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SCENES

Water Scenarios for Europe and for Neighbouring States

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Thematic priority: Global change and ecosystems

D4.6
Socio-economic and environmental impacts of future changes in Europe's freshwater resources

Main report

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Harm Duel & Karen Meijer
Deltares, the Netherlands

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Contributors to this report (in alphabetical order by last name):

Name	Institute
Mike Acreman	Centre for Ecology and Hydrology, UK:
Kees van Diepen	Alterra, The Netherlands
Harm Duel	Deltares, The Netherlands
Martina Flörke	Centre for Environmental Systems Research, Germany
Mateusz Grygoruk	Warsaw University of Life Sciences, Poland
Helen Houghton-Carr	Centre for Ecology and Hydrology, UK
Claire Jacobs	Alterra, The Netherlands
Leon van Kouwen	Deltares, The Netherlands
Cedric Laize	Centre for Ecology and Hydrology, UK
Sibren Loos	Deltares, The Netherlands
Fulco Ludwig	Wageningen University, The Netherlands
Karen Meijer	Deltares, The Netherlands
Tomasz Okruszko	Warsaw University of Life Sciences, Poland
Thierry Rieu	ENGREF, France
Kathryn Roscoe	Deltares, The Netherlands
Christof Schneider	Centre for Environmental Systems Research, Germany
Iwan Supit	Wageningen University, The Netherlands
Carine Wesselius	Deltares, The Netherlands
Lineke Woelders	Deltares, The Netherlands

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Preface

SCENES is a four year European research project developing scenarios on the changes in the quantity and quality of fresh water resources in pan-Europe due to climate change, land use change and socio-economic development. The water scenarios are developed based on the SAS-approach that combines storylines with simulations. The storylines are developed by Pan-European Panel (PEP). SCENES has produced four different socio-economic storylines, each is combined with two different climate change scenarios. This report depicts the socio-economic and ecological impacts of pan-European changes in freshwater resources on water system services (Water for Food, Water for Nature, Water for People and Water for Industry and Energy).

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Contents

Appendix

1 Introducing the SCENES project

1.1 The SCENES Project

SCENES is a four year European research project under the Sixth Framework Programme. The project delivers a set of comprehensive scenarios of Europe's freshwater futures up to 2030 and 2050, covering all of "Greater" Europe reaching to the Caucasus and Ural Mountains, and including the Mediterranean rim countries of North Africa and the near East (further referred to as pan-Europe). These scenarios will provide a reference point for long-term strategic planning of European water resources development, alert policymakers and stakeholders about emerging problems, and allow river basin managers to test regional and local water plans against uncertainties and surprises which are inherently embedded in a longer term strategic planning process. Within SCENES, scenarios are understood as descriptions of possible futures that reflect different perspectives on past, present and future developments. Stakeholder-driven storylines provide an internally consistent picture of how water resources in pan-Europe may develop. In addition, state-of-the art models complement the storylines by providing numerical information. Each scenario has its specific consequences for the state of the future pan-European waters and the functioning of its services. Within the SCENES project, the focus is on the water system services 'Water for Food', 'Water for Nature', 'Water for People' and 'Water for Industry and Energy'. These consequences of the future changes in Europe's water resources on the water system services are expressed by means of a set of impact indicators.

1.2 This report

This report is presenting the outcome of the analysis and synthesis of the socio-economic and environmental impacts on water system services (Water for Food, Water for Nature, Water for People, and Water for Industry and Energy) from changed water availability and water use under different possible futures. It provides a concise overview of the approaches applied in Chapters 2 (indicators and modelling framework) and 3 (introducing the scenarios driving the changes in water resources) and of the key messages regarding the impacts of the changes in water resources for the selected water system services in Chapter 4. Further analysis on regional impacts is presented in Chapter 5. Chapter 6 discusses what the main driving forces are for the impacts on the water system services. The implications for water relevant EU policies are discussed briefly in Chapter 7. In the final chapter, the perspectives of the indicator based assessment of the future changes in water resources are discussed.
The findings presented in this report result from analysis of impacts for individual indicators. These indicator results are available in five separate appendices:

- Volume A: Generic indicators
- Volume B: Water for Food
- Volume C: Water for Nature
- Volume D: Water for People
- Volume E: Water for Industry and Energy

2 Analysis Framework

2.1 Indicator based assessment of water scenarios

Indicator frameworks are useful tools to structure information in complex processes and to communicate this information to policy makers, stakeholders and the general interested audience. Indicators are widely used to communicate environmental issues. More specifically, environmental indicators are used for four major purposes (Gabrielsen & Bosch, 2003):

- to supply information on environmental problems, in order to alert policy-makers;
- to support policy development and priority setting, by identifying key factors that cause pressure on the environment;
- to monitor or predict the effects and effectiveness of policy responses, and;
- to raise public awareness on environmental issues.

Within SCENES, the DPSIR framework is adopted as a starting point for structuring the project. The DPSIR indicator framework (see Figure 2.1) is widely adopted (Gabrielsen & Bosch, 2003). Within the SCENES context, changes in climate, economy, land use and population are driving forces (D) that result in pressures (P) to the (aquatic) environment and, subsequently, into changes in the state of freshwater resources (S), e.g. river flow regime, water levels in lakes, nutrient concentrations in rivers and lakes. These changes then have environmental and economic impacts (I) on the functioning of water systems, on the water system services and even on the economic and social performance of society (Kristensen, 2004). In case of undesired impacts, responses (R) by society or policy makers can affect drivers, pressures, state or impacts.

To describe, evaluate and assess the *impacts* of changes in water resources on water system services a set of quantifiable indicators has been developed. The following criteria were applied for the identification of impact indicators.

With respect to their policy and stakeholder relevance:

- The impact indicators contribute to the scenario development process at Pan European scale and regional scale.
- The impact indicators are relevant for evaluating European policies.
- The indicators match the interest of stakeholders (scenario panels).

With respect to providing quantitative information on the scenarios:

- The impact indicators selected have to be significantly influenced by changes in Europe's water resources due to climate, land use and water use change.
- The relationships between impact indicators and the status of Europe's water resources can be described by dose-response relationships.
- The data requirements of the impact indicators can be met.
- The impact indicators can be calculated using WaterGAP output, possibly in combination with other data.

Policy and stakeholder relevance
Stakeholders are primarily EU level policy makers. At smaller scales, there may be other stakeholders that will find the information useful. Although results are not likely to be of sufficient detail to make plans at river basin or national level, the results can be used as a first step in assessing what problems may occur in order to provide focus for more detailed planning at lower scales. In Pan-European Panels, during which storylines have been developed, stakeholders have been involved from major European research institutes, think tanks and policy advice institutes aiming at river basin, EU or global environmental and water management (Kämäri et al., 2008). Following the notion that

the type of information is relevant primarily at EU level policy making, the question is how specific indicators can provide relevant information.

First, do the indicators provide information that can be used to evaluate current policy objectives? Within the context of water scenarios, the major policies to consider are the Water Framework Directive, the Flood Directive, Natura2000 and the Common Agricultural Policy. This is further discussed in Chapter 7.

Second, as part of the storyline development, the Pan-European Panel identified important issues either at present or in the future. Indicators should contribute to an assessment of whether these issues are likely to cause problems in the future and where these problems are most likely to occur (hot spots). In the PEP storyline development workshops, the participants specified a number of objectives for the European water system that they would like to see achieved in 2050. In Table 2.1 these objectives are listed and linked to three main issues of water scarcity, ecosystem and environmental protection and floods. A fourth issue is societal impact that results from changes in water scarcity, floods and in the ecosystem or environment. The SCENES indicators make the four issues explicit.

Table 2.1. Objectives mentioned in the Pan European Panel meetings and main issues to which the objectives are related.

Objective	Issue
Improved quality & quantity	Water scarcity/ecosystem and environmental protection
Sufficient for the desired uses	Water scarcity
Sustainable use	Ecosystem and environmental protection
No flood damage	Floods
Little impact of droughts	Water scarcity
Restoration of natural environments / habitats	Ecosystem and environmental protection
Efficient water use	Water scarcity
True costs of water, low	Societal impacts
Equitable access to water	Societal impacts

Data availability
The available data and tools pose specific requirements for the indicators. The calculation of changes in state with the Water GAP model is done at a grid cell resolution of 5 by 5 arc minutes grid (longitude and latitude; approximately 6 x 9 km in Europe) and aggregated to basin level). This resolution of the quantified SCENES results makes them particularly suitable for two purposes:

- To analyse whether policy objectives are likely to be met at EU level.
- To identify hot spots where certain problems are likely to take place in the future.

Based on these requirements, within SCENES, we distinguish two types of impact indicators (Figure 2.1):

- *Generic hydrological impact indicators*: indicators that are addressing the hydrological changes in freshwater availability and quality in terms of too much (flood events), too little (drought events, water stress) or too dirty (water pollution). These indicators provide less information on the socio-economic and ecological and environmental consequences of changed water availability, but are easy for stakeholders to understand.

- *Impact indicators for water system services*: indicators that are addressing the environmental, ecological and socio-economical consequences of changes in the state of fresh water resources on the water system services selected: Water for Food, Water for Nature, Water for People and Water for Industry and Energy. The evaluation of impacts using these indicators requires good understanding of the calculation approach. The indicators selected can more directly be linked to policy objectives.

The total set of impact indicators is listed in Annex 1.

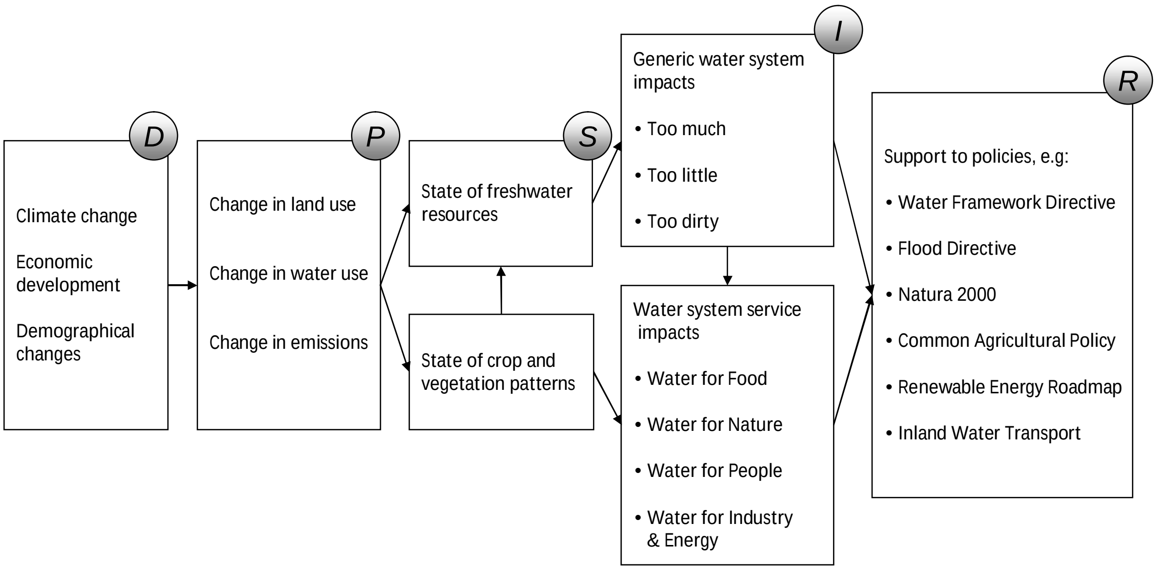


Figure 2.1. The SCENES indicator framework.

2.2 Modelling framework

To compute the impact of climate change and water use by different sectors on future water resources, the WaterGAP model is applied in SCENES (Döll et al. 2003, Flörke & Alcamo 2005, Verzano, 2009; Aus der Beek et al., 2010). In addition, different modelling tools (e.g. CGMS, HABITAT) were applied to calculate the environmental and socio-economic impacts of the changes in water availability and water quality on the water system services.

2.2.1 Modelling Water Use and the Availability of Water Resources: WaterGAP

For the quantification of the pan-European SCENES scenarios and to compute the impact of climate change and other important driving forces on future water resources the water model WaterGAP (Water – Global Assessment and Prognosis) was used (Alcamo et al. 2003, Döll et al. 2003). WaterGAP was developed and further improved at the Center for Environmental Systems Research and is designed for large-scale grid-based applications and its capabilities to simulate water availability and water use are well tested in various scenario assessments: e.g. Global Environment Outlook GEO-4 (Rothman et al., 2007), State of the European Environment (EEA, 2005), Millennium Ecosystem Assessment (Alcamo et al., 2005a). The model version applied in SCENES, WaterGAP3 (Verzano, 2009), herein referred as WaterGAP, computes both water availability and water uses on a 5 by 5 arc minutes grid (longitude and latitude; 6 x 9 km in Europe), covering whole Europe. WaterGAP consists of two main components: a Global Hydrology Model to simulate the terrestrial water cycle and a Global Water Use Model (Flörke and Alcamo 2005) to estimate water withdrawals and water consumption of the domestic, thermal electricity production, manufacturing, and agricultural sectors (Figure 2.2). The aim of using the Global Hydrology Model was to simulate the characteristic macro-scale behaviour of the terrestrial water cycle in order to estimate monthly and daily water availability for pan-Europe. Herein, water availability is defined as the total river discharge, which is the sum of surface runoff and groundwater recharge. The upstream/downstream relationship among the grid cells is defined by a global drainage direction map (DDM5) which indicates the drainage direction of surface water. Additionally, the flow length per grid cell is enhanced by applying an individual meandering factor for each grid cell derived from a high-resolution DDM (HydroSHEDS, Lehner et al. 2008). In a standard model run, river discharges in approximately 180,000 grid cells (approximately 2000 river basins >140 km² drainage area) in Europe are simulated. The effect of changing climate on runoff is taken into account via the impacts of temperature and precipitation on the vertical water balance. River discharge is affected by water withdrawals and return flows. In WaterGAP, natural cell discharge is therefore reduced by the consumptive water use in a grid cell, whereas most of the water withdrawn is returned, probably with reduced quality, to the environment for subsequent use. Water use for the agricultural and electricity production sectors are calculated on grid scale, but for domestic and manufacturing sectors on a country scale. These country-scale estimates are downscaled to the grid size within the respective countries using generic downscale algorithms.

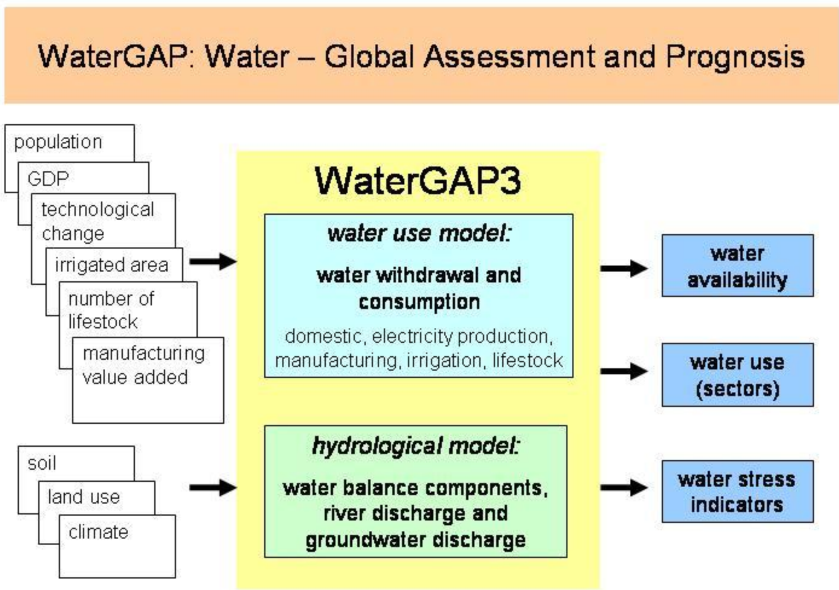


Figure 2.2. The main structure of WaterGAP.

The baseline climate input including monthly information on precipitation and temperature covered the timeframe 1961 – 1990. For the model simulations a combination of the datasets CRU TS 2.1 (Mitchell and Jones, 2005) and CRU TS 1.2 (Mitchell et al. 2004) was used. Although the CRU TS 1.2 dataset has a higher spatial resolution (10 arc minutes) it covers only the predominant part of Europe. In order to get information for grid cells that were not covered, the CRU TS 2.1 dataset with a spatial resolution of 30 arc minutes was applied. Then both datasets were simply downscaled into a standard gridded data set of mean monthly precipitation and temperature from the CRU time series with the differences between current and future conditions computed by the climate models (delta change approach). Following this method, 30-year monthly time series of temperature and precipitation were derived for the scenario period (2040-2069). The future 30-year time series has the climate variability of the control period (1961-1990).

2.2.2 CGMS

CGMS is the Crop Growth Monitoring System as applied by the Joint Research Centre of the European Commission. The heart of CGMS is the WOFOST crop growth simulation model, whose underlying principles have been discussed by van Keulen & Wolf (1986). The initial version of this model was developed by the Centre for World Food Studies and AB-DLO (van Diepen et al., 1988; 1989). Implementation in CGMS and its structure is described by Supit et al. (1994a).

In WOFOST first, instantaneous photosynthesis, calculated at three depths in the canopy for three moments of the day, is integrated over the depth of the canopy and over the light period to arrive at daily total canopy photosynthesis. After subtracting maintenance respiration, assimilates are partitioned over roots, stems, leaves and grains as a function of the development stage, which is calculated by integrating the daily development rate, described as a function of temperature and photoperiod. Assimilates are then converted into structural plant material taking into account growth respiration. Leaf area growth is driven by temperature and limited by assimilate availability.

