‘Anomalies’ in the Meuse/Moselle behaviour

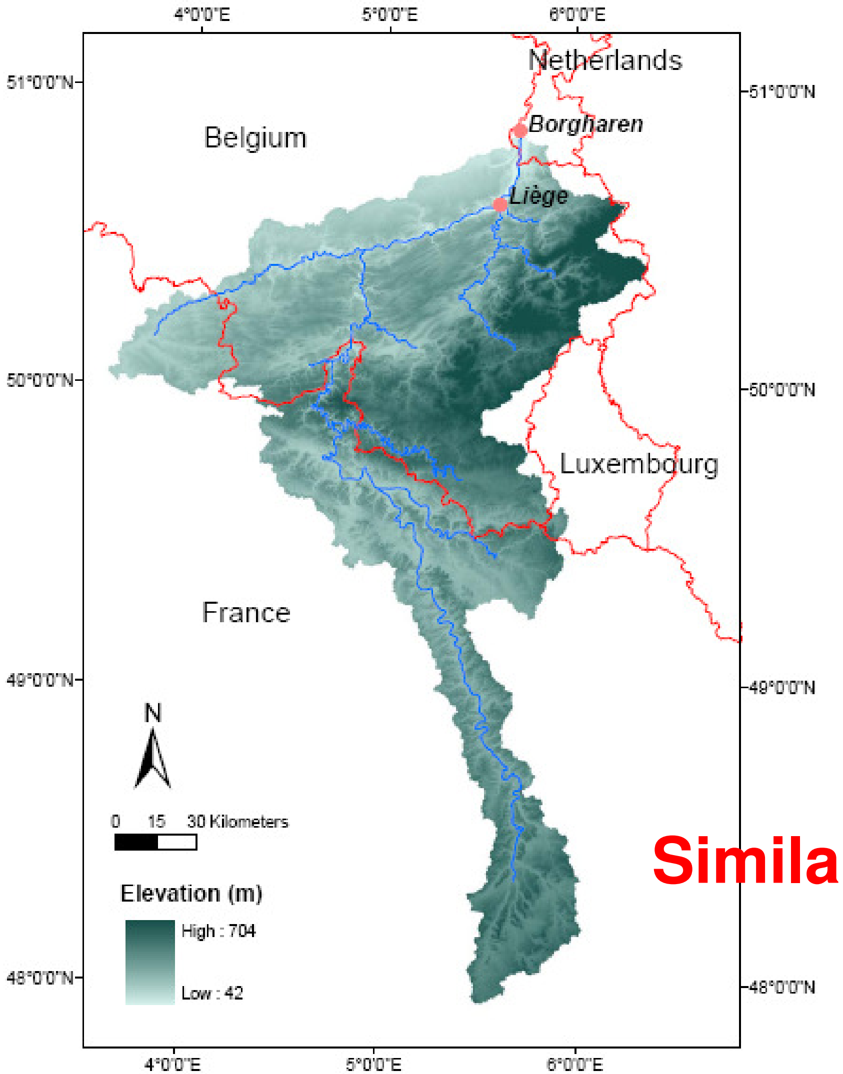
Or how to model flood events

TU Delft

by: Hubert H.G. Savenije

Professor of Hydrology, Delft University of Technology
Chair National Committee for IAHS, The Netherlands
Chair National Committee of Unesco-IHP, The Netherlands
Chair of the Netherlands Hydrological Society (NHV)

Anomaly ?



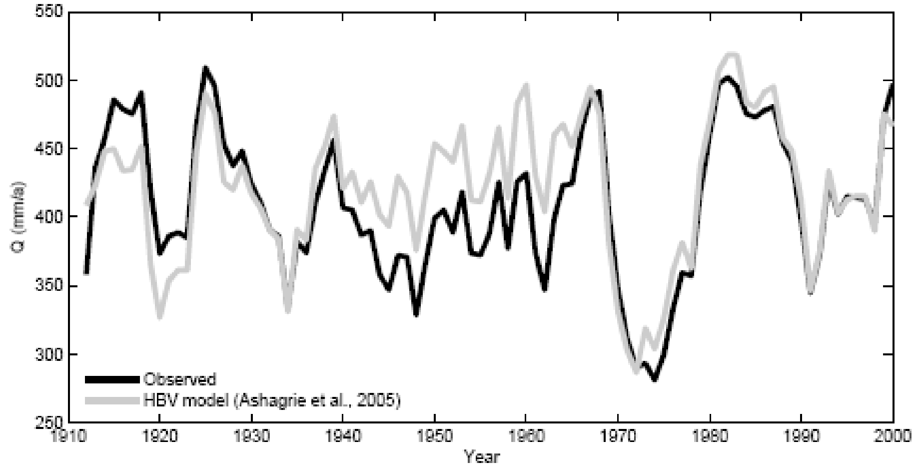


Fig. 2. Comparison of observed and simulated hydrograph after Ashagrie et al. (2006). The observed discharge appears to be considerably overestimated in the central part of the observation period.

Similar 'anomaly' in the Moselle/Mosel

Hydrol. Earth Syst. Sci., 13, 1727–1737, 2009
www.hydrol-earth-syst-sci.net/13/1727/2009/

Hydrology and Earth System Sciences

Anomaly in the rainfall-runoff behaviour of the Meuse catchment. Climate, land-use, or land-use management?

F. Fenicia[1,2], H. H. G. Savenije[1], and Y. Avdeeva[1]

[1]Water Resources Section, Faculty of Civil Engineering and Geosciences, Delft University of Technology, P.O. Box 5048, 2600 GA Delft, The Netherlands
[2]Centre de Recherche Public – Gabriel Lippmann, Belvaux, Luxembourg

Conceptual Model

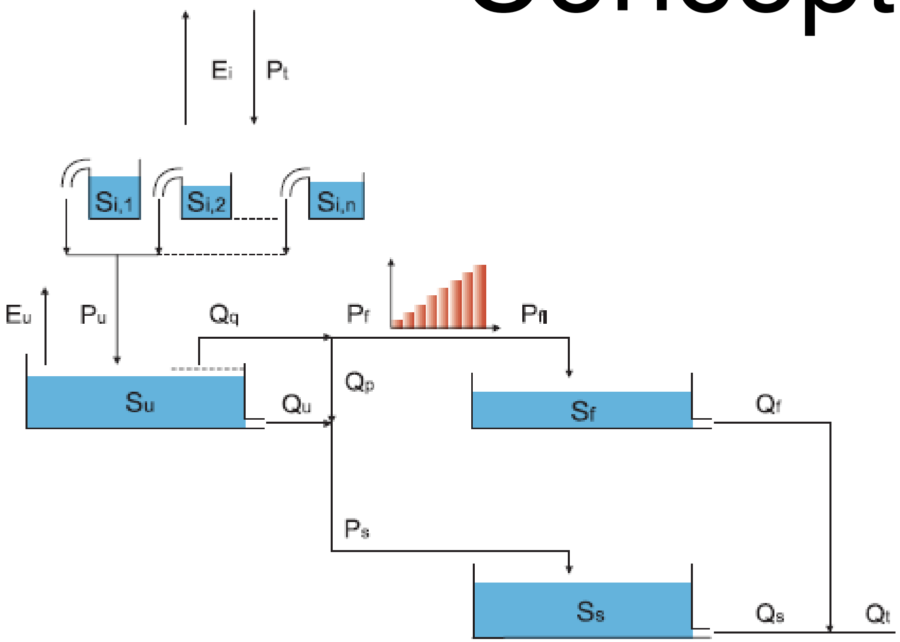


Fig. 4. Schematic representation of the FLEX model.

