Need to improve SWMM's subsurface flow routing algorithm for green infrastructure modeling

Joong Gwang Lee [1], William Shuster [2], and Sudhir Kshirsagar [3]

[1] Center for Urban Green Infrastructure Engineering (CUGIE Inc), Cincinnati, OH, USA

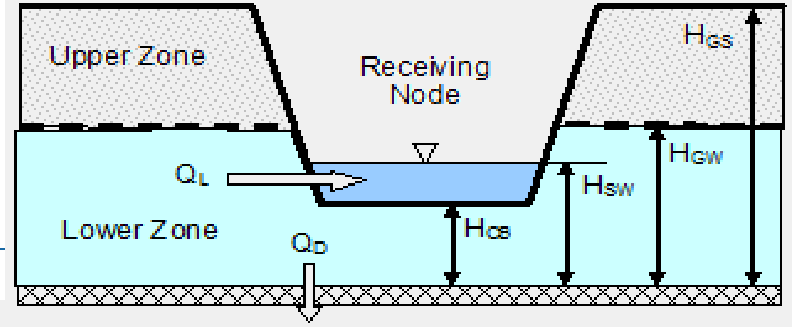
[2] U.S. Environmental Protection Agency, Cincinnati, OH, USA

[3] Global Quality Corp., Covington, KY, USA

Introduction

- Originally, the subsurface flow of infiltrated water was considered an insignificant process in SWMM.
- However, subsurface flow can be significant where the drainage area has high pervious surfaces, high groundwater tables, or a combination of these.
- Implementing infiltration LID or GI practices would also increase volume inputs to the local water cycle, with enhancement of subsurface flows.
- This study aims to identify the need of updating the existing algorithms of subsurface flow routing in SWMM, and consequently improve its GI modeling capabilities.

SWMM can simulate various subsurface flows



$Q_L = A1(H_{GW} \_ H_{CB})^{B1} - A2(H_{SW} - H_{CB})^{B2} + A3(H_{GW} H_{SW})$

Storage Seepage Editor

Properties of soil beneath storage unit:

Property	Value
Suction Head	0
Conductivity	0
Initial Deficit	0

Surface | Soil | Storage | Drain

Thickness (in. or mm)	12
Void Ratio (Voids / Solids)	0.75
Seepage Rate (in/hr or mm/hr)	0.5
Clogging Factor	0

Response	R	T	K
Short-Term			
Medium-Term			
Long-Term			

R = fraction of rainfall that becomes I&I

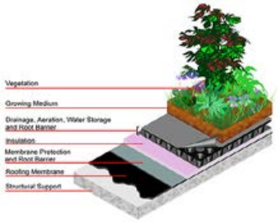
T = time to hydrograph peak (hours)

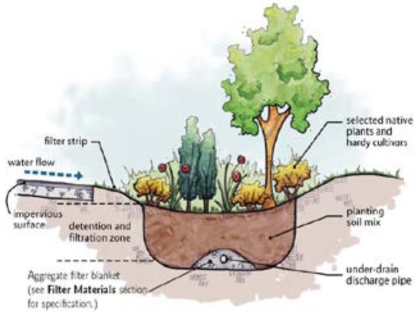
K = falling limb duration / rising limb duration

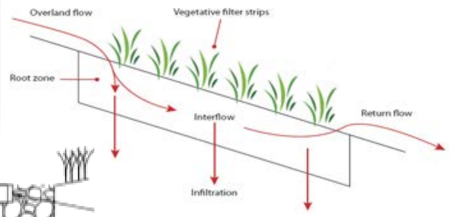
- Groundwater (GW) release from a subcatchment to a node
- Percolation out of storage units
- Percolation out of low impact development (LID) controls
- Rainfall derived inflow and infiltration (RDII) at a node

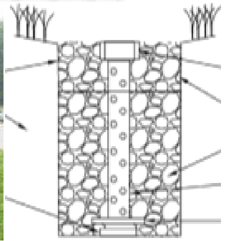
Structural LID/BMP/GIs

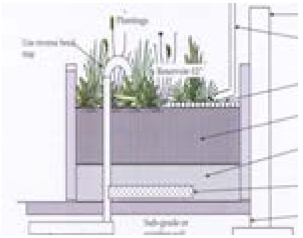
- Disconnected pervious areas
- Bioretention/Rain garden
- Porous pavement
- Vegetated swale/Bioswale
- Vegetative filter strip
- Infiltration trench
- Green roof
- Rain barrel/Cistern
- Disconnection of paved areas & roofs from the drainage system
- Soil amendments to alleviate compaction, improve infiltration

