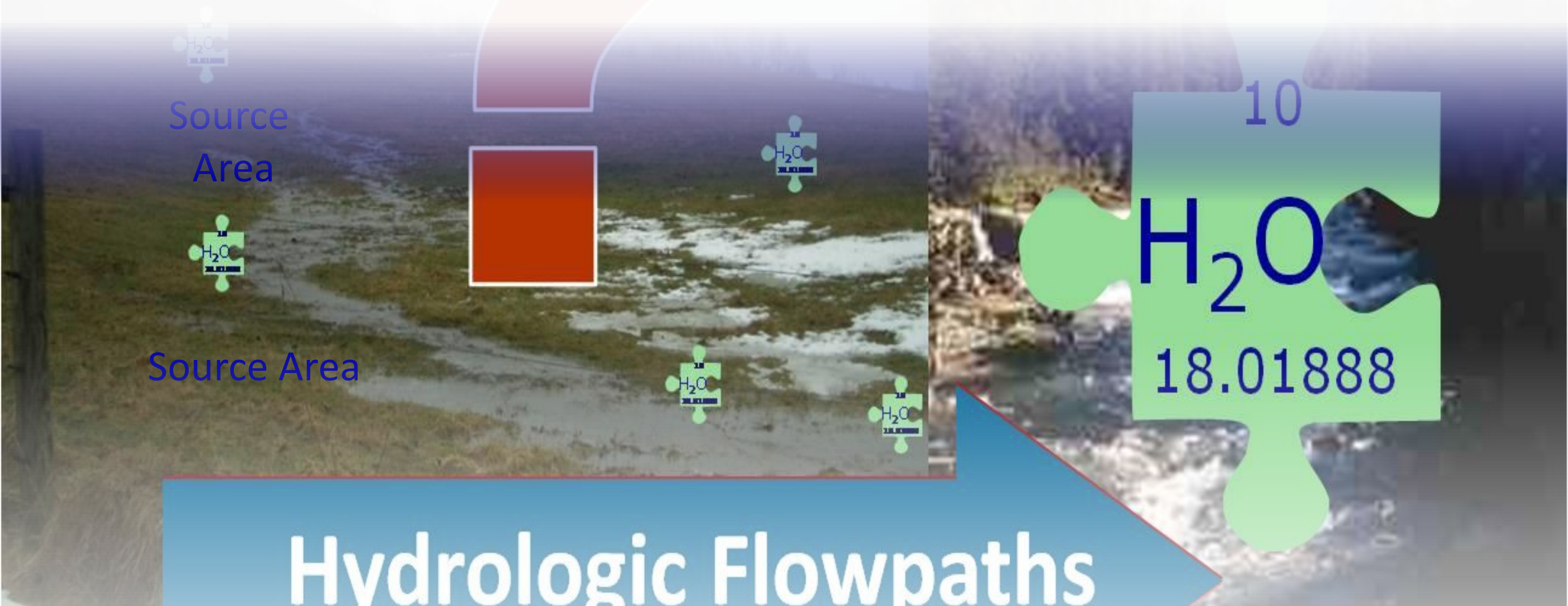
Can Complexity Simplify Modeling

Can Hydrologic Complexity Simplify Watershed Modeling



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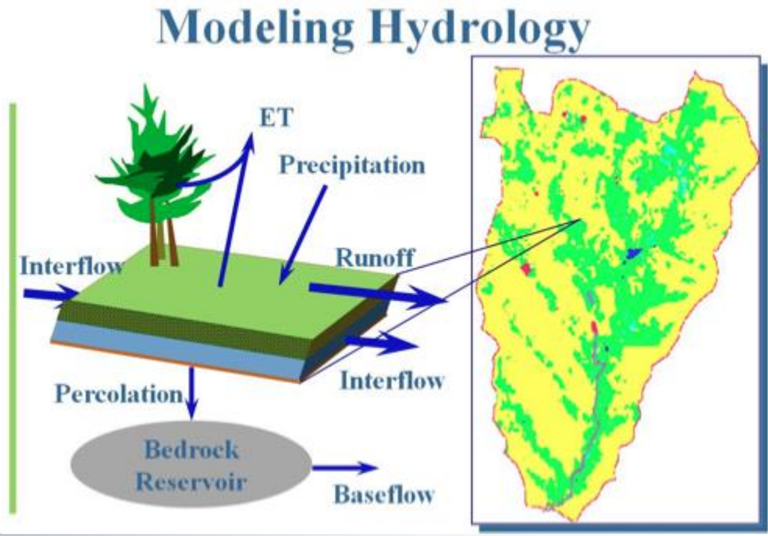
My Thoughts

- First, I don't like calibration, but it is often necessary
  - Calibration tells us what we don't know or can't figure out about the system
- Goal: to provide actionable info about *intra*-watershed processes to inform management
- My Rules:
  - Use as much 'real' data as is available
  - Determine parameter values *a priori* if possible
  - Constrain parameters to realistic ranges
  - Be wary of purely fitting parameters or parameters we don't understand the function of or what they do

Outline

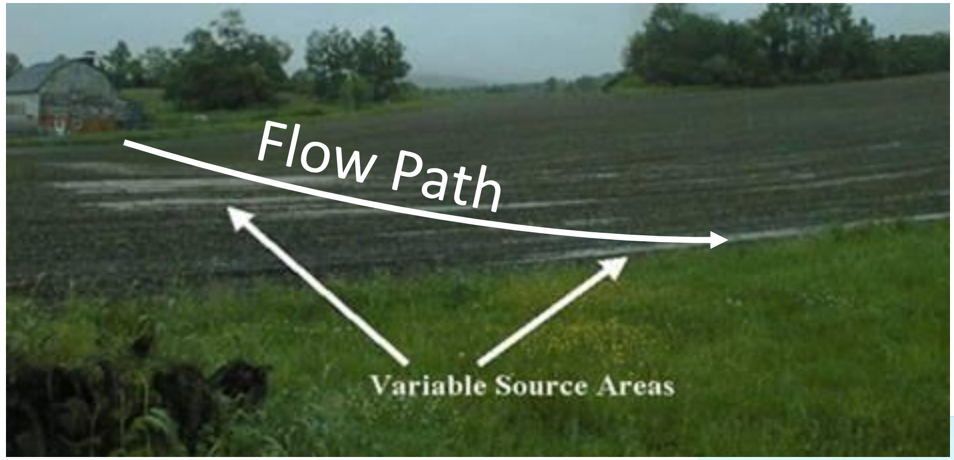
- Context: Hydrologic complexity as an example
    - Variable Source Area Hydrology and Soil Physics
    - Snowmelt/Accumulation
- Summary



Can we use Hydrologic Complexity to Constrain Models?