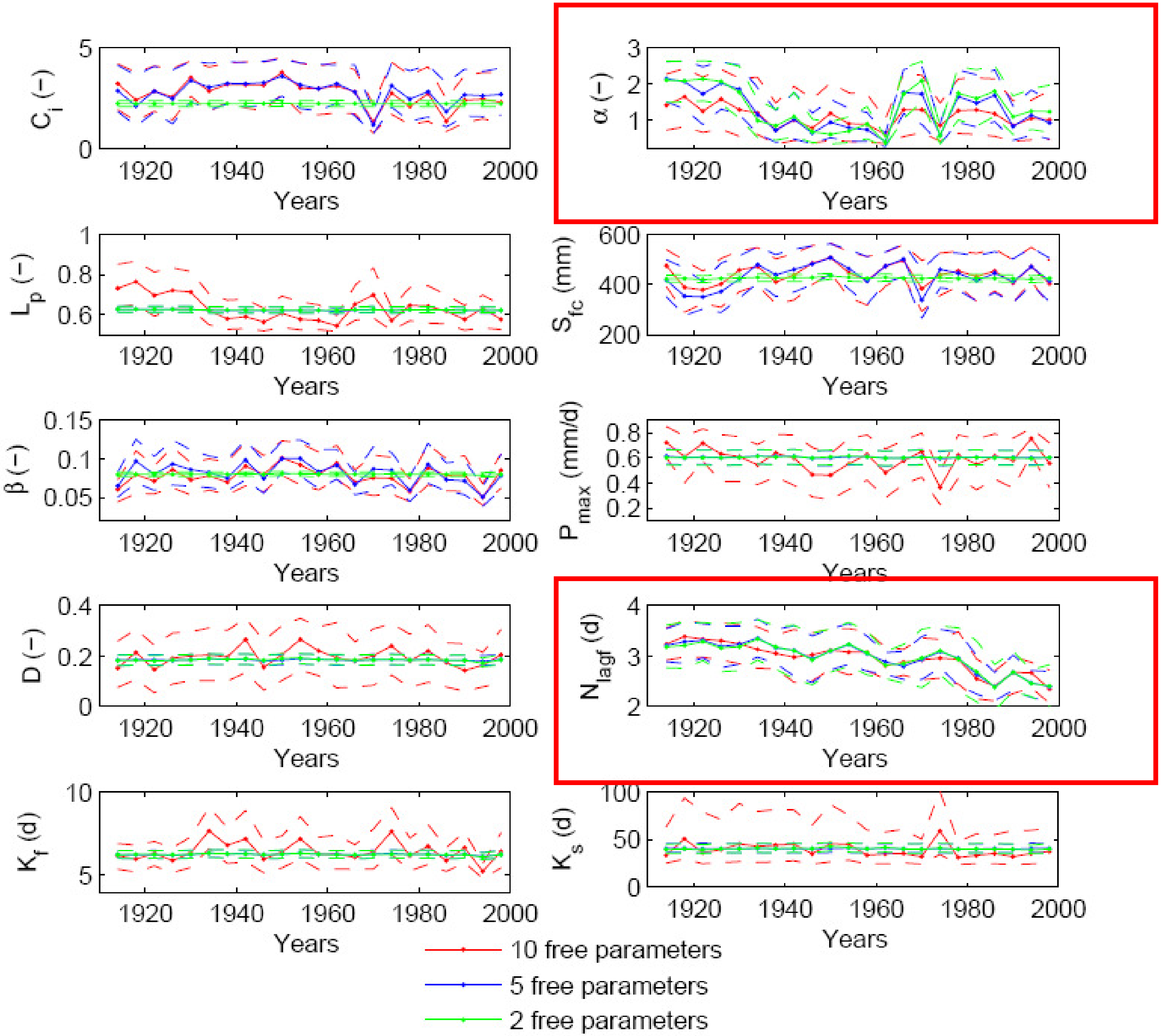
Table 1. Interception threshold varies between I_{max} and I_{min}.

Land-use	I_{max} (mm)	I_{min} (mm)
Urban	1	1
Pasture	2	2
Agriculture	3	1
Deciduous	3	1
Coniferous	3	3

Penman Monteith Equation

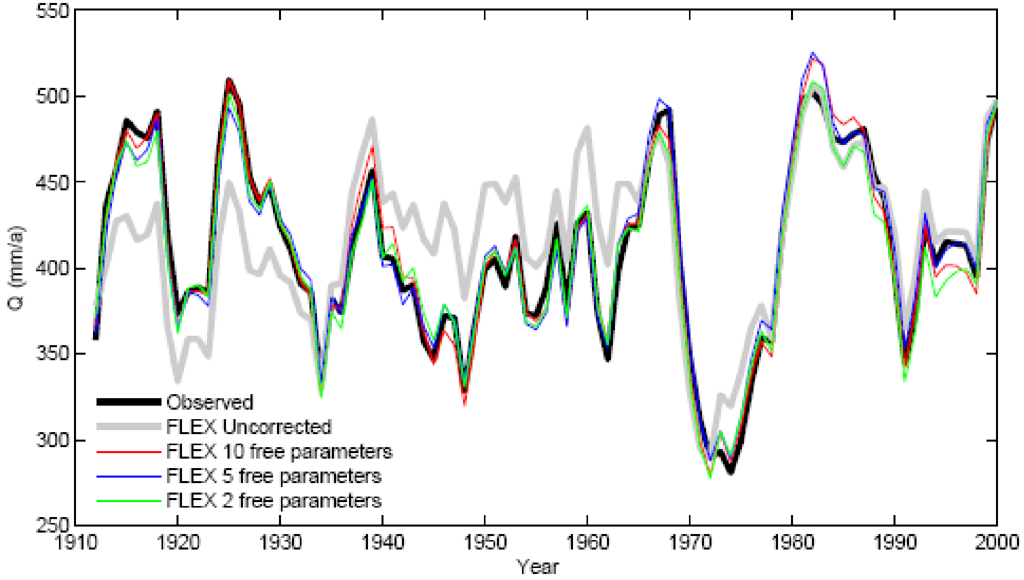
$$E_p = \frac{1}{\lambda \rho_w} \frac{s R_n + c_p \rho_a (e_a - e_d)/r_a}{s + \gamma (1 + \alpha r_c / r_a)}$$

Parameter	Description	Units
E_p	Potential evaporation	m/s
λ	Latent heat coefficient	J/kg
ρ_w	Density of water	kg/m^3
R_n	Net radiation	W/m^2
s	Slope of the temperature-saturation vapour pressure curve	kPa/K
c_p	Specific heat of air at constant pressure	J/(kg K)
ρ_a	Density of air	kg/m^3
e_d	Actual vapour pressure of the air	kPa
e_a	Saturation vapour pressure for the air temperature	kPa
γ	Psychrometric constant	kPa/K
r_a	Aerodynamic resistance	s/m
r_c	(Bulk) surface resistance	s/m
α	Stomatal resistance coefficient	–

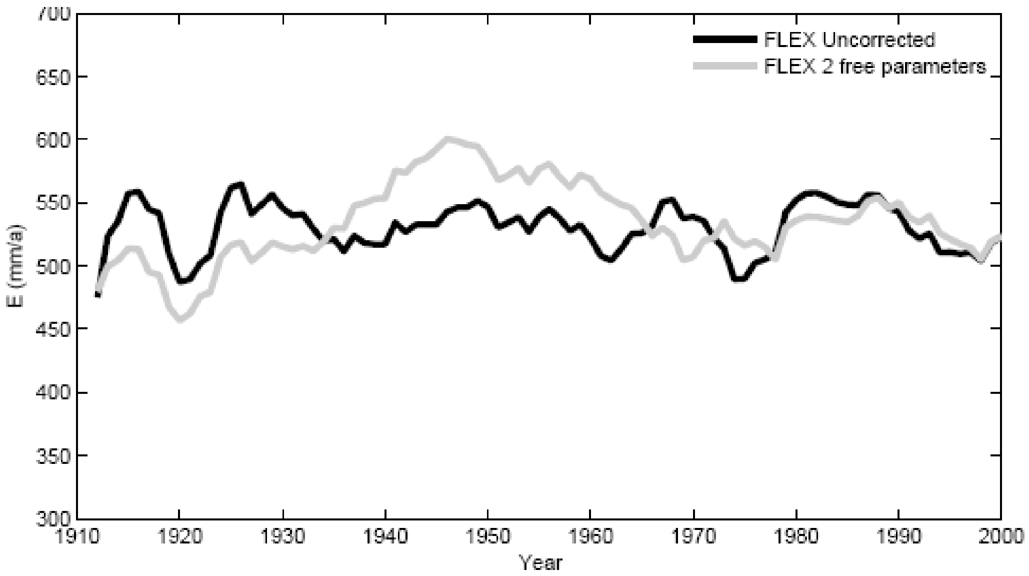


C_i (−)
α (−)
L_p (−)
S_{fc} (mm)
β (−)
P_{max} (mm/d)
D (−)
N_{lagf} (d)
K_f (d)
K_s (d)
Years
1920
1940
1960
1980
2000
10 free parameters
5 free parameters
2 free parameters

Anomaly disappeared



Anomaly disappeared by time-variable Lag Time and Evaporation conductivity factor



Real evaporation was substantially larger during industrial period of active forestry

Is this proof ?

- No, it is an indication that land management is as important as land use in hydrology
- It shows that forests and agriculture are key to the hydrology (and water quality) of the Meuse

What about climate and land-use effects on Floods ?

