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Improving Life through Science and Technology

Development of Algorithms for Urban BMPs in SWAT: Sand Filters

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2011 International SWAT Conference, Toledo, Spain, June 15-17, 2011

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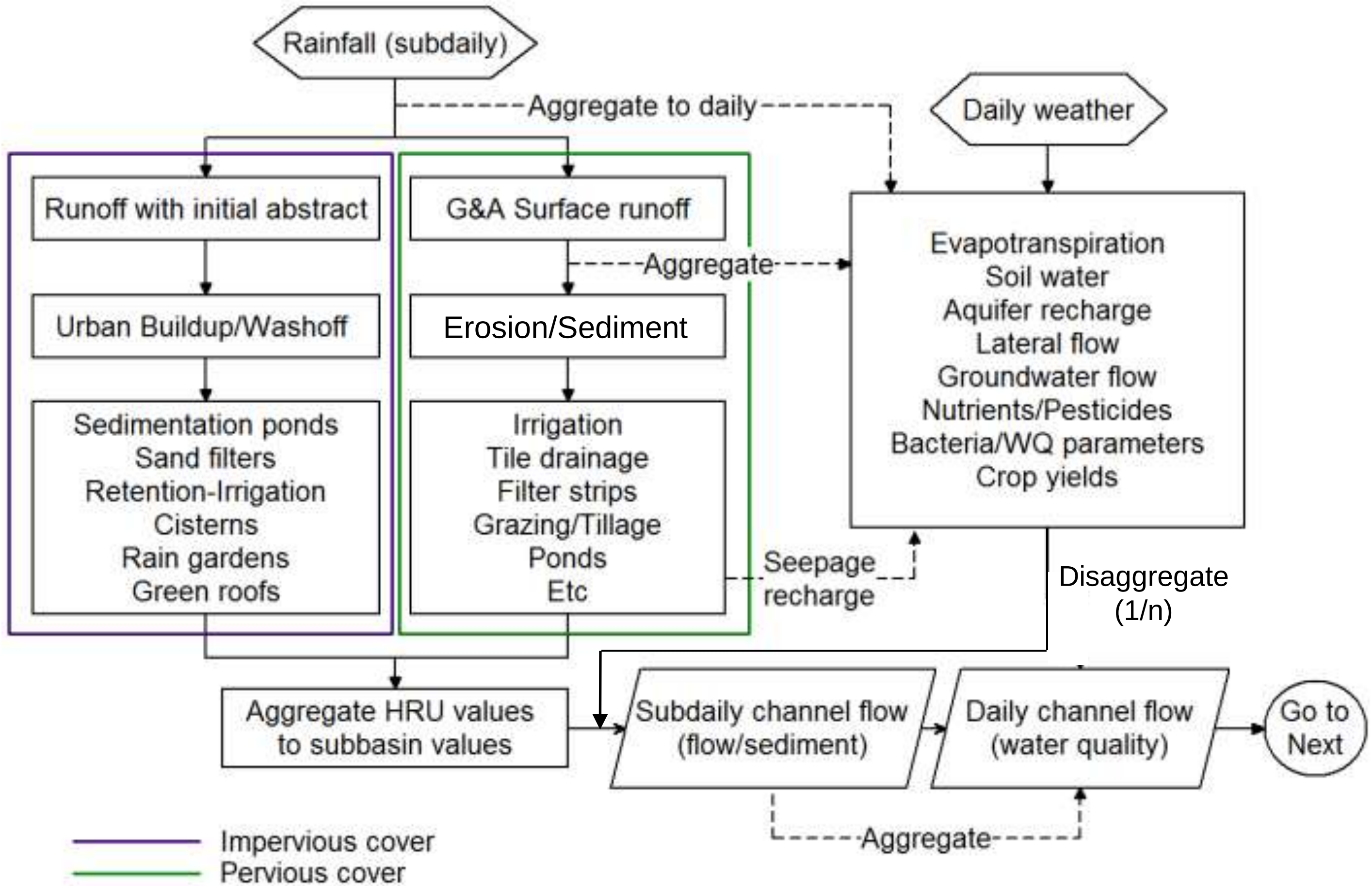
Project Goals

- ❑ Develop reliable sub-daily modules for continuous simulation
  - ❑ Surface runoff, stream flow
  - ❑ Erosion and sediment transport
- ❑ Develop algorithms for urban BMPs/LIDs
  - ❑ Improve SWAT urban processes
  - ❑ Sedimentation ponds, filtration ponds, retention-irrigation
  - ❑ Detention ponds, wet ponds
  - ❑ Cisterns, rain gardens, green roofs (through 2012)
  - ❑ Simulate flow and sediment through the BMPs

