Integrating wetlands and riparian zones in regional hydrological modelling

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Outline

Introduction

Model concept: - the SWIM model
- the riparian zone module

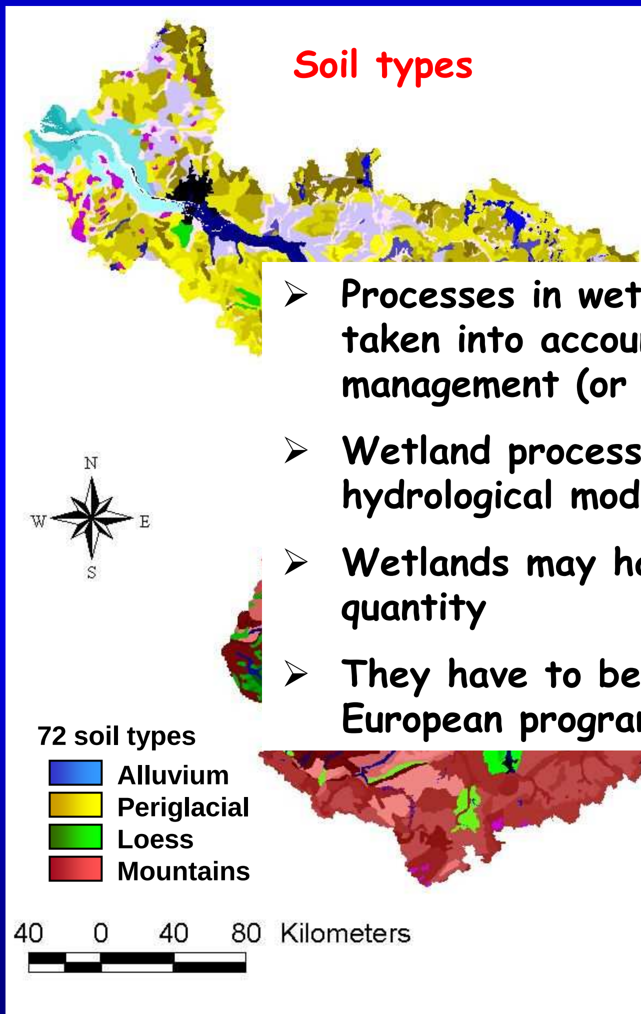
Case study area: - the Nuthe basin

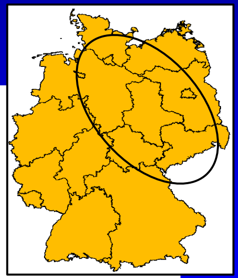
Effects on: - water balance
- nitrogen balance

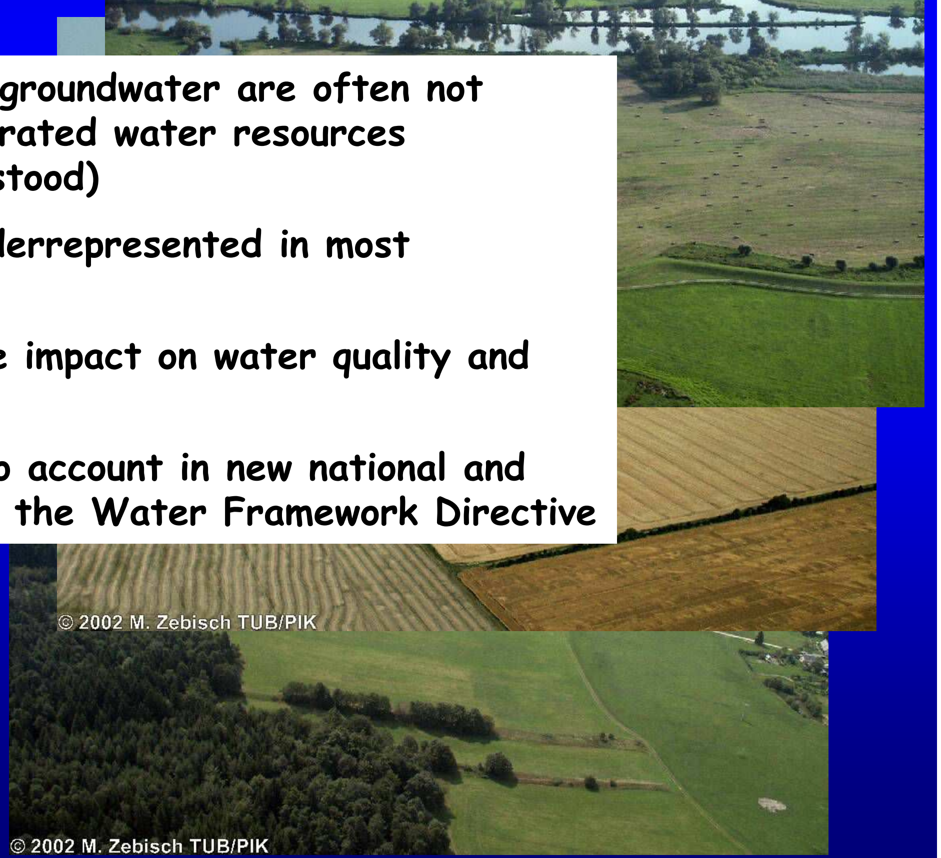
Conclusions/outlook

Model concept
Study area
Results

Motivation

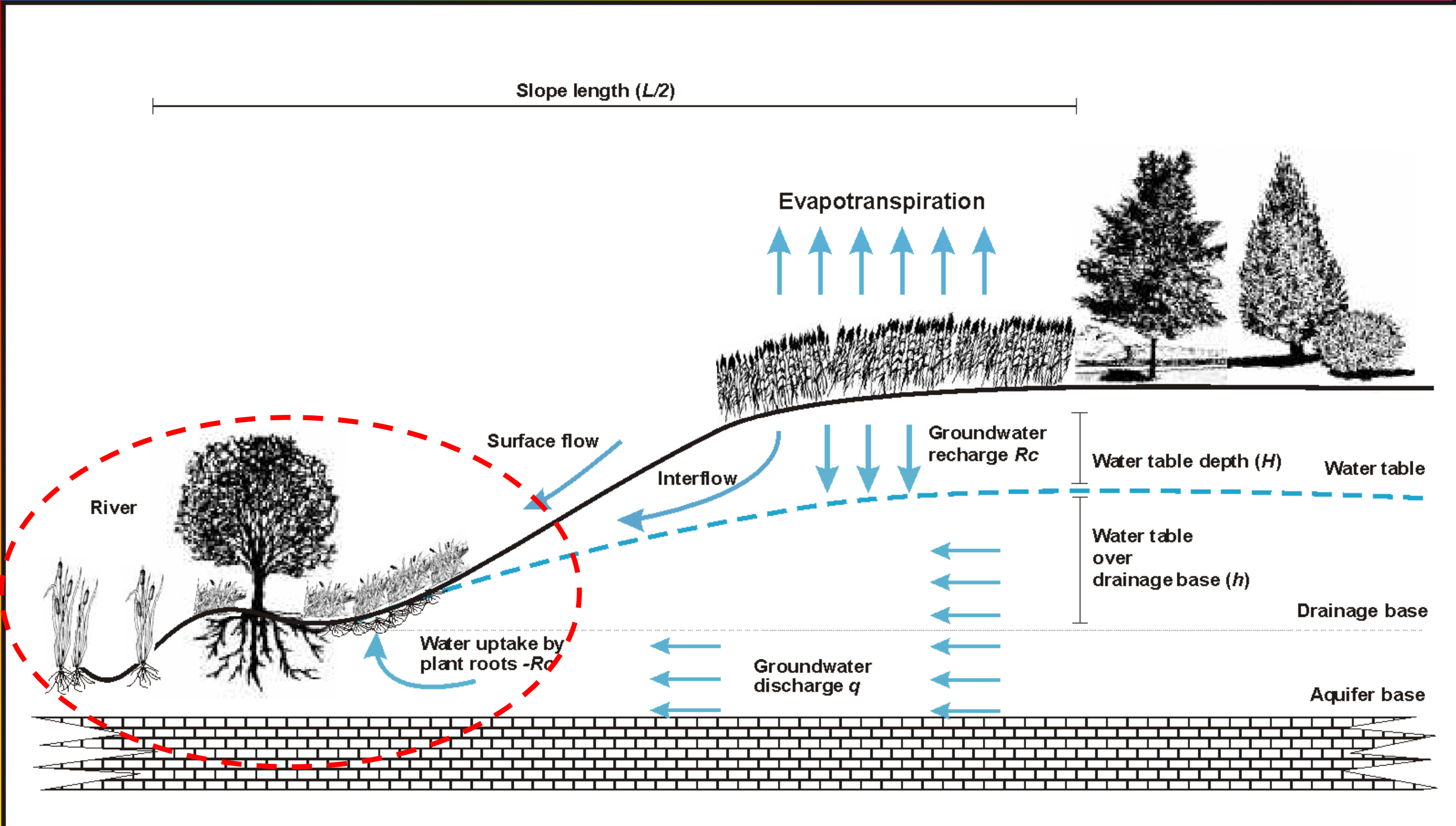






- Processes in wetlands and groundwater are often not taken into account in integrated water resources management (or not understood)
- Wetland processes are underrepresented in most hydrological models
- Wetlands may have a large impact on water quality and quantity
- They have to be taken into account in new national and European programmes, like the Water Framework Directive

Water fluxes at the catchment scale



⇒ Riparian zones and wetlands serve as an interface between upland and river network,
1) they interacts with groundwater,
2) lateral fluxes from upland pass through riparian zone