Aboveground dry matter accumulation and its distribution over leaves, stems and grains on a hectare basis are simulated from sowing to maturity on the basis of physiological processes as determined by the crop's response to daily weather: (rainfall, solar radiation, photoperiod, minimum and maximum temperature and air humidity), soil moisture status and management practices (i.e. sowing density, planting date, etc.). Water supply to the roots, infiltration, runoff, percolation and redistribution of water in a one-dimensional profile are derived from hydraulic characteristics and moisture storage capacity of the soil.

The historical weather data are taken from the MARS-STAT Data Base provided by the Monitoring Agricultural Resources (MARS) Unit of the Institute for Environment and Sustainability of the JRC of the EC at Ispra, Italy. These data consists of daily values of maximum and minimum temperature, wind speed, global radiation and vapor pressure, rainfall, interpolated from station data to a 50x50km climatic grid (Beek et al., 1992; van der Voet et al., 1993; Micale and Genovese, 2004). Weather data have been collected from the Global Telecommunication System (GTS) of the World Meteorological Organization as well as from national and sub national station networks. Presently, data from nearly 7000 stations is available. Of these stations about 2500 receive daily meteorological information. Missing global radiation values are computed automaticallyfrom data from the GTS: sunshine duration, a combination of cloudiness and the temperature range or only the temperature range. Other missing data are replaced by long term average values. From 1976 a more or less complete European coverage is available

CGMS simulates two production situations: potential and water-limited. The potential situation is defined by temperature, daylength, solar radiation and crop characteristics (e.g. leaf area dynamics, assimilation characteristics, dry matter partitioning, etc.). The water-limited situation, in addition, is characterized by water availability derived from root characteristics, soil physical properties, rainfall and evapotranspiration. In both situations optimal supply of nutrients is assumed. For each situation, both total aboveground dry matter and grain dry matter per hectare are calculated.

Simulations are performed per Elementary Mapping Unit (EMU), the intersection of a Soil Mapping Unit (SMU), grid cell and administrative region, Nomenclatures des UnitésTerritorialesStatistiques (NUTS).

2.2.3 HABITAT

HABITAT is a GIS-based framework that allows for the analysis of spatial changes in an integrated and flexible way. In SCENES, HABITAT has been applied to develop a water quality (nutrients, algae, macrophytes) module based on point and diffuse emission input as well as a water temperature module for the main river stem based on heat discharges and low flow conditions in which WaterGAP output could be integrated. The spatial processing of data allowed for a regional analysis of changing conditions of water quality and thermal energy related impacts on water bodies such as bathing water quality, macrophyte diversity, risk for algae blooms and available cooling water.

3 Pan-European Water Scenarios

In SCENES, the Pan-European Panel (PEP) has developed four socio-economic storylines for 2030 and 2050. In the quantification process, the four storylines for 2050 have been combined with two climate scenarios. Both the socio-economic scenarios and the climate change scenarios used are discussed in this chapter.

3.1 Scenario development approach

Within SCENES, the Storyline And Simulation (SAS) approach (Alcamo, 2001) is adopted to develop pan-European water scenarios. The SAS-approach has been successfully applied at pan-European scale (Cumming et al. 2005, Alcamo et al. 2005b). The SAS approach accounts for all steps considered essential to develop scenarios at a single scale (see Figure 3.1). Important steps include the establishment of a scenario panel and scenario team (1-2); construction of storylines (3) that are quantified and revised (4-6) in an iterative procedure (7); and publication and distribution (10) after review and finalization (8-9). The *scenario team* is a group of experts responsible for the coordination of the scenario development process and for the quantification of the driving forces and pressures on the water resources. The *scenario panel* is a core group of key stakeholders that is responsible for the development of the storylines. In SCENES, scenario panels have been formed at the pan-European level and for pilot areas within four European regions: Mediterranean, Baltic, Lower Danube and Dnepr-Don. The pan-European Panel (PEP) was responsible for the storylines development at pan-European level. Input from regional panels was used as part of the enrichment process of the storylines development at pan-European level. Within SCENES, the iterative scenario development process consists of 4 cycles of storyline development and quantification of storylines.

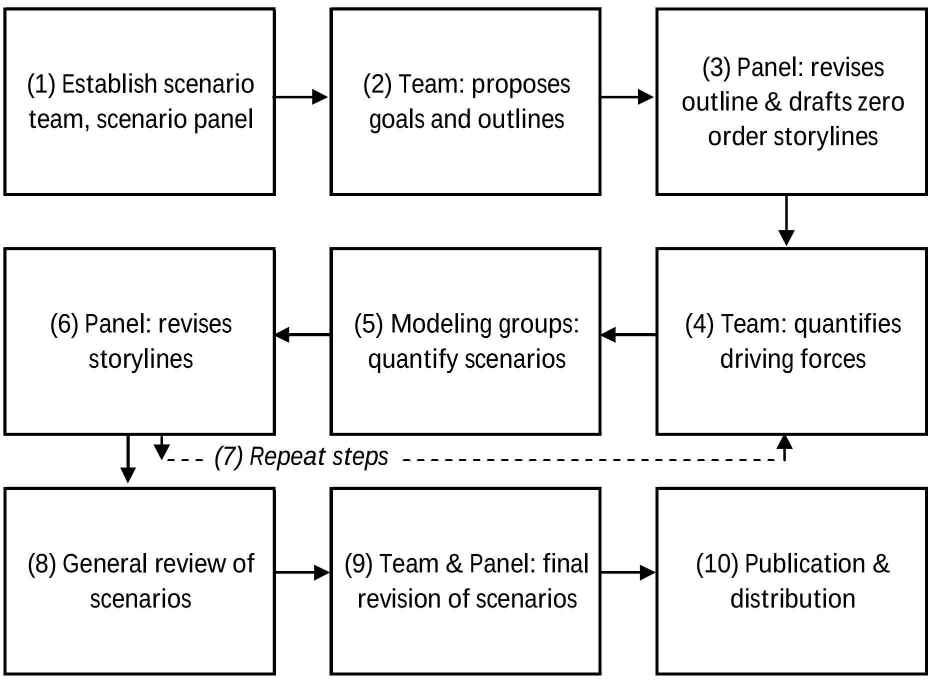


Figure 3.1. Overview of SAS (Story And Simulation) approach to scenario development.

3.2 Socio-economic scenarios

Four scenarios have been developed in the form of narrative, qualitative stories (Figure 3.2):

- Economy First, where priority is for economic growth
- Fortress Europe, in which the priority is to be self sufficient
- Policy Rules, where policies determine the future
- Sustainability Eventually, which aims at sustainable development

The four scenarios mainly focus on addressing the prospects for water use in the most important economic sectors in Europe and the future of the European Water Framework Directive. In addition, the focus of the four storylines is on potential conflicts, trade-offs and the complementarities between the society oriented and the nature-oriented water system services. Each narrative storyline describes three periods: the beginning (2008-2015), the middle period (2015-2030) and the final period (2030-2050). A detailed description of the socio-economic scenarios can be found in SCENES report D2.10.

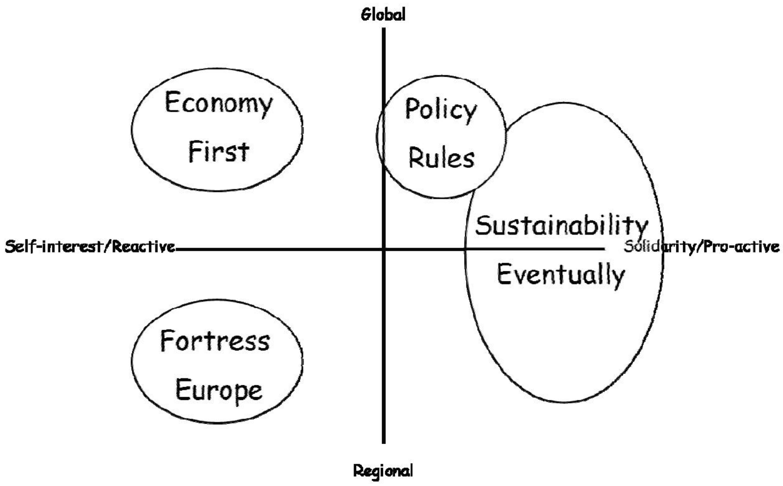


Figure 3.2. Four socio-economic scenarios developed in SCENES.

3.2.1 Sustainability Eventually

Sustainability Eventually sketches the transition of a globalizing and market-oriented to environmental sustainability. Local initiatives are leading and the landscape becomes a basic unit. This fundamental change in human behaviour, governance structures and the level of decision making is exerted by a phase of strong top-down policies. Quick change measures are accompanied by slow change measures for the long run.

The attempt to address multiple goals – economic, environmental as well as social – results in trade offs at the expense of economical development. Economy is thus characterized by slow growth, with most growth being in the northern part of Europe.

The multiple goals will not be reached at the same speed and through the same path however, due to regional and spatial differences, resulting in a split between water poor (especially the South) and water rich countries. This is partly due to very different water related issues. This split will not be carried through to political levels, but does involve close collaboration between water poor countries on water related issues, but some devastating effects from climate change cannot be prevented. Internal migration to areas with favourable climatic conditions will intensify, especially when above mentioned water scarcity issues in water poor countries are addressed.

The shift towards a more landscape policy, will lead to better management of Natura 2000 sites, with farmers contributing to management of farmland with high nature-value. This and a decrease in food demand will lead to land use changes.

Regional EU initiatives to develop environmental technology for the purpose of for example water saving will increase and efforts are made to share these technologies, resulting in introduction in eastern Europe as well. Water demand is thus strongly reduced by water savings and a decrease in water demand. In 2050, a balance is reached between water supply and demand: especially less water is needed for industrial activities.

3.2.2 Policy Rules

Policy Rules explores the implications if government and policy dominate the trajectory of water use in Europe. The emphasis on a top down approach contrasts with the largely (accept for the first phase) bottom-up approach in Sustainability Eventually. Planning and direction, which are coordinated by governing bodies, prevail over spontaneous initiatives of the markets whose effectiveness is hampered by lack of coordination. EU level government and policy play an increasingly dominant role over national and provincial law.

In this scenario, the EU gains a stronger hold on policy at a European level, resulting from high energy costs, access to energy supplies, meeting increasing water demands and adaptation to climate change. Political integration remains a challenge due to the obligation to comply with various EU directives, especially the WFD. Integration of candidate EU members is challenged by shifts in political directions, climatic conditions, economic (food and energy prices) processes, consumption of increasingly scarce water and migration/urbanization. This leads to EU policies becoming slowly more ineffective. The EU responds by setting different but narrowed priorities regions. This in turn leads to disparity in economic growth prospect and intensification of its causes. Ecosystem services begin to deteriorate as well. These processes reinforce public awareness and the EU seizes the chance to raise awareness even more and act upon it. Policies to de-carbonize Europe expand river basin planning to encompass multiple objectives and to address local and regional issues. These acts are met with massive support. In the end, this finds Europe at the forefront of this new socio-economic paradigm of public/private partnership and leads a global shift in this direction while its own economic growth recovers.

3.2.3 Fortress Europe

Fortress Europe describes the conservative attitude and focus on security of Europe against non-EU countries in general. After the financial crisis in the first decade of 21^{rst} century, many countries and economic pacts try to protect their market against influences from other parts of the world. The EU expands its border on the Balkans but enlargement in general is always evaluated in the light of security and remains a point of discussion up to 2050.

EU funding, legislation and policy such as the WFD is re-evaluated and weakened at points where it does not contribute to solving security issues. National governments increase their strength but still feel the need to cooperate. Environmental and social research suffers a lack of funds. The development of technological innovations will be hampered as well and as such, Europe relies on existing fossil fuel (coal and oil) and nuclear power plants.

In the middle period, Europe increases its protectionism as regions like Russia and Chine increase their power and implements strong policies. This leads to a more protectionist agricultural policy as the EU strives for self-sufficiency; especially in regions were crop production is high. Farming is also subsidized in areas with high nature value and food is spread over countries.

A switch to more effective agricultural techniques and renewable energy sources comes as environmental losses are increasingly perceived as security issues. Industries and businesses pay little attention to these issues. Water pricing is implemented and water poor countries have a strict upper limit on the amount of water that can be purchased and conflicts over water are on the rise.

Europe keeps on getting stronger and when water scarcity problems arise, nature often comes last as security related sectors are favoured. Trade outside the EU is hampered by diminishing trust and taxes, but inside the EU, trade increases. Resources in the EU are strictly managed, leading to fading out agriculture and industry in general in areas where it uses too many resources, leading to increased sustainable land and resource use. This however, leads to social unrest since water poor countries are struggling, inside as well as outside the EU. This leads to migration from poor to rich regions, but high security makes this difficult.

At the end consumption patterns start to improve somewhat and climate change issues are seen as a threat, so adaptation measures are taken. Public unrest arises as they bear the burden of strong regulation. In response the EU invests in non-security related sectors and opens up the trade barriers. This increases economic strength.

3.2.4 Economy First

Globalization and liberalization is embraced in order to reduce barriers to trade and create new enterprises and opportunities. Technological and business innovations spread quickly, both within the region and around the globe. Economic growth rates are promising, but income inequality grows over time due to massive cutbacks in social security systems. Less people can afford university education, resulting in shortages in the high-skilled labour force. This trend is exacerbated by the ageing population.

Increased immigration fills gaps in the workforce but creates social and ethnic tensions. The ability of governments to regulate markets and respond effectively to societal and environmental problems diminishes. European integration remains restricted to the completion of the internal market; and regulatory competencies are cut back.

International institutions and regimes are weakened. Governments rely mainly on market based instruments (voluntary agreements, tax incentives) rather than legislation. Multinational companies dictate environmental standards/progress. With growing income inequalities, a relatively few rich people enjoy their lives while it becomes harder and harder for the majority to keep their living standards. In the first half of the scenario, there is a rapid diffusion of knowledge and innovations around the globe, but basic research in some areas struggles with lack of funds. High levels of education are achieved, but there is some targeting of opportunities to people who can afford to pay. This is seen in part by the increasing number of private universities. There are no equal opportunities for education. Europe experiences a brain drain to other regions later in the period.

3.3 Climate change scenarios

The development of climate change scenarios is not part of SCENES. Therefore, climate change scenarios were selected from existing data outside the project.

Basis for the climate change scenarios is the scenario development carried out by the Intergovernmental Panel on Climate Change (IPCC) for its Special Report on Emission Scenarios (SRES). Using a two dimensional axis approach to describe a range of future demographic, economic, technological and behavioural changes, the four SRES storylines (A1, A2, B1 and B2) represent different world futures in two distinct dimensions (figure 3.3): a focus on economic versus environmental values and global versus regional governance. The SCENES storylines differ from the SRES storylines, but are characterised in a similar way: global versus local, economic versus environmental.

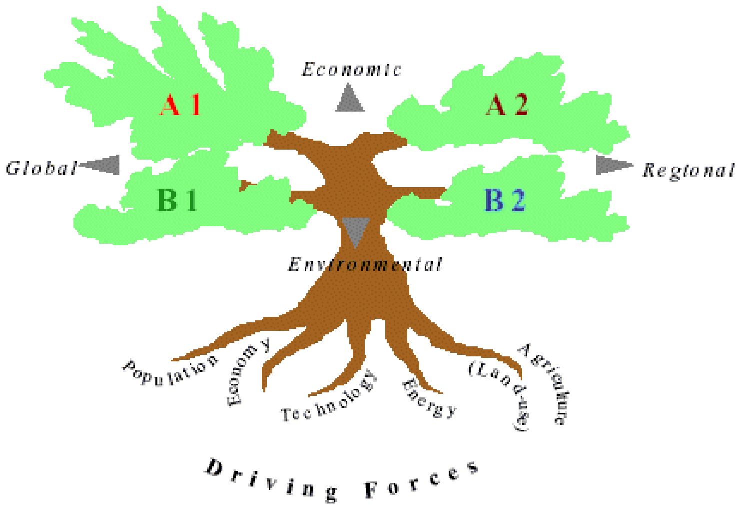


Figure 3.3. The SRES worlds and emission scenarios (source: Nakicenovic & Swart., 2000)

With respect to climate change, the SRES storylines were translated into greenhouse gas emission scenarios and, therefore, provide input to global circulation models (GCM) to quantify the future changes in climate. There is a set of climate models available, producing a wide range of possible future climate conditions. Instead of making ensemble runs, which is often done to deal with uncertainty, two models have been identified to cover a range of possible climate situations under A2 emission scenario (worst case emission scenario). Each SCENES storyline is combined with these two climate scenarios, resulting in a total of eight future scenarios.

The following climate models were selected:

- The IPSL-CM4 model from the Institute Pierre Simon Laplace, France (IPCM4).
- The MICRO3.2 model from the Center for Climate System Research, University of Tokyo, Japan (MIMR).

Both the IPCM4-A2 and MIMR-A2 climate scenarios indicate high temperature increase, especially in Northern and Eastern Europe (Figure 3.4). The projections for precipitation are completely different between the two climate scenarios. The future changes in precipitation are rather minor in MIMR-A2 scenario, whereas IPCM4-A2 climate scenario shows dramatic changes in precipitation in Europe, with a strong decline in the Mediterranean region and a significant increase in northern Europe (Figure 3.5).

