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Development of Subdaily Erosion and Sediment Transport Models in SWAT

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Project Overview:

Development of subdaily urban SWAT

Sub-hourly flow

Sub-hourly erosion and sediment transport

Stormwater BMPs

Urban SWAT

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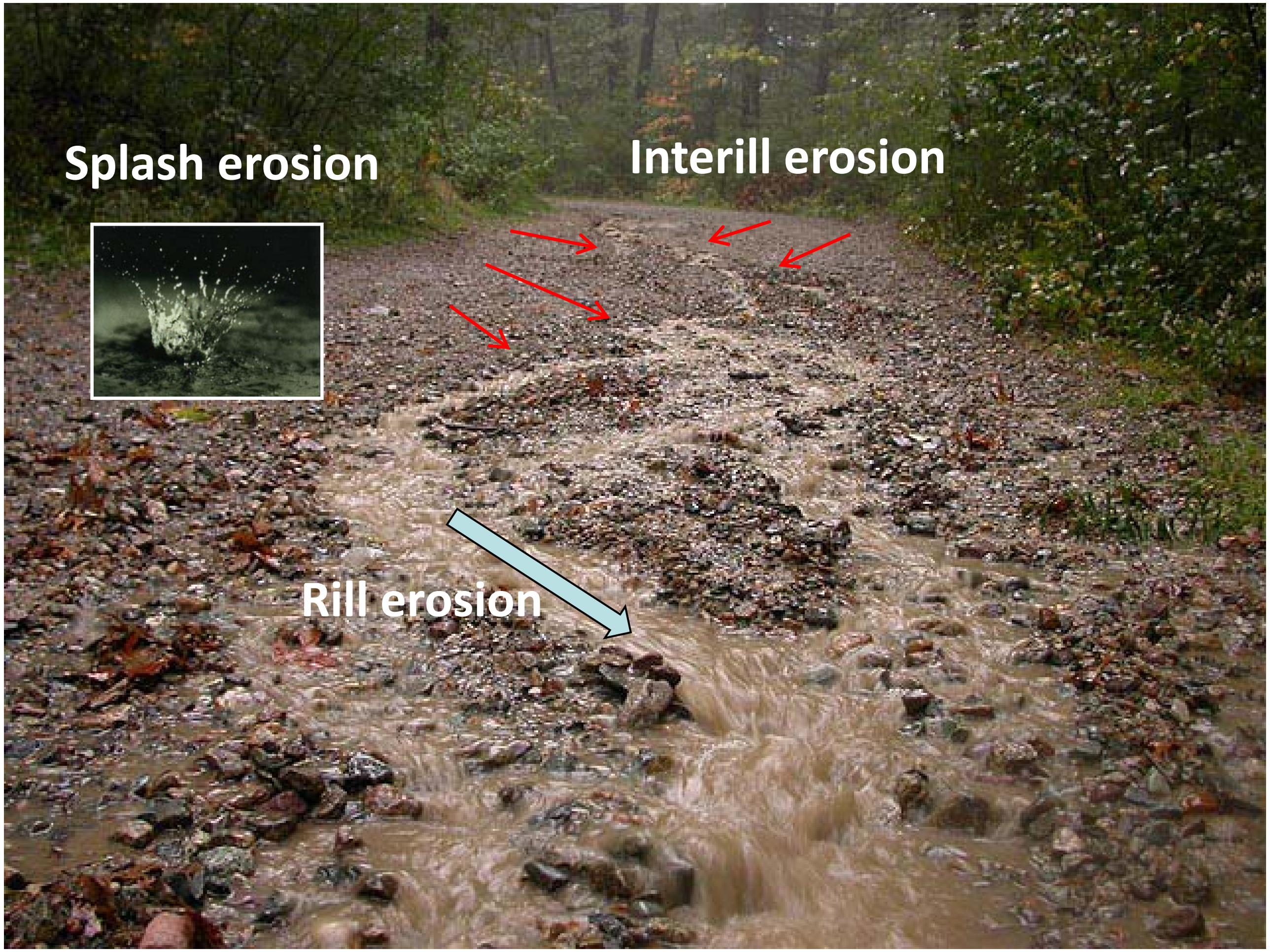
Motivation

