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SCENES

Water Scenarios for Europe and for Neighbouring States

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

Volume A: Generic indicators

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RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Preface

SCENES is a four year European research project developing scenarios for 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 a Pan-European Panel (PEP). This report describes impacts of future changes in Europe's freshwater resources in terms of generic water indicators.

This report is deliverable D4.6 of the FP6 Project SCENES (EU contract GOCE 036822).

Contents

1 Introduction

SCENES impact indicators

This report is an appendix to deliverable D4.6 of the SCENES Project. Deliverable D4.6 is reporting the results of an analysis of the socio-economic and ecological impacts of future changes in Europe's freshwater resources. In the SCENES project water scenarios have been developed describing possible future climate and socio-economic developments and the impacts of these scenarios. The impacts are expressed through a set of indicators covering a wide range of topics.

Within SCENES, we distinguish two types of impact indicators:

- Generic hydrological impact indicators: indicators that are addressing the hydrological changes in freshwater availability and quality in terms of too much (flood events) or too little (drought events, water stress).
- 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 water system services: Water for Food, Water for Nature, Water for People and Water for Industry and Energy.

The total set of impact indicators is listed in Table 1.1. The indicator ID's refer to water system services. The generic hydrological indicators have "Water" as ID.

Table 1.1 Overview of SCENES impact indicators

ID	Name
Water 1	Water Consumption Index
Water 2	Water Stress Index
Water 3	Water Scarcity Index
Water 4	Change in frequency of flood events
Water 5	Change in flood hazards
Water 6	Change in frequency of river low flow
Water 7	Change in magnitude of river low flow
Water 8	Change in mean annual river flow
Food 1	Agricultural crop production
Food 2	Irrigation water withdrawals
Food 3	Water stress in irrigation
Nature 1	Environmental flows
Nature 2	Floodplain wetlands
Nature 3	Ecosystem services of wetlands
Nature 4	Change in water supply to wetlands
Nature 5	Aquatic macrophyte diversity in lakes
Nature 6	Habitat suitability for river water temperature for fish
People 1	Domestic water stress
People 2	Flood risk
People 3	Risk for harmful algal blooms in shallow lakes and reservoirs
People 4	Domestic water availability
Industry 1	Extra demand for cooling water
Industry 2	Navigability of large rivers
Industry 3	Cooling water stress

SCENES scenarios and indicator quantification

For quantification of future scenarios, four socio-economic scenarios are combined with two climate change scenarios. The socio-economic scenarios are based on UNEP's GEO4 scenarios and adjusted in a participatory exercise with key European scientists. Four scenarios resulted which are called: Economy First (EcF), Fortress Europe (FoE), Policy Rules (PoR), and Sustainability Eventually (SuE). Two climate scenarios are used which were generated by two different global circulation models (GCM's): MIMR and IPCM4, following the SRES A2 emission pathway. The reference period (2000s) is represented by the climate normal period (1961-1990) for river discharges and considers the water uses of the year 2005 (except for irrigation for which demand is influenced by the variation in evaporation and precipitation).

These eight scenarios have been used as input for the global water model WaterGAP (Water – Global Assessment and Prognosis; Alcamo et al. 2003, Döll et al. 2003). The resulting output for a baseline (2000s) and eight future (2050s) situations has formed the basis for the quantification of the indicators.

This report

The indicators are discussed in detail in five Appendices:

- Volume A: Generic indicators (this volume)
- Volume B: Water for Food
- Volume C: Water for Nature
- Volume D: Water for People
- Volume E: Water for Industry & Energy

This report, Volume A, discusses the generic indicators. Each generic indicator chapter starts with an introduction to the indicator, followed by the method that was used to calculate the indicator. Next, the results are described. Each chapter ends with a synthesis and the most important key messages that could be derived from the analysis.

The indicator chapters are preceded by two chapters. Chapter 2 discusses the method applied to analyse the regional variations in impacts as well as to assess whether climate change or socio-economic development is the more dominant driving force for changes in the indicator. Chapter 3 provides an overview of the results for main input data used for the computation of the indicators, consisting of either input for or output from WaterGAP.

Chapter 12 discusses the key findings that can be drawn from the analysis of the generic indicators.

References

Alcamo, J., Döll, P., Henrichs, T., Kaspar, F., Lehner, B., Rösch, T. & Siebert, S., 2003. Development and Testing of the WaterGAP 2 Global Model of Water Use and Availability, *Hydrological Sciences Journal,* 48 (3): 317–337.

Döll, P., Kaspar, F. & Lehner, B., 2003. "A Global Hydrological Model for Deriving Water Availability Indicators: Model Tuning and Validation", *J. Hydrol.*, 270, pp. 105-134.

2 Method to analyse indicator maps

The objective of producing indicator maps is to obtain an image of possible futures in Europe. There are three questions that we would like to have answered for each indicators as well as for the combined set of indicators:

- What is the overall image per region?
- Are there big differences between regions?
- Can socio-economic changes or climate changes be identified as dominant driving forces of these changes?

This chapter discusses the method used to obtain an overall image of possible future developments using the resulting maps per indicator in order to provide an answer to these questions.

2.1 Analysis approach regional impacts

Per indicator, the different maps were compared. This has been done first of all by describing the observed changes. After that, a more objective comparison of the different maps per indicator was made by scoring the changes in each region (Northern Africa, Western Europe, Northern Europe, Southern Europe, Central/Eastern Europe, Eastern Europe and Western Asia). This was done through the following steps:

1. For each indicator, positive and negative changes for each scenario with respect to the baseline were identified on each scenario map
2. The changes with respect to the baseline were evaluated for each region: Northern Africa, Western Europe, Northern Europe, Southern Europe, Central/Eastern Europe, Eastern Europe and Western Asia.
3. For this evaluation of the indicator, the following system was used:
   ++ = Positive change for the whole region, or almost the whole region

   \+ = Positive change for part of the region, other part unchanged

   o = No changes for the whole region, or almost the whole region

   +/- = Partly positive, and partly negative changes are observed

   \- = Negative change for part of the region, other part unchanged

   -- = Negative change for the whole region, or almost the whole region
4. The times a certain score was given is counted for each score, per region and per indicator.
5. The +/- scores were divided by two and added to the minus and the plus score. This means that a +/- score can be understood as 0.5 + and 0.5 -.
6. Per region and indicator, this is further translated in two aspects: 1: focus and 2: uncertainty (L(ow), M(edium) and H(igh).
7. From the table with these final results for all indicators conclusions are drawn on what future a region may face for different aspects and how certain this is.

The results for steps 1-3 are included in the chapters for the individual indicators. The results for steps 4-7 are included in the synthesis chapter 12.

2.2 Analysis approach climate change or socio-economic change the most important driving force

The following steps were taken for an analysis of whether climate change or socio-economic changes is a dominant factor determining indicator results:

- As a first step, results for consumptive use and withdrawals have been compared to climate change (change in mean annual runoff). This analysis (reported in Chapter 3) showed that climate change does not have a dominant impact on water use (through changes in irrigation demand as a result of net precipitation).
- This meant that if the pattern of the socio-economic scenarios is more dominant, we can assume that this is indeed the result of the socio-economic scenarios and not of climate change
- Based on these assumptions, for each indicator it was indicated whether socio-economic changes (SE) or climate change (CC) had a more dominant impact, or whether the combined influence (SE/CC) is clearly visible. This was done through considering all maps in combination.

2.3 Limitations:

- Not all indicators have a result for North-Africa;
- In the regional subdivision, the UK is part of North-Europe. However, particularly the area around London shows patterns more similar to western Europe than to Scandinavia. To let the results for Northern Europe not to be influenced too much by the patterns observed around London, the results for London have been considered to be part of western Europe;
- Flood hazard has results for increased frequency only. As a result many cells are missing. The difference between decrease in flood hazard and 'no data' is therefore unclear. The result may be that the images are interpreted as too negative;
- For the generic indicators, increase in low flows and mean annual runoff and decreases in high flows are interpreted as a positive change. This is true from a human perspective, where drought leads to drinking water shortages and decreases in high flows decrease floods. However, from an environmental perspective, all changes in flow regime may lead to negative environmental impacts;
- Indicators have not been weighted;
- Low flows, mean annual river flow and flood hazard can only show a change in state. The eventual impact will depend on population, water demand etc.

3 Main input data for the impact indicators

3.1 Introduction

In order to be able to understand the resulting maps for the eight climate change/socio-economic change combinations, this chapter discusses the main input data for the impact indicators. These input data are either state parameters that results from an earlier step in the calculation process (water availability, consumptive use, withdrawals) or driving forces (population growth, GDP). We start with the analysis of changes in water availability, which is purely climate driven. Through the impact of changes in precipitation and evaporation on irrigation water demands, consumptive use and withdrawals can be influenced by both socio-economic developments and climate change. We analyse to what extent climate change is visible in the results. The main changes in population growth and GDP are briefly discussed.

The results from this chapter form the basis for analysis of the results in the following chapters.

3.2 Mean annual river flow

Figure 3.1 and 3.2 show the change in average annual water availability for the IPCM4 and MIMR scenarios. The mean annual river flow is influenced by climate change only. The regional impacts as deviation from the baseline (in which drier is indicated as negative and wetter as positive) are presented in Table 3.1.

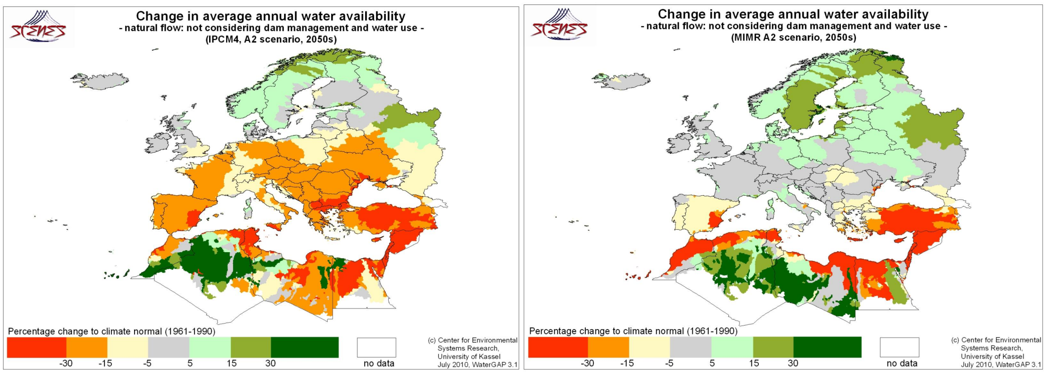


Figure 3.1 and 3.2 Change in average annual water availability for a) IPCM4 and b) MIMR scenarios

Table 3.1 Regional impacts as deviation from the baseline scenario – annual water availability

	Northern Africa	Western Europe	Northern Europe	Southern Europe	Central/Eastern Europe	Eastern Europe	Western Asia
IPCM	+/-	--	++	--	--	+/-	--
MIMR	+/-	o	++	-	+	+	--

Both climate change scenarios show increases in northern and eastern Europe and in part of northern Africa. The scenarios also agree on increased drought along the North African coast, western Asia and Southern Europe. The differences between the scenarios seem however larger than the similarities. The zone from France, UK stretching toward Ukraine hardly changes compared to the baseline in MIMR, while in IPCM this zone will get noticeably drier.

3.3 Low flows (Q90)

Low flows are defined as the discharge which is exceeded 90% of the time. Figure 3.3 and Figure 3.4 show the changes in low flows (Q90) for the two scenarios IPCM4 and MIMR. The low flows are influenced by climate change only. The regional deviations compared to the baseline scenario are included in Table 3.2. Increases in low flows are indicated as a positive changes and decreases in low flows as negative change. It should be noted that an increase in low flows is not necessarily a positive change, for example higher low flows may negatively impact riparian ecosystems.

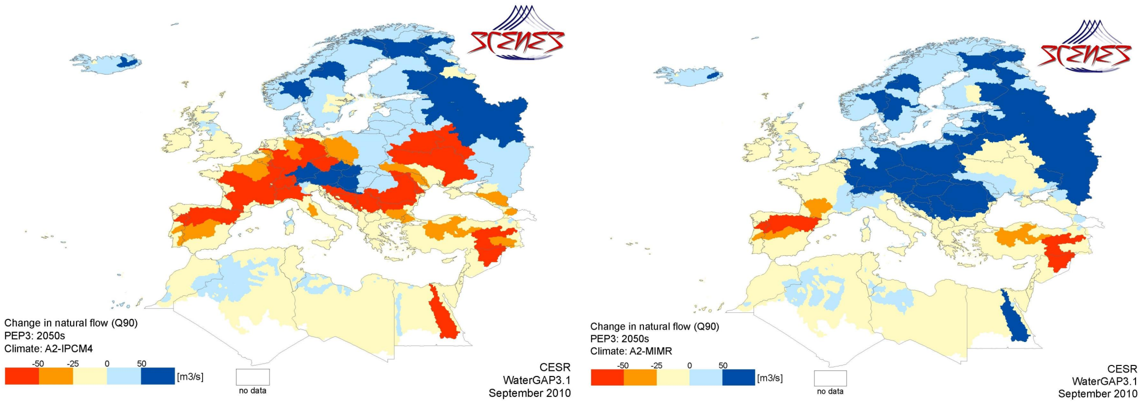


Figure 3.3 and 3.4 Change in natural low flow (Q90) for a) IPCM4 and b) MIMR scenarios

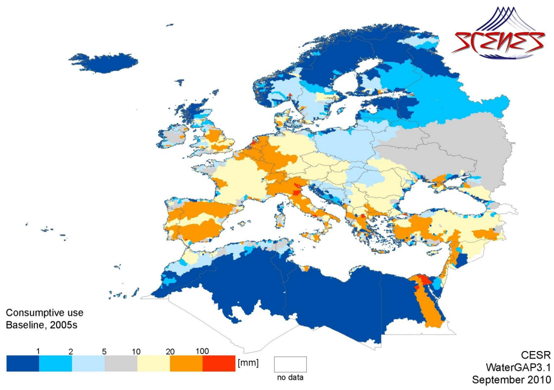
Table 3.2 Regional impacts as deviation from the baseline scenario – low flow (Q90)

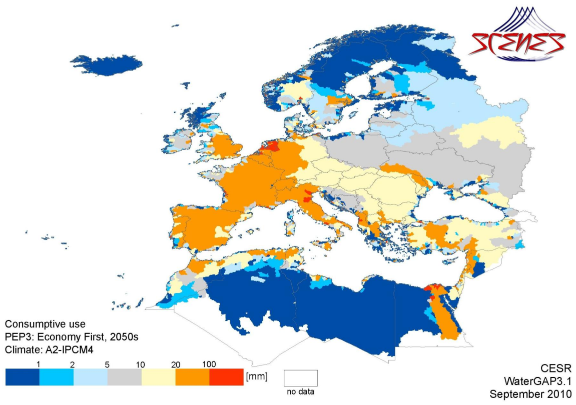
	Northern Africa	Western Europe	Northern Europe	Southern Europe	Central/Eastern Europe	Eastern Europe	Western Asia
IPCM	-	- -	+	-	+	+/-	-
MIMR	+	+	+	-	+	+	-

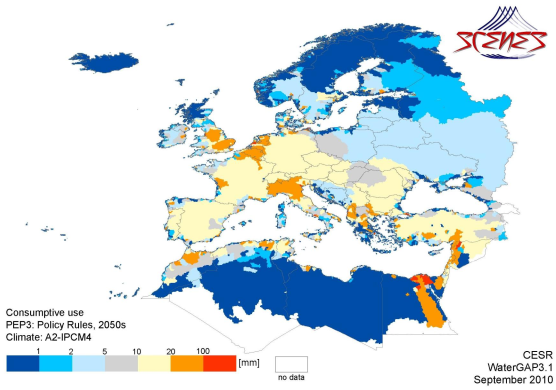
The observed changes in the magnitude of low flows are quite similar in most regions, except for northern Africa and western Europe. The two scenarios agree on higher low flow in northern and eastern Europe as well as in part of Africa. Low flows will be lower in parts of Spain and Turkey. With respect to western and central Europe IPCM shows drier conditions were MIMR shows unchanged or wetter conditions. The Nile basin has reduced low flows under IPCM and increased low flows under MIMR.