Model concept
Study area
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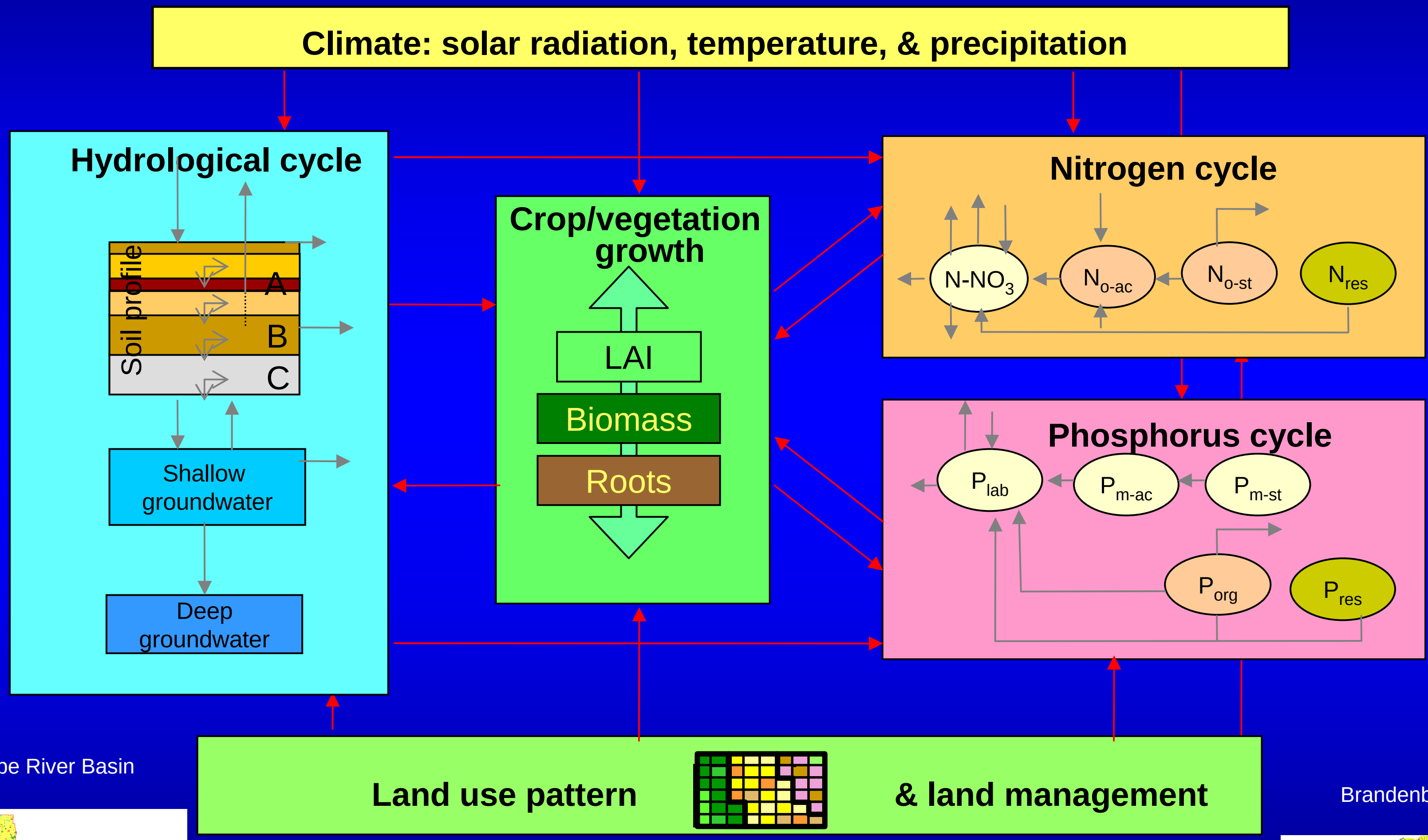
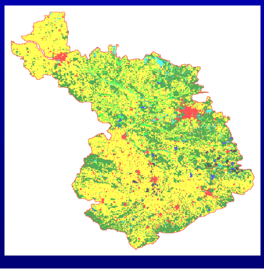
Soil and Water Integrated Model (SWIM, Krysanova et al. 1998)

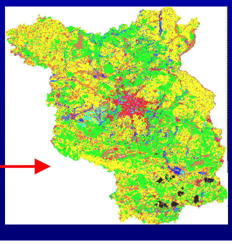


Elbe River Basin



for application in river basins and at the regional scale

Brandenburg



Model concept
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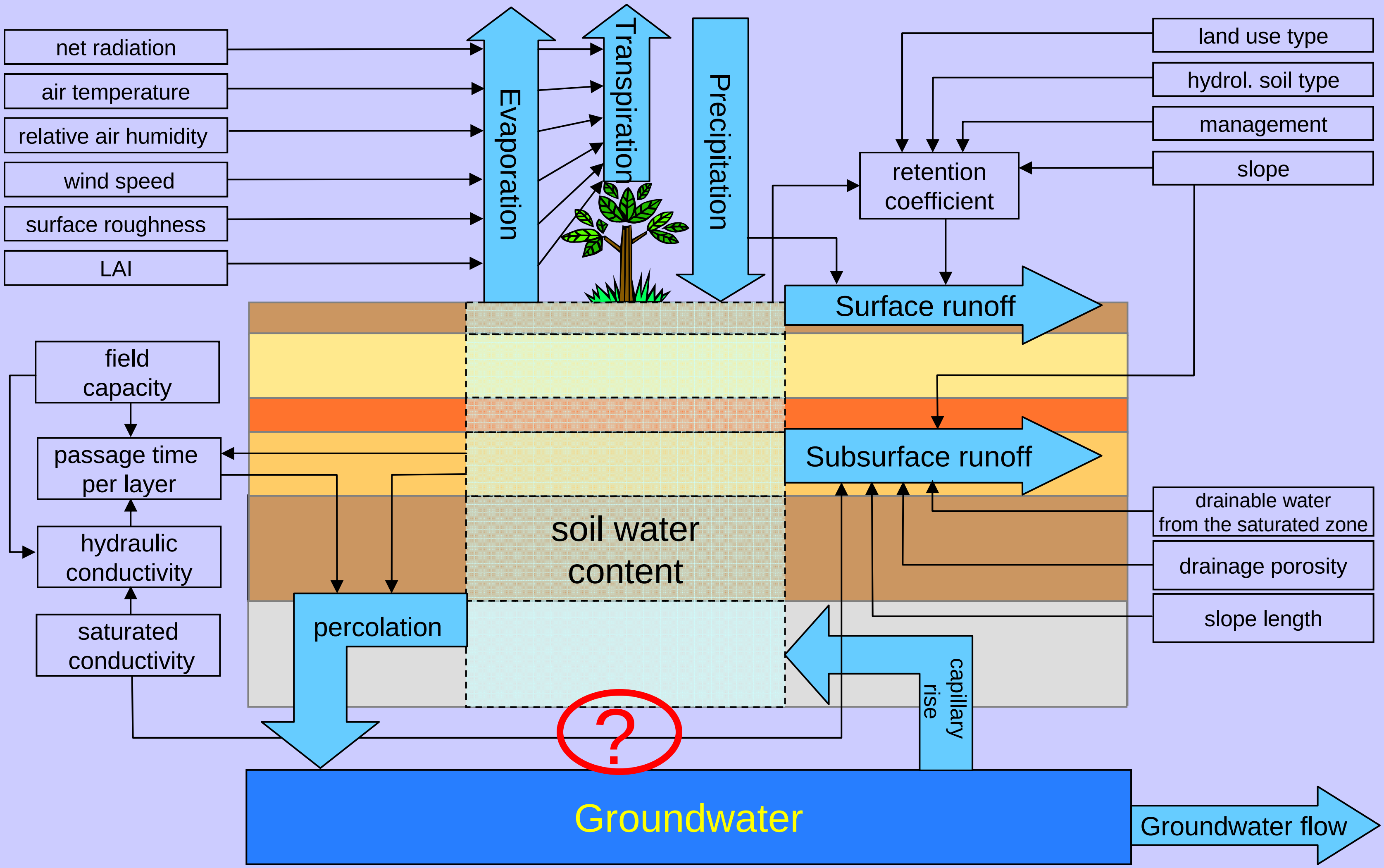
Hydrological cycle in SWIM: vertical fluxes



? Soil and groundwater interact only via percolation and capillary rise

Model concept
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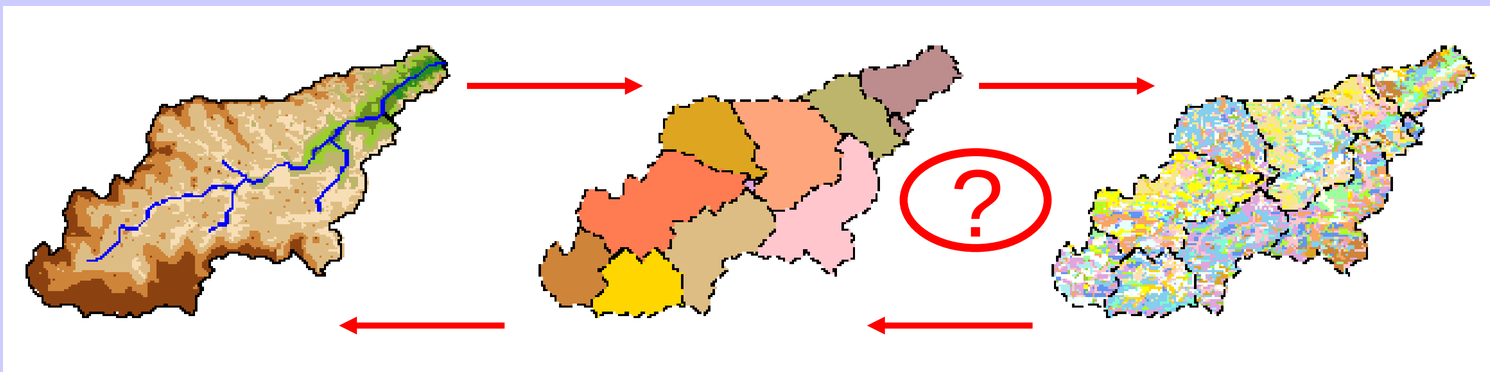
Lateral fluxes in SWIM

basin | sub-basins | hydrotopes



river routing (water, N, P, sed.) | aggregation of lateral flows | water, N, P cycling, vegetation growth

? All lateral fluxes from a subbasin come directly to the river network

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Model Extension

Model definition: A riparian zone or wetland is defined as a hydrotope with shallow g-w table (where plant roots can reach groundwater) having lateral inflow from upland areas

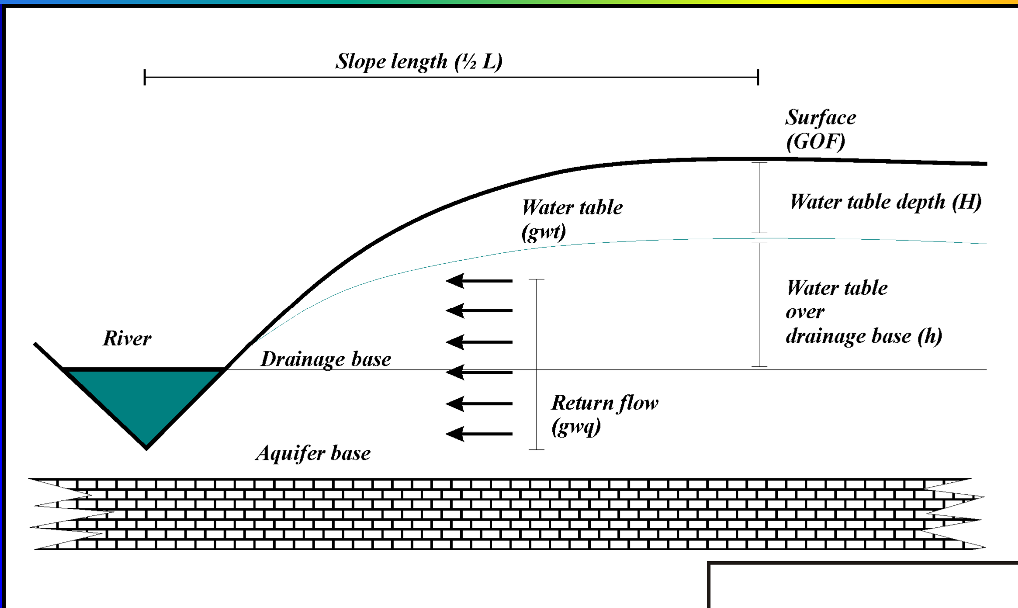
The main changes introduced in the model:

A. implementation of daily groundwater table dynamics at the hydrotope level and soil-groundwater interaction,

B. implementation of nutrient retention in groundwater and interflow (residence time and denitrification),

C. implementation of water and nutrient uptake by plants from groundwater in riparian zones and wetlands.

A. Groundwater dynamics at the hydrotope level

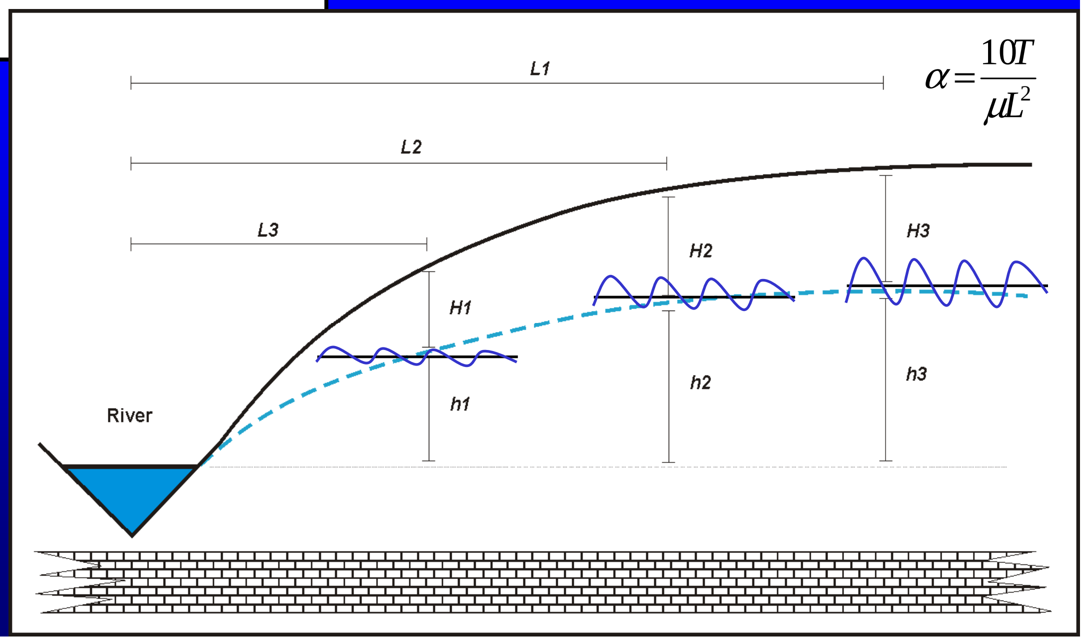


Before in SWIM:
water table is defined daily for each subbasin

New approach in SWIM:

- water table is defined daily for each hydrotope
- automatic calibration

(Hattermann et al. 2004)



B. Nitrogen Retention in Groundwater and Interflow

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

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

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

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

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

=> Basic equation

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

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

⇒ K = mean residence time,
⇒ λ = turnover coefficient,
⇒ C = concentration

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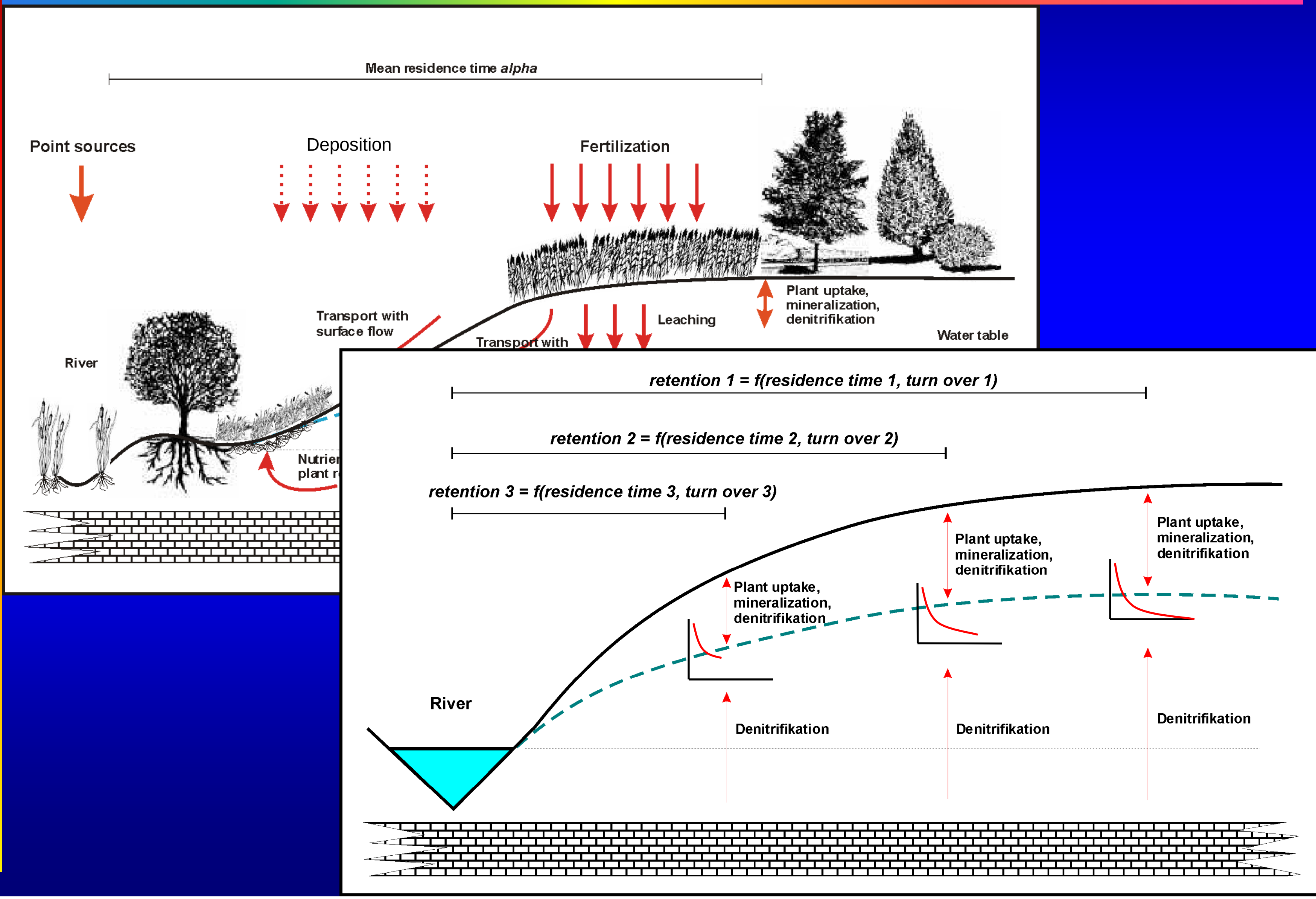
B. Nitrogen Transport and Retention



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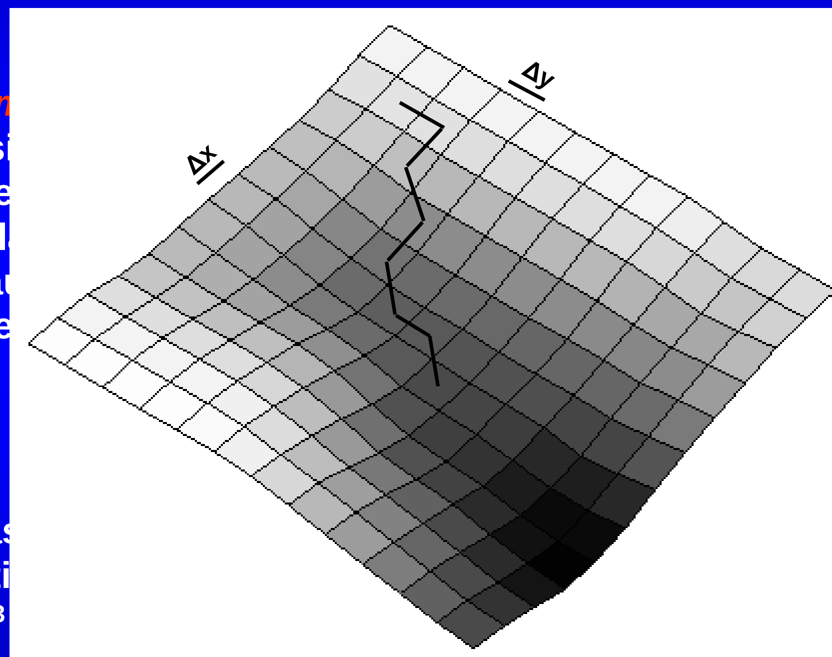
B. & C. Nitrogen retention and plant uptake: Parameter estimation

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

The *distance L* to the river is calculated following the gradient in groundwater table to the river.

