The future of Europe's freshwaters – perspective up to 2030

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Abstract

In the first phase of the SCENES project a scenario exercise based mostly on information developed under UNEP's Fourth Global Environment Outlook (GEO-4) has been performed. The objective of this phase was to provide numerical estimates of the response of Europe's waters to the driving forces specified in the storylines of the GEO-4 scenarios. In particular, researchers were identifying regions in Europe with rapidly changing water withdrawals and possible water shortages under the various scenarios. The quantification of GEO-4 storylines concerning water use, availability and stress was performed using the WaterGAP model.

First results are available from the fast-track scenarios up to 2030 for pan-Europe. Under the climate change assumptions of the GEO-4 scenarios, only a small change is computed in water availability in Central Europe up to 2030. However, this result masks significant seasonal changes: a 5 to 25% increase (depending on location) is computed for the winter season and 5 to 25% decrease for the summer season for the Security First scenario. Although they show a similar impact of climate change, the scenarios differ greatly in their estimates of future water withdrawals in Europe. According to a scenario assuming a strengthening of water-saving actions (Sustainability First), total water withdrawals may decline by more than 50% in Central and Northern Europe. Even under a scenario (Security First) without major water-saving actions, water withdrawals decrease by 25 to 50% in Western Europe, parts of the Baltic countries and Scandinavia because of the saturation of water demand in the household sector, and because of expected improvements in the efficiency of water use in all economic sectors.

Thus the first results already show that annual average indicators are inadequate in describing the future of water resources in Europe. The focus of scenario studies should be on changes expected in seasonal indicators, for example, on the availability of water during the summer versus winter season.

1. Introduction

The aim of the SCENES project (Water Scenarios for Europe and for Neighbouring States, Kämäri *et al.* in press) is to assess the environmental consequences of key socio-economic and political developments in Europe with particular regard to the future state of water resources. Therefore a comprehensive set of policy-relevant and plausible scenarios will be built and analysed in order to provide a vision for Europe's water for the next twenty to forty years. In a first step, fast-track scenarios are provided as a starting point for the development of European scenarios and preliminary regional scenarios. These fast-track scenarios are based on available tools and information and allow time to assemble new information on driving forces and indicators and to build new tools (models and databases) to produce "better" scenarios. At the same time the full scenario process (Phase II) can be organized. The

SCENES project area covers all of "Greater" Europe, an area that in the following is called pan-Europe, reaching to the Caucasus and Ural Mountains, and including the Mediterranean rim countries of north Africa and the near East.

In a global study of IPCC scenarios A2 and B2, Alcamo *et al.* (2007) concluded that for these scenarios increasing water stress is caused mainly by increasing water withdrawals, and the most important factor for this increase is the growth of domestic water use, followed by increasing water use for industry and agriculture. Further they concluded that the principal cause of decreasing water stress is the greater availability of water due to increased annual precipitation related to climate change.

Following both the aim of the SCENES project and the earlier findings by Alcamo *et al.* (2007) this presentation deals especially with socio-economic factors impacting domestic water withdrawals and climate factors affecting water availability and water withdrawals for irrigation. For the effects of climate factors seasonal aspects have special emphasis.

2. Material and methods

The fast-track scenarios in SCENES are based on the most recent global scenario exercise, the GEO-4 scenarios (Global Environmental Outlook Report No. 4 of UNEP, http://www.unep.org/geo/geo4/media/). The GEO-4 scenarios are a consistent set of both global and world-regional scenarios that explore how current socio-economic and environmental trends may change along different development paths up to 2050. A set of four scenarios investigating different policy approaches and societal choices is used to present qualitative and quantitative data for the world and seven world-regions including Europe.

The key assumptions of the GEO-4 scenarios are as follows:

- ***Markets First***: The world is driven by the global demand for goods-and-services. The private sector, with active government sector support, pursues maximum economic growth, trusting this to be the best path toward the improvement of the environment and human well-being for all.
- ***Policy First***: Strong policy constraints are placed on market forces in order to minimise their undesirable effects on humans and the environment. The government sector, with active private and civic sector support, implements strong policies intended to improve the environment and human well-being for all, while still emphasizing economic development.
- ***Security First***: People become increasingly preoccupied with fears of a multi-dimensional global catastrophe (e.g. natural disasters, disease pandemics, international terrorism). The government sector and certain private sector actors compete for control in efforts to improve, or at least maintain, human well-being for selected groups.
- ***Sustainability First***: A world in which a new development paradigm emerges in response to the challenge of sustainability. The civic, government and private sectors work collaboratively to improve the environment and human well-being for all, with a strong emphasis on equity.

For GEO-4, the global water model WaterGAP has provided estimates of future water resources, in particular of water use (for the domestic, manufacturing, electricity production, irrigation and livestock sectors), water availability, and water stress. The driving force assumptions for the water-related calculations are based on the GEO-4 regional storylines that are quantified by the

- International Futures Model (socio-economic drivers) (http://www.ifs.du.edu/),
- IMAGE2 Model (climate change, electricity production, livestock) (http://www.mnp.nl/image), and
- IMPACT Model (irrigated area) (http://www.ifpri.org/themes/impact.htm).

