A hydrologic model to bridge the gap between conceptual and physically based approaches

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A hydrologic model to bridge the gap between conceptual and physically based approaches

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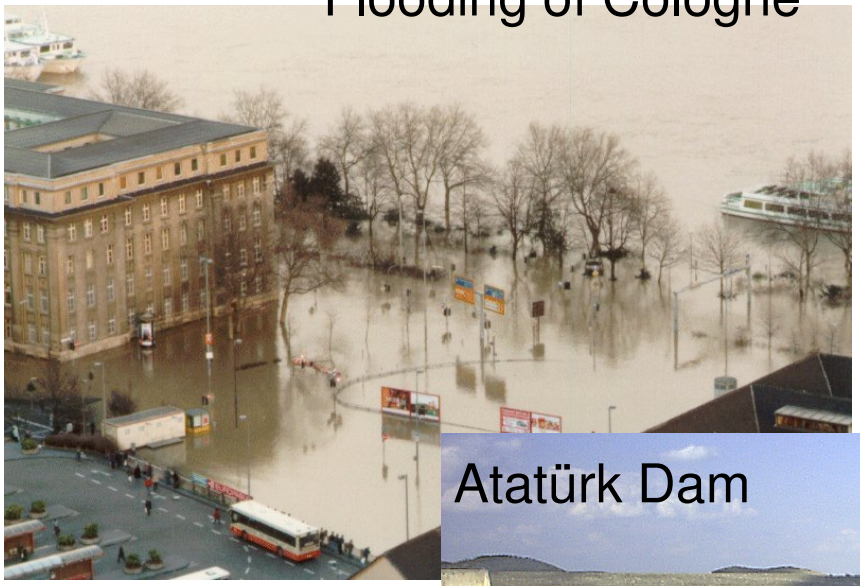
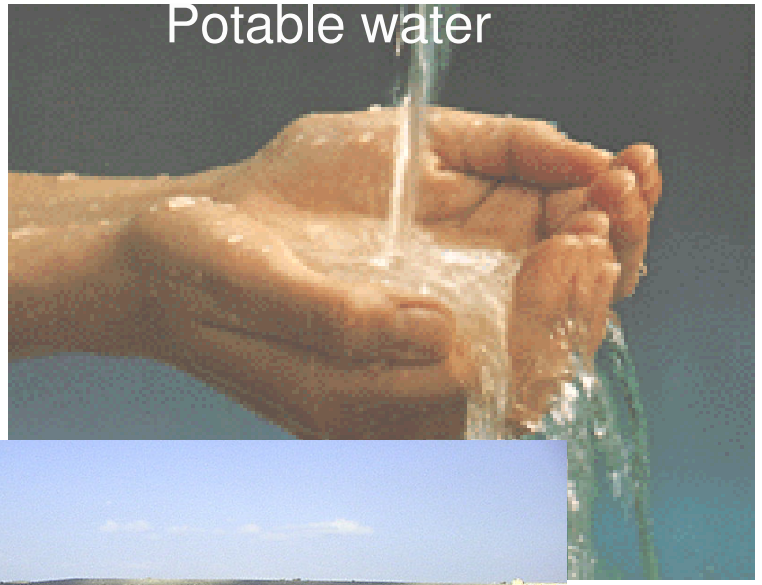
Without any doubt, we need reliable hydrologic models

Flooding of Cologne





to simulate und develop water resources systems

INTRODUCTION

In civil engineering hydrological models are mostly developed and applied as part of water resources system models to be an important basis for decision making on investment

Example 1: Ruhr area, Germany, reconstruction of a heavily modified industrial landscape, 5 10^9 € in 10 years, ongoing

Example 2: The Ebro Basin development, Spain, several 10 reservoirs, 1-3 times the investment of Ex. 1, discussed

Example 3: The EU water directives, enormous investment , impossible to quantify, ongoing

Water resources systems combine hydrology, hydraulics, systems control und others

For my part, engineering hydrology is not and does not want to be a basic science !!! No ivory towers.

INTRODUCTION

Trade off between physically based and conceptual models, let us not ask for either ... or, there is ***a best one for each purpose***, not a generally best one

Physically based models

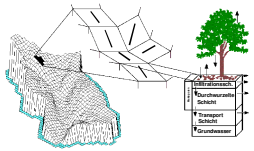
Pros:
- (non linear) physical modelling which can be checked for plausibilty
- spatially detailed
- Describe interactions between elementary units

Cons:
- numercical solutions
  => high computational effort
  => mostly restricted to flood event computation
- large number of data and parameters

Conceptual models

Pros:
- analytical solutions provide
  => high computational efficiency
  => allow long term simulation

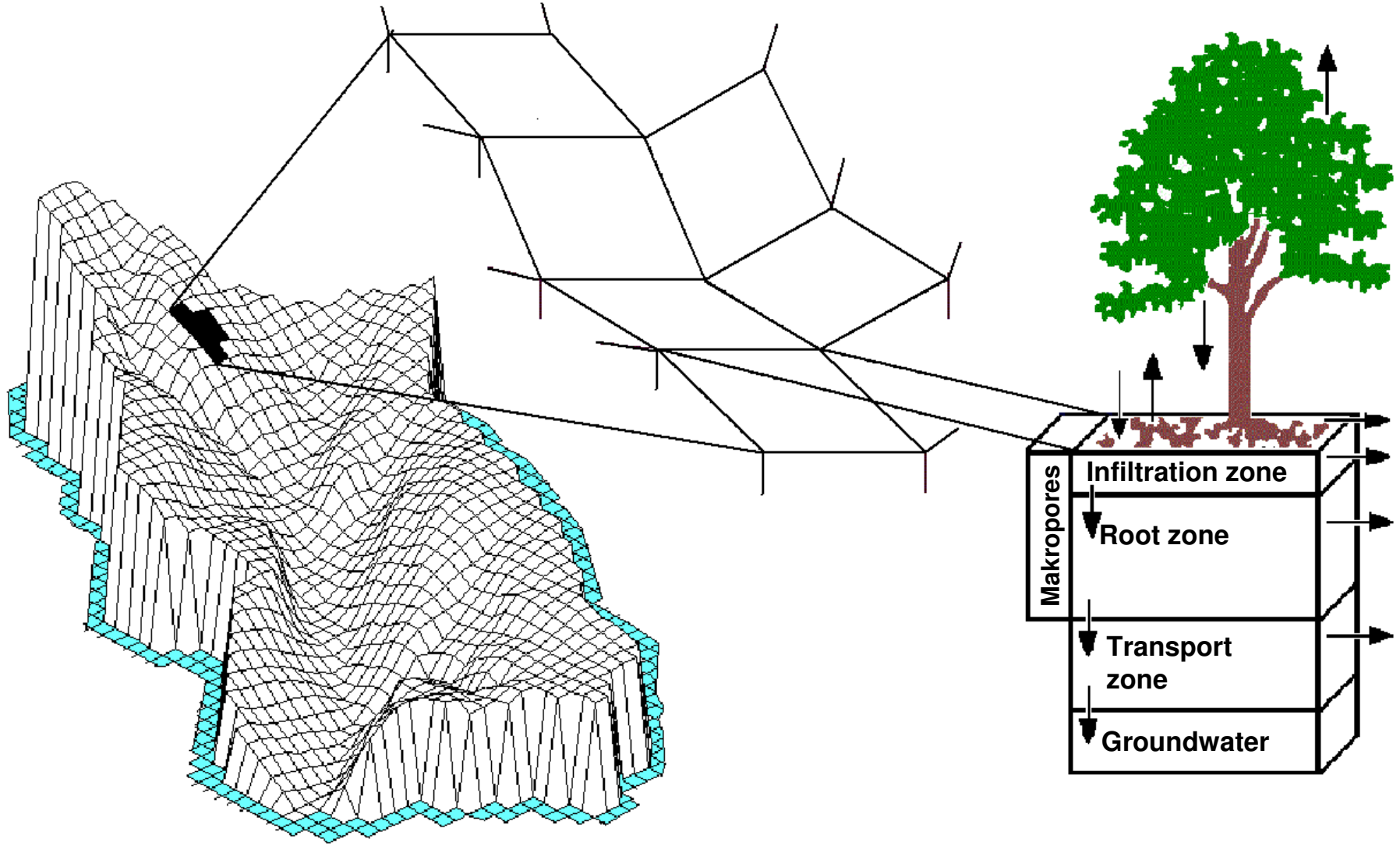
Cons:
- mostly linear approaches
- little interaction between elementary units
- less transparent aggregated process simulation



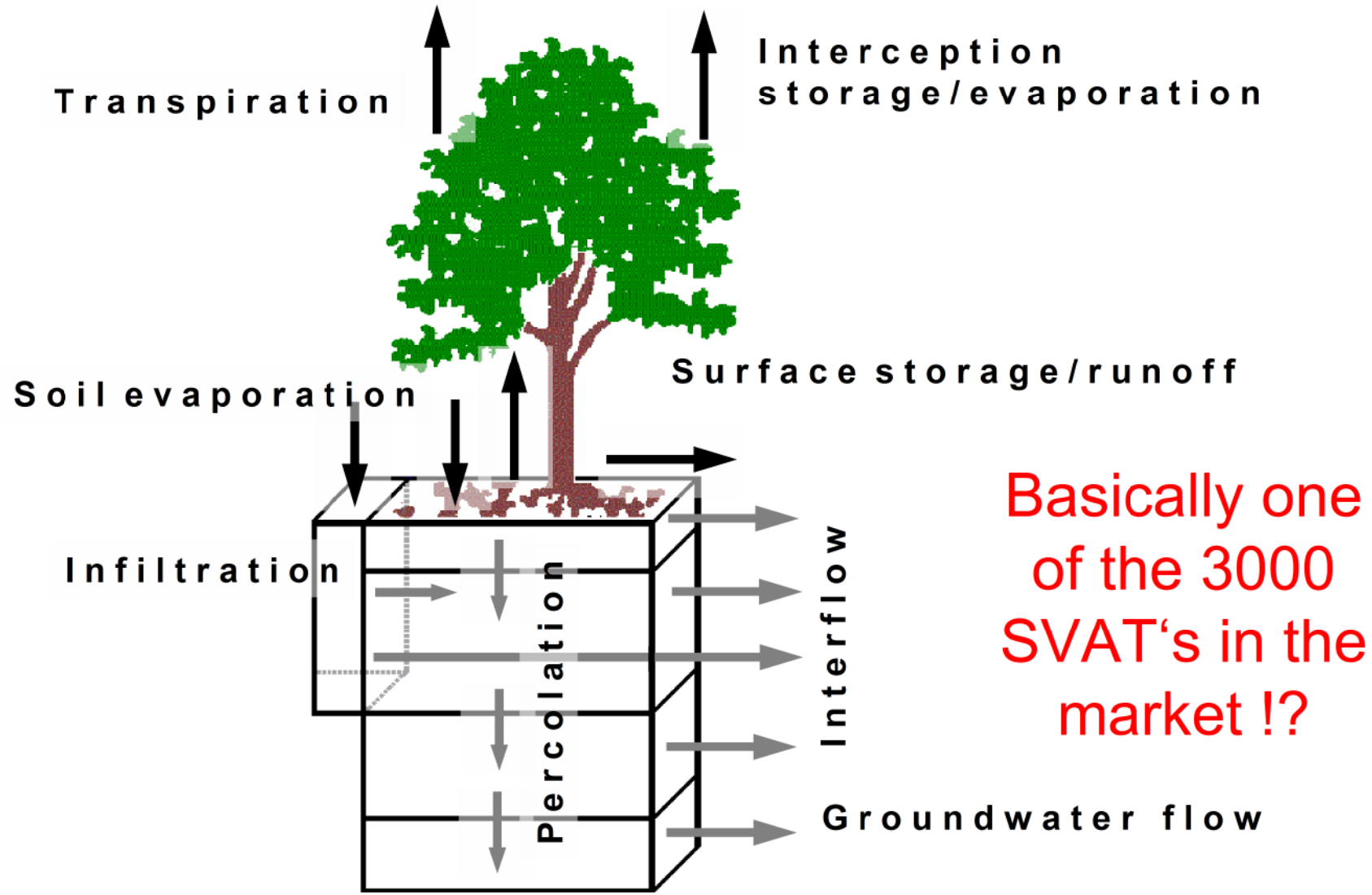
Modelling concept: Objectives

- continuous long term simulation of water balances at arbitrary temporal scales including flood periods
- high spatial decomposition and description of interactions among neighbouring elements
- consideration of all relevant prozesses and their interaction
- best possible analytical equivalent to non linear physical differential equations
- efficient computational realisation
- closely coupled with GIS technology

Modelling concept: principles

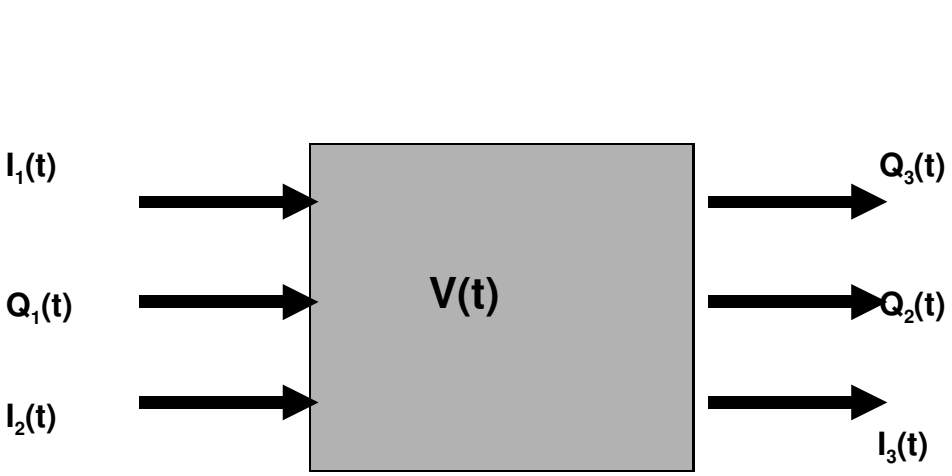


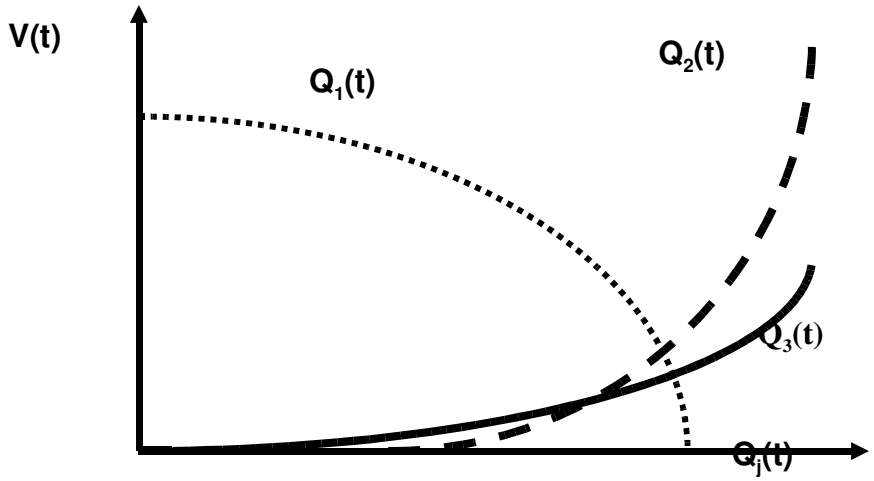
Modelling concept: local processes in/ on elemenraty units



Basically one of the 3000 SVAT‘s in the market !?

