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GLOWA Danube

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

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Literature

- **This presentation is largely based on the paper:**
  - **Barthel, R. (2011):** ***An indicator approach to assessing and predicting the quantitative state of groundwater bodies on the river basin scale with a special focus on the impacts of climate change. Hydrogeology Journal (2011) 19,3: 525–546. DOI: 10.1007/s10040-010-0693-y***
- **Other directly related papers:**

  - Barthel, R., Janisch, S., N. Schwarz, A. Trifkovic, D. Nickel, C. Schulz, W. Mauser (2008): An integrated modelling framework for simulating regional-scale actor responses to global change in the water domain. Environmental Modelling and Software, 23, 1095-1121 (doi:10.1016/j.envsoft.2008.02.004)
  - Barthel, R., Janisch, S., Nickel, D. & Trifkovic, A. (2010): Using the Multiactor-Approach in GLOWA-Danube to Simulate Decisions for the Water Supply Sector under Conditions of Global Climate Change. – Water Resources Management, 24,2, 239-275 (DOI - 10.1007/s11269-009-9445-y)
  - Barthel, R. Rojanschi, Wolf, J. & Braun, J. (2005): Large-scale water resources management within the framework of GLOWA-Danube. Part A: The groundwater model. - Physics and Chemistry of the Earth, 30, 6-7, 2005, Pages 372-382
  - 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
  - Barthel, R., Reichenau, T., Mürth, M., Haag, I., Schneider, K., Hennicker, R. und W. Mauser (in press): Folgen des Globalen Wandels für das Grundwasser in Süddeutschland - Teil 1: Naturräumliche Aspekte: Grundwasser, online first DOI 10.1007/s00767-011-0179-4.
  - Barthel, R., Krimly, T., Elbers, M., Soboll, A., Wackerbauer, J., Hennicker, R., Janisch, S., Reichenau, T., Dabbert, S., Schmude, J., Ernst, A. und W. Mauser (in press): Folgen des Globalen Wandels für das Grundwasser in Süddeutschland - Teil 2: Sozioökonomische Aspekte . Grundwasser, online first DOI 10.1007/s00767-011-0180-y.
  - Gaiser T, Printz A, Schwarz von Raumer H G, Götzinger J, Dukhovny V A, Barthel, R., Sorokin A, Tuchin A, Kiourtsidis C, Ganoulis I, Stahr K (2008): Development of a regional model for integrated management of water resources at the basin scale. - Physics and Chemistry of the Earth, 33, 1-2, 2008, Pages 175-182
  - Soboll, A, Elbers, M., Barthel, R., Schmude, J., Ernst A., Ziller, R. (2011): Scenarios of future water demand: Regional scale modelling of the human-environment-system to support decision making under global change conditions. Mitigation and Adaptation Strategies for Global Change 16,4 (2011) 477-498. - DOI: 10.1007/s11027-010-9274-6.
  - Stoll, S., Hendricks Franssen, H. J., Barthel, R., and Kinzelbach, W.: What can we learn from long-term groundwater data to improve climate change impact studies?, Hydrol. Earth Syst. Sci. Discuss., 8, 7621-7655, doi:10.5194/hessd-8-7621-2011, 2011.

- GLOWA-Danube:
  - Home page: http://www.glowa-danube.de/eng/home/home.php
  - GLOWA-Danube Atlas: http://www.glowa-danube.de/atlas/
  - 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/

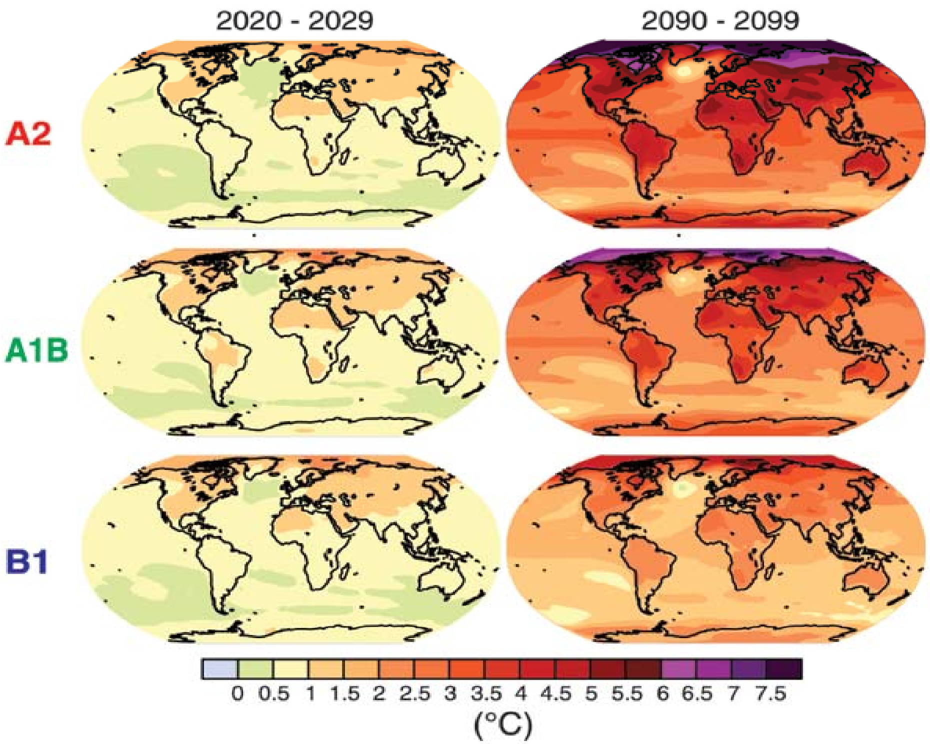
Outline

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



Global Scale

⟺

Local Scale

- 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**"