For a complete overview of the SCENES fast-track results see Flörke *et al.* (2007). One reason for concentrating on the Security First and Sustainability First scenarios in this presentation is that these scenarios show the most contrasting development for Gross Domestic Product per capita by 2030 leading e.g. to most divergent water withdrawals.

WaterGAP (Water – Global Assessment and Prognosis) is a global water model developed at the Center for Environmental Systems Research of the University of Kassel, Germany. WaterGAP version 2.1 computes both water availability and water use on a 0.5° global grid (Alcamo *et al.* 2003, Döll *et al.* 2003, Flörke and Alcamo 2004). The model aims at providing a basis for an assessment of current water resources and water uses, and for the impacts of climate change and socio-economic drivers on changes in the water system and in water stress. WaterGAP consists of two main components: a Global Hydrology Model to simulate the terrestrial water cycle and a Global Water Use Model to estimate water withdrawals and water consumption (Figure 1). A sub-model for water quality is currently being developed.

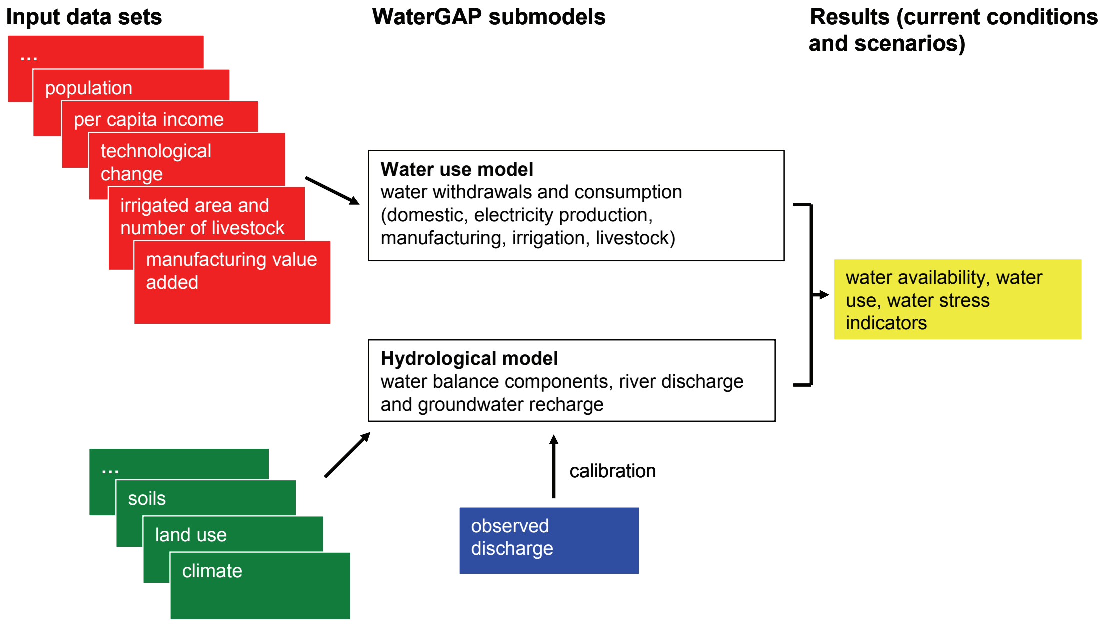

Figure 1. Schematic overview of the WaterGAP model, its input requirements and results.

In the hydrological model the water availability is defined as the total river discharge composed of surface runoff and groundwater recharge. The runoff produced inside a cell and the simulated inflow from upstream cells is transported through a series of storages representing the groundwater, lakes, reservoirs, wetlands, and rivers. Finally, the resulting cell outflow is routed along the drainage direction map to the next downstream cell (Döll and Lehner, 2002). Each individual grid cell is thus assigned to a drainage basin. In a standard global run, the discharges in approx. 11.000 large river basins are simulated.

Water withdrawal is the total volume of water abstracted from surface or groundwater sources within a river basin for various anthropogenic uses. A part of the withdrawn water is the so-called consumptive use, i.e. the amount of used water which evaporates into the atmosphere and is therefore lost for the water resources of the respective basin. Return flow is the part of the withdrawn water that is discharged back to the river basin after use. Natural water availability is reduced by the consumptive water use in a grid cell as calculated by the water use model. Sub-models determine both the water withdrawals and water consumption in five sectors. For most water use sectors – except for irrigation – only a small amount of water is actually consumed, whereas most of the water withdrawn is returned to the environment for subsequent use. Water uses for different sectors in more than 180 countries worldwide are simulated.

The overall approach of the scenario analysis in SCENES is based on the Story-and-Simulation Approach (SAS, Alcamo 2001). This method involves the development of narrative storylines during a series of stakeholder workshops in which the WaterGAP results will be used as one source of information to describe the present state and possible future development of water resources in Europe. On the pan-European scale this process is taking place in workshops of the so called pan-European Scenario Panel (PEP), involving a group (15-20 persons) of key stakeholders working at international level.

Pan-Europe as defined for the SCENES fast-track simulations consists of countries covered by four GEO-4 sub-regions (Table 1).

Table 1. GEO-4 sub-regional breakdown and countries covered by WaterGAP.

