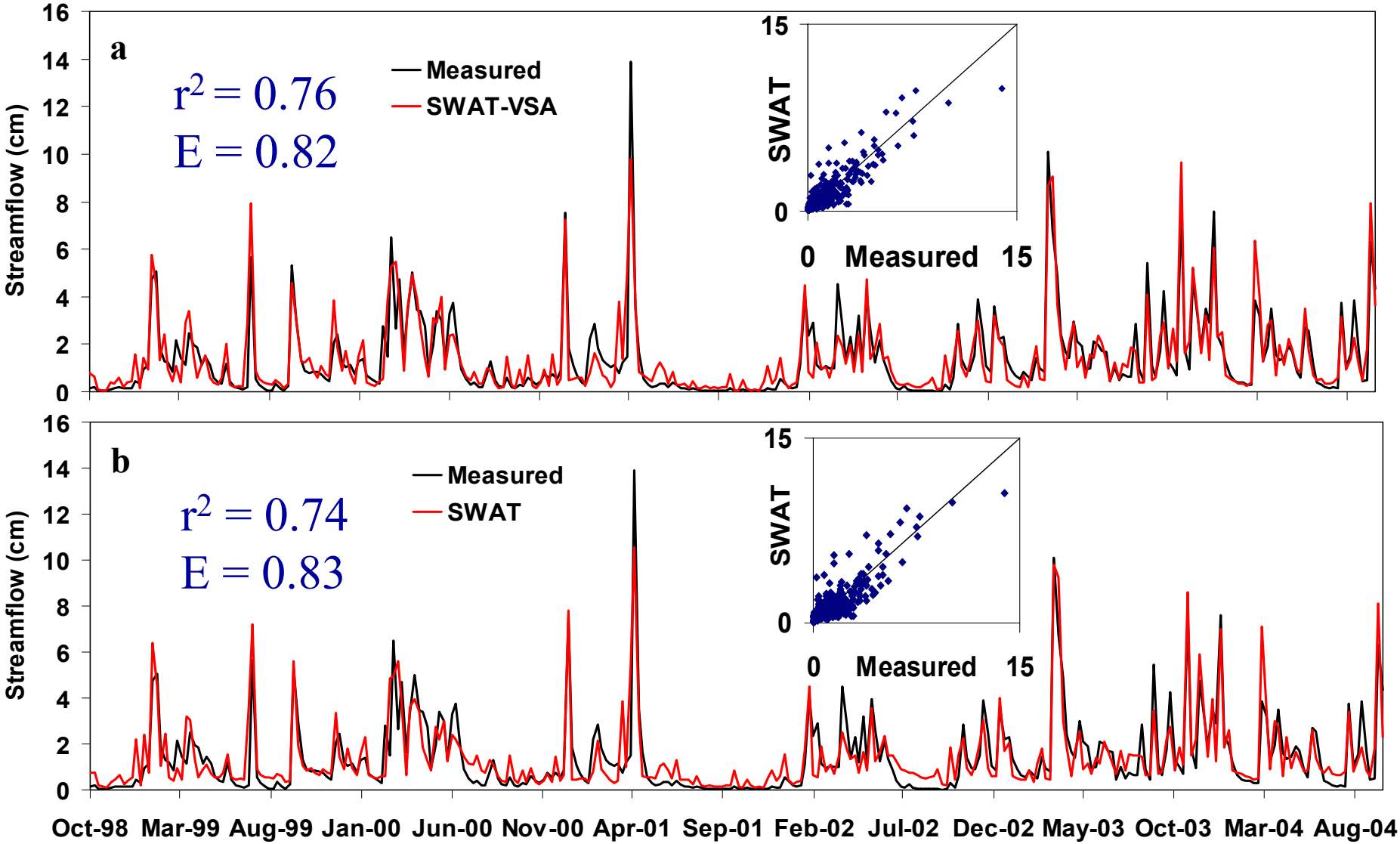


- SWAT-VSA defines HRUs as the coincidence of soil topographic index (and soil) and landuse
  - Weighted average of soil properties nested with in an area weighted index class

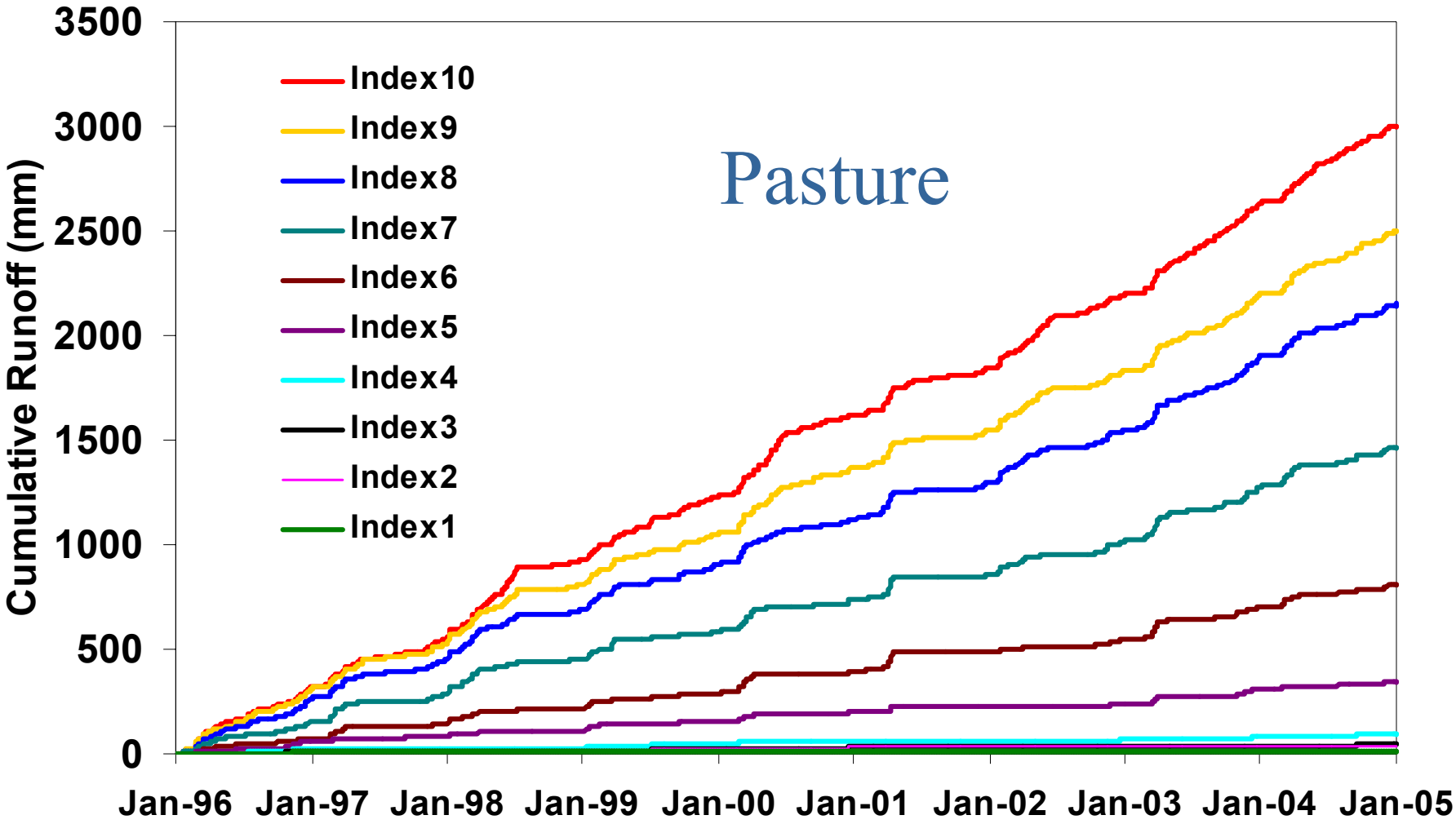
- So runoff/P loss is now not the same here (lowland pasture)
- As here (upland pasture)

