Propagation of Uncertainty in Large Scale Eco-hydrological Modelling

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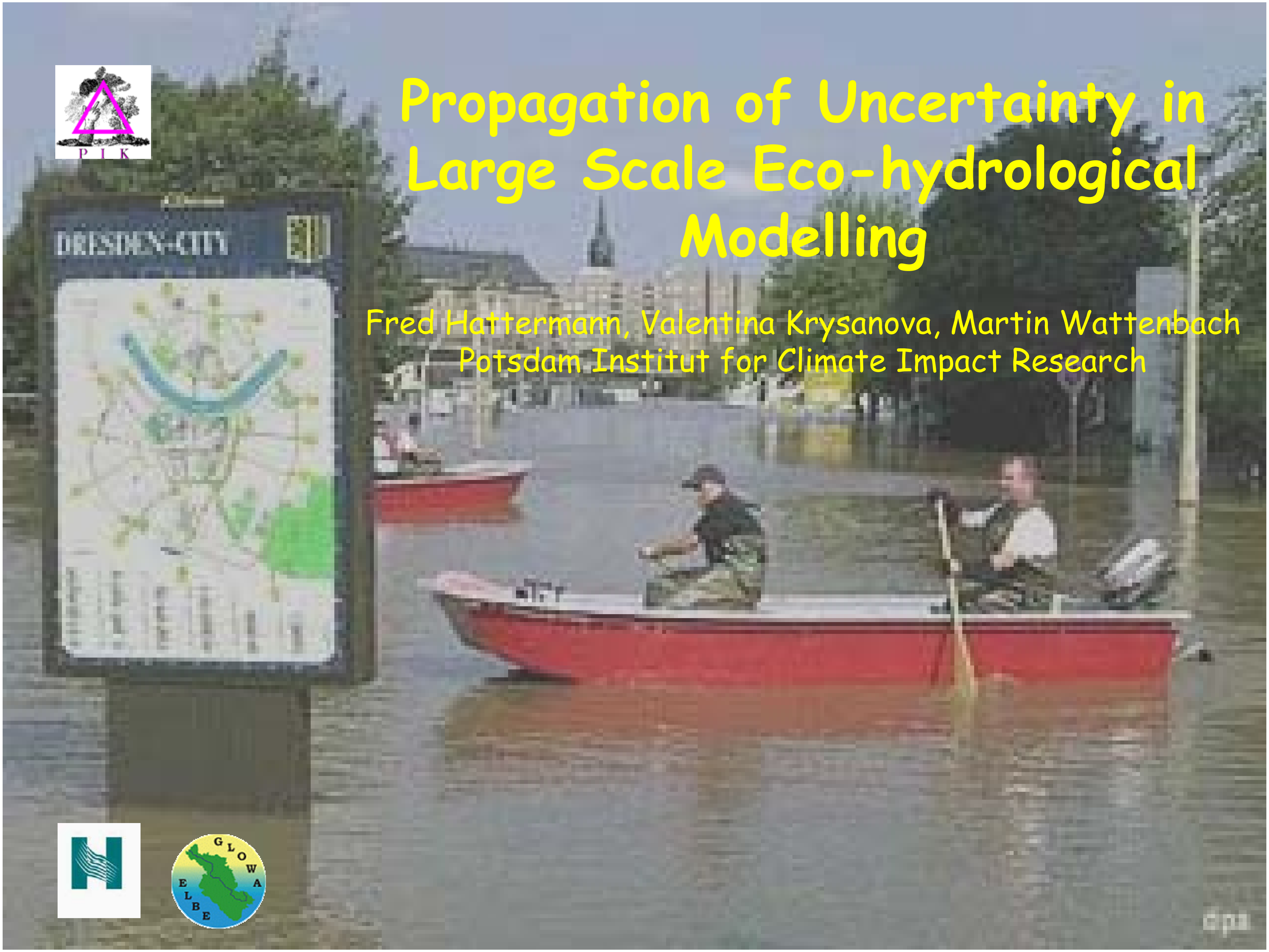

Outline

- Model validation including sensitivity and uncertainty analysis
- Scenario uncertainty in water supply under global change

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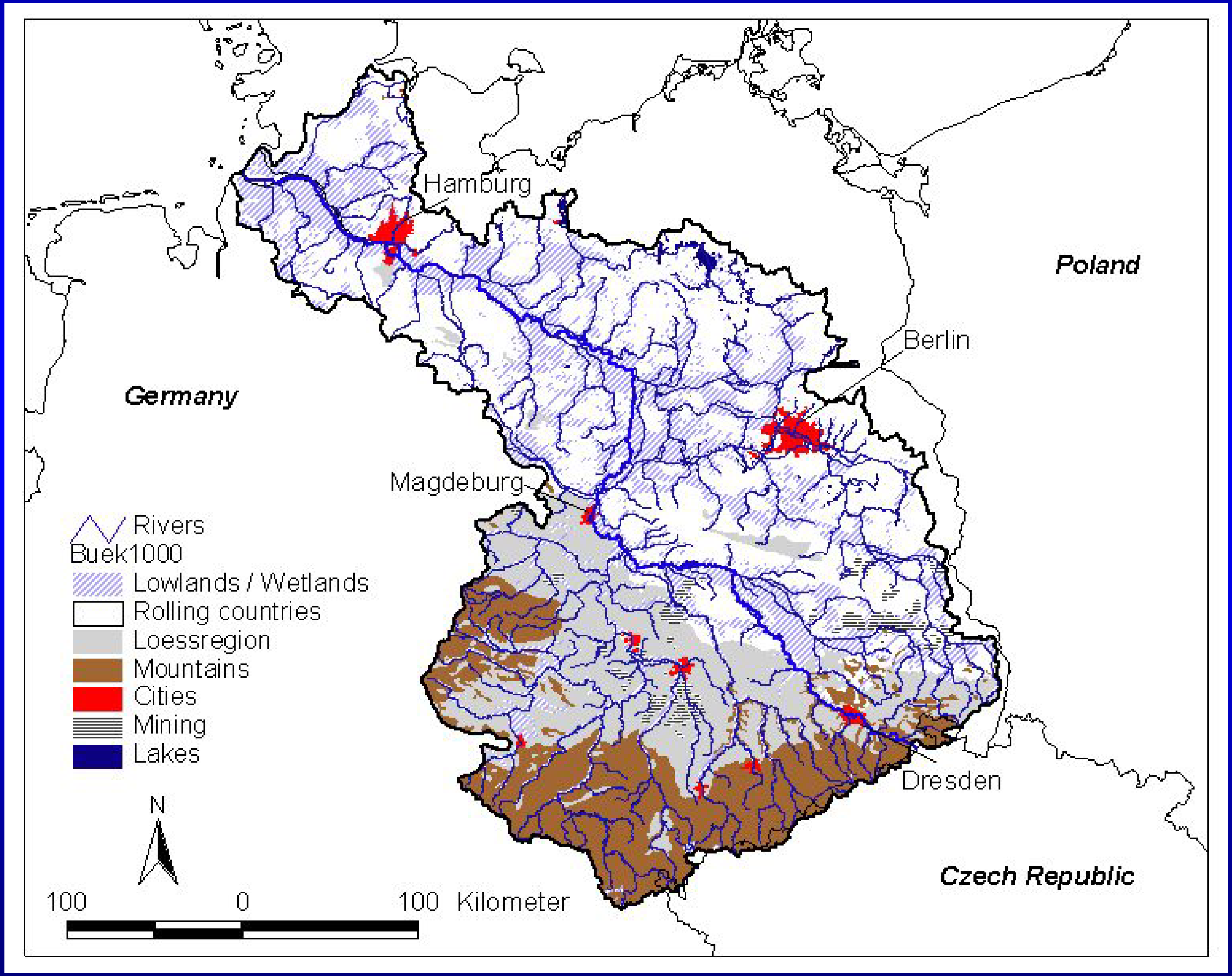
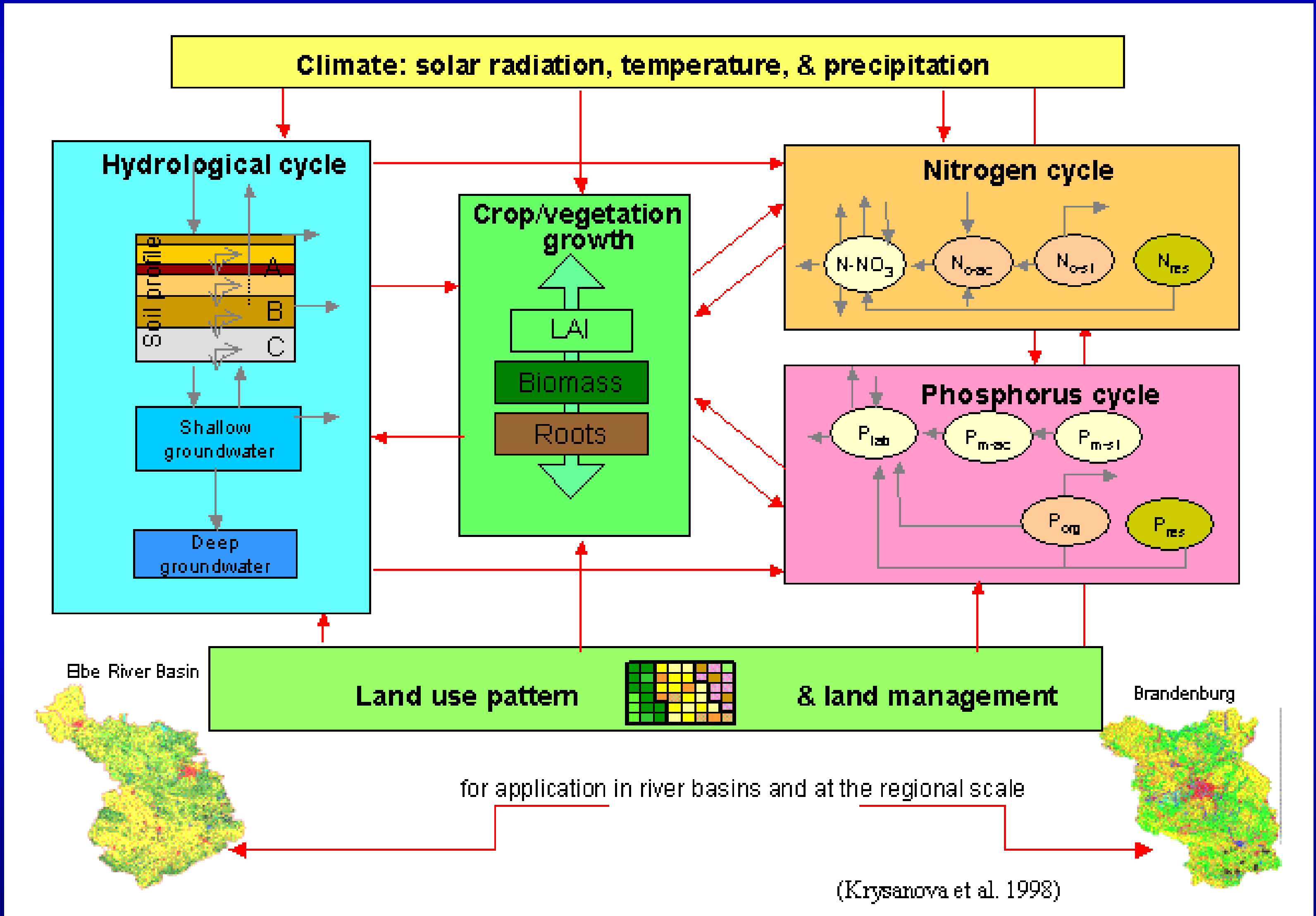
The River Basin (Elbe)



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



Hydrological Validation Considering Sensitivity and Uncertainty

Steps in the validation process:

1. Multi-scale, multi-site and multi-criteria hydrological validation
2. Definition of data and model parameter uncertainty
3. Analyses of the uncertainty in the model results

Discharge deviation (***difference*** river discharge observed $\boldsymbol{Q_{obs}}$ – simulated $\boldsymbol{Q_{sim}}$):

$$deviation = \frac{\sum Q_{sim} - \sum Q_{obs}}{\sum Q_{obs}} * 100$$

Nash & Sutcliffe – ***efficiency.*** The Nash & Sutcliffe efficiency is defined from – oo to 1.

$$efficiency = 1 - \frac{\sum (Q_{obs} - Q_{sim})^2}{\sum (Q_{obs} - \overline{Q}_{obs})^2}$$

