University of South Carolina

UNIVERSITY OF SOUTH CAROLINA

Incorporating Shallow Aquifer Uncertainty to Streamflow Prediction in a Forested Wetland Coastal Plain Watershed

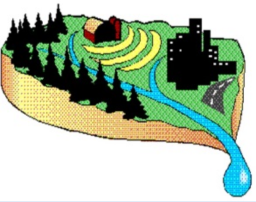
Dan Tufford, PhD, Environment & Sustainability Program
Seydehzahra Samadi, PhD, Department of Civil & Environmental Engineering
Greg Carbone, PhD, Department of Geography

GSA Annual Meeting
Denver, CO
October 27, 2013

carolinas integrated sciences & assessments cisa

NOAA

The Geological Society of America 1888 125 Years 2013 Celebrating Advances in Geoscience



Outline

1. What is uncertainty in hydrologic modeling?

2. Soil and Water Assessment Tool (SWAT) model and SUFI-2 algorithm reduced model bias and uncertainty effectively,

3. The study area and Coastal Plain characteristics

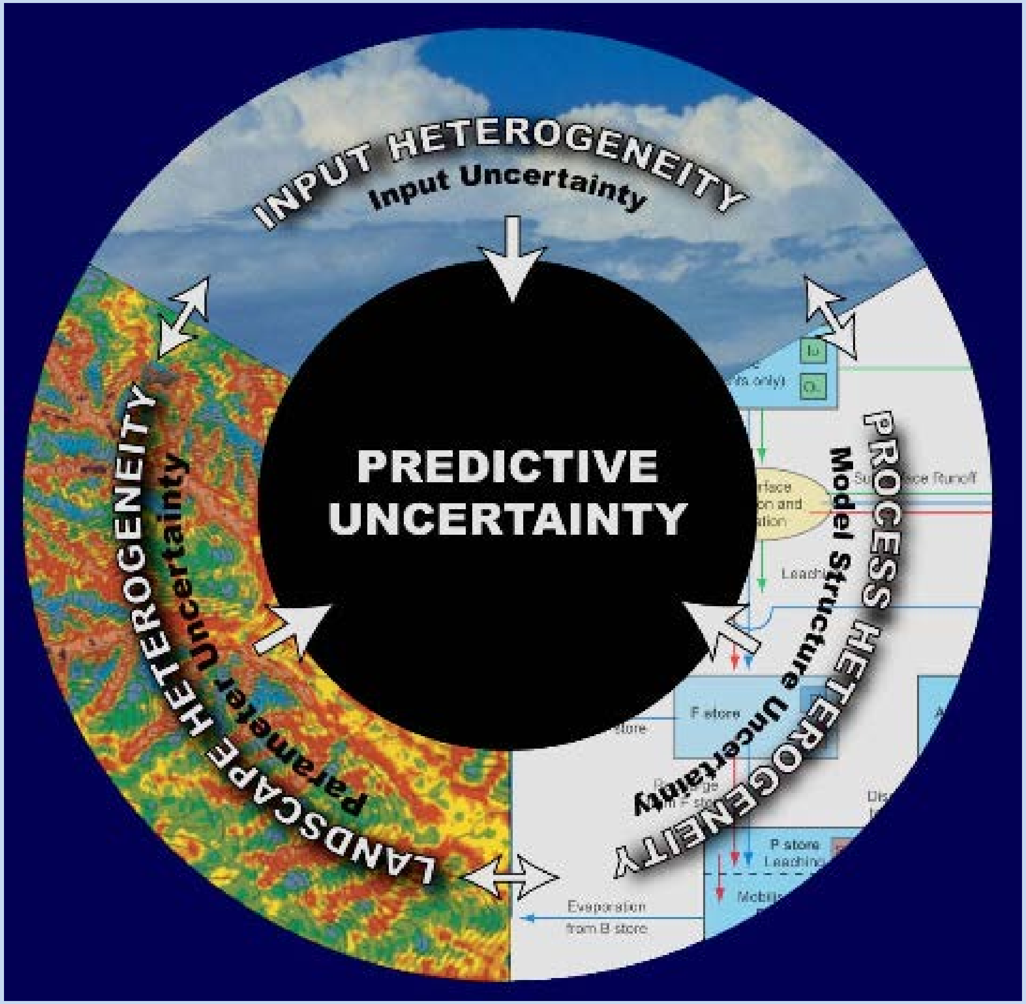
4. Sensitivity analysis and uncertain parameters

5. Prediction uncertainty bands analysis before and after incorporation ground water (GW) parameters and streamflow prediction

6. Water budget quantification

7. Summary and Conclusion

Hydrologic model prediction uncertainty ?



From: Predictive uncertainty and links with climatic and land scape heterogeneity (Sivapalan et al., 2003)

Predictive uncertainty=

Input uncertainty

+

Parameter uncertainty

+

Model structure uncertainty

+

Initial condition uncertainty

Measured data uncertainty + predictive uncertainty = TOTAL UNCERTAINTY

SWAT : The modeling framework

- **Soil and Water Assessment Tool (SWAT)**
  - hydrologic and water quality model
  - developed by the USDA Agricultural Research Service (USDA-ARS).

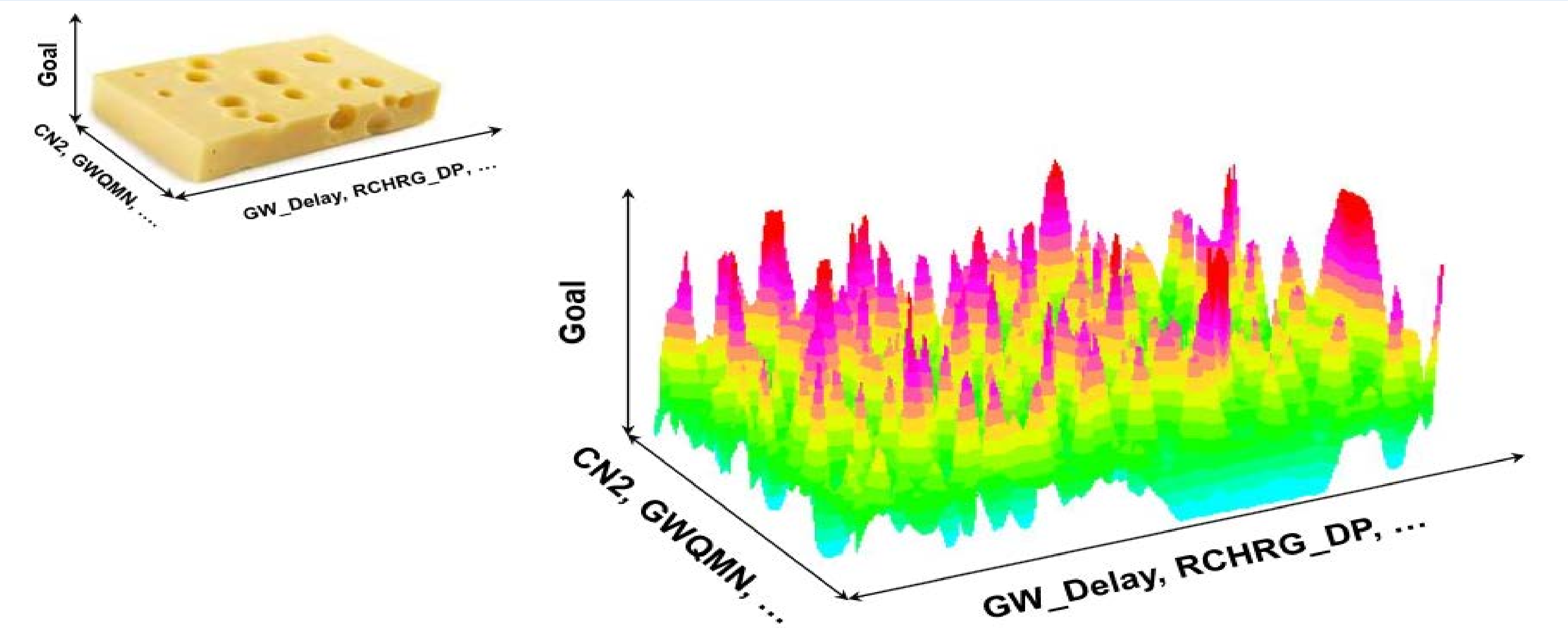
- **Continuous, watershed-scale simulation model**
  - that operates on a daily and sub-daily time steps
  - to assess the impact of different management practices
    - water, sediment, and agricultural chemical yields.

