Virtual Experiments to Explore Non-Linear Soil Moisture-Hydrology Interactions at the Hillslope Scale

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Objectives

- To examine the factors that control lateral subsurface flow generation at the hillslope scale
- To explore the interactions between controlling factors
- To document non-linear and hysteretic behavior
- To contribute to a framework for a general classification of hillslopes
  - E.g. Biosphere 2: help to learn about the hydrologic response of hillslopes (key interactions, storages and flow-paths)

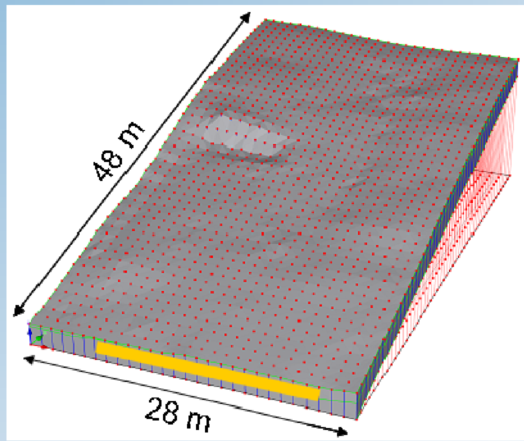
Modeling approach

- Virtual experiment approach: model calibration and evaluation based on field observations
- Topography and subsurface stormflow data from an existing research hillslope were used to define the “base case scenario”
- Numerical 3D FE model (Hydrus-3D) that solves the Richards equation for water flow in variably saturated porous media

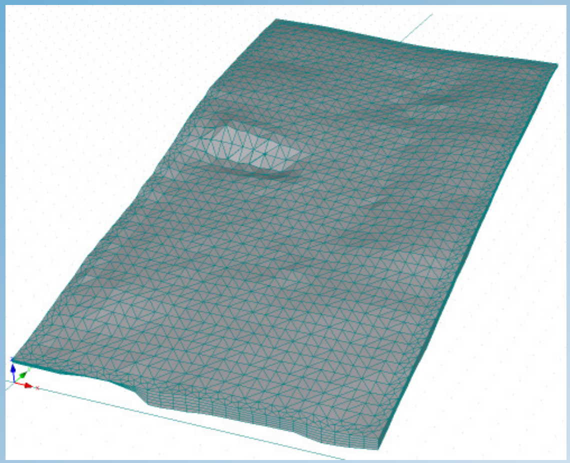
Panola Mountain Research Watershed: e.g. Freer at al. (WRR 2002), Tromp-van Meerveld (WRR 2006a and b)

Base case scenario

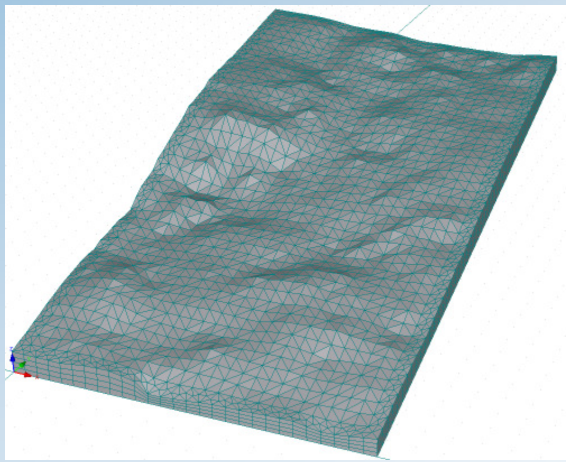
- Irregular geometry; two layers representing soil and bedrock
- slope 13°
- Variable soil depth (0-1.86 m); mean 0.62 m, cv 56%
- Subsurface flow collection system (20 m wide)



