Chapter 6
GLOWA-Danube Results and Key Messages

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Abstract The research project GLOWA-Danube used a transdisciplinary approach to explore the regional impacts of global change (climate, demography, economy) on the availability and use of the water resources in the Upper Danube basin in the period from 2011 to 2060. An intensive dialogue with stakeholders in the region resulted in consolidated scenarios for the future development, which were simulated with the integrated simulation tool DANUBIA, specifically developed for this purpose within the project. The key messages and results are complied in this paper. They show that water resources will become scarcer in the future but not scarce. The range of uncertainty depending on the selected scenario is documented. The significant impacts on a large variety of natural processes and societal activities are compiled.

Keywords GLOWA-Danube • DANUBIA • Upper Danube • Climate Change • Key messages

6.1 Introduction

In order to investigate the regional effects of climate change in the Upper Danube catchment, the integrative decision support system DANUBIA was developed within the frame of the research project GLOWA-Danube. It consists of various natural and social sciences-based components (see Chaps 2, 3, 4 and 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34). DANUBIA was successfully validated with an extensive data set from the past, which proved the value of the data-rich Upper Danube watershed as a field laboratory for global change research. Several versions of combinations of impacts of global change factors on the regional water resources were simulated using an ensemble of scenarios for the future development of climate and society, which spanned a feasible range of possible developments and spanned the scenario funnel schematically described in Fig. 6.1.

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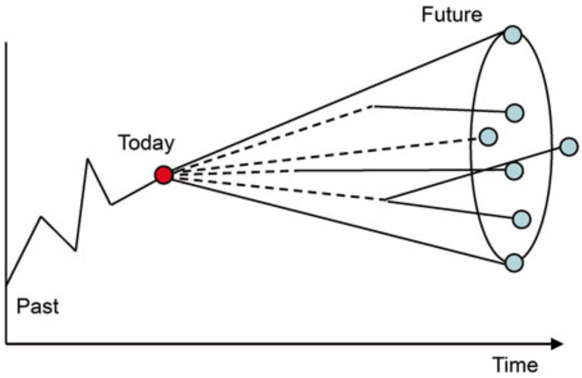
Fig. 6.1 Schematic funnel of a range of scenarios exploring the future



The main focus was placed on examining the natural resource water and its usage. The climate scenarios developed cover the time period 2011–2060. They are based on the moderate A1B emission scenario from the Fourth IPCC Assessment Report. The following statements summarise the results achieved by the GLOWA-Danube team of scientist.

6.2 The Methodological Approach of GLOWA-Danube

Both the regional impacts of climate change and the potential adaptation strategies are complex due to the multiple linkages and interactions between climatic, geographic and social factors. These complex linkages often make the analysis of direct cause-effect relations difficult or even impossible. DANUBIA was therefore developed as a simulation tool from scratch to take these linkages into consideration and to represent complex interactions and feedbacks. DANUBIA makes use of the latest software tools, such as Unified Modeling Language (UML) for design and parallel distributed computing. The development of DANUBIA was completed successfully. It has proven itself as a flexible framework to interactively couple the various components of the different disciplines involved in GLOWA-Danube and to realistically represent their interactions. Meanwhile, the framework has proved its operational capability in a variety of different applications.

DANUBIA is an expandable, scale-independent model that can be regionalised. It is available as open-source for further simulations of future human-environment interactions, applicable to a wide range of questions.

6.3 The Regional Development of Climate

We were able to show that a significant rise of surface air temperature already took place in the past in the Upper Danube watershed (see Chap. 23). The measured temperature increase in the Upper Danube from 1960 to 2006 was 1.6 °C, which is more than twice as high as the global average. Beyond this general trend of increasing temperatures, the available scientific knowledge on the possible future temperature development opens up a wide range of scenarios. Our discussions with the stakeholders regarding our findings and the available knowledge on climate scenarios led to the common denominator that the impacts of a likely temperature increase ranging between 3.3 and 5.2 °C over the period 1990–2100 should be analysed further (see Chaps. 47, 48, 49, 50, and 51).

On the basis of measured precipitation data from the past, a tendency for decreasing precipitation in the summer months and increasing precipitation in the winter months was observed (see Chap. 13). This trend has been taken into account in the development of the regional climate scenarios for the Upper Danube. We can expect more precipitation in winter (between +8 and +47 %) and less precipitation in summer (between −14 and −69 %) in the Upper Danube watershed. Overall, the annual precipitation will decrease slightly in the future (see Chaps. 47, 48, 49, 50, and 51).

Although moderate assumptions for the future climate were made based on the consensus reached among and with the stakeholders and none of the “worst-case” scenarios of the global emissions or climate development were considered, the change in the climate of the Upper Danube watershed is clearly more significant than the global average – especially when considering the strong climate change signal already observed in the past.