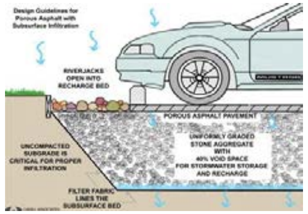




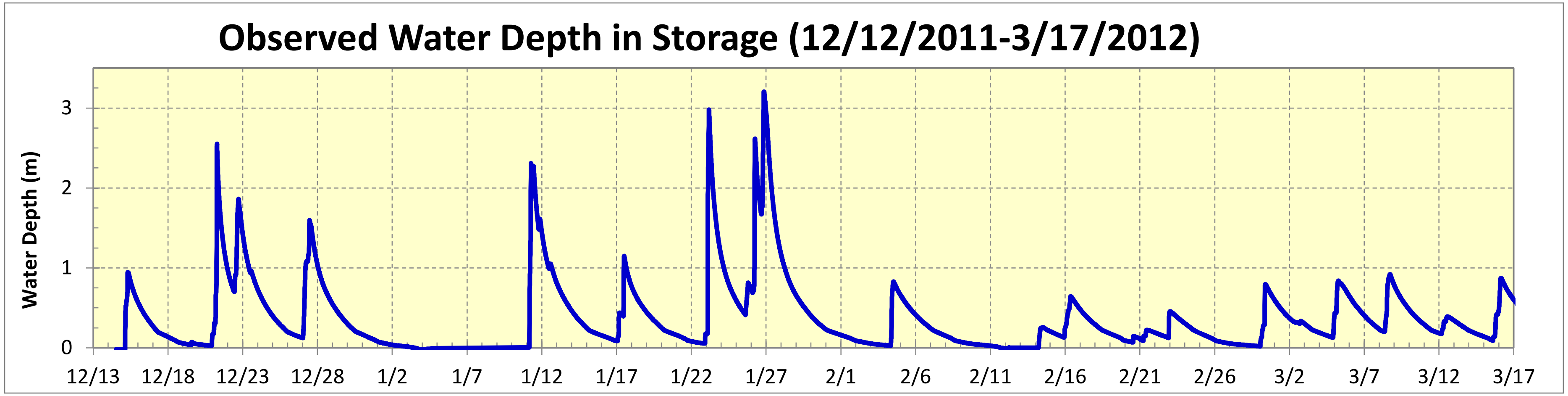


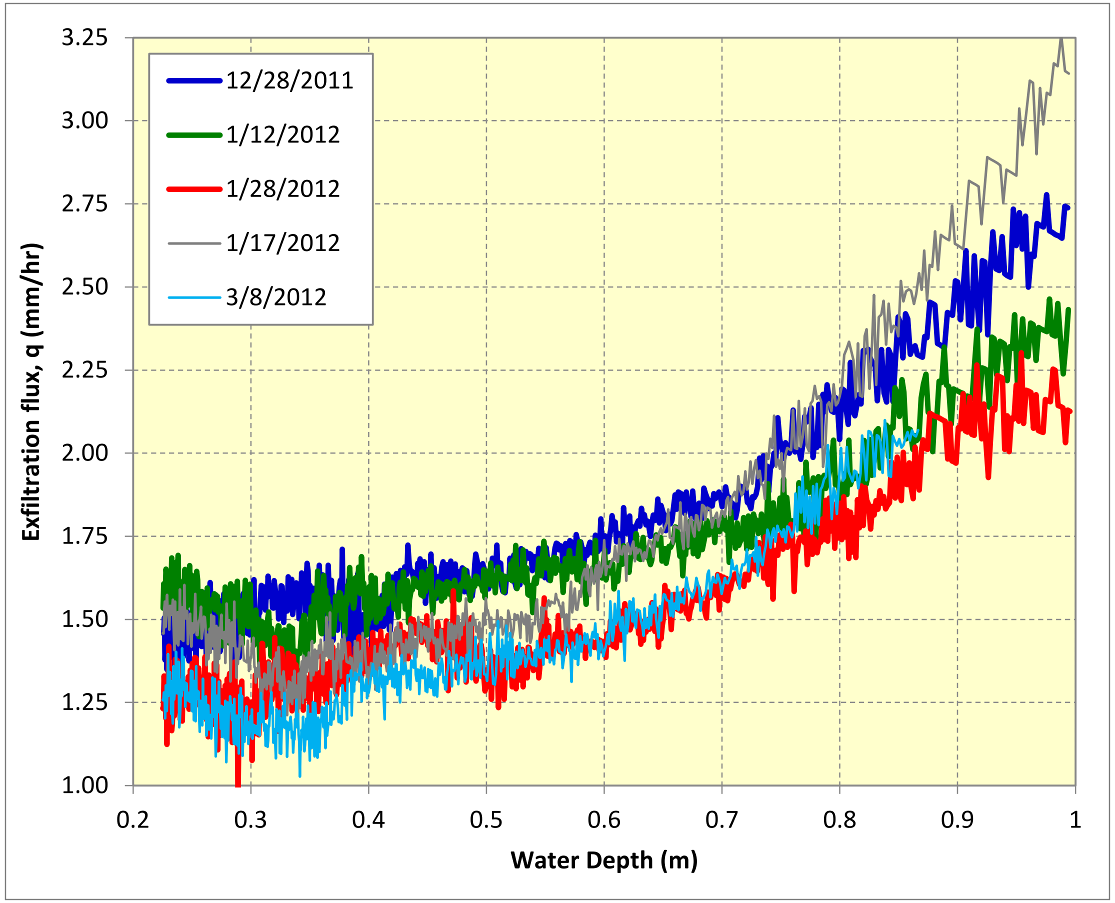


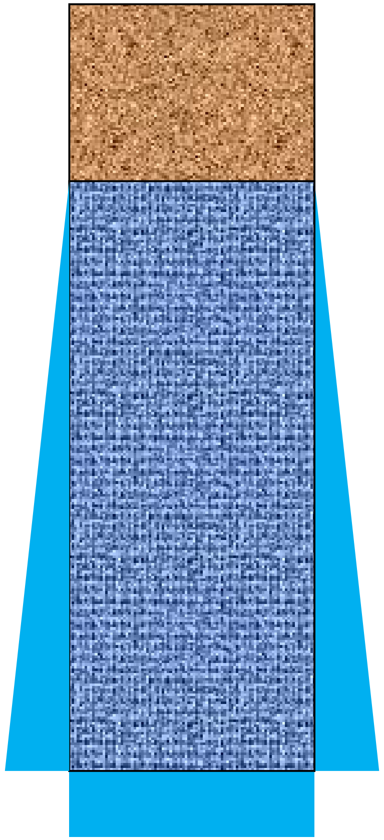




Exfiltration from LID Control

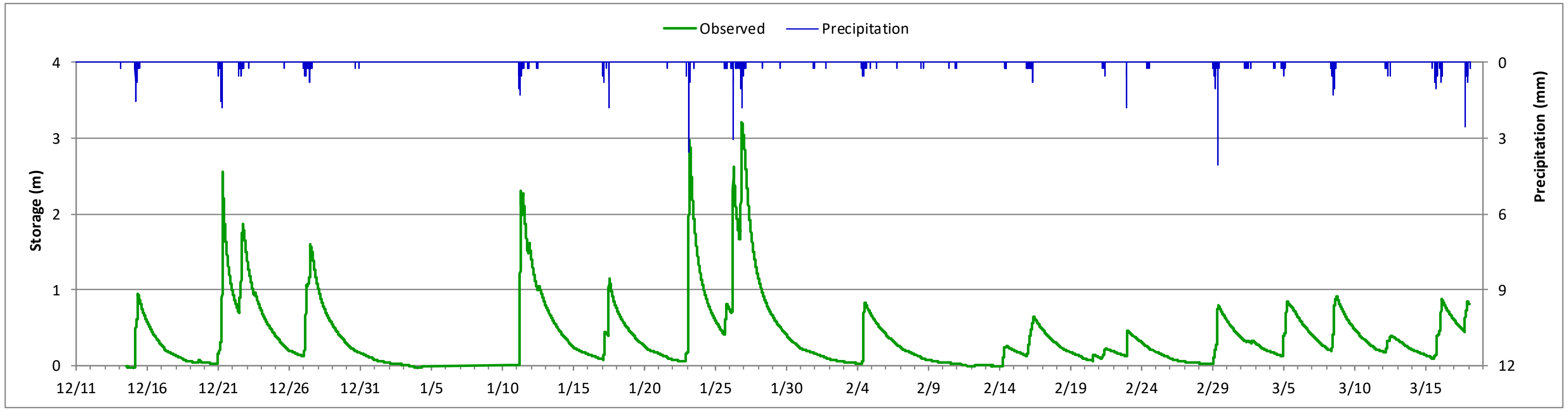