- **SWAT applied across the U.S. and world**
  - applications include
    - hydrology, sediment and pollutants, and climate change

- To understand the model uncertainty we used SWAT-CUP (Soil and Water Assessment Tool-Calibration Uncertainty Program) Modeling.

SWAT-CUP (SWAT Calibration Uncertainty Program)

- Developed by **Eawag**, Swiss Federal Institute
- analyze prediction uncertainty of SWAT model
  - calibration and validation results
- SUFI-2 (Abbaspour, et al., 2007)
  - Sequential Uncertainty FItting Algorithm
  - Accounts for all sources of uncertainty in driving variables
    - conceptual model, parameters, and measured data



Swiss Cheese Effect (Karim C. Abbaspour, 2009, SWAT -CUP User manual)

SWATCUP Model Theory

a) 95 PPU: 95 Percent Prediction Uncertainty, This value is calculated at the 2.5% and 97.5% levels of an output variable, disallowing 5% of the very bad simulations.

b) Objective Function: Coefficient of determination (R2), Nash-Sutcliffe (1970) coefficient etc.

c) p-factor: The percentage of observations covered by the 95 PPU

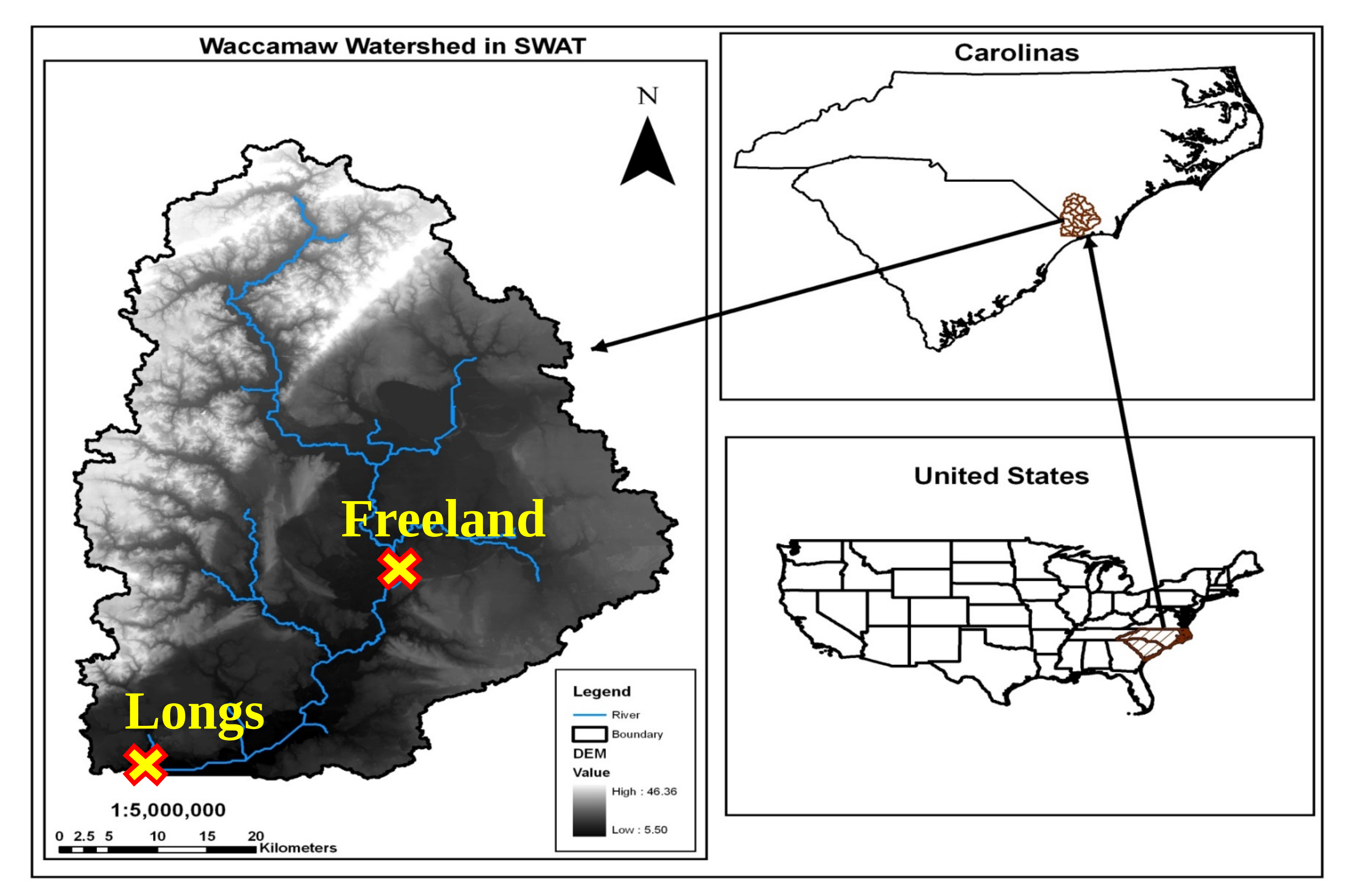
d) r-factor: Relative width of 95% probability band

e) T-test: provides a measure of sensitivity, large absolute value represents more sensitivity

f) P- value determined the significance of sensitivity. A value close to zero has more significance.