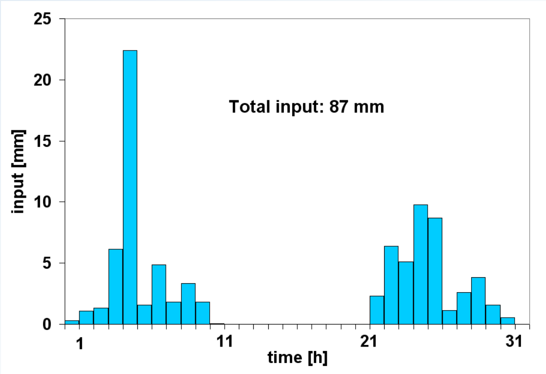
Surface topography with soil layers



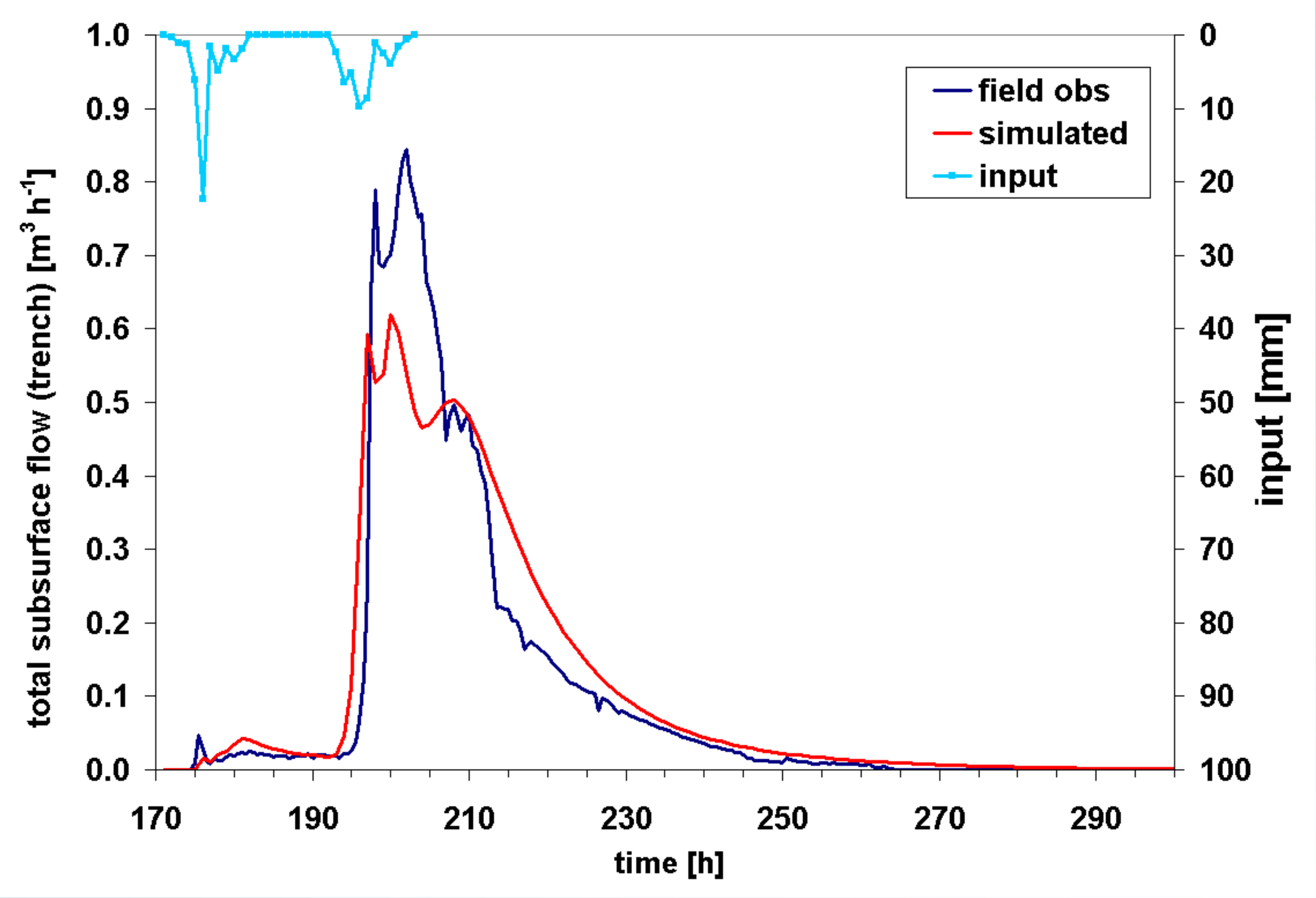
subsurface topography with bedrock



Original storm event

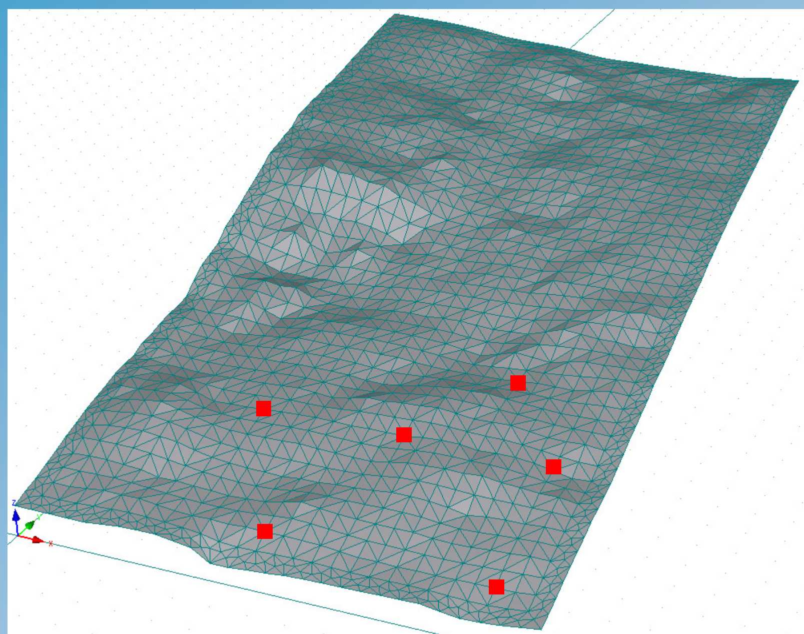


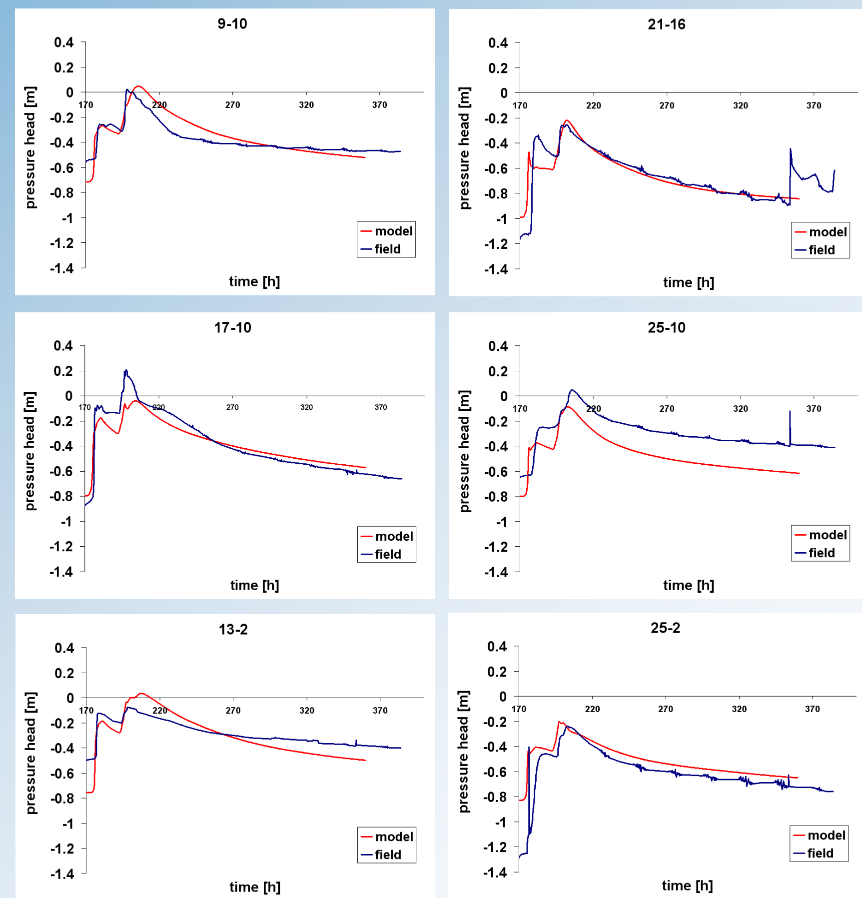
Calibration



Evaluation

- Evaluation against tensiometer data (0.5-0.6 m below surface)

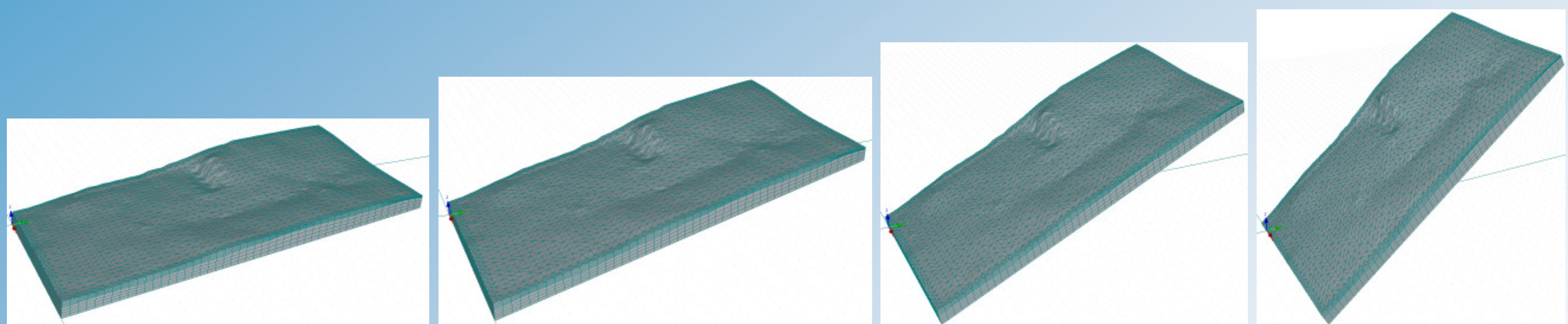


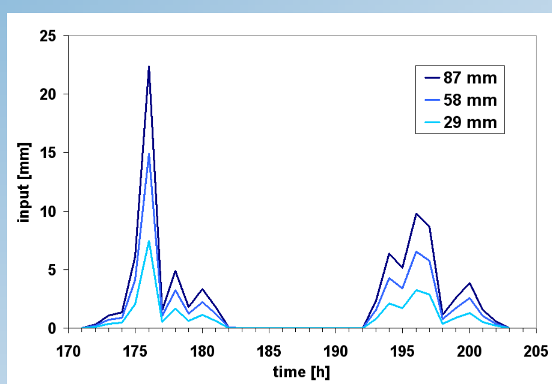


→ model setup is capturing major internal flow behavior

Variation of control factors

	Low	**M**edium	**H**igh	**v**ery **H**igh
Soil depth (mean)	0.624 m	0.91 m	1.21 m	-
Difference K_s soil-bedrock	10^1	10^2	-	-
Slope angle	6.5°	13°	26°	40°
Storm size	29 mm	58 mm	87 mm	-





K_s(soil) 0.65 m h^{-1} – K_s(bedrock) 0.006 m h^{-1}

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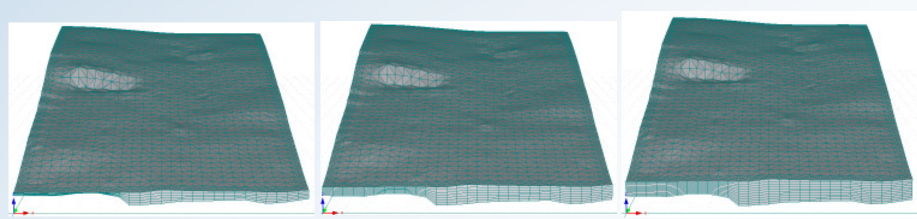
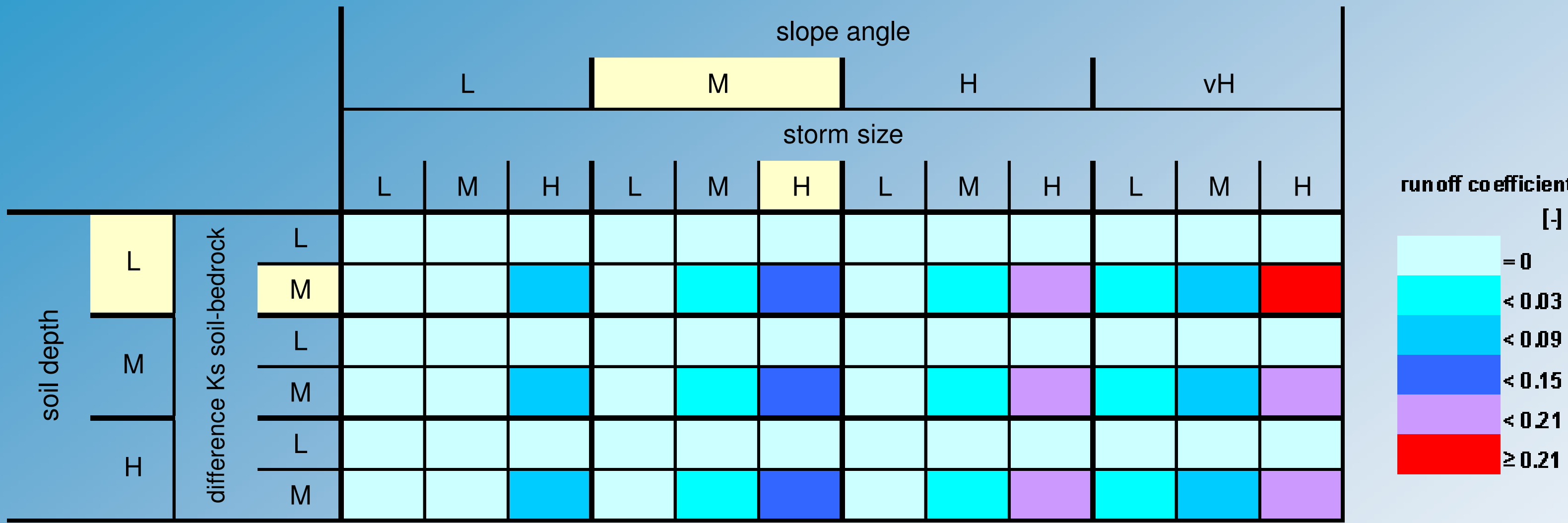


