Reducing equifinality by using spatial wetness information and reducing complexity in the SWAT-Hillslope model

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Outline

- Brief description of the SWAT-Hillslope model
- Comparisons of SWAT-Hillslope and SWAT2012
- Parameter uncertainty in SWAT-Hillslope
- Equifinality vs. model complexity
- Conclusions and recommendations

SWAT 2012 and SWAT-Hillslope model

Original SWAT

- Runoff determined by curve number
- HRU in SWAT is a combination of land use, soil, and slope
- All HRU connected with stream

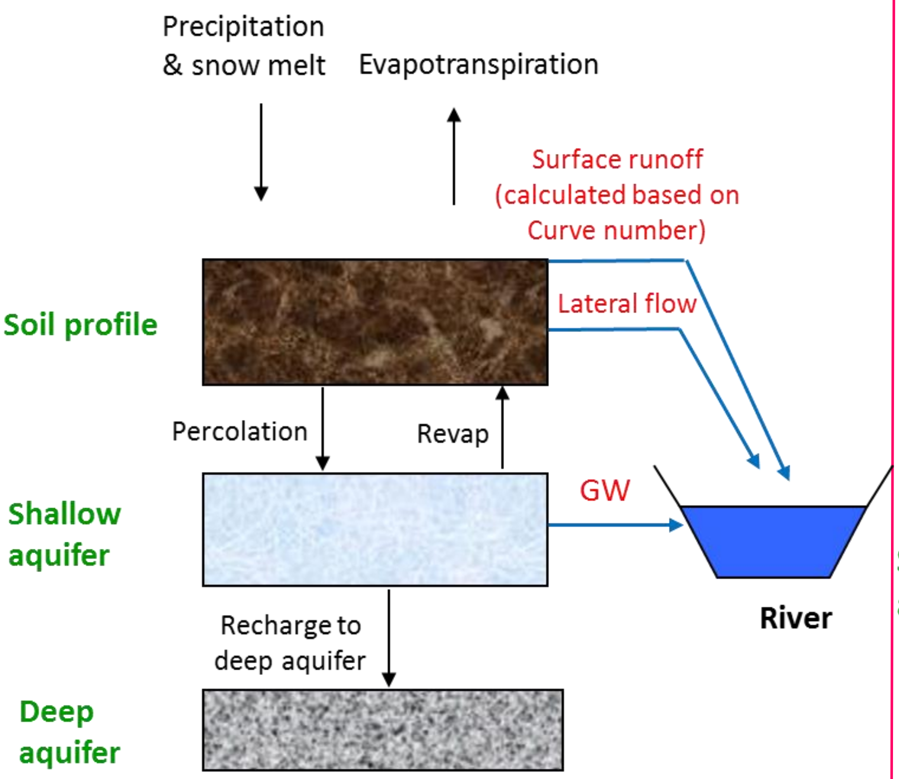
SWAT_Hillslope

- Runoff when soil is saturated or low infiltration
- HRU in SWAT-Hillslope is a combination of land use, soil, slope and wetness class

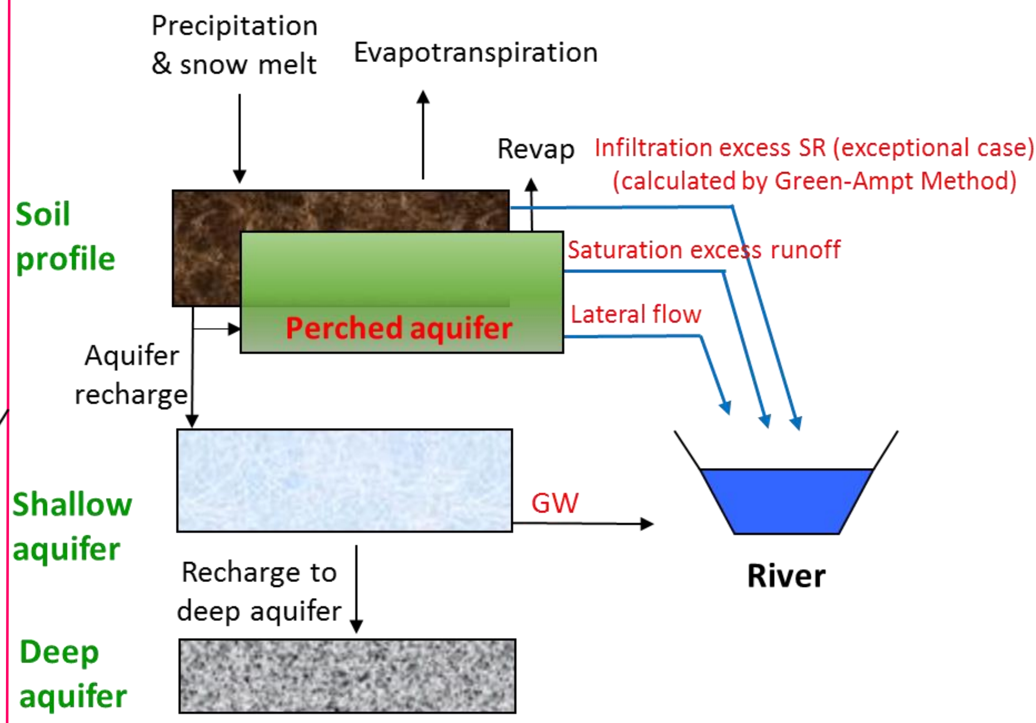
  Wetness class consists of groups of similar topographic indices
- Perched water table source of interflow and connects wetness classes