SWAT Urban Modelling



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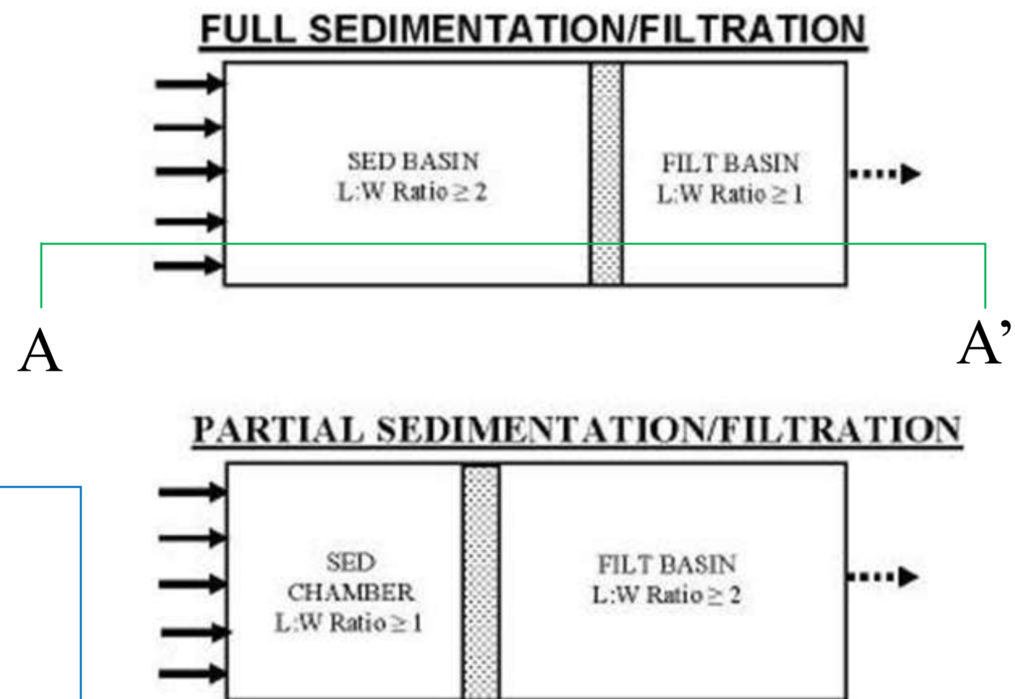
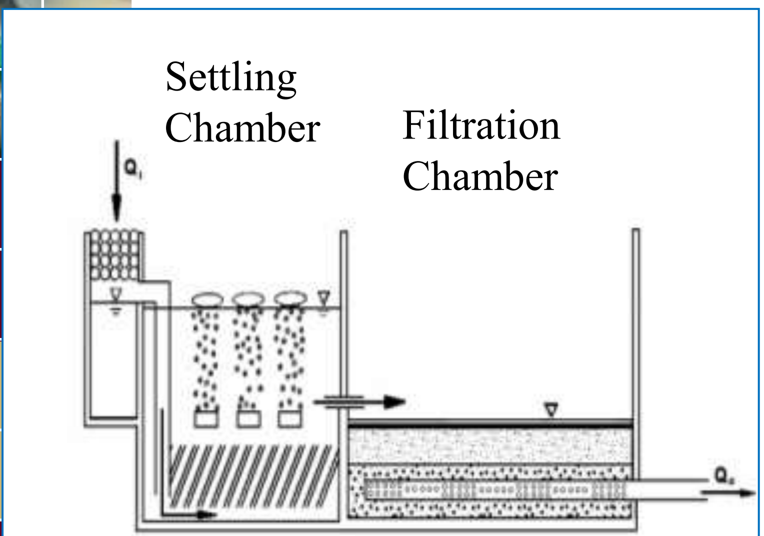
Sand Filters

- ❑ Purpose: remove pollutants from urban stormwater through settling and filtration
- ❑ Use the full or partial type system based on location, stormwater volume, and land availability (City of Austin, Texas, USA)
- ❑ Scope of the model usage:
  - ❑ Performance evaluation
  - ❑ Sandfilter design

Sand Filters





(A-A')

Filtration Processes

- Water Balance

$$\frac{\partial V_w}{\partial t} = Q_{in} + R - E - Q_{thru} - Q_{bypass}$$

- A modified Green & Ampt equation calculates unsaturated flow through sand filter
- Darcy's law for saturated flow
- Orifice flow from under-drain pipe assuming hydrostatic pressure
- Weir overflow: water and pollutants bypass the BMP