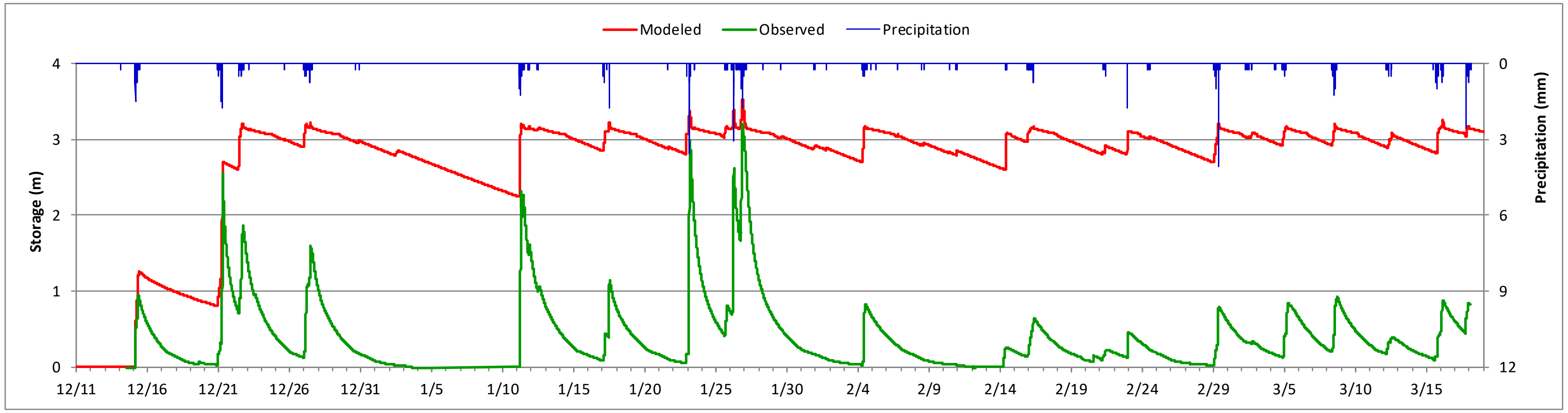


Exfiltration from LID Control

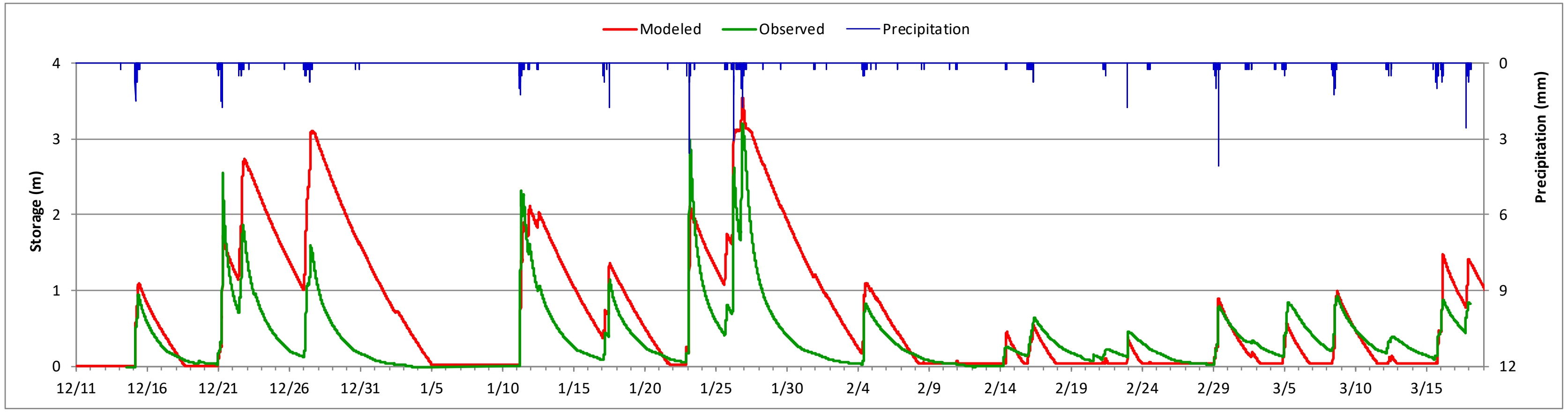
- Observed stage data from an infiltration trench



- Modeled stage data (seepage only at the bottom)

