Identification of point and diffuse sources and role of retention processes in large river basins: comparison of three approaches

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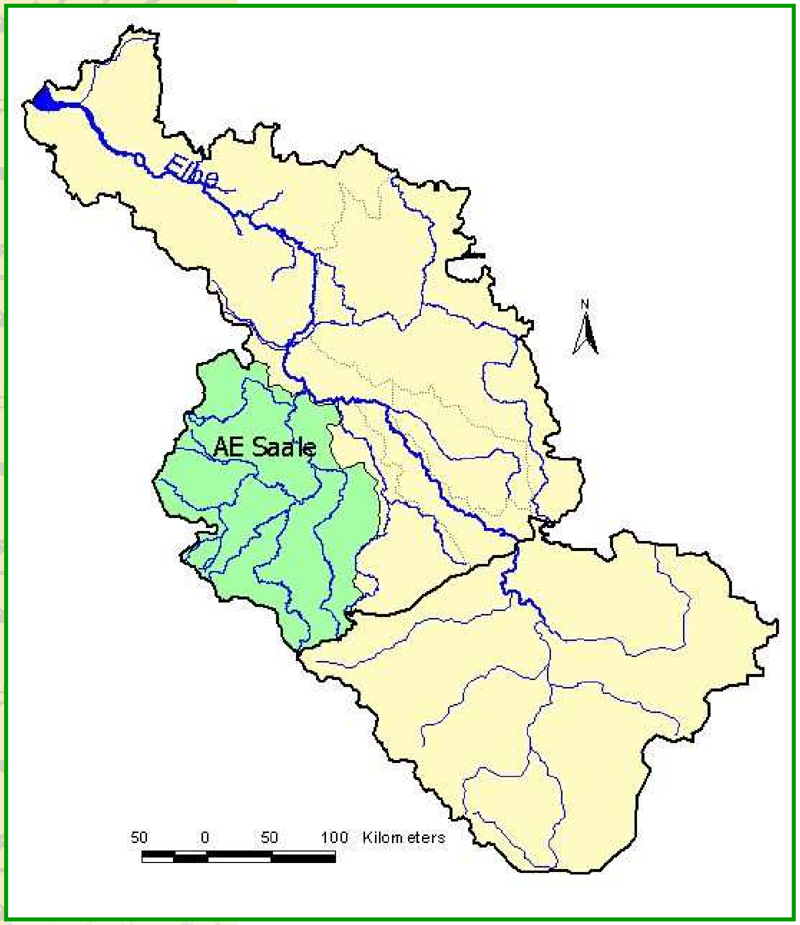
Outline

1. Case study basin: Saale
2. Model SWIM
3. Three approaches for nutrient retention in large basins
4. Step 1: retention in the landscape - three pathways
5. Step 2: retention in the landscape - differentiation of retention coefficients for three pathways
6. Conclusions and outlook

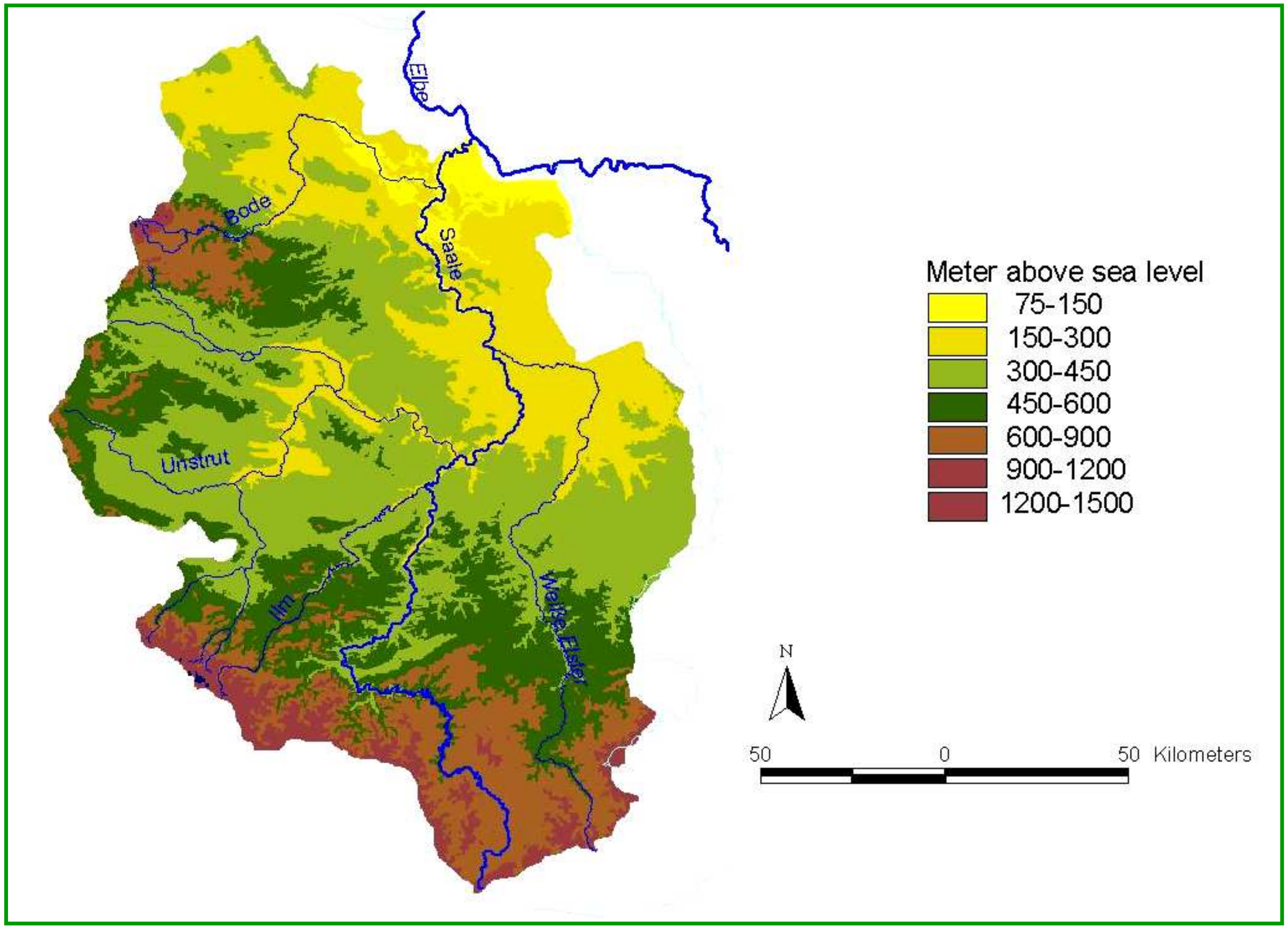
Diversity of landscapes in the Elbe basin

