Integrated water resources assessment: an approach for information exchange between natural science and socioeconomic models

GLOWA Danube

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Abstract

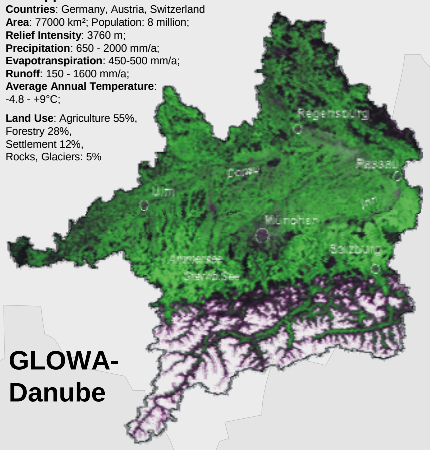
The present and future state of our water resources has become a major concern in science and practice – not only because of the European **Water Framework Directive**. In particular in **Global Change** research it is inevitable to look at processes in an integrated way. An important tool are models that integrate the main physical components of the water cycle such as atmosphere, biosphere, rivers and groundwater with the socioeconomic part, i.e. human activities (water demand, land use etc.). One important question is, how natural science models can meaningfully and realistically be linked to socioeconomic models.

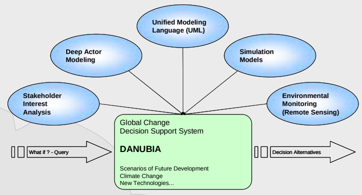
In this contribution an approach for information exchange from natural science to socioeconomic models is introduced. The essential purpose of the approach is the assessment and communication of the quantitative and qualitative state of groundwater resources on the regional scale. It is based on a small set of physical, intuitively-understandable parameters and groundwater body characteristics. As a result a so-called 'flag' is calculated for each groundwater body and time step which can be interpreted as warnings, prohibitions or laws and they can be fully abided or completely ignored, which seems to be an accurate analogy to reality. The approach was developed within the framework of **GLOWA-Danube** and implemented in the **DSS DANUBIA** The socioeconomic models in DANUBIA follow a multi-actor approach. Actors (e.g. a farmer or a household type) base their decisions (e.g. decisions on crop types) partly on these flags.

The assessment of **Global Change** impacts on the availability of water and the sustainability of water resources management activities is a key issue in **integrative hydrological research**. The development of methods for sustainable water resources management under globally changing boundary conditions requires the integration of transdisciplinary expertise. The principle objective of the GLOWA-Danube project is to support the analysis of water-related global change scenarios and the investigation of sustainable methods for future water resources management in the Upper Danube Basin (77.000 km²) by means of the Global Change decision support tool DANUBIA.

The Upper Danube Catchment:
Countries: Germany, Austria, Switzerland
Area: 77000 km²; Population: 8 million;
Relief Intensity: 3760 m;
Precipitation: 650 - 2000 mm/a;
Evapotranspiration: 450-500 mm/a;
Runoff: 150 - 1600 mm/a;
Average Annual Temperature:
-4.8 - +9°C;

Land Use: Agriculture 55%,
Forestry 28%,
Settlement 12%,
Rocks, Glaciers: 5%





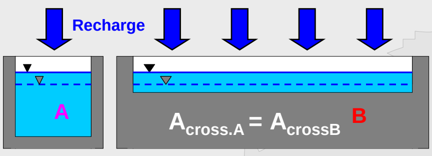
DANUBIA

DANUBIA integrates 16 natural-science and socio-economic simulation models within five main components: Atmosphere, Land-surface, Rivernetwork, Groundwater and Actor.

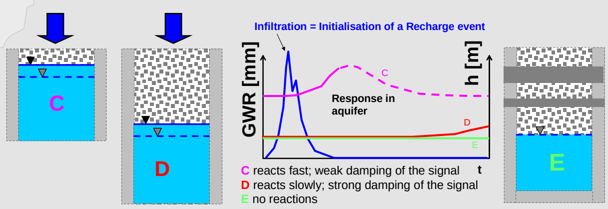
The data exchange between main components as well as between single simulation models is specified by corresponding interfaces.

