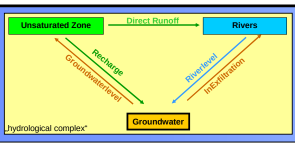

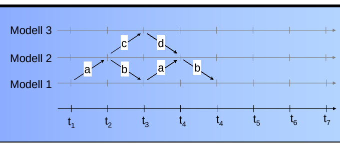

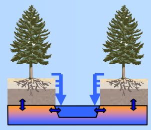

Design of the DANUBIA DSS

- with a special focus on the coupling of groundwater models (MODFLOW) with hydrological models

Roland Barthel,
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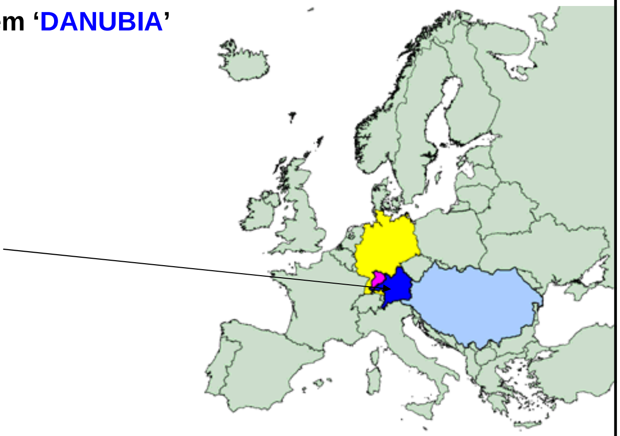
Federal Ministry of Education and Research

Outline

- **General Coupling and Integration Concept of the GLOWA-Danube Project : The DANUBIA DSS**
- **Coupling MODFLOW to**
  - **Hydraulic and SVAT Models**
  - **to Socio-Economic Models**
- **Selected Results**
- **Conclusions**

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

- **Consequences of Global (Climate) Change in the Upper Danube Catchment** (Water Supply, Land Use, Agriculture, Economy, Tourism ..)
- **Decision Support System 'DANUBIA'**



What is DANUBIA ? (1)

- DANUBIA is
  - a coupled simulation system, comprised of **16 individual sub-models**
  - **models run on different computers** and exchange data via internet protocols
    - theoretically completely distributed
    - actually: Cluster with 26 nodes
  - **6 socio-economic models, 10 natural science models**
  - mainly well-established, widely used **standard models** (e.g. MODFLOW, DAFLOW, MM5) in the natural science sector,
  - mainly **newly developed, context specific models** in the socio-economic sector (e.g. 'WaterSupply')

What is DANUBIA ? (2)

- DANUBIA is (continued)
  - all models coupled via a **JAVA based framework architecture** (link to data base, control of spatial and temporal aspects of data exchange, control of data types, visualization ….)
  - **models, interfaces, framework conceptualized using UML**
  - able to provide a **large number of output variables** in tabular form, maps, movies etc.
    - currently restricted to about 75
  - a **user friendly web interface** is under development
    - currently results and use are restricted to model developers
  - Upon completion of the third project phase DANUBIA will be available to the public under a **public license agreement** (2010)

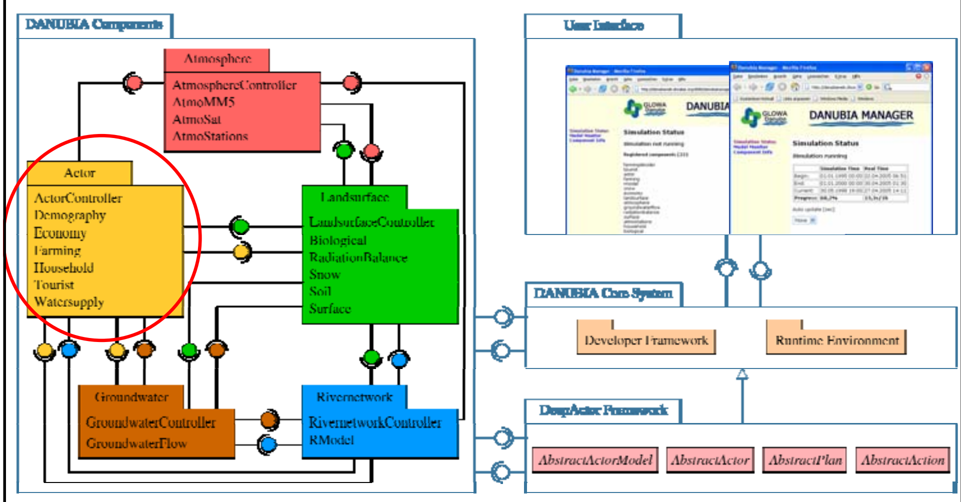
The Central Glowa-Danube Infrastructure

Parallel cluster computer to run DANUBIA:

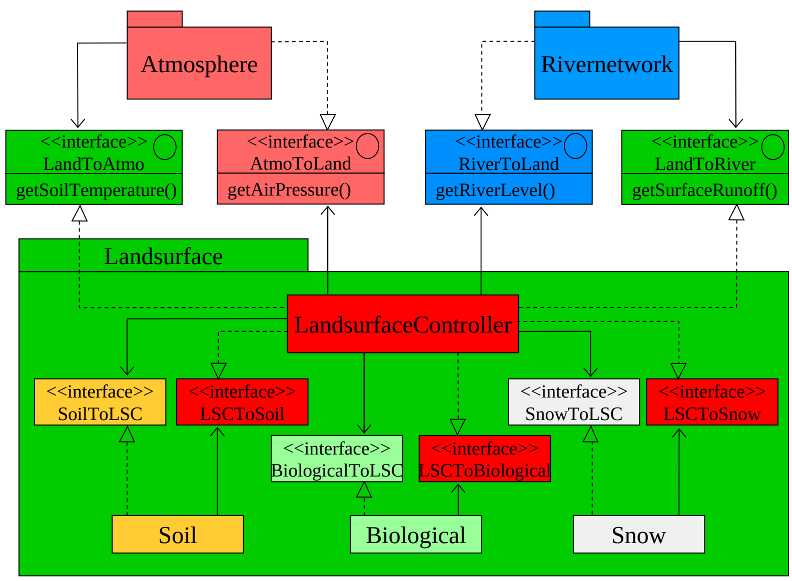
- **26 nodes**
- **52 CPUs**
- **30 GB RAM**
- **1 TB Storage**

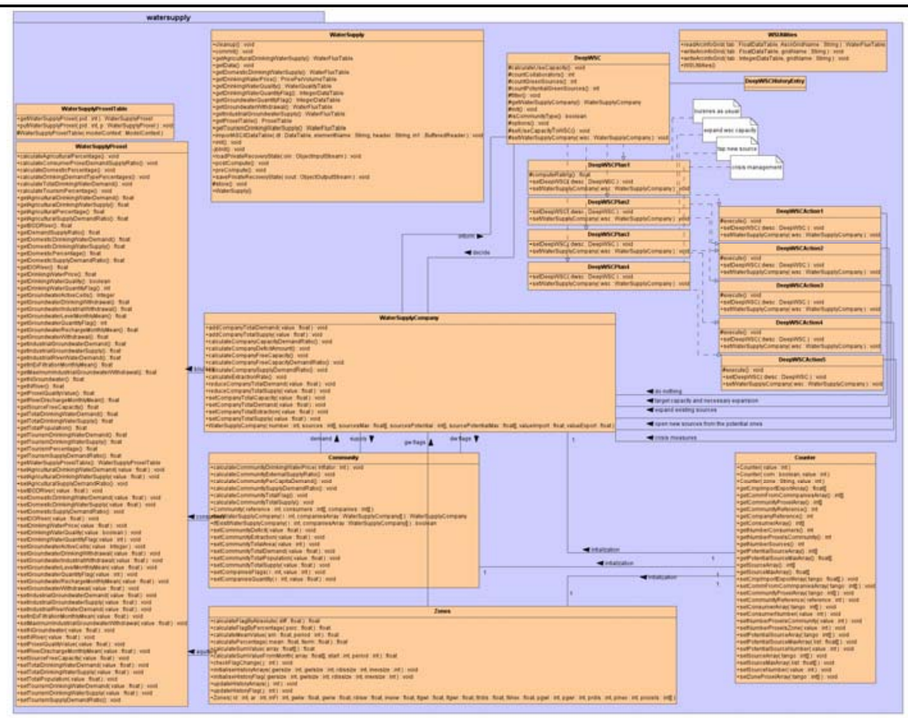
To simulate a 30 Year scenario ~ 10 days