- There are a number of aspects of the hydrologic response that can be used as the underlying linkages to constrain a calibration
  - Storage versus Discharge relationships
  - Storage versus Saturated Area relationships
  - Water Balance, a universal concept that is also scalable
  - Terrain Attributes
  - Probability distribution of Soil Depths, Infiltration Capacity Heterogeneity
- Goal: represent complex processes/landscapes without over parameterization or inducing model instability

Variable Source Areas



Most Watershed Models were not intended to capture this complexity

- Soil and Water Assessment Tool (SWAT)
- General Watershed Loading Function (GWLF)
- Agricultural Nonpoint Source Pollution Model (AGNPS)
- Hydrologic Simulation Program Fortran (HSPF)

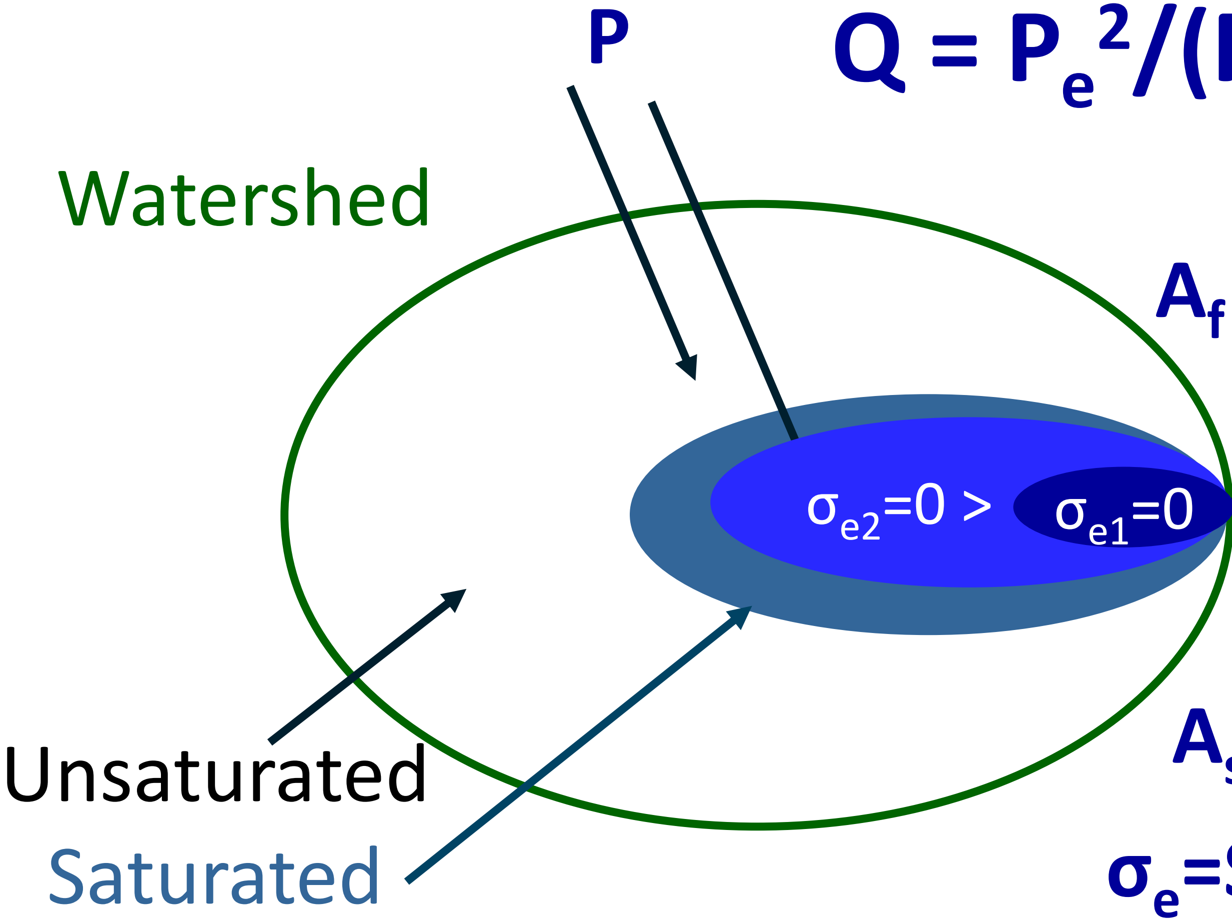
The Curve Number as an example

$$\text{"Runoff"} = P_e^{\,2}/(P_e+S)$$

$$S = 25400/CN - 254$$

Tables link CN to land use and soil drainage class. CN is then calibrated

Parameter Estimation



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

$$A_f = \partial Q/\partial P_e$$

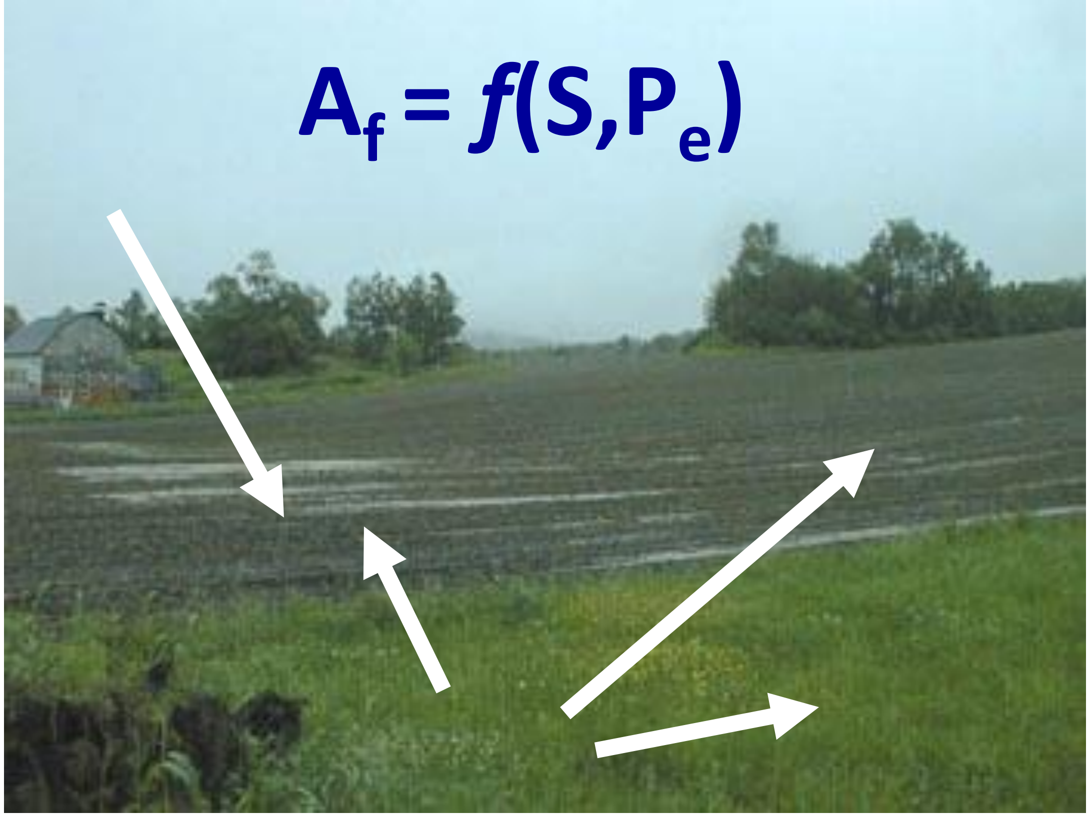
$$A_f = 1-(S^2/(P_e+S)^2$$

$$A_s = 1-(S^2/(\sigma_e+S)^2$$

$$\sigma_e=S(\surd(1/(1-A_s))-1$$

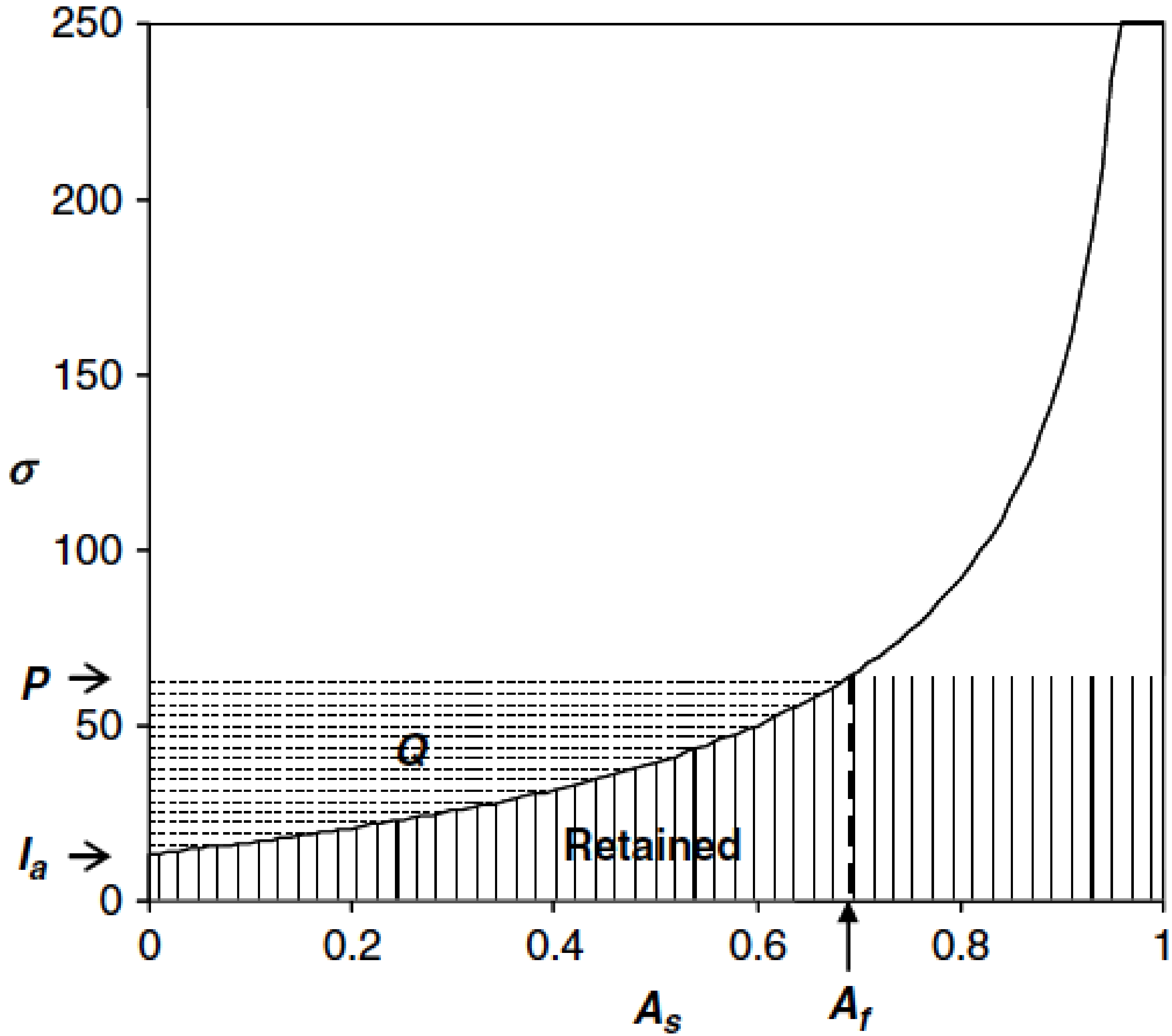
$$A_{f,}\ A_{s,}\ \sigma_e = f(S,P)$$

We know how much area is contributing…

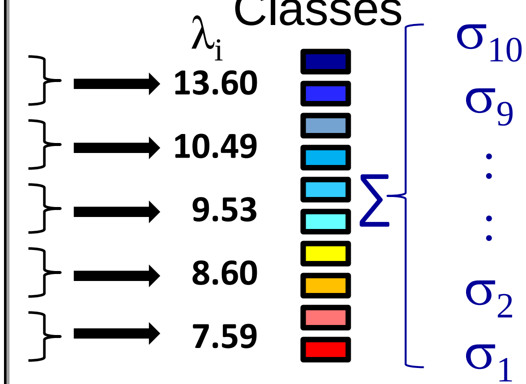


$A_f = f(S, P_e)$

…but from where in the landscape?