Input data

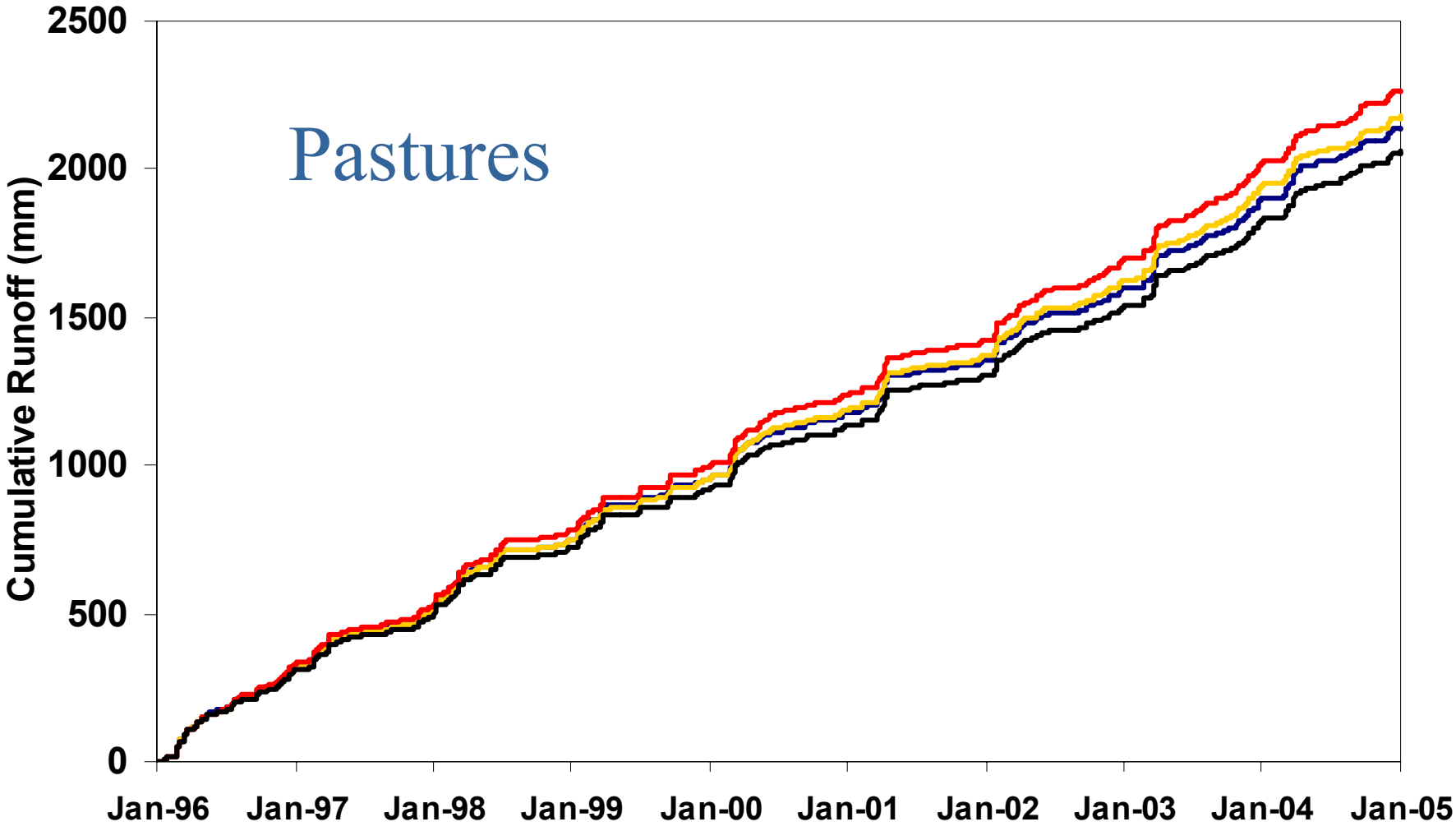
Index	CNII	AWC
		$cm^3\ H_2O\ cm^{-3} soil$
One	34.08	0.13
Two	42.12	0.17
Three	45.83	0.19
Four	51.50	0.22
Five	59.46	0.25
Six	68.77	0.30
Seven	78.43	0.35
Eight	86.72	0.39
Nine	93.23	0.43
Ten	98.20	0.47

