Process-based simulation of Distributed Flood Control Measures

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Distributed Flood Control Measures




Agriculture
↓
Conservation soil tillage
Drainage removal
Moor revitalisation

Forestry
↓
Afforestation
Forest conversion

Retention Basins
↓
Small ponds
Field storages
Uncontrolled basins

River Restoration
↓
Flow path extension
Floodplain forest

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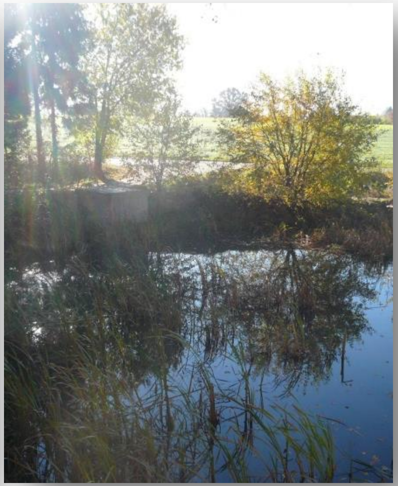
Problem

Distributed Flood Control Measures

Agriculture

Forestry



Retention Basins

River Restoration

Distributed in the catchment area

Punctual and linear

Runoff generation

Runoff concentration

Flood routing

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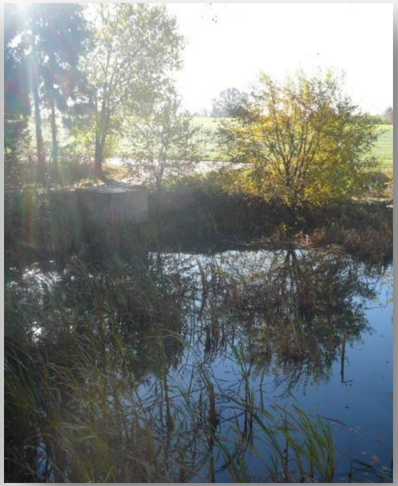
Problem

Distributed Flood Control Measures



Agriculture

Forestry

Retention Basins

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Objectives

Distributed Flood Control Measures

Process-based modeling

Influence of land use on soil-hydraulic properties

Runoff generation | Runoff concentration | Flood routing

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Objectives

Distributed Flood Control Measures

Process-based modeling

Influence of land use on soil-hydraulic properties

Verification of the modeling assumptions by field measurements

Runoff generation | Runoff concentration | Flood routing

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Distributed Flood Control Measures

Process-based modeling

Quantification of the effectiveness

Show sensitivities and sensible combinations

Verification of the modeling assumptions by field measurements

Runoff generation — Runoff concentration — Flood routing

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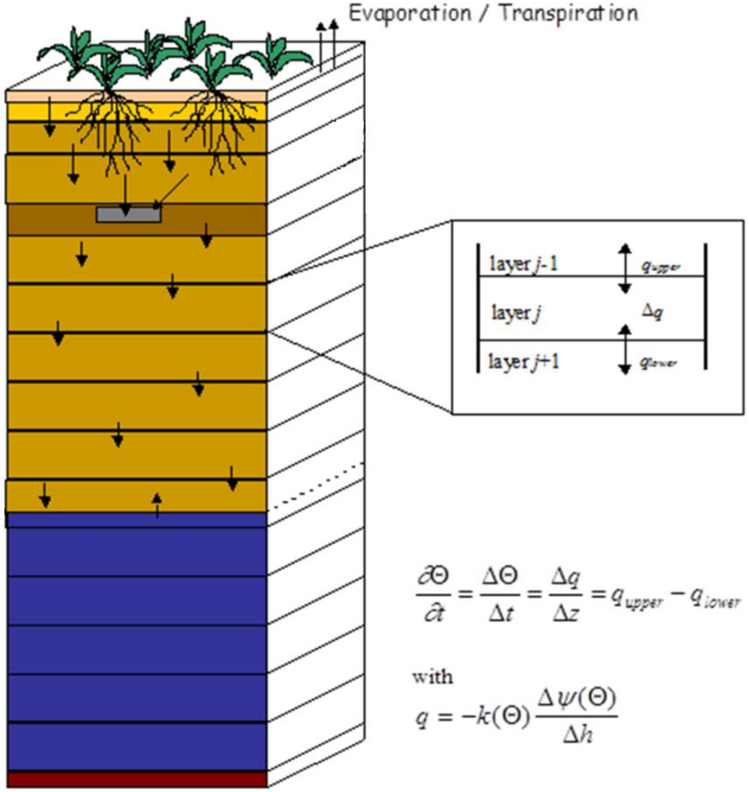
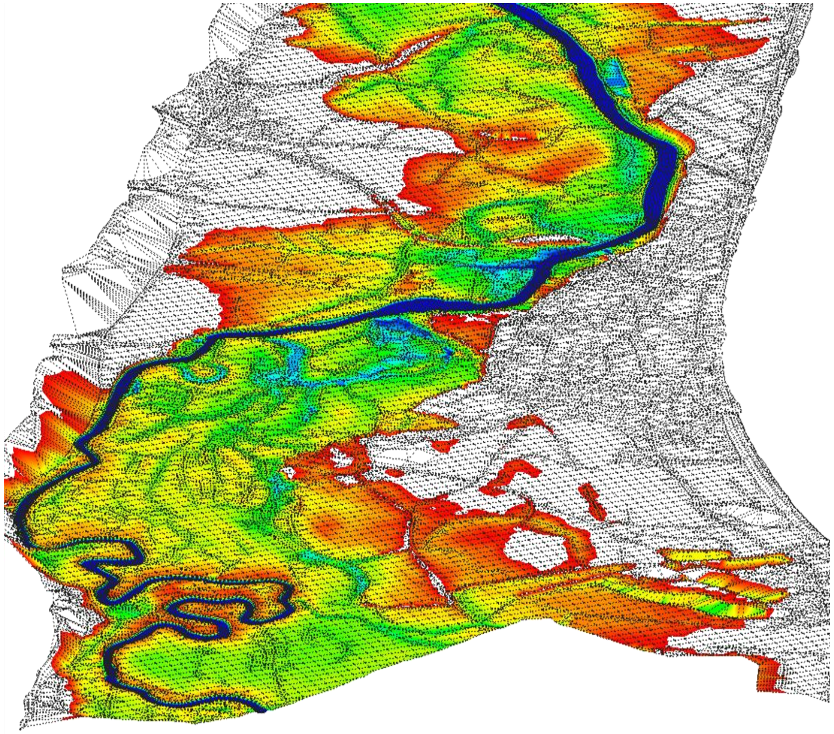
Modeling approach

Coupled use of….

WaSiM

HYDRO_AS-2d





Runoff generation

Runoff concentration

Flood routing

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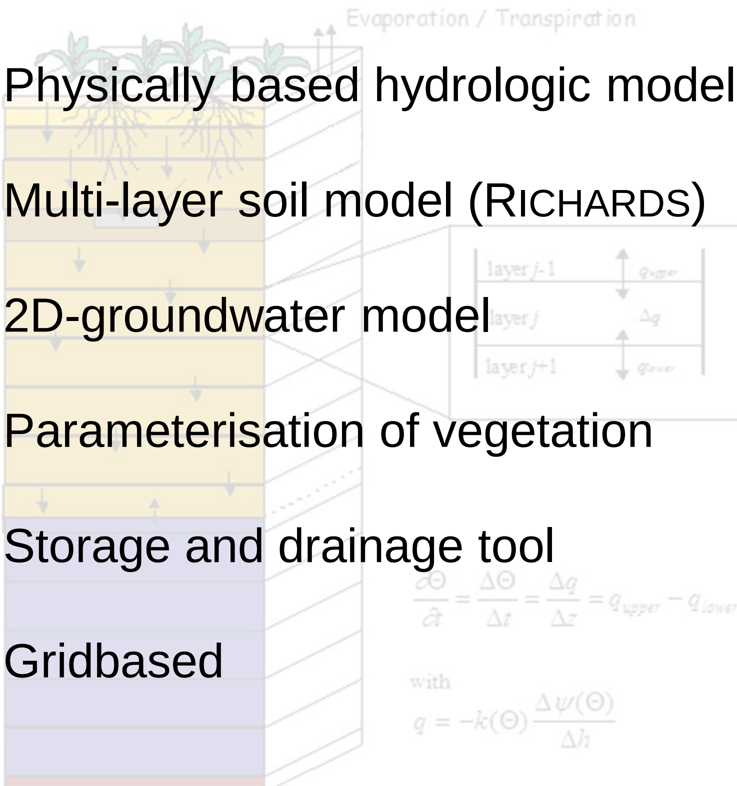
Modeling approach

Coupled use of….

WaSiM



Physically based hydrologic model

Multi-layer soil model (RICHARDS)

2D-groundwater model

Parameterisation of vegetation

Storage and drainage tool

Gridbased

HYDRO_AS-2d

Runoff generation Runoff concentration Flood routing

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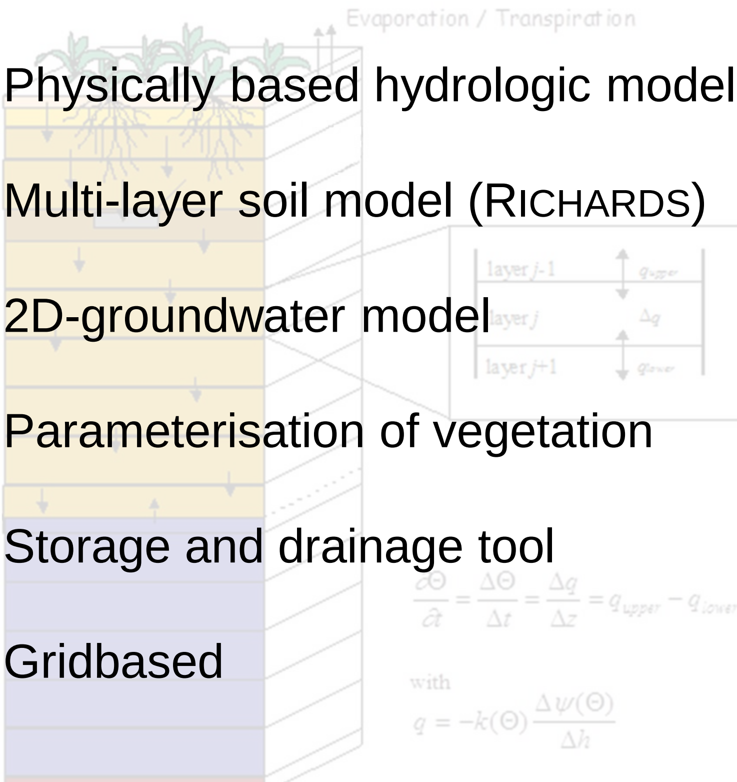
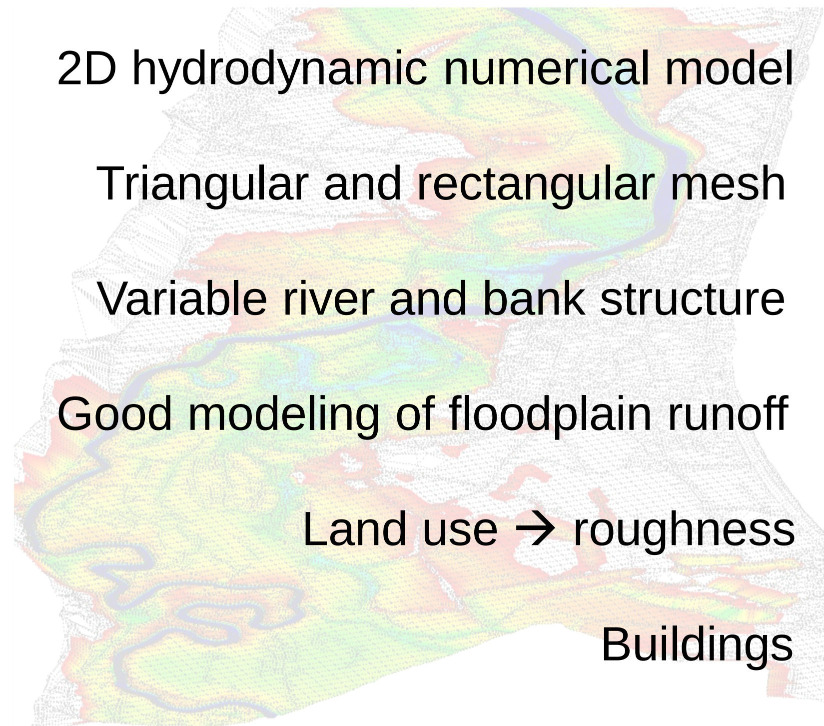
Modeling approach

Coupled use of….





