3 GLOWA case studies

3.1 Danube

Impact of Global Change on the Upper Danube
Global Climate Change will have significant long term impacts on water resources. These will include an increase in extreme events (floods and low flows), a decline in snow cover, deglaciation in the Alps and changes in natural vegetation and agriculture in the Upper Danube. In order to plan future investments in water resources, energy, agriculture, tourism and industry a detailed analysis of the impact of Climate Change is required.

The GLOWA-Danube project (www.glowa-danube.de) focuses on the mountainous regions of the Alps and the forelands of the Upper Danube. (Figure 3.1). The Upper Danube is the headwater of Europe's second largest river, has more than 11 million inhabitants, and extends from temperate lowlands to glaciated mountain ranges higher than 3500 m. For further details see Box 3.1.

The Upper Danube has a current water surplus serving the large downstream regions of the Danube. Water resources are optimised to meet the demands of transport, tourism, irrigation, hydropower generation and industry using extensive reservoir storage and water transfer schemes. These demands will be sensitive to expected climate change because of the large altitudinal gradient (approximately 3000 m), the importance of both snow and glacial melt water (Figure 3.2) and the anticipated changes in seasonal water availability. Any change in water resources in the Upper Danube will also affect the large and developing population in downstream Central and Eastern European countries which have recently joined the European Union. These complex environmental, economic, social and political factors make it essential to study the impact of climate change.

No single scientific discipline is capable of understanding these complex interactions. This challenge

Figure 3. 1 The Upper Danube Basin

Box 3.1 The River Danube

- Overall length approx. 2,850 km
- Total catchment area 817,000 km²
- Size of the Upper Danube project area 77,000 km²
- Current population in the Upper Danube catchment of approximately 11.2 million (2006)
- Averaged annual rainfall in the catchment 1,240 mm (1971–2000)
- Averaged annual discharge at gauge Achleiten (near Passau) 1,430m^3/s (1901–2005)
- Water quality in the region is currently among the best in Europe
- The Alps are currently the largest surplus water region in Europe

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Figure 3.2
The confluence of the river Inn (coloured green by cold water from glaciers) and the river Danube at Passau, Germany.

was addressed within the GLOWA project by co-operation between a group of researchers from different natural and socio-economic science disciplines, consisting of hydrologists, water resources engineers, meteorologists, glaciologists, geographers, ecologists, environmental economists, environmental psychologists and computer scientists.

4 Meeting the challenge of the GLOWA programme

4.1 Danube: The future of low-flows in the Upper-Danube Basin

Introduction
It is the goal of GLOWA-Danube to develop and validate integration techniques, models and new monitoring methods to assess the impact of Global Change on the water resources of the medium-sized (area 77,000 km²) Upper Danube basin.

The project has developed the network-based decision support system DANUBIA (Figure 4.1) to identify strategies for the management of water by analysing different global change scenarios for the period 2011–2060. The results are iteratively discussed with key stakeholders to evaluate alternative options and outcomes for water allocation and use.

The following research questions were addressed:

- How large is the expected impact of climate changes on water-use?
- How will the changing water availability affect agriculture?
- How will demographic and technological change affect the water consumption of the population?

The environment in the Upper Danube is comparable to that in many other mountainous areas, and thus the approach is transferable to other regions such as the Pyrenees, Himalayas, Andes, Caucasus and Ethiopian Highlands.

The decision support system DANUBIA
DANUBIA is a coupled predictive simulation model. It includes for the first time model components for natural sciences, socio-economic processes and their interactions. The hydrological component is a spatially distributed, physically based hydrological model that uses inputs from regional climate models for predicting the impacts of Climate Change. Physical components describe the natural processes of hydrology, hydrogeology, plant physiology, yield and glaciology. The model enables the impact of different demand scenarios and decision making by the agriculture, economy, water supply, domestic and tourism sectors to be estimated by simulating decision making based on the structure of societies, their framework and priorities (Figure 4.1). All components of DANUBIA run parallel on an inexpensive LINUX-cluster. It was carefully and successfully validated with comprehensive data sets for the years 1970–2005. DANUBIA will be made available as “Open source” at the end of the third project stage in 2010. It will be of particular value to decision makers in policy, economics, and administration.