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

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

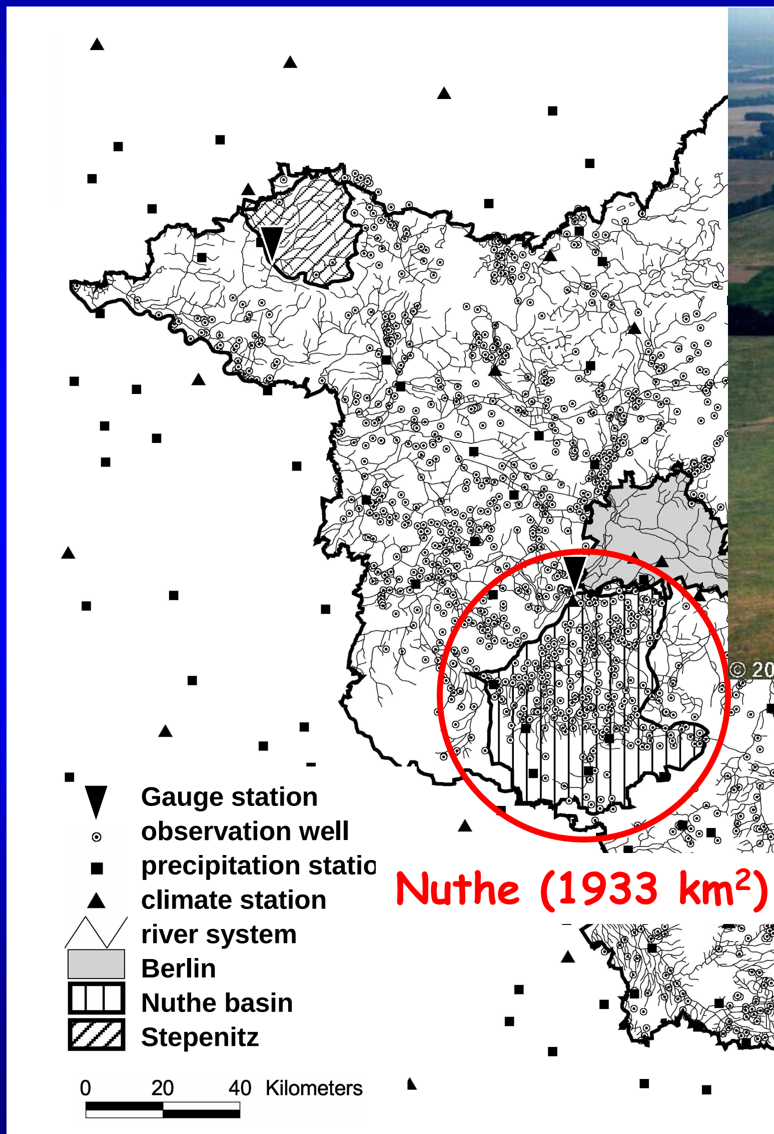


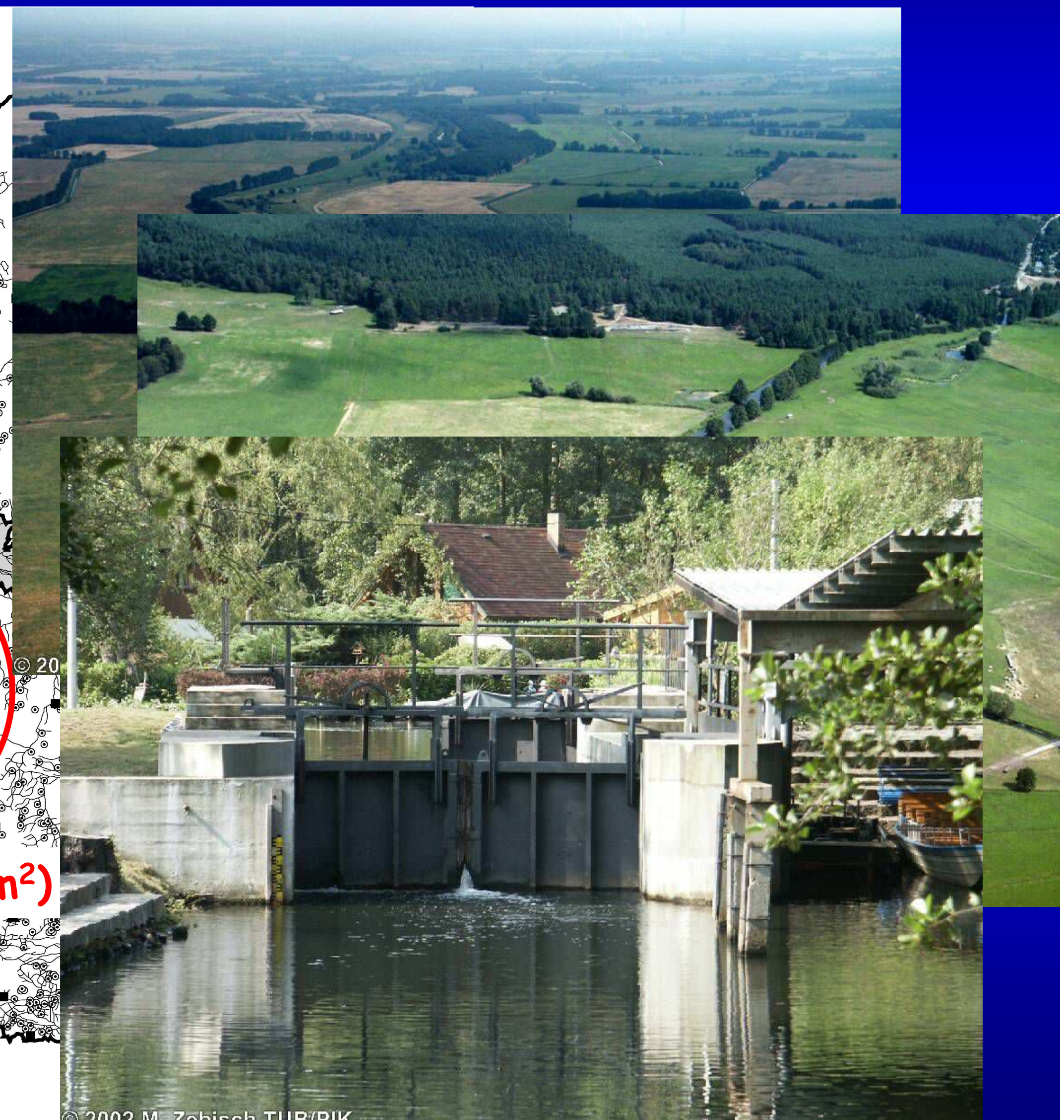
The *n* w path, permeability,
porosi subsurface flow and
gradie surface flow. It can be
calcul here *k* in m d^{-1} is the
hydrau mensionless hydraulic
gradie up to > 1000 years).

The *turnover coefficient λ* concentration of the
catchment sediments. It was 993) for the Elbe basin
as initial values (a half-life ti orresponds to λ values
between 6·10^{-4} d^{-1} and 2·10^{-3}

The *maximum N uptake by plants* from groundwater and interflow is limited by the available lateral discharge and was calculated using the flow accumulation method which calculates the amount of nutrients flowing through a spatial unit of the catchment following the groundwater gradient, and by the plant demand using a resistance function.

The Nuthe Basin





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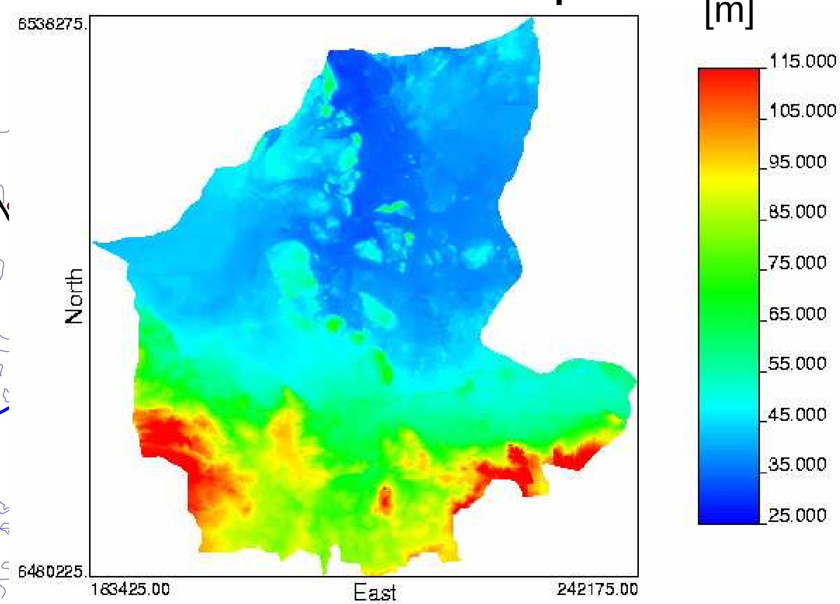
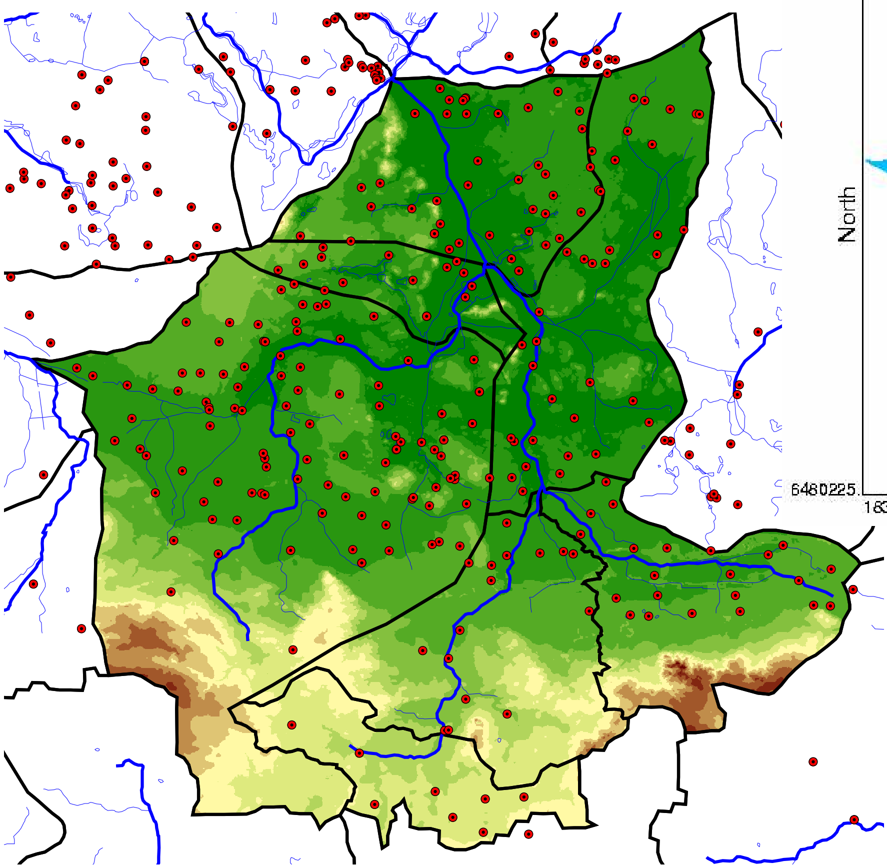
The Nuthe Basin: Groundwater Table





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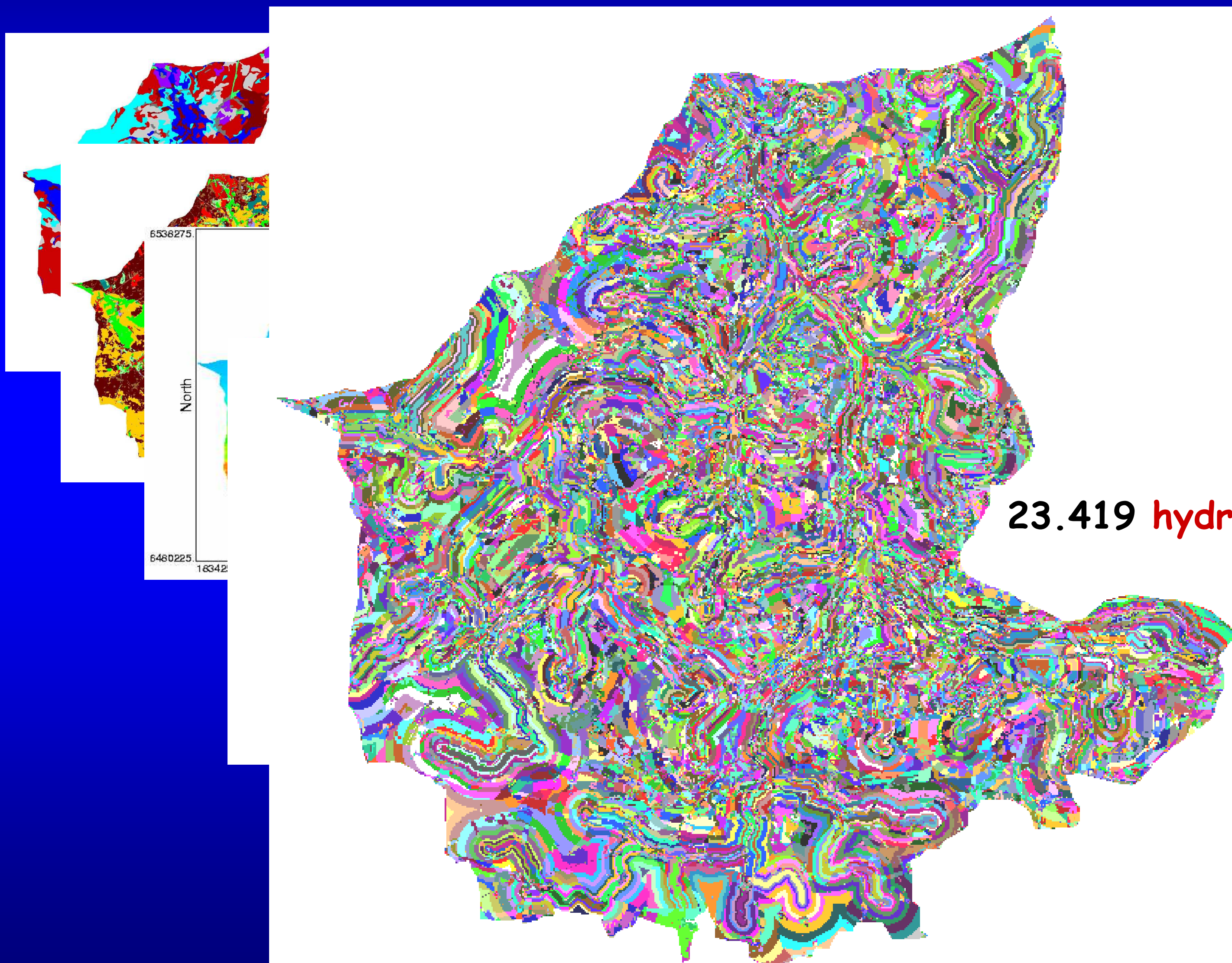
Spatial heterogeneity and delineation of hydrotopes