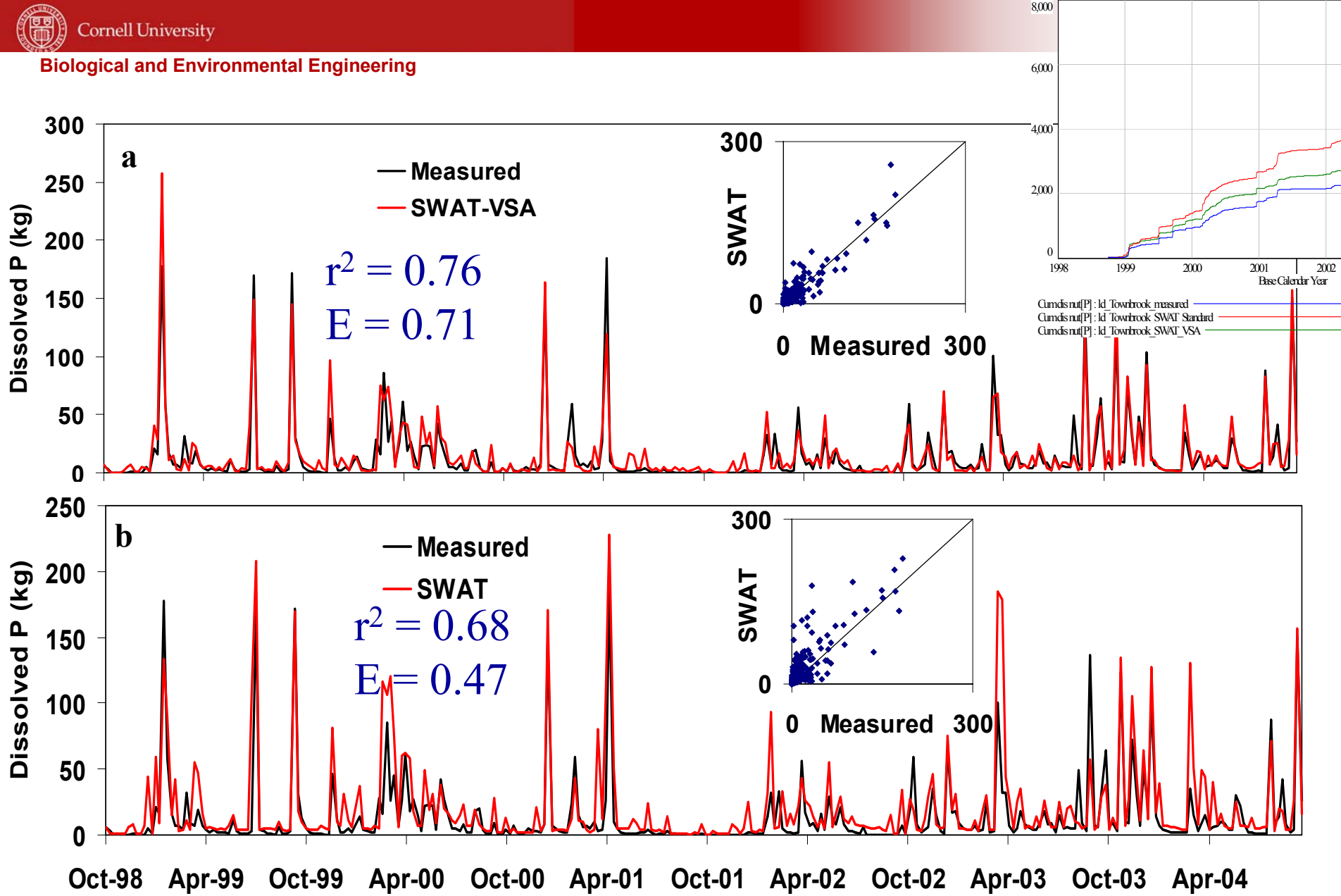

a
$r^2 = 0.76$
$E = 0.82$
Measured
SWAT-VSA
SWAT
Measured
Streamflow (cm)
b
$r^2 = 0.74$
$E = 0.83$
Measured
SWAT
SWAT
Measured
Streamflow (cm)
Oct-98 Mar-99 Aug-99 Jan-00 Jun-00 Nov-00 Apr-01 Sep-01 Feb-02 Jul-02 Dec-02 May-03 Oct-03 Mar-04 Aug-04