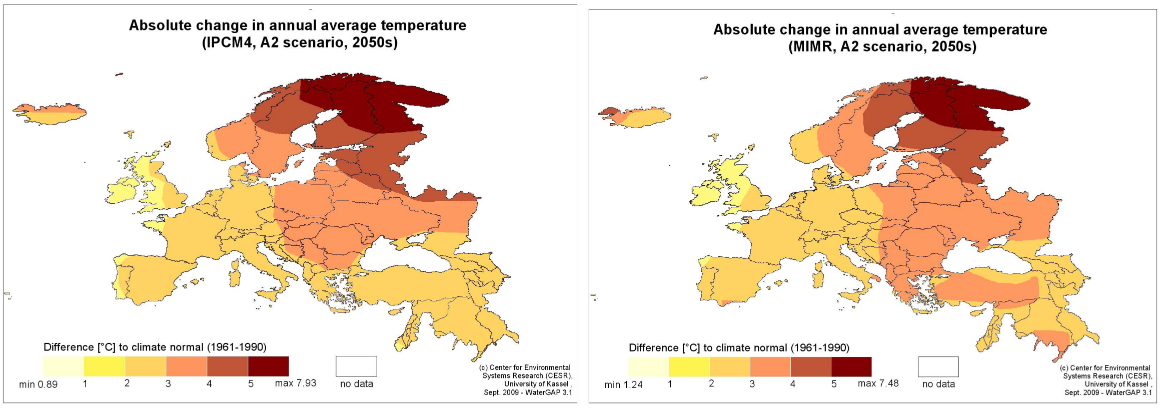


Figure 3.4. Absolute change in annual average temperature between current situation and 2050s according to IPCM4-A2 (left) and MIMR-A2 (right).

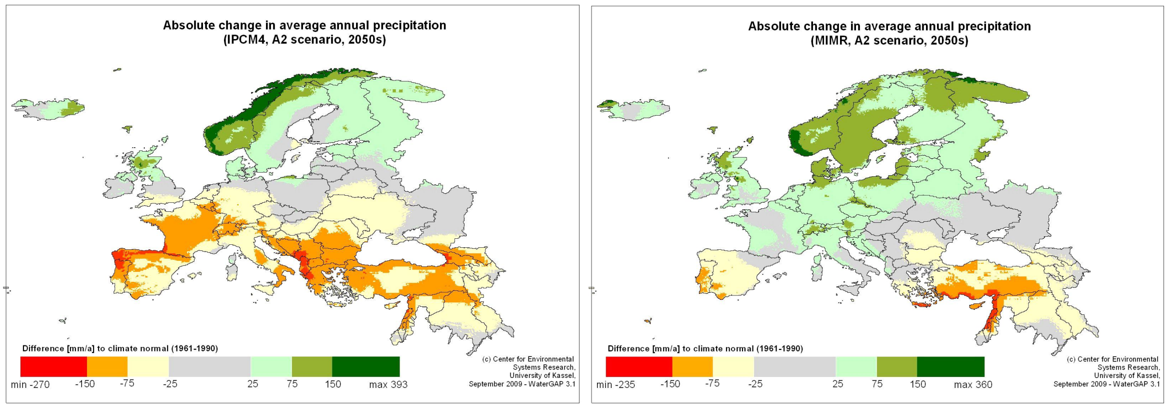


Figure 3.5. Absolute change in average annual precipitation between current situation and 2050s according to IPCM4-A2 (left) and MIMR-A2 (right).

4 Europe's water future

What does the future of Europe look like in terms of water? This chapter presents the key messages on the main developments that can be expected with respect to the availability of water resources in general and for the four water system services: Water for Food, Water for Nature, Water for People and Water for Industry and Energy. The messages presented in this chapter are a result of the analysis of the full set of indicators. A more detailed discussion per indicator can be found in the separate volumes to this report. To understand the impacts on the water services, we first sketch an overall image of how average, high and low flows may change and to what extent water shortages are likely to be expected.

4.1 Water resources

Key messages:

- *Climate change has a significant impact on the water availability in pan-Europe; however both direction and change depend on the climate scenario selected.*
- *Extreme discharge levels may become more frequent and intense in parts of the Mediterranean region, parts of Western Europe, parts of Western Asia, parts of Central Europe and Southern Scandinavia. There are also large areas where flood hazard decreases.*
- *Both climate scenarios selected indicate a significant decline in average water availability in Mediterranean region during in summer period, resulting in deterioration of the low flow conditions.*
- *Water system services will experience increased water stress in the Mediterranean region and (depending on the climate and socio-economic scenarios) locally in Western and Eastern Europe as well.*

The climate scenarios do not simply translate into 'wetter' or 'drier' conditions. The two climate scenarios present two very different patterns of annual water availability (Figure 4.1). Both climate scenarios are with respect to annual water availability consistent only for Northern Europe (wetter) and the North-African Coast, Western Asia and Eastern Spain (drier). The broad band over Central Europe ranging from the Iberian Peninsula and France and the Benelux in the west, to Russia in the east will experience lower annual average water availability under the IPCM4-A2 scenario, while the annual water availability will be the same or higher in this region under the MIMR-A2 scenario.

Figure 4.2 shows the changes in frequency of the current once per 100 year discharge compared to the current situation for different climate scenarios. In the blank areas the high discharges occur less frequent, but the exact frequency is unknown. Northern Africa was not included at all in this analysis. Under MIMR increased flood hazard becomes apparent around the Mediterranean area, as well as in parts of Europe and western Asia. Under IPCM4 climate scenarios, it is especially Southern Spain that is expected to experience large increases in flood hazards. In section 4.4, this information is combined with indicators for flood damages to assess change in flood risk.

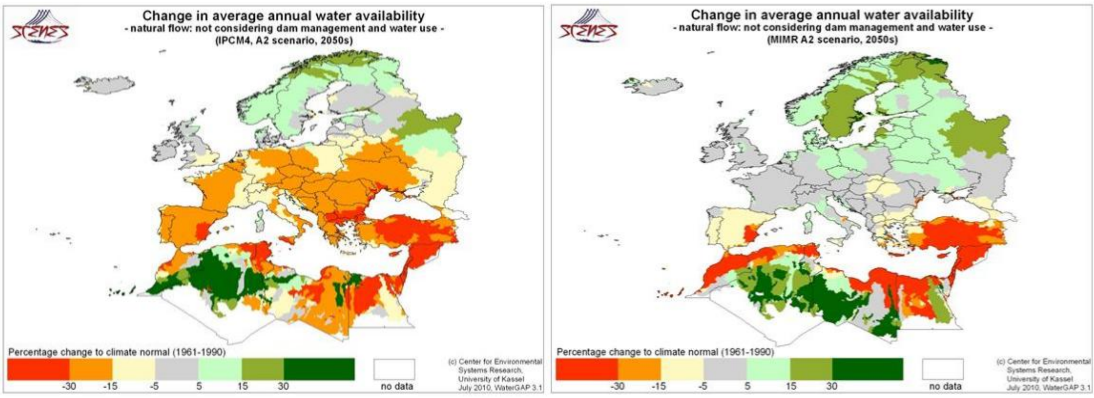


Figure 4.1. Changes in water availability under A2 emission scenario according to two different climate models: IPCM4 (left) and MIMR (right).

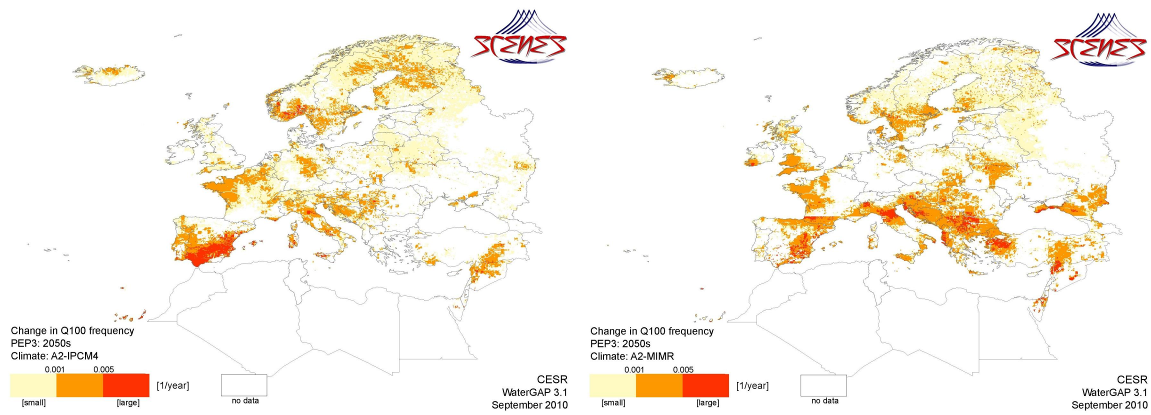


Figure 4.2. Changes in frequency of the current once per 100 year discharge compared to the current situation for different climate scenarios: left IPCM4-A2, right MIMR-A2.

The Mediterranean region, especially the Iberian peninsula, Turkey, Western Asia and North-Africa will experience more frequent and more severe low flow conditions under both climate scenarios (Figure 4.3). In addition, low flow conditions will also be worsening in western Europe and Ukraine. On contrary, central, eastern and northern Europe will experience wetter conditions during low flow situations.

Within SCENES, three indicators provide information on whether water users (including nature) may experience shortage. The Water Stress Index (also known as Water Exploitation Index) considers gross water use (withdrawals), while the Water Consumption Index is based on net water use (consumption). The Water Scarcity index combines net water use with low flow conditions to consider the circumstances under which a shortage may occur. The overall picture is that future water stress within a region may differ significantly between the socio-economic scenarios. Under the scenarios Policy Rules and Sustainability Eventually the water stress is limited to the North-African coast, Western Asia and individual basins in North-Africa, Western Europe, the Mediterranean and the Moldau basin. Under the scenarios Economy First and Fortress Europe scenario water stress is experienced in much larger areas including also almost the entire area of Western and large parts of Eastern Europe. When considering consumptive use, the areas experiencing shortage are small and the differences between the socio-economic scenarios are small as well.

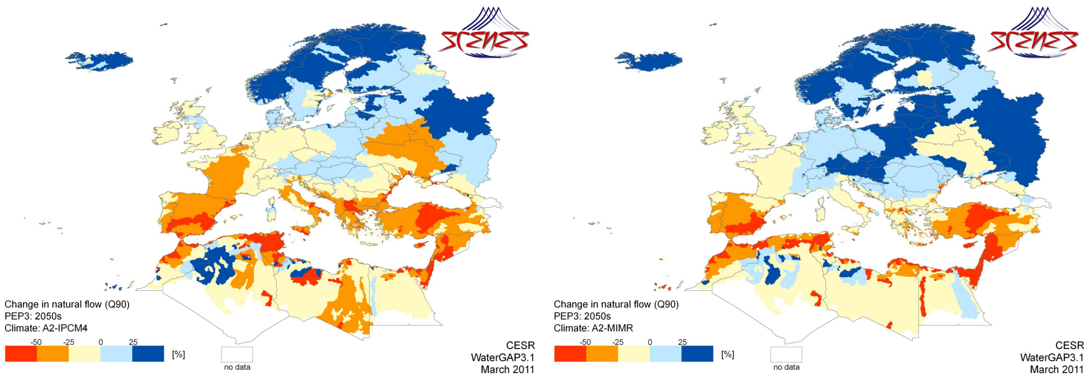


Figure 4.3. Changes in low river discharges (Q_{90}) compared to the current situation under different climate scenarios: left IPCM4-A2, right MIMR-A2.

4.2 Water for Food

Key messages:

- *For agriculture, socio-economic drives, technological development and agricultural policies are more important than climate change as a factor influencing irrigation water withdrawals and water stress.*
- *Innovations in water technology can compensate climate change impacts on agriculture.*
- *Irrigation water stress increases, because of the larger areas requiring irrigation when conditions become warmer.*
- *For the Mediterranean region, irrigation water stress will decrease as a result of increased irrigation efficiency and a reduction in (irrigated) agricultural land.*

Water demand in agriculture is both depending on available water resources and water consumption that is directly derived from the crop consumption in rain fed agriculture and the irrigation water demand in irrigated regions. These two last variables are mainly related to economic conditions through the choice of rain fed versus irrigated agriculture, of cropping patterns and of irrigation technologies. These economic conditions are supposed to have much larger variations than the climate conditions due to the uncertain evolution of the global economy and the European public policies (CAP mainly).

Overall, the changes in water availability during summer and over the year provide a first estimate of the effect of climate change on irrigation water availability. The largest decreases in water availability at river basin scale are found for southern Europe in the IPCM climate scenario. These maximum decreases are more than 30-40% compared to the baseline, but in large areas in the middle and southern European zones the decrease is less prominent and varies between 0-30%. The IPCM scenario is drier than the MIMR scenario. A decline of irrigated area of the same order of magnitude is sufficient to reduce the water withdrawals with the same percentage, and to compensate for the increased irrigation water stress, that would result from the lesser water availability.

According to the scenarios, the reduction in irrigated areas is indeed about 30% in many southern countries, but in many other country-scenario combinations the irrigated area is multiplied by a factor 2, 3 or even higher. This means that the differentiating effect of change in irrigated area alone is stronger than the effect of decreased water availability. Apart from the increase or decrease in irrigated area the water stress is determined by the change in irrigation efficiency by application of improved technology. The difference in irrigation water stress between areas and between scenarios can to a large extent be explained by improved technology. This does not affect the consumptive use much, but it does affect the gross water use, the volumes abstracted from the system. By moving from surface irrigation to drip irrigation the field efficiency may increase from about 0.33 to over 0.70.

For 2050, agricultural water stress (precipitation deficit) in summer will increase significantly in Western Europe (e.g. France). Consequently due to the agricultural adaptation to the overall water deficit, resulting in development of irrigated areas in Western Europe. This will result in an increased irrigation water stress (Figure 4.4). These observations on the changes in irrigation represent the general pattern as the policy scenarios may show contrasting developments in changes in irrigated area and in efficiencies between countries, regions and scenarios. In addition, the effects of irrigation on the total agricultural production is limited in most countries north of the Alps, because only a small fraction of the cropland is irrigated.

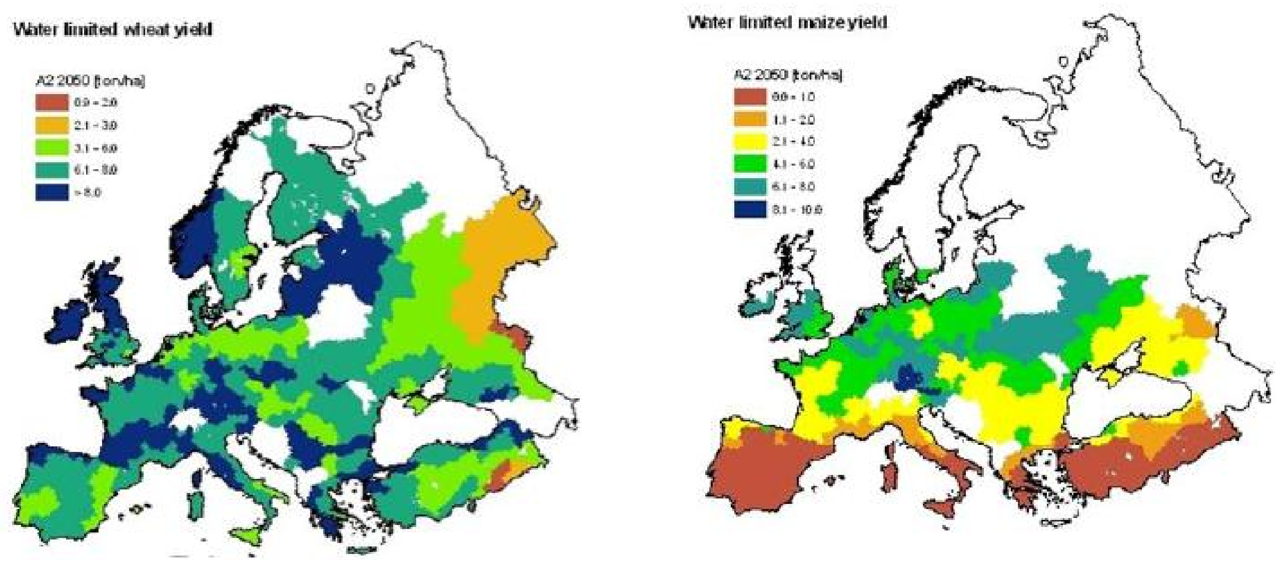


Figure 4.4. Water limited wheat and maize yield in 2050s according A2 climate scenarios (CGMS).

Major differences in irrigation water stress between areas and between scenarios can to a large extent be explained by an balance between lower water demand due to improved technology and decline of irrigated area and higher scarcity of the water resources available. This does not affect the consumptive use much, but it does affect the gross water use, the volumes abstracted from the system.

4.3 Water for Nature

Key messages:

- *Flow regime alternations will affect the majority of European river and wetland ecosystems and consequently ecosystems services as well.*
- *Many rivers and lakes will experience a decline in macrophyte biodiversity as a result of high nutrient levels.*
- *Future water temperature in rivers will affect fish populations and communities in many European river catchments.*

The vast majority of river and riparian wetland ecosystems in Europe will experience significant ecological changes, as alterations in flow regime will have a severe impact on hydrological requirements of river and riparian wetland ecosystems (Figure 4.5). The most affected will be these ones which ecological values depend on flood pulse regime.

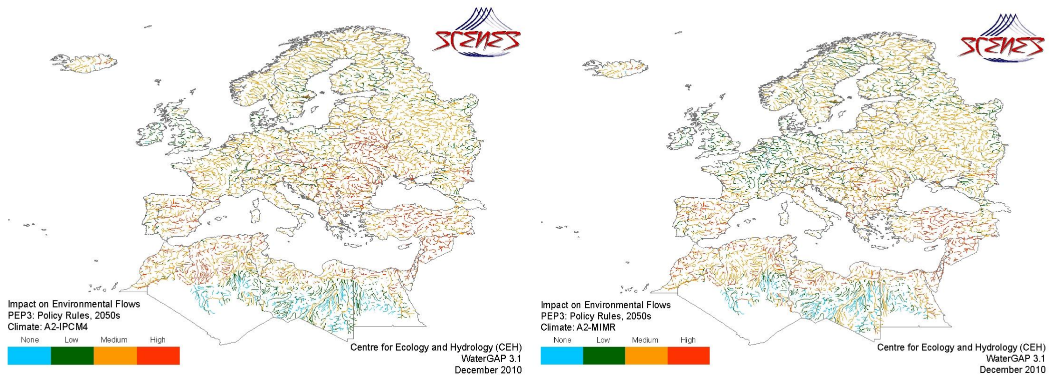


Figure 4.5. Impacts of climate scenarios (left IPCM4-A2, right MIMR-A2) on environmental flow requirements of river ecosystems.