23.419 hydrotopes

Model concept
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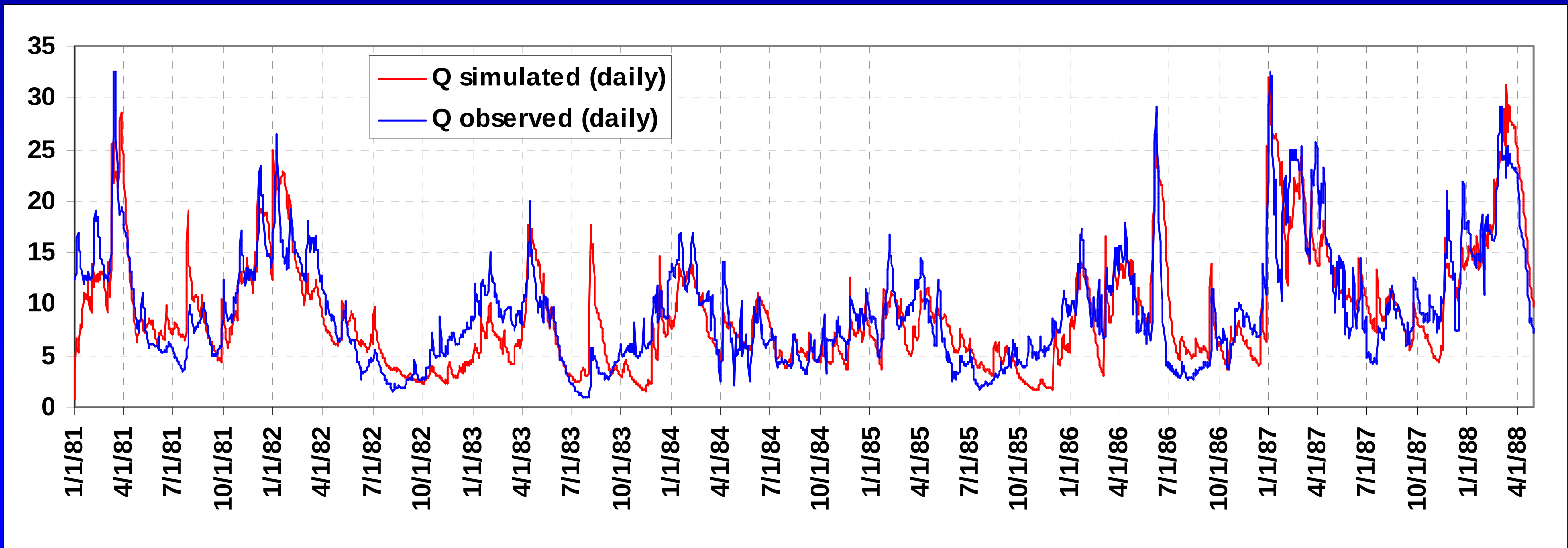
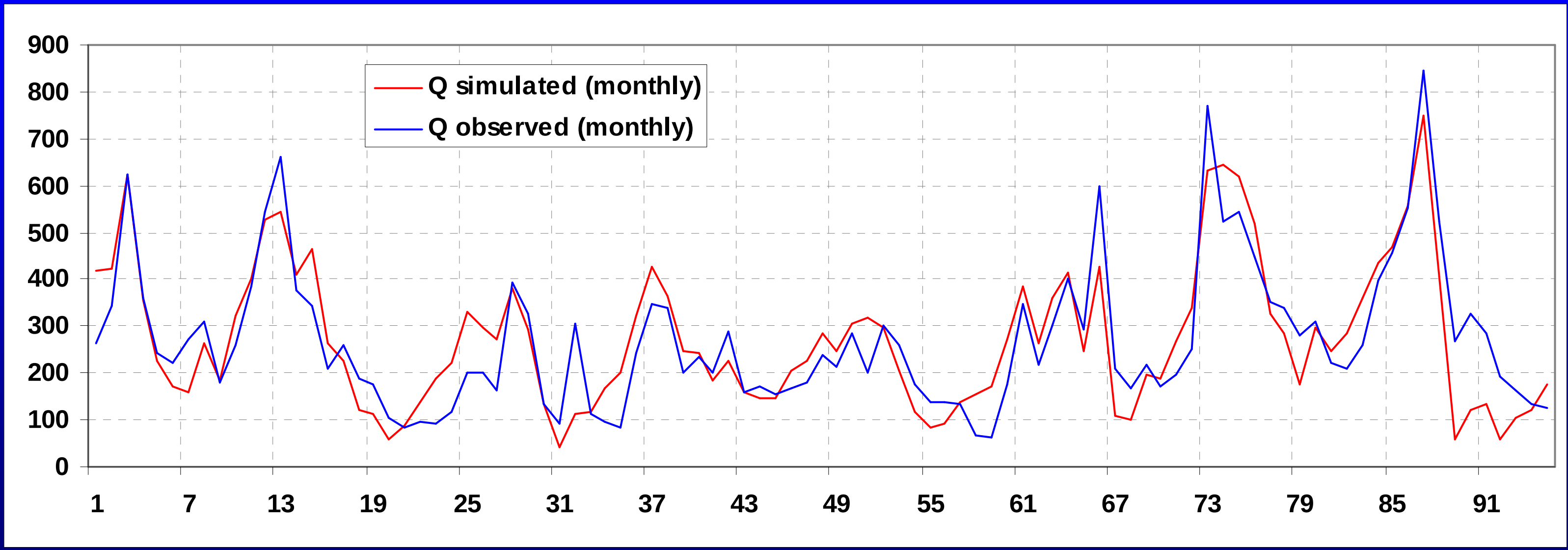
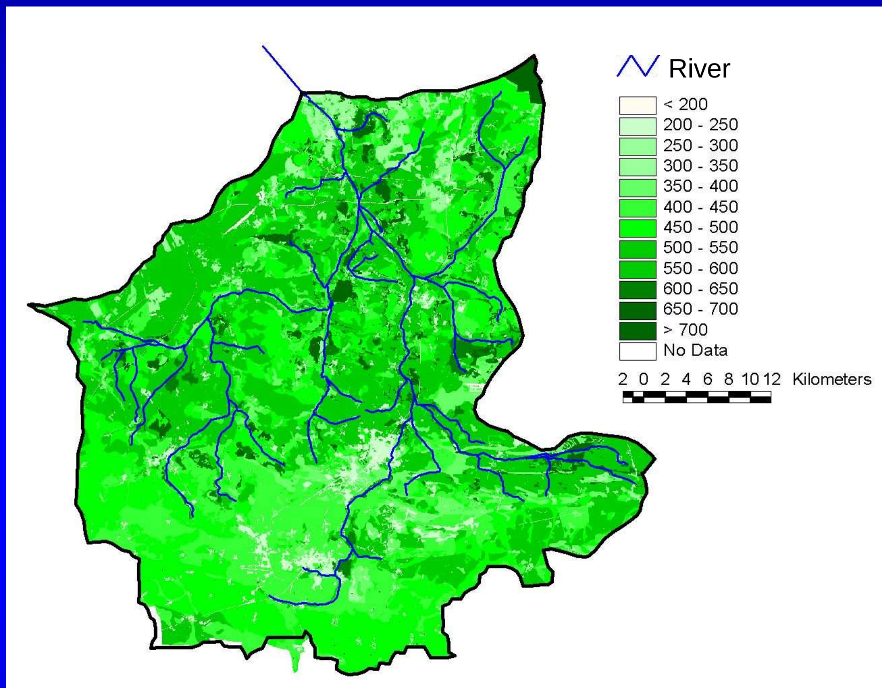
River Discharche at Gauge Babelsberg (daily N&S 0.62)