Case study basin: Saale

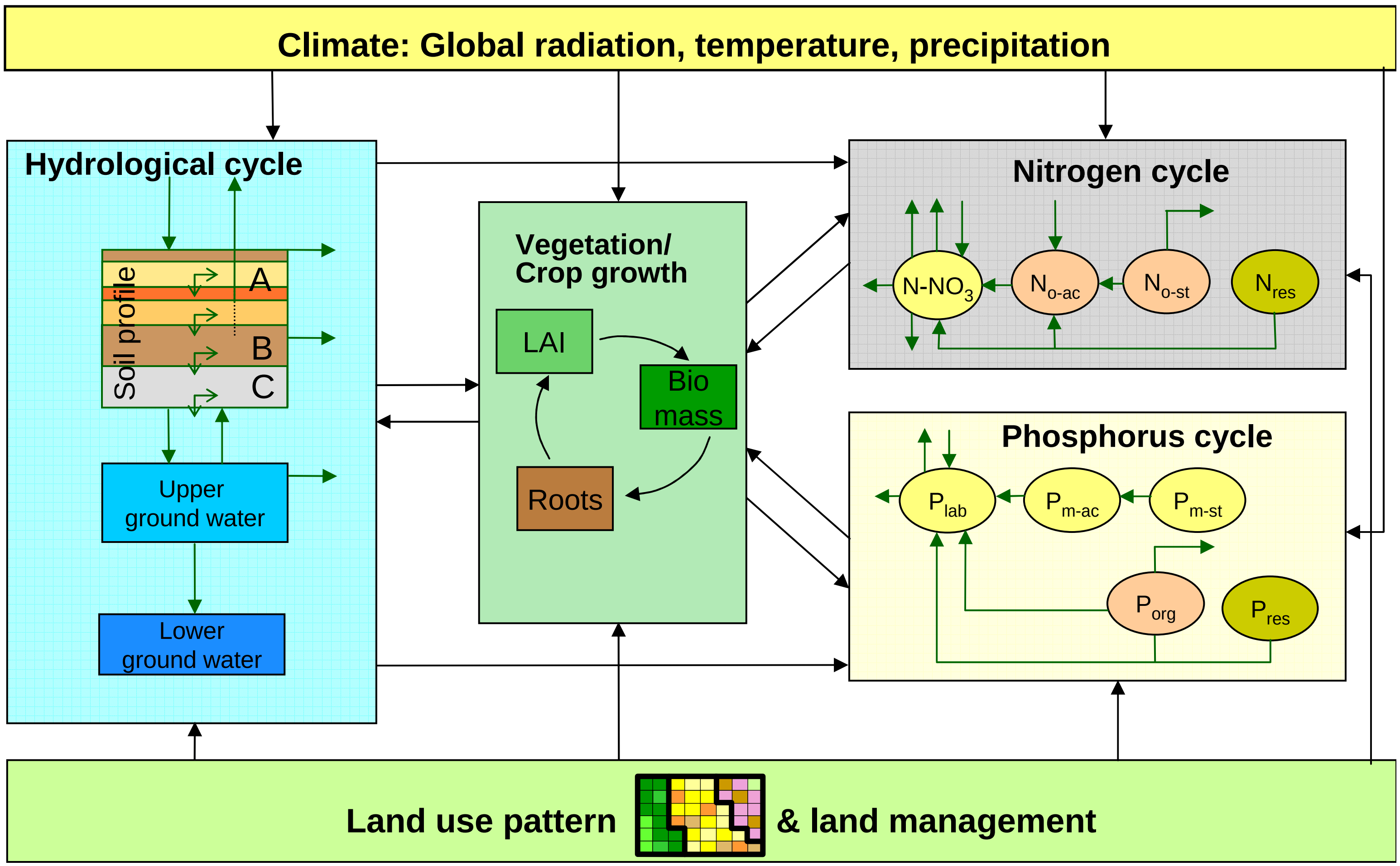


- Second largest tributary of the Elbe
- Length 413 km
- Drainage basin ~ 24000 km²