Region	Countries
Northern Africa	Algeria, Egypt, Libyan Arab Jamahiriya, Morocco, Sudan, Tunisia, Western Sahara
Western Europe	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom
Central Europe	Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Republic of Macedonia, Romania, Slovakia, Slovenia, Serbia and Montenegro, Turkey
Eastern Europe	Armenia, Azerbaijan, Belarus, Georgia, Republic of Moldova, Russian Federation, Ukraine

3. Results

Large volumes of water are withdrawn each year from Europe's freshwater reservoirs by society. Major water users are households, factories, thermal power plants and irrigation projects. The left map in Figure 2 shows the sum of all water withdrawals on a river basin level. The units of the map [mm per year] indicate how much water is withdrawn per unit area of a drainage basin. High water withdrawals occur as expected in Western and Southern Europe, due to water withdrawals for electricity production (e.g. Rhine) and irrigation purposes (Po river basin). Also in the high withdrawal category are intensely irrigated areas of Northern Africa and the Middle East. The most important sector per river basin is shown in the right map of Figure 2. Most of European water resources are used for irrigation requirements (taking into account that livestock water use is only a small part of agricultural water use), followed by water used for cooling purposes in thermal power plants, then the domestic and manufacturing sectors.

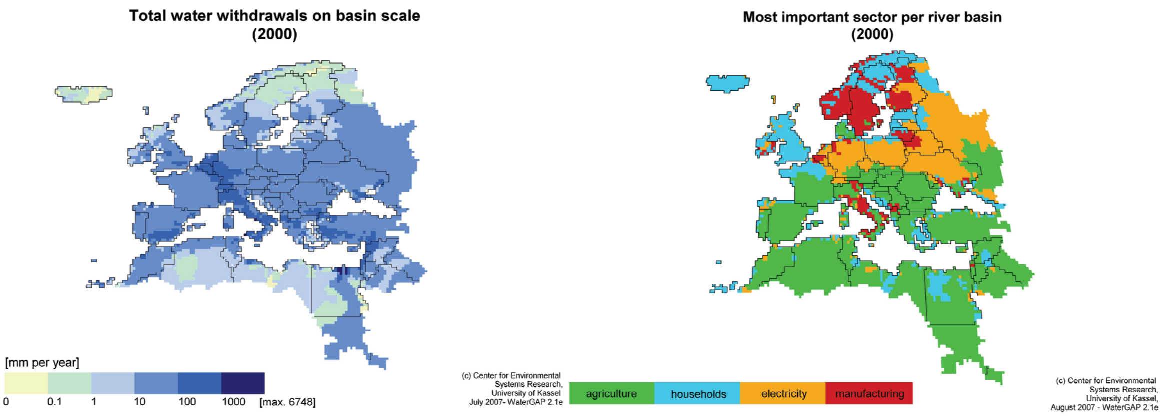

Figure 2. Total water withdrawals and the most important water use sectors for the base year 2000 according to drainage basins.

Both Security First and Sustainability First scenarios lead to a marked difference in the development of total water withdrawals in Europe (Figure 3). For most of Europe the Security First scenario leads to increases of more than 25% in total water withdrawals in 2030 (left map) whereas the Sustainability First scenario shows an opposite picture in form of reduced water withdrawals by more than 25% in 2030 (right map). The increases under the Security First scenario result from an assumed water use behaviour that follows traditional patterns accompanied by reluctant scientific and technological innovations and stagnation in water use efficiency. On the other hand, decreases in water withdrawals under the Sustainability First scenario are caused by a slower uptake of water and other resource use with rising income in combination with the promotion of technology transfers and efficiency improvements. An additional factor leading to the reduction in total water withdrawals under the Sustainability First scenario is the policy reaction anticipating climate change that promotes renewable energy sources affecting the water use of the electricity production sector.

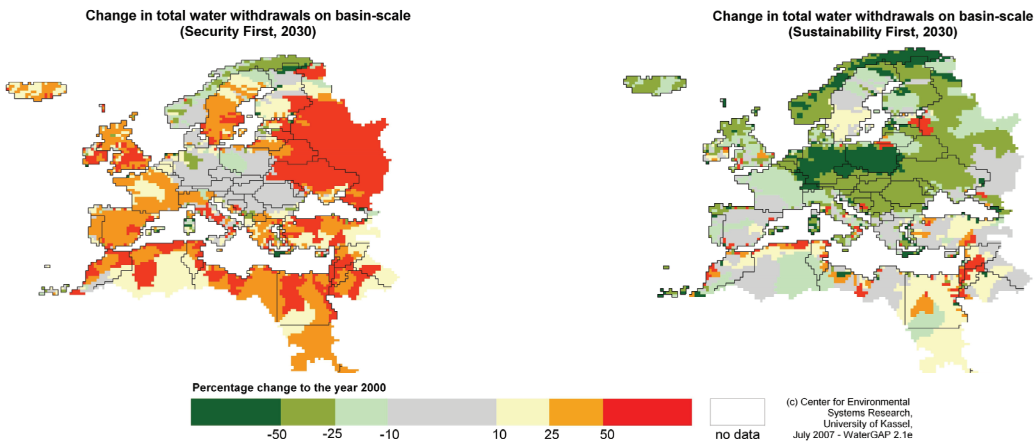

Figure 3. Percentage change in total water withdrawals for European river basins as compared to the base year (2000), realized with two different scenarios for 2030.

