REVISITING SWAT AS A SEMI-DISTRIBUTED SATURATION-EXCESS RUNOFF MODEL FOR HUMID CLIMATES

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CONCLUSION

RANKING HRU'S WITH RESPECT TO TOPOGRAPHIC INDEX AND INTRODUCING A SLOPE LENGTH THAT IS SMALL UPHILL AND LONG DOWNHILL, SWAT CAN SIMULATE THE LOCATION OF SATURATED AREAS WELL ON SOILS WITH A RESTRICTING LAYER IN HUMID CLIMATES

Hydrology 101

Surface soils in humid areas have generally saturated conductivities many times greater than the rainfall intensity

Rain water infiltrates and moisture content will increase for sloping soils with a hardpan

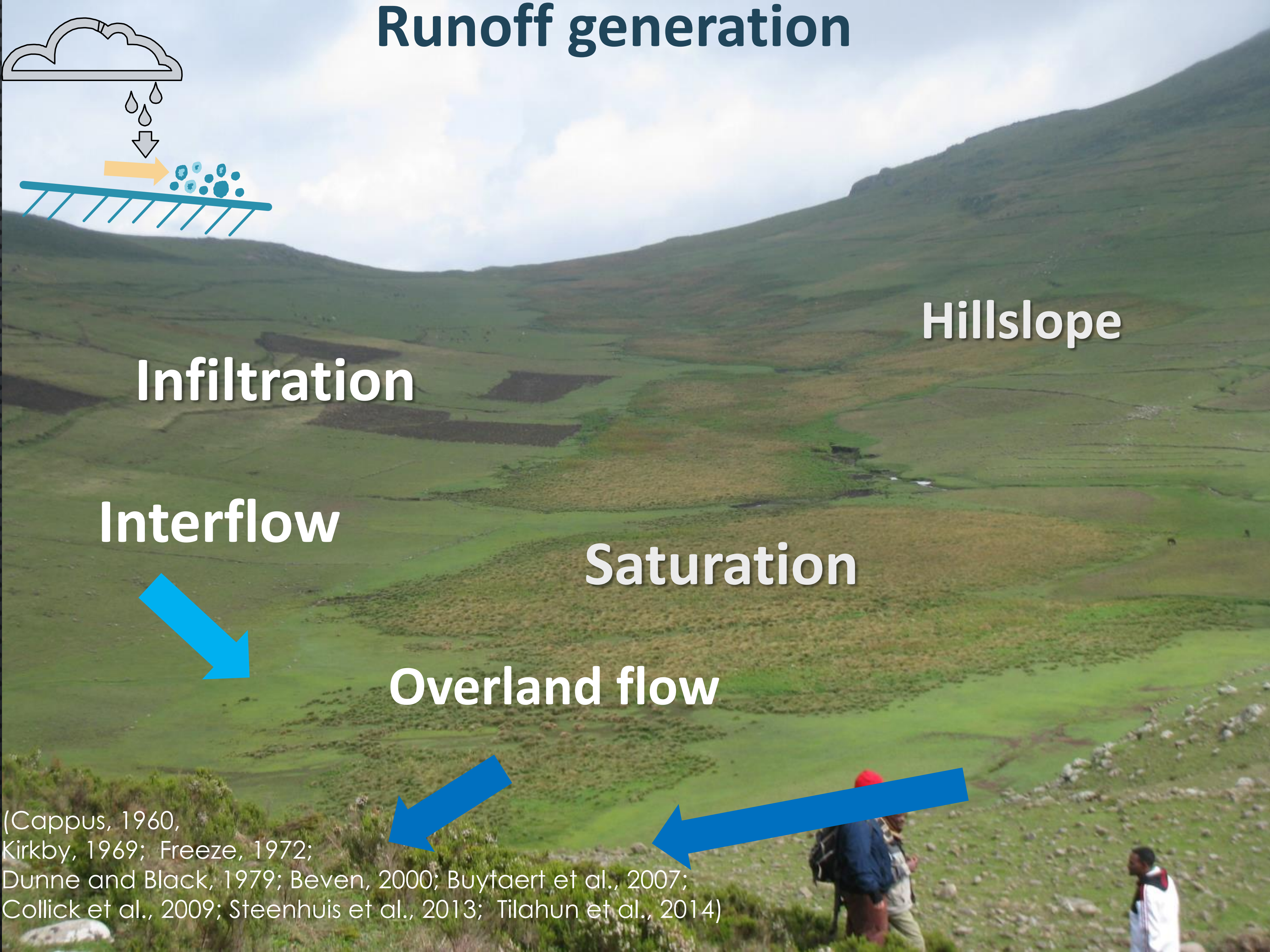
Water will run down the slope through the soil as laterflow.

Interflow accumulates in locations where the slope becomes less (i.e., valley bottoms)

Surface runoff occurs when soil is saturated

Saturation excess runoff is the rule rather than the exception in humid climates

Runoff generation



SWAT2012

In SWAT HRU's can contain several hillslopes and moisture content across the hillslope

Hillslope has average moisture content

SWAT is, therefore, not ideally suited for modeling the location of the overland flow areas

OBJECTIVE

Trick SWAT in becoming a saturation excess model that can simulate the location of surface runoff accurately

TWO ADAPTATIONS TO SWAT DISCUSSED

SWAT-HS   SWAT –HILLSLOPE

SWAT-WIL   SWAT-WITH IMPERMEABLE LAYER

STEP 1 (BOTH MODELS)
REDEFINE HRUs
EACH HRU HAS A SPECIFIC LOCATION ON THE HILLSLOPE

- Redefine HRU so that topographic information is preserved
- Use $topographic\ index = \frac{Conbtributing\ area}{slope * soil\ depth * conductivity}$
- Rank HRUs along the hillslope (and group them in wetness classes)