WaSiM	HYDRO_AS-2d
Physically based hydrologic model	2D hydrodynamic numerical model
Multi-layer soil model (RICHARDS)	Triangular and rectangular mesh
2D-groundwater model	Variable river and bank structure
Parameterisation of vegetation	Good modeling of floodplain runoff
Storage and drainage tool	Land use → roughness
Gridbased	Buildings

Runoff generation Runoff concentration **Flood routing**

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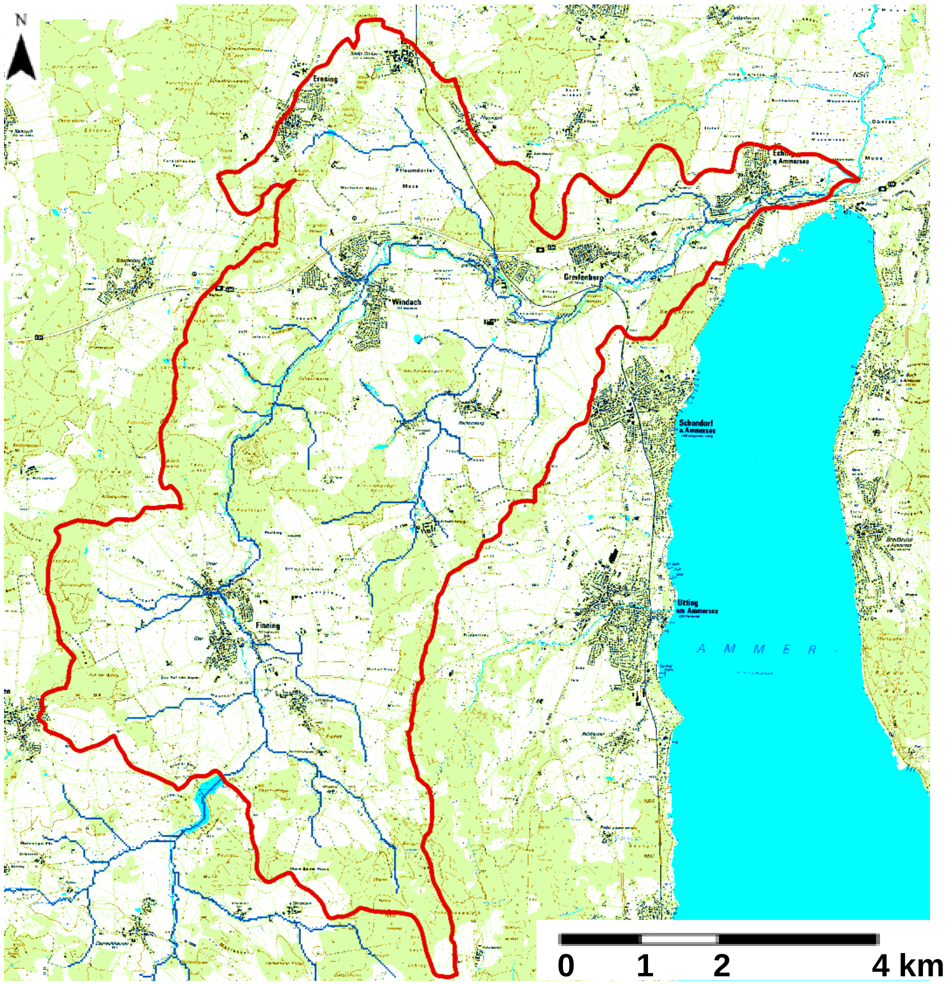
Modeling approach

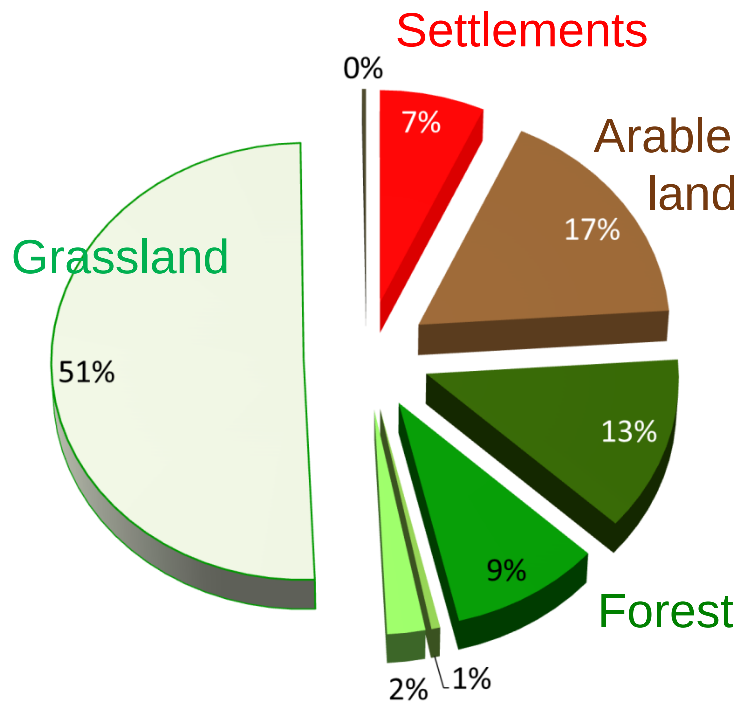
Modeling area: Windach catchment (northern part)



Size: 65 km²

Upper moraine

Main soil type: Luvisol



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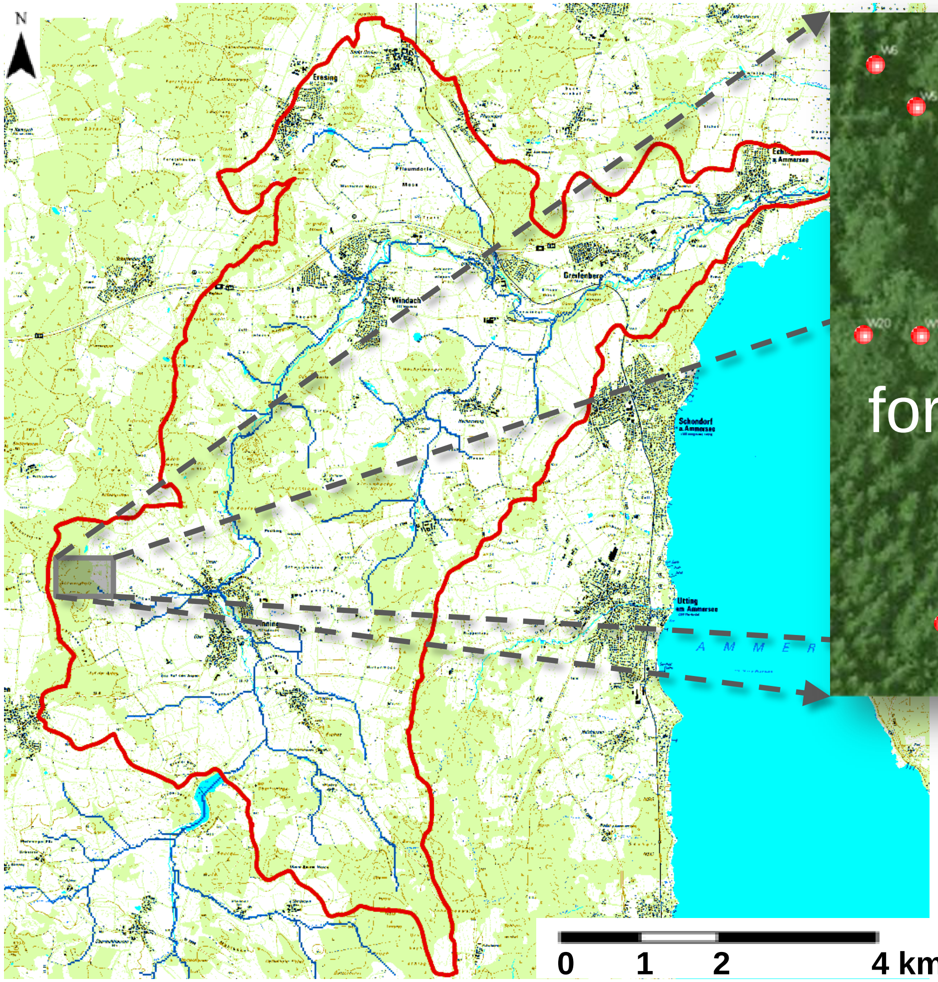
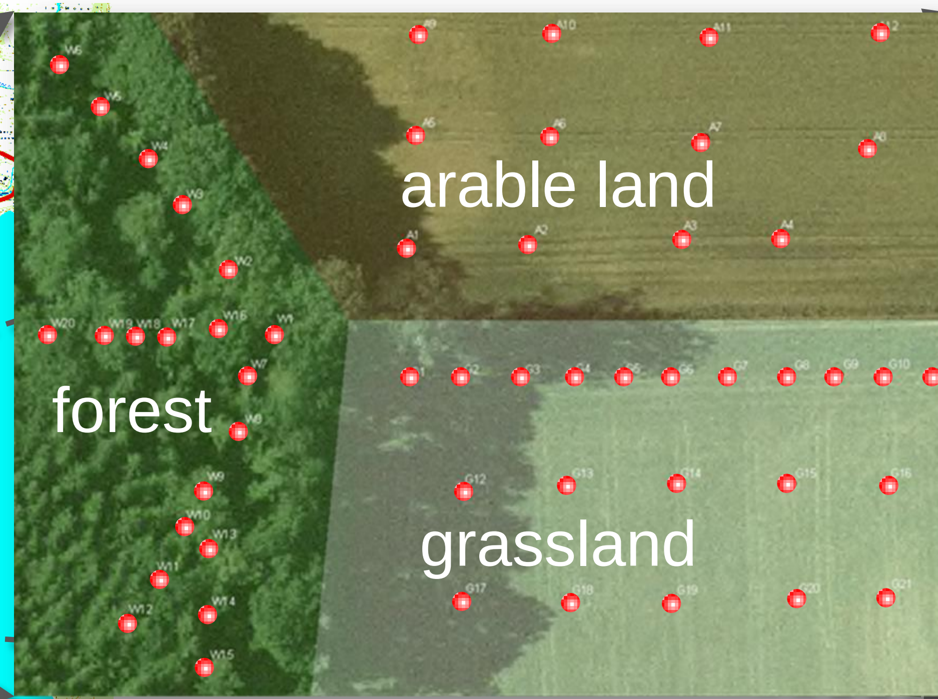
Modeling approach

Modeling area → **survey area**





1. **Soil map** analysis

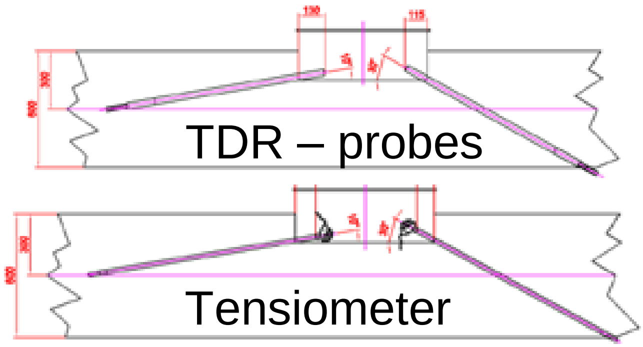
   → Main soil type: Luvisol

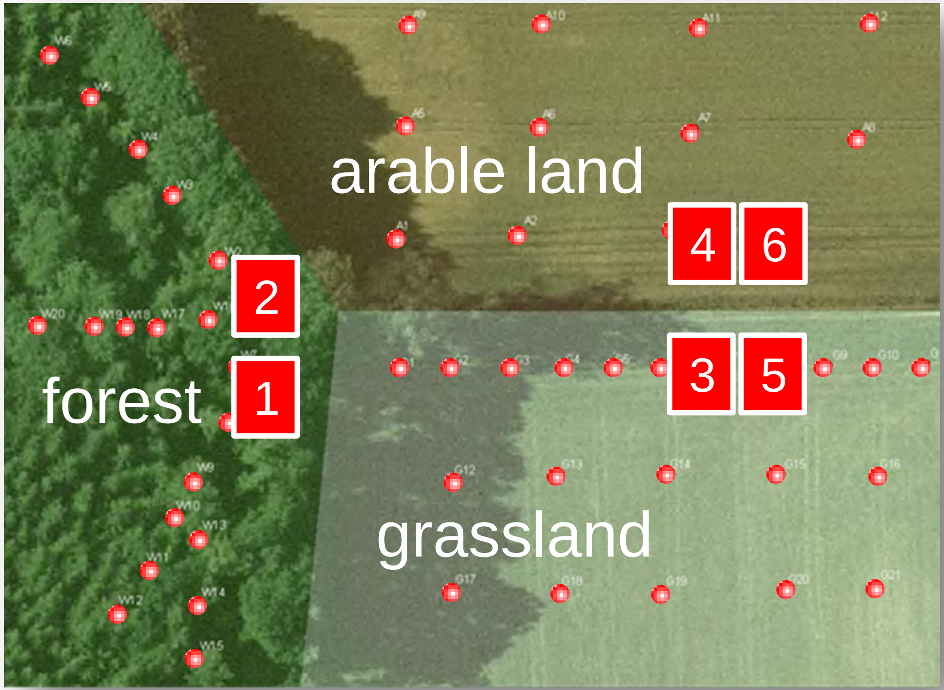
2. **Boring rod** analysis: n = 53 (●)

Modeling approach

survey area

Measurement technology:





Laboratory samples:

- **B**ulk **D**ensity
- **O**rganic **C**ontent
- **pF-curve**

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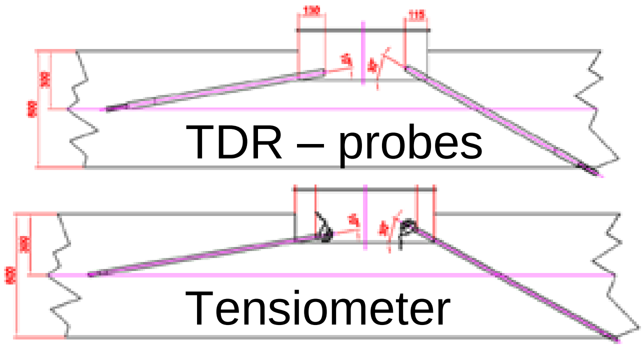
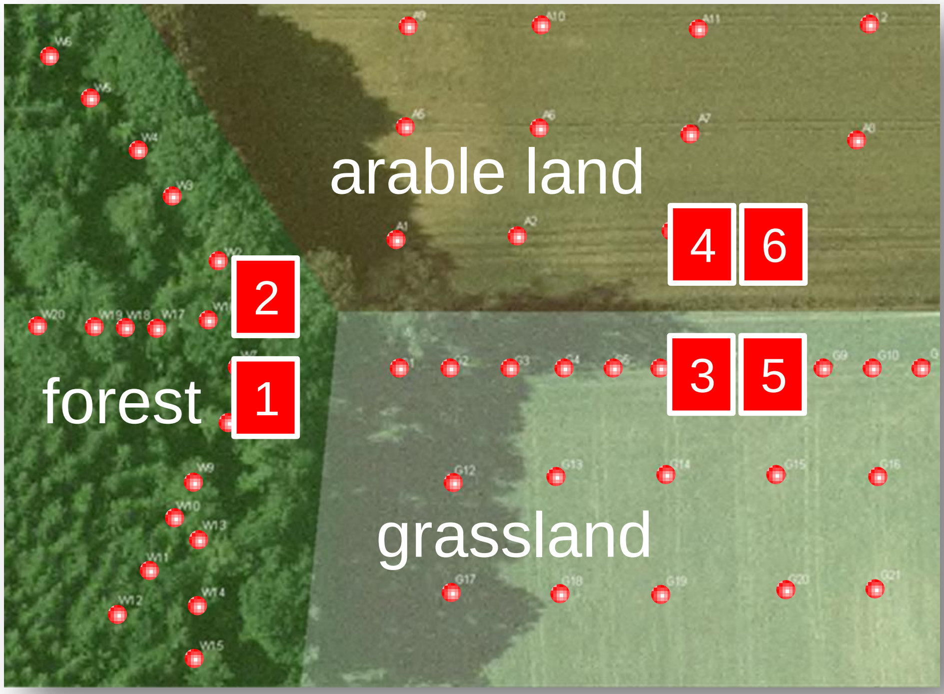
Modeling approach

survey area

Measurement technology:





Laboratory samples:

- **B**ulk **D**ensity
- **O**rganic **C**ontent
- **pF-curve**

→ Correlation BD - OC: $R^2 = 0{,}67$

→ **Grassland:** highest OC and lowest BD

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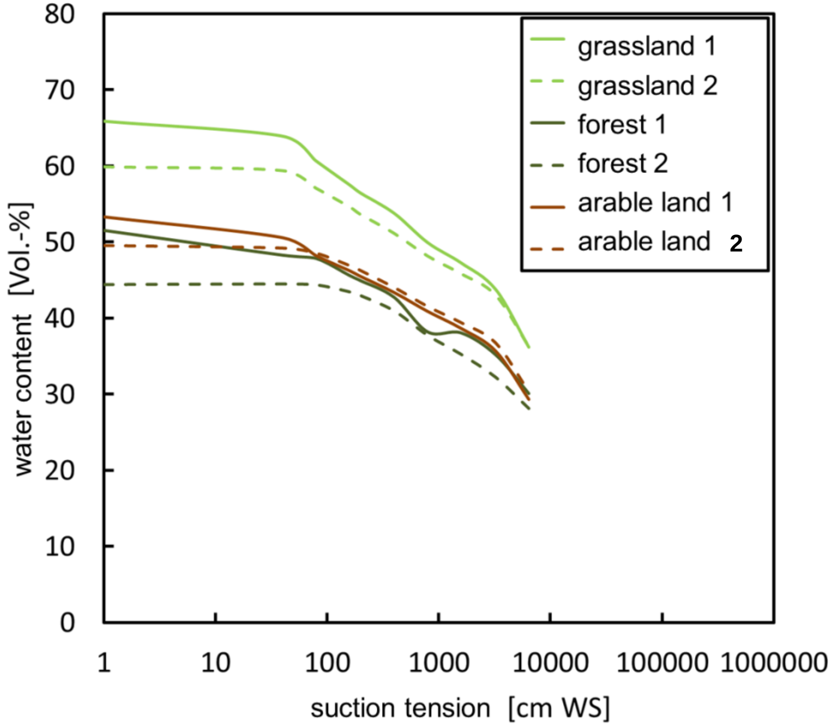
Modeling approach

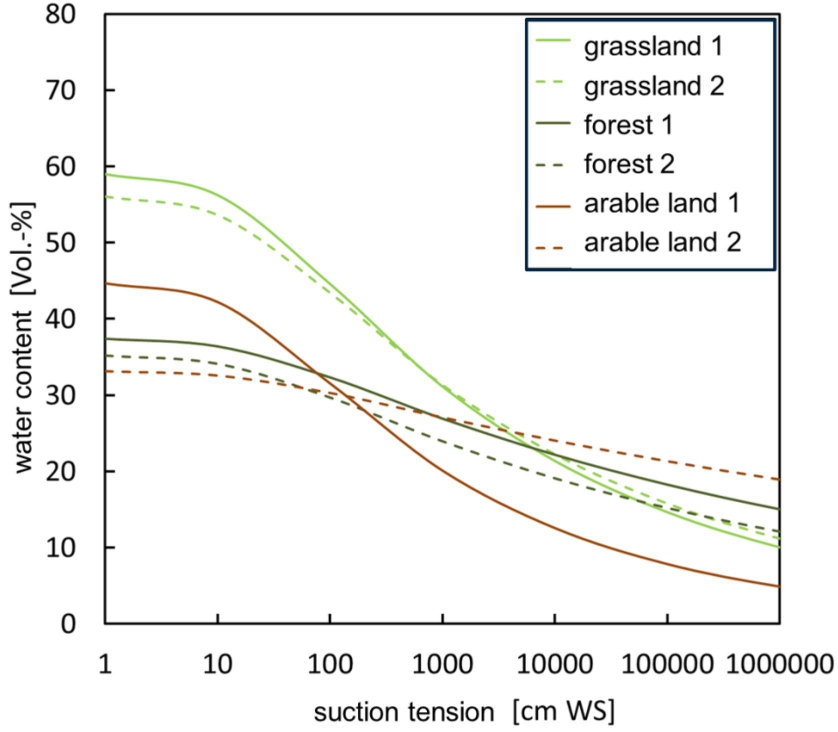
survey area

Generation of pF-curves (n = 24):

Laboratory (e.g. 10 cm):



Field survey (e.g. 30 cm):



→ **Grassland:** comparative good soil hydraulic properties

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Modeling approach

Measurement results: basis for model parameterisation (WaSiM)

Soil parameterisation: VAN GENUCHTEN → $\Theta_s, \Theta_r, \alpha, n, m$

→ pF-curve (*Van Gen.*): $\psi(\Theta) = \frac{1}{\alpha}\left[\left(\frac{\Theta - \Theta_r}{\Theta_s - \Theta_r}\right)^{-1/m} - 1\right]^{1/n}$

→ unsaturated conductivity (*Mualem-Van Gen.*):

$$\frac{k(\Theta)}{k_s} = \left[\frac{\Theta - \Theta_s}{\Theta_s - \Theta_r}\right]^{1/2} \cdot \left[1 - \left(1 - \left(\frac{\Theta - \Theta_r}{\Theta_s - \Theta_r}\right)^{1/m}\right)^m\right]^2$$

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WaSiM-ETH:

RICHARDS-Equation

$$\frac{\partial \Theta}{\partial t} = \frac{\partial}{\partial z}\left[k(\psi) \cdot \left(\frac{\partial \psi}{\partial z} - 1\right)\right]$$

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Modeling approach

Measurement results: basis for model parameterisation (WaSiM)

Grain size, BD, OC → **P**edo**t**rans**f**erfunction → $\Theta_s, \Theta_r, \alpha, n, m$

WaSiM-ETH:

RICHARDS-Equation

$$\frac{\partial \Theta}{\partial t} = \frac{\partial}{\partial z}\left[k(\psi) \cdot \left(\frac{\partial \psi}{\partial z} - 1 \right) \right]$$

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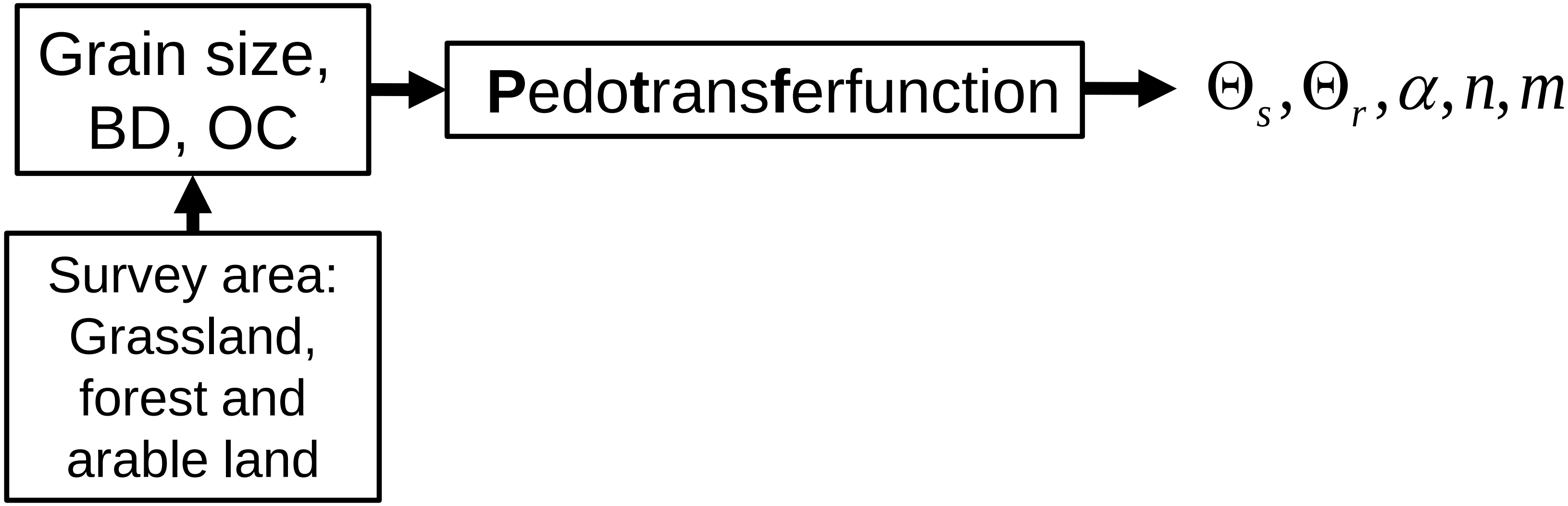
Measurement results: basis for model parameterisation (WaSiM)



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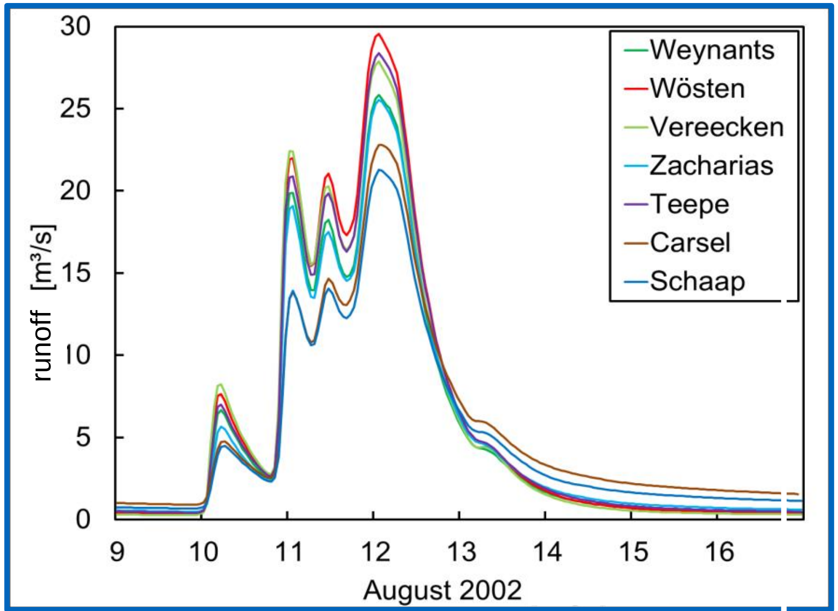
Measurement results: basis for model parameterisation (WaSiM)

Grain size, BD, OC → **Pedotransferfunction** → $\Theta_s, \Theta_r, \alpha, n, m$

Survey area: Grassland, forest and arable land

WEYNANTS et al. (2008),
WÖSTEN et al. (1999),
VEREECKEN et al. (1989),
ZACHARIAS et al. (2007),
TEEPE et al. (2003),
CARSEL & PARRISH (1988),
SCHAAP & LEIJ (1998)



Most suitable PTF ?

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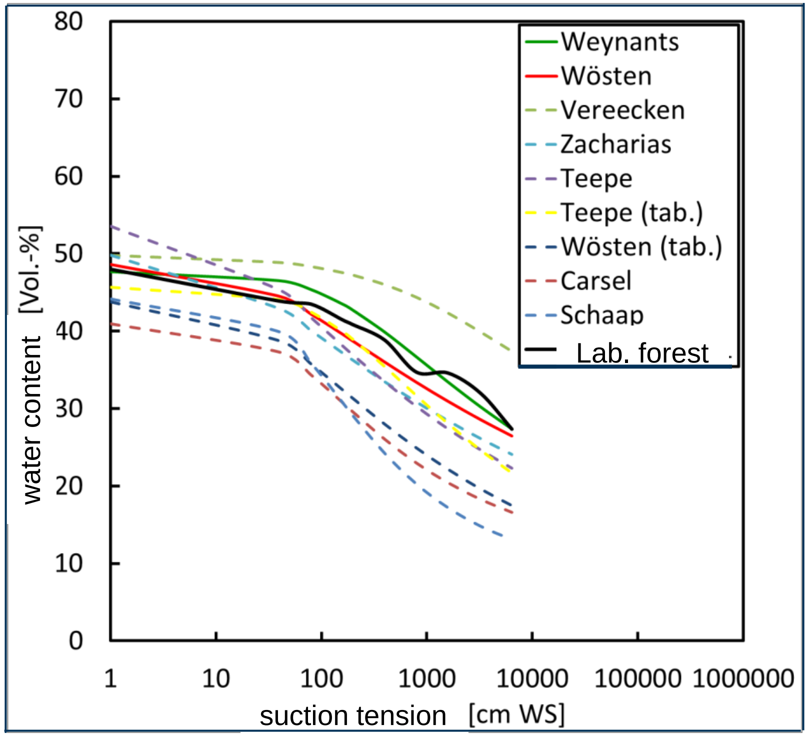
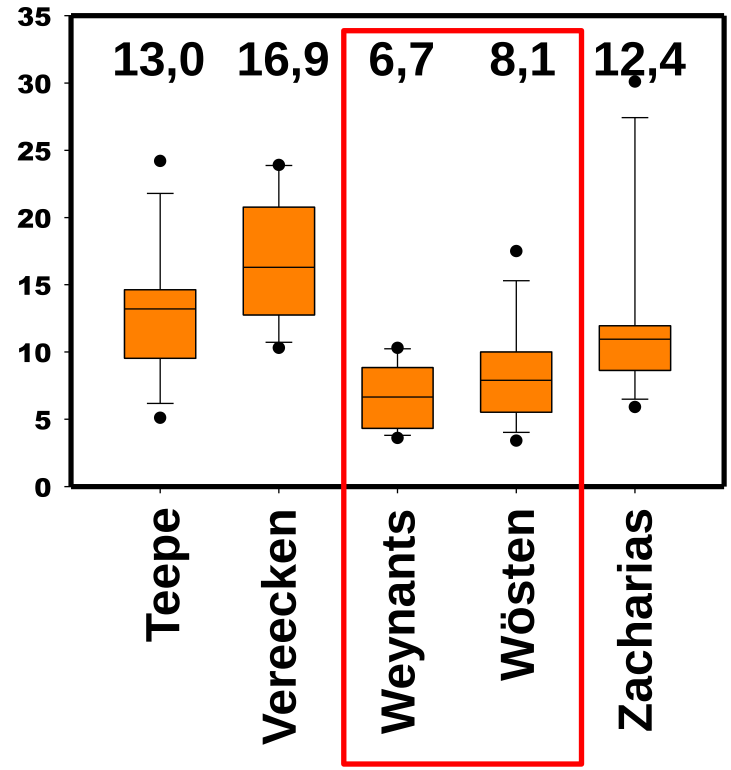
Measurement results: basis for model parameterisation (WaSiM)

pF-curves (laboratory, n = 12): suitable pedotransferfunction

Example:



Boxplots $RMSE/\bar{x}$ **average value in %:**



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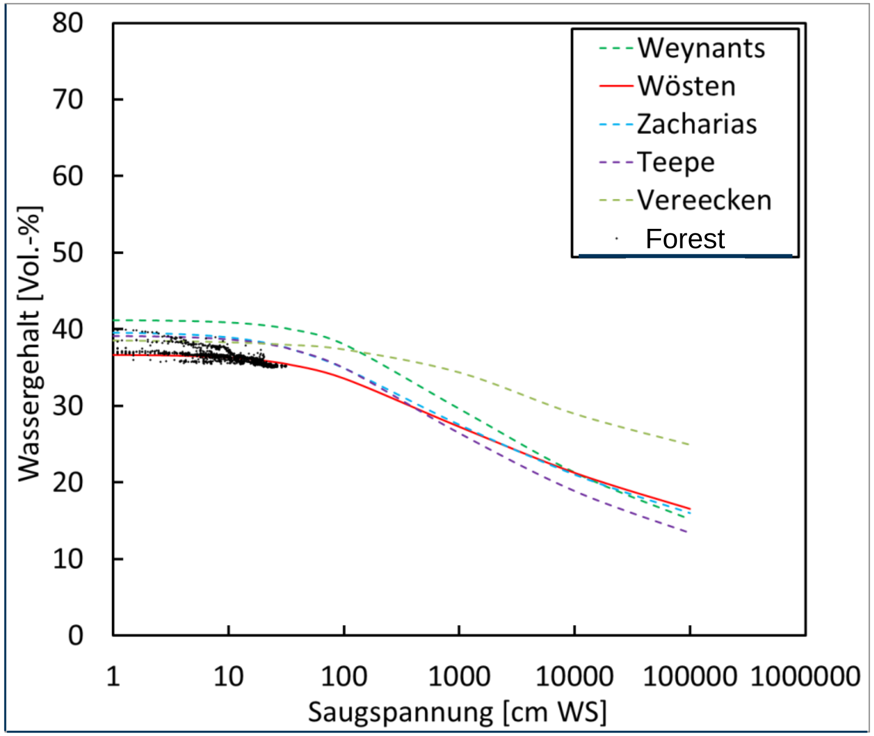
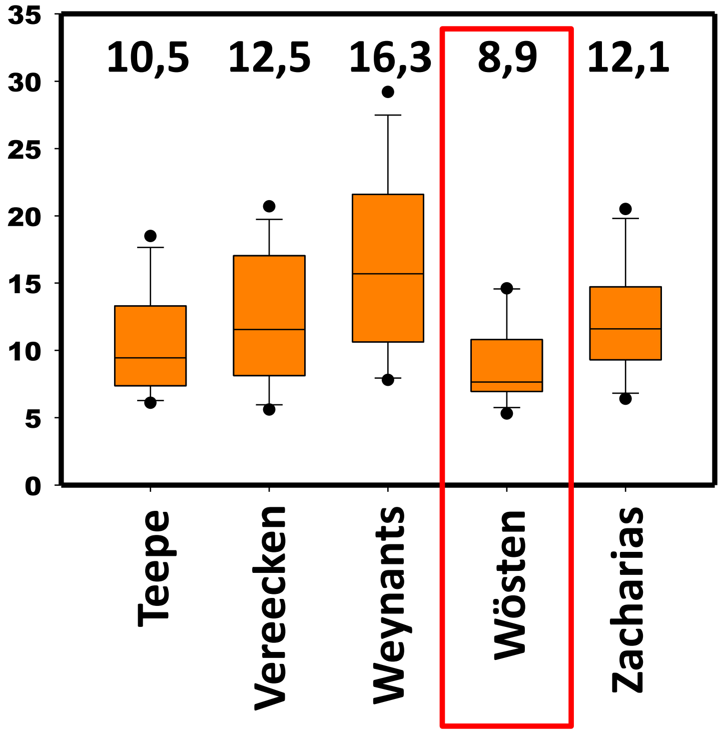
Measurement results: basis for model parameterisation (WaSiM)

pF-curves (field measurement, n = 12): suitable pedotransferfunction

Example:



Boxplots $RMSE/\bar{x}$ **average value in %:**



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Measurement results: basis for model parameterisation (WaSiM)

Suitable pedotransferfunction → **WÖSTEN et al. (1999)**

$$\psi(\Theta) = \frac{1}{\alpha}\left[\left(\frac{\Theta - \Theta_r}{\Theta_s - \Theta_r}\right)^{-1/m} - 1\right]^{1/n} \qquad \frac{k(\Theta)}{k_s} = \left[\frac{\Theta - \Theta_s}{\Theta_s - \Theta_r}\right]^{1/2} \cdot \left[1 - \left(1 - \left(\frac{\Theta - \Theta_r}{\Theta_s - \Theta_r}\right)^{1/m}\right)^m\right]^2$$

Θ_s [Vol.-%]	0,7919 + 0,001691·clay - 0,29619·BD - 0,000001491·silt² + 0,0000821·OC² + 0,02427·clay⁻¹ + 0,01113·silt⁻¹ + 0,01472·ln(silt) - 0,0000733·(OC·clay) - 0,000619·(BD·clay) - 0,001183·(BD·OC) - 0,0001664·(OB·silt)
Θ_r [Vol.-%]	0
α [1/cm]	exp(-14,96 + 0,03135·clay + 0,0351·silt + 0,646·OC + 15,29·BD - 0,192·OB - 4,671·BD² - 0,000781·clay² - 0,00687·OC² + 0,449·OC⁻¹ + 0,0663·ln(silt) + 0,1482·ln(OC) - 0,04546·(BD·silt) - 0,4852·(BD·OC) + 0,00673·(OB·clay))
n [-]	exp(-25,23 - 0,02195·clay + 0,0074·silt - 0,1940·OC + 45,5·BD - 7,24·BD² + 0,0003658·clay² + 0,002885·OC² - 12,81·BD⁻¹ - 0,1524·silt⁻¹ - 0,01958·OC⁻¹ - 0,2876·ln(silt) - 0,0709·ln(OC) - 44,6·ln(BD) - 0,02264·(BD·clay) + 0,0896·(BD·OC) + 0,00718·(OB·clay)) + 1

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Measurement results: basis for model parameterisation (WaSiM)

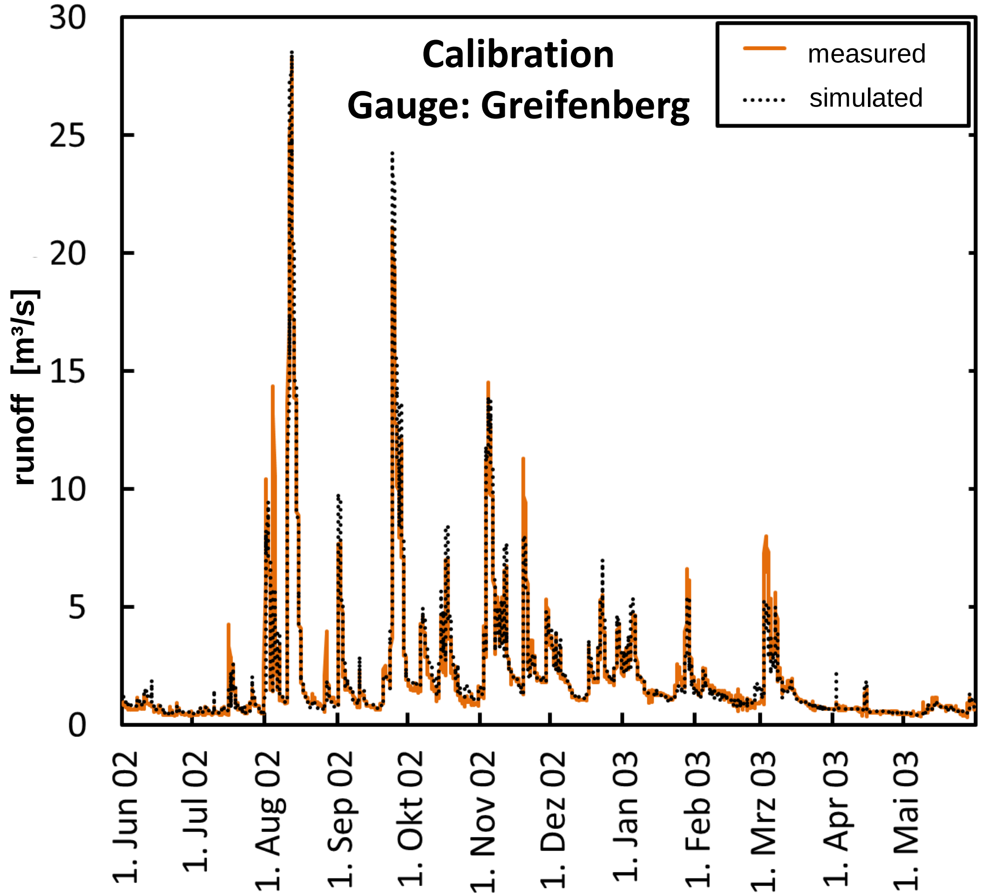
Suitable pedotransferfunction → **Wösten et al. (1999)**

grain size | bulk density | organic content

→ Land use depended soil parameterisation

Θ_s [Vol.-%]	$0{,}7919 + 0{,}001691 \cdot clay - 0{,}29619 \cdot BD - 0{,}000001491 \cdot silt^2 + 0{,}0000821 \cdot OC^2 + 0{,}02427 \cdot clay^{-1} + 0{,}01113 \cdot silt^{-1} + 0{,}01472 \cdot \ln(silt) - 0{,}0000733 \cdot (OC \cdot clay) - 0{,}000619 \cdot (BD \cdot clay) - 0{,}001183 \cdot (BD \cdot OC) - 0{,}0001664 \cdot (OB \cdot silt)$
Θ_r [Vol.-%]	0
α [1/cm]	$\exp(-14{,}96 + 0{,}03135 \cdot clay + 0{,}0351 \cdot silt + 0{,}646 \cdot OC + 15{,}29 \cdot BD - 0{,}192 \cdot OB - 4{,}671 \cdot BD^2 - 0{,}000781 \cdot clay^2 - 0{,}00687 \cdot OC^2 + 0{,}449 \cdot OC^{-1} + 0{,}0663 \cdot \ln(silt) + 0{,}1482 \cdot \ln(OC) - 0{,}04546 \cdot (BD \cdot silt) - 0{,}4852 \cdot (BD \cdot OC) + 0{,}00673 \cdot (OB \cdot clay))$
n [-]	$\exp(-25{,}23 - 0{,}02195 \cdot clay + 0{,}0074 \cdot silt - 0{,}1940 \cdot OC + 45{,}5 \cdot BD - 7{,}24 \cdot BD^2 + 0{,}0003658 \cdot clay^2 + 0{,}002885 \cdot OC^2 - 12{,}81 \cdot BD^{-1} - 0{,}1524 \cdot silt^{-1} - 0{,}01958 \cdot OC^{-1} - 0{,}2876 \cdot \ln(silt) - 0{,}0709 \cdot \ln(OC) - 44{,}6 \cdot \ln(BD) - 0{,}02264 \cdot (BD \cdot clay) + 0{,}0896 \cdot (BD \cdot OC) + 0{,}00718 \cdot (OB \cdot clay)) + 1$

Model calibration and validation (WaSiM)



NASH-SUTCLIFFE-coefficient:

$$R^2 = 1 - \frac{\sum_i \varepsilon_i^{\,2}}{\sum_i \left(x_i - \bar{x}\right)^2}$$

Calibration (´02 -´03):

$R^2 = 0{,}94$

$V_{sim} / V_{mes} = 1{,}03$

$Q_{bas} / Q_{tot} = 0{,}29$

Validation (´03 -´05):