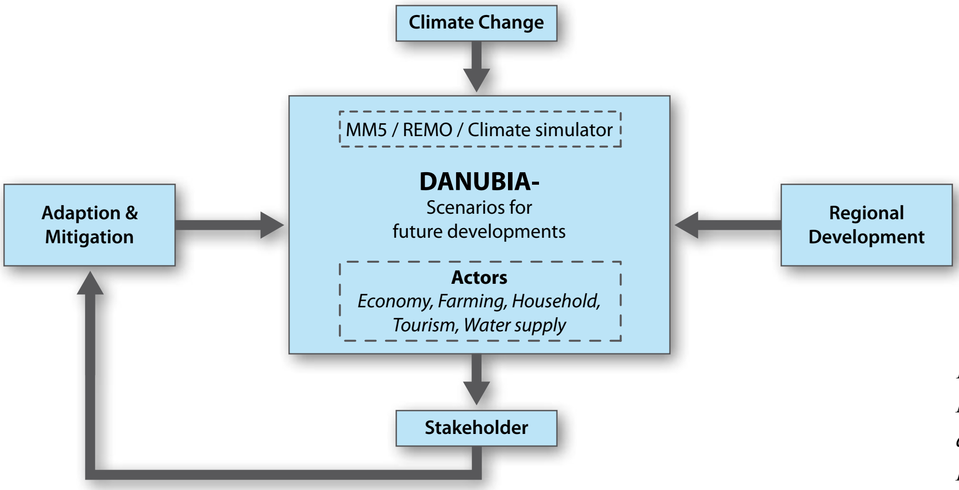

Figure 4.1
Model of the scenario-based decision support system DANUBIA

Excerpt from IHP/HWRP-Berichte, Heft 7, 2008, ISSN 1614-1180

Scenarios of future low-flows in the Upper-Danube Basin

Low river flows are characterized by a prolonged period with below the seasonal average discharge and are a critical limiting factor for the utilization of water resources. Low-flows are the result of reduced storage of water in soils, rocks, snow packs, glaciers and lakes and are caused by prolonged dry periods, increased evaporation and freezing temperatures. They can reduce hydropower production, limit the availability of cooling water for thermal power stations, restrict navigation and lead to considerable financial costs. The impacts of low flows have been mitigated by reservoir construction which enable surplus water to be stored during periods of high river discharge and released during dry periods. Additionally water can be transferred from regions with a surplus to drier regions.

From a global perspective climate change is usually perceived as an expected long term increase in average air temperature, which is assumed to be estimated with low uncertainty in magnitude and spatial distribution. However predicted changes in rainfall are much less certain and for Central Europe IPCC expect no significant change in mean annual rainfall but significant increases in winter and a corresponding decrease in summer rainfall. A key question of global importance that GLOWA has addressed using DANUBIA is: “How serious will the impact of changing climate be on low flows and what are suitable adaptation strategies to mitigate adverse impacts?” (Mauser 2008). Figure 4.2 and Figure 4.3 show the results (not calibrated against historical river flow data) for the period between 1971 and 2003 for the Passau gauge (close to the outlet of the 77,000 km² Upper Danube basin). The daily discharge, annual minimum 7-day average flow and the annual variability of low-flows are well captured by the model compared with the measured historical data.

