GOCE 036822

SCENES

Water Scenarios for Europe and for Neighbouring States

Instrument: Integrated Project

Thematic priority: Global change and ecosystems

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

Volume E: Water for Industry and Energy

Due date of deliverable: 31.03.2011
Actual submission date: 29.04.2011

Start date of project: 1.11.2006 Duration: 54 months

Lead contractor: Deltares Revision version 1

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
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 indicators for 'Water for Industry and Energy'.

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 8 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
- Volume B: Water for Food
- Volume C: Water for Nature
- Volume D: Water for People
- Volume E: Water for Industry & Energy (this volume)

This report, Volume E, discusses the Water for Industry & Energy indicators. Each 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.
Chapter 5 of this Volume discusses the key findings that can be drawn from the analysis of the generic indicators.

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, used in chapter 5 is discussed in chapter 2 of Volume A.
Chapter 3 of Volume A 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.

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 Water for Industry 1 – Extra demand for cooling water

2.1 Introduction

Due to the economic growth and population increase, electricity generation in many European countries has an increasing trend. This also increases the demand for water and the output of heat discharges. Heat discharges influence the water temperature of a river. High water temperatures limit cooling possibilities for the industry and energy sector (Peñailillo et al., 2008). Data on the Rhine River shows that the number of days per year that water temperature exceeds 24°C has increased over the last few decades (Table 2.1).

Table 2.1. Number of days with measured water temperature >24°C, Rhine river, the Netherlands (source: Bresser et al., 2005).

Year	Number of days >24°C
1976	23
1981	3
1994	41
2003	39

Electricity generation is extremely important in today's society. Therefore, possible reductions in electricity generation as a result of reduced cooling water capacities of rivers provide relevant policy information. Cooling water problems involve exceedance of a certain temperature and duration of time above a critical threshold, the Design Temperature of the river water. The Design Water Temperature is assumed to be 24°C throughout pan-Europe, above which limited river water intake and discharge will be put in place.

The purpose of this indicator is to highlight possible cooling water problems for existing industrial plants due to future changes as envisaged in the SCENES scenarios. This can be expressed in the additional flow of water (make-up water demand) which is required to compensate the reduced cooling water capacity of the water.

2.2 Method

Calculation approach

This indicator represents the demand for extra cooling water relative to the natural water availability in rivers ($m^3\ s^{-1}$) during low flow conditions, in order to keep the river water temperature below the Design Temperature.

Water Temperature is calculated by adding natural background water temperature, and the temperature surplus associated with the discharge of cooling water from industrial activity along the river network. Additionally cooling of the river water during transport downstream is calculated using a function explaining how the original temperature surplus decreases exponentially in time towards zero:

$$\theta = \theta_0 \cdot \exp\left(\frac{-Z \cdot t}{H \cdot \rho_w \cdot c_{Pw}}\right)$$

where θ_0 is the original temperature surplus, Z is the self-cooling coefficient (W.m^{-2} °C^{-1}), t is time, ρ_w is water density (1000 kg m^{-3}), c_{Pw} is the specific heat capacity (4195 J kg^{-1} °C^{-1}) and $H = 0.26 \cdot Q^{0.4}$ as in Alexander et al. (2000), where H is water depth (m), and Q is annual average discharge (m^3 s^{-1}).

Natural background water temperature in calculated from an air-water temperature relationship for each pan-European region (Table 2.2).

Table 2.2. Relationship between air and water temperature for 6 pan-European regions (Segrave, 2009).

SCENES region	Air-water temperature relationship
Northern Europe	WaterTemp = 0.89*AirTemp + 1.55
Eastern Europe	WaterTemp = 0.90*AirTemp + 2.35
Western Europe	WaterTemp = 1.02*AirTemp + 2.12
Southern Europe	WaterTemp = 0.93*AirTemp + 1.28
Western Asia	WaterTemp = 0.80*AirTemp + 3.94
Northern Africa	WaterTemp = 0.63*AirTemp + 7.87

It is interesting to note that the warmer, tropical climates generally have lower coefficients and higher Y-intercepts. Lower coefficients are likely to be due to the fact that the temperature variance between extremes (summer-winter) is lower in these countries and the fact that evaporation and back radiation reduce the rate of water temperature increase at higher temperatures (less slope). The higher Y-intercepts correspond with the fact that the background temperature is higher. Water availability in July has been assumed to represent low flow conditions. The discharge values from July were chosen

Temperature surplus (θ_0) is calculated as follows:
Discharge of cooling water was taken from national data on energy production projections. Total electricity production in each country was projected by using the historic Total Electricity Generation vs. GDP slope and then varying it by scenario, time period, and region. The share of the total electricity generated by thermal generation was estimated by applying changes to the present shares according to scenario storylines.