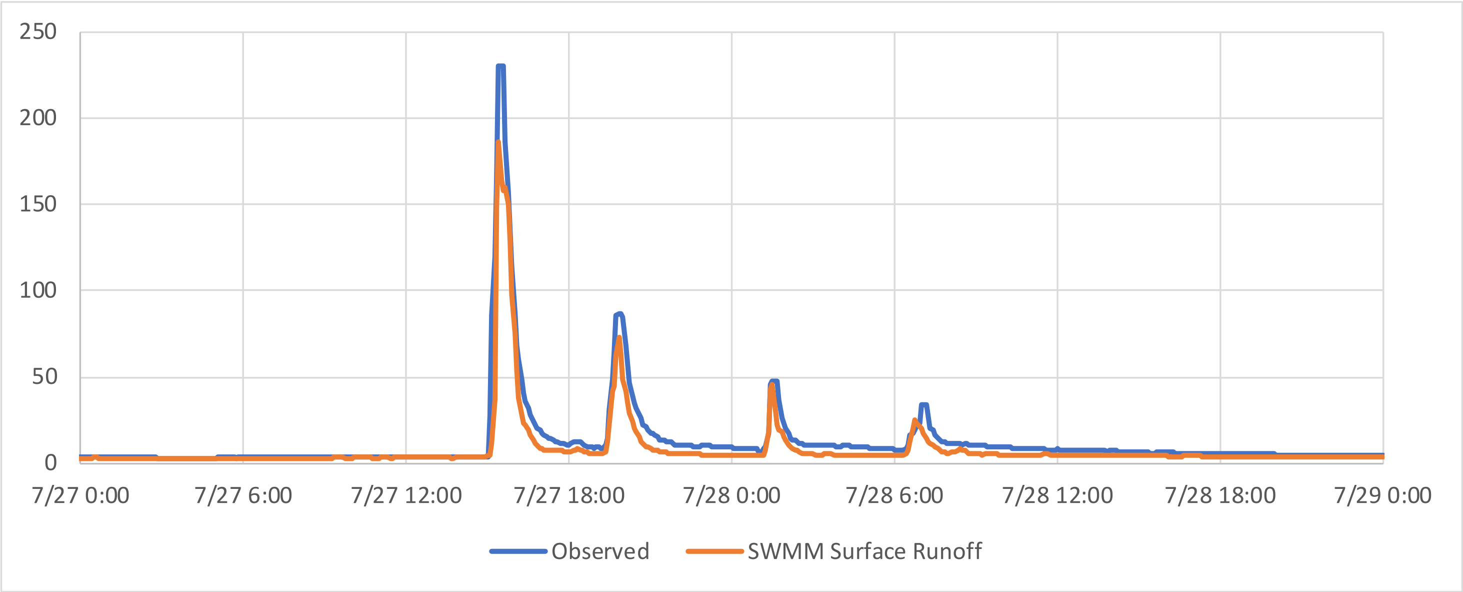


- Calibrated stage data (applied about 7 times higher Ksat than the modeled)