$R^2 = 0{,}93$

$V_{sim} / V_{mes} = 1{,}00$

$Q_{bas} / Q_{tot} = 0{,}44$

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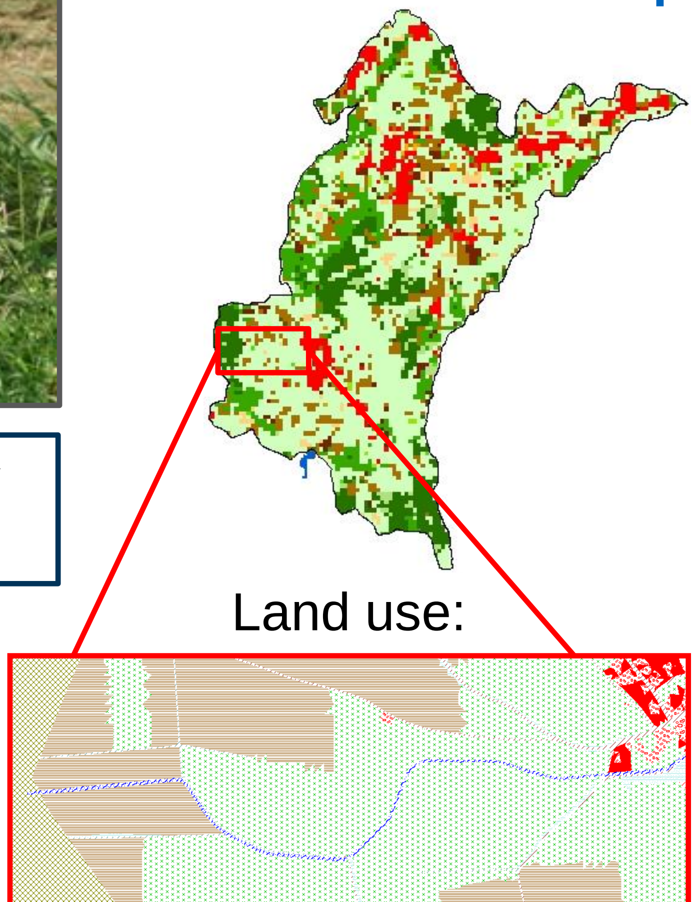
Modeling approach

Coupling of models: WaSiM & HYDRO_AS-2d

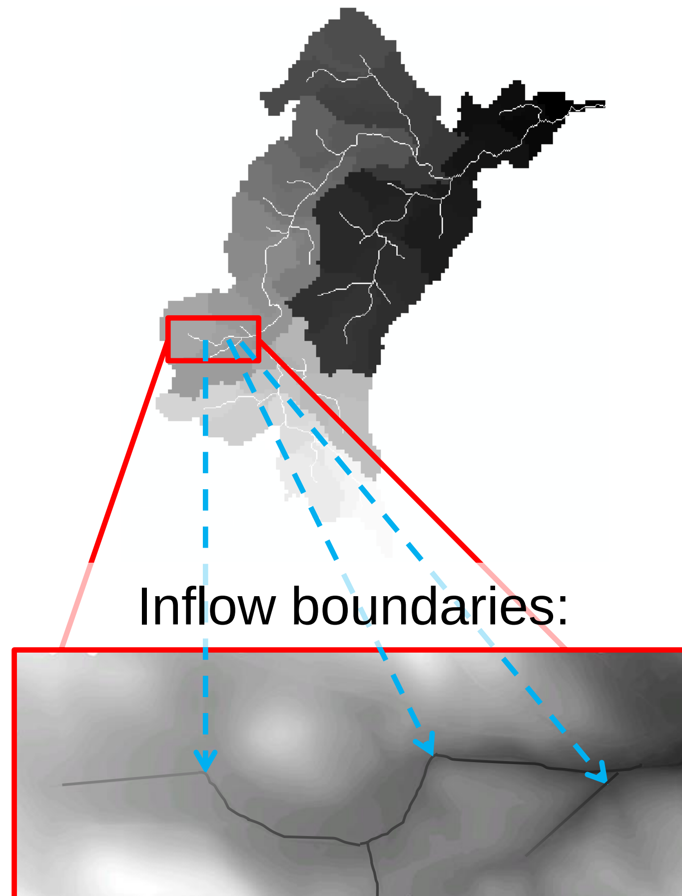
Geometry (DGPS)

Example Saubach:

Land use:

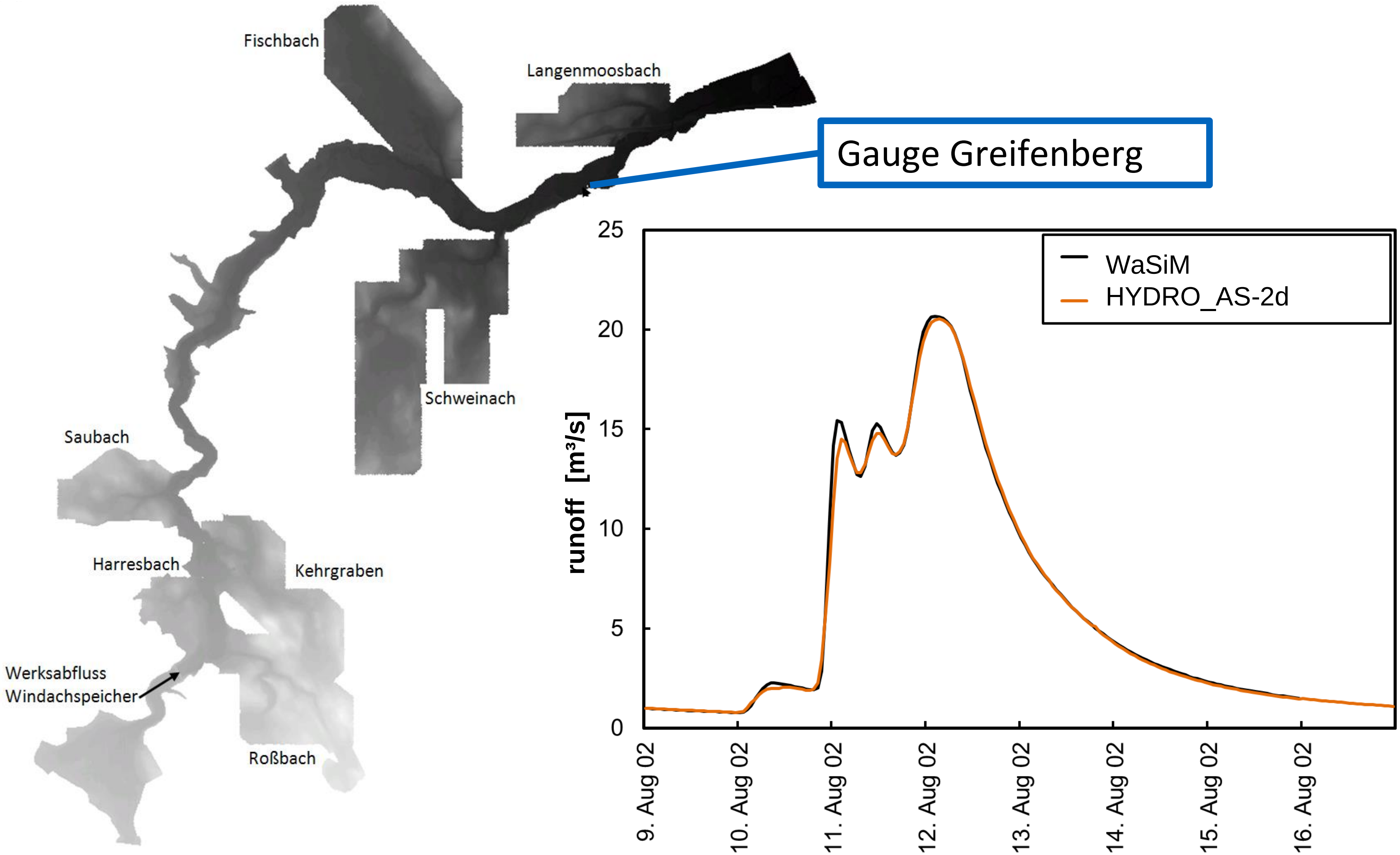


Inflow boundaries:



Modeling approach

Coupling of models: WaSiM & HYDRO_AS-2d



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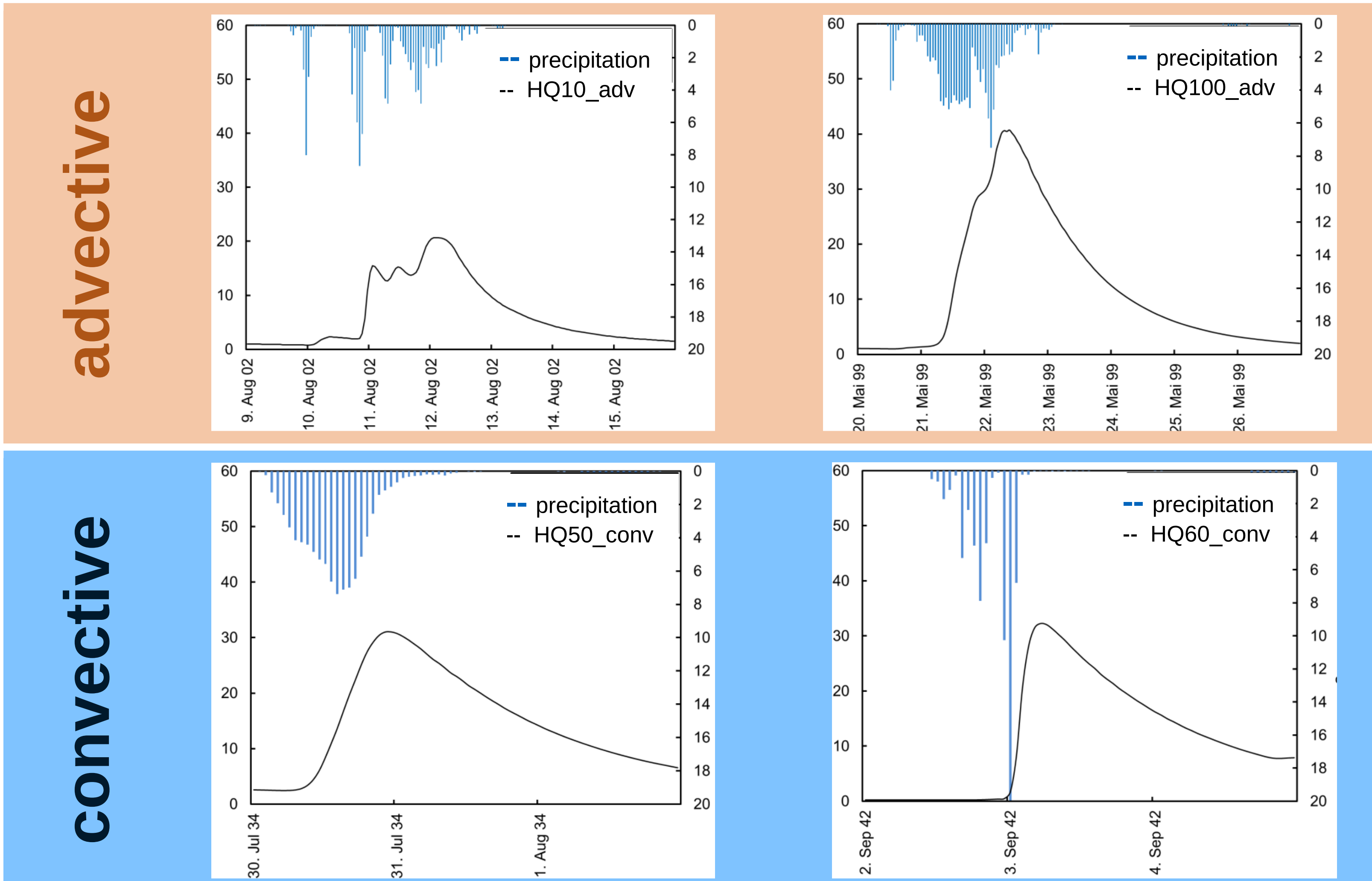
Results

Simulated events



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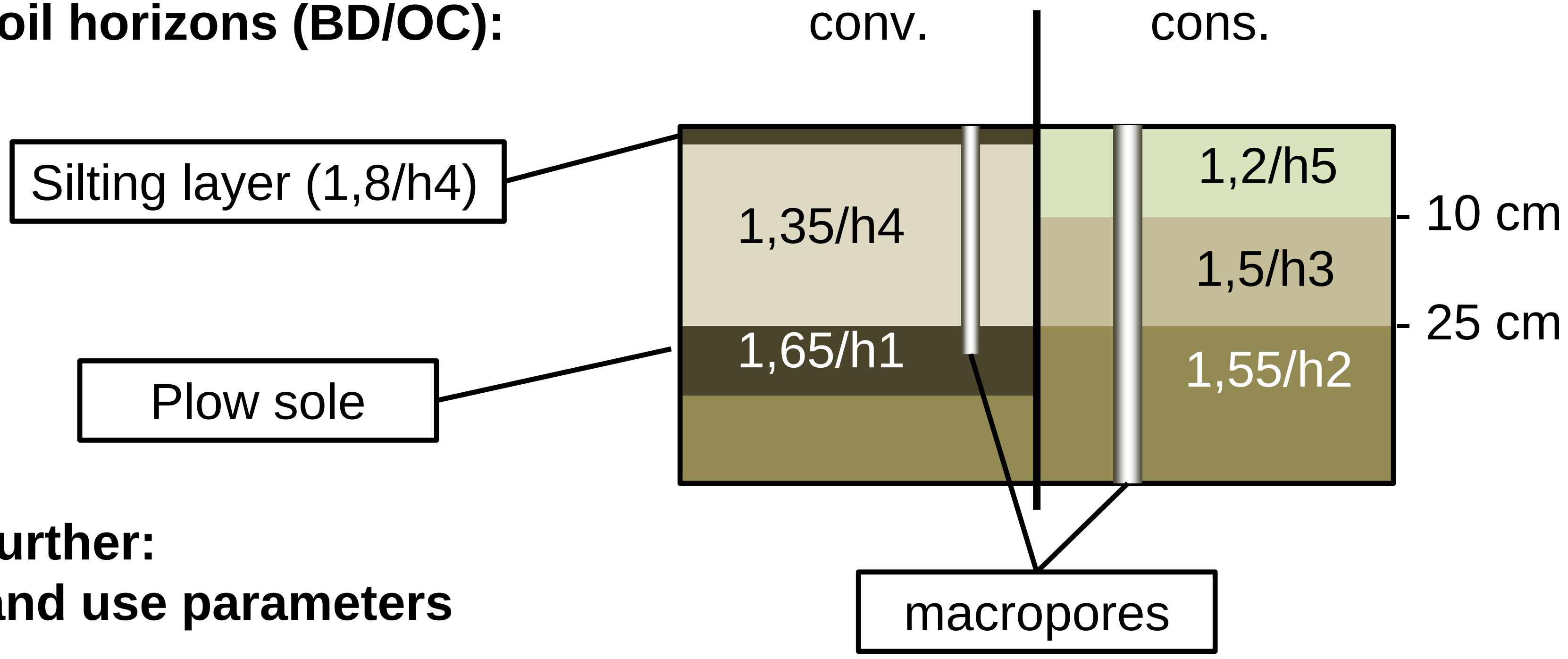
Agriculture: conservation soil tillage