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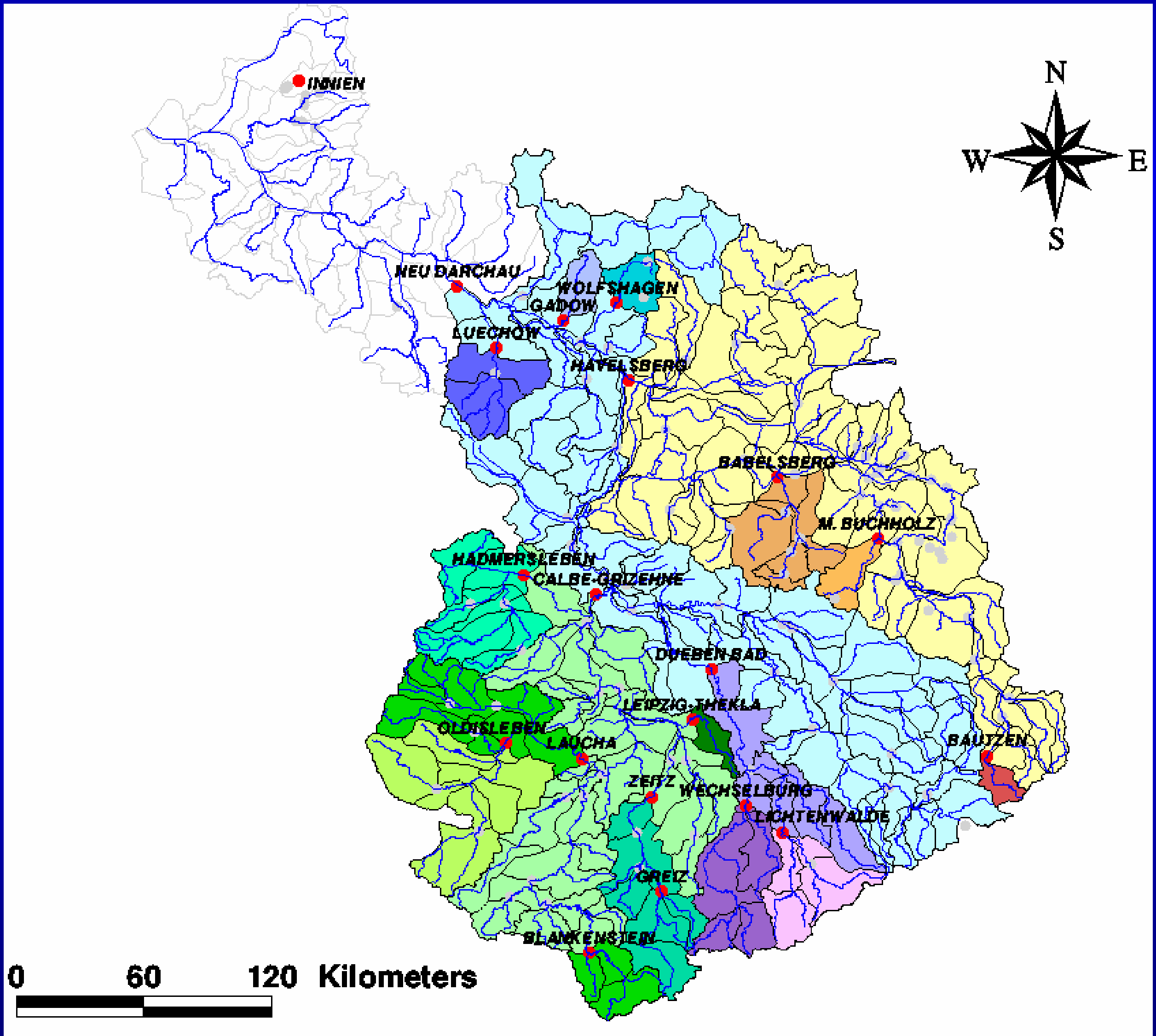
Basins where Model Validations were performed (Hydrology, Nutrient Transport, Crop Yields)



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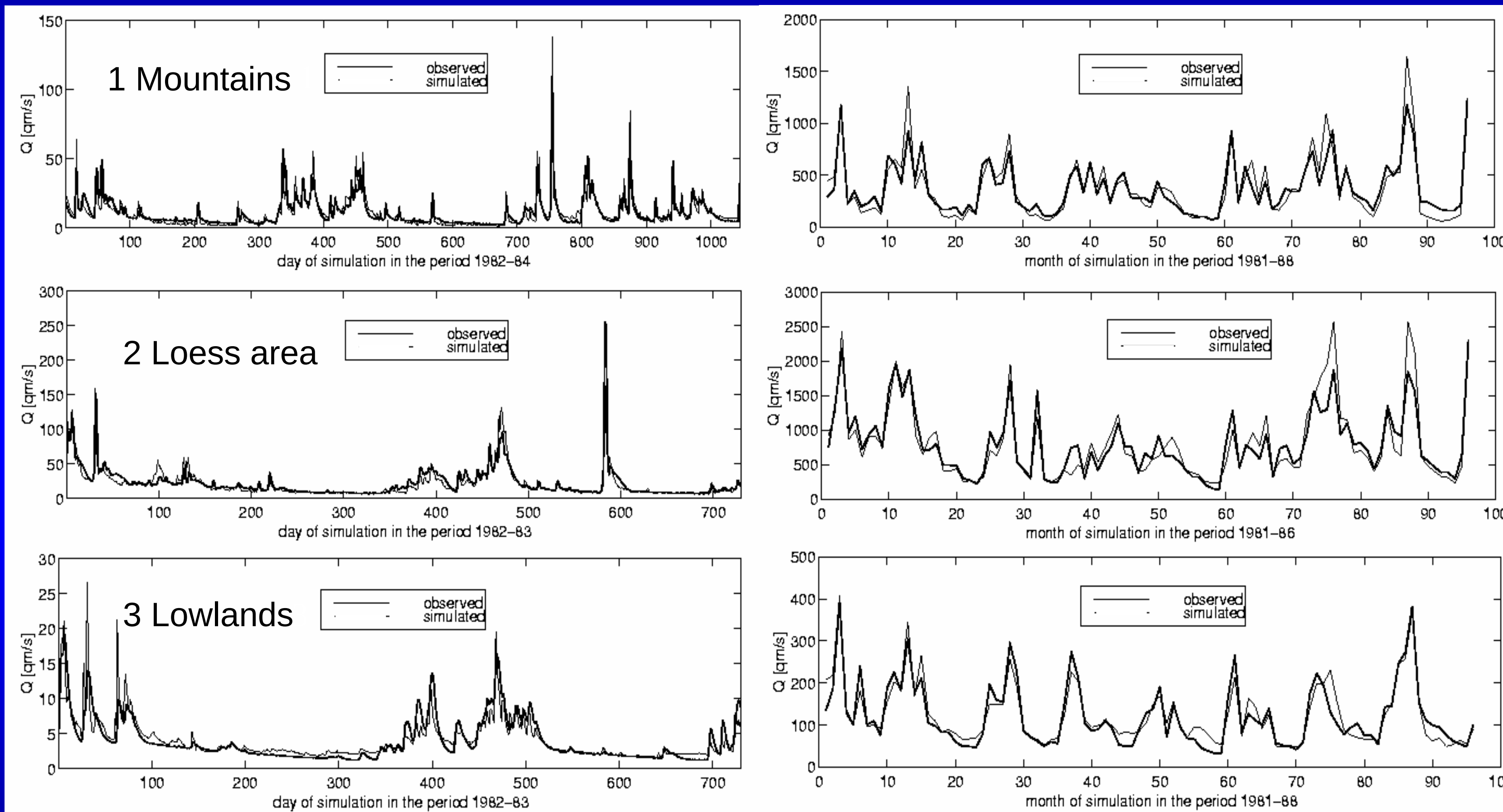
Hydrological validation results in different types of landscapes in the Elbe river basin



1: Selbnitz, area 1013 km², located in the southern mountains
Efficiency: 0.79

2: Upper Mulde, area 2091 km², located in the loess regions
Efficiency: 0.75

3: Stepenitz, area 1392 km², located in the northern pleistocene
Efficiency: 0.72

observed ———
simulated ▬▬▬

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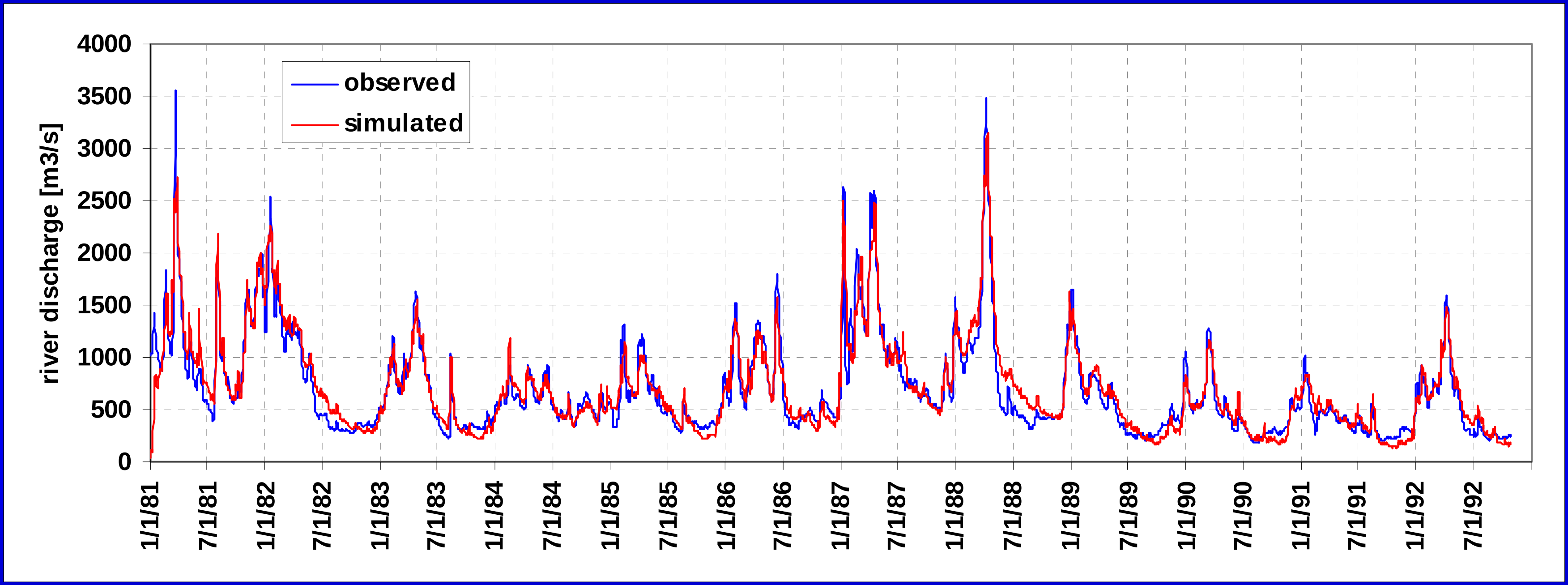
Hydrological validation for the entire basin



River discharge of the total Elbe basin (calibration period 1981-86, validation period 1987-92, efficiency 0.92).

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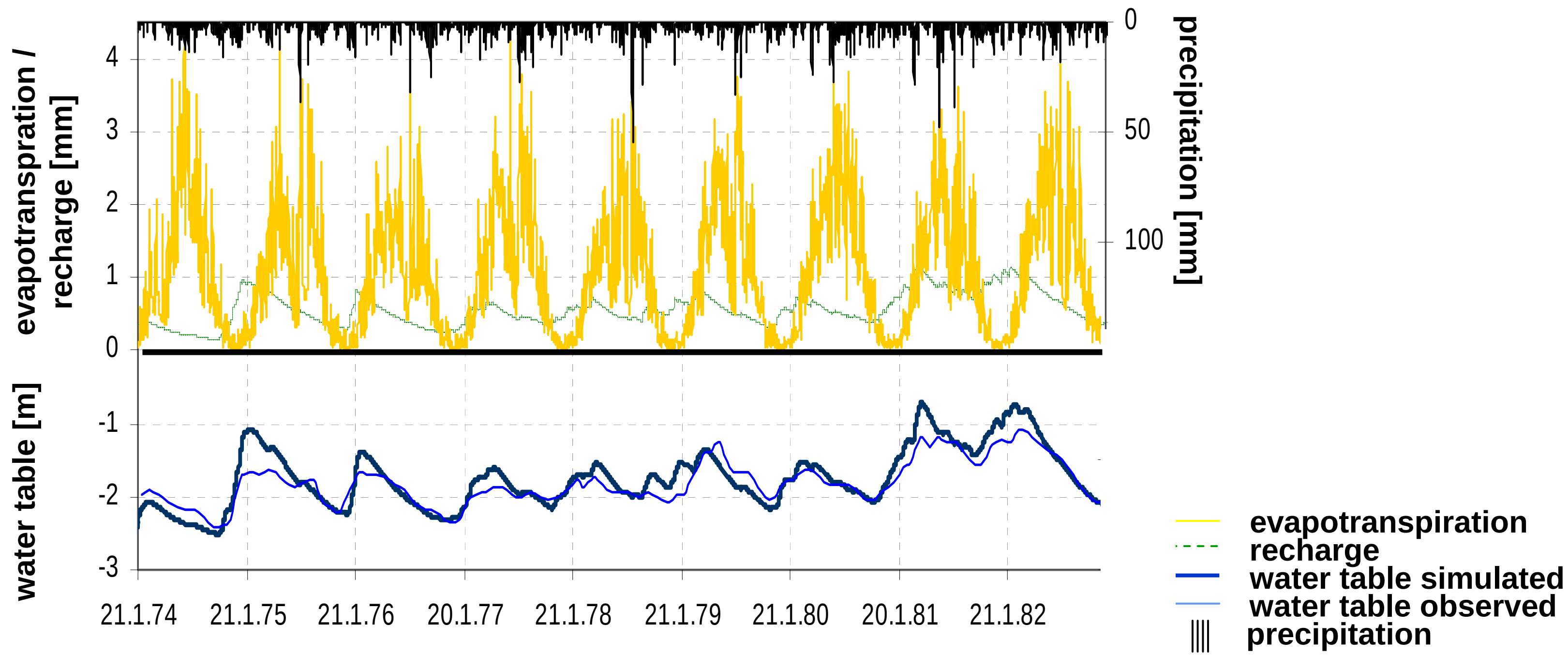
Multi-criteria validation at multi sites