Modelling concept: Basic module



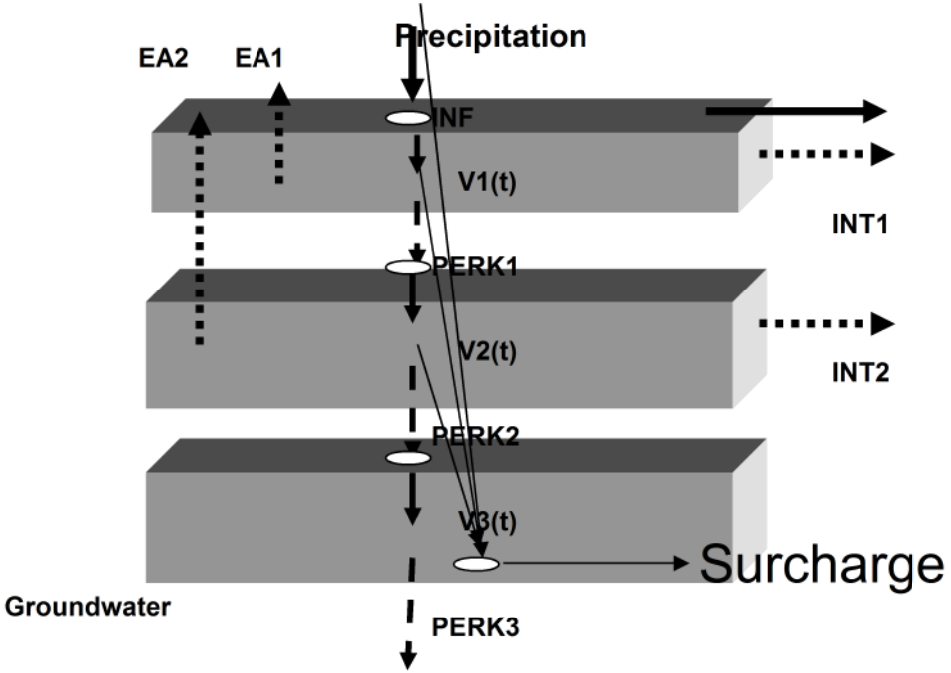


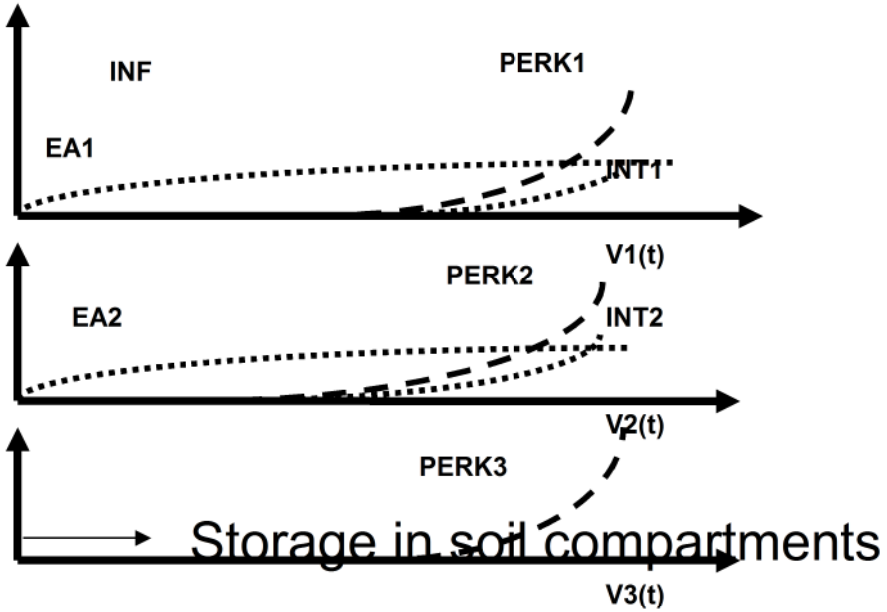
The hydrologic and water resources system is defined as a system of non linear storages and related multiple input / output processes, being known functions of storage or constant or known a priori

(see HSA9.01-ITH2B-001)

Modelling concept: Basic module

Example soil mositure storage

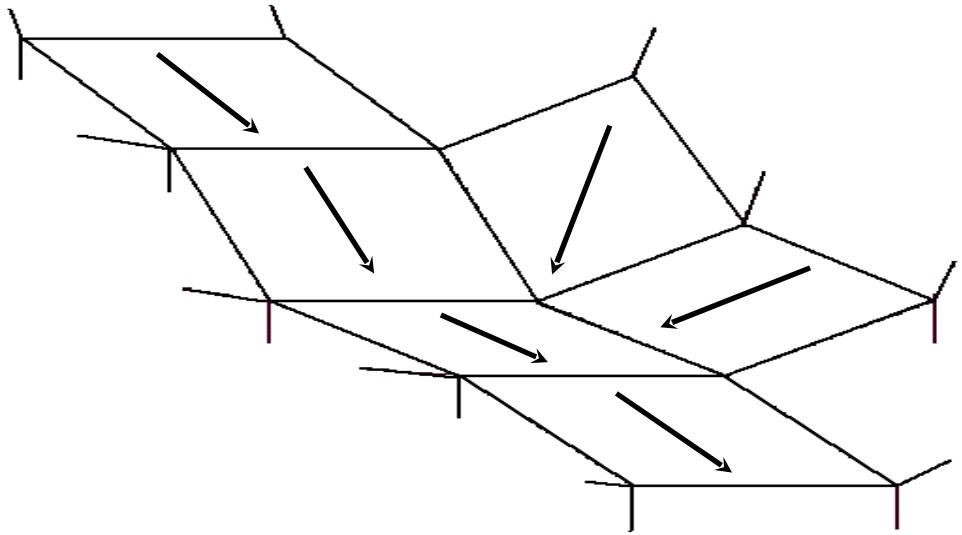




V1	V2	V3
+ Infiltration INF	+ Infiltration from V1 PERK1	+ Infiltration from V2 PERK2
- actual Evapotranspiration EA1	- actual Evapotranspiration EA2	- Percolation PERK3
- Percolation PERK1	- Percolation PERK2	
- Interflow INT1	- Interflow INT2	

Modelling concept: Basic module

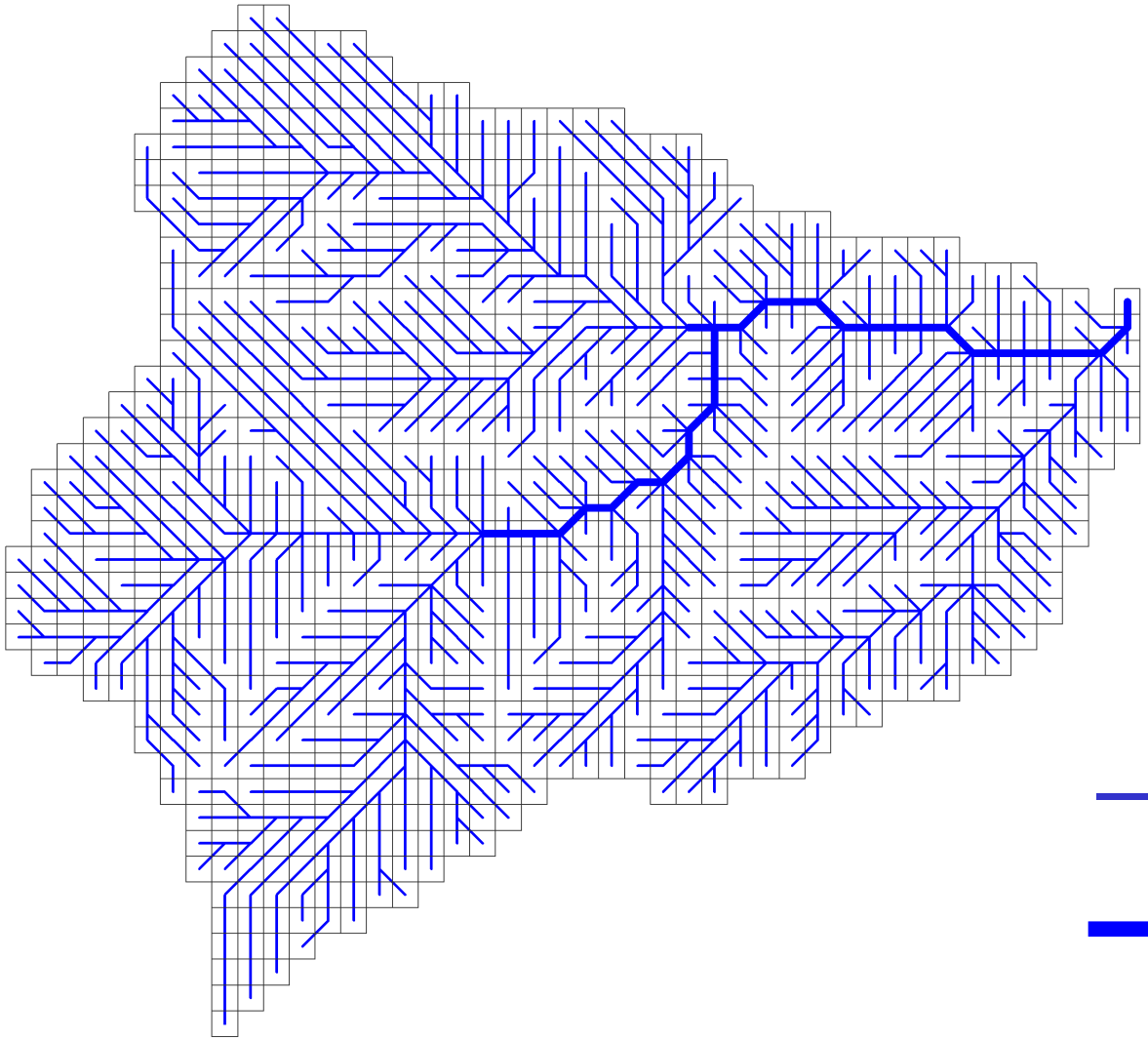
General concept: flow follows gravity on surface



Limitation: The surface and sub surface flow occurs to gravity at surface!!!

The model does not completely observe conservation of momentum, only conservation of mass

Modelling concept: The GIS-cascade system



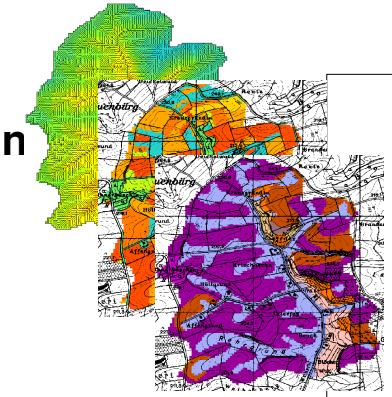
Control section

Overland flow paths

Channel flow

Modelling concept: Overall scheme

Slope
Flow concentration
Spatial rainfall distribution
Land use
Soils



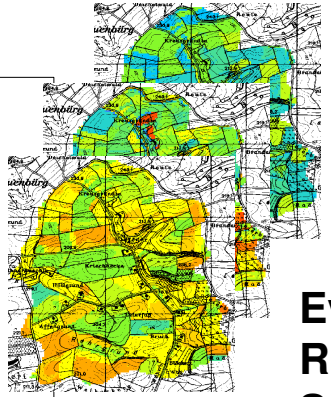
GIS (IDRISI)

Flow scheme

WB_RM

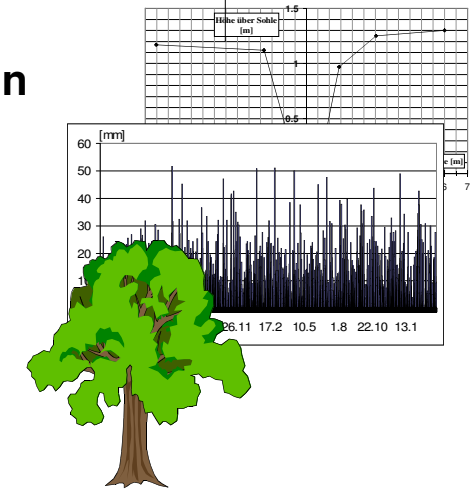
Input

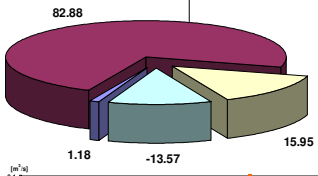
Output



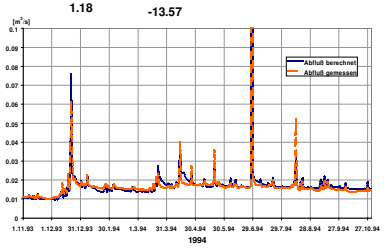
Evaporation depth
Runoff depth
Soil moisture

Simulation control
basic system definition
Input time series
Channel data
Land use parameters
Soil parameters

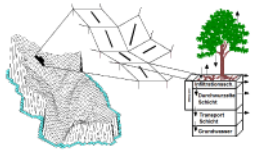




Water balances



Time series
all processes
at all elements



Modelling concept: point validation and integration

Interception
(model intercomparison)

Hillslope model
(Landfill Frankfurt)

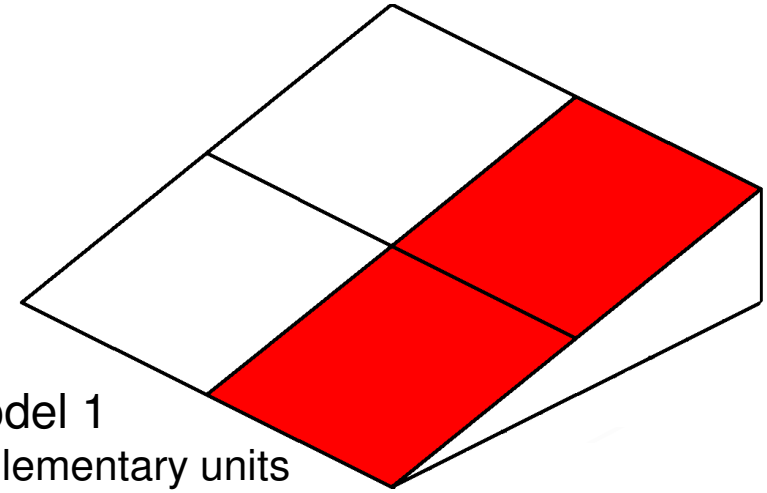
Surface runoff
(runoff experiments by Izzard)

Soil moisture on elementary units
(Lysimeter station Senne)

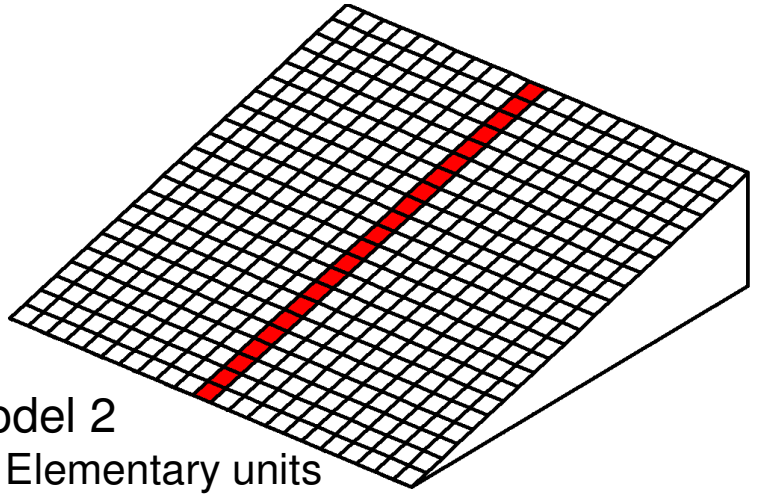
Integration to complete model
(Weiherbach catchment)