Hydrologic response characteristics

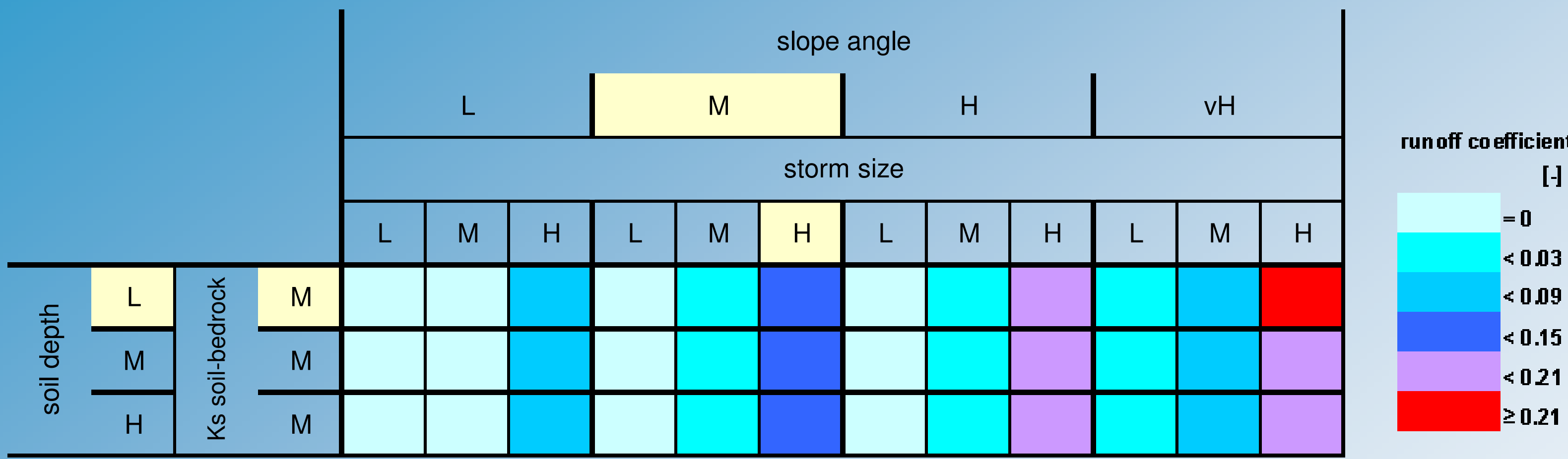
- Results are evaluated with respect to characteristics of hydrologic response
  - Runoff coefficient
  - time to peak
  - duration of total subsurface flow (SSF)
  - peak discharge
  - variability of trench section contribution to total SSF
  - variability of peak discharge in each trench section

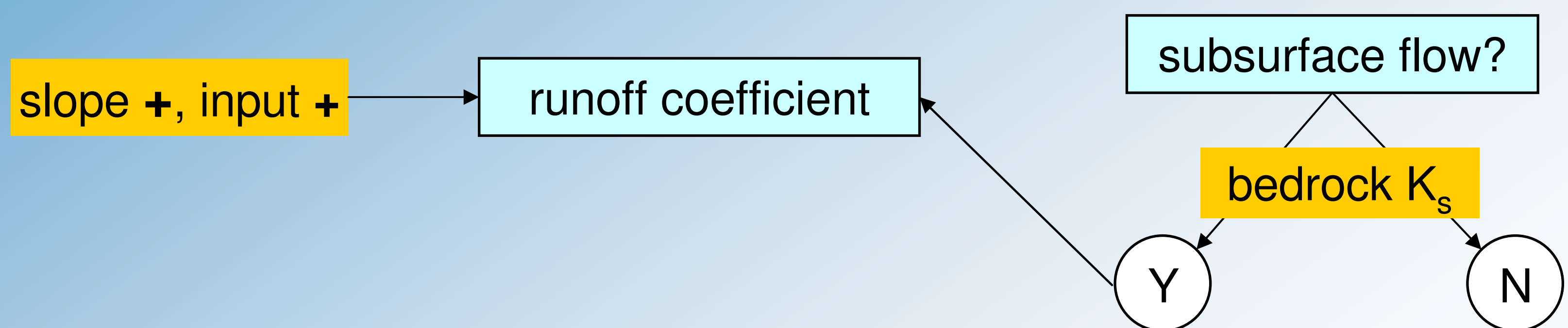
		slope angle											
		L			M			H			vH		
		storm size											
soil depth	difference Ks soil-bedrock	L	M	H	L	M	H	L	M	H	L	M	H
L	L												
L	M												
M	L												
M	M												
H	L												
H	M												