Soil horizons (BD/OC):



Further:
land use parameters

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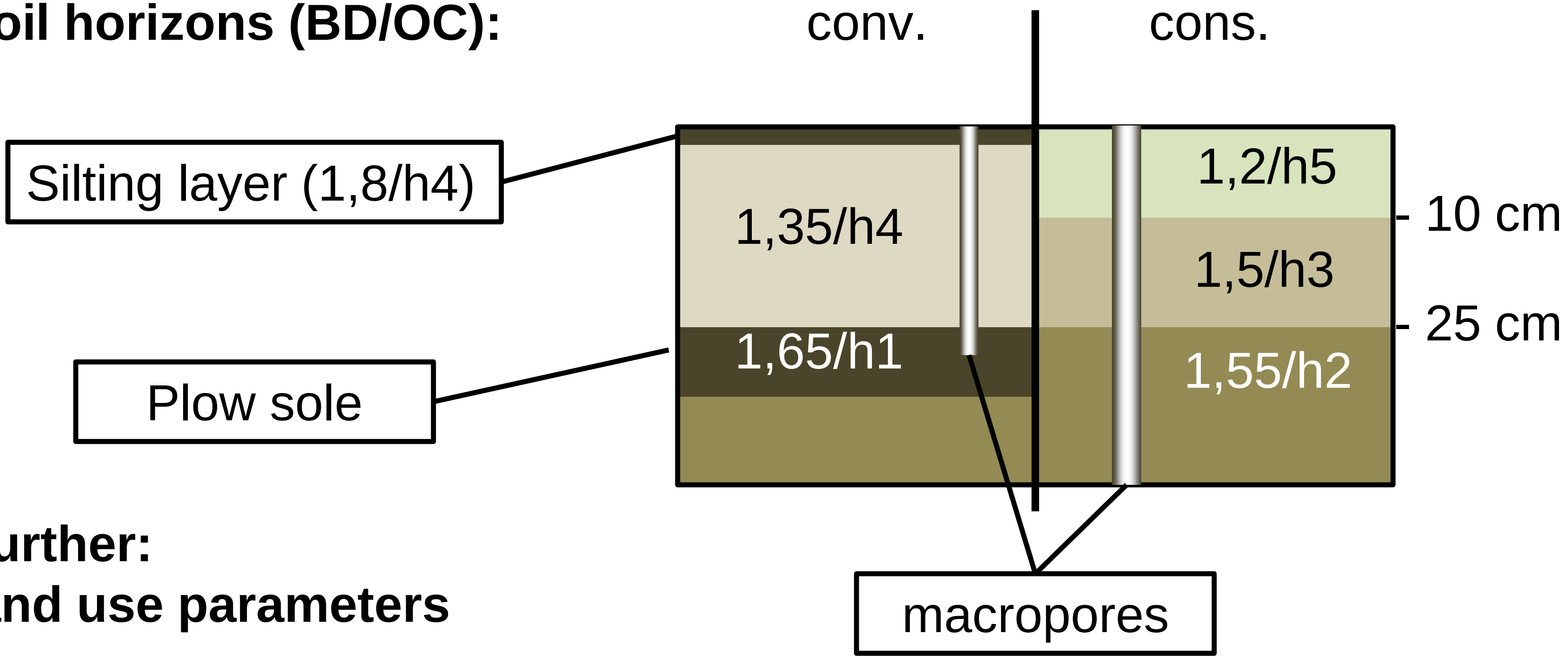
Results

Agriculture: conservation soil tillage

Soil horizons (BD/OC):



Further:
land use parameters

Primary effect: Shifting within the runoff components

Effectiveness (max. 5 % peak reduction) depending on:
Time to peak and fraction of surface runoff

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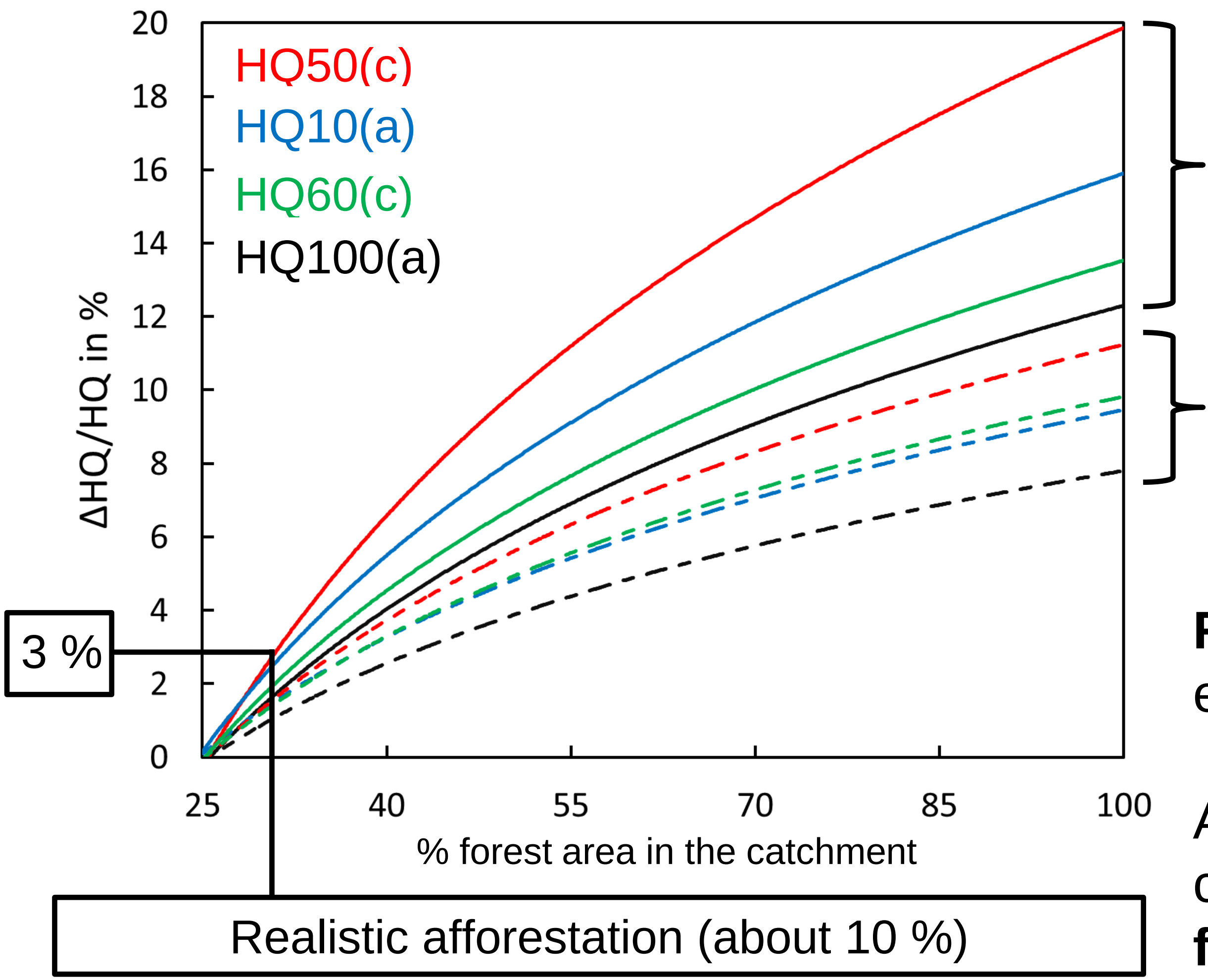
Results

Forestry: Afforestation (soil structure & interception)



…arable land / grassland

…grassland

Runoff volume / peak essential for effectiveness

Additional forest conversion: **factor ca. 1,5**

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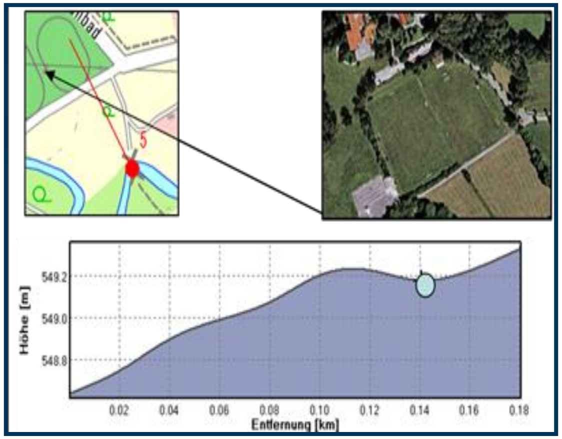
Results

Small Retention Basins (5000 m³ - 50000 m³)

GIS-Analysis:
Topogr. & aer. photo

Location suitable?
Basin structure
Vulnerability



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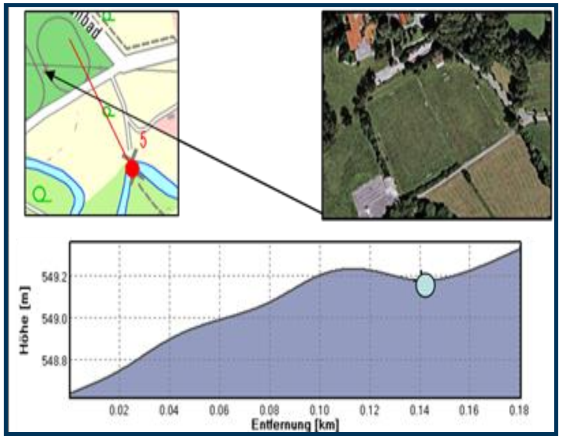
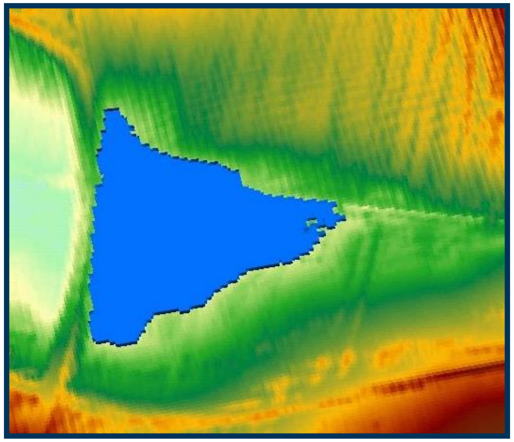
Results

Small Retention Basins (5000 m³ - 50000 m³)

GIS-Analysis: Topogr. & aer. photo	Field survey & DGPS measurement
↓	↓
Location suitable? Basin structure Vulnerability	GIS – Analysis: DEM-1 & DGPS Dam/volume





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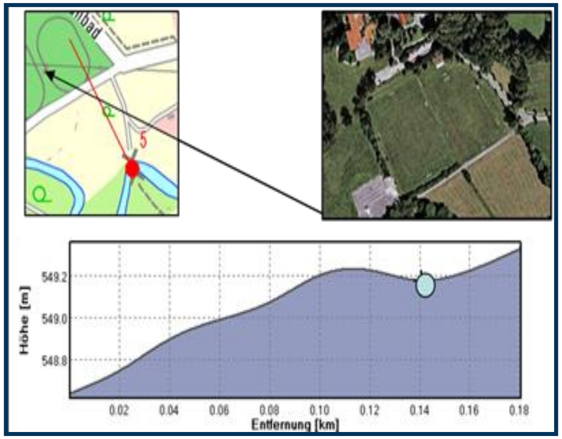
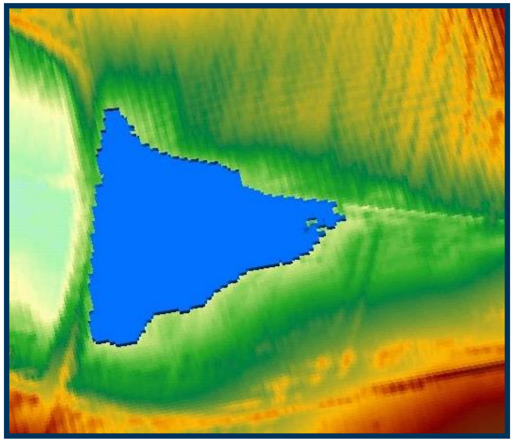
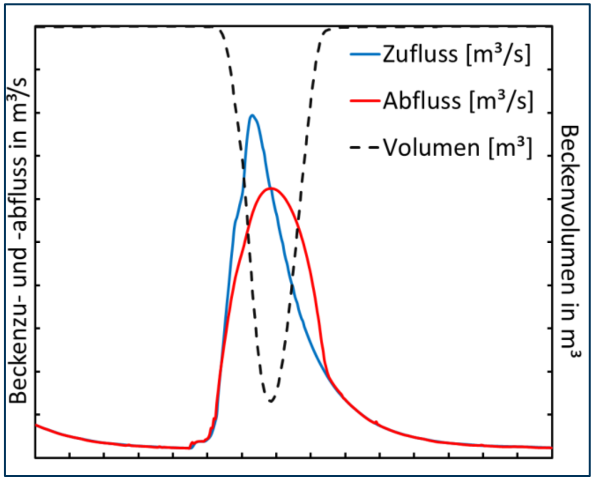
Results