Modelling concept: point validation (Izzard, 1946)

Surface flow simulation on impervious area



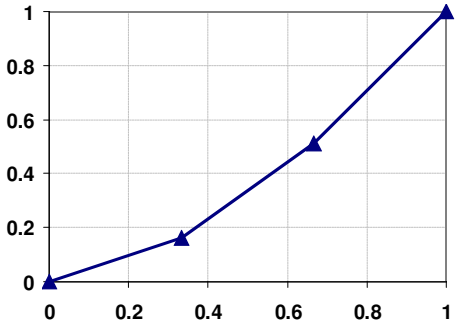
Model 1
2 Elementary units



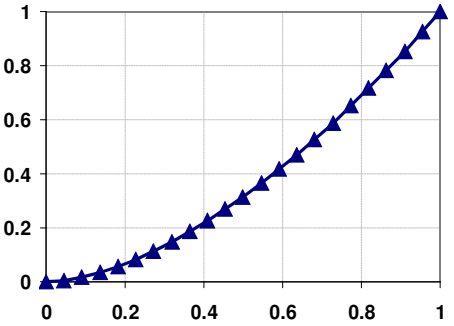
Model 2
22 Elementary units

Discretisisation of storage-flow function

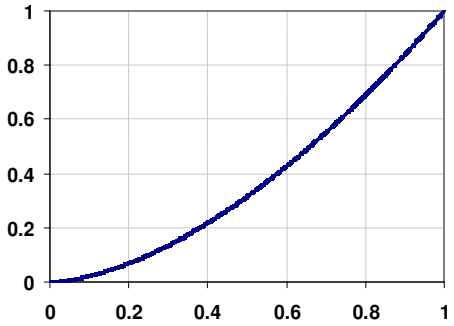
grob



fein

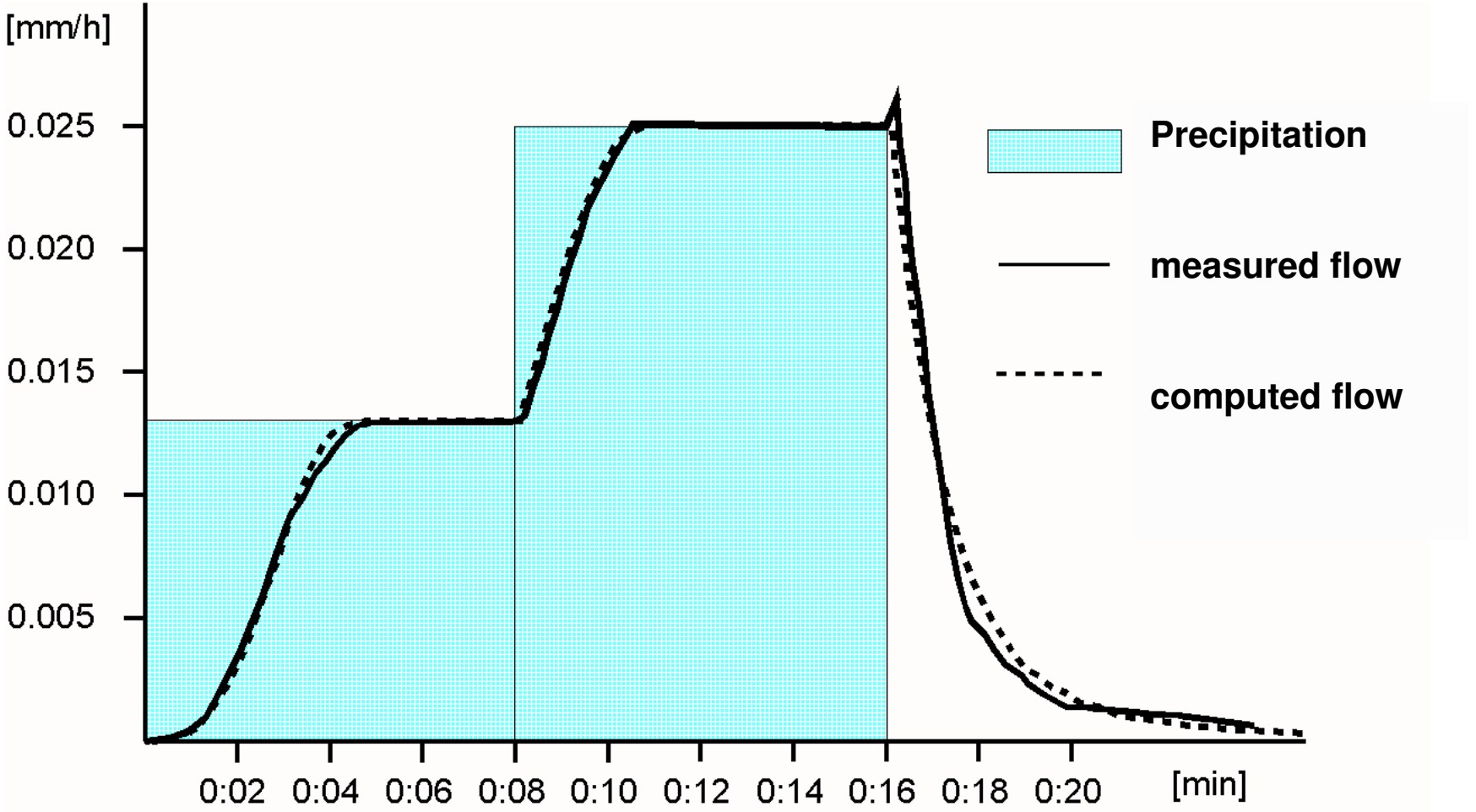


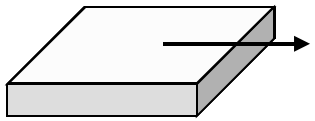
sehr fein



Modelling concept: point validation (Izzard, 1946)

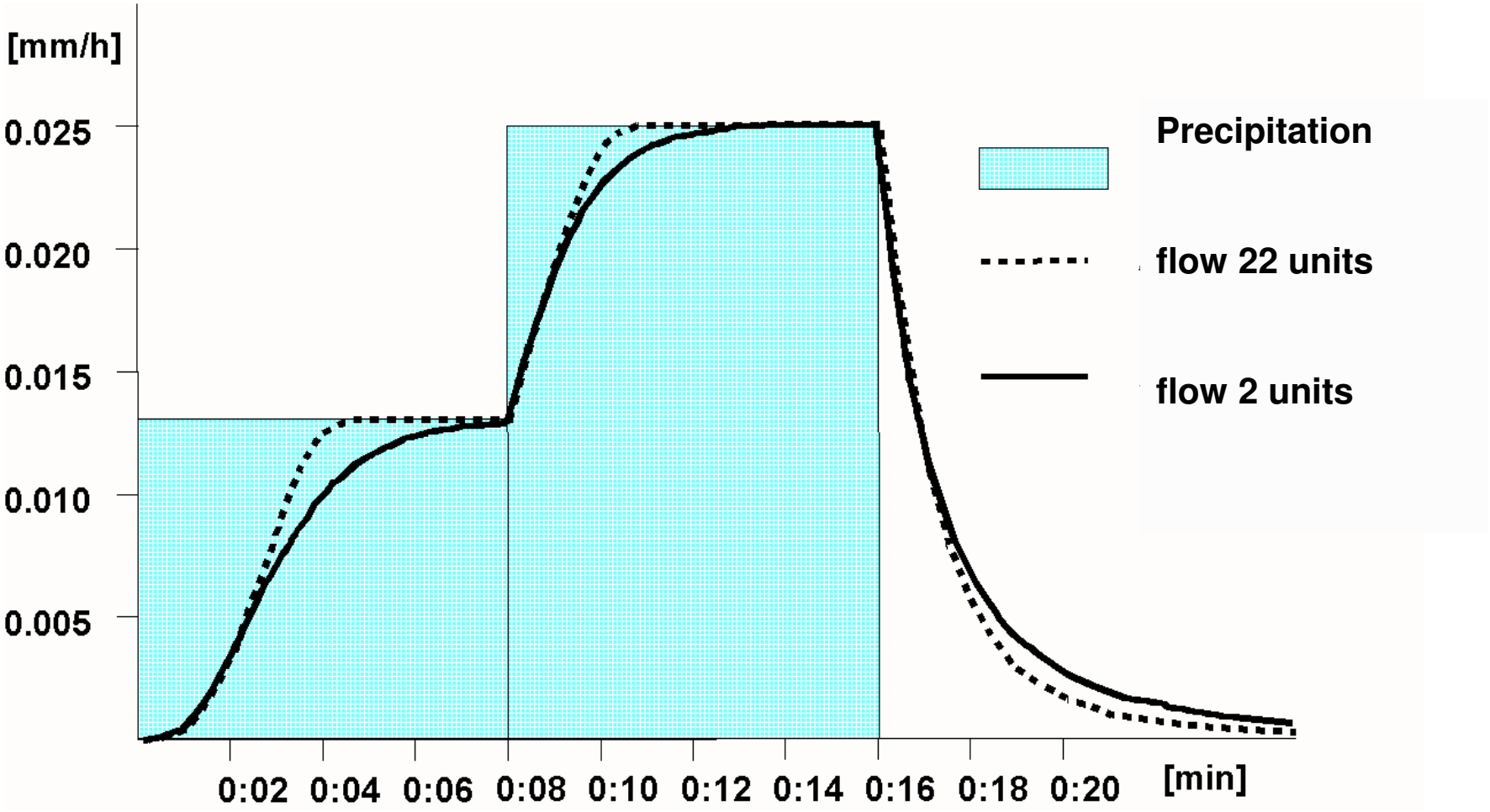
22 Elementary units

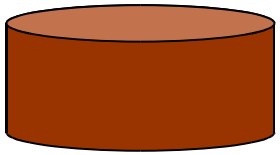




Modelling concept: point validation

Variable spatial resolution 2 versus 22 elementary units





Modelling concept: point validation lysimeter

$$\frac{\delta\Theta}{\delta t} = \frac{\delta}{\delta z}\left[K_u \left(\frac{\delta \psi_m}{\delta z} + 1 \right) \right] + S(t,z)$$

Θ = soil moisture = f (t,z) [mm, cm³/cm³,..]

ψ_m = soil tension= f(t,z) [cm, kPa,..]

k_u = unsaturated hydraulic conductivity = f(ψ) [m/s, mm/h,mm/d,..]

z = space coordinate (one dimensional vertical) [m]

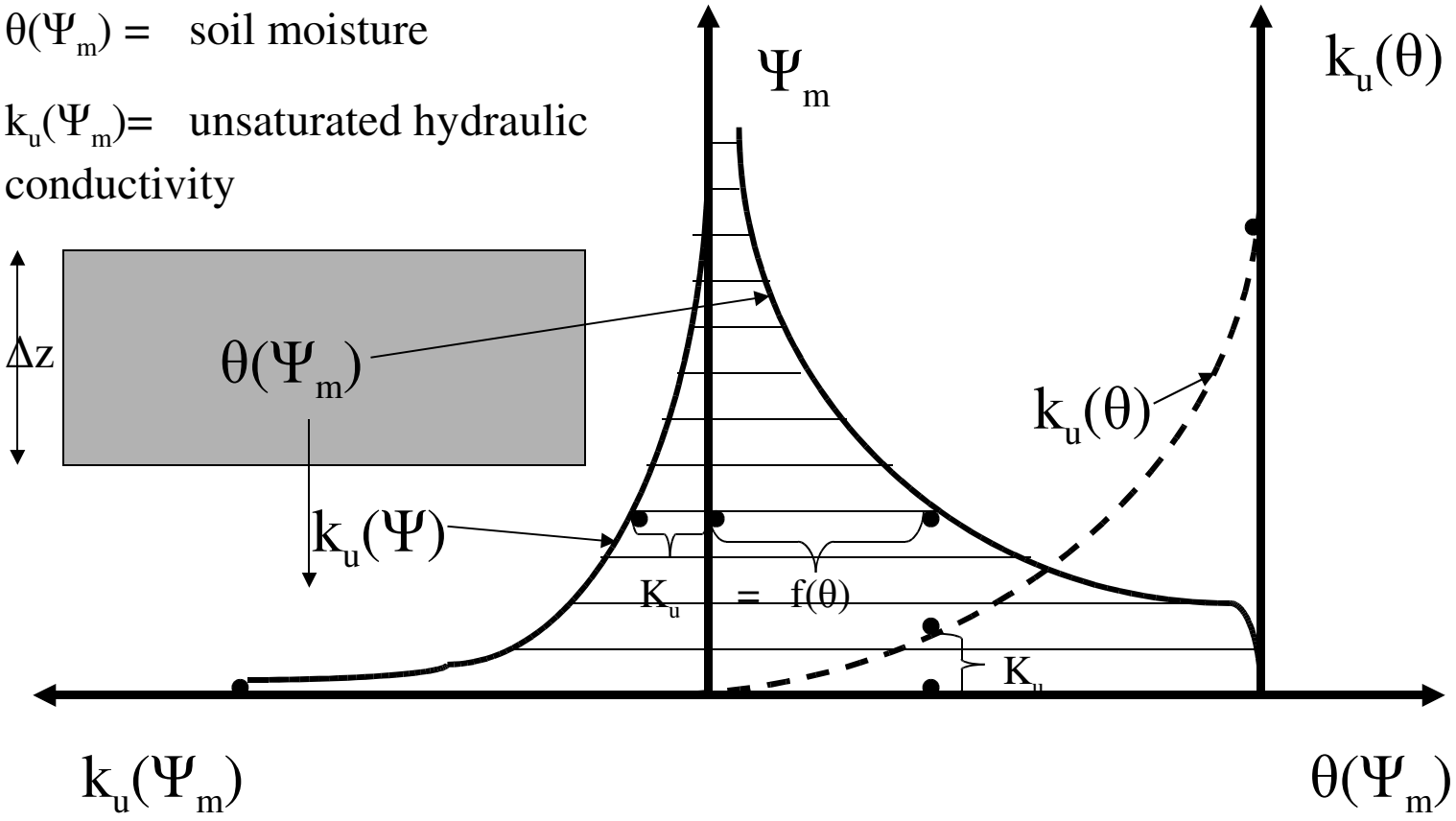
t = time [s,h,d]