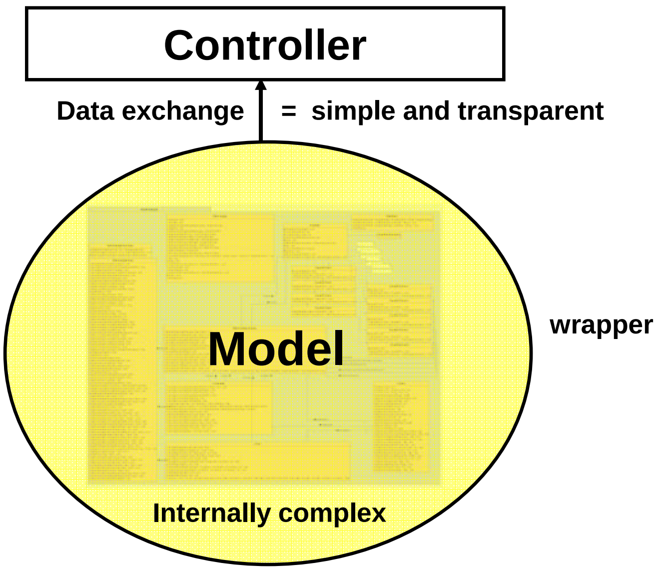
The DANUBIA Architecture



The DANUBIA Architecture

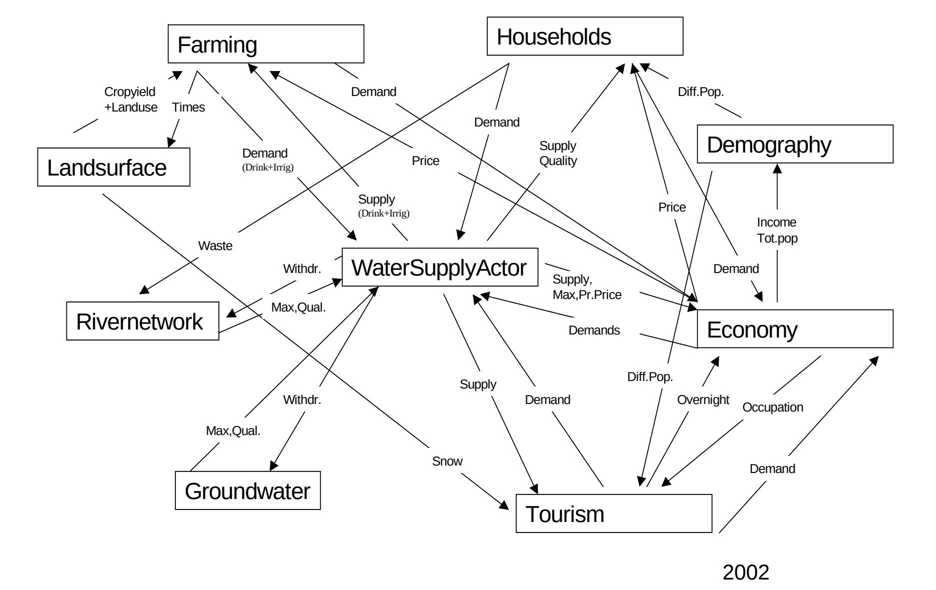






Idea: Reduce complexity and redundancy

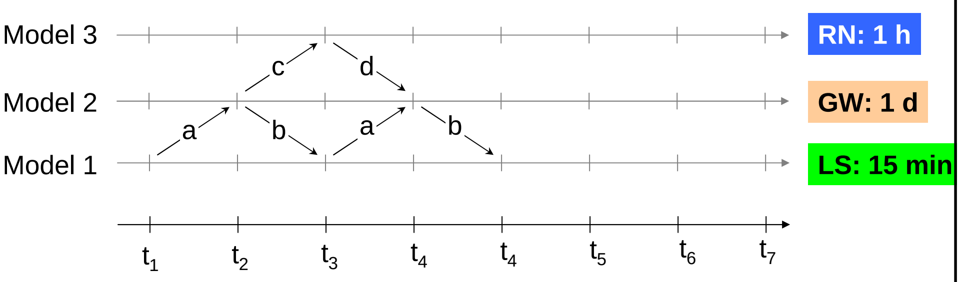
Coupling: Analysis of dependencies (static view)



Model Coupling: 1) “strong” coupling **(GLOWA-Danube)**

Problems: delay, (unwanted) feed back, validity of exchange data …

Model: timestep



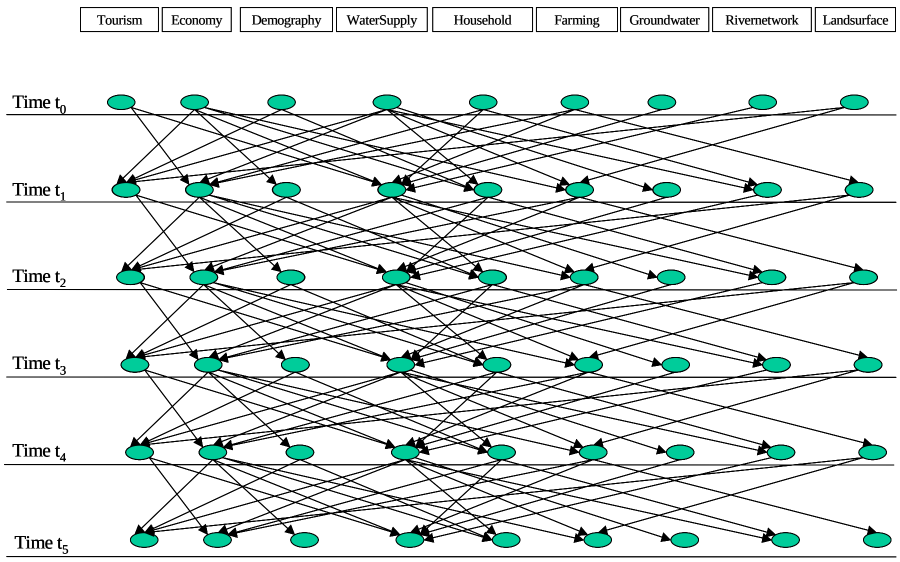
Models

1: LandSurface
2: GroundWater
3: RiverNetwork

Variables

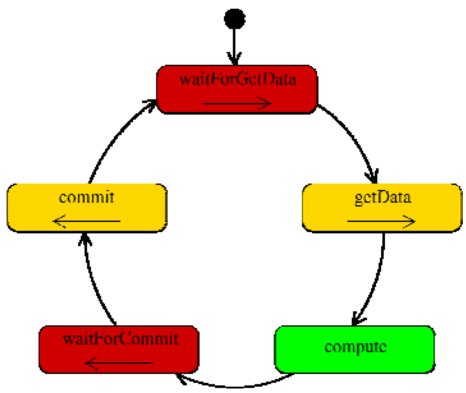
a: groundwater recharge
b: groundwater level
c: infiltration
d: river level

Coupling: Analysis of dependencies (dynamic view)



Observation: The scheme is valid only if all the Actors compute at the same time step. The non-Actors group (Groundwater, Rivernetwork, Landsurface) compute at much smaller time steps (one hour, one day), but I did not know how to represent it.

