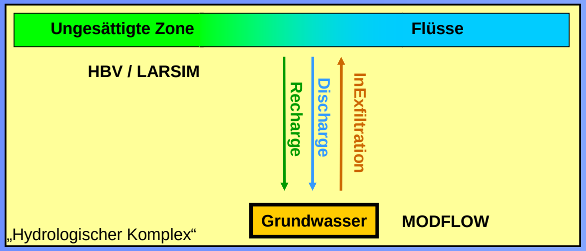

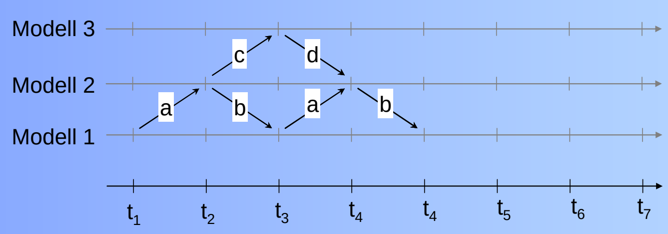

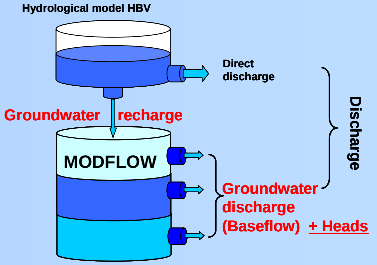

Modeling the interaction between groundwater, surface water and unsaturated zone on the regional scale

Lessons learned from two integrated projects

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- Motivation for integrated water resources modeling and model coupling on the regional scale
- The research projects
- Selected aspects and issues of groundwater-surface water interactions in large scale integrated systems
- Conclusions

1. European Water Framework Directive
2. Evaluation of regional effects of Global (Climate) Change on the water cycle
3. An obvious general need for more integral approaches on larger spatial and temporal scales

Modeling interactions between systems of the water cycle means:

- coupling of individual existing models (sectoral models) or
- use of integrated schemes (e.g. MikeSHE)

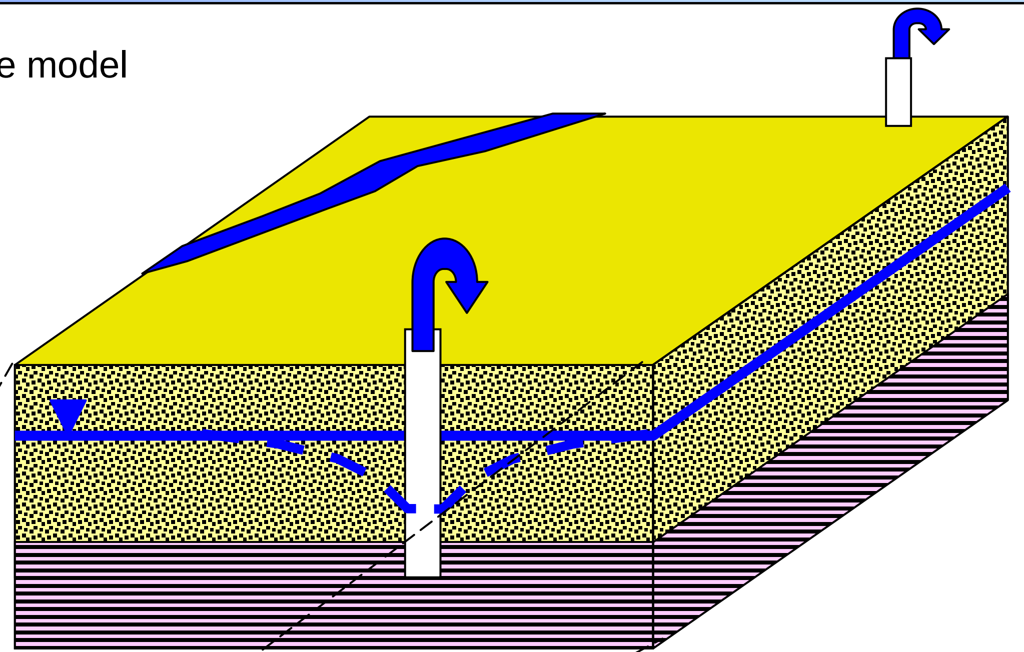
But: even integrated schemes are based on coupling sectoral concepts. Concepts that solve groundwater-surface water-unsaturated zone problems in an integral way do not exist yet.

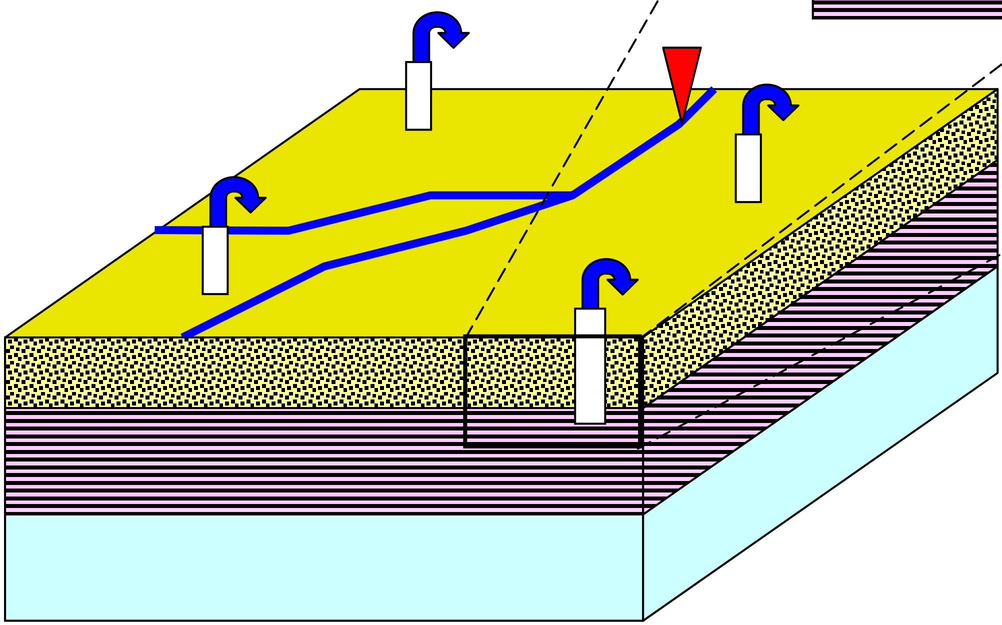
Why is modeling interactions (model coupling) important on larger scales?

local model: e.g. pumping test analysis (inverse model to estimate T,S):

simulation period: hours to days
recharge: constant or negligible
river: constant head or negligible
other withdrawals: negligible

conclusions: simple, steady state boundary conditions;
→ „neighboring systems“ not relevant





regional model: e.g. scenario simulations for resources management (many wells)

Simulation period: years to decades
recharge: variable (time/space), extremely relevant
river: strong interdependency – measurable quantity!
withdrawal: demand predictions/calculations!