6.4 The Development of Society

The socio-economic scenarios in GLOWA-Danube were based on the societal megatrends from SinusSociovision of Sinus Institut, Heidelberg (http://www.sinus-institut.de/), which refer to the conditions in society as a whole and their likely change in the future. Thus, the societal scenarios hold a correspondingly high level of abstraction. To implement these in GLOWA-Danube, specifications of the more general megatrends were developed and adapted to each participating subproject. For the development of the social-based orientation towards the future, three scenarios were developed which take into account inter alia new technologies, the globalisation and demographic, economic and political development (see Chap. 52). The scenario baseline represents the current status quo and assumes this status quo valid in the future. The specific realisation depends on the respective discipline and its component in DANUBIA. The scenario public welfare describes a society, which is characterised by a return to the responsibility of the whole society and by placing a high value on general welfare and sustainable development. The scenario *Performance* describes the opposite trend to the scenario public welfare. In this scenario more emphasis is placed on economic efficiency and the performance of the individual. Figure 6.2 shows the menu of scenarios, which allows to formulate a total of 60 scenarios as combinations of selections 1–3. They can be used to investigate the effectiveness and efficiency of adaptation actions in selection 4, which are proposed by the stakeholders.

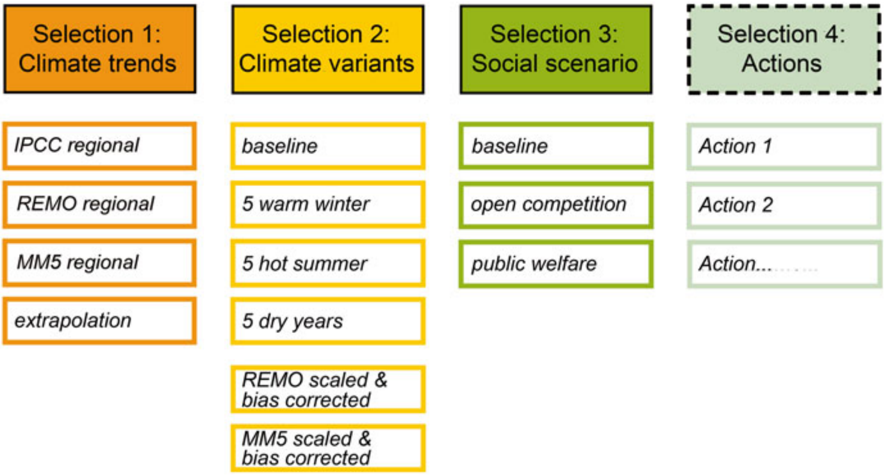


Fig. 6.2 Menu of climate scenarios and social scenarios in GLOWA-Danube, which can be combined

6.5 Water Balance

The simulated results show that the water availability in the Upper Danube will decrease during the period 2011–2060, but water will not become scarce (see Chap. 53). Comparing the period 2036–2060 with 1971–2000, a decrease in water availability is found which varies between 5 and 25 % depending on the climate scenario.

Apart from the slight decrease in precipitation, a complex network of interactions, primarily the increasing air temperature coupled with a strongly increasing evapotranspiration, is responsible for this development. As such, the evapotranspiration will increase on average by about 10–25 %, depending on the applied climate scenario (see Chap. 58). As a result of the decreasing precipitation, the rising temperature and the higher evapotranspiration, the river discharge in the Upper Danube catchment will be reduced in the future as well. The reduction varies between 5 and 35 % until the year 2060 depending on the applied climate scenario. At a regional level, the reduction will be least in the Alps, whereas along the Danube River, it will be the strongest. Thus, the annual water delivery of the Upper Danube from the gauge in Achleiten to the downstream users will be reduced by 9–31 %, by 2060, based on the different scenarios (see Chap. 53).

The groundwater recharge in the total catchment area will be reduced by 5–21 %, when comparing the time period 2036–2060 with 1971–2000, due to the increase of evapotranspiration and the slight decrease in precipitation (see Chap. 59). Increasing temperatures lead to a strong reduction in the depth of the snow cover and to a reduction of snow cover duration by 30–60 days at all altitudes, until the year 2060 (see Chap. 57). Snow conditions, which in 2006 prevail at altitudes of about 1,000 m asl, are likely to be found at altitudes of 2,000 m asl around 2060. In the summer months, precipitation on high peaks will increasingly fall in the form of rain instead of snow. As a consequence, there will be less snow storage available in the mountains; therefore, a decrease in the portion of snowmelt water contribution on the total water discharge is expected (see Chap. 60). The intense reduction of the snow storage and the earlier snow melting in the Alps lead to a pronounced forward displacement of the annual peak of river discharge from summer to spring, as well as to a strong to very strong reduction in the low-flow discharges of the main rivers in the Upper Danube catchment (Fig. 6.3).