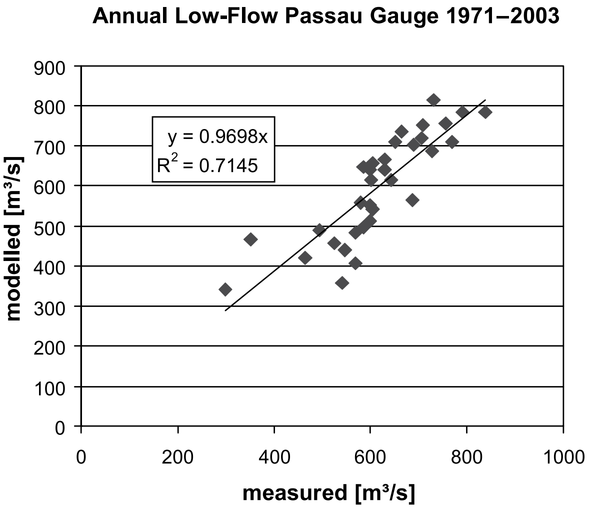

Figure 4.2 *Measured and modelled annual low-flow (minimum 7-days average discharge) for the reference period of 1971–2003 at Passau gauge, Upper Danube basin.*

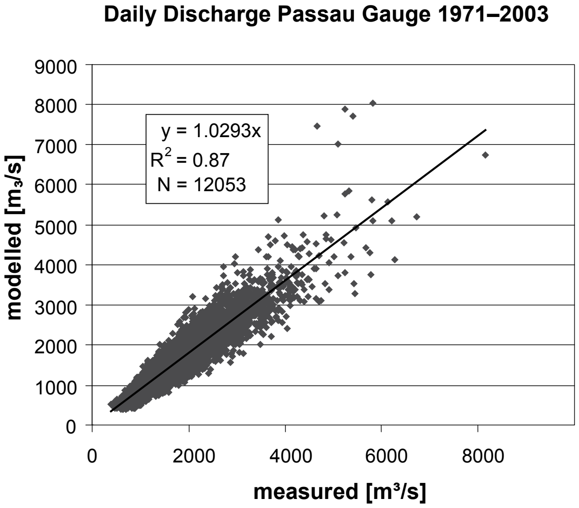

Figure 4.3 *Measured and modelled daily discharge for the reference period of 1971–2003 at Passau gauge, Upper Danube.*

Based on these results the model was used to estimate scenarios of river flows for the period from 2011 to 2060 using the output of a stochastic climate generator. It used the IPCC-A1B scenario, which resulted in a 3 degrees temperature increase in the Upper Danube watershed by the year 2060. Using measured meteorological data a large number of possible rainfall and temperature series were derived which followed the predicted long term temperature trends. These were then used to model ensembles of predicted river flows. Seventeen of these were selected based on criteria such as the driest 5-year period in the first 25 years or the hottest summer between 2035 and 2060. All selected scenarios were used together with a scenario which assumed that no further change in temperature will occur. Figure 4.4 shows the result of the ensemble model runs.