To convert the thermal energy production to actual heat discharged to the cooling water, the thermal efficiency of a power plant, defined as the ratio of produced electricity to the heat generated during the process of electricity production, is needed. The thermal efficiency usually amounts to 34% for nuclear power plants, 45% for conventional thermal power plants and approximately 60% for combined heat and power type of plants (Langford, 1990). It was assumed that most European power plants in Europe are of the conventional type. Therefore, to correct for thermal efficiency, the thermal energy production was multiplied by a factor 55/45.

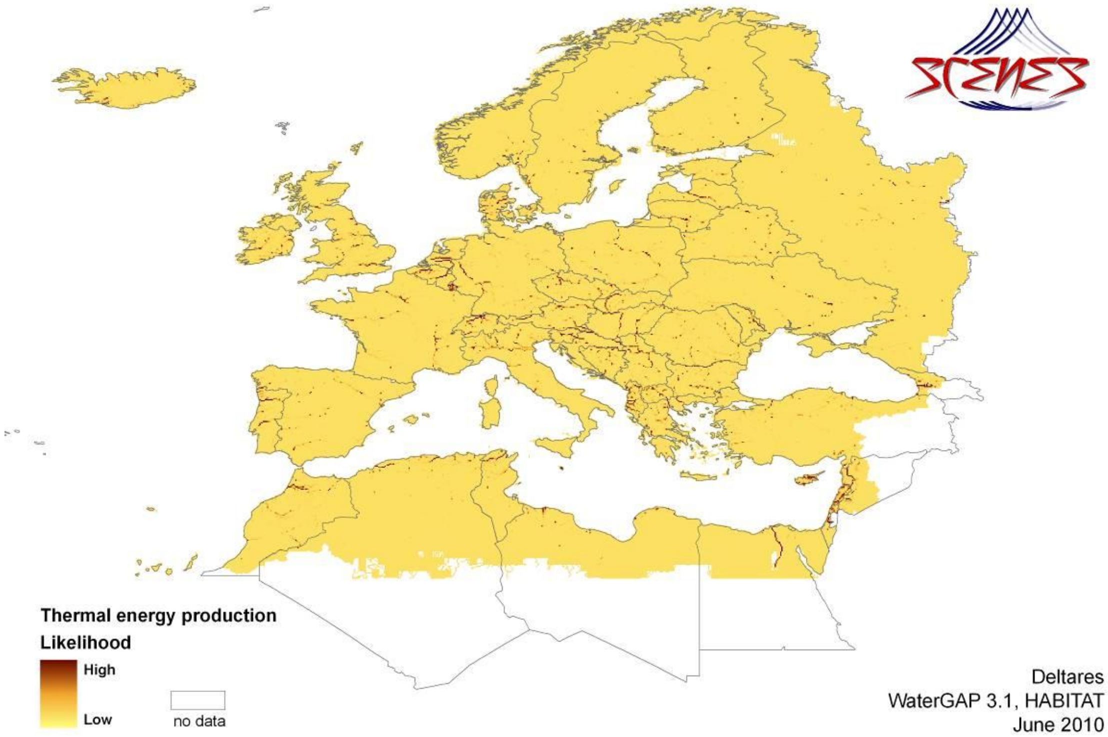

Figure 2.1. Map showing the location likelihood of power plants that produce Thermal Energy Production.

Finally, the thermal energy production was distributed using a likelihood map (Figure 2.1). It was computed from population and discharge data, assuming the most likely location of power plants is along large rivers in highly populated areas.

Make-up water is that taken in from the cooling water source, in this case withdrawn from the river. Extra make-up water demand is directly related to temperature difference reduction. This indicator is calculated by determining the difference between the maximum design discharge, were the water temperature will not exceed the design temperature maximum of in this case 24°C, and required discharge associated with a projected river water temperature (>24°C).