Hydrological processes

Original SWAT

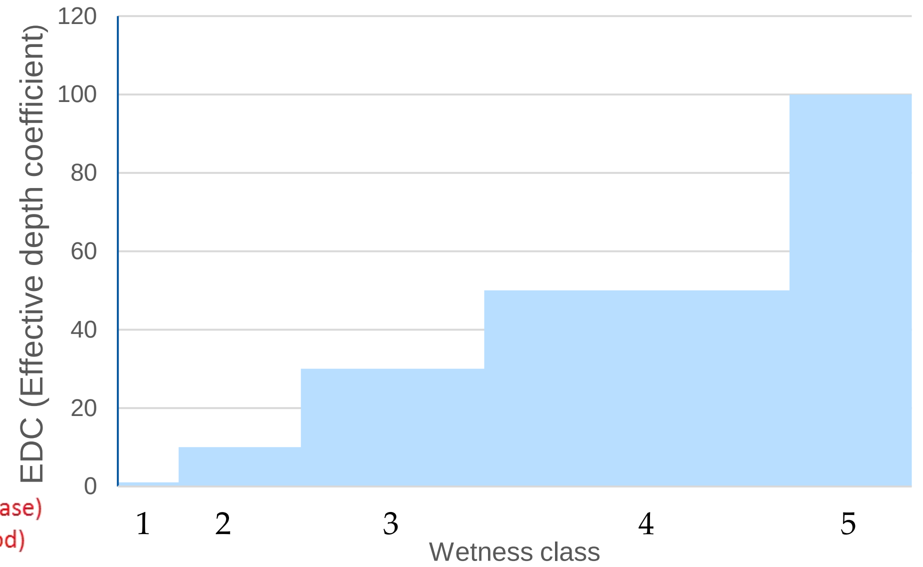


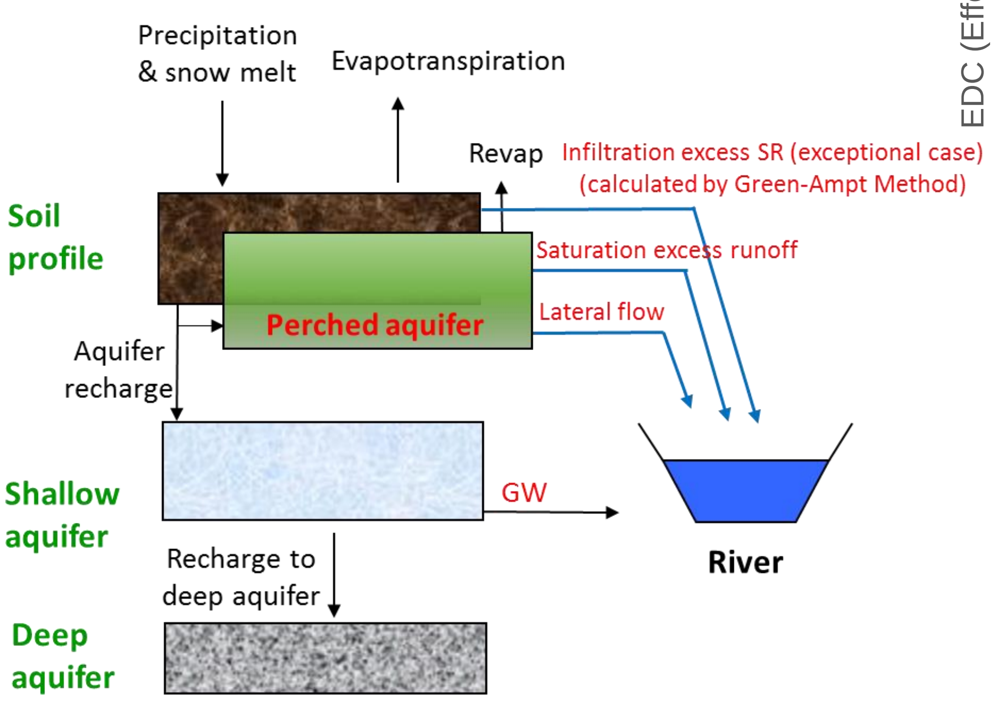
SWAT_Hillslope

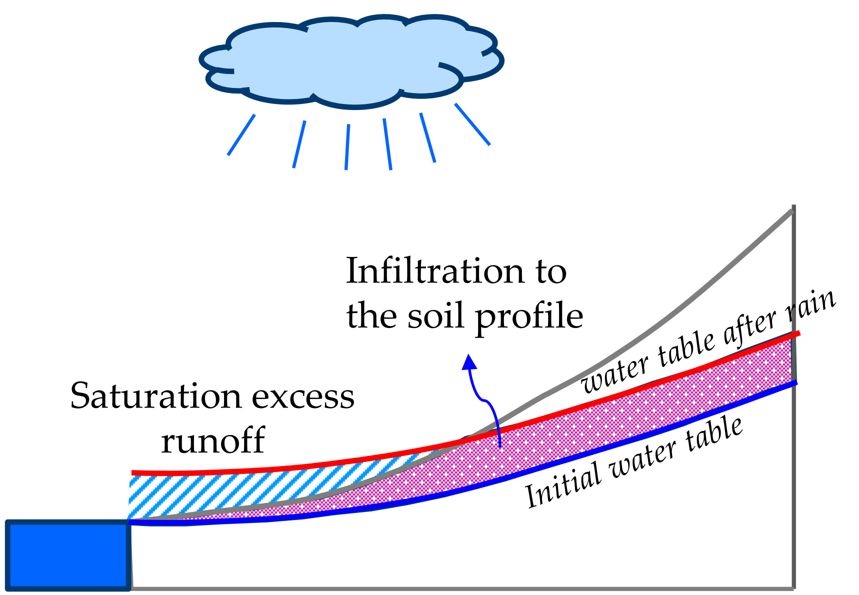


Description of the SWAT-Hillslope model

Assign a value of EDC (effective depth coefficient) to each wetness class. This value represents the water storage capacity in each wetness class







Case study: Town Brook watershed

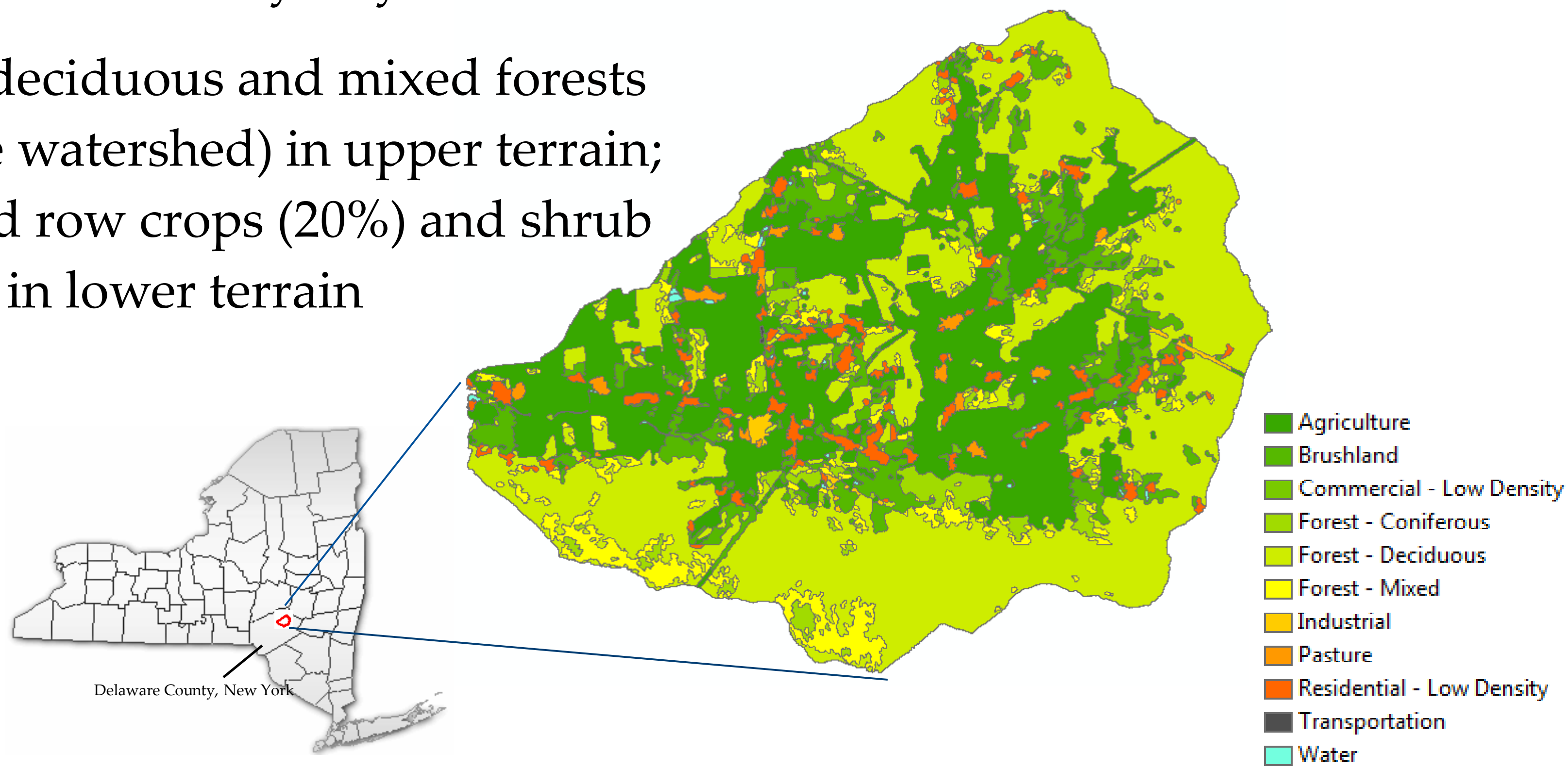
Area: 37 km^2, in the Catskill Mountains of New York State.

Climate: humid with average temperature of 8^{o}C and average annual precipitation of 1123mm.

Elevation: 493 to 989 m.

Soil: silty loam and silty clay loam

Land use: deciduous and mixed forests (60% of the watershed) in upper terrain; pasture and row crops (20%) and shrub land (18%) in lower terrain



SWAT-Hillslope set up for Town Brook watershed

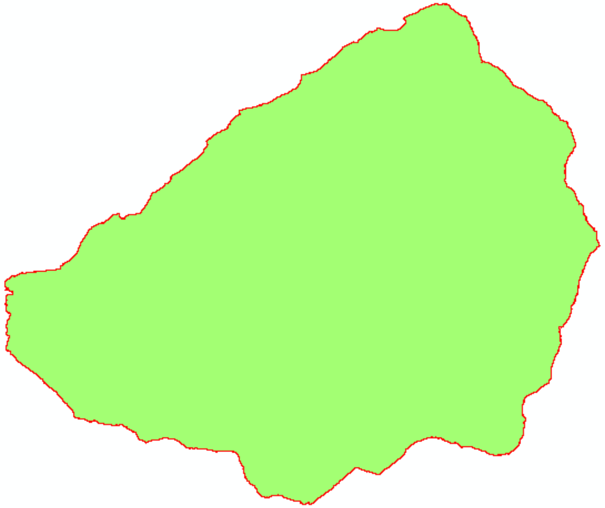
simple → complex

#HRU's

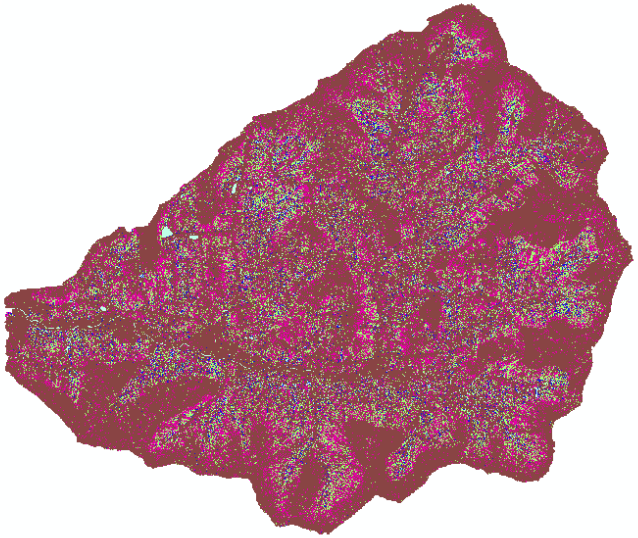
SWAT-Hillslope setups	Wetness class	Soil type	Land use	Number of HRUs
TB1	5	1 average of dominant soil types	1 AGRL	**5**
TB2	5	5 1 soil type for each wetness class	1 AGRL	**5**
TB3	5	5 1 soil type for each wetness class	3 Agriculture, Forest, Residence	**15**
TB4	5	17 detailed soil types	3 Agriculture, Forest, Residence	**28** threshold: soil 1%, land use: 1%
TB5	5	17 detailed soil types	11 detailed land use	**62** threshold: soil 1%, land use: 1%

Prepare soil maps

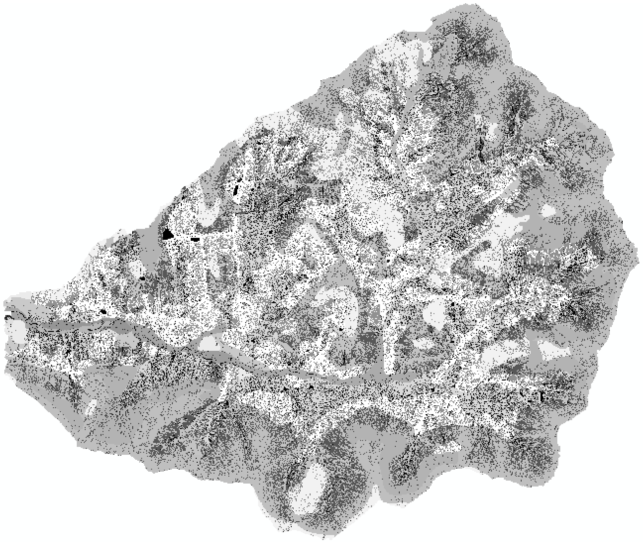
- Source: SSURGO
- Several soil maps were prepared from simple to complex maps