Filtration Processes

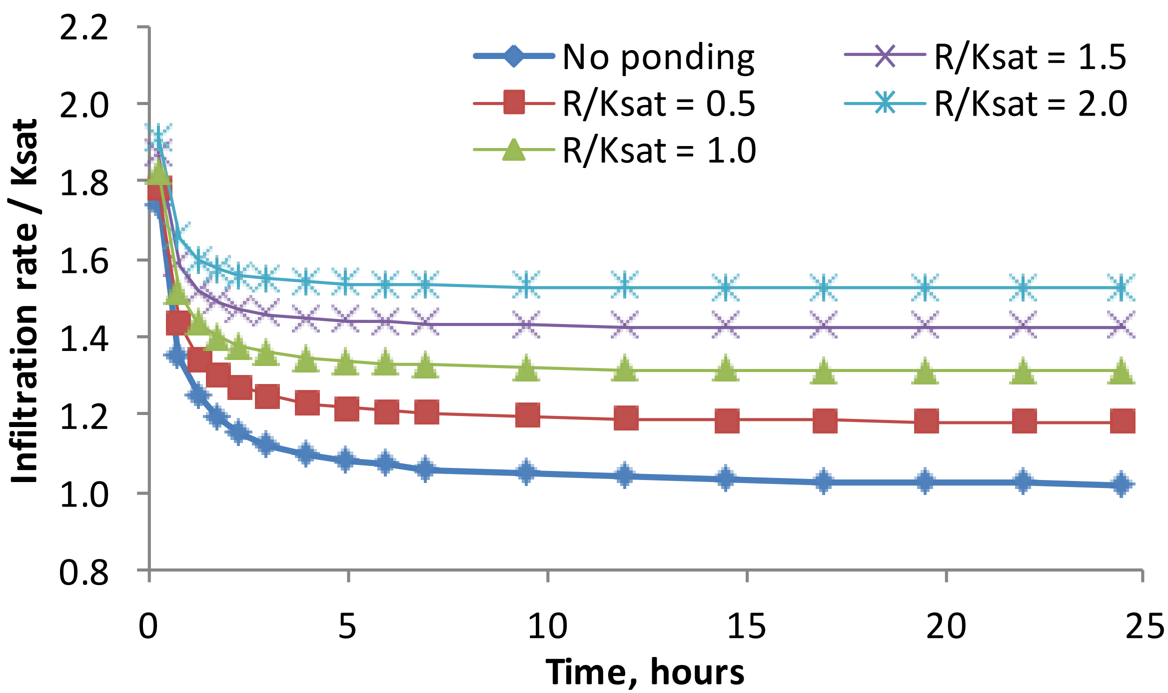
- ❑ Modified Green & Amt equation

$$\frac{dF}{dt} = K\left(1 + \frac{(h + \Psi)\cdot \Delta\theta}{F}\right)$$

- ❑ F= Cumulative infiltration, mm
- ❑ K= Hydraulic conductivity, mm/hr
- ❑ h= Ponding depth above filter surface, mm
- ❑ Ψ= Suction head at the wetting front, mm
- ❑ $\Delta\theta$= Change in water content of sand filter

Filtration Processes

- Consideration of surface ponding vs. no ponding



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Filtration Processes

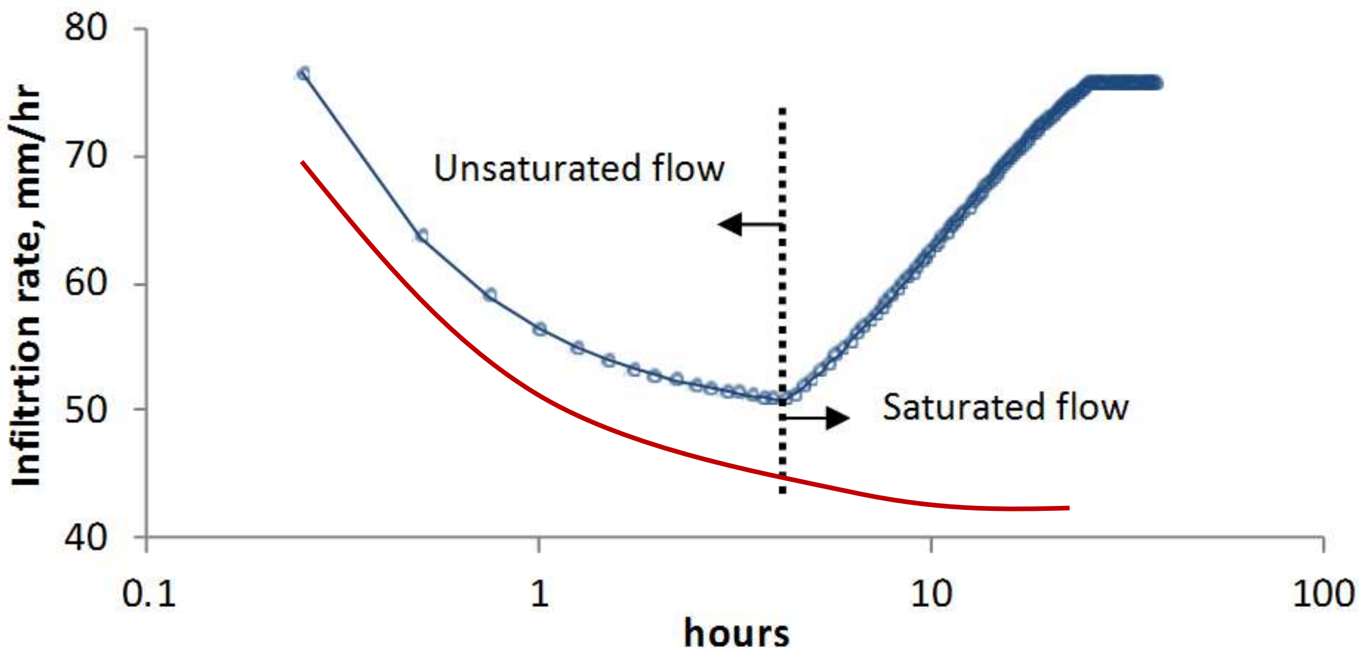
- Darcy's law

$$\frac{dF}{dt} = K\left(\frac{h+L}{L}\right)$$

  - F= Cumulative infiltration, mm
  - K= Hydraulic conductivity, mm/hr
  - h= Ponding depth above filter surface, mm
  - L= Total depth of filter media, mm