All SCENES scenarios show that many rivers and lakes in Western, Central and Southern Europe will remain suffering from high nutrient levels resulting in a decline of biodiversity and a moderate or poor ecological status (Figure 4.6). Main source of the high nutrient levels are the nutrient emissions from agriculture. There is a distinct variability in nutrient emissions from agriculture between the socio-economic scenarios and not surprisingly, scenario Sustainability Eventually shows clearly the best results as the reduction in nutrient emissions from agriculture is the strongest in this scenario.

In the current situation, water temperature is a limiting factor for fish in rivers in highly industrialized and urbanized catchments due to cooling water discharges, especially in Western Europe. For future scenarios temperature rise is mainly caused by climate change and will affect fish communities in rivers in many catchments in Europe. Only in Northern Europe, fish populations are not affected significantly by increase of river water temperature. The differences between the scenarios are rather small (Figure 4.7).

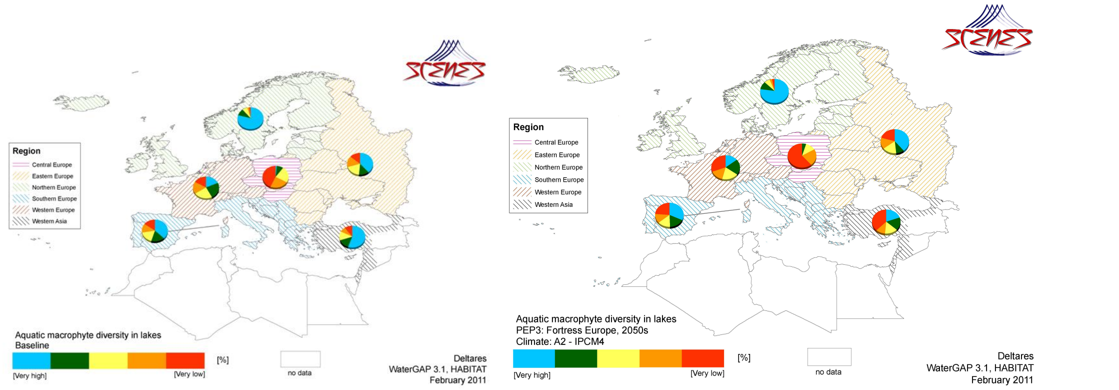


Figure 4.6. Macrophyte diversity in lakes: left Baseline scenario, right Fortress Europe/IPCM4

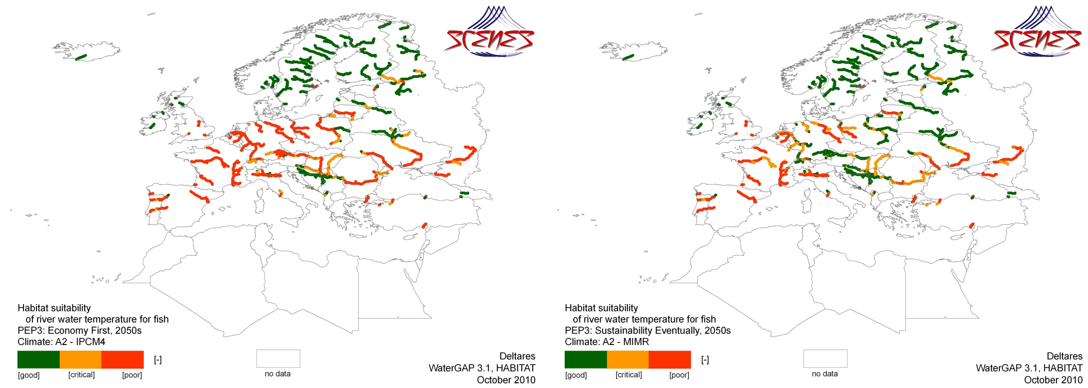


Figure 4.7. Habitat suitability for fish in rivers based on water temperature: left Economy First/IPCM4, right Sustainability Eventually/MIMR.

4.4 Water for People

Key messages:

- *Domestic water use is not likely to face major problems*
- *Harmful algal blooms will seriously jeopardizes bathing water quality in large parts of Europe in all scenarios.*
- *Risks for loss-of-life due to floods will reduce while risks for damage increase*

The impacts on domestic water calculated for the worst case scenario in which domestic water use has the lowest priority in water allocation show only small isolated areas that possibly face shortages for domestic water. It is possible though those shortages occur locally during certain seasons. Figure 4.10 shows that the change in the most extreme scenario (Economy First/IPCM4) is small compared to the baseline scenario.

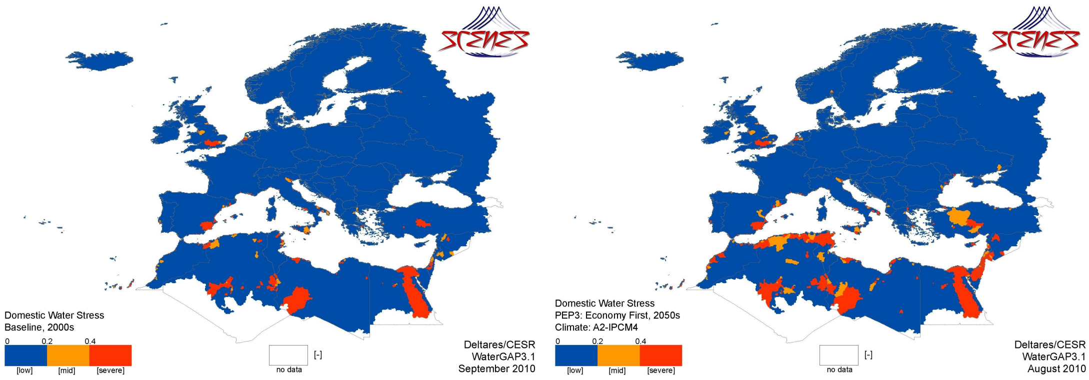


Figure 4.10. Domestic water stress: left Baseline scenario, right Economy First/IPCM4.

Although compared to the baseline scenario the risk for harmful algal blooms decreases under all scenarios, 85% of the water bodies remain at high risks for harmful algal blooms (Figure 4.11).

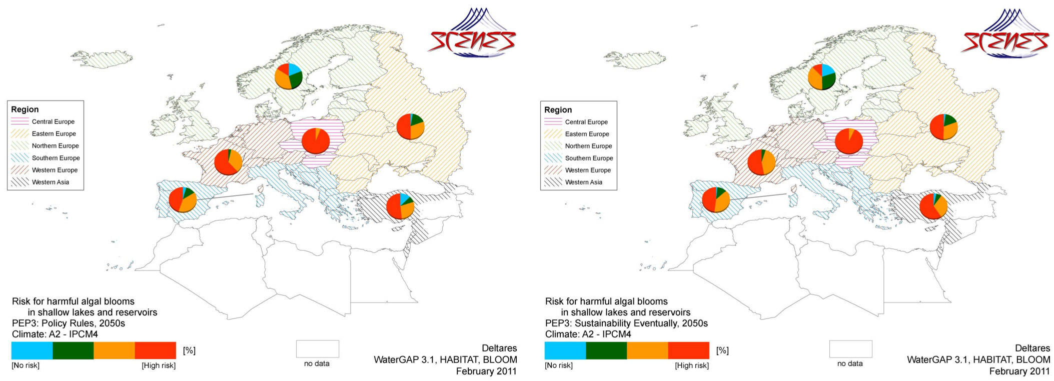


Figure 4.11. Impacts of water scenarios on risks for harmful algal blooms in inland bathing waters: left Policy Rules, right Sustainability Eventually, both under IPCM4.

Although flood hazards (the frequency and magnitude of high discharges) increase in several part of Europe (see section 4.1), flood risks (in which risks are defined as the combination of both hazard and expected damage) do not necessarily change in the same direction. Future flood risks are strongly driven by socio-economic aspects. Expected damage of flood hazards is either expressed as risk for material damage (related to GDP) or as risk for loss-of-life (related to population numbers). Where population numbers decrease, which is the case in almost the entire pan-European area in 2050 for all scenarios except Sustainability Eventually, the flood risk decreases (Figure 4.12). GDP increases all over Europe for all scenarios except again Sustainability Eventually, leading to an increased flood risk under most scenarios.

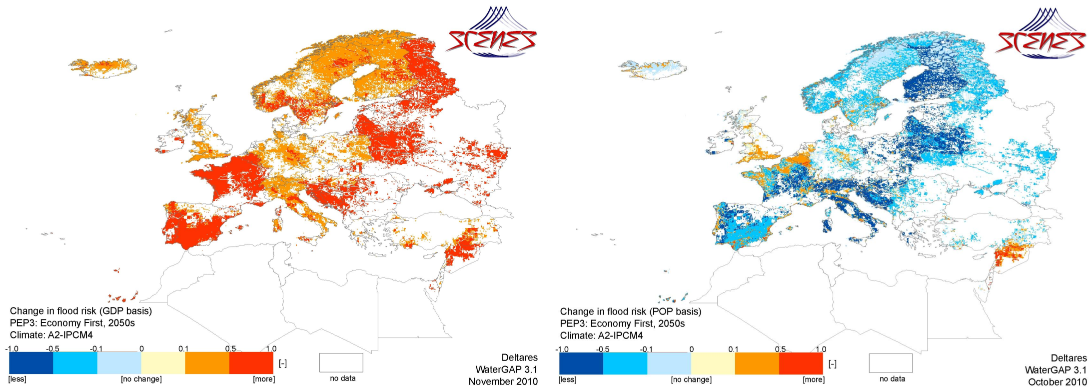


Figure 4.12. Change in Flood Risk under Economy First/IPCM4: left based on GDP, right based on population numbers.

4.5 Water for Industry and Energy

Key messages:

- *Cooling water capacity in rivers will decline and restrain electricity generation by thermal power plants along rivers and lakes in large parts of Europe*
- *Climate change affects the navigability of the main navigation routes in Western Europe in negative ways*
- *Inland water transport will experience more low flow conditions in the rivers Rhine, Meuse, Seine and Loire and under MIMR in Lower Danube as well*

Climate change has a profound impact on future water demand for cooling purposes for electricity generation. Increase of water temperature of rivers and less water availability in summer period will limit the cooling water capacity of rivers. This may put a large pressure on energy production by power plants in the future for all scenarios in dry summer periods, except in northern Europe (Figure 4.13).

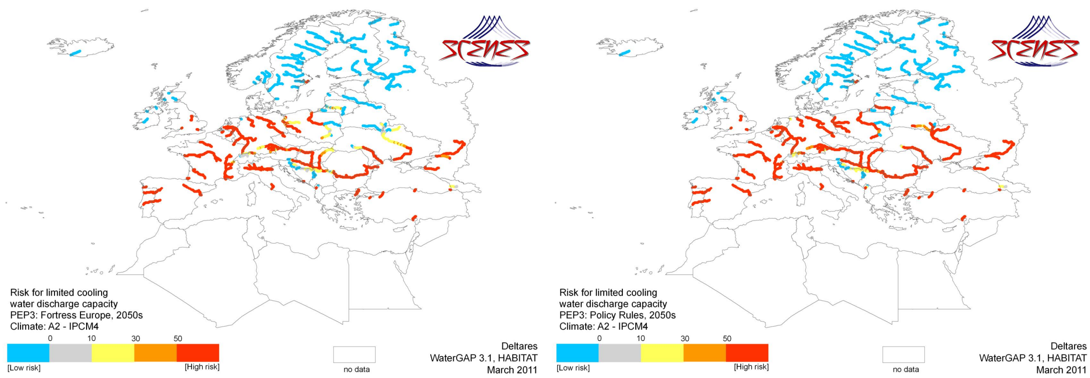


Figure 4.13. Risks for decline of cooling water discharge capacity under different socio-economic scenarios: left Fortress Europe, right Sustainability Eventually.

The upper reaches of the rivers Rhine and Danube will experience less severe low flow conditions under both scenarios (Figure 4.14). The rivers Rhone, Seine, Meuse and lower reaches of the river Rhine will have longer durations of low flows under both climate scenarios. The river Elbe and the downstream reaches of the river Danube will experiences shorter low flow conditions under MIMR, but a longer duration of low flow conditions under IPCM4.

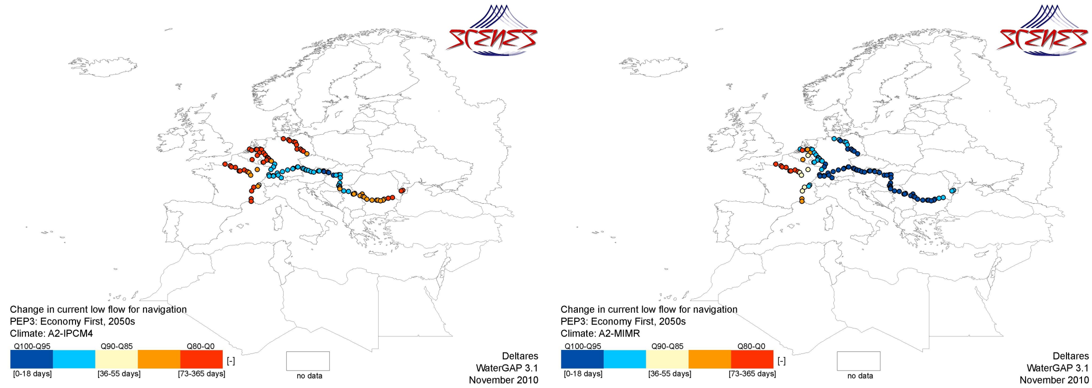


Figure 4.14. Duration of low flow conditions on main navigation routes: left Economy First/IPCM4, right Economy First/MIMR.

5 Region by region cross-sectoral impact analysis

Based on the synthesis tables in each of the individual impact indicator chapters in volumes A-E of the appendix to this report, Table 5.1 summarises the regional variation in impact for the climate and socio-economic scenarios: Fortress Europe (FoE), Policy Rules (PoR), Economy First (EcF) and Sustainability Eventually (SuE). For each scenario, the traffic-light colour coding indicates the severity of the impact in each sector in each region, whilst the letter coding indicates the variation within that sector. An overall assessment is given for each scenario in which an equal weighting is given to the indicators in each sector, and to each sector in the overall assessment, though some sectors and/or regions have more impact indicators than others. However, whilst this approach is somewhat subjective and biased, it gives a rapid visual impression of the sectoral and regional impact.

5.1 Regional summaries

5.1.1 North Africa (NA)

North Africa is one of the largest SCENES regions and one of the most spatially heterogeneous. Parts of the region, particularly the Morocco-Algeria-Tunisia coastal zone and the Nile valley, already show medium-high overexploitation of water and experience water stress and/or scarcity, and domestic and irrigation water stress throughout much of the year, due to high demand relative to availability. Under the SCENES scenarios, some parts will experience wetter and other parts drier conditions. The Morocco-Algeria-Tunisia coastal zone, especially, will experience drier conditions. Mean annual flows across the region will likely show an increase to the west and inland, apart from the costal zones which experience a high decrease, and a decrease to the east. Areas already experiencing low mean annual flows are likely to find this situation worsens. Drier conditions combined with an increase in water demand, will result in an increased shortage of water as indicated by the water shortage indicators.

The general patterns for exploitation of water largely replicate the baseline. Under all scenarios there may be serious problems associated with these stresses increasing in parts of the region that do not currently experience it such as inland areas. There is a strong indication of degradation with a decrease in domestic water availability (Figure 5.1).

Yields of rain-fed crops, such as maize, will decrease in North Africa due to higher temperatures increasing respiration losses and the limited precipitation amounts during the growing season. Thus, an increase in irrigation water withdrawals can be seen for North Africa in 2050 because of the increase in irrigated area. Water stress in agriculture is likely to be very high, particularly along the Mediterranean coast in Tunisia and Morocco and along the lower Nile.