The low flow at the gauge in Achleiten near Passau will be reduced by 25–53 % by the year 2060. In combination with increasing water temperatures, this may result in a reduction of the availability of water for cooling thermal power stations and to restrictions posed on navigation during summer (see Chaps. 54 and 61). The strong reduction in the low-flow discharges along the Danube will be opposite to an expected increase in the low-flow discharges in the Alpine valleys. Reasons for this are the complex interaction between a higher proportion of precipitation expected to fall as rain in winter and an increased evapotranspiration with reduced rainfall in the summer. The increased proportion of rain and snow melt contribute to an increase of low-flow discharges in the Alpine valleys, while the higher evapotranspiration and decrease in precipitation in the summer are conducive to accentuated low-water situations in the Alpine foothills and in the northern part of the Upper Danube catchment.

Fig. 6.3 Glacier skiing area “Schneeferner” at the Zugspitze (Photo Markus Weber)

The reduction in the mean annual run-off and the shift of the peak in spring in turn influence the energy production from hydropower. Thus, under a constant, business-as-usual reservoir management, a change in the seasonal cycle of the inflows and outflows can be expected, as well as a more even filling of the reservoirs towards a more balanced seasonal cycle (see Chap. 68) (Fig. 6.4).

The electricity generated from the installed hydropower plants is a main source of renewable energy in the Upper Danube catchment. The amount of electricity generated will be significantly reduced by 3–16 %, due to the decrease in run-off in the future, the extent of which varies depending on the chosen future climate scenario and the subcatchment considered. The decrease is particularly strong after the occurrence of several consecutive dry years. In the southern area of the watershed, the drop in hydropower energy production is slightly attenuated during the first-scenario years because of an increase in run-off from the melting glaciers (Fig. 6.5).

Indeed, the glaciers in the catchment of the Upper Danube will have disappeared almost completely between 2035 and 2045. The simulations show that the water stored in glaciers at present cannot provide an essential additional water contribution necessary to ensure and maintain today's water balance in the Upper Danube catchment. However, the melting of glaciers will lead to a slight increase in discharge in Passau of about 2 % during the period 2011–2035. In the headwater regions, the glaciers therefore make a non-negligible contribution to the increase in the low flows during this period. After the year 2035, the meltwater flow from the glaciers will go down due to disappearing glaciers. This will further amplify the general decrease in run-off (see Chap. 56).

Regarding the development of the natural flood discharge in the Upper Danube basin, no clear trend emerged from our research. The results suggest that at the gauge in Achleiten, there will be no major changes to the flood peaks and the frequency of their occurrence. However, the results do show a clear increase in the flood peaks in the Alpine valleys and in the head watersheds. In the head watersheds, the flood peaks increase until 2060 in part by a factor of 3 (see Chap. 55).

Fig. 6.4 The "Finstertal" reservoir in the Kühtai/Tyrol (Photo Markus Weber)

Fig. 6.5 Glacial ice in the Ötztal (Photo Markus Weber)

Fig. 6.6 Flooding in a mountain stream in the Ötztal in August 2006 (Photo Markus Weber)

Both the increasing flood peaks and the aforementioned changes in the low-flow discharge can be attributed mostly to the change in the precipitation type in alpine regions from snow to rain and the resulting reduction in water storage contribution from snow (Fig. 6.6).

The results presented show the partly severe consequences of climate change on the water resources of the Upper Danube. The water supply to the downstream users, who depend on the Danube river water and who use it intensively, will be moderately to significantly reduced in the future. The synopsis of the results shows that the role of the Upper Danube as a "surge chamber" for the Danube downstream users should be re-evaluated for the future.

6.6 Water Consumption and Water Supply

The simulations of the water consumption behaviour of households show that the private per capita consumption of water in the Upper Danube basin during the period under consideration, from 2011 to 2060, will be significantly reduced (Fig. 6.7).

In the second half of the simulation period, a significant slowdown of this reduction is observed. The decrease can mainly be attributed to a widespread implementation of water-saving technologies in households and the changing consumer behaviour. The adoption of water-saving technologies varies depending on innovation, environment and social scenario. In some cases even, a universal spread of technologies is achieved. The decline in the per capita water consumption is partly compensated by the rising population numbers at the beginning of the simulation period. However, overall, the simulations show a decline in private drinking water consumption by about 20–25 % until 2060 (see Chaps. 65 and 67).