Step 2: (Both Models)
Redefine Surface Runoff Process

Surface runoff for each HRU is equal to the amount of Rainfall minus what can be stored in the soil

Since most runoff occurs downslope with small a slope model suould increase the moisture content

STEP 3: SWAT-HS
INCREASE RUNOFF IN HRU'S DOWN SLOPE

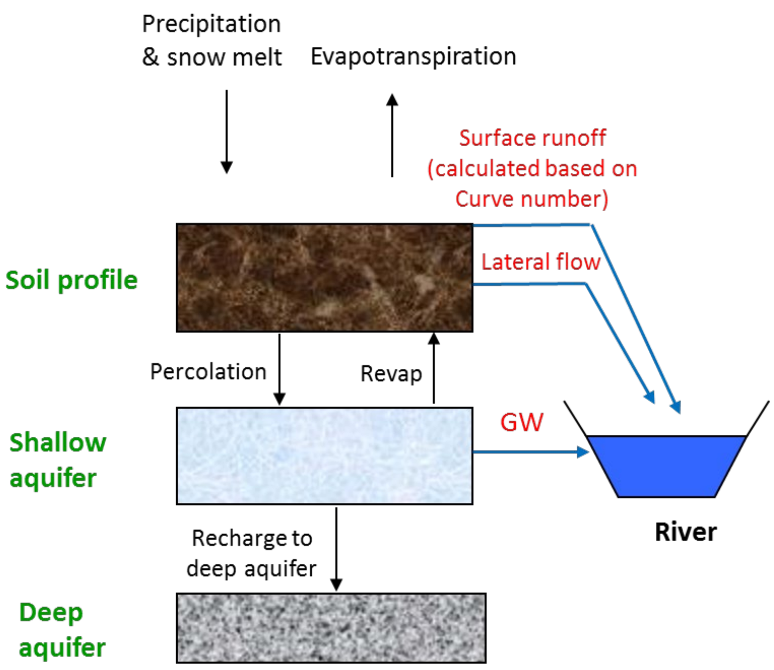
SWAT-HS (HILLSLOPE): INTRODUCE A SURFACE AQUIFER THAT TRANSMIT WATER TO HRU'S TO HRUs WITH GREATER TOPO INDEXES WHEN SOIL IS ABOVE FIELD CAPACITY.

DESCRIBED IN HOANG L, SCHNEIDERMAN EM, STEENHUIS TS, MOORE KEB, OWENS EM, MUKUNDAN, STEENHUIS TS 2017. PREDICTING SATURATION-EXCESS RUNOFF DISTRIBUTION WITH A LUMPED HILLSLOPE MODEL: SWAT-HS. HYDROLOGICAL PROCESSES 31:2226-2243. DOI: 10.1002/HYP.11179

SWAT-HS was developed by modifying the latest version of SWAT (SWAT2012)

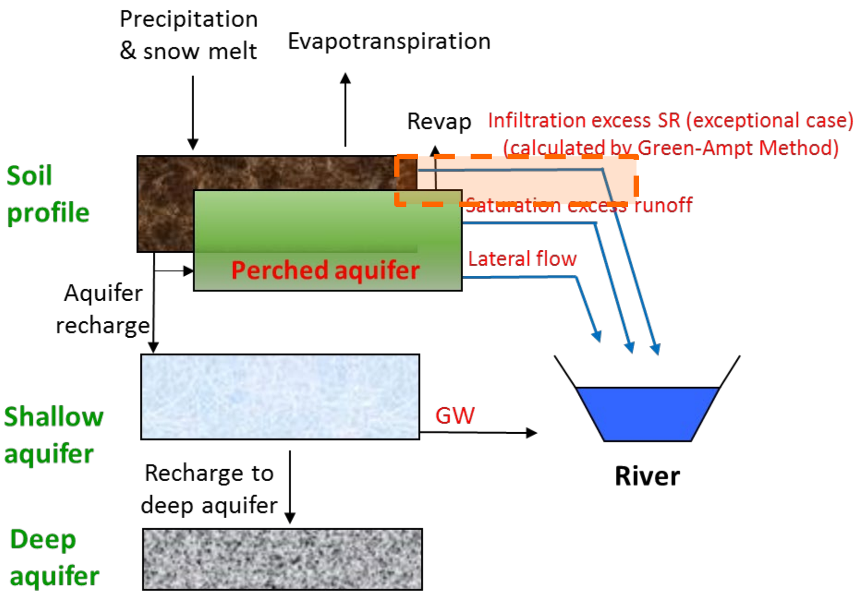
SWAT2012

- Runoff is simulated as infiltration-excess runoff



SWAT_HS

- Runoff is simulated separately for infiltration-excess and saturation-excess runoff



Step 3: SWAT-WIL
Increase runoff in HRU's down slope

SWAT-wil (with impermeable Layer): restrict percolation out of rootzone and redefine the slope length so that upslope HRU drain fast via interflow and downslope remain wet

Maintain SCS hydrology

SWAT-WILL: CONVERTING SCS RUNOFF EQ. TO SATURATION EXCESS

SCS RUNOFF EQUATION $Q = \frac{P^2}{P+S}$

ALL RAIN FALLING ON STUARTED AREA RUNS OF AND ALL RAIN FALLS ON UNSATURATED SOILS INFILTATES, HENCE AREA SATURATED,

$A_s = \frac{\Delta q}{\Delta p}$…….. DIFFERENTIATION Q WITH P

$$A_s = 1 - \frac{S^2}{(P+S)^2}$$

STEENHUIS, T.S., M. WINCHELL, J. ROSSING, J.A. ZOLLWEG, AND M.F. WALTER. 1995. SCS RUNOFF EQUATION REVISITED FOR VARIABLE-SOURCE RUNOFF AREAS. ASCE J. IRRIG. DRAIN. 121:234-238