Coordinated Behaviour of DANUBIA Models

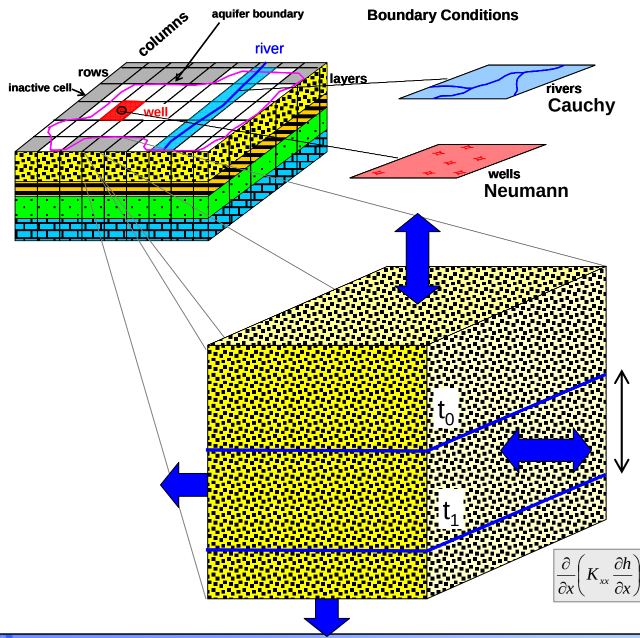


- A model is blocked (**waitForGetData**) if the coordination condition for **getData** is not satisfied (similarly, **waitForCommit**).
- The correctness of the coordination can be **formally verified** with **model checking techniques**.

The challenges of coupling 16 models

- All models use the **same spatial discretisation** of 1 km by 1 km:
  - Simplifies data exchange.
  - poses severe problems namely to socio economic models, hydraulic models, meteorological models (usually not raster based or much finer or coarser rasters)
- Models have **different temporal discretisation** ranging from 15 min (plant growth) to one year (agro-econmic model)
  - (Irresolvable) feedbacks and delays of data exchange
  - Tracing errors and uncertainty is almost impossible

Integration of MODFLOW into the DANUBIA DSS



The MODFLOW (Finite Difference) Numerical Concept

For each cell, for each timestep:

changing fluxes – from cell to cell, from cell to sinks, from sources to cells

→ **water balance**

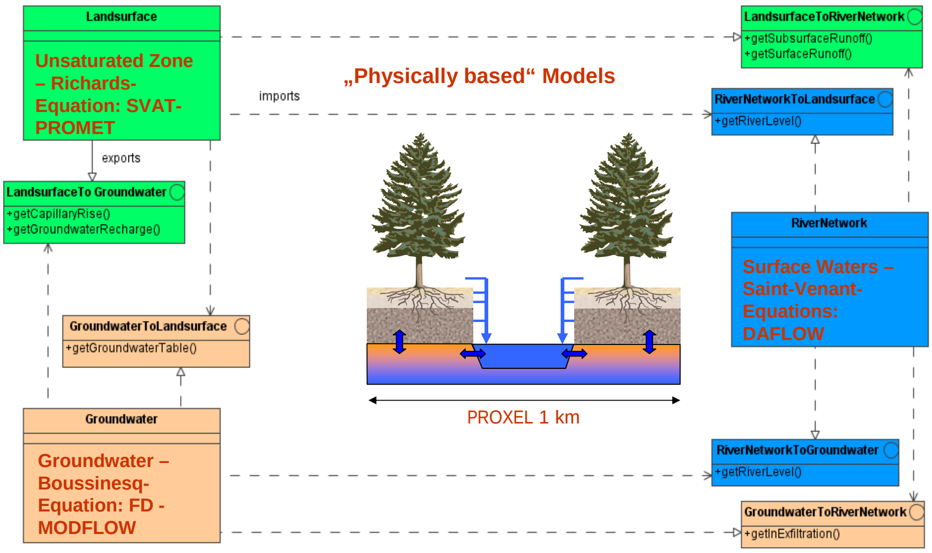
→ **head changes**

→ **storage changes**

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_S\frac{\partial h}{\partial t}$$

Coupling of hydrological models in GLOWA-Danube

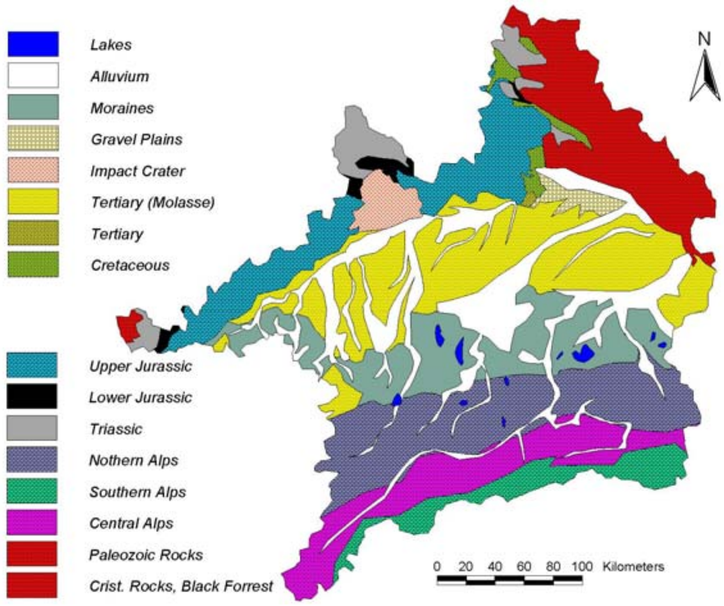
Important DANUBIA philosophy: Make interfaces as simple as possible!
⇒ minimize number of exchange parameters