Modelling concept: point validation lysimeter

Ψ_m = mean soil tension

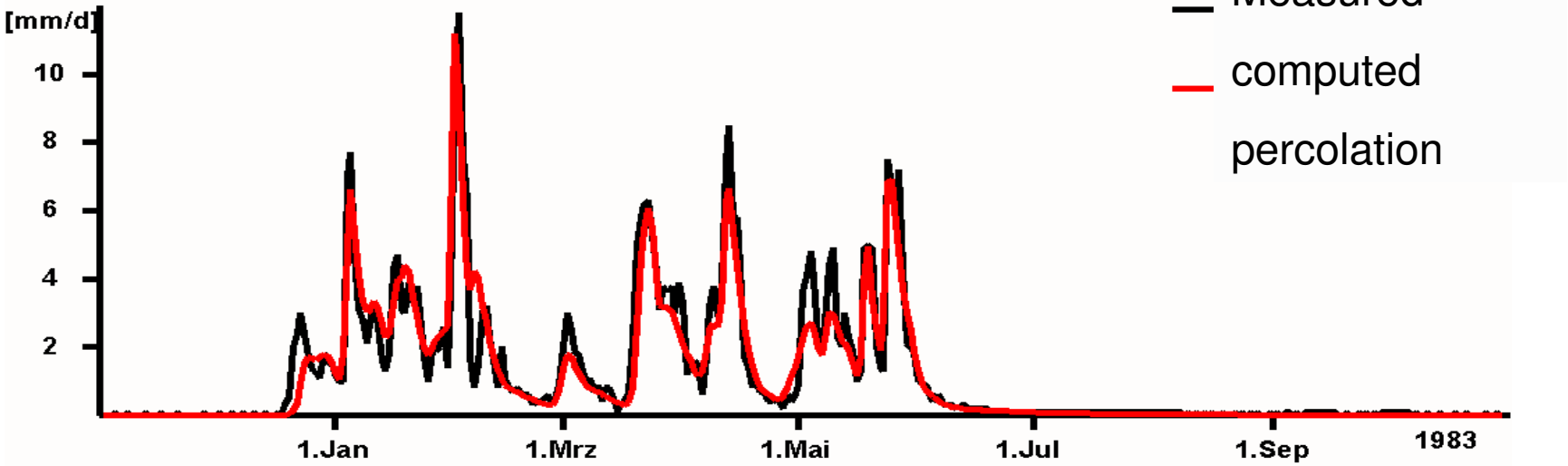
$\theta(\Psi_m)$ = soil moisture

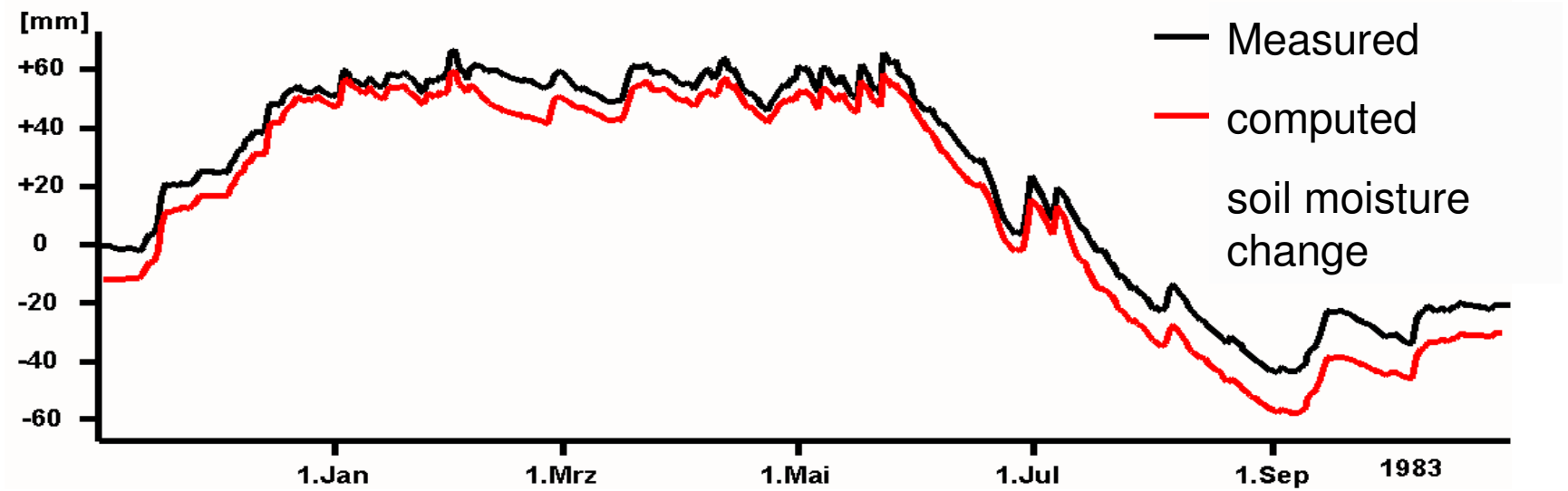
$k_u(\Psi_m)$= unsaturated hydraulic conductivity



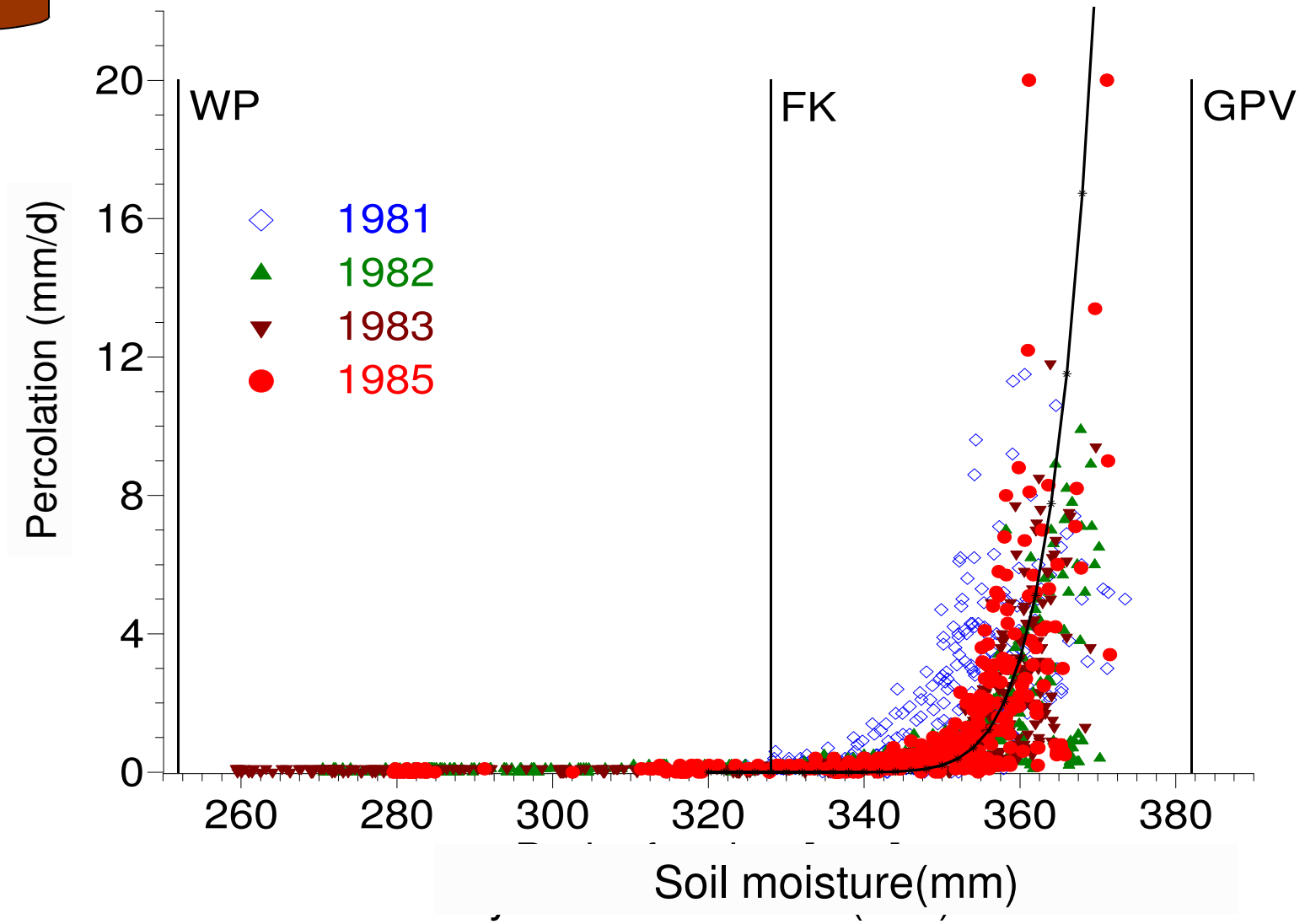
Percolation from a soil compartment

Modelling concept: point validation lysimeter

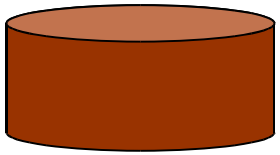




Modelling concept: point validation lysimeter



Determination of storage flow function for lysimeter



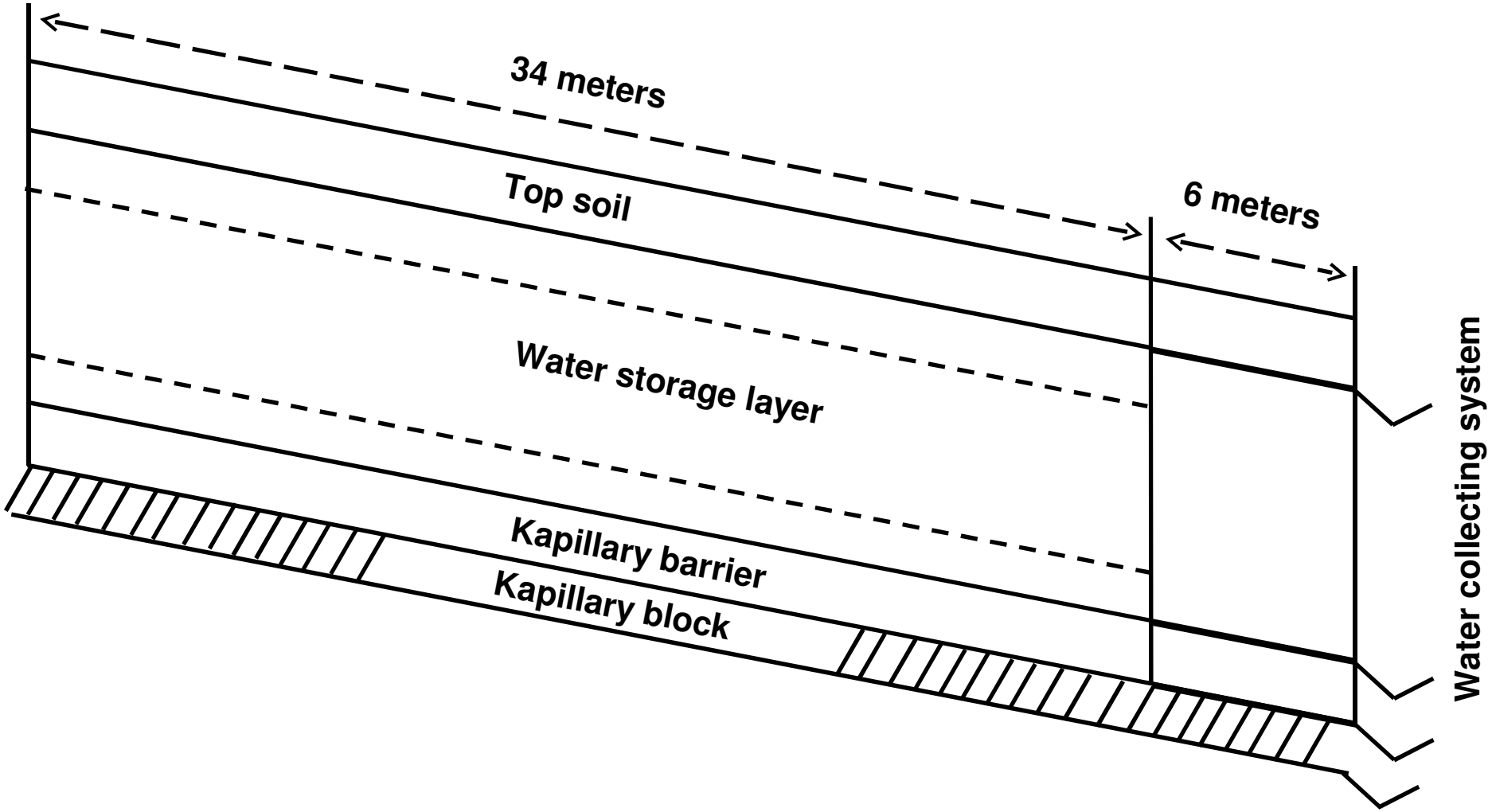
Modelling concept: point validation lysimeter

	Bodenart	WP [mm/m]	FK [mm/m]	Gpv [mm/m]	Kf [mm/h]	Θr_perk [mm/m]	Θmax_perk [mm/m]	α
Lysi 1	Sand	18	78	380	20	42	266	4
Lysi 2	Schluff	108	257	336	4.3	260	305	7
Lysi 4	Lehm	252	328	382	1	330	370	7

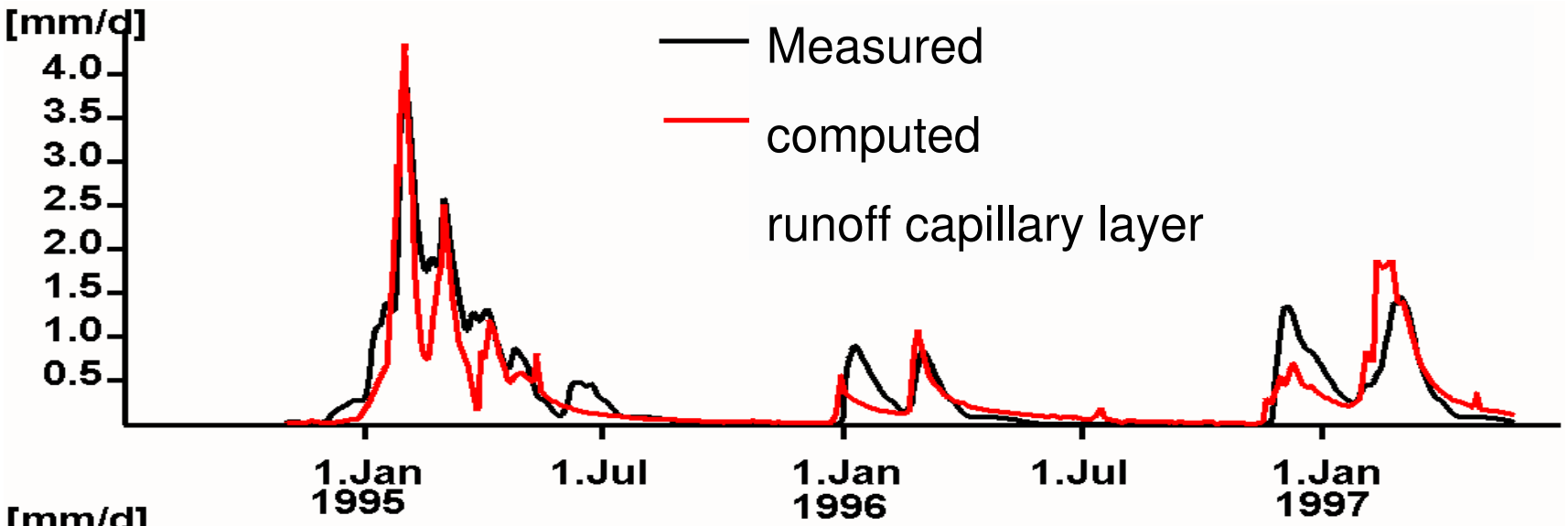
Determination of storage flow function for three lysimeters