Filtration Processes

- Consideration of surface ponding vs. no ponding



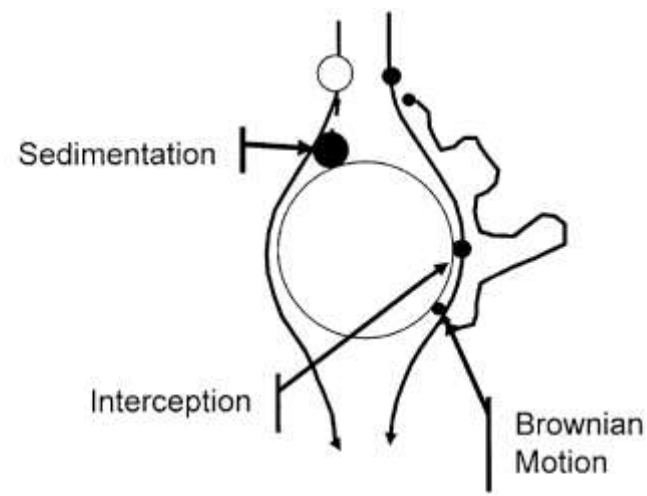
(Constant inflow: K=40mm/hr, R=80mm/hr)

Particles Removal

- Single Isolated Collector model by Yao et al. (1971)

$$E_r = 1 - \exp\left\{ -\frac{3}{2}\left(\frac{(1-\varepsilon)\alpha\eta}{d_c}\right)L \right\}$$

- E= Removal efficiency
- ε= Filter porosity
- α= Collision frequency
- η= Attachment efficiency
- d_c= Filter media diameter
- L = Filter thickness



(Particle capture mechanism)

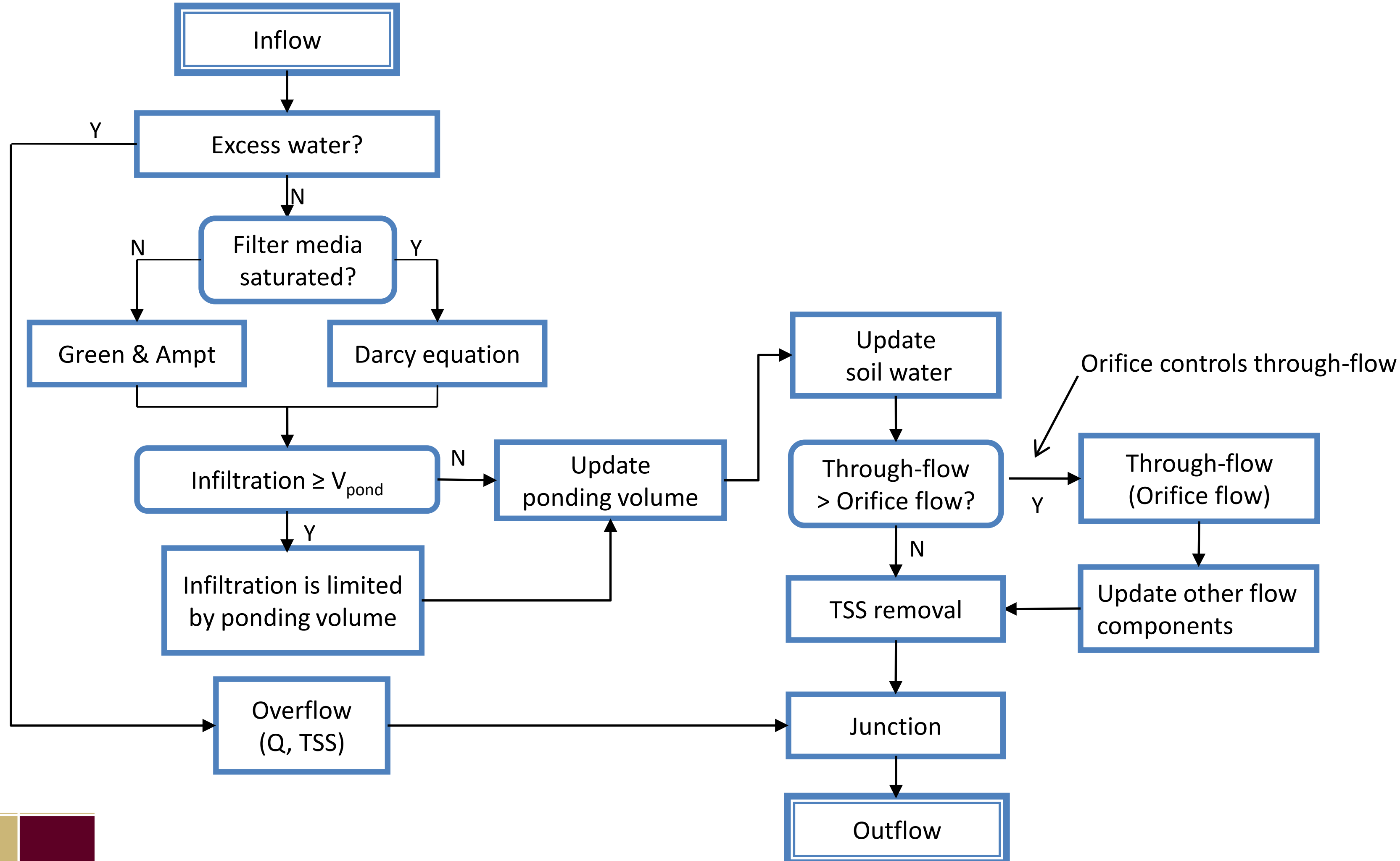
Clogging

- Depth filtration theory derived from Darcy's law (Mays and Hunt, 2005; Li and Davis, 2008)