Small Retention Basins (5000 m³ - 50000 m³)

GIS-Analysis: Topogr. & aer. photo	Field survey & DGPS measurement	Implementation in WaSiM, n=19
Location suitable? Basin structure Vulnerability	GIS – Analysis: DEM-1 & DGPS Dam/volume	Storage equation V-Q-relation Outlet optimisation







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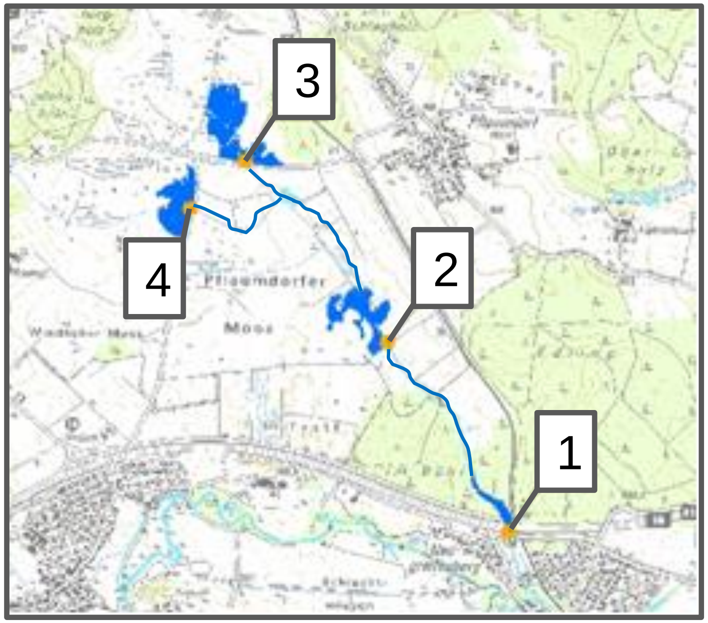
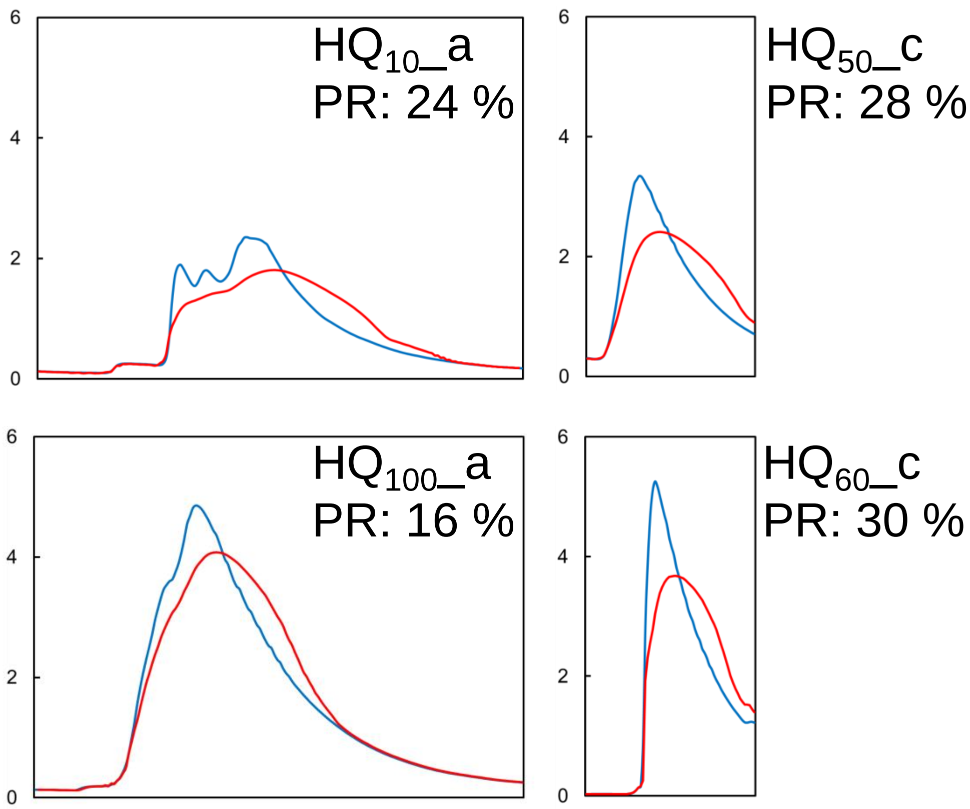
Example Fischbach (8,3 km²):
4 Retention basins, V_{tot} = 53 888 m³ and sV = 6,5 mm





Without basins [m³/s]
With basins [m³/s]

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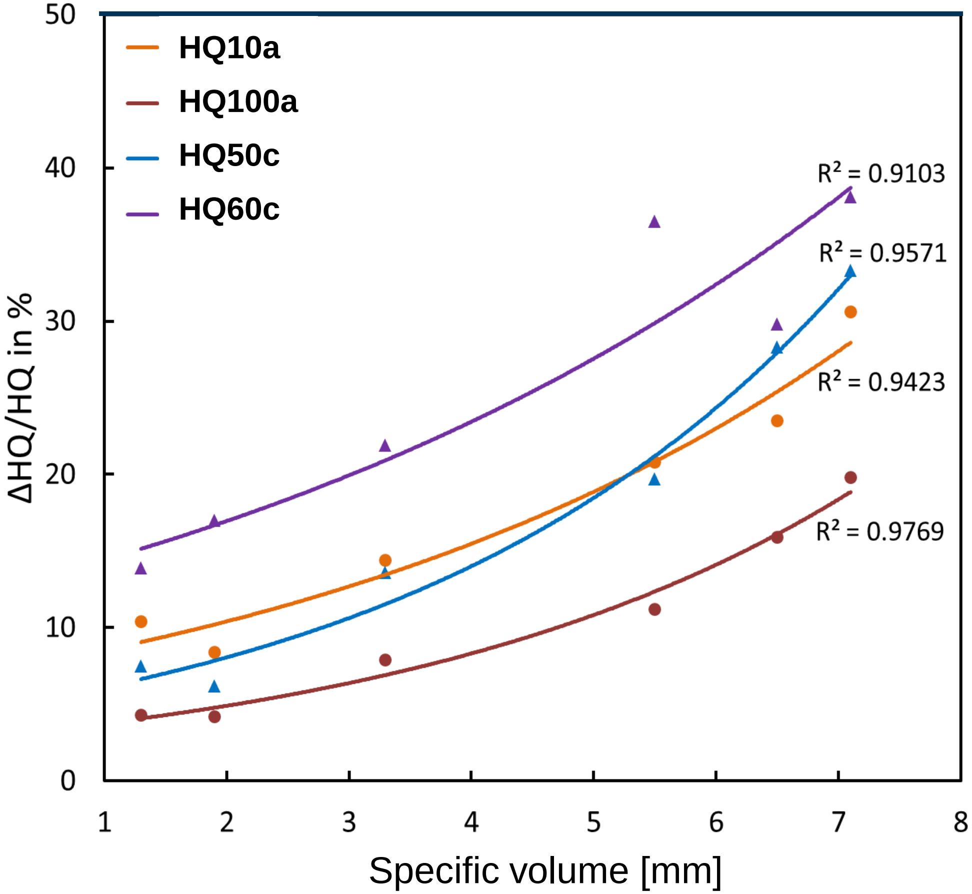
Relation between peak reduction, sV and flood event:



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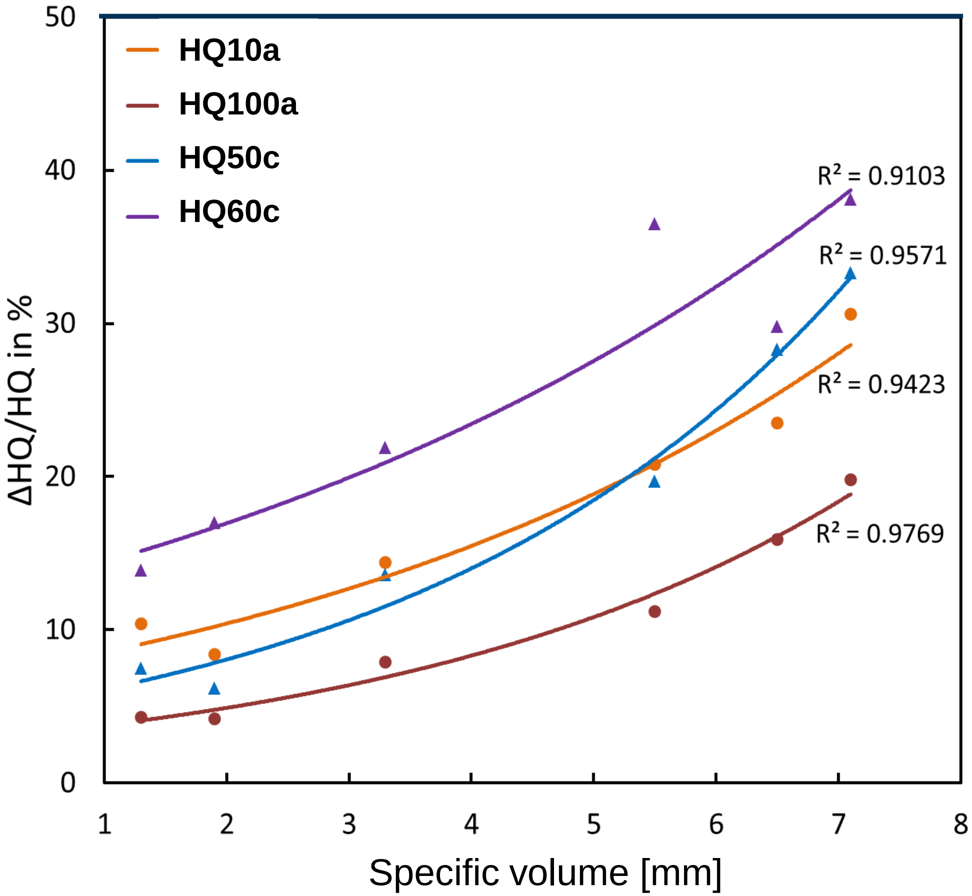
Relation between peak reduction, sV and flood event:



Results Windach catchment (65 km², sV = 3,6 mm):

HQ_{10}_a:	14 %
HQ_{100}_a:	10 %
HQ_{50}_c:	15 %
HQ_{60}_c:	22 %

Criteria:
sV and runoff volume until peak

Most effective ditributed flood control measure

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Results

Restoration of rivers

Cross section changing

River widening

Flow path extension: 11 % - 32 %

Example: Saubach

Additional: floodplain forest (roughness)

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Example: Saubach

Additional: floodplain forest (roughness)

Peak reduction (small catchments):

- without floodplain forest: ca. 5 % (HQ_{10}) / slope max. 1 %
- with floodplain forest: between 5 % (HQ_{10}) and 16 % (HQ_{60})

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Whole catchment:

	advective:		convective:	
	HQ_{10}	HQ_{100}	HQ_{50}	HQ_{60}
without forest:	5,9 %	0,9 %	3,5 %	2,4 %
with forest:	6,4 %	5,0 %	11,1 %	11,0 %