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



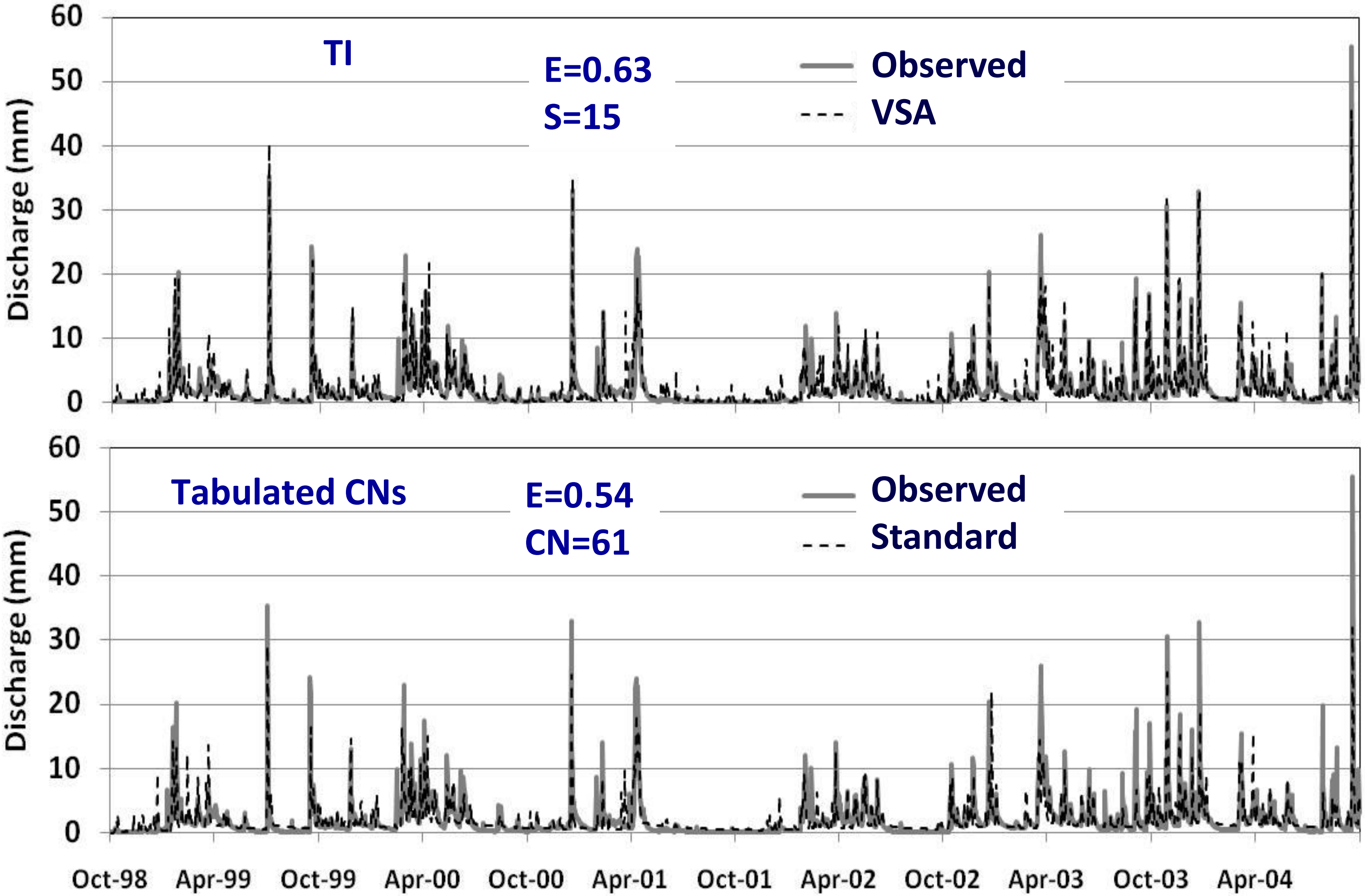
$= S$

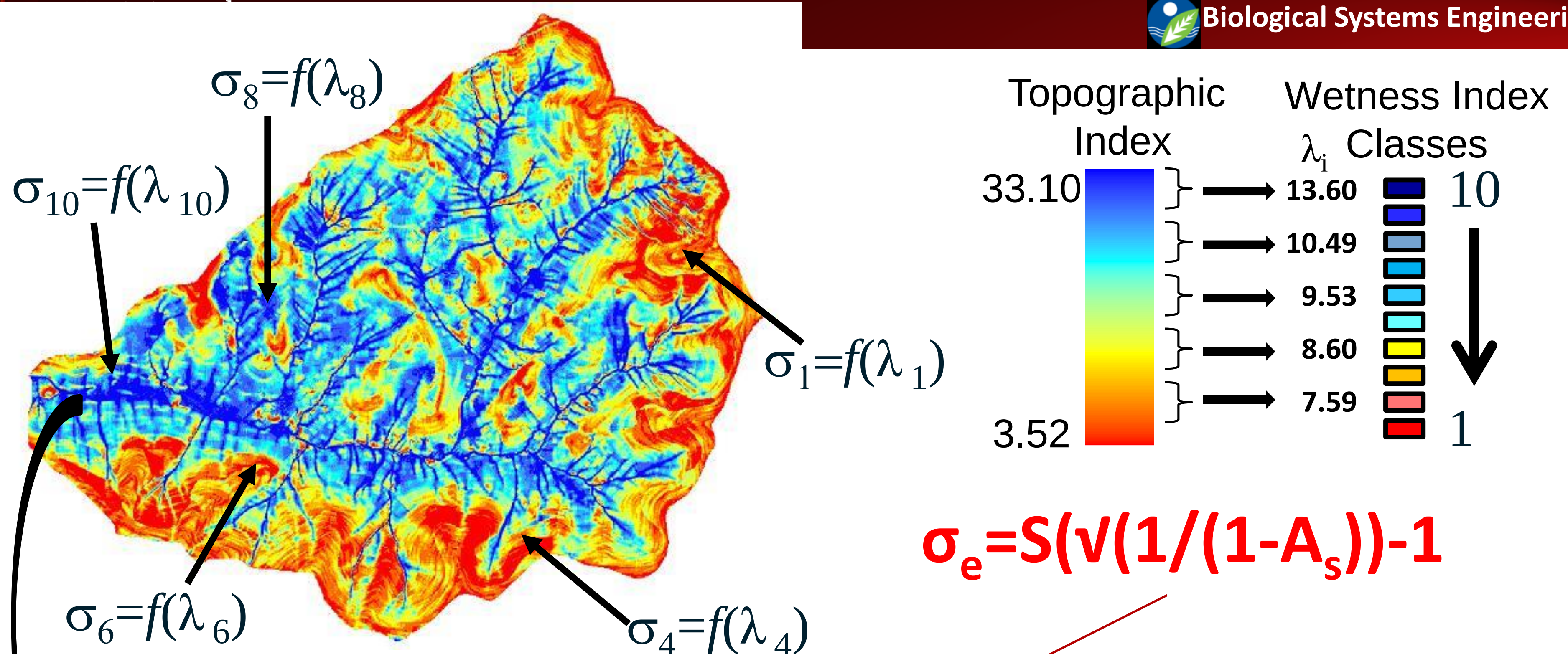
$\sqrt{(1/(1-A_s))}-1$

σ_i = local storage

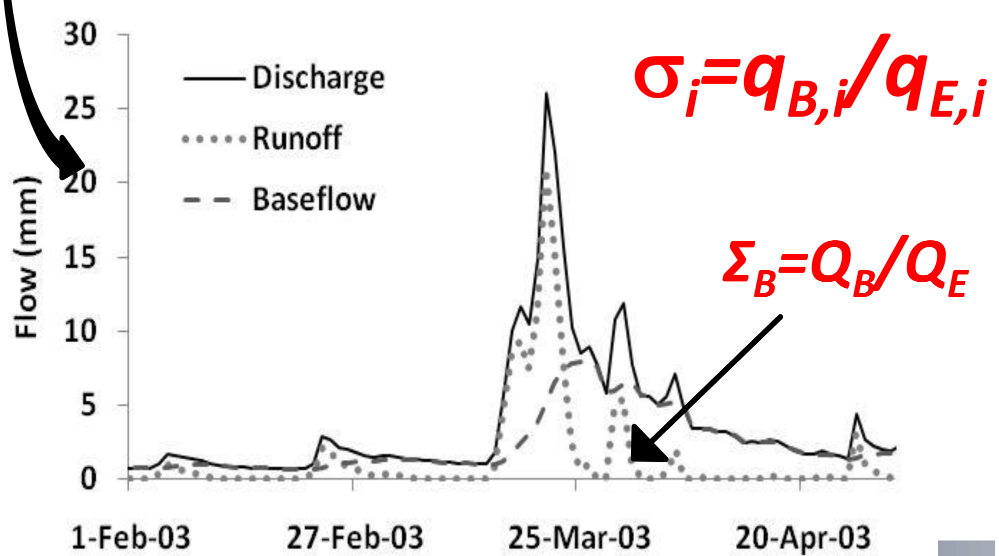
ıston et al., 2008. *J. Hydrol*
Easton et al., 2011. *Hydrol. Proc*