- The Modified Universal Soil Loss Equation (MUSLE) in SWAT 2005/2009 is intended for daily upland erosion and sediment transport modeling in overland flow
- The MUSLE is an empirical model developed for predicting long-term average soil loss and is NOT adequate for subdaily continuous simulations
- Subdaily erosion and sediment transport is not available in SWAT 2005/2009
- Modeling subdaily erosion processes is important to better understand:
  - the impact of urban flash storms on the creek/channel degradation
  - urban nonpoint sources
  - performance of urban BMPs/LIDs

Upland erosion processes



Splash erosion

- The kinetic energy (KE) model (Brandt, 1990)
  - Soil detachment is a function of kinetic energy delivered by raindrops
  - Adapted from the EUROSEM model
- The KE is estimated based on canopy height and rainfall intensity
- Soil property is represented by soil detachability coefficient (k)

$$KE_{leaf} = 15.8H_p^{0.5} - 5.87$$

$$KE_{direct} = 11.87 + 8.73\log_{10}R_i$$

Leaf drainage

Direct through-fall

$$D_R = k \cdot KE \cdot e^{-\varphi h}$$

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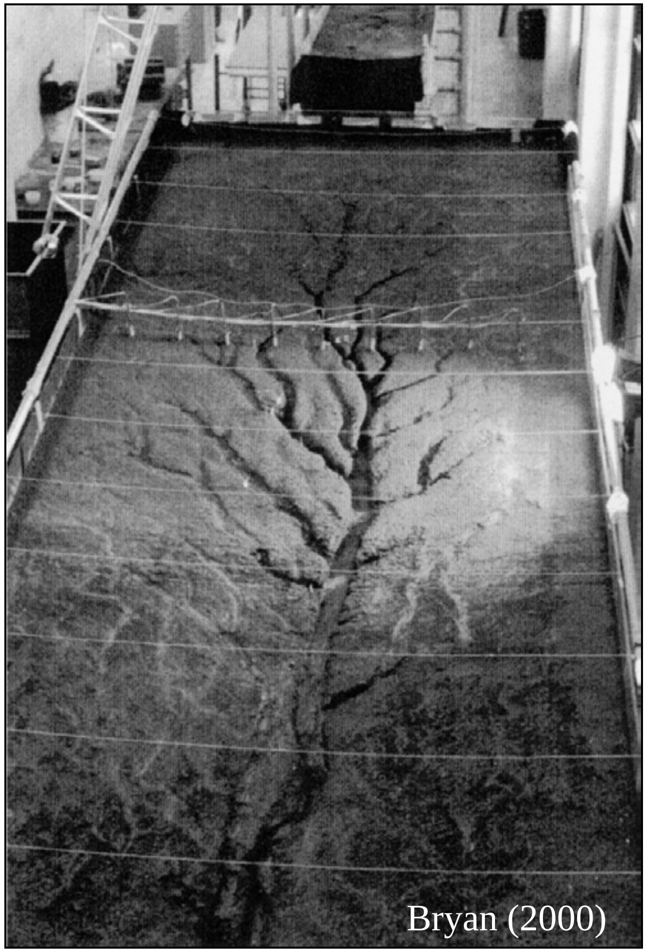
Overland flow erosion

- Overland flow erosion is related to average bed shear stress
  - Physically based model
  - Adapted from a modified ANSWERS model
  - An erodibility factor (K_f) approximated from USLE K factor reflects rill and interill erosion susceptibility
  - A crop factor (C_f) represents the combined effects of canopy, mulch, and other incorporates