1 soil type for the whole watershed



1 soil type for each wetness class
→ 5 soil types



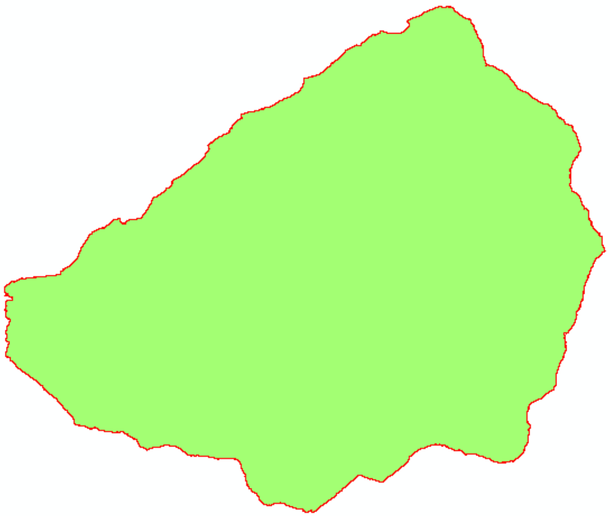
SSURGO detailed soil types
→ 17 soil types

simple → **complex**

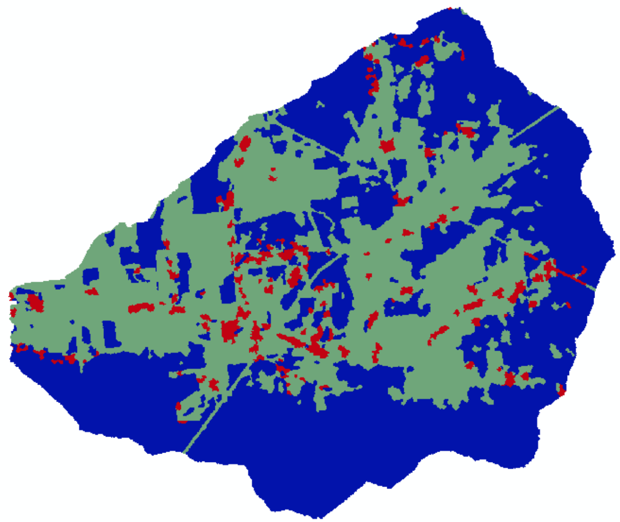
SWAT-Hillslope set up for Town Brook watershed

Prepare land use map

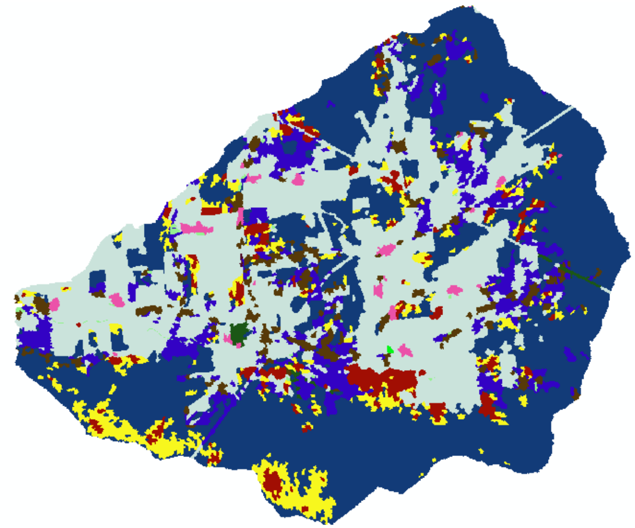
- Source: NYCDEP
- Several land use maps were prepared from simple to complex maps



1 land use for the whole watershed (AGRL)



3 dominant land uses: agriculture, forest and residence areas



All land uses included

simple → **complex**

SWAT-Hillslope set up for Town Brook watershed

Model calibration

Step 1: Calibrate snow melt parameters

Step 2: Calibrate flow parameters

Step 3: Adjust storage capacity of wetness classes

Method of calibration:

- Generate 10,000 random parameter sets by Monte Carlo sampling method
- Run 10,000 simulations with SWAT-Hillslope
- Choose the good performance parameter sets (NSE ≥ threshold)

Results and discussions

Performance of SWAT-Hillslope on flow simulation

Model performance guidelines (Moriasi et al., 2007)

Performance rating	*NSE*	*PBIAS* (%)	*RSR*
Very good	$0.75 < NSE \leq 1.00$	$PBIAS < \pm 10$	$0.0 \leq RSR \leq 0.5$
Good	$0.65 < NSE \leq 0.75$	$\pm 10 \leq PBIAS < \pm 15$	$0.5 < RSR \leq 0.6$
Satisfactory	$0.50 < NSE \leq 0.65$	$\pm 15 \leq PBIAS < \pm 25$	$0.6 < RSR \leq 0.7$
Unsatisfactory	$NSE \leq 0.50$	$PBIAS \geq \pm 25$	$RSR > 0.7$

SWAT-Hillslope performance

Warming up

1998 - 2000

Calibration

2001 - 2007

Validation

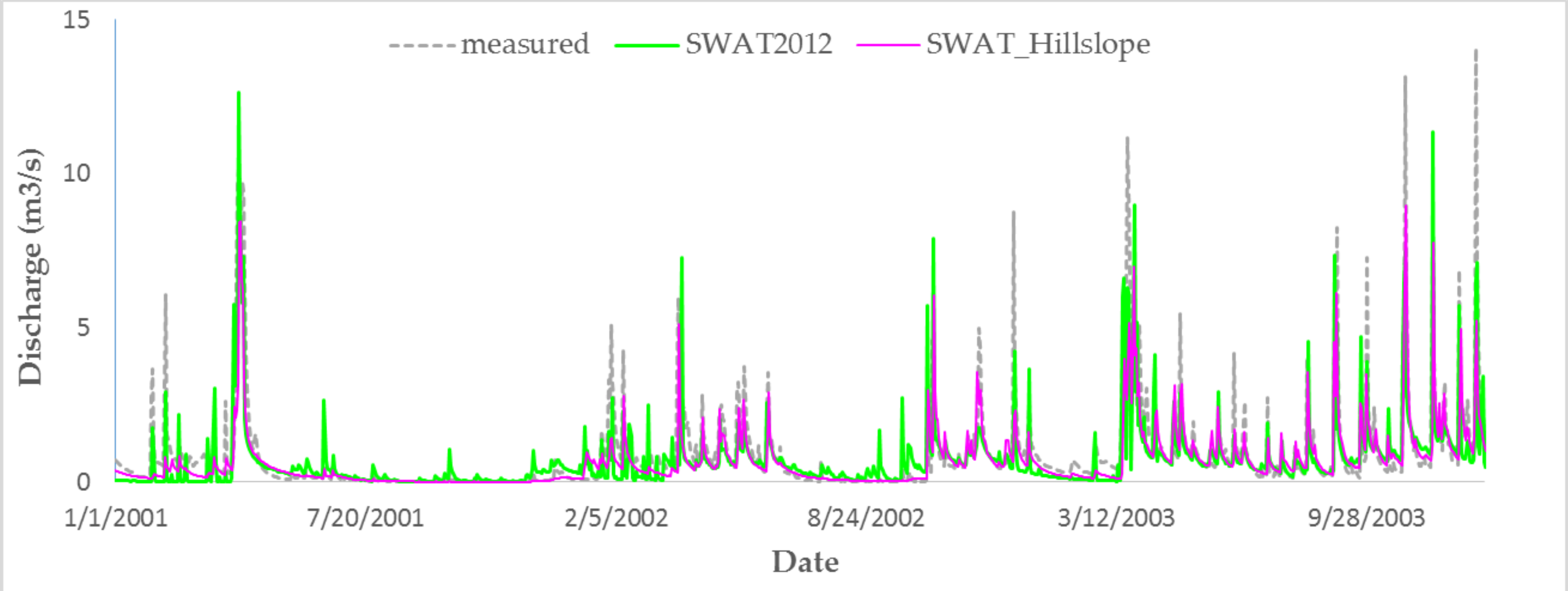
2008 - 2012

Period	Time steps	Criteria		
		NSE	*PBIAS*	*RSR*
Calibration	Daily	0.66	11.13	0.58
	Monthly	0.82	11.2	0.42
Validation	Daily	0.54	2.05	0.68
	Monthly	0.76	2.27	0.49
Validation (excluding 2011)	Daily	0.61	7.17	0.63
	Monthly	0.78	7.41	0.48