SWAT-VSA Runoff



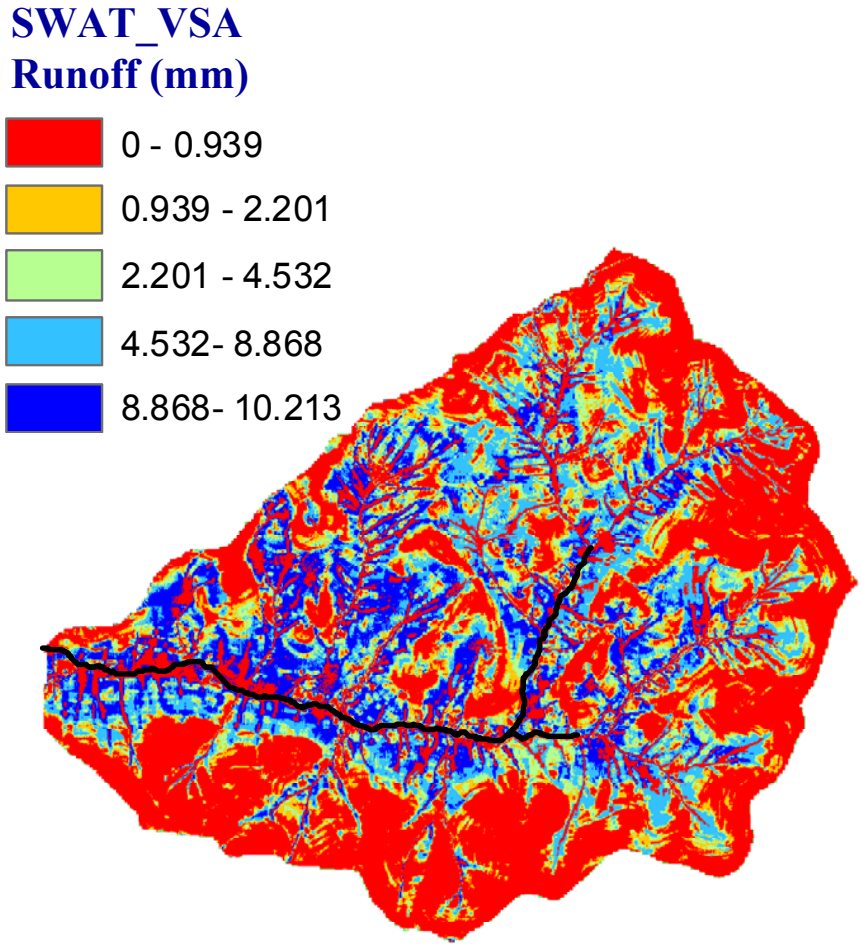
SWAT-Standard Runoff



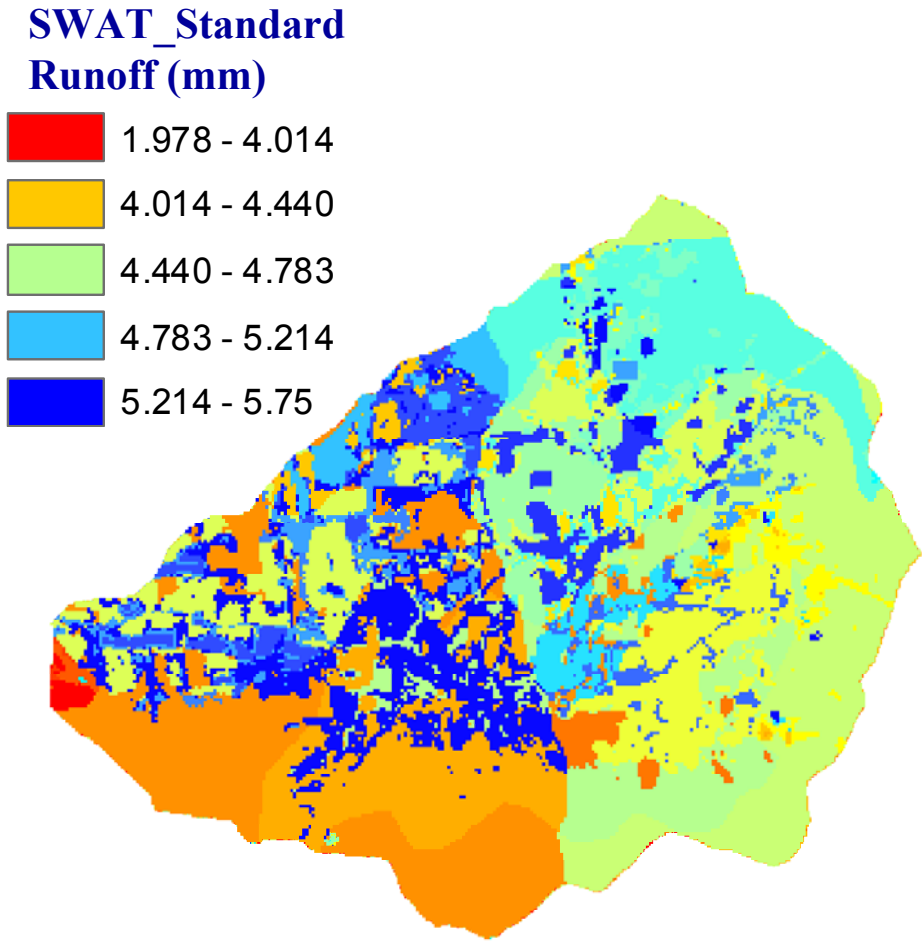

a
Measured
SWAT-VSA
$r^2 = 0.76$
$E = 0.71$
Dissolved P (kg)
300
250
200
150
100
50
0
SWAT
0 Measured 300
8,000
6,000
4,000
2,000
0
1998
1999
2000
2001
2002
Base Calendar Year
Cumdis nut[P] : ld_Townbrook_measured
Cumdis nut[P] : ld_Townbrook_SWAT_Standard
Cumdis nut[P] : ld_Townbrook_SWAT_VSA
b
Measured
SWAT
$r^2 = 0.68$
$E_f = 0.47$
Dissolved P (kg)
Oct-98
Apr-99
Oct-99
Apr-00
Oct-00
Apr-01
Oct-01
Apr-02
Oct-02
Apr-03
Oct-03
Apr-04