$$D_F = 11.02 \alpha K_f C_f \tau^{\beta}$$

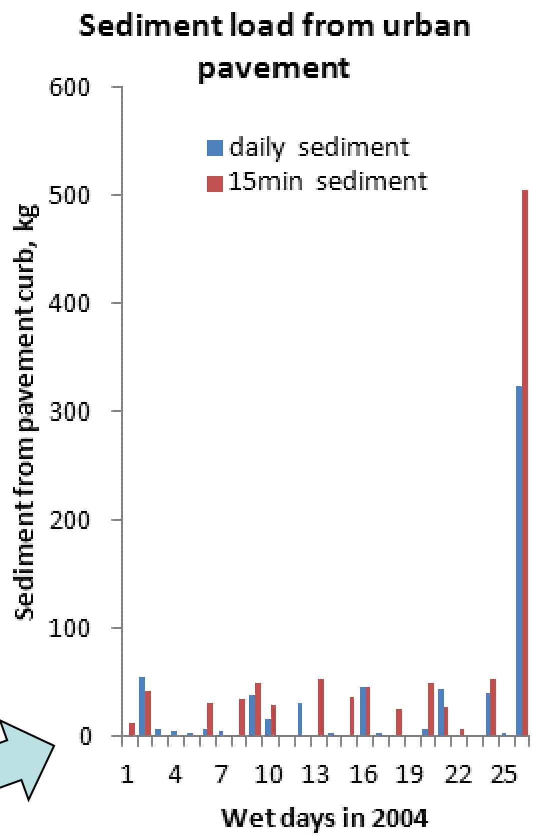
$$\tau = \gamma h S_f$$


Bryan (2000)

TSS from urban pavement

- Build-up/Wash-off on urban impervious cover is simulated at any time interval
- Street cleaning practices can be set in *.mgt files and simulated with the build-up/wash-off commands

Build-up is more accurately modeled with 15min rainfall data because dry period is evaluated every 15 minutes
Wash-off process is also better simulated with 15min interval because daily simulation relies on estimated daily peak flow for computing the wash-off amount



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Instream sediment routing

- The Bagnold’s stream power function (default in SWAT) tends to work better on large river basins
- Brownlie model (1982)
  - Developed based on dimensional analysis and alluvial channel observations
  - Critical grain Froude number for entrainment of sediment
- Yang model (1996)
  - Different models for sand (d_{50}<2mm) and gravel bed (2mm<d_{50}<10mm)

Summary of applicability

Richardson et al. (2001)

- Based on bed material

Model	**Gravel***	**Sand****	**Silt*****
Bagnold		O	O
Brownlie	O	O	Δ
Yang	O	O	

*gravel: 2-64mm, **sand: 0.062-2mm, ***silt: 0.004-0.062mm

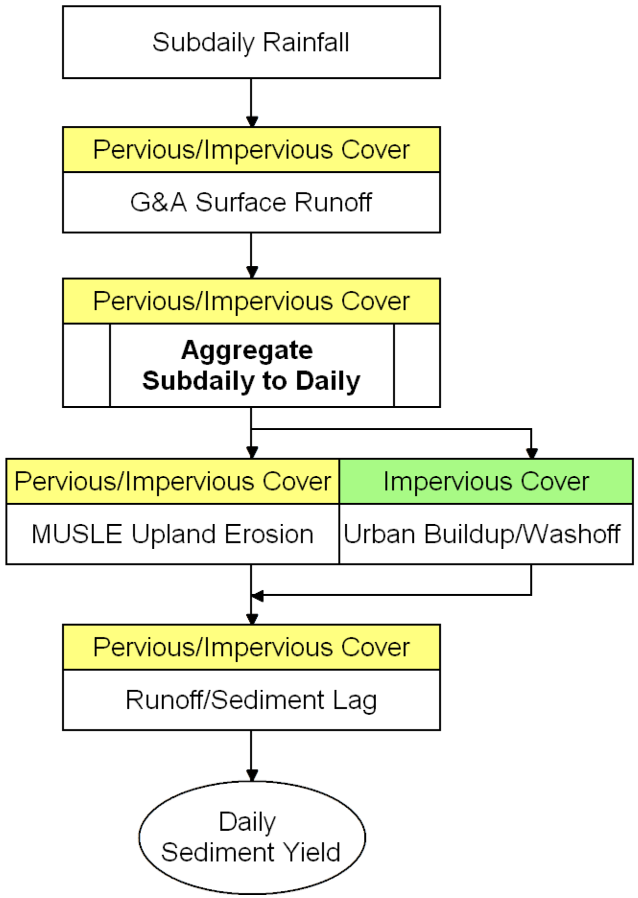
- Based on the scale of river

Model	**Large***	**Intermediate****	**Small*****
Bagnold	O		
Brownlie		O	O
Yang			O