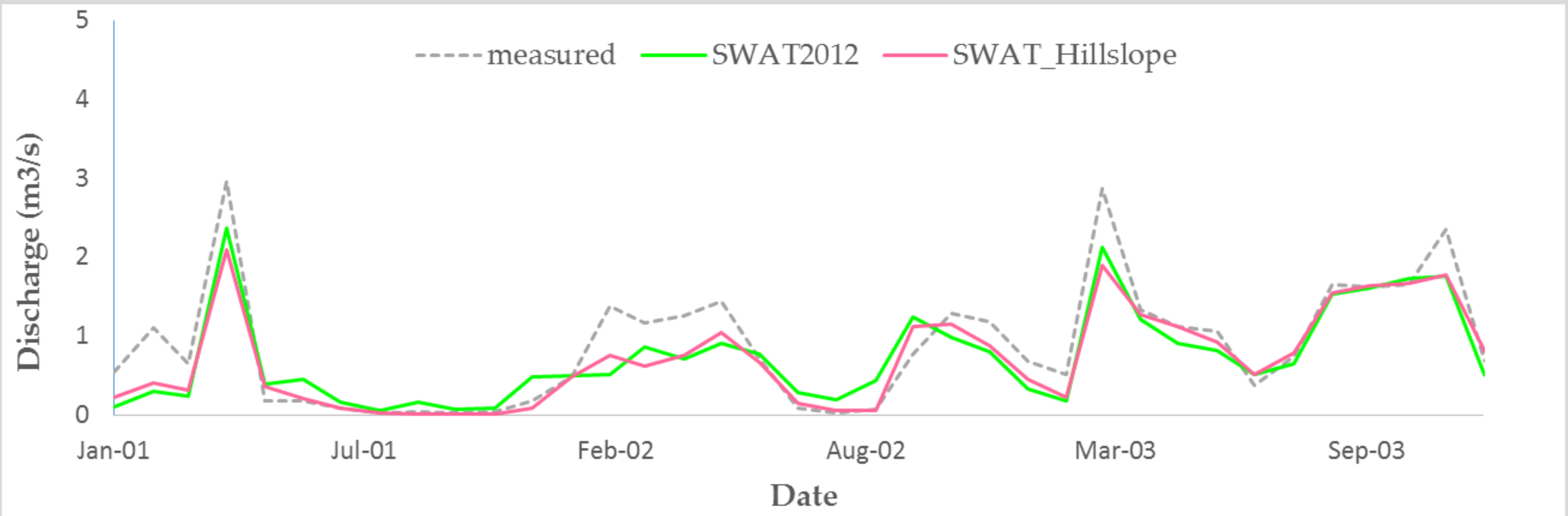
Performance of SWAT-Hillslope on flow simulation

Outlet discharge

Daily



Monthly

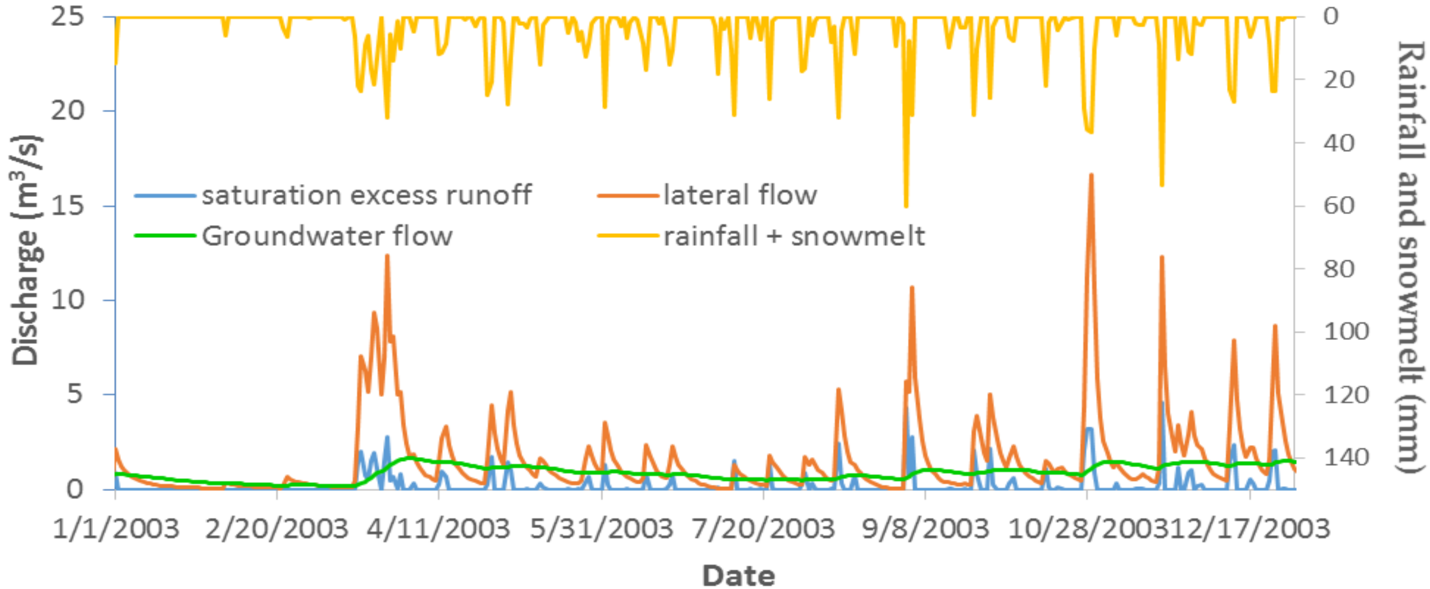


Performance of SWAT-Hillslope on flow simulation

Flow components

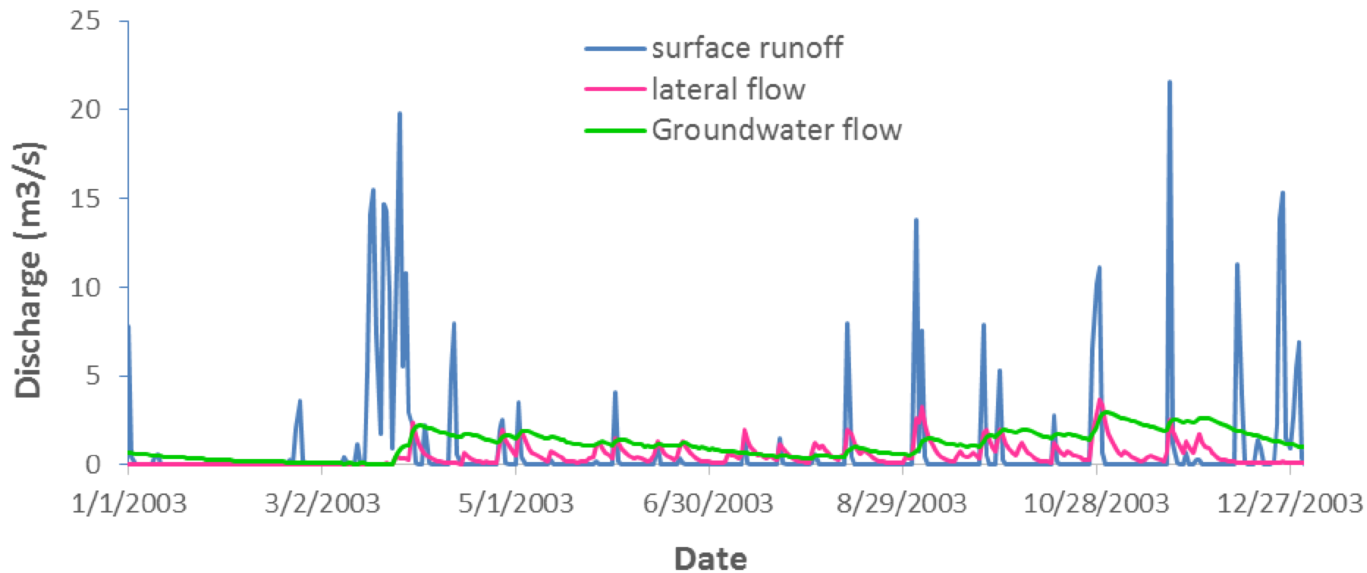
SWAT-Hillslope

Lateral flow is the most significant contribution to streamflow



SWAT2012

Surface runoff plays an important contribution, in high rainfall event

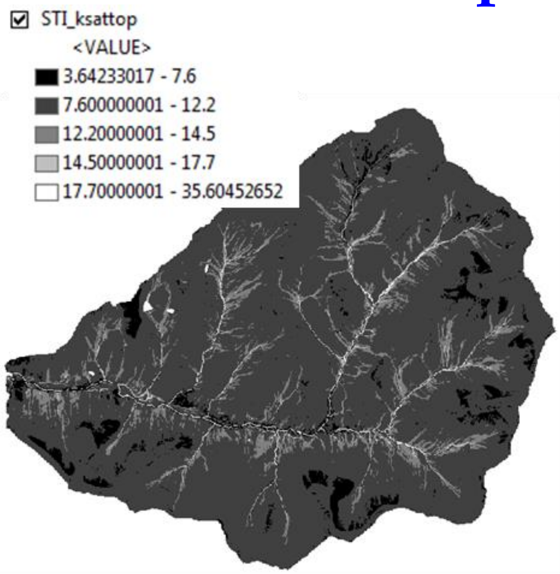


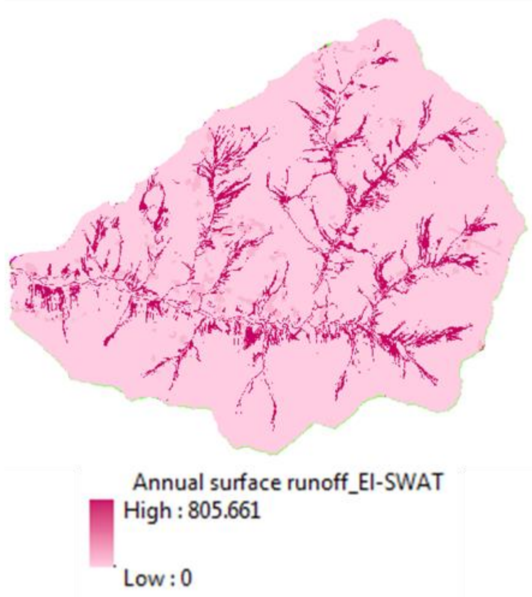
Spatial distribution of annual surface runoff

