E6 GLOWA-Danube results and key messages

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, which consists of various natural science based and social science based submodels (see chapters E2 to E4 and 2.1 to 2.12). Several impacts on 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.

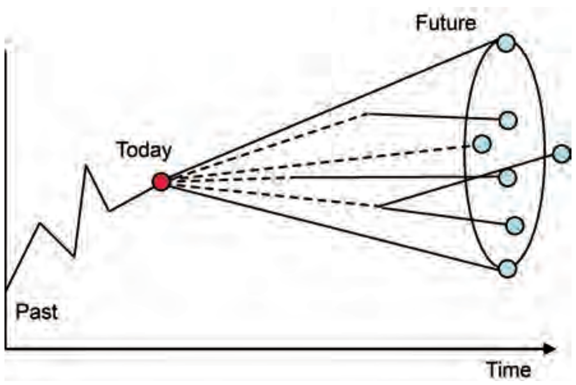

Figure E6.1: Schematic of a range of scenarios.

The main focus was placed on examining the natural resource water and on its usage. The climate scenarios developed cover the time period 2011-2060, and they are based on the moderate A1B emission scenario from the IPCC. The following statements summarize the results of the GLOWA-Danube research project.

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 linkages are responsible for often unrealistic and sometimes impossible analyses of direct cause and effect. To take these linkage requirements into consideration and to respect possible interactions, DANUBIA was developed as a simulation tool, from scratch. For this purpose, the latest software tools, such as Unified Modelling Language (UML) and parallel distributed computing, were used. The development of DANUBIA was completed successfully. It has proven itself as a flexible framework to couple the various submodels of the different disciplines involved in GLOWA-Danube and 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 made region specific. It is available for further simulations of future human-environment interactions, applicable to a wide range of questions.

3. The regional development of climate

Already in the past, a significant rise of surface air temperature in the Upper Danube watershed was shown (see chapter 1.9). The measured temperature increase in the Upper Danube was an average of 1.6°C, which is more than twice as high as the global average. The cognition of the future temperature trends spans a wide range of scenarios beyond this general increase. The likely temperature increase ranges between 3.3°C and 5.2°C over the period 1990 to 2100 (see chapter S1-S5).

On the basis of measured precipitation data from the past, a tendency for decreasing precipitation in the summer months and increasing precepitation in the winter months was observed (see chapter 1.9). This trend has been taken into account in the development of the climate scenarios for the investigation area. 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 rainfall will decrease slightly in the future (see chapter S1-S5).

Although moderate assumptions for the future climate were made 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 ranges clearly above the global average – especially when considering the strong climate change signal already observed in the past.

4. The development of society

The social scenarios in GLOWA-Danube are based on the so-called social megatrends from SinusSociovision, which refer to the situation of the society as a whole and its change in the future. Thus, the social scenarios hold a correspondingly high level of abstraction. To implement these in GLOWA-Danube, a specification of the megatrends was developed, through a concrete, substantive expression in every involved subproject. For the development of the social base orientation towards the future, three scenarios were developed which take into account inter alia new technologies, the globalisation as well as demographic, economic and political decisions (see chapter S6). The scenario ***baseline*** depicts the current status quo and represents this status quo in the future as well depending on the submodel. 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 the common good and sustainable development. The scenario ***open competition*** 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.

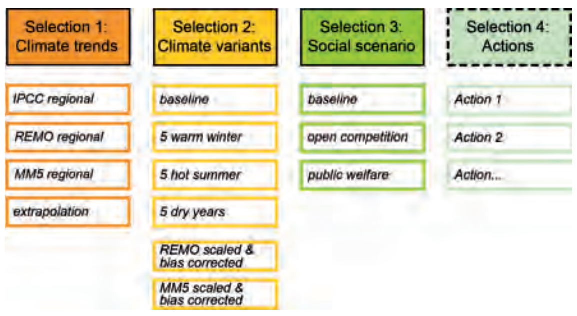

Figure E6.2: Climate scenarios and social scenarios in GLOWA-Danube.

5. Water balance

The simulated results show, the ***water availability*** in the Upper Danube will decrease during the period 2011-2060 but it will not become scarce (see chapter 3.1.1). 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 strong increase of the evapotranspiration, is responsible for this development. As such, the ***evapotranspiration*** will increase on average by about 10% to 25%, depending on the applied climate scenario (see chapter 3.1.6). 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% to 31%, by 2060, based on the different scenarios (see chapter 3.1.1).