Table 5.1 Regional variation in impact for each scenario and sector

		NA		WE		NE		Med E		CEE		EEE		WA	
		IPCM4	MIMR	IPCM4	MIMR	IPCM4	MIMR	IPCM4	MIMR	IPCM4	MIMR	IPCM4	MIMR	IPCM4	MIMR
A Generic	EcF	L	H	M	M	H	H	L	M	H	H	H	H	L	L
	FoE	L	L	M	L	H	H	M	M	H	M	M	H	L	L
	PoR	L	M	M	L	H	H	M	H	L	M	M	H	M	M
	SuE	L	L	H	H	H	H	H	H	L	M	M	M	H	M
B Food	EcF	H	H	H	H	L	L	H	H	L	L	L	L	L	L
	FoE	H	H	H	H	L	L	H	H	L	L	L	L	L	L
	PoR	H	H	M	M	L	L	H	H	L	L	L	L	H	H
	SuE	H	H	M	M	L	L	H	H	L	L	L	L	H	H
C Nature	EcF	L	L	L	M	L	L	L	M	L	M	M	M	L	L
	FoE	L	L	L	M	L	L	L	M	L	L	L	L	L	L
	PoR	L	L	M	H	L	M	L	M	L	M	M	M	L	L
	SuE	L	L	L	M	M	M	L	M	M	M	L	M	L	L
D People	EcF	L	M	M	M	H	H	H	H	H	H	L	L	L	L
	FoE	L	M	M	M	H	H	M	H	H	H	L	L	M	M
	PoR	M	L	H	M	H	H	H	H	H	H	L	L	H	H
	SuE	M	L	H	H	H	H	H	H	M	M	L	M	M	M
E Industry	EcF	L	L	M	M	L	L	L	L	M	H	L	M	L	L
	FoE	L	L	M	M	L	L	L	L	M	H	L	M	L	L
	PoR	L	L	M	H	M	L	M	M	H	H	L	M	H	H
	SuE	L	L	H	H	M	L	H	H	H	H	L	M	H	H
Overall	EcF	L	L-H	M	M	L-H	L-H	L-H	M-H	L-H	M-H	L-M	L-M	L	L
	FoE	L	L-M	M	M	L-H	L-H	L-M	M-H	L-H	L-H	L	L-M	L	L
	PoR	L-M	L-M	M	M-H	L-H	L-H	M-H	M-H	L-H	M-H	L-M	L-M	M-H	M-H
	SuE	L	L	M-H	M-H	M-H	L-H	H	H	L-M	M	L	M	M-H	M-H

Key: NE – Northern Europe, WE – Western Europe, Med E –Mediterranean/Southern Europe, CEE - Eastern Europe (Central), EEE – Eastern Europe (Eastern), WA – Western Asia, NA - North Africa, EcF – Economy First, FoE – Fortress Europe, PoR – Policy Rules, SuE – Sustainability Eventually, L – No/little variation across sector, M – Some variation across sector, H – High variation across sector, green = low impact, yellow / amber = moderate impact and red = high impact

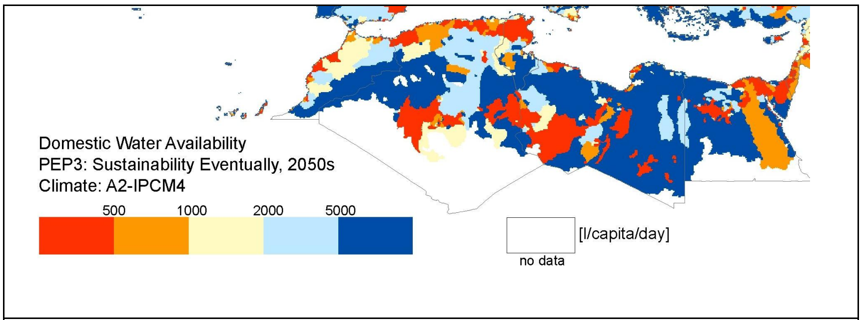


Figure 5.1. North Africa: domestic water availability under Sustainability Eventually scenario combined with the IPCM4 climate scenario.

Water for the environment will be negatively impacted in terms of quantity. For water quality there is no information. Environmental flows show low impacts inland to high impacts in the coastal zone. This is a composite index based on many aspects of the flow regime, so may be representative of other quantity-based nature indicators.

North Africa demonstrates low internal consistency within and between sectors and scenarios, with a high variation in impacts across the region for some sectors and scenarios, and low variation for others. The minor differences between the socio-economic scenarios suggest that climate is the dominant driver. Impacts under MIMR climate scenarios are slightly better than those under IPCM4 scenarios, particularly in the Nile Valley. EcF and FoE scenarios are worse than PoR and SuE scenarios. In North Africa, the current situation is likely to largely remain under PoR and SuE scenarios, but worsen under EcF and FoE scenarios particularly in the Morocco-Algeria-Tunisia coastal zone that already experiences low water availability relative to demand.

5.1.2 Western Europe (WE)

Western Europe shows a high level of variability, with some high demand centres already experiencing water stress and/or scarcity throughout much of the year. The development of water availability in this region under the SCENES scenarios is highly uncertain because of a high level of inconsistency and uncertainty across the region: some indicators show positive changes and other negative changes. For instance, both higher flow and lower flows will appear more frequently or will be more severe. In what direction water use will develop is also uncertain.

Water consumption is high by 2050 under EcF and FoE scenarios in France, Benelux countries and Northern Germany and water scarcity is very high in these areas as a result of demand during low flow periods. There are also spots of high or over-exploitation around major urban areas. Under EcF scenario combined with IPCM4 climate scenario there is high water exploitation in parts of Northern France, Belgium and the Netherlands and mid-level exploitation in Northern Germany and Southern France. At the other extreme, almost all of Western Europe has low exploitation under SuE scenario combined with MIMR climate scenario. Droughts are likely to get worse and be more frequent in terms of low flows. They will be most significant in France and Germany and to a lesser extent in Southern Netherlands. Nearly all water bodies are already at high risk under the baseline, and this changes little, though the proportion in the very high class decreases very slightly. Water temperature is likely to be too high for all scenarios which project significant problems for cooling water discharges for industry and power plants (Figure 5.2).

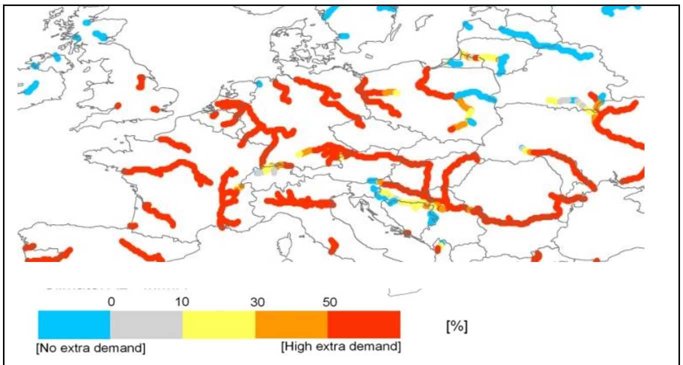


Figure 5.2 Western Europe: extra demand for cooling water under Policy Rules scenario combined with the MIMR-A2 climate scenario.

Maize production is likely to decrease in Southern France by the 2050s due to higher temperatures and less rainfall reducing yields. However, further north in Western Europe, maize may growth better as temperatures increase and approach an optimum, although potential yield increases are limited. Winter crops, such as winter wheat, may profit from the climate change expected by 2050. The EcF scenarios show that France and Northern Germany may have the highest irrigation withdrawals, whilst Germany is expected to show improved technology and irrigation efficiency. As a result, water stress for irrigation will be medium in France and low elsewhere in Western Europe. For the 2050s, annual water stress for agriculture does not change substantially compared to the baseline. Summer water stress will significantly increase in Western Europe (e.g. France), where the irrigated area is expected to increase.

The flow regime will change, but the direction of that change is not clear, varying significantly across the region and with both climate and water use scenario. Environmental flows are anticipated to decrease under all scenarios with impacts greater in Southern France and downstream (for example, some French headwaters are not impacted in the MIMR climate scenario. Water availability for wetlands is likely to reduce with greater drying in the north and less in the south: Northern France, Benelux (IPCM) and Eastern Germany are most impacted. Under the MIMR climate scenario, Benelux countries are not impacted, and some areas show an increase in water availability. The IPCM4 climate scenario shows a 50% decrease in flood volume over whole region leading to degradation of floodplain ecosystems. In contrast, MIMR suggests much more regional variation with a 50% increase in France, but a 50% decrease in Germany. In general floods may occur earlier in the year. Ecosystem services show some losses in the region, especially around the Alps (South-East France, Southern Germany). Generally loss in ecosystem services is worst for the EcF scenario and best for FoE scenario; under PoR scenario there is more regional variation in loss of services.

In Western Europe, the results for different scenarios range from negative impacts for the entire region to positive impacts for the entire region. The emphasis is however on negative impacts. There is a moderate level of internal consistency within and between sectors and scenarios, with a medium variation in impacts across the region. Under the SCENES scenarios, this region becomes wetter. Impacts are generally highest under the EcF scenarios and least under SuE scenarios, with marginally greater impacts under IPCM4 climate scenarios than under MIMR scenario.

5.1.3 Northern Europe (NE)

Northern Europe is a large SCENES region covering a geographical area including Iceland, the British Isles and Scandinavia and the Eastern Baltic. The region shows a reasonably high level of variability, with some parts such as South-East UK and other high demand centres already experiencing water stress and/or scarcity throughout much of the year. Under the SCENES scenarios, this region becomes wetter. Mean annual river flows across the region will likely increase; mean annual runoff, low flows and high flows will also increase.

Northern Europe is unlikely to experience problems due to water scarcity in any sector. There are generally very few impacts on water availability for consumption with the exception of South-East UK and South-East Sweden under IPCM4. Water stress is likely to be severe in these areas, particularly in the summer but low elsewhere. The lowest impacts are expected under SuE scenario combined with MIMR climate scenario where only South-East UK shows moderate stress. Patterns of water scarcity generally match water stress, with severe impacts in South-East UK under both EcF and FoE scenario combined with IPCM4, but less under SuE combined with MIMR in this area, and low impacts everywhere else. Increases in drought frequency and severity are also limited to local areas of southern UK and South-East Sweden. Even though population and GDP increase, domestic water availability and domestic water stress decrease. GDP-based flood risk increases, but the population-based flood risk is expected to decrease. There is a decrease in the number of water bodies at high risk, from nearly 75% to around 50%. Water temperature is projected to remain good across the region in 2050, apart from Southern England, and all the scenarios are consistent in showing no additional demand for cooling water for industry across the region, with the exception of south-east UK where cooling water stress increases in areas where demand is high.

Agriculture is broadly little impacted in Northern Europe. Production of maize may improve due to higher temperatures, but increases in yield will be limited. Winter rain-fed crops, such as winter wheat, may profit from the climate change expected in the year 2050. Irrigation efficiency shows stagnation under EcF and PoR scenarios and modest increases under FoE and SuE scenarios. However, irrigation withdrawals will be very low, except in places of water shortage, such as Southern UK and South-East Sweden.

Water for the environment will show relatively little impact across the region with many of the indicators remaining unchanged or close to the baseline. Flood volumes may increase in magnitude by 10% or more under IPCM4 climate scenarios in North-West UK and Norway, but decrease in South-East UK and Finland. Environmental flows are anticipated to decrease moderately under all scenarios with impacts lowest in Northern and Western UK, Northern Sweden and Southern Finland. There are no impacts on water for wetlands in UK, Sweden and northern Finland, whereas some reduction is possible in Norway and Southern Finland. There are likely to be only minor changes in ecosystem services in the region with little different between scenarios; the east coast of UK may be slightly more impacted than the west coast.

There is a high level of internal consistency within and between sectors and scenarios, with a low to medium variation in impacts across the region. Under the SCENES scenarios, this region becomes wetter. Impacts under the IPCM4 climate scenarios are consistently worse situation than under the MIMR scenarios. In general, the worst impacts for all indicators are south-east UK which shows more similarity to the neighbouring Western Europe region than to the rest of the Northern Europe region (Figure 5.3). The EoF scenario tends to exhibit the most severe results, followed by FoE, PoR and SuE.

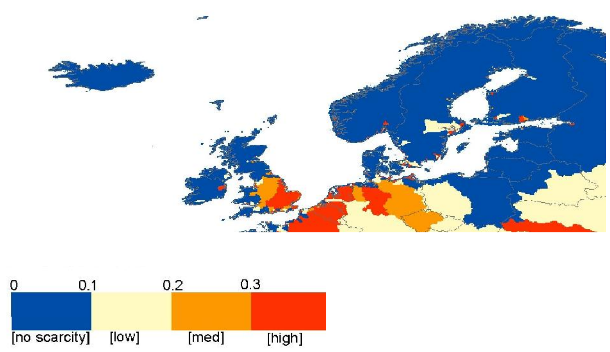


Figure 5.3. Northern Europe: Water scarcity index under Economy First scenario combined with the IPCM4-A2 climate scenario.

5.1.4 Southern Europe (MedE)

The Mediterranean Europe region is non-contiguous comprising, from west to east, the Iberian peninsula, Italy and the majority of the Balkan peninsula. As such it is quite spatially heterogeneous. Parts of the region, particularly the Iberian peninsula and Greece have a low baseline water availability and already show medium-high overexploitation of water and experience water stress and/or scarcity, and domestic and irrigation water stress throughout much of the year, due to high withdrawals relative to availability. Under the SCENES scenarios, water availability in this region in the future is likely to decrease, particularly in the southern parts. Mean annual flows across the region decrease across the under IPCM4 climate scenarios, and predominantly in Eastern Spain under MIMR climate scenarios. Areas already experiencing low mean annual flows are likely to find this situation worsens. Although the general availability decreases, decreases in consumptive use mean that the three generic water shortage indicators show primarily an improvement.

Consumptive use generally declines in Southern Europe by the 2050s, but there is great spatial variation in water availability. Whilst parts of Spain, particularly the south, show high or over-exploitation, in many other areas impacts are low or medium, with a few hot spots in Italy and Greece. The EoF scenarios tend to exhibit the most severe results, followed by FoE scenarios. The least severe results are for SuE and PoR scenarios with only a few mid and high spots in Spain and Italy. Water stress shows a similar pattern with severe stress in parts of Spain, Italy and Greece. The most severe conditions are expected under EcF scenario combined with IPCM4 climate scenario, with lower severity under MIMR climate scenarios and least impacts under SuE scenarios. Water scarcity will also be high in Spain, Portugal and Greece, whereas no problems are expected for the Northern Adriatic countries. Droughts are likely to become more frequent in Spain, parts of Northern Italy and Balkans, particularly from IPCM4 climate scenarios. In contrast, under MIMR climate scenarios, droughts may be less frequent in Northern Italy, Croatia and Bosnia. Drought severity is likely to be significantly worse by 2050 with severe reduction in low river flows particularly in Northern Spain and Northern Italy. There are no significant differences between socio-economic scenarios, but drought severity is critically dependent on the climate change model; under IPCM4 climate scenarios, indicators show significant reductions, but under MIMR scenarios, there are major increases in the magnitude of low flows.

Almost all water bodies are already at high risk under the baseline, and this situation improves slightly for all scenarios. Water temperature will be relatively high to support river ecosystems in Spain, Northern Italy and North-East Greece for all scenarios. Cooling water demand and natural water temperature are expected to increase (except for PoR and SuE scenarios), particularly in Spain, Portugal and Northern Italy, so that water stress for cooling purposes is also expected to increase putting pressure on power plants' demand for cooling water during periods of low flows.

Impacts on agriculture are complex. The viability of rain-fed crops, such as maize, decreases in Mediterranean Europe by the 2050s, due to reduced yields, owing to higher temperatures and lower precipitation. Projected yields are particularly low in Spain and Portugal. Irrigation demand reduces slightly as a result of improved technology and irrigation efficiency. Decreases in irrigated area are projected to occur in Italy, Greece and Portugal, but a move to more intensive irrigation on remaining land. Annual water stress in irrigation in Mediterranean Europe decreases, which is due to both increased irrigation efficiency and a reduction in irrigated land. There appears to be a shift in irrigated area from Mediterranean Europe to Western Europe. However, irrigation water stress is summer is severe for example Spain and Portugal (Figure 5.4), but also slightly decreases in 2050 compared to the baseline. Differences in water stress in irrigation under different climate scenarios are caused partially by a different distribution of water availabilities in Europe under the two climate scenarios IPCM4 and MIMR.

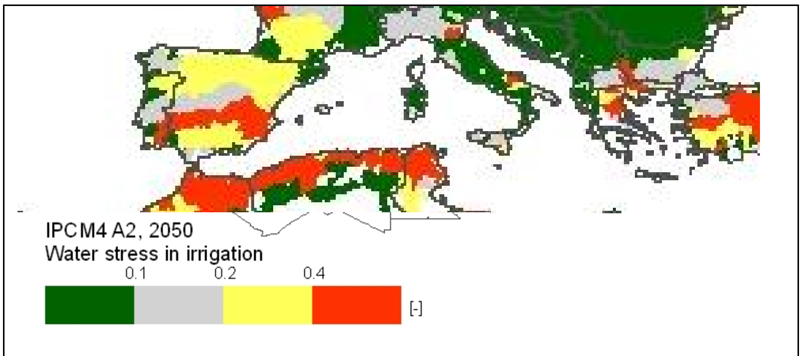


Figure 5.4. Mediterranean Europe: Water stress in irrigation under Economy First scenario combined with the IPCM4-A2 climate scenario.

For water for the environment, the future is highly uncertain due to a high level of inconsistency and uncertainty across the region. That the flow regime will change is clear, but the direction of that change is not, varying significantly within individual countries as well as across the region and with both climate and water use scenario. Environmental flows are expected to decrease under all scenarios very significantly in Spain and Greece probably leading to major degradation of freshwater ecosystems. The situation is slightly worse for IPCM4 climate scenarios than MIMR scenarios. Flood volumes are likely to decrease by 50% or more under IPCM4 in Northern Spain and North-Western part of Italy with an associated small decrease in flood duration, leading to a degradation of floodplain ecosystems. This is sharply contrasted by a 25-50% increase in flood volume everywhere in Southern Europe under MIMR. For example, the IPCM4 climate scenarios show a loss of ecosystem services in South-West Spain, but less elsewhere in Spain and only minor losses across the rest of the region. EcF and SuE scenarios show the biggest impact, exceeding FoE and PoR scenarios, and probably resulting from land use change. MIMR climate scenarios show smaller losses than IPCM4 scenarios with impacts restricted to Spain. The geographical extremes, Spain and Greece are often more badly impacted than Italy and the western Balkans.

Impacts under the IPCM4 climate scenarios are consistently worse situation than under the MIMR scenarios. In general the worst impacts for all indicators are in Spain, particularly in Southern Spain. Impacts are mixed in Italy and Greece, with some hot spots of high impact. Former Yugoslavia countries show low impacts. EoF scenario tends to exhibit the most severe results, with FoE in second place; PoR combined with IPCM4 tends to show the same pattern as FoE combined with MIMR. The least severe results are for SuE and PoR scenarios, with the best one varying with indicator. SuE tends to have hot spots in Spain and Italy.