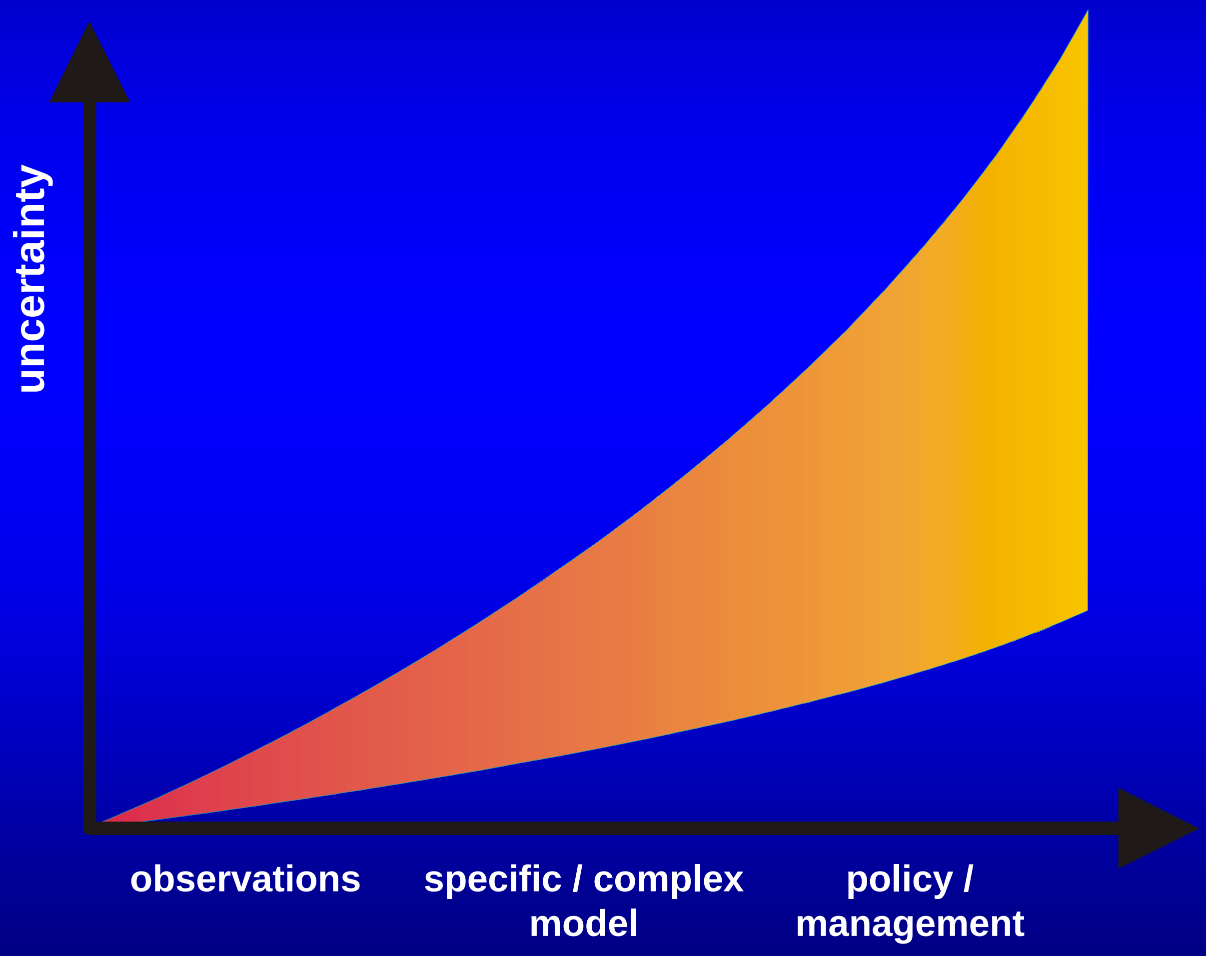


Comparison of simulated against observed groundwater table dynamics.

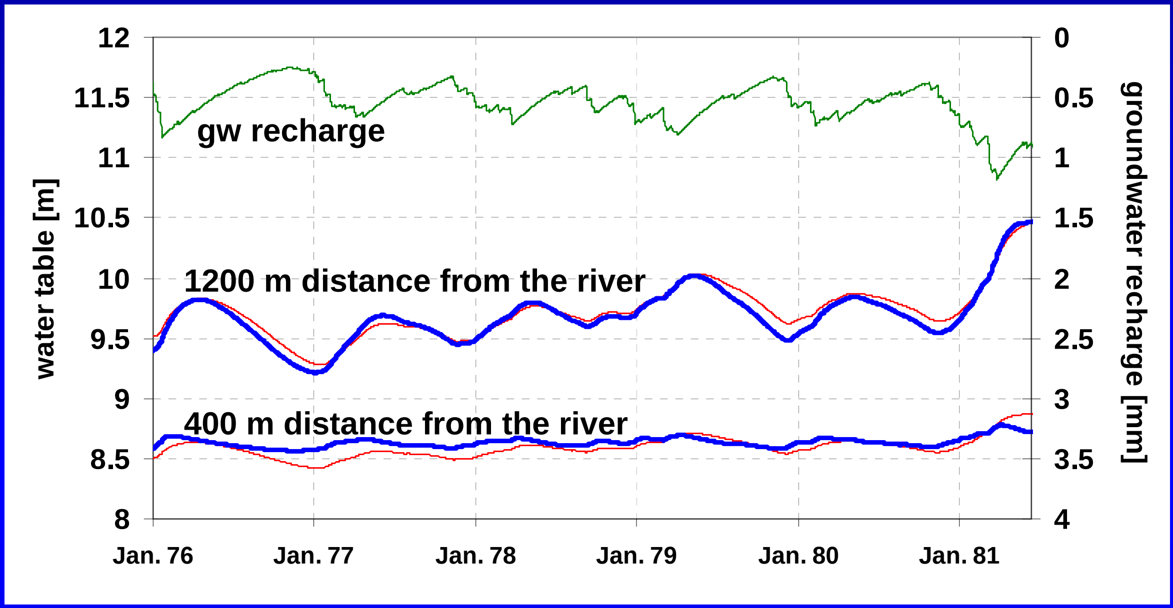
Sensitivity and Uncertainty Analyses: Sources of Uncertainty

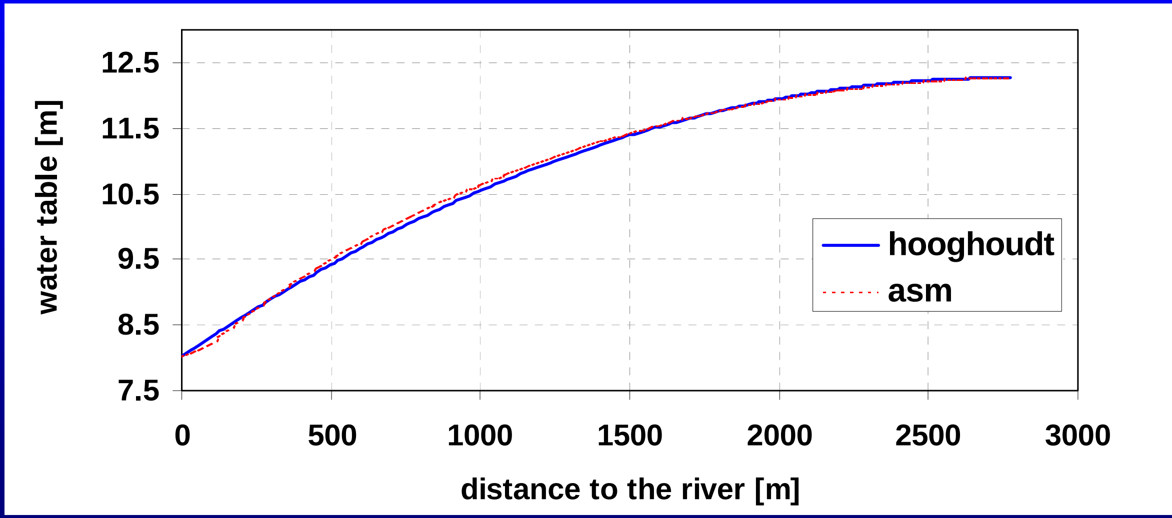
- **input data** (of soil maps, soil parametrization, land use, climate data, digital elevation, biomass energy ratio, and others),
- **model parameters** (leaf area index, storage capacities, reaction factors),
- **model structure** (lumped - semi-distributed, river routing)
- **socio-economic and policy developments and impacts** (projections into the future)

Sources of Uncertainty



Model Comparison Hooghoudt-Equation Boussinesq-Equation (Groundwater Modul)





Comparison of groundwater table dynamics calculated by the simplified linear groundwater model (based on the Hooghoudt-Equation) and a numerical solution of the non-linear Boussinesq-Equation under well defined boundary conditions.

Transient

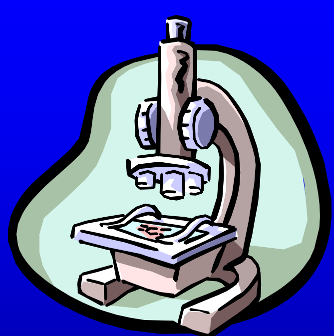
Steady state

Sensitivity and Uncertainty Analyses

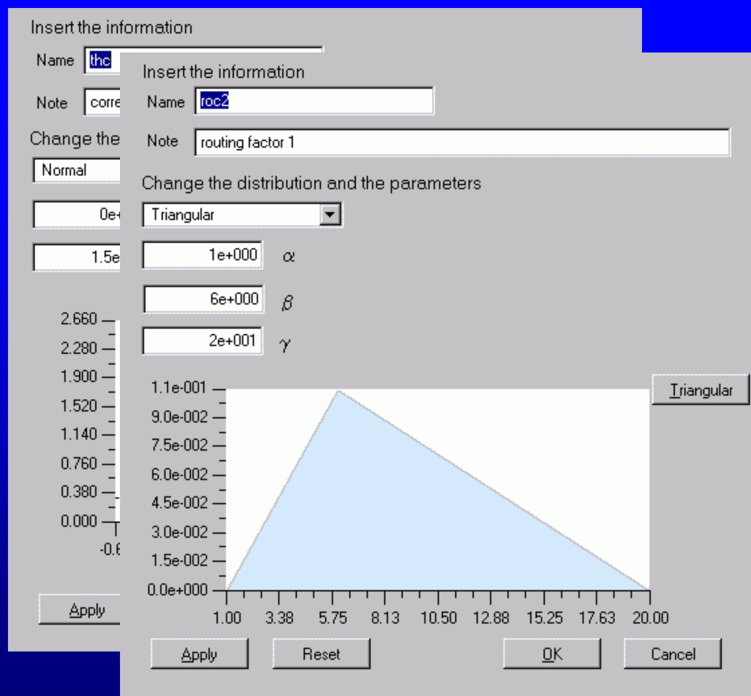
- A Monte Carlo Simulation was used to analyse the uncertainty or reliability of the model results and the sensitivity to changes in the input data and model parameters
- The analyses is based on 300 simulations with randomly sampled input parameters (deterministic model – stochastic model).
- The uncertainty in data and parameters is expressed by probability distribution functions (correlations can be taken into account)
- The Latin Hypercube method was used in order to be sure that parameter combinations from the whole parameter space are represented in the limited number of simulations.
- The sensitivity was calculated using the Partial Correlation Coefficient (PCC), a measure of linear relationship between parameter value and model result.