Case study basin: Saale



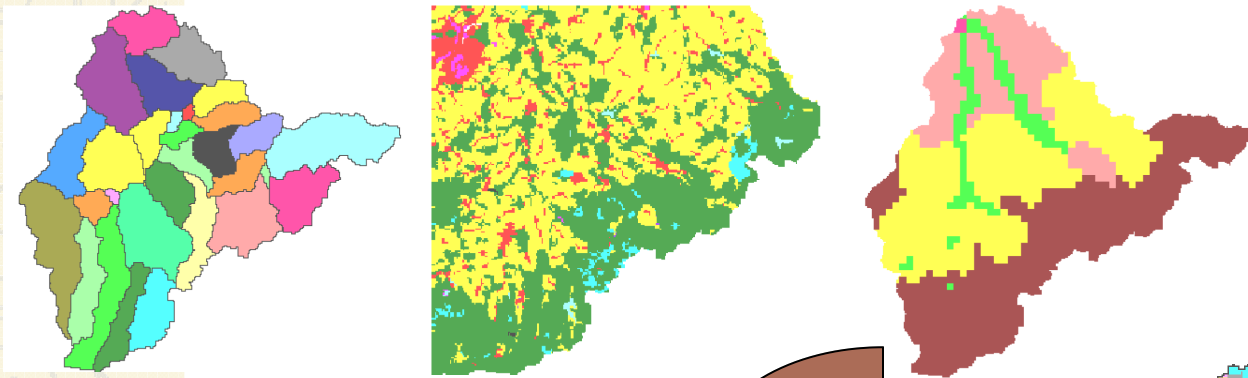
SWIM (Soil and Water Integrated Model)



SWIM was developed in PIK (Potsdam) based on **SWAT-93** and **MATSALU** for climate and land use change impact studies