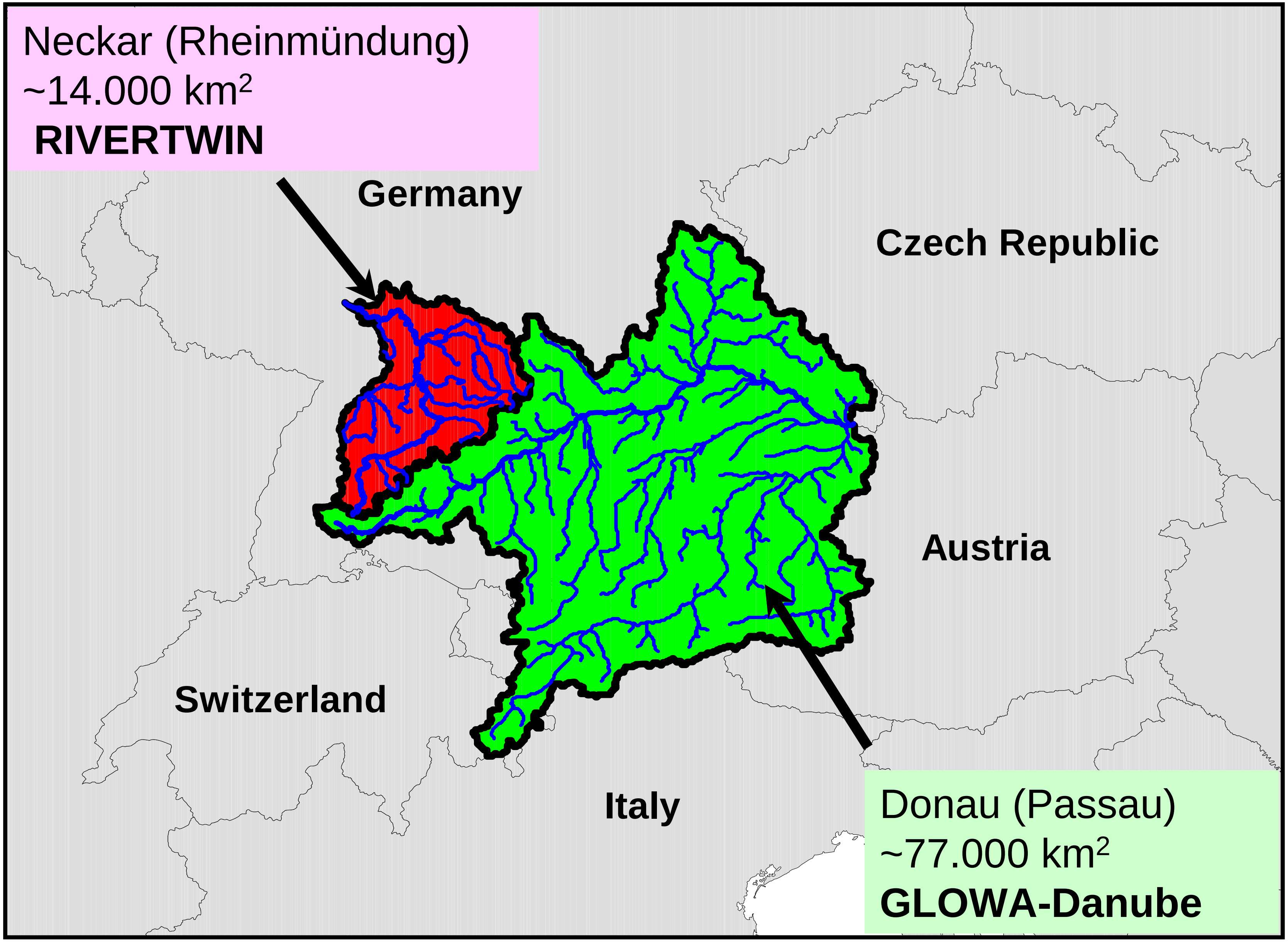
conclusions: complex, dynamic boundary conditions;
→ interactions with „neighboring systems“ relevant

Intermediate Conclusions

- Modeling water related processes on the
- regional scale with a
- long term perspective (scenarios) requires an
- integrated approach, i.e. coupled modelling of the interactions between groundwater, surface waters, unsaturated zone, atmosphere, biosphere and more.

- **GLOWA-Danube**: Integrative Techniques, Scenarios and Strategies for the Future of Water in the Upper Danube Basin (German Ministry of Research and Education, BMBF, www.glowa.org)
  - 2001-2007 (2010)

- **RIVERTWIN** - a Regional Model for Integrated Water Management in Twinned River Basins (European Commission, www.rivertwin.org)
  - 2004-2007

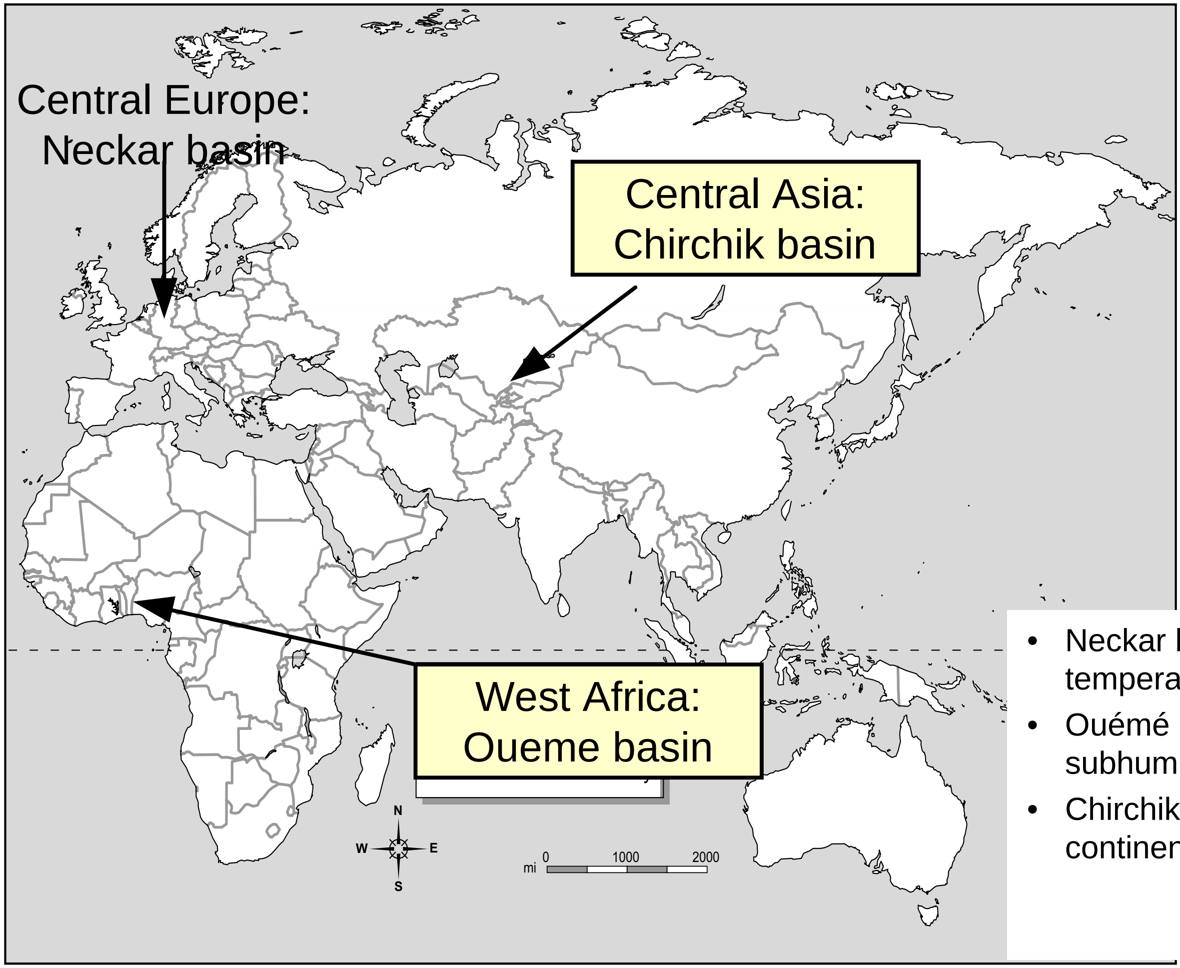

Neckar (Rheinmündung)
~14.000 km^2
RIVERTWIN
Germany
Czech Republic
Austria
Switzerland
Italy
Donau (Passau)
~77.000 km^2
GLOWA-Danube