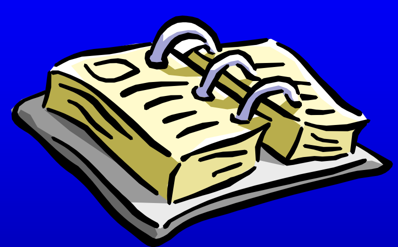
Defining the Parameter Distributions

expert knowledge



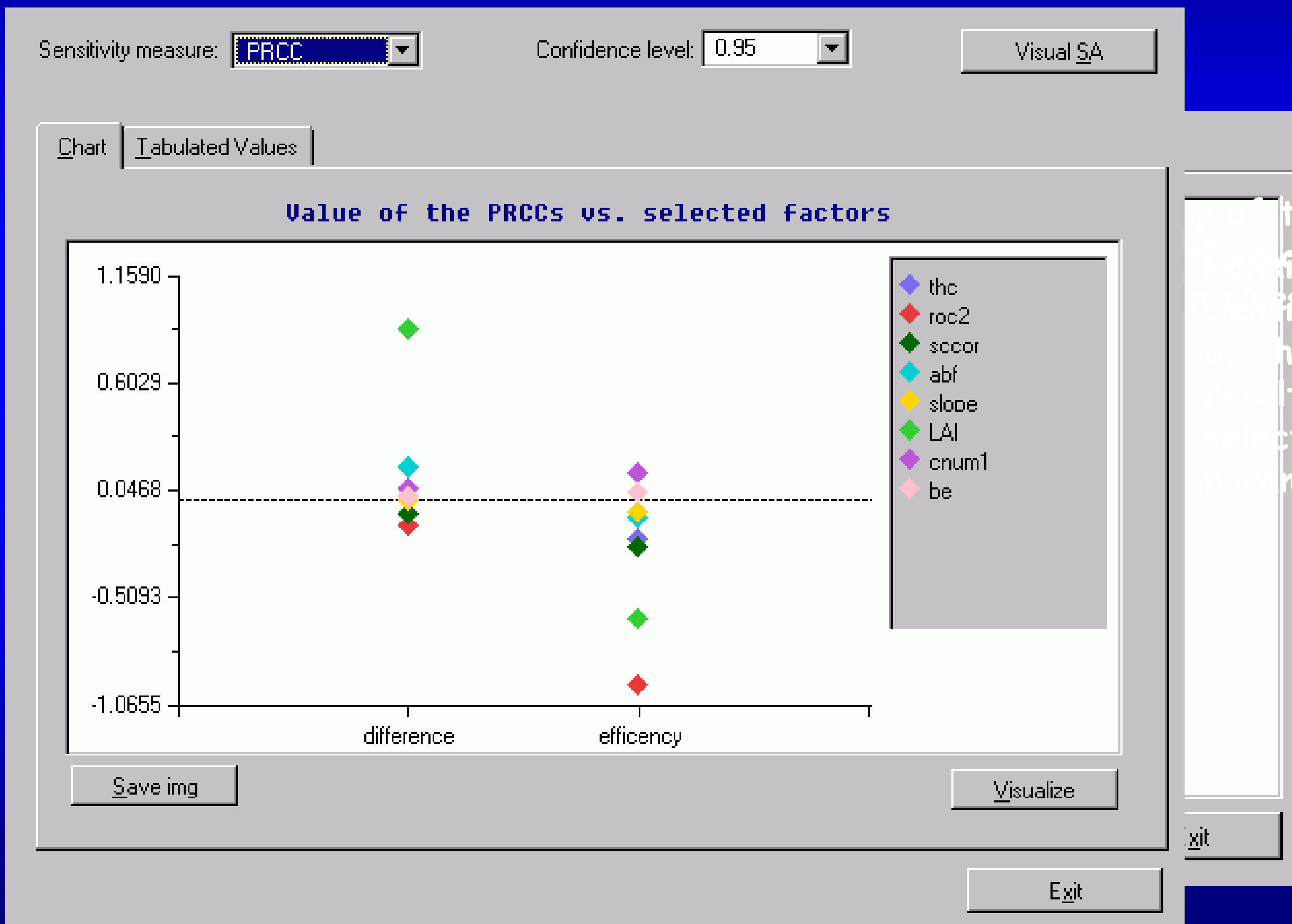
observations





data records

Examples: Sensitivity and Uncertainty Analyses



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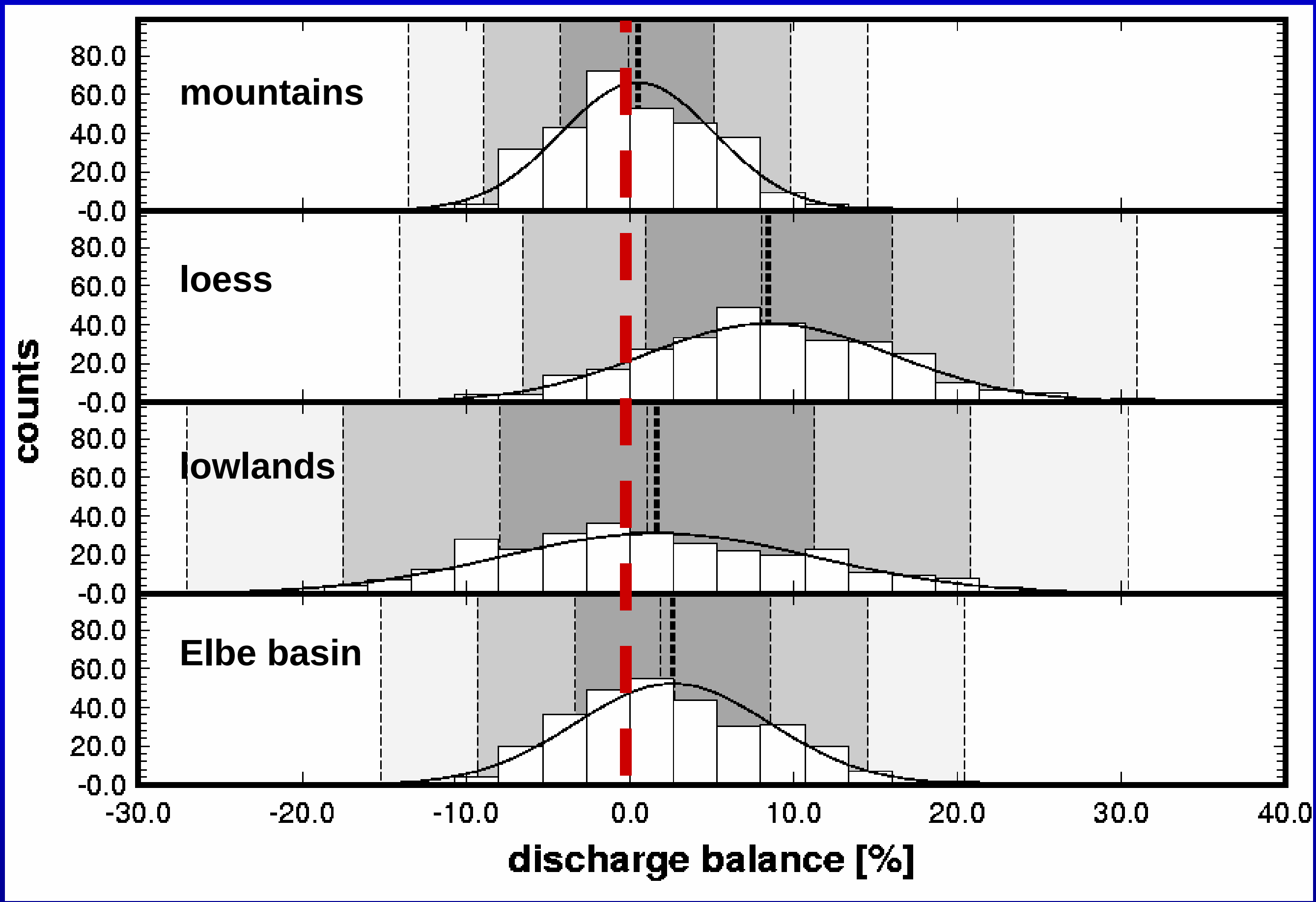
Results of the Uncertainty Analyses: Discharge Deviation



Left: ***Reliability*** **of the** ***water balance*** **(difference discharge observed – simulated).**

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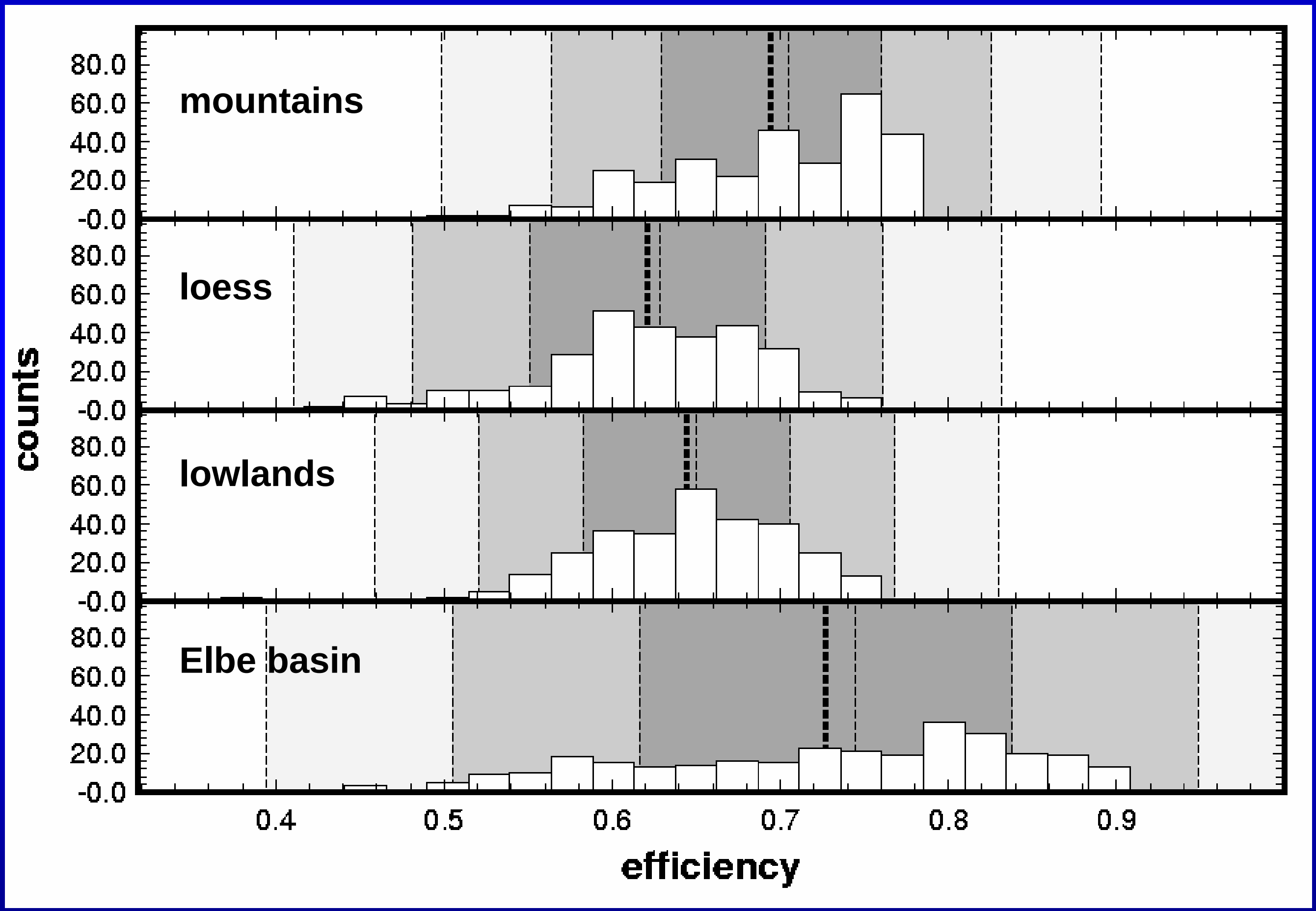
Results of the Uncertainty Analyses: Efficiency



Left: ***Reliability*** **of the** ***efficiency*** **(model performance).**

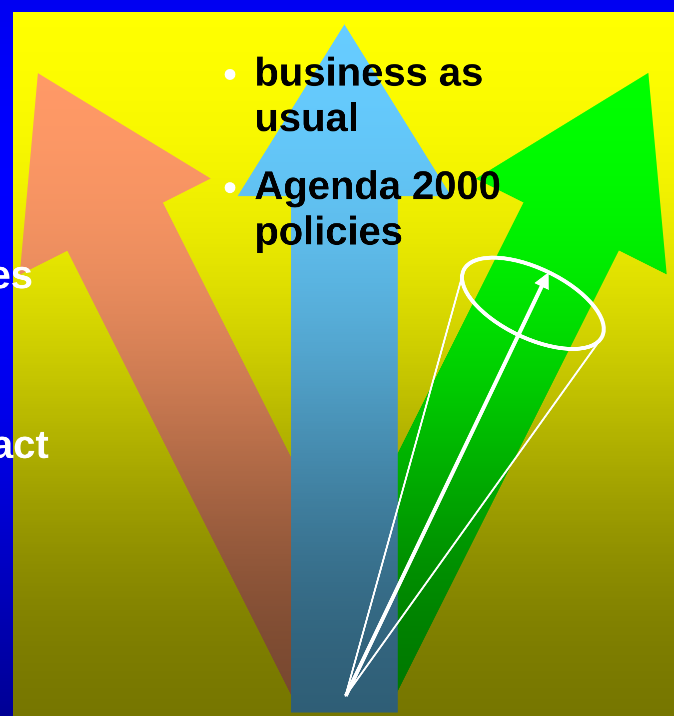
Climate Change – the Scenario Conditions