5.1.5 Central Eastern Europe (CEE)

Central Eastern Europe (Central) is the SCENES region with the smallest surface area. The region is fairly spatially heterogeneous, and parts already experience water stress and/or scarcity and irrigation water stress throughout much of the year, except the winter season. Under the SCENES scenarios, for many indicators, particularly the generic ones, no change will take place. For a number of indicators there can be either improvements or degradations for parts of the basin, and the western, southern and/or eastern parts of the region may sometimes follow the behaviour of the adjacent regions. Mean annual flows across the region will likely show a moderate decrease under IPCM4 climate scenarios, compared to a small increase under MIMR scenarios. Hence, the development of water availability in this region is highly uncertain. However, water availability during low flows is likely to increase.

The general patterns for exploitation of water largely replicate the baseline. Domestic water availability may decrease slightly. Although population and GDP increase, the domestic water availability and domestic water stress are not expected to change much. GDP-based flood risk is expected to increase, whereas population-based flood risk is expected to decrease. Almost all water bodies are already at high risk under the baseline, and this situation changes very little, with a very minimal improvement for SuE scenarios. Cooling water demand increases and cooling water stress increase, putting pressure on power plants' demand for cooling water during periods of low flows. This is largely temperature (i.e. climate) driven, compounded by increased demands.

Navigability is independent of temperature and, because of increased water availability during low flow periods, is expected to improve. Similarly river drought frequency and severity are not expected to deteriorate (Figure 5.5).

The western part of the region may start requiring irrigation withdrawals, such as the Czech Republic. In Poland and Hungary, water needs remain low due to increased technological innovations in irrigation water demands for EcF and FoE scenarios, and a mix of small decreases and increases in the other scenarios.

Water for the environment will be consistently negatively impacted across the region for all scenarios. The flow regime will change and flood volumes and durations may decrease, though timing will remain the same or be slightly earlier due to changes in snow/glacial melt patterns. Environmental flows show moderate impacts in terms of water quantity. Other quantity and quality indicators show losses in ecosystem services, and significant changes in wetland water supply, aquatic macrophyte diversity and fish habitat suitability, with a medium to high level of uncertainty.

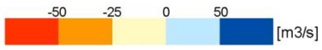
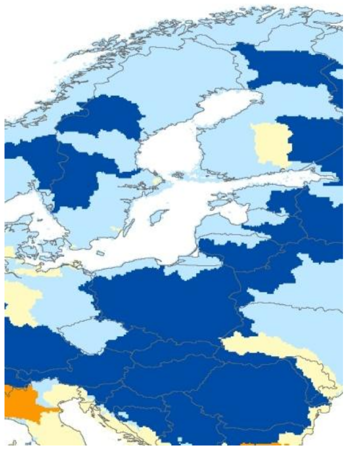


Figure 5.5. Central East-Europe: change in severity of river flow droughts under Fortress Europe scenario combined with the MIMR-A2 climate scenario.



Central Eastern Europe shows a low level of internal consistency within and between sectors and scenarios, with a low to high variation in impacts across the region. There is a greater difference between the socio-economic scenarios from the water quality-type indicators than from the water quantity indicators, the latter suggesting that climate is the dominant driver. Impacts under MIMR climate scenarios are slightly better than those under IPCM4 scenarios, and EcF and FoE scenarios are worse than PoR and SuE ones. Whilst SuE is usually the socio-economic scenario with lowest impacts, for the Food sector it is PoR. In Central Eastern Europe, the current situation is likely to largely remain under PoR and SuE scenarios, but worsen under EcF and FoE scenarios. However, while the results show that water quantity should not be a regular problem in this region, the quality of that water may make it unusable without treatment.

5.1.6 Eastern Eastern Europe (EEE)

Eastern Eastern Europe is one of the largest SCENES regions, extending from Arctic in the north to the Black Sea in the south, and from Poland in the west to the Urals in the East. The region is spatially heterogeneous. Results show that, firstly, changes are likely to occur, are often local, and may be both positive and negative, and secondly, that the far southern part of the region often shows more similarity to Western Asia, than to the rest of Eastern Eastern Europe. Parts of the region, particularly the southern part of the region, already show medium-high overexploitation of water under all scenarios due to high demand relative to availability, and experience water stress and/or scarcity and domestic and irrigation water stress throughout much of the year, except the winter season. Mean annual flows across the region will likely show an increase to the north and a decrease to the south, more severe under IPCM4 climate scenarios than under MIMR scenarios. Areas already experiencing low mean annual flows are likely to find this situation worsens. Water availability in this region is likely to increase overall.

The general patterns for exploitation of water largely replicate the baseline. Under all scenarios, there may be serious problems associated with domestic water stress in parts of the region that do not currently experience it; in other parts, the situation may improve. Domestic water availability in this region is likely to increase; even though population is expected to grow. Domestic water stress is not expected to change much. Around 25% of water bodies are at no or low risk during the baseline and this proportion increases slightly for the PoR and SuE scenarios, with similar risks to the baseline for the EcF and FoE scenarios. Increasing temperature and highly uncertain withdrawals and excess temperatures, mean that cooling water stress is likely to increase, putting pressure on power plants' demand for cooling water during periods of low flows. A high incidence of low flows may cause some navigation problems in the Danube, though this is highly uncertain.

In the southern part of the region, irrigation water withdrawals are already high under the baseline and this situation remains unchanged an improvement in technology counterbalancing any increase in demand. Specific hotspots include the Danube Delta and the Black Sea coast.

Water for the environment will be consistently negatively impacted across the region (Figure 5.6). Environmental flows show moderate to high impacts in the centre, south (the southern part bordering Western Asia particularly affected) and west of the region and lower impacts to the north and east. The flow regime will change and flood volumes and durations may decrease moderately or severely throughout most of the region, except in the far south which may remain unchanged; timing will remain the same or be slightly earlier due to changes in snow/glacial melt patterns. Losses in ecosystem services and changes in water supply to wetlands are expected, with the worst impacts in the southern part of the region. Decreases in aquatic macrophyte diversity and fish habitat suitability are expected for all SCENES scenarios except PoR and SuE, with the highest impacts again in the southern part of the region.

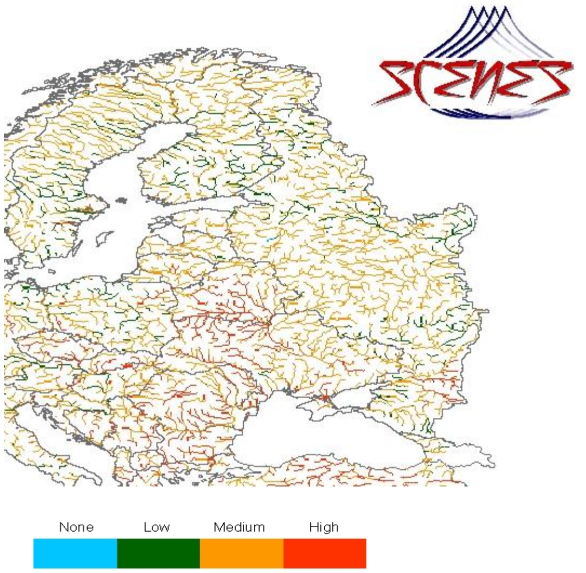


Figure 5.6. Eastern East-Europe: Impact on environmental flows under Sustainability Eventually scenario combined with the IPCM4-A2 climate scenario.

Eastern Eastern Europe has a moderate internal consistency within and between sectors and scenarios, and a usually medium to high variation in impacts across the massive region. Impacts under MIMR climate scenarios are slightly better than those under IPCM4 scenarios, and EcF and FoE scenarios are worse than PoR and SuE scenarios. In Eastern Eastern Europe, the current situation is likely to largely remain under PoR and SuE scenarios, but worsen under EcF and FoE scenarios, particularly in the southern part which already experiences some problems due to high demand relative to availability.

5.1.7 Western Asia (WA)

Western Asia is a spatially heterogeneous SCENES region including parts of the Mediterranean and Black Sea coasts, the near East and Turkey. Parts of the region already show medium-high overexploitation of water and experience water stress and/or scarcity, and domestic and irrigation water stress throughout much of the year, due to high demand relative to availability. Under the SCENES scenarios, the area will mainly become drier and water shortage will become an increasing problem. Mean annual flows across the region will likely show a large decrease.

The general patterns for exploitation of water largely replicate the baseline. However, parts of Western Asia that do not currently experience problems with domestic water availability and domestic water stress may start experiencing them. Mean annual water availability is likely to decrease throughout this region, resulting in decreasing domestic water availability. Domestic water stress is expected to remain largely unchanged (Figure 5.7). The number of water bodies in Western Asia at high risk is expected to increase significantly (currently around 25% are at no or low risk) from the baseline. Due to increasing temperature, the cooling water demand, which is already high under the baseline should remain the same or increase leading to an overall increase in cooling water stress. Cooling water stress which is already high remains unchanged or may decrease in some areas, though parts of the region still show severe cooling water stress under the PoR and SuE scenarios.

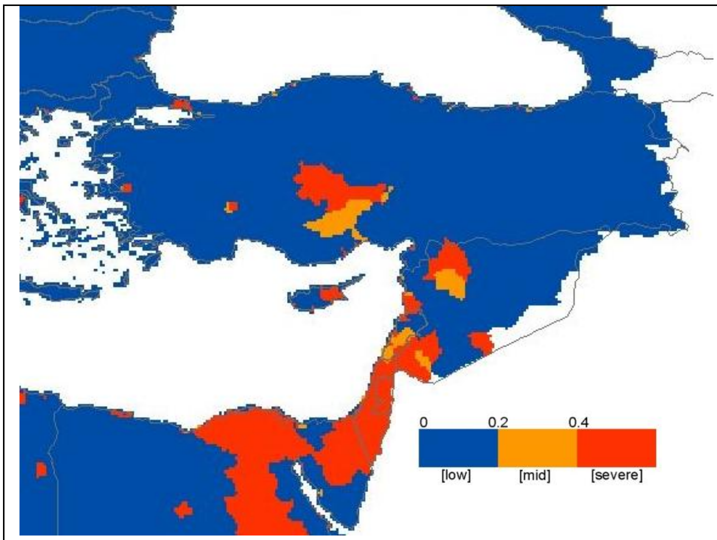


Figure 5.7 Western Asia: Change in domestic water stress under Policy Rules scenario combined with the MIMR-A2 climate scenario.

Rain-fed crop (e.g. maize) yields will decrease in Western Asia due to higher temperatures increasing respiration losses and the limited precipitation amounts during the growing season. Under all scenarios there may be moderate reductions in the extent of areas requiring irrigation withdrawals, but a possible decrease in the quantity of water required, accompanied by technological improvements which may save water, too.

Water for the environment will be negatively impacted in terms of both quantity and quality. Environmental flows show moderate to high impacts across the region. This is a composite index based on many aspects of the flow regime, so may be representative of other quantity-based nature indicators. A decrease in aquatic macrophyte diversity and a decrease in fish habitat suitability are to be expected, though there is a high level of uncertainty.

The different areas of Western Asia behave similarly or differently within and between sectors and scenarios, with a high variation in impacts across the region for some sectors and scenarios, and low variation for others. For some indicators the southern part of the region may behave like the adjacent part of North Africa, whilst the northern part of the region may follow the behaviour of the southern part of Eastern Eastern Europe. Impacts under MIMR climate scenarios are slightly better than those under IPCM4 scenarios, and EcF and FoE scenarios are generally worse than POR and SuE scenarios. In Western Asia, the current situation is likely to worsen under all scenarios, especially in the areas that already experience low mean annual flows and low water availability relative to demand, and particularly for the EcF and FoE scenarios.

5.2 Discussion

There are big differences between regions in terms of the direction and severity of impacts, and the uncertainty with respect to the direction of future change varies over Europe. The IPCM4 climate scenario consistently showed worse impacts than the MIMR scenario across pan-Europe. This can be largely explained by the changes in gross water availability (Figure 4.1) in terms of mean river flows in the 2050s. Impacts are broadly related to latitude. From the IPCM4-A2 climate scenario, severe reductions in water availability are evident in parts of Tunisia, Egypt, Turkey, Greece, Bulgaria Macedonia, and South-East Spain. Significant reductions are projected across Central Europe from Portugal to Ukraine. Limited change is anticipated in the UK, Denmark, Southern Finland, Latvia and North-West Russia. Increased water availability is more likely for Norway, Sweden and Northern Finland. From the MIMR-A2 climate scenario, less severe impacts are expected with little change from current conditions throughout Central Europe, increases in water availability in Northern Europe, but reductions along the Mediterranean coast of North Africa, South-East Spain and Turkey. In summary, IPCM4-A2 climate scenario projects drier, warmer conditions.

There is a clear distinction between the four different socio-economic scenarios. In the majority of cases, Sustainability Eventually (SuE) caused the least impacts, followed by Policy Rules (PoR) and then Fortress Europe (FoE), with Economy First (EcF) causing the worst impacts. The explanation for this is that, for almost all regions, EcF and FoE scenarios result in increases in consumptive use of water, which includes water evaporated, incorporated into products or crops and consumed by humans and livestock. Exceptions are Southern Europe where consumptive use decreases and Western Asia where water use remains constant. For PoR and SuE scenarios, all regions show either no change or a decrease in consumption, except for North Africa where consumptive use increases.

The sectors least or most impacted varied very much with region, with impacts generally reducing towards the north of pan-Europe and worsening towards the east and south. Overall, the People sector is probably least impacted, followed by Food, then Nature, with the Industry sector most impacted. Whilst it could be thought that this might reflect the priorities given to different sectors, in WaterGAP all water demands are lumped together with no distinction between the different sectors or prioritisation of one sector over others. The exception to this is Nature which is not treated as a sector with a distinct water demand; as in the baseline, the Nature impact indicators are generated from the water left after the other sectors have satisfied their requirements.

For the generic indicators, negative changes in the future are likely for North Africa, Western Europe and West Asia. In Northern Europe and Central Eastern Europe, the conditions are generally wetter and water shortage will not change much. For Mediterranean Europe and Eastern Eastern Europe changes can be either negative or positive.

Within the overall People sector, for some indicators, such as domestic water stress, most regions experiences hardly any change. For domestic water availability the changes, and also the differences between regions, are more pronounced. Variability within the sector is highest to the north and west of Europe, decreasing to the south and east. The least impacted region is Central Eastern Europe and the most impacted is North Africa. Indeed selected locations in Mediterranean Europe, West Asia and North Africa may already experience shortage for domestic water use. In reality the situation presented by the scenarios is likely to be less severe, because domestic water use is not expected to have the lowest priority. This also means that for those regions where no domestic water shortage problem is indicated for this worst-case scenario, there is indeed very little chance that such a problem may occur in the future. The water quality situation degrades for all regions except Northern Europe and is rather constant across scenarios.

The impact results from the Food sector show that the irrigated area in Western Europe (e.g. France) increases in 2050, while irrigated areas in the Southern Mediterranean Europe (Greece, Spain, Portugal and Italy) decrease. There appears to be a shift in irrigated area from the Mediterranean Europe to Western Europe. This is due to the better climatic conditions expected in 2050 for Western Europe. Furthermore, socio-economic drivers, technological development and agricultural policies are more important than climate change as factors influencing irrigation water withdrawals and irrigation water stress.

For the Nature sector overall, the water for nature indicators show impacts across pan-Europe, the severity and direction of that impact is greater in some regions than in others, though variability overall within the sector is low to medium across the pan-Europe. The least change will be felt in Northern Europe, which has relatively high water availability and low demand so can absorb any decrease in the former and decrease in the latter to some extent. This is followed by Eastern Eastern Europe which is likely to experience more severe impacts in terms of water quality than water quantity. The situation is more serious for Mediterranean and Central Eastern Europe and West Asia where the direction and magnitude of impacts is highly variable and uncertain.

For the Industry sector overall, the least impacts and variability are in Northern Europe, as a result of the relative small amount of withdrawals, low population densities and a high latitude, followed by Eastern Eastern Europe, with medium-high or high impacts and variability in all other regions, particularly southern regions where temperatures are already high and expected to increase in future scenarios and where low flows are expected to increase as well. The impacts will be greatest in drier periods. For some indicators, such as extra demand for cooling water, most regions experiences high stress. This is largely due to increased climatic water temperatures. Differences between regions are quite pronounced, as a result of the differences in withdrawals between regions as well as the scenarios. Navigability of rivers is only analysed for large rivers regions and the scenarios show in Western Europe inland water transport will experience increased low conditions in the future.

The least impacted region is Northern Europe, reflecting its baseline high water availability and low water demand, which provide a buffer to enable it to absorb implications of climate and water use change. The worst impacted region is West Asia, followed by North Africa and Mediterranean Europe. These regions already have a high water demand relative to supply, so it is likely that the areas already experiencing problems will see these worsen and new areas may start to see negative impacts.

6 What is driving the changes in impacts

6.1 Climatic drivers versus socio- economic drivers

Will policy measures help to obtain a better water future for Europe, or does climate change dominate our water future? To answer this question, a simple analysis is carried out to gain insight in whether climate change or socio-economic developments dominate the results for the indicators. When climate change is the dominant driver for changes in the impacts, the results for the SCENES scenarios would differ according to the two climate scenarios, but not according to the four socio-economic scenarios. For a given climate scenario, the results of the four policy scenarios associated with it would be similar to a large extend. On the other hand, when socio-economic changes are the dominant drivers for changes in the impacts, for a given SCENES socio-economic scenario, the results of the two climate scenarios associated with it would be similar.

Climate change is included in the scenarios by variations in monthly values of temperature, precipitation and evapotranspiration. They form the basis for the description of the hydrological and thermal regimes which control the functioning of ecosystems and agriculture and determine water availability and water use in all sectors. Water availability may be modified by changes in land cover, man-controlled return flows, diversions and retentions.