SWAT-WILL:
CONVERTING SCS RUNOFF EQ. TO SATURATION EXCESS

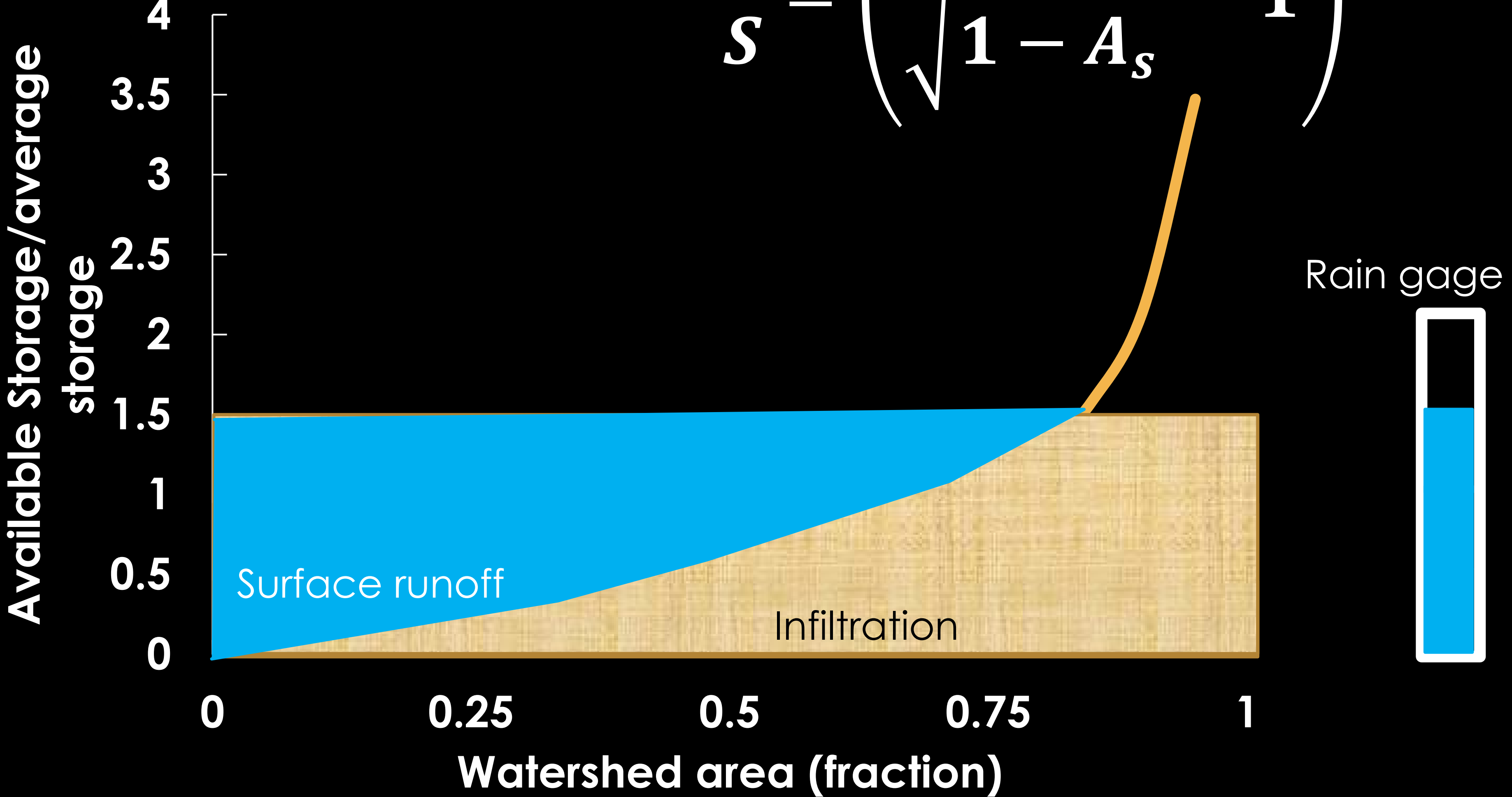
BASED ON THE AMOUNT OF RAIN REQUIRED TO SATURATE THE SOIL PROFILE, THE AVAILABLE STORAGE, A_S , A FUNCTION OF THE AREA SATURATED CAN BE EXPRESSED AS A FUNCTION OF THE AREA