Spatial disaggregation

Subbasins **Land use** **Soils**



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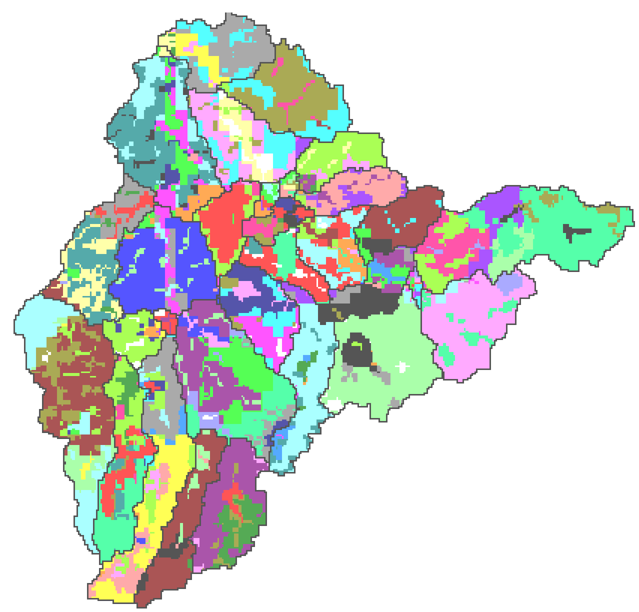
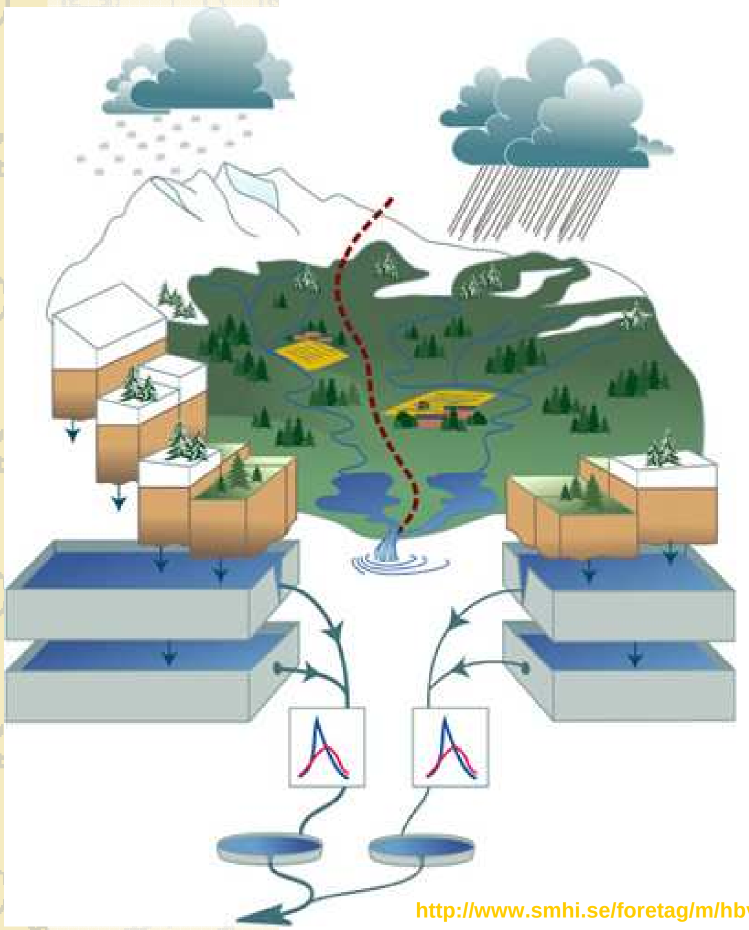
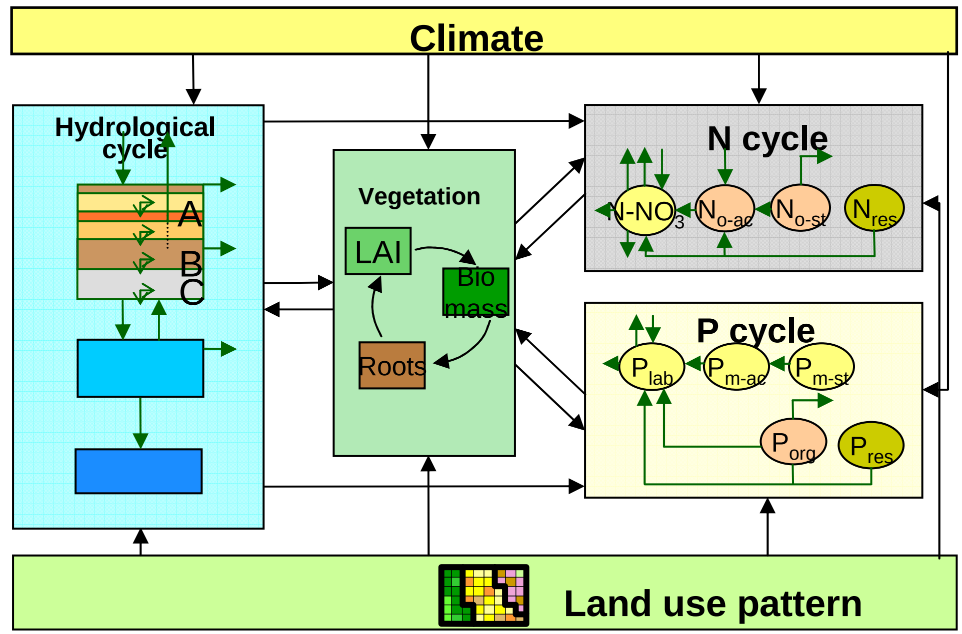


Hydrotops are sets of units in subbasins with uniform land use and soils

From the hydrotope to the basin level



http://www.smhi.se/foretag/m/hbv_demo/



Nutrient retention in watersheds: 3 approaches

Three approaches:

1) retention in a landscape is described separately for surface, subsurface and groundwater flows by a linear differential equation (Hattermann et al., 2005) as a function of mean residence time T and decomposition rate λ, with constant T_{sur}, T_{sub}, T_{gw} and λ_{sur}, λ_{sub}, λ_{gw} for the basin;
2) the same as in the first approach, but differentiating T_{sur}, T_{sub}, T_{gw} and λ_{sur}, λ_{sub}, λ_{gw} for hydrotopes depending on soil properties and g-w conditions; &
3) coupling SWIM with the model WASP to additionally describe retention processes in the river network in combination with approaches 1 or 2.

Approach 1: nutrient retention

$$\frac{\partial c}{\partial t}+\frac{\vec{u}}{R}\nabla c-\nabla\left(\frac{Dg}{R}\nabla c\right)-\frac{\sigma}{R}+\lambda c+\frac{q}{mn_f R}(c-c_{in})=0$$

c = *concentration* n = *eff. porosity*
m = *aquifer thickness* λ = *turnover coeff*
R = *faktor of retardation*

Classical approach:
the convection-dispersion equation
But:
-it is nonlinear and has to be solved numerically
- high data demand

Simplifications:
- Full mixture during the transport process
- Residence time is normally distributed
- Linear degradation

$$\frac{dC_t}{dt}=C_{t,in}-C_{t,out}-\lambda C_t$$

$$C_t = KC_{t,out}$$

$$C_{t,out}=C_{t,in}\frac{1}{1+K\lambda}(1-e^{-(1/K+\lambda)t})+C_{t-1,out}e^{-(1/K+\lambda)t}$$