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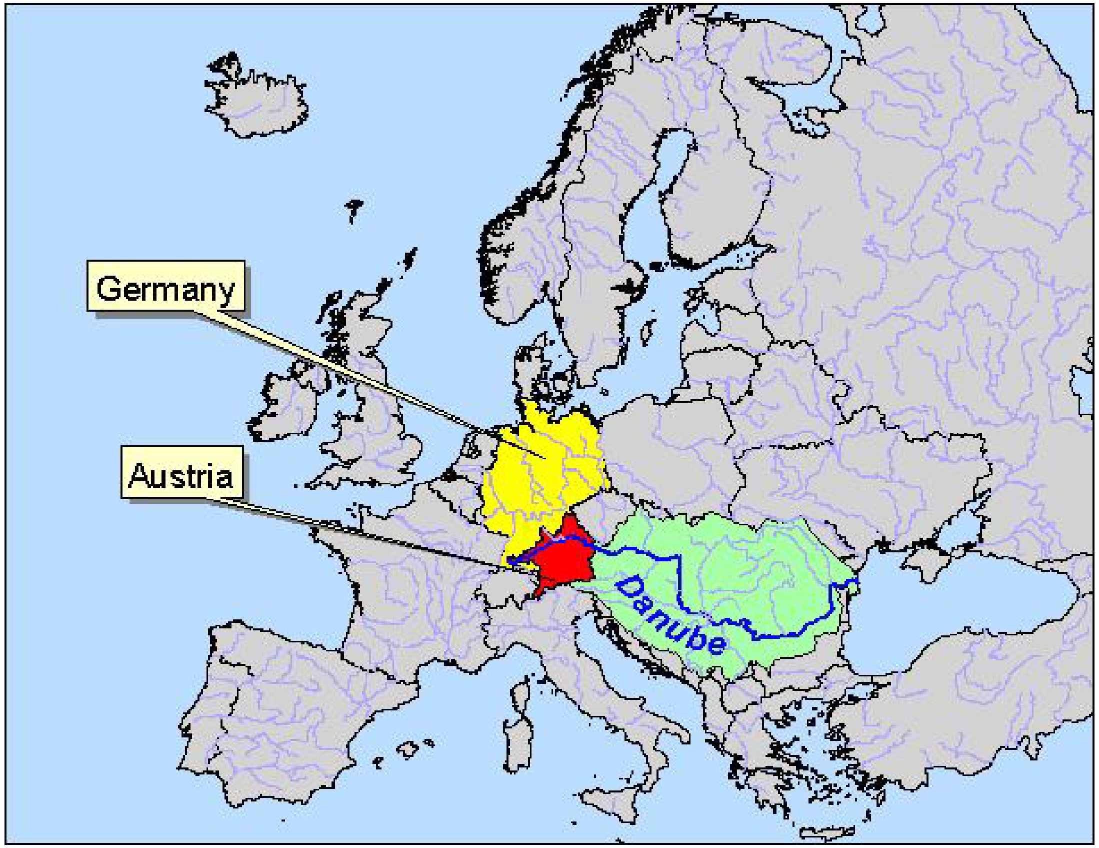
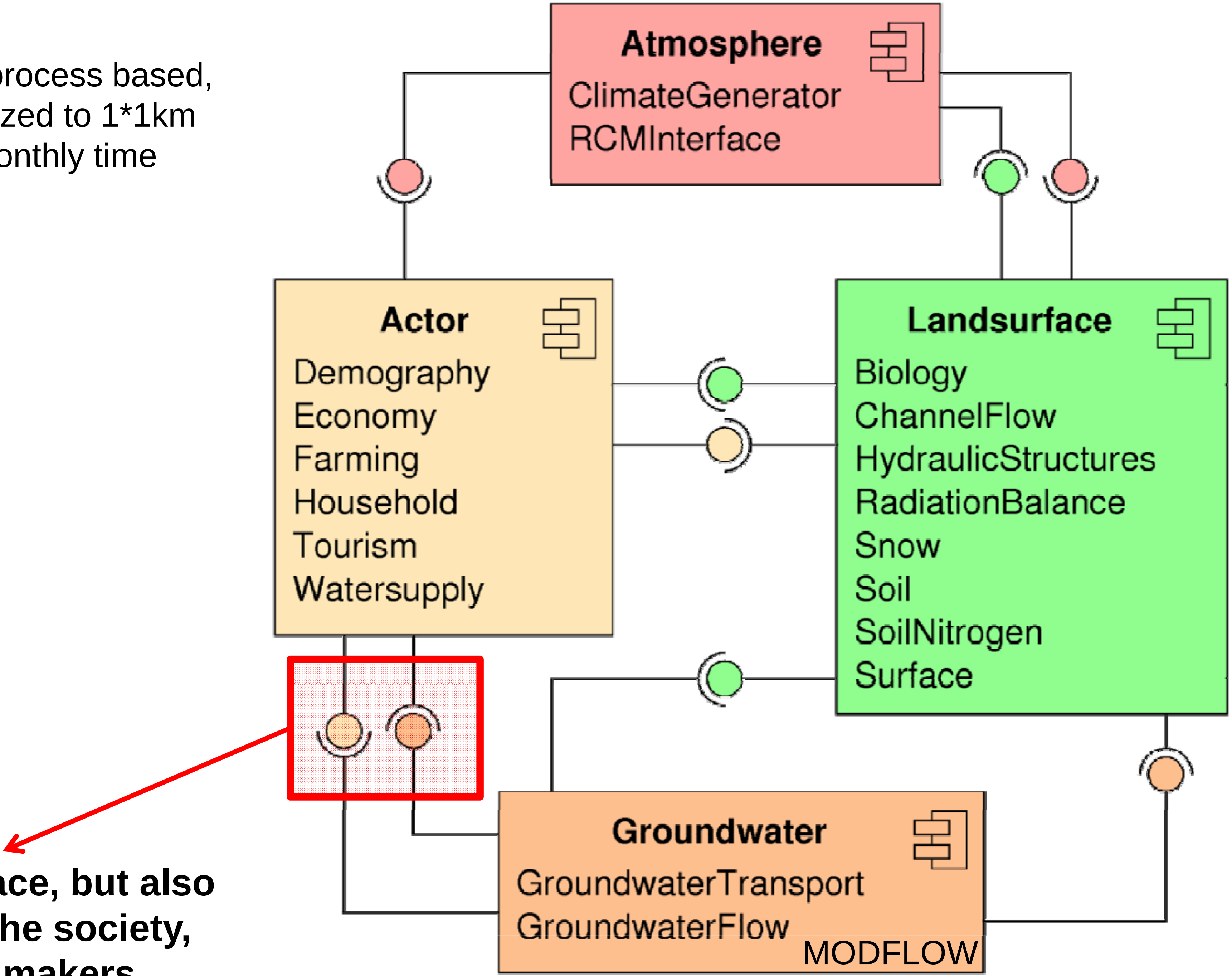
- **Consequences of Global Change in the Upper Danube Catchment**
- **Integrated / Interdisciplinary Approach:** 12 research groups from different disciplines (Meteorology … Tourism Research)