(Karim C. Abbaspour, 2011, SWATCUP User manual)

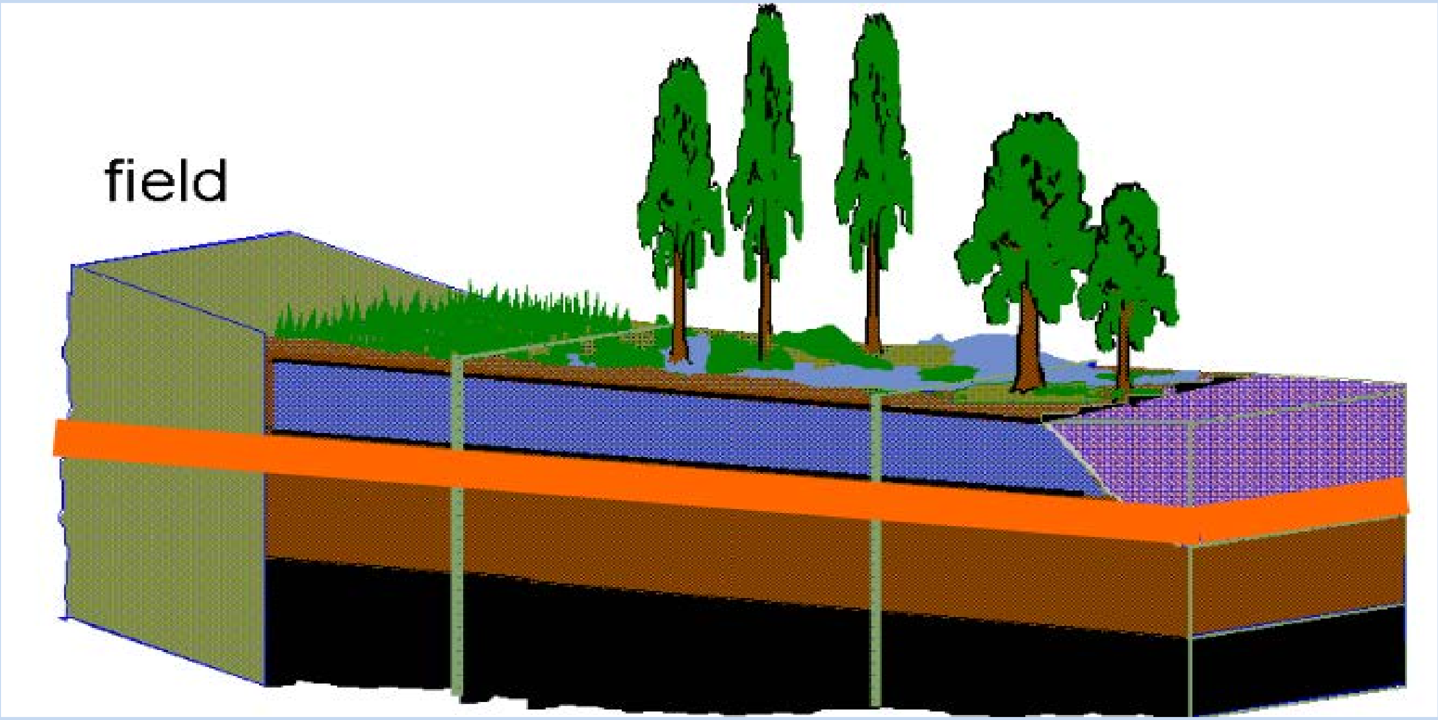
A complex hydrologic system



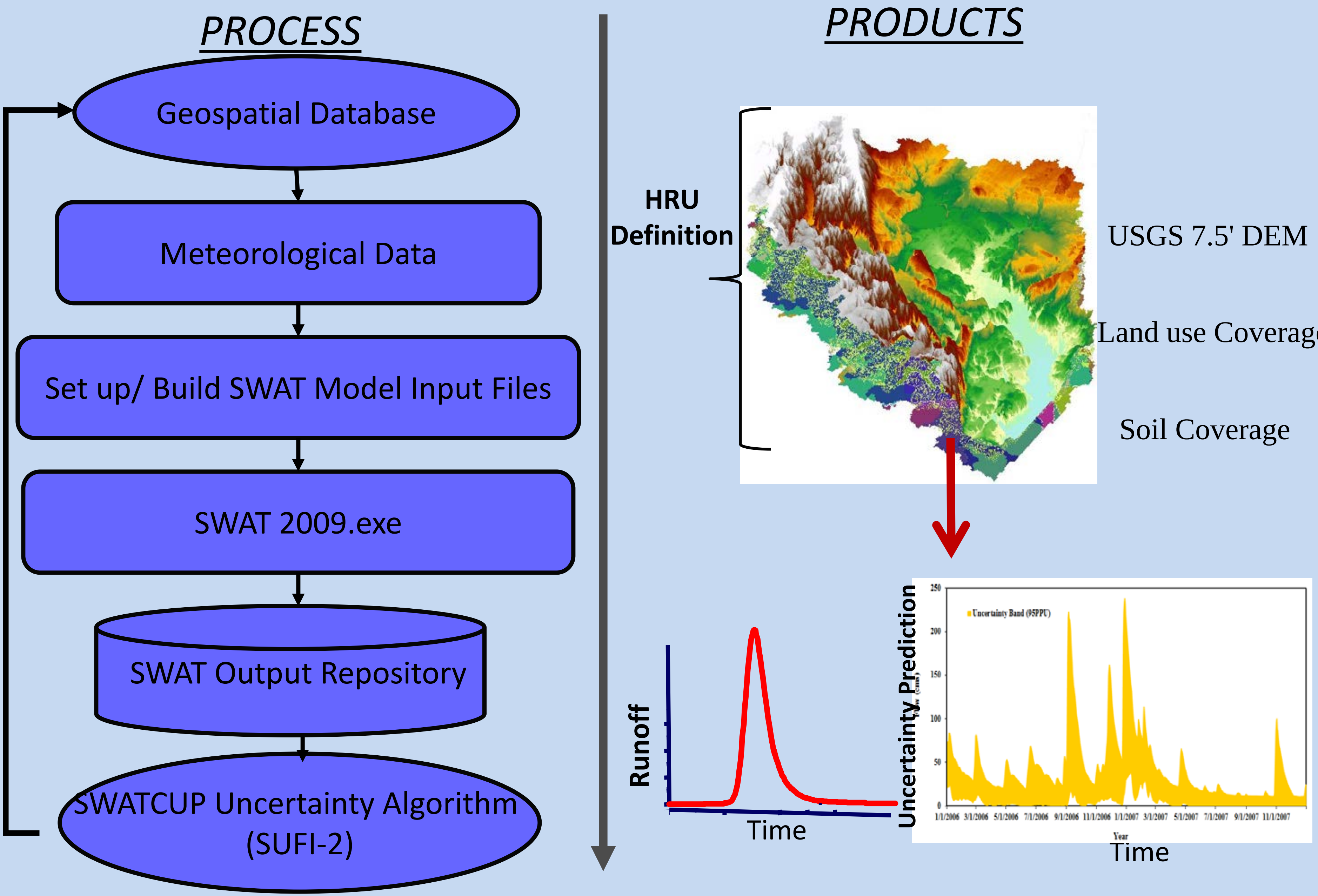
311,685 ha (delineated by SWAT model)   Slope 0-5%, precp.(avg. 1300 mm), temp (16.88 °C) more than 60% forest or forested wetland land covers, *shallow water table in 90% of the watershed*