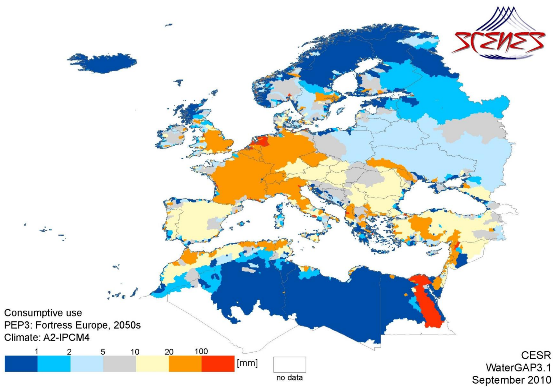
3.4 Consumptive use

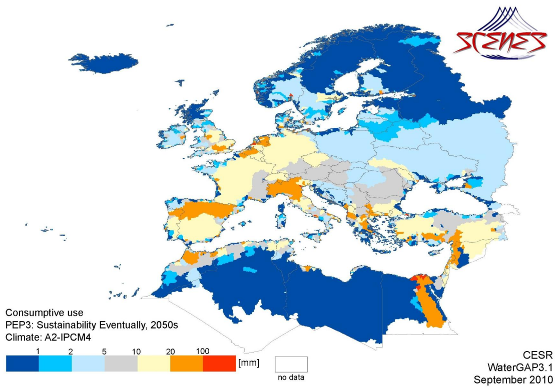
The consumptive use is the water that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from an immediate water environment (water body, surface- or ground-water source, basin). In short, it is the net water use in a basin, after excess water is returned to the system. The consumptive use for both the baseline scenario and the eight combinations of climate change and socio-economic change are included in Figure 3.5 until 3.13. Table 3.3 represents the increases and decreases in consumptive use for the different regions.

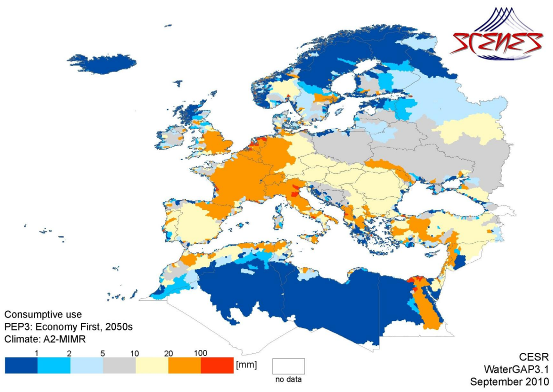

Consumptive use
Baseline, 2005s
1 2 5 10 20 100
[mm]
no data
CESR
WaterGAP3.1
September 2010

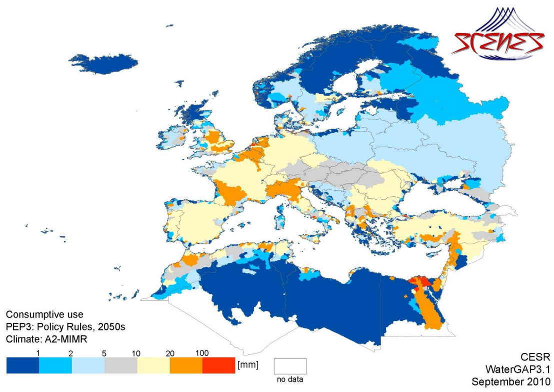

Consumptive use
PEP3: Economy First, 2050s
Climate: A2-IPCM4
1 2 5 10 20 100
[mm]
no data
CESR
WaterGAP3.1
September 2010


Consumptive use
PEP3: Policy Rules, 2050s
Climate: A2-IPCM4
1 2 5 10 20 100
[mm]
no data
CESR
WaterGAP3.1
September 2010


Consumptive use
PEP3: Fortress Europe, 2050s
Climate: A2-IPCM4
1 2 5 10 20 100
[mm]
no data
CESR
WaterGAP3.1
September 2010


Consumptive use
PEP3: Sustainability Eventually, 2050s
Climate: A2-IPCM4
1 2 5 10 20 100
[mm]
no data
CESR
WaterGAP3.1
September 2010


Consumptive use
PEP3: Economy First, 2050s
Climate: A2-MIMR
1 2 5 10 20 100
[mm]
no data
CESR
WaterGAP3.1
September 2010


Consumptive use
PEP3: Policy Rules, 2050s
Climate: A2-MIMR
1 2 5 10 20 100
[mm]
no data
CESR
WaterGAP3.1
September 2010

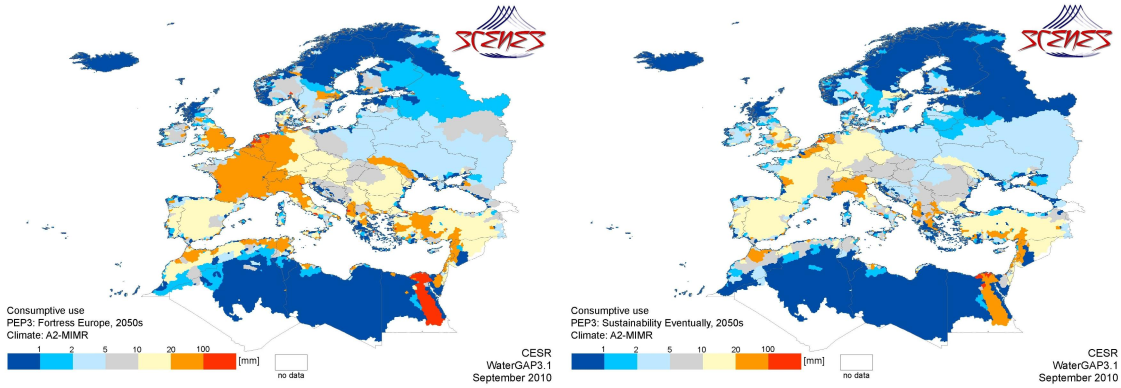


Figure 3.5 until 3.13 (left to right). Consumptive water use for the baseline situation (3.5) and under different climate scenarios (Figure 3.6 until 3.9 under IPCM, 3.10 until 3.13 under MIMR) and socio economic scenarios (Figure 3.6 and 3.10: Economy First. Figure 3.7 and 3.11: Policy Rules. Figure 3.8 and 3.12: Fortress Europe. Figure 3.9 and 3.13: Sustainability Eventually).

Table 3.3 Regional impacts as deviation from the baseline scenario – consumptive use

		Northern Africa	Western Europe	Northern Europe	Southern Europe	Central/Eastern Europe	Eastern Europe	Western Asia
IPCM	EcF	-	-	-	o	-	-	o
	FoE	--	-	-	+	o	-	o
	PoR	-	+	o	+	o	o	o
	SuE	-	+	o	+	o	+	o
MIMR	EcF	-	-	-	+	-	-	o
	FoE	--	-	-	+	o	-	o
	PoR	-	+	o	+	o	o	o
	SuE	-	+	o	+	o	+	o

The results show that the Economy First and Fortress Europe results mainly in increases in consumptive water use, for almost all regions. Exceptions are Southern Europe, where the consumptive use decreases, and Western Asia where the water use remains constant. For the Policy Rules and Sustainability Eventually scenarios all regions show either no change or a decrease in consumption, with the exception of Northern Africa where consumptive use increases for all scenarios. Under the IPCM4 scenario the results are a bit more negative than under the MIMR scenario.

3.5 Withdrawals

The withdrawals represent the gross water demand, including all the water that may later be returned to the system. The results for the baseline situation and the eight future scenarios are presented in Figure 3.14 until 3.22.

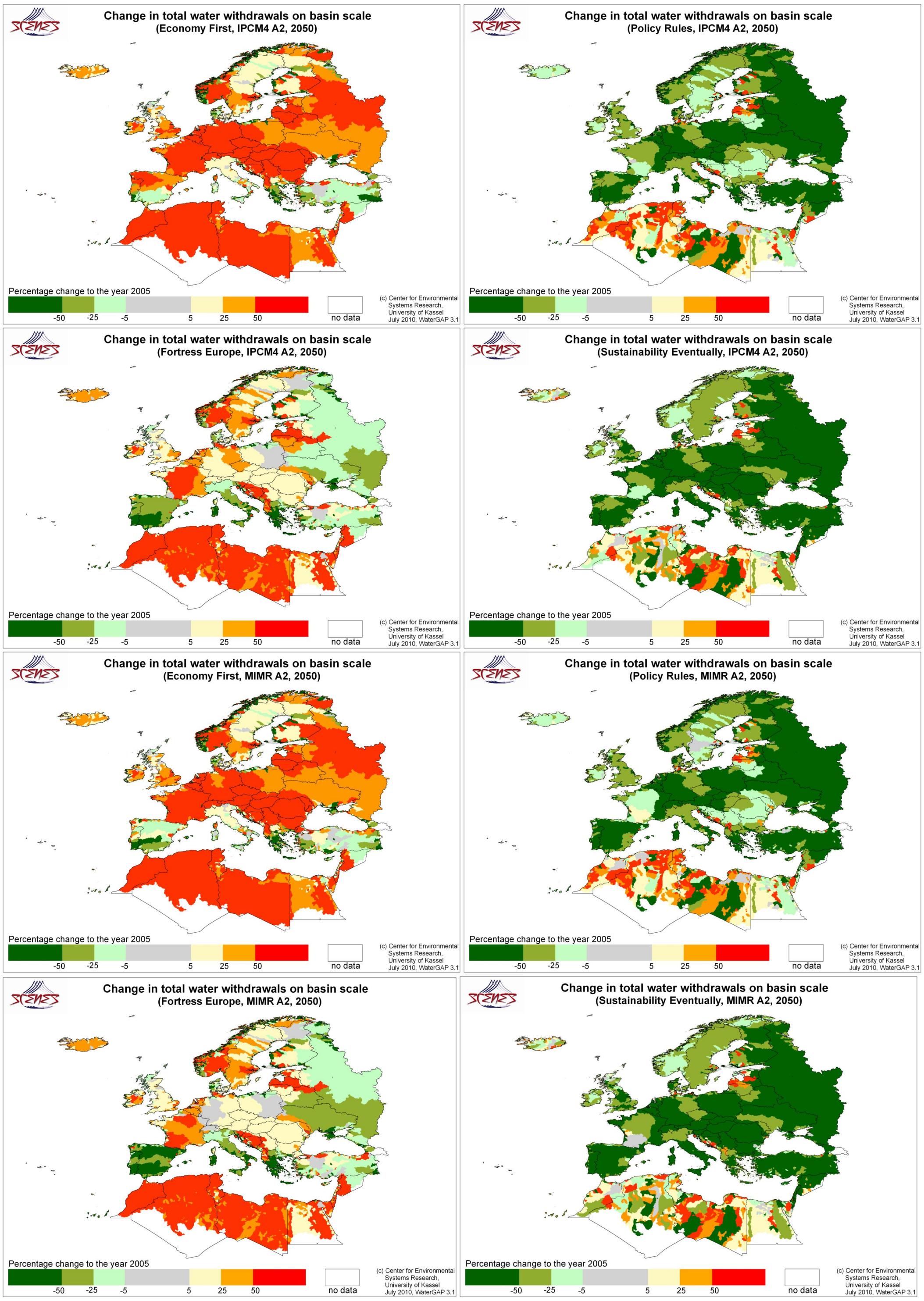


Figure 3.14 until 3.22 (left to right). Withdrawals for the baseline situation (3.14) and under different climate scenarios (Figure 3.15 until 3.18 under IPCM, 3.19 until 3.22 under MIMR) and socio economic scenarios (Figure 3.15 and 3.19: Economy First. Figure 3.16 and 3.20: Policy Rules. Figure 3.17 and 3.21: Fortress Europe. Figure 3.18 and 3.22: Sustainability Eventually).

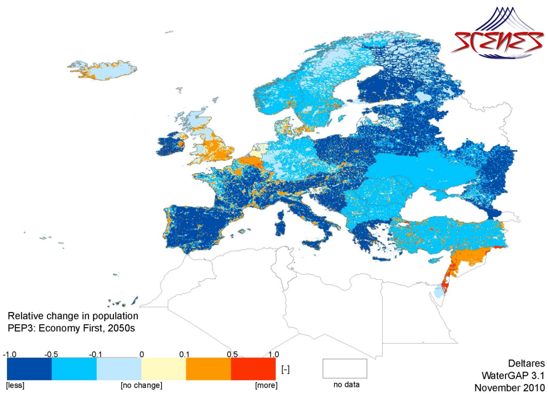
Table 3.4 Regional impacts as deviation from the baseline scenario – withdrawals

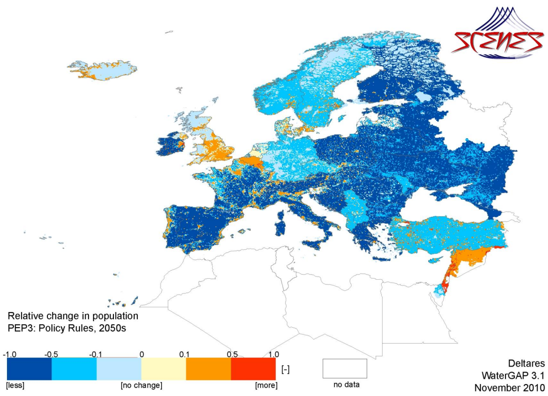
		Northern Africa	Western Europe	Northern Europe	Southern Europe	Central/Eastern Europe	Eastern Europe	Western Asia
IPCM	EcF	--	--	--	+/-	--	--	+/-
	FoE	--	--	--	+/-	-	++	+/-
	PoR	+/-	++	+/-	++	++	++	+/-
	SuE	+/-	++	+/-	++	++	++	++
MIMR	EcF	--	--	--	+/-	--	--	+/-
	FoE	--	--	--	+/-	-	++	+/-
	PoR	+/-	++	+/-	++	++	++	++
	SuE	+/-	++	+/-	++	++	++	++

Under the baseline scenario, the highest withdrawal rates can be observed in England, the Benelux, northern Italy, Greece, Turkey, Israel and the Nile delta. Differences in withdrawals in the future are mainly caused by different scenario assumptions. Under the Economy First and Fortress Europe, the highest positive withdrawal changes are seen: over 50% increase with respect to the baseline scenario for almost all of Europe (Economy First) and for Scandinavia, western Europe, northern Africa and Israel (Fortress Europe). For the Sustainability Eventually and Policy Rules, mainly negative withdrawal changes are seen: almost all of Europe experiences a decrease of water withdrawals of 25 to over 50%. The decrease in withdrawals in the Mediterranean area is caused by improvements in irrigation technology.

3.6 Population growth

Figures 3.23 until 3.26 show the relative change in population for the four socio-economic scenarios. Table 3.5 presents the regional results. In this table decreases in population are marked as a positive change and increases in population as a negative change.





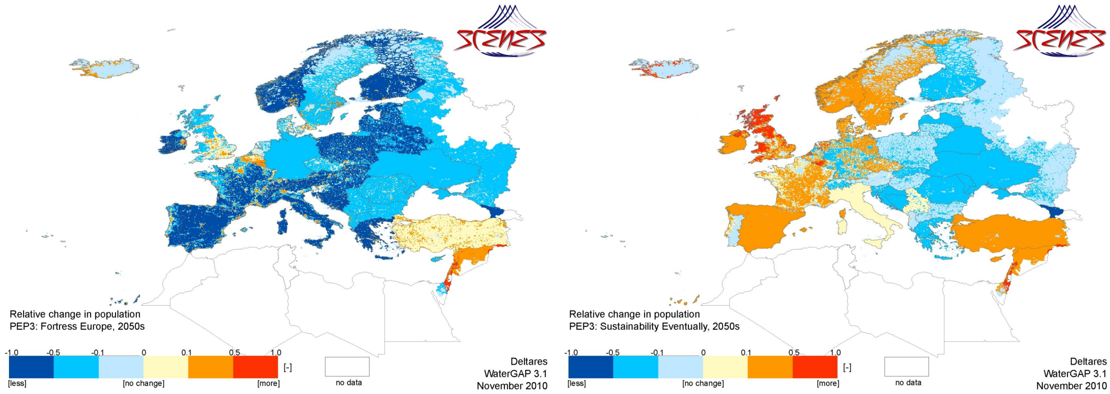


Figure 3.23 until 3.26 (left to right). Relative change in population for Economy First (3.23), Policy Rules (3.24), Fortress Europe (3.25) and Sustainability Eventually (3.26).