$$\frac{K}{K_0} = \frac{1}{(1 + \gamma\sigma_v)^2}$$

  - K= Hydraulic conductivity of filter media
  - K_0= Initial hydraulic conductivity
  - γ= Empirical constant
  - σ_v= The volume of deposited particles per unit filter volume

SWAT Sandfilter Algorithm



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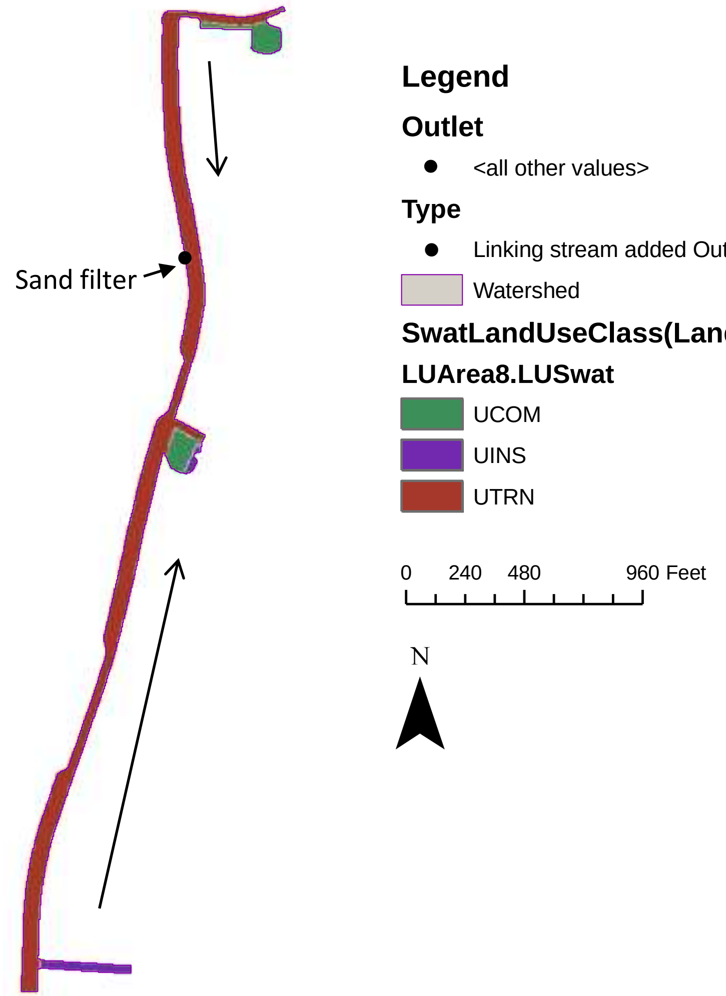
Case Study (Jollyville Sandfilter)

- A partial system in highly urbanized area in Austin, TX USA
- Drainage area is 2.8ha
- 100% urban, 90% impervious cover
  - Roads: 84%
  - Commercial: 11%
  - Offices: 5%
- High res. DEM (1ft x 1ft)
- Sandfilter is located at the watershed outlet



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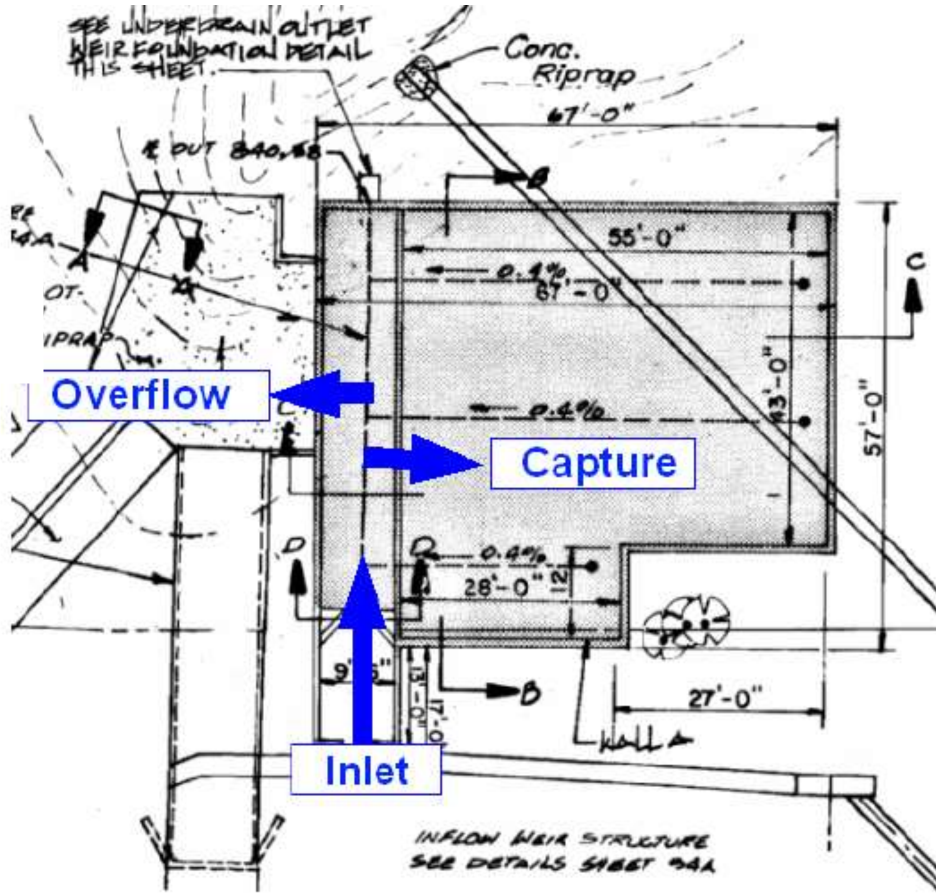
Jollyville Sandfilter