Do we understand flood generating processes sufficiently?

Threshold processes in Physics

- Heat transport driven by heating
  - molecular diffusion
  - convective transport
  - turbulent transport
  - boiling

Hydrol. Earth Syst. Sci., 13, 1273–1297, 2009
www.hydrol-earth-syst-sci.net/13/1273/2009/

Hydrology and Earth System Sciences

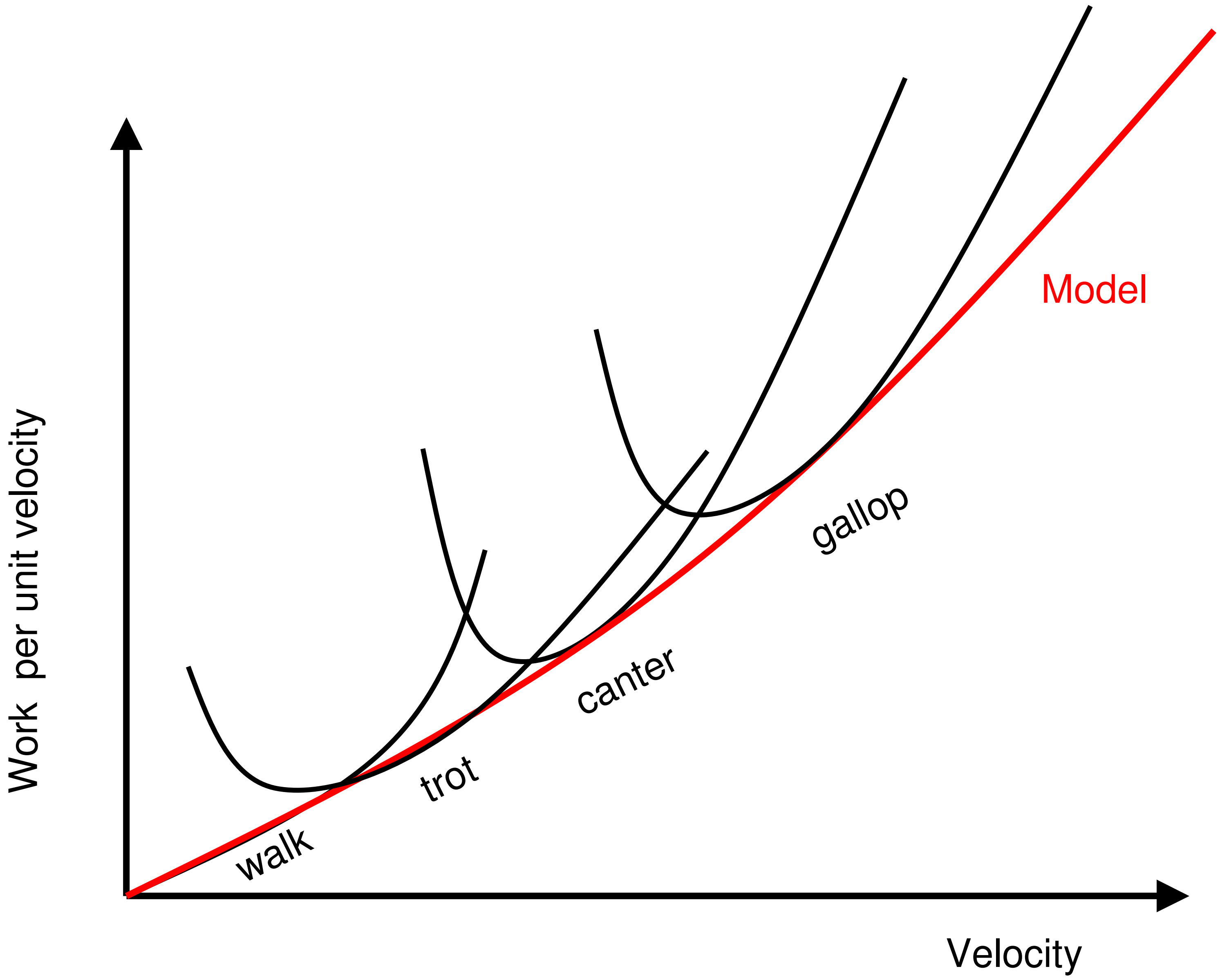
Zehe & Sivapalan (2009)
HESS

Threshold behaviour in hydrological systems as (human) geo-ecosystems: manifestations, controls, implications

E. Zehe[1] and M. Sivapalan[2,3]

[1]Institute of Water and Environment, Department of Hydrology and River Basin Management, Technische Universität München, Arcisstrasse 21, 80330 Munich, Germany
[2]University of Illinois at Urbana-Champaign, Departments of Geography and Civil and Environmental Engineering, 220 Davenport Hall, 607 South Mathews Avenue, Urbana, IL 61801, USA
[3]Department of Water Management, Faculty of Civil Engineering, Delft University of Technology, P.O. Box 5048, 2600 GA Delft, The Netherlands


walk
trot
canter
gallop


Model
gallop
canter
trot
walk
Work per unit velocity
Velocity

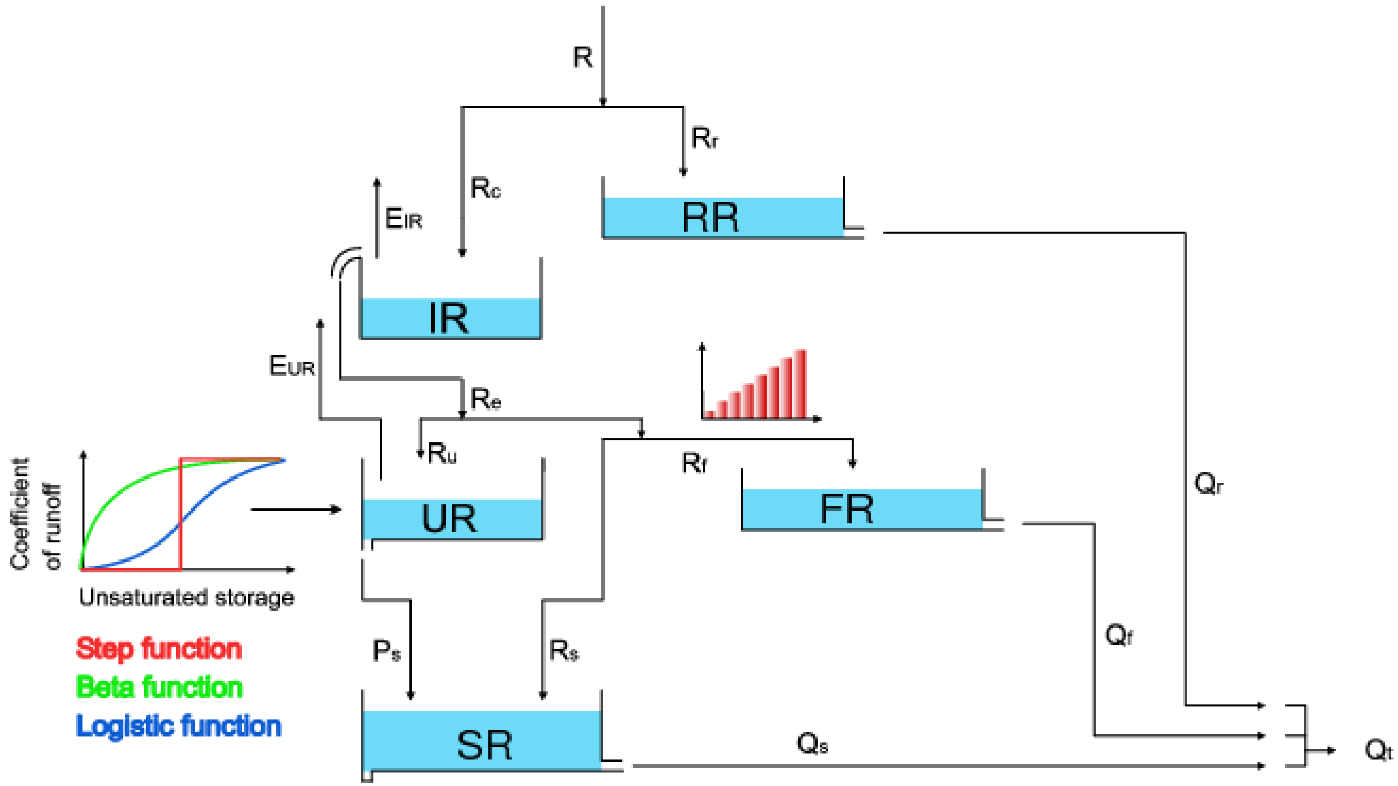
Knowledge questions

- We don’t fully understand the mechanisms
- We don’t know when a certain mechanism is dominant, or when the switches take place
- We don’t know the triggers for the switches
- We don’t know what happens when the entire system switches into “gallop”