Principles of Groundwater Resources Assessment

Groundwater resources are difficult to assess because of their three-dimensional nature, their limited accessibility and the resulting lack of data. One problem here is that the extent of a groundwater resource (width, depth ..) can not be exactly defined – impermeable, well defined boundaries do only exist in textbooks. The main parameters that can be used in the assessment are groundwater (piezometric) levels and groundwater recharge can usually only be determined point wise or not very accurately. Actual values of both parameters cannot directly be related to the actual quantity stored in a groundwater body or to the amount available in the future. For that purpose a trend analysis of the past is necessary. Every groundwater body reacts differently: reactions to changes of outer boundary conditions (withdrawal, climate change etc.) are damped and delayed; exchange with other aquifers takes place. Simple schematic examples are shown below:



Example 1: Reactions of two simple schematic aquifers with different geometrical properties to recharge: Even if the same recharge rate leads to the same head change the consequences for the status (both in terms of supply and in ecology) is quite different.

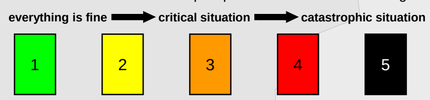


Example 2: Reactions of three schematic aquifers with different depth to the groundwater table (A and B) or covered by impermeable layers in the unsaturated zone.

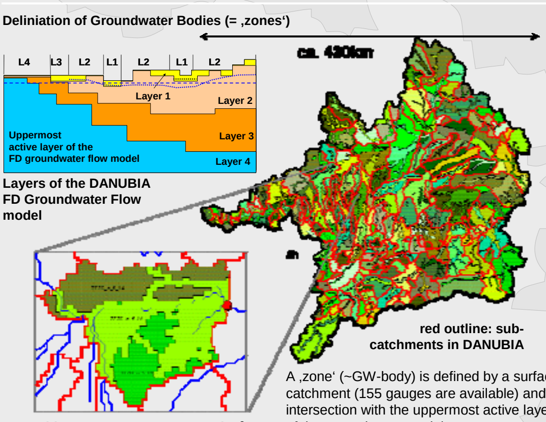
Conclusion 1: Changes of groundwater levels or changes in recharge have different meaning at different locations and cannot be generalized to assess the state of a groundwater body

Changes of natural systems are usually measured and quantified by means of characteristic parameters (here e.g.: recharge and groundwater levels). However, changes of these parameters cannot be used as *absolute* measures of the state of a groundwater resource since they include site specific characteristics. Consequently, they can not be used directly in decision making: **they have to interpreted**. A groundwater level or a groundwater level time series can only be analyzed meaningfully by a groundwater expert, who knows the local hydrogeological characteristics of the site where the measurement was taken. To couple natural science models and socioeconomic models meaningfully and realistically it is therefore necessary to include this expert knowledge in the modelling process and interpret physical signals into categorized intuitively understandable output..

Conclusion 2: The state of a resource has to be categorized in order to be used in decision making – to make the decision making process transparent and understandable for all experts (or models) involved. The approach suggested here aims at bridging a gap between groundwater experts and decision makers: Complex processes are reduced to flags:



Deliniation of Groundwater Bodies (= ‚zones')



A ‚zone' (~GW-body) is defined by a surface catchment (155 gauges are available) and its intersection with the uppermost active layer of the groundwater model.