K = mean residence time,
λ = decomposition rate,
C = concentration

Approach 1: The mean residence time

$$K = \sum_{i=1}^{n} \frac{dz_i}{v_s(z_i)}$$

$$L = \sum_{i=1}^{n} dz_i$$

$$v_s(z) = \frac{-k * J(z)}{S}$$

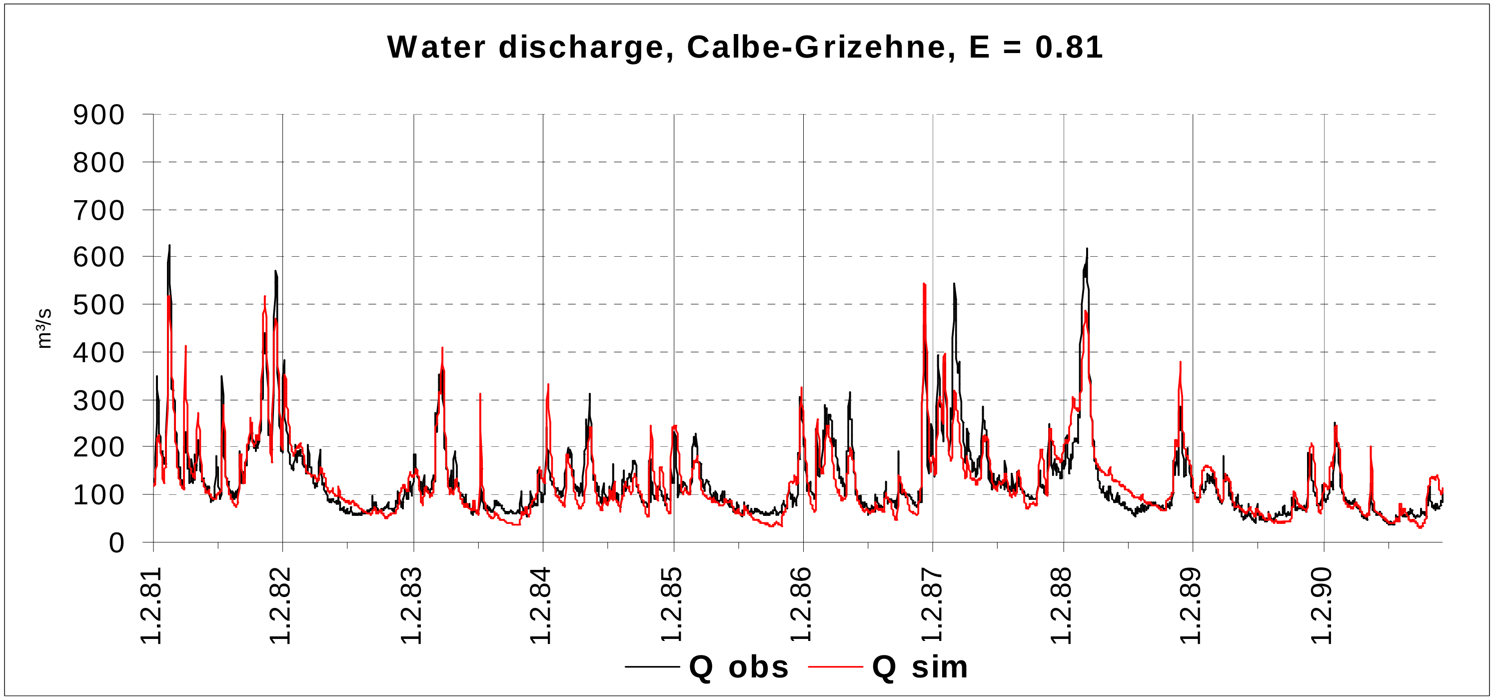
- The mean residence time
- K = f (flow path, permeability, porosity, gradient in groundwater table) for subsurface flow
- K = f (flow path, permeability, porosity, and gradient in topography and Manning's roughness) for surface flow.
- The distance L to the river is calculated following the gradient in groundwater table to the river.
- K can be estimated using the seepage velocity v_s (m d^{-1}), where k is hydraulic conductivity of the spatial unit z, J is dimensionless hydraulic gradient, and S is the specific yield (average ~40 years, up to > 1000 years).