Knowledge questions (2)

- Rainfall-runoff processes are complex: a multitude of processes,
- Heterogeneity, need for calibration
- Equifinality, undeterminable parameters
- Site specific combinations of processes and properties ('races')

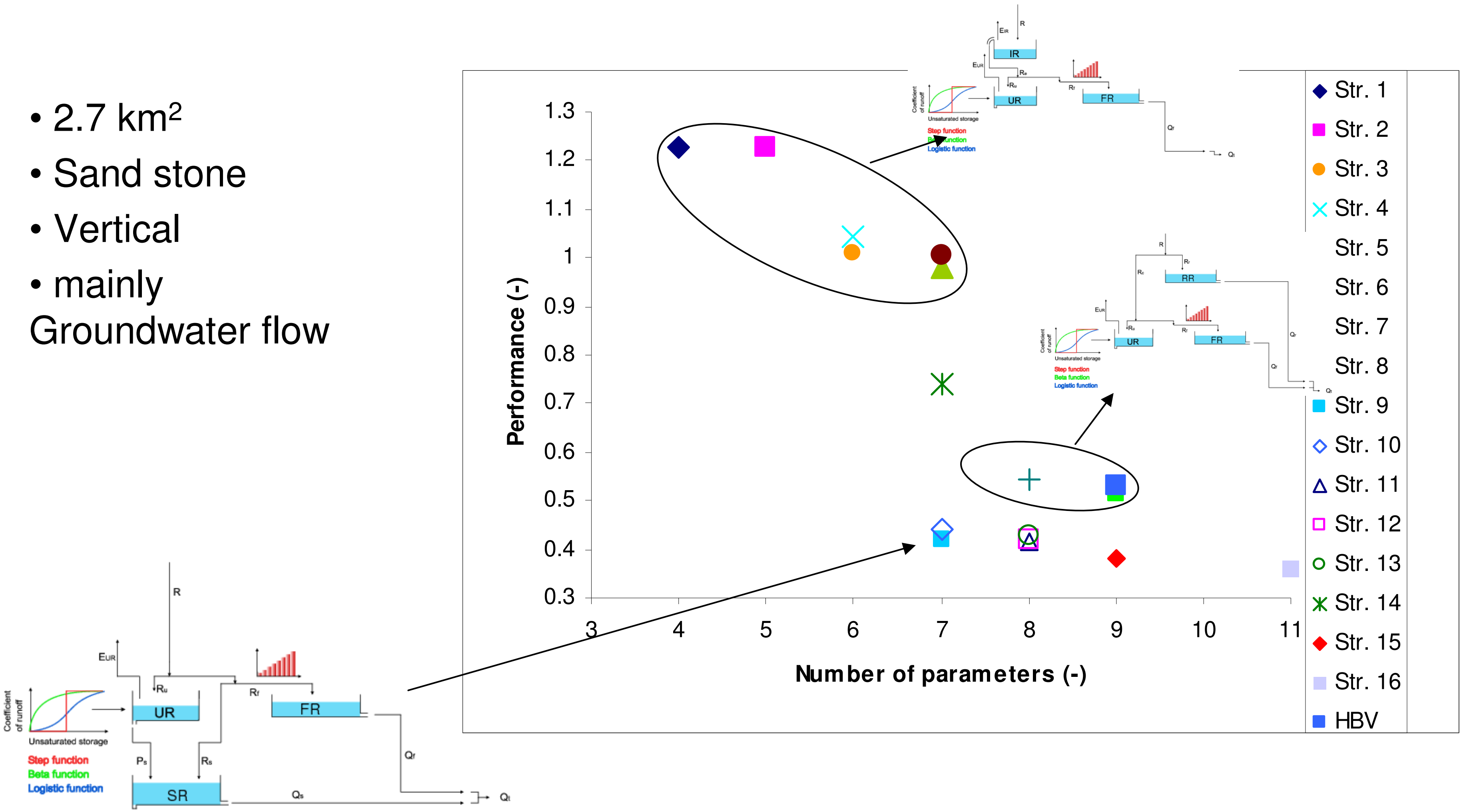
A multitude of mechanisms



Fenicia et al. (2008)
Water Resources Research

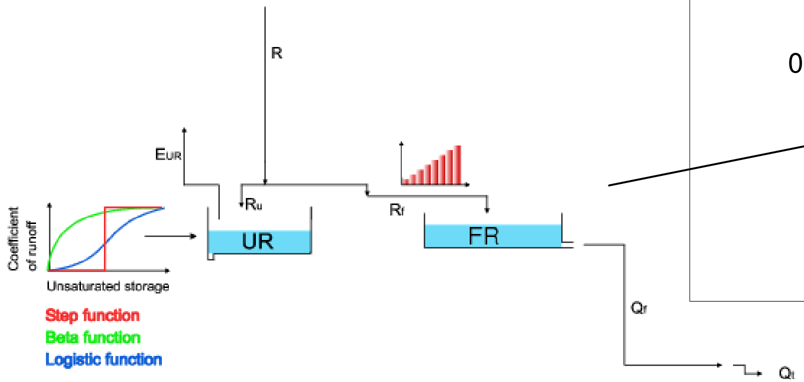
Huewellerbach

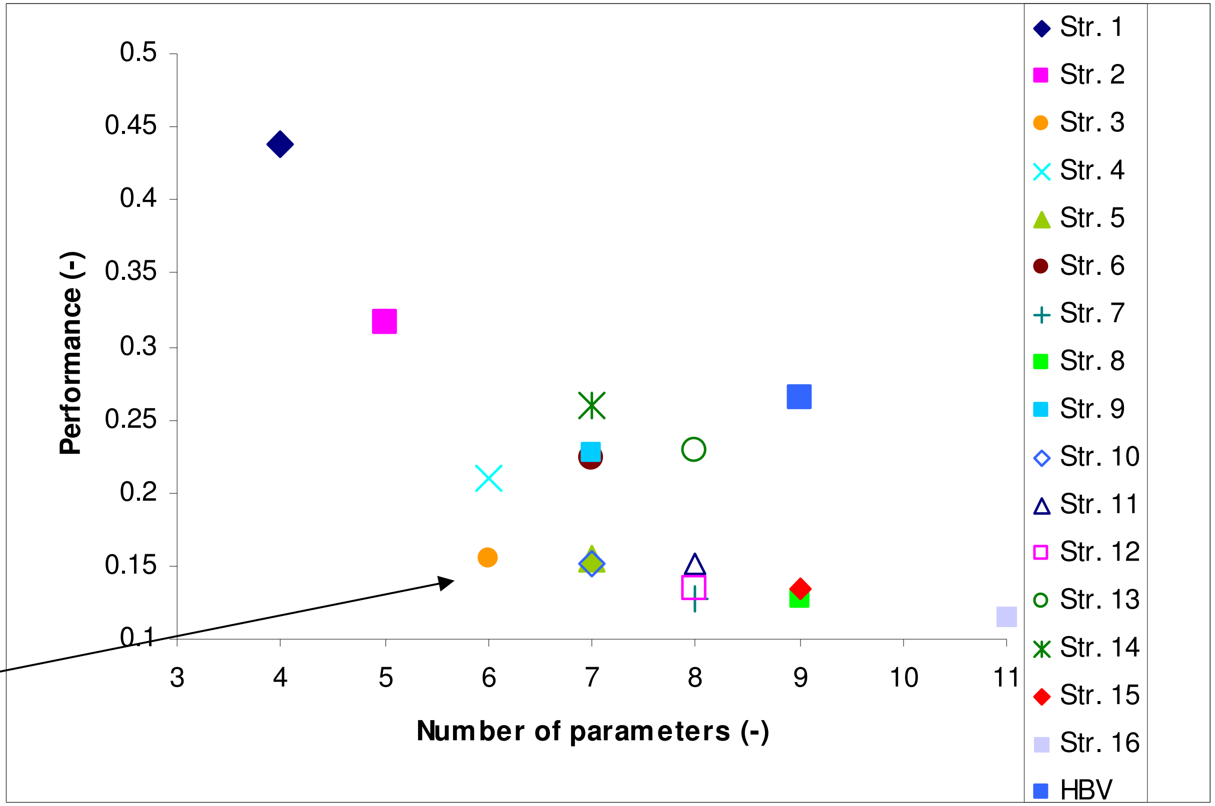
- 2.7 km²
- Sand stone
- Vertical
- mainly Groundwater flow