Runoff

SWAT-VSA

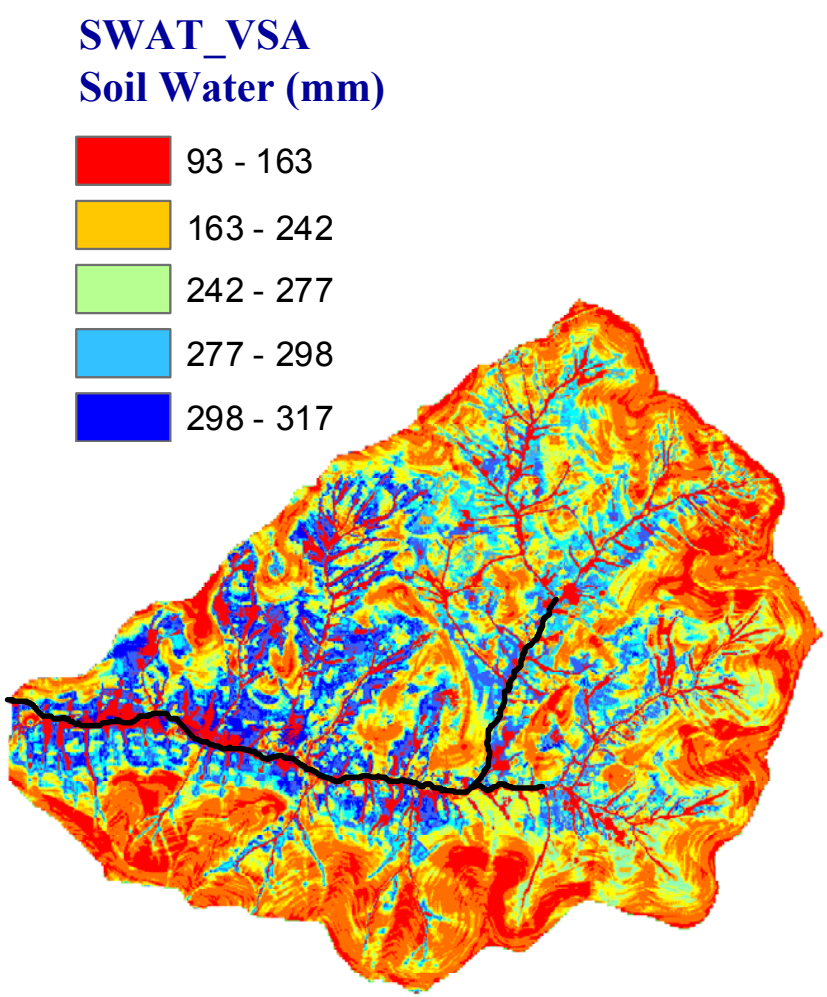


SWAT-Standard

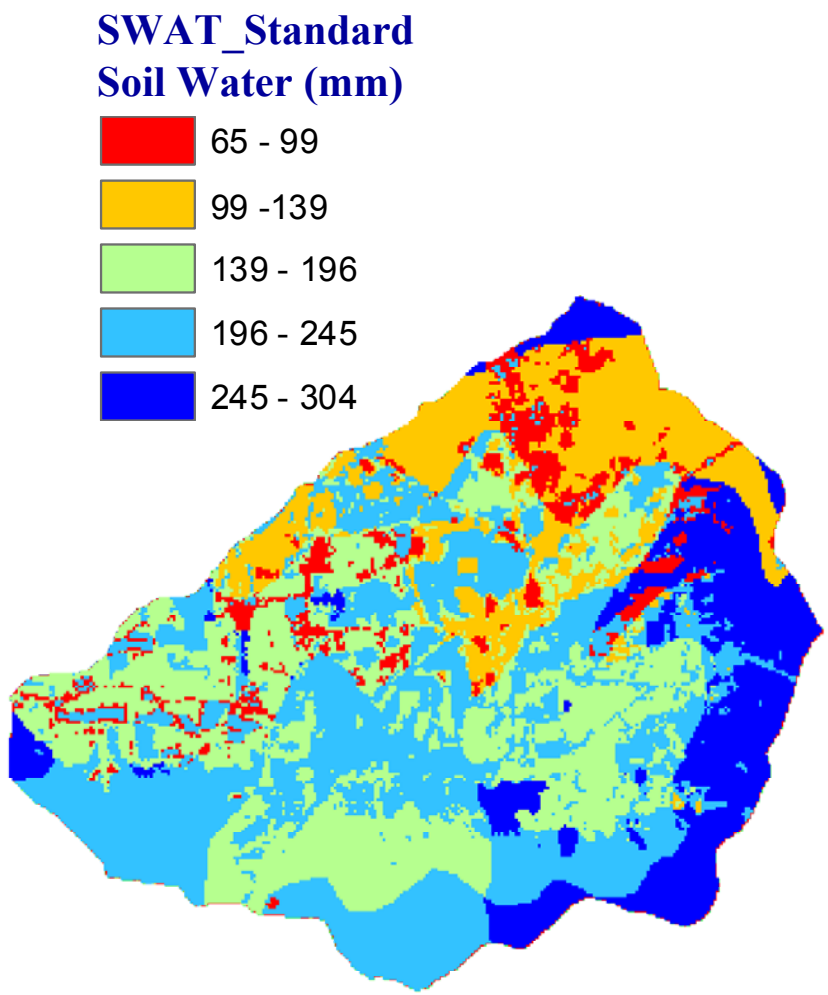


Soil Water

SWAT-VSA



SWAT-Standard

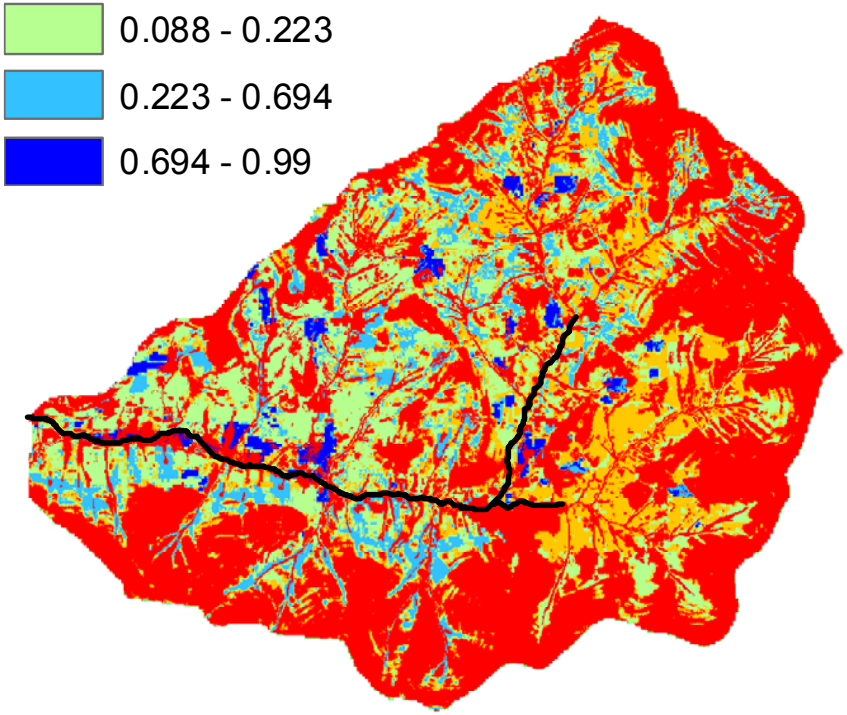


Phosphorus

SWAT-VSA

SWAT_VSA
Dissolved P (kg ha^{-1})

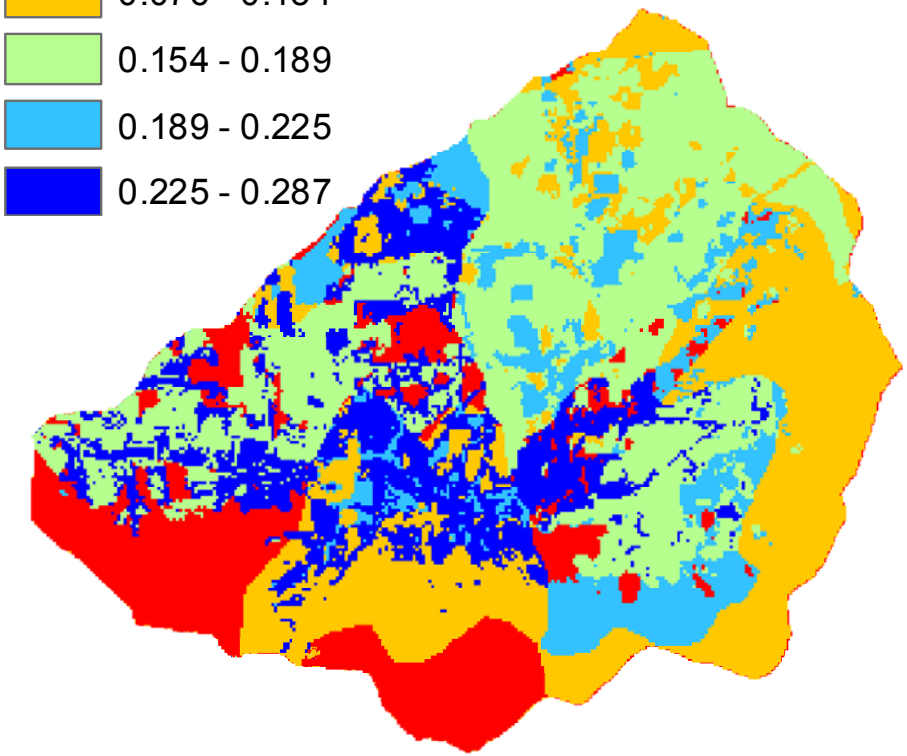
- 0 - 0.044
- 0.044 - 0.088
- 0.088 - 0.223
- 0.223 - 0.694
- 0.694 - 0.99