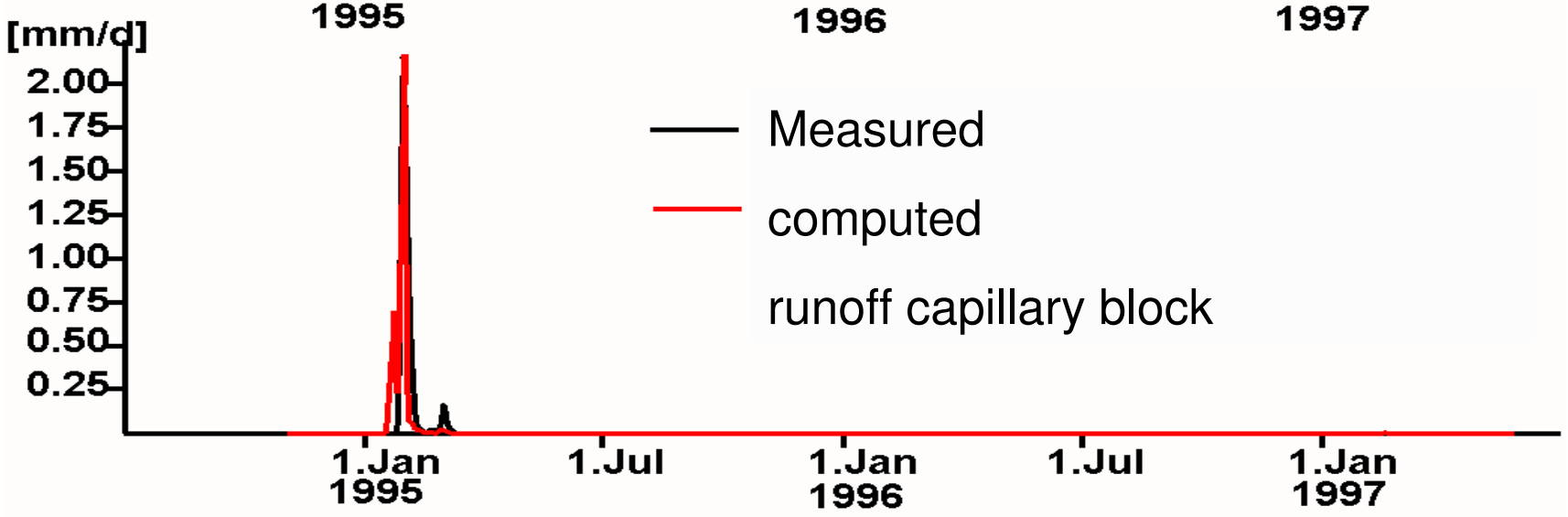
to be transfered without major modification

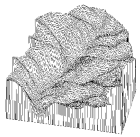
Modelling concept: point validation landfill



Modelling concept: point validation landfill



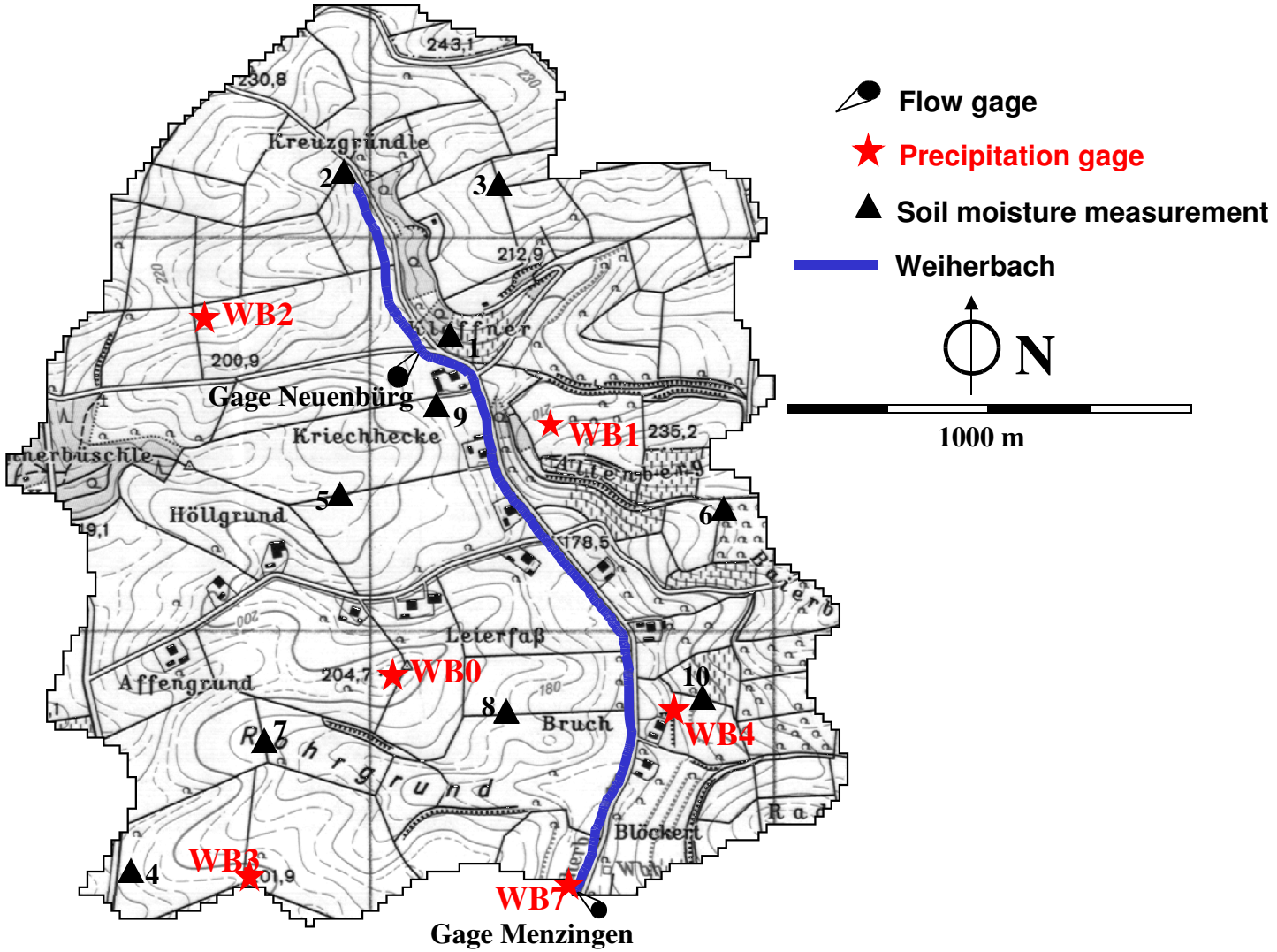




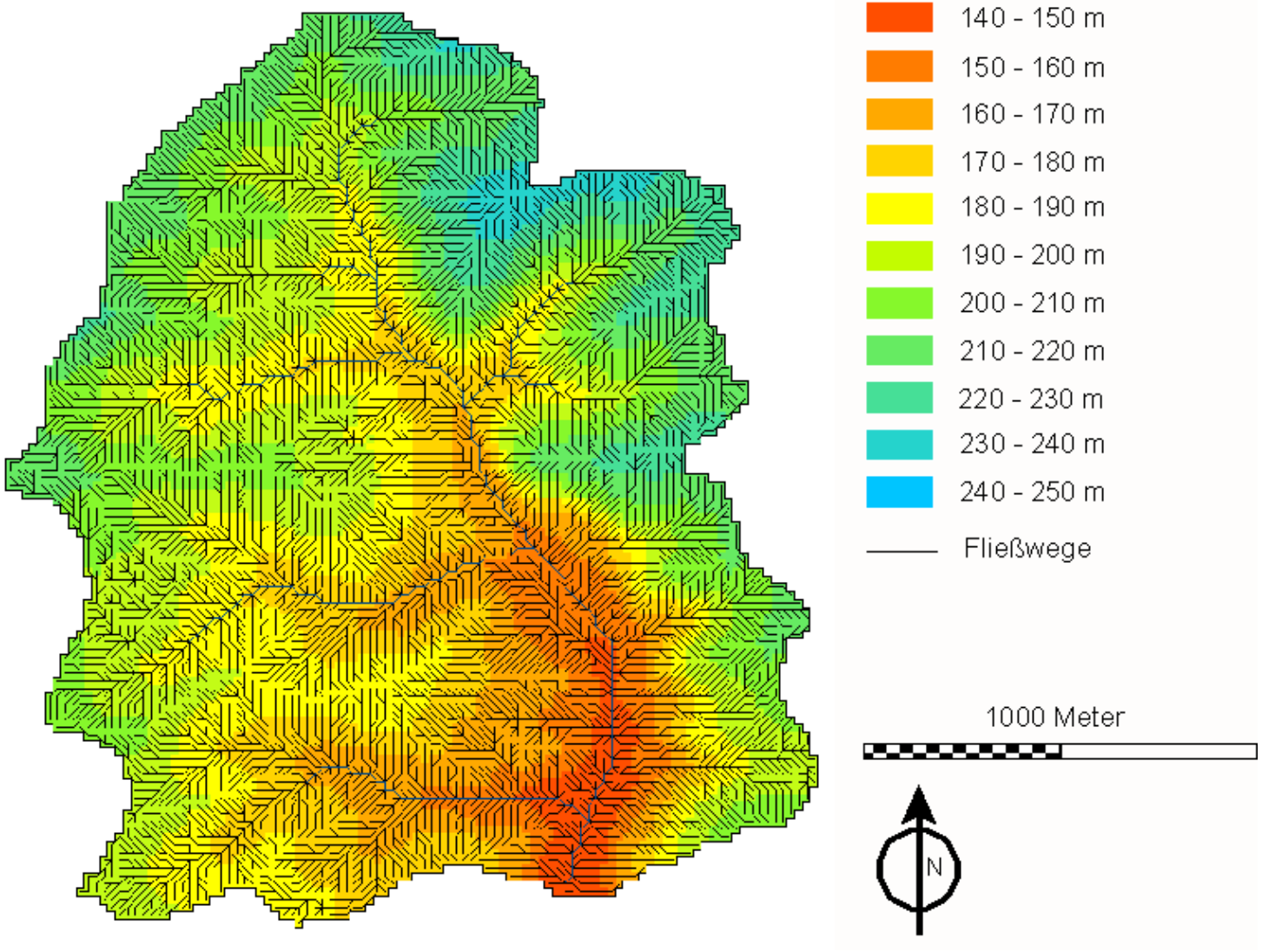
Modelling concept: integration on catchment
The test catchment Weiherbach

Location:	Kraichgauer Hügelland
Gage:	Menzingen
Area:	3.46 km^2
Elevation:	141 - 248 m
Land use:	18.7 % pasture und meadows
	71.6 % agricultural fields
	5.9 % partially sealed
	3.8 % forest
Soils:	Pararendzina / colluvium on loess
Hydrology:	Precipitation = 670 mm/a
	Runoff: MQ = 17.5 l/s HQ = 7.67 m^3/s
Simulation Period:	11.1991 - 08.1996
Simulation type:	longterm with daily valued / detailed flood simulation

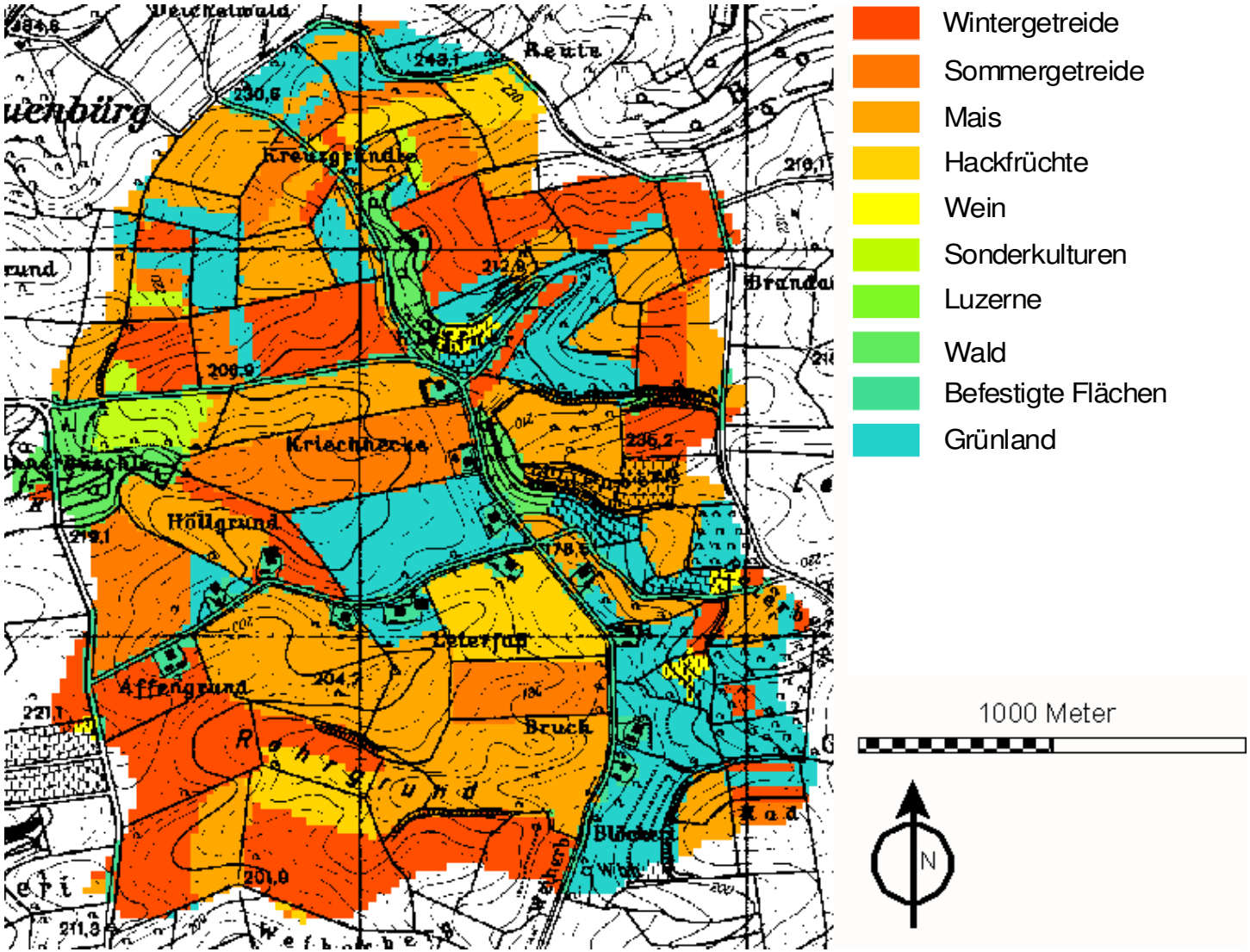
Modelling concept: integration on catchment
Measurement network