Year
2050
2025
2000

IPCC A1: Globalisation/ Liberalisation

- no trade barriers
- no support policies
- no preferences for regional food
- large climate impact

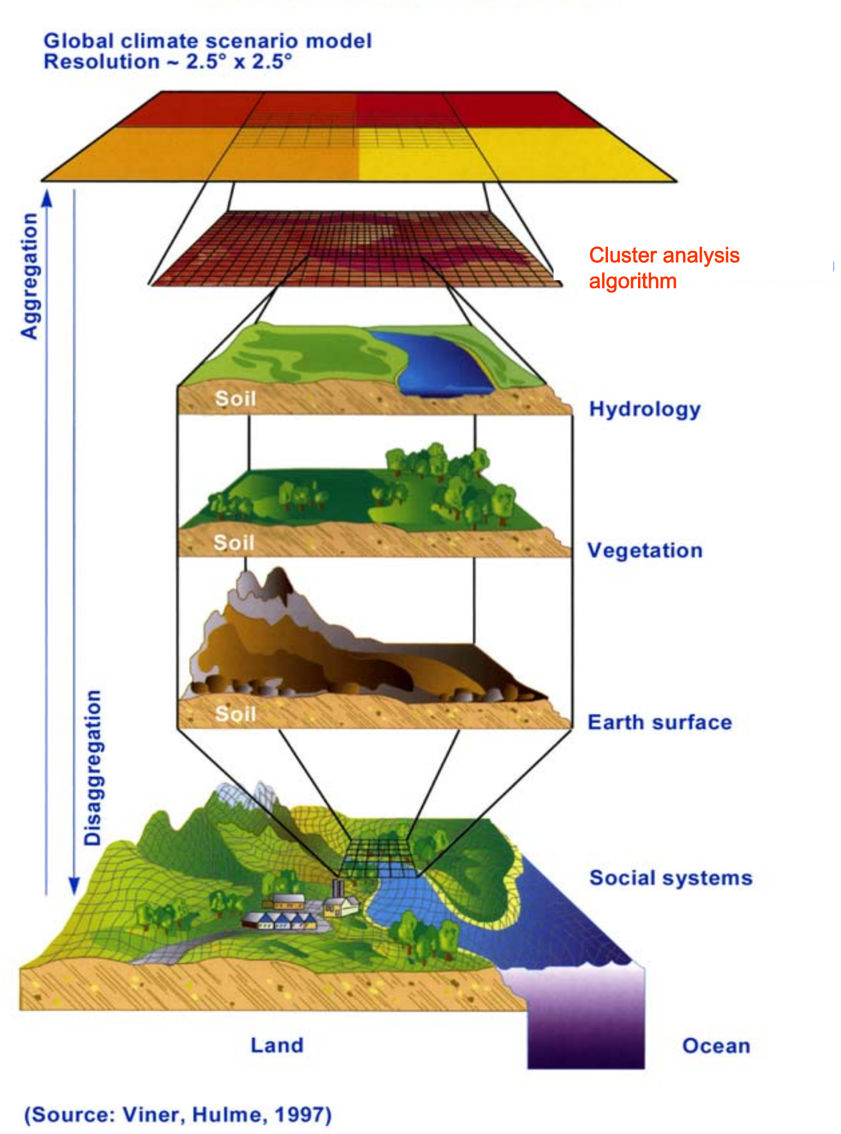
Reference-Scenario



IPCC B2: Regionalisation/ Ecological Development

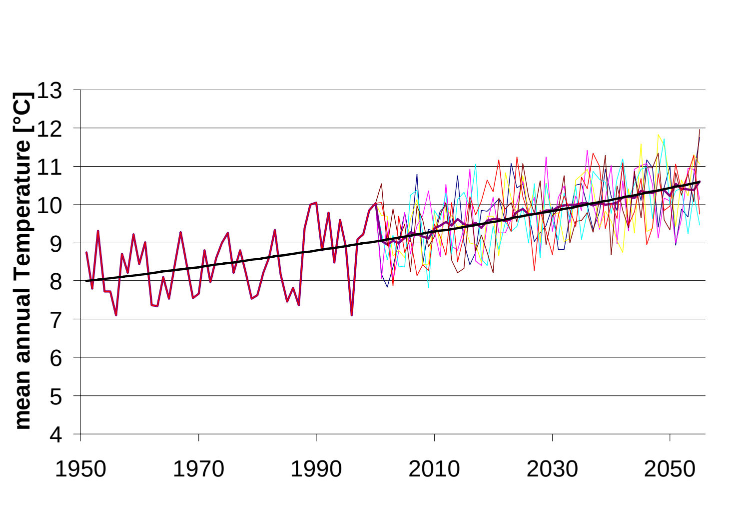
- limited trade
- support policies for regional and/or organic production
- strong preferences for regional food
- moderate climate impact

Climate Change – Preprocessing of GCM - Output

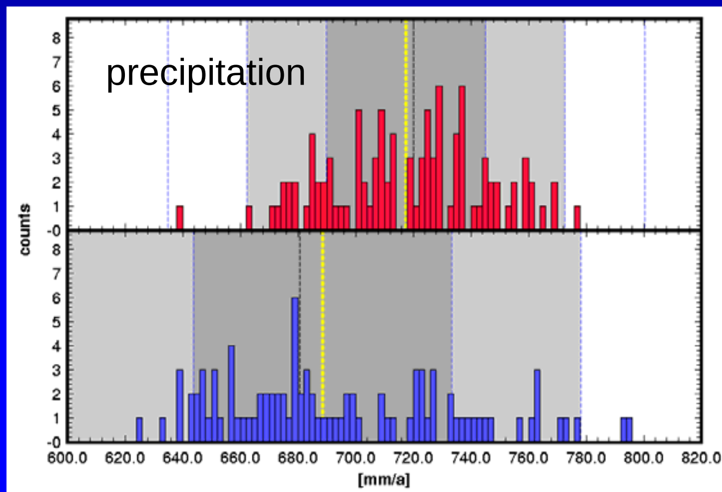


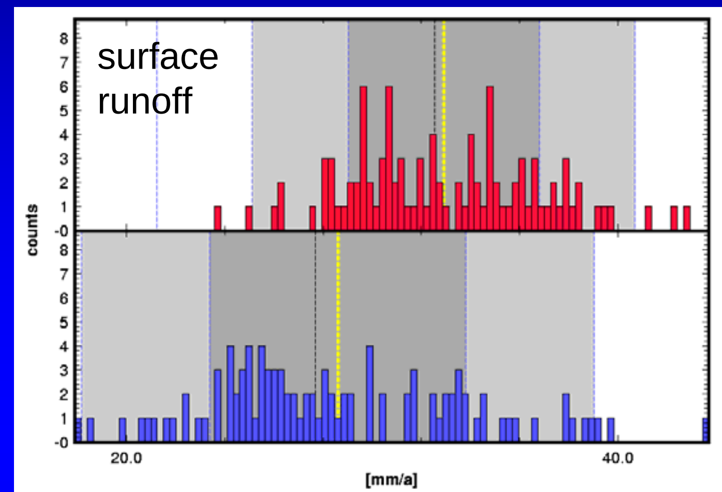
(Source: Viner, Hulme, 1997)

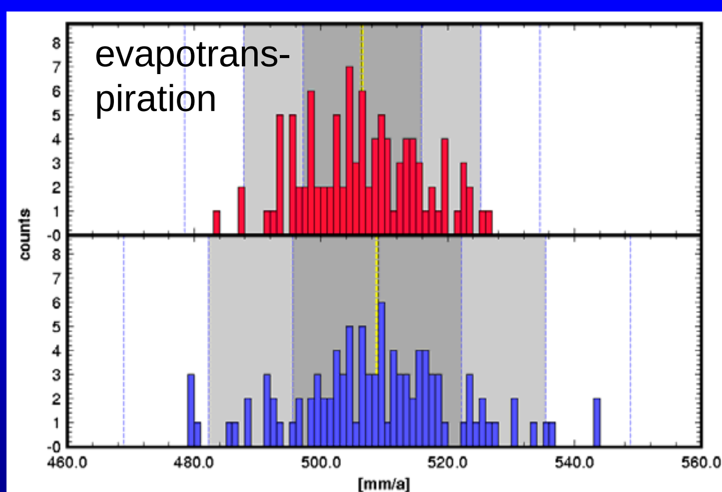
1. Disaggregation of the GCM (Global Climate Model) - output using a cluster analysis algorithm.
2. The stability of the main statistical characteristics (variability, frequency distribution, annual cycle, persistence) has to be maintained.
3. 100 realisations of the climate scenario with different temperature, precipitation etc. are generated.
4. Each scenario realisation is the input for one SWIM model run.

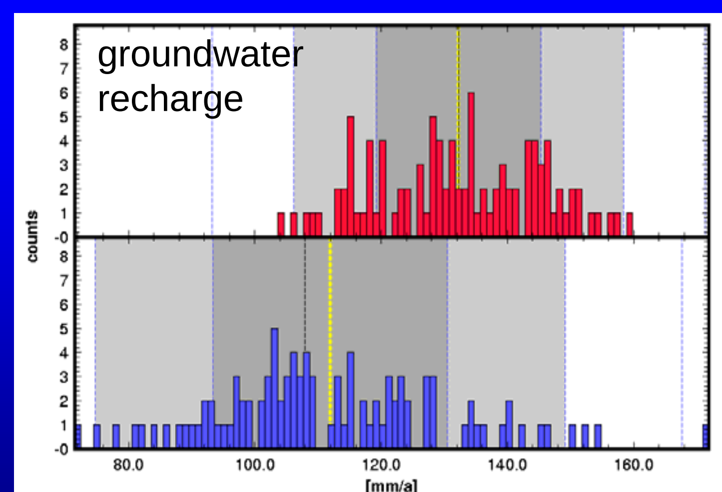


Changes in Water Fluxes under Scenario Conditions in the Elbe River Basin – Mean Annual Values









red: 2000-05 / blue: 2051-55

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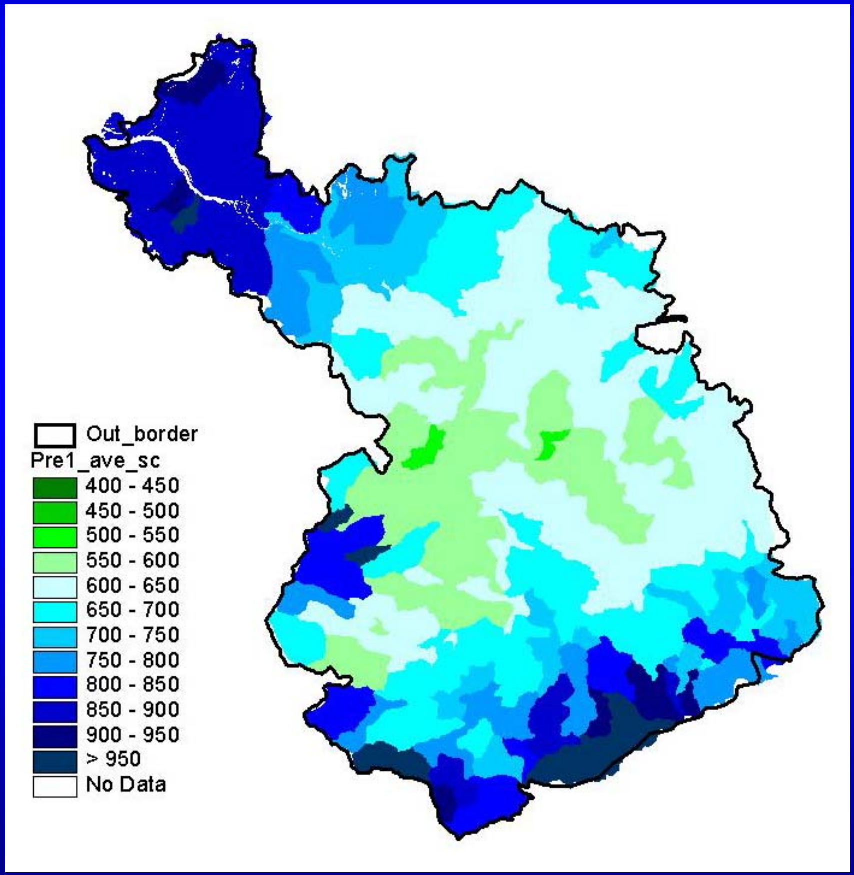
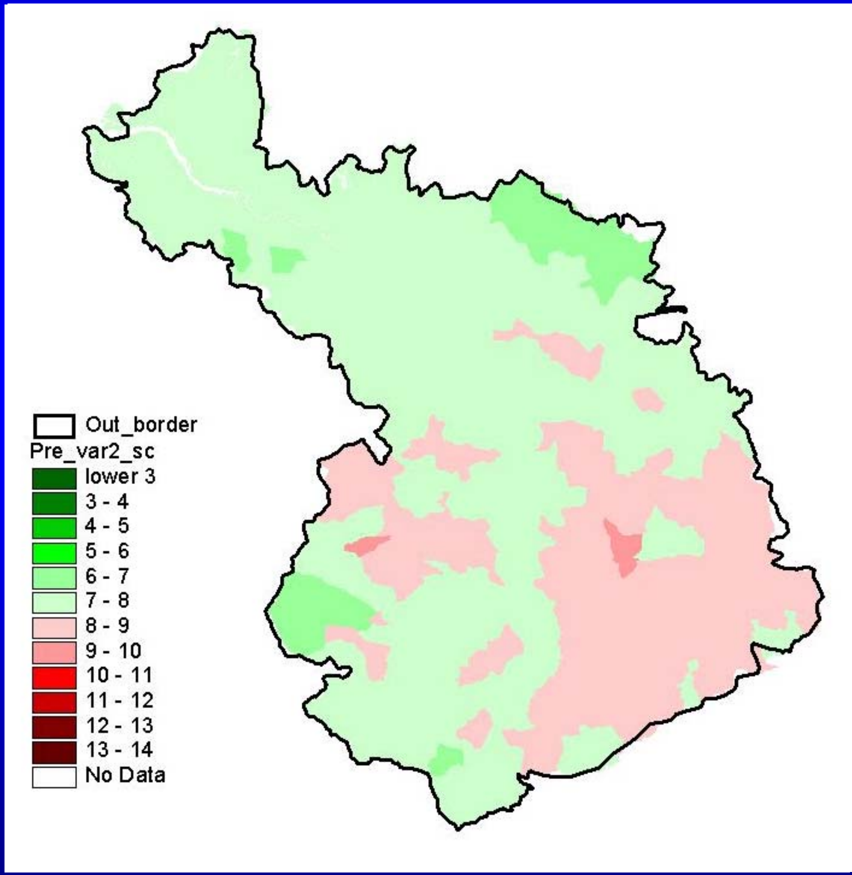
Change in Precipitation under Climate Scenario Conditions