GLOWA-Danube (www.glowa-danube.de): Summary

- **Consequences of Global Change in the Upper Danube Catchment** (Water Supply, Land Use, Agriculture, Economy, Tourism ..)
- **Decision Support System '****DANUBIA****'**, comprised of 16 <u>**fully**</u> coupled individual models
- **Integrated / Interdisciplinary Approach:** 12 research groups from different disciplines (Meteorology … Tourism Research)

- **Subproject Groundwater and Watersupply at Stuttgart:**
  - Groundwater flow model plus a module for Nitrogen Transport
  - Watersupply and –distribution model

- **EU Global Water Initiative (www.euwi.org) → Applying the principles of the European WFD** to other continents



- Integrated model,
- GIS based, 10 individual models, **loose** coupling
- Approach:
  1) Integrated Model Neckar
  2) Transfer to other basins

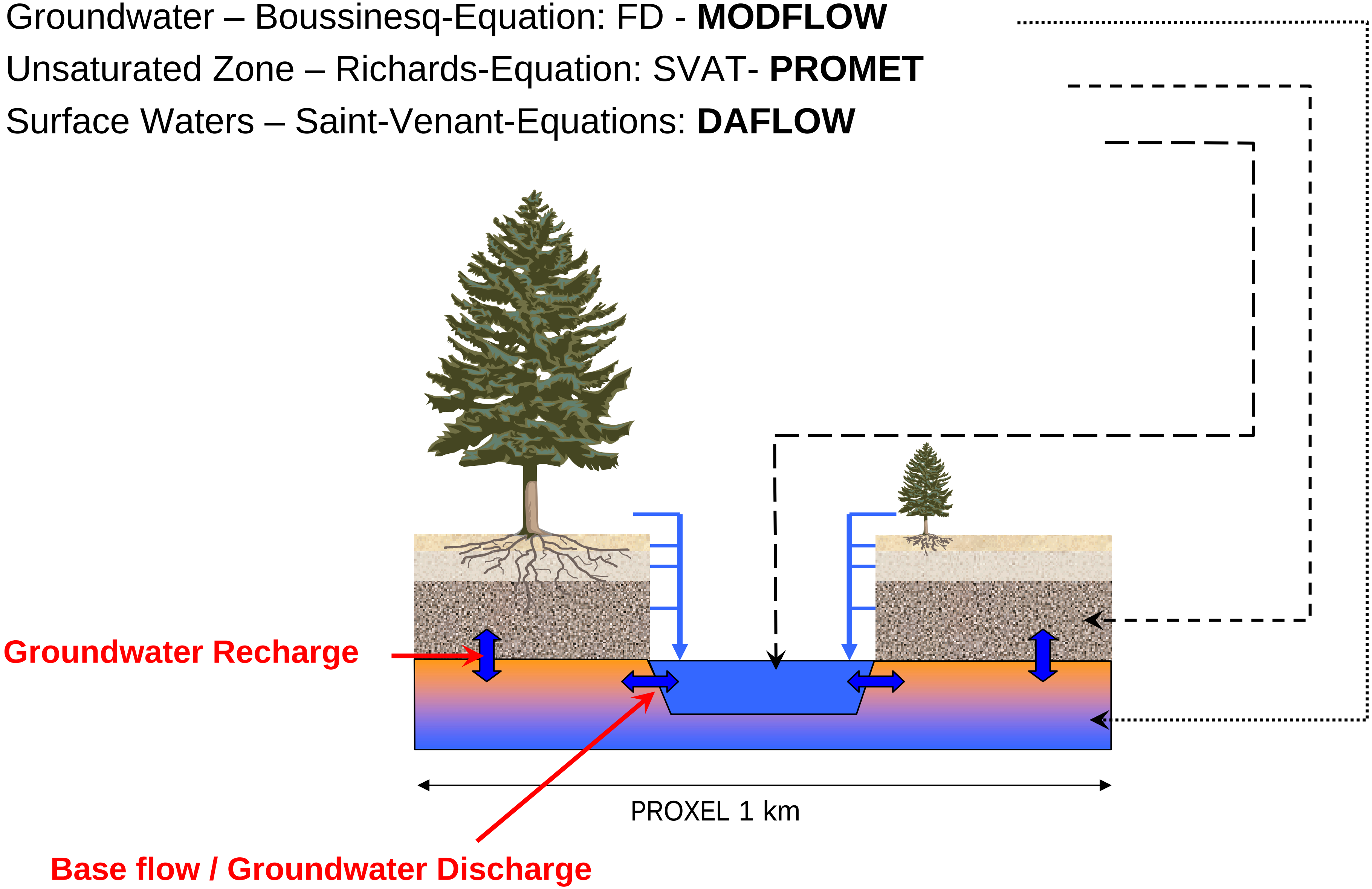
- Neckar basin (Germany, temperate-humid);
- Ouémé basin (Benin, tropical-subhumid);
- Chirchik basin (Uzbekistan, continental-semiarid).

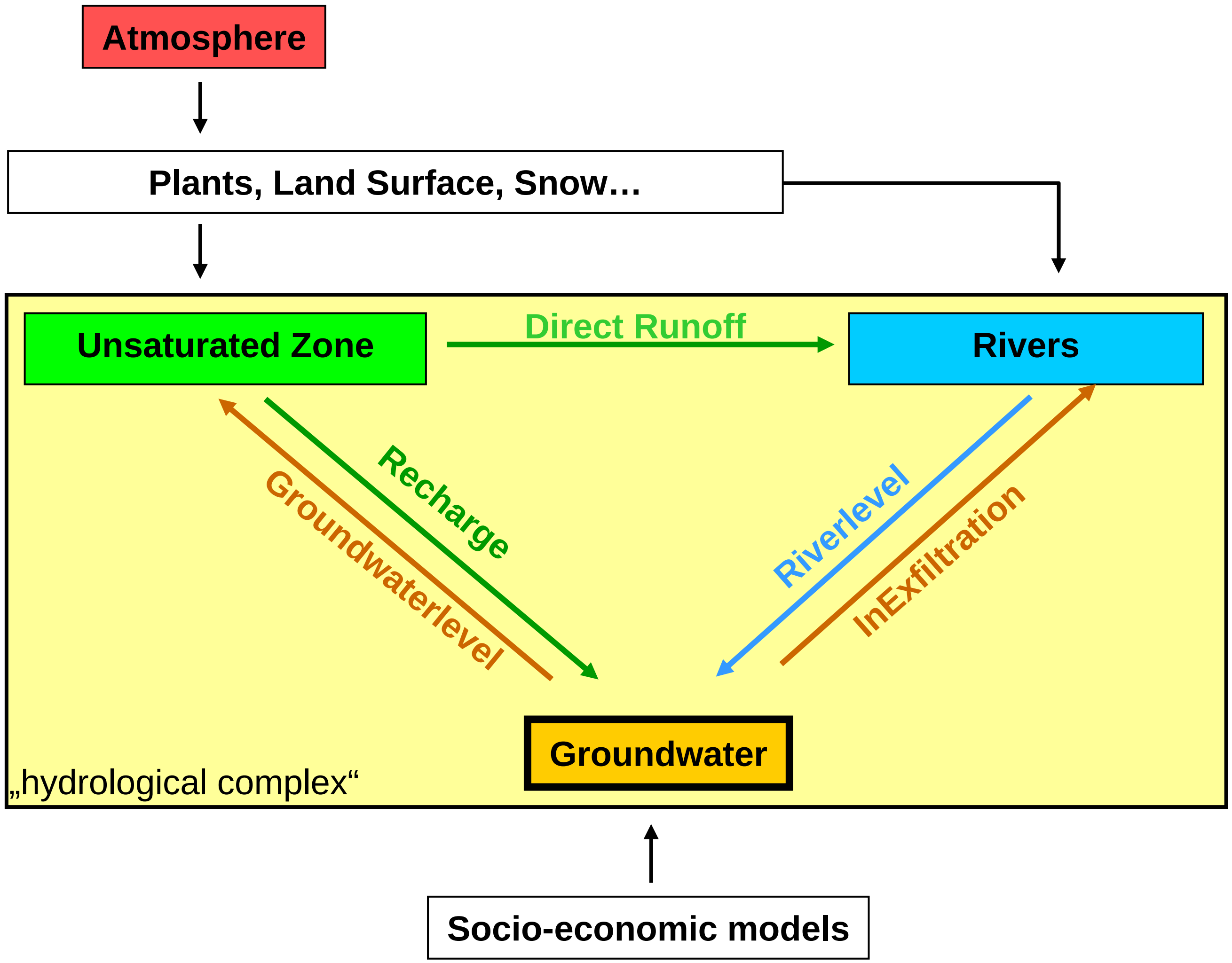
„Physically based“ Models:

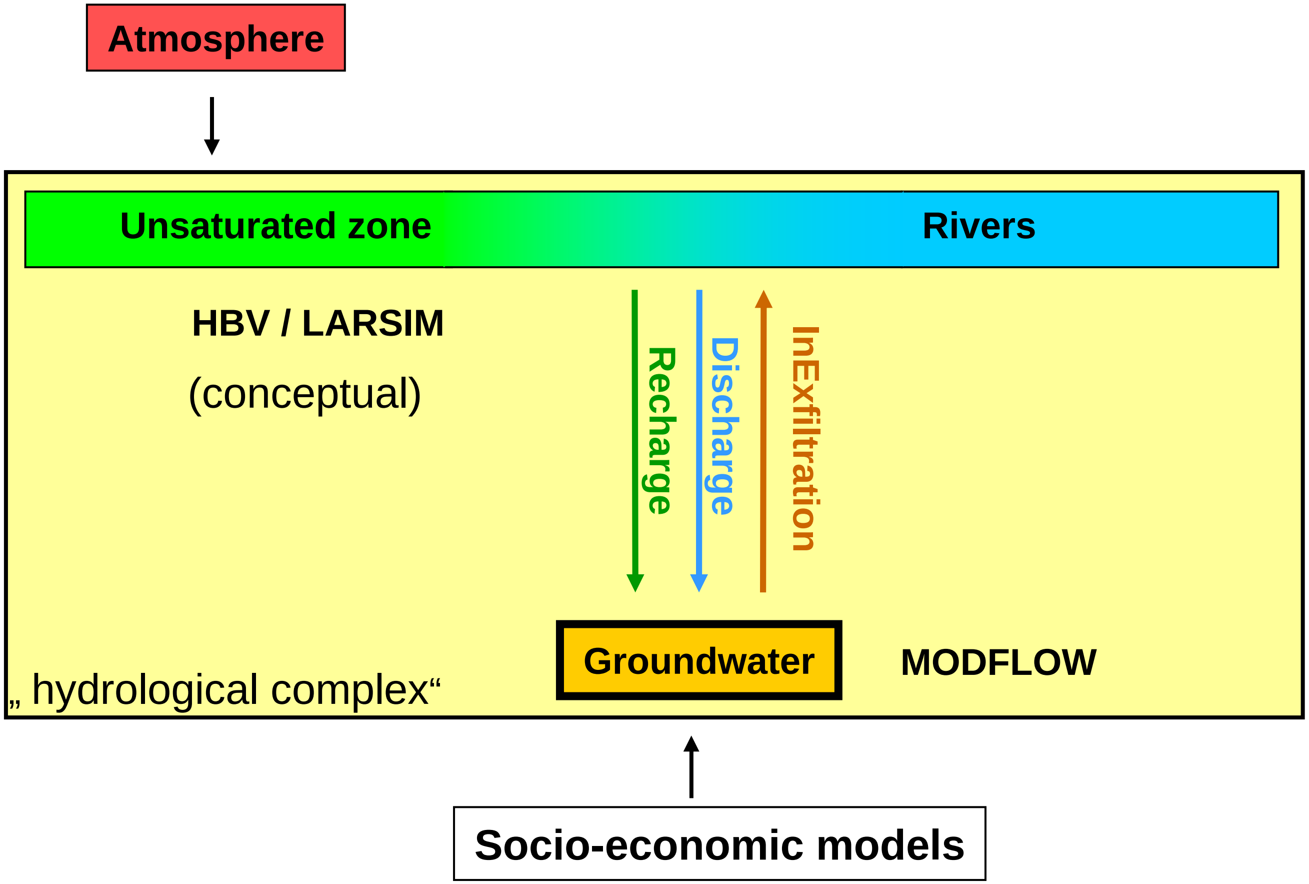
Groundwater – Boussinesq-Equation: FD - **MODFLOW**

Unsaturated Zone – Richards-Equation: SVAT- **PROMET**

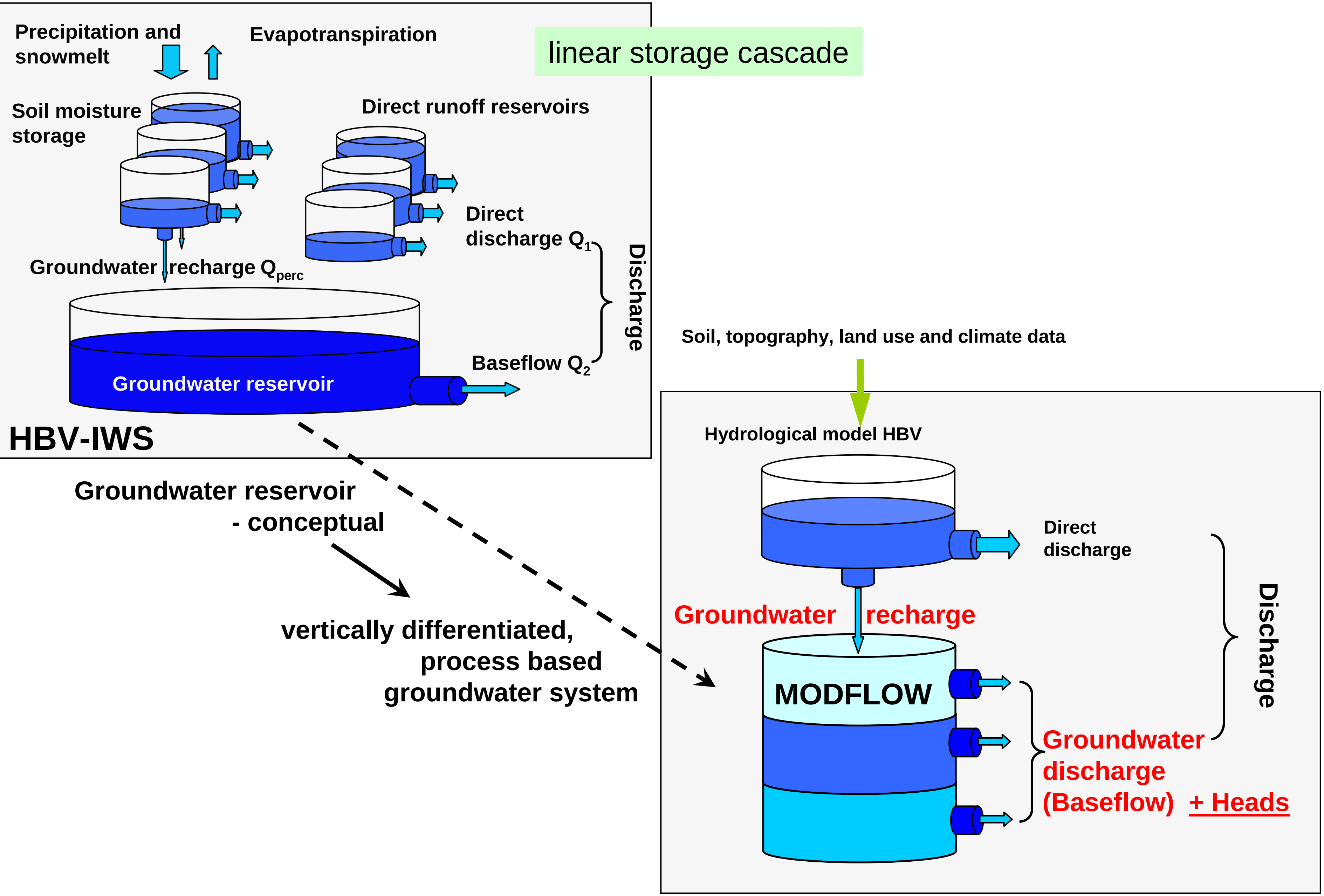
Surface Waters – Saint-Venant-Equations: **DAFLOW**