Discharge weir

Forebay/Filter area divider

Inlet weir



Calibration

- Flow/TSS calibrated/validated at the outlet of the filter
- Field data
  - 1 minute flow monitored using an auto-logger at the inlet/outlet
  - TSS data collected several times per storm event using an auto-sampler
- Calibration
  - Period: 4/25/1997-4/26/1997
  - Total rainfall: 81mm
  - Total inflow: 2,266m^3
  - Peak inflow: 0.26m^3/s
- Validation
  - Period: 5/09/1997
  - Total rainfall: 41mm
  - Total inflow: 1,128m^3
  - Peak inflow: 0.62m^3/s

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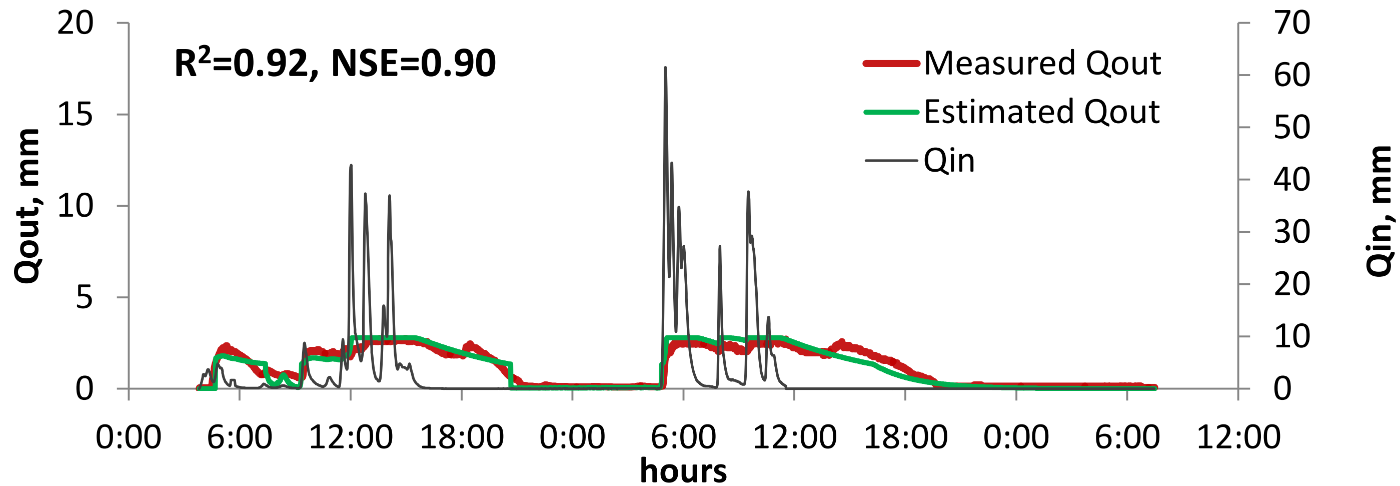
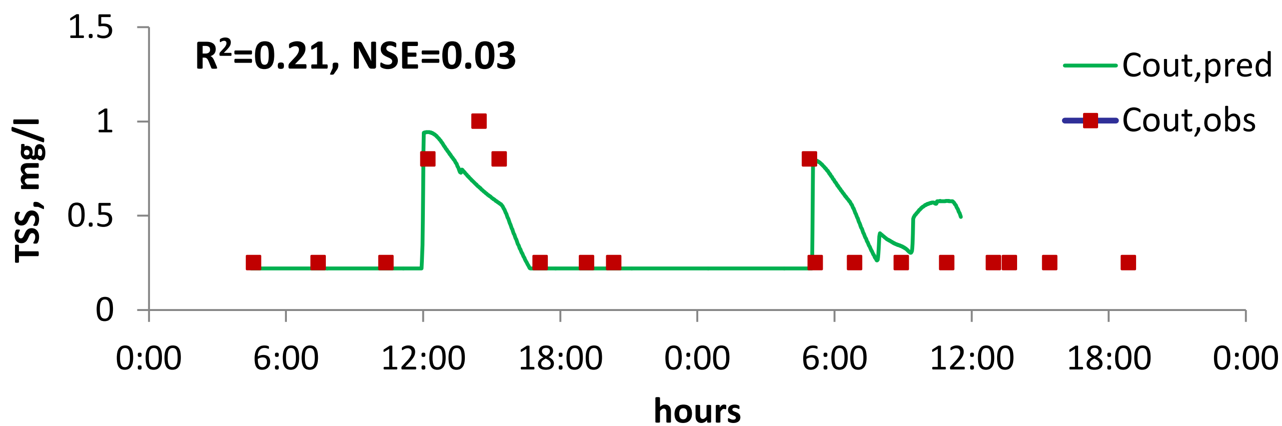
Calibration