Runoff coefficient

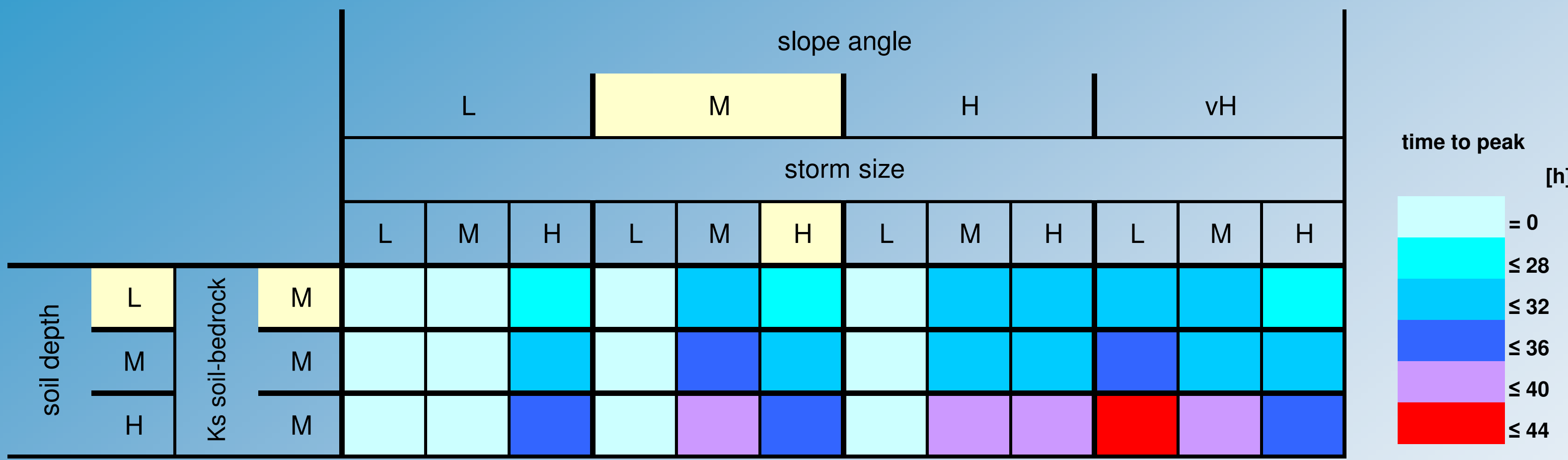


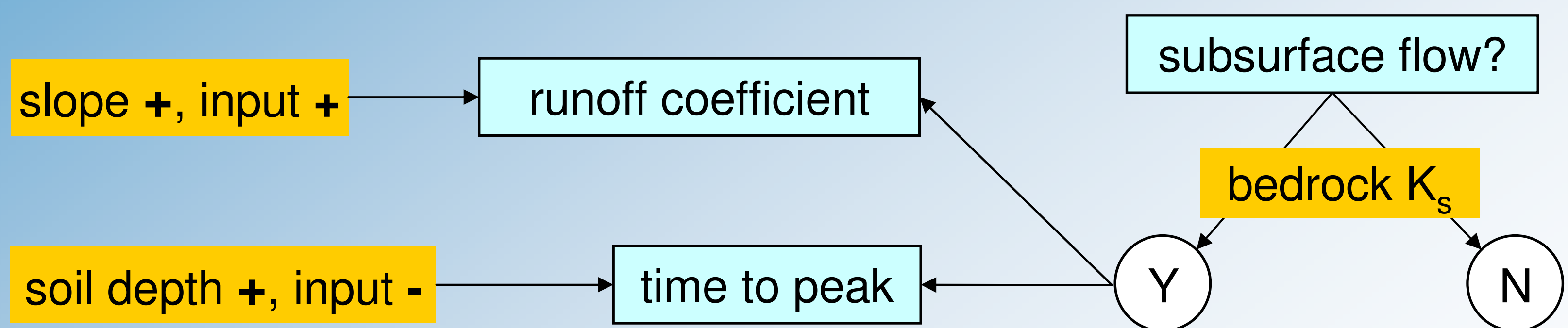
Runoff coefficient



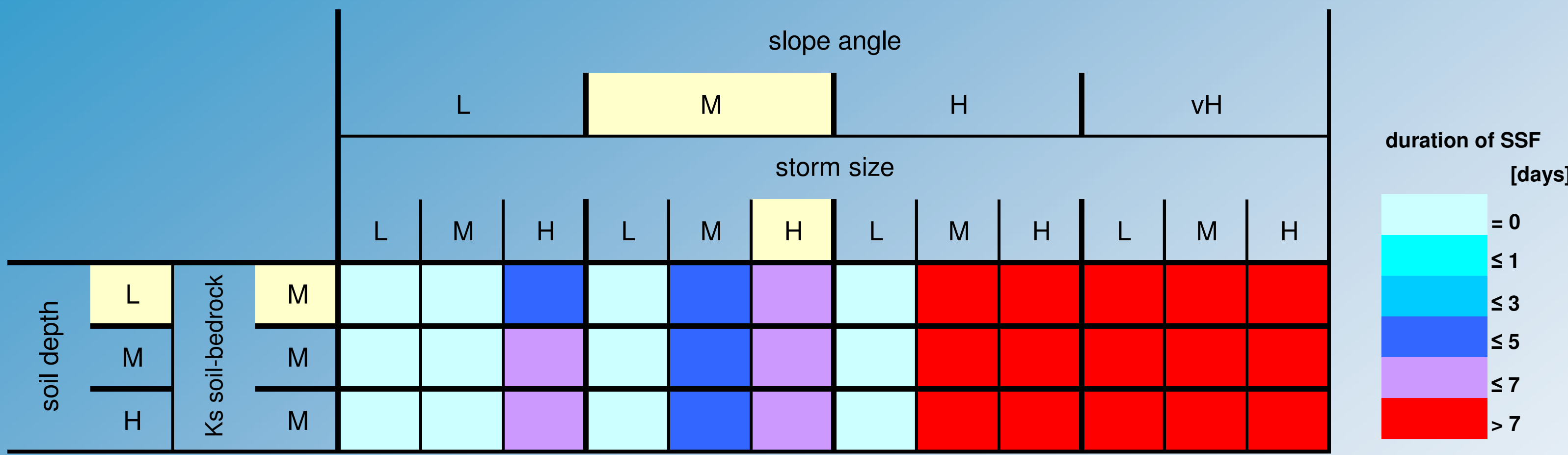


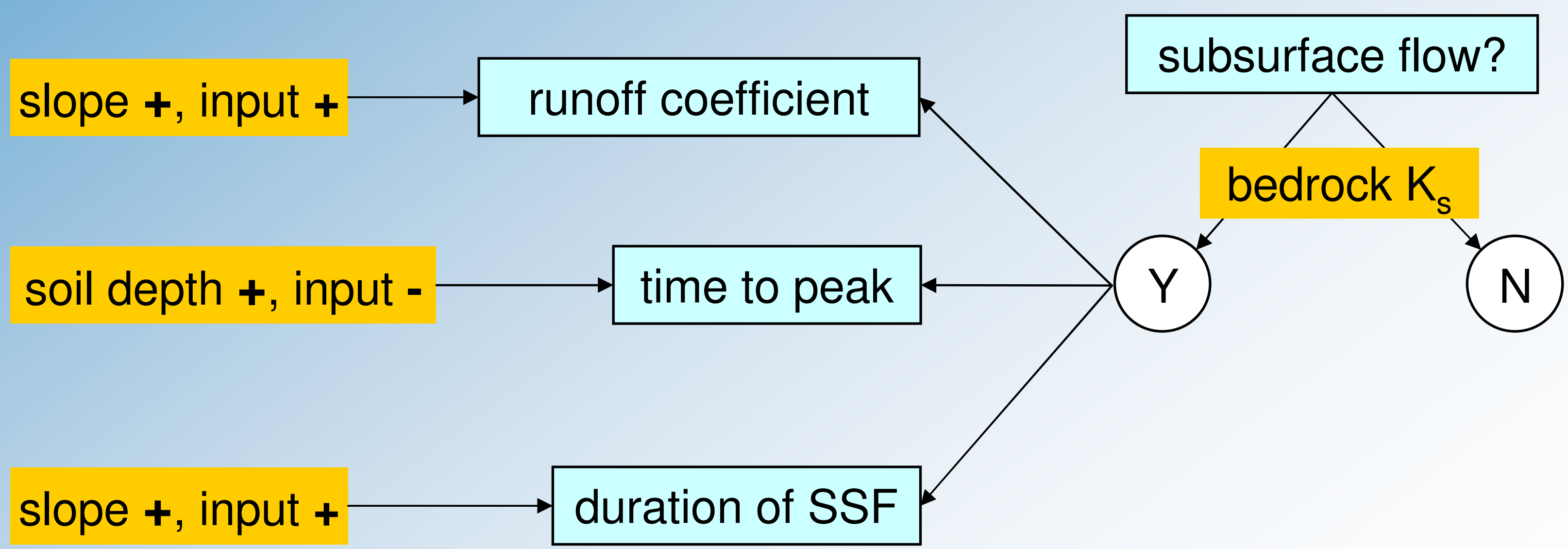
Time to peak


slope angle
L
M
H
vH
storm size
L
M
H
L
M
H
L
M
H
L
M
H
soil depth
L
M
H
Ks soil-bedrock
M
M
M
time to peak
[h]
= 0
≤ 28
≤ 32
≤ 36
≤ 40
≤ 44

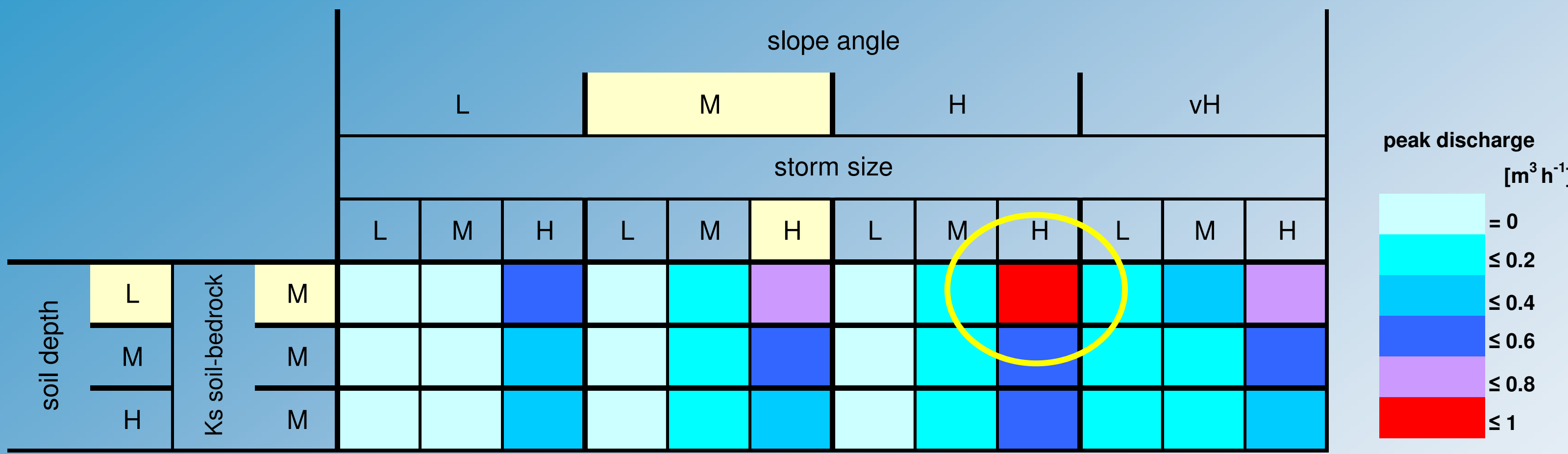

slope +, input +
runoff coefficient
subsurface flow?
bedrock K_s
Y
N
soil depth +, input -
time to peak