The two sides of dynamic model coupling

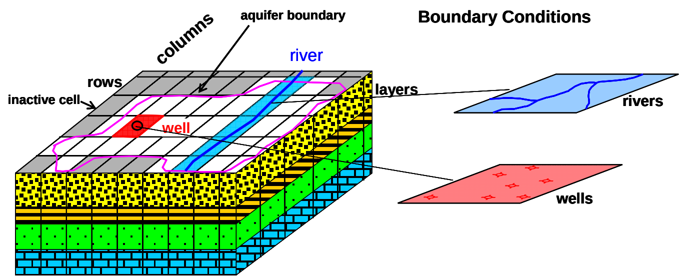
1. ‘Technically’:
   - How to control and link two different codes? (software engineering or programming problem)
2. ‘Conceptually’:
   – How to guaranty that the linkage makes sense, i.e. is a meaningful representation of natural processes
3. Do the individual models to be coupled make sense at all?

The conceptual hydrogeological model: Geological Overview



Coupling MODFLOW - Technically: Interfaces

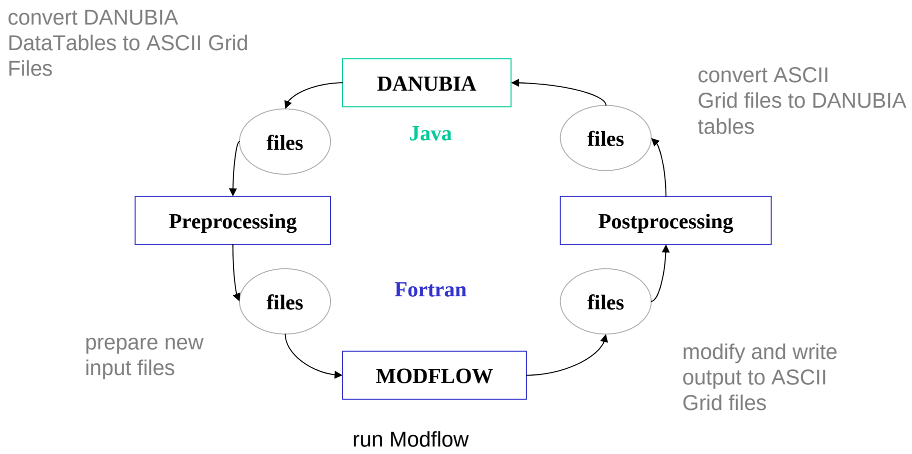
- MODFLOW advantage:
  - **Modular design**: boundary conditions (i.e. interfaces in a wider sense) can be used and parameterized individually (→ **packages**)
  - boundary condition files (packages) are read at each stress period
- DANUBIA approach:
  - Output from DANUBIA partner models (e.g. groundwater recharge) is read and aggregated at each time step (e.g. 1h) within the JAVA environment and converted to the required package files



Coupling MODFLOW: Time Control

- **Problem:**
  - In a coupled system like DANUBIA the system must control the individual models (read – run – write)
- **MODFLOW advantage:**
  - Each stress period represents a fully completed OS command
  - Therefore the whole process can be controlled using OS command sequences (**batch files, shell scripts**)

Coupling MODFLOW



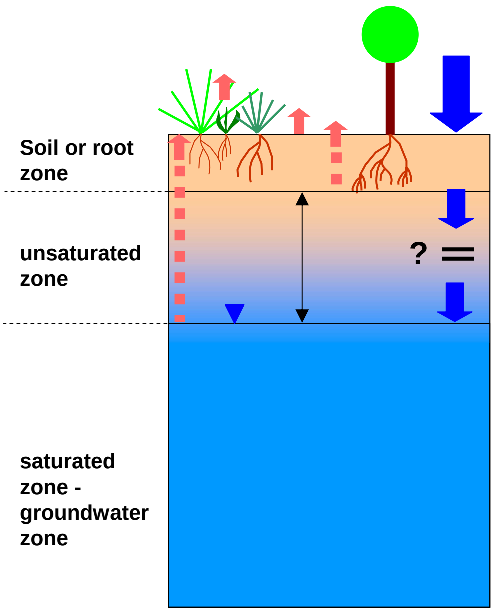
Process mainly based on OS commands and Fortran code executed from JAVA code