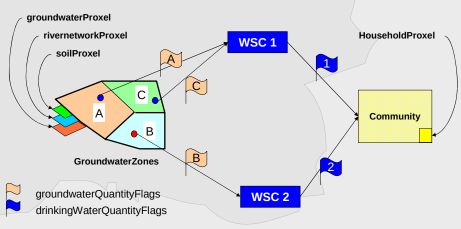
Resulting zones: 405 – 5 to 1500 km²

The approach to assess and interpret the state of Groundwater Resources

The assessment includes a **scale-appropriate delineation of groundwater bodies** based on surface catchments and a method to assess the state of such a groundwater body ('zone') based on its geometric and hydraulic properties and a **time series analysis of groundwater levels, groundwater recharge and river discharge**. A 'flag' is calculated for each groundwater body and time step (here: one month). Any decision maker or actor in a socio economic model can now use these simple, pre-interpreted values in its decision making process. This approach leaves room for individual needs and preferences of each actor. The flags can be interpreted as warnings, prohibitions or laws and they can be fully abided or completely ignored - as in reality.

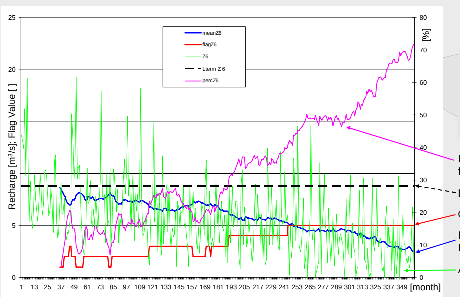
Workflow:

1. **Initialization**: For each zone, read the following parameters:
   – Initial Flag: The state of the groundwater resource at the beginning of the simulation period
   – Parameter period: Defines the relevant period length for each parameter and zone. E.g. If a groundwater body (zone) reacts very slow (long delay between increased infiltration and reaction of groundwater levels) the relevant period will be accordingly short.
   – Parameter weight: Defines the influence that changes of a specific parameter have on the state of a groundwater resources. E.g. a for a deep, confined aquifer the actual recharge situation (month, years) is only a weak indicator for the current and near future state.
   – Parameter long term average: Mean values for a parameter and zone in a reference period
   – Parameter monthly averages (used if period < 12 month)
2. **Import:**
   – At each time step, read the parameters calculated by the Groundwater, the RiverNetwork and the Soil model components of DANUBIA
3. **Parameter Flag Calculation**:
   – Aggregate parameters (sum, average, min, max) for each zone
   – Calculate the moving average of each parameter in each zone for the period defined in "parameter period"
   – Compare and classify the deviation of the moving average either to
     • The long term average of this parameter in the zone (in case the period is longer than 12 month)
     • Or to the long term average of the corresponding period in the past: e.g. if the actual month is September and the period is 6 month, the moving average of is compared to the long term mean of April to September (i.e. ~ a 'reference summer')



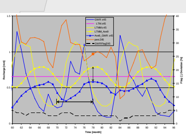
4. **Flag Calculation**:
   – Calculate the weighted average of all parameter flags
   – Apply filters and rules to prevent unwanted effects → GroundwaterQuantityFlag **Calculation**
   – Use GroundwaterQuantityFlags to **calculate** DrinkingWaterQuantiyFlags
5. **Export:** Flags to Actor Models in DANUBIA

Flag Calculation and Results



Calculation of a Parameter Flag (here Groundwater Recharge) for one zone

In case the period is smaller than 12 month:



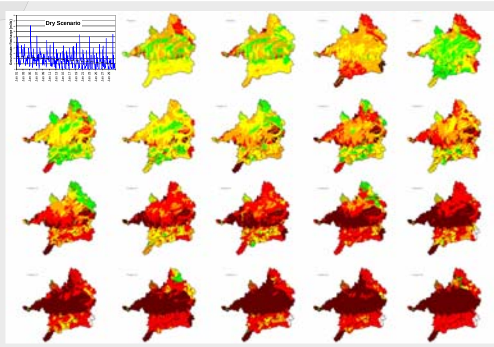
Deviation of Groundwater Recharge (moving average) from long term mean [%]

Long term mean of Groundwater Recharge

Groundwater Recharge Flag

Moving Average (period = 36 month) of Groundwater Recharge

Aggregated Groundwater Recharge (per month and zone)



GroundwaterQuantityFlags for a **extremely** dry (and not very realistic!) scenario for the years 2001 to 2031 and related results for one month in 2011 of the same simulation.