As an example of the five water use sectors in WaterGAP, Figure 4 shows the future development in domestic water use for Security First (left map) and Sustainability First (right map) scenarios for 2030. Even though domestic water withdrawals make up only 13% of the total water withdrawals in pan-Europe it is a sector where the influence of socio-economic drivers, one key issue in the SCENES project, can be well depicted. The results for the Security First scenario indicate that the usage of water in the domestic sector will increase in most countries within the study region (>10%), especially in Northern Africa, Middle East and in parts of Ukraine and Turkey where future water withdrawals are expected to increase by more than 50%. Rising water withdrawals in the domestic sector are caused by growing population and the neglect of water conservation. However, a slower economic growth tends to slow down the increase slightly.

In contrast to Security First, the Sustainability First scenario visualizes a marked change in the development of domestic water withdrawals (right map): this scenario leads to significant decreases of water use in the domestic sector by more than 25% in Europe (except in parts of Ukraine and Turkey). While a higher population and economic growth leads to higher withdrawals, the adoption of water-saving behaviour with strong emphasis on faster technological improvements tends to lower the use of water. But still, until the 2030s, large increases are seen in most parts of Northern Africa and the Middle East.

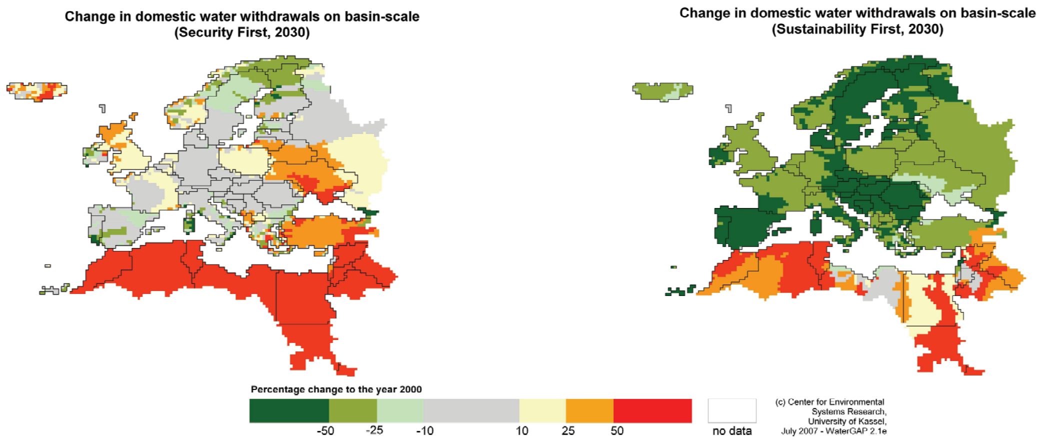

Figure 4. Percentage change in domestic water withdrawals for European river basins as compared to the base year (2000), realized with two different scenarios for 2030.

The intensity of water use in households [m³/(cap-year)] depends on many factors including the amount of household income which is related to the amount of water-using appliances in a household. Higher water prices are also known to dampen the demand for water in the domestic sector. Then the number of future water users will obviously determine the magnitude of water use in the domestic sector. The economic growth assumptions are based on the GEO-4 country-scale projections calculated by the International Futures model (IFs). Economic activity grows significantly over the whole scenario period. The Sustainability First scenario has a lower overall GDP per capita than Markets First and Policy First, but the level of increase is still quite high: fourfold in Eastern Europe, almost threefold in Central Europe, and nearly twofold in Western Europe. Even in Security First, the development of economic activity increases by a factor of 4 in Eastern Europe (2 in Central Europe and 1.7 in Western Europe, respectively). The expected increases (in percent) are much higher in Eastern Europe, but the per capita income in this region still remains lower than in the other two sub-regions.

The future population trends are also calculated by the IFs model. There are significant differences in the growing rates and contrary trends occur among the different UNEP sub-regions. A further increase of population is projected for Western Europe between 2000 and 2030. The largest absolute growth occurs under Sustainability First, minor increases are expected in Security First. Central Europe's population development shows the same trend as seen in Western Europe, but with a higher increase between 2000 and 2030. Also there the maximum increase is expected in Sustainability First and the minimum growth in Security First. The Eastern Europe countries face a considerable reduction in population between 2000 and 2030. The highest decline is assumed for Security First.

Domestic water use is calculated annually per country as a product of water use intensity and population. Country-scale estimates of domestic water use are downscaled by the model to a 0.5° grid using demographic and socio-economic data (Alcamo *et al.* 2003) and then re-aggregated to the river basin scale for further calculations. Water use intensities are represented as a function of income: the wealthier the population the more water is used. The relationship between water use intensity and income is derived for each country by fitting a sigmoid curve to historical data from each country. Future estimates of water use intensity follow the run of the curve and stabilize after a maximum level is reached for the Security First scenario and indicate a more water-intensive lifestyle whereas the water use intensity declines under the Sustainability First emphasizing a conservation-conscious use of water with rising income. Then, additional driving forces determine how water use intensities change due to structural and technological changes. The concept of technological change accounts for the effect that improving technology makes appliances more water efficient and as a result, contributes to reductions in water use. The main concept of the model follows the approach described in Flörke and Alcamo (2004).