Table 3.5 Regional impacts as deviation from the baseline scenario – population

		Northern Africa	Western Europe	Northern Europe	Southern Europe	Central/Eastern Europe	Eastern Europe	Western Asia
IPCM	EcF	NA	+/-	++	++	++	++	++
	FoE	NA	+/-	++	++	++	++	--
	PoR	NA	+/-	++	++	++	++	++
	SuE	NA	-	-	+/-	++	++	--

The population development under the Sustainability Eventually scenario is different from the population development seen under the other scenarios. The other scenarios show a general population decrease in most of Europe, except for the area around London and the Benelux. Also in Turkey some increase in population is observed. Under the Sustainability Eventually scenario, however, far more increases are observed. Spain, western Europe, the UK, Scandinavia and Turkey all are expected to encounter population increases. Also, the decreases in the other regions are not as strong as observed for the other scenarios.

3.7 Basis for evaluating whether climate change or socio-economic change is the main driving force – analysing water use

Part of the analysis of the results for the impact indicators is the assessment of whether climate change or socio-economic change presents the major driving force. To perform this analysis it is important that for all input parameters it is clear whether the input parameter presents a change in climate or a socio-economic change. For most input parameters this can be unambiguously assessed. An exception is formed by the parameter water use. Water use, both the consumptive use and the withdrawals are affected by socio-economic change (land use, irrigation efficiencies, cropping patterns) and climate change (net precipitation). It is therefore interesting to analyse what is the most important driving force determining consumptive use and water withdrawals. It can be assumed that if climate change had an important role the patterns from the water availability maps would be visible in the water use maps and that results for water use between climate change scenarios would show larger differences then between socio-economic scenarios.

Comparing the result maps for water use with the maps for availability shows that the patterns shown on the water use maps and the differences between the scenarios do not show much similarity with the patterns of water availability maps. The maps for a certain socio-economic scenario do show differences for the two climate scenarios, but this is not the dominant factor. From this analysis we conclude that water use is dominated by the socio-economic developments and not by climate change. In the further analysis in this Volume in which the most dominant driving force is assessed for indicators that are based on availability and use, we consider water use to be a socio-economic change driven parameter.

4 Water 1 – Water Consumption Index

4.1 Introduction to indicator

The Water Consumption Index is the annual total water *consumption* in relation to the long-term average availability of the freshwater water resources within a river (sub)basin. The water consumption index is considered widely as a generic impact indicator for water stress (EEA, 2003). The WEI identifies those countries, regions and (sub)basins that have a high consumption in relation to their resources and therefore are prone to suffer problems of water stress.

4.2 Method

Calculation approach

The Water Consumption Index is the water consumption-to-availability ratio. The calculation can be expressed as:

$$\frac{\text{Water consumption (m}^3\text{/year)}}{\text{Water availability (m}^3\text{/year)}}$$

Input data

The following WaterGAP output is used to calculate the indicator:

- Total water availability
- Total consumptive use for domestic purposes, electricity, manufacturing, irrigation and livestock

Spatial and temporal scales

The Water Consumption Index is calculated on river basin level. WaterGAP output at grid cell level is aggregated at river basin level. Annual averages (mm/year) are calculated for both water consumption and water availability.

Thresholds/classes

The thresholds used to define the level of water consumption in relation to resource availability are:

<10% = low consumption level
10-20% = medium consumption level
20-30% = high consumption level
>30% = overconsumption: risks for water shortage

The thresholds are chosen arbitrarily. EEA (2003) shows water consumption index figures ranging from (almost) zero to 30%. According to EEA (2003) the average water consumption index in Europe is 3%.

Uncertainties

The indicator is calculated through further processing of WaterGAP output. Modelling rainfall-runoff and water use at the large scale to cover entire Europe will have uncertainties as a result of scale itself and gaps in data. Projecting water use and availability for future scenarios is uncertain by its very nature. Alcamo *et al.* (2000) provides more information on the uncertainties involved and their order of magnitude, although improvements have been made to the model since then. To minimise uncertainties results are aggregated at the basin level.

High uncertainty exists regarding the estimation of water consumption y means of less data available, i.e. not measured, for model testing.

Validation
The WaterGAP results on water withdrawals are validated as part of the modelling process. The hydrological model is calibrated against river discharge time series from 200 stations in Europe. No further validation is carried out as part of the indicator calculations.

4.3 Results

4.3.1 Baseline

See Figure 4.1. The map shows that for the baseline situation, most river basins in western, central and eastern Europe have medium to low consumption index. Also large areas of northern Africa have a low consumption index. A high water consumption index is mainly found in most river basins around the Mediterranean Sea. Especially in the Iberian Peninsula, North Africa (Morocco, Algeria, Tunisia and Libya), the Nile Basin, Israel, Turkey and Greece large areas of high or overconsumption with respect to resource availability are found. But also smaller spots of overconsumption are present in northern Italy and Ukraine.

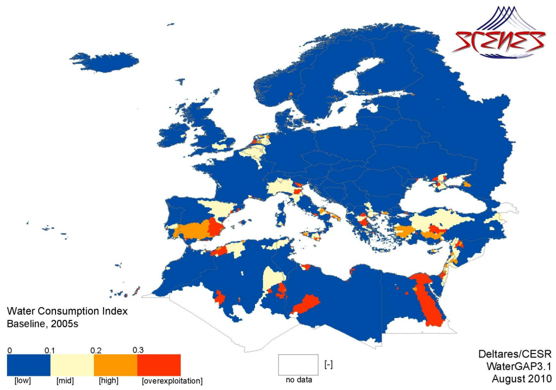


Figure 4.1 Baseline scenario of Water Consumption Index

4.3.2 Future Scenarios

General pattern
See Figure 4.2 until 4.9. Overconsumption of water can be seen in the Nile basin and delta, the North African coast (Morocco, Libya, Tunesia), central Turkey, Eastern Spain and Israel for all socio-economic scenarios. Also in urban areas around the Black Sea, Italy and in Western Europe overconsumption of water can be seen. The Economy First scenario shows the highest water consumption index. Sustainability Eventually shows the lowest water consumption indices. Fortress Europe and Policy Rules have water consumption indices in between the other two scenarios, Fortress Europe having higher water consumption indices and Policy Rules having lower water consumption indices.

Economy First
Overconsumption of water can be seen in the Nile basin, the North African coast (Morocco, Libya, Tunesia), central Turkey, Eastern Spain and Israel. In urban areas high consumption rates or even overconsumption can be seen. This is the case around the Black Sea, Italy and in Western Europe.

In general, low water availabilities in Turkey, the Iberian Peninsula and northern Africa in combination with high consumption rates resulting from irrigation in the Nile Delta, Turkey, Greece, Northern Italy and urban areas around the Black Sea can be seen. These are responsible for the high water consumption indices that are seen under this scenario.

Fortress Europe

Overconsumption of water can be seen in the Nile basin, the North African coast (Morocco, Libya, Tunesia), central Turkey, Eastern Spain and Israel due to irrigation. Also, in the Benelux area, water consumption will be high. Higher consumption rates can also be seen in other urban areas. This is mainly the case around the Black Sea and Italy.

In general, low water availabilities in Turkey, the Iberian Peninsula and northern Africa in combination with high consumption rates in the Nile Delta, Turkey, Greece, Northern Italy and urban areas around the Black Sea are responsible for the pattern that is seen under this scenario.

Policy Rules

Large parts of Europe show low water consumption. In the Nile basin, the North African coast (Morocco, Libya, Tunesia), central Turkey, Eastern Spain and Israel areas with overconsumption and high consumption of water can be found, however. Higher consumption rates can also be seen in other urban areas. This is mainly the case around the Black Sea and Italy.

In general, low water availabilities in Turkey, the Iberian Peninsula and northern Africa in combination with high consumption rates in the Nile Delta, Turkey, Greece, Northern Italy and urban areas around the Black Sea are responsible for the pattern that is seen under this scenario.

Sustainability Eventually

Large parts of Europe show low water consumption. In the Nile basin, the North African coast (Morocco, Libya, Tunesia), central Turkey, Eastern Spain and Israel areas with overconsumption and high consumption of water can be found. Higher consumption rates can also be seen in other urban areas. This is mainly the case around the Black Sea, Italy and the Benelux.

In general, low water availabilities in Turkey, the Iberian Peninsula and northern Africa in combination with high consumption rates in the Nile Delta, Turkey, Greece, Northern Italy and urban areas around the Black Sea are responsible for the pattern that is seen under this scenario.

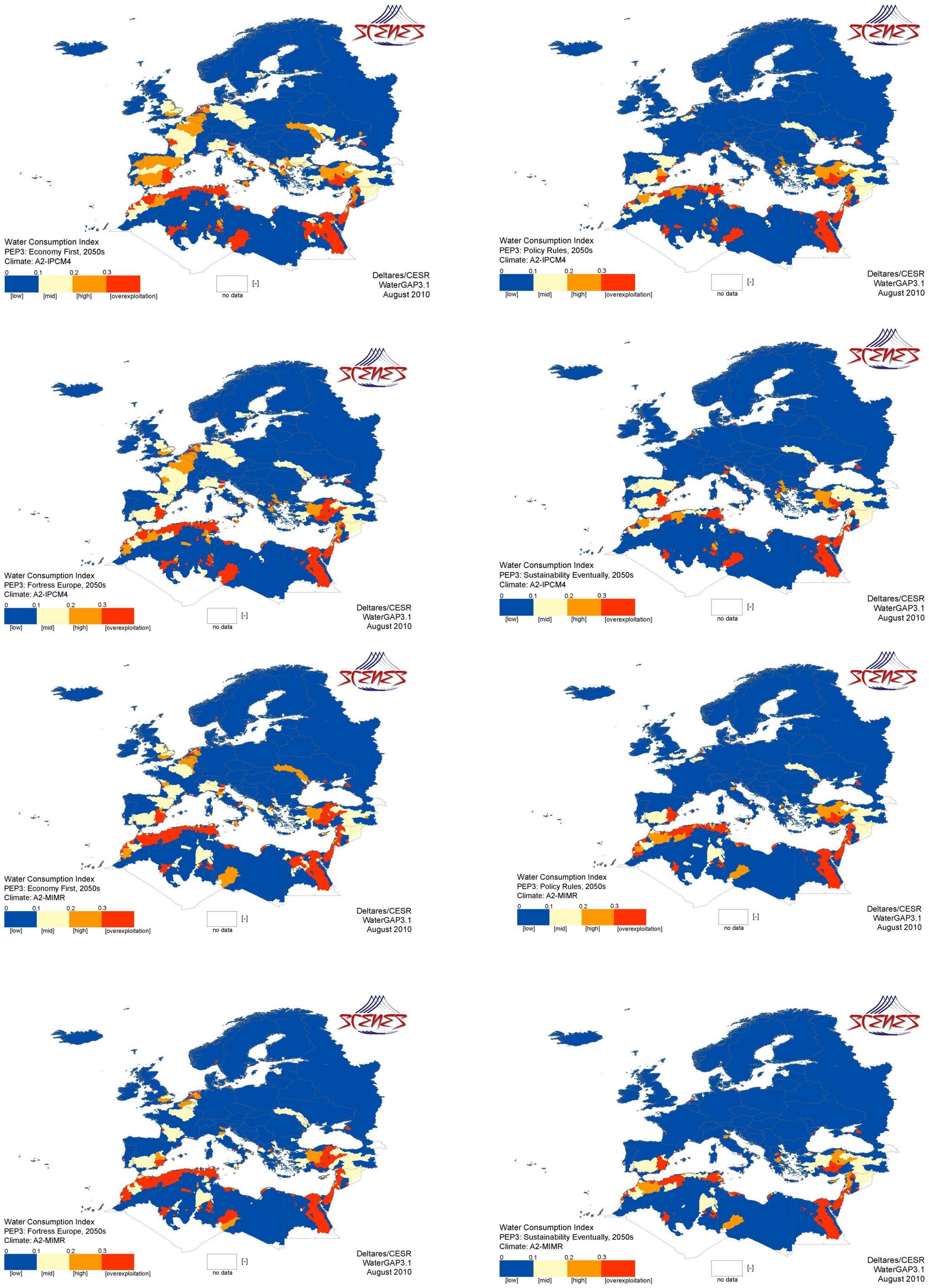


Figure 4.2 until 4.9 (left to right). Water Consumption Index under different climate scenarios (Figure 4.2 until 4.5 under IPCM, 4.6 until 4.9 under MIMR) and socio economic scenarios (Figure 4.2 and 4.6: Economy First. Figure 4.3 and 4.7: Policy Rules. Figure 4.4 and 4.8: Fortress Europe. Figure 4.5 and 4.9: Sustainability Eventually).

4.4 Synthesis

Regional observations

The Nile Basin, the North African coast, central Turkey, eastern Spain and to a lesser extent the Benelux and Northern Italy show the highest water consumption indices under all scenarios. The lowest water consumption indices are found in northern Europe. Compared to the baseline scenario, these general patterns of the distribution of water consumption indices over Europe are the same. However, per region, changes with respect to the baseline scenario can be observed, which are summarised in *Table 4.1*. Northern Africa, Eastern Europe and Western Asia are all negatively affected under all scenarios. Northern Europe and Central/Eastern Europe show hardly any changes, while Southern Europe can mainly be expected to experience positive changes. For Western Europe the image is mixed, with negative impacts for the Economy First and Fortress Europe scenarios and no change for the Policy Rules and Sustainability Eventually scenarios.

Table 4.1 Regional impacts as deviation from the baseline scenario – Water Consumption Index

		Northern Africa	Western Europe	Northern Europe	Southern Europe	Central/ Eastern Europe	Eastern Europe	Western Asia
IPCM	EcF	-	-	o	-	o	-	-
	FoE	-	-	o	+	o	-	-
	PoR	-	o	o	+	o	-	-
	SuE	-	o	o	+	o	-	-
MIMR	EcF	-	-	o	+	o	-	-
	FoE	-	-	o	+	o	-	-
	PoR	-	o	o	+	o	-	-
	SuE	-	o	o	+	o	o	-

Climate change versus socio-economic changes

The Water Consumption Index is calculated with use of water availability (which is fully dependent on climate change) and water consumption (which is mostly dependent on socio-economic factors, but to some degree also on climate change). When the Water Consumption Index maps are compared to the components they are derived from, it can be concluded that this indicator is influenced by both socio-economic factors and climate change. The climate change patterns can be recognized in the higher indices in the North African coast for the MIMR scenario and higher indices in the Iberian Peninsula for the IPCM scenario for all socio-economic scenarios. The differences in water exploitation index seen under different socio economic scenarios are caused clearly influenced by different water consumption rates in Europe under these scenarios. This leads in general to higher indices under the Economy First and Fortress Europe scenarios, and to higher indices in densely populated areas like the Benelux, northern Italy, and the Nile basin and delta. The most positive changes can be found in the SuE-MIMR scenario, while EcF- IPCM shows most negative changes. There is no clear distinction between climate change or socio-economic impacts, both reinforce each other in some cases, and weaken each other in other cases.

Future projections

In general the results for this indicator are similar for all scenarios, and the differences between the results are small. The future situation is still relatively good, but it should be noted that the observed trends are mostly negative.

Also, it should be noted that the observed trends, although not equally strong under every scenario, mostly have the same direction (increase, decrease or no change) under all climate and socio economic scenarios in a particular region. The projected changes in water consumption index are therefore considered to be relatively certain.