Selected Conceptual Aspects of integrating MODFLOW

Example A) Groundwater Recharge to link unsaturated zone and groundwater

Example B) Groundwater and River Levels to link groundwater and rivers

1) Groundwater Recharge to connect unsaturated zone and groundwater



Precipitation

Infiltration

Percolation

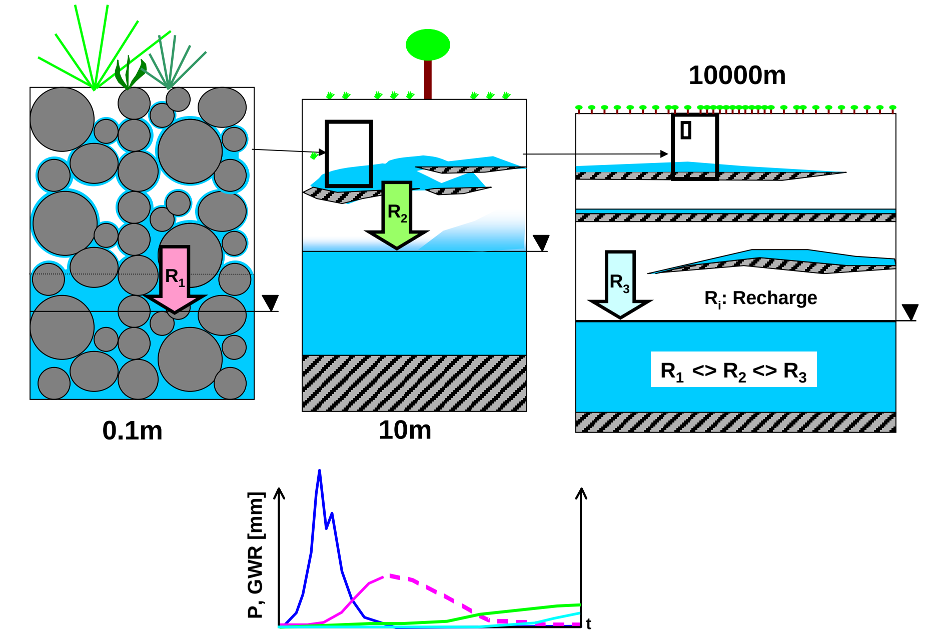
Groundwater Recharge: Definition used in many physically based unsaturated zone models (also: lysimeters)

Groundwater Recharge: Standard definition used in groundwater modelling

but actual recharge depends on:

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

Grundwasserneubildung auf verschiedenen Skalen



2) Groundwater - River Interactions: Using the MODFLOW River or Drain Package

RIVER PACKAGE

$$Q_{RIV} = \frac{K_R * L * W}{M}(H_{RIV} - h) = C_{RIV}(H_{RIV} - h)$$

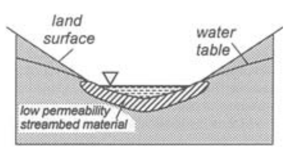
DRAIN PACKAGE

$$Q_D = K * L(h - d) = C_D(h - d)$$

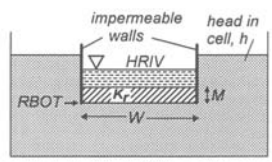
where: K: hydraulic conductivity of the river/drain bottom, L: Length of the river in a cell, W: width, M: thickness h hydraulic head

- Problems:
  - Numerical Stability (River Package)
  - How to define Groundwater and River Levels using a common datum?
  - Definition of a hydrologically consistent DEM on a coarse raster
  - …

RIVER PACKAGE



(a)

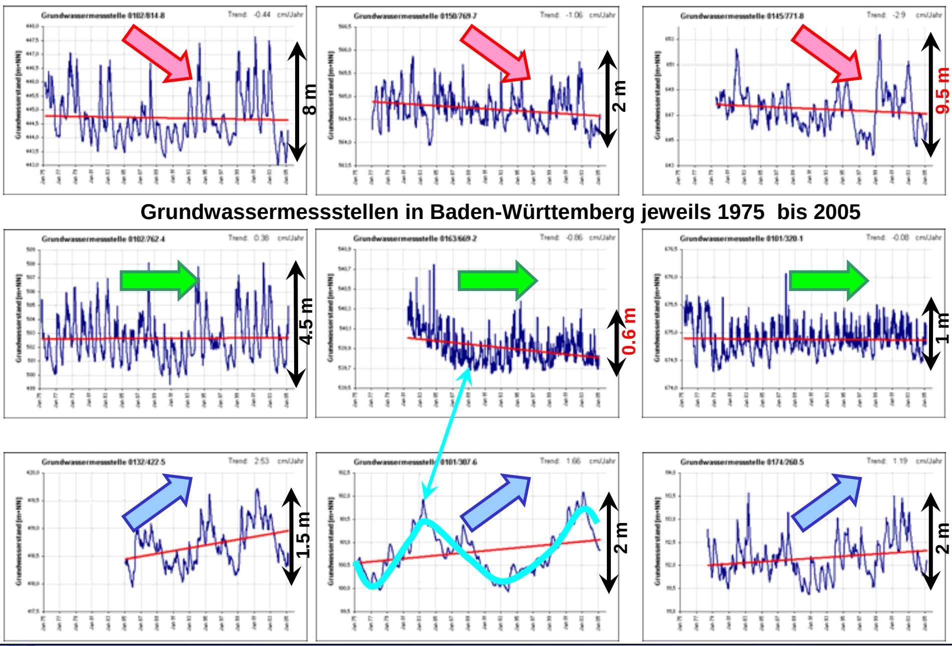


(b)

Coupling MODFLOW to socio-economic models

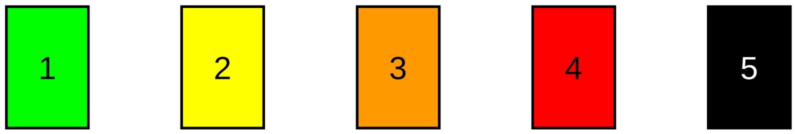
- Interface Socio Economic Model to MODFLOW:
  - Water Demand – Extraction from Wells
  - Can be easily realized using the well package
- Interface MODFLOW to Socio Economic Model:
  - groundwater level is not a sufficient input parameter for a socio economic model