Input data

Data on Thermal Energy Production was obtained from the Centre for Ecology and Hydrology (CEH). Water availability or river discharge where 90% of the monthly values during the total 30 year period are higher than the provided discharge (Q_{90}; WaterGAP 3.1 output) was used to calculate discharge and represent low flow conditions. Air temperature for the different scenarios was derived from the CRU and climate scenarios (IPCC, 2007).

Thresholds and critical values

The amount of extra demand in make-up water (m^3 h^{-1}) is presented as a percentage excess in make-up water demand over and above the design maximum water temperature. Make-up water temperatures less than or equal to the maximum design temperature (24°C) thus results in 0% excess water demand.

Table 2.3. Extra water demand: risk classes.

Water temperature (°C)	Extra make-up water demand (%)	Cooling reduction risk
T < 24.5	< 10	Minor
24.5 < T < 25.5	10 – 30	Moderate
25.5 < T < 26.0	30 – 50	Major
26.0 < T	> 50	Severe

Validation

Actual temperatures in the Rhine were compared with modelled results. The temperature surplus in the Rhine River closely meets the computed value (~4°C versus ~3°C for the baseline situation).

Uncertainty and sensitivity

The relationship between air and water temperature is a very rough method to estimate water temperature. The actual water temperature may be influenced by numerous factors, such as humidity and wind speed that are not taken into account explicitly.

The thermal energy production data contains annual values, but the focus of this indicator is on low flow conditions during the warmest month (July). Annual country values are assumed to be spread equally over the year. The model results are sensitive to the distribution method of the thermal energy production country data, both temporal and spatial (using the likelihood map), as well as the efficiency of energy production (assuming 45% of production to electricity net).

The roughest increment of time for defining this duration element is days, since it is unlikely that these critical temperatures will continue for weeks or months. But the only data available is on a monthly scale, so the duration related element of cooling water problems was be left out of this indicator. This is a limitation.

No differentiation has been made between cooling systems (e.g. with or without a cooling tower). The Design Water Temperature is arbitrarily set to 24°C for all European regions. However, this value may differ for individual countries based on their policy and natural water temperature.

2.3 Results

The temperature thresholds have been applied to the derived model results: river water temperatures for the combined socio-economic and climate scenarios. Maps have been created depicting the grid cells of large river and its tributaries falling in a class from no extra demand to high extra demand >50% (Figure 2.2 to 2.10). It should be noted that absolute extra water demand is much higher for large rivers than for small rivers with equal extra demand expressed in percentage.

2.3.1 Baseline scenario

In the baseline situation many rivers show no extra demand for cooling water except for the larger rivers in Western Europe (high electricity production) and southern Europe (natural background temperature close to the Design Water Temperature).
Most rivers in the Atlantic and Mediterranean region require extra cooling water in order to remain below the design temperature of 24°C during low flow conditions.