4.5 References

Alcamo, J., Henrichs, T. & Rösch, T., 2000. World water in 2025 – Global modeling and scenario analysis for the World Commission on Water for the 21st century. Report A0002, Center for Environmental Systems Research, University of Kassel, Kurt Wolters Strasse 3, 34109 Kassel, Germany.

EEA, 2003. Europe's water: an indicator assessment. European Environment Agency, Copenhagen, Denmark.

5 Water 2 - Water stress index

5.1 Introduction to indicator

Water stress indicator is defined as the total withdrawal of freshwater resources in relation to the long-term average availability of the freshwater water resources within a river (sub)basin. Water stress can be the result of high population density, intensive water use, low water availability (climate driven) or a combination of these pressures. The indicator provides to policy makers a quick overview of which areas may encounter water shortage problems. This indicator is widely used in scenario studies to address water shortage issues (Alcamo et al., 2003; 2007).

5.2 Method

Calculation approach

Water stress is defined as the withdrawals-to-availability ratio. The withdrawals of five social and economic water use sectors are included. These are water for domestic use, irrigation, livestock use, manufacturing, and thermal electricity generation (cooling water).

The calculation can be expressed as:

$$\frac{\text{Water withdrawals (m}^3\text{/year)}}{\text{Water availability (m}^3\text{/year)}}$$

Input data

The following WaterGAP output is used to calculate the indicator:

- Total availability (WaterGAP)
- Total water withdrawals for domestic purposes, electricity, manufacturing, irrigation and livestock (WaterGAP)

Spatial and temporal scales

The indicator Water stress index is calculated on river basin level. WaterGAP output at grid cell level is aggregated to river basin scale. Water stress index is based on annual averages of water withdrawals and water availability.

Thresholds/classes

The thresholds used to define the level of water stress are:

<0.2	= low water stress
0.2-0.4	= medium water stress
>0.4	= high water stress

These classes are used in various studies (Alcamo *et al.*, 2003, Alcamo *et al.,* 2007) and adopted by UNEP and World Water Commission.

Uncertainties

The indicator is calculated through further processing of WaterGAP output. Modelling rainfall-runoff and water use at the large scale to cover entire Europe will have uncertainties as a result of scale itself and gaps in data. Projecting water use and availability for future scenarios is uncertain by its very nature.

Alcamo *et al.* (2000) provides more information on the uncertainties involved and their order of magnitude. To minimise uncertainties results are aggregated at the basin level.

Validation

We make direct use of WaterGAP output, which has already been validated. The applicability and accurateness of the water stress index has been tested through evaluation at pilot area level, by the pilot areas in the Mediterranean region (Guadiana, Candelaro, Seyhan) and in the Black Sea region (Crimea, Lower Don). All pilot areas indicate that the indicator is useful and that the calculated values for the baseline situation represent the situation in the pilot area.

5.3 Results

5.3.1 Baseline scenario

See Figure 5.1. Most river basins in Europe currently experience low or mid water stress. The largest areas with severe water stress (more than 40% of available water abstracted) are located in the Iberian Peninsula and northern Africa (mainly Libya, Algeria and Tunisia), and in large parts of Turkey. Smaller areas of severe water stress are found in Belgium, Germany and Italy.

The water stress in the southern part of Europe, North Africa and eastern Europe is mainly caused by low water availability in combination with high water withdrawals. The water stress in the western part of Europe is mostly the result of high water withdrawals, as the water availability in these regions is usually not very low.

The low water stress in areas in North Africa is mainly the result of a low withdrawal in these areas, as the water availability in these areas is not high. Generally, the low water stress in (northern) Europe is the result of a high enough water availability to compensate for the withdrawals in these areas. However also in Europe, areas with low water availability can have a low water stress because also the withdrawals are low. This is for instance the case in France and in eastern Europe.

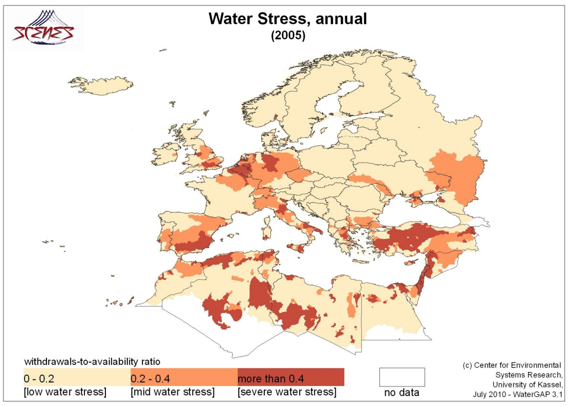


Figure 5.1. Water stress index under the baseline scenario.

5.3.2 Future scenarios

General pattern
See Figure 5.2 until 5.9. High water stress can be seen along the North African coast (Morocco, Libya, Tunesia), central Turkey, Eastern Spain, Israel, western Europe for all socio-economic scenarios. Also in urban areas around the Black Sea, Italy and in Western Europe (Benelux, parts of Germany, France and England) high water stress can be seen. The Economy First scenario shows the highest water stress. Sustainability Eventually shows the lowest water stress. Fortress Europe and Policy Rules have water stress indices in between the other two scenarios, Fortress Europe having higher water stress and Policy Rules having lower water stress indices.

Economy First
High water stress can be seen in large parts of Europe under both the IPCM4 and the MIMR climate scenarios. The area with mid to severe water stress ranges from The North African coast and Spain all the way to east Russia and West Asia. The difference between IPCM4 and MIMIR is mainly seen in Spain and Portugal (sever stress under IPCM4, low to mid stress under MIMR). In general, low water availabilities in the Iberian Peninsula and northern Africa in combination with high withdrawal rates in Turkey, Greece, Israel and the Benelux cause the patterns of water stress seen under this scenario.

Fortress Europe
This scenario shows an increase in water stress compared to the baseline scenario. Water stress is lower than under the Economy First scenario. Still, under both climate scenarios, large parts of Western, Eastern (Central and East), and Southern Europe as well as of Norhtern Africa face sever water stress. Under the MIMR scenario the stress is less severe than under IPCM4, especially in Southern and Eastern Europe.

Policy Rules
Almost no water stress is observed under this scenario. The pattern is very similar to the baseline scenario. Some areas in Europe will experience high water stress, however. The Iberian Peninsula, Turkey, Israel and the western part of Northern Africa will locally experience high water stress. In these areas also some mid water stress can be observed. In general, relatively low water availabilities in the Iberian Peninsula and northern Africa in combination with relatively high withdrawal rates in Turkey and Israel are responsible for the pattern that is seen under this scenario.

Sustainability Eventually
Almost no water stress is observed under this scenario. The pattern is very similar to the baseline scenario. Some areas in Europe will experience high water stress, however. The Iberian Peninsula, Turkey, Israel and the western part of Northern Africa will locally experience high water stress. In these areas also some mid water stress can be observed. In general, relatively low water availabilities in the Iberian Peninsula and northern Africa in combination with relatively high withdrawal rates in Turkey and Israel are responsible for the pattern that is seen under this scenario.

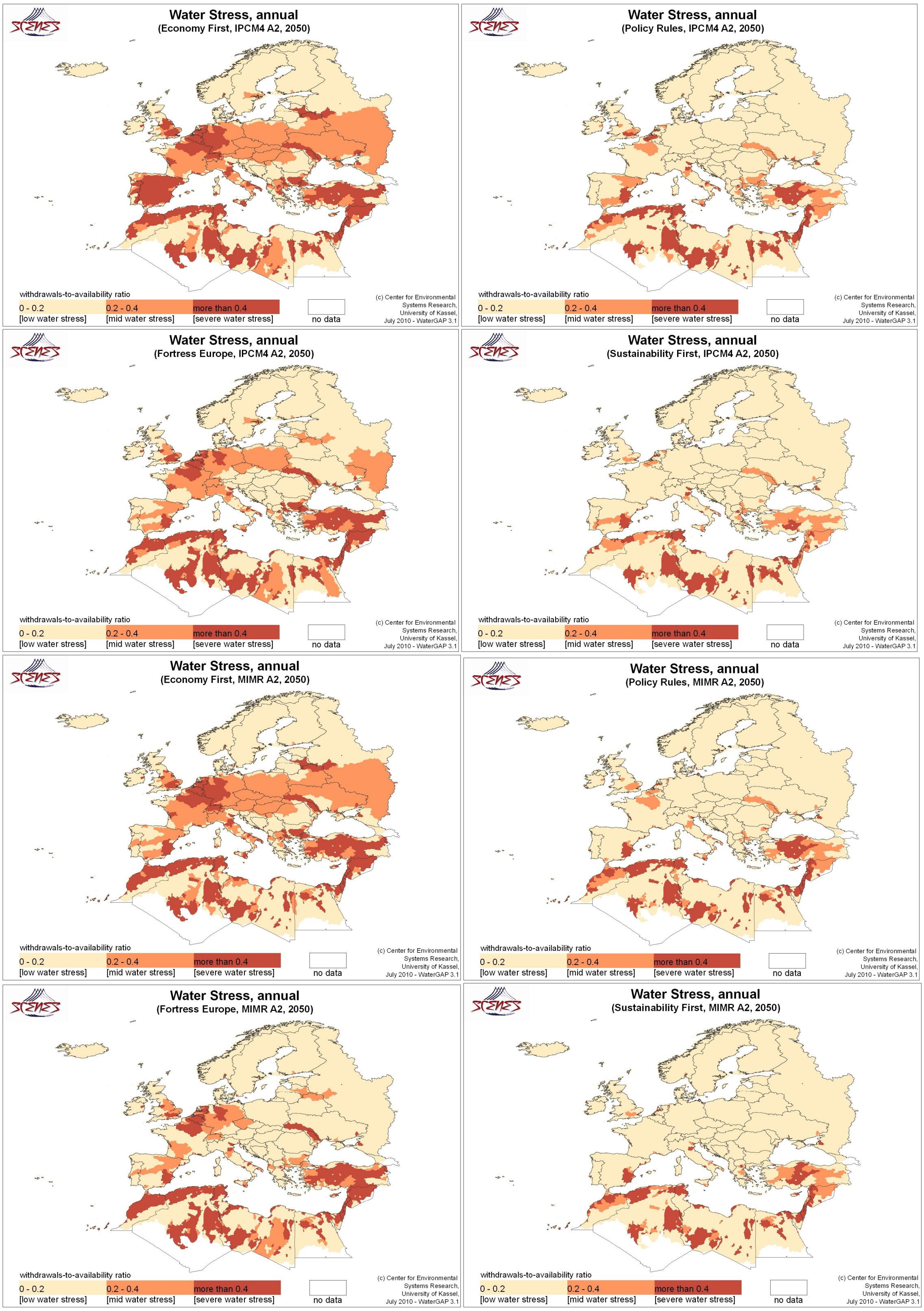


Figure 5.2 until 5.9 (left to right). Water Stress Index under different climate scenarios (Figure 5.2 until 5.5 under IPCM, 5.6 until 5.9 under MIMR) and socio economic scenarios (Figure 5.2 and 5.6: Economy First. Figure 5.3 and 5.7: Policy Rules. Figure 5.4 and 5.8: Fortress Europe. Figure 5.5 and 5.9: Sustainability Eventually).

5.4 Synthesis

Regional observations

The North African coast, central Turkey, eastern Spain, Israel and to a lesser extent the Benelux, England and Greece show the highest water stress indices under all scenarios. Compared to the baseline scenario, these general patterns of the distribution of water stress indices over Europe are the same. However, per region, changes with respect to the baseline scenario can be observed, which are summarised in Table 5.1. Northern Africa shows mainly negative results, while Northern Europe shows no change. All other regions show a mixture with mainly negative results for the Economy First scenarios, and negative or no change for the Fortress Europe scenarios. The results in these regions are mainly positive or no change for the Policy Rules scenario while generally positive for the Sustainability Eventually Scenario.

Table 5.1 Regional impacts as deviation from the baseline scenario – Water Stress Index.

		Northern Africa	Western Europe	Northern Europe	Southern Europe	Central/Eastern Europe	Eastern Europe	Western Asia
IPCM	EcF	- -	- -	o	- -	- -	- -	-
	FoE	- -	-	o	o	- -	-	-
	PoR	-	+	o	o	o	+	o
	SuE	o	+ +	o	+ +	o	+	+
MIMR	EcF	- -	- -	o	-	- -	- -	_
	FoE	- -	o	o	o	o	+/-	_
	PoR	-	+	o	+ +	o	+	o
	SuE	-	+ +	o	+ +	o	+ +	o

Climate change versus socio-economic changes

The differences in water stress seen under different climate scenarios are caused partially by a different distribution of water availabilities in Europe under these climate scenarios. This leads in general to higher indices in the North African coast for the MIMR scenario and higher indices in the Iberian Peninsula for the IPCM scenario. The differences in water stress seen under different socio economic scenarios are caused partially by different water withdrawal rates in Europe under these scenarios. This leads in general to higher indices under the Economy First and Fortress Europe scenarios. The patterns of the socio-economic scenarios show stronger differences among each other than the patterns of the climate change scenarios, which indicates that socio-economic factors are likely to influence this indicator more than climate change. The Economy First scenario under the IPCM climate scenario is the most extreme. The Sustainability Eventually scenario under the MIMR climate scenario shows generally the lowest water stress indices. For some regions the pattern between socio-economic scenarios is the same but slightly less bad for the MIMR climate scenario.

Future projections

Under the Policy Rules scenario and the Sustainability Eventually scenario (both climate scenarios), a decrease in water stressed river basins can be seen whereas under the Economy First and Fortress Europe (both climate scenarios) an increase in water stress indices is projected. Since the projected changes show a negative trend for two socio economic scenarios and a positive trend for the other two socio-economic scenarios, it can not be derived with certainty if the water stress index will increase or decrease in the future.

5.5 References

Alcamo, J., Henrichs, T. & Rösch, T., 2000. World water in 2025 – Global modeling and scenario analysis for the World Commission on Water for the 21st century. Report A0002, Center for Environmental Systems Research, University of Kassel, Kurt Wolters Strasse 3, 34109 Kassel, Germany.

Alcamo et al. 2003: global estimates of water withdrawals and availability under current and future business-as-usual conditions. Hydrological Sciences Journal 48: 339-348

Alcamo et al. 2007: future long term changes in global water resources driven by socio-economic and climatic change. Hydrological Sciences Journal 52: 247-275

6 Water 3 – Water Scarcity Index

6.1 Introduction to indicator

The competition for water resources and the impact of water scarcity for society, environment, ecosystems and economic sectors is the strongest in periods with low flow conditions. The water scarcity index is the total consumptive use of freshwater resources within a river (sub)basin in relation to the average low flow conditions (Q_{90}), which refers to the discharge exceeded during 90% of the time). The index provides insight in the extent to which the water that is reliably available over time is sufficient to meet the consumptive demands.

6.2 Method

Calculation approach

The water scarcity index is calculated as the total water consumptive use divided by Q_{90} at river (sub)basin scale. The calculation can be expressed as:

$$\frac{\text{total water consumptive use } (m^3/\text{year})}{Q_{90}(m^3/\text{year})}$$

Input data

- Total consumptive use (output WaterGAP)
- Q_{90} (output WaterGAP, see indicators Water 6 and Water 7 for more information on the calculation of the Q_{90} based on natural flow (no impacts of human water use or regulation)

Spatial and temporal scales

The indicator water scarcity index is calculated on river basin level based on annual figures.

Thresholds/classes

The thresholds used to define the level of water scarcity index are:

<10% = no water scarcity
10-20% = low water scarcity
20-30% = medium water scarcity
>30% = high water scarcity

For this indicator the same classes as for the water consumption index were chosen. This provides an extra class and smaller differences between thresholds than the water stress index and is therefore more suitable to distinguish between low values of water scarcity.

Uncertainties

The indicator is calculated through further processing of WaterGAP output. Modeling rainfall-runoff and water use at the large scale to cover entire Europe will have uncertainties as a result of scale itself and gaps in data. Projecting water use and availability for future scenarios is uncertain by its very nature. Alcamo *et al.* (2000) provides more information on the uncertainties involved and their order of magnitude. To minimise uncertainties results are aggregated at the basin level.