The reduction in the groundwater recharge, which is observed in all climate scenarios, leads to only occasional isolated, local, temporary shortages in drinking water supply, and this is only in the second simulation period (2036–2060) under

Fig. 6.7 Different types of water consumption (Artwork: Center for Environmental Systems Research, University of Kassel by Anna von Lilienfeld-Toal)

declining withdrawals. The intensity of shortages naturally increases with decreasing rates of groundwater recharge. The areal extent of the decline in abstractions plays only a minor role thereby. Areas that are particularly affected are those with very small-scale supply structures, which withdraw the groundwater from shallow, spatially limited aquifers (e.g. in north-eastern Bavaria). At the same time, there is a tendency towards a strong precipitation decline at the northern edge of the Alps and in parts of the alpine foothills which affects groundwater recharge. Under an assumed declining water demand, the water availability in the catchment area will be sufficient secure public drinking water supply, even under extreme climatic conditions. However, this will require appropriate adaption measures to buffer the local and temporary shortages, for example, tapping into alternative areas, or enabling water delivery from water companies in the proximity, or from remote water supply systems. Currently, it is not possible to estimate the impacts of the potential need for irrigation water for agriculture. The impacts of climate change on deep water aquifers during the simulation period cannot be significantly determined as these react slowly to changes, and the uncertainties in the water-bearing stratum of the models are too high.

6.7 Winter and Summer Tourism

The changes in winter tourism are characterised by dwindling snow cover durations, depending on regional and elevation factors. This may span 30–60 days, depending on the chosen climate scenario. The diminishing guaranteed snow cover at lower elevations intensifies the concentration of winter tourism at higher-located and well-developed ski areas with adequate infrastructural facilities. In these skiing areas, due to the increase in precipitation expected in winter, the snow conditions will not deteriorate despite higher temperatures. In fact, snow conditions may even improve in some regions. However, a decrease in the number of optimum skiing days is expected in the whole study area. Optimum skiing days are characterised by different factors, such as a lack of rainfall, adequate snow cover, sunshine, little wind speed and pleasant temperatures (Fig. 6.8).

Due to the high investment costs for producing artificial snow and due to a lower guarantee of snow cover, an economically viable operation will not be sustained in some low-lying ski areas, especially since the advent of higher temperatures will often cause the use of snow cannons to be impossible. In the second half of the simulation period, depending on the chosen scenario, between 20 and 50 % of today's ski areas will no longer be able to secure their existence through ski tourism (see Chap. 62). As a result of higher temperatures in the summer, locations with a high percentage of holiday travellers may reckon with a growth in the number of visitors, which may compensate for the losses experienced during the winter season, to some extent. Climate change therefore also affects summer tourism, although to a lesser extent than the winter tourism.

Fig. 6.8 Snow cannon in the Stubai (Photo Markus Weber)

6.8 Agriculture and Forestry

All of the investigated climate change scenarios show that the increasing atmospheric CO_2 concentrations and the higher temperatures will lead to an increase in crop yields (see Chap. 70). The water-use efficiency of the vegetation (ratio of biomass production to water transpired) will improve significantly for C3 plants. Thus, transpiration amounts do not increase proportionally to the amount of biomass produced. Occasionally, there may be reductions in the yields of crop grown on light soils due to water stress during dry years as a consequence of soil drying, especially along the Danube River (Fig. 6.9).

The mineralization of organic matter in the soil will increase. Thus, the soil nitrogen availability will improve, provided that the soil contains sufficient organic matter. These effects, which are influenced inter alia by the temperature increase of the upper soil layer (see Chap. 71), vary to different degrees, depending on the local climate factors at a small scale.

The harvest dates of grain cereals will be advanced by about 3 weeks. In addition, the harvest dates of summer grain and winter grain will be closer in the season. However, the ratio of different crop types will hardly change during the period under consideration. The number of days with rain at the time of the cereal harvest will be reduced. However, since the interannual variability will increase, it can be generally assumed that the planning reliability for farmers will decline in the future (see Chap. 76).

Fig. 6.9 Mature spring wheat (Photo Markus Weber)

The concentration of nitrate in the percolation water increases slightly during the scenario period; however, the climate impacts on nitrate leaching can be controlled from a perspective of water pollution management through appropriate adaptation strategies such as fertiliser application management (see Chap. 72). In the future, merely locally, there will be a menace to the quality of groundwater through nitrate leaching. This will occur in regions where already high background concentrations of nitrate loads are present and a continuing need for action will exist (see Chap. 73). None of the investigated societal scenarios demonstrated a climate-related deterioration of the income situation of farmers (see Chap. 70).

In all climate scenarios, an increase in the wildfire risk is expected due to the higher potential evaporation and to less rainfall occurring in the spring and summer months (see Chaps. 74 and 75).

6.9 Industrial Water Usage

The vulnerability of the industrial sector to climate change can be assessed as being low in the Upper Danube catchment. There are solely regionally limited losses of growth, of up to 0.4 per mill per year. In some regions, economic growth even benefits from climate change. The industry responds to water shortages foremost by optimising their processes and subsequently with circuit or multiple uses, and thus they can avoid a production constraint as a consequence of a resource shortage (see Chap. 66).