SWAT-Hillslope Distribution of surface runoff follows topography and concentrates in locations with high topographic index

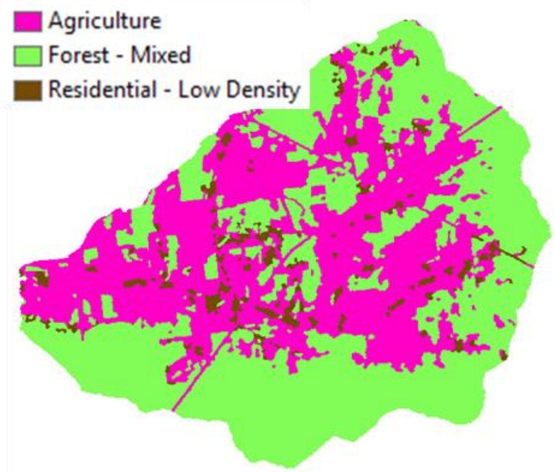
SWAT2012 The distribution of surface runoff predicted by SWAT2012 follows the distribution of land use

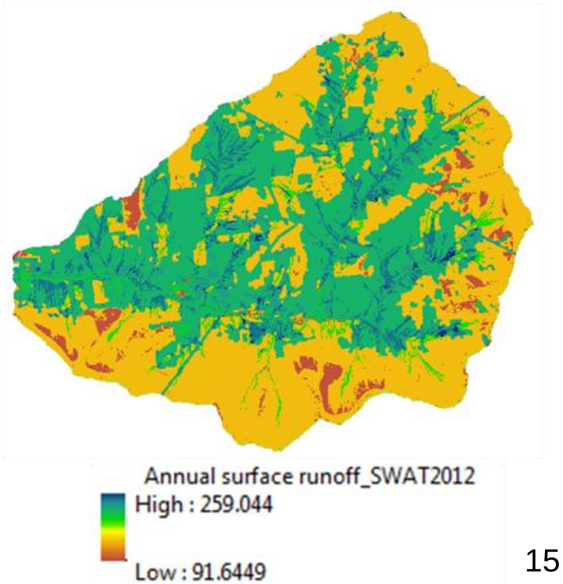
SWAT-Hillslope





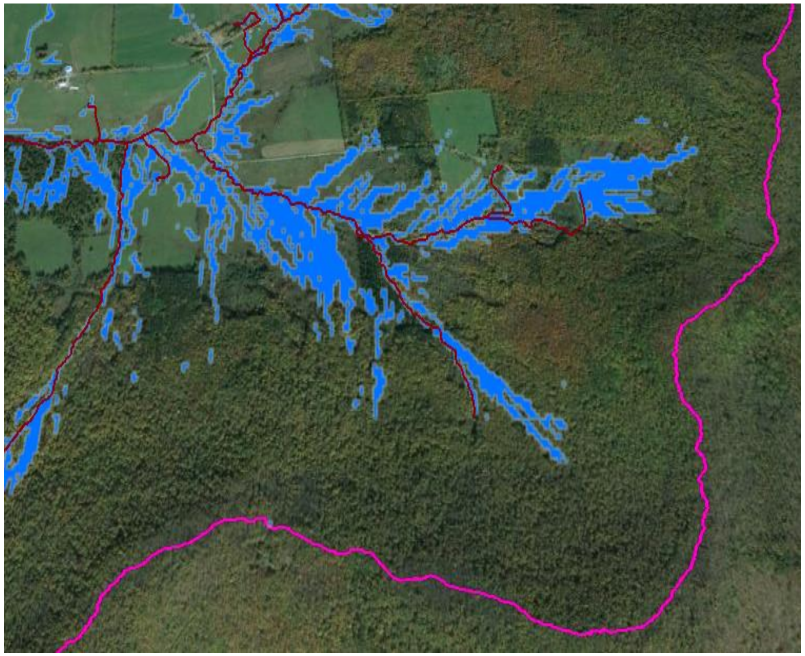
SWAT2012



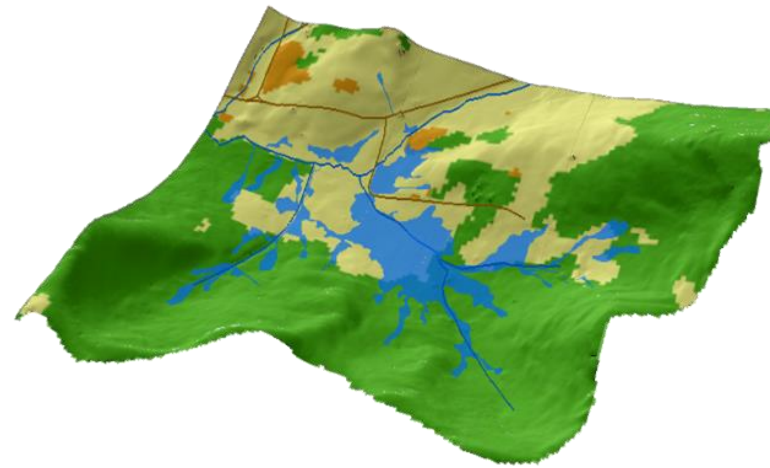


Performance of SWAT-Hillslope on flow simulation

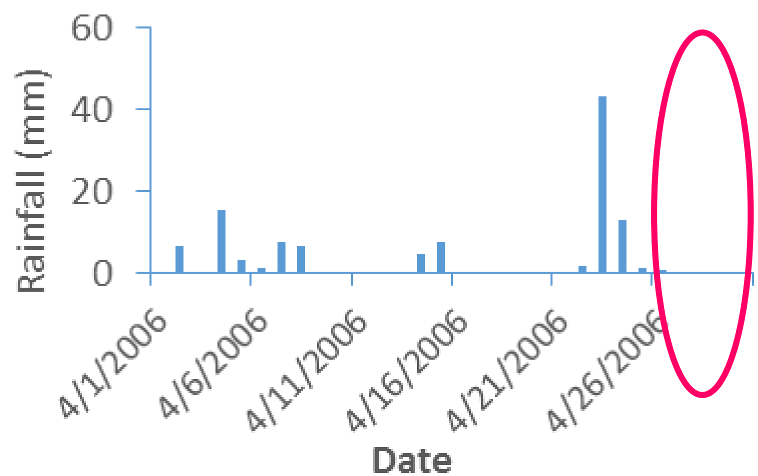
Spatial distribution of saturated areas



(b) Saturated areas by SWAT-Hillslope



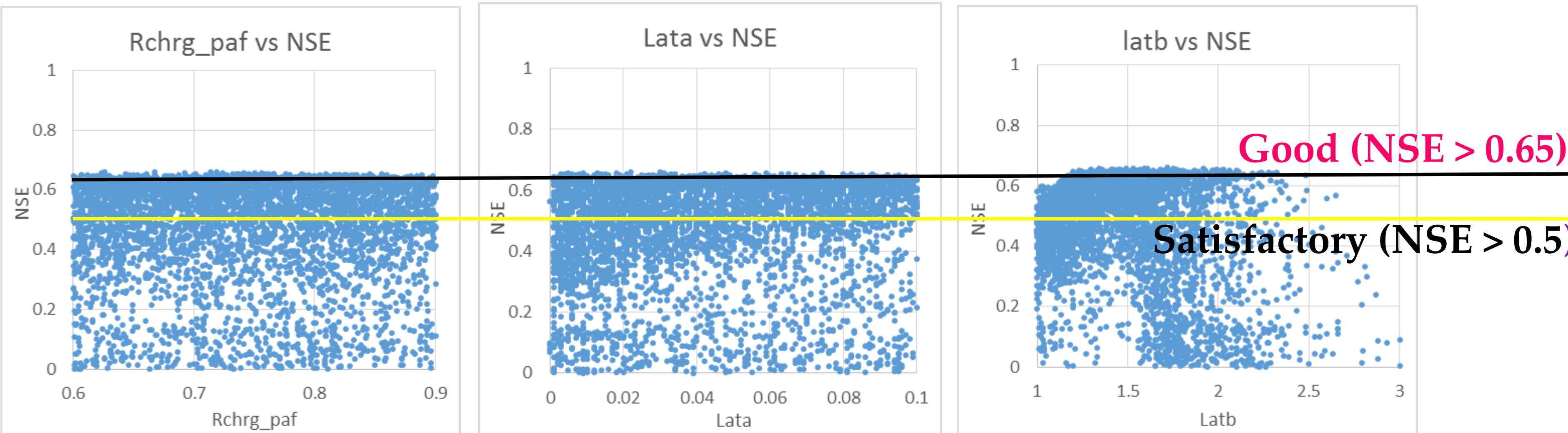
(a) Observations in 28-30/04/2006

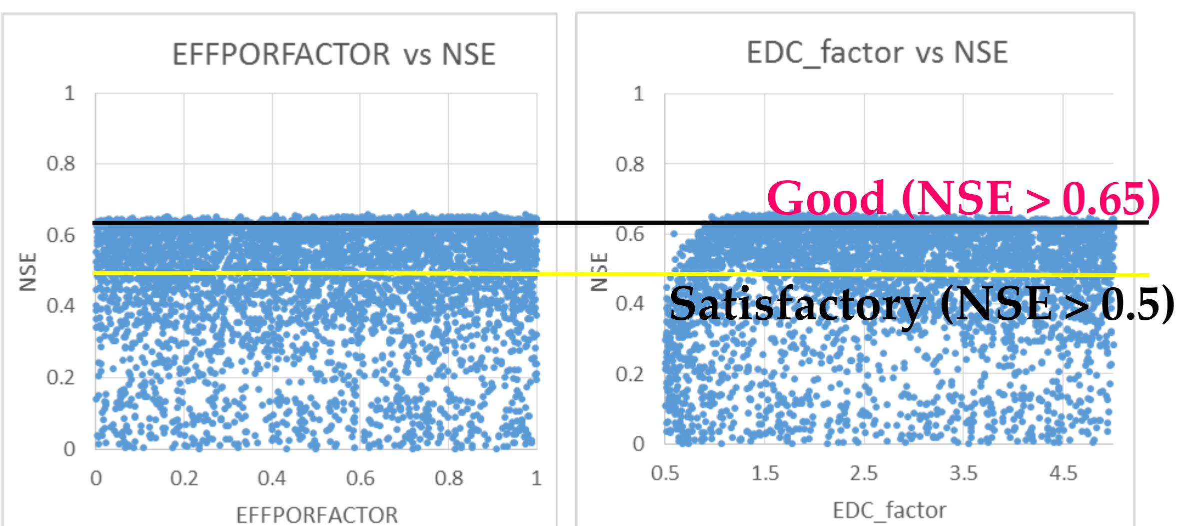


(c) Rainfall in April 2006

- SWAT2012: no surface runoff. No rain from 28-30/04/2006
- SWAT-Hilllslope: Interflow and predicted saturated areas in agreement with field observations

Parameter uncertainty





Name	Definition
RCHRG_PAF	Fraction of root zone percolation that recharges the perched aquifer
latA	Perched aquifer non-linear reservoir coefficient
latB	Perched aquifer non-linear reservoir coefficient
EFFPOR FACTOR	Fraction of effective porosity that can hold water under saturated conditions
EDC_ FACTOR	Calibration factor for adjusting *edc* values

Parameter uncertainty vs. model complexity

- Good parameters are broadly distributed within the ranges in models with different complexity

- These ranges are comparable in 5 models

Increasing model complexity does not improve model performance

simple → complex

	E-SWAT model setups				
	TB_1	TB2	TB3	TB4	TB5
Number of "satisfactory" models (NSE ≥ 0.5)* *Total number of simulations = 10000*	2580	3081	2735	2566	2564
Number of "*good*" models (NSE ≥ 0.65)	23	534	435	160	128
Max NSE	0.66	0.68	0.67	0.66	0.66
Range of good parameters					
RCHRG_PAF	0.66 - 0.89	0. 6 - 0.9	0.6 - 0.9	0.6 - 0.9	0.6 - 0.9