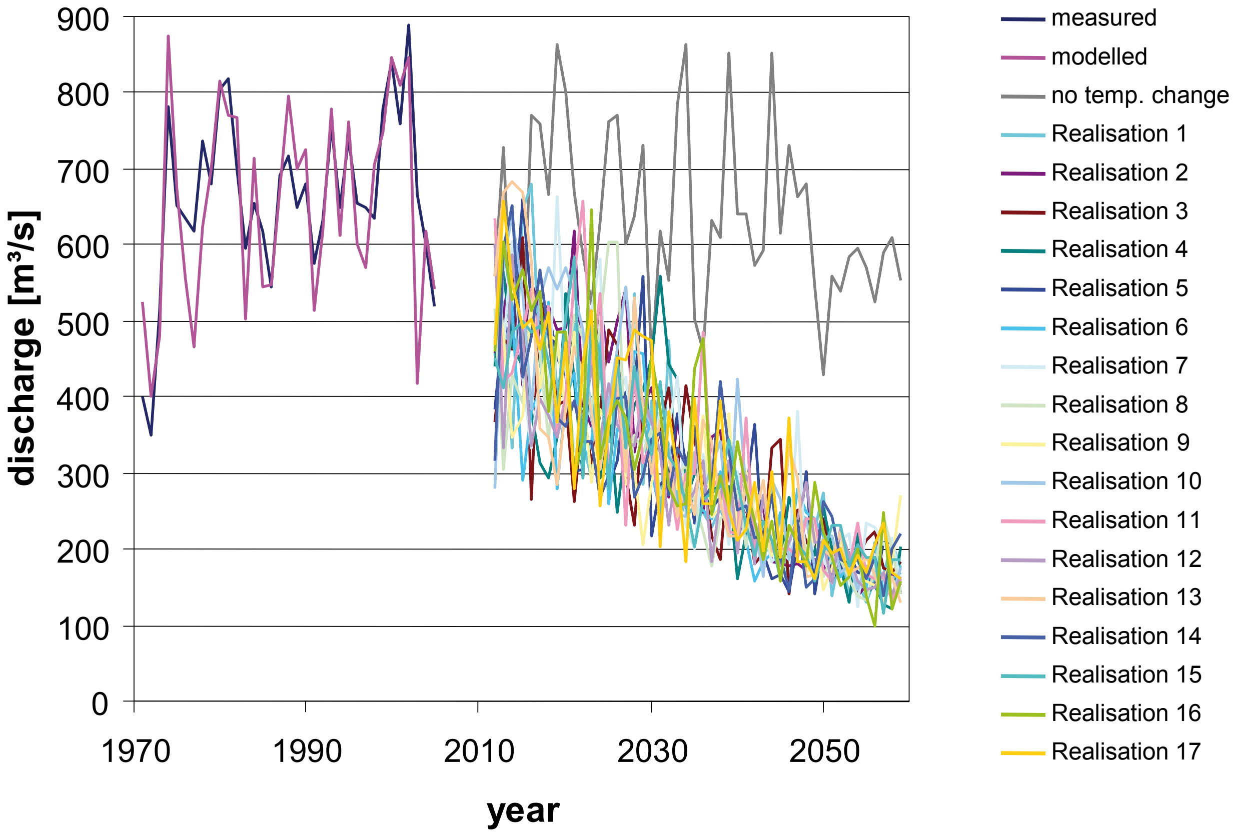

Figure 4.4 *Measured and modelled (left part of graph) and projected annual low-flow (minimum average 7-days discharge) for a scenario with no further temperature change (grey curve right part of graph) and an ensemble of 17 statistically equivalent realisations of the IPCC-A1B scenario at Passau gauge in the Upper Danube watershed.*

The measured and modelled historical annual minimum low-flows are compared in the left part of Figure 4.4. As has already been shown in Figure 4.2 good agreement between observed and modelled flows was achieved with DANUBIA.

The right part of Figure 4.4 shows the results of a wide range of possible future scenarios of annual minimum low flows. It can be clearly seen that the no-climate-change scenario (grey line) produces a future very similar to the past. The ensemble of A1B scenarios shows a consistently high decrease in annual minimum low-flows for all ensemble members together with the uncertainty range caused by statistical fluctuations in the climate inputs. These statistical variations are very similar to variations which are observed today. Future low flows are estimated to be approximately one third of today's values – a considerable reduction. These important results are currently being discussed by local stakeholders to identify possible adaptation strategies, which will then be implemented in DANUBIA and tested for their effectiveness and efficiency.

Box 4.1 Summary

Scenarios of the regional consequences of climate change on the water resources form the basis both for a structured dialogue with stakeholders in the watershed and for the simulated decisions of actors in the social science context of GLOWA-Danube.

It is essential to develop uncalibrated but validated models of the hydrologic processes, to cover the full range of expected future hydrologic change. The example shows both the performance of the developed model as well as the analysis of future low-flow in the Upper Danube watershed based on an ensemble of 17 realisations of the IPCC-A1B climate scenario. The results were discussed with stakeholders, who will develop investment strategies for water related infrastructure.