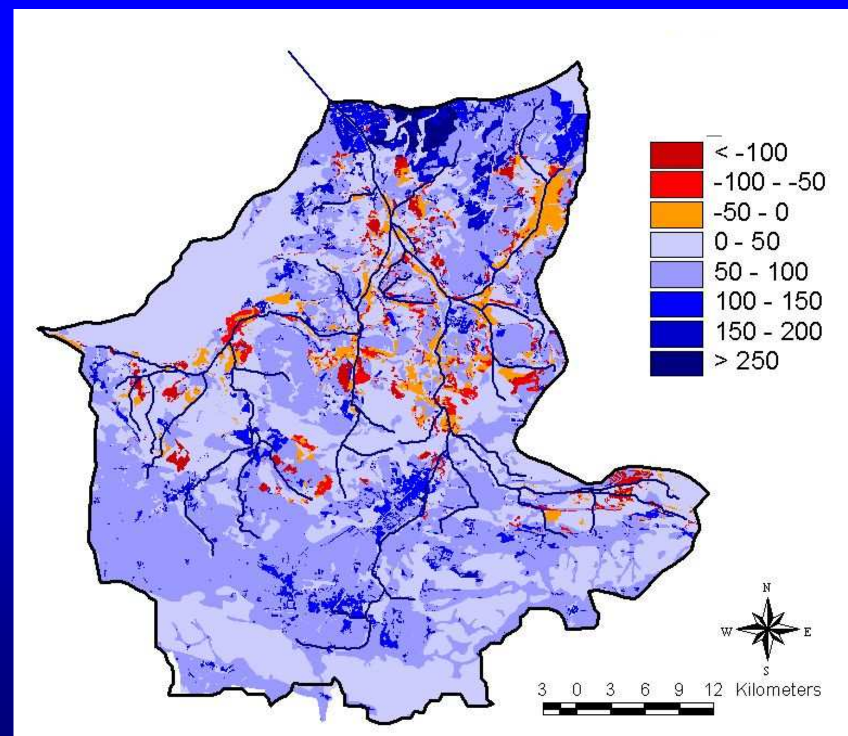




Evapotranspiration and groundwater recharge

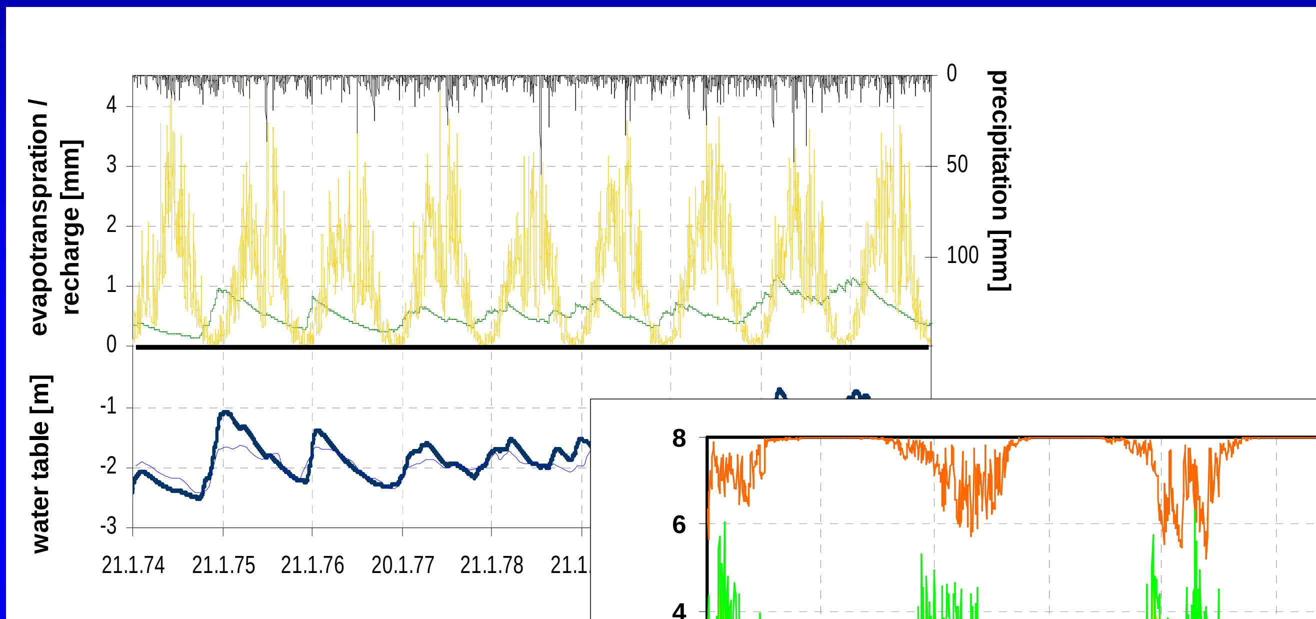


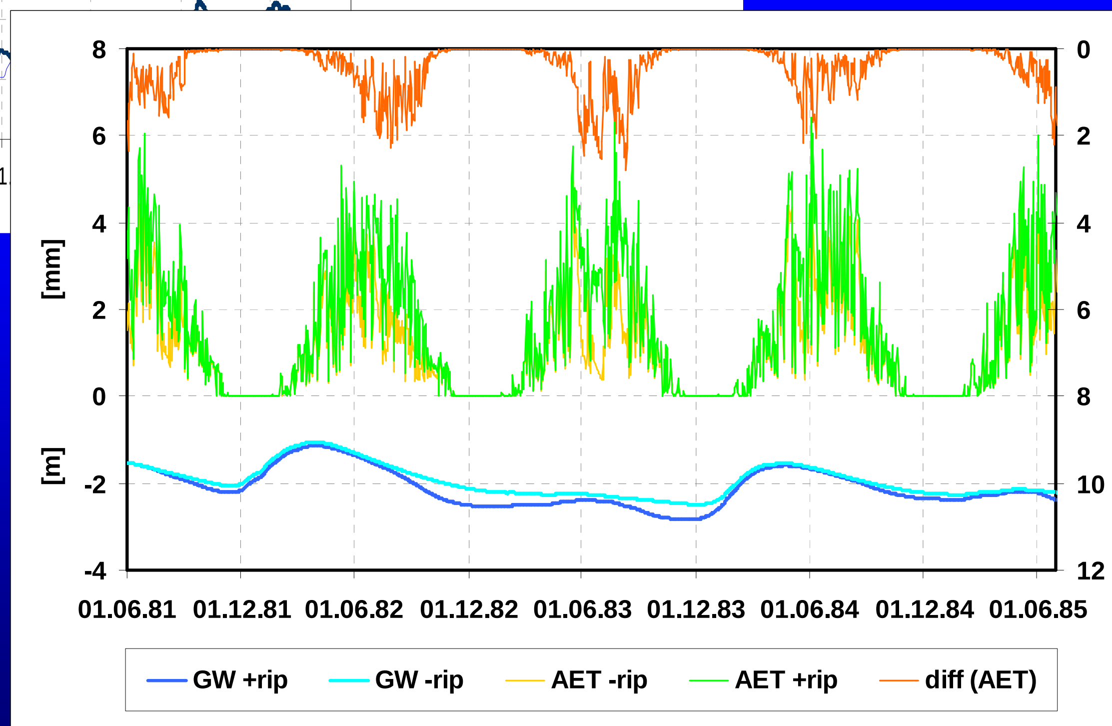
Evapotranspiration [mm/a]:
Additional evapotranspiration from groundwater in wetlands is about 24 % of the total plant water uptake (~48 % of river discharge)



Groundwater recharge [mm/a]

Groundwater table dynamics in a hydrotope





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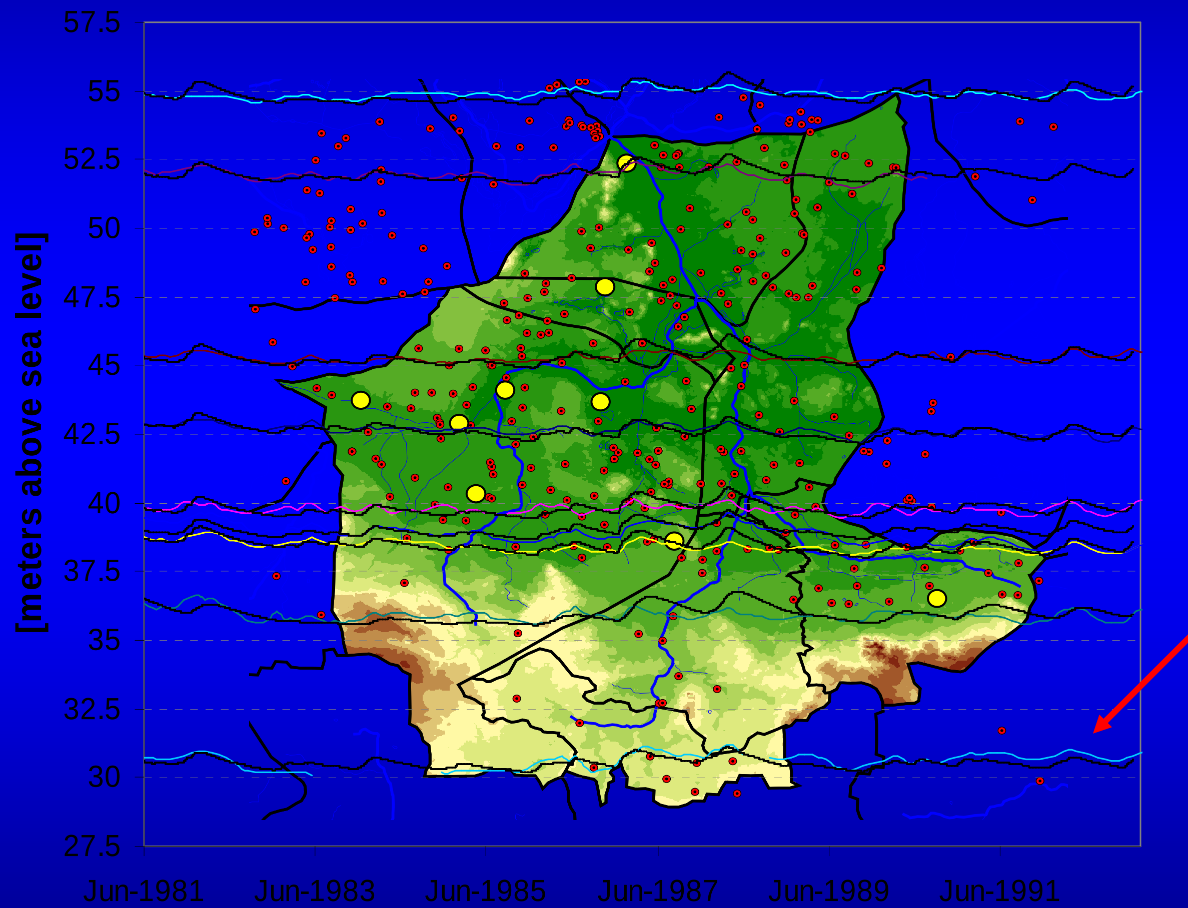
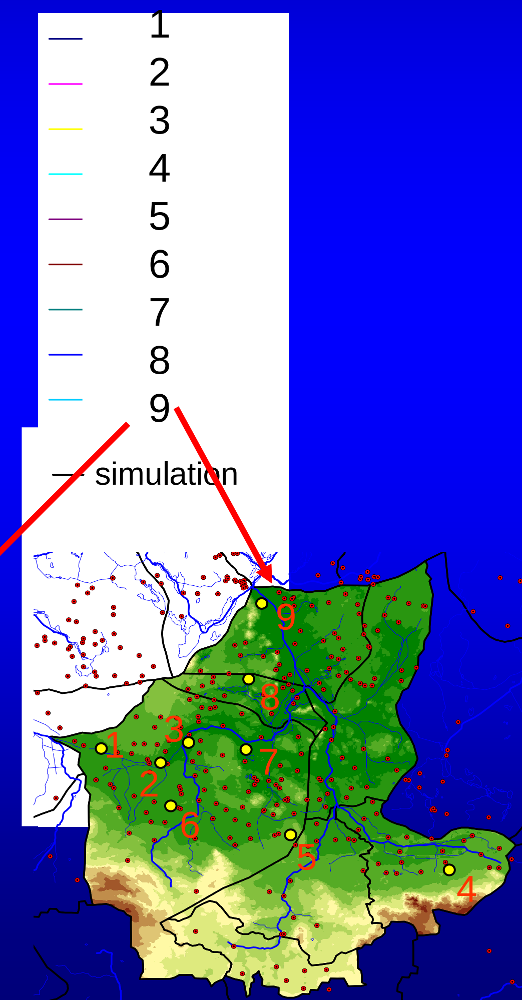
Groundwater table dynamics in 9 observation wells





Top: Groundwater dynamic simulated (black lines) and observed.
Right: Location of the observation wells.