Atmosphere
Plants, Land Surface, Snow…
Unsaturated Zone
Direct Runoff
Rivers
Recharge
Groundwaterlevel
Riverlevel
InExfiltration
Groundwater
„hydrological complex“
Socio-economic models


Atmosphere
Unsaturated zone
Rivers
HBV / LARSIM
(conceptual)
Recharge
Discharge
InExfiltration
Groundwater
MODFLOW
„ hydrological complex“
Socio-economic models

Coupling Approach in **RIVERTWIN**



Coupled Model Results (RIVERTWIN): River Discharge and Baseflow

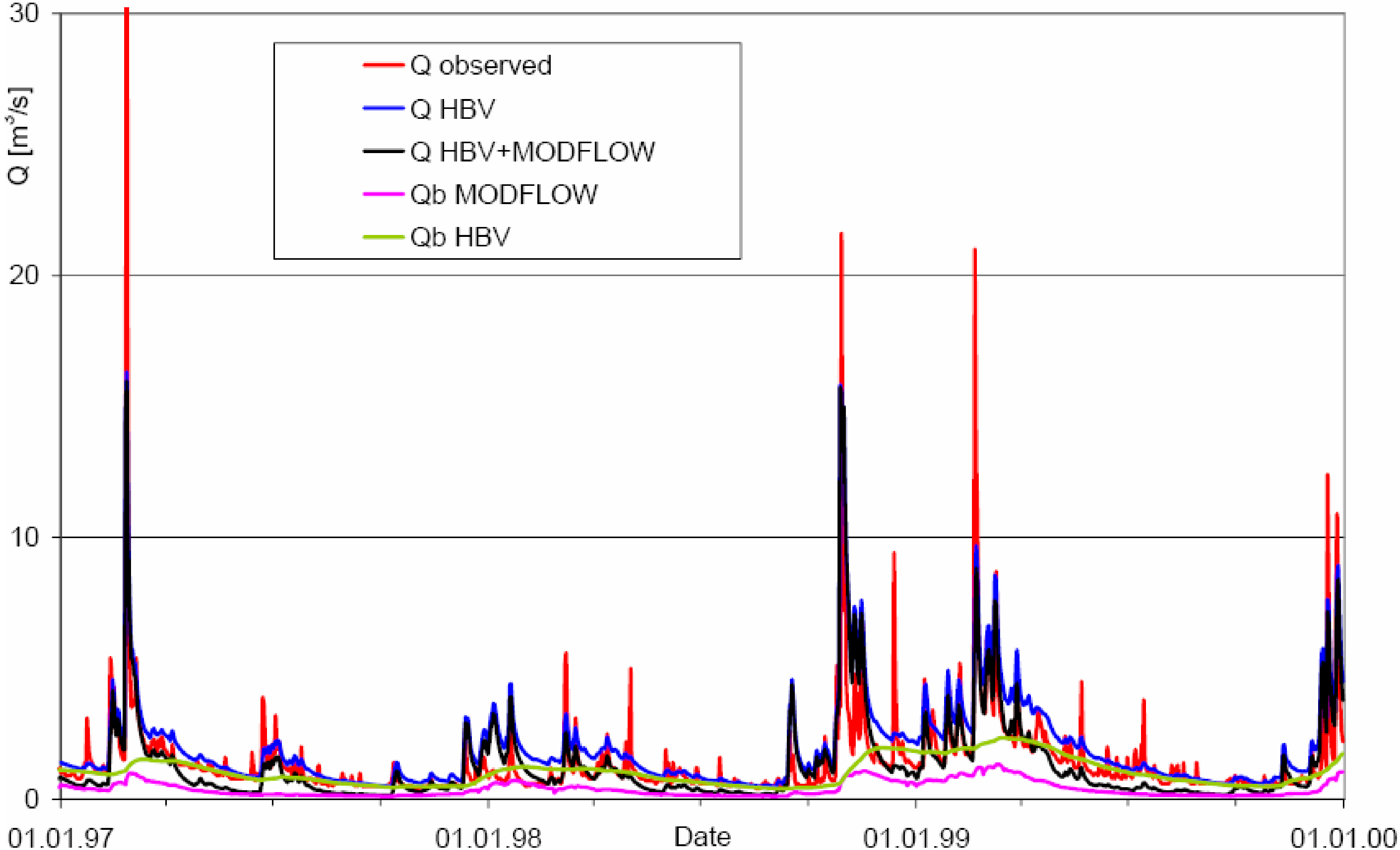
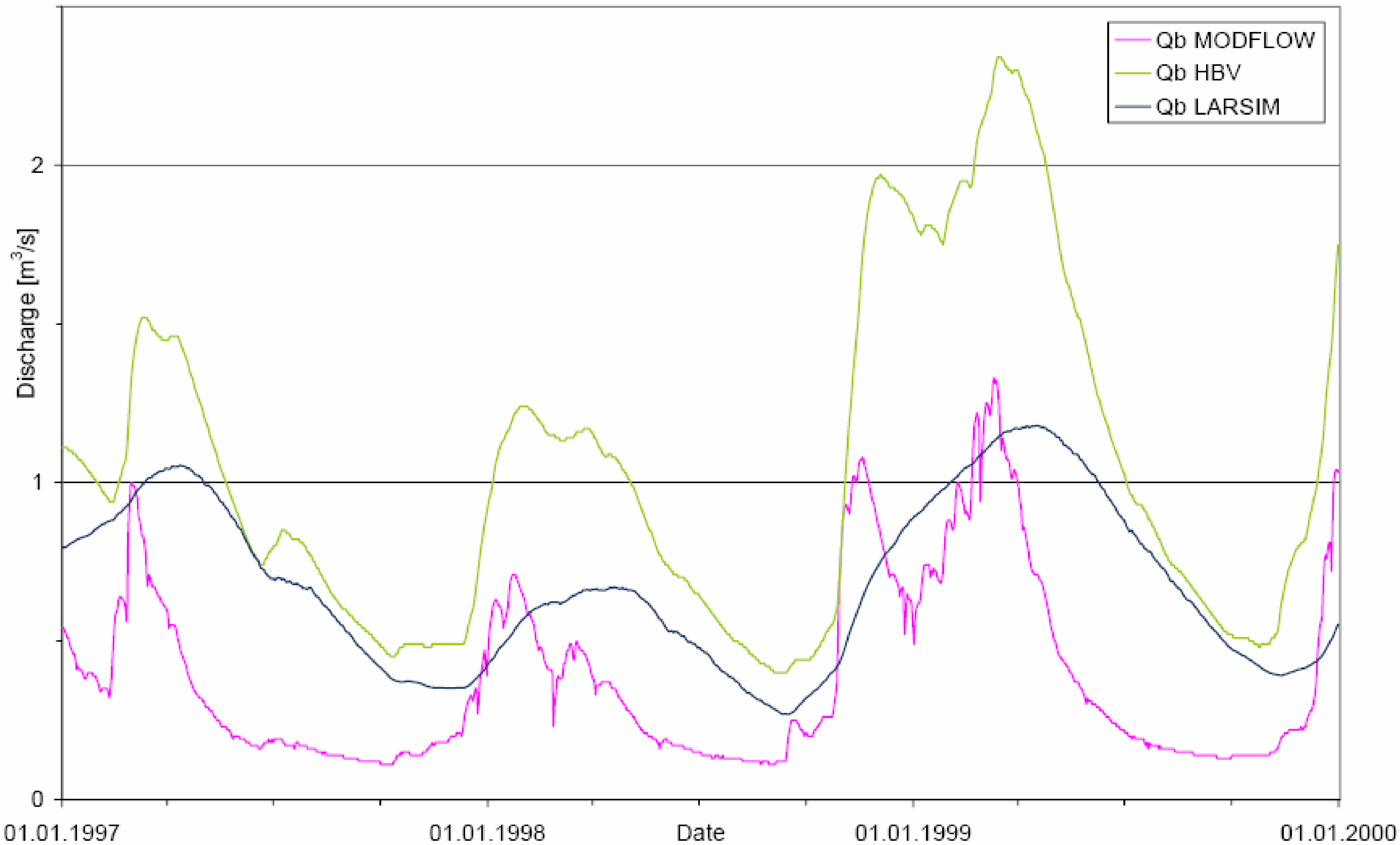