Grundwasserstände: Entwicklung



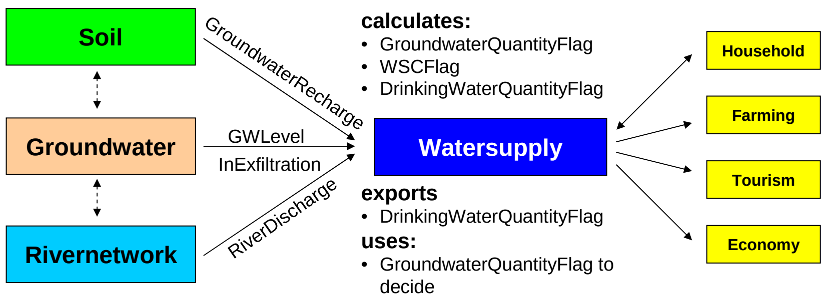
Natural science values to interpreted "signals" (flags)

everything is fine → critical situation → catastrophic situation



The integrated assessment concept in GLOWA-Danube

From each model cell → For each zone → To each model cell

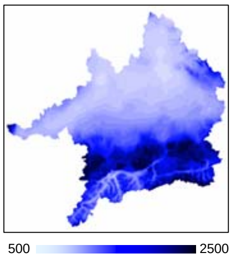


read from partner model → aggregate values calculate flags → send flags

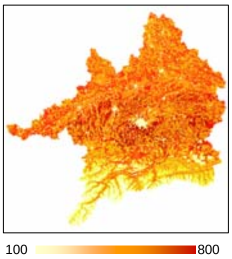
Results: Model Validation

Water Balance of the Upper Danube, Period 1971-2000

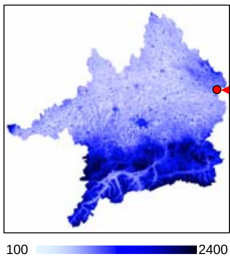
Precipitation - **Evapotranspiration** = **Runoff**



1078 mm/a



481 mm/a



597 mm/a

Mean Discharge at Gauge Achleiten (76653 km², 1971-2000): **587 mm/a**

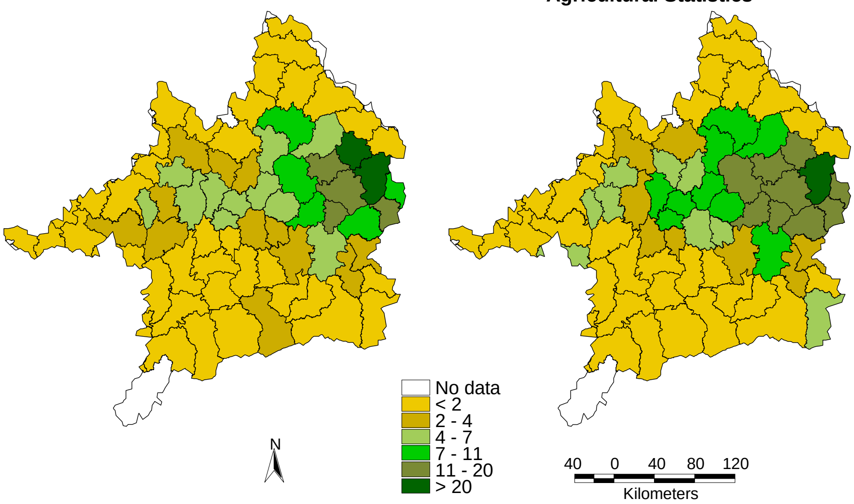
+ 1.7 %

But: the long term average of the discharge at one gauge is not a means to validate a DSS!