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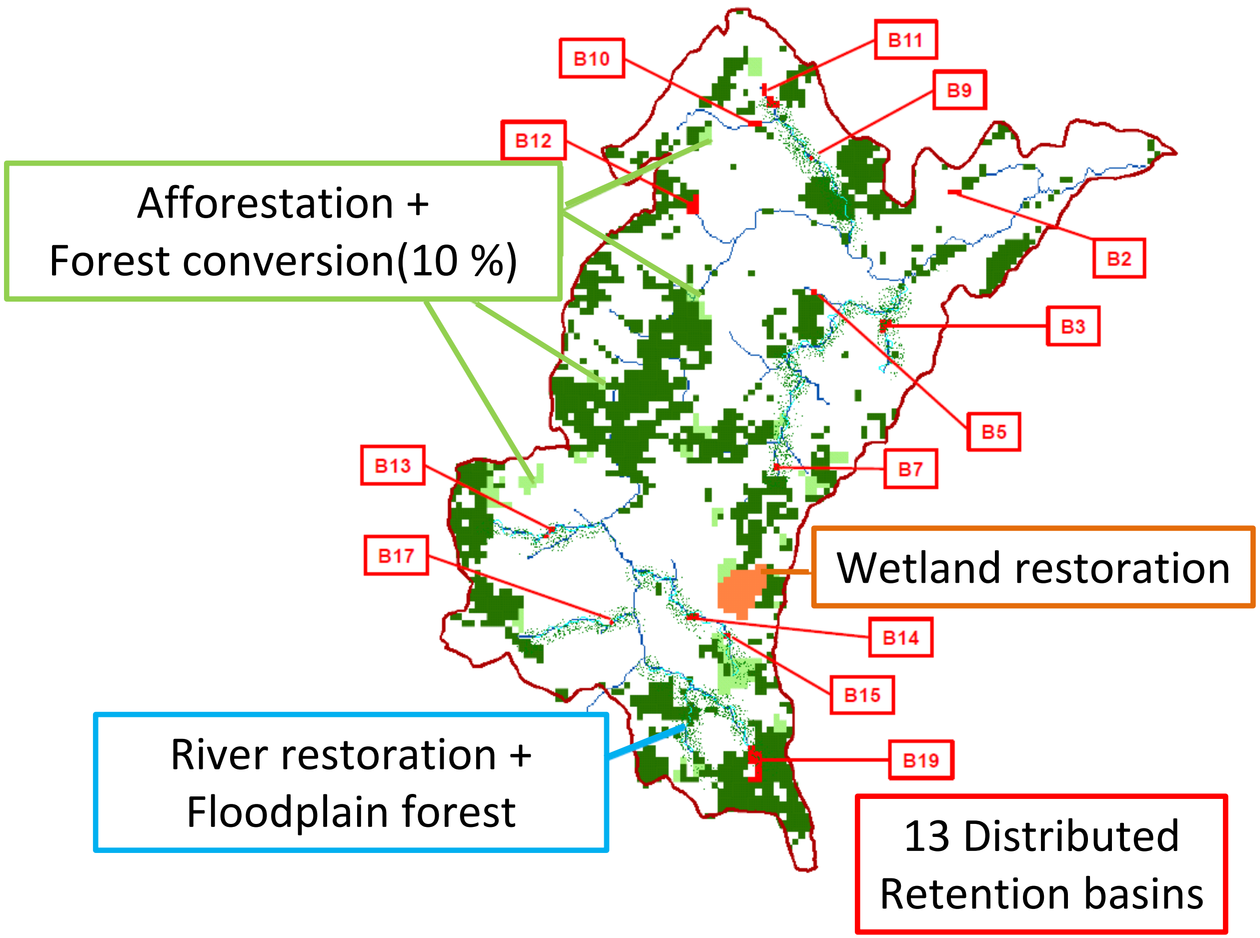
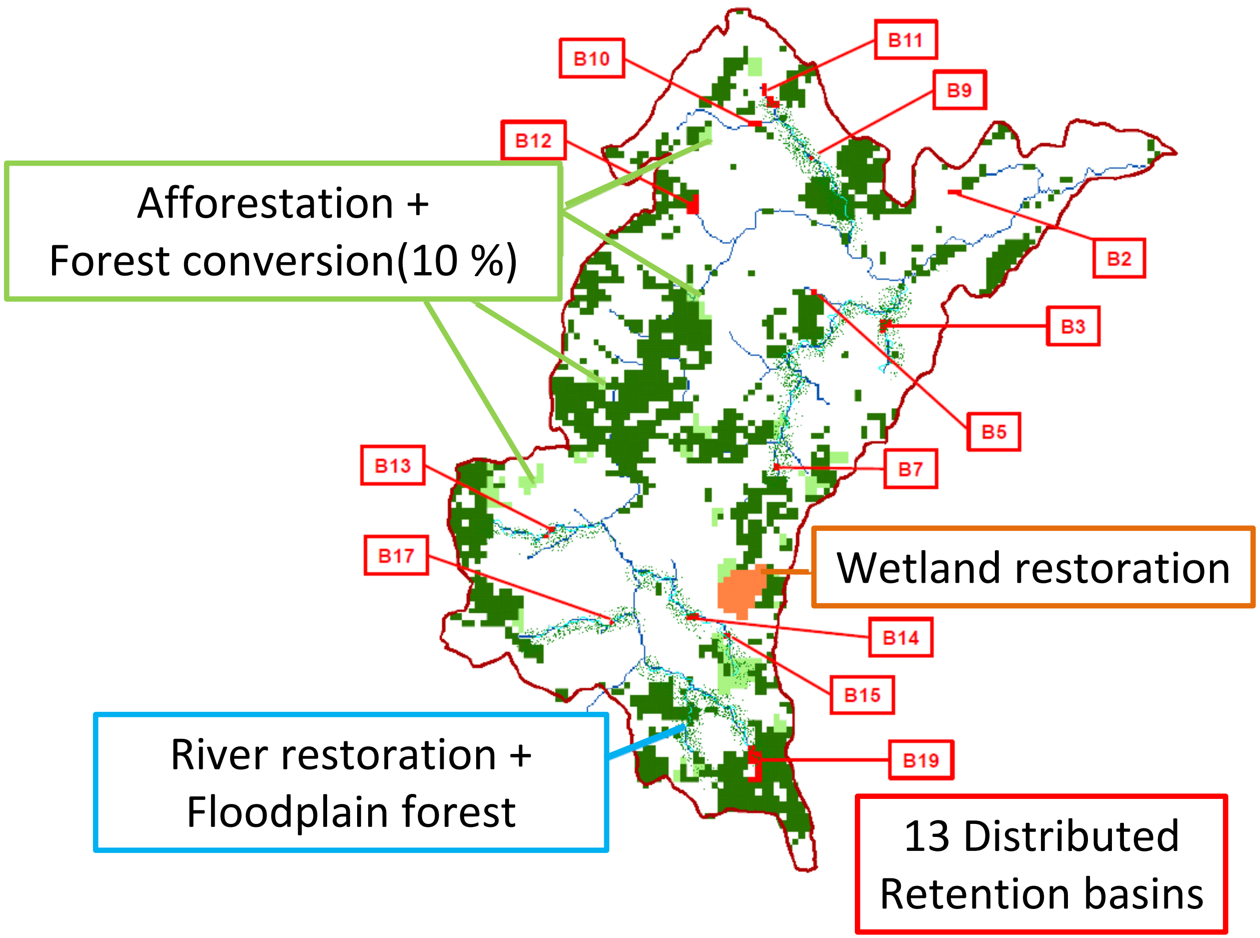
Measurement concept



Results

Measurement concept



Peak reduction:

Windach Catchment:

- HQ_{10}_a: 18 %
- HQ_{100}_a: 11 %
- HQ_{50}_c: 19 %
- HQ_{60}_c: 26 %

Subcatchments:

- HQ_{10}_a: 12 % - 28 %
- HQ_{100}_a: 9 % - 28 %
- HQ_{50}_c: 9 % - 32 %
- HQ_{60}_c: 22 % - 46 %

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Measurement results – survey area

→ Boring rod analysis, field measurements and laboratory analysis: Soil hydraulic properties depend on land use, tillage and vegetation

→ Identification of a suitable PTF for the Windach catchment: WÖSTEN et al. (1999)

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Measurement results – survey area

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Soil hydraulic properties depend on land use, tillage and vegetation

→ Identification of a suitable PTF for the Windach catchment:
WÖSTEN et al. (1999)

→ Model assumptions concerning soil hydraulic properties and regional distribution of soils include considerable uncertainties

→ Model parameterising without measurements is not advisable

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Conclusions and Outlook

Modeling approach

→ Successful coupling of WaSiM and HYDRO_AS-2d

→ Strengths in modeling runoff generation and flood routing

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→ Suitable approch for process based modeling of single and combined distributed flood control measures

→ Very good calibration and validaion results

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Modeling approach

→ Successful coupling of WaSiM and HYDRO_AS-2d

→ Strengths in modeling runoff generation and flood routing

→ Suitable approch for process based modeling of single and combined distributed flood control measures

→ Very good calibration and validaion results

→ Further research required: Runoff concentration

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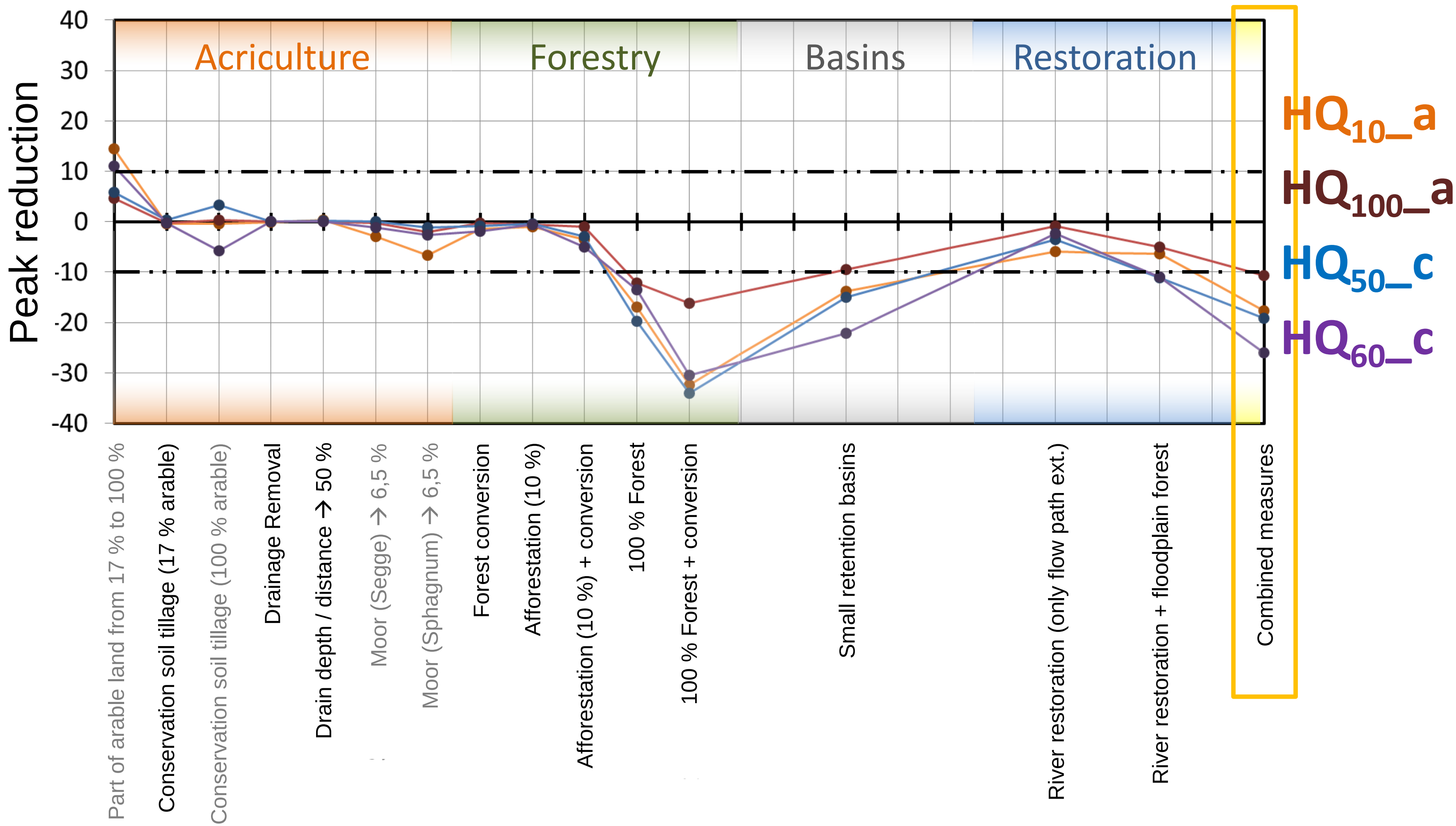
Effectiveness of ditributed flood control measures



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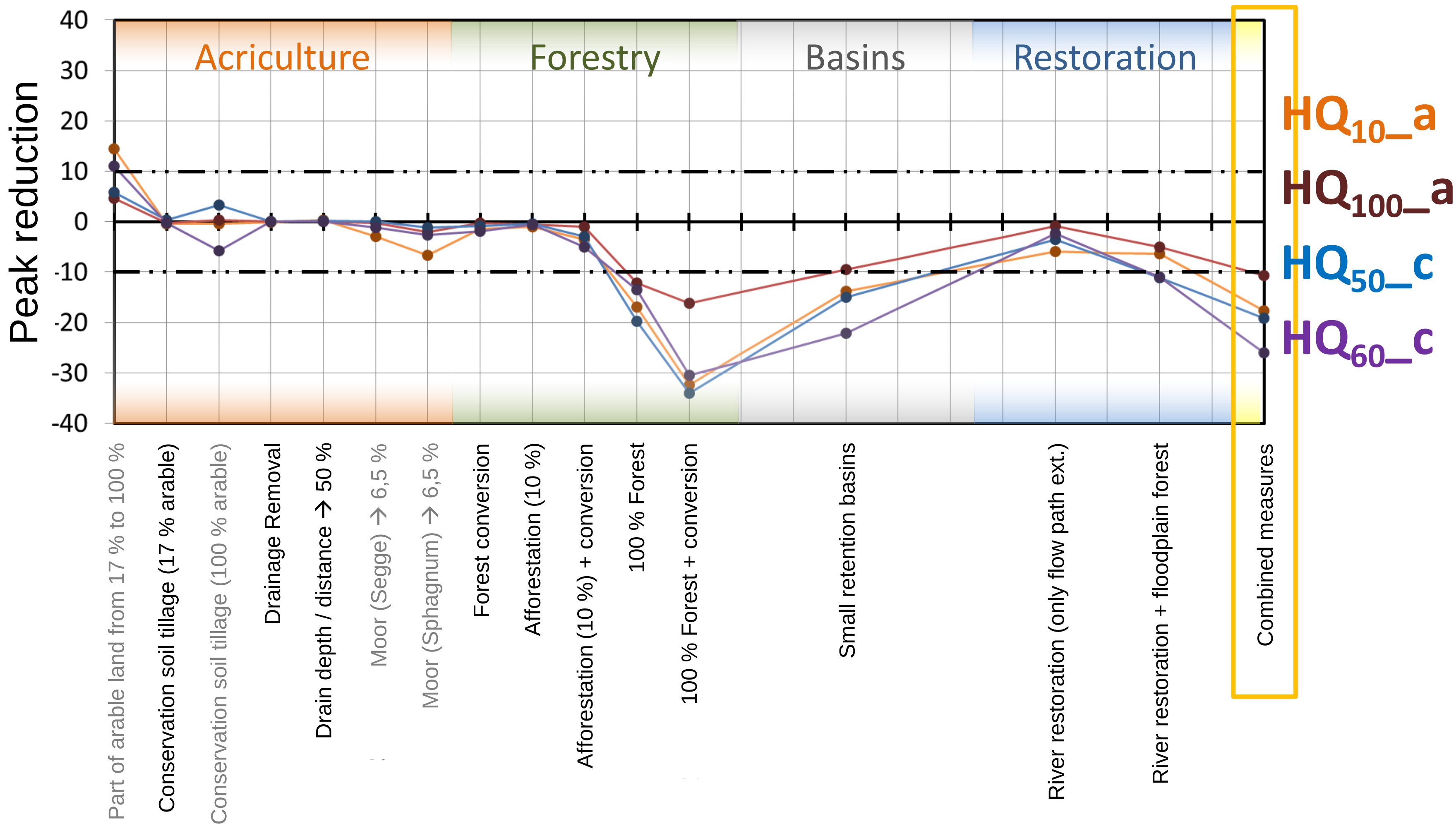

Thank you !!!

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