The ***groundwater recharge*** in the total catchment area will be reduced by 5% to 21%, when comparing the time period 2036-2060 with 1971-2000, due to the increase of evapotranspiration and the slight decrease in precipitation (see chapter 3.1.7). Increasing temperatures lead to a strong reduction in the ***height of the snow cover*** and to a reduction of ***snow cover duration*** by 30 to 60 days at all altitudes, until the year 2060 (see chapter 3.1.5). Snow conditions, which prevail nowadays at altitudes of about 1000 m a.s.l., are likely to be found at altitudes of 2000 m a.s.l. in the future. 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 chapter 3.1.8). The intense reduction of the snow storage and the earlier snow melting in the Alps leads to a pronounced forward displacement of the annual availability of water from summer to spring, as well as to a strong to a very strong reduction in the low flow discharges of the main rivers in the Upper Danube catchment.

Figure E6.3: Glacier skiing area "Schneeferner" at the Zugspitze (photo M. Weber).

The ***low flow*** at the gauge in Achleiten near Passau will be reduced by 25% to 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 limitations for shipping in the summer (see chapter 3.1.2 and 3.1.9). A strong reduction in the low flow discharges along the Danube is expected on the one hand, while an increase in the low flow discharges in the Alpine valleys is expected on the other hand. Reasons for this are due to 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 water flows 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.

The reduction in the mean annual runoff and the shift of the peak in spring, in turn influence the ***energy production from hydropower***. Thus, under a constant 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 chapter 3.2.7).

Figure E6.4: The "Finstertal" reservoir in the Kühtai/Tyrol (photo M. Weber).

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, due to the decrease in runoff in the future, the extent of which varies, depends 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 attenuated in the first scenario years because of the melting water from the glaciers.

Figure E6.5: Glacial ice in the Ötztal (photo M. Weber).

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 water contribution to ensure a balanced water management 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 these 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 reduction in the quantity of the melt water from the remaining glaciers contributes to the general decrease in runoff (see chapter 3.1.4).

Regarding the trends of the natural ***flood discharges*** in the Upper Danube basin, no clear picture emerges. The results suggest that at the gauge in Achleiten, there will be no major changes to the flood discharges. 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 chapter 3.1.3). 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.

Figure E6.6: Flooding in a mountain stream in the Ötztal in August 2006 (photo M. Weber).

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. 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 2011-2060, will be significantly reduced.

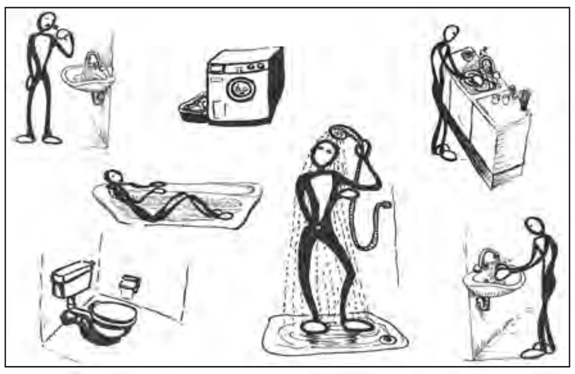

Figure E6.7: Different types of water consumption (artwork: Anna v. Lilienfeld-Toal).

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% to 25% until 2060 (see chapter 3.2.4 and 3.2.6).

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 only in the second simulation period (2036-2060) under declining withdrawals. These shortages naturally become more extensive, the lower the rate of groundwater recharge is. 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 for the interests of 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.

7. Winter and summer tourism

The changes in winter tourism are characterized by dwindling snow cover durations, depending on regional and elevation factors. This may span 30 to 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 characterized by different factors, such as a lack of rainfall, adequate snow cover, sunshine, little wind speed and pleasant temperatures.

Figure E6.8: Snow cannon in the Stubai (photo M. Weber).

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 able to 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 climate run, between 20% and 50% of today's ski areas will no longer be able to secure their existence through ski tourism (see chapter 3.2.1). 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.

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 chapter 3.3.1). The water use efficiency of the vegetation (ratio of biomass production to water transpired) will improve significantly for C_3 plants. Thus, transpiration amounts do not increase proportionally to the amount of biomass produced. Occasionally there may be reductions in the crop yields grown on light soils, during dry years as a consequence of soil drying, especially along the Danube river.

Figure E6.9: Ripe spring wheat (photo M. Weber).

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 chapter 3.3.2), 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 three 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 inter-annual variability will increase, it can be generally assumed that the planning reliability for farmers will decline in the future (see chapter 3.3.7).

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 fertilizer application management (see chapter 3.3.3). 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 be required (see chapter 3.3.4). None of the investigated social scenarios demonstrated a climate-related deterioration of the ***income situation*** of farmers (see chapter 3.3.1).

In all climate scenarios an increase in the ***forest fire risk*** is expected due to the higher potential evaporation and to less rainfall occurring in the spring and summer months (see chapter 3.3.5 and 3.3.6).

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 optimizing 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 chapter 3.2.5).