Collick et al. 2015. *Hydrol. Proc.*

"Estimation"

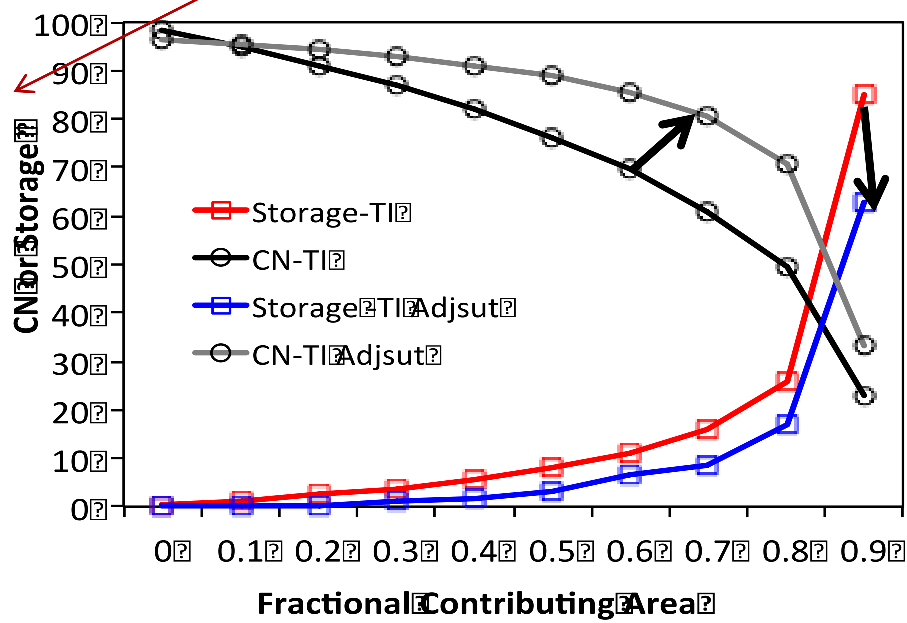

Discharge (mm)
60
50
40
30
20
10
0
TI
E=0.63
S=15
Observed
VSA
Discharge (mm)
Tabulated CNs
E=0.54
CN=61
Observed
Standard
Oct-98
Apr-99
Oct-99
Apr-00
Oct-00
Apr-01
Oct-01
Apr-02
Oct-02
Apr-03
Oct-03
Apr-04



