Assessment of the quantitative state of groundwater resources on the regional scale under conditions of Climate Change in Southern Germany.

Roland BARTHEL*, with contributions by S. Stoll, H. Hendricks-Franssen, W. Kinzelbach and W. Mauser

*Institute of Hydraulic Engineering (IWS), University of Stuttgart,
Pfaffenwaldring 61, D-70569 Stuttgart, ++49 711 685-66601, roland.barthel@iws.uni-stuttgart.de
• This presentation is largely based on the paper:

• Other directly related papers:
  – Barthel, R., Jagelke, J., Gaiser, T., Printz, A. & Götzinger, J. (2008): Aspects of choosing appropriate concepts for modelling groundwater resources in regional Integrated Water Resources Management – Examples from the Neckar (Germany) and Ouémé catchment (Benin). - Physics and Chemistry of the Earth, 33, 1-2, 92-114
Additional information on the projects

• GLOWA-Danube:
  – DANUBIA Modelling system Open Source (source code and documentation):
    http://www.glowa-danube.de/de/opendanubia/allgemein.php
    (currently the OpenDanubia web page is only available in German, software documentation is however available in English)

• RiverTwin:
  – Home page: http://www.rivertwin.org/
1. The significance of the regional scale and the importance of integrated approaches in climate change impact studies

2. Climate change impact studies in southern Germany:
   - GLOWA-Danube (BMBF)
   - Rivertwin (EC)
   - ETH-Zurich (Swiss National Science Foundation)

3. Assessment strategy developed in GLOWA-Danube

4. Conclusions
Importance of the regional scale: (1) Bridging the gap

Global Scale

Local Scale
Importance of the regional scale: (2) Integrate dependencies and feedbacks

- Climate Change impact assessment has to be integrative:
  - Climate Change affects groundwater directly but also indirectly (→ changing demands, land use changes etc.)
  - Groundwater interacts with other “systems” in various ways (→ surface waters, groundwater dependent ecosystems etc.)

  ➔ Extremely complicated network of dependencies, feedbacks, adaptations

- Feedbacks can only be analysed at the regional scale:
  - Closed balances (→ interaction with SW)
  - Capture source and sink / cause and effect relations (→ land use)

- The regional scale is the most important “management scale”
• Climate Change impact assessment has to be integrative:
  – Climate Change affects groundwater directly but also indirectly
  – Groundwater interacts with other “systems” in various ways
    ➔ Extremely complicated network of dependencies, feedbacks, adaptations

• Feedbacks can only be analysed at the regional scale:
  – Closed balances
  – Capture source and sink / cause and effect relations

• The regional scale is the most important “management scale”
• Consequences of Global Change in the Upper Danube Catchment

• **Integrated / Interdisciplinary Approach:** 12 research groups from different disciplines (Meteorology ... Tourism Research)
DANUBIA Simulation System

All models are process based, spatially discretized to 1*1km cells, daily or monthly time steps

Model interface, but also interface to the society, the decision makers

Workshop “Climate Change Impacts on Groundwater October 12th 2011, Warsaw
GLOWA-Danube Global Change Scenarios

<table>
<thead>
<tr>
<th>Choice 1: Climate Trends</th>
<th>Choice 2: Climate Type</th>
<th>Choice 3: Social Trends</th>
<th>Choice 4: Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPCC regional</td>
<td>Baseline</td>
<td>Baseline</td>
<td>Information Cooperation</td>
</tr>
<tr>
<td>REMO regional</td>
<td>5 warm Winters</td>
<td>Free is fair</td>
<td>Subsidies for Water saving techn.</td>
</tr>
<tr>
<td>MM5 regional</td>
<td>5 hot Summers</td>
<td>Shared destiny</td>
<td>Build reservoirs</td>
</tr>
<tr>
<td>Trend Extrapolation</td>
<td>5 dry years</td>
<td></td>
<td>...</td>
</tr>
</tbody>
</table>

Scenario development:

➤ A widely underestimated, extremely important task in Climate Change impact assessment !!
Results: Groundwater recharge and groundwater levels (temporally)

All results simulated using coupled simulations with DANUBIA;
Scenario results are based on one single scenario combination.