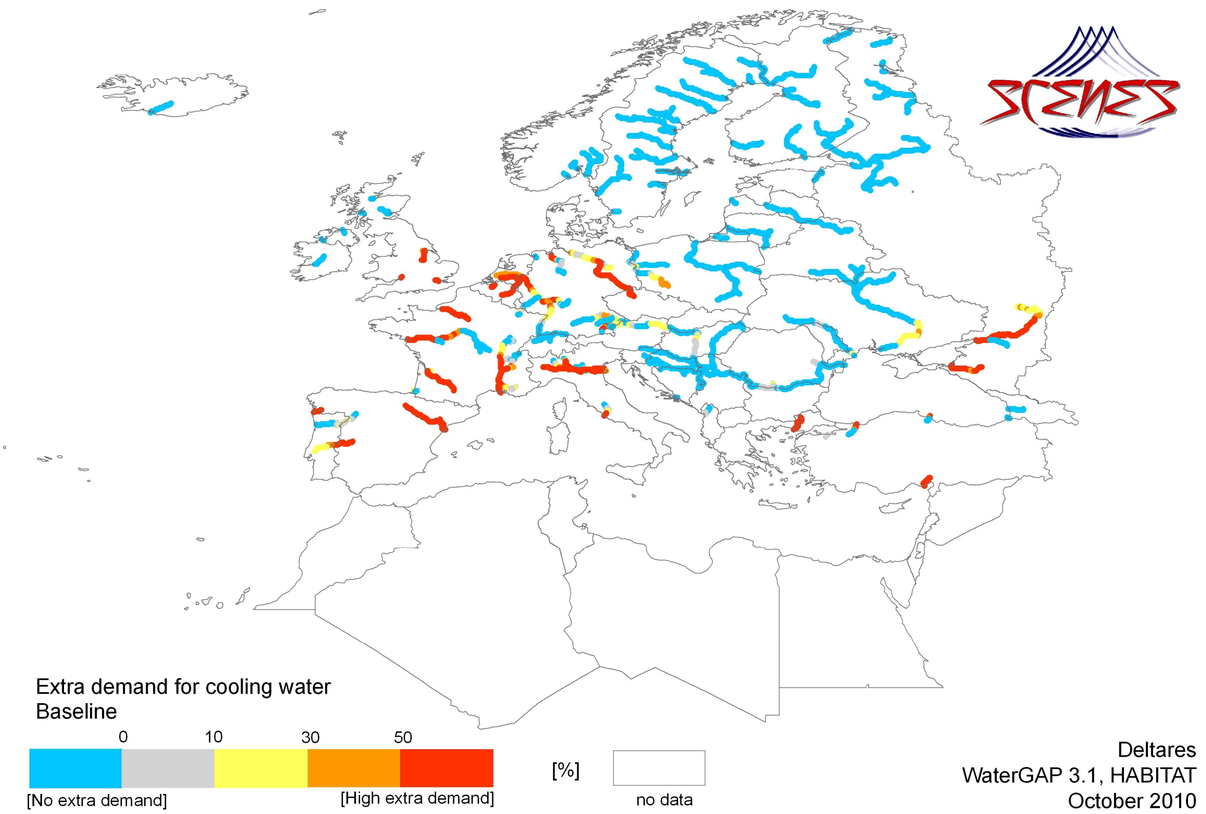

Figure 2.2 Extra water demand for cooling water for the baseline scenario

2.3.2 Future scenarios

General pattern

A severe increase in cooling water demand can be observed for all scenarios, except for the Northern European region (Figure 2.2). The demand increases in many places to more than 50% of the available water. In general, climate change related temperature rise alone (Figures 2.11 to 2.12) results in a shift from no demand to critical demand for extra cooling water, whereas a high demand is observed for river sections in densely populated and industrialized areas.

Socio economic and climate scenarios

The increase in extra water demand is most pronounced in the Economy First scenario in which almost the entirety of Europe shows a high demand. The Sustainability Eventually scenario shows the best results with some upstream sections of rivers and parts of the Rhine having a moderate extra demand. Although the least deterioration is estimated for SuE in Western and Central Europe most rivers still show a high demand for extra cooling water. Eastern Europe shows the best results for the FoE scenario. Differences are small, but applying the IPCM4-A2 model results in a higher extra demand compared to MIMR-A2, this is the result of a drier climate (and less water for cooling) under the IPCM4-A2 climate scenario and warmer climate (higher natural temperature) for entire Europe when excluding the central part.