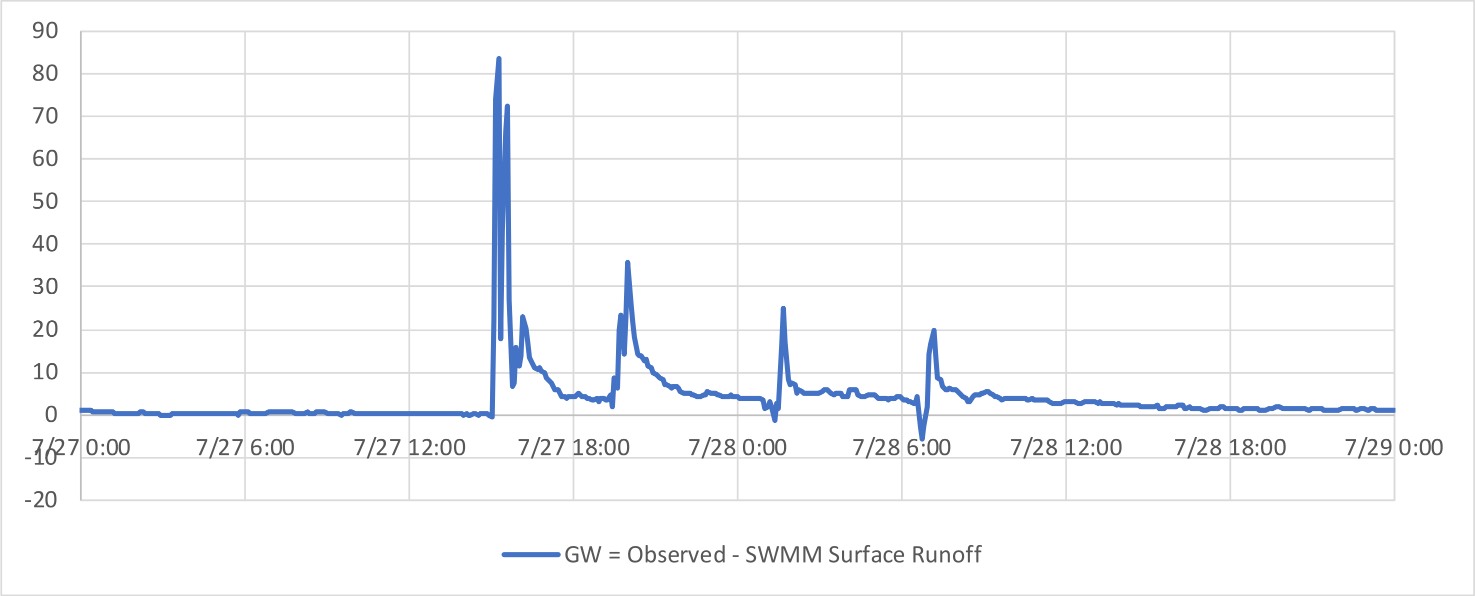


Sub-Surface Runoff to CSS

- Observed total flow; and modeled surface runoff

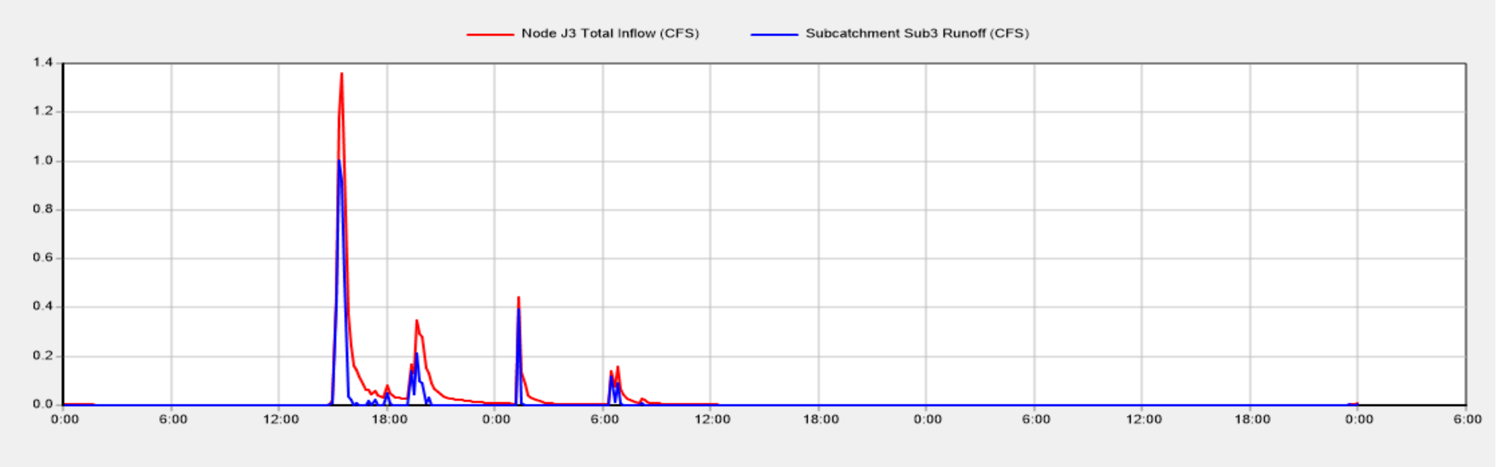


- Non-surface runoff = Observed – Modeled surface runoff

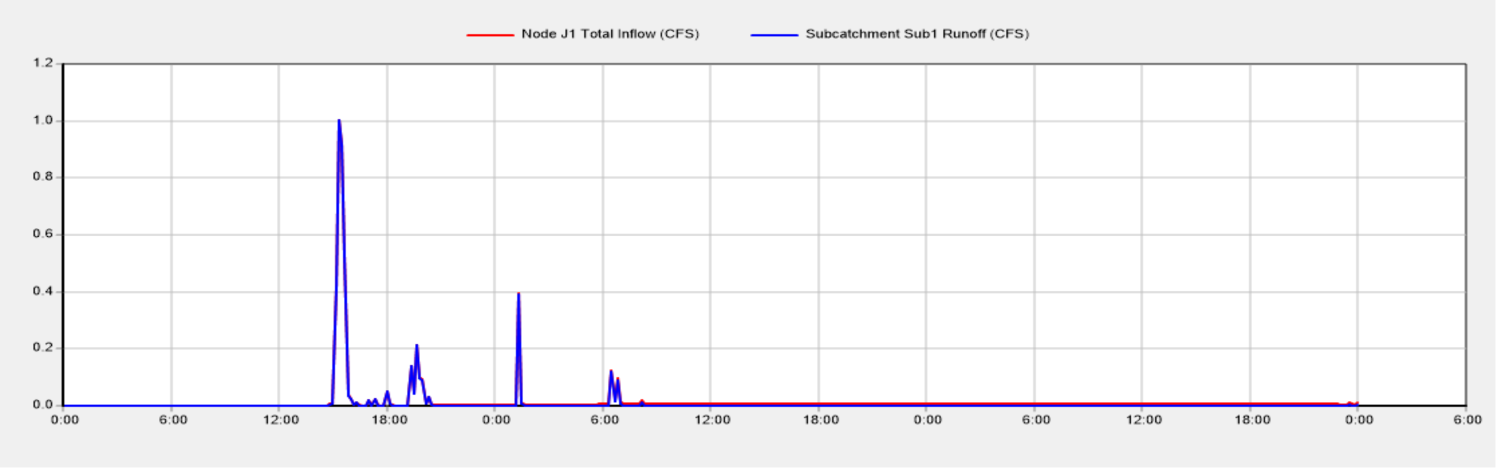


Sub-Surface Runoff to CSS

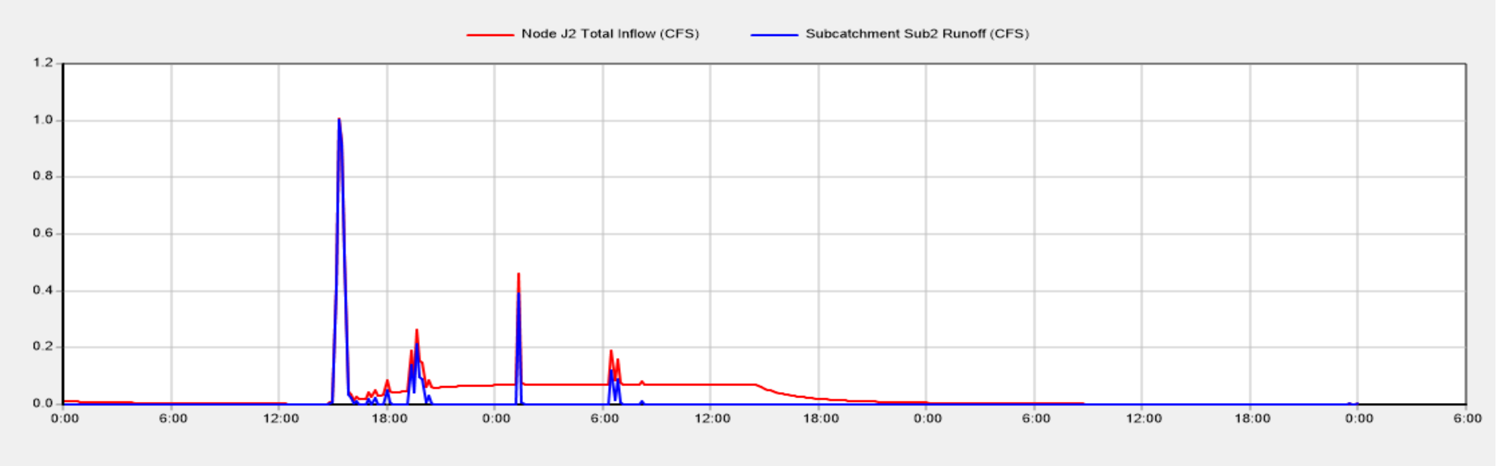
- RDII R/T/K
  - Short: 0.3/0.2/1.8
  - Medium: 0.2/0.55/2
  - Long: 0.2/1.65/4



- GW parameters
  - Eab=10; Ecb=20; Egw=20
  - A1=0.01; B1=2; Esf=25



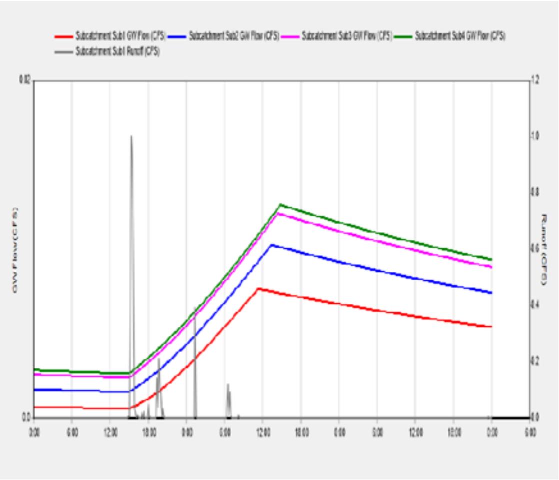
  - Eab=10; Ecb=20; Egw=20
  - A1=5; B1=2; Esf=40