Estimates of future climate change depend on many factors including the trend of greenhouse gas emissions and the climate model used for calculating climate change. Climate change projections used in GEO-4 were calculated by the IMAGE 2.2 model. All scenarios show a distinct increase of the global mean temperature, averaged for Europe of about 1.7°C and 2.0°C above pre-industrial levels in 2050 for Sustainability First and Security First, respectively. The differences are not big because of the inertia of the global climate system. Climate policies implemented in the first half of the 21st century might have their greatest effect on global climate only after 2050. The total emissions of regional air pollutants decline in all scenarios other than Security First. This is a clear consequence of the lack of emissions controls in that scenario.

Scenarios take into account seasonal variability in future precipitation during summer (June to August) and winter (December to February) compared to today's level in percentage changes (Figure 5). In the summer months, as shown in the right map, a significant decrease (<-15%) in precipitation is expected in Southern and South-Eastern Europe as well as in the Maghreb region. No big changes are estimated for the rest of the European continent. The map on the left shows the changes in precipitation during winter which indicate a wetter climate over most of Europe, with the exception of Northern Africa and the Eastern Mediterranean region.

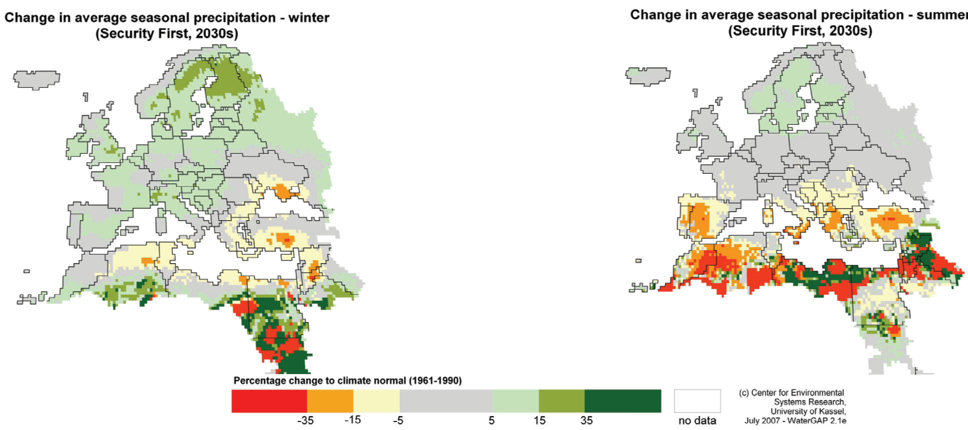

Figure 5. Change in long-term average precipitation for winter and summer as calculated for the Security First scenario; 2030s projections compared to today's level on a grid cell scale.

Water is a renewable resource because the loss of moisture by transpiration through plants or evaporation from surfaces is continuously returned as precipitation. Waters within a basin are often stored in reservoirs and distributed within a basin by gravity flow. The average annual renewable water resources available in European river basins based on the 30-year climate time series 1961-90 show a clear difference in the distribution over pan-Europe (Figure 6). The average annual water availability ranges between above 1000 mm/year in Western Norway, Britain's West Coast, and Southern Iceland to below 100 mm/year in parts of Spain and Turkey, large parts of the Ukraine, Southern Russia, Northern Africa and the Middle East region.

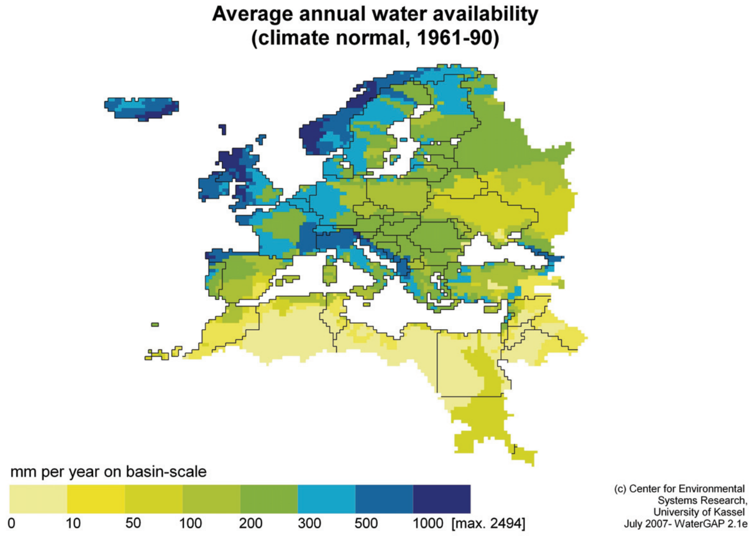

Figure 6. Long-term average renewable water availability according to drainage basins.

Relatively small changes in annual water availability (Figure 7, left map) are computed for most of Europe's river basins for the Security First scenario up to the 2030s. This is because climate changes intensity with time during the 21st century under most published climate scenarios. Therefore climate impacts up to 2030 are not as strong as they are later in the century. In general, long-term annual water availability declines in the Mediterranean rim countries as well as in the Black Sea region. Especially in these regions, a decrease in annual water availability well above 50% is calculated. Conversely, nearly all of Scandinavia and Northern Russia display an increase in annual water availability up to 25%. The causes of these changes are warmer temperatures (causing higher evapotranspiration) and therefore a changing trend in future precipitation.