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

GLOWA-Danube **Global Change** Scenarios

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

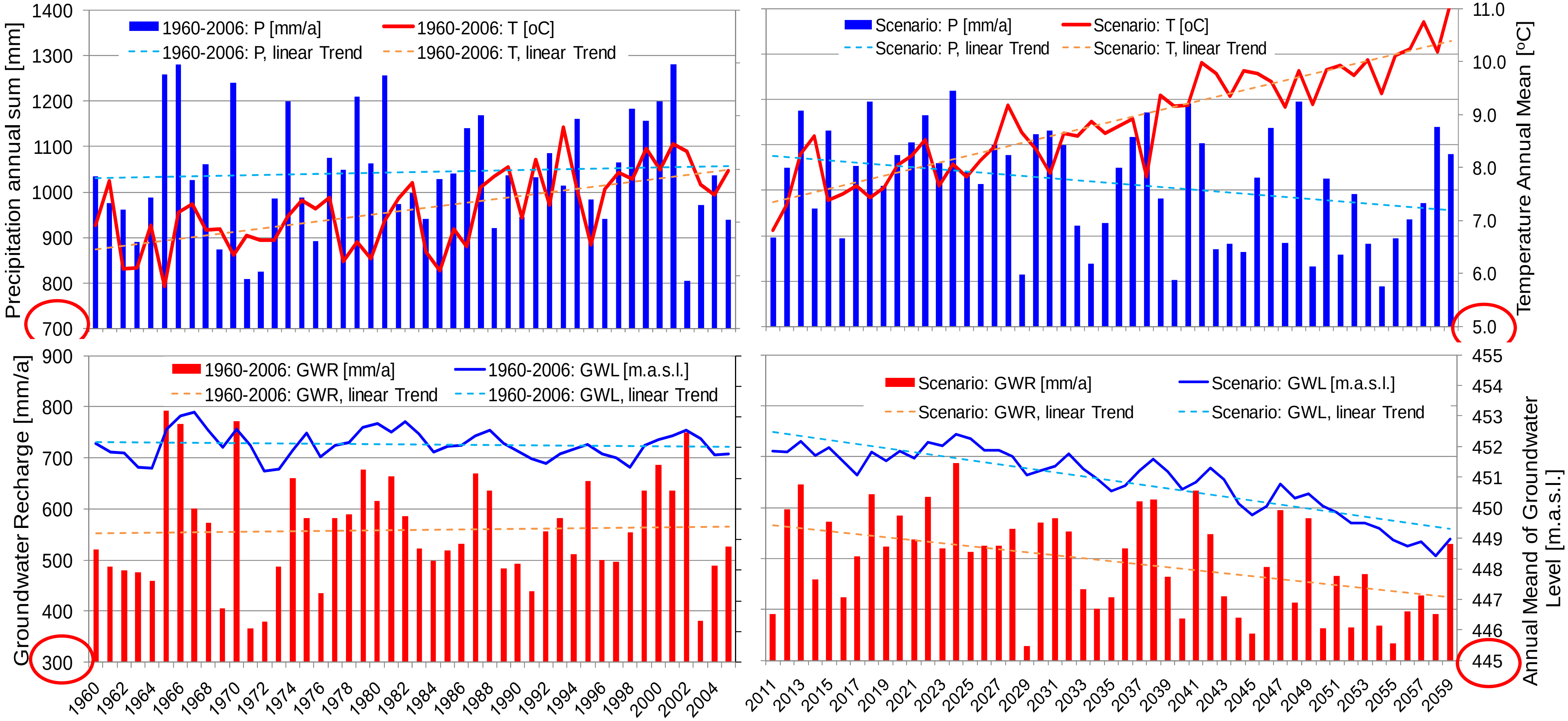
Scenario development:

➡ 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;

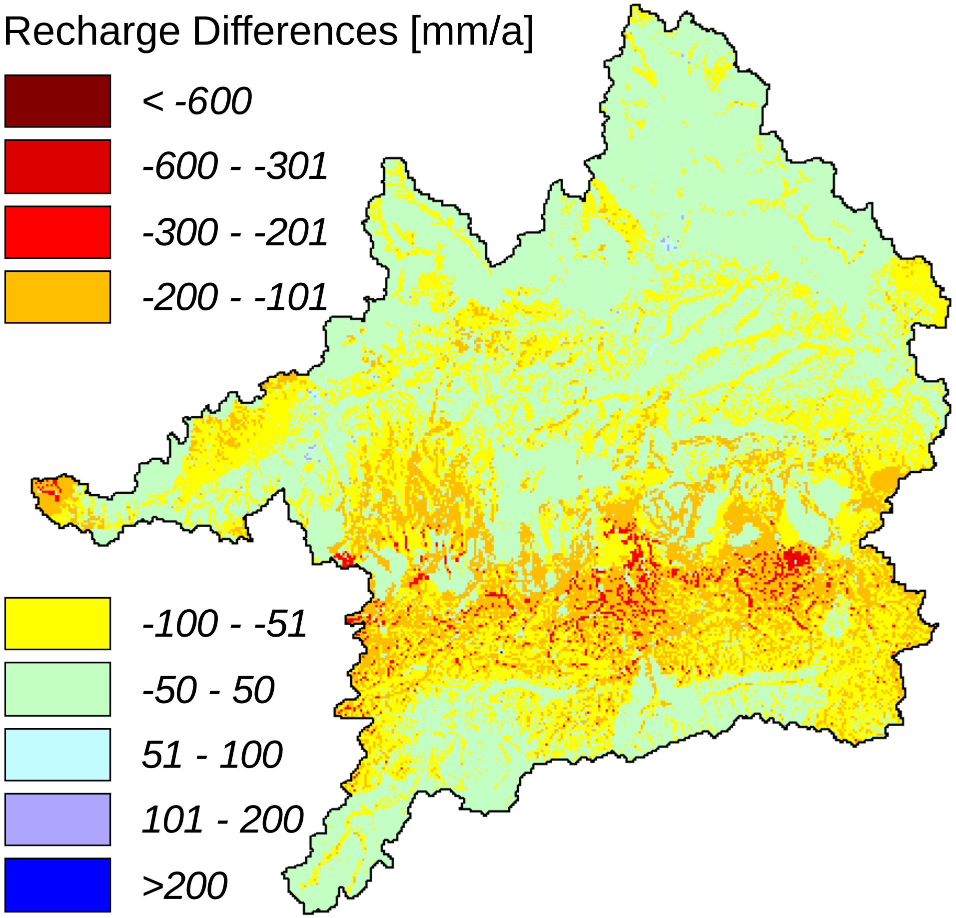
Scenario results are based on one single scenario combination.



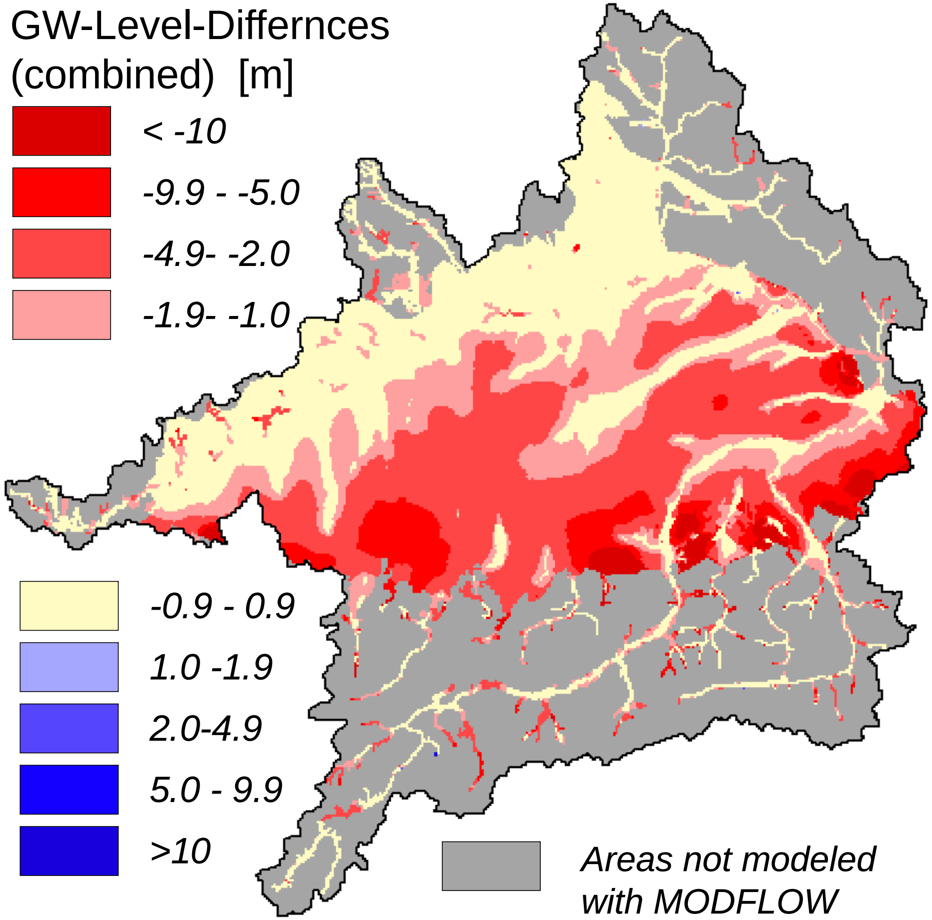
Reference Period (1960-2006)
(simulated using observed climate data)