4.2 Danube: Modelling the human-nature interaction in DANUBIA

Global change research of the water cycle poses a special challenge, i.e. to describe in detail the intertwining of natural and social processes. Changes in natural drivers lead to adaptation needs and social reactions, which in turn are based on a very high number of individual preferences, decisions and learning processes each influencing each other. To represent such complexity and to allow for the integrated simulation of societal and natural processes in DANUBIA, the DEEPACTOR framework was developed. It provides a common conceptual and architectural basis for the modelling and implementation of the socio-economic simulation models in GLOWA-Danube. The framework applies the “agent-based” simulation approach used in modern social sciences, which is based upon concepts of distributed artificial intelligence. Decision making entities such as individuals, organisations, and companies are explicitly modelled and simulated as ‘actors’. An actor observes its social, economic and physical environment and selects one action from a set of alternatives as a reaction to its observations. The actions in turn have impacts on the natural environment and other stake holders. Different actors may respond differently depending upon their knowledge or access to data, their memory capacity, preferences, budget and location. Some of these parameters may vary over time, making agent-based models realistic social science process models.

To illustrate the interplay of natural and societal processes, it is interesting to observe the DANUBIA Groundwater, Water Supply, and Household models. Water Supply is an actor model of the water supply sector comprising water abstraction, treatment and distribution. Household is another actor model for modelling in detail the domestic water use. While the suppliers usually have good knowledge of the groundwater availability, the individual consumers simply consume without being fully aware of the technical issues of groundwater distribution and availability. Apart from delivering water to the modelled consumers in DANUBIA, the Water Supply model provides them with information about the state of the water supply system (Barthel, Mauser & Braun, 2008; Barthel, Nickel, Meleg, Trifkovic & Braun, 2005). This information is provided in a condensed form using “flags”. Flags assume integer values from 1 (good) to 4 (catastrophic). The Water Supply model calculates two flags at each time step based upon a set of physical parameters, interfacing Groundwater on one hand and the Households on the other. The ‘groundwater quantity’ and ‘groundwater quality’ flags describe the system state of the groundwater resources in a defined zone. The ‘drinking water quantity' flag is a water supply evaluation of the quantitative changes in availability of drinking water resources that is committed to the water users.

The interpretation of changes in the state of the groundwater bodies by the water supply companies can vary depending on their sensitivity to sustainability

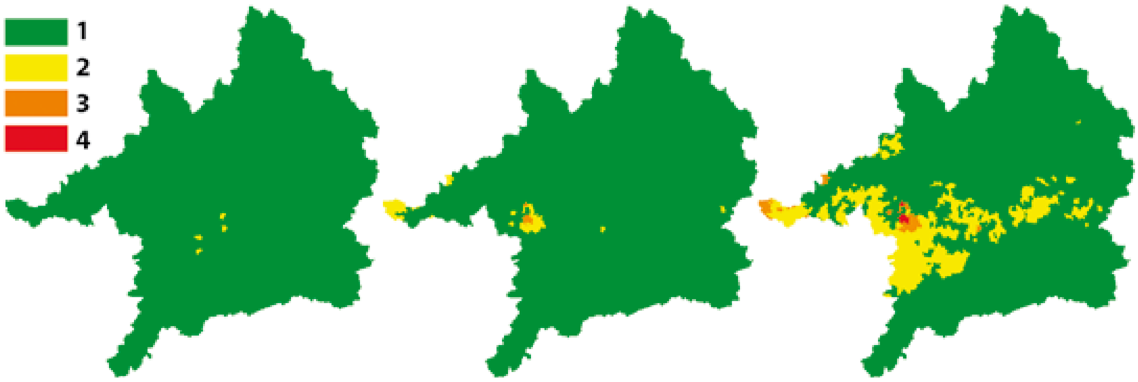

Figure 4.5 Spatial distribution of the modelled drinking water quantity flags [from 1 (good) to 4 (catastrophic)] for the upper Danube catchment in July 2038 for the business as usual climate scenario and non-sensitive (left), middle (middle) and sensitive (right) behavioural modes of water supply companies.