Reference Period (1960-2006)
(simulated using observed climate data)

Scenario Period (2011-2060)
(simulated using the REMO-regional–Baseline climate scenario data)
Results: Groundwater recharge and groundwater levels (spatially)

Groundwater recharge deficits

Recharge Differences [mm/a]
- < -600
- -600 - -301
- -300 - -201
- -200 - -101
- -100 - -51
- -50 - 50
- 51 - 100
- 101 - 200
- >200

Groundwater level changes

GW-Level-Differences (combined) [m]
- < -10
- -9.9 - -5.0
- -4.9 - -2.0
- -1.9 - -1.0
- -0.9 - 0.9
- 1.0 - 1.9
- 2.0 - 4.9
- 5.0 - 9.9
- >10

Areas not modeled with MODFLOW

REMO-Regional-Baseline Scenario
Günzburg district
Danube low lands, arable land, wide alluvial aquifers

Ostallgäu district
pre-alpine, grassland, narrow alluvial and tertiary aquifers
Summary of results (groundwater quantity)

• Catchment-wide:
  – Increasing temperature, decreasing precipitation, decreasing groundwater recharge – decreasing groundwater heads
  – Shift of annual maxima and minima (more recharge in winter)

• Locally:
  – Strong differences due to spatial changes of precipitation (and landuse) patterns
  – **Strong differences due to different response of different aquifers**
Questions

• (How reliable / certain are these results?)

• What do those results really mean?:
  – How can we use those results for decision making i.e. translate them to categories of “good” and “bad”, “better” and “worse”?
  – How can we compare and assess the situation in different locations?
Past observations: Different “response types”

- Increasing Seasonality

- Decreasing Similarity

Time series classification
And
Hydrogeological Similarity

Standardized 30 year time series
Origin of different response types: Different hydrogeological settings

(a) Shallow unconfined, direct connection to river, low thickness
(b) Shallow unconfined, direct connection to river, high thickness
(c) Deep unconfined, no direct connection to a river

Legend:
- K: hydraulic conductivity (aquifer)
- S, Sy: storativity, specific yield (~storage capacity) (aquifer)
- K_{UZ}: hydraulic conductivity (unsaturated zone)
- d_{UZ}: thickness of unsaturated zone
- T: thickness of aquifer
- R: recharge (dominant)

(d) confined, no direct connection to a river, no direct recharge from precipitation
(e) System comprising several aquifers; separated (e1), partly connected (e1)
How is this helpful for the assessment of climate scenarios?

• Wells with similar behavior are located in similar hydrogeological settings \(\rightarrow\) "Hydrogeological Response Units"

• Knowing that, we “just” need to:

  – Identify and separate “hydrogeological response units” with similar responses to change ("groundwater body delineation"),

  – Understand what different responses in different “hydrogeological response units” mean (analyze response mechanisms)

  – Find out which state variables are suitable to assess the changes (indicator development)
The ‘Flag’ concept of GLOWA-Danube to express an aquifers state

**State variables**
- Groundwater Level
- Groundwater Recharge
- Baseflow

Spatially aggregated to “groundwater bodies”

Evaluation of trends for characteristic response periods

Classification based on comparison with reference periods

Classification using a weighted combination of different indicators

405 groundwater bodies from:
- 155 SW catchments
- 4 main regional aquifers
- 6 main landscape units

Groundwater Quantity Index ("Flag")

Everything is fine ➔ critical ➔ catastrophic

1 ➔ 2 ➔ 3 ➔ 4 ➔ 5
Different weighting of state variables, different “characteristic response times”

(a) Shallow unconfined, direct connection to river, low thickness

(b) Shallow unconfined, direct connection to river, high thickness

(c) Deep unconfined, no direct connection to a river

Legend:
- K: hydraulic conductivity (aquifer)
- S, S_y: storativity, specific yield (~storage capacity) (aquifer)
- K_UZ: hydraulic conductivity (unsaturated zone)
- d_UZ: thickness of unsaturated zone
- T: thickness of aquifer
- R: recharge (dominant)

(d) confined, no direct connection to a river, no direct recharge from precipitation

e) System comprising several aquifers; separated (e_1), partly connected (e_1)
Assessment Results

Recharge Differences [mm/a]

-600 - -301
-300 - -201
-200 - -101
-9.9 - -5.0
-4.9 - -2.0
-1.9 - -1.0

GW-Level-Differences (combined) [m]

-100 - -51
-50 - 50
51 - 100
101 - 200
>200

1 – 1.5 - very good
1.5 – 2.5 - good
2.5 – 3.5 - critical
3.5 – 4.5 - bad
4.5 – 5 - very bad

Areas not modeled with MODFLOW

Workshop “Climate Change Impacts on Groundwater October 12th 2011, Warsaw
Conclusions

• Assessment of climate change impacts on groundwater quantity (and quality) requires:
  – A regional scaled analysis
  – Integration of the entire hydrological cycle
  – A good understanding of system behavior in the past
  – **Very** intelligent approaches to groundwater body delineation and regionalization of local observations
  – Individual evaluation and weighting of state variables for indicator development

• **Much more reliable (regional) scenarios of precipitation!!!**
Thank your for your attention!

Barthel, R.: An indicator approach to assessing and predicting the quantitative state of groundwater bodies on the regional scale with a special focus on the impacts of climate change. *Hydrogeology Journal 19,3 (2011) 525-546*