Validation

The indicator is calculated through further post-processing of WaterGAP outputs, which are in itself validation as part of the development of the WaterGAP model.

The water scarcity index has also been evaluated by four pilot areas: Crimea, Lower Don, Guadiana and Candelaro. All pilot areas indicate that the indicator is useful and that the calculated values for the baseline situation represent the situation in the pilot area.

Crimea and Guadiana computed the indicator with locally available data for this purpose. Based on these calculations it was found that values based on local data and from WaterGAP fall within the same range. However, the Q_{90} that was calculated in Crimea as part of this calculation is higher than the value calculated by WaterGAP. Guadiana indicated that Q_{90} calculation results were not available in the same format and based on the same calculation approach as used in WaterGAP. Use of the Q_{90} in the indicator calculation was therefore perceived to be confusing.

6.3 Results

6.3.1 Baseline scenario

See Figure 6.1. Areas with a high water scarcity index are mainly found in the Iberian Peninsula, North Africa, Israel, Turkey and Greece. Also areas with a high water scarcity index are found in France, Italy and Ukraine. Areas with low water scarcity are found in Ukraine and Russia. Large areas in northern Europe and Central/Eastern Europe do not have water scarcity.

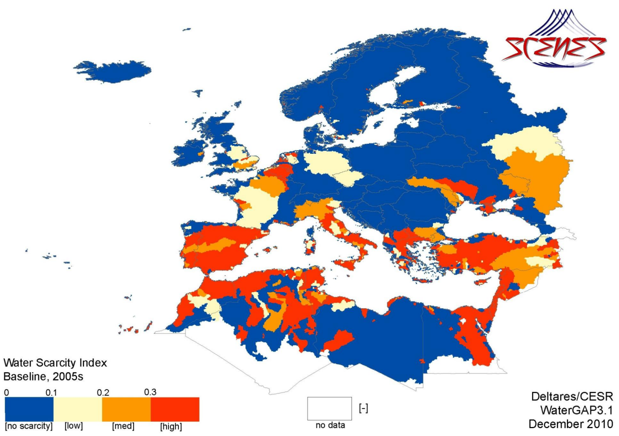


Figure 6.1. Water scarcity index under the baseline scenario.

6.3.2 Future scenarios

General pattern

See Figure 6.2 until 6.9. High water scarcity indices can be seen along the North African coast (Morocco, Libya, Tunesia), the Iberian Peninsula, the Nile basin, Turkey, Greece and Israel for all socio-economic scenarios. High to mid water scarcity indices can be found in Western Europe (France, England, Benelux) and in the Moldau basin. Low water scarcity indices are found in Northern and Central Europe.

The Economy First scenario shows the highest water scarcity indices. Sustainability Eventually shows the lowest water scarcity index. Fortress Europe and Policy Rules have water scarcity indices in between the other two scenarios, Fortress Europe having higher water scarcity indices and Policy Rules having lower water scarcity indices.

Economy First

Under this scenario, vast areas with high water scarcity can be seen. Areas with high water scarcity are situated in Western Europe (France, Benelux, England), the Iberian Peninsula, Northern Africa, Turkey, Greece, Italy and the Moldau basin. Low water scarcity indices are found in northern and central Europe. In general, high water consumption rates in these areas coincide with low flows in generally the same areas, which cause the patterns of water scarcity seen under this scenario.

Fortress Europe

Under this scenario, vast areas with high water scarcity can be seen with a comparable pattern and extent as under the Economy First scenario, with a few differences however. Areas with high water scarcity are situated in the Nile basin, Western Europe (France, Benelux, England), the Iberian Peninsula, Northern Africa, Turkey, Greece, Italy and the Moldau basin. Low water scarcity indices are found in northern and central Europe. In general, high water consumption rates in these areas coincide with low flows in generally the same areas, which cause the patterns of water scarcity seen under this scenario.

Policy Rules

Significant areas with high water scarcity can be seen, but not as extensive as under the Economy First and Fortress Europe scenario. Areas with high water scarcity are situated in Western Europe (France, Benelux, England), the Iberian Peninsula, Northern Africa, Turkey, Greece, Italy and the Moldau basin. Low water scarcity indices are found in northern and central Europe. In general, high water consumption rates in these areas coincide with low flows in generally the same areas, which cause the patterns of water scarcity seen under this scenario.

Sustainability Eventually

Significant areas with high water scarcity can be seen, but not as extensive as under the Economy First and Fortress Europe scenario. This scenario in general provides the least areas with high water scarcity. Areas with high water scarcity are situated in Western Europe (France, Benelux, England), the Iberian Peninsula, Northern Africa, Turkey, Greece, Italy and the Moldau basin. Low water scarcity indices are found in northern and central Europe. In general, high water consumption rates in these areas coincide with low flows in generally the same areas, which cause the patterns of water scarcity seen under this scenario.

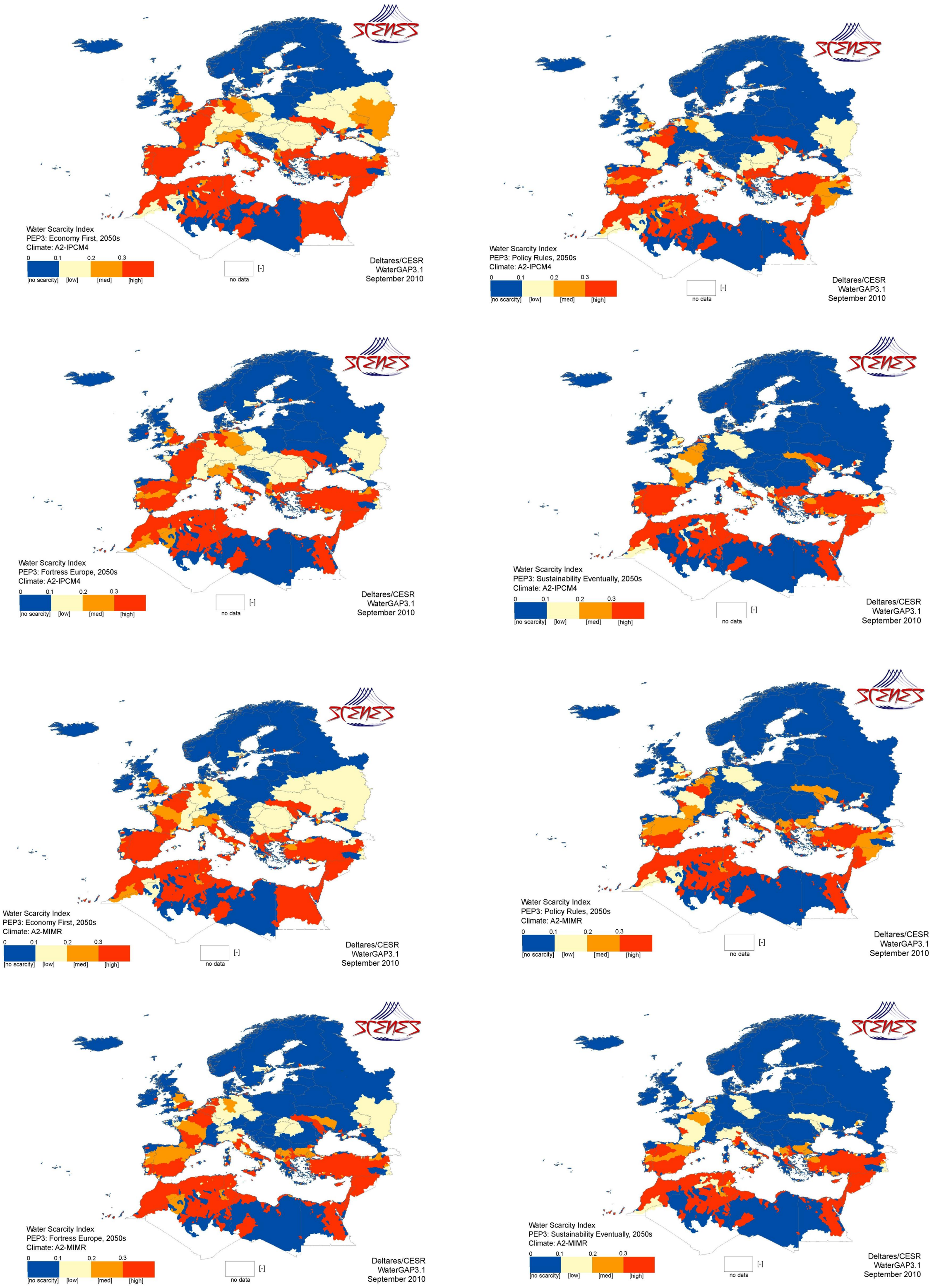


Figure 6.2 until 6.9 (left to right). Water Scarcity Index under different climate scenarios (Figure 6.2 until 6.5 under IPCM, 6.6 until 6.9 under MIMR) and socio economic scenarios (Figure 6.2 and 6.6: Economy First. Figure 6.3 and 6.7: Policy Rules. Figure 6.4 and 6.8: Fortress Europe. Figure 6.5 and 6.9: Sustainability Eventually).

6.4 Synthesis

Regional observations
Northern Africa, Turkey, the Iberian Peninsula, Israel, Greece, and western Europe (France, England, Benelux show the highest water scarcity indices under all scenarios. Compared to the baseline scenario, these general patterns of the distribution of water scarcity indices over Europe are the same. However, under all socio economic scenarios, the water scarcity indices will change.

This means an intensification for most regions, but some regions also show an improvement. For an overview of each region, see Table 6.1. For northern Europe, all scenarios expect no changes with respect to the baseline scenario, also in Central/Eastern Europe the majority of the scenarios indicate no change. For Northern Africa the change is always negative, but for the Economy First this change occurs in a larger part of the area then under the other scenarios. Western Europe and Western Asia show a range between no or negative change, while Southern and Eastern Europe have area with positive and area with negative change.

Table 6.1 Regional impacts as deviation from the baseline scenario – Water Scarcity Index

		Northern Africa	Western Europe	Northern Europe	Southern Europe	Central/Eastern Europe	Eastern Europe	Western Asia
IPCM	EcF	--	--	o	-	-	-	-
	FoE	-	--	o	-	-	+/-	-
	PoR	-	o	o	+/-	o	+/-	o
	SuE	-	o	o	+/-	o	+	-
MIMR	EcF	--	--	o	-	o	+/-	-
	FoE	-	-	o	+	o	+/-	-
	PoR	-	o	o	+	o	+	o
	SuE	-	o	o	+	o	+	-

Climate change and socio-economic change
The Economy First scenario is the most extreme scenario and Sustainability Eventually the least extreme. Both climate change and socio-economic change influence the indicator. However, the general patterns in the Q90 influence the water scarcity index more than the changes in Q90 under the different scenarios. Therefore, the water scarcity index is the largest in areas with high water consumption and in general a low Q90. The driver influencing the pattern of water scarcity indices the most is water consumption, so socio-economic scenarios are considered the dominant driving force.

Future scenarios
Norhtern Afirca, Northern Europe and Central/Eastern Europe show (largely) the same trend (or no trend) for all scenarios. In other regions a ranges are shown from no change to negative change (Western Europe and Western Asia) or between scenarios or subregions with positive and with negative impacts (Southern Europe and Eastern Europe). Therefore, the uncertainty of the future development of this indicator is considered to be moderately high.

6.5 References

Alcamo, J., Henrichs, T. & Rösch, T., 2000. World water in 2025 – Global modeling and scenario analysis for the World Commission on Water for the 21st century. Report A0002, Center for Environmental Systems Research, University of Kassel, Kurt Wolters Strasse 3, 34109 Kassel, Germany.

7 Water 4 – Change in frequency of flood events

7.1 Introduction to indicator

The change in frequency at which a certain discharge occurs gives an indication of whether or not high water events will occur more or less often in the future. Flood risk is composed of the probability of an event occurring and the damages that result from such an event. The change in frequency of a discharge addresses the former – that is, it gives an indication whether the probability of high-water events will increase in the future.

7.2 Method

Calculation approach

The calculations were done with WaterGAP by Verzano (2009). This section summarizes the methodology.

Step 1:

Fit a distribution to annual maxima (AM) and extrapolate the 1/100-year discharge under baseline conditions, as follows:

- Calculate the annual maximum (AM) discharge over 30-year series
- Calculate mean (M), variance (V), and skewness (Sk) for the arithithmetic and logarithmic AM series
    - If S of the logarithmic AM series (Slog) is Slog > 0, a Log-Pearson III-distribution is applied.
    - If Slog < 0 and Sarithm > 0, a Pearson III distribution is used, based on the arithmetic AM series.
    - If Slog < 0 and Sarithm < 0, an arithmetic Pearson-III distribution is applied with a corrected skewness (Sarithm = 2Varithm) to avoid negative values of the distribution

Step 2:

The process described in Step 1 is repeated for the climate scenarios, i.e. fitting distributions to the annual maxima as computed by WaterGAP under future climate scenarios.

Step 3:

The future frequency of occurrence of the baseline 1/100-year discharge is determined using the discharge distribution computed under climate scenarios.

Step 4:

The change in frequency is then simply calculated as the difference in frequency between the baseline (fixed at 1/100 year) and the future scenario.

Input data
- Daily discharge, baseline and future scenarios based on monthly climate change input. (WaterGAP)

Spatial and temporal scales
The temporal scale is daily but WaterGAP was not calibrated for daily discharge, so this use induces some uncertainty. The results are not intended to be analyzed at grid-cell scale but rather at basin scale to get an overall spatial sense of the trend.

Thresholds
No thresholds were considered in the calculation of this indicator.

Uncertainties
Uncertainties include statistical uncertainty of extrapolation, uncertainty in the WaterGAP input (used at daily temporal scale, but calibrated at monthly or annual temporal scale), and choice of statistical distribution. Also uncertainties do exist due to downscaling of GCM climate input as well as deriving of daily input (needed by WaterGAP) from monthly climate.

Limitations
In cases where the 1/100-year discharge decreased in the future, the frequency of the baseline 1/100-year discharge in the future was not calculated. The decrease in discharge translates to a reduction in flood hazard, and the research was solely interested in flood hazard increases.

Validation
WaterGAP is validated against 100-year floods derived from measured time series of 119 European gauging stations for the time period 1950-2002.

7.3 Results
The results presented here (Figure 7.1 and 7.2) show a change in frequency of the 1/100-year discharge, where a change represents the frequency in the future minus the frequency of the baseline scenario. The change in frequency is independent of the socio-economic storylines and is therefore only given for the two climate models, IPCM4 and MIMR.

As mentioned in section 7.2 under *Limitations* the change in frequency was only computed for cells which showed in increase in frequency (i.e. an increase in hazard). Areas in the following figures that are blank indicate areas which experienced a decrease in frequency.

The scale in the following figures contains three categories, representing three levels of frequency change (Δf):

1) $\Delta f < 0.001$ [small change]
2) $0.001 < \Delta f < 0.005$ [medium change]
3) $\Delta f > 0.005$ [large change]

Note that a change in frequency of 0.001 corresponds to a future return period of 90 years (relative to the 100 years of the baseline scenario, for the same magnitude discharge), and a frequency of 0.005 corresponds to a future return period of 67 years.

Climate model IPCM4

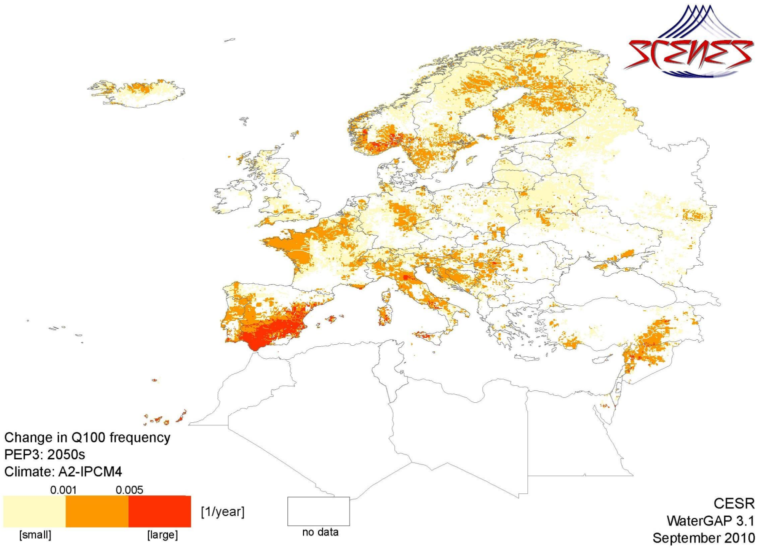


Figure 7.1. Change in Q100 frequency under the IPCM scenario.

