Re-conceptualizing the Soil Moisture Accounting of CN-based Runoff Estimation Method in SWAT

Adnan Rajib, Venkatesh Merwade, and Cibin Raj

Purdue University, USA

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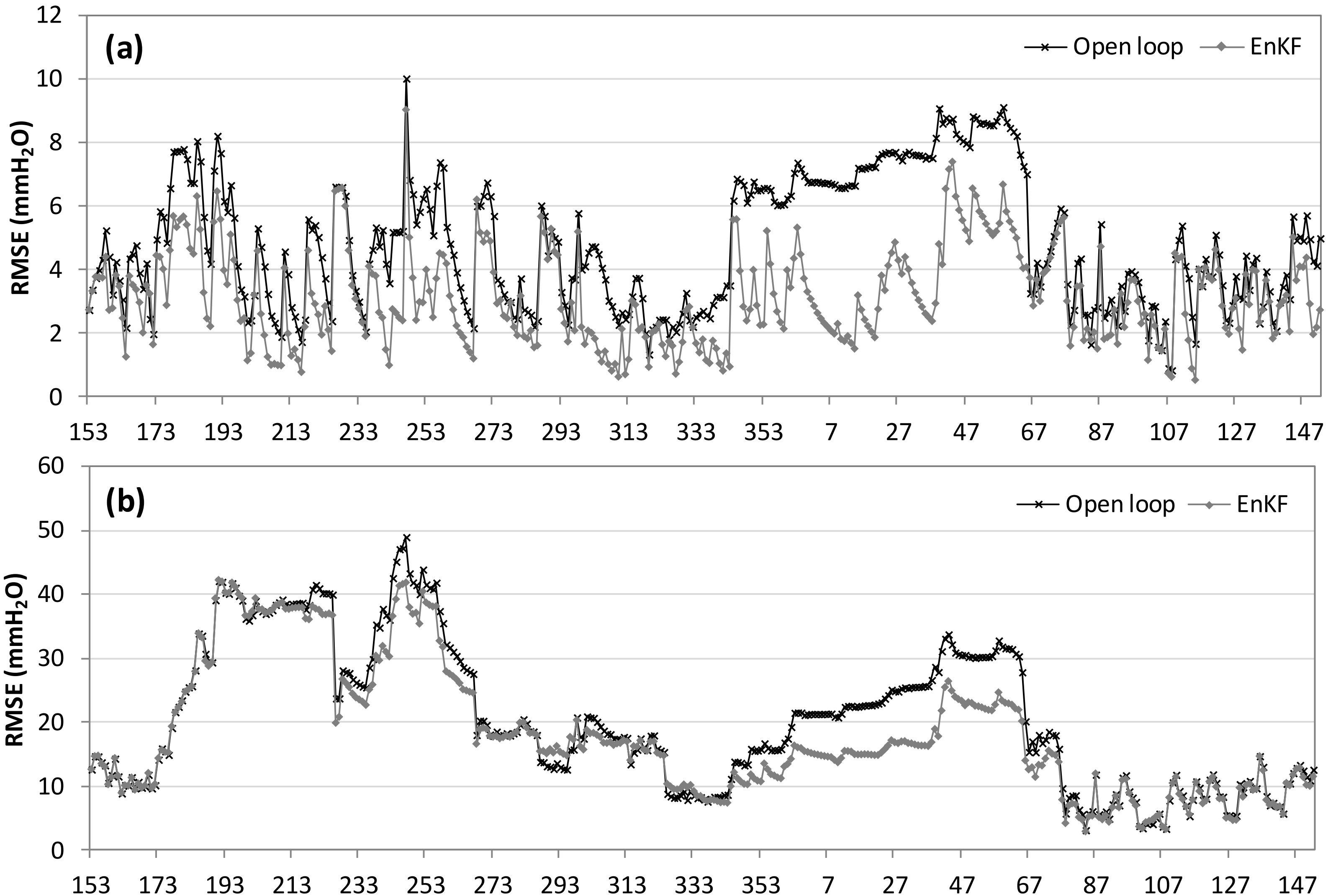
Presentation Outline

- Motivation
- CN method in SWAT
- Objective
- Study Area and Methodology
- Results
- Future Work

Role of Soil Moisture

- Soil moisture plays an important role in the overall runoff generation process
- Availability of soil moisture data
  - Remotely Sensed
  - Field Observations
- Data assimilation
- Many models, including SWAT, are unable to provide better model output by using improved soil moisture data