Scenario Period (2011-2060)
(simulated using the **REMO-regional–Baseline** climate scenario data)

Groundwater recharge deficits

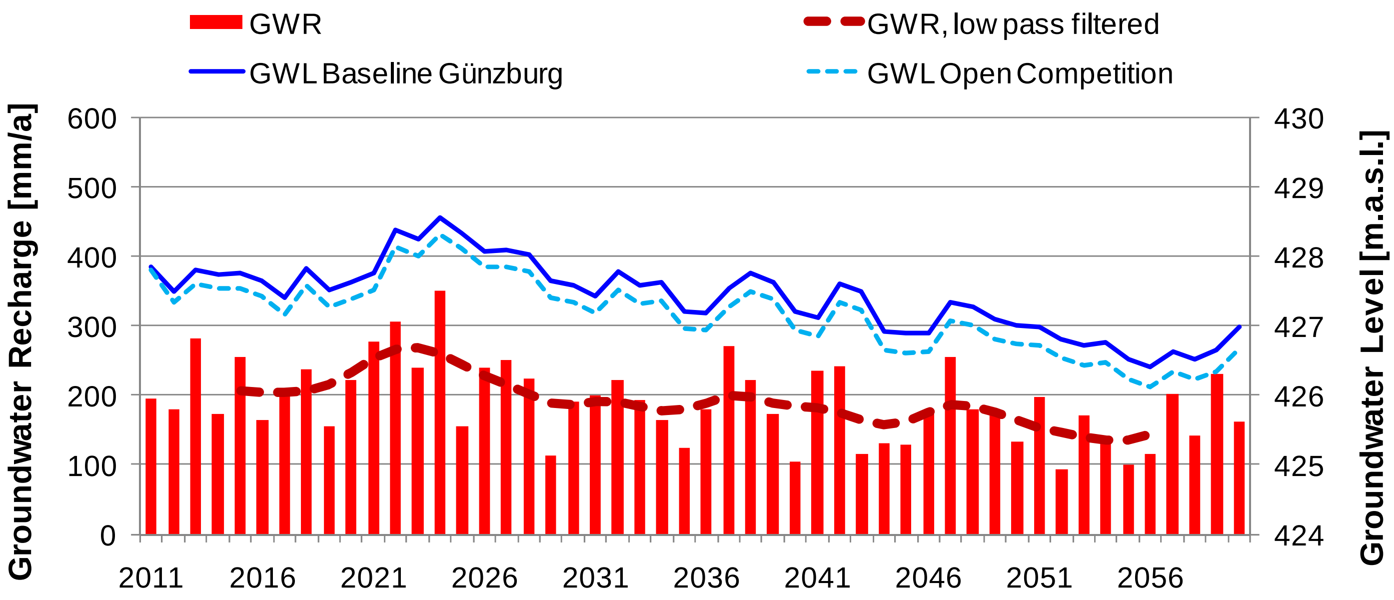


Groundwater level changes

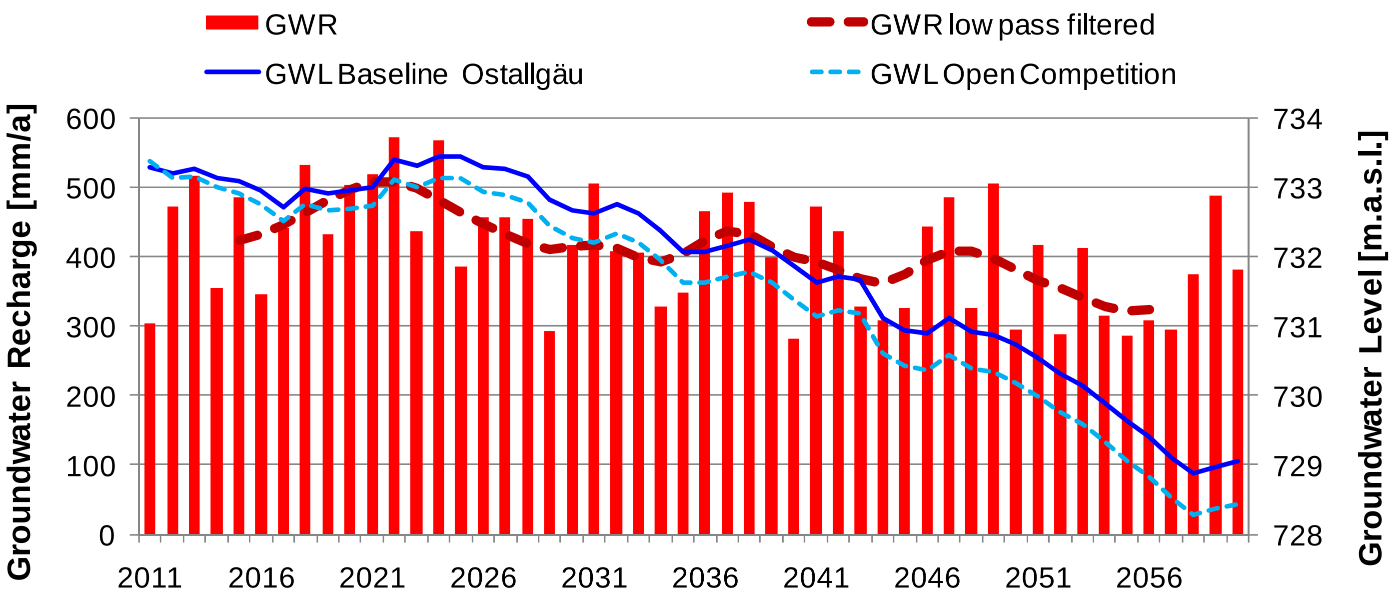


Differences Scenario 2036-2060 minus Reference (1971-2000)
REMO-Regional-Baseline Scenario