$\sigma_8=f(\lambda_8)$
$\sigma_{10}=f(\lambda_{10})$
$\sigma_1=f(\lambda_1)$
$\sigma_6=f(\lambda_6)$
$\sigma_4=f(\lambda_4)$
Topographic Index
33.10
3.52
Wetness Index λ_i Classes
13.60
10.49
9.53
8.60
7.59
10
1
$\sigma_e=S(\sqrt{(1/(1-A_s))}-1$

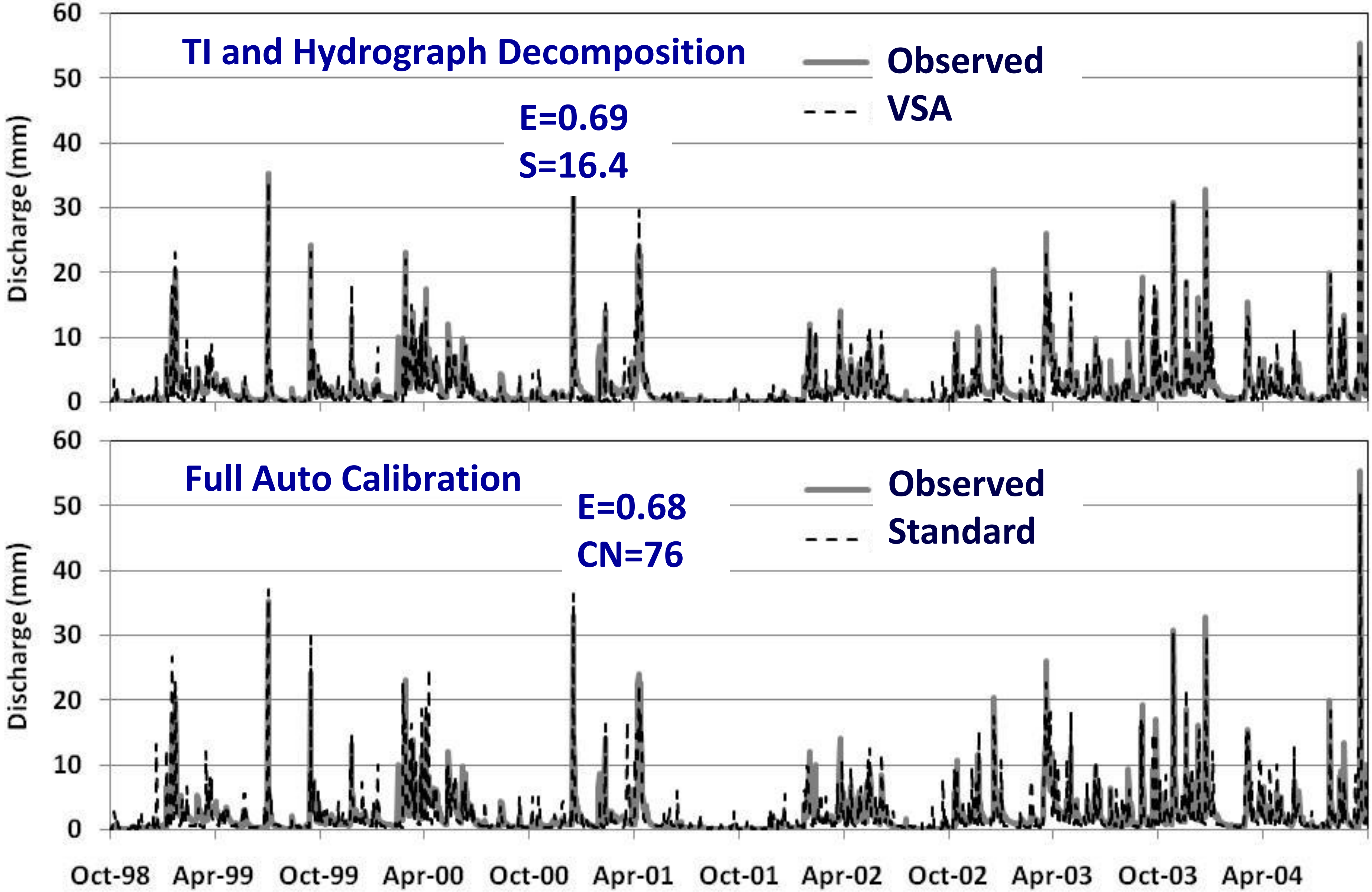


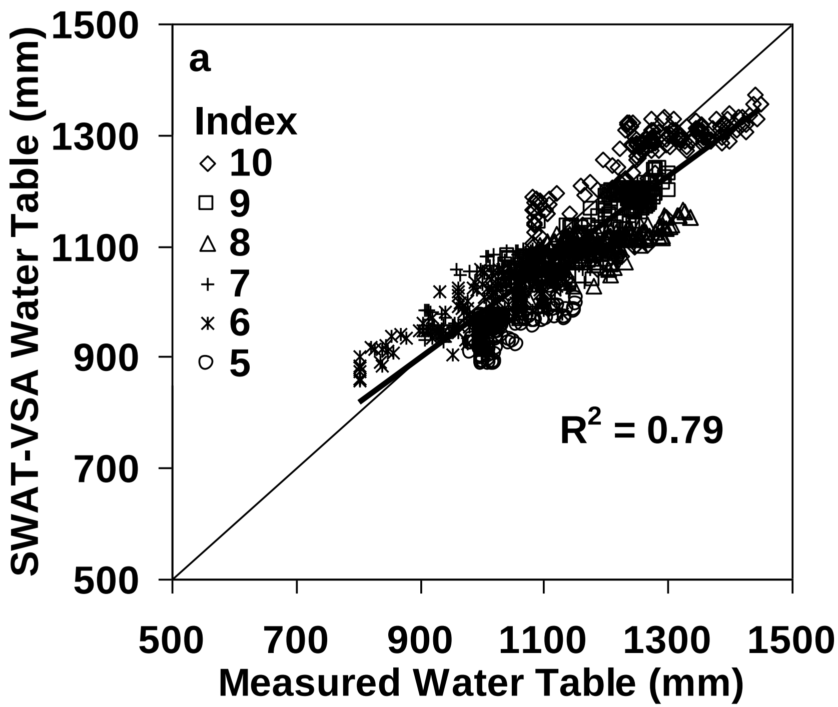
Discharge
Runoff
Baseflow
Flow (mm)
30
25
20
15
10
5
0
1-Feb-03
27-Feb-03
25-Mar-03
20-Apr-03
$\sigma_i=q_{B,i}/q_{E,i}$
$\Sigma_B=Q_B/Q_E$