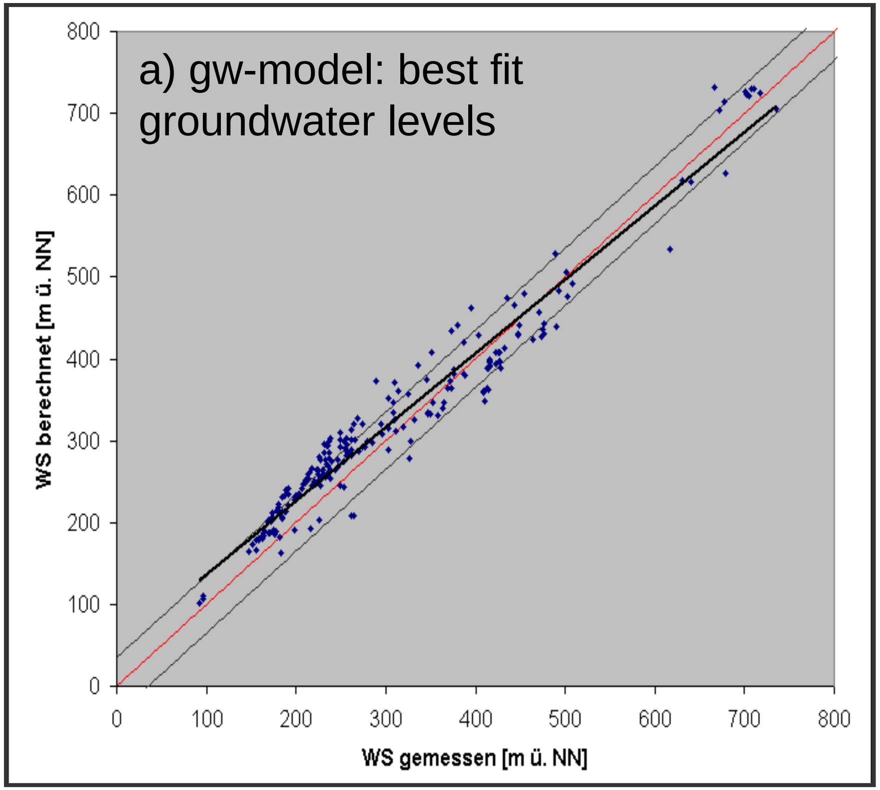
Fig. 6. Observed and simulated discharge at Neuenstadt (1997–1999), red: observation, blue: HBV, black: direct runoff from HBV plus groundwater runoff from MODFLOW, magenta: groundwater runoff simulated with MODFLOW, green: groundwater runoff simulated with HBV.

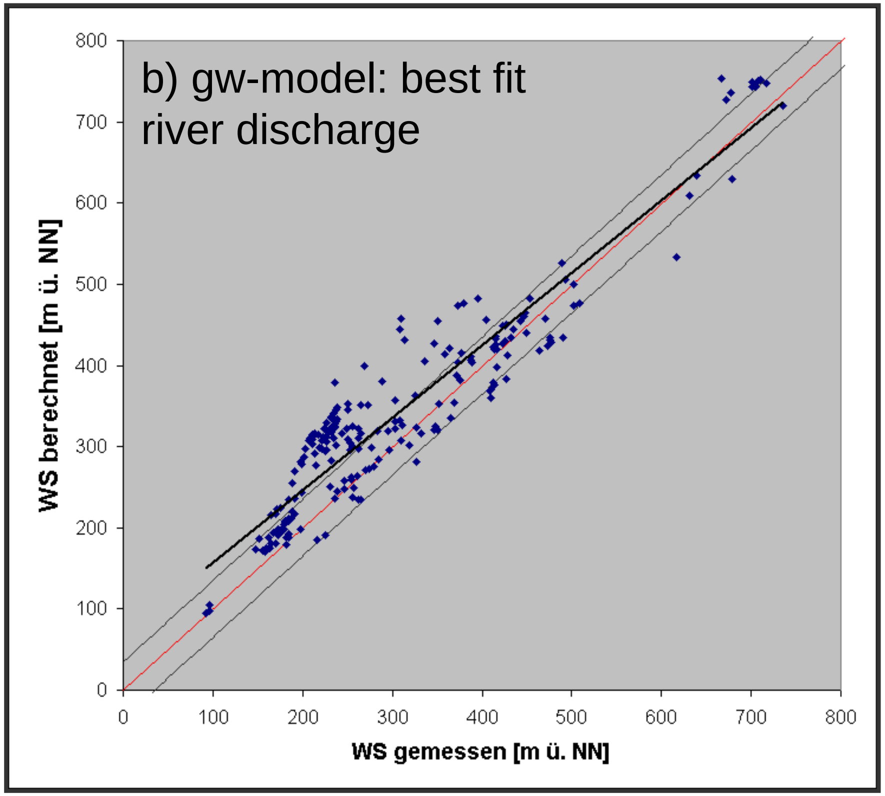
Adv. Geosci., 9, 1–7, 2006

Baseflow



Simulated groundwater runoff hydrographs of MODFLOW, HBV and LARSIM at Neuenstadt (1997–1999).