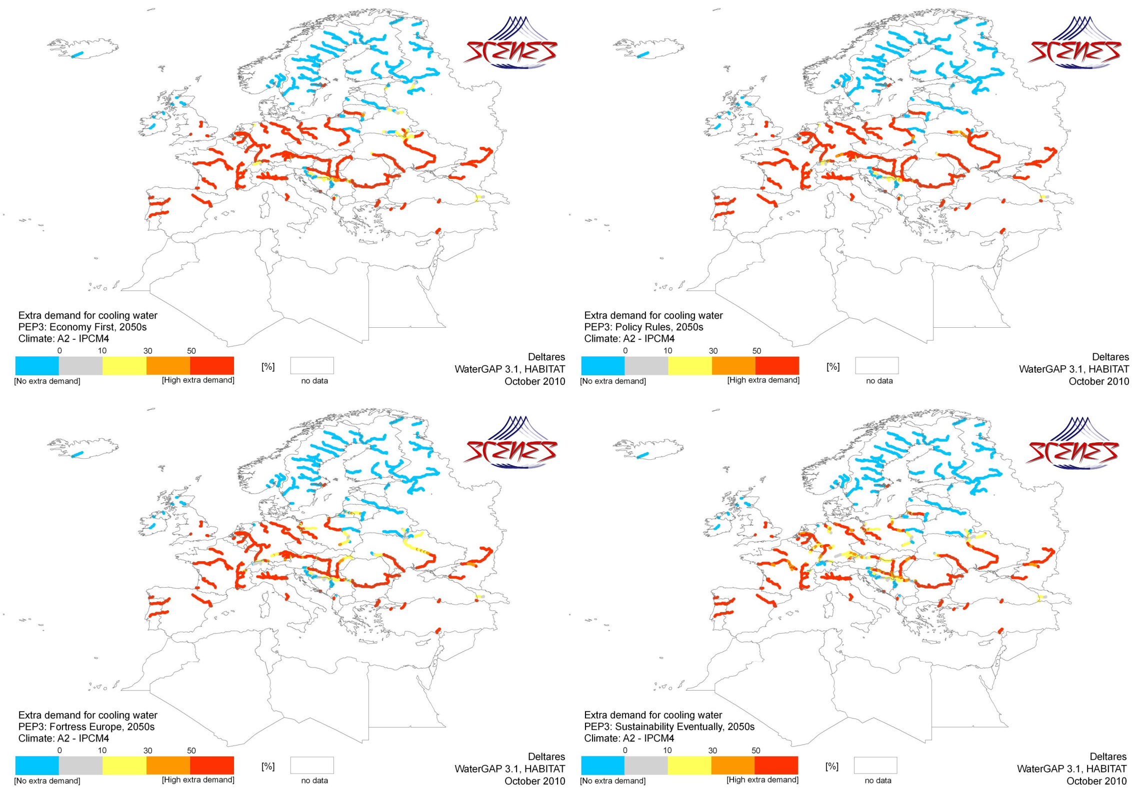

Figure 2.3 until 2.6 (left to right). Extra demand for cooling water under the IPCM scenario. Economy First: Figure 2.3. Policy Rules: Figure 2.4. Fortress Europe: Figure 2.5. Sustainability Eventually: Figure 2.6.