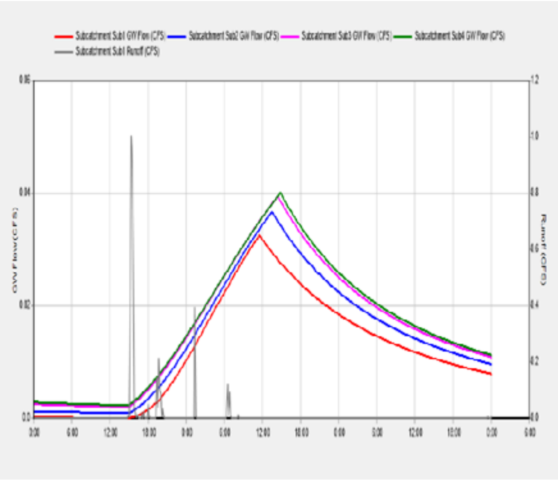


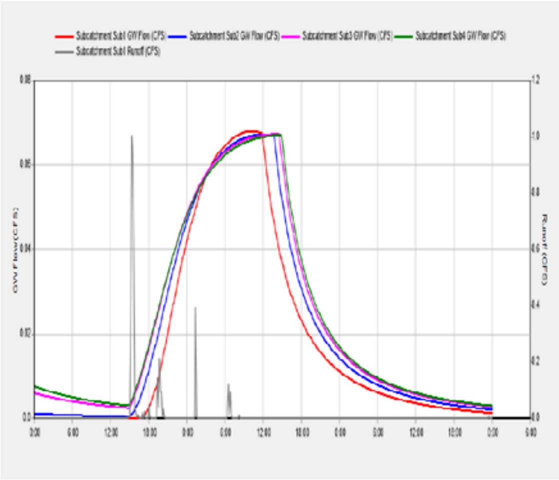
Sub-Surface Runoff to CSS

GW parameters: Eab=10; Ecb=20; Egw=20; Esf=25-30-40-60

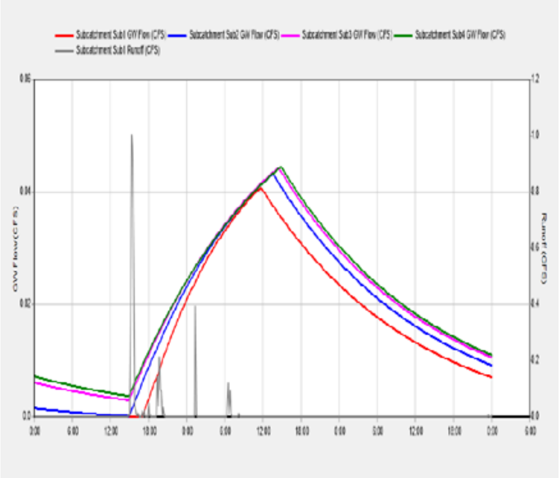
- L: A1=0.01; B1=2
- C: A1=0.1; B1=2
- R: A1=1; B1=2