Figure 7.1 shows large areas that are blank, indicating that the frequency decreased there. Of the increases, large areas experience only small increases in frequency. The largest increases are seen in southern Norway and Sweden, Finland, Italy, southern Spain (strongest increases on the eastern side), western France, a small area in Germany around Berlin, and in Turkey around the Euphrates.

Climate model MIMR

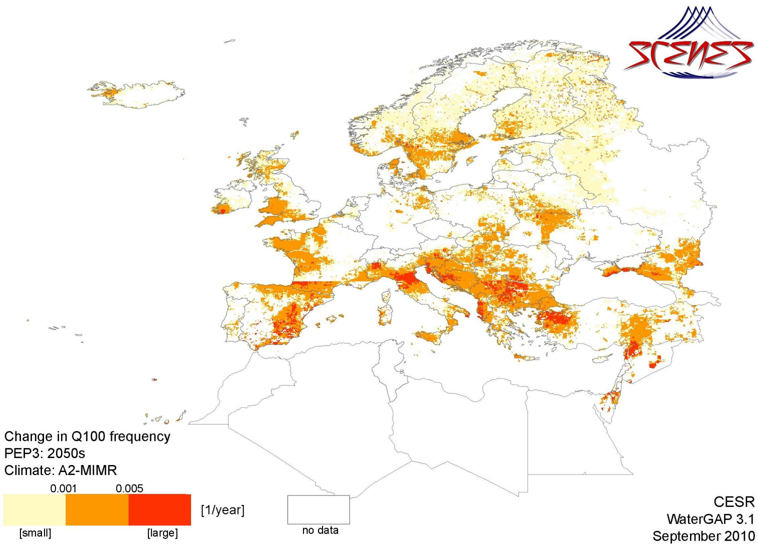


Figure 7.2. Change in Q100 frequency under the MIMR scenario.

Figure 7.2 shows large areas that are blank, indicating that the frequency decreased there. Scandinavia and northern Russia experience weak increases in frequency, whereas the rest of the increases are in the medium to strong range. The Balkan states see large areas with increases, as does northern Italy, northern and eastern Spain, western France, south-eastern UK, south-eastern Ireland, southern Sweden, parts of Ukraine, and Turkey around the Euphrates.

7.4 Synthesis

Regional observations and climate change
Under MIMR, frequencies increase much more strongly and in more area of the Balkan states (and western Turkey) than under IPCM4. Furthermore, northern Italy experiences stronger increases. Under MIMR, Germany experiences almost no increases in frequency, while under IPCM4 there is a substantial area with medium increases as well as additional areas with small increases. Spain is also quite different under the two models; under IPCM4, strong increases are seen over large areas in southern Spain, while under MIMR, these increases are more moderate and on the eastern side and southern tip there are almost no increases. Portugal experiences almost no increase in frequency under MIMR and large areas with moderate increase under IPCM4. Under MIMR, western UK and south-western Ireland see medium increases in frequency, while under IPCM4 increases are weak and occur over a smaller area. Southern Norway experiences a larger area with stronger increases under IPCM4 than MIMR.

Despite these differences, in general, the observed changes have the same direction (positive, negative or no change) for each region. See also Table 7.1 for a summary on the observed changes in this area.

Table 7.1 Regional impacts as deviation from the baseline scenario – flood hazard frequency

	Northern Africa	Western Europe	Northern Europe	Southern Europe	Central/Eastern Europe	Eastern Europe	Western Asia
IPCM	NA	-	-	-	o	NA	NA
MIMR	NA	-	-	- -	o	NA	NA

Future projections
Both climate scenarios project similar changes in the different regions, although there are some differences in magnitude of these changes. However, the direction of the changes is mostly supported by both climate scenarios. Therefore, the future projections of this indicator are considered to be relatively certain. It should however be noted that the image that the maps convey is influenced by the fact that only increases in hazard are shown and that decreases in hazard are left out. The results may have been interpreted too negatively.

7.5 References

Verzano, K., 2009. Climate Change Impacts on Flood Related Hydrological Processes: Further Development and Application of a Global Scale Hydrological Model, PhD thesis, International Max Planck Research School on Earth System Modelling.

8 Water 5 – Change in flood hazards

8.1 Introduction to indicator

The change in discharge associated with a certain frequency gives an indication of what magnitude of discharge can be expected at such a return frequency. Increases in the 1/100-year discharge indicate that for the same probability of occurrence, the magnitude of an event will increase, which will increase the flood risk. Flood risk is composed of the probability of an event occurring and the damages that result from such an event. The change in magnitude of discharge for a given frequency addresses the latter – that is, for the same probability the damages will be higher due to the higher magnitude of the discharge.

8.2 Method

Calculation approach

The calculations were done with WaterGAP by Verzano (2009). This section summarizes the methodology.

Step 1:
Fit a distribution to annual maxima (AM) and extrapolate the 1/100-year discharge under baseline conditions, as follows:

- Calculate the annual maximum (AM) discharge over 30-year series
- Calculate mean (M), variance (V), and skewness (Sk) for the arithithmetic and logarithmic AM series
    - If S of the logarithmic AM series (Slog) is Slog > 0, a Log-Pearson III-distribution is applied.
    - If Slog < 0 and Sarithm > 0, a Pearson III distribution is used, based on the arithmetic AM series.
    - If Slog < 0 and Sarithm < 0, an arithmetic Pearson-III distribution is applied with a corrected skewness (Sarithm = 2Varithm) to avoid negative values of the distribution

Step 2:
The process described in Step 1 is repeated for the climate scenarios, i.e. fitting distributions to the annual maxima as computed by WaterGAP under future climate scenarios, and extrapolating the 1/100-year discharge.

Step 3:
The indicator is calculated simply as the difference as the difference in 1/100-year discharge between the future scenario and the baseline scenario.

Input data

- Daily discharge, baseline and future scenarios based on monthly climate change input. (WaterGAP)

Spatial and temporal scales

The temporal scale is daily but WaterGAP was not calibrated for daily discharge, so this use induces some uncertainty. The results are not intended to be analyzed at grid-cell scale but rather at basin scale to get an overall spatial sense of the trend.

Thresholds

No thresholds were considered in the calculation of this indicator.

Uncertainties

Uncertainties include statistical uncertainty of extrapolation, uncertainty in the WaterGAP input (used at daily temporal scale, but calibrated at monthly or annual temporal scale), and choice of statistical distribution. Also uncertainties do exist due to downscaling of GCM climate input as well as deriving of daily input (needed by WaterGAP) from monthly climate.

Validation

WaterGAP is validated against 100-year floods derived from measured time series of 119 European gauging stations for the time period 1950-2002.

8.3 Results

The results presented here (Figure 8.1 and 8.2) show a <u>change in</u> 1/100-year discharge magnitude, where a change represents the magnitude in the future minus the magnitude of the baseline scenario. The change in frequency is independent of the socio-economic storylines and is therefore only given for the two climate models, IPCM4 and MIMR.

Climate model IPCM4

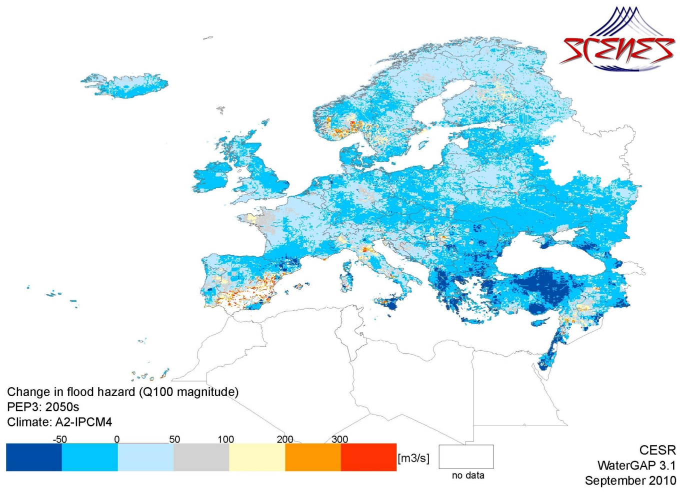


Figure 8.1. Change in flood hazard (Q100 magnitude) under the IPCM scenario.

The patterns shown here are in fact the same seen for the change in frequency of the baseline 1/100-year discharge (see section 7.3). That is, where there is an increase in frequency of the current 1/100-year discharge, there is also an increase in the discharge magnitude associated with a 100-year return period. In section 7.3 however, frequencies for discharges that decreased were not computed. In the figure above, the strength of these decreases can be seen. Most of the decreases that occur are rather mild, between 0 and -50 m^3/s. There are areas of stronger decreases in Turkey and parts of Greece. For a discussion of the increases, the reader is referred to section 7.3.

Climate model MIMR

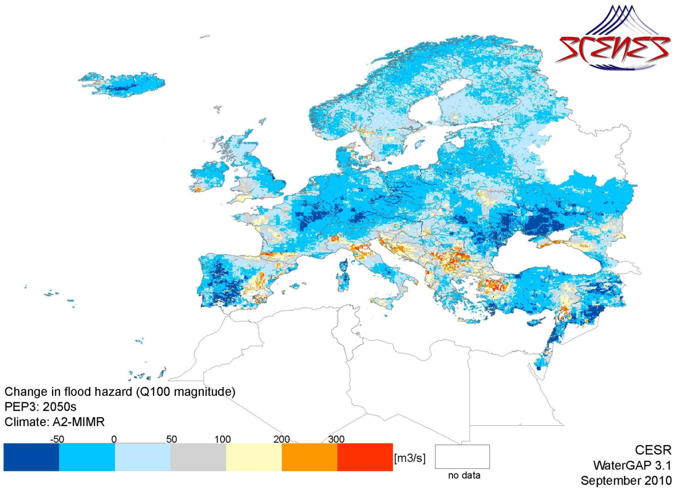


Figure 8.2. Change in flood hazard (Q100 magnitude) under the MIMR scenario.

As with the previous map, the patterns shown here are in fact the same seen in section 7.3. Decreases in flood hazard (i.e. discharge magnitude) are largely in the 0 to -50 m^3/s range, with stronger decreases in large parts of Spain, Ukraine, and limited parts of France and Germany. For a discussion of the increases, the reader is referred to section 7.3.

8.4 Synthesis

Regional observations and climate change
IPCM4 shows large decreases in western Turkey and Greece that are not found in the MIMR model results. MIMR shows substantial decreases in Ukraine, Spain, and parts of France in Germany that are not found in the IPCM4 model. MIMR shows in general more area with decreases than the IPCM4 model. For comparison of the increases, the reader is referred to section 7.3. For a summary on the observed changes for each region under the two climate scenarios, see Table.

Table 8.1 Regional impacts as deviation from the baseline scenario – flood hazard magnitude

	Northern Africa	Western Europe	Northern Europe	Southern Europe	Central/Eastern Europe	Eastern Europe	Western Asia
IPCM	NA	o	-	-	o	o	+/-
MIMR	NA	-	o	- -	o	+/-	+/-

Future projections
As both climate models project largely the same pattern, but also significant differences, it can not be stated with certainty what the developments on the future flood hazard in Europe will be.

8.5 References

Verzano, K., 2009. Climate Change Impacts on Flood Related Hydrological Processes: Further Development and Application of a Global Scale Hydrological Model, PhD thesis, International Max Planck Research School on Earth System Modelling.

9 Water 6 - Change in frequency of river low flow

9.1 Introduction to indicator

To understand changes in water availability, not only average discharges, but also changes in extremes need to be analysed. Future climate projections suggest that global warming is likely to favour conditions for the development of droughts in many regions of Europe. Southern parts of Europe are most prone to reductions in low flows. Changes in frequency of low flow conditions and duration of low water levels are impacting riparian ecosystems and economic sectors, including inland water transport (EEA, 2008). For this purpose, two indicators are included in this study: the change in frequency of low discharges and the change in magnitude of low discharges with a certain frequency. This chapter discusses the change in river low flow frequency, the changes in low flow magnitude are discussed in Chapter 10. This indicator can be combined with additional information to understand other impacts, and forms the basis for the indicator on navigation impacts that is included in this study as well (See Annex D).

As a low discharge the discharge that is exceeded 90% of the time is chosen. This Q_{90} has a certain magnitude in the current situation. As indicator it is computed how frequent this same magnitude occurs under the scenarios for the future. In the calculation of river discharge human impacts through use of water or through regulation of flows (reservoirs) are taken into account.

9.2 Method

Calculation approach

The Q_{90} is calculated through further processing of monthly discharges calculated by WaterGAP. Q_{90} means that 90% of the monthly values during the total 30 year period are higher than this discharge. The Q_{90} is determined for the baseline sceario by sorting 30-year monthly results and taking the 0.1 percentile. Subsequently, tor the eight future scenarios the frequency of this discharge is determined.

As mentioned above, the river discharge is calculated for the situation with human impacts. For this calculation, the consumptive water use of the sectors domestic, electricity production, manufacturing industry, irrigation and livestock are included in the calculation of the water balance. Consumptive water use considers the water which is actually consumed and therefore it is the difference between water withdrawals and return flows. In addition, the operation of dams is considered. From the European Lakes and Reservoir Database (ELDRED2, developed and provided by the EEA) all reservoirs with a storage capacity higher than 0.1 km^3 (590 reservoirs) are included in WaterGAP. To estimate realistic operation rules, the management scheme according to the algorithm of Hanasaki et al. (2006) is applied

Input data

River discharges computed with human impacts (WaterGAP output). To calculate frequencies, time series of 30 years have been used. To limit the amount of data that needs to be processed, the frequency analysis is performed for a selection of grid cells.

Spatial and temporal scales
The frequency of the baseline Q_{90} for the scenarios is calculated for a number of locations along several rivers.

Thresholds
The results are presented as classes of discharge with a certain frequency.

Q_{100}-Q_{95} = strong decrease in frequency of river low flows (wetter)
Q_{95}-Q_{90} = decrease in frequency of river low flows (wetter)
Q_{90}-Q_{85} = little change in frequency of river low flows (neutral)
Q_{85}-Q_{80} = increase in frequency of river low flows (drier)
Q_{80}-Q_{0} = strong increase in frequency of river low flows (drier)

In the figures presented, the decrease in low flow frequency is blue coloured and an increase is coloured red. This assumes that less frequent low flows (wetter conditions) is a positive change. For many uses this is indeed the case, but it should be noted that from an ecological point of view most deviations from the natural flow regime will lead to ecological change and may be considered negative.

Uncertainties
The indicator is calculated through further processing of WaterGAP output. Modelling rainfall-runoff and water use at the large scale to cover entire Europe will have uncertainties as a result of scale itself and gaps in data. Projecting water use and availability for future scenarios is uncertain by its very nature. Alcamo *et al.* (2000) provides more information on the uncertainties involved and their order of magnitude. To minimise uncertainties results are aggregated at the basin level.

Validation
The WaterGAP results are validated as part of the modelling process. No further validation is carried out as part of the indicator calculations.

9.3 Results
Figures 9.1 until 9.8 show the results for the scenarios. There are no baseline results since the indicator is calculated as change compared to the baseline only (in the baseline situation the frequency is 90% of the time for all locations by definition).