Approach 1: The decomposition rate

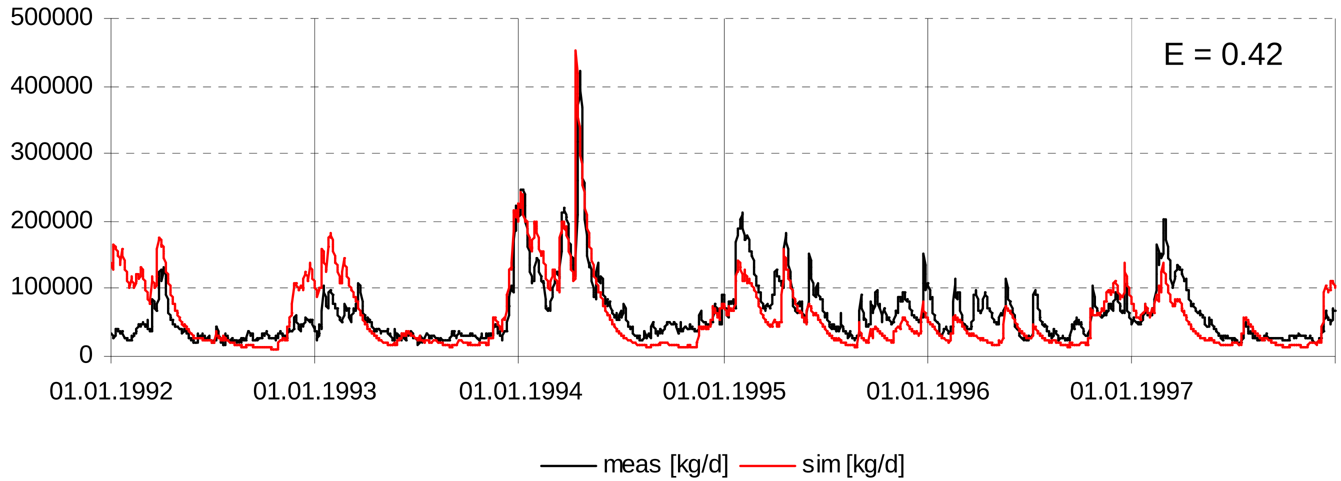
The decomposition rate λ is a function of redox potential and carbon concentration of the catchment sediments.

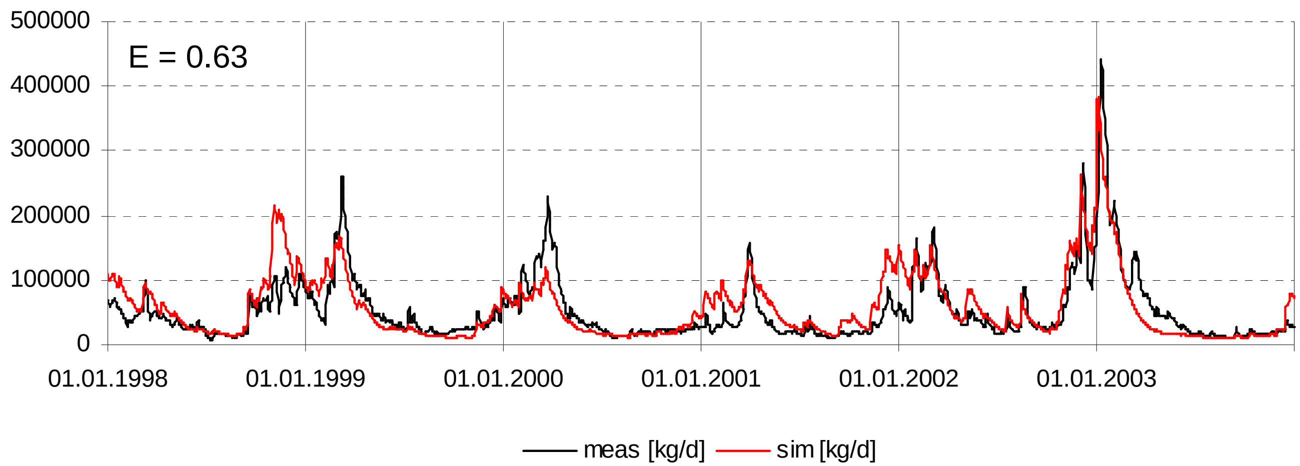
Initial values can be established using data from Wendland et al. (1993): a half-life time of nitrate N between 1 and 3 years, which corresponds to λ values between $6 \cdot 10^{-4}$ d^{-1} and $2 \cdot 10^{-3}$ d^{-1}.

Validation using first approach: water discharge



Validation using first approach: N-NO_3 load





Approach 2: differentiated retention coefficients

Nutrient retention in a landscape is described separately for surface, subsurface and groundwater flows as a function of mean residence time T and decomposition rate λ,

and T_{sur} , T_{sub} , T_{gw} , λ_{sur} , λ_{sub} , λ_{gw} are differentiated depending on soil properties and g-w conditions.

Estimation of Denitrification conditions in soils of Central Europe

Bodentyp	Bodenwasser-verhältnisse (Soil water)	Nährsubstrat (nutrients)	Temperatur (temperature)	pH-Wert (PH)	Gesamt-einstufung (TOTAL)
Podsol	–	–	–	–	–
podsolige Braunerde	o	–	–	–	–
podsolierte Parabraunerde	o	–	–	–	–
Braunerde (basenarm)	–o	o	–	–	–
Syrosem	–	–	–	–	–
Pararendzina	o	o+	+o	+	o
Rendzina	o	o+	o	+	o
Braunerde (basenreich)	o	o+	o	o+	o
Parabraunerde	o	o+	o	–o+	o
Pseudogley	+	–	o–	o–	+
Tschernosem	o+	+	+	+	+
Pseudogley	+	–o	o–	o–	+
Gley	+	+	–	o	+
Aueböden	+	+	o	+	+
Marschböden	+	+	o	+o	+
Niedermoor	+	+	o	+	+
Hochmoor	+	+	o	–	+