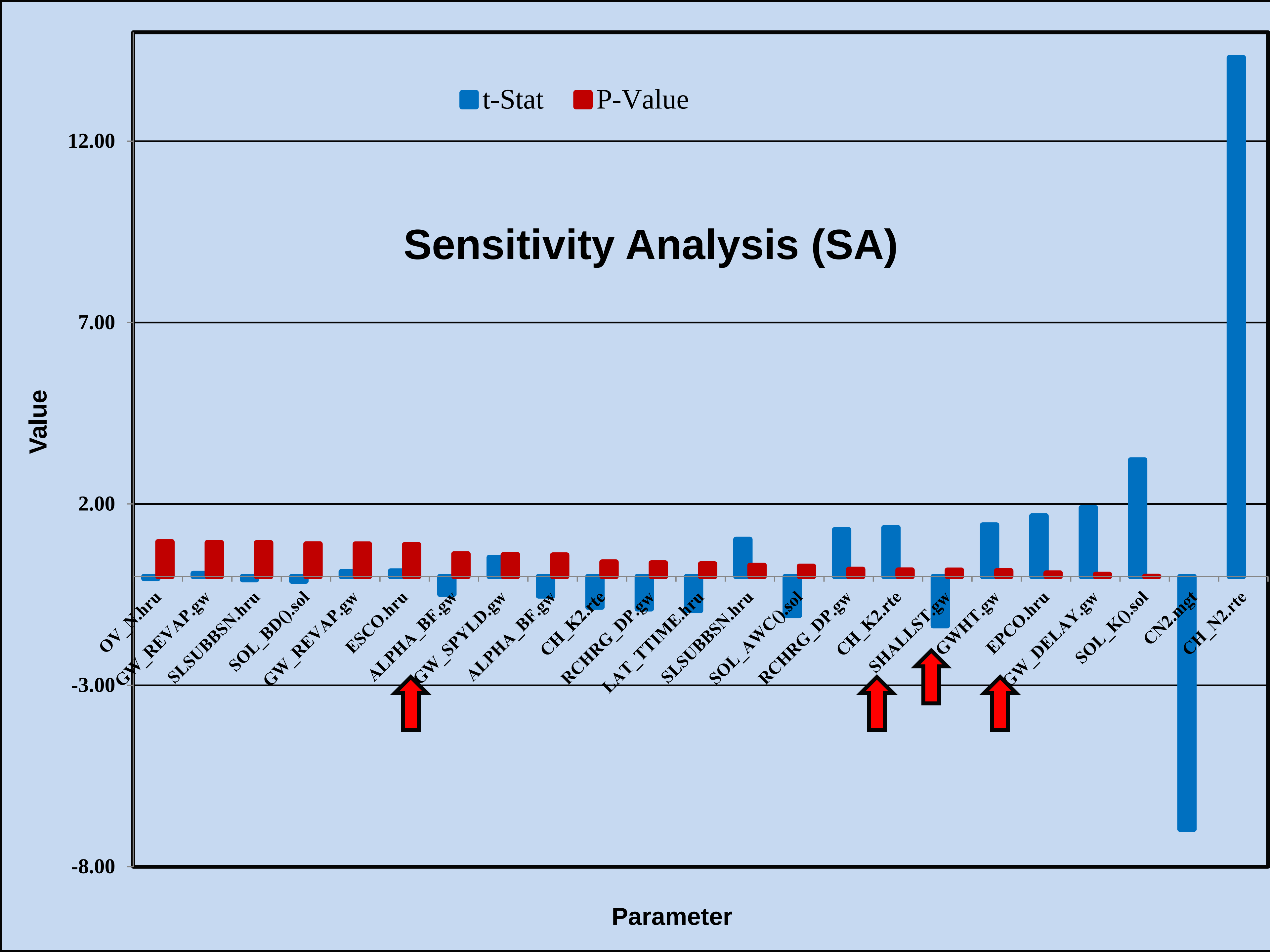
Coastal Plain Characteristics

- Low land area
- Dense vegetation
- Poorly drained soil in lowlands, very well drained in uplands
- Complex surficial and sub-surficial hydrologic interaction
- Broad floodplains
- Large riparian storage
- Shallow surficial aquifer underlain by confining layer
- Saturated during periods of high rainfall and low evapotranspiration



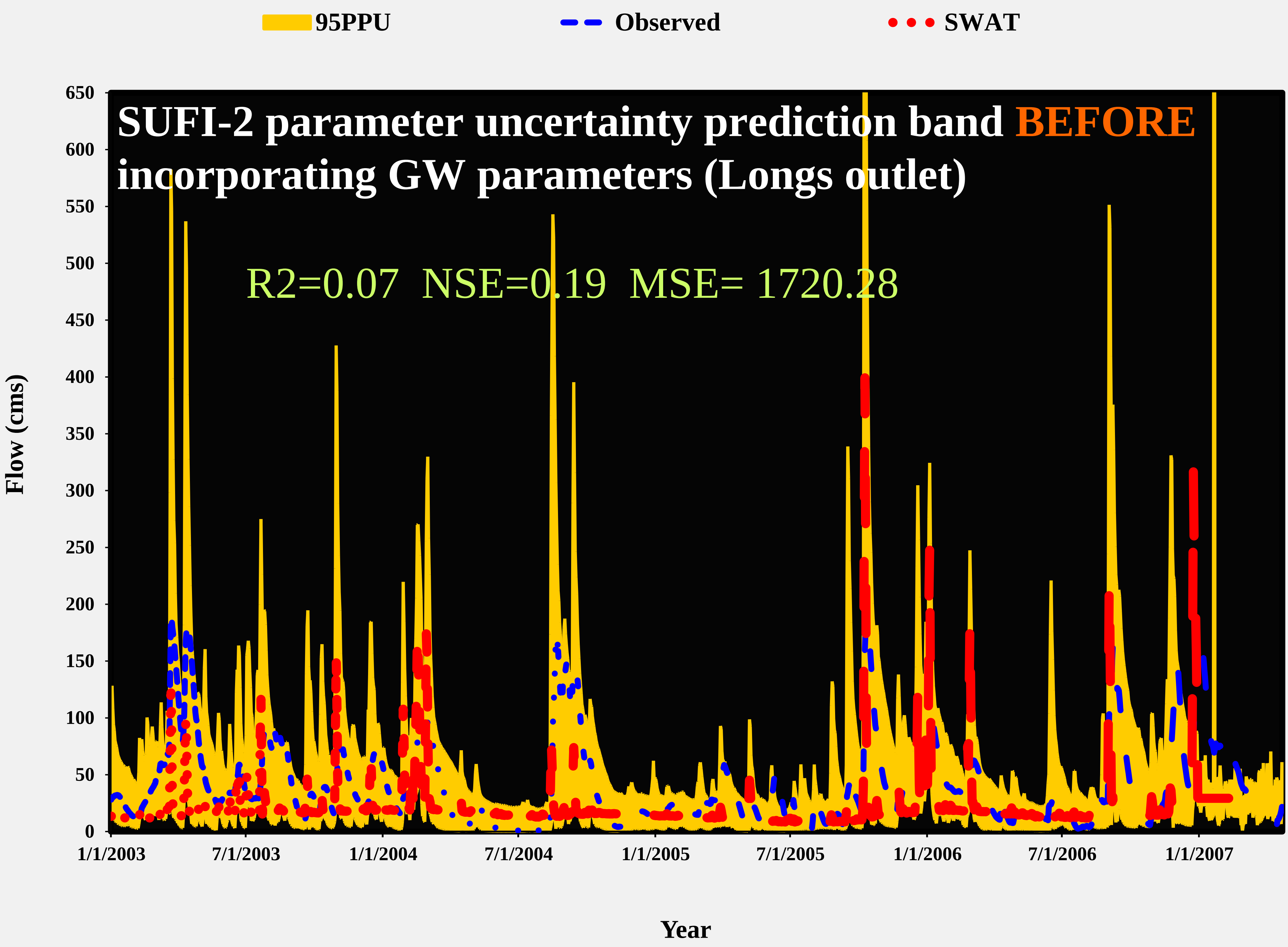
Conceptual Design of SWAT model in Waccamaw watershed