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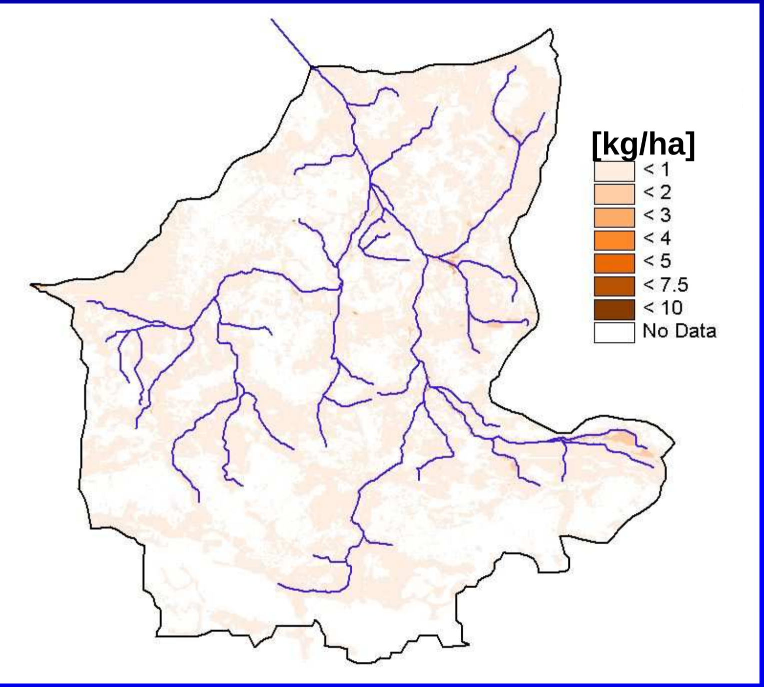
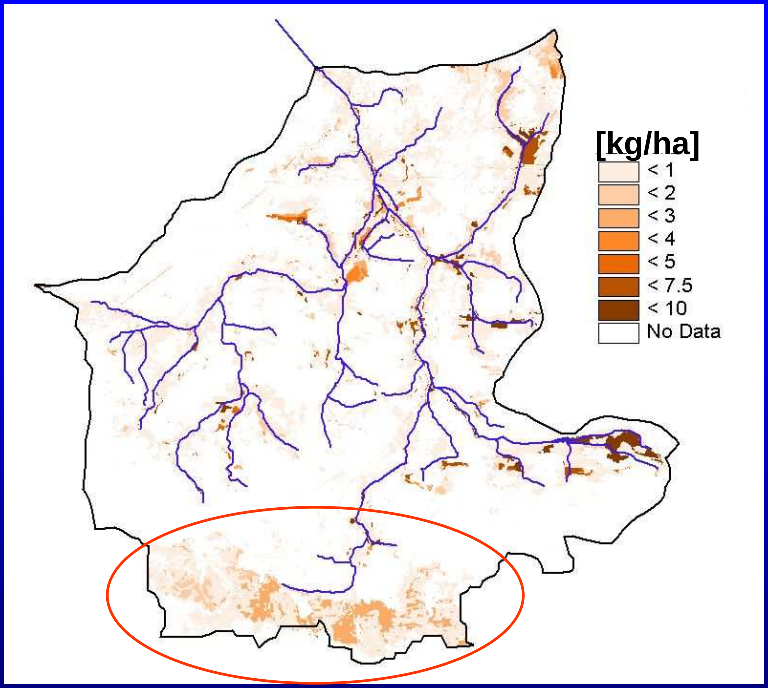
Nitrate Leaching into Riparian Zones



Nitrate-N input from groundwater to riparian zone



Nitrate-N input from interflow to riparian zone

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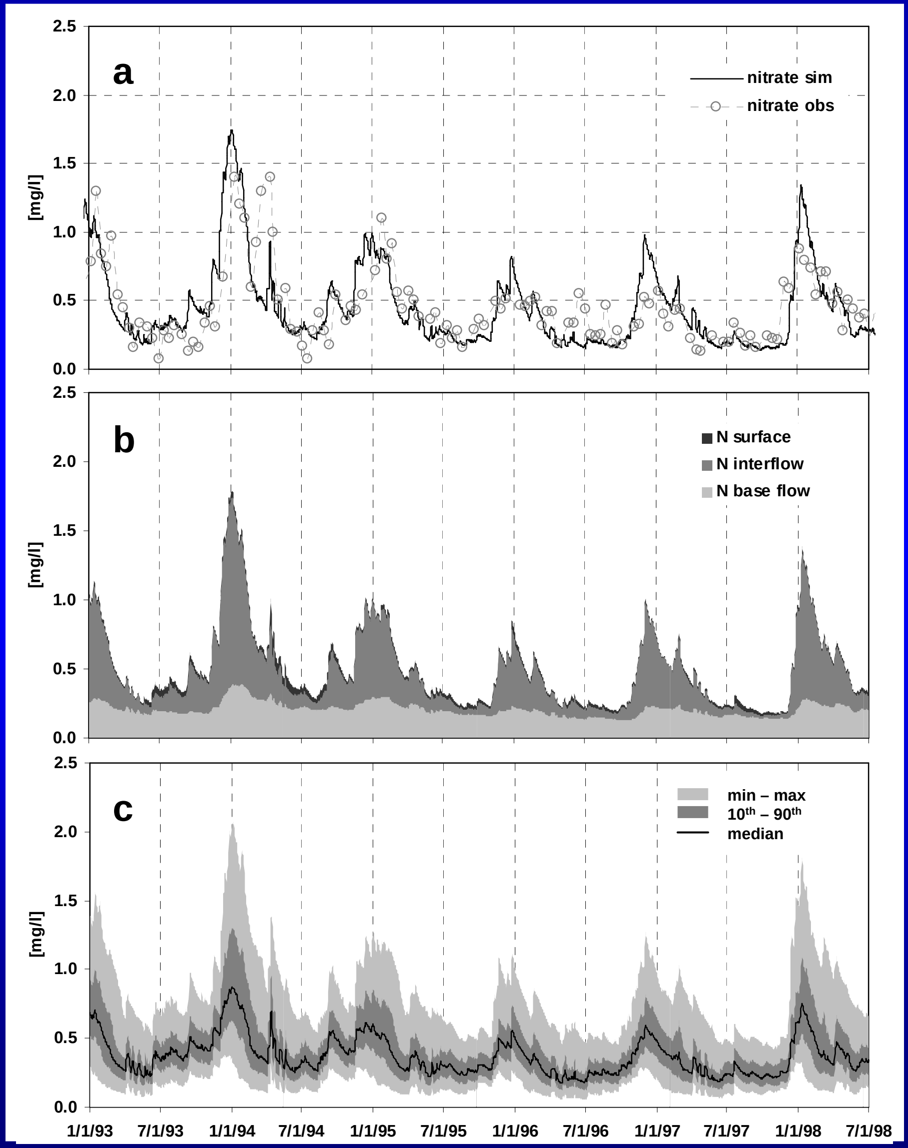
Nitrate Concentration in River



Nitrate N concentration: simulated and observed

Nitrate-N from two major flow paths

Evaluation of the uncertainty of the results (Latin Hypercube method, variation of 28 model parameters for hydrology and nutrient retention): 100%, 80% and median

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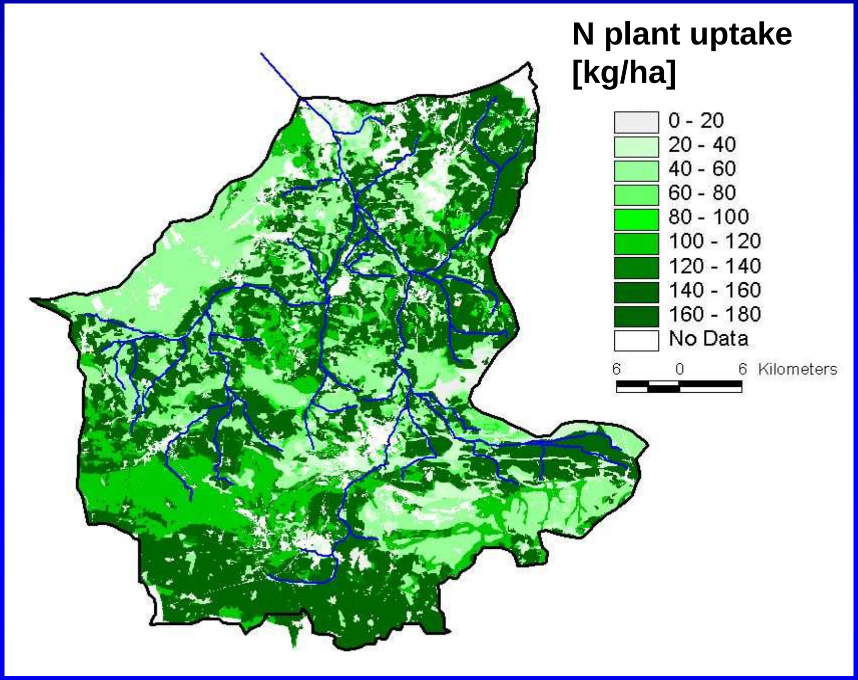
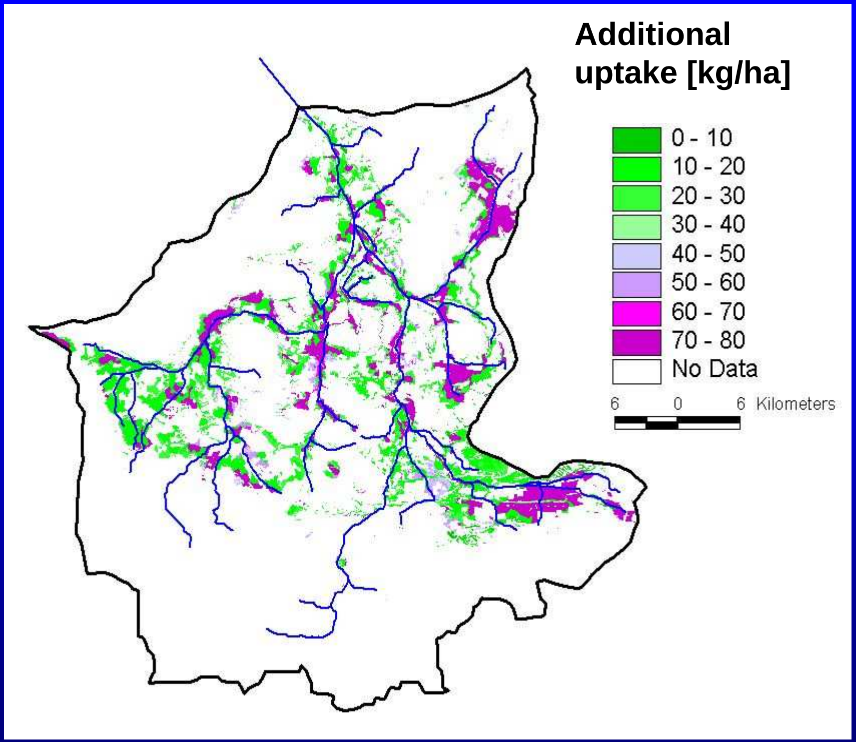
Simulated Nitrate-N uptake in the basin and in riparian zones