Projected changes in water availability can differ considerably between summer (upper right map) and winter (lower right map). In comparison to the annual changes, water availability decreases during summer (June to August) by more than 5% in most parts of Europe under the Security First scenario in the 2030s. Additionally, reduced annual water availability is projected for the Danube river basin, Norway, Iceland, and parts of France. The number of river basins showing an increase (> 5%) in water availability is reduced compared to the left map. Notable is an increase in water availability in the Nile river of more than 25% due to an increase in precipitation. In winter time (December to February) water availability is projected to increase in most European river basins. Only in Mediterranean rim countries as well as in the southern Ukraine will less water be available.

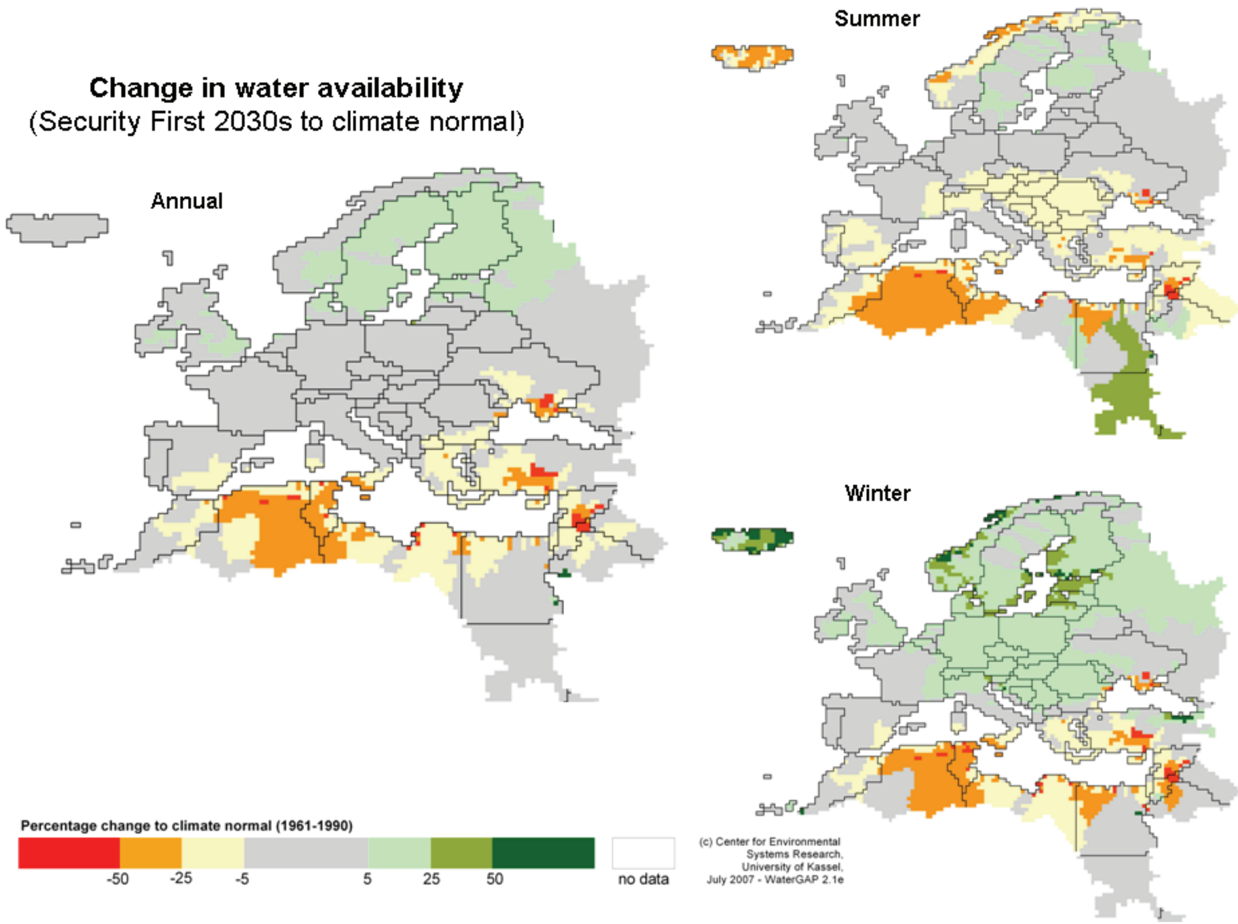

Figure 7. Change in water availability according to drainage basins. Comparison of annual (left map) and seasonal (right maps) results as calculated with WaterGAP for today's climate (1961-90) and for the 2030s (IMAGE 2.2 climate input for the Security First scenario).

Throughout history irrigation has been an important user of water resources in large parts of pan-Europe. WaterGAP computes net and gross irrigation requirements which reflect an optimal supply of water to irrigated crops. The amount of water needed by irrigated crops depends on many factors among which are the type of crop and cropping system, the irrigation method and its level of technology, as well as the local climate and topography. Obviously, where the efficiency of irrigation is lower, more water is required.