Lata	0.007 – 0.08	0.001 - 0.1	0.001 - 0.1	0.001 - 0.1	0.003 - 0.1
Latb	1.33 - 1.92	1.06 – 2.32	1.17 – 2.32	1.20 – 2.32	1.20 – 2.11
Alpha_bf	0.20 - 0.95	0.0 – 1.0	0.0 – 1.0	0.02 – 0.99	0.07 – 0.99
GW_delay	14 – 193	3 – 200	0.2 – 199	7 – 198	7 – 198
EFFPORFACTOR	0.24 - 1.0	0.0 – 1.0	0.0 – 1.0	0.03 – 1.0	0.03 – 1.0
EDC_FACTOR	1.3 – 3.9	0.67 – 5.0	0.97 – 5.0	0.97 – 5.0	0.97 – 4.76
EPCO	0.02 – 0.70	0.0 – 1.0	0.0 – 1.0	0.02 – 1.0	0.02 – 1.0
ESCO	0.005 – 0.6	0.0 – 1.0	0.0 – 0.96	0.005 – 0.96	0.005 – 0.96
CANMX	1.14 – 4.92	0.02 – 5.0	0.03 – 5.0	0.68 – 4.97	0.80 – 4.97
SURLAG	2.4 – 22.1	0.5 - 24	0.1 - 24	0.4 – 23.9	0.4 – 23.8

Equifinality vs. model complexity

simple → **complex**

	SWAT-Hillslope model setups				
	TB_1	**TB2**	**TB3**	**TB4**	**TB5**
Number of "satisfactory" models (NSE ≥ 0.5)* *Total number of simulations = 10000*	2580	3081	2735	2566	2564
% of measurements falling into "satisfactory" uncertainty bounds	**83.9%**	**84.2%**	**84.1%**	**82.5%**	**82.2%**
Number of "*good*" models (NSE ≥ 0.65)*	23	534	435	160	128
% of measurements falling into uncertainty bounds in <u>calibration period</u>	**44.2%**	**66.4%**	**65.0%**	**58.1%**	**57.3%**
% of measurements falling into uncertainty bounds in <u>validation period</u>	**40.6%**	**53.4%**	**42.3%**	**43.8%**	**43.2%**

Equifinality vs. model complexity

- TB2 setup gave the best results among all set ups: achieved the highest NSE, captured the highest percentage of measurements both in calibration and validation periods.

TB2 set up
- Wetness map: 5
- Soil type: 5
- Land use: 1 (AGRL)
- Number of HRUs: 5

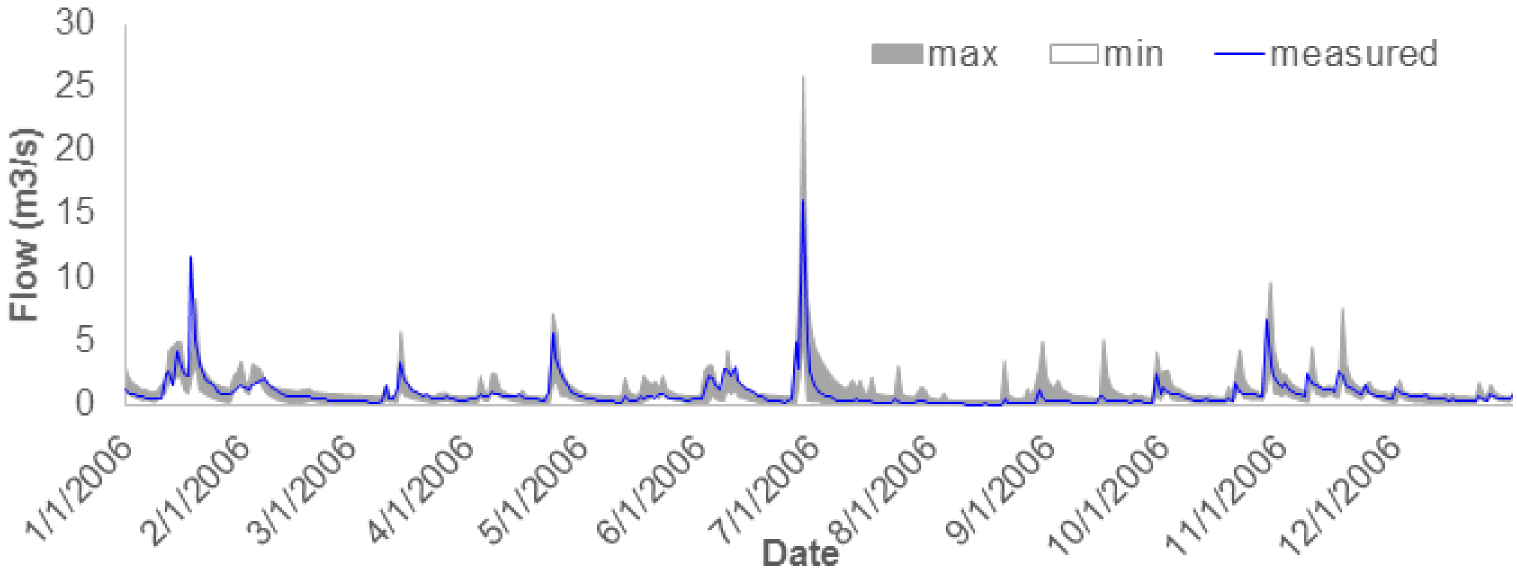
- TB1 setup with homogenous soil and land use gave the worst performance: captured the lowest percentage of measurements because of over-simplification

- The most complicated set up did not give the best results

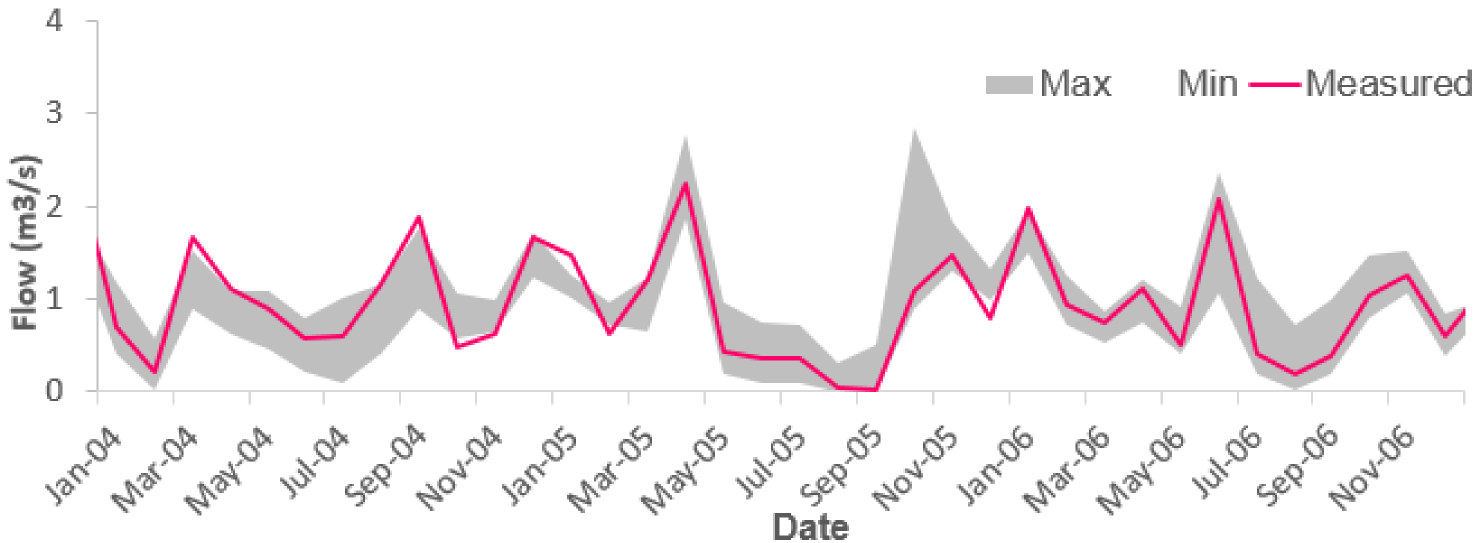
Uncertainty of modeled result (results from TB2 setup)