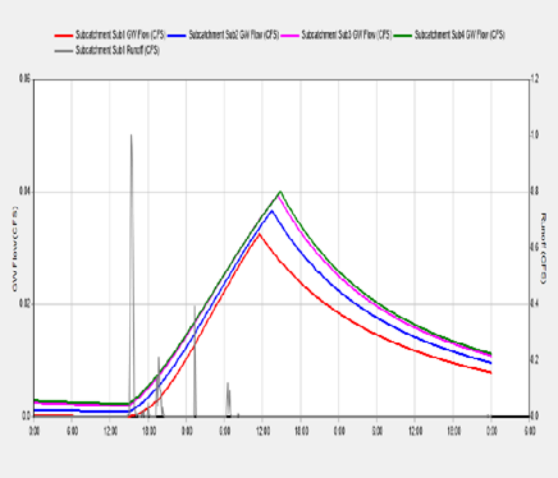


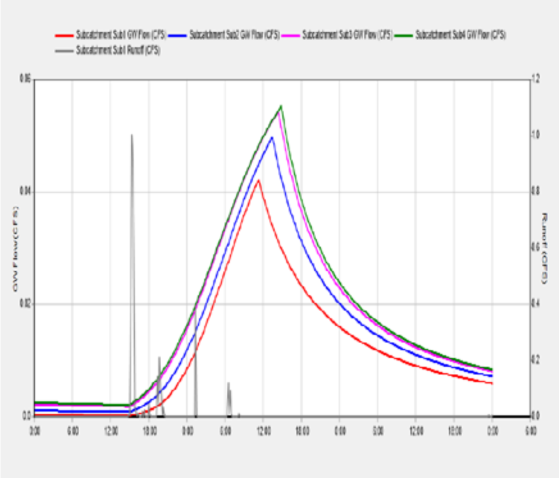




- L: A1=0.1; B1=1
- C: A1=0.1; B1=2
- R: A1=0.1; B1=5







Our Approaches

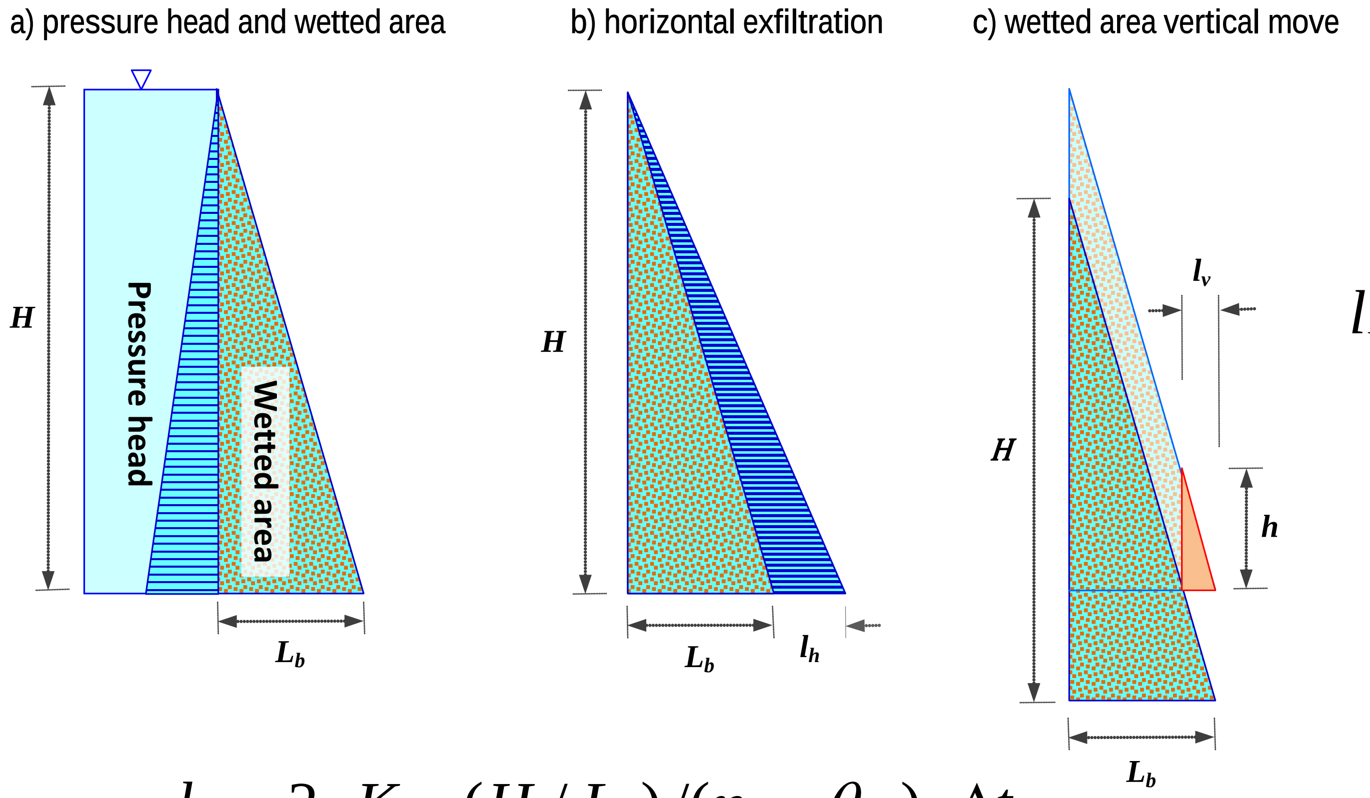
- **Based on Darcy's equation:**

$$Q = K\,A\,\mathrm{d}H/\mathrm{d}L$$

Where, Q = rate of water flow [L^3T^{-1}], K = hydraulic conductivity [LT^{-1}], A = cross-sectional area in flow [L^2], dH/dL = hydraulic gradient [dimensionless], H = hydraulic head [L], and L = flow length between the points of interest [L].

- ✓ An appropriate site-specific value for *K* can be estimated using field data.
- ✓ Suitable approximation must be applied for estimating *A* as a function of *H* and the size of drainage area.
- ✓ The appropriate value of *L* from a drainage area to a channel system can be initially estimated using GIS.
- ✓ Geometric approximation would also need to be applied when we estimate *A*, *H*, and *L* between the points of interest.
- ✓ Some alternatives can be examined using the custom lateral or groundwater flow equation editor in SWMM.

Horizontal Exfiltration from an LID/Storage Unit



$$l_v = (L_b / H) \cdot h$$

$$h = K_h / (\eta_s - \theta_{fc}) \cdot \Delta t$$

$$l_h = 2 \cdot K_h \cdot (H / L_b) / (\eta_s - \theta_{fc}) \cdot \Delta t$$

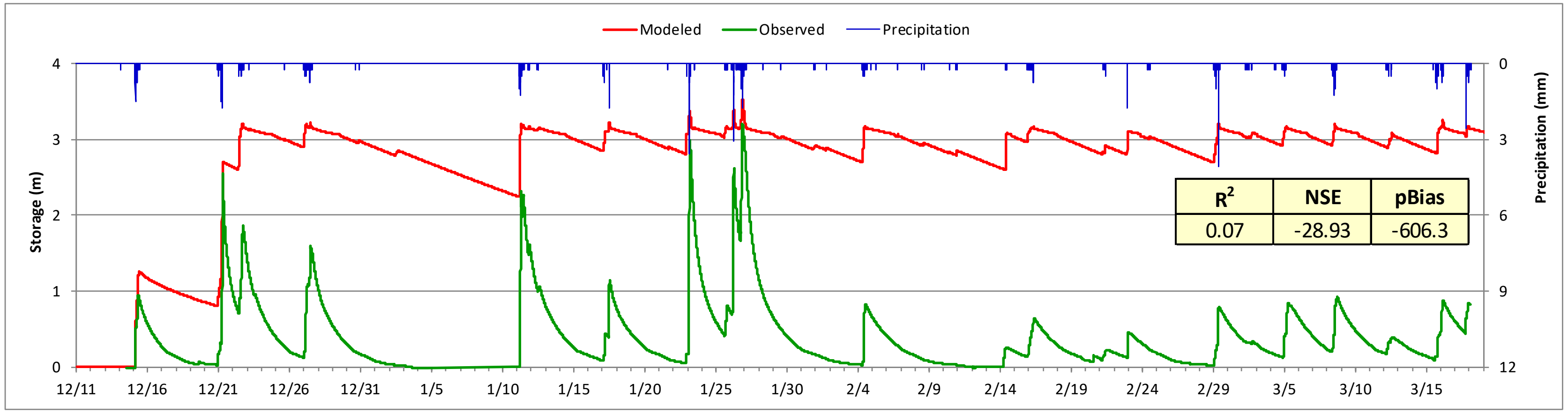
$$Q_h = K_h \cdot A_s \cdot (H / L_b)$$

$$\Delta L_b = l_h - l_v = K_h \cdot (2 \cdot H / L_b - L_b / H) / (\eta_s - \theta_{fc}) \cdot \Delta t$$

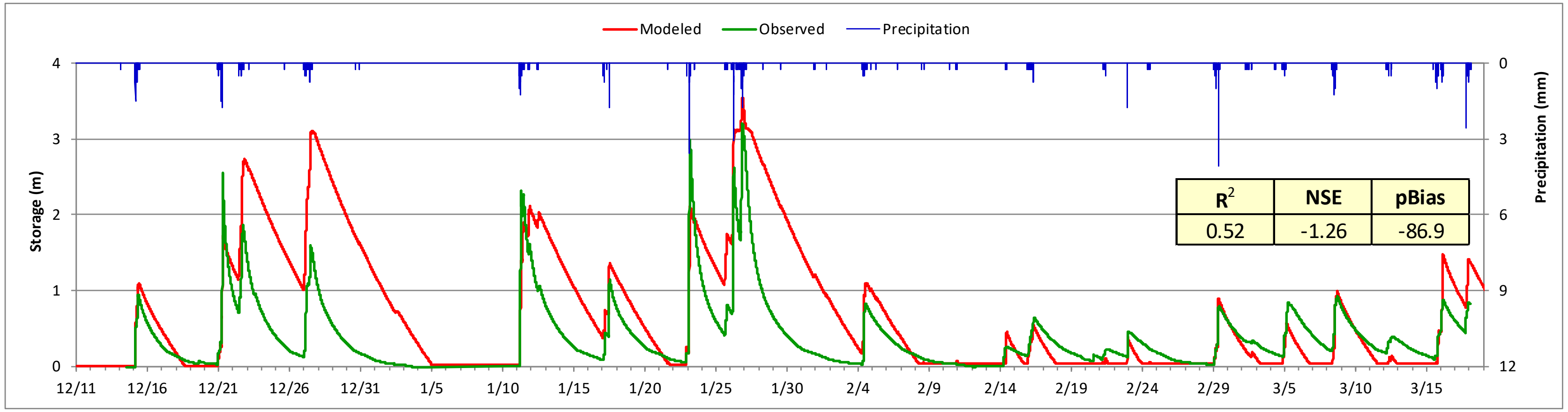
Reference: Lee, J.G., Borst, M., Brown, R.A., Rossman, L., and Simon, M.A. (2015). "Modeling the hydrologic processes of a permeable pavement system." Journal of Hydrologic Engineering, 20(5): 04014070. ASCE. https://ascelibrary.org/doi/abs/10.1061/(ASCE)HE.1943-5584.0001088