In addition, water withdrawals and consumption, emissions and vulnerability to floods are driven by a number of socio-economic factors, which in turn depend on scenario assumptions for population numbers, economic activity in the form of GDP, thermal electricity production, agricultural land use and production, and efficiency of water technologies. Such factor values vary over time and by scenario and by region. The effects of the drivers on the water withdrawals and water use are in general controlled by linear relationships. Water withdrawal is primarily a man-controlled action and is a function of human behaviour, related to the socio-economic conditions. Water withdrawals may exceed water availability by overexploitation. Key determinants for withdrawals are the size of the population, the Gross Domestic Product (GDP), size and location of infrastructure, level of technology, consumption attitudes.

Regionally and scenario-wise consistent sets of values have been created for:

- Final population of a time period as a percentage of the initial population.
- Gross Domestic product (GDP) growth rate is an indicator of economic growth and development; the total electricity production per unit GDP as a measure of the energy intensity of an economy and the efficiency of the energy sector; this information was combined with the share of the total electricity generated by thermal generation.
- Land use change and demand for agricultural production.
- Extent and share of irrigated area.
- Technological change expressed as irrigation efficiency.
- Technological change expressed as volume of water per capita for domestic purposes.
- Connection to public sewage system expressed as percent connectivity of the population.

A very special case is the influence of land use changes. Future land conversion has been explicitly modelled taking into account the demand for urban land and protection of nature areas on the one hand and the demand for cultivated land and its productive potential for achieving the required world agricultural production on the other hand. The conversion of agricultural land is allocated to the spatial grid based on an optimization procedure for each of the countries/regions of the world food system model. As a consequence, land use change is a compound driver, resulting from competing claims on land for agriculture and non-agricultural land use, productive quality of the land, availability and current use of land, legal land use limitation and location and accessibility.

Regional trade, market regulation and market prices are important drivers as well. In SCENES these factors are not explicitly modelled, but implicitly taken into account through the storylines.

Table 6.1. provides an overview on what is the main driver for changes in impacts based on a comparison between the scenarios. The more plus signs indicated under climate change or socio-economic change, the more dominating this factor is in determining the scenario impacts in terms of a particular indicator. The impact is determined based on the following criteria:

- *The difference between all scenario results and the baseline*. To determine the impact of the driving forces the change compared to the baseline scenario needs to be considered. It is possible that for example impacts vary little between the IPCM4 and MIMR scenarios, but that both scenarios strongly deviate from the baseline scenario.
- *The difference between the scenario results.* When the results for an indicator vary a lot between the four socio-economic scenarios but show similar results for the two climate scenarios, we conclude that the socio-economic developments dominate the impacts for that indicator. When the differences between the four socio-economic scenarios are small, but the two climate scenarios show very distinct results, climate change is the dominating factor.
- *Whether climate change and socio-economic changes compensate each other.* Climate change and socio-economic change may enhance each other or compensate each other. It is important to consider the actual processes that lead to a certain scenario result.

Table 6.1 shows that:

- Both climate change and socio-economic change can be the dominant factor, depending on what impact is considered.
- For Water for Nature the indicators are mainly climate change dominated when impacts are related to water quantity.
- For both Water for People and Water for Food impacts are mainly driven by socio-economic changes.
- For Water for Industry and Energy the impacts are mainly driven by climate change.
- The way an indicator is defined determines which factor is dominated. The water scarcity index and the low flow indicators are both calculated using the Q_{90} and consumptive water use. Nevertheless, the water scarcity indicator is socio-economic change dominated, while the low flow indicator is climate change dominated. This is the result of the calculation method as defined for the indicator, there are two differences:
    - The water scarcity index focuses on availability of water for consumptive use in low flow situations; the low flow indicator calculates change in low flow based on consumptive use.
    - The water scarcity index make calculation based on annual averages. The low flow indicator considers the monthly flow after consumptive use, and then determines the resulting Q_{90}.

- Climate change and socio-economic change do not necessarily enhance each other, although this is the case for most impacts. This is the case for the indicator on algal blooms: nutrient emissions increase but due to the increase in temperature, the changes in risks on algal blooms are limited.

Table 6.1. Indication of importance of climate change and socio-economic driving forces.

Water System Service	Indicator	climate change	socio-economic drivers
Water resources	Water Consumption Index	+	++
Water resources	Water Stress Index	+	++
Water resources	Water Scarcity Index	+	++
Water resources	Change in frequency of flood events	+++	
Water resources	Change in flood hazards	+++	
Water resources	Change in frequency of river low flow	++	+
Water resources	Change in magnitude of river low flow	++	+
Water resources	Change in mean annual river flow	+++	
Food	Agricultural crop production	++	+
Food	Irrigation water withdrawals	+	++
Food	Water stress in irrigation	+	++
Nature	Environmental flows	+++	
Nature	Floodplain wetlands	+++	
Nature	Ecosystem services of wetlands	++	+
Nature	Change in water supply to wetlands	+++	
Nature	Aquatic macrophyte diversity in lakes	+	++
Nature	Habitat suitability for river water temperature for fish	++	+
People	Domestic water stress	+	++
People	Flood risk	+	++
People	Risk for harmful algal blooms in shallow lakes and reservoirs	+	++
People	Domestic water availability	+	++
Industry and Energy	Extra demand for cooling water	++	+
Industry and Energy	Navigability of large rivers	+++	
Industry and Energy	Cooling water stress	+	++

6.2 Baseline versus SCENES scenarios

The scenario results for 2050 are compared with the baseline results to identify the changes between scenarios. These differences refer to the final (2050) future stage only, and do not allow reflecting on the pathway followed from 2005 to 2050 as described in the storylines. In fact, some storylines differ more in their pathway than in the end state. Policy Rules and Sustainability Eventually scenarios are quite similar in their water conditions by 2050, Economy First represents the opposite extreme, while Fortress Europe is often somewhere in between these contrasting positions. The trends and changes in final value of the socio-economic parameters are far from uniform over the pan-European area. Some particular cases may be observed. For instance a strong decrease in GDP per capita (-40%) in Western Europe is assumed in Sustainability Eventually scenario, because the quality of life gets priority above wealth, while in most other regions the change is limited between plus or minus 10%, except in Southern Europe, where it increases by over 50%.

In Economy First scenario, there is with respect to water withdrawals a strong increase (>25%) over most of Europe and North Africa, except for Scotland, around the Gulf of Bothnia (parts of Sweden and Finland), southern half of Iberian Peninsula, Italy, Greece and Turkey, where the changes in total water withdrawals on a river basin basis are between -25 and +25 %. The effect of climatic difference between IPCM and the less dry MIMR scenarios is obvious in Spain.

In Fortress Europe scenario, the overall tendency is still towards increased water withdrawals as compared to the baseline, but east of the EU27 area the future total withdrawals are lower, while within the EU27 the total area with strong increases in water withdrawals is much smaller. The highest increases in Europe are limited to some hotspots centred on France, South Norway, Latvia and Croatia. The situation in North Africa remains one of strongly increasing total water withdrawals.

In Policy Rules scenario, the turn to a situation with lower total withdrawals is nearly complete. The overall pattern is towards decreased withdrawals, except in North Africa where the pattern is mixed, and except Estonia, Latvia and a few small river basins, distributed along the coasts in Europe. The tendency and pattern of decreased withdrawals is strengthened under Sustainability Eventually scenario, with more or less the same exceptions as for Policy Rules scenario.

6.3 Drivers per sector

The water use in the domestic, industrial end electricity sectors is mainly driven by socio-economic conditions, but even in these sectors differences between scenarios are related to climatic conditions as well, as decisions on water withdrawals are based on physical water availability, combined with judgements on socio-economic consequences of water extraction. Differences in results between policy scenarios are related to targeted regulatory policies, which in turn are based on assumptions on scarcity, pricing, ecological considerations, and the political framework settings. The water use in the agricultural sector, especially the decisions to irrigate crops or not, depends on a mixture of climatic water availability and socio-economic drivers.

6.3.1 Water for Nature

Water for Nature is a particular case, as it is mostly affected by Climate Change drivers. The changes observed in almost all indicators but ecosystem services of wetlands and macrophyte diversity in lakes are related to the precipitation and temperature change as induced by GSM models and WaterGAP. As a result the output differences between socio-economic scenarios are smaller then those imposed by the different climatic scenarios. Of course it means also that for the large part of Europe, where we have not a good match of outputs of different climate models situation for future development remains unclear. Other three main factors influencing nature: nitrate load, the land shift and water temperature change are induced by the socio-economy drivers – agriculture and energy generation.

In principle, natural aquatic and wetland ecosystems will be found in and along rivers and lakes in watersheds without any human interference upstream. In this natural reference situation, the hydrological conditions are determined by the natural river flow regime, not influenced by the economic sectors. In reality, most natural aquatic and wetland ecosystems experience the influence of the other sectors, and in this way, the combined total upstream water withdrawal by all other sectors becomes an additional driver for any flow-related impact indicator, which modifies the impact of the purely climatic drivers. As flow/hydrological regimes are determining largely the ecosystem processes and functioning as well as the direction of ecological developments of the aquatic and wetland ecosystems (Bullock & Acreman, 2003), changes in flow regimes and hydrology by climate change and water withdrawals for economic sectors will have a large impact on the aquatic and wetland ecosystems (Schneider et al., 2011, Okruszko et al., subm.). Apart from flow/hydrological regime, the ecosystem quality depends also on water quality (references), as influenced by nutrient loadings, pollution, and oxygen status and water temperature.

All scenarios show that river, lake and wetland ecosystems will experience severe stress due to changes in hydrology, increased water temperature and high nutrient levels.

6.3.2 Drivers in the energy sector

Concerning the European energy sector, the Sustainability Eventually scenario has the lowest electricity production among all scenarios in most regions, and the Economy First scenario the highest. The other two are usually in between them, where the Fortress Europe scenario shows a slightly lower energy production than the Policy Rules scenario, which in the logic of the scenarios is attributed to the more pressing need for a high efficiency in Fortress Europe. The highest energy scenario for 2050 shows usually an energy production of about twice the baseline value.

In the neighbouring regions North Africa and West Asia, the foreseen changes are much stronger, up to four times as high in the high energy scenario, and twice as high in the lowest energy scenarios. Also, the logic of the scenarios is different. While in Europe the Economy First scenario has the highest energy production and the Fortress Europe scenario ranks on the third place, this pattern is mirrored in West Asia where Fortress Europe leads to the highest energy production with Economy First on the third place.

In 2005, the energy sector was the most important water use sector in most of the area north of the line from Paris to the Black Sea and south of the line Amsterdam-Moscow. This position is maintained in 2050s in Economy First as well as in Fortress Europe. In the scenarios Policy Rules and Sustainability First, the dominance of the energy sector has vanished almost completely, and replaced by industry/agriculture/domestic (in that order) in Policy Rules, and by domestic/agriculture/industry in Sustainability Eventually.

6.3.3 Drivers in the food sector

The change in total crop area over Europe shows a rather stable pattern as compared to changes in the irrigated agriculture sector. In all scenarios the dominant trend is a decline of the total crop area, generally between 15-40% with a maximum of 60%. In contrast, in the neighbouring regions West Asia and the Maghreb the dominant trend is towards increase in crop area. The changes in cropped area influence the water balance of river basins through the terms evapotranspiration and surface runoff, and thus the water availability. In addition water withdrawals for irrigation may influence the water availability. Within Europe, the total crop area is not considered as a main driver for any water use sector, as the water use in the Food sector is attributed to the water withdrawals for irrigated cropping only, while most of the cropping in Europe is rain fed.

In the baseline situation the shares of irrigated land is mostly between 10 and 20% in Mediterranean Europe, and 2-4% in the rest of Europe, with notable exceptions like Netherlands, Denmark, Sweden and Norway where 10-20% of the cropped area is equipped for irrigation. The share of irrigated area in some countries is close to zero: Ireland, Finland, Baltic countries, Poland and Belarus.

Irrigated agriculture sector
In the irrigated agriculture sector, the changes in irrigated area and the irrigation efficiency are the main drivers. A strong variation in changes in these two drivers appears over regions, countries, and scenarios, but overall the relative changes in irrigated area are stronger than in irrigation efficiency. The irrigation efficiency is considered as a purely socio-economic driver which varies according to the policy scenarios and countries, but for a given combination of policy scenario and country, the irrigation efficiency is the same for both climate scenarios. The changes in irrigated area follow a similar pattern, but they are determined by water availability as well, and therefore, the change in irrigated area may vary by climate scenario for a given combination of policy scenario and country.

Relative changes in irrigated area
In most countries the irrigated area expands in nearly all scenarios, in some relatively modest increases (10-30%) are given, but often strong increases of two-, to tenfold and higher are projected. Especially in countries with small acreages in the baseline situation the relative increase may look impressive (e.g. the Baltic countries), but the absolute increase may still be very modest. The strong growth of over 50 percent in Syria is in contrast to its neighbours. On the other hand, a strong decline in irrigated areas is foreseen for nearly all scenarios in a number of countries located outside the core of Europe: Denmark, Russia, Ukraine, Israel, Lebanon, Turkey, Cyprus, Greece, Slovenia, Italy, Spain and Portugal. This decline in irrigated area varies up to 60% of the baseline situation; the average national values of the countries where a decline in irrigated area is projected are 15-35% decrease in area.

For a given socio-economic scenario the changes in irrigated area are different for the climate scenarios IPCM and MIMR, because these figures are the result of an optimization procedure. Among the policy scenarios Economy First and Fortress of Europe have the largest irrigated areas and Sustainability Eventually scenario the smallest. Analysis of the relative changes in irrigated area show that the differences between the countries within a scenario are high. For a given country the differences between scenarios are less extreme.

Within a given policy scenario the differences between the climate scenarios in changed irrigated areas are quite small for most countries. In several countries, the future irrigated area under IPCM scenario is consistently larger than under MIMR. This is the case in Finland, the Baltic countries, Belarus, Slovakia, Romania, Ukraine and all countries east of them, and also in Spain. These differences between climate scenarios are considerable in the Baltic countries, Slovakia, Ukraine and Georgia, and minor in the other countries. The opposite situation that the irrigated area under IPCM climate is consistently smaller than under MIMR climate occurs in Hungary, Bosnia, Malta, Serbia and France, where the differences in the first three countries are considerable. In all other countries the differences vary from positive to negative, and usually small, but in some cases larger and in opposite directions. Because for a given country the differences in change in irrigated area between the four policy scenarios are usually larger than between the two climate scenarios, the effect of the socio-economic scenarios is dominant in the results.

Relative changes in irrigation efficiency
The values and changes in irrigation efficiency vary over socio-economic scenarios and countries. The baseline values range between 0.25-0.7. In the Economy First scenario the irrigation efficiency does not improve, except in Eastern Eastern Europe, where relative changes in efficiency of 25-55% are projected. In the other scenarios, the final value in 2050 depends on irrigation technique, crop and country. On average over all countries the highest future irrigation efficiency is achieved in Sustainability Eventually scenario. The top values are related with continuous drip irrigation in some southern countries (0.85), followed by sprinklers (0.78) and the lowest is supplementary irrigation (0.45). In the scenarios Fortress Europe and Policy Rules the gains in efficiency are comparable to the gains in Sustainability Eventually, but restricted to a limited set of countries. Fortress Europe scenario has the most efficient irrigation within Europe, namely in Western, Northern and Central Europe, but no efficiency gains in West Asia and half of the possible gains realised in North Africa. Policy Rules scenario fails to achieve efficiency gains in the heartland of Europe (Western, Northern and Central Europe), while reasonable gains are achieved in Southern Europe and maximum efficiency gains in West Asia and North Africa. Hence, there is some balance in this driver between the regions Northern Europe, Western Europe and Central Eastern Europe on the one hand, and Southern Europe, West Asia and North Africa on the other. Remarkably, for Eastern East Europe, all scenarios show identical country-specific efficiency gains for all scenarios of on average 35% (except for Ukraine in Economy First scenario: 0%).

Climate change as a driver
Finally, the climate change is a driver, by changes in precipitation and evapotranspiration. Less rainfall and higher evapotranspiration leads to a faster drying out of the soil and increases the need for irrigating the crop. This effect is especially visible where the soil water balance changes from water-sufficient to water deficient situations during the crop growing season, which applies to the middle and northern latitudes in Europe. The changes in water deficiency are controlled by changes in rainfall, of which the geographical pattern varies over Europe and differs between climatic scenarios. Yet, the climatic effects are less visible in the maps produced in this project than the socio-economic effects as the latter are derived from national statistics which vary more strongly between the countries than climatic values. On the other hand, the size of the river basin plays a role. The large river basins are trans-national, and both country- and climate-related differences in the river hydrology are averaged over the basin, or large parts of the basin. The smallest river basins show local effects in their results, e.g. due to the effect of large populations on domestic water use, which pressure in reality may be spread over adjacent basins.

Conclusion on water for food drivers
From the above it can be seen that in general the relative changes in irrigated area are larger than the relative changes in irrigation efficiencies. Most changes in irrigation withdrawals can be related to differences in irrigated area. The differences in irrigation efficiencies are equally relevant to explain the finer differences between some scenarios and countries. For example, where the changes between socio-economic scenarios in irrigated area are quite similar, as is the case in the scenarios Economy First and Fortress Europe, the differences between these two scenarios is caused primarily by differences in irrigation efficiency. Due to its lower irrigation efficiency the water withdrawals in Economy First are much higher than in Fortress Europe. Both factors, changes in irrigated areas and in irrigation efficiencies vary strongly between socio-economic scenarios, regions and countries, and therefore contribute to the visual differences in pan-European scenario results. The effect of climatic change on the crop water balance is more gradual.