Streamflow

Daily



Monthly



Uncertainty of modeled result (results from TB2 setup)

Probability of saturation

After filtering by comparing with the observed saturated areas in 28-30 April 2006

Number of good parameter sets

534

	Probability of saturation (%)
Wetness 1	68.3 - 100
Wetness 2	6.9 – 86.3
Wetness 3	0.3 - 75
Wetness 4	0
Wetness 5	0

Number of good parameter sets

150

	Probability of saturation (%)
Wetness 1	78.1 - 100
Wetness 2	49.2 – 86.3
Wetness 3	26 - 75
Wetness 4	0
Wetness 5	0

More information and observations will help to choose the most reasonable parameter sets and reduce the uncertainty of modeled results

Conclusions and recommendations

- SWAT-Hillslope successfully simulates separately the infiltration-excess runoff and saturation excess runoff
- SWAT-Hillslope performed well in simulating streamflow as well as the spatial distribution of saturated areas
- As in many hydrological models, equifinality is also a problematic issue in SWAT-Hillslope

Conclusions and recommendations

- The testing in models with different complexity revealed that the most complicated model does not necessarily give the better simulated results
- Reducing the model complexity by simplifying soil and land use types can increase the model performance, however, we should be cautious to not over-simplify
- Reducing the model complexity does not aid in reducing equifinality. However, using all available spatial information and observations on locations of saturated soils can aid in finding the most realistic parameter set and in reducing uncertainty.

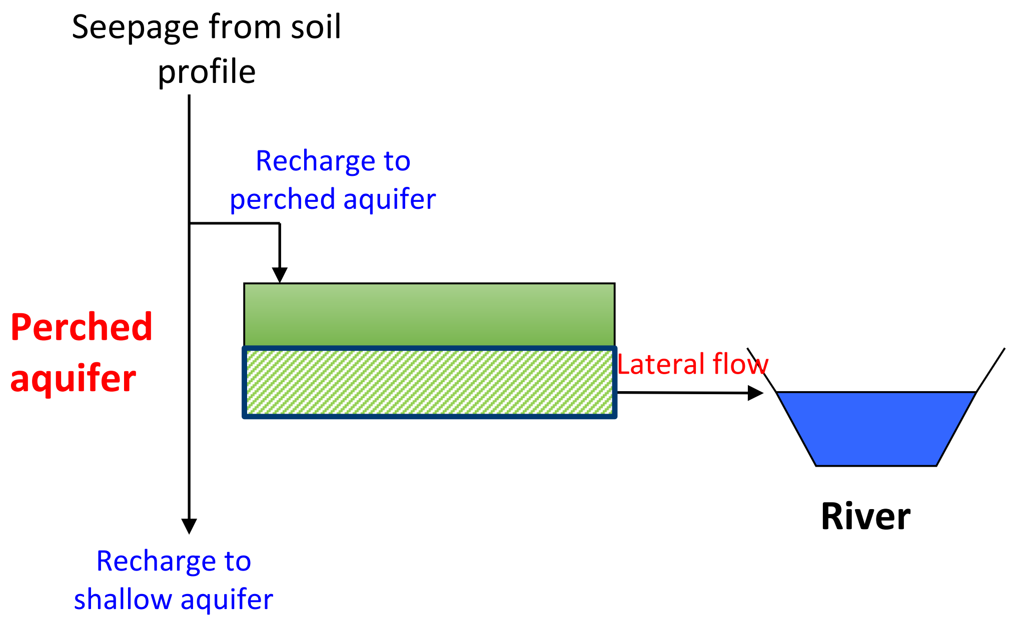
Thank you
For your attention

Description of the SWAT-Hillslope model

Lateral flow is calculated based on the depth of water in perched aquifer at the beginning of the time step (the result from previous time step) and the recharge to perched aquifer in the current time step by a **non linear reservoir equation**:

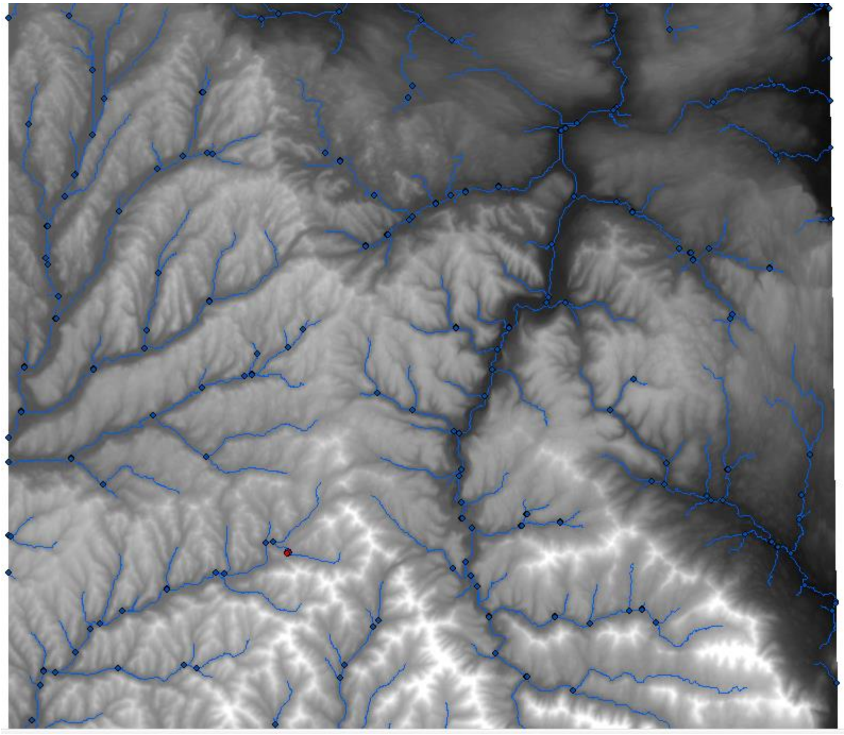
$$\texttt{latqsub = lata * (}\underbrace{\texttt{(sub\_perchst2(sb) - perchst\_datum)}}_{\text{Available perched storage}}\texttt{ + }\underbrace{\texttt{sub\_rchrgpa(sb)}}_{\text{Recharge}}\texttt{)\^{}latb}$$

Lata, latb are parameters for calibration

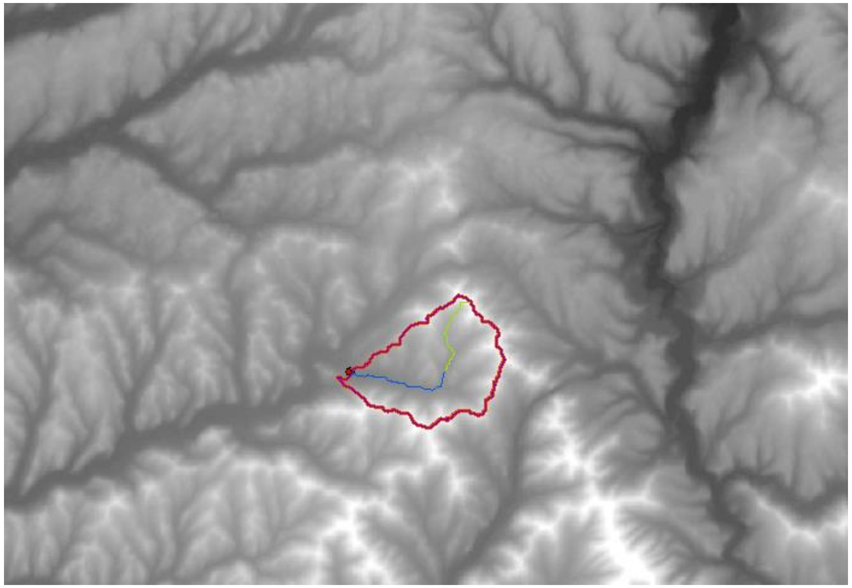


Watershed delineation

- ✓ Resolution: DEM 10m x 10m
- ✓ Geographic coordinate system: *WGS_1984*
- ✓ DEM is projected to the coordinate system : *NAD 1983 Zone 18N*