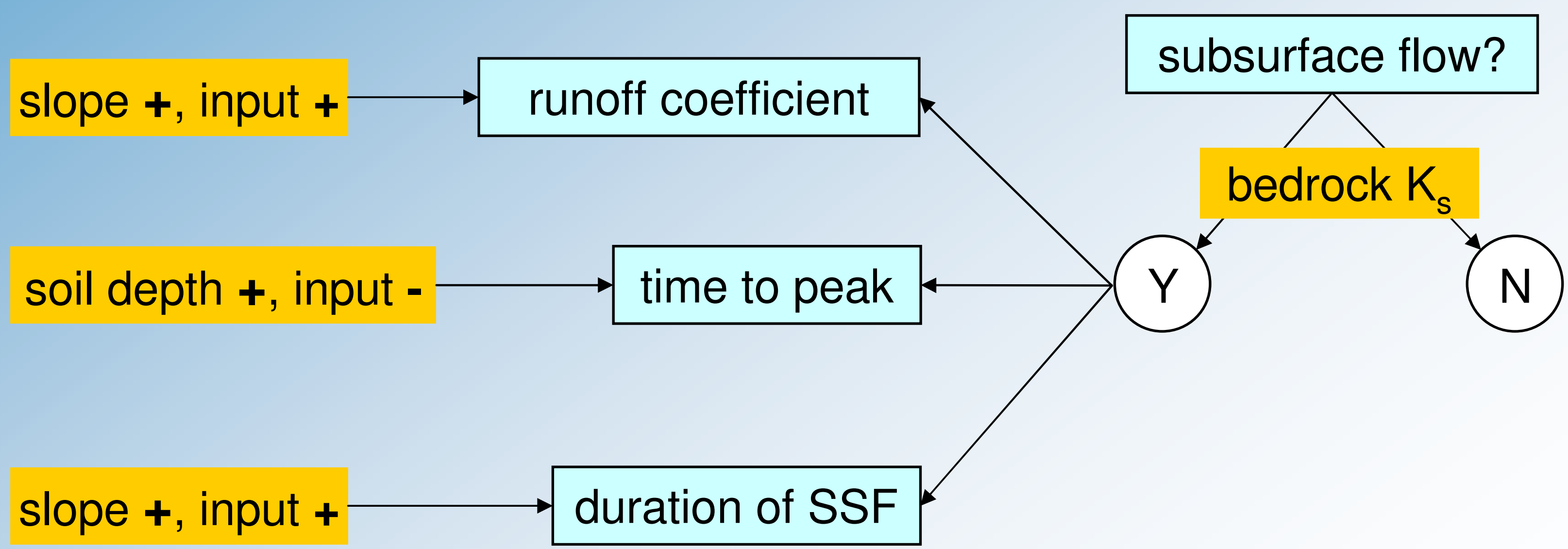
Duration of subsurface flow



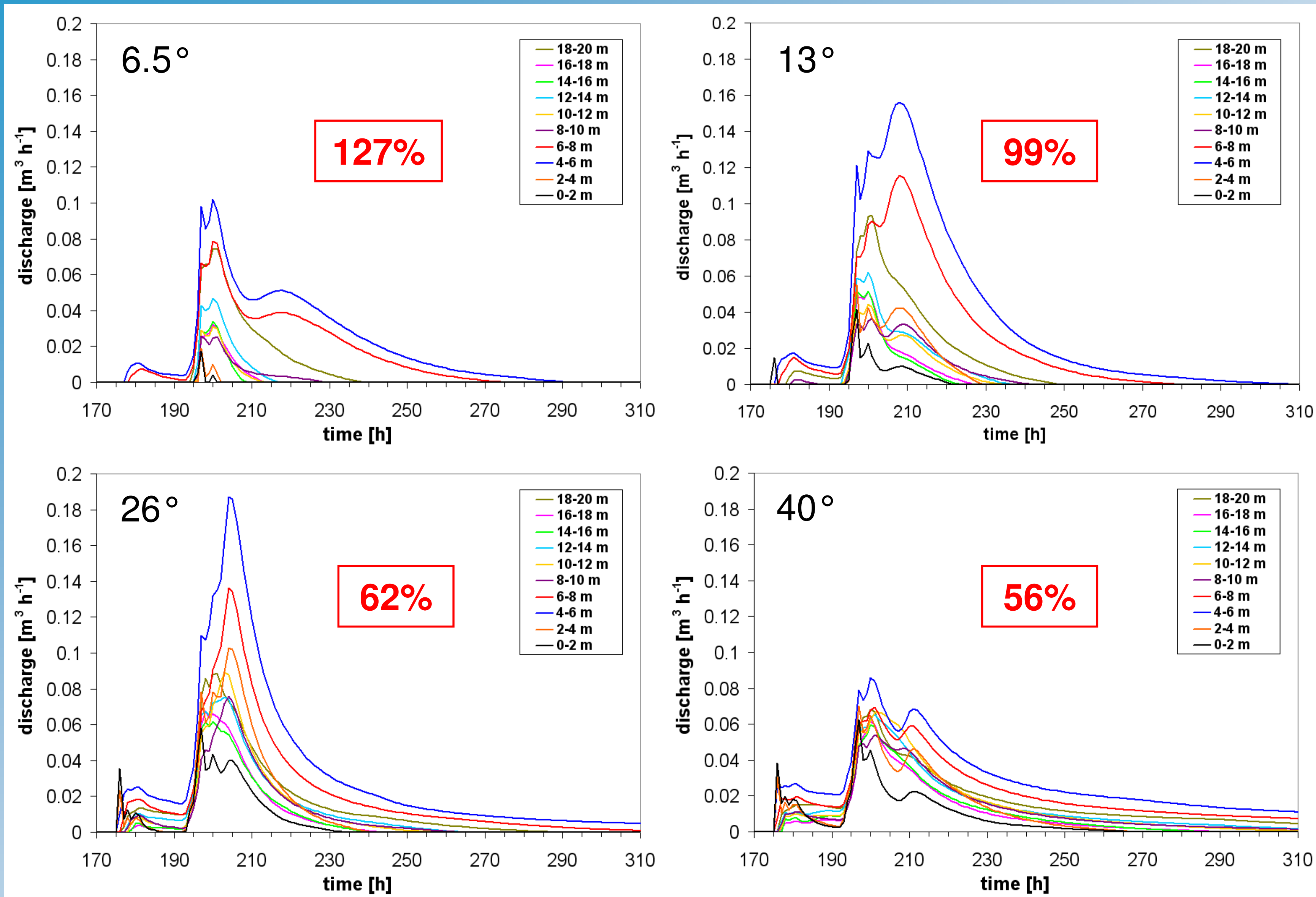


Peak discharge

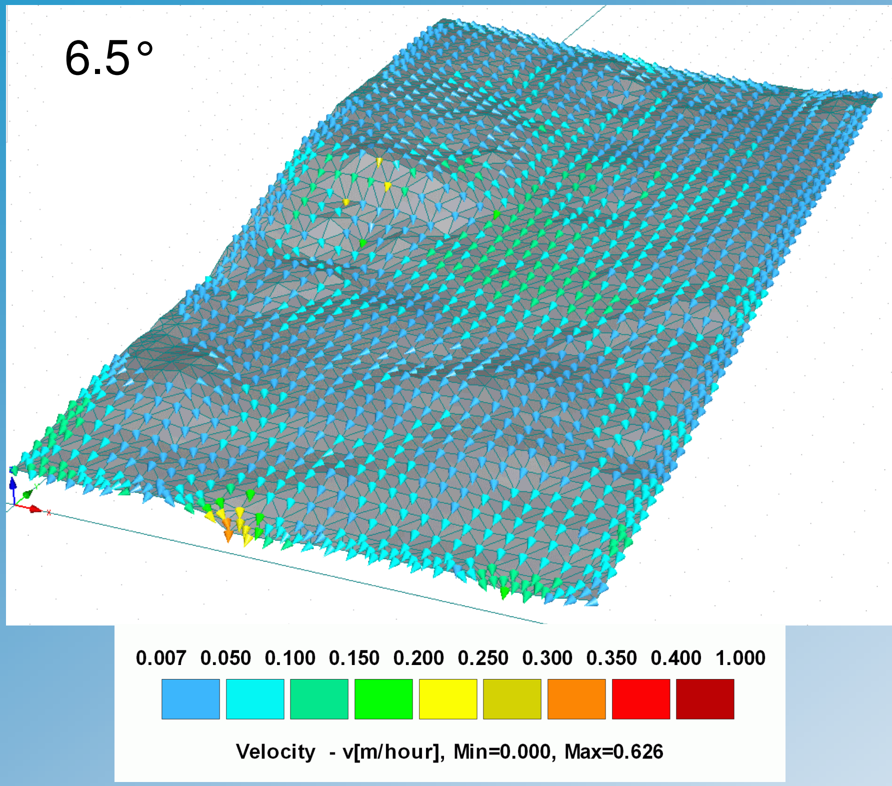


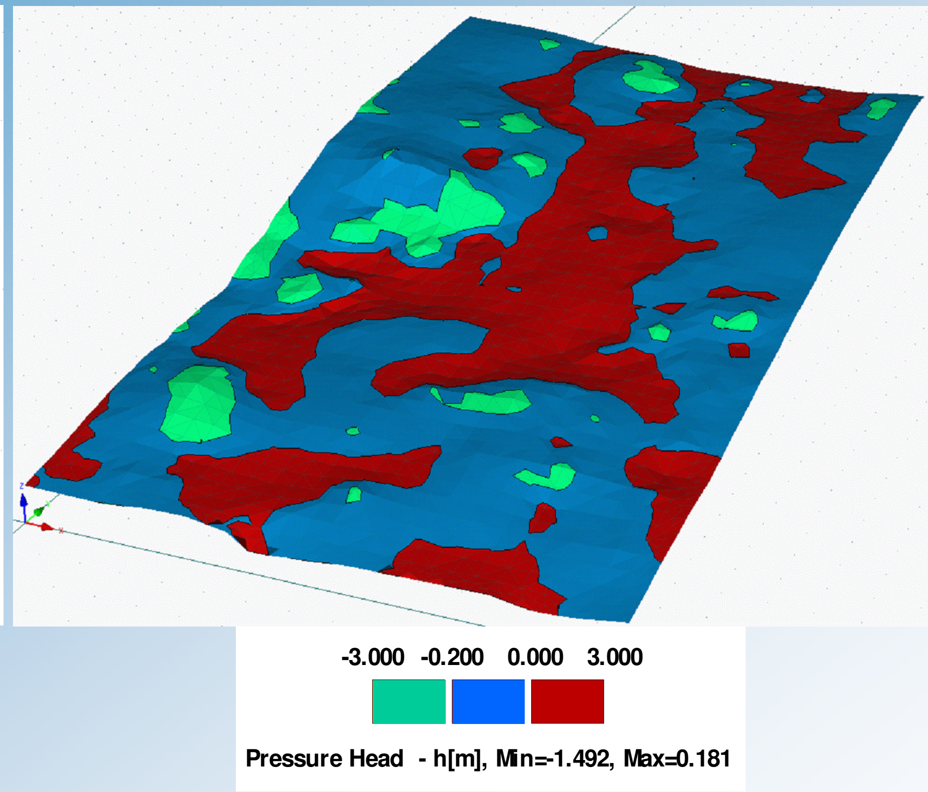


Slope variations - Subsurface flow in 2 m sections

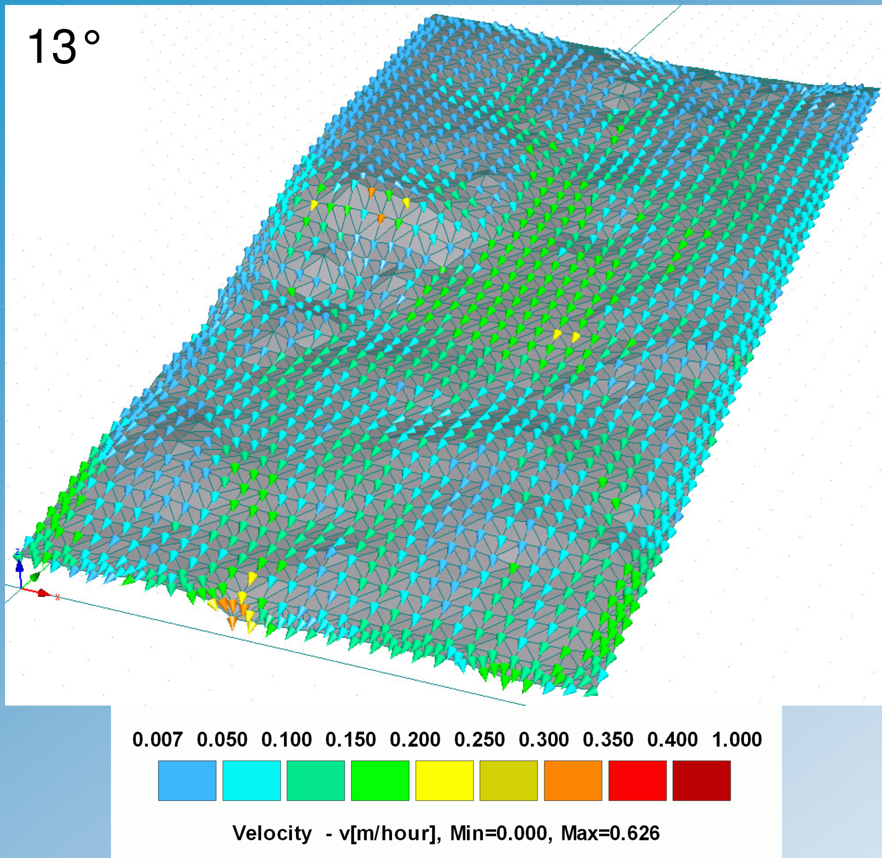


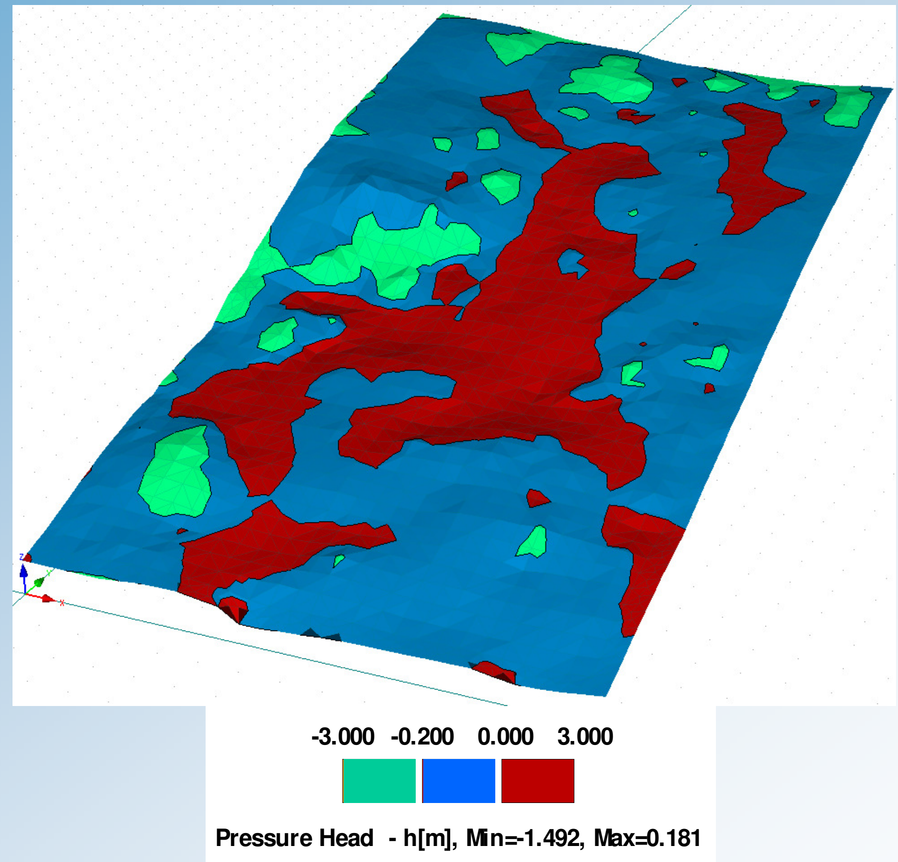