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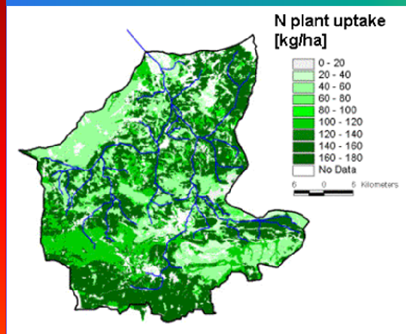
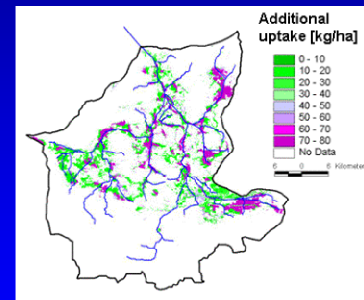
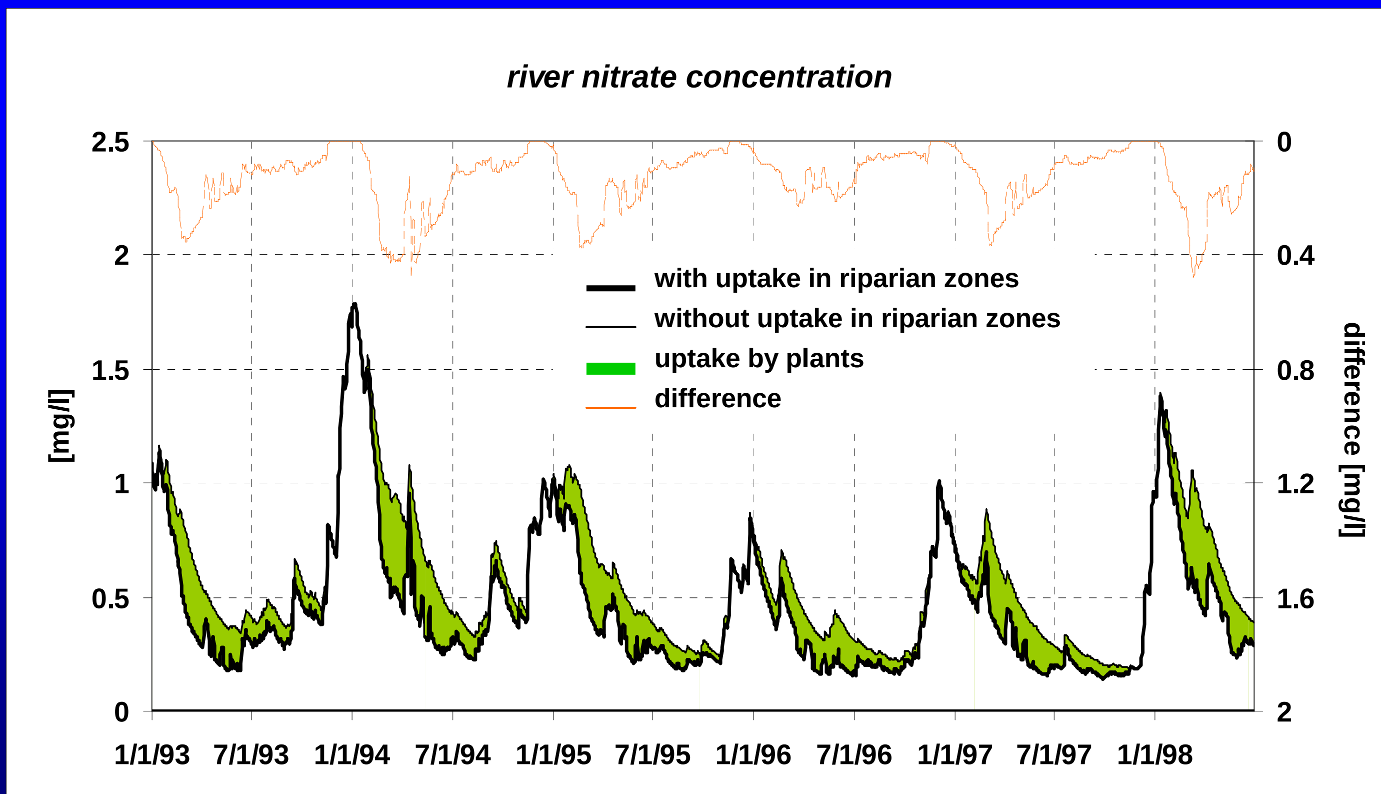
The effect of additional N uptake in riparian zones on N concentrations in the river



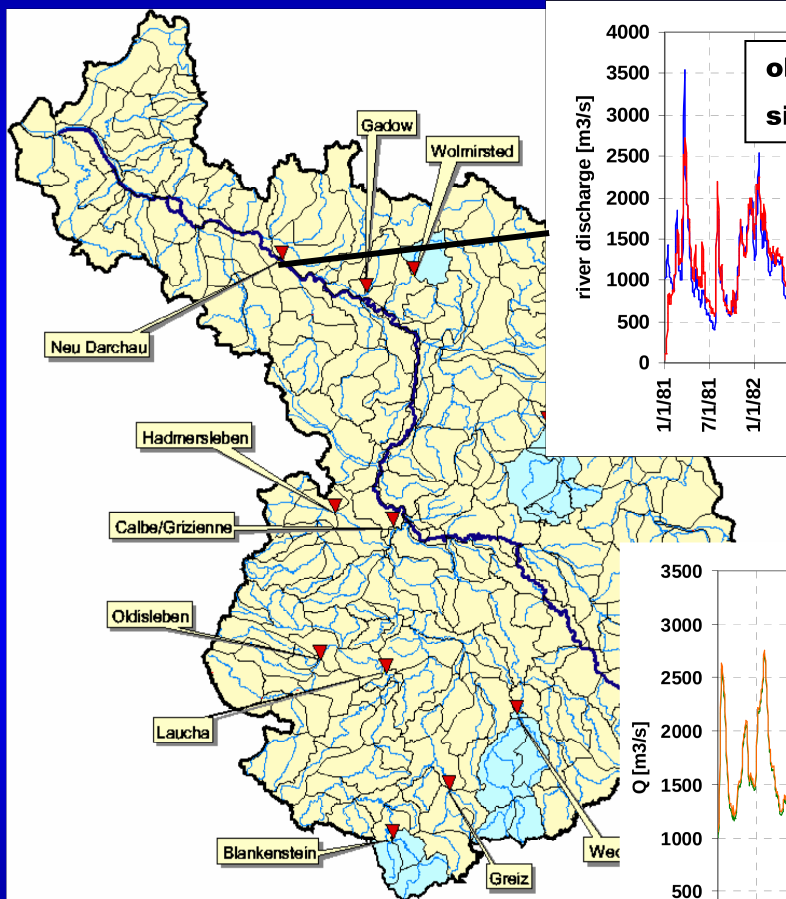


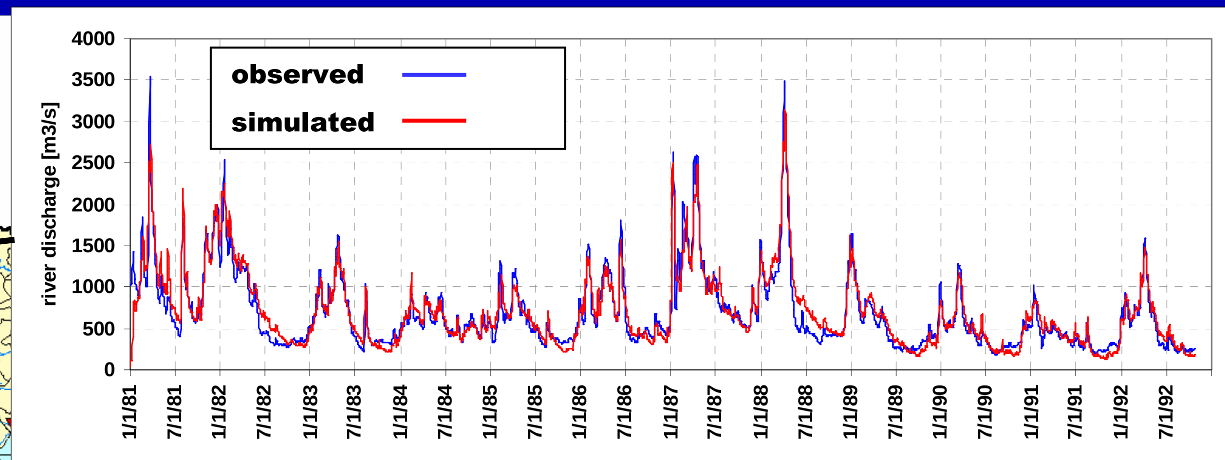


Summary and Conclusions

- A correct representation of spatial heterogeneity is necessary to reproduce the water and nutrient fluxes at the basin scale.
- Riparian zones and wetlands have a high potential to reduce river flow (additional evapotranspiration) and nutrient loads (additional plant uptake) to surface water. In our case study additional evapotranspiration of about 24 % and additional nitrate uptake of about 6 % were simulated (~ 48 % of river discharge and ~24 % of river load).
- Ecohydrological models integrating relevant hydrological, biogeochemical and vegetation processes at the river basin scale can serve as a basis to investigate land use and climate changes impacts at the regional scale.

Outlook


Gadow
Wolmirsted
Neu Darchau
Hadmersleben
Calbe/Grizienne
Oldisleben
Laucha
Blankenstein
Greiz


river discharge [m3/s]
observed
simulated
0
500
1000
1500
2000
2500
3000
3500
4000
1/1/81
7/1/81
1/1/82
7/1/82
1/1/83
7/1/83
1/1/84
7/1/84
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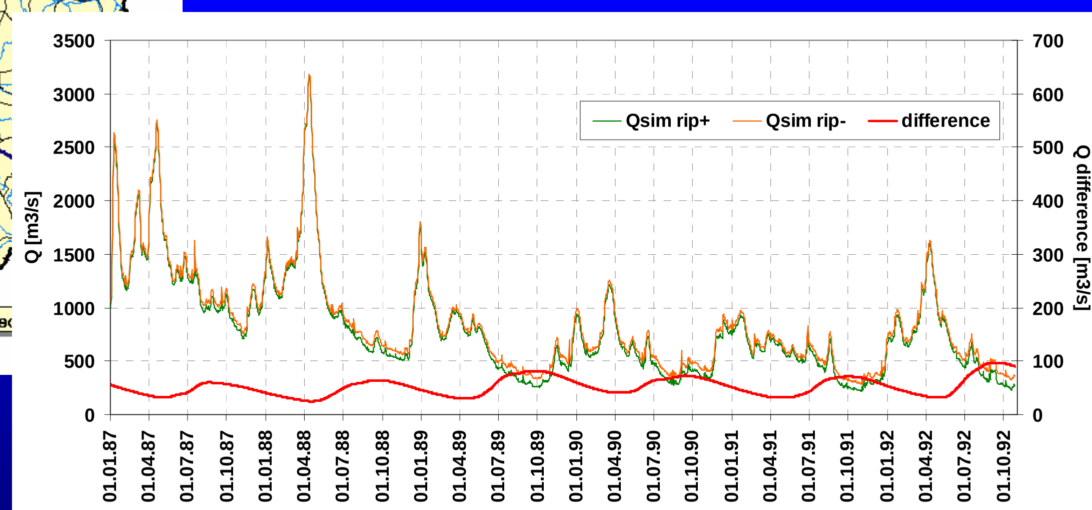
1/1/92
7/1/92


Q [m3/s]
Q difference [m3/s]
Qsim rip+
Qsim rip-
difference
0
500
1000
1500
2000
2500
3000
3500
0
100
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700
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01.07.88
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