Results: Model Validation

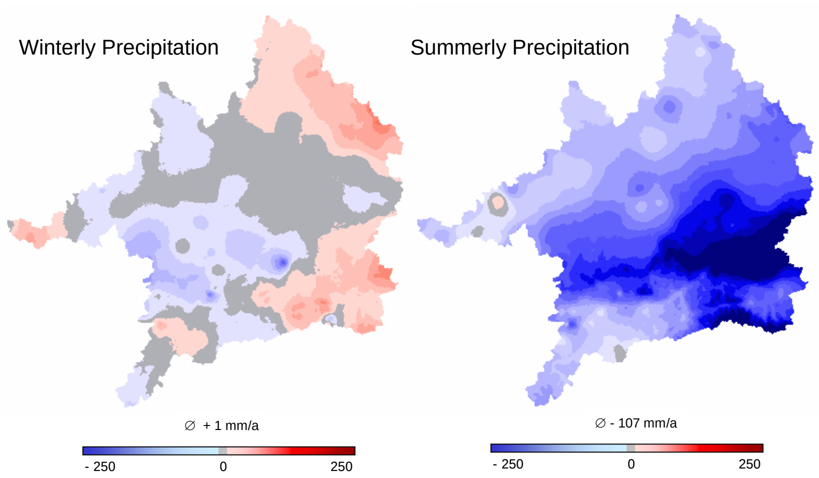
Maize 2003 in % of arable land

DANUBIA Model Results **Agricultural Statistics**

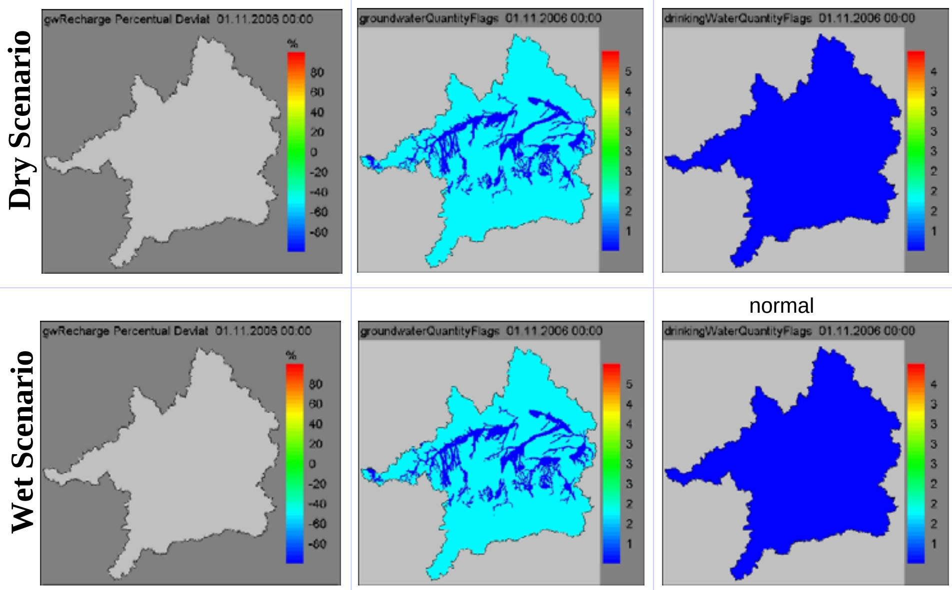


Results: Scenario Simulations

IPCC-Szenario B2 (delta T = 2.7K/100a) Trend in Seasonal Precipitation Pattern 2005 -> 2104



GroundwaterRecharge Deviation from Reference | **GroundwaterQuantityFlag** | **DrinkingwaterQuantityFlag**

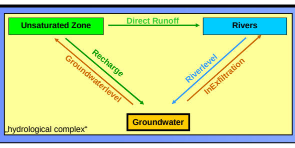


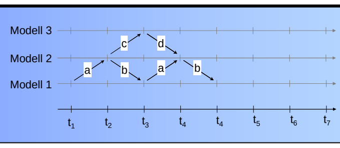
- GLOWA-Danube Summary:
  - an extremely sophisticated modeling framework has been built
  - the system is working, yet it is not applicable in practice yet
  - three more years to go will hopefully be enough to make the necessary improvements

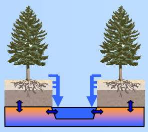
- Include stakeholders early to define the management problems and objectives of modeling clear enough
- Analysis your management tasks, data availability and other resources very carefully in order to find out **which models to use**, **how complex the system must be and how simple it can be**

Specific recommendations

- Do not attempt to couple everything
  - If dependencies are small, ignore them
- Do not always attempt model the entire area as a whole
  - If natural divisions exist - use them
- Each interruption of the process chain (spatial or dependencies) gives you the possibility to limit uncertainty and error propagation and therefore better control







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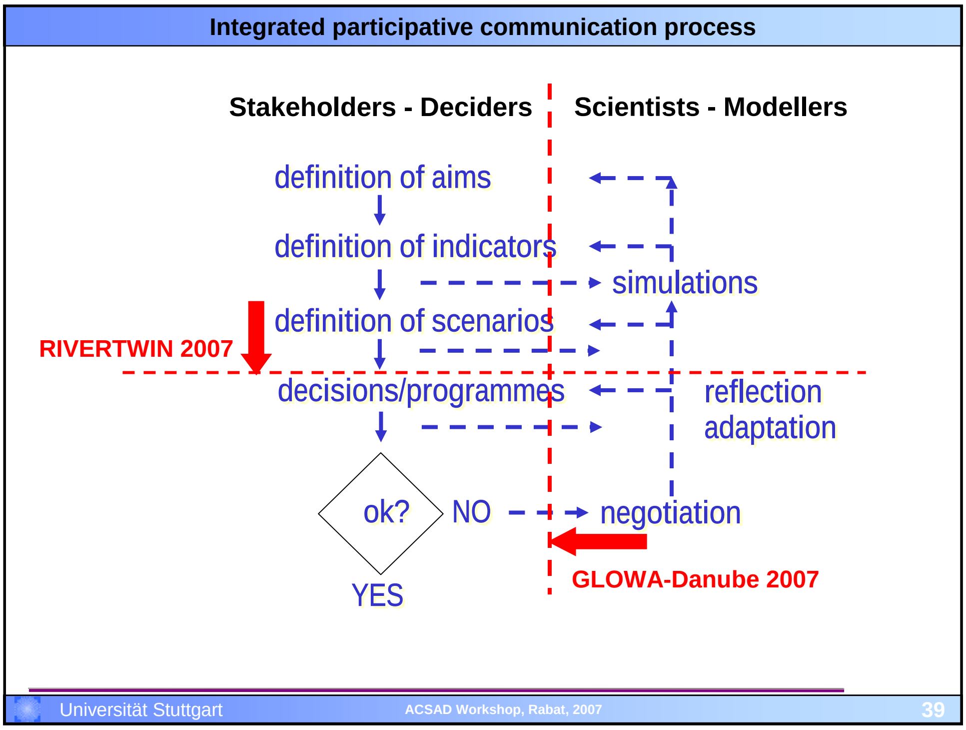
Thank your for your attention!

Federal Ministry of Education and Research bmb+f

GLOWA Danube


Integrated participative communication process
Stakeholders - Deciders
Scientists - Modellers
definition of aims
definition of indicators
simulations
definition of scenarios
RIVERTWIN 2007
decisions/programmes
reflection
adaptation
ok?
NO
negotiation
YES
GLOWA-Danube 2007
Universität Stuttgart
ACSAD Workshop, Rabat, 2007
39