Delineate the watershed based on the location of outlet



Creating wetness map: based on topographic index

- ✓ Calculate topographic index

$$\lambda = \ln\left(\frac{\alpha}{\tan(\beta) K_s D}\right)$$

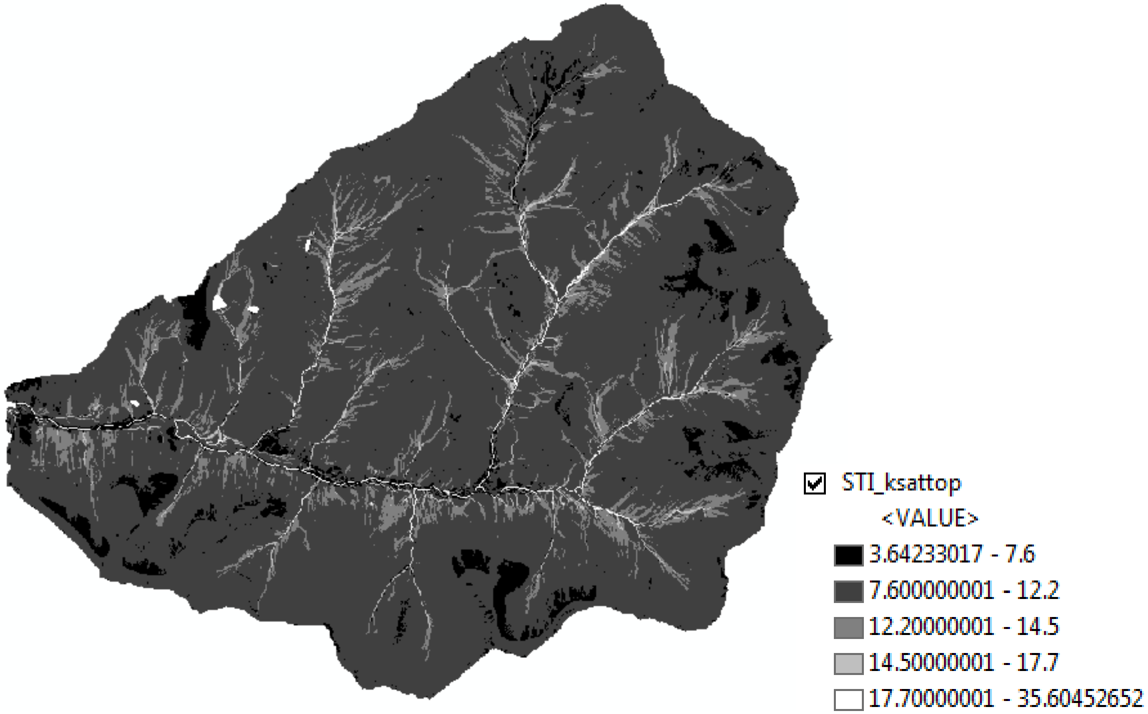
λ: soil topographic index (STI), unit: ln(d m $^{-1}$)

α: upslope contributing area per unit contour length (m)

$tan(\beta)$: the local surface topographic slope

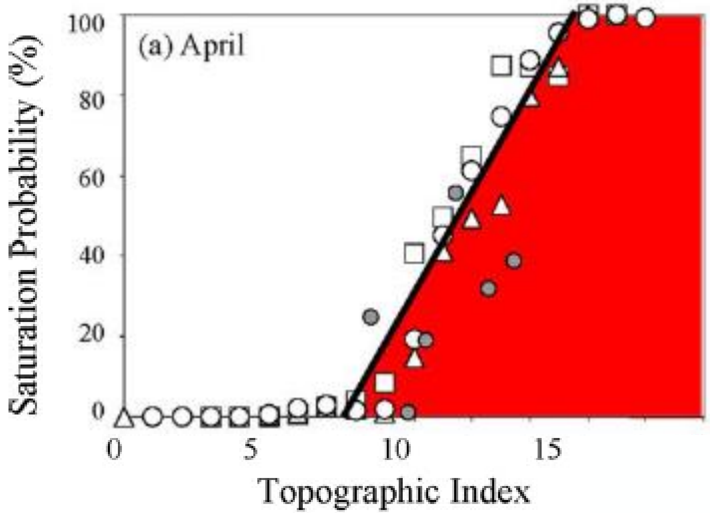
K_s: mean saturated hydraulic conductivity of the soil (m d^{-1})

D: soil depth (m)



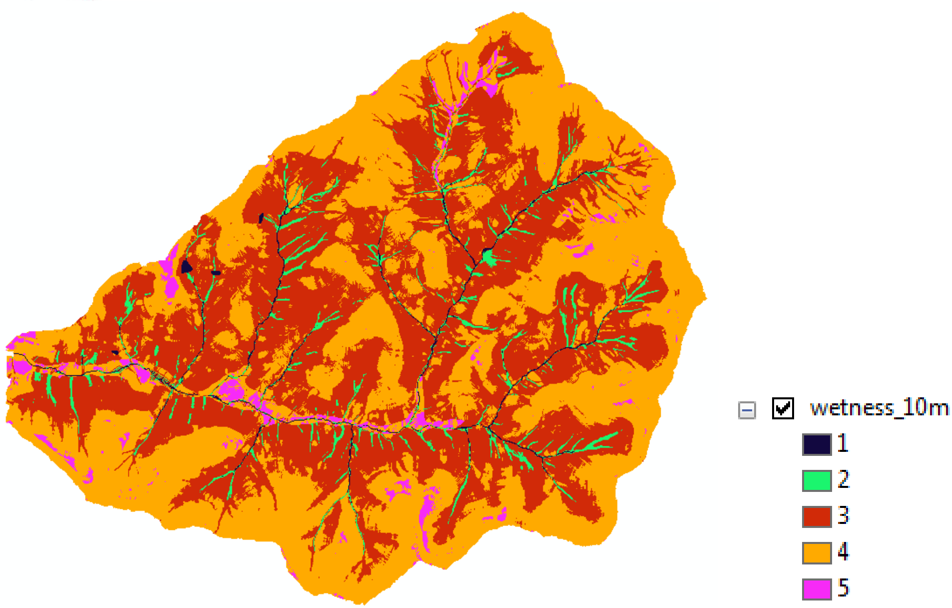
Creating wetness map: based on topographic index

✓ Classify to wetness classes



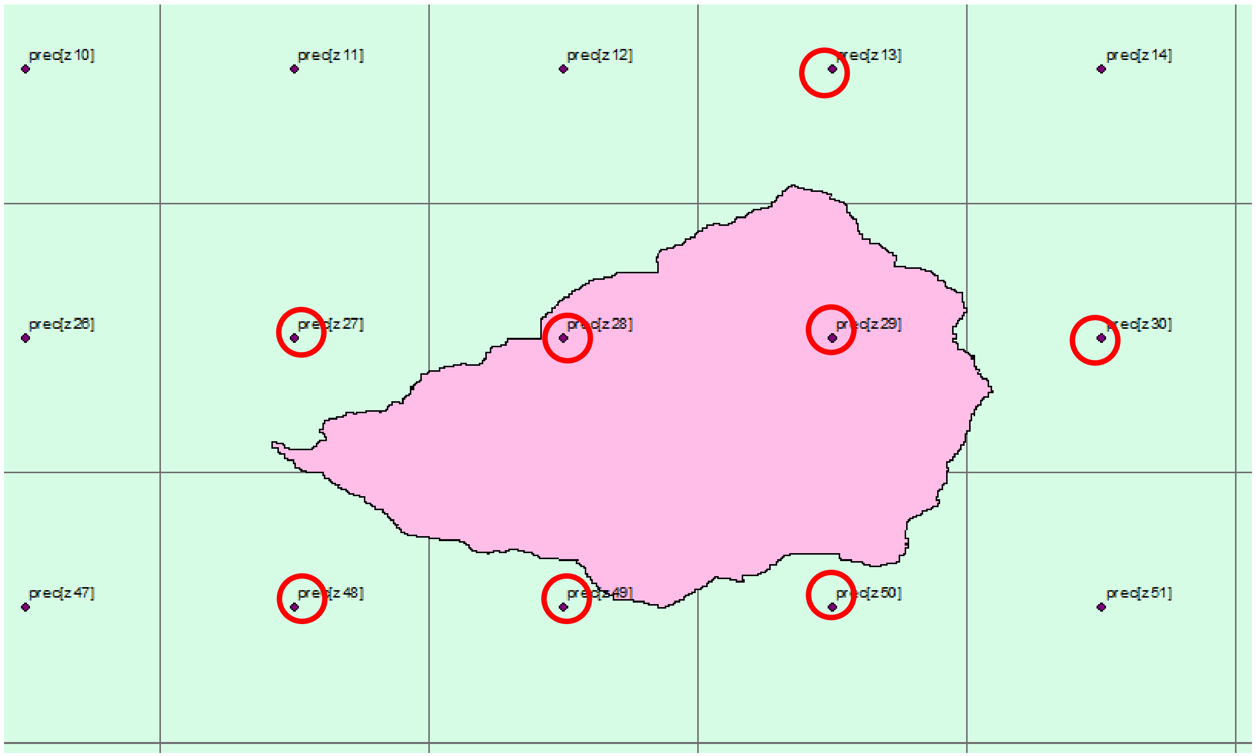
(Agnew et al., 2006)

No	STI	Wetness	% of watershed	Characteristics
1	< 7.6	5	5.1	Dry
2	7.6 – 12.2	4	84.98	
3	12.2 – 14.5	3	8.2	
4	14.5 – 17.7	2	1.12	
5	>17.7	1	0.59	Wet



Weather input

Precipitation, temperature data is available in PRISM gridded data



Data for the whole watershed which is assumed to be taken at the centroid of the watershed is interpolated from data of surrounding stations by inverse distance weighting method