Weierbach

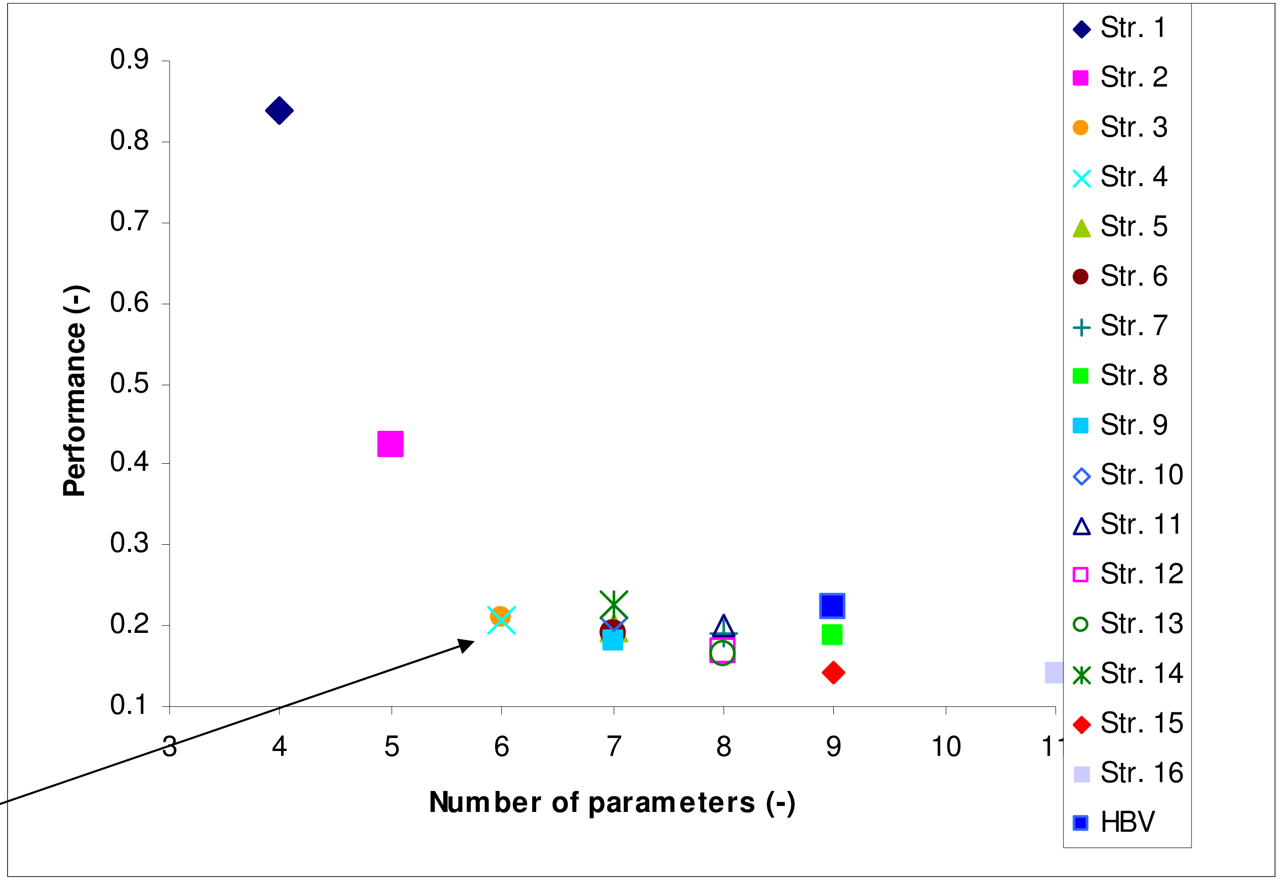
- 0.5 km²
- Schist
- Lateral
- Steep
- Rapid subsurface flow

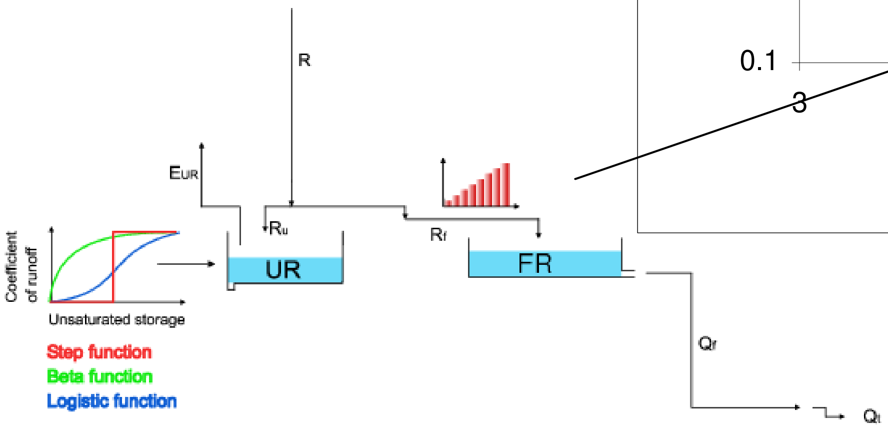




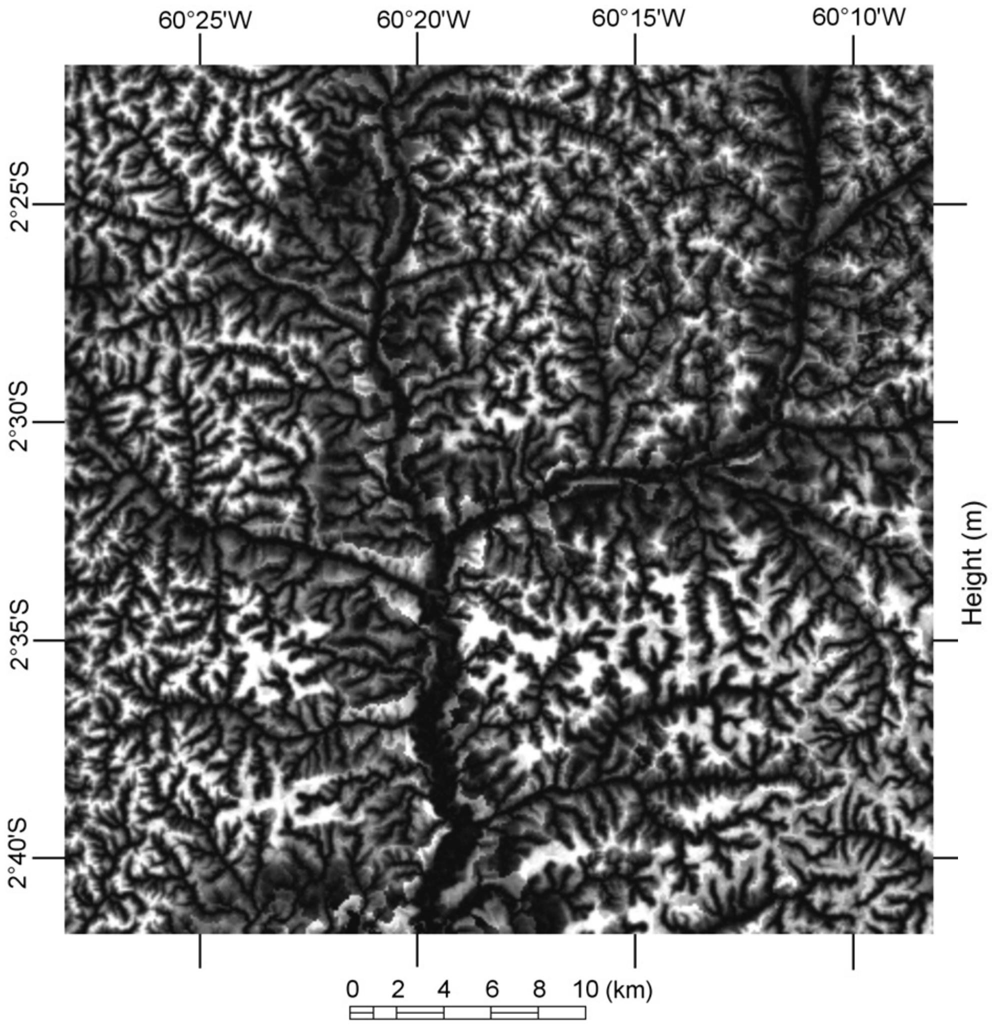
Wollefsbach

- 4.5 km^2
- Marls (eroded)
- Lateral
- Rapid subsurface flow / Hortonian overland flow