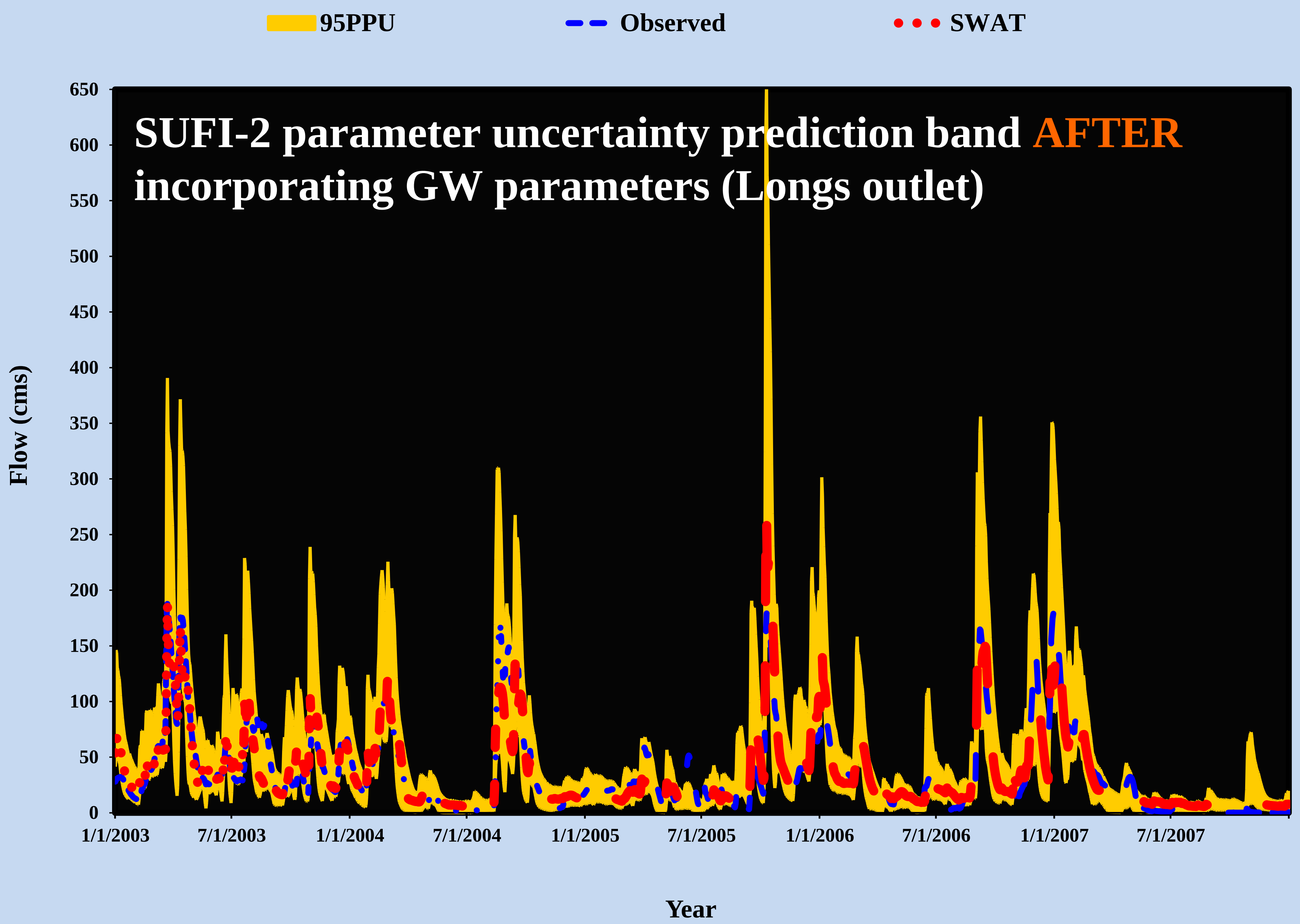




Sensitivity Analysis (SA)
t-Stat
P-Value
Value
Parameter
12.00
7.00
2.00
-3.00
-8.00
OV_N.hru
GW_REVAP.gw
SLSUBBSN.hru
SOL_BD().sol
GW_REVAP.gw
ESCO.hru
ALPHA_BF.gw
GW_SPYLD.gw
ALPHA_BF.gw
CH_K2.rte
RCHRG_DP.gw
LAT_TTIME.hru
SLSUBBSN.hru
SOL_AWC().sol
RCHRG_DP.gw
CH_K2.rte
SHALLST.gw
GWHT.gw
EPCO.hru
GW_DELAY.gw
SOL_K().sol
CN2.mgt
CH_N2.rte