$$\sigma = S\left(\sqrt{\frac{1}{1-A_s}} - 1\right)$$

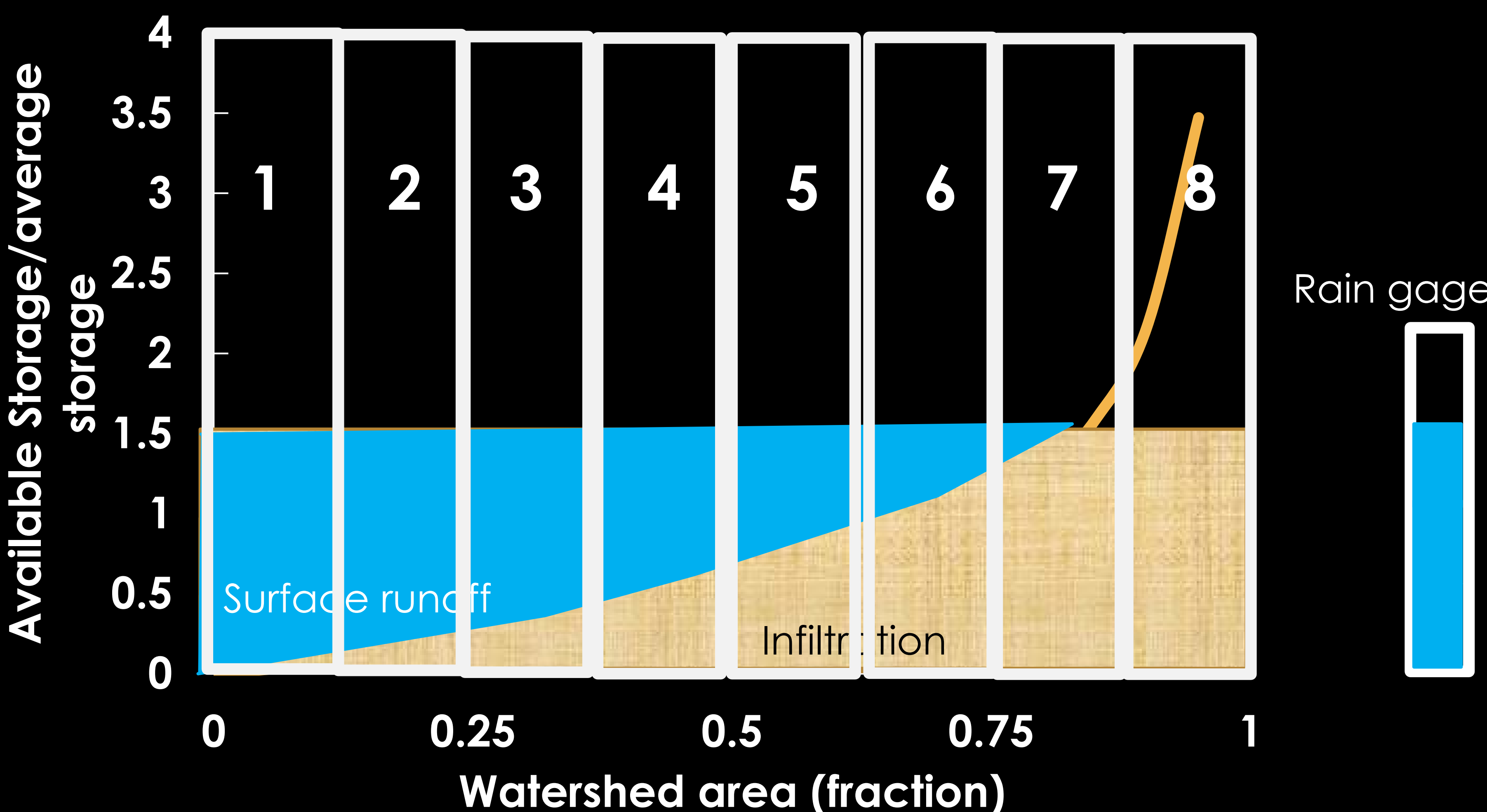
σ = AMOUNT OF WATER TO FILL UP THE SOIL ABOVE FIELD CAPACITY AS A FUNCTION OF THE AREA

SCHNEIDERMAN, E.M., T.S. STEENHUIS, D.J. THONGS, Z.M. EASTON, M.S. ZION, G.F. MENDOZA, M.T. WALTER, AND A.L. NEAL. 2007. INCORPORATING VARIABLE SOURCE AREA HYDROLOGY INTO THE CURVE NUMBER BASED GENERALIZED WATERSHED LOADING FUNCTION MODEL. HYDROL. PROC. 21:3420-3430 DOI: 10.1002/HYP6556.

$$\frac{\sigma}{S} = \left(\sqrt{\frac{1}{1 - A_s}} - 1\right)$$

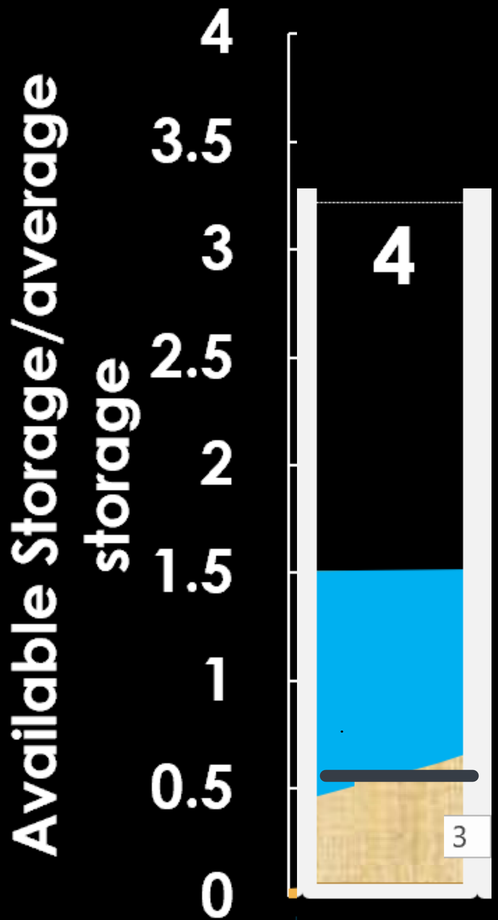


Add HRUs



Available Storage/average storage
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
Surface runoff
Infiltration
0
0.25
0.5
0.75
1
Watershed area (fraction)
Rain gage

SIMULATE HRU



Storage of rainfall is equal to the amount of water that need to be removed before the next day so that the next day the same amount of water can be stored

Storage of rainfall is equal to the amount of water that need to be removed before the next day so that the same amount of water can be stored on the next day

Fluxes out of an HRU

~~Downward percolation~~

Lateral flow

~~Evaporation~~

Consequently setting the lateral flow equal to the storage predicted by the SCS method, saturation excess runoff can be simulated