Mean annual precipitation 2001 - 2005



Variance (% of mean precipitation in 2051 - 2055)



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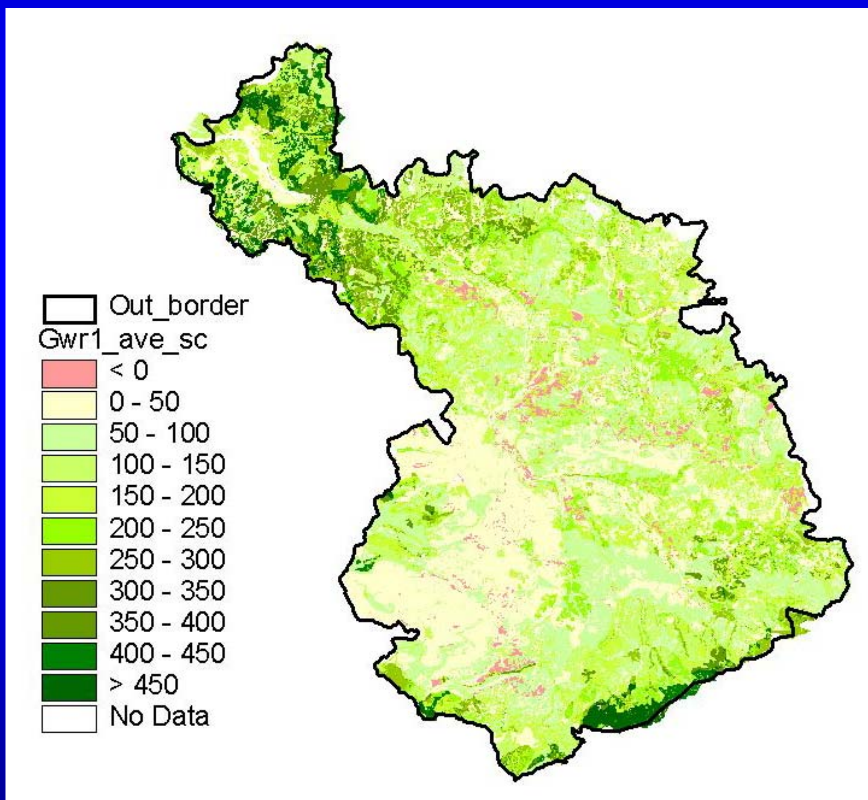
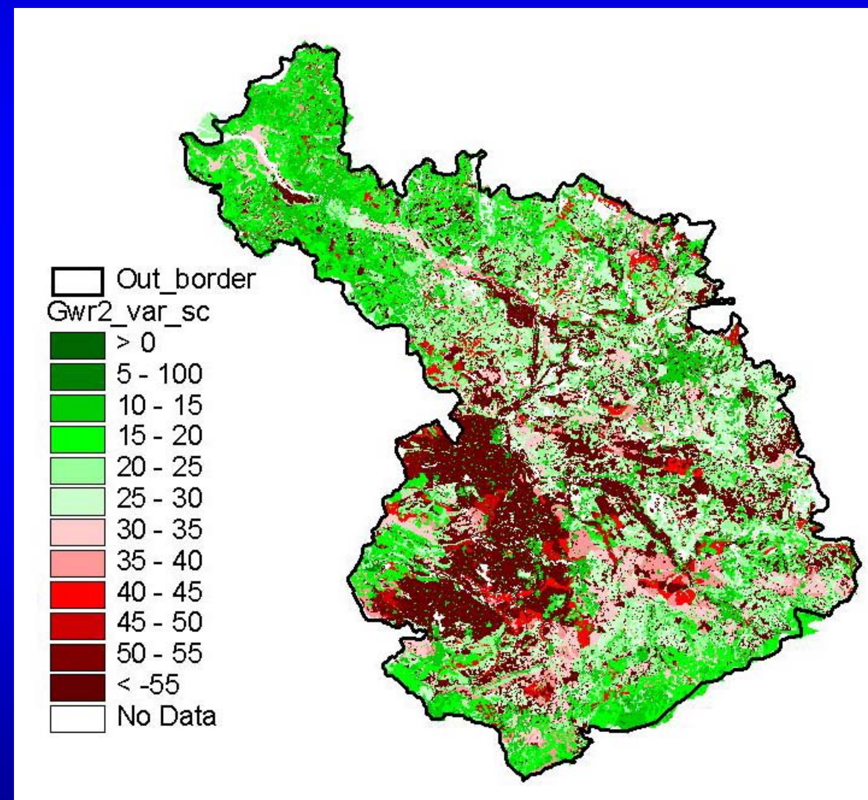
Change in Groundwater Recharge under Climate Scenario Conditions

Mean annual groundwater recharge 2001 - 2005



Mean annual groundwater recharge 2051 - 2055



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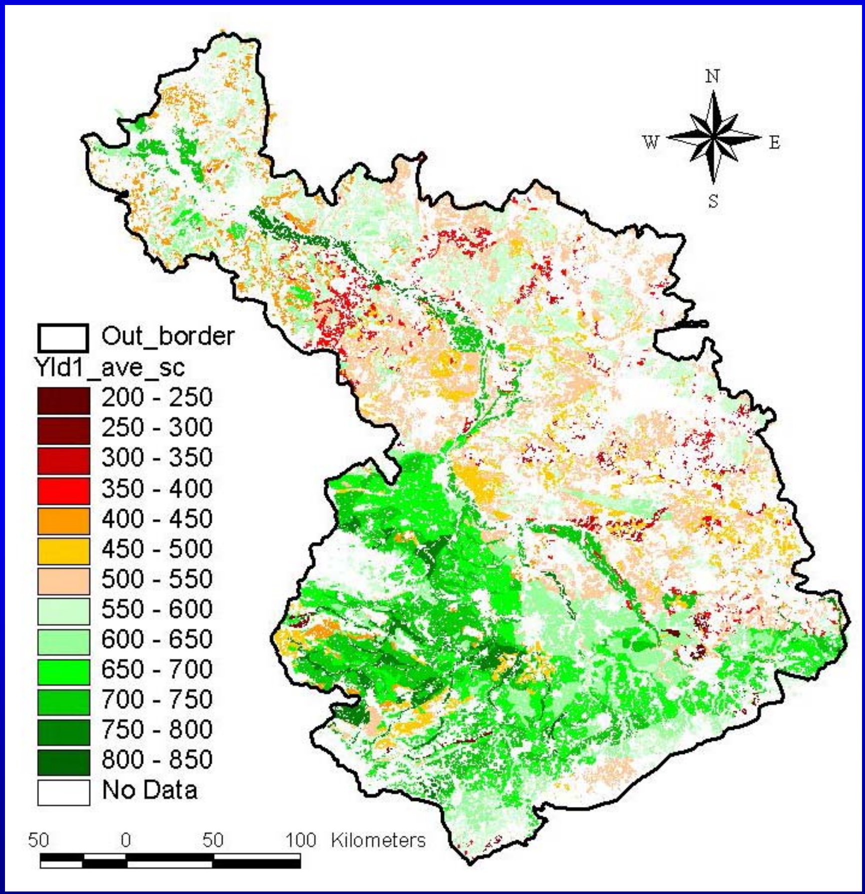
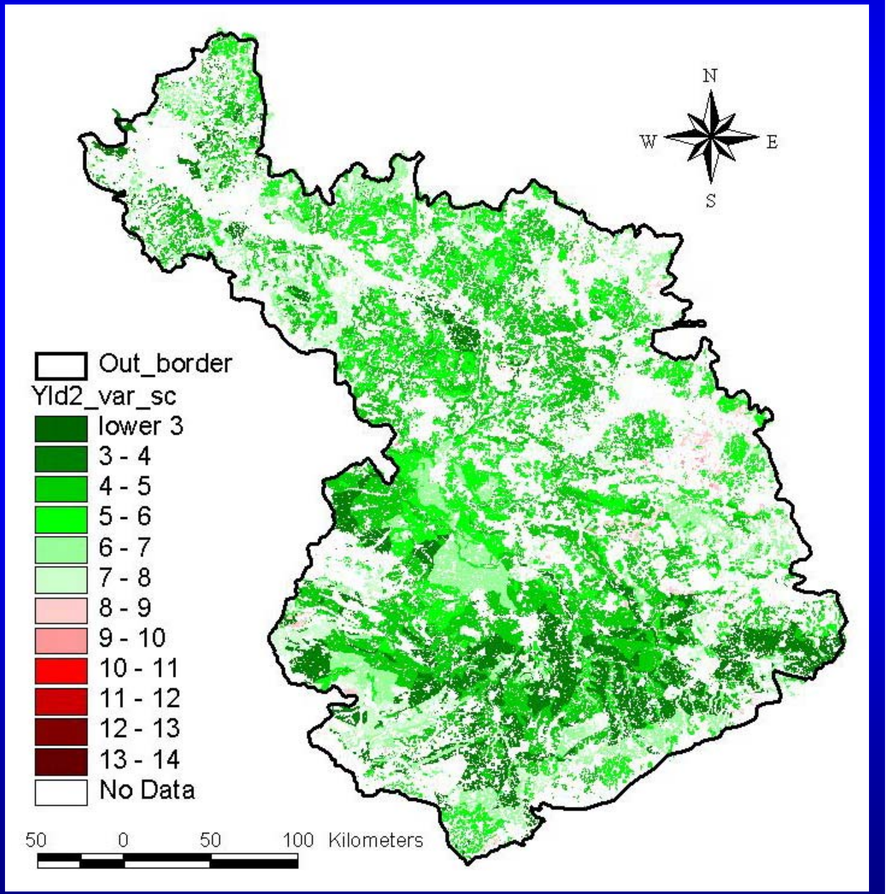
Change in Crop Yields under Climate Scenario Conditions

Mean annual crop yields 2001 - 2005



Variation (%) of mean annual yields (2051 - 2055)