The change in water withdrawals for irrigation according to the Security First scenario gives a different angle to seasonal variability (Figure 8). An increase in average annual water withdrawals for irrigation would be the result of this scenario for most of pan-Europe. For the region north of the Mediterranean Sea this is mainly due to changes in summer water withdrawals (Figure 8, lower right map). This results partly from climate change, i.e. small changes in summer precipitation, except for Spain, southern Italy, the Balkan countries and Turkey, in addition to an increase in air temperature. The main factor is, however, the Security First scenario assumptions that imply a decrease in water use efficiency and thus lead to an increase in water withdrawals. The decrease in water withdrawals in certain basins in northern Africa during summer results from increased precipitation in areas where the share of irrigated agriculture is low and, in addition, summer may not be the main growing season. On the other hand, during winter many southern Mediterranean countries and some Mediterranean islands like Cyprus and Malta would see a high increase in water withdrawals for irrigation. This is due to a climate change induced decrease in water availability (Figure 7) that is coupled with a substantial increase in irrigated area and a decrease in water use efficiency (19% technological change) following the socio-economic assumptions of the Security First scenario.

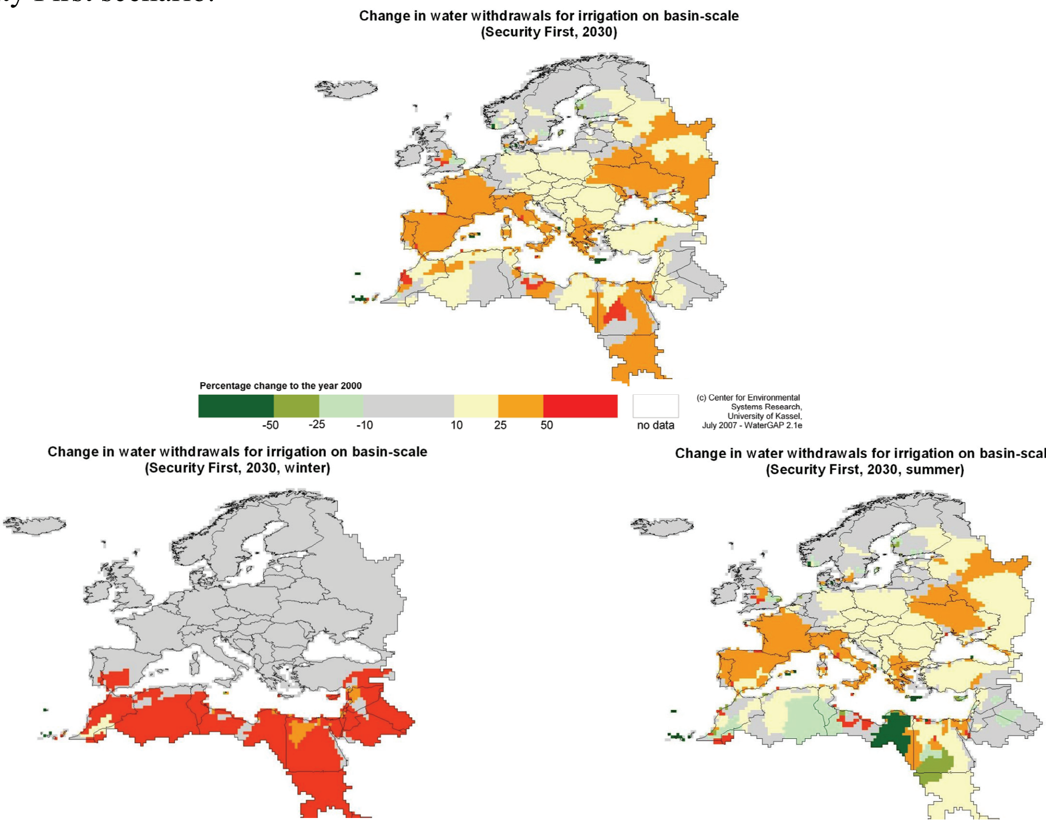

Figure 8. Change in water withdrawals for irrigation according to drainage basins. Comparison of annual (upper map) and seasonal (lower maps) results as calculated with WaterGAP for today's climate (1961-90) and for the 2030s.

Using the concept of "water stress" the average conditions of water resources can be compared. Water stress is a measure of the amount of pressure put on water resources and aquatic ecosystems by the users of these resources, including municipalities, industries, power stations and agricultural users (see for example, Alcamo *et al*. 2000, Alcamo *et al*. 2007, Vorösmarty *et al*. 2000, Cosgrove and Rijsberman 2000). Generally speaking, the larger the volume of water withdrawn, used, and discharged back into a river, the more it is degraded and/or depleted, and the higher the water stress. The higher the water stress the stronger the competition between society's users and between society and ecosystem requirements (Raskin *et al*. 1997, Alcamo *et al*. 2003). Here the conventional measure of water stress, the withdrawals-to-availability ratio is used (w.t.a.). This indicator has the advantage of being transparent and computable for all river basins. A drainage basin is assumed to be under low water stress if w.t.a. ≤ 0.2; under medium water stress if $0.2 <$ w.t.a. ≤ 0.4 and under severe water stress if w.t.a. > 0.4.

Drainage basins are in the severe water stress category where water use is high (Belgium, The Netherlands) or in countries having arid climates and where water availability is low relative to water use (Mediterranean region, Ukraine) (Figure 9). Current conditions (upper maps) are defined as water availability averaged over the climate normal period 1961-90 and water use for the year 2000. The lower maps of Figure 9 show future water stress conditions for winter and summer periods under Security First Scenario for the different European drainage basins. In the Mediterranean region same areas would face severe water stress in 2030 for both seasons than before because of the Security First assumptions (increasing water use and decreasing water availability). Due to higher winter time precipitation and no or only low water use requirements for irrigation, water stress in winter would be low for most other parts of pan-Europe. The image for summer time water stress highlights the effects of reduced precipitation and water required for irrigation which will have consequences on conflicting water use requirements if water cannot be collected in other seasons in reservoirs and distributed in the summer period.