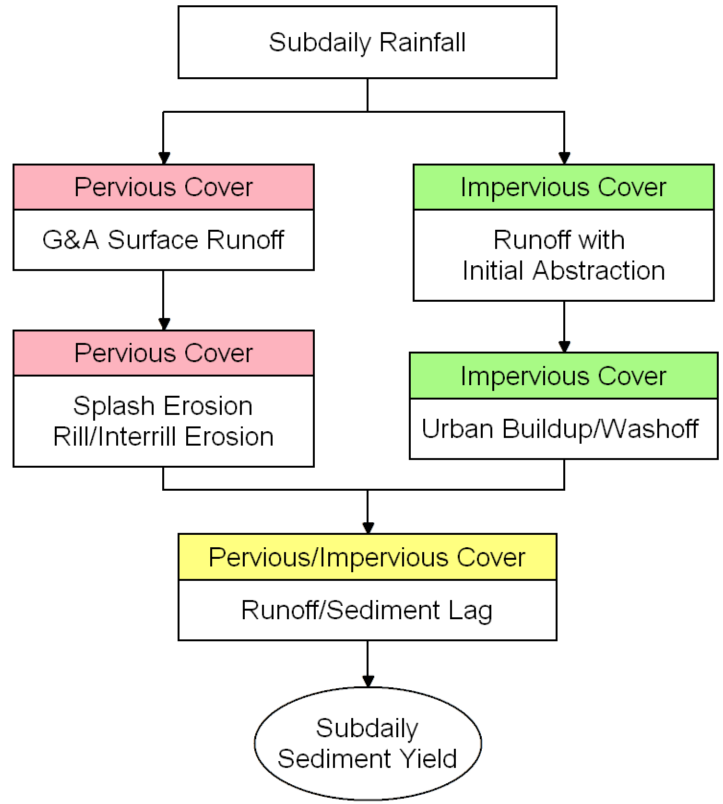
*width: >50m, depth: >3m **width: 10-50m, depth: 1-3m
***width: ≤10m, depth: ≤1m

SWAT integration

SWAT 2005



Urban SWAT



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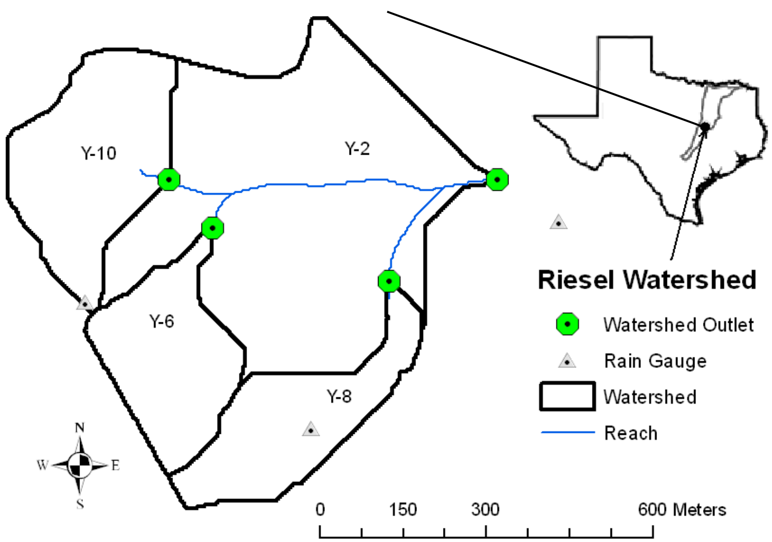
Case study