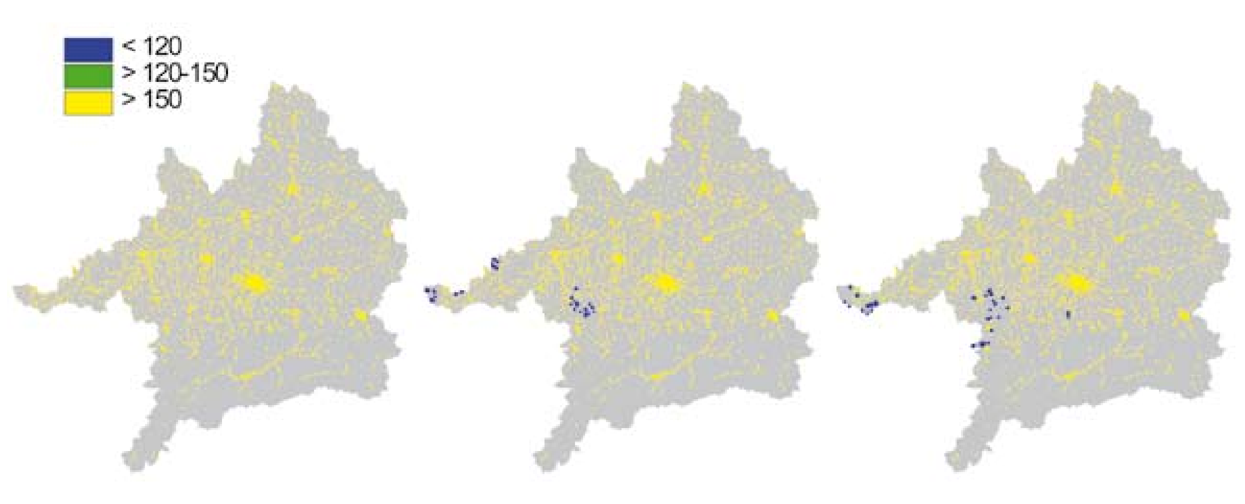

Figure 4.6 *Spatial distribution of modelled domestic water use (in litres per household per day) in the upper Danube catchment in July 2038 for the business as usual climate scenario. As in Figure 4.5, the runs relate to non-sensitive (left), middle (middle) and sensitive (right) behavioural modes of water supply companies. The households show a high water consumption (July), except for the regions where flags have been shown.*

threats and their willingness to communicate them to the water users. Currently, we consider three such interpretations, ranging from ‘non-sensitive’ (i.e. disregarding changes and not communicating them, and trying to satisfy demand by implementing supply side technical measures of higher abstraction rates) over ‘middle’ (i.e. taking a pragmatic and economically oriented approach) to ‘sensitive’ (i.e. giving higher priority to sustainability issues, communicating them immediately and taking appropriate measures). Figure 4.5 shows a comparison of the resulting spatial distribution of drinking water quantity flags for a “business as usual” type climate scenario.

The drinking water quantity flags communicated by the water suppliers can be interpreted as different levels of public awareness regarding water availability. They influence the households’ water use. The extent of this influence depends on the individual household’s lifestyle, budget, location, and technical infrastructure (Ernst, Schulz, Schwarz & Janisch, 2008). As can be seen from Figure 4.6, the affected households reduce their water use according to the information received.

In addition to societal reactions to water related changes, the Household model also incorporates the increased household distribution of water saving technologies, e.g. water-saving shower heads or rain-harvesting systems. Political scenarios (like subsidising a technology) have also been applied and show the take up of innovation in the catchment over time, thus further reducing domestic water consumption (Schwarz & Ernst, in press).