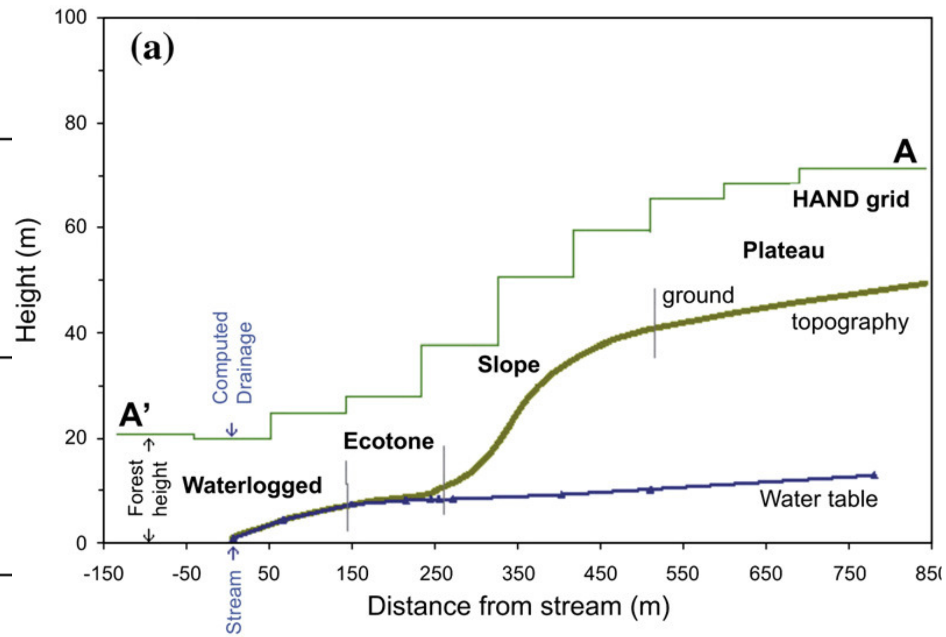


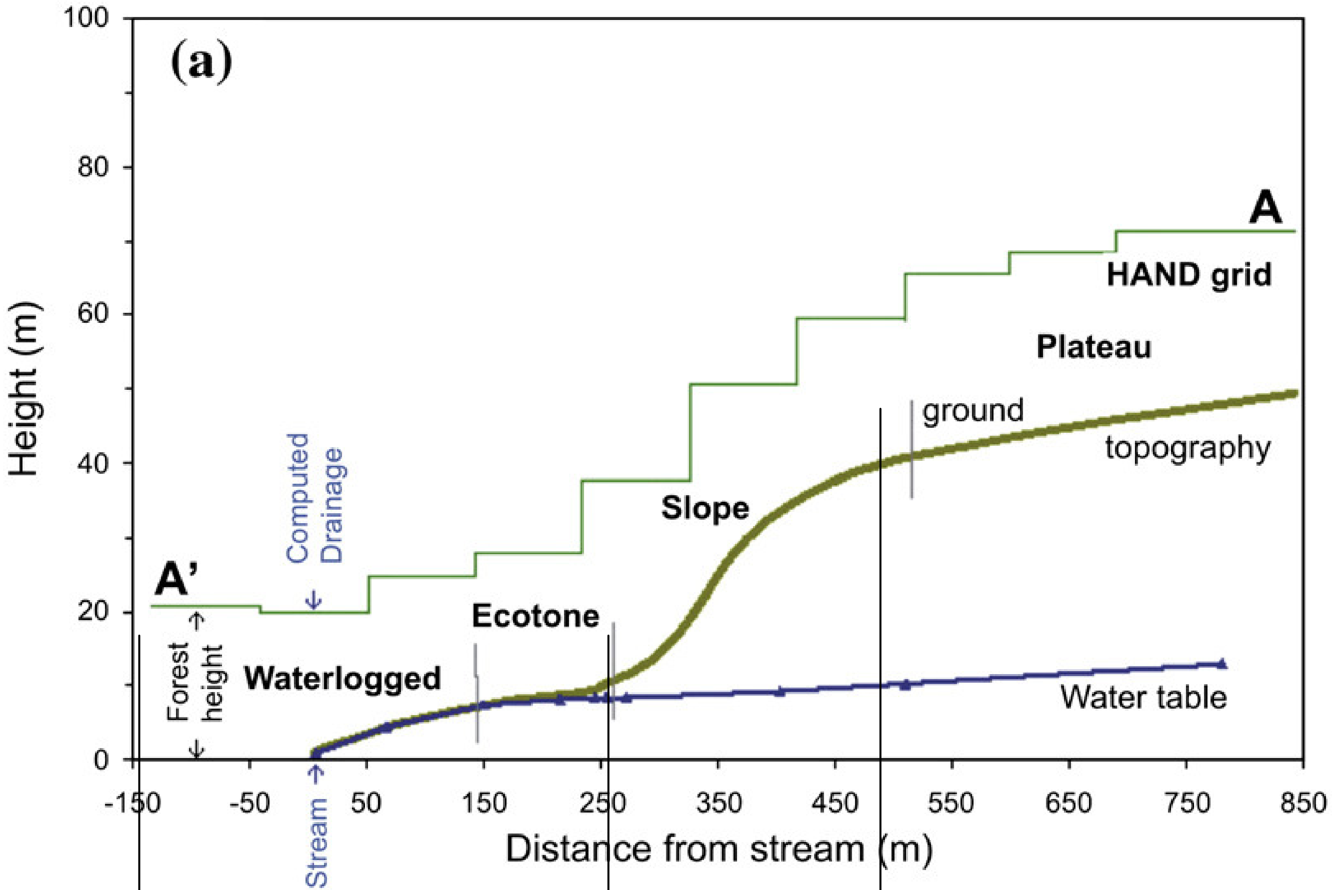


Topography as a driver

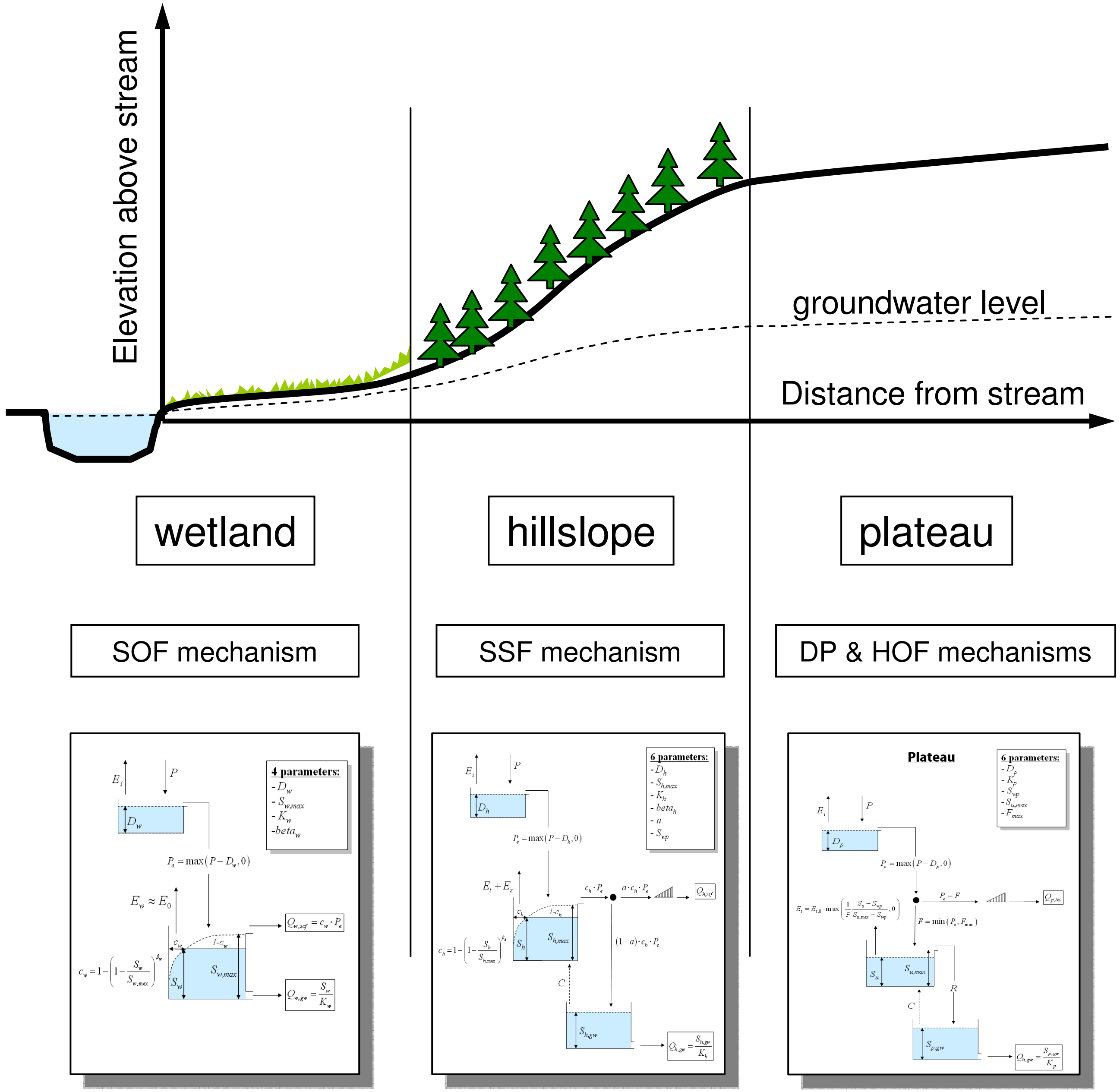


Renno et al. (2008)
Remote Sensing of Environment





Drainage direction:	Lateral	Lateral	Vertical
Land use:	Grass/wetland	Forest	Agriculture
Soil:	Shallow	Variable	Deep
Dominant mechanism:	Saturation overland flow	Rapid subsurface flow	Groundwater flow / Hortonian overland flow

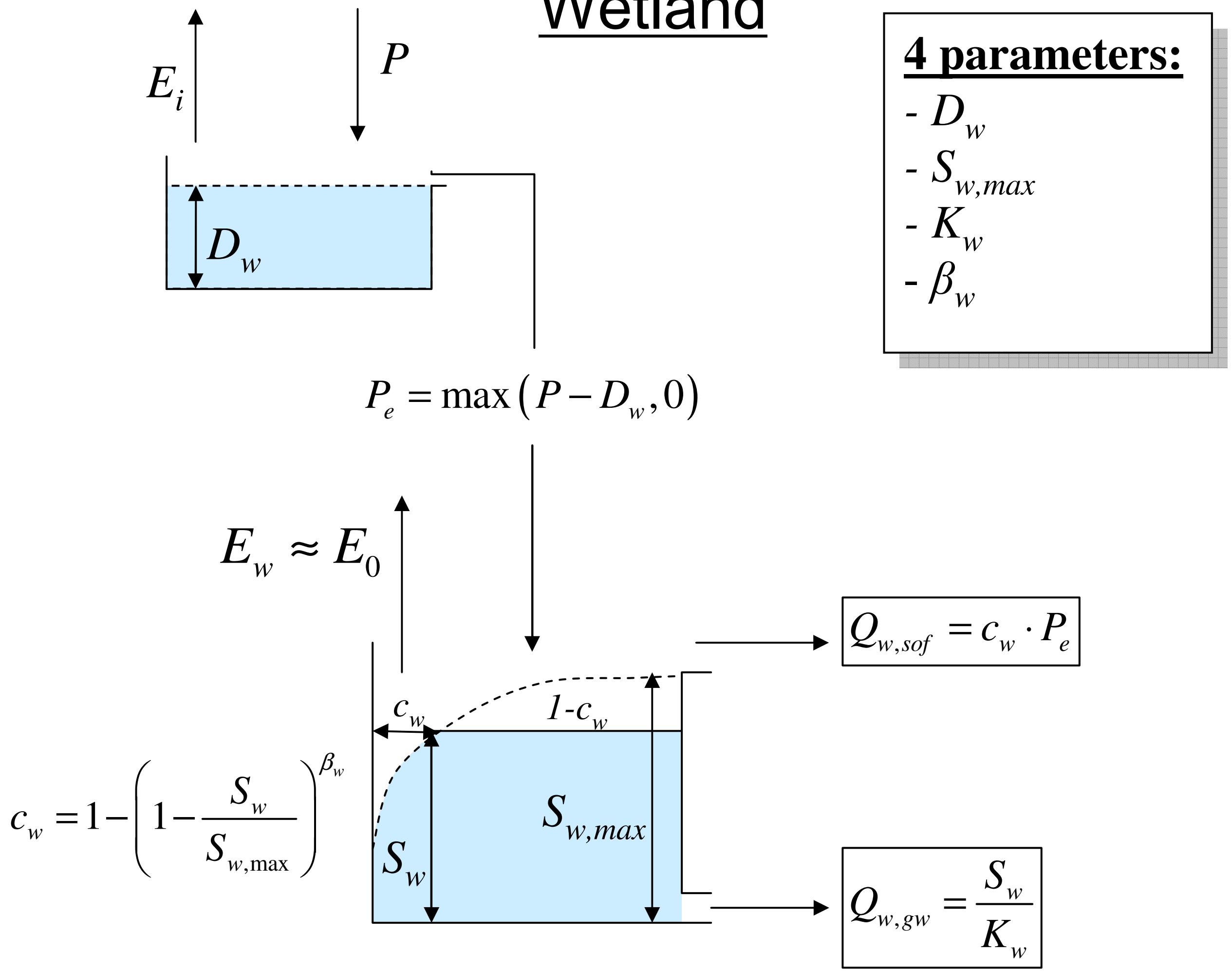


Elevation above stream
groundwater level
Distance from stream
wetland
hillslope
plateau
SOF mechanism
SSF mechanism
DP & HOF mechanisms
4 parameters:
6 parameters:
Plateau
6 parameters:

Three model classes