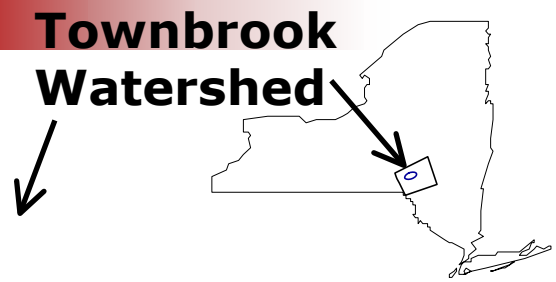


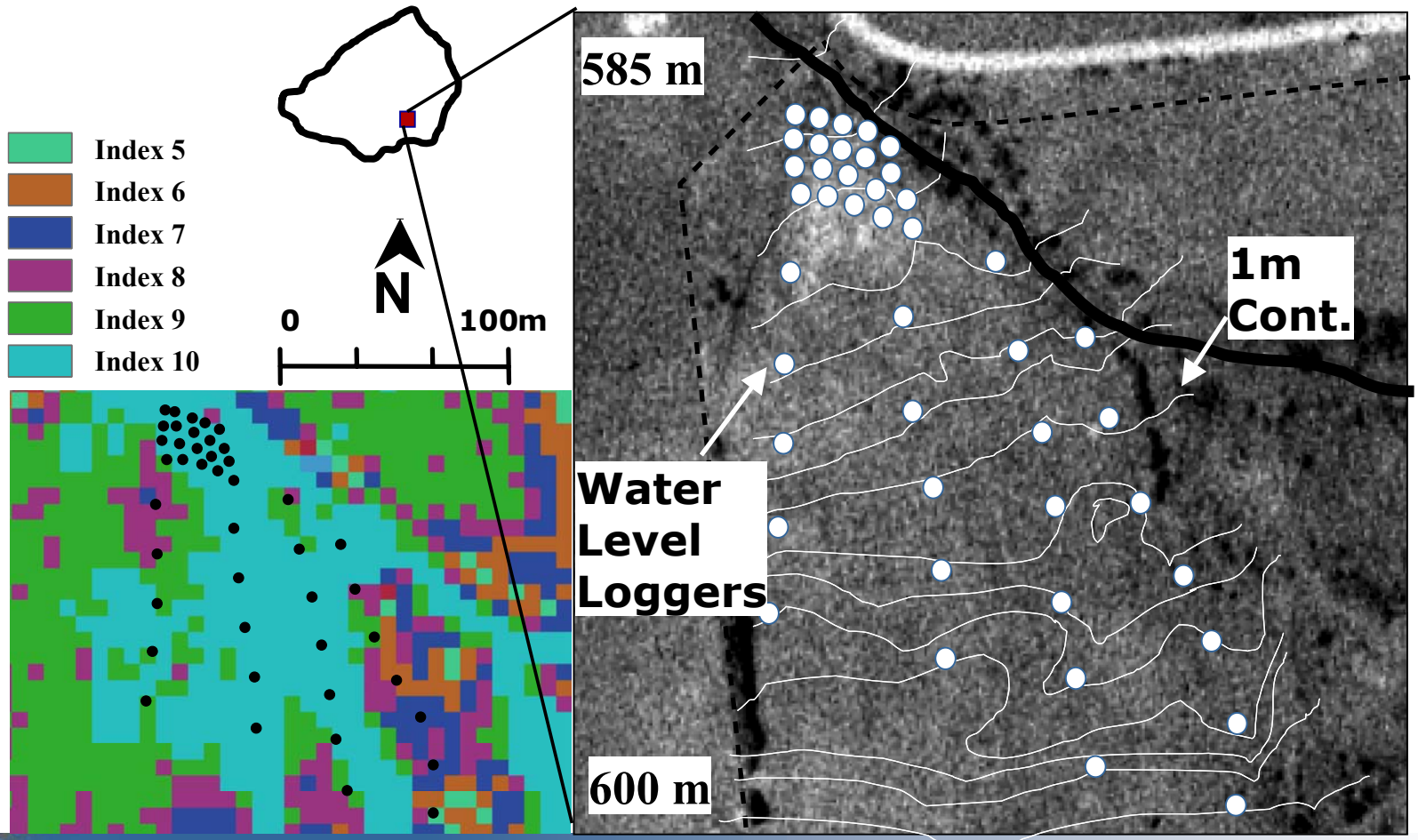
SWAT-Standard

SWAT_Standard
Dissolved P (kg ha^{-1})

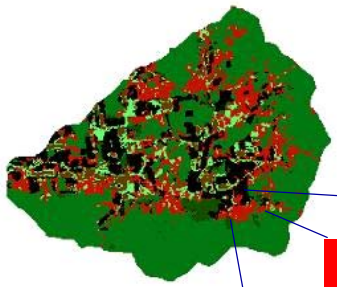
- 0 - 0.076
- 0.076 - 0.154
- 0.154 - 0.189
- 0.189 - 0.225
- 0.225 - 0.287

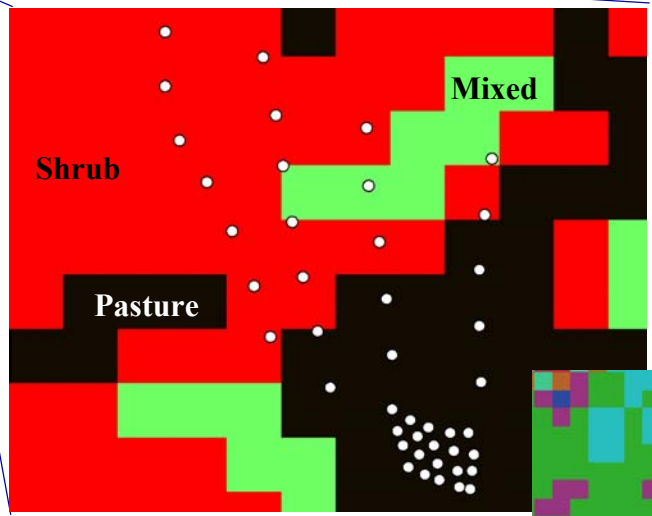


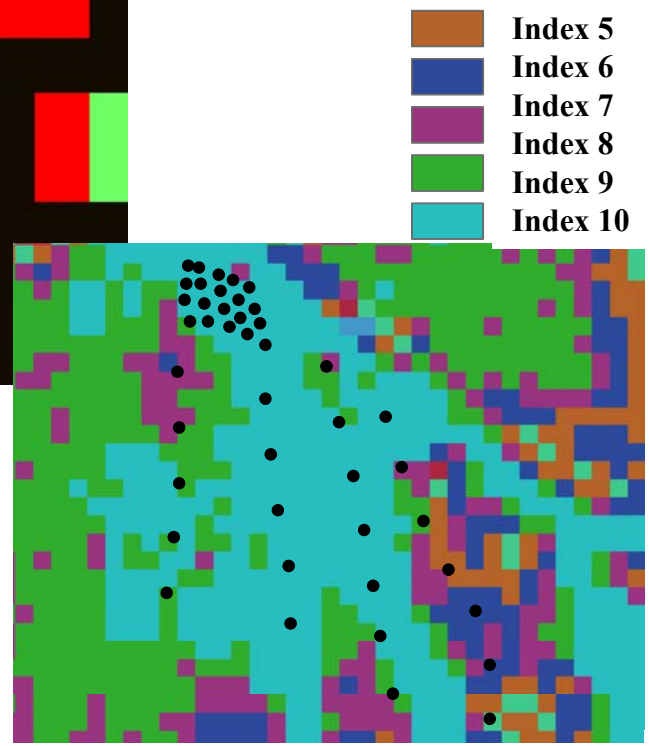

Townbrook
Watershed


Index 5
Index 6
Index 7
Index 8
Index 9
Index 10
N
0
100m
585 m
600 m
1m
Cont.
Water
Level
Loggers