Previous Work



CN Method in SWAT

$CN_{II}\ (t+1) = 25400/\ [S(t+1) + 254]$

$CN_{II}\ (t)$

$CN_{I}\ (t)$

Wilting Point

$CN_{III}\ (t)$

FC condition

FC, SAT

$S_{max},\ w_1,\ w_2$

$SW(t)$

$S(t) = S_{max}\ [1 - SW(t)/\ \{SW(t) + \exp\ (w_1 - w_2 .\ SW(t)\}\ ]$

$I_a = 0.2\ S(t)$

$P_e\ (t) = P(t) - I_a(t)$

$Q\ (t) = P_e^{\ 2}(t)\ /\ [P_e(t) + S(t)]$

If $P(t) > I_a$

$SW_{(t+1)} = SW_{(t)} + [P_{(t)} - Q_{(t)} - ET_{(t)} - Q_{qw(t)}]$

Water Balance

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Modification Perspective

Role of Soil Moisture Level (SW) in SWAT

- SW is used only in
  - Calculating Retention Parameter, S
  - Updating daily CN
- Contribution of SW is lumped in $\boldsymbol{I_a}$

$SW(t) \rightarrow S(t) \rightarrow I_a(t) \rightarrow SURQ(t)$

- Runoff is calculated based on a single lumped condition $\boldsymbol{P > I_a}$
- No volumetric contribution of SW inside runoff equation

Expression of Time: Why Needed?

- Originally, CN method is an event-based model, valid for cumulative P
- An actual storm event can
  - continuously span over several time-steps, *or*
  - end-up ahead of the time-step

based on the chosen time-threshold of a continuous simulation

- For continuous simulation, CN method should be valid <u>at any instant</u> along a storm

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Objective

- To incorporate a SMA-based CN approach within SWAT's existing model-structure, with a view to identify potential changes in hydrologic components compared to SWAT's conventional CN method

Methodology

$$Q = \frac{(P - I_a)^2}{P + S - I_a} \quad \text{if } P > I_a$$

Original CN Method

$$V = V_0 + P - Q \longrightarrow V = V_0 + \frac{(S + I_a)P - I_a^2}{P + S - I_a}.$$

With respect to time

$$dQ/dt = dP/dt \left[\frac{(P - I_a)(P + 2S - I_a)}{(P + S - I_a)^2} \right] \quad \text{if } P > I_a.$$

$$\frac{dV}{dt} = \boxed{dP/dt} - \boxed{dQ/dt}$$

$$dQ/dt = dP/dt \left[\frac{V - (V_0 + I_a)}{S} \left(2 - \frac{V - (V_0 + I_a)}{S} \right) \right] \quad \text{if } V > V_0 + I_a$$

New Soil Moisture Threshold (S_a)

Features of the New Model:

1. Expression of time, dP/dt and dQ/dt
2. New SW-based threshold for runoff to occur (**$V > V_0 + I_a$**)
3. Application SW(t) in directly in Q(t) equation

After Michel et al. (2005)

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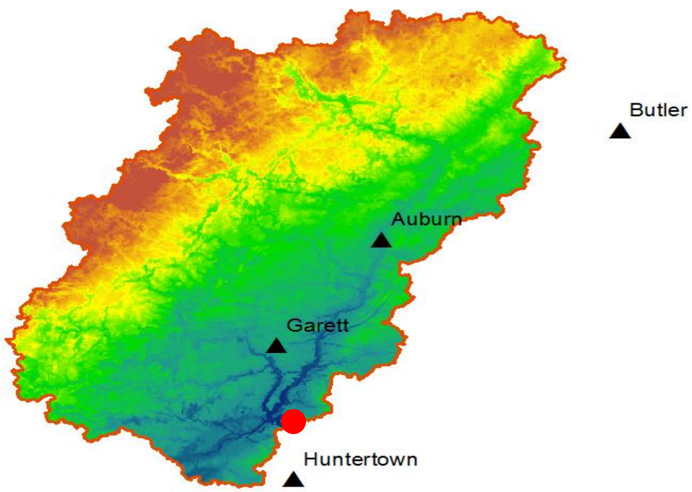
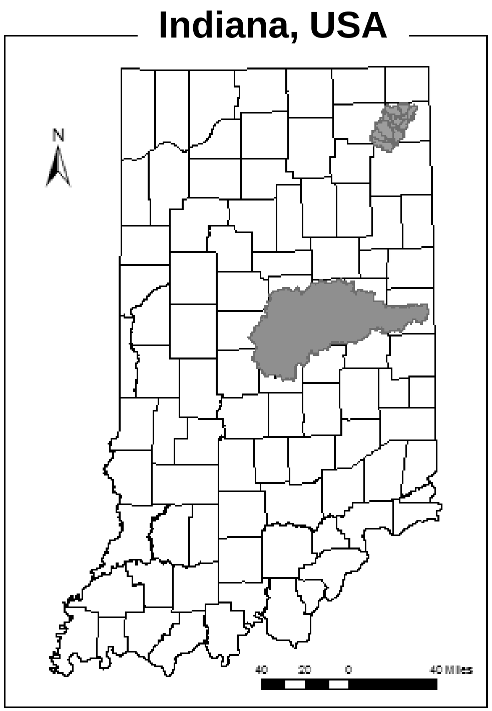
Study Areas



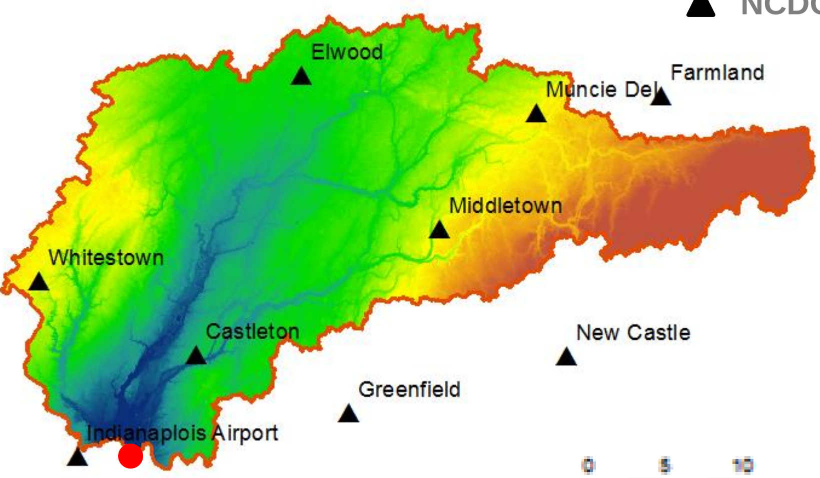
Cedar Creek
270 sq. miles

Land Use	Area %
Agriculture	71
Developed	11
Forest	14
Water	4

Outlet: USGS 04180000
Cedar Creek near Cedarville, IN



USGS gauge
NCDC Weather Station



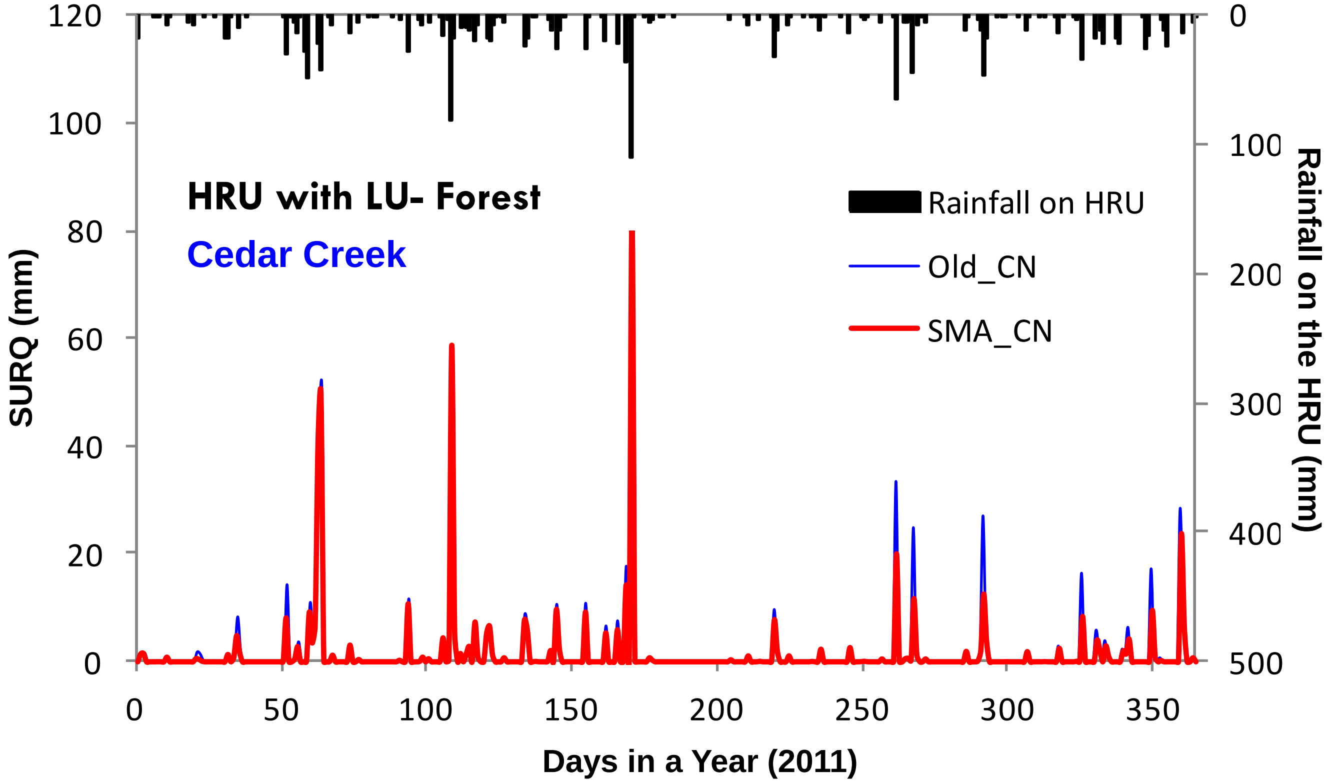
White River
1635 sq. miles

Land Use	Area %
Agriculture	67
Developed	26
Forest	6
Water	1

Outlet: USGS 03353000
White River at Indianapolis, IN

Results

Surface Runoff (SURQ)

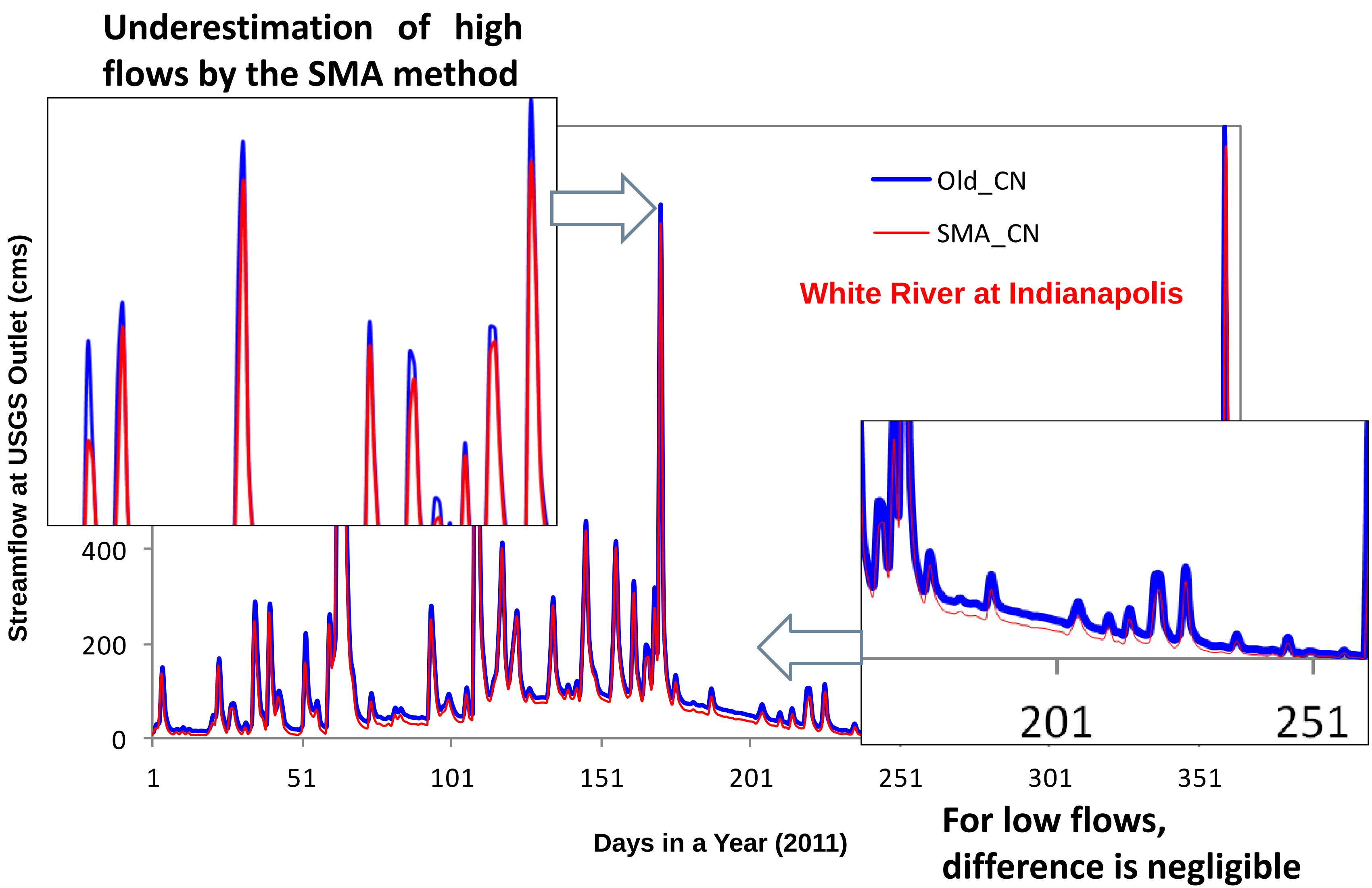


- SMA-based SURQ values are underestimated
- The difference shown by the SMA based method is more prominent in case of urban areas

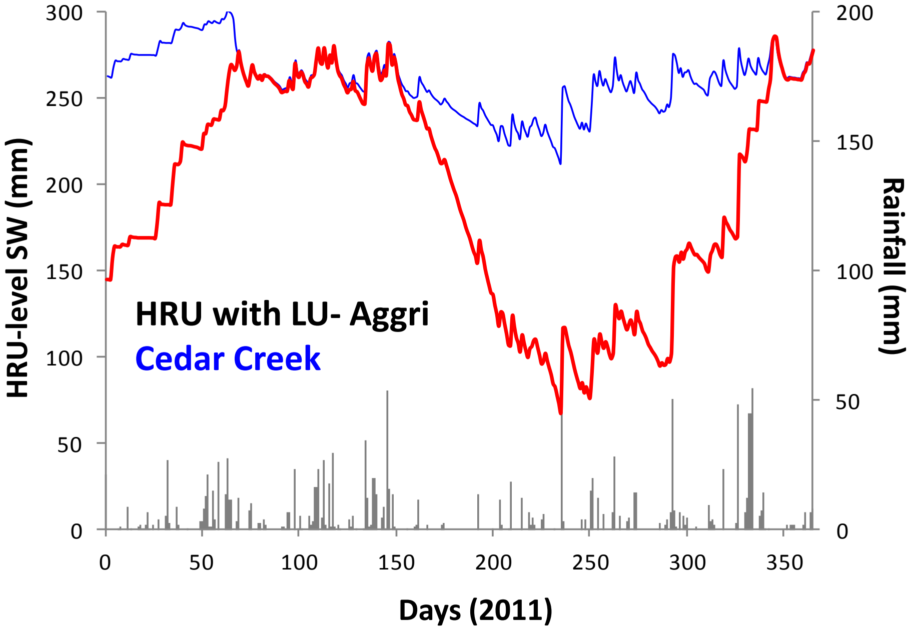
The overall lowering of SURQ by the modified method is a desired outcome with respect to *Williams et al. (2012), Neitsch et al. (2011)* and *Kannan et al. (2008)*, who noted the over-estimating tendency of SWAT's conventional CN based runoff estimation method

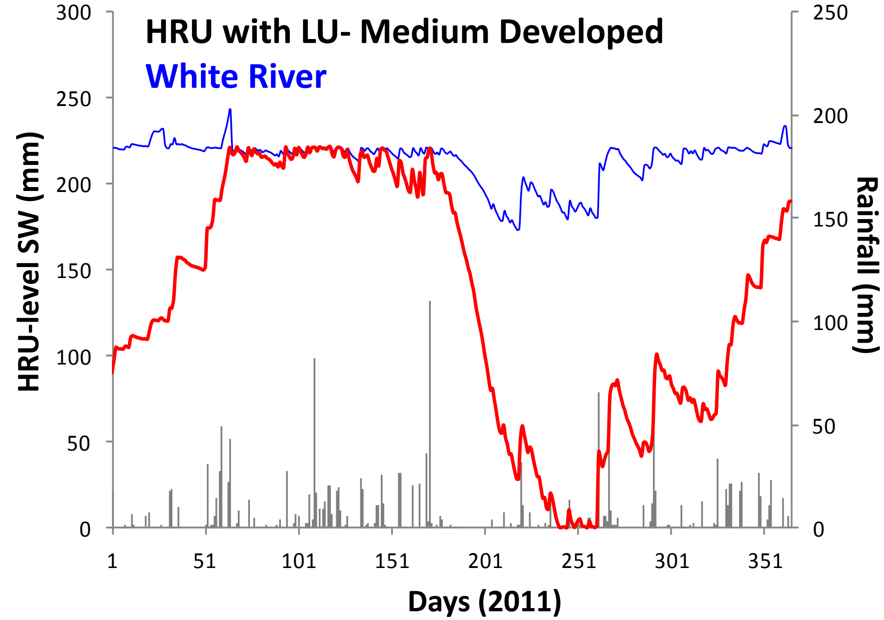
Results

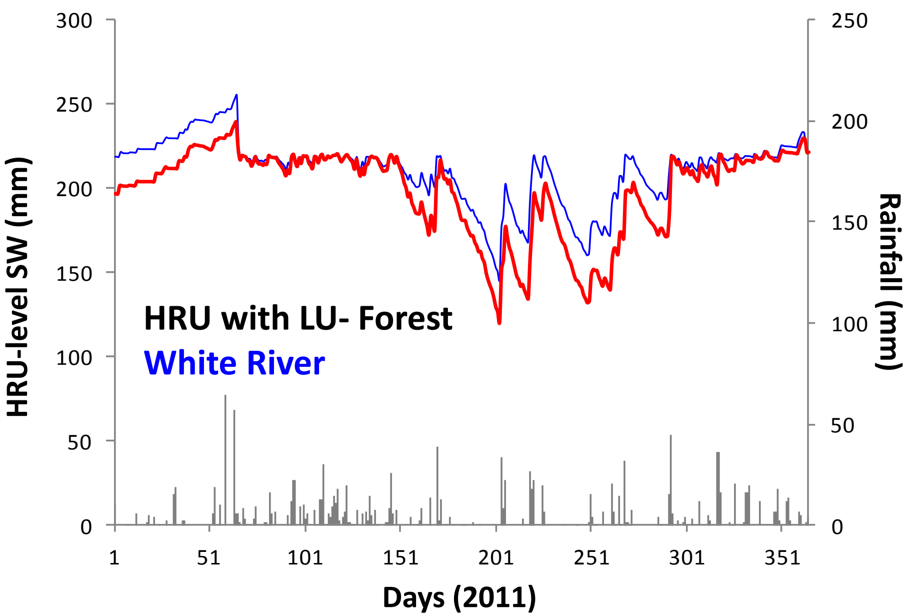
Streamflow at the USGS Outlet



Soil Moisture: Individual LU Contexts







Rainfall (mm)

Old_CN SMA_CN

- **Lower SW in summer**
- **Similar SW in Spring (all LU types)**
- **Difference is negligible for Forested HRUs**

Lower SURQ, Lower SW in the SMA method

Net Water Balance?

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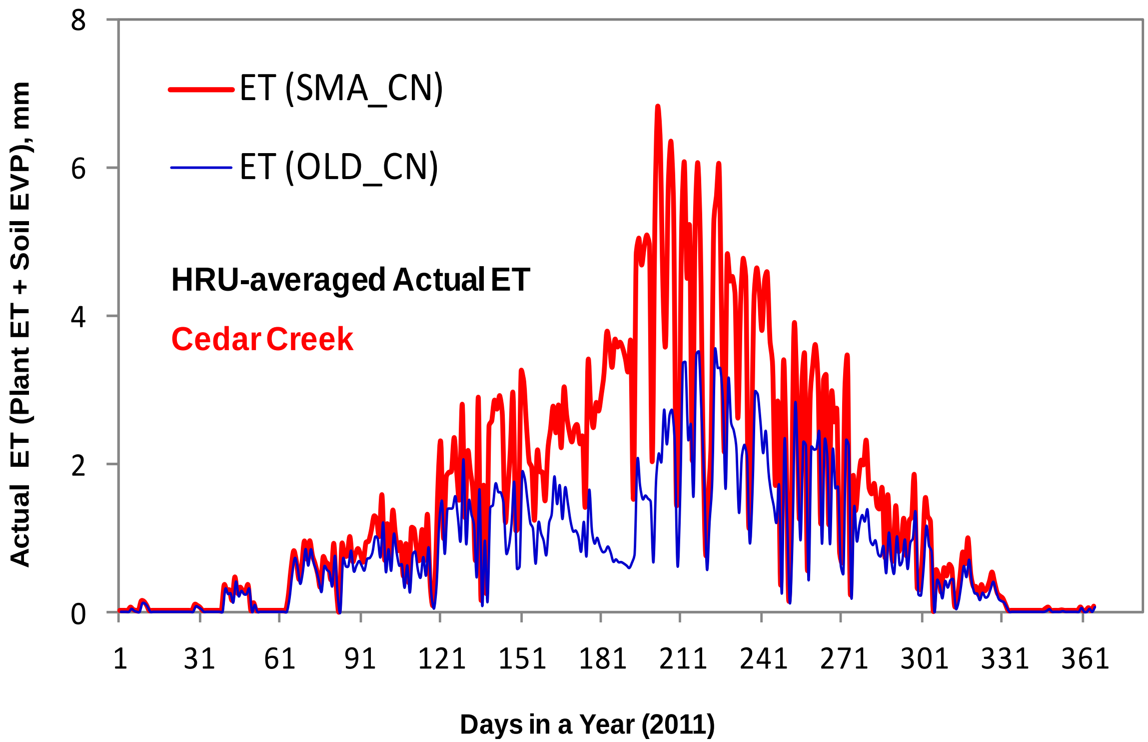
Results

Higher Evapotranspiration



The change in the partitioned amounts of Actual Soil and Plant ET need to be evaluated

- **PET** remains the same for both methods
- Higher **ET** amounts by the modified method particularly in summer days; matches otherwise

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RESULTS:

Higher Evapotranspiration

SWAT's ET Estimation Structure

PET

Full depletion of **canstor**

PET_{remain} = PET - canev

partitioning if ***PET > canstor***

soil

es_max

Maximum possible soil evaporation for the day

Actual Soil Evp in a day

plant

ep_max

Maximum possible Plant uptake for the day

Actual Plant Uptake in a day

Actual ET

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Summary

- A modified CN method is incorporated into existing SWAT source code which is more realistic from SMA perspective
- Individual HRU results reveal lowering of surface runoff with lesser soil moisture by the SMA technique compared to the conventional model
- The reduction in soil moisture along with other related ground water components in the modified model has found to have been attributed with a higher ET.
- The change in the partitioned amounts of actual soil and plant ET need to be evaluated

Future Work

- Tracking of additional variables like the canopy storage, potential maximum moisture retention, actual soil evaporation and plant uptake are likely provide more information on the water partitioning within SWAT
- Vigorous experimentations are necessary under diverse scenarios of landuse, irrigation and tile drainage, cropping pattern, water quality, and climatic change

Thank You!

Contact:

Venkatesh Merwade
vmerwade@purdue.edu
http://web.ics.purdue.edu/~vmerwade

SWAT Modification

Sub-routine Call Structure for Runoff Estimation

(Partial)

- Call simulate
  - Call command
    - Call Subbasin
      - Call surface
        - Call canopyint
        - Call snom
        - Call crackvol
        - Call dailycn
        - Call volq
          - Call surq_SMA_daycn
          - Call surq_daycn
          - Call surq_greenampt
      - Call etpot
      - Call etact
      - Call crpmd
        - Call SWU

- **sub-routine *dailycn***
  - Updates retention parameter and curve number at individual time-steps
  - Kept unaltered
- **sub-routine *surq_daycn***
  - Contains runoff equations
  - Extracted in Visual Fortran compiler and re-coded. Compiled with rest of the codes
  - This can be kept as a separate new sub-routine (e.g. ***surq_SMA_daycn***)

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