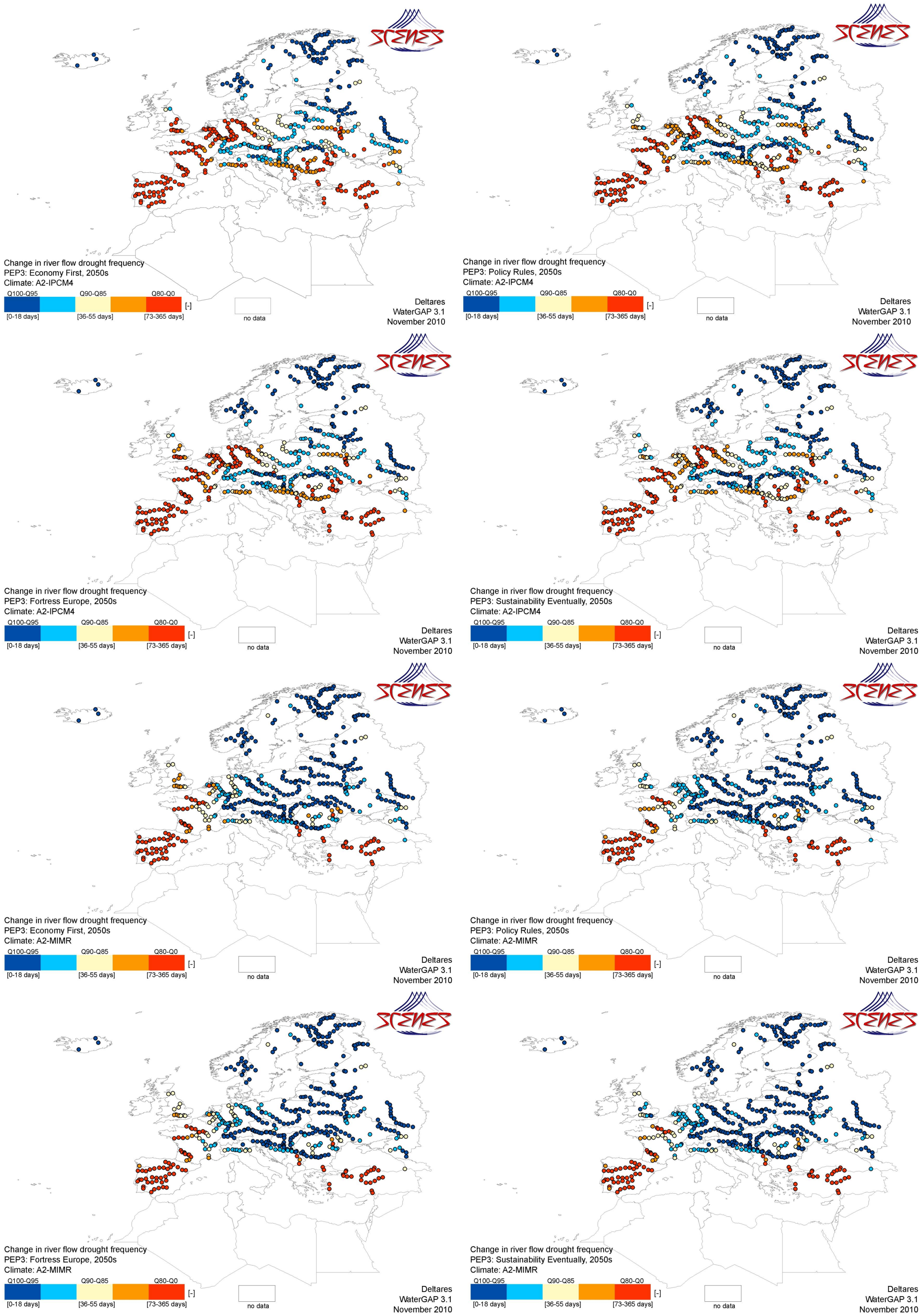


Figure 9.1 until 9.8 (left to right). Change in river flow drought frequency under different climate scenarios (Figure 9.1 until 9.4 under IPCM, 9.5 until 9.8 under MIMR) and socio economic scenarios (Figure 9.1 and 9.5: Economy First. Figure 9.2 and 9.6: Policy Rules. Figure 9.3 and 9.7: Fortress Europe. Figure 9.4 and 9.8: Sustainability Eventually).

The results show that the socio-economic scenario show similar patterns under a certain climate scenario. The results differ between the two climate scenarios. All scenarios under both climate scenarios shows more frequent low flows in France, Belgium, Spain, Portugal, Turkey and the UK, and less frequent low flow situations in the central, east and northern Europe. Under the IPCM4 scenario the increase in low flow frequency is more severe and cover a larger area than under the MIMR scenario. Under the MIMR scenario large areas in Central, East and Northern Europe experience less frequent low flows.

9.4 Synthesis

Regional observations

The largest changes in river flow drought frequencies are observed in the western and southern parts of Europe, while central en northern Europe experience low river flow drought frequencies. See also Table 9.1 for a more detailed overview of the regional changes in river flow drought.

Table 9.1 Regional impacts as deviation from the baseline scenario – low flow frequency

		Northern Africa	Western Europe	Northern Europe	Southern Europe	Central/Eastern Europe	Eastern Europe	Western Asia
IPCM	EcF	NA	-/+	+ +	-	+	-/+	-
	FoE	NA	-/+	+ +	-	+	-/+	-
	PoR	NA	-/+	+ +	-	+	-/+	-
	SuE	NA	-/+	+ +	-	+	-/+	-
MIMR	EcF	NA	-/+	+ +	-/+	+ +	+ +	-
	FoE	NA	-/+	+ +	-/+	+ +	+ +	-
	PoR	NA	-/+	+ +	-/+	+ +	+ +	-
	SuE	NA	-/+	+ +	-/+	+ +	+ +	-

Climate change and socio-economic changes

As can be derived from Table 9.1 this indicator is mostly influenced by climate change. Socio economic changes also have an effect, but this effect is less strong than the effect of climate change.

Future projections

Because the direction of the observed changes per region is generally the same for all scenarios, the projections for this indicator are considered to be relatively certain. However, under different climate scenarios, some differences in magnitude of the changes can be seen. So, although the direction of change is relatively certain, the magnitude of change is not.

9.5 References

Alcamo, J., Henrichs, T. & Rösch, T., 2000. World water in 2025 – Global modeling and scenario analysis for the World Commission on Water for the 21st century. Report A0002, Center for Environmental Systems Research, University of Kassel, Kurt Wolters Strasse 3, 34109 Kassel, Germany.

EEA, 2008. Impacts of Europe's changing climate: 2008 indicator based assessment. Joint EEA-JRC-WHO report. European Environment Agency, Copenhagen, Denmark.

Hanasaki, N., Kanae, S., Oki, T, 2006. A reservoir operation scheme for global river routing models. Journal of Hydrology 327, 22-41.

10 Water 7 - Change in magnitude of river low flow

10.1 Introduction to indicator

To understand changes in water availability, not only average discharges, but also changes in extremes need to be analysed. Future climate projections suggest that global warming is likely to favour conditions for the development of droughts in many regions of Europe. Southern parts of Europe are most prone to reductions in low flows. Changes in frequency of low flow conditions and duration of low water levels are impacting riparian ecosystems and economic sectors, including inland water transport (EEA, 2008). For this purpose, two indicators are included in this study: the change in frequency of low discharges and the change in magnitude of low discharges with a certain frequency. This chapter discusses the change in river low flow magnitude. The other indicators was the topic of the previous chapter.

As a low discharge the discharge that is exceeded 90% of the time is chosen. This Q_{90} is calculated for both the current and the future situation. In the calculation of river discharge human impacts through use of water or through regulation of flows (reservoirs) are taken into account.

10.2 Method

Calculation approach

The Q_{90} is calculated through further processing of monthly discharges calculated by WaterGAP. Q_{90} means that 90% of the monthly values during the total 30 year period are higher than this discharge.

As mentioned above, the river discharge is calculated for the situation with human impacts. For this calculation, the consumptive water use of the sectors domestic, electricity production, manufacturing industry, irrigation and livestock are included in the calculation of the water balance. Consumptive water use considers the water which is actually consumed and therefore it is the difference between water withdrawals and return flows. In addition, the operation of dams is considered. From the European Lakes and Reservoir Database (ELDRED2, developed and provided by the EEA) all reservoirs with a storage capacity higher than 0.1 km^3 (590 reservoirs) are included in WaterGAP. To estimate realistic operation rules, the management scheme according to the algorithm of Hanasaki et al. (2006) is applied.

The results are presented as change in Q_{90} in future scenarios as compared to the baseline scenario.

The calculation can be expressed as:

$$\frac{Q_{90}(2050) - Q_{90}(1961\text{-}1990)}{Q_{90}(1961\text{-}1990)} * 100\%$$

Input data

Monthly average discharge with consumptive use and regulation (output WaterGAP).

Spatial and temporal scales
The basis for the calculation are the total monthly river discharges at basin level. The change in Q_{90} magnitude is therefore also presented at basin level.

Classes
The results are presented in classes that are chosen to achieve an even spread of different classes all over Europe.

Uncertainties
The indicator is calculated through further processing of WaterGAP output. Modelling rainfall-runoff and water use at the large scale to cover entire Europe will have uncertainties as a result of scale itself and gaps in data. Projecting water use and availability for future scenarios is uncertain by its very nature. Alcamo *et al.* (2000) provides more information on the uncertainties involved and their order of magnitude. To minimise uncertainties results are aggregated to the basin level.

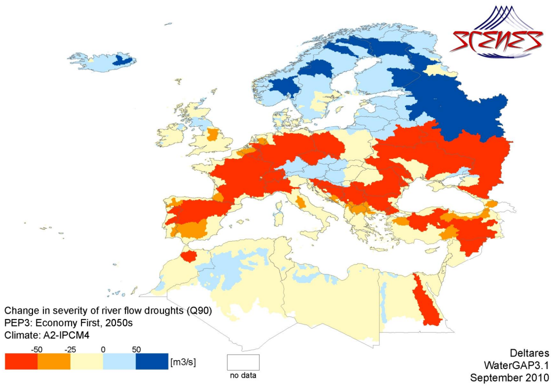
Validation
The indicator is computed through direct post-processing of WaterGAP results, which have been validated as part of the development of the WaterGAP model.

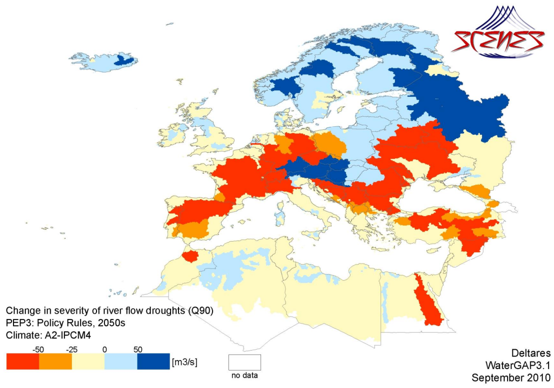
In addition, the results have been evaluated by 3 pilot areas: Lower Don, Guadiana, and Candelaro. The opinions differ both with respect to the applicability of the indicator in the way it is calculated and with respect to the values calculated for the indicator. The Lower Don considers the indicator useful and the results representative of the actual situation. Guadiana indicated that the indicator in itself is useful, but that Q_{90} values are available for the pilot area basin with different units. When conversion to other units is done, and values from various river stretches are extrapolated to the scale of the basin, the results are in the same order of magnitude as the WaterGAP output.

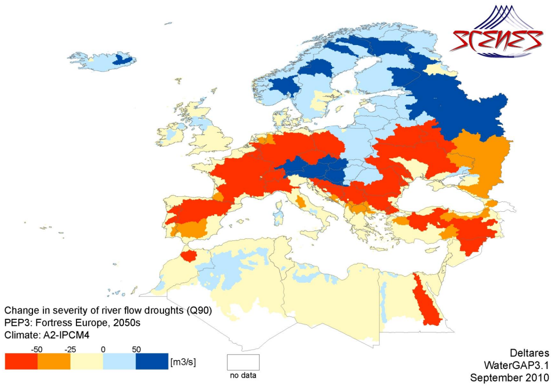
Candelaro indicated that because of the different units and the quantification at the basin scale, it is difficult to interpret the results and compare them to locally available data. The indicator was therefore evaluated as not interesting for the pilot area.

In response to the reactions from the pilot areas, we recalculated the indicator into m^3/s, which corresponds to the unit of available data. Presentation at the basin scale is done to minimise uncertainties due to the fact that local infrastructure and other local properties of the system are not included in WaterGAP. However, for some indicators the results are presented for selected cells in the river basin. This may be a more suitable approach for this indicator as well.

10.3 Results
Figures 10.1 until 10.8 show the resulting changes in river flow droughts for the eight SCENES scenarios. Since the results show change with respect to the baseline, the baseline map is not included.







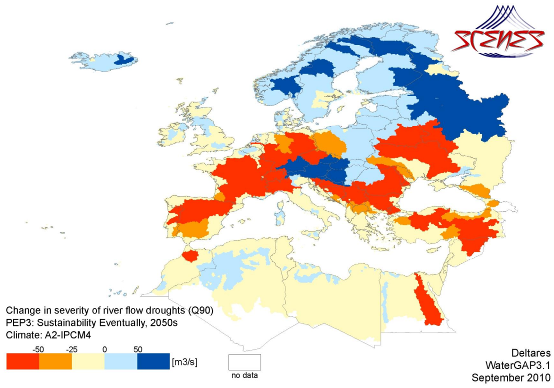
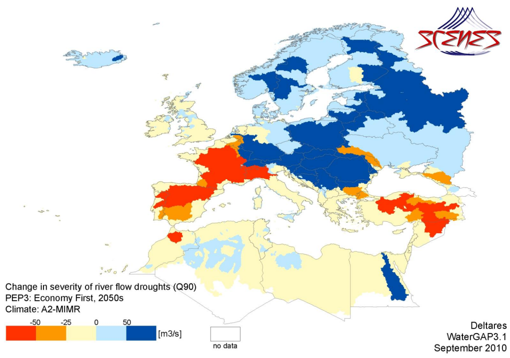
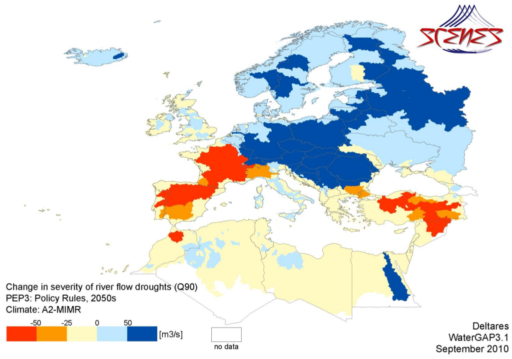
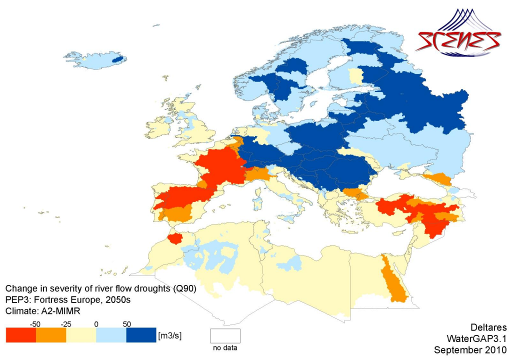


Figure 10.1 until 10.4 (left to right). Change in severity of river flow droughts under the IPCM climate scenario and socio economic scenarios (Figure 10.1: Economy First. Figure 10.2: Policy Rules. Figure 10.3: Fortress Europe. Figure 10.: Sustainability Eventually).







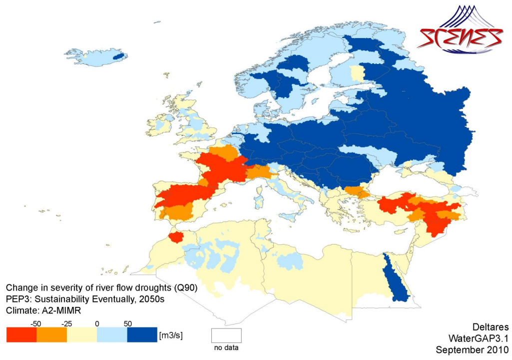


Figure 10.5 until 10.8 (left to right). Change in severity of river flow droughts under the MIMR climate scenario and socio economic scenarios (Figure 10.5: Economy First. Figure 10.6: Policy Rules. Figure 10.7: Fortress Europe. Figure 10.8: Sustainability Eventually).