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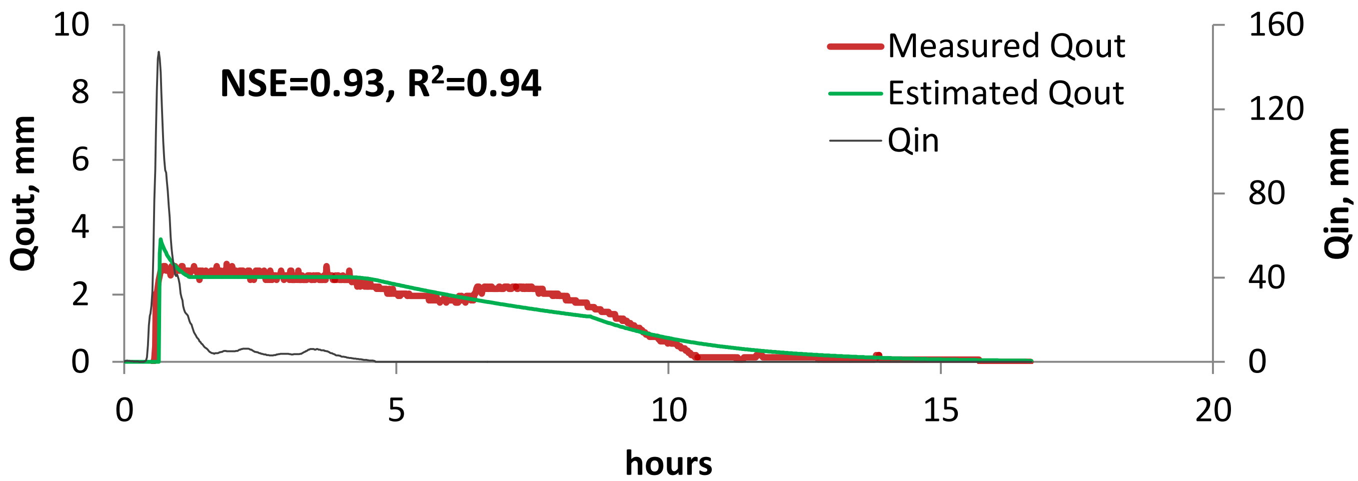
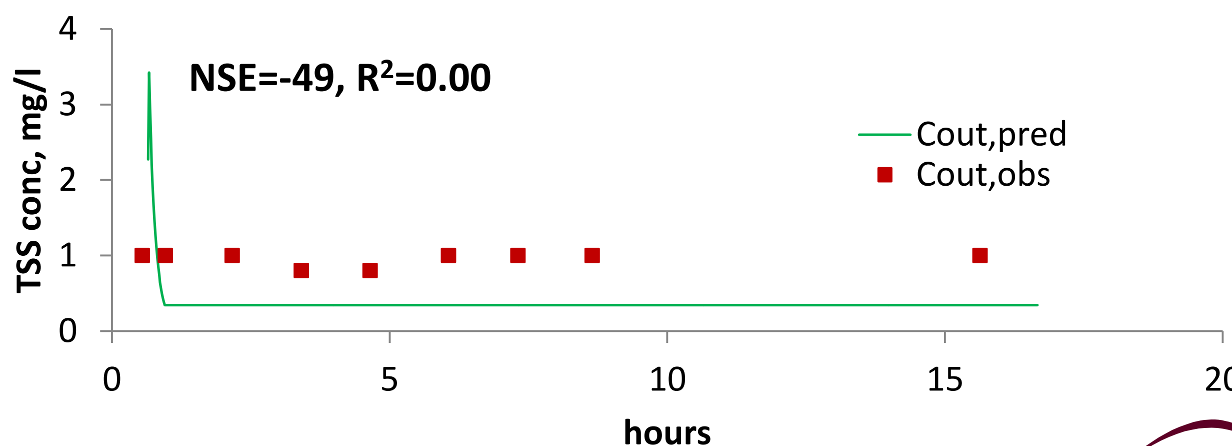
Validation



NSE=0.93, R^2=0.94
Measured Qout
Estimated Qout
Qin
Qout, mm
Qin, mm
hours
10
8
6
4
2
0
160
120
80
40
0
0
5
10
15
20