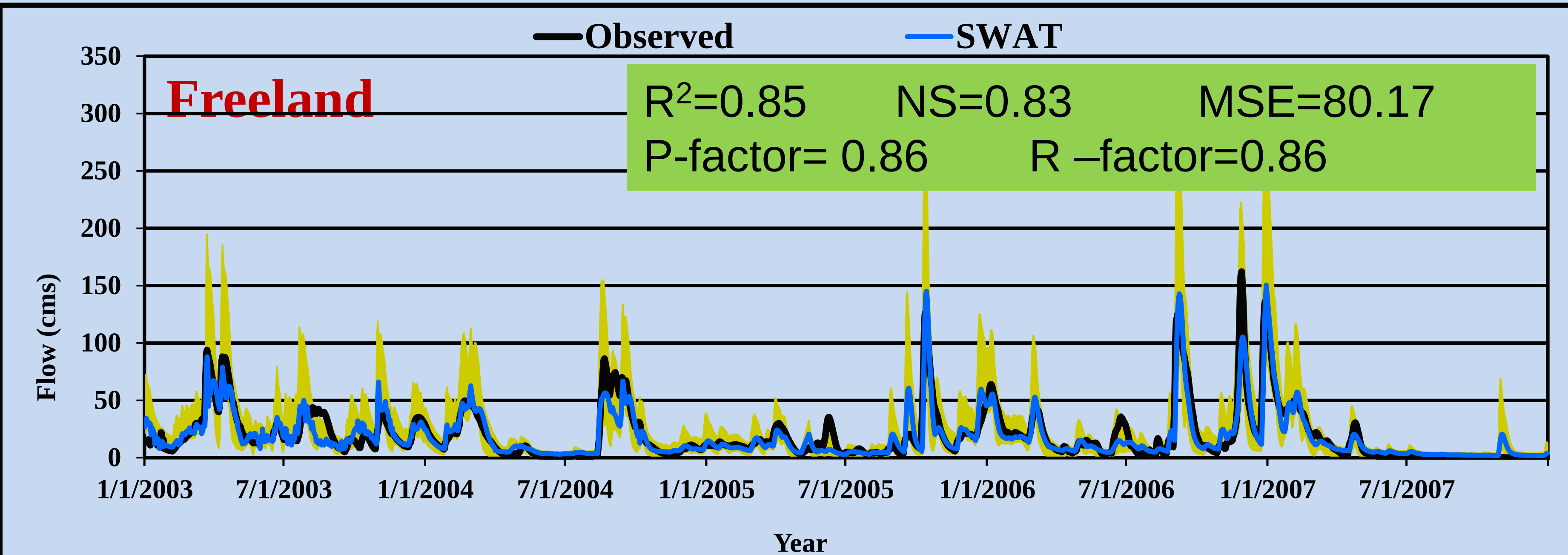
Aggregate parameter	Name of SWAT parameter	Sensitivity
CH_N2.rte	Manning's "n" value for the main channel	Most Sensitive
SOL_K().sol	Saturated hydraulic conductivity (mm/hr)	
CN2.mgt	SCS runoff curve number for moisture condition II	
GW_DELAY.gw	Groundwater delay time (days)	
EPCO.hru	Plant uptake compensation factor	
RCHRG_DP.gw	Deep aquifer percolation fraction	Moderate Sensitive
SHALLST.gw	Initial depth of water in the shallow aquifer (mm H2O)	
GWHT.gw	Initial groundwater height (m)	
OV_N.hru	Manning's "n" value for overland flow	
SLSUBBSN.hru [b]	Average slope length (m)	
ESCO.hru	Soil evaporation compensation factor	
ALPHA_BF.gw	Base flow alpha factor (days)	
CH_K2.rte	Effective hydraulic conductivity in tributary channel alluvium (mm/hr)	Less Sensitive
LAT_TTIME.hru	Lateral flow travel time (days)	
SOL_AWC().sol	Available water capacity of the soil layer (mm H2O/mm soil)	
GW_REVAP.gw	Groundwater "revap" coefficient	
GW_SPYLD.gw	Specific yield of the shallow aquifer (m3/m3)	

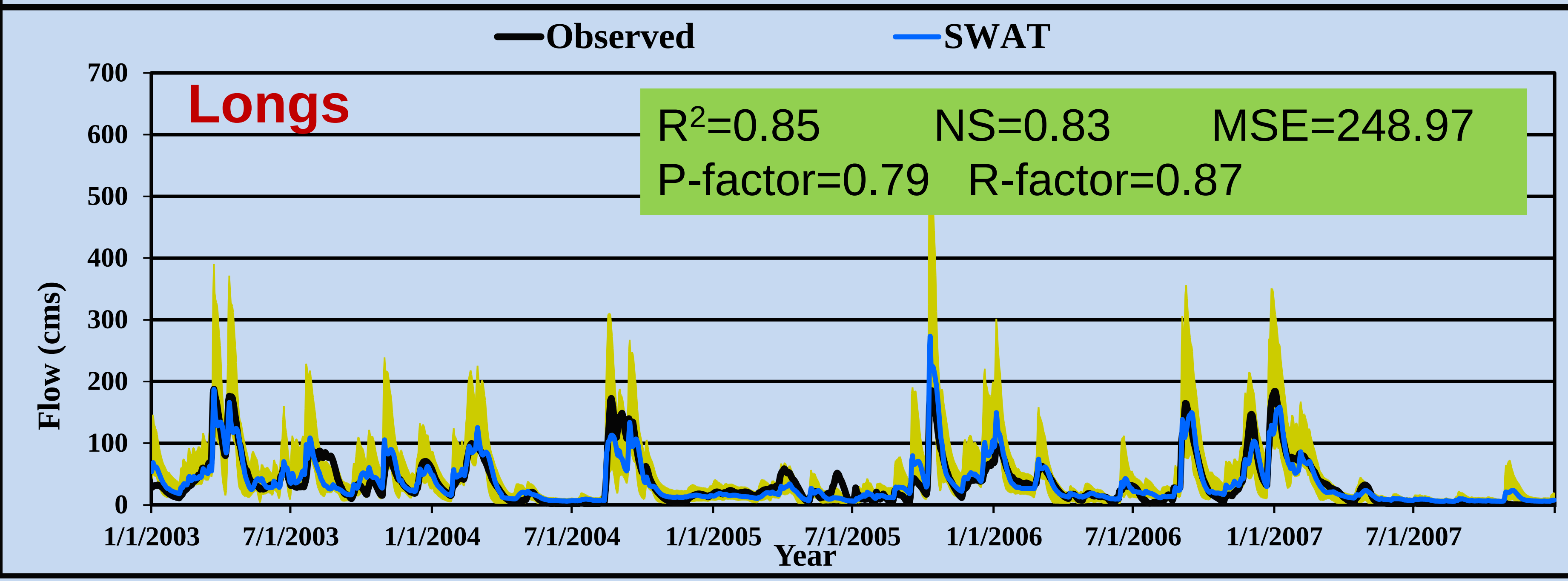

95PPU
Observed
SWAT
SUFI-2 parameter uncertainty prediction band BEFORE incorporating GW parameters (Longs outlet)
R2=0.07 NSE=0.19 MSE= 1720.28
Flow (cms)
650
600
550
500
450
400
350
300
250
200
150
100
50
0
1/1/2003
7/1/2003
1/1/2004
7/1/2004
1/1/2005
7/1/2005
1/1/2006
7/1/2006
1/1/2007
Year