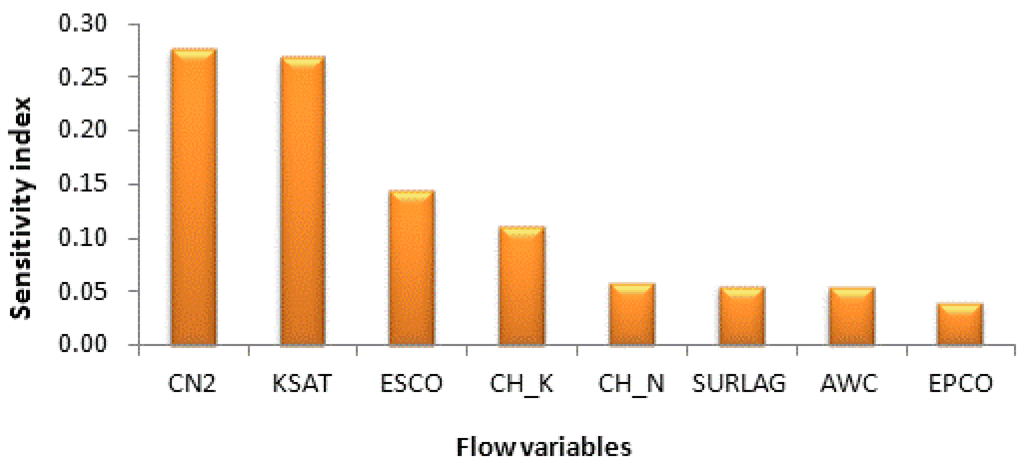


The Riesel Y-2 watershed

- Area: 46.2 ha
- Land Use: Mixture of cropping and pasture systems
- Soil: Houston Black
  - Strong potential for shrinking and swelling
  - Very low hydraulic conductivity
- 15minute rainfall and daily temperature (max/min) collected at 3 weather stations

Sensitivity analysis: Flow

- Latin Hypercube-OAT procedures applied to the stream flow at the watershed outlet
- Variables related to infiltration, ET, and channel flow were relatively more influential than soil water variables, probably due to the prevalence of the Houston black soils



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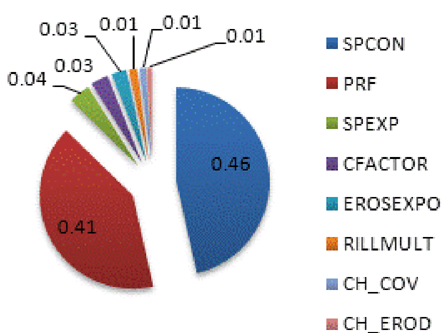
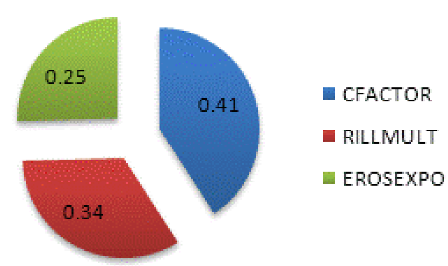
Sensitivity analysis: Sediment

- Latin Hypercube-OAT procedures applied to the sediment yields at the watershed outlet
- Instream sediment variables are significant in the Bagnold model and the Yang model, while overland flow erosion variables are more influential in the Brownlie model

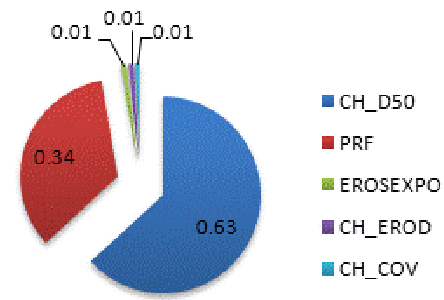
Bagnold Model



Brownlie Model



Yang Model



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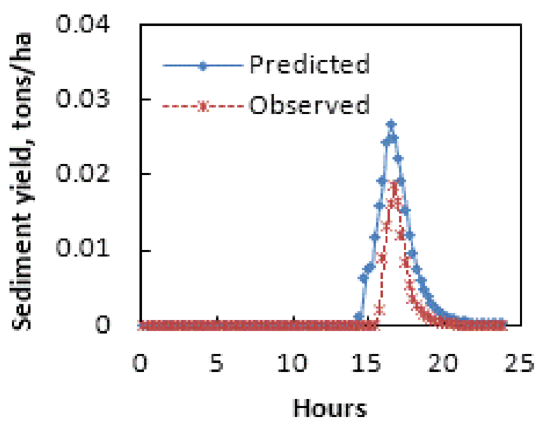
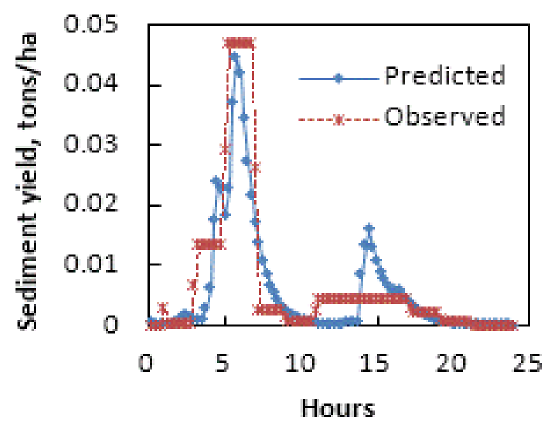
Calibration (Year 2001)