Flow velocities and saturation



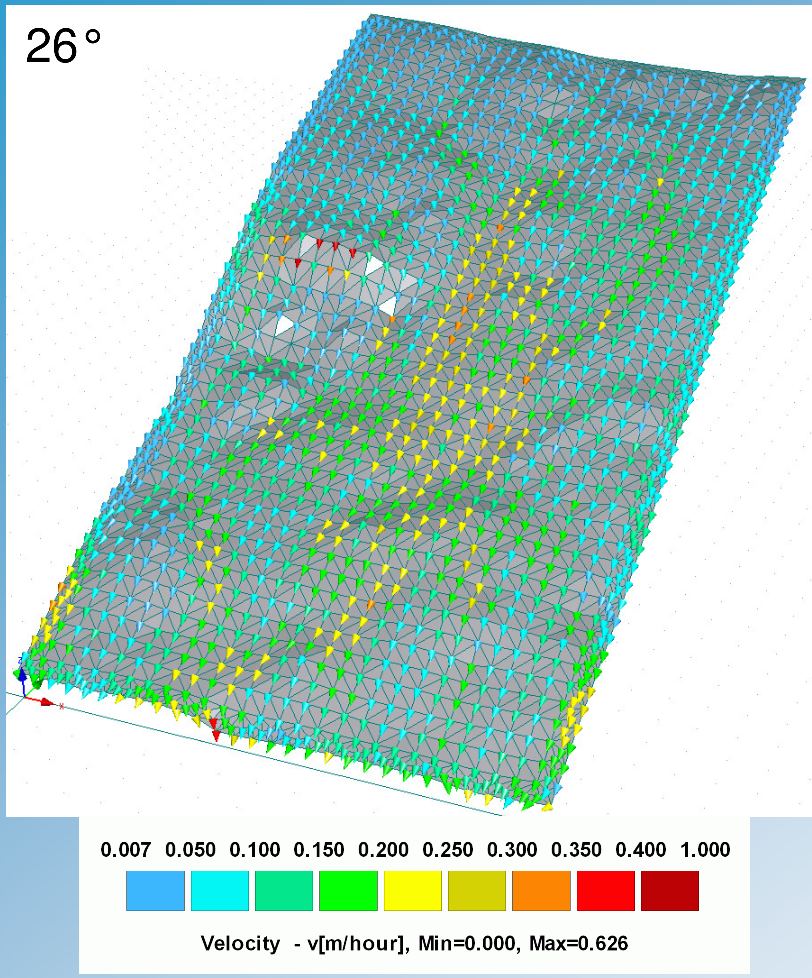


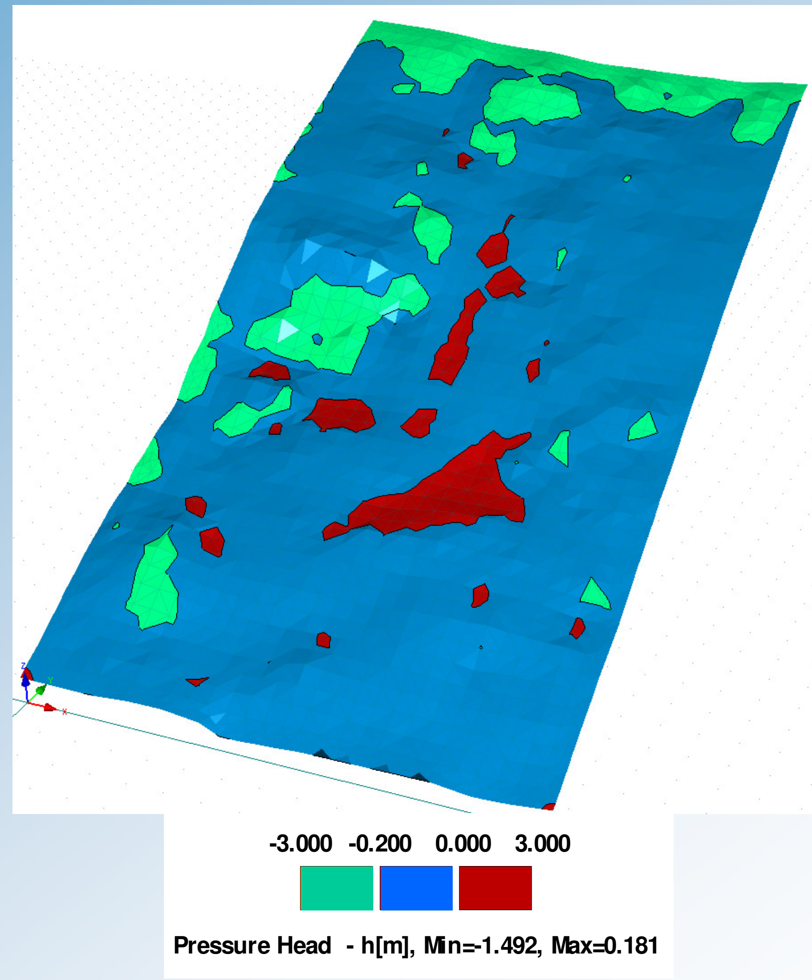
Flow velocities and saturation



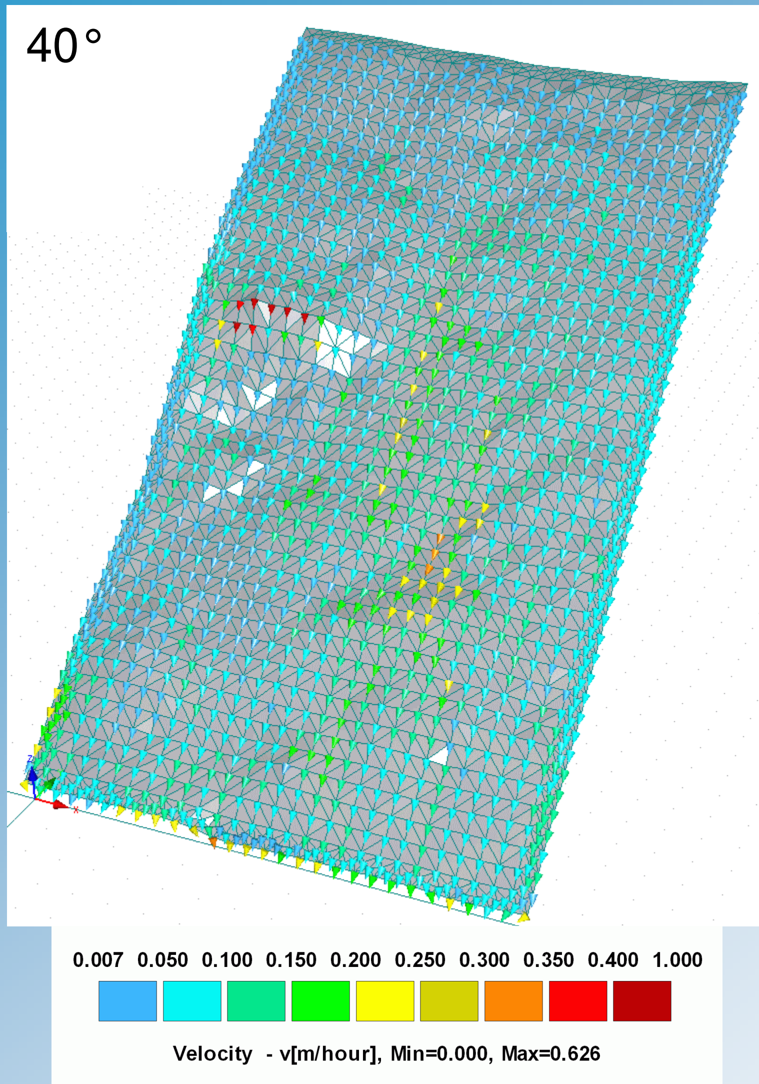


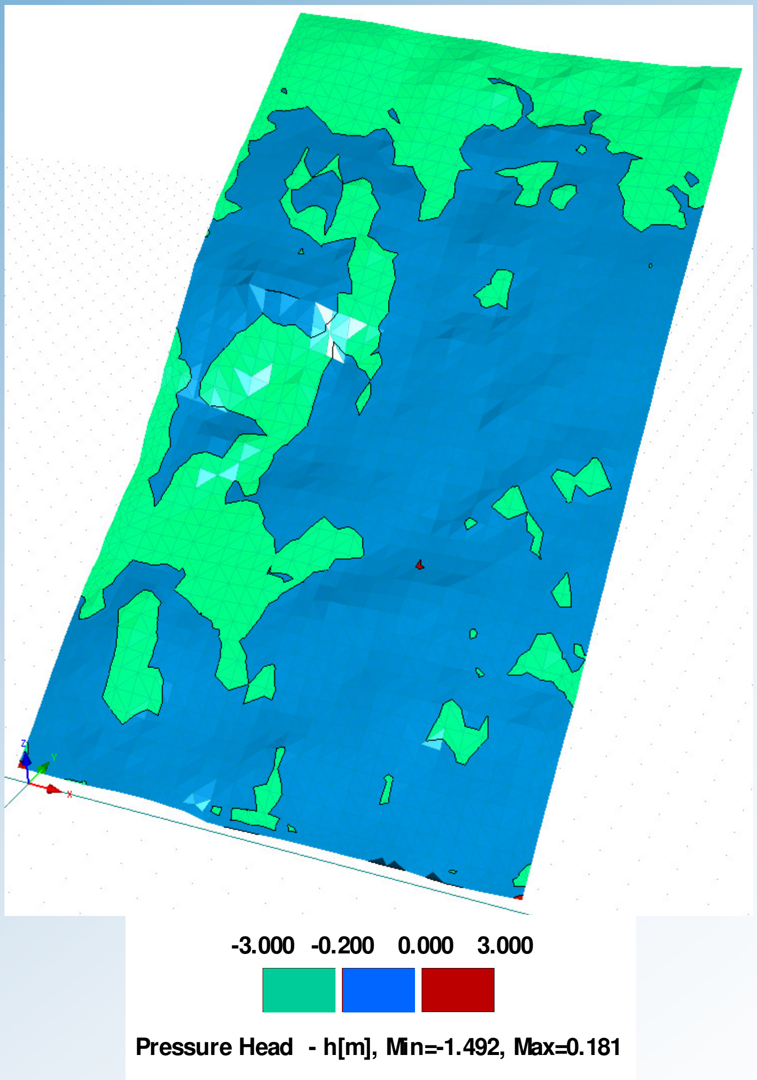
Flow velocities and saturation



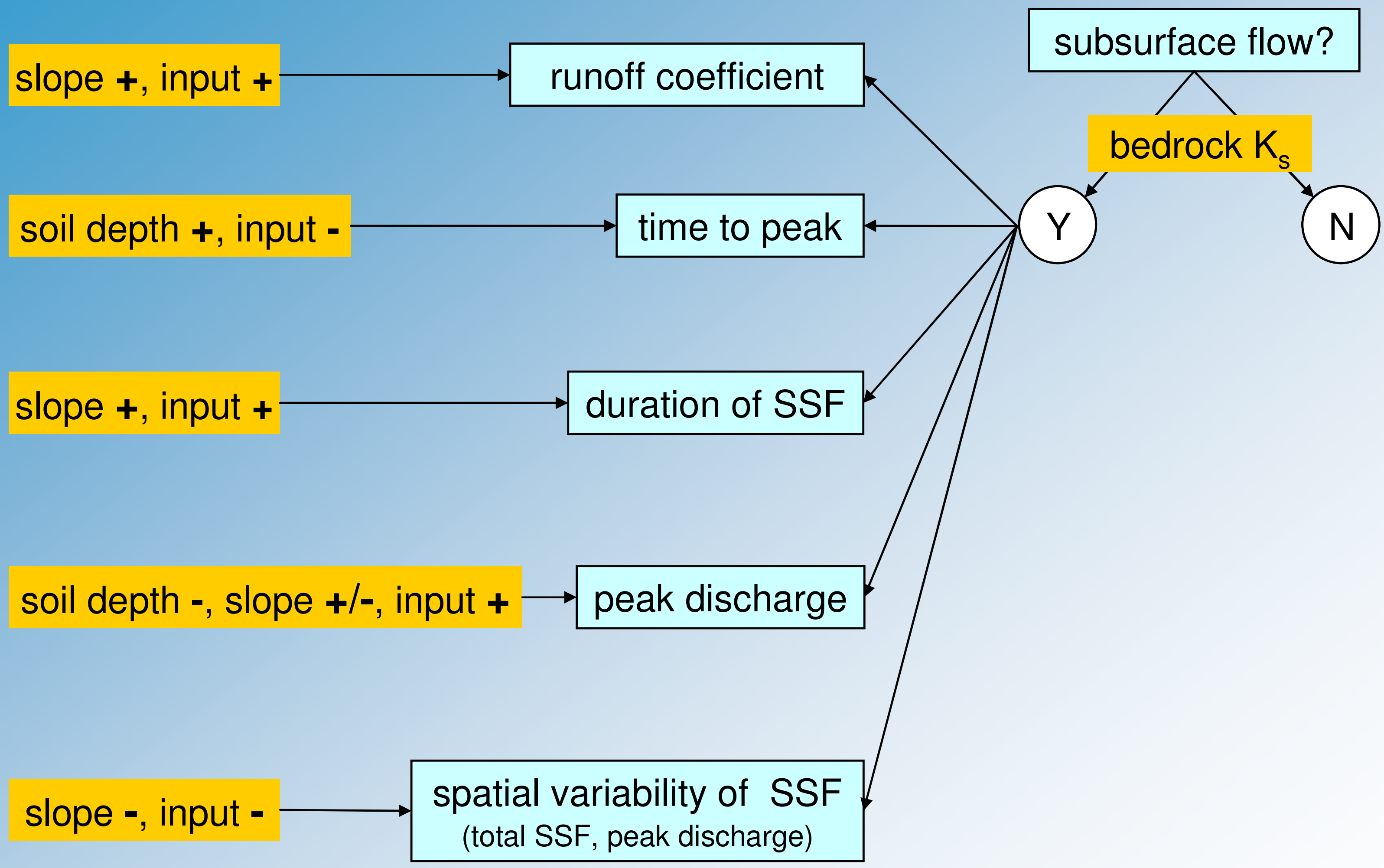


Flow velocities and saturation