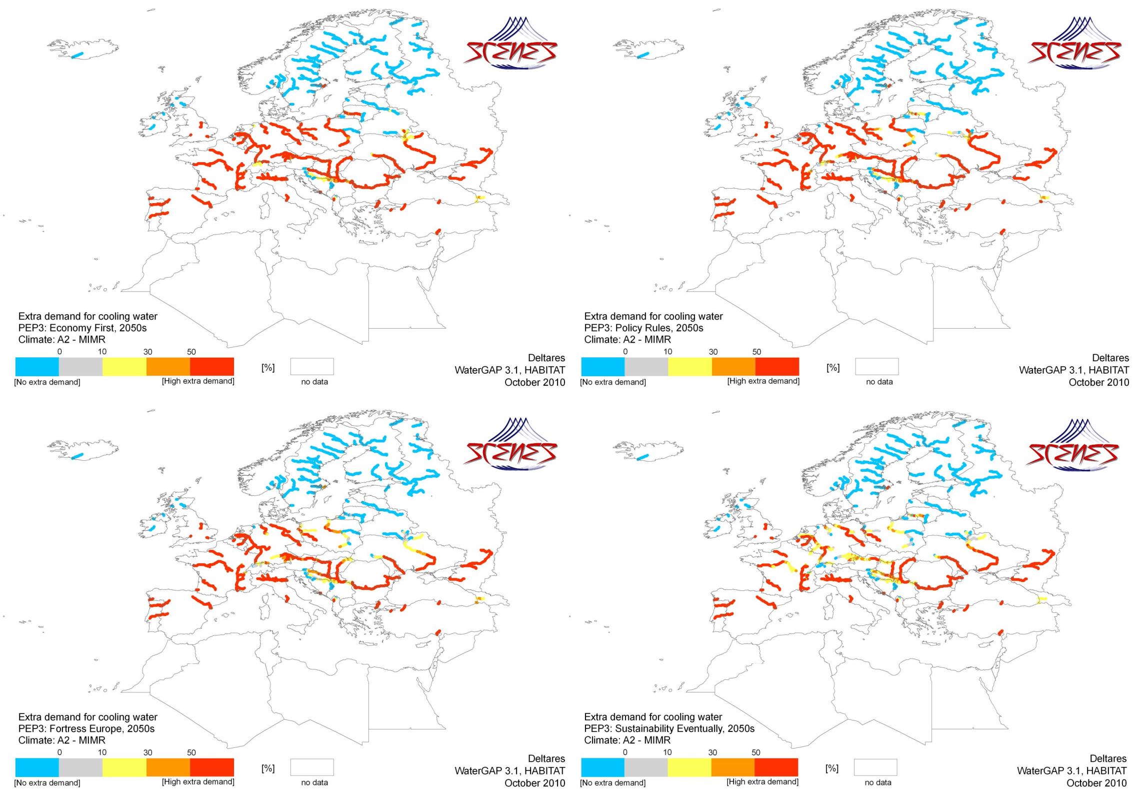

Figure 2.7 until 2.10 (left to right). Extra demand for cooling water under the MIMR scenario. Economy First: Figure 2.7. Policy Rules: Figure 2.8. Fortress Europe: Figure 2.9. Sustainability Eventually: Figure 2.10.

Natural and excess water temperature

The water temperature changes in future as a result of changing natural temperature (climate) and a temperature surplus (excess temperature from cooling water discharge). As can be seen in Figures 2.11 to 2.12 both climate scenarios lead to an increase in natural water temperature for all rivers. In Figures 2.13 to 2.14 the most extreme combined climate and socio-economic scenarios are shown. The excess temperature may both decrease and increase. For Policy Rules (IPCM4-A2) most rivers show an increase in excess temperature, mainly in Western, Eastern and Southern Europe. For Sustainability Eventually (MIMR-A2) many river in Western and Central Europe show a decrease in excess temperature. However, when looking at the combination of the change in natural and excess temperature, the estimated decrease in excess temperature for SuE is compensated by the natural temperature increase. Therefore the SuE scenario does not show a decrease in water temperature and the related extra demand for cooling water (Figures 2.3 to 2.10).

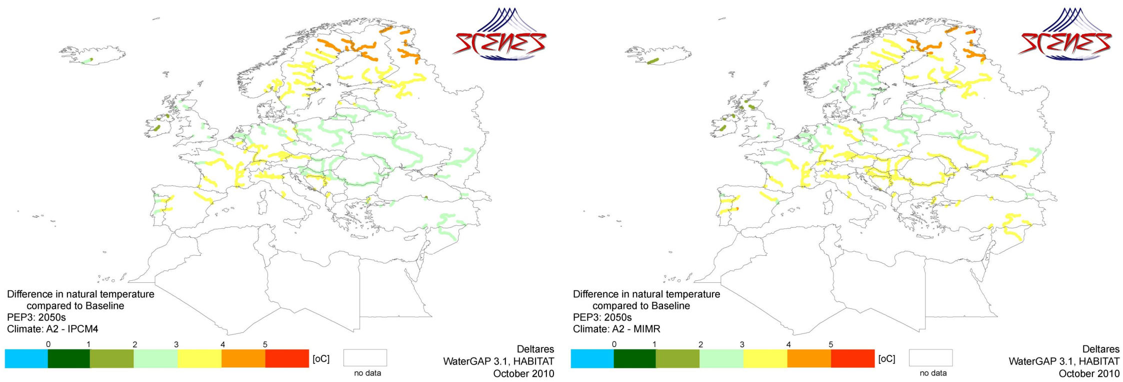

Figure 2.11 (left) and 2.12 (right) Change in natural temperature in rivers between the baseline scenario and the climate scenarios IPCM4-A2 (Figure 2.11) and MIMR-A2 (Figure 2.12).