RECALCULATE LATERAL FLOW

$$Q_{lat} = C\,SW_{excess}$$

$$C = a_{djf}\;\frac{2\,K_{sat}\,sin\,\alpha}{\phi_d L^{SWAT2012}}$$

CHANGE THE SLOPE LENGTH SUCH THAT THE LATERAL FLOW EQUAL TO THE STORAGE PREDICTED BY THE SCS METHOD, THE SATURATION EXCESS RUNOFF CAN BE SIMULATE

$$\sigma = S\left(\sqrt{\frac{1}{1-A_s}} - 1\right)$$

CALCULATING IN LATERAL FLOW IN SWAT-WIL

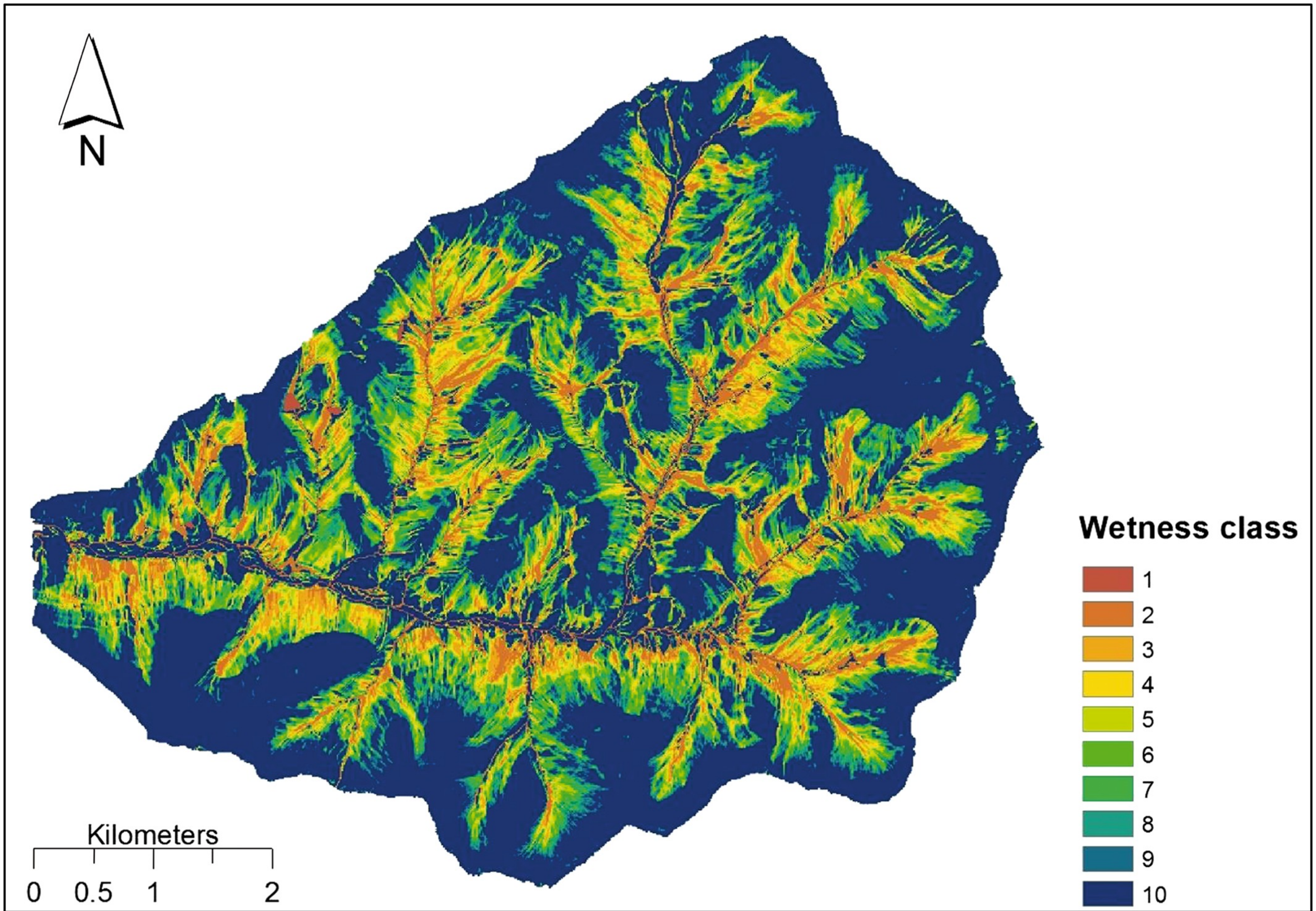
$$Q_{lat} = C\, SW_{excess}$$

$$\mathbf{C} = a_{djf} \frac{2\, K_{sat} \sin \alpha}{\phi_d L^{wil}}$$

$$L^{wil} = \frac{a_{djf}\; K^{*}_{sat} D\; \mathrm{SIN}\; \alpha}{\left(\sqrt{\frac{1}{1 - A_s}} - 1\right) S} \Delta t$$

APPLICATION TO NEW YORK CITY SOURCE WATERSHEDS

RANKING HRU (GROUPED IN WETNESS CLASSES



CALCULATING THE SLOPE LENGTH

SWAT Wetness Class	Topographic index	Area %	DEP_IMP (mm)	Slope	Slope Length m	CN2
1	>	0.59	457	0.04	1662	1
2	16.7 – 17.7	6.1	457	0.09	307	1
3	15.8 – 16.7	6.2	457	0.12	135	1
4	14.8 – 15.8	6.2	457	0.13	87	1
5	13.8– 14.8	6.4	457	0.14	65	1
6	12.9 – 13.8	6.2	457	0.15	51	1
7	11.9 – 12.9	6.9	457	0.17	43	1
8	10.9 – 11.9	6.7	457	0.18	36	1
9	10 – 10.9	6.0	457	0.20	31	1
10	<10.9	48.7	6000	0.26	21	35