95PPU
Observed
SWAT
SUFI-2 parameter uncertainty prediction band AFTER incorporating GW parameters (Longs outlet)
Flow (cms)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
1/1/2003
7/1/2003
1/1/2004
7/1/2004
1/1/2005
7/1/2005
1/1/2006
7/1/2006
1/1/2007
7/1/2007
Year

Sequential Uncertainty Fitting (SUFI-2) Procedure



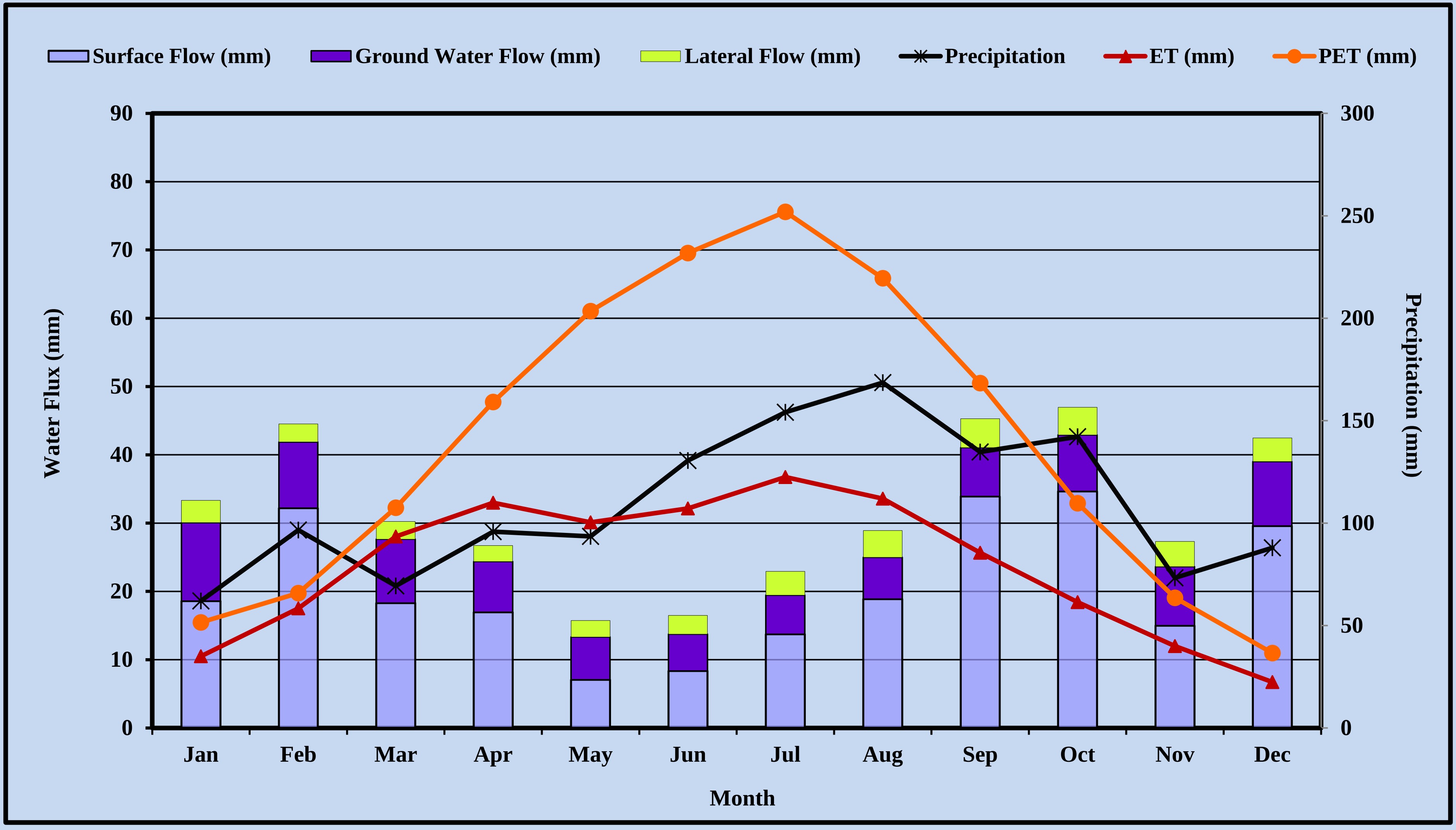


Water Balance Components (2003-2007)