Regressionsgerade y = 0.9x + 46,5
Bestimmtheitsmaß R^2 = 0,9521
Mittlerer Absoluter Fehler MAE = 30,77 m
Standardabweichung RMSE = 30,91 m

Regressionsgerade y = 0.8917x + 68,207
Bestimmtheitsmaß R^2 = 0,8885
Mittlerer Absoluter Fehler MAE = 35,1217 m
Standardabweichung RMSE = 35,1142 m

⇨ coupled results: the better the discharge, the worse the groundwater levels

Problematic Aspects

Model conceptualization and model coupling using

- Groundwater Recharge
- Baseflow (better groundwater runoff / groundwater discharge)

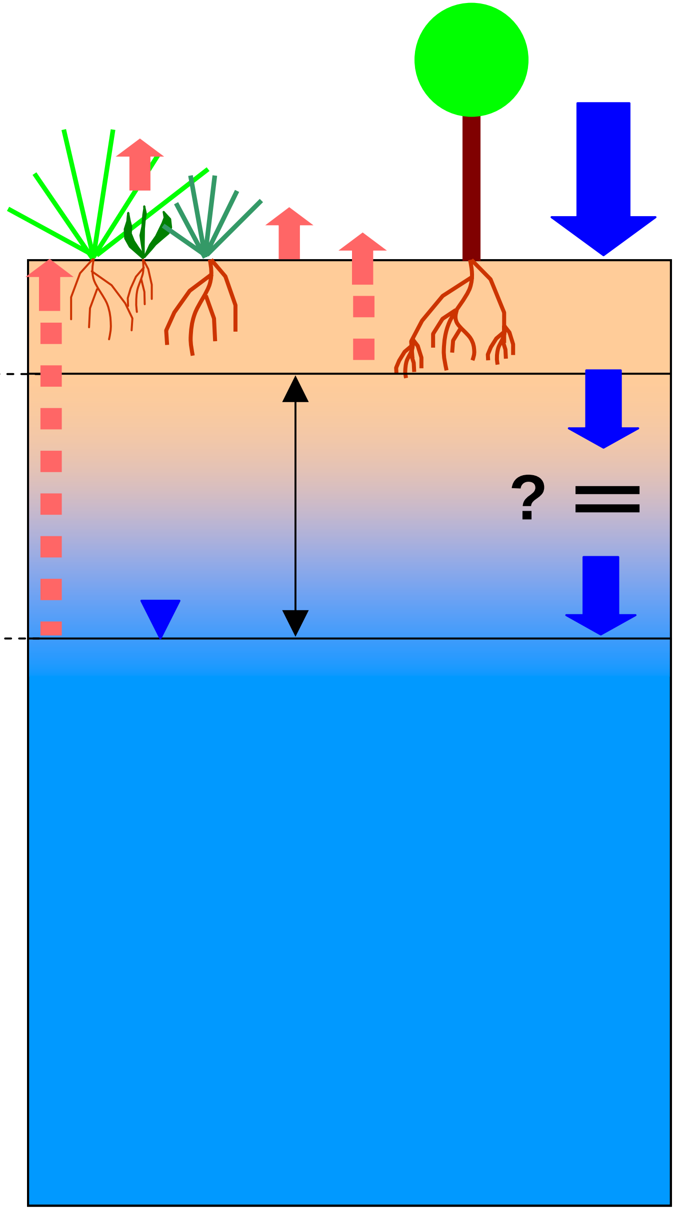
As coupling parameters

Groundwater Recharge as a process connecting unsaturated zone and groundwater

Soil or root zone

unsaturated zone

saturated zone - groundwater zone



Precipitation

Infiltration

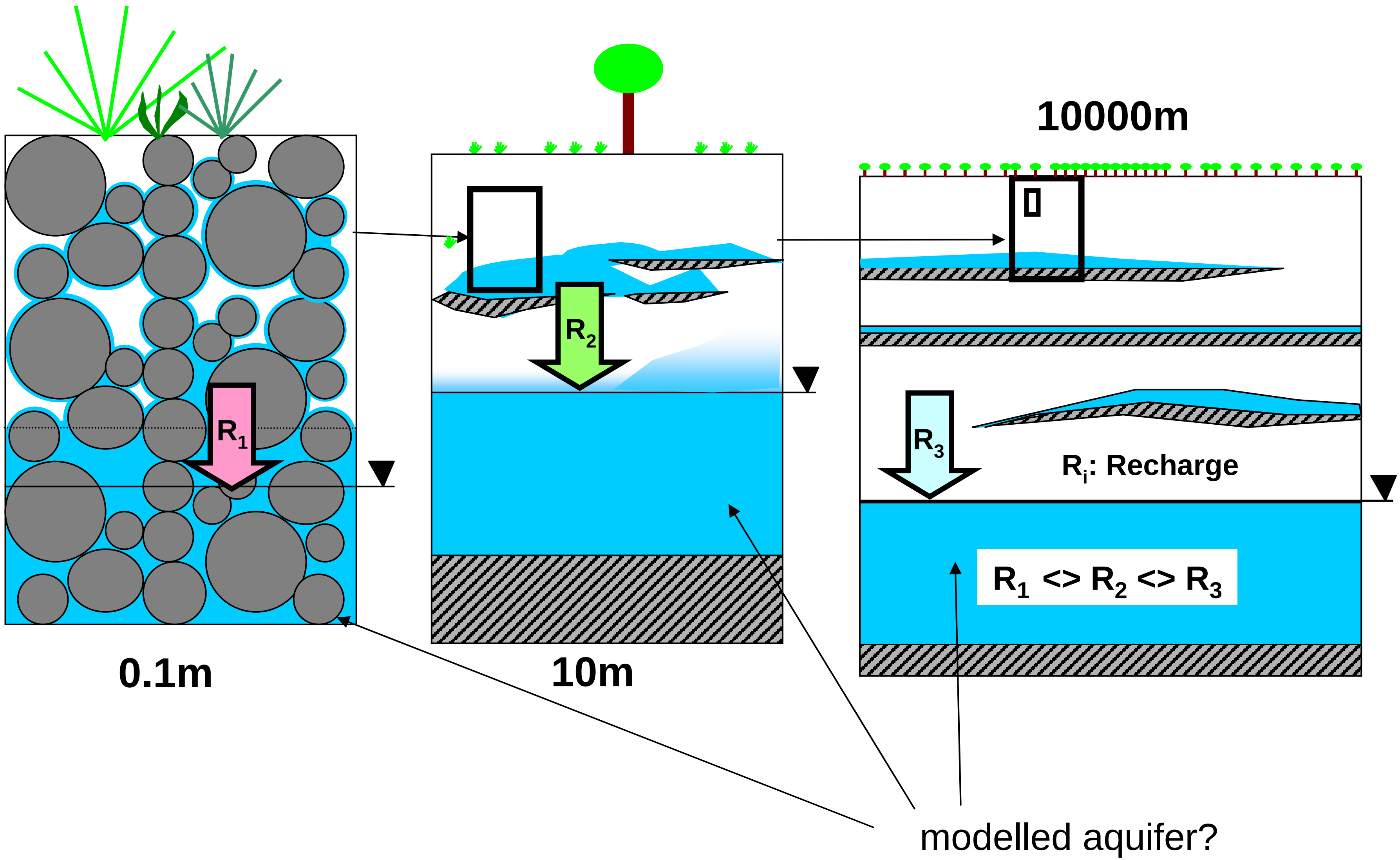
Percolation

Groundwater Recharge: Definition used in many physically based unsaturated zone models (also: lysimeters)