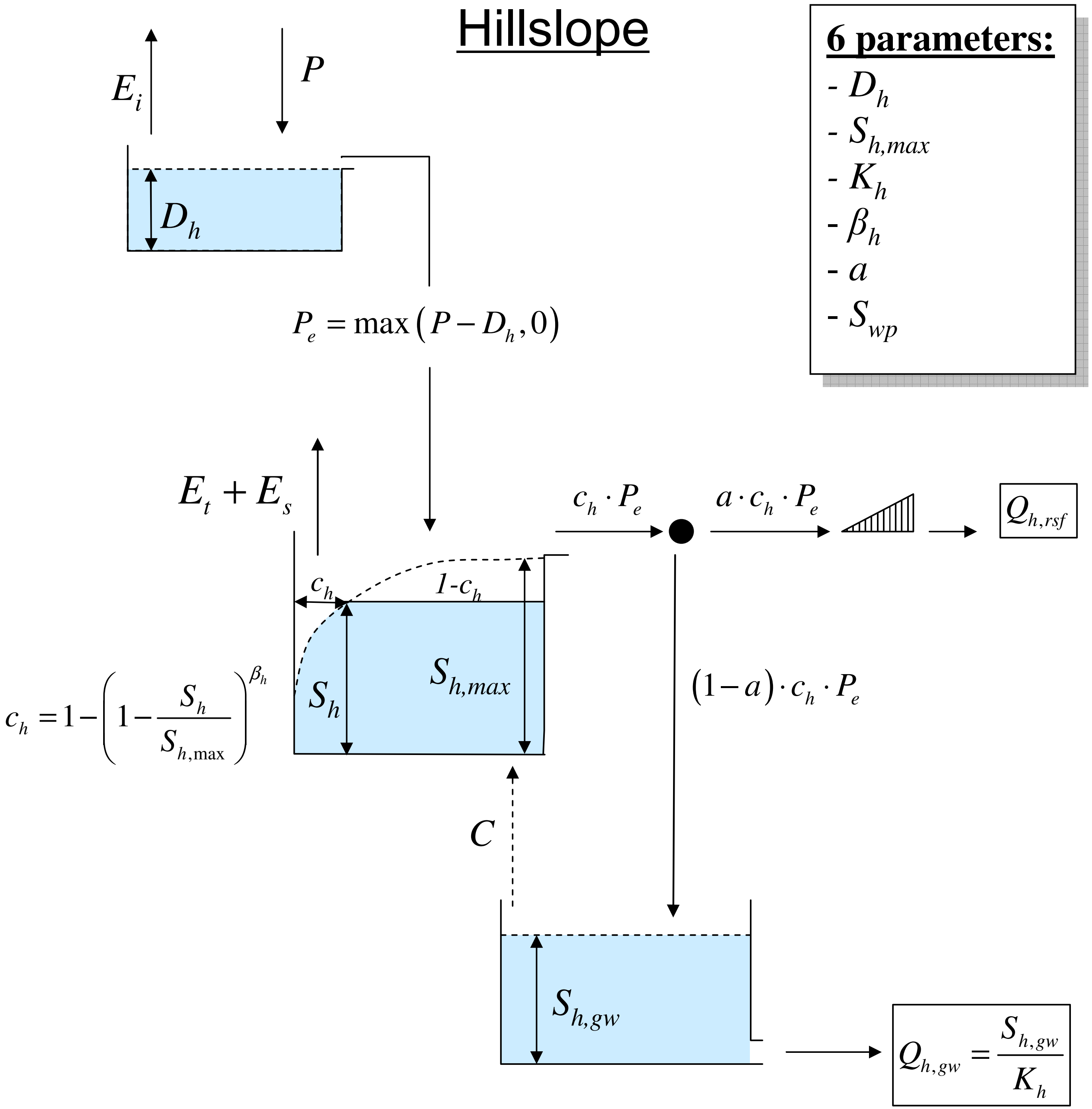
Classes:	**Wetland**	**Hill slope**	**Plateau**
Topography	flat	steep	undulating
Land use	pasture, wetland	forest, nature	agriculture, pasture
Soils	shallow	shallow	deep
Dominant mechanism	saturation overland flow	storage excess sub-surface flow	groundwater flow
drainage	not well-drained	well-drained	not well-drained
drainage direction	lateral	lateral	vertical
time scale	very fast	fast	very slow
Supporting mechanism	groundwater flow	groundwater flow	infiltration excess flow (during high intensity rainfall)
drainage	not well-drained	not well-drained	well-drained
drainage direction	vertical	vertical	lateral
time scale	very slow	slow	fast