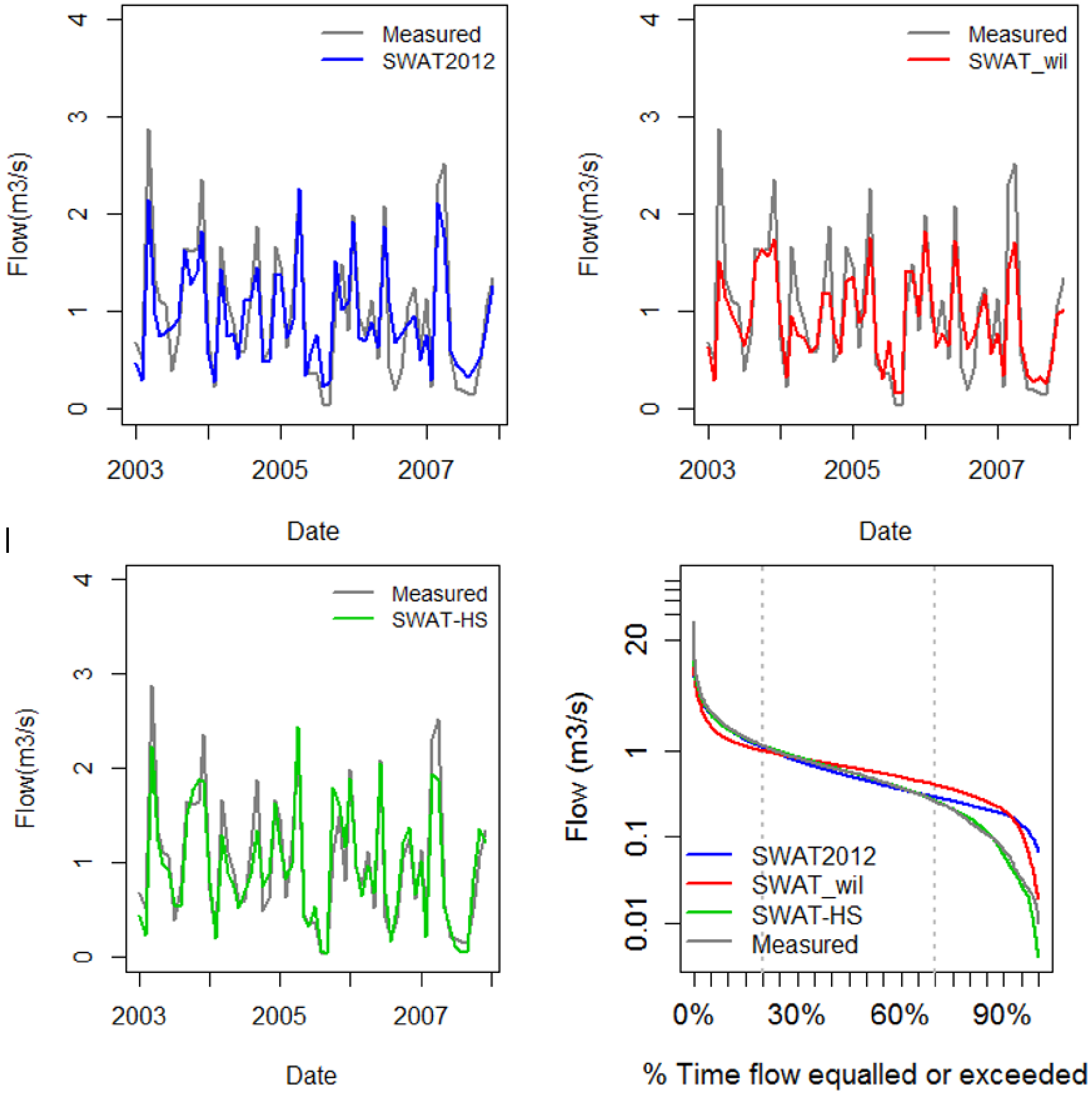
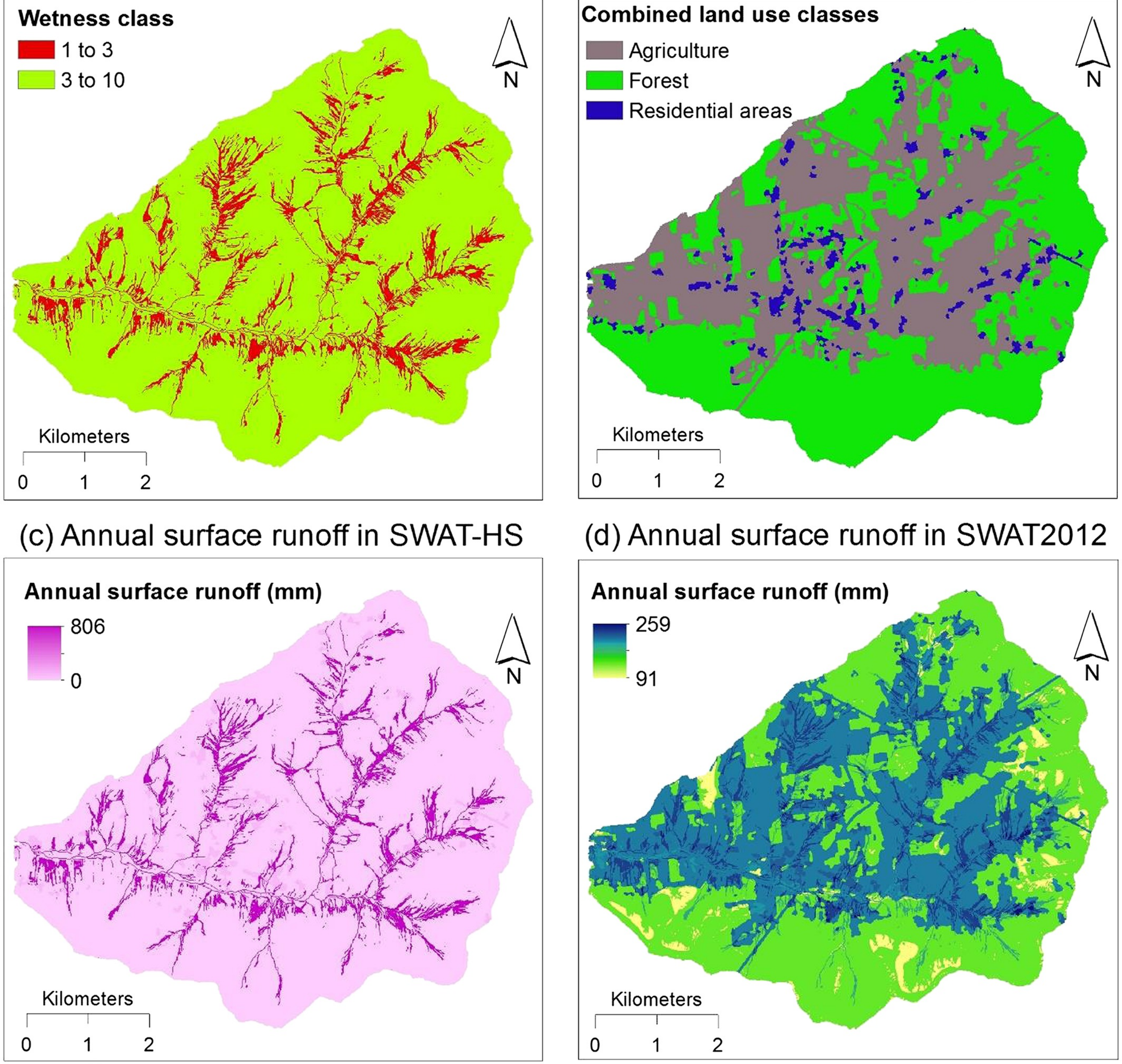
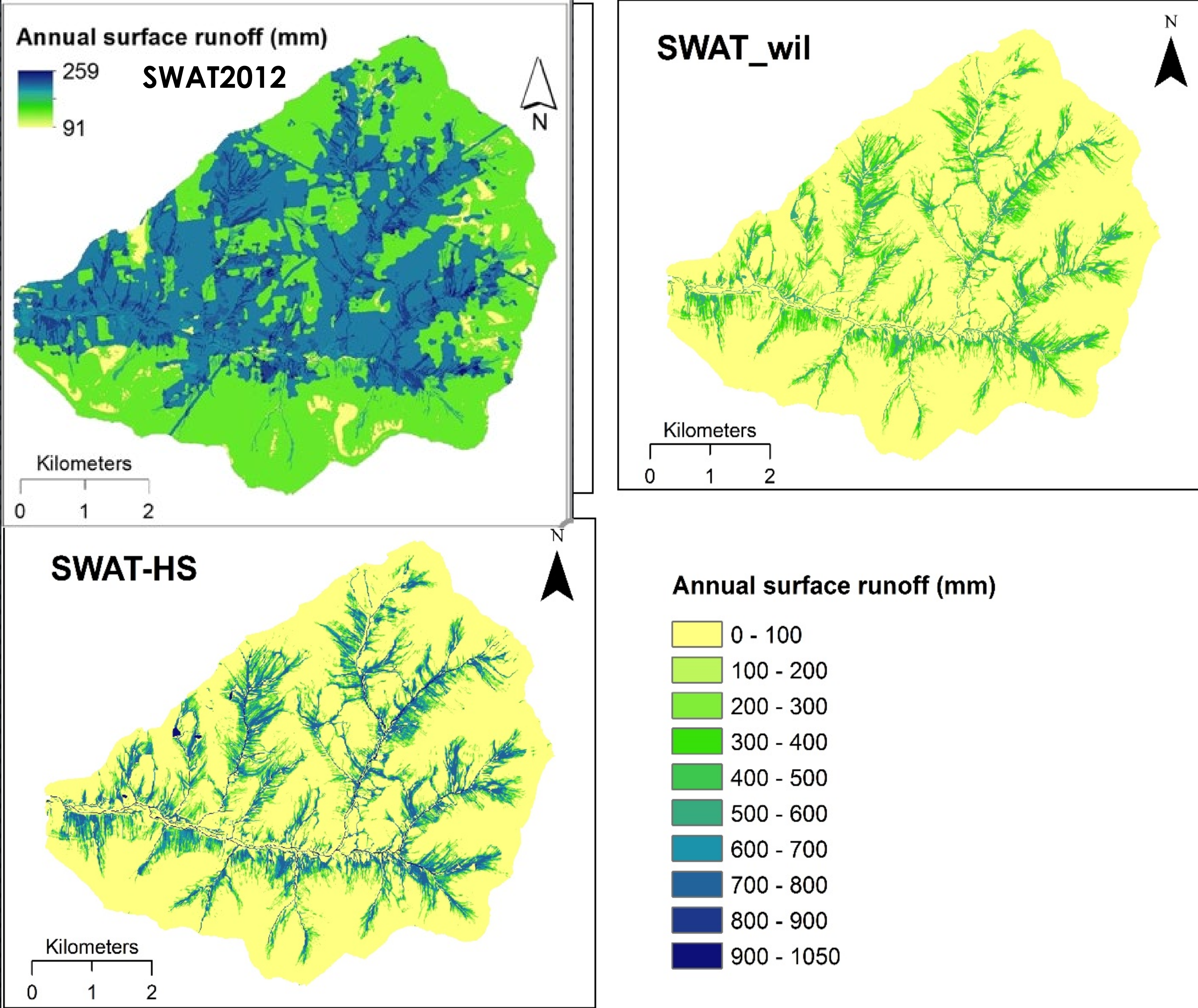
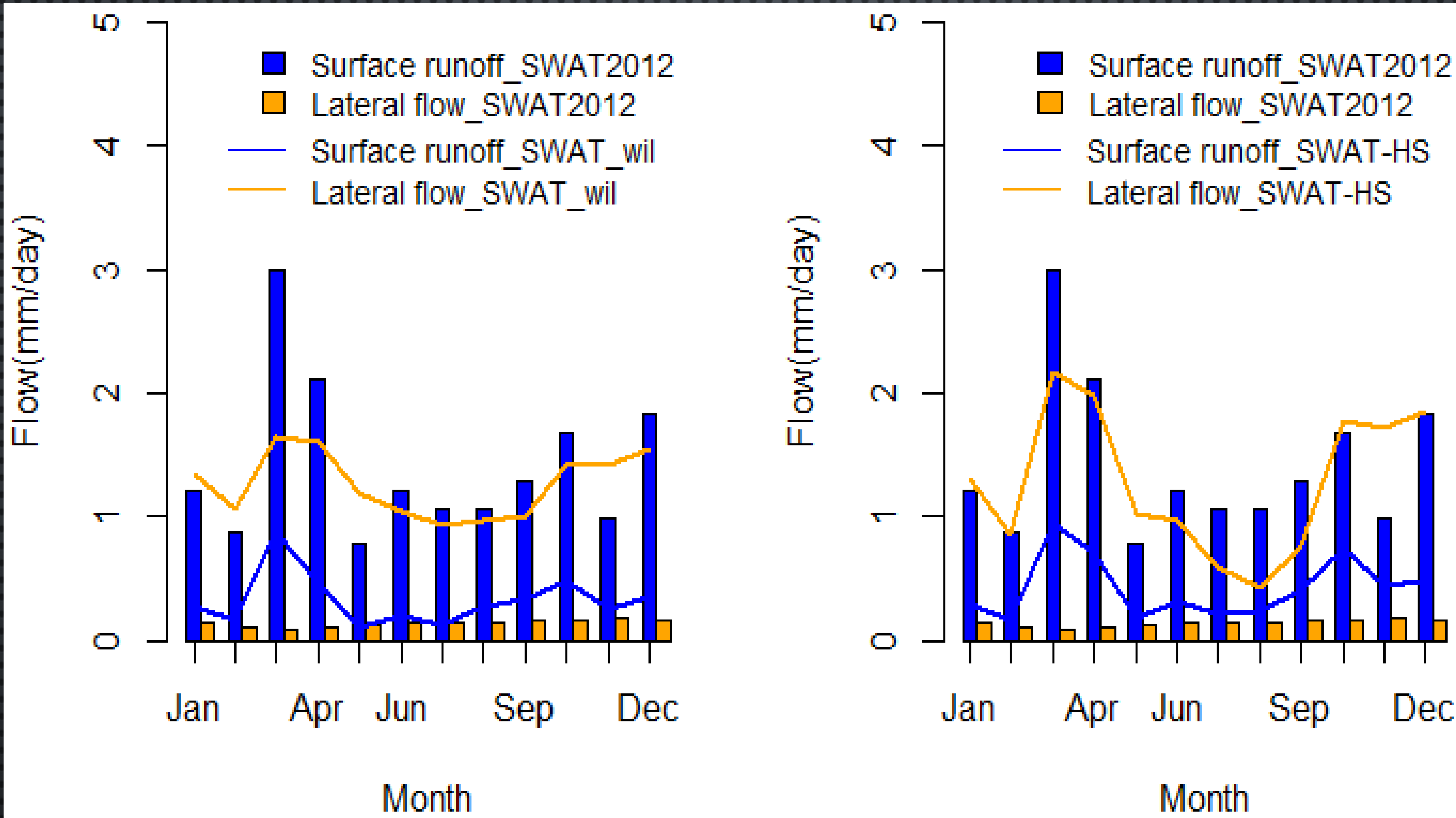


Fig. 1: Comparison of monthly time series of streamflow and flow duration simulated by SWAT2012, SWAT-wil, and SWAT-HS with measured streamflow.


Wetness class
1 to 3
3 to 10
N
Kilometers
0 1 2
Combined land use classes
Agriculture
Forest
Residential areas
N
Kilometers
0 1 2
(c) Annual surface runoff in SWAT-HS
(d) Annual surface runoff in SWAT2012
Annual surface runoff (mm)
806
0
N
Kilometers
0 1 2
Annual surface runoff (mm)
259
91
N
Kilometers
0 1 2



Annual surface runoff (mm)
259
91
SWAT2012
N
Kilometers
0 1 2
SWAT_wil
N
Kilometers
0 1 2
SWAT-HS
N
Kilometers
0 1 2
Annual surface runoff (mm)
0 - 100
100 - 200
200 - 300
300 - 400
400 - 500
500 - 600
600 - 700
700 - 800
800 - 900
900 - 1050



Mean daily stormflow components by month predicted by SWAT-wil and SWAT-HS models compared against SWAT2012

Conclusion

Ranking HRU's with respect to topographic index and introducing a slope length that is small uphill and long downhill, SWAT can simulate the location of saturated areas well on soils with a restricting layer in humid climates