Local results



Günzburg district
Danube low lands,
arable land,
wide alluvial aquifers



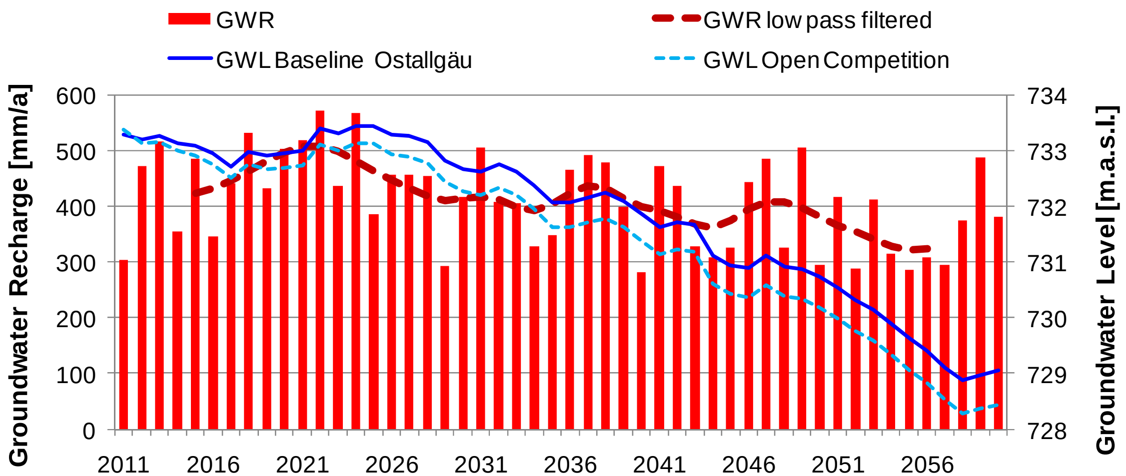
Ostallgäu district
pre-alpine, grass-
land, narrow alluvial
and tertiary aquifers

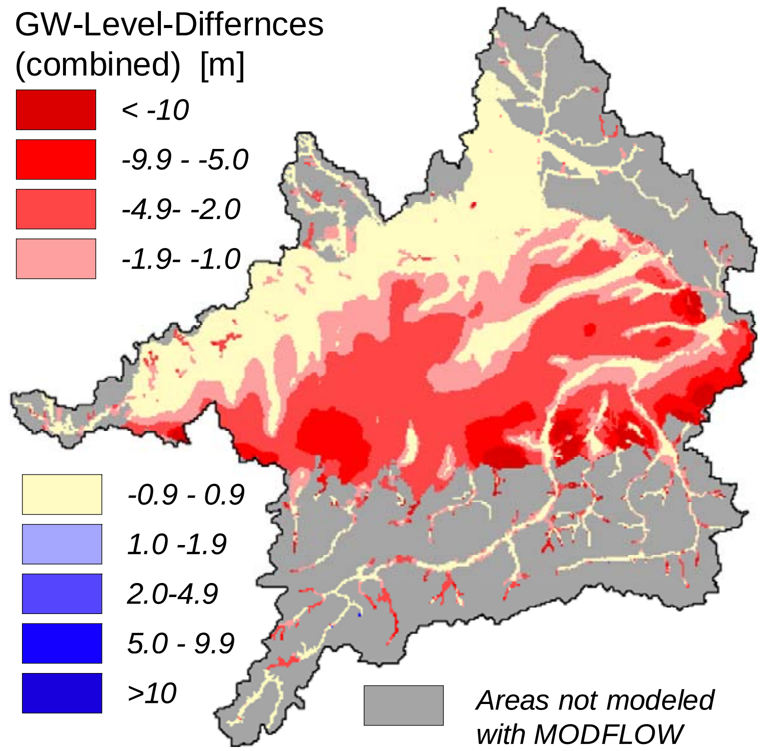
Summary of results (groundwater quantity)

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

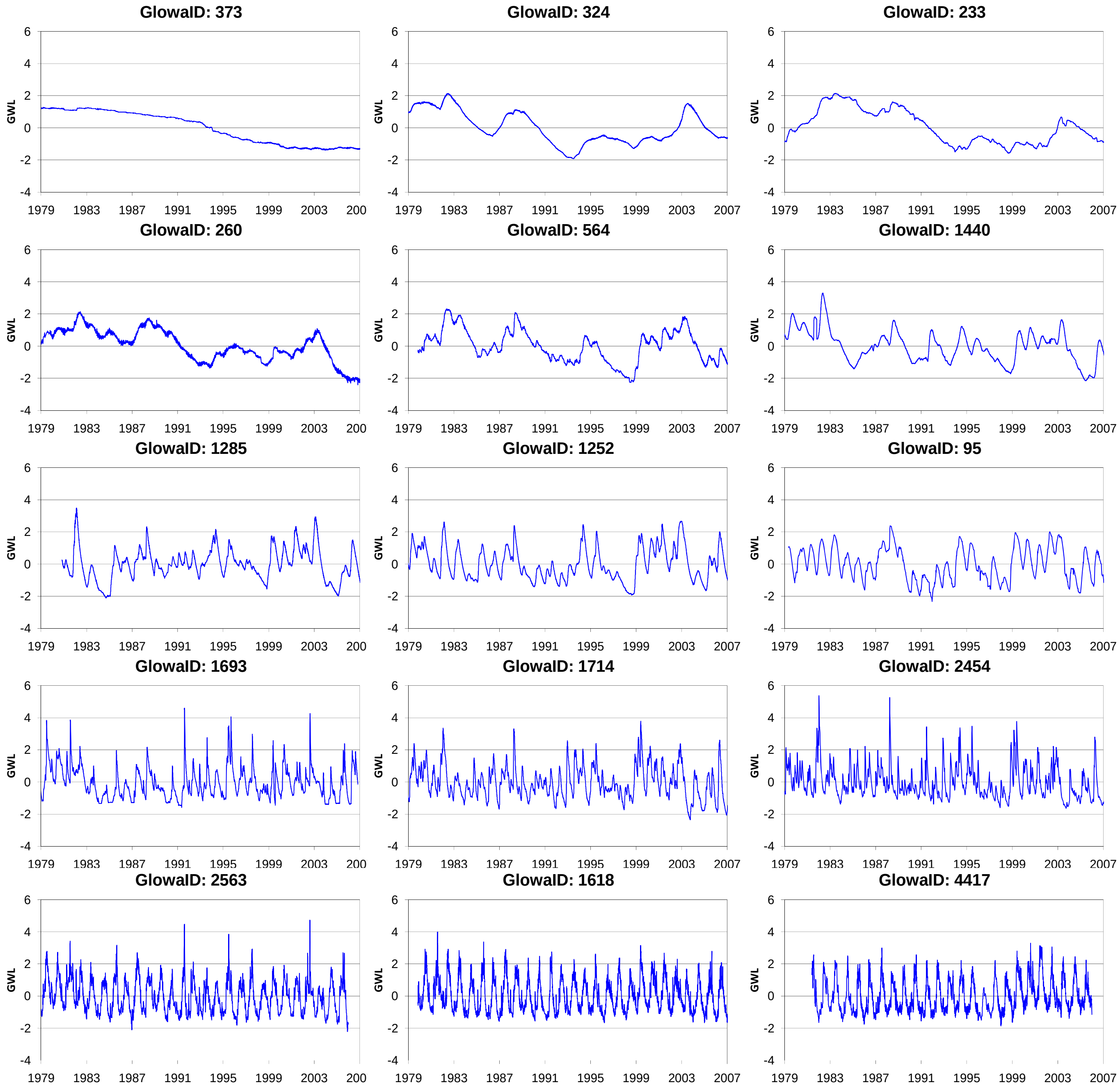
- Locally:
  - Strong differences due to spatial changes of precipitation (and landuse) patterns
  - **Strong differences due to different response of different aquifers**