Wetland

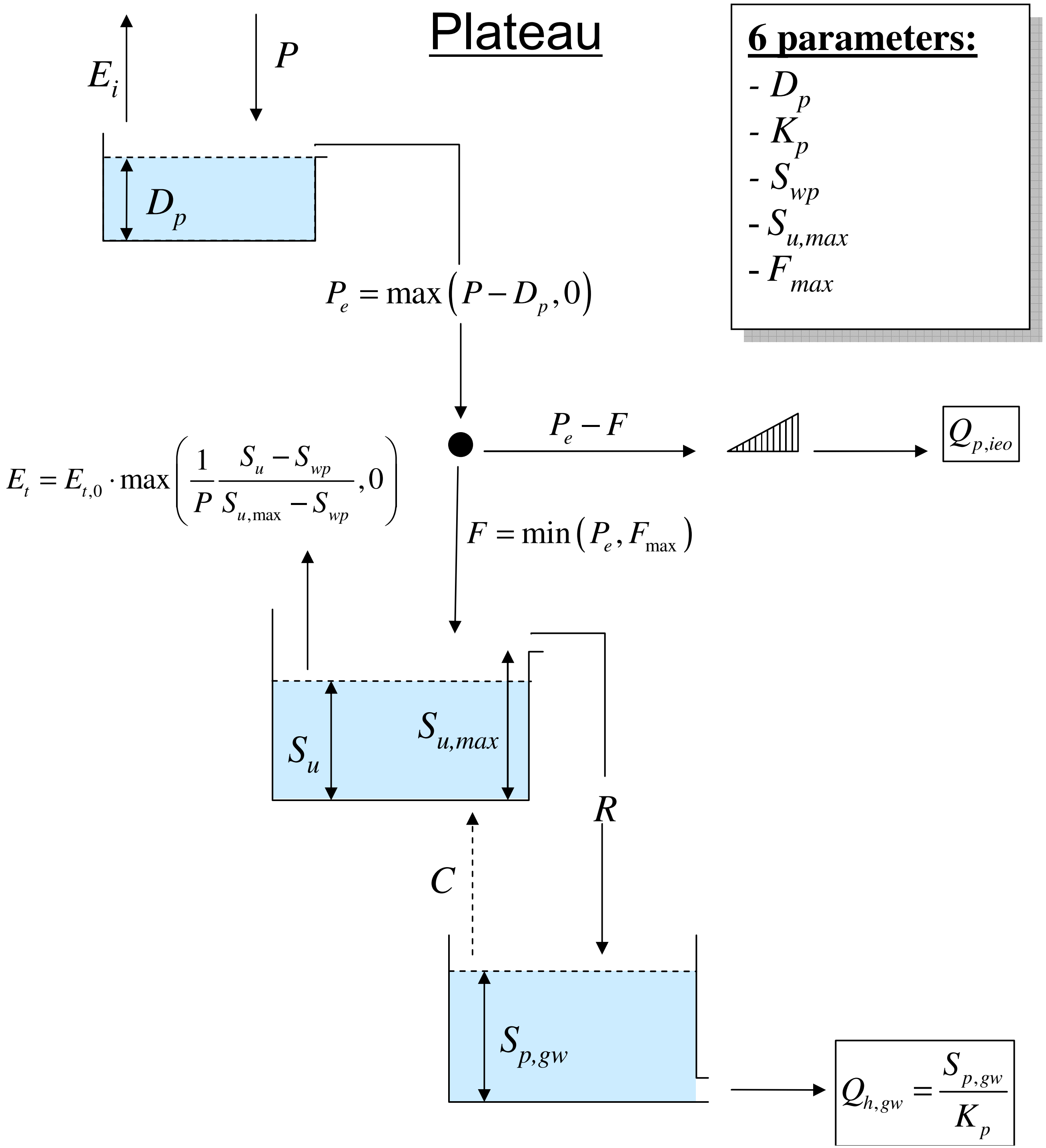


E_i
P
D_w
4 parameters:
- D_w
- $S_{w,max}$
- K_w
- β_w
$P_e = \max\left(P - D_w, 0\right)$
$E_w \approx E_0$
c_w
$1\text{-}c_w$
$c_w = 1 - \left(1 - \frac{S_w}{S_{w,\max}}\right)^{\beta_w}$
S_w
$S_{w,max}$
$Q_{w,sof} = c_w \cdot P_e$
$Q_{w,gw} = \frac{S_w}{K_w}$

Hillslope



6 parameters:
- D_h
- $S_{h,max}$
- K_h
- β_h
- a
- S_{wp}
E_i
P
D_h
$P_e = \max\left(P - D_h, 0\right)$
$E_t + E_s$
$c_h \cdot P_e$
$a \cdot c_h \cdot P_e$
$Q_{h,rsf}$
c_h
$1\text{-}c_h$
S_h
$S_{h,max}$
$c_h = 1 - \left(1 - \frac{S_h}{S_{h,\max}}\right)^{\beta_h}$
$(1-a) \cdot c_h \cdot P_e$
C
$S_{h,gw}$
$Q_{h,gw} = \frac{S_{h,gw}}{K_h}$



Plateau
6 parameters:
- D_p
- K_p
- S_{wp}
- $S_{u,max}$
- F_{max}
E_i
P
D_p
$P_e = \max\left(P - D_p, 0\right)$
$P_e - F$
$Q_{p,ieo}$
$E_t = E_{t,0} \cdot \max\left(\frac{1}{P}\frac{S_u - S_{wp}}{S_{u,\max} - S_{wp}}, 0\right)$
$F = \min\left(P_e, F_{\max}\right)$
S_u
$S_{u,max}$
R
C
$S_{p,gw}$
$Q_{h,gw} = \frac{S_{p,gw}}{K_p}$

Characteristics of sub-models

Model:	**Wetland**	**Hillslope**	**Plateau**
Dominant mechanism	saturation overland flow	rapid sub-surface flow	groundwater flow
parameters	D_{w} [L/T], cc $S_{\mathrm{w,\,max}}$ [L], **fc** β_{w} [-], **fc**	D_{h} [L/T], cc $S_{\mathrm{h,\,max}}$ [L], **fc** β_{h} [-], **fc** a [-], **fc** T_{h} [T], **fc**	D_{p} [L/T], est $S_{\mathrm{u,\,max}}$ [L], est S_{wp}[L], est p [-], est K_{p} [T], est
Supporting mechanism	groundwater flow	groundwater flow	infiltration excess flow (during high intensity rainfall)
parameters	K_{w} [T], est	K_{h} [T], est	F_{max}[L/T], est T_{p} [T], est

Ways forward

- Classification of catchments into sub-systems based on topography, geology, ecology, landuse
- Developing simple lumped conceptual sub-system models (as simple as possible)
- Combining these in parallel (or possibly in series)
- Feed these sub-models with spatially distributed rainfall
- ‘Space for Time’ exchange

Conclusion

- There is a definite need for more knowledge on how the system behaves, both under normal and under extreme conditions
- There is a need to cooperate in the development of adequate tools
- There is a need to share operational knowledge, information and experiences

h.h.g.savenije@tudelft.nl

TU Delft