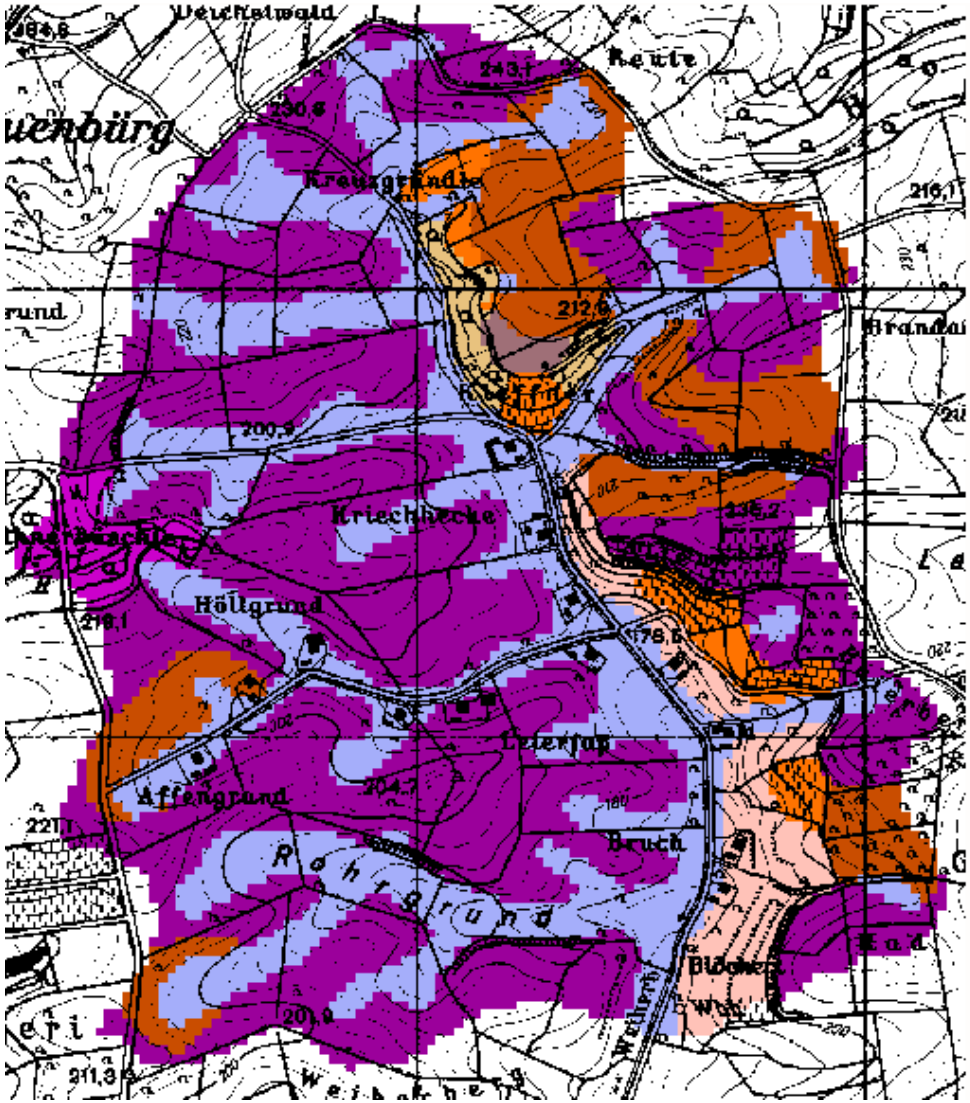
Modelling concept: integration to catchment scale
Elevation



Modelling concept: integration to catchment scale
Land use



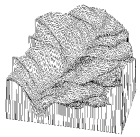
Modelling concept: integration to catchment scale
Soil types



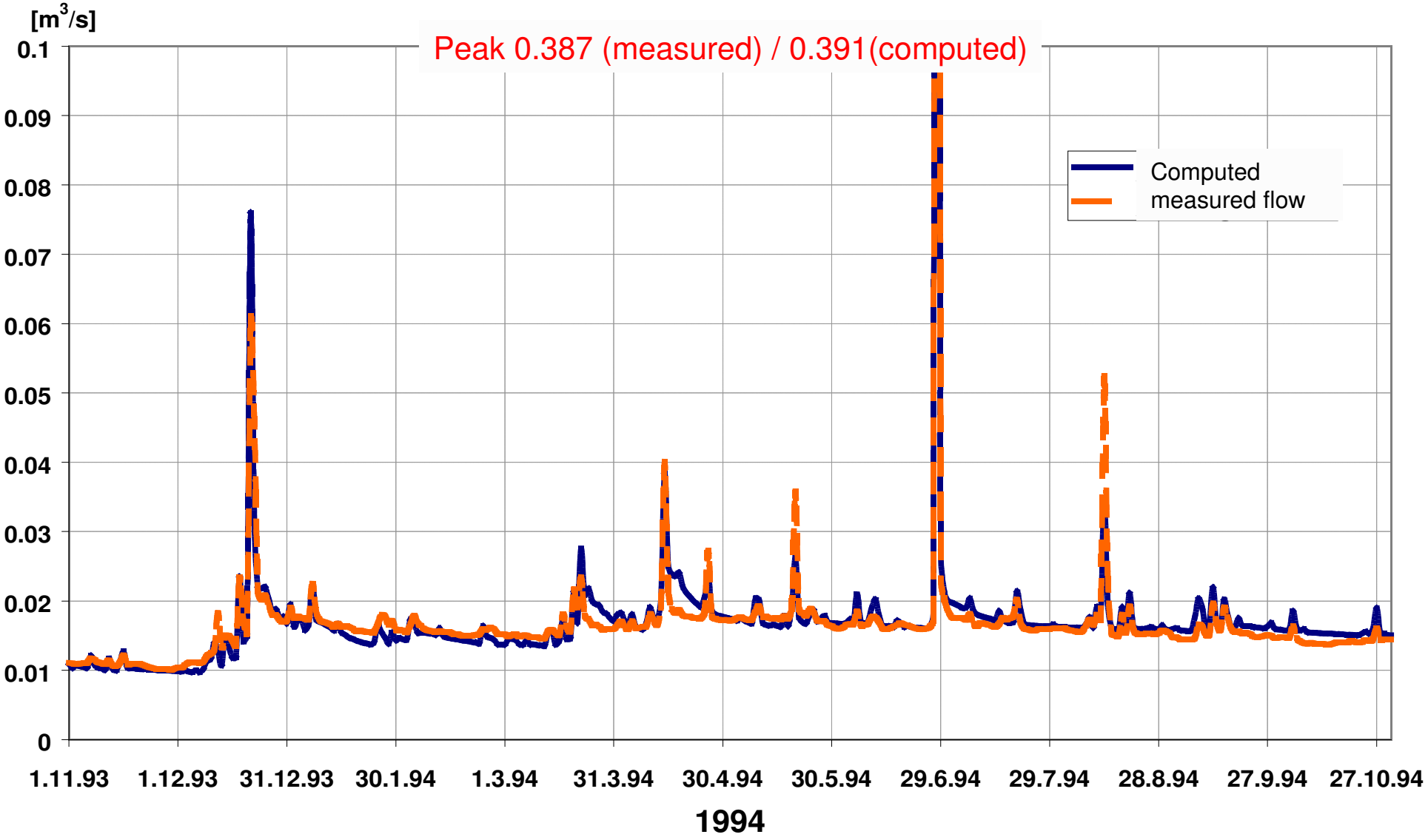
Bodentyp 1: Schwach lehmiger Schluff
Bodentyp 2: Lehmiger Ton (gesteinsunterlagert)
Bodentyp 3: Schluffig toniger Lehm
Bodentyp 4: Lehmiger Shluff
Bodentyp 5: Schluffiger Lehm
Bodentyp 6: Lehmiger Schluff
Bodentyp 7: Schluffiger Lehm (gesteinsunterlagert)
Bodentyp 8: Schluffig lehmiger Sand

1000 Meter

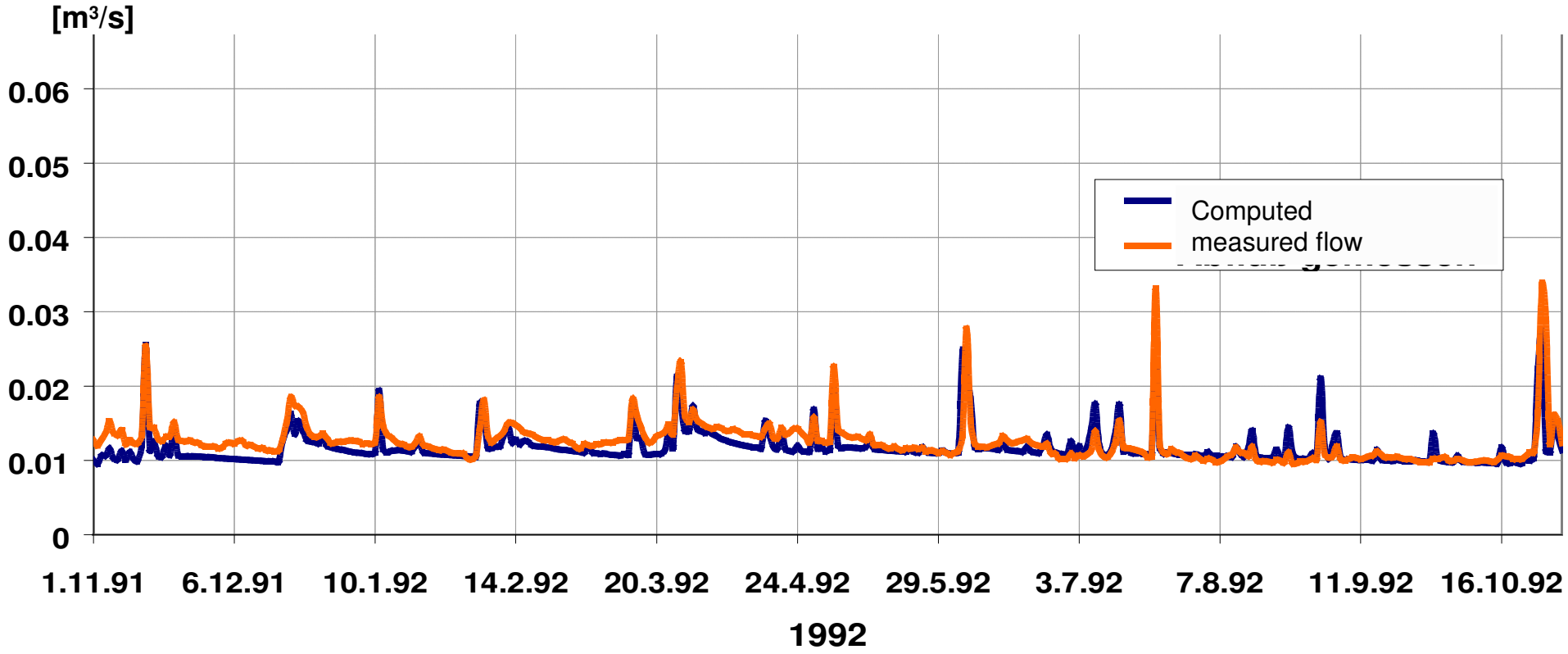
N



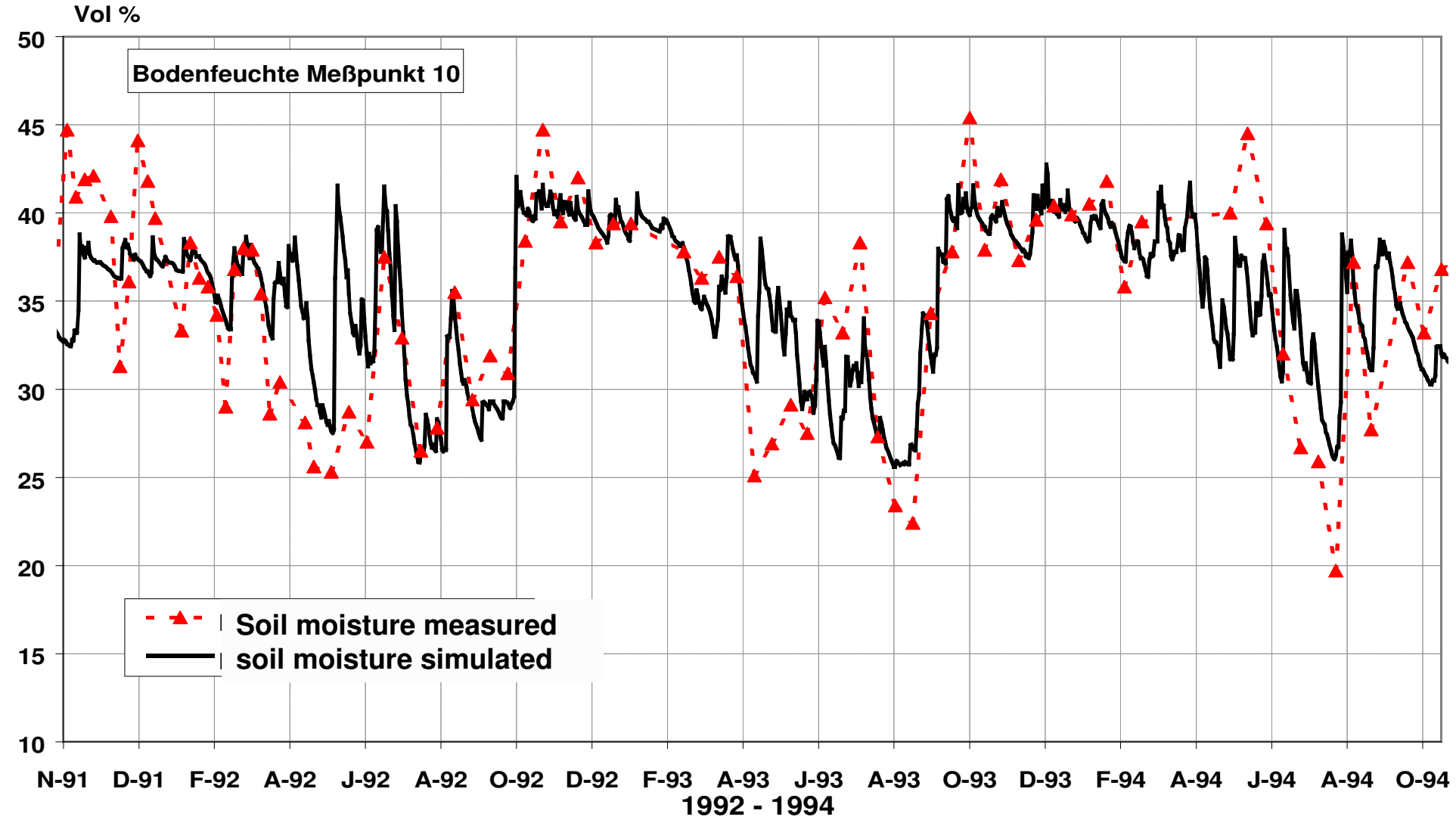
Modelling concept: application on catchment scale
Continuous simulation 1994