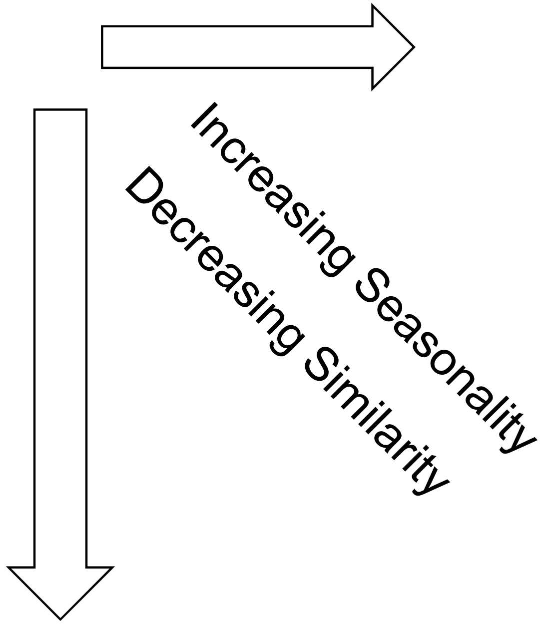
- (How reliable / certain are these results?)
- **What do those results really mean?:**
  - How can we use those results for decision making i.e. translate them to categories of “good” and “bad”, “better” and “worse”?
  - How can we compare and assess the situation in different locations?





Past observations: Different „response types“

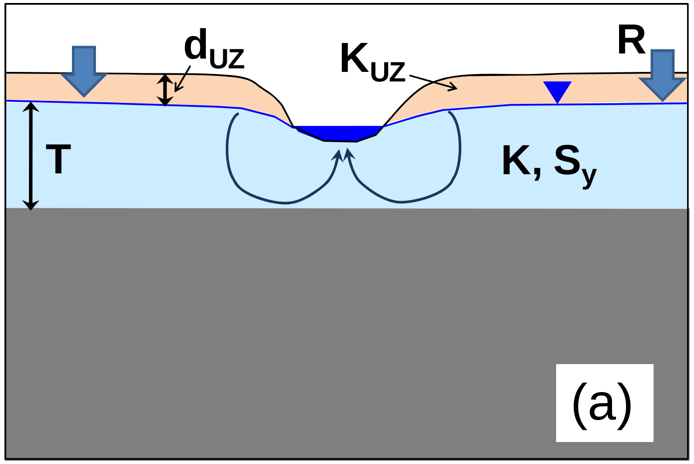




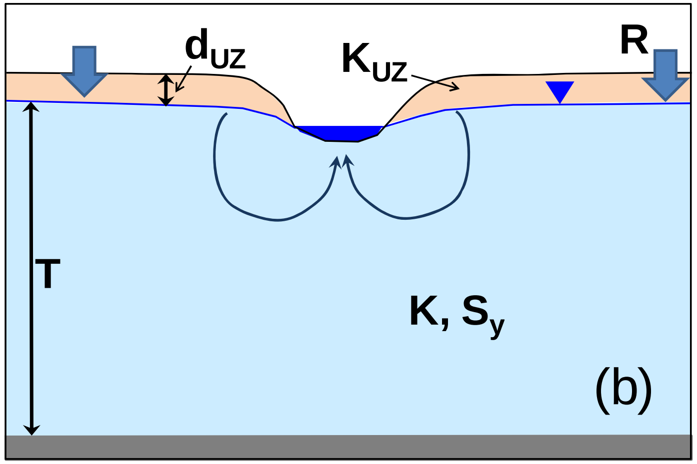
Time series classification
And
Hydrogeological Similarity

Standardized 30 year time series

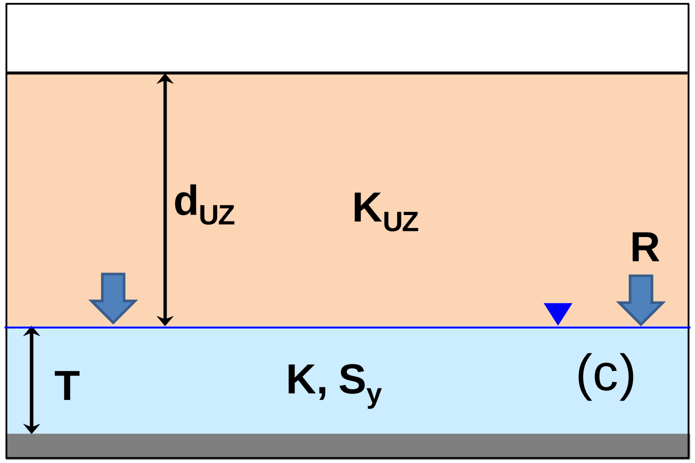
Origin of different response types : Different hydrogeological settings



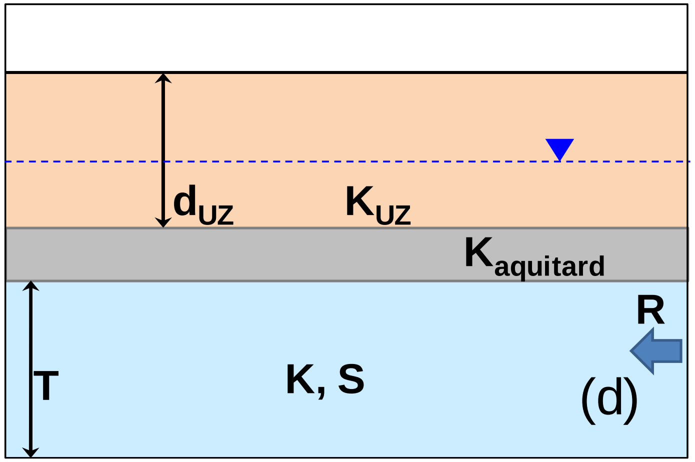
a) Shallow unconfined, direct connection to river, low thickness



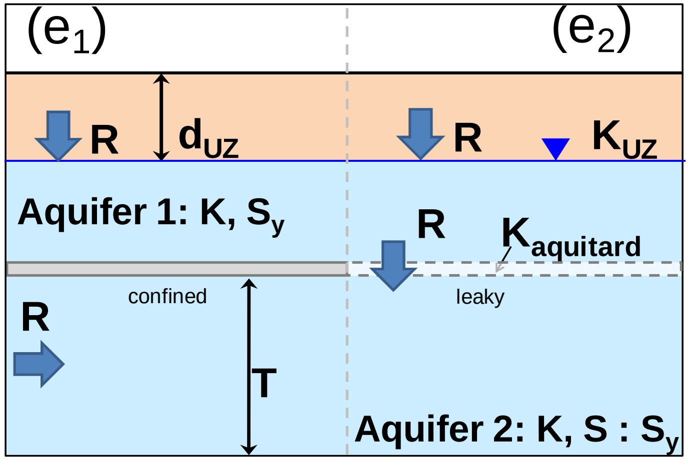
b) Shallow unconfined, direct connection to river, high thickness



c) Deep unconfined, no direct connection to a river



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)

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)

How is this helpful for the assessment of climate scenarios?