7 Implications to policies

7.1 Introduction

The future of Europe’s waters will be influenced by a combination of many environmental, social, political, and policy drivers, such as global (climate) change, population growth, land use change, economic and technological developments. Political developments will have impact on Europe's waters. Amongst the most important policy drivers are the current and future agricultural, industrial, energy, trade, transportation and environmental policies.

Indicators can help to improve the design and implementation of the EU policies, as they enhance evidence-based decisions, management and accountability. Indicators provide information to support policy makers and stakeholders in the monitoring of the state of water resources and to quantify the impacts of policies to environmental conditions.

Examples of the policy-relevant information provided by indicators are:

- Indicators can be used in scenarios for planning and implementation of national and regional policies
- Indicators are useful in the assessment of Programme of Measures in the River Basin Management Plans (RBMP)
- Indicators can be used by river basin managers to test their WFD-related management plans against uncertainty and surprises in the freshwater systems of Europe.
- Indictors provide input to plans for financing national water infrastructure; to support river basin management plans under WFD.
- Impacts demonstrated by indicators for future scenarios can alert water planners to emerging problems that could affect their planning.
- Indicators can help water planners anticipate the link between economic activity and water availability – e.g. Will there be enough water for irrigation, for power plant withdrawals, for hydroelectricity?

The SCENES indicator framework was developed to deliver this kind of information. The framework analyses the effects of changes in the fresh water resources in pan-Europe in 2050, for the scenarios described in chapter 3.

7.2 Policy implications

The European policies relevant for European waters are:

- Protecting water quality across Europe: Water Framework Directive (WFD), Nitrate Directive, Urban Waste Water Directive
- Nature conservation, species conservation, protecting ecosystems: Natura 2000 (Birds and Habitats Directive), Freshwater Fish Directive
- Farm support, market payments and rural development: Common Agricultural Policy (CAP).
- Managing extreme events: Floods Directive, Water Scarcity and Droughts
- Ensuring clean bathing waters: Bathing Water Directive.
- Ensuring drinking water resources: Drinking Water Directive

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7.2.1. Water Framework Directive (WFD)

The objective of the Water framework directive is to prevent deterioration, enhance and restore bodies of surface water, achieve good chemical and ecological status of such water by 2015 at the latest and to reduce pollution from discharges and emissions of hazardous substances.

The results of the various SCENES scenarios show that the ecological status of many waters is unlikely to improve, and, therefore, will not meet the WFD requirements. Even for the most environment-friendly scenario Sustainability Eventually, water pollution (nutrients) will remain problematic. None of the future scenarios shows a significant improvement in nutrient levels in rivers and lakes in comparison to the current situation, resulting in a decline of biodiversity. In addition, the increase in water temperature in 2050 in rivers will affect fish populations and communities in many European river catchments. Consequently, many rivers and lakes will not support a good ecological status according the WFD requirements.

Additional measures have to be included in updates of the river basin management plans for numerous river basins in Europe. Nutrient emissions from agriculture should be reduced significantly to support the achievement of ecological objectives in lakes, rivers and coastal areas. The interaction between agriculture and the quality of surface water for the different land uses should be more closely analysed, as well as the effectiveness of measures to reduce emissions from agriculture. For instance, well organised manure management systems can significantly reduce nutrient loads.

WFD objectives should allow adaptation of ecosystems to climate change. Changes in hydrological and thermodynamic conditions will have a significant impact on future reference conditions. Moreover, climate adaptation strategies to extreme events (e.g. room for rivers) will have an impact on the ecological potential as well. Therefore, ecological objectives should be reformulated to take into account climate change impacts and adaptation strategies. In short:

- A better scientific underpinning of climate change impacts and climate strategies is needed for the defining future ecological objectives and rehabilitation strategies. European research projects such as Eurolimpacs and REFRESH are a start, but more research is needed.
- Long term climate change projections need to be considered (after 2050!) in the WFD (and in other climate related policies, RBMP etc).

7.2.2. Nitrates directive

The Nitrates Directive, Which forms an integral part of the Water Framework Directive, aims to protect water quality across Europe by preventing nitrates from agricultural sources polluting surface waters and by promoting the use of good farming practices. One of the measures in the scope of good farming practices is that the Nitrates Directive obliges Member States to limit the use of livestock manure to a maximum of 170 kg of nitrogen per hectare. The European Commission granted the Netherlands the right to derogate from the obligation, implying that farmers could use up to 250 kg of nitrogen per hectare on grasslands. Austria and Germany were granted the right to use up to 230 kg per ha year nitrogen from livestock manure in cattle farms.

The SCENES scenarios shows that a fertilizer use with maximum of 170 kg/ha is not adequate in improving the water quality in lakes and rivers to such an extent that the nutrient levels in rivers and lakes are supporting good ecological status. With farming being responsible for most nitrate inputs to surface waters, a further reduction of the limit for the use of nitrogen fertilizers is advisable. A limit with a maximum of 100 kg/ha as used in the Sustainability Eventually scenario shows improved macrophyte diversity in most European regions, but further measures are needed to reduce the nutrient emissions to rivers and lakes to meet the ecological requirements of the WFD.

7.2.3. Urban Waste Water Directive

The Urban Waste Water Directive is concerning the collection, treatment and discharge of urban waste waters and the treatment and discharge of waste water of certain industrial sectors. The Directive requires collection and treatment of waste water in all urban areas of >2000 population equivalents and secondary treatment of all discharges from urban areas of >2000 population equivalents and advanced treatment for settlements over 10,000 person equivalents in designated sensitive areas and their catchments.

Agriculture is and will be the main pollution source for nutrients in Europe's rivers and lakes. However, urban settlements are also a significant contributor to the total amount of nutrient loading to rivers and lakes. Therefore, in addition to actions to reduce nutrient loading from agricultural areas, policy actions are needed to reduce the nutrient loading from urban settlements in order to meet the ecological requirements of the WFD in near future.

7.2.4. Natura2000

Natura2000 is an ecological network of protected areas in the territory of the European Union. The legal basis for Natura2000 comes from the Birds Directive and the Habitats Directive, which form the backbone of the EU's internal biodiversity policy.

The SCENES scenarios for the Nature impact indicator (environmental flows) shows that the flow regime will be altered from the current baseline state across all regions and under all scenarios. The various elements of the flow regime (floods, average flows, low flows) influence freshwater ecosystems, so any alteration will affect existing ecosystems significantly. The Water for Nature analysis indicate that it will become increasingly difficult to meet existing environmental quality objectives and increasingly costly to implement control measures and water management plans. There will be similar implications for the Natura2000 network of sites of ecological significance protected under the Birds Directive and the Habitats Directive, as pressures on these ecosystems increases, especially those which values are depended on flood pulse regime, increases.

In addition, SCENES results demonstrate that climate change has large effects to both hydrology and water temperature, which influences ecology and biodiversity. The Natura2000 objectives are focusing on conservation of species, habitats and ecosystems and in many cases; these objectives are vulnerable for changes in hydrology and water temperature. The question is whether the resilience of Natura2000 objectives to climate change can be enhanced through climate adaptation and restoration strategies. This question can not be answered through the SCENES project, but should be answered by current EU research projects (e.g. REFRESH) and future projects.

7.2.5. Freshwater Fish Directive

The Freshwater Fish Directive aims to protect and improve the quality of rivers and lakes to encourage healthy fish populations. With regard to temperature of the river water, thermal discharges are not allowed to increase the temperature downstream of the point of thermal discharge (at the edge of the mixing zone) above 21.5°C for Salmonid waters and 28°C for Cyprinid waters.

Water temperature is a limiting factor for fish in rivers in highly industrialized and urbanized catchments due to cooling water discharges, especially in Western Europe. The SCENES scenarios show that more fish communities will be affected in rivers in many catchments in Europe due to the additional temperature rise, mainly caused by climate change. The current thermal discharges need to be reduced to support fish communities in the near future with natural warming of the rivers due to climate change.

7.2.7. Common Agricultural Policy

The policy framework relevant for agricultural water use in the Mediterranean is mainly given through the Common Agricultural Policy (CAP) and the Water Framework Directive (WFD). EU water law has traditionally focussed on water quality issues, while water scarcity is a growing problem in a number of EU member states. The introduction of the WFD in 2000 has provided the first coherent legal tool to address the issue of water scarcity at EU level (Farmer, 2010).

The CAP is a complex system of European Union agricultural subsidies and programmes. The aim is to provide farmers with a reasonable standard of living, consumers with quality food at fair prices and to preserve rural heritage. There has been considerable criticism of CAP in the past years mainly that it results in intensification. The CAP today has been substantially reformed. It is now based in decoupling and freedom to farm and is no more responsible to the increase in water consumption.

The SCENES analysis for agriculture shows that for southern Europe and northern Africa, water availability is expected to decrease in 2050. In the Mediterranean region, the average annual decrease is 15-30%, and more severe and more frequent droughts are expected. In western Europe, the annual decrease is 10-20%. The Water for Food analysis demonstrated that these effects can be compensated by socio-economic measures and technological development, such as improved irrigation technologies (sprinkler and drip irrigation). The Water for Food indicators demonstrated that the projected increase in efficiency result in substantial water savings, on average 40% for the scenarios Fortress Europe, Policy Rules and Sustainability Eventually. The potential water savings from the scenarios are large and stress the potential for policy action at EU level.

7.2.8. Flood Directive

The EU Flood Directive requires that Member States reduce the flood risk (probability multiplied by the resulting damage) for those areas where the risk is considered significant. This requires as a first step an assessment of the flood hazards (magnitude and probabilities) and possible consequences (damages and loss of life).

Climate change is a most important driver with respect to the magnitude and timing of extreme events. The message that can be obtained from the SCENES analysis is that indeed under climate change flood hazard is likely to increase in many areas of Europe, and most significantly in the Mediterranean. The increase of flood risk depends on whether one considers changes in damage (for which GDP is used as proxy) or change in loss of life (related to population growth). The areas with strong GDP growth are generally the same areas that according to the socio-economic scenarios within SCENES experience population declines and vice versa. This means that in many areas in Europe flood risk increases as a result of one of these processes. Which process is the more dominant determines which types of measures (protection, spatial planning or evacuation) will be the most logical.

7.2.9. Water Scarcity and Droughts

Water scarcity and drought are different phenomena although they are liable to aggravate the impacts of each other. In some regions, the severity and frequency of droughts can lead to water scarcity situations, while overexploitation of available water resources can exacerbate the consequences of droughts. Therefore, attention needs to be paid to the synergies between these two phenomena, especially in river basins affected by water scarcity.

As (hydrological) droughts is totally climate driven, water scarcity occurs where there are insufficient water resources to satisfy long-term average requirements. It refers to long-term water imbalances where water demands exceed the water supply capacity of the natural system to a large extent. Water availability problems frequently appear in areas with low rainfall but also in areas with high water abstraction levels for drinking water supply, irrigation and/or cooling water requirements. Large spatial and temporal differences in the amount of water available are observed across Europe. In near future water scarcity and droughts will become more intense en frequently in Europe; this is asking for clear policy actions on the short term.

7.2.10. Bathing Water Quality Directive

The Bathing water quality directive states that the monitoring of bathing water quality parameters shall take place in bathing waters where most bathers are expected and the greatest risk of pollution is expected. If the bathing water is classified as ‘poor’, Member States shall take adequate measures to prevent, reduce or eliminate the causes of pollution, and inform the public.

The class definition as indicated in the bathing water quality Directive (excellent, good, sufficient, poor) correspond to the classes “no risk”, “low risk”, “medium risk” and “high risk” for the occurrence of high Chlorophyll-a concentrations and the risk for algae blooms. The threshold at a Chlorophyll-a concentration of <10 µg/L is identified by WHO (1999) as being relatively mild and/or with low probabilities of adverse health effects. At <50 µg/L the risk is defined as moderate probability of adverse health effects and when the levels are exceeding 50 µg/L there is a very high probability of adverse health effects.

Although for most SCENES scenarios an improvement is seen, many waters remain in the ‘poor’ water quality class and should therefore be extensively monitored. In all scenarios, harmful algae blooms will seriously jeopardize bathing water quality in large parts of Europe. Adequate measures to reduce or eliminate the causes of pollution are still needed irrespectively of the scenario for many waters across Europe.

7.2.11. Drinking Water Directive

To make sure drinking water everywhere in the EU is healthy, clean and tasty, the Drinking Water Directive sets standards for the most common substances that can be found in drinking water. In the DWD a total of 48 microbiological and chemical parameters must be monitored and tested regularly. In principle WHO guidelines for drinking water are used as a basis for the standards in the Drinking Water Directive. Toxic substances are not considered within SCENES, bit risk analysis of future projections of high occurrence of algal blooms demonstrated that this is a serious point of concern (see 7.2.1).

7.3 Conclusions

The quantification of water scenarios with the indicator framework proved a useful tool to understand impacts for the difference water use sectors and implications to policies. The implications at EU policies was presented for each of the sectors studied in SCENES: agriculture, nature, people and industry.

The SCENES scenarios show that the potential water savings in agriculture are large, which stresses the potential for policy action at EU level.

No significant improvement in nutrient levels in rivers and lakes is seen in the scenarios, resulting in a decline of biodiversity, poor or moderate ecological quality and high risks for harmful algal blooms. Consequently many water bodies will not support a good ecological status according the WFD requirements. Many inland bathing waters are exposed to high risks for algal blooms. In addition, the increase in water temperature will degrade fish populations and communities in many European river catchments. This calls for additional measures in the river basin management plans:

- A reduction of the limit for the use of nitrogen fertilizers is needed;
- Thresholds for water temperature are needed to support fish communities in the near future with natural warming of the rivers due to climate change;
- Long term climate change projections need to be considered (after 2050) in the WFD.

The Flood Directive is acknowledging to importance of climate adaptation strategies to cope with flood hazards, as large parts of Europe are prone for flood hazards. Future risk for flood hazards may improve in some areas in Europe, but may worsen in other areas. The situation is more dramatic when the consequences in terms of damages and risks for loss of lives are taken into account. Therefore, flood risks management plans should be based on

SCENES water scenarios project a decline of future cooling water discharge capacities of rivers. As thermal power plants are big water users, energy production plans should taken into account the possible future limitations of discharging cooling water. In addition, cooling water discharge may have also an large impact on river ecosystems and therefore ecological standards based on thresholds for supporting the biological quality elements of the water Framework Directive, should be developed.

8 Final remarks

The SCENES project has delivered a framework for scenario development. This framework consists of conceptual models to develop consistent storylines through participatory processes, methodologies to generate data on the future of driving forces and pressures and a toolbox to quantify future changes in water quantity and water quality at pan-European scale, including a core set of impact indicators to evaluate and assess the ecological, environmental and socio-economic impacts on water system services.

Water scenarios are a powerful tool to increase awareness of future water issues. However, to cope with the rapidly changing world, water outlooks needed to be frequently updated. Therefore, we recommend launching an on-going stakeholder driven water scenario development process, to establish a European water scenario team to facilitate the scenario development process. In the next outlook on European water futures, special attention should be paid to environmental flow requirements, climate adaptation strategies and water quality issues (both nutrients and contaminants).

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Annex 1: list of indicators

Generic water system indicators

ID	Name	Short description
Water 1	Water Consumption Index	Ratio of consumptive use to water availability
Water 2	Water Stress Index	Ratio of withdrawals to water availability
Water 3	Water Scarcity Index	Ratio of consumptive use to water available during 90% of the time
Water 4	Change in frequency of flood events	Change in frequency of a discharge with the magnitude of the current once per 100 year discharge
Water 5	Change in flood hazards	Change in magnitude of the once per 100 year discharge
Water 6	Change in frequency of river low flow	Change in frequency of a discharge with the magnitude that is currently exceeded 90% of the time
Water 7	Change in magnitude of river low flow	Change in magnitude of the discharge which is exceeded 90% of the time
Water 8	Change in mean annual river flow	Change in mean annual river flow

Water system service indicators.

ID	Name	Short description
Food 1	Agricultural crop production	Changes in crop production resulting from changes in temperature, precipitation and CO2 concentration
Food 2	Irrigation water withdrawals	Irrigation water use divided by irrigation efficiency
Food 3	Water stress in irrigation	Ratio of irrigation water withdrawal to water availability
Nature 1	Environmental flows	The number of ecologically-relevant flow parameter that have altered significantly under each scenario
Nature 2	Floodplain wetlands	Change in duration of overbank flows
Nature 3	Ecosystem services of wetlands	Changes in number of ecosystem services of wetlands as a result of changes in water balance parameters
Nature 4	Change in water supply to wetlands	Changes in hydrological factors responsible for proper wetland functioning
Nature 5	Aquatic macrophyte diversity in lakes	Diversity of aquatic macrophytes in lakes in relation to nitrogen emissions
Nature 6	Habitat suitability for river water temperature for fish	Suitability of river water as fish habitats in relation to water temperature
People 1	Domestic water stress	Ratio of domestic water use (withdrawals) to water available for domestic use (Total availability minus consumptive use by economic sectors)
People 2	Flood risk	Change in flood risk (hazard * damage) based on the once per 100 year discharge (hazard) and, separately, on changes in GDP and population numbers (damage)
People 3	Risk for harmful algal blooms in shallow lakes	Risk for harmful algal blooms in shallow lakes and reservoirs as a function of nitrogen

	and reservoirs	concentration and water temperature
People 4	Domestic water availability	Ratio of water available for domestic use (Total availability minus consumptive use by economic sectors) and population numbers
Industry 1	Extra water demand for cooling water	Extra water demand for cooling water as a result of the changed cooling capacity due to temperature changes
Industry 2	Navigability of large rivers	Change in number of days with low flows that hamper navigation on main navigation routes (based on the change in frequency of a discharge with the magnitude that is currently exceeded 90% of the time)
Industry 3	Cooling water stress	Ratio of cooling water withdrawals to water available during 90% of the time