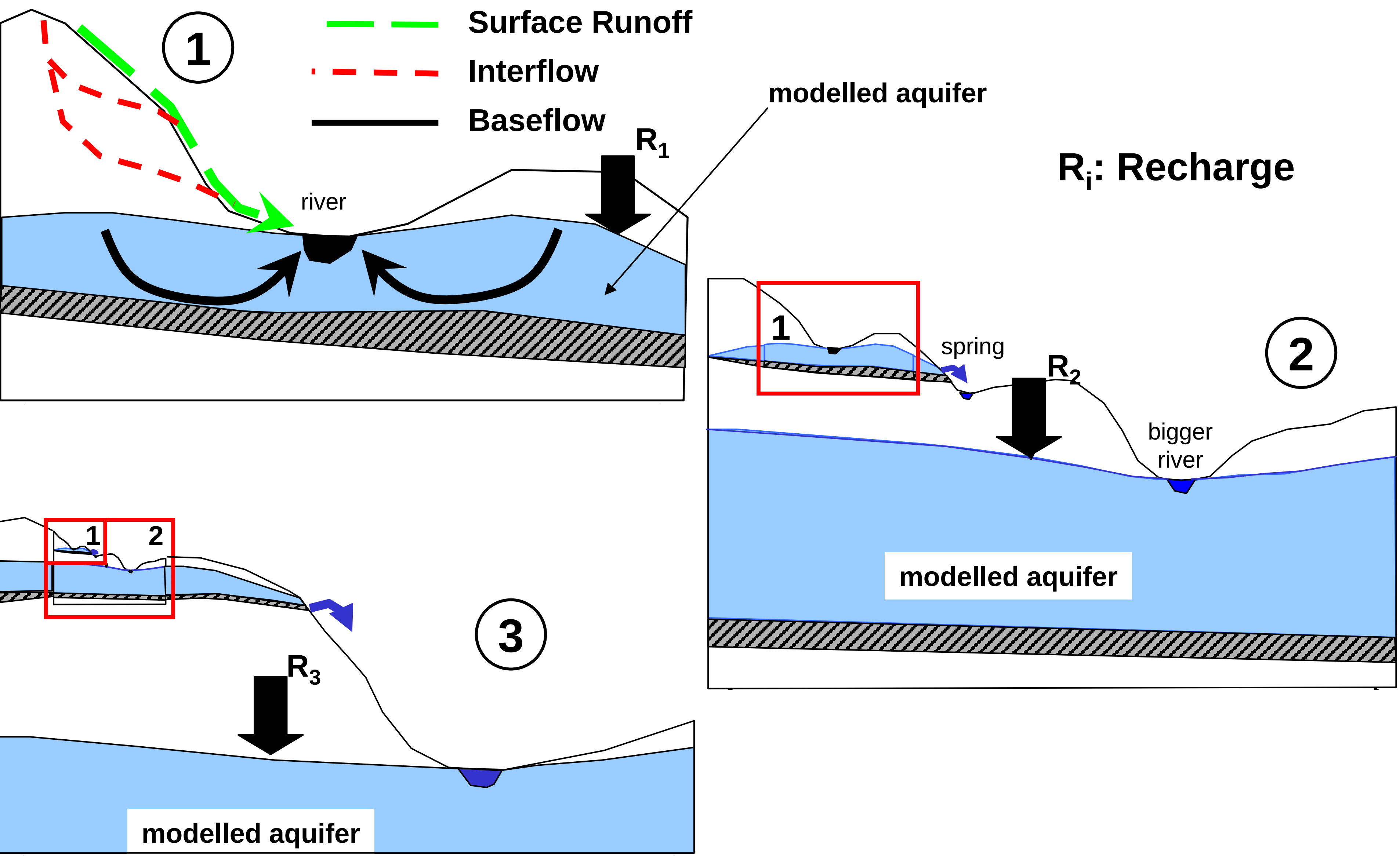
Groundwater Recharge:
Standard definition used in groundwater modelling / DIN 4049

no – actual recharge depends on:

- depth to the groundwater
- relief
- heterogeneities in the unsaturated zone
- lateral flow



R_2
10000m
R_1
R_3
R_i: Recharge
$R_1 <> R_2 <> R_3$
0.1m
10m
modelled aquifer?



1
Surface Runoff
Interflow
Baseflow
river
R1
modelled aquifer
Ri: Recharge
1
spring
R2
2
bigger river
modelled aquifer
1
2
3
R3
modelled aquifer

Modeling the interaction between groundwater, surface water and unsaturated zone on the regional scale

Conclusions – Lessons learned

- data availability for regional models
- the role of temporal and spatial **discretisation**: upscaling, downscaling, aggregation and dis-aggregation
- specific problems of modelling the dynamic relations of groundwater and surface water systems on the regional scale
- error propagation in coupled systems
- conceptual versus deterministic models for scenario simulations?
- definition of meaningful coupled scenarios
- weak versus strong coupling
- …

Potential benefits of model coupling

- **General: more results available / more complete description of hydrological processes**
- **Enhanced calibration options / multi-objective optimization**
  - e.g. measured discharge in addition to measured groundwater levels to calibrate groundwater flow models
- **Means to identify conceptual errors in models and to better understand hydrological / hydrogeological systems**
  - e.g. identification of groundwater in- and outflow from and to the catchment
- **Better representation of cross-system processes:**
  - e.g. plausibility checks for groundwater recharge calculations
- **In practice:**
  - the above mentioned advantages are quite often compensated by the high demand of computation time and storage capacity of the coupled models.

Important aspects to consider

- Modeling the interactions of groundwater and surface water systems on the regional scale requires very thorough, consistent conceptualization of all processes and system parameters

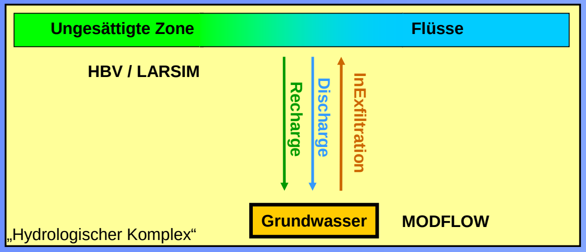
- The coupling concept must be context specific and the sectoral models to be coupled must be appropriate for:
  - scale, regional conditions (hydrogeology, geomorphology), specific problems to be solved ….

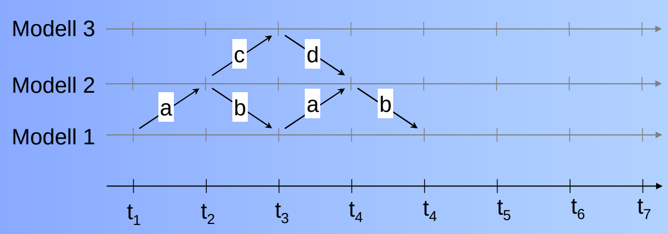
- Coupled models require a joint calibration (difficult to realize for regional models)

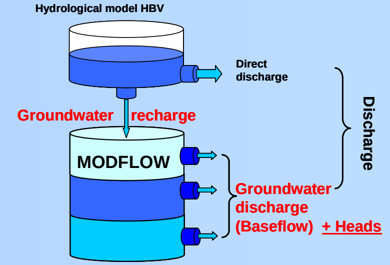
- Merely hydraulic approaches (flow - potential based) are not sufficient. Hydrochemistry, natural tracers, isotopes, have to be included to achieve meaningful results!

- make sure that terms (e.g. ‘parameter’), processes (e.g. ‘groundwater recharge’) and strategies (e.g. ‘calibration’) are defined in a consistent way by all disciplines involved!

- acknowledge, that the results of coupled system might be worse than the results of a standalone sectoral model – be able to compromise







Modeling the interaction between groundwater, surface water and unsaturated zone on the regional scale

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Thank you for your attention!

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