- **Wells with similar behavior are located in similar hydrogeological settings → "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**)

State variables
Groundwater Level
Groundwater Recharge
Baseflow

spatially aggregated to "**groundwater bodies**"

⇨ Evaluation of trends for **characteristic response periods**

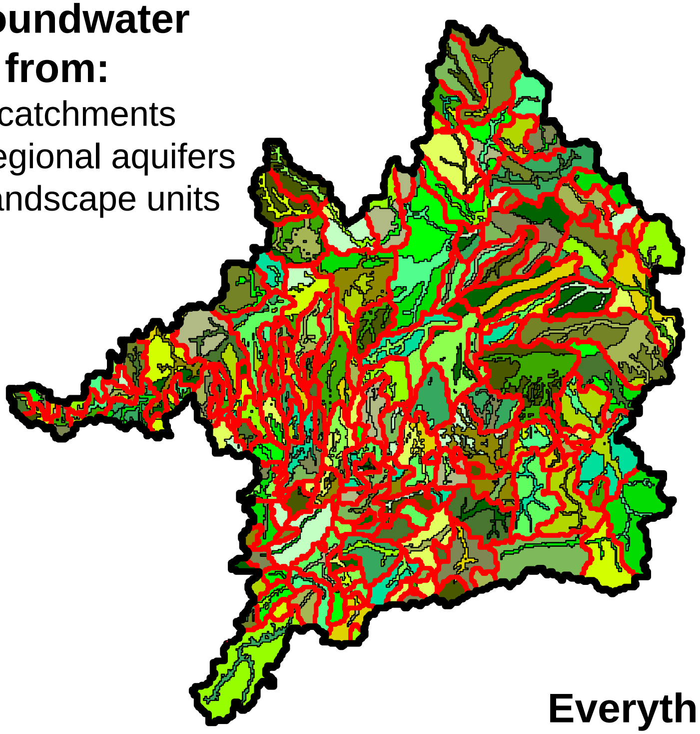
⇨ classification based on comparison with **reference periods**

⇩

Classification using a **weighted combination** of different indicators

⇩

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

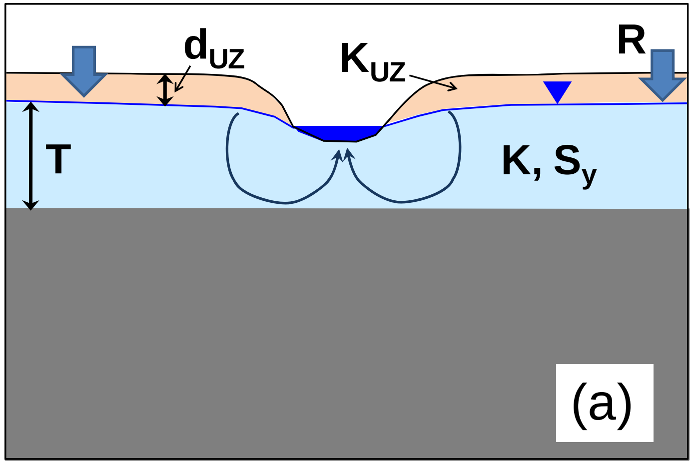


Everything is fine ➡ **critical** ➡ **catastrophic**

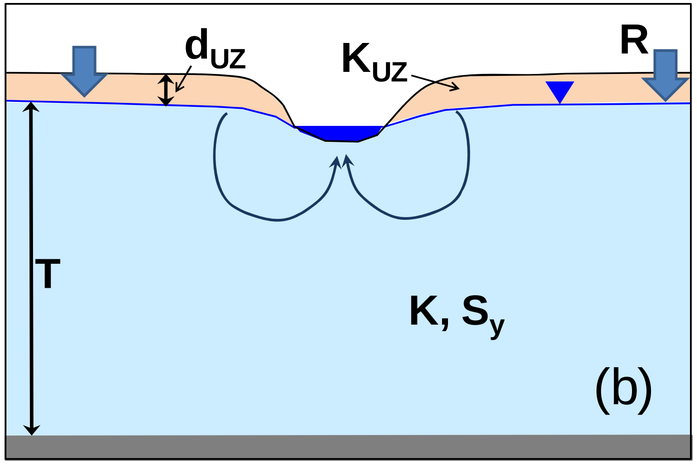
Groundwater Quantity Index ("Flag")

1	2	3	4	5

Different **weighting** of state variables, different “**characteristic response times**”



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



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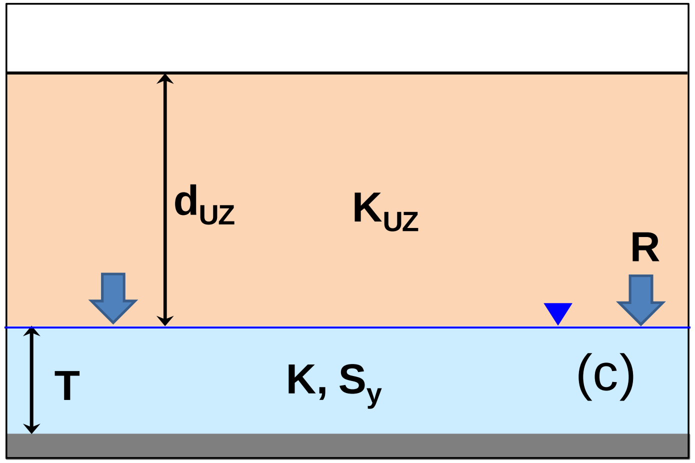

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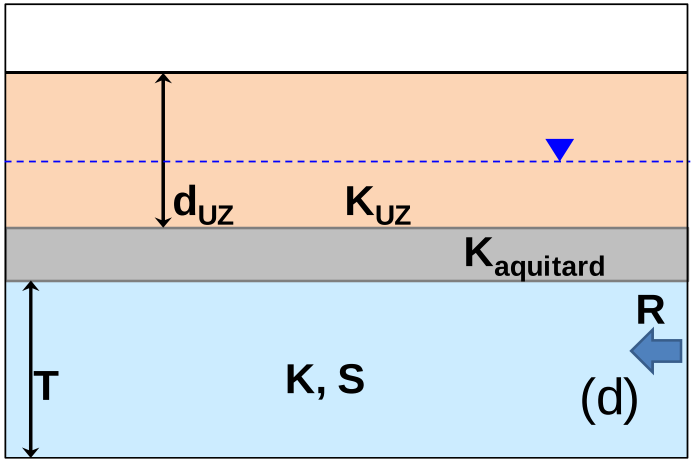