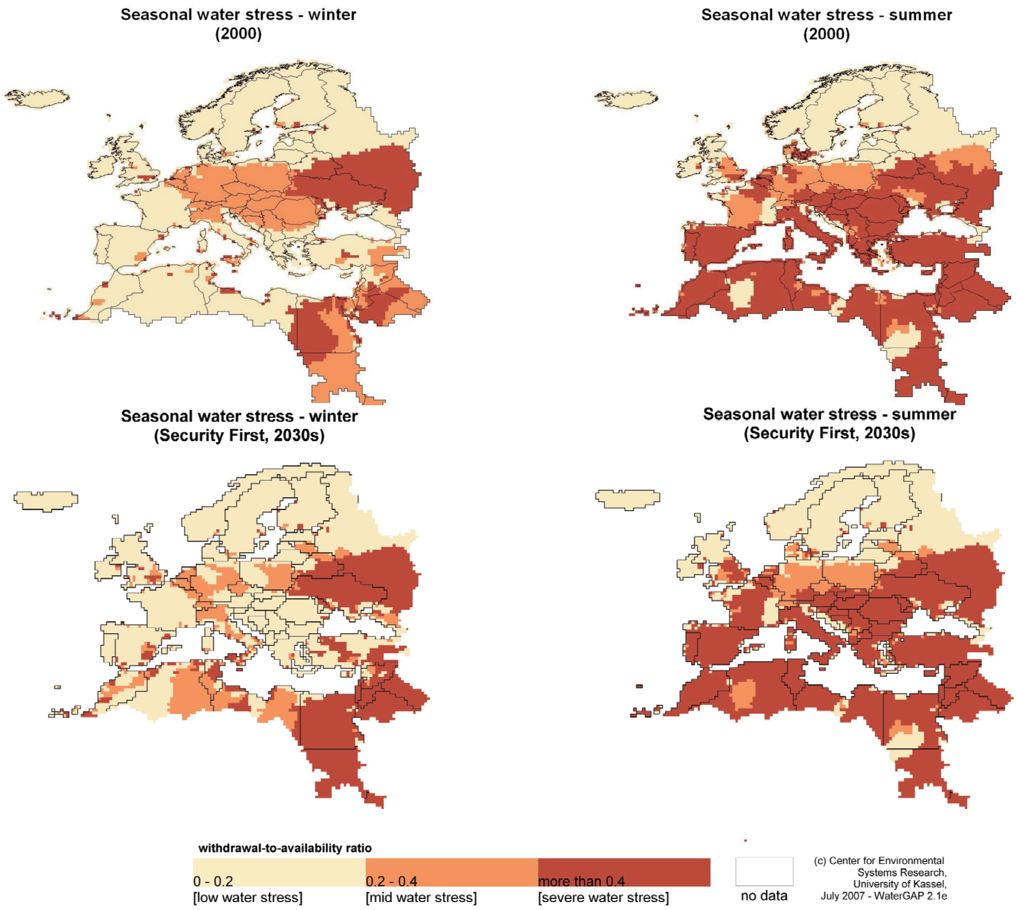

Figure 9. Water stress in 2000 and in 2030 under the Security First scenario (winter and summer) according to drainage basin.

4. Conclusions and outlook

The GEO-4 scenarios show a range of plausible futures: pressure on water resources could increase or decrease. These changes seem to be both scenario and region dependent.

Comparing Sustainability First scenario to the Security First scenario highlights the effect of changing population and economic growth as well as efficiency improvement leading to higher domestic water withdrawals. Faster technological improvements and improved water-saving behaviour can outweigh these effects and lead to lower withdrawals.

According to annual average changes, only minor changes would be detected according to the Security First scenario in Europe: it would become drier around certain countries around the Mediterranean but no big changes would be expected in the rest of Europe. In comparison to the annual changes, water availability decreases during summer by more than 5% in most parts of Europe under the Security First scenario in the 2030s, whereas in winter water availability is projected to increase in most European river basins. Only in Mediterranean rim countries as well as in the southern Ukraine will less water be available.

Seasonal water use (here: irrigation) stresses the Mediterranean region, not only in summer but also in winter. To a certain degree the stress is due to climate change. In a scenario like Security First, however, to an even higher degree it is due to decrease in water use efficiency and increase in irrigated area. The scenario assumptions, security of supply meaning growth in demand for food at the expense of water resources and the environment, play a decisive role here.

First results of the SCENES fast-track thus show that annual average indicators are inadequate in describing the future of water resources in Europe. The focus of scenario studies should be on changes expected in seasonal indicators, for example, on the availability of water during the summer season versus winter season. The next step is now to present these fast-track results to the pan-European panel within the framework of the scenario exercise of the SCENES project. How does the panel deal with this big uncertainty about impacts changing pressure on water resources? Which elements remain important? Which new pressures emerge?

Acknowledgements

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