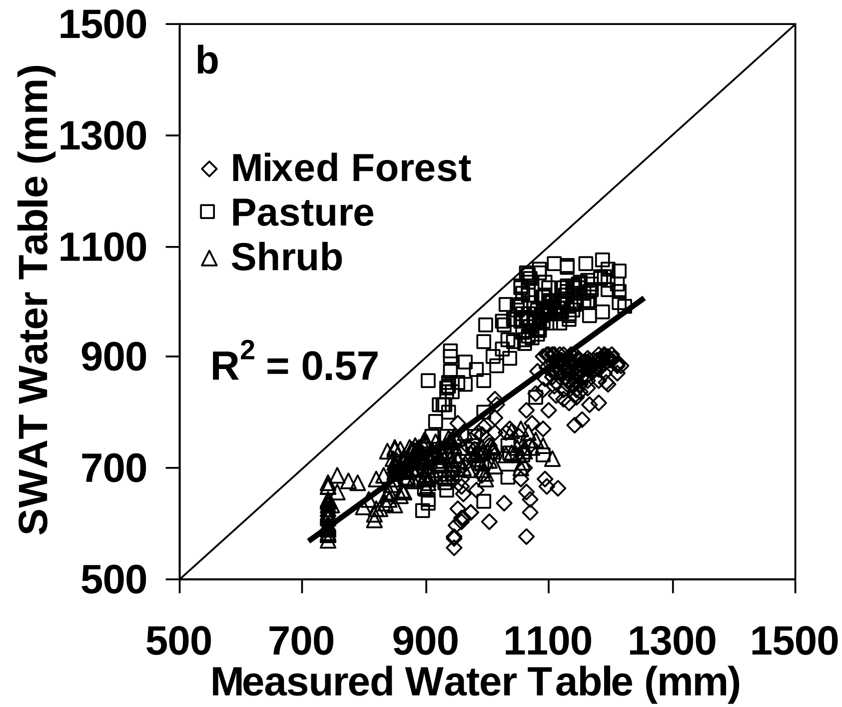


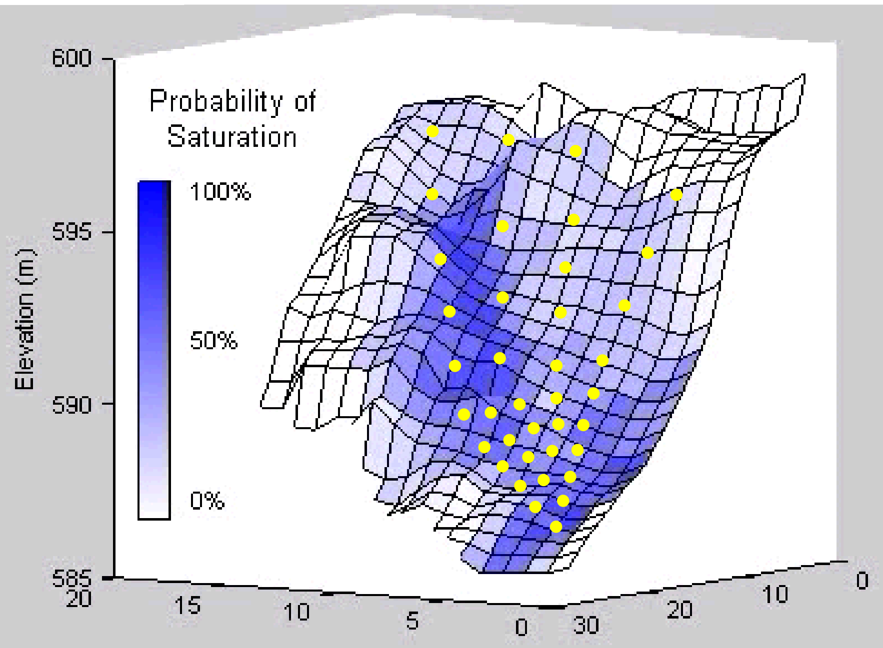
Storage-TI
CN-TI
Storage TI Adjsut
CN-TI Adjsut
CN or Storage
100
90
80
70
60
50
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Fractional Contributing Area

"Calibration"




a
Index
10
9
8
7
6
5
R^2 = 0.79
1500
1300
1100
900
700
500
SWAT-VSA Water Table (mm)
500 700 900 1100 1300 1500
Measured Water Table (mm)


b
Mixed Forest
Pasture
Shrub
R^2 = 0.57
1500
1300
1100
900
700
500
SWAT Water Table (mm)
500 700 900 1100 1300 1500
Measured Water Table (mm)


Probability of Saturation
100%
50%
0%
Elevation (m)
600
595
590
585
20
15
10
5
0
30
20
10
0

Demo

Snow Melt/Accumulation

- Many watershed models use a temperature index to 'model' snowmelt and snow accumulation
  - $M = MF\ (T_a - T_{base})$
- Simple, but requires calibration and cannot be applied outside the range of conditions for which they were calibrated
  - e.g., Assessing Landuse or Climate Change