Wendland et al. Atlas zum Nitratstrom in der Bundesrepublik Deutschland

+ good conditions for D:

gley, pseudogley, loess, marsch, moor, tschernosem

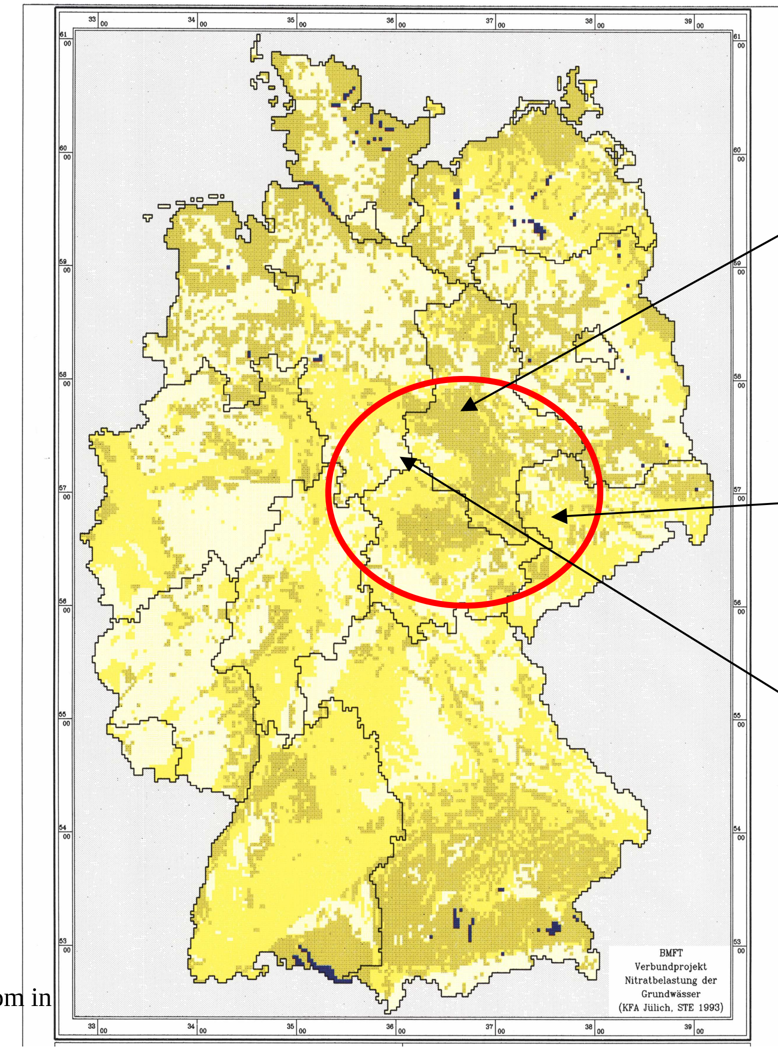
O neutral conditions for D:

brown soils, parabrown soils, rendzina, pararendzina

— poor conditions for D:

podsol, podsol-brown soils, syrosem

Denitrification conditions in soils, Germany



+ loess soil

O brown soils

— podsol

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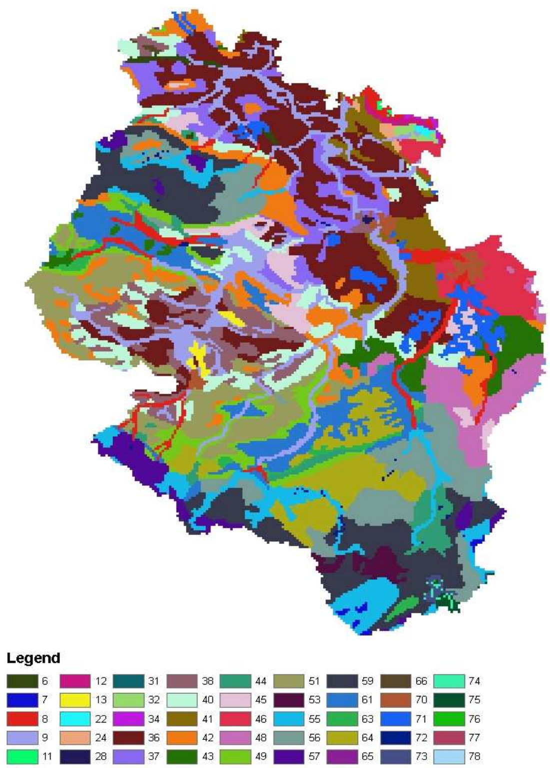
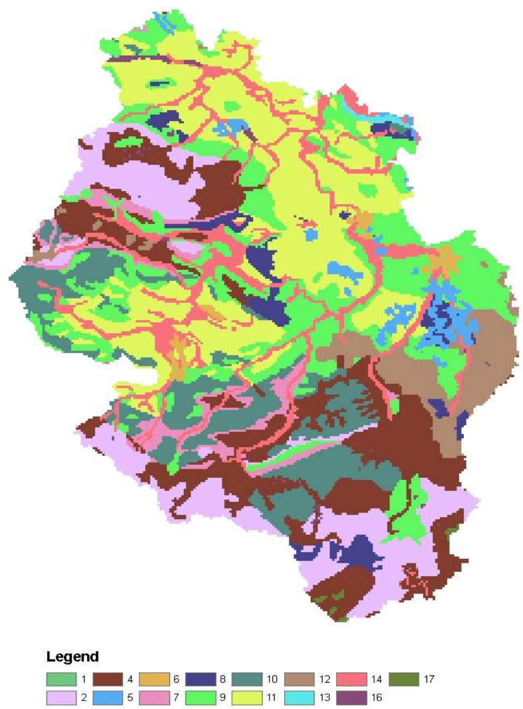
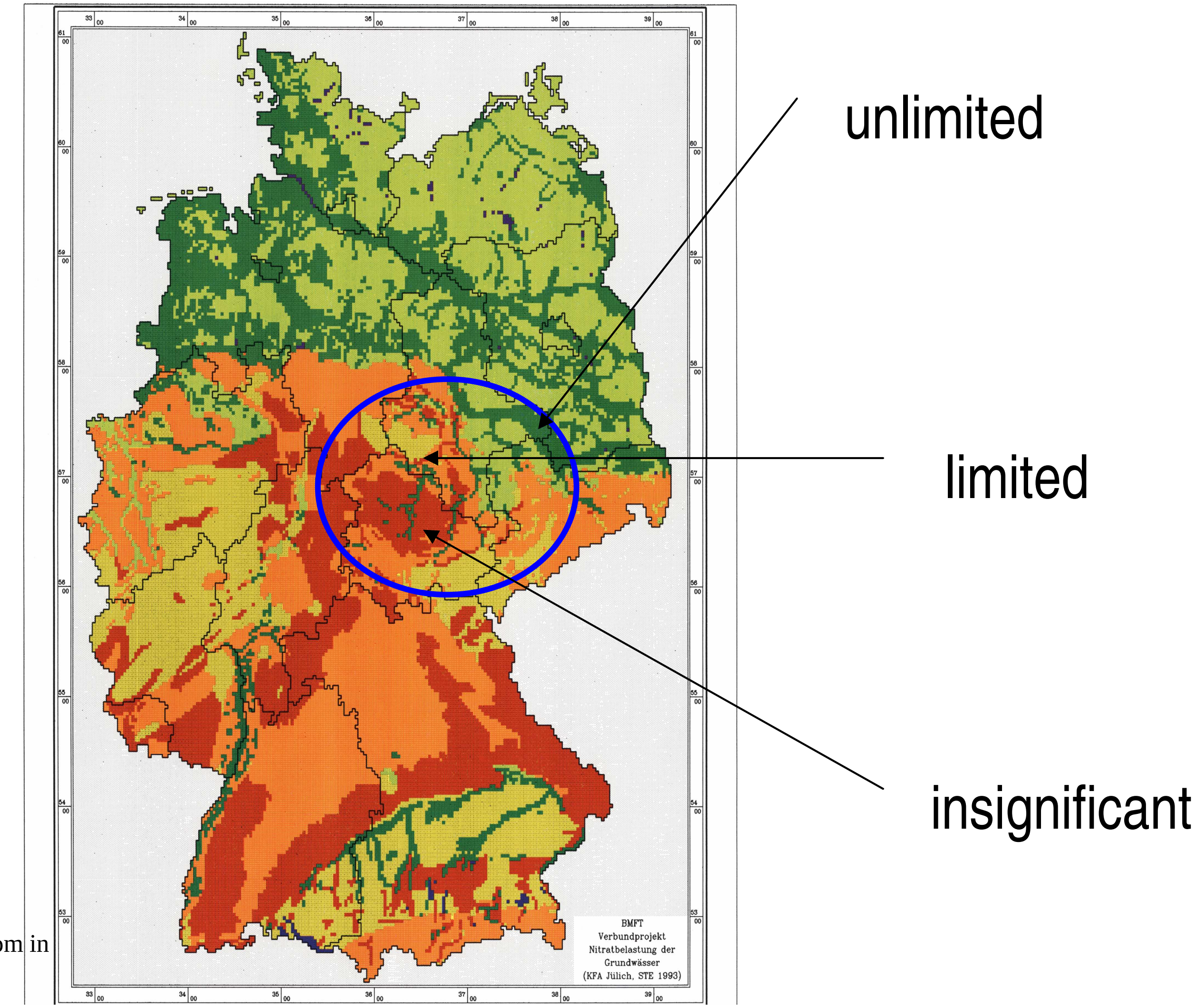
Aggregation of soil types for the II approach

45 SWIM soil types → **14 denitrification soil types** → **3 denitrification categories**





Denitrification conditions in groundwater, Germany



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Conclusions and outlook

Water quality modelling in large river basins should include consideration of retention processes on the way to river network.

The **I hypothesis** to be proved: in large river basins the residence time and decomposition rate should be differentiated based on soil properties and groundwater conditions.

The **II hypothesis** to be proved: in large river basins description of nutrient retention processes in river (e.g. coupling SWIM with WASP or QUAL2E) is needed to better represent water quality.