Exfiltration from LID Control

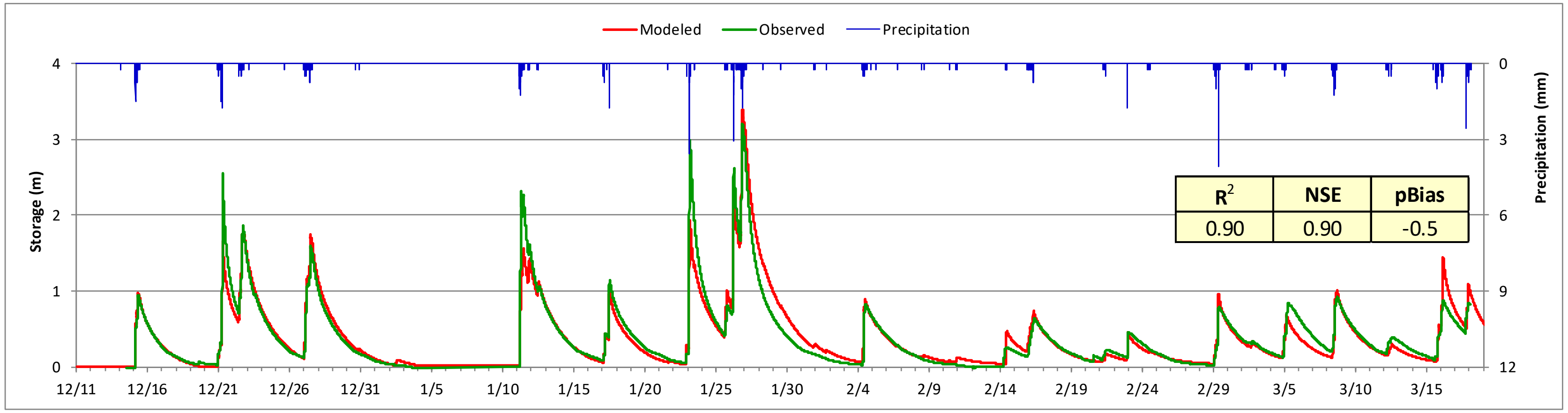
- Modeled stage data (seepage only at the bottom)



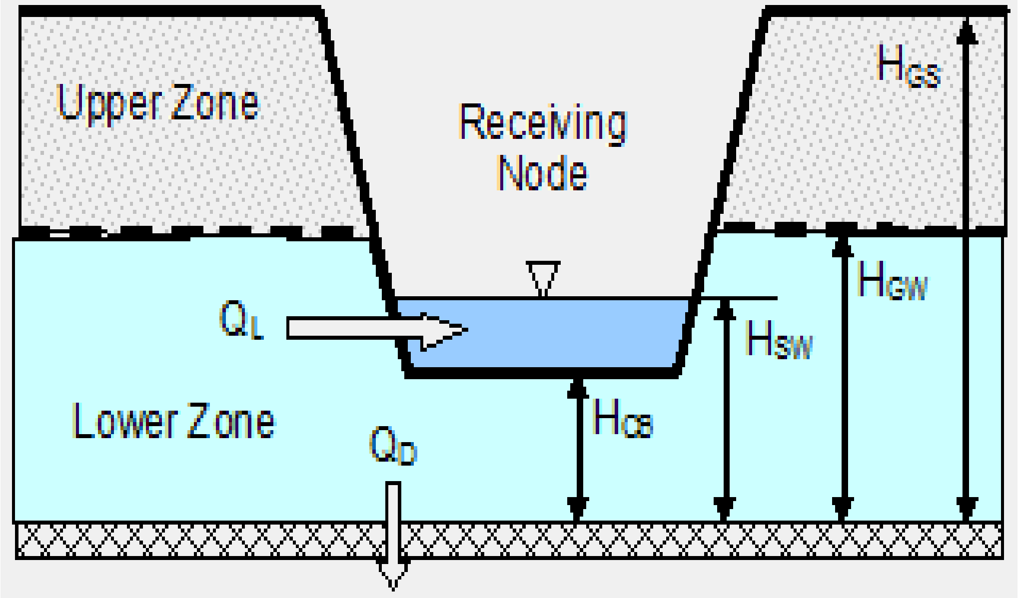
- Calibrated stage data (applied about 7 times higher Ksat than the modeled)



- Modeled by new algorithms, for both vertical and horizontal exfiltration



GW Algorithm (Hypothesis)



- Alternative Approach

  QL = Ksat * H * A / Lgw (Gaining when H>0; Losing when H<0)

  GD = Kpercol * Asub

  Where, QL: lateral inflow/exfitration of the sewer (cfs, not cfs/ac); QD: deep percolation (cfs, not in/hr); H = Hgw – Hsw; When (Hgw > Hsw), A = SQRT(Asub) * (Hgw – Hsw) * F; When (Hgw ≤ Hsw), A = Lsewer * (Hsw – Hgw) * F; Hgw = Egw – Eab; Esw = Ecb + Dw; Hsw = Esw – Eab; Ecb = (Invert_up + Invert_down) / 2

  Ksat: Ksat of each subcatchment; Lgw: shortest distance from subcatchment to channel; Lsewer: length of the channel; Esurf: subcatchment surface elevation; Eab: aquifer bottom elevation; Ecb: channel bottom elevation; Egw: groundwater surface elevation; Esw: elevation of water in channel; Dw: depth of flow in the channel; F: fractional adjuster to model the condition of the sewershed; Kpercol: percolation rate

  Color Legends: Fixed; Dynamic; Caution

Preliminary Trial and Result