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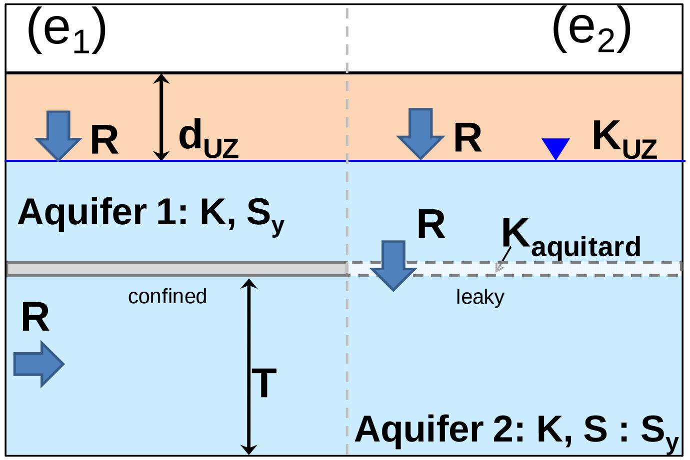

e) System comprising several aquifers; separated (e_1), partly connected (e_1)

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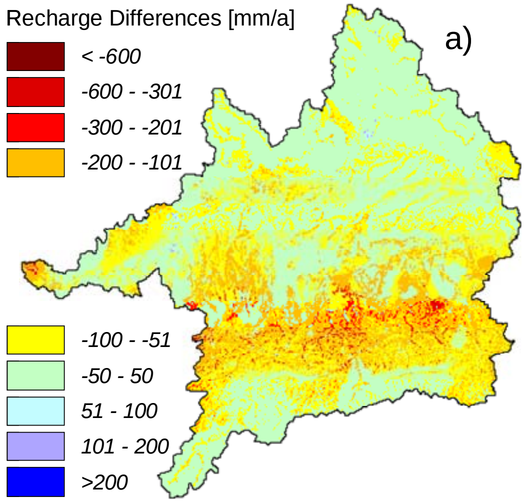
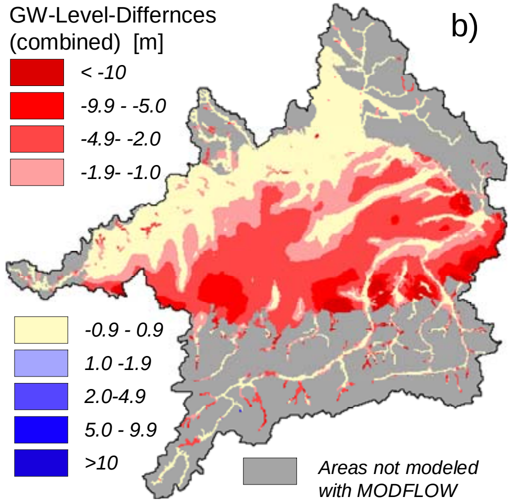
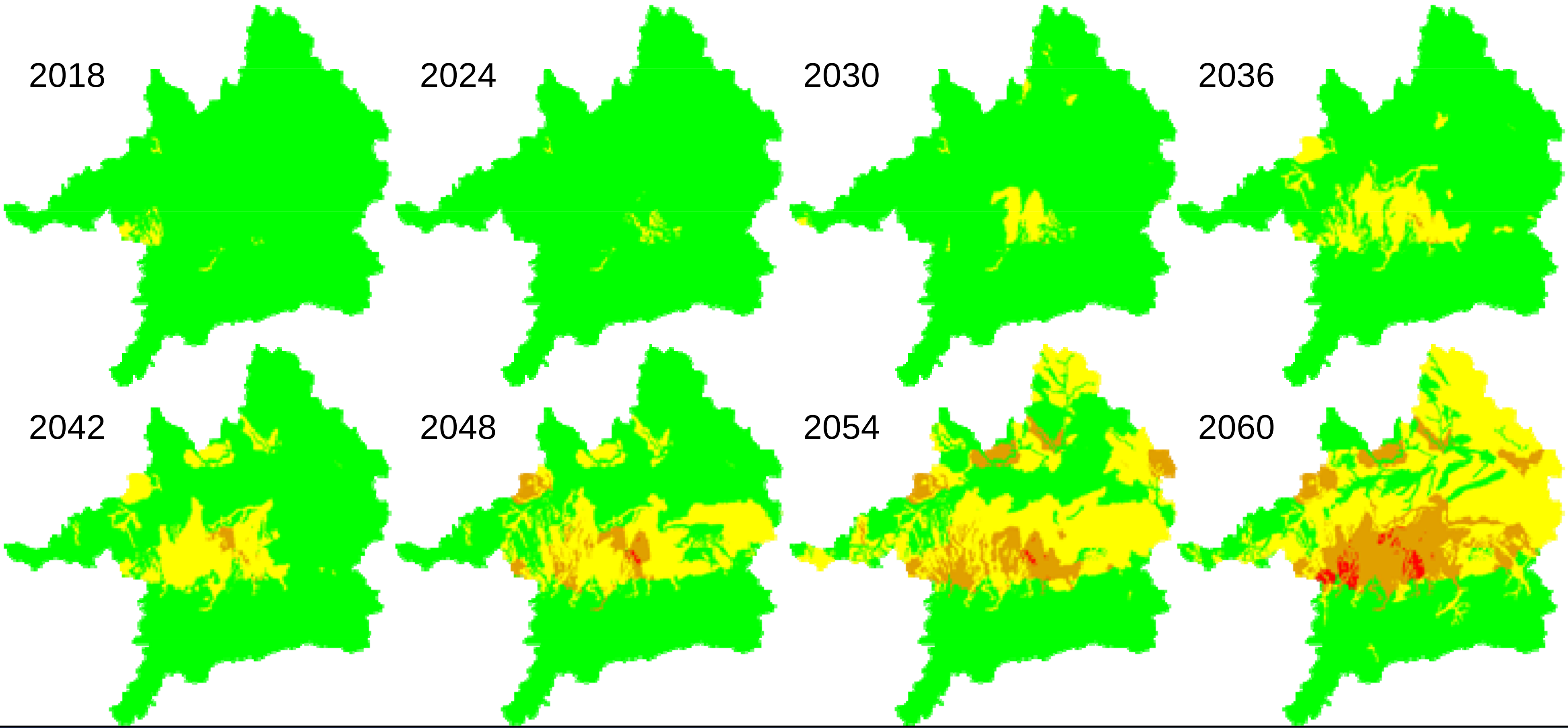
T:	thickness of aquifer
R:	recharge (dominant)

Assessment Results

- 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







- 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***