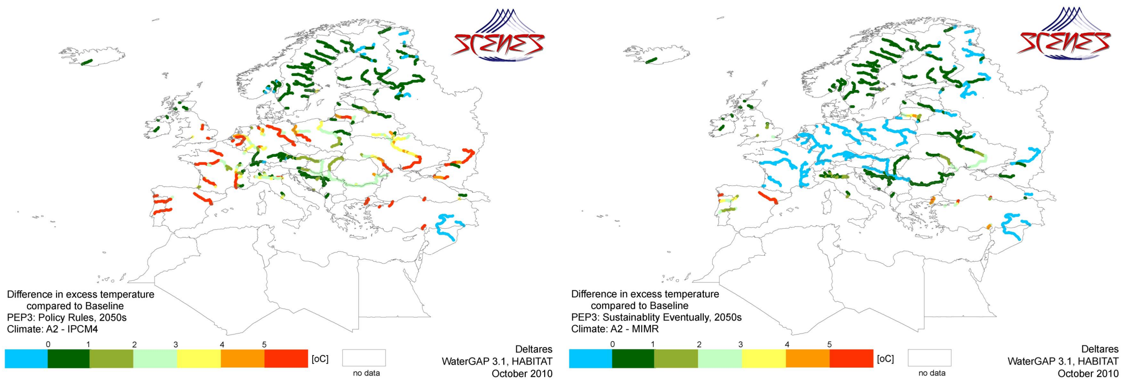

Figure 2.13 (left) and 2.14 (right) Change in excess temperature in rivers between the baseline scenario and socio-economic scenarios Policy Rules IPCM4-A2 (Figure 2.13) and Sustainability Eventually MIMR-A2 (Figure 2.14).

2.4 Synthesis

Climate change has a profound impact on future water demand for cooling purposes for electricity generation. Due to the economic growth and population increase this even further increases the demand for cooling water. This may put a large pressure on power plants in the future for all scenarios in periods of low flows. However, the results are based on a design water temperature of 24°C, which is applied in the Netherlands. Impacts can be smaller if the design temperature is higher in for example Mediterranean countries. For a summary of the observed changes in all regions, see Table 2.4.

Table 2.4. Regional observations on changes with respect to the baseline scenario

		Northern Africa	Western Europe	Northern Europe	Southern Europe	Central/Eastern Europe	Eastern Europe	Western Asia
IPCM	EcF	*no data*	--	-	--	--	-	--
	FoE	*no data*	--	o	--	--	-	--
	PoR	*no data*	--	-	--	--	-	--
	SuE	*no data*	--	-	--	--	-	--
MIMR	EcF	*no data*	--	-	--	--	-	--
	FoE	*no data*	--	o	--	--	-	--
	PoR	*no data*	--	o	--	--	-	--
	SuE	*no data*	--	o	--	--	-	--

2.5 References

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3 Water for Industry 2 – Navigability of large rivers

3.1 Introduction to indicator

River discharges and water levels may change in the future as a result of both climate change and socio-economic developments. One of the economic sectors that will be impacted when discharges decrease or when low discharges occur during longer periods is the navigation sector.

Reduced discharges lead to lower water levels which implies a decreased water depth. Therefore, ships cannot be fully loaded and more trips have to be made to transport an equal amount of tons. With low discharges, water levels can be maintained through weirs. Although this maintains the load capacity, the waiting time at shiplocks will increase. If available, ships may choose alternative routes. With or without alternative routes, low discharges will cause the navigation sector to encounter delays and increased energy costs.

The total increase in transportation costs harms the competitive position of inland waterway transport compared to other transportation modalities, such as rail transport or road transport. It is hard to estimate what the social economic consequences of the modal shift are; this depends on the transportation costs of other modalities, the duration of low water levels, the capacity of other transport means etc.

For an overview of the effect chain of climate change on inland water transport, see Figure 3.1.

The policy relevance of an indicator is highest when it represents the factors as low as possible in the effect chain of Figure 3.1. However, this requires information regarding economic impacts, which is not available. An important parameter is water depth and the duration of low water depths. To calculate water depth from discharges Q-H relationships are required. In rivers regulated by weirs, these relationships are ambiguous and therefore water depths can only be calculated using a hydro-dynamic model.

As an alternative, an indicator is defined based on discharge information only. For navigation it is important during what number of days navigation is either impossible or restrained. Therefore, as indicator the change in frequency of current low flows is chosen. The low flow threshold is based on information for the river Rhine, one of the main navigation routes in Europe. On the Rhine, navigation is not allowed when the discharge is beneath the "agreed low flow" (In Dutch: Overeengekomