Modified Green-Ampt Method in EPA SWMM

EWRI 2016

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October 15-16, 2015

Overview

- History
  - Implementation in SWMM
  - Examples
  - Formulation
- Algorithm improvement
  - Anomalies
  - Identifying the error
  - Resolution
- Example

Green-Ampt equation (1911)

$$f_p = K_s\left(1 + \frac{\psi_s \theta_d}{F} \right)$$ Eqn. 4-27

f_p = infiltration capacity, (in/hr)

k_s = saturated hydraulic conductivity (in/hr)

ψ_θ = capillary suction (in)

θ_d = initial moisture deficit

F = cumulative infiltration volume (in)

Green-Ampt-Mein-Larsen (GAML)

- 1973: Mein-Larson formulation for steady rainfall

Prior to saturation $F < F_s$, $f = i$. Saturation occurs when

$$F_s = \frac{K_s \psi_s \theta_d}{i - K_s} > F$$

- 1978: Chu adaptation for unsteady rainfall
- 1979: Coded into SWMM 3 by R. Mein
- 1993-2002: Minor refactoring by W. Huber
- 2004: Re-coded in C by L. Rossman

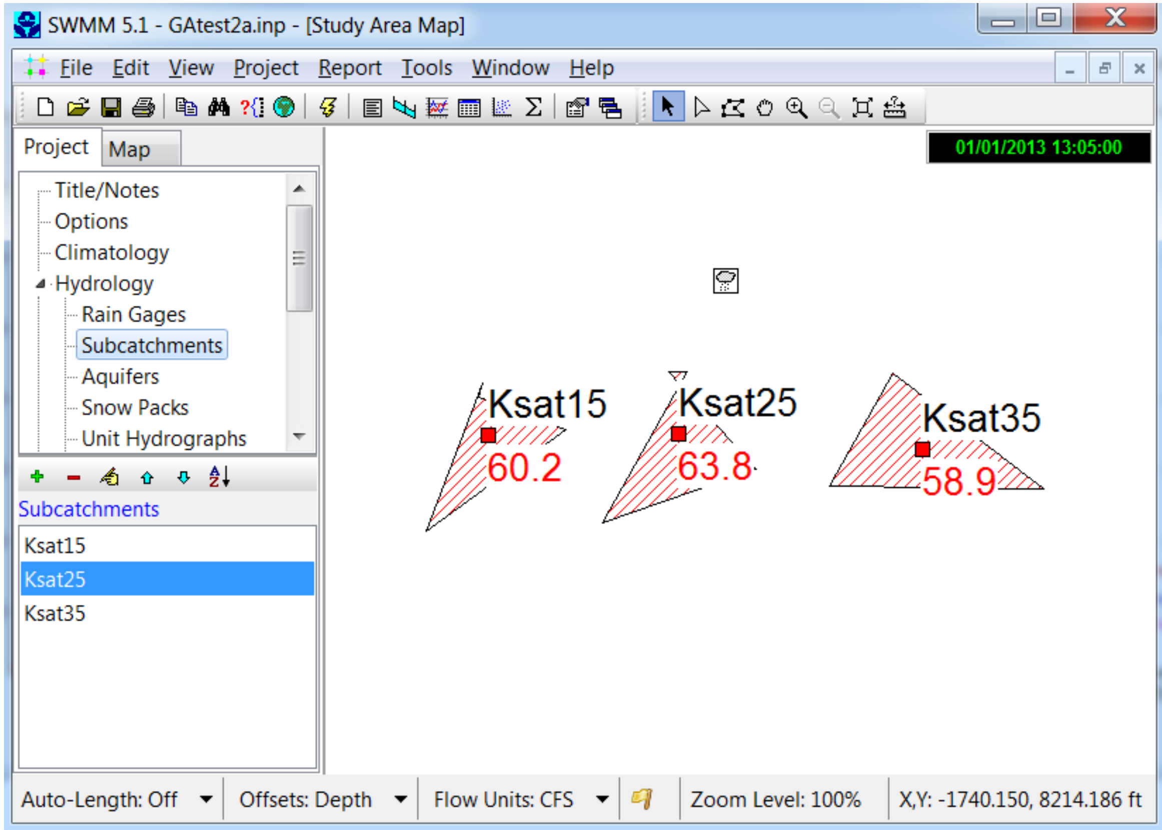
Tweaks 2005-2010

- Corrections to the way water volume in the upper soil zone is depleted during dry periods. 5.0.06 (2005)
- The point at which the time to drain the upper soil zone is first calculated was moved from time 0 to the time of first rainfall. 5.0.12 (2008)
- Infiltration rate corrected for the case when surface becomes saturated part way through current time step. 5.0.14 (2009)
- Explicitly include effect of ponded water depth on infiltration rate. 5.0.015 (2009)
- Infiltration rate no longer allowed to be less than smaller of saturated hydraulic conductivity and available surface moisture. 5.0.21 (2010)

Model Comparison

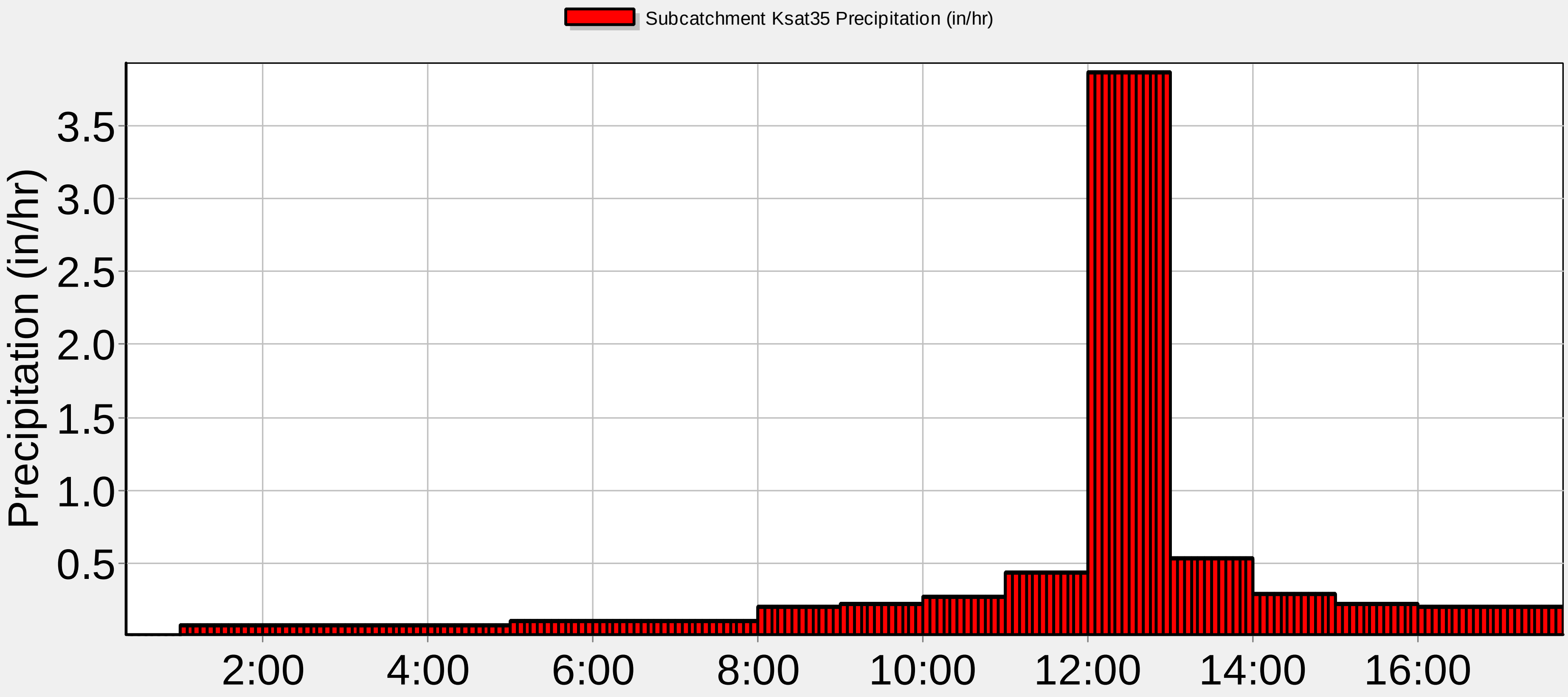
- Project technical memo
  - XPSWMM vs. EPA SWMM
  - Hydrology matches for Horton and NRCS infiltration, but not for Green-Ampt
  - XP Solutions noted that under certain conditions, EPA SWMM does not vary for changing capillary suction; CDM Smith independently confirmed this result

Sensitivity Analysis

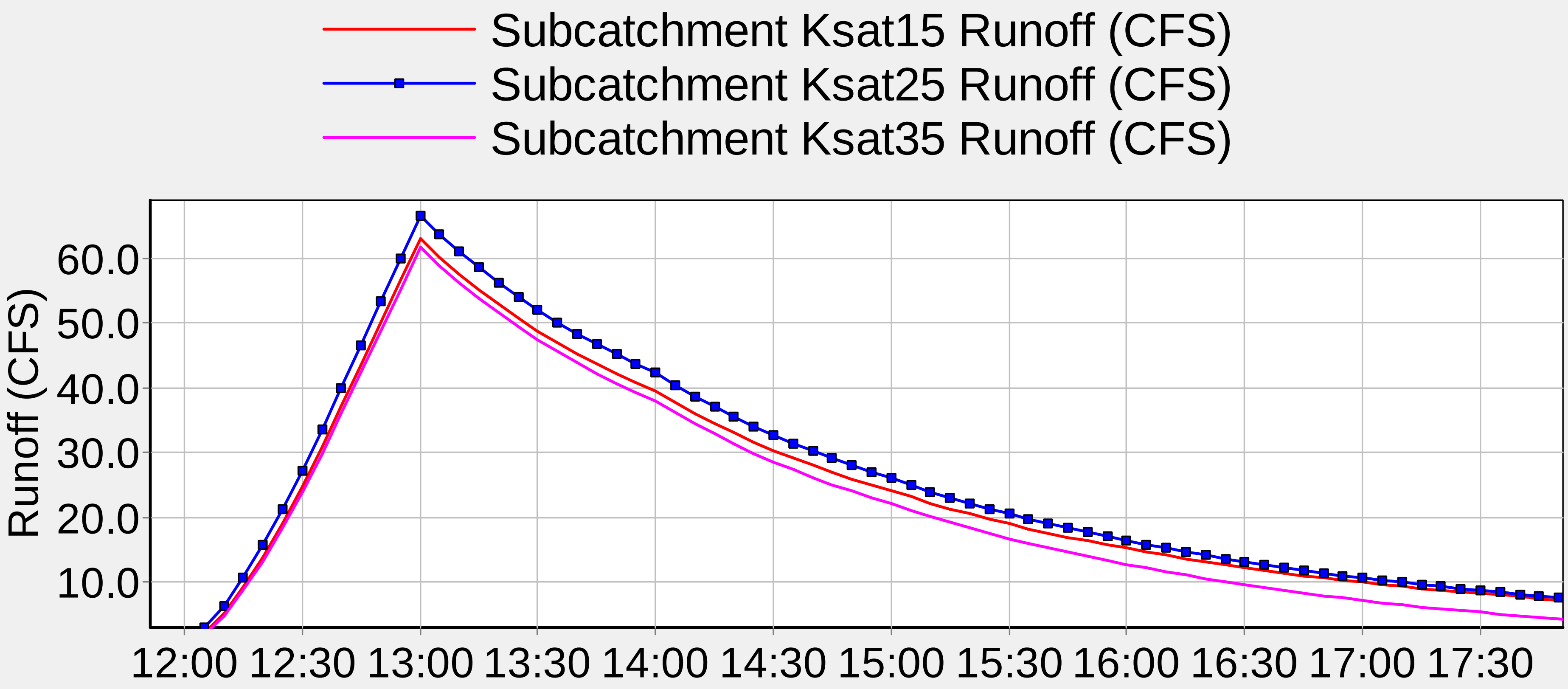


- Identical subbasins
  - 50 acres
  - 1000 ft width
  - 1% slope
  - Zero imperviousness
  - 0.25 pervious N
  - 6 inch NRCS Type II hyetograph
- Vary Ks, IMD, Su to pinpoint anomaly

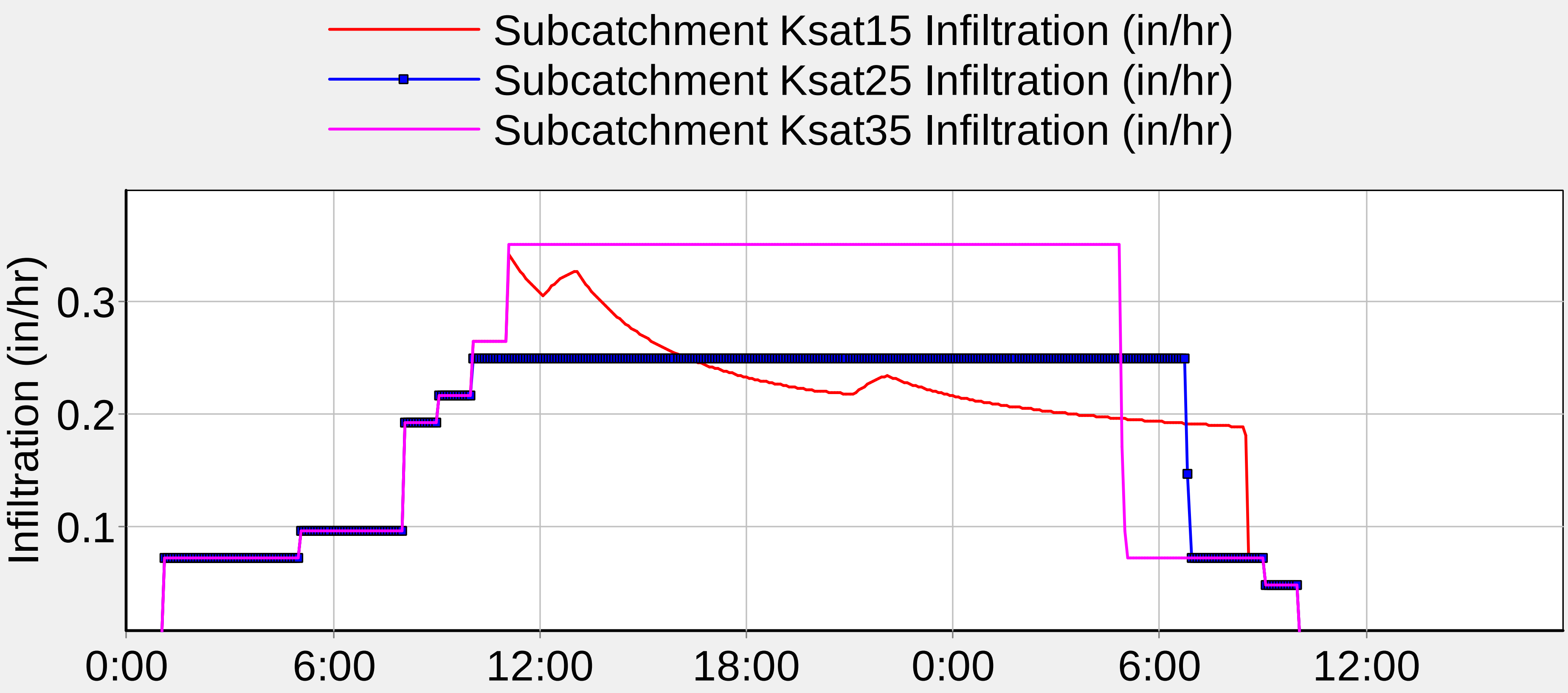
Test model SWMM 5.1.006



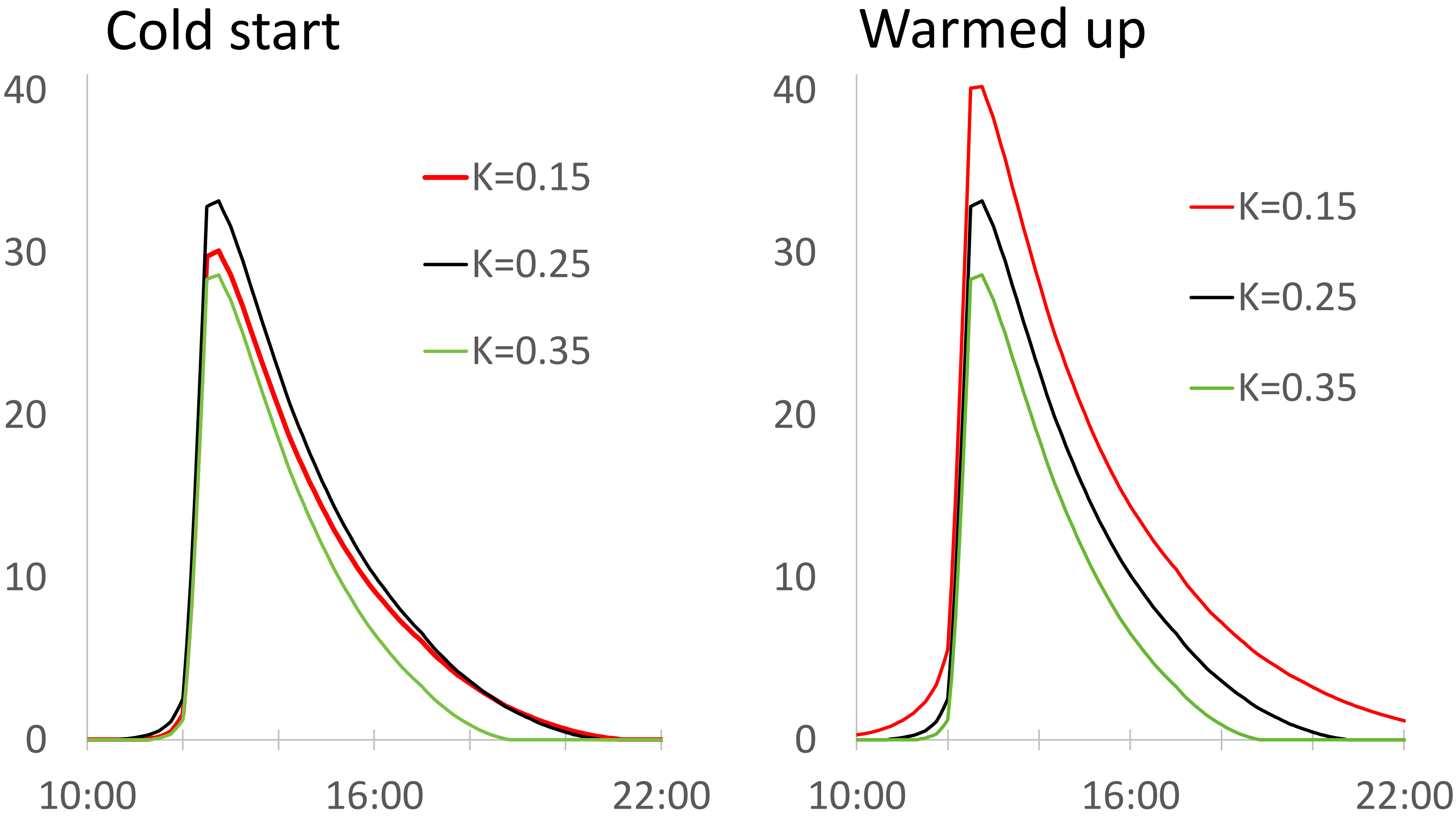
Sensitivity Analysis



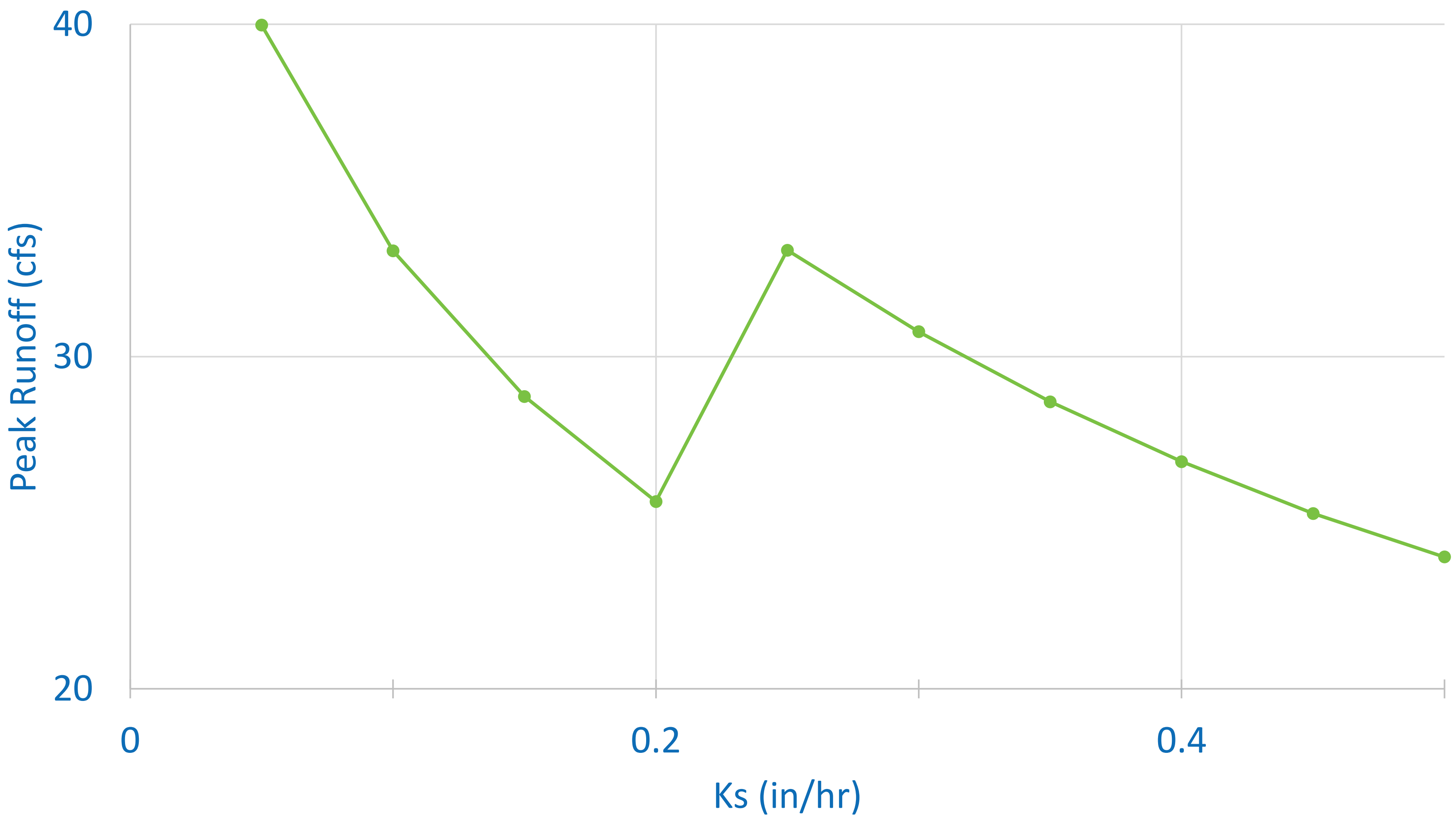
Infiltration rate



Sensitivity Analysis



Sensitivity analysis



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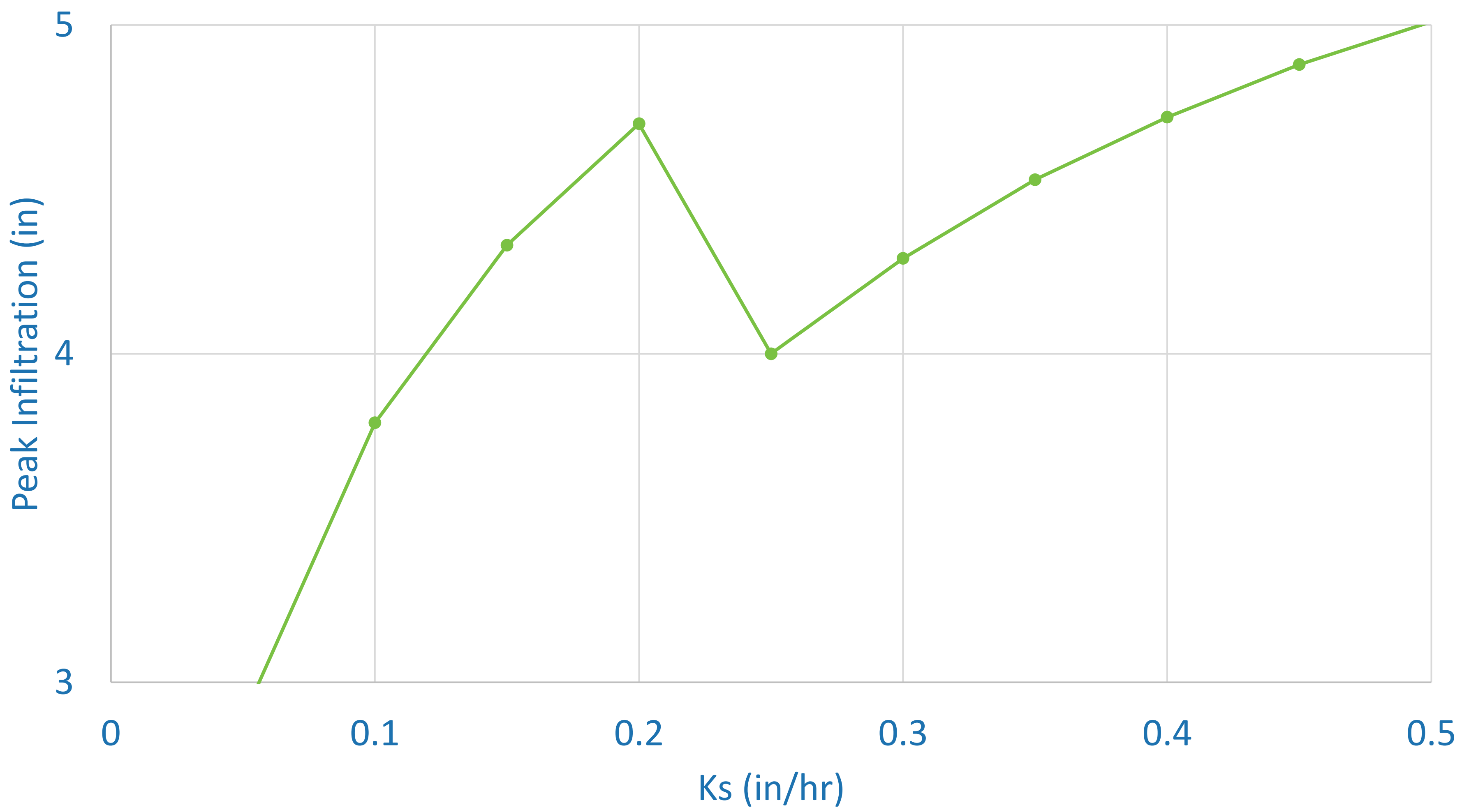
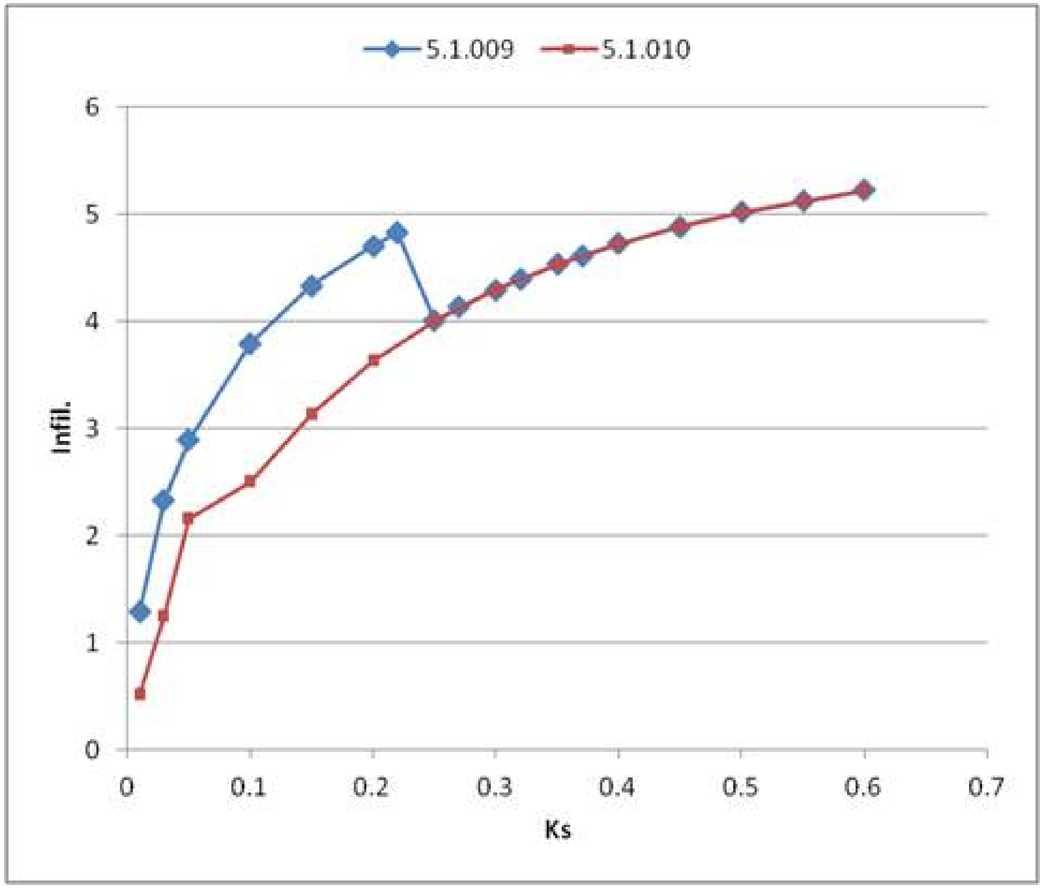


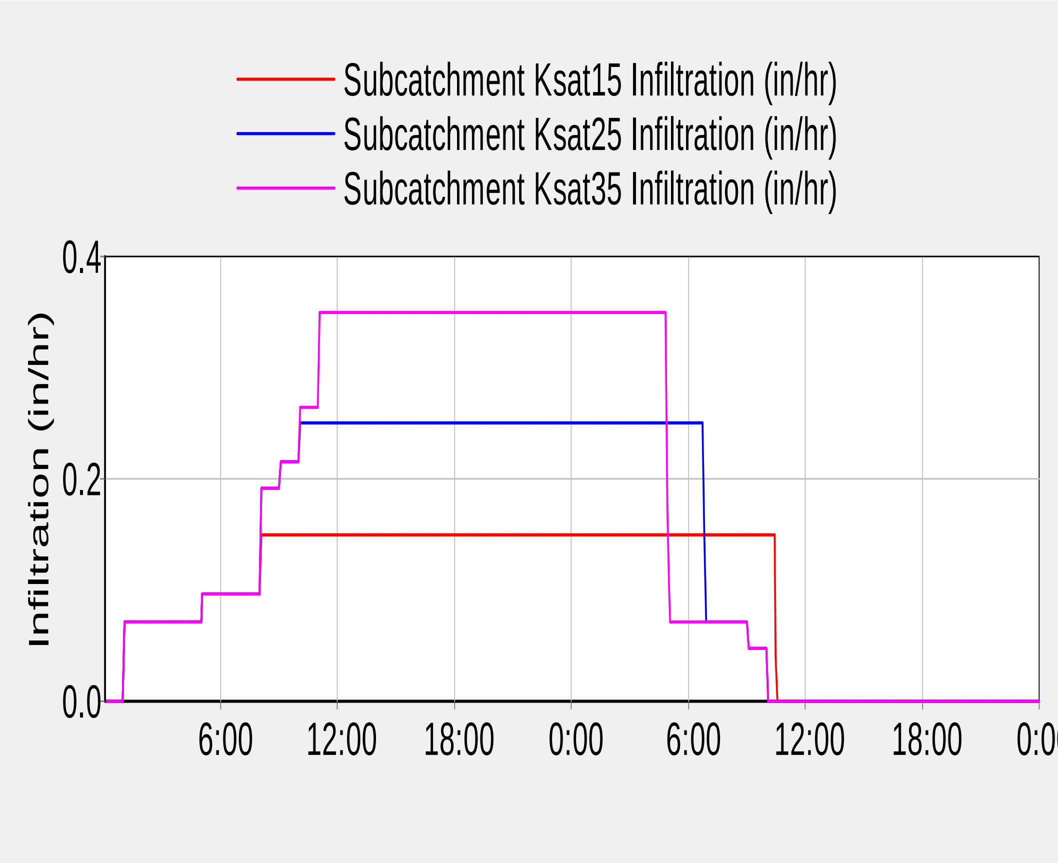
SWMM 5.1.010 vs SWMM 4.4

- Differences in the code between earlier and current versions of SWMM
  - Event separation time initialization
  - Solver convergence limits
- Base Green-Ampt infiltration in SWMM 5.1.010 revises the methodology to match SWMM 4



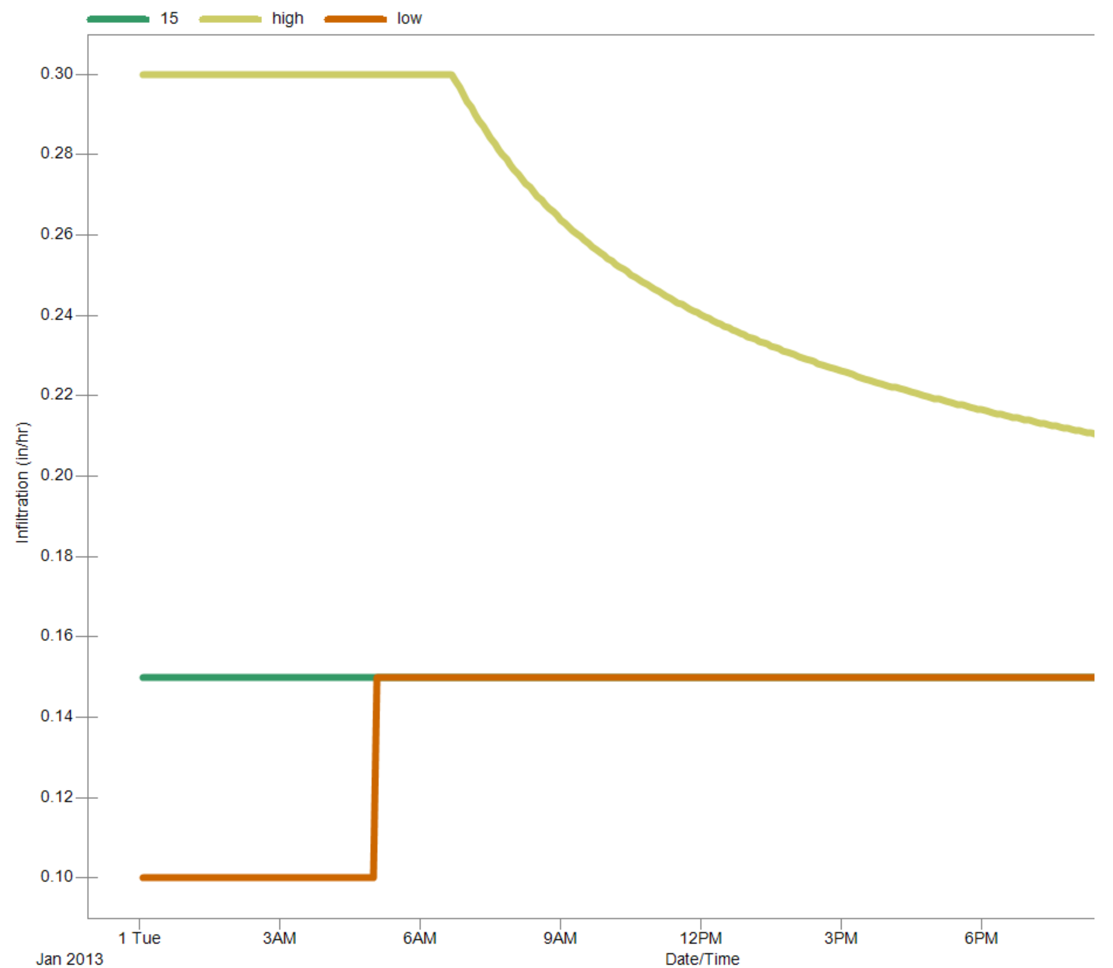
Were there issues in SWMM 4? SWMM 3?

- At this point – Lew and others considered the problem solved. But…
  - Our concerns were with the higher K_s values producing too little infiltration
  - Now all K_s values in this range match the infiltration rate



Were there issues in SWMM 4? SWMM 3?

- Sensitivity test with three simple catchments, but varying rainfall
  - K_s = 0.15 in/hr, IMD = 0.25, Su = 8 in
  - “low” rainfall: 0.1 in/hr for 5 hours, then 0.3 in/hr
  - “15 ” i = K_s = 0.15 in/hr for 5 hours, then 0.3 in /hr
  - “high” rainfall: 0.3 in/hr for the entire run



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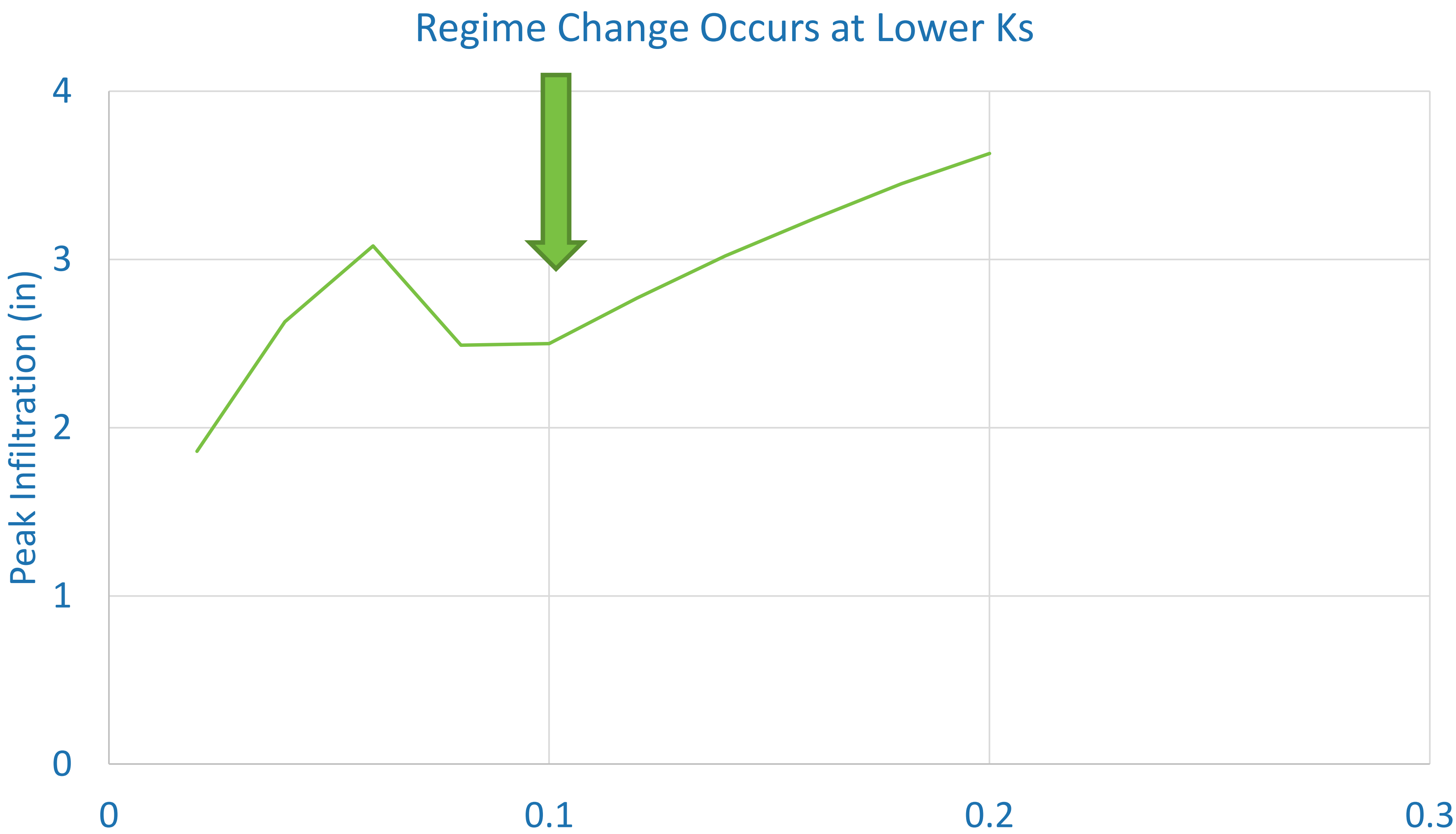


The Issue

- The algorithm has two parts:
  - Mein-Larson estimate of infiltration
  - Soil moisture accounting

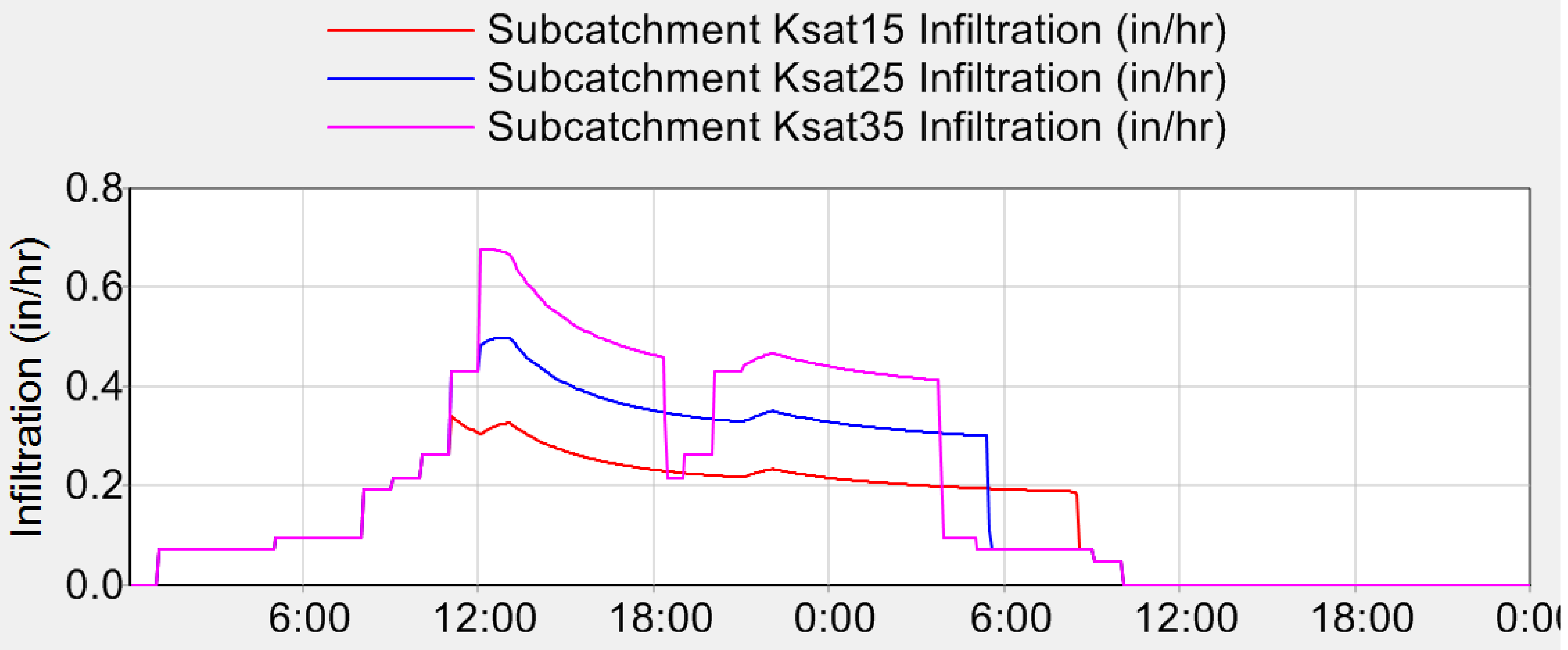
- In continuous simulation, soil moisture accounting drives estimate moisture deficit
- In NRCS design storm, moisture deficit driven to zero by low intensity rainfall well before peak

The Solution

- Code revised so initial time remaining until next wet period set to large value
- At first time period where i > K_s , TR set as usual
- Since original method had been used for 30 years, we needed to research it more:
  - Followed up with Wayne Huber
  - Wayne Huber contacted Russell Mein

```
// --- rainfall does not exceed Ksat
if ( ia <= ks )                                                    //(5.1.008)
{
    dF = ia * tstep;
    infil->F += dF;
    infil->Fu += dF;
    infil->Fu = MIN(infil->Fu, Fumax);
    if ( modelType == GREEN_AMPT &&  infil->T <= 0.0 )            //(5.1.010)
    {
        infil->IMD = (Fumax - infil->Fu) / infil->Lu;
        infil->F = 0.0;
    }
    return ia;
```

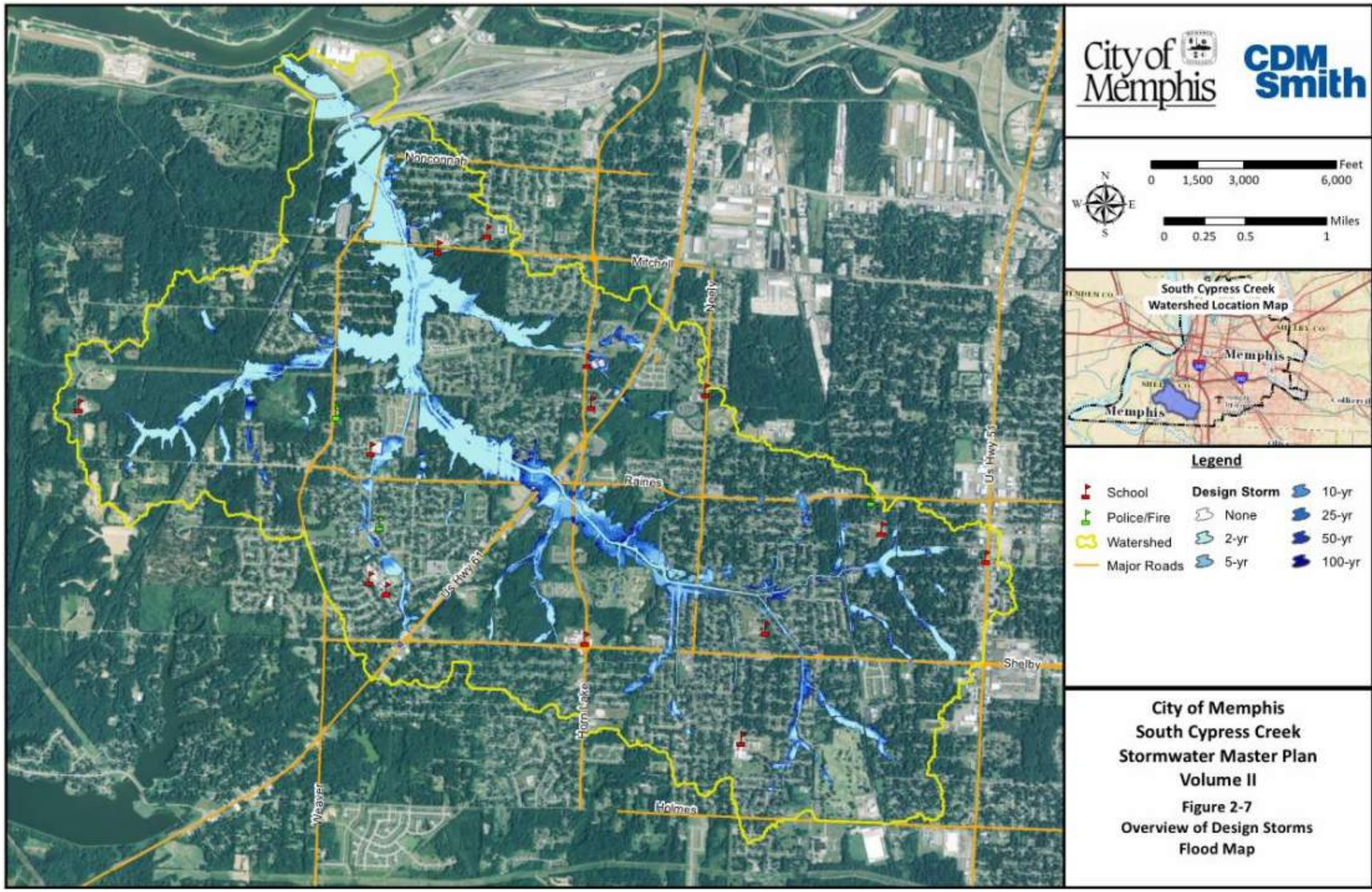
Same test case – Modified GAML



Test Case: Memphis South Cypress Creek

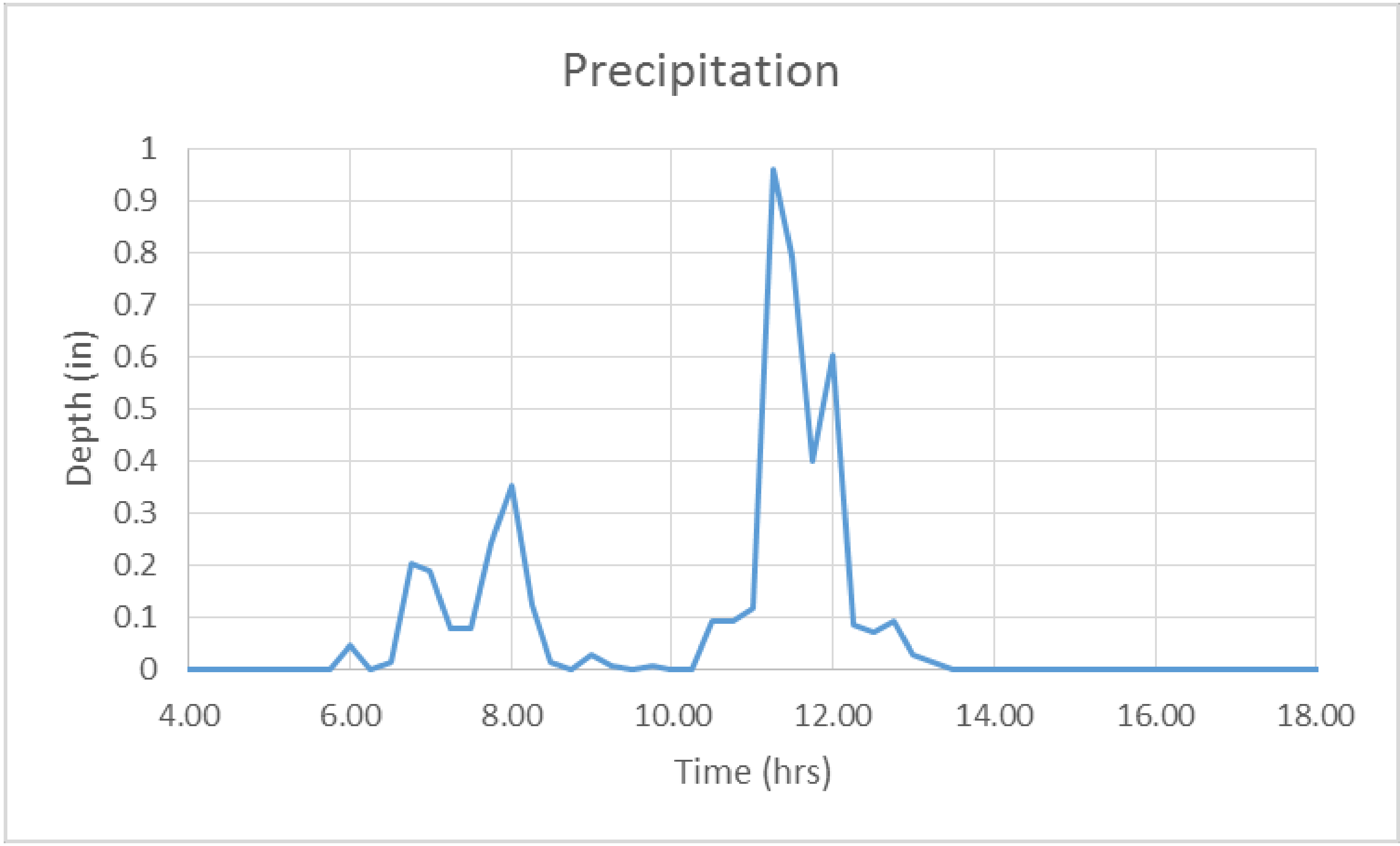
- 13 mi² with 179 subcatchments from 6.5 to 187.7 acres, averaging 46 acres

- 24% impervious
- Elev: 190 ft to 380 ft
- Soils from sandy loams to clay; 88% classified as B (Memphis Silt Loam)



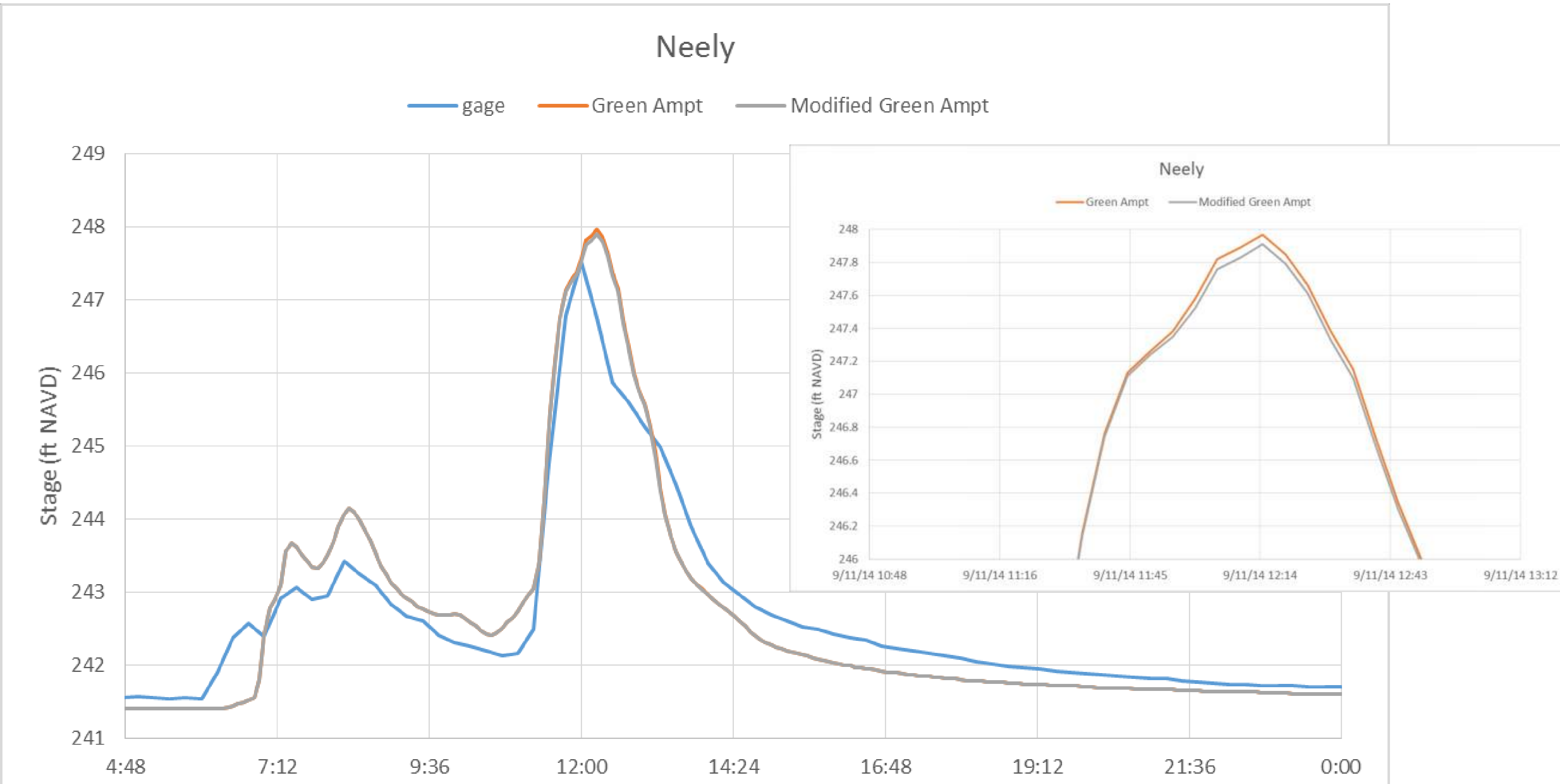
September 2014 Storm

- 4.8-inch storm
- Peak Intensity ~ 1 inch in 15-mintes
- Dry antecedent condition



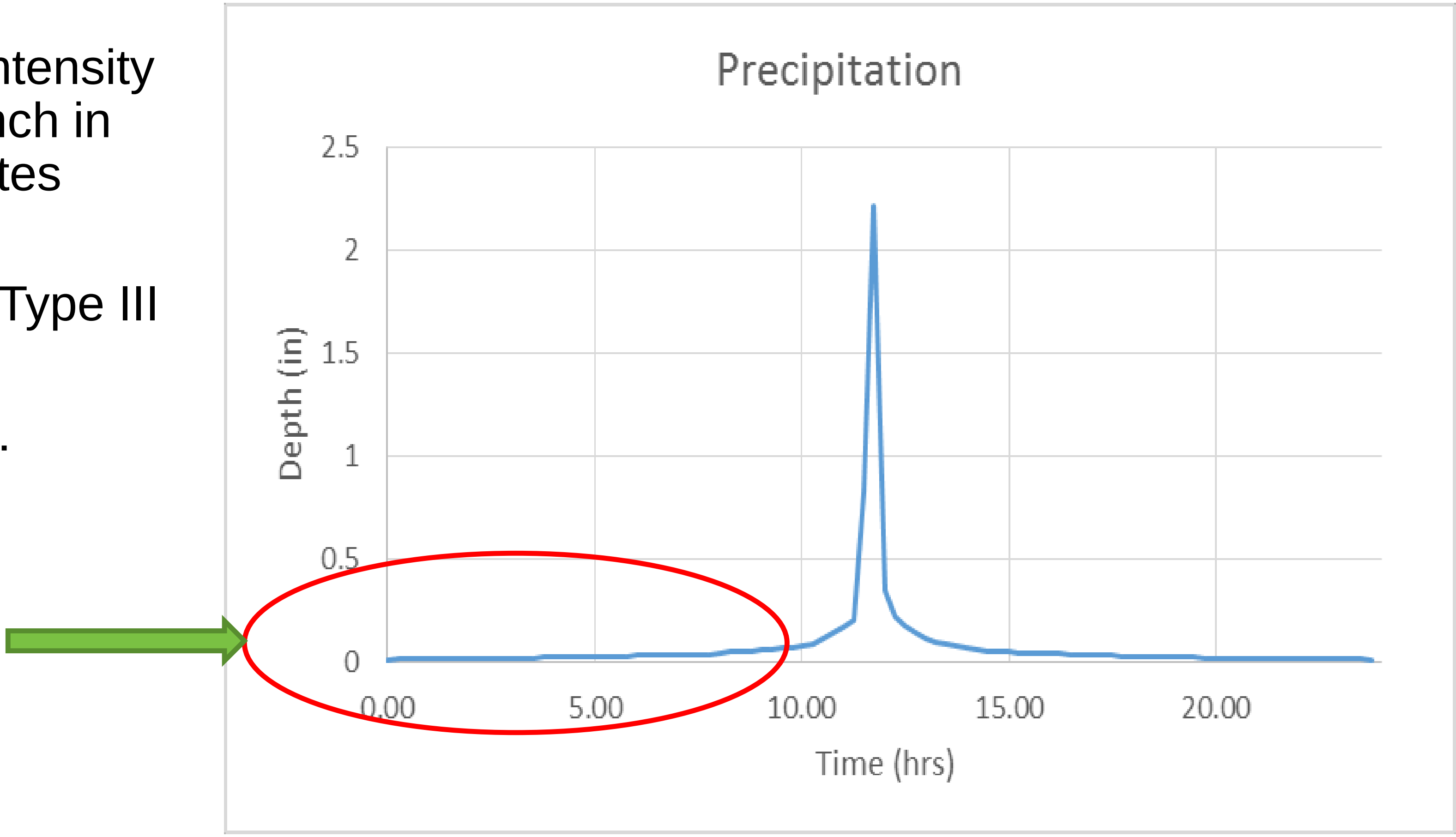
September 2014 Storm

– Stream Gage at Neely Road



100-Year Storm

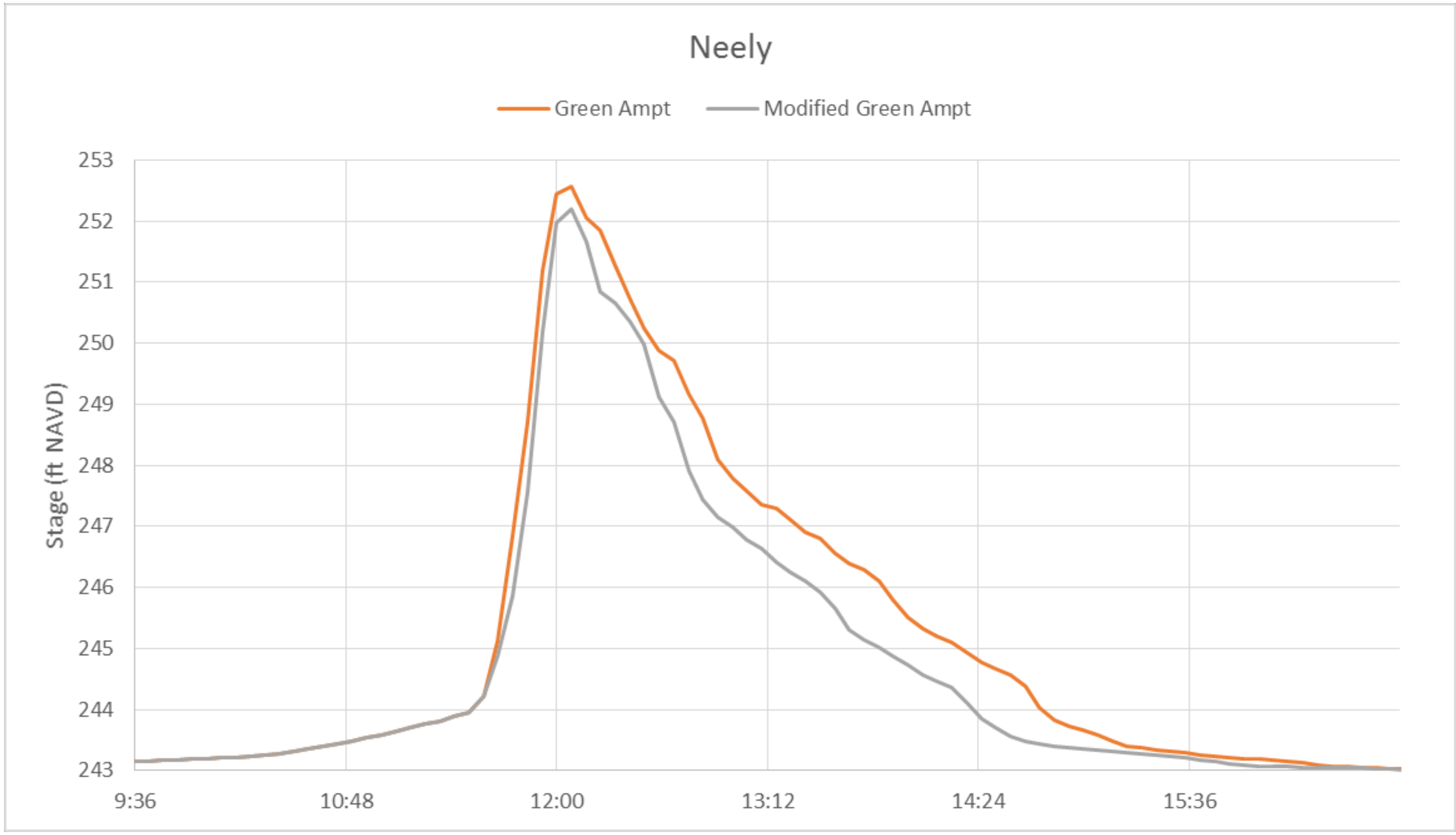
- 8-inch storm
- Peak Intensity ~ 2.2 inch in 15-mintes
- NRCS Type III
- Issue…



100-Year Storm

- Without infiltration cutoff at Ksat, infiltration increases 15% to 20% within the subbasins

- GA Peak Outfall Flow = 9830 cfs
- Mod GA Peak Outfall Flow = 8140 cfs
- 17% less



Code revisions

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Build 5.1.007 (9/15/2014)
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Engine Updates:

7.   The initial cumulative infiltration into the upper soil
     zone for Green-Ampt infiltration had been incorrectly
     set to the maximum value instead of zero.

8.   All of the Green-Ampt infiltration functions were
     re-factored to make the code easier to follow.


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Build 5.1.010 (08/05/15)
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Engine Updates:

1.  A modified version of Green-Ampt infiltration (MODIFIED GREEN AMPT) was
    added that no longer redistributes upper zone moisture deficit during
    low rainfall events. The original authors of SWMM's Green-Ampt model
    have endorsed this modified version. It will produce more infiltration
    for storm events that begin with low rainfall intensities, such as the
    SCS design storm distributions.
```

Conclusions

“I am impressed and pleased that there are people out there who keep checking model output. Unfortunately most model results are accepted by users without question” - Russel Mein