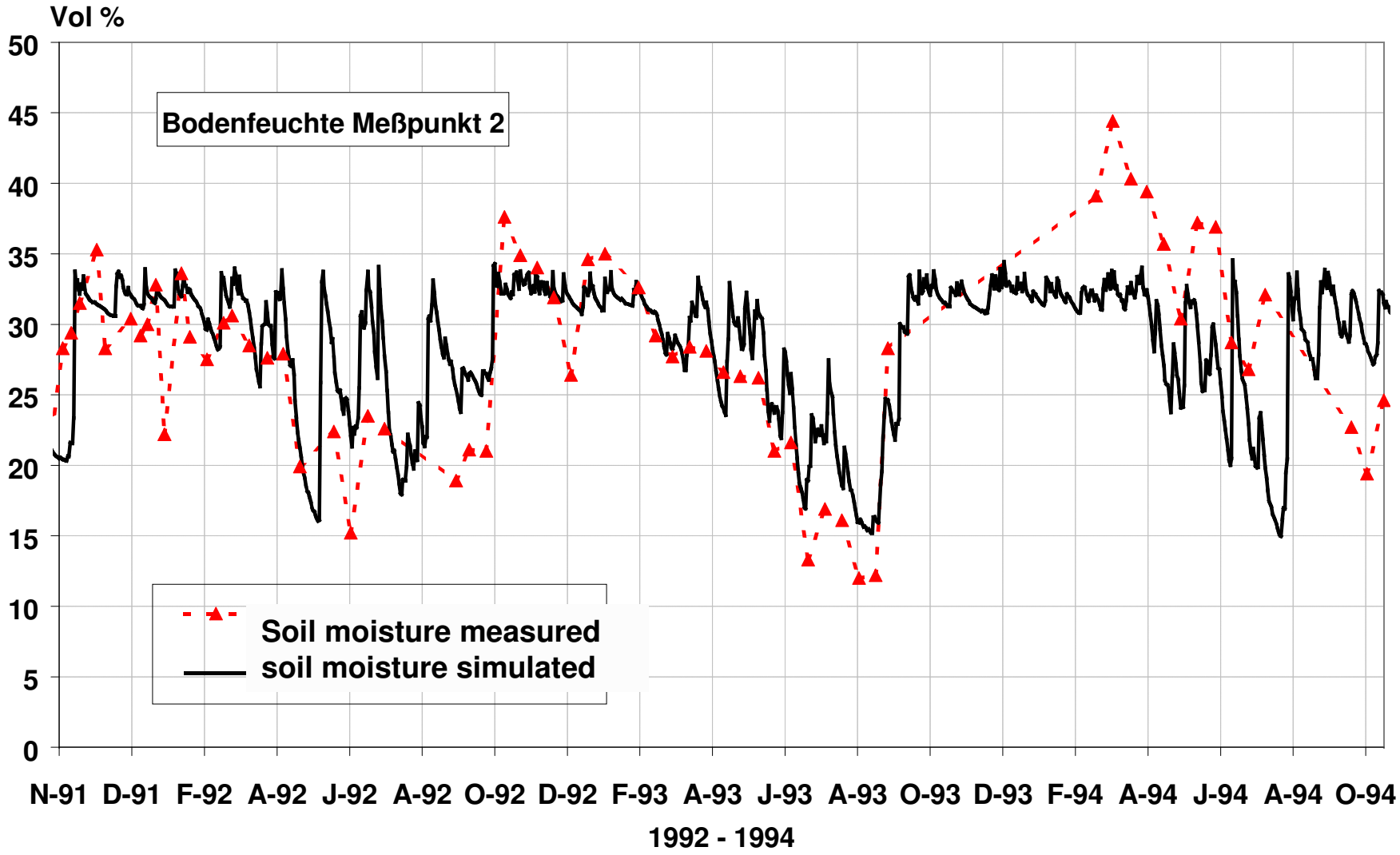
Modelling concept: application on catchment scale
Continuous simulation 1992



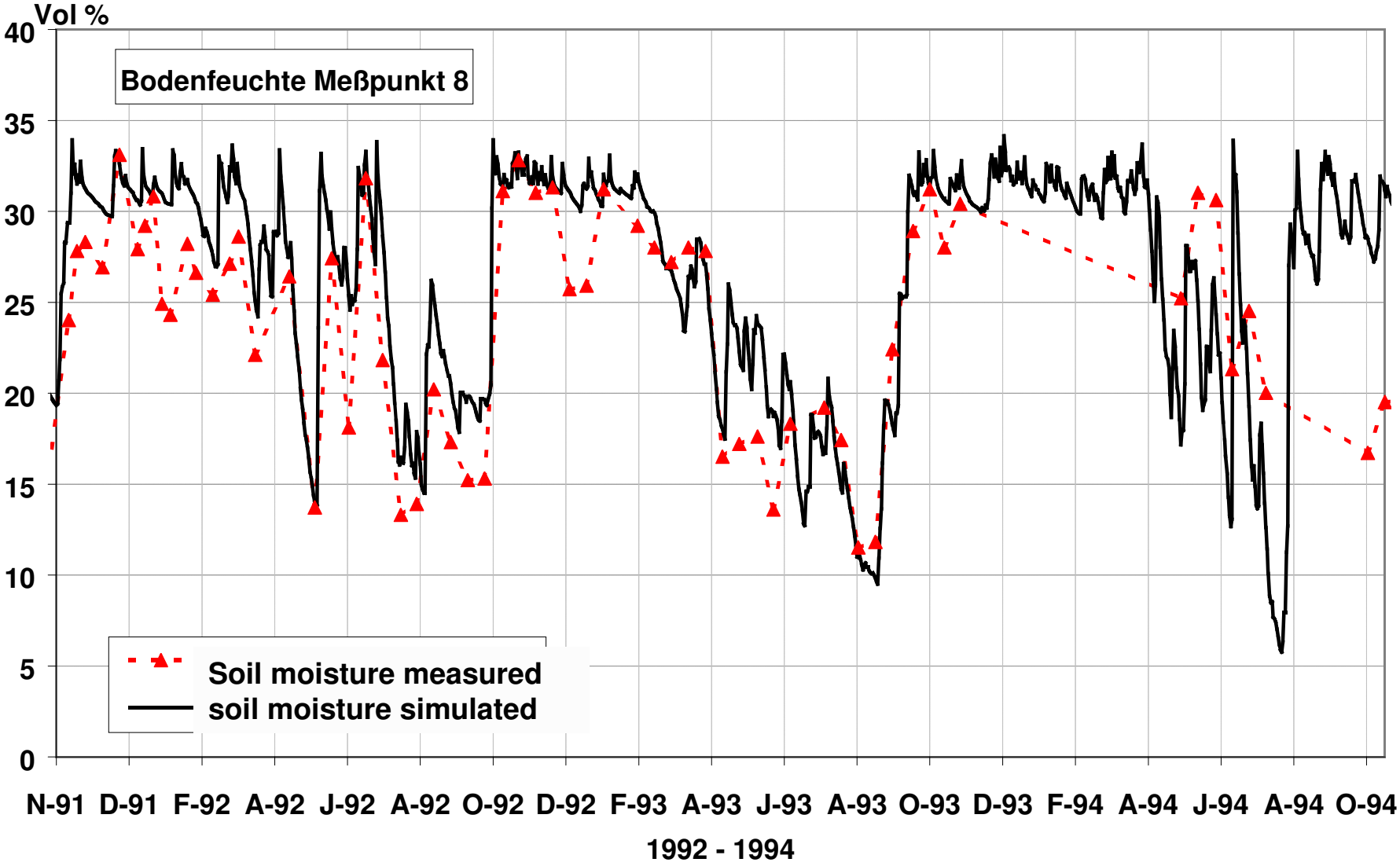
Modelling concept: application on catchment scale
Continuous uncalibrated soil moisture 1992- 1994



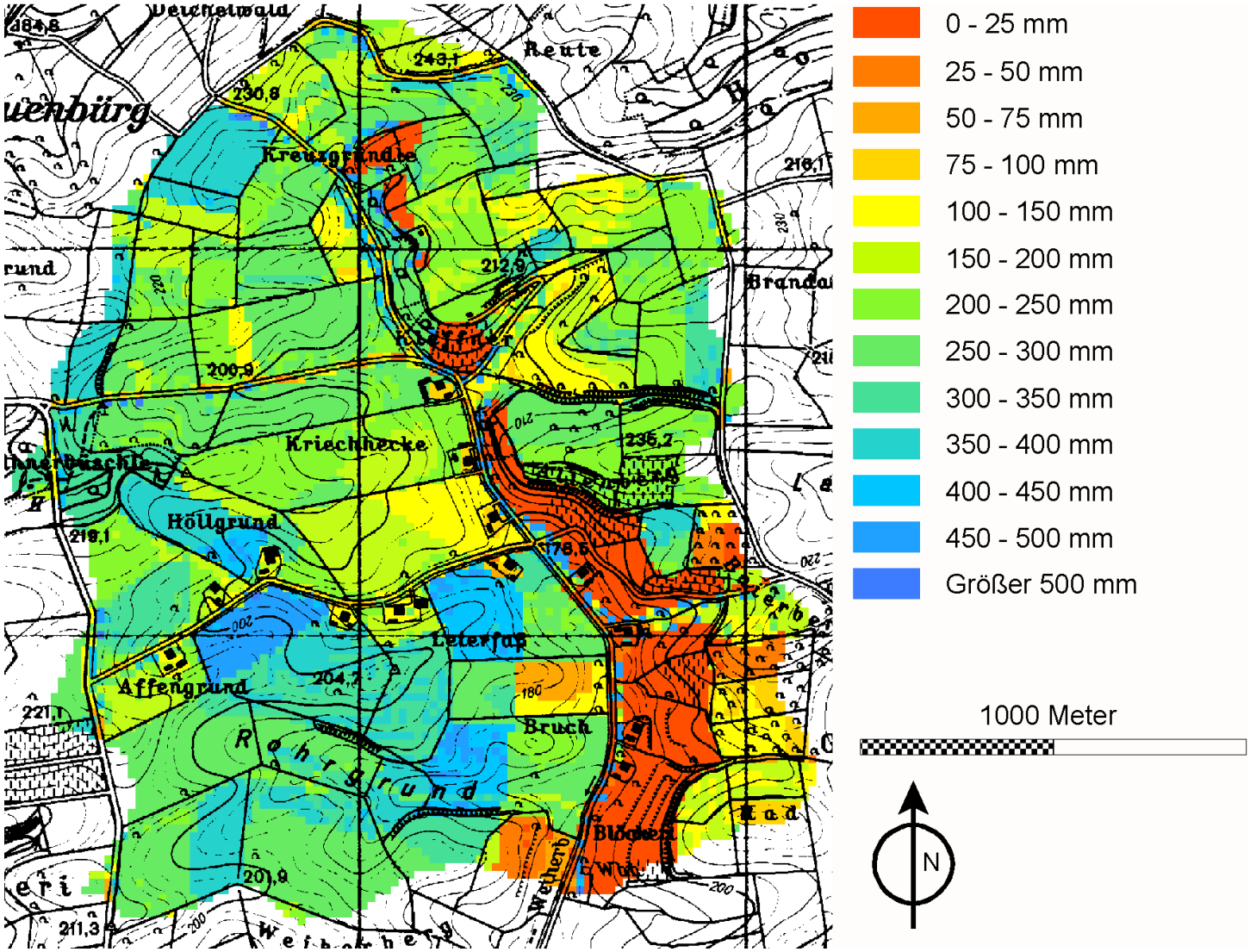
Modelling concept: application on catchment scale
Continuous uncalibrated soil moisture 1992- 1994



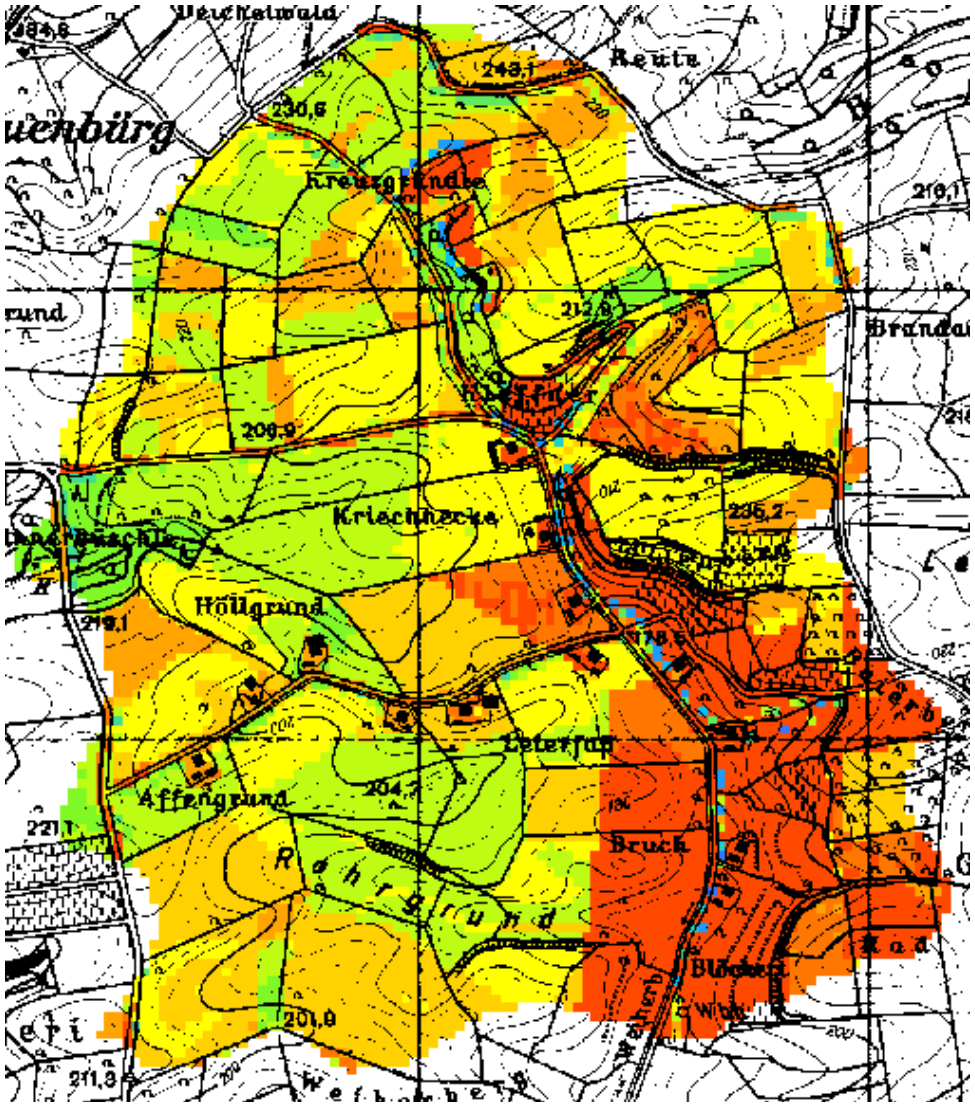
Modelling concept: application on catchment scale
Continuous uncalibrated soil moisture 1992- 1994



Modelling concept: application on catchment scale spatial distribution of yearly groundwater 1994