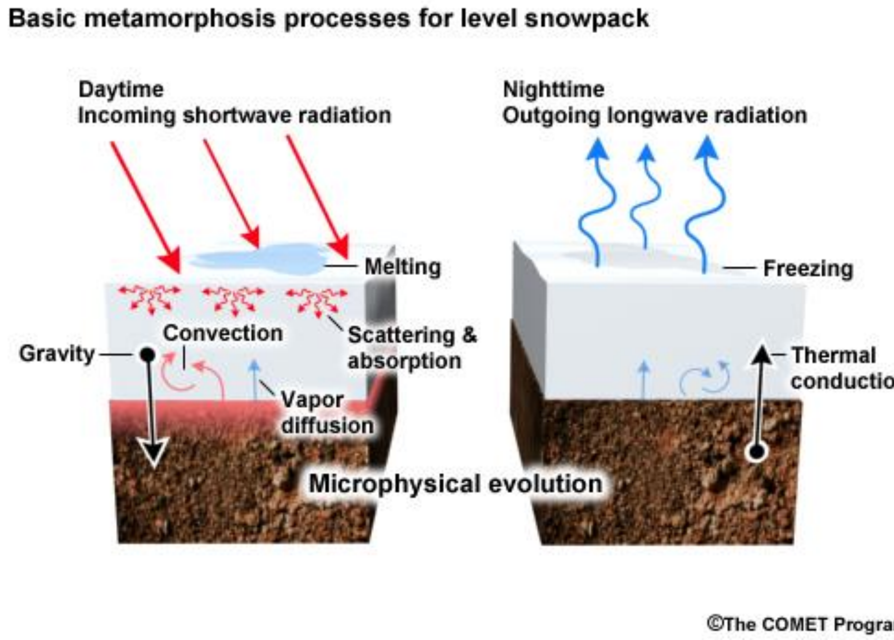
Temperature Index

Parameters	**Mean**	**Standard Deviation**	**CV**
Snowfall temperature [C]	-1.27	2.62	-2.06
Snow melt base temperature [C]	0.02	3.62	181.00
Melt factor on June 21 [mm H_2O/C-day]	-1.62	2.67	-1.65
Melt factor on December 21 [mm H_2O/C-day]	-0.27	3.41	-12.63
Snow pack temperature lag factor	0.15	3.13	20.87

Can this be used to predict anything?

Surface Radiation Budget

$$\Delta SWE = \frac{(S + L_a - L_t + H + E + G + P - SWE(C\Delta T_s))}{\lambda}$$



ΔSWE - change snow water equivalent

S - net incident solar radiation

L_a - atmospheric long wave radiation

L_t - terrestrial long wave radiation

H - sensible heat exchange

G - ground heat conduction

P - heat added by rainfall

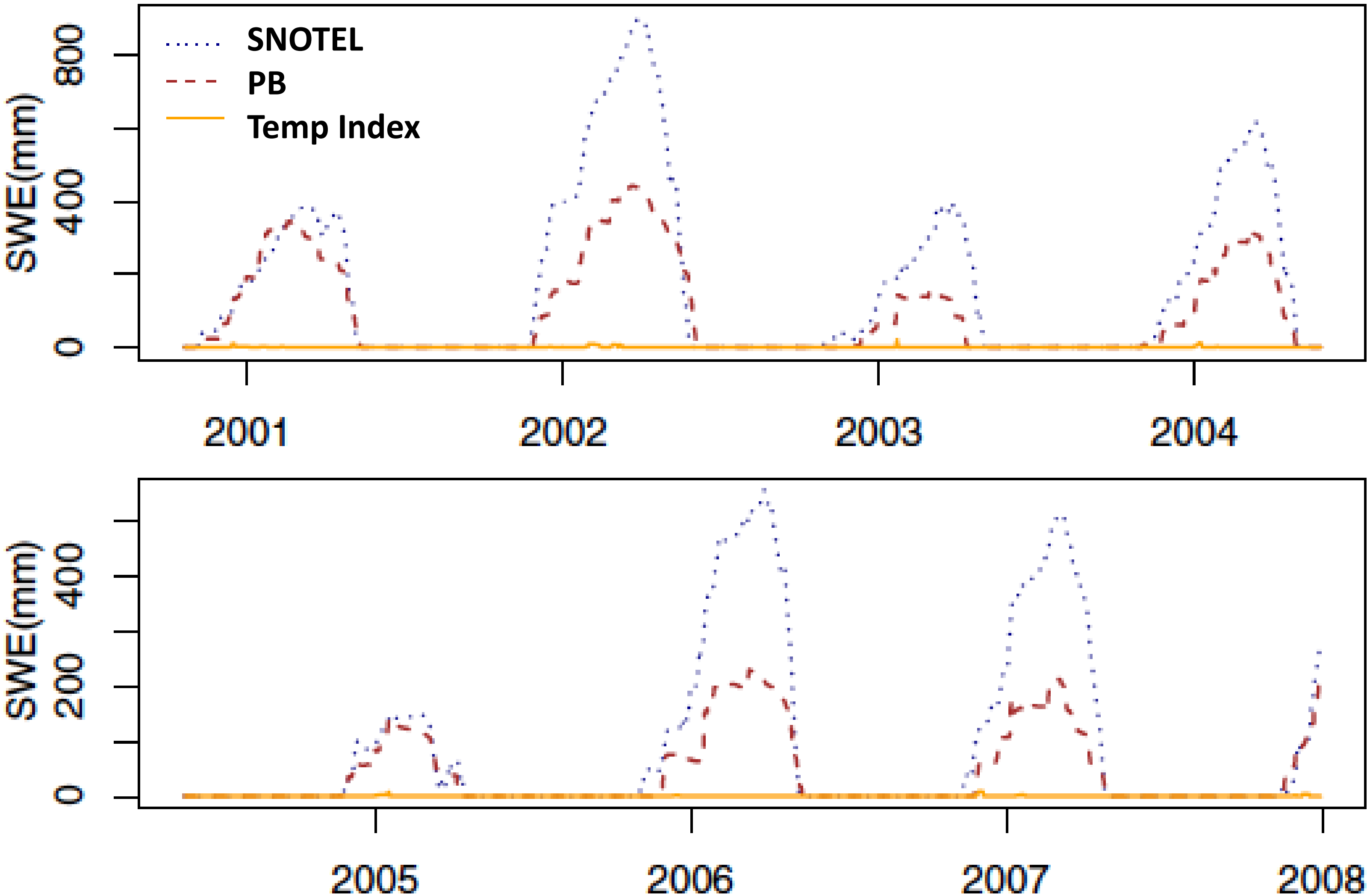
E - energy flux latent heat, vaporization & condensation

SWE($C \Delta T_s$) - change of snowpack heat storage

λ - latent heat of fusion

Fuka et al 2012 *JAWRA*

Complexity actually helps with calibration issues…



JAWRA

Summary

- Be careful with un/loosely constrained calibration
- Constrained calibration can improve process representation reducing computational needs and represent the correct physical processes
- Difference between initial model estimates and calibrated model tells us what we don’t know about the system
- improve landscape management by ensuring watershed info is translatable to the landscape level
  - Where should we focus efforts/money?