Box 4.2 Summary

Modelling the human-nature interaction is one essential feature of DANUBIA. For the social process models, the technique of agent-based modelling is used and directly interfaced with the natural science process models. The example given here shows the Water Supply model conveying information about resource sustainability to the domestic water users, e.g. in the form of public statements or recommendations. This information is the result of an interpretation of natural states driven by the preferences of the respective water supply company.

The end users, represented in the Household model, in turn interpret the information given and translate it into individual behaviour, e.g. by changing water use habits. It also influences their investment in water saving technology in the household.

5 Lessons for sustainable development

5.1 Danube: The significant impact of climate change on low flows in mountainous regions

Climate change in the mountainous Upper Danube will result in a significant decrease in river flows derived from snow and glacial melt and reduced summer rainfall (Figure 5.1). A detailed analysis identified the scale, seasonal and spatial distribution of the impacts on several aspects of water use. For example, seventy percent of Austria's electric power supply depends on hydropower, which is partly produced in the Upper Danube. The predicted change in hydrological regime will strongly influence power infrastructure in the region and the design and operation of hydropower schemes in the Alps. This conclusion stimulated discussion with stakeholders on the efficient future implementation of management tools and long term investments to adapt to the changes in river flow.

Box 5.1 Summary

Reduced water storage in snow and summer rainfall together with melting glaciers and increased evapotranspiration will lead to a decreased summer runoff. This will strongly affect the planning and operation of water resource schemes in order to adapt to climate change.

5.2 Danube: The complex interaction between climate change and crop production

The reduction in rainfall and increased evapotranspiration will lead to a reduction in soil moisture available for crop production. It can be expected that large areas in the drier parts of the Upper Danube will require irrigation to sustain today's crop yield. At the same time the wetter areas near the Alps will change their optimum agricultural production.

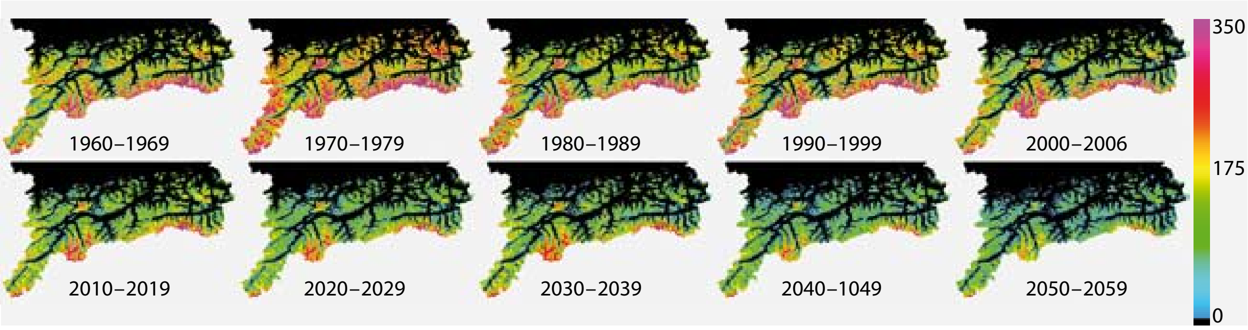

Figure 5.1 Scenario simulations of the average annual snow cover in the German and Austrian Alps of the Upper Danube basin. The simulations show the decadal change in the number of days with snow storage of more than 50 mm over the course of one century from 1961 to 2060

Box 5.2 Summary

The increased temperature and reduced precipitation in summer will have a strong influence on agriculture. Large areas in the Upper Danube watershed will need irrigation to sustain today's agricultural yield. Other areas may change from grassland to agriculture.

The present land use of meadows and forest are predicted to change to areas suitable for growing wheat and maize without the need for irrigation. This change of land use potential together with irrigation in the drier regions will increase the demand for groundwater abstraction and reduce summer low flows. As a result the export of water to downstream countries will be considerably reduced.

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