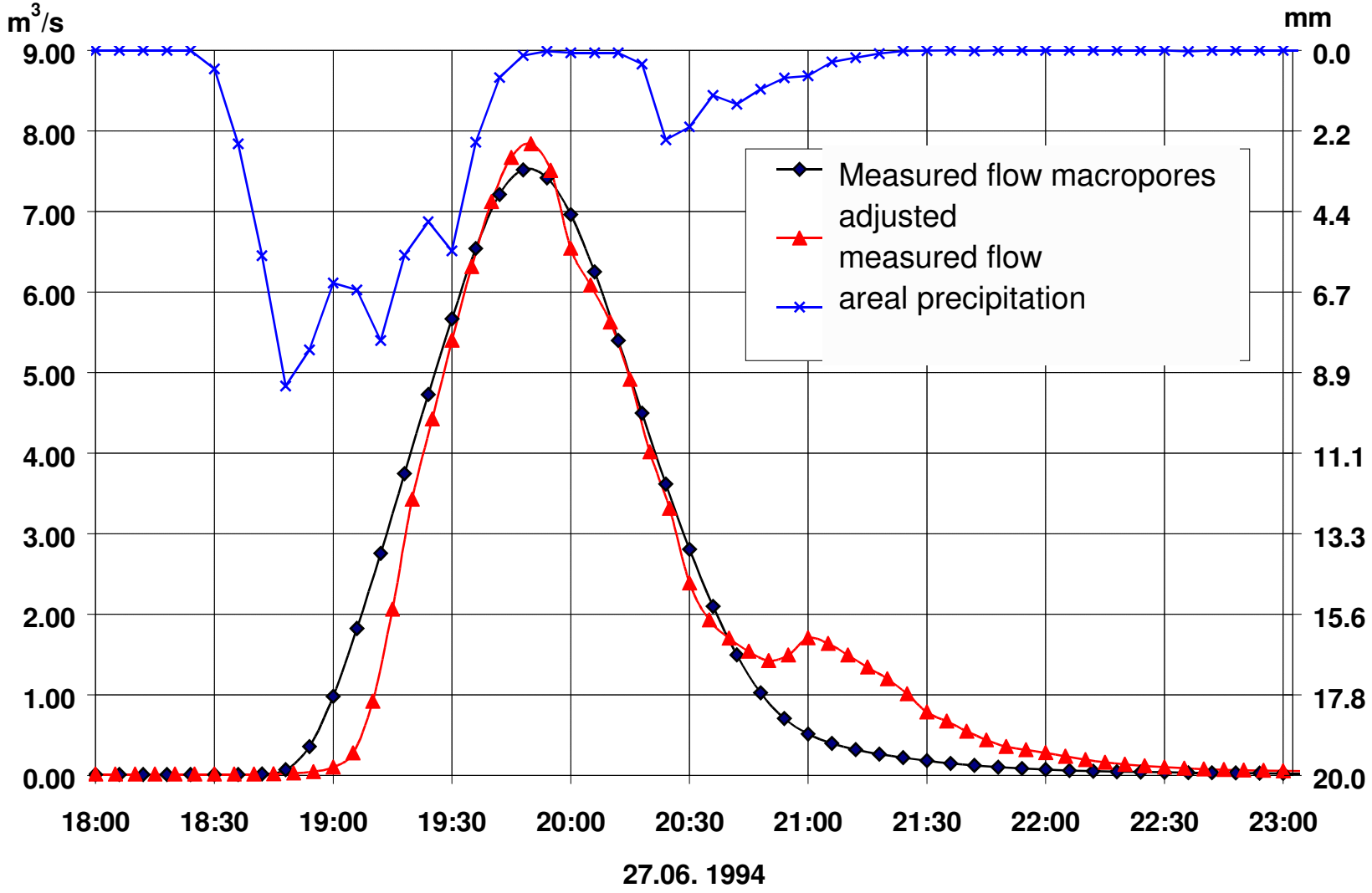


Modelling concept: application on catchment scale spatial distribution of yearly groundwater 1993

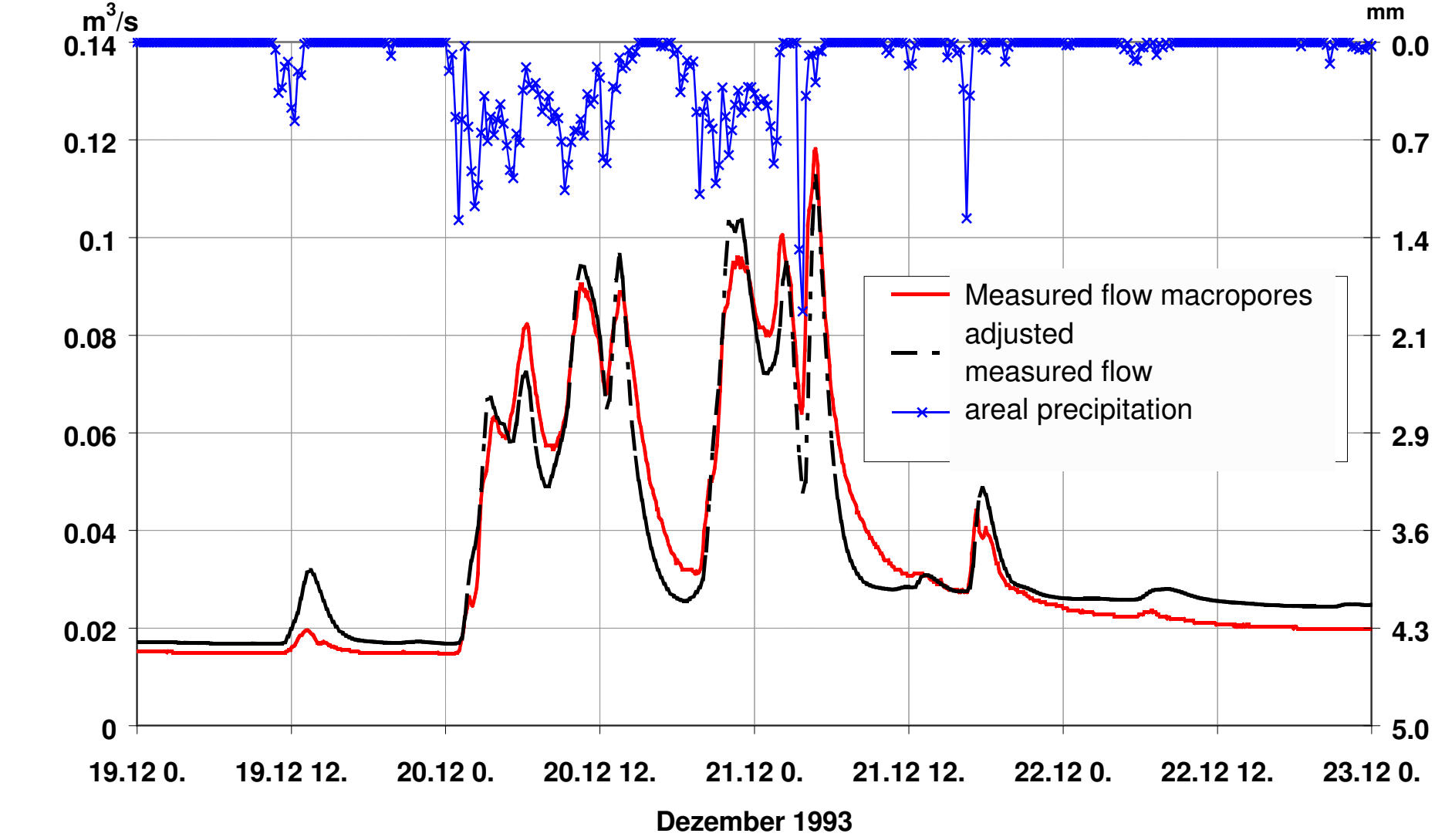


0 - 25 mm
25 - 50 mm
50 - 75 mm
75 - 100 mm
100 - 150 mm
150 - 200 mm
200 - 250 mm
250 - 300 mm
300 - 350 mm
350 - 400 mm
400 - 450 mm
450 - 500 mm
Größer 500 mm

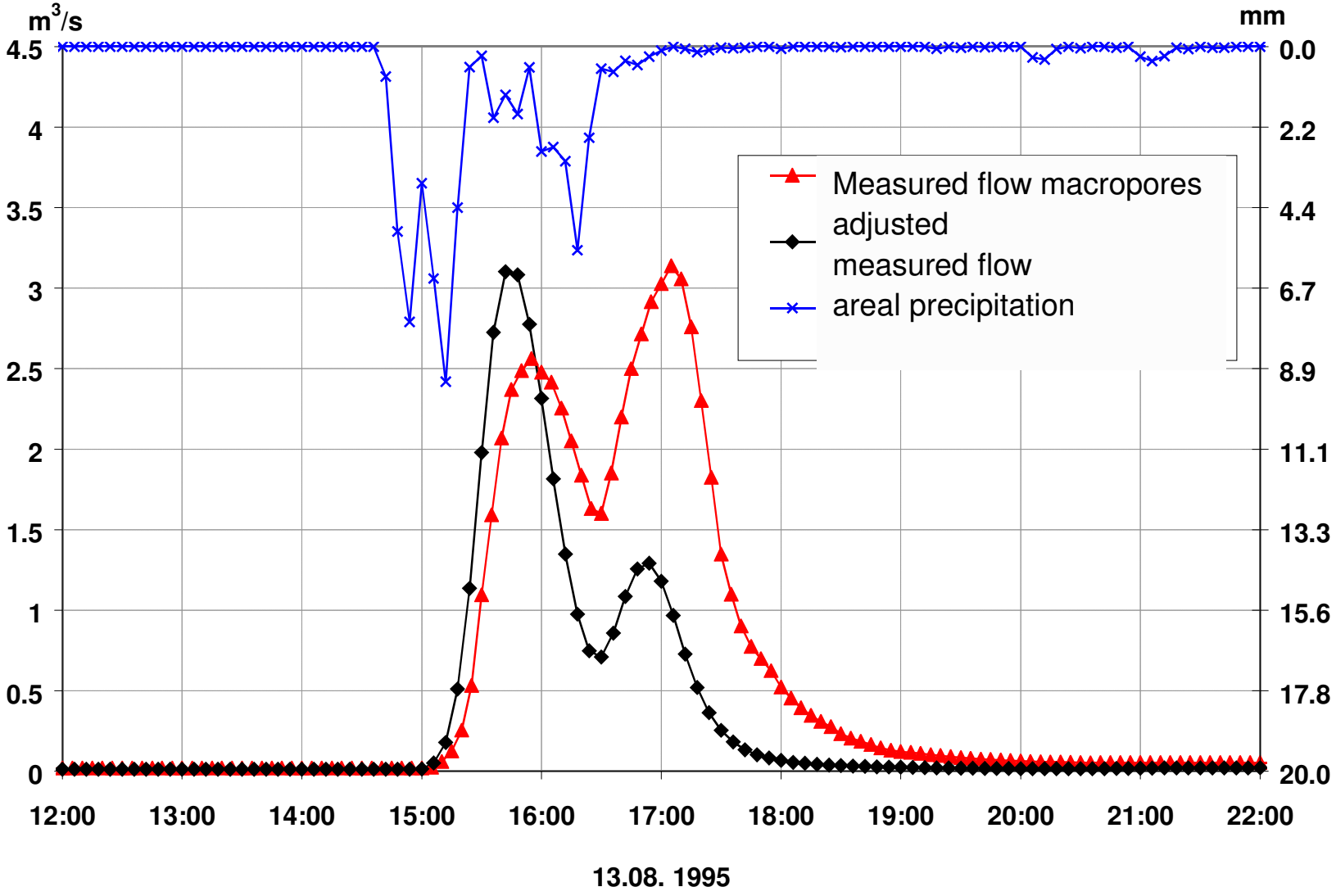
Modelling concept: application on catchment scale flood event no 4



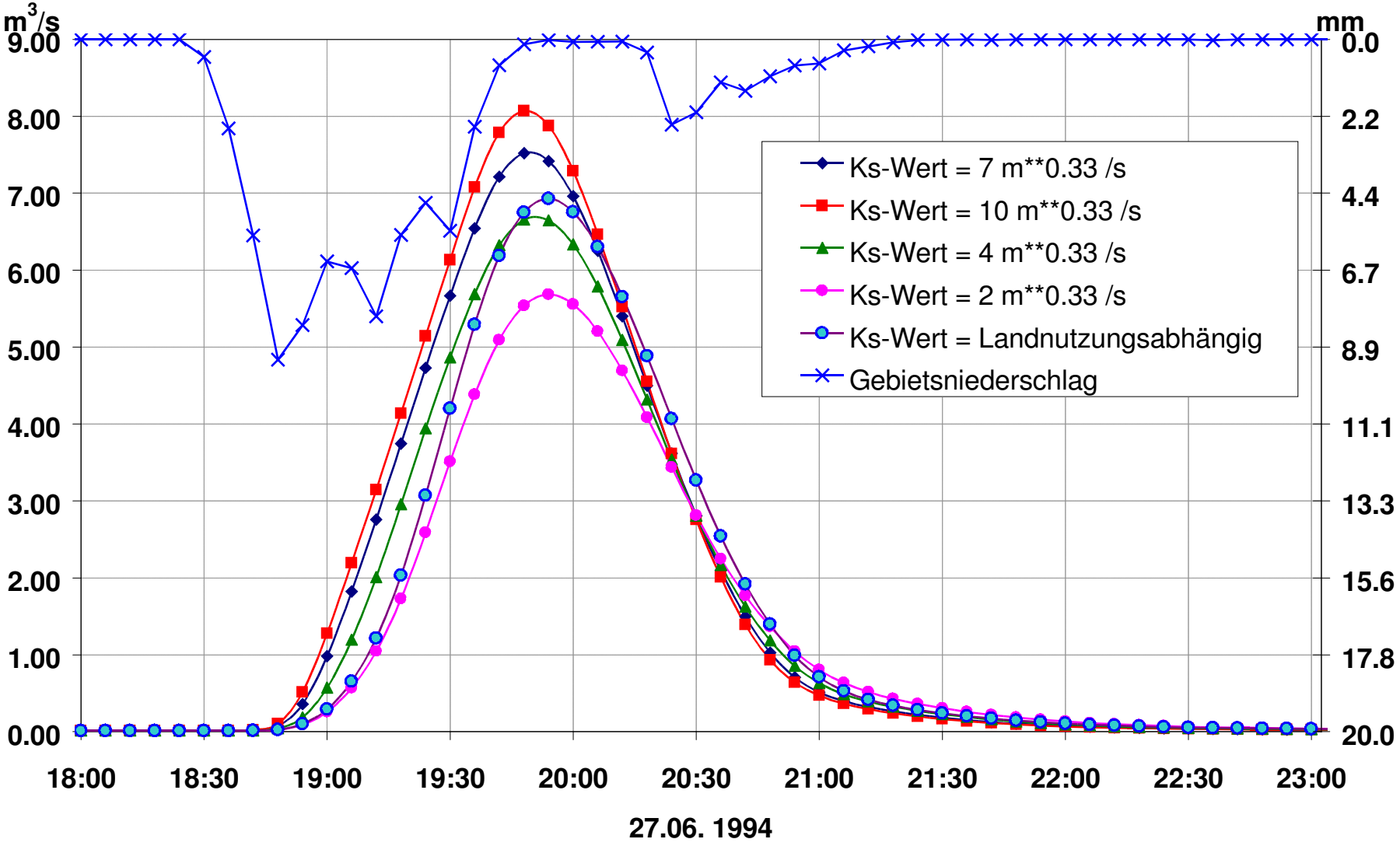
Modelling concept: application on catchment scale flood event no 2

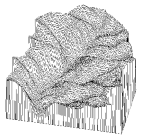


Modelling concept: application on catchment scale flood event no 7



Modelling concept: application on catchment scale flood event no 4- sensitivity Manning‘s n (ks=1.49/n)





Modelling concept: application on catchment scale goodness of fit criteria

	$MQ_{\_gem}$	$MQ_{\_ber}$	Korrelationskoeffizient	
Jahr	**[m³/s]**	**[m³/s]**	**Regression (r)**	**Nash-Sutcliffe (r)**
1991	0.014	0.014	0.83	0.78
1992	0.012	0.012	0.77	0.72
1993	0.013	0.012	0.88	0.72
1994	0.017	0.017	0.99	0.99
1995	0.020	0.018	0.94	0.92
1996	0.021	0.019	0.75	0.46
Gesamt			0.96	0.96

$MQ_{\_gem}$	$MQ_{\_ber}$	$NQ_{\_gem}$	$NQ_{\_ber}$	$HQ_{\_gem}$	$HQ_{\_ber}$
[m³/s]	[m³/s]	[l/s]	[l/s]	[m³/s]	[m³/s]
0.016	0.015	10	9	0.387 *	0.391 *

Summary

A GIS based model was presented, that is based on non linear, physically relationships between inflow, outflow and interrelated storage compartment

The model uses parameters (LAI, kstrickler, PWP, FC, Total pore volume) which can be mostly derived from analog und digital maps and from measurements

It has proved that the initial runs are often close to measurements. Thus it seems to be usefull for ungaged catchments