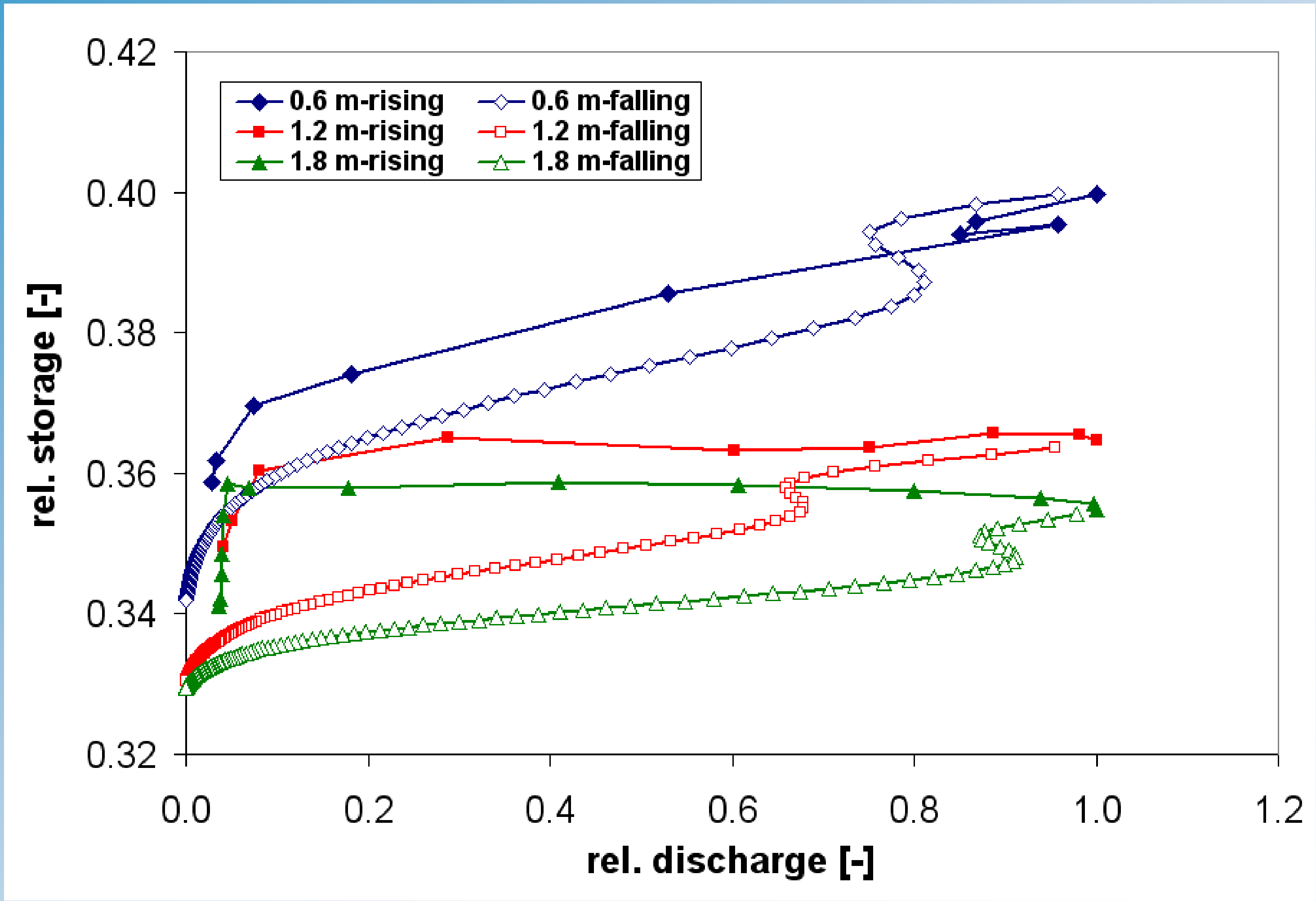


Controls on subsurface flow



Soil depth variations: storage-discharge relationship

- Slope 13 °, storm size 87 mm



ongoing work…

Conclusions

- The virtual experiment approach with HYDRUS 3D was helpful in exploring the factors that control lateral subsurface flow generation at the hillslope scale
- Bedrock permeability is a key factor for inducing lateral subsurface flow
- Soil depth leads to a dampening of the hydrologic response
- Complex interaction between topography and slope controlling subsurface saturation, flow paths, velocities and spatial variability
- Ongoing work is exploring the storage-discharge relationship and how it is affected by control factors