Year 2001	Type	Julian date	Predicted vs. Observed		Statistical measures		
			Pred	Obs	NSE[1]	R2	PBIAS
	Annual	-	-	-	**0.64**	**0.66**	**25%**
Flow	Event	67	0.186[2]	0.176	0.78	0.78	-6%
	Event	350	0.387	0.5	0.66	0.82	23%
	Annual	-	-	-	**0.36**	**0.36**	**10%**
Sediment	Event	67	0.258[3]	0.114	0.08	0.85	-127%
	Event	350	0.551	0.638	0.72	0.74	14%

[1]Nash and Sutcliffe Efficiency [2]15min average flow (m3/s) [3]Total sediment yield (tons/ha)



(Day 67)



(Day 350)

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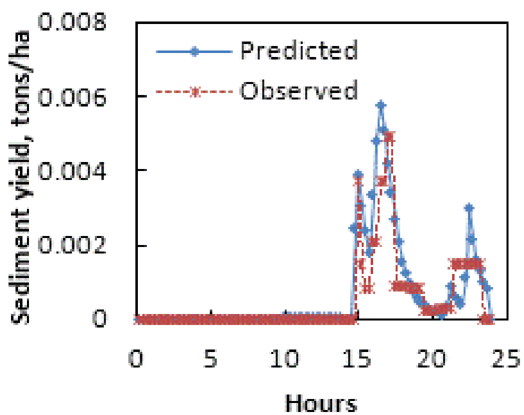
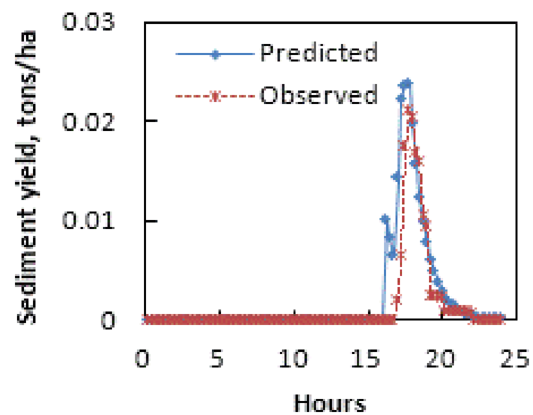
Validation (Year 2002)

Year 2002	Type	Julian date	Predicted vs. Observed		Statistical measures		
			Pred	Obs	NSE[1]	R2	PBIAS
Flow	**Annual**	-	-	-	**0.57**	**0.68**	**-9%**
	Event	294	0.078	0.11	0.62	0.66	30%
	Event	364	0.117	0.102	0.84	0.88	-19%
Sediment	**Annual**	-	-	-	**0.16**	**0.22**	**-95%**
	Event	294	0.066	0.049	0.58	0.75	-34%
	Event	364	14.574	12.704	0.6	0.88	-19%

[1]Nash and Sutcliffe Efficiency [2]15min average flow (m3/s) [3]Total sediment yield (tons/ha)



(Day 294 in October)



(Day 364 in December)