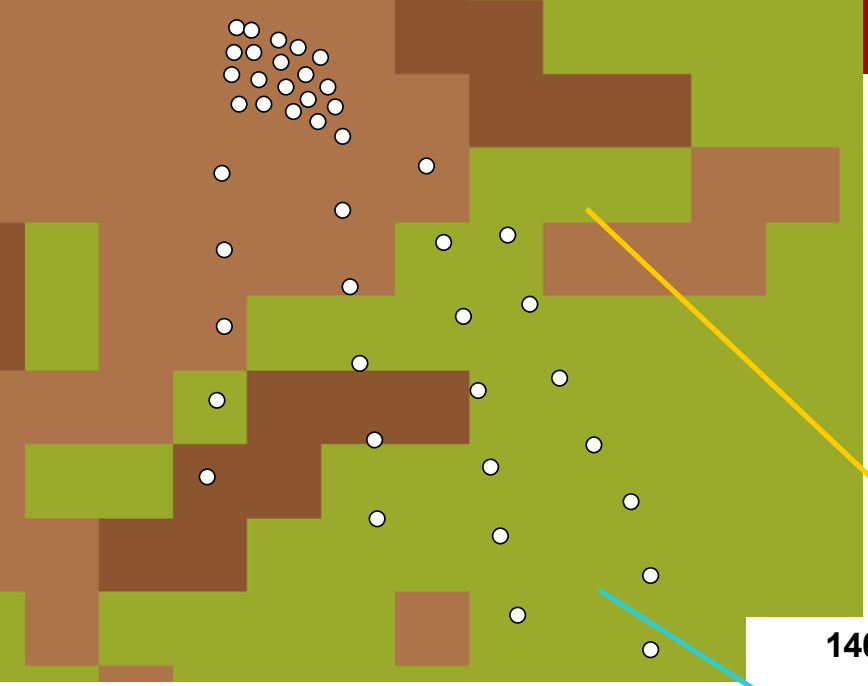
Distributed Predictions

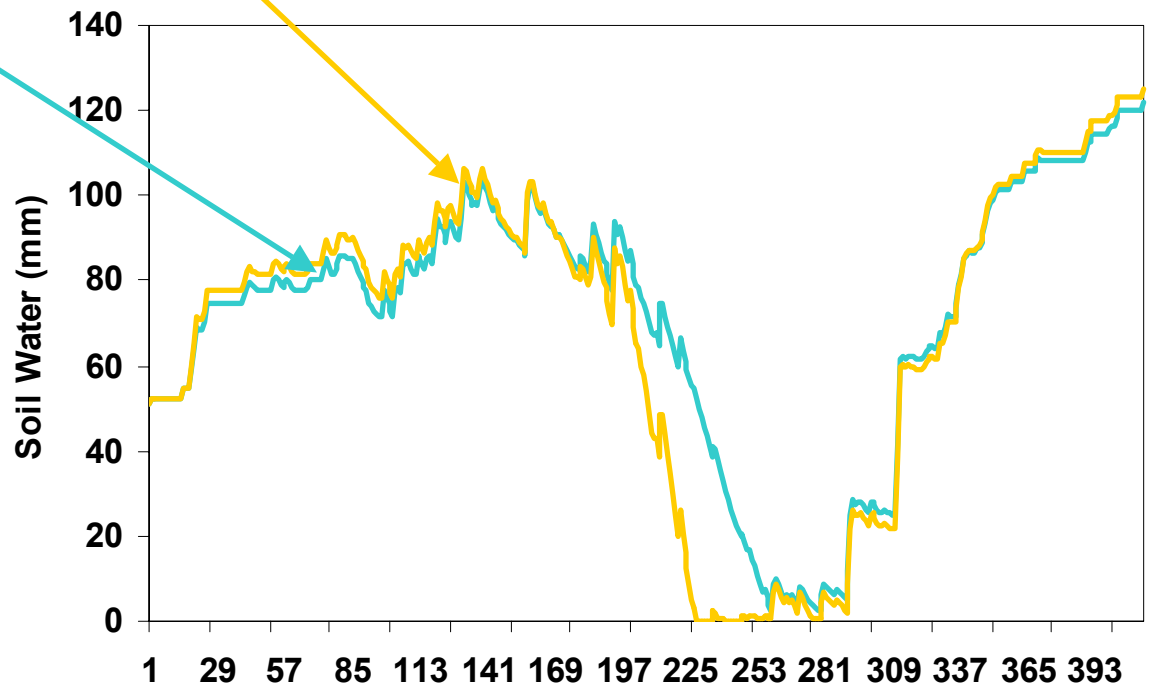


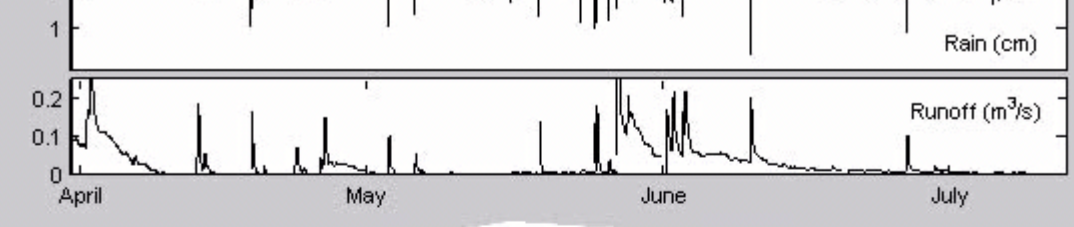


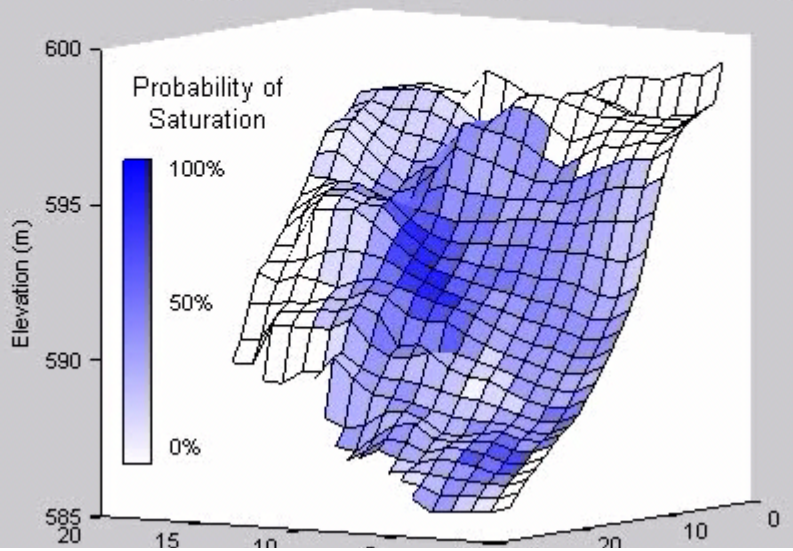


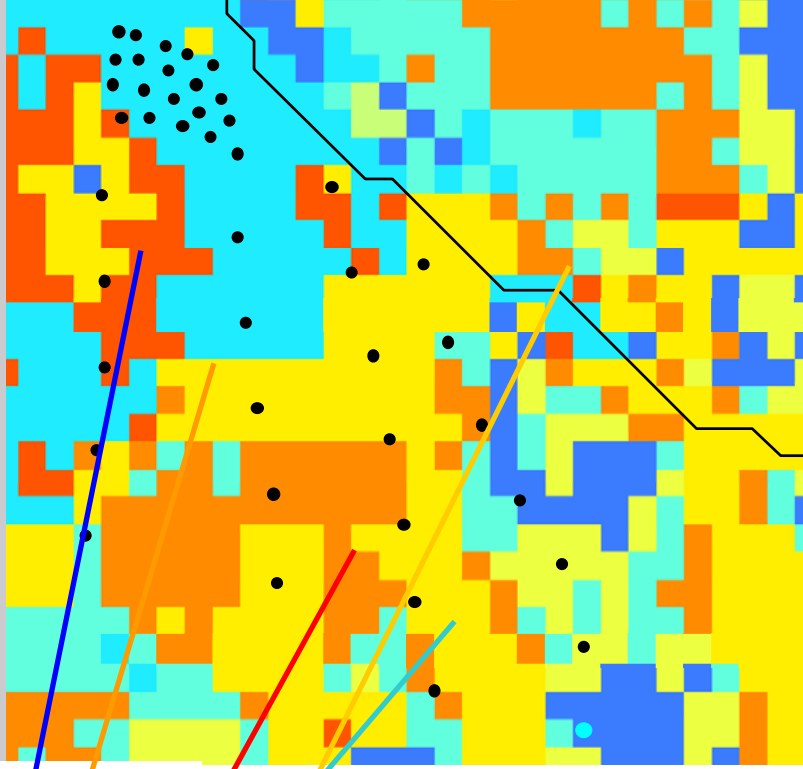
SWAT-Standard

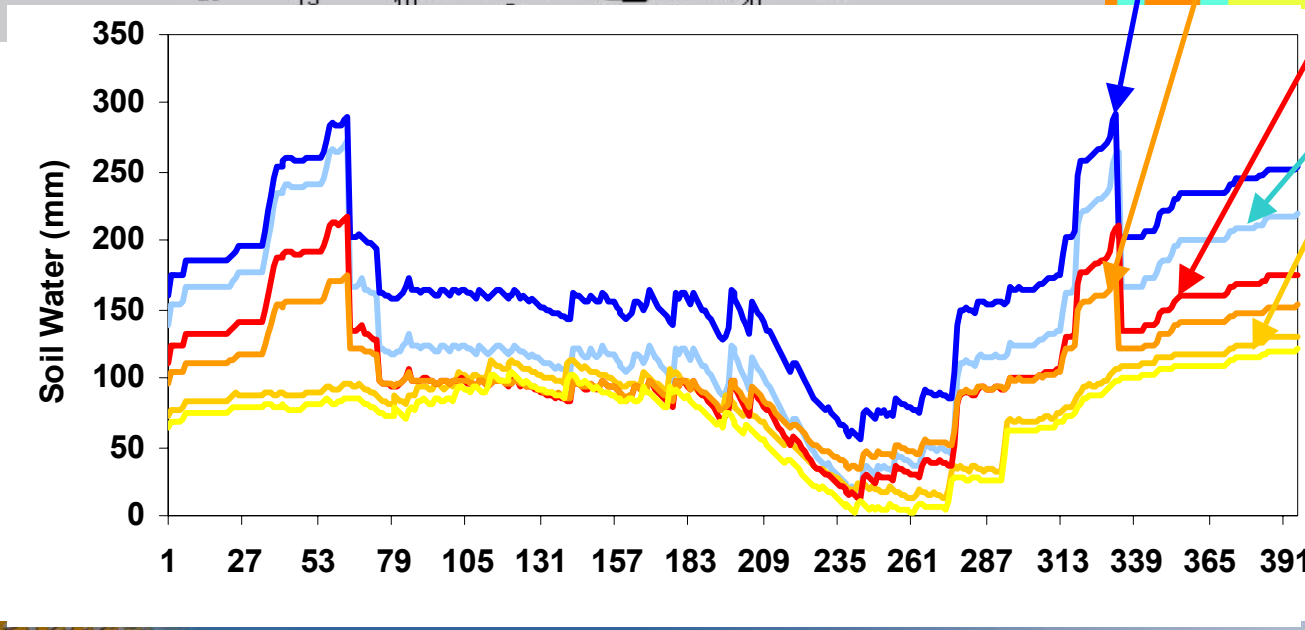




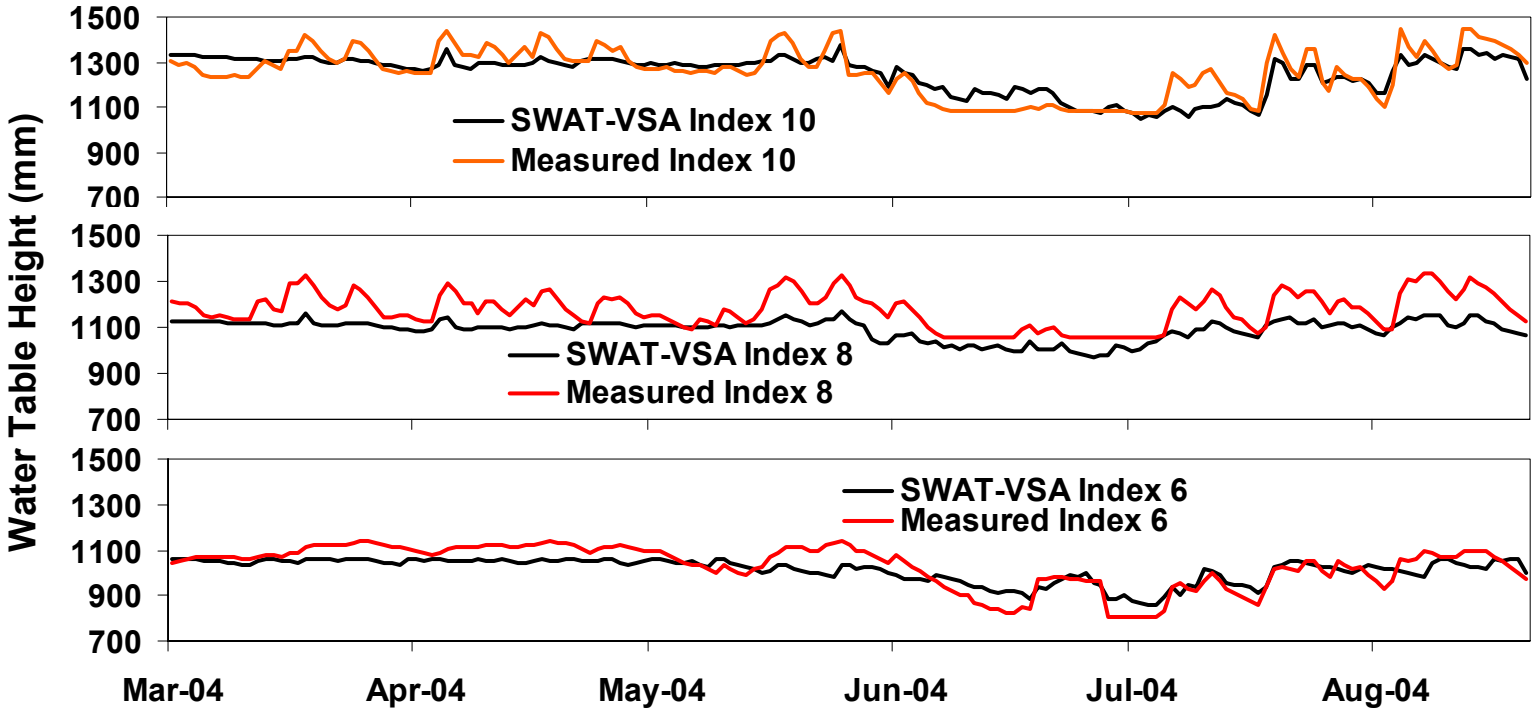

Rain (cm)
Runoff (m3/s)
0.2
0.1
0
April
May
June
July


Probability of Saturation
100%
50%
0%
Elevation (m)
600
595
590
585




Soil Water (mm)
350
300
250
200
150
100
50
0
1
27
53
79
105
131
157
183
209
235
261
287
313
339
365
391

SWAT-VSA


Water Table Height (mm)
1500
1300
1100
900
700
SWAT-VSA Index 10
Measured Index 10
SWAT-VSA Index 8
Measured Index 8
SWAT-VSA Index 6
Measured Index 6
Mar-04
Apr-04
May-04
Jun-04
Jul-04
Aug-04

Re-conceptualizing Water Quality Models

- Rationale and Objectives
- Curve Numbering VSA hydrology
- Proof of Concept: SWAT meets SWAT-VSA
- Conclusions

Conclusions

- The Curve Number Runoff Model is not a critical limitation to developing realistic water quality models
- SWAT can be "convinced" to model VSA hydrology
  - Phosphorus is more accurately predicted
  - Conceptually it appears to correctly capture VSA phenomena


Thank You