Evapotranspiration= 72% Surface Flow= 19 %

Groundwater Flow= 7 % Lateral Flow= 3 %

Mean Annual Rainfall =1308.75 mm

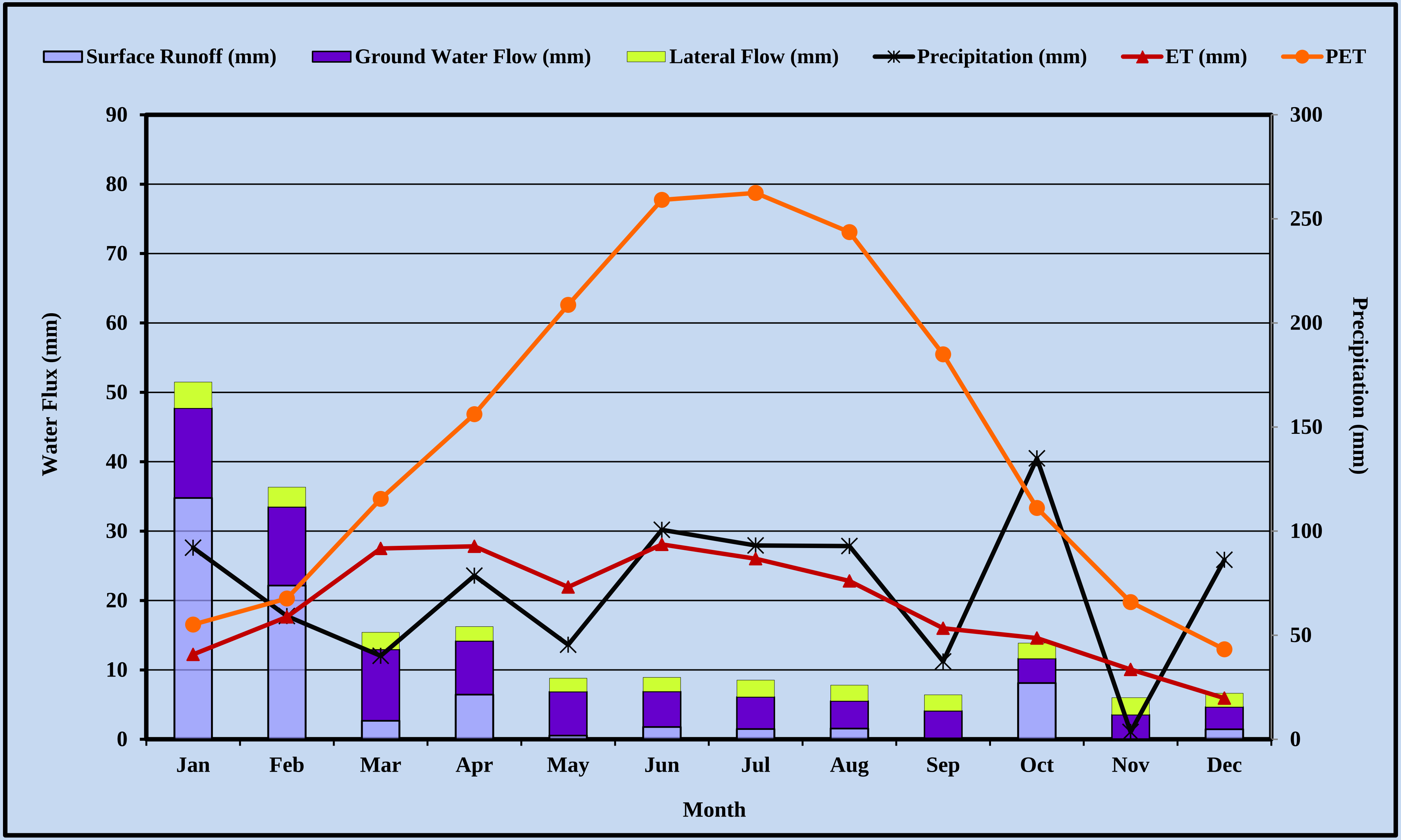


Water Balance Components for Dry Year (2007)

Evapotranspiration= 80% Surface Flow= 9%

Groundwater Flow= 9% Lateral Flow= 3 %

Mean Annual Rainfall = 863.96 mm

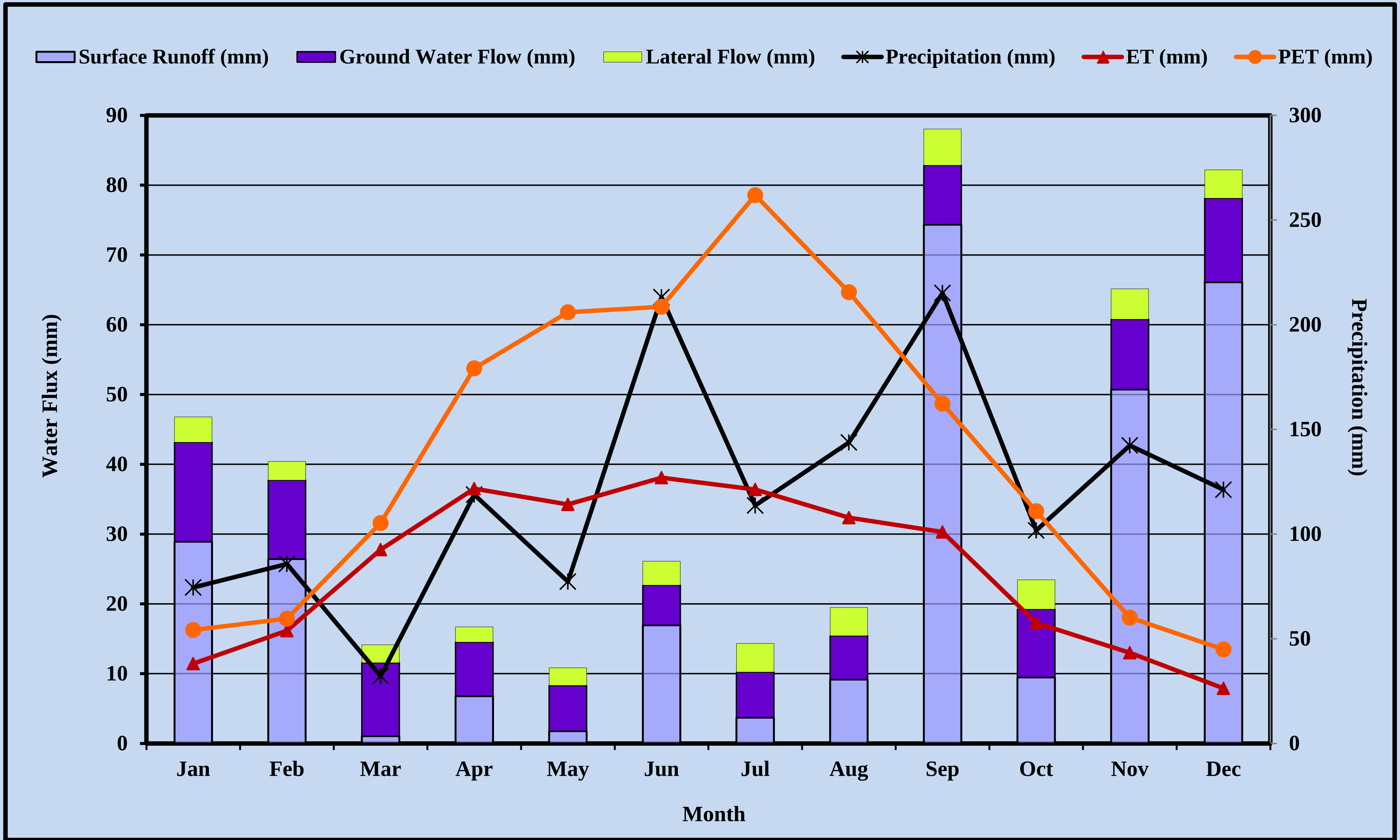


Water Balance Components for Wet Year (2006)

Evapotranspiration= 70% Surface Flow= 20 %

Groundwater Flow= 7 % Lateral Flow= 3 %

Mean Annual Rainfall =1439.55 mm



Summary and Conclusions

- Hydrologic simulations of low gradient watersheds
  - SWAT can be very good
  - SUFI-2 algorithm effectively reduced model bias and uncertainty
  - There were significant differences in the R2 and NSE values with and without incorporating ground water parameters to the calibration process.
- The SUFI2 algorithm
  - showed the most sensitivity
  - evenly distributed 95PPUs bands
    - incorporating ground water parameters
- Ground water component is a major contributor to stream flow
  - especially in dry period.
  - highest in January in wet and dry periods
  - lowest during June in wet year.
- Surface flow and groundwater flow contributions to stream flow
  - almost same in dry period

Summary and Conclusions
Continued

- Model is still sensitive/uncertain
  - Manning's "n" value for the main channel
  - saturated hydraulic conductivity (mm/hr)
    - even after 2000 simulation iterations
  - dry period in compare to wet period.
- Vary hydraulic parameters over wet and dry periods
  - compensating for differences in subsurface wetness
- Hydrologic prediction of Coastal Plain landscape
  - difficult because of complex ground water structure
    - dominated by a shallow water table aquifer
  - prevalence of wide floodplains and dense vegetation
- Critical to understand because
  - High development pressure disrupts normal processes
    - Many unseen (below surface)
  - Vulnerable to impacts from climate change and sea level rise

This research was sponsored by a grant from the
National Oceanic and Atmospheric Administration /
Climate Program Office to
Carolinas Integrated Sciences & Assessments (CISA).

Thank You ☺