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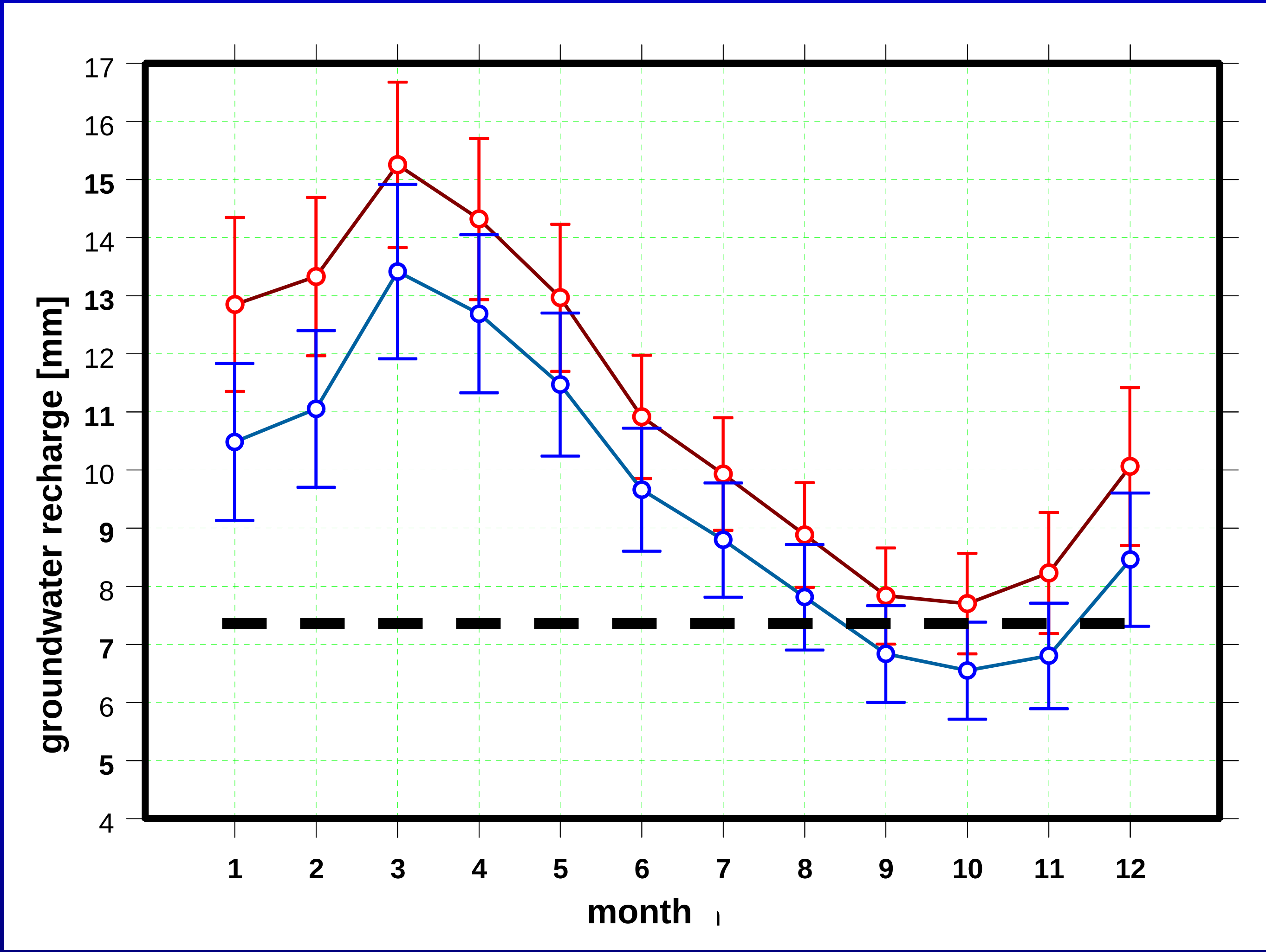
Example: Changes in Mean Monthly Groundwater Recharge



Restoration of the nature sanctuary „Nieplitz lowlands“

Summary and Conclusions

- By using the ecohydrological model SWIM in the German Elbe river basin it was shown that the model performance varies in different subregions of the basin such as mountains, loess regions and lowlands
- Hydrological responses, and accordingly the propagation of uncertainties are different in those subregions, due to the differences in essential hydrological characteristics
- The uncertainty of modelling results has been found higher in lowlands then in mountainous regions
- A multi-criteria validation and adjustment of model parameters can help to reduce uncertainty in the model results
- According to the global change scenarios the climate will become dryer in East Europe, but the uncertainty in the scenario results is high and thus even wetter conditions may occur in the future, although with a lower probability
- The uncertainty in the model results has to be considered in the scenario simulations, e.g. by Gaussian Error Propagation

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Validation results: river discharge

river	gauge station	topography	efficiency daily	efficiency monthly	rel. diff. In discharge
Saale	Blankenstein	mountains	0.81	0.86	4.2
Mulde	Wechselburg	mountains / loess	0.76	0.83	-6.1
Löcknitz	Gadow	lowlands	0.72	0.81	6.6
Elbe	Neu-Darchau	integrates all	0.92	0.94	9.7

Top: Results for the validation period (1987-92) of three subbasins (one located in the mountains, one in the loess area and one in the lowlands) and the total Elbe basin.

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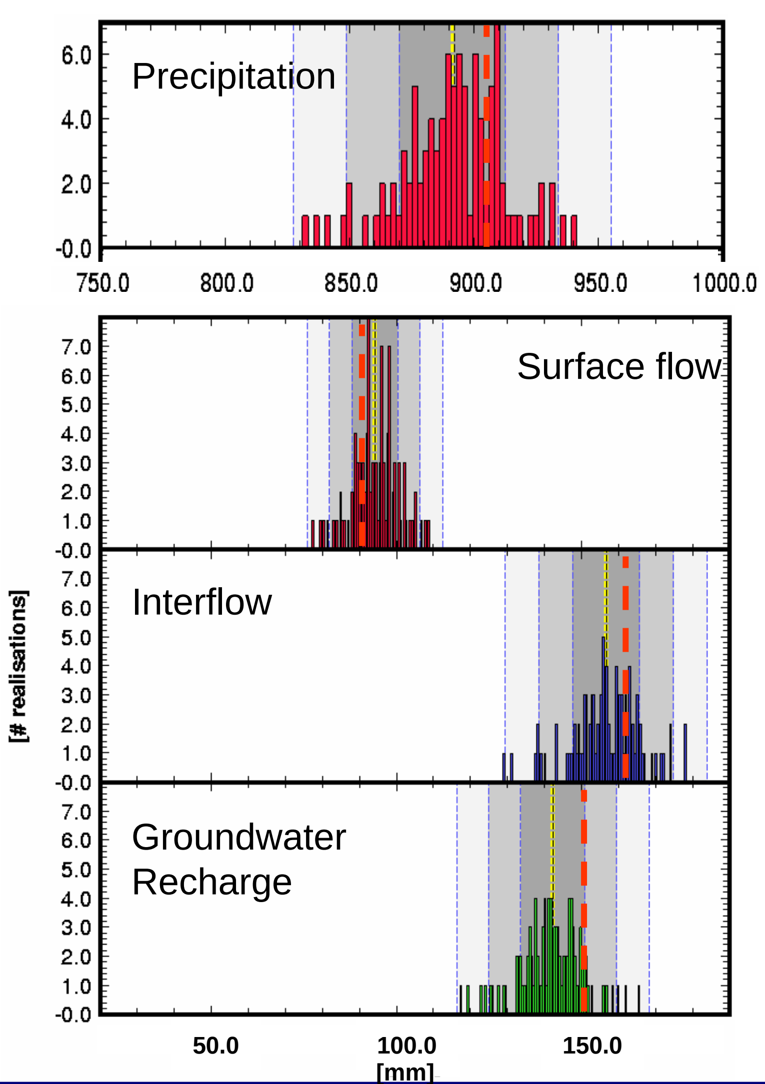
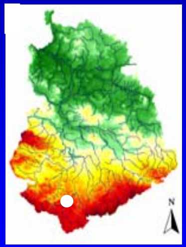
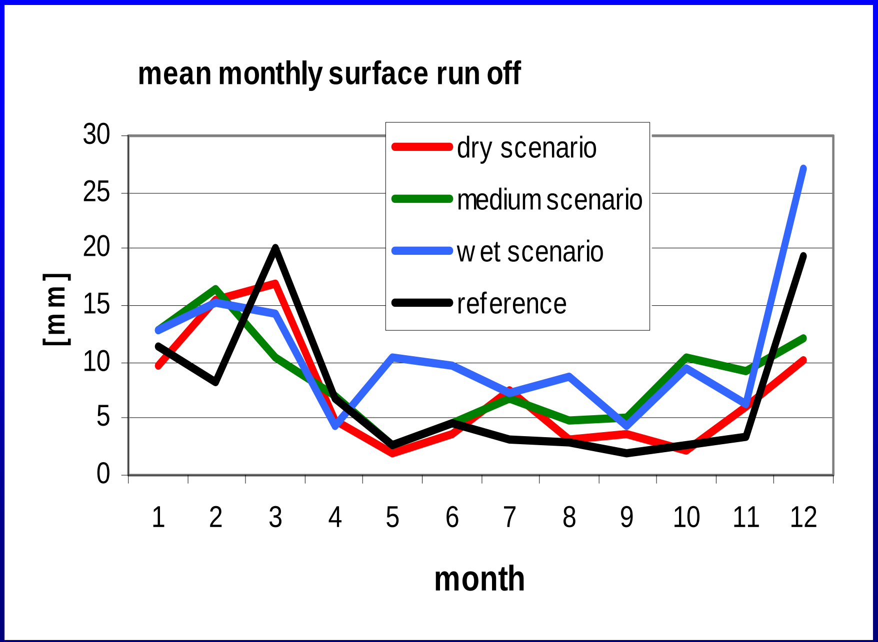
Climate impacts on precipitation and vertical flows (mountains)



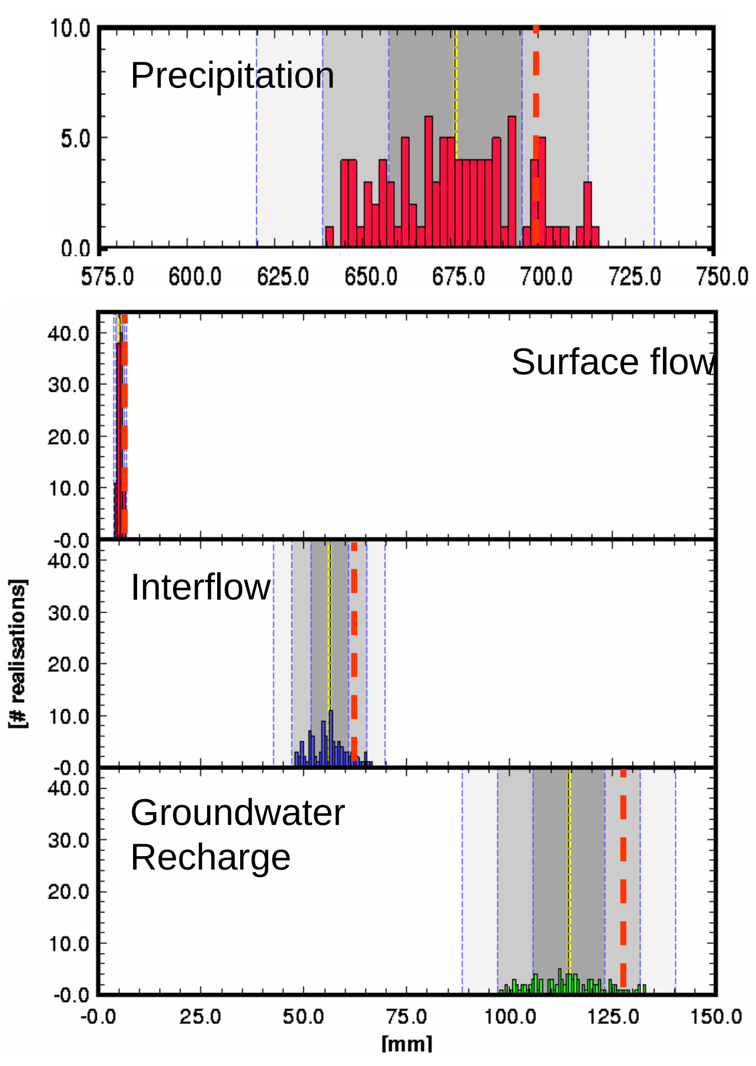
Value of the reference period

Mean value of the 100 ralisations





Climate impacts on precipitation and vertical flows (lowlands)