The maps show a clear distinction between the low flow magnitudes resulting from the MIMR scenario and the IPCM4 scenario. Under MIMR northern, central and eastern Europe all experience increased magnitudes that are exceeded 90% of the time. Under the IPCM4 scenario this is observed for northern Europe and for parts of Eastern Europe. Under IPCM4 a much larger area ranging from Spain, France and Belgium to the eastern boundary of Europe experiences decreased magnitudes of low flows, with variations between the socio-economic scenarios where Policy Rules and Sustainability Eventually are a bit less severe.

10.4 Synthesis

Regional observations

The regional observations are summarised in Table 10.1. The table reveals that northern Europe, Central/Eastern Europe and Easterp Europe largely experience higher low flows, although under IPCM there are part of Central/Eastern and Easter Europe where the low flows decrease. For southern Europe and western Asia the low flow magnitude decreases, independent of the socio-economic or climate scenario. For northern Africa and western Europe the direction of impacts depends greatly on the climate scenario, and the future for those region is in this respect very uncertain.

Table 10.1 Regional impacts as deviation from the baseline scenario – low flow magnitude

		Northern Africa	Western Europe	Northern Europe	Southern Europe	Central/Eastern Europe	Eastern Europe	Western Asia
IPCM	EcF	-	-	+	-	-	+	- -
	FoE	-	-	+	-	+/-	+/-	- -
	PoR	-	-	+	-	+/-	+/-	- -
	SuE	-	-	+	-	+/-	+/-	- -
MIMR	EcF	+	+/-	+	-	+	+	- -
	FoE	-	+/-	+	-	+	+	- -
	PoR	+	+/-	+	-	+	+	- -
	SuE	+	+/-	+	-	+	+	- -

Climate change and socio-economic changes

Both from the maps and from the more detailed analysis presented in the paper climate change seems the more dominant factor determining the future low flows in Europe.

Future projections

With the exception of northern Africa and western Europe, the various scenarios show a consistent direction for the development of low flow conditions in the future. For Northern Europe, Central/Eastern Europe and Eastern Europe this direction is largely towards wetter conditions, while for Southern Europe and Turkey these are towards drier conditions.

10.5 References

Alcamo, J., Henrichs, T., Rösch, T., 2000. World water in 2025 – Global modeling and scenario analysis for the World Commission on Water for the 21st century. Report A0002, Center for Environmental Systems Research, University of Kassel, Kurt Wolters Strasse 3, 34109 Kassel, Germany.

EEA, 2008. Impacts of Europe's changing climate: 2008 indicator based assessment. Joint EEA-JRC-WHO report. European Environment Agency, Copenhagen, Denmark.

Hanasaki, N., Kanae, S., Oki, T, 2006. A reservoir operation scheme for global river routing models. Journal of Hydrology 327, 22-41.

11 Water 8 - Change in mean annual river flow

11.1 Introduction to indicator

Changes in temperature and precipitation patterns due to climate change modify the annual water budget of river basins as well as the timing and seasonality of river flows. The consequent changes in water availability may affect ecosystems and socio-economic sectors. The indicator change in mean annual river flow' provides insight in the long-term average water availability (EEA, 2008).

11.2 Method

Calculation approach

Relative change (in %) in mean annual or seasonal river flow in relation to reference period (1961-1990). The calculation can be expressed as:

$$\frac{\text{Average river discharge future scenario - Current average discharge}}{\text{Current average discharge}} * 100\%$$

Input data

- Monthly average discharge (mm)

Spatial and temporal scales

The computation are carried out with annual average values at the river basin level

Thresholds/classes

The following class thresholds are chosen to present the results for this indicator in maps.

> 30%	significant increase
5 / 15%	increase
-5 / +5%	minor change
-5 / -15%	decrease
<-30%	significant decrease

Uncertainties

The indicator is calculated through further processing of WaterGAP output. Modelling rainfall-runoff and water use at the large scale to cover entire Europe will have uncertainties as a result of scale itself and gaps in data. Projecting water use and availability for future scenarios is uncertain by its very nature. Alcamo *et al.* (2000) provides more information on the uncertainties involved and their order of magnitude. To minimise uncertainties results are aggregated at the basin level.

Validation

We make direct use of WaterGAP output, which has already been validated.

11.3 Results

Baseline

See Figure 11.1. In the baseline scenario, average annual water availabilities are highest in northern Europe (Scandinavia, the UK) and in the Benelux and central Europe. The lowest water availabilities are found in northern Africa, Turkey, the Iberian Peninsula and Russia.

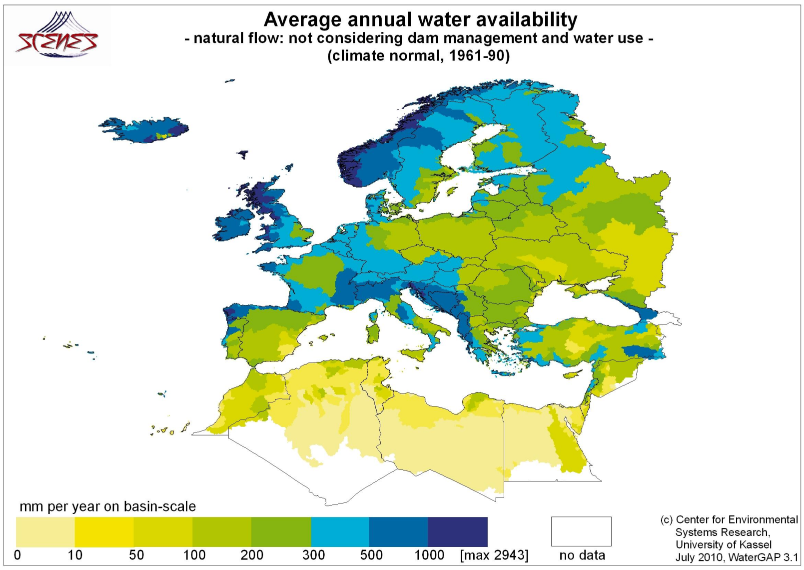


Figure 11.1. Annual water availabilities under the baseline scenario.

Future scenarios

Figure 11.2 and 11.3 show the results for the two climate scenarios IPCM and MIMR. The changes in mean annual river flow are calculated based on hydrological modelling only, and no withdrawals or other socio-economic factors are included in the computations. Therefore, only 2 maps are calculated.

IPCM

For the IPCM scenario, the mean annual river flow decreases significantly (-30%) in eastern Spain, Tunisia, Egypt, Israel, Turkey and Greece. In western Europe (Spain, France, Benelux), central Europe, and in parts of Turkey and North Africa the mean annual river flow decreases with 15 to 30%. The decreases take place in areas that were already experiencing a low mean annual river flow in the baseline scenario, like Turkey and Egypt, but also areas that did not experience really low river flows (western Europe, central Europe). The highest increases in mean annual river flow are found in Scandinavia, where availabilities were already high, and in North Africa (inland).

MIMR

For the MIMR scenario the mean annual river flow decreases significantly in eastern Spain, the North African coast (Turkey, Libya, Tunisia, Egypt), Israel and Turkey. Water availabilities were already low in these areas in the baseline scenario. The highest increases in mean annual river flow are found in Scandinavia, where availabilities were already high, and in the Nile basin and North Africa (inland).

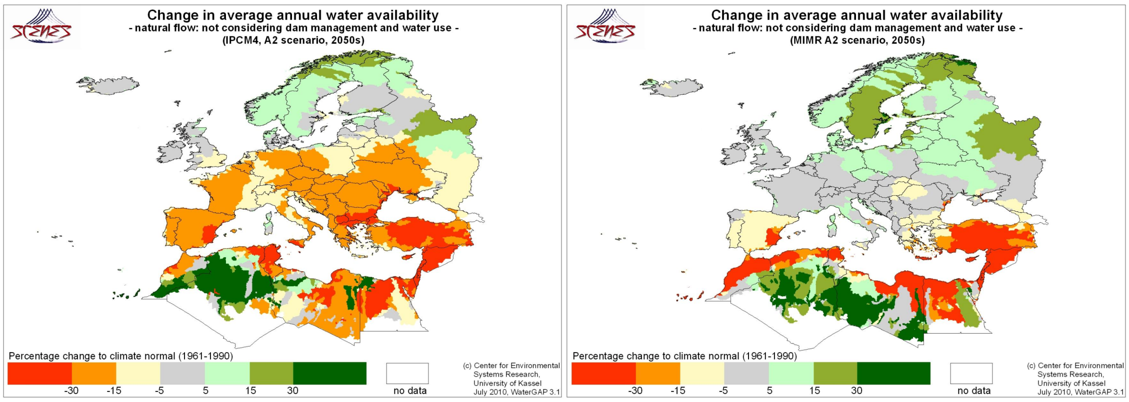


Figure 11.2 and 11.3. Change in average annual water availability under the IPCM scenario (11.2) and the MIMR scenario (11.3).

11.4 Synthesis

Regional observations and climate change

Under both climate scenarios, the mean annual river flow decreases in Turkey, parts of the North African coast, Israel and eastern Spain. In these areas, the mean annual river flow was already low in the baseline. As both climate scenarios show these changes it may be concluded that the situation in these areas probably will get worse. Under the IPCM scenario, also large areas in western and central Europe will experience a decrease in mean annual river flow. As this pattern is not seen under the MIMR scenario, it is less certain that a decrease will take place in these areas.

Both climate scenarios furthermore expect an increase in mean annual river flow in Scandinavia, where mean annual river flow is already high in the baseline scenario, and in the inland of Nothern Africa. In the latter region, mean annual river flows are very low in the baseline. A slight absolute increase in river flow therefore easily leads to a significant percentual increase, which could explain the significant increases in this region.

Table 11.1 shows a summary of these observations. The expected changes for many regions are different under both climate scenarios. The IPCM scenario in general expects more negative changes than the MIMR scenario. Also, despite the different scores, the direction of the score (positive, negative, no change) is often the same. For some regions, both scenarios expect similar changes. This holds for northern Africa, northern Europe and western Asia.

Table 11.1 Regional impacts as deviation from the baseline scenario – annual water availability

	Northern Africa	Western Europe	Northern Europe	Southern Europe	Central/Eastern Europe	Eastern Europe	Western Asia
IPCM	+/-	-	+	- -	-	+/-	- -
MIMR	+/-	o	+	-	o	+	- -

Future projections

Because for some regions, both climate scenarios expect the same developments, and for others the scenarios expect developments in the same direction, the projections for this indicator are assumed to be moderately likely.

11.5 References

Alcamo, J., Henrichs, T. & Rösch, T., 2000. World water in 2025 – Global modeling and scenario analysis for the World Commission on Water for the 21st century. Report A0002, Center for Environmental Systems Research, University of Kassel, Kurt Wolters Strasse 3, 34109 Kassel, Germany

EEA, 2008. Impacts of Europe's changing climate: 2008 indicator based assessment. Joint EEA-JRC-WHO report. European Environment Agency, Copenhagen, Denmark.

12 Key messages

Based on the findings for the generic indicators, this Chapter provides an answer to three general questions:

- What is the overall image per region?
- Are there big differences between regions?
- Can socio-economic changes (SE) or climate changes (CC) be identified as dominant driving forces of these changes?

To answer these questions the analysis for all scenarios is aggregated into an indication per indicator and per region of where the focus lies (positive, negative, no change, or a combination) and what the uncertainty is with respect to future changes (do the different scenarios point in the same direction or not) as presented in Table 12.1.

In Table 12.1, the indicators are grouped slightly differently and the main input data are included as well:

- Climate-driven input:
  - Mean annual runoff
  - Low flows (combination of changes in frequency and magnitude)
  - High flows (combination of changes in frequency and magnitude)

- Socio-economic driven input:
  - Consumptive use
  - Withdrawals

- Indicators in which climate change and socio-economic change have been combined:
  - Water consumption index
  - Water stress index
  - Water scarcity index

What is the overall image per region?

Northern Africa
Northern Africa covers a large area of which some parts will experience wetter and other parts drier conditions. Especially the coastal zone will become drier. Combined with an increase in water demand, this results in increased shortage of water as indicated by the three water shortage indicators. The uncertainty for these results is low to medium. For Northern Africa no results are available for changes in high flows.

Western Europe
In western Europe the overall image is that both higher flow and lower flows will appear more frequently or will be more severe. In what direction water use will develop is uncertain. 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.

Table 12.1 Aggregation of generic indicator results

Region	Climate						Socio-economic				Impacts					
	Mean Annual Runoff		Low flow		High flow		Cons. Use		With-drawals		Water Cons. Index		Water Stress Index		Water Scarcity Index	
	Focus	Uncertainty	Focus	uncertainty	Focus	uncertainty	Focus	uncertainty	Focus	uncertainty	Focus	uncertainty	Focus	uncertainty	Focus	uncertainty
N. Africa	-/+	M	-/+	M			-	L	-/+	M	-	L	-	M	-	L
W. Europe	-	M	-/+	M	-	L	-/+	M	-/+	H	0/-	M	-/+	H	0/-	M
N. Europe	++	L	+	L	-	L	0/-	M	-/+	H	0	L	0	L	0	L
S. Europe	-	M	-	L	-	L	+	L	+	M	+	L	-/+	H	-/+	M
C/E. Europe	-/+	H	+	L	0	L	0	L	-/+	H	0	L	0/-	M	0	L
E. Europe	-/+	M	+	L	0	M	-/+	M	-/+	H	-	L	-/+	H	-/+	M
W. Asia	--	L	-	L	-/+	M	0	L	-/+	M	-	L	-/+	M	-	M

Northern Europe
The results for northern Europe show that this area becomes wetter: mean annual runoff, low flows and high flows increase. Northern Europe does not show a change for water scarcity.

Southern Europe
The general availability decreases, but due to decreases in consumptive use, the three water shortage indicators (WCI, WSI, Water scarcity index) show primarily an improvement. Floods increase. It is interesting to observe that due to technological developments in the irrigation sector, the withdrawals show a strong decrease in some scenarios, while this translates only in a limited decrease in consumptive use.

Central/Eastern Europe
The overall result is that for many indicators no change will take place. For a number of indicators there can be either improvements or degradations for parts of the basin.

Eastern Europe
The overall result is that changes are likely to occur, but can be both positive and negative. These changes are often local.

Western Asia
The results show mainly that the area will become drier and that water shortage will become an increasing problem.

Are there big differences between regions?
As expected there are big differences between regions in terms of the direction and severity of impacts. Also the uncertainty with respect to the direction of future change varies over Europe.

Table 12.1 shows that negative changes in the future are likely for Northern Africa, Western Europe and Western Asia. In Northern Europe and Central Eastern the condition are generally wetter and water shortage will not change much. For Southern Europe and Eastern Europe changes can be either negative or positive.

Can socio-economic changes or climate changes be identified as dominant driving force of these changes?

The water stress index seems dominated by the socio-economic scenarios. The other indices for shortage: water consumption index and water scarcity index seem equally influenced by both climate change and socio-economic scenarios. Socio-economic impacts lead to more severe changes from the baseline for the water withdrawals than for the consumptive use. It therefore makes sense that in the water stress index, which is based on withdrawals, the socio-economic influence is more pronounced than in the water consumption index and water scarcity index which are based on consumptive use.

The changes in low flows are dominated by climate change. The changes in flood hazard and mean annual river flow do not take socio-economic scenarios into account and are therefore automatically climate driven only.

Table 12.2 summarises whether climate change (CC) or socio-economic change (SE) seems dominant.

Table 12.2 Dominant driving force per indicator

Region	CC or SE?
Water consumption index	SE/CC
Water stress index	SE
Water scarcity index	SE/CC
Change in frequency of river low flow	CC
Change in magnitude of river low flow	CC
Change in frequency flood events	CC
Change in flood hazard	CC
Change in mean annual river flow	CC