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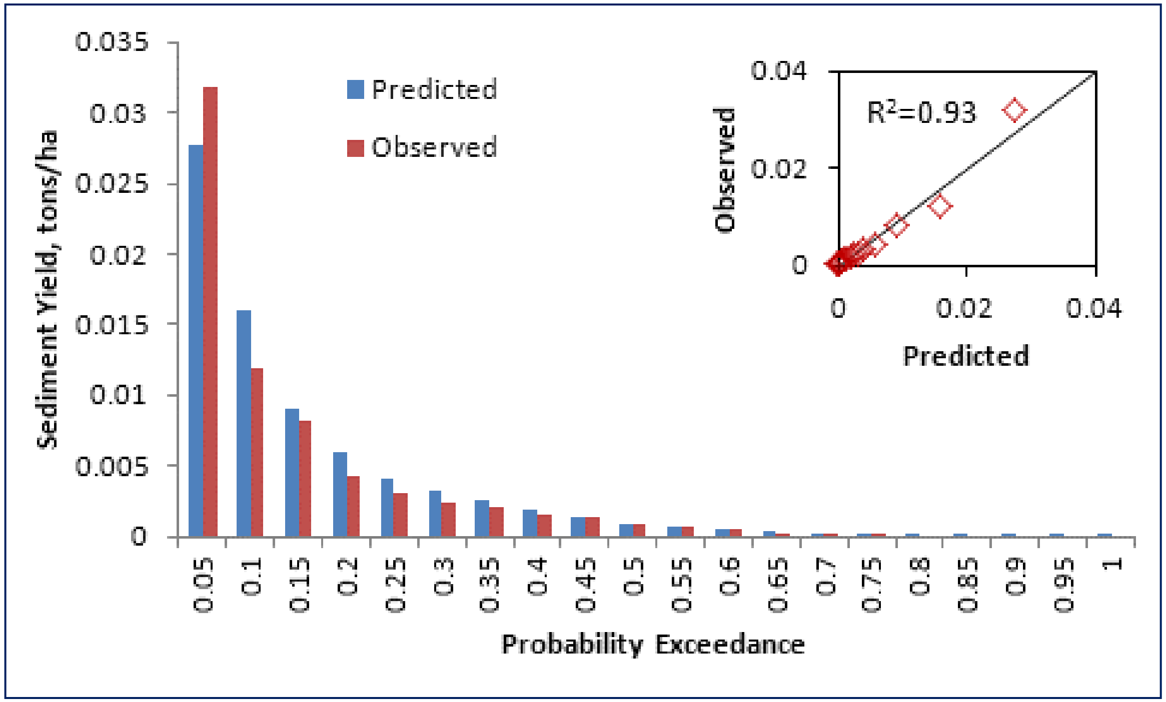
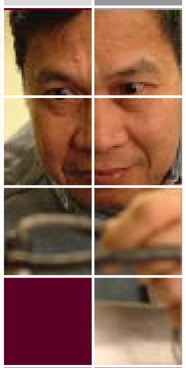
Exceedance curve



- Sediment of the upper 5% high flow is underestimated
- As a result, sediment load is over-compensated for intermediate size storms
- Overall, sediment yield is well predicted

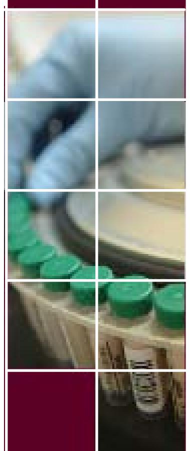
Summary and future tasks



- Physically based models for modeling splash erosion, overland flow erosion, and instream sediment routing at any subdaily time interval were developed in urban SWAT
- Sensitivity analysis shows that different sets of variables need to be calibrated for different sediment models
- Long term sediment prediction with 15min interval shows a marginally good result. More testing at different scales needs to be conducted for better understanding of the model performance
- Build-up/wash-off routines will be tested
- Modules for urban BMP structures will be developed
- Performance of urban BMPs in Austin, TX will be evaluated
- The urban SWAT will be used as a decision supporting tool for designing urban stormwater management plans by the City of Austin, the City of McKinney, and the City of Celina (possible) in the central Texas area

Questions?

Review of subdaily flow model



- SWAT source code was modified for sub-hourly flow simulation
  - The Green & Ampt infiltration with Mein and Larson method for runoff
  - A gamma function unit hydrograph method
  - A new runoff lag equation for subdaily intervals
  - Channel flow and impoundments (ponds, reservoirs)
  - Urban runoff from impervious cover is separately estimated and routed
- Soil water, base flow and ET are simulated daily and evenly distributed for each time step through the day