NSE=-49, R^2=0.00
Cout,pred
Cout,obs
TSS conc, mg/l
hours
4
3
2
1
0
0
5
10
15
20

Filter performance (Field data)

- Method: Use the event mean concentration (EMC) to calculate removal efficiency

$$Removal\ Efficiency = \left(1 - \frac{Outlet\ TSS}{Inlet\ TSS}\right) \times 100$$

- Calibration period:
  - TSS_{in}= 116.5 mg/l, TSS_{out}=0.37 mg/l
  - Removal efficiency=**99.7%**

- Validation period:
  - TSS_{in}= 153.3 mg/l, TSS_{out}=1.07 mg/l
  - Removal efficiency=**99.3%**

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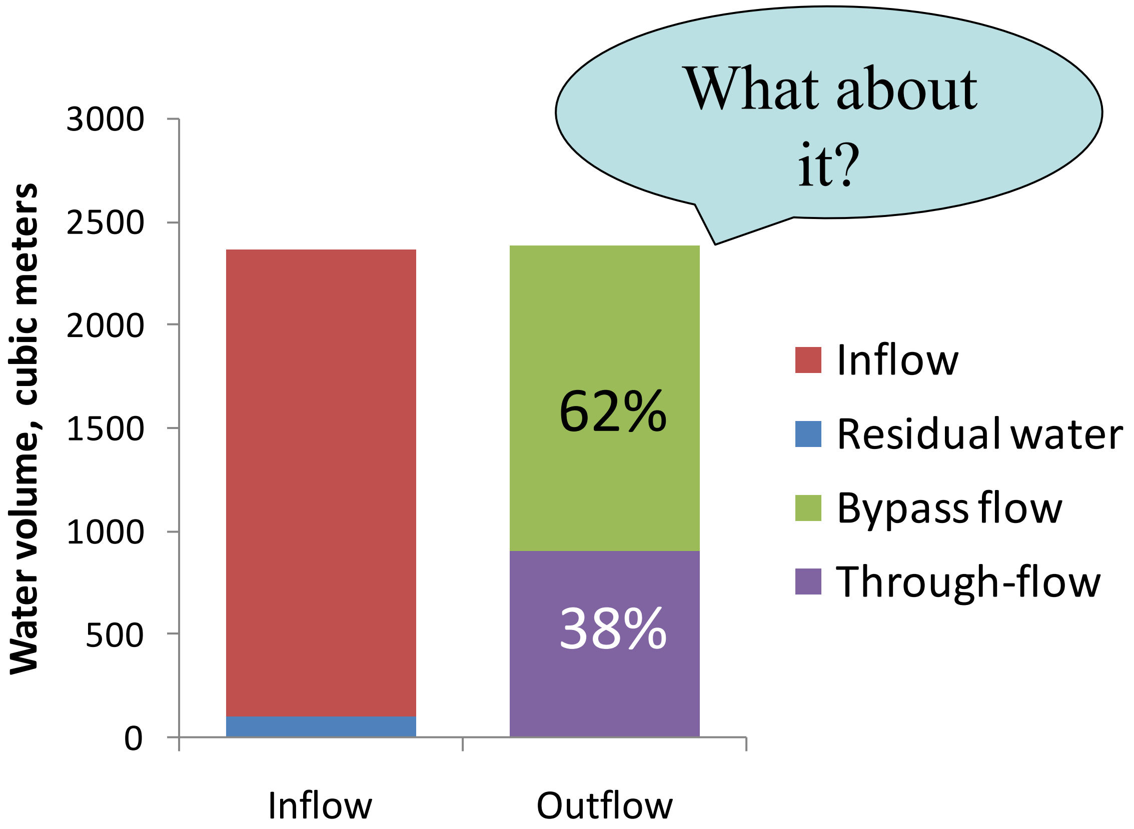
Filter performance (Actual?)



Water Balance – calibration period

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Filter performance

- Method: Include through-flow and bypass-flow to calculate the event mean concentration (EMC)

- Calibration period
- TSS_{in}= 247.5kg, TSS_{out}=0.33kg, TSS_{bypass}=137.1kg, $TSS_{deposit}$=110.1kg
- Removal efficiency=45%
- TSS deposit (assuming TSS density=1.6g/cm^3, porosity=0.4): 0.4mm

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Summary

- The new SWAT-Sandfilter algorithm simulates urban stormwater and TSS through sandfilters in urban watersheds
- The model can be used flexibly for either performance evaluations or design purposes
- A modified Green&Ampt equation was proposed for calculating unsaturated filer flow. Saturated flow is simulated using Darcy’s law
- The model successfully reproduced stormwater flows through filter media at the Jollyville site in terms of timing, peak rate, and total flow volume
- The physically-based model for TSS removal did not perform very well as indicated in the case study
- Sediment removal efficiency was above 99% when estimated with event mean values, but significantly decreased (<50%) when bypass amount was included in the calculation

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Future work

- The model will be tested for long term periods at different locations, based on the availability of data
- TSS algorithm will be improved by adding (1) a regression model and (2) effluent probability method
- TSS clogging will be tested with a long-term simulation

Questions?

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