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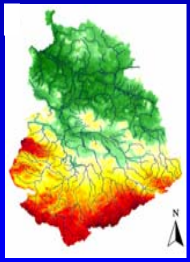
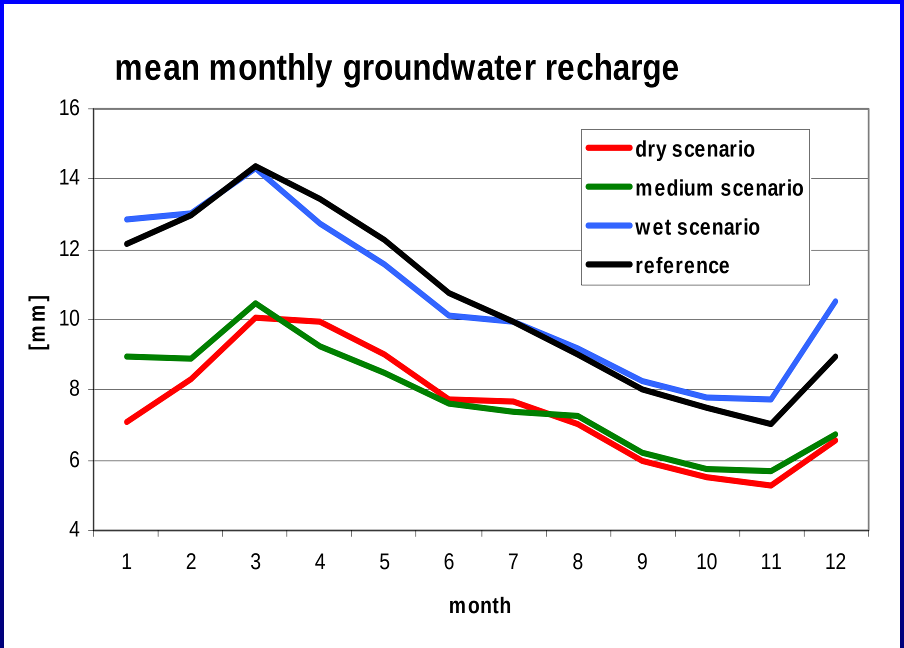
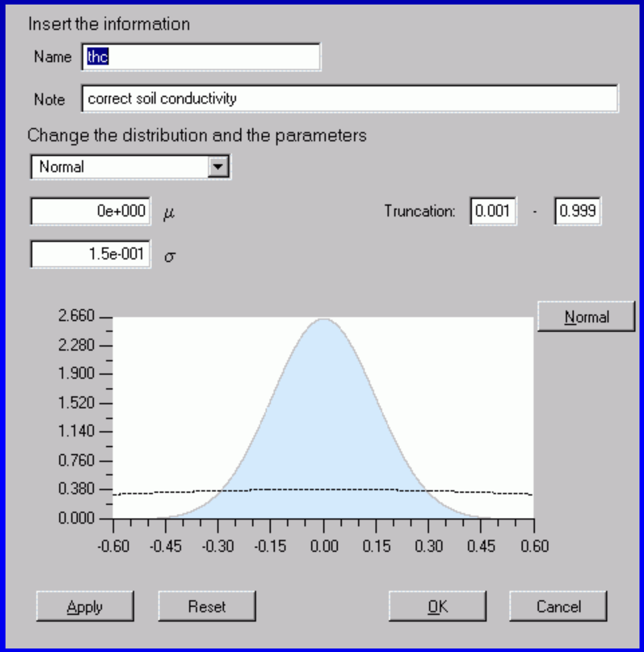
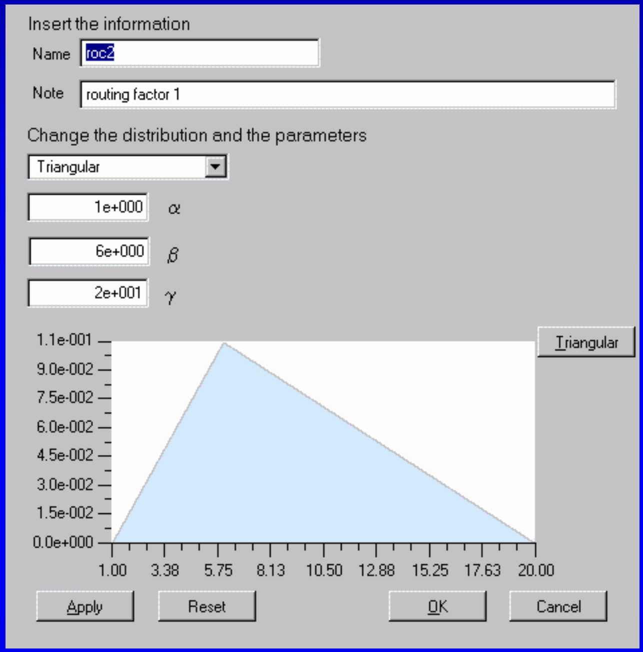
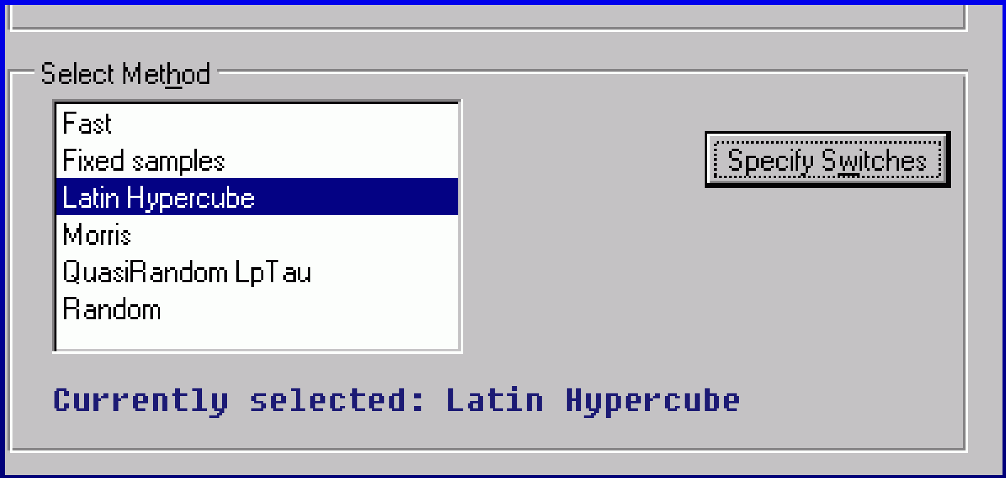




Pre-processing: Defining the Parameter Space







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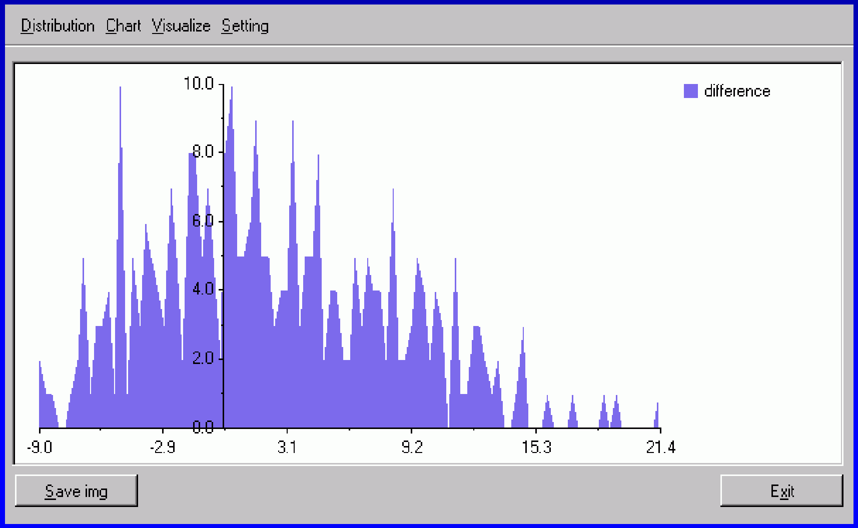
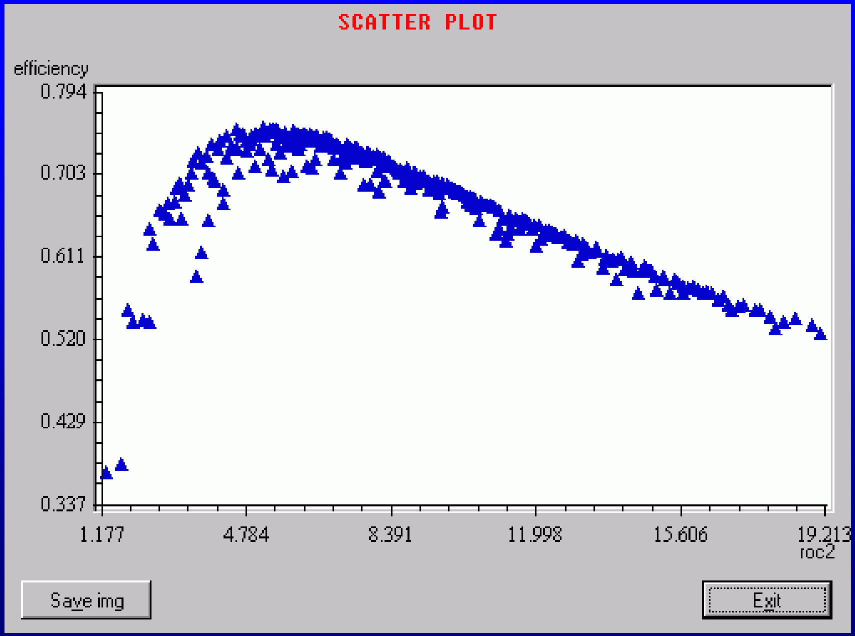


Uncertainty expressed by the distribution of model results.



Sensitivity to one single parameter

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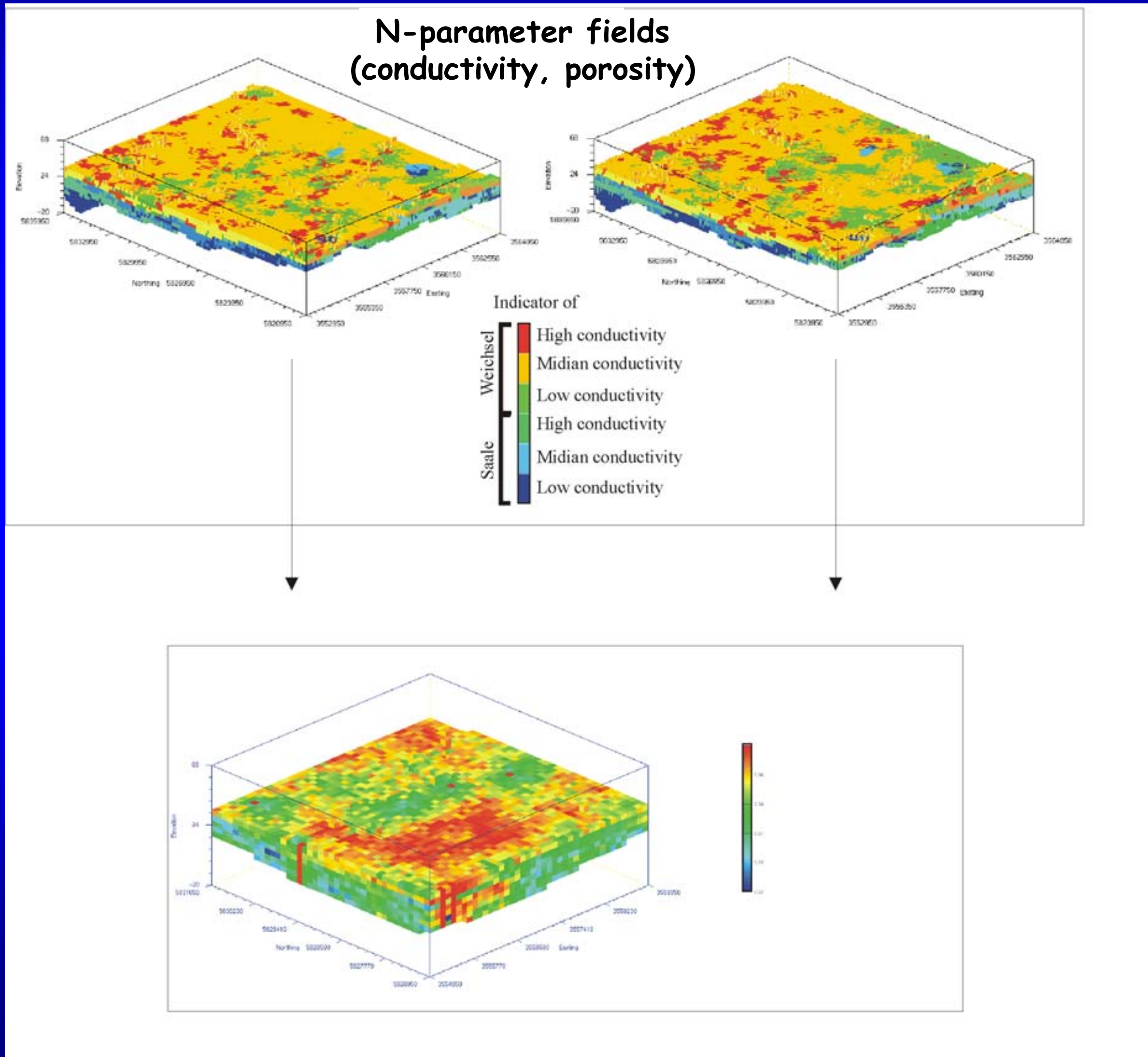
Uncertainty in Water Management

Uncertainty – small scale



Certainty of the geological reconstruction

Reconstruction of the sub-surface by geostatistical simulation techniques based on drill hole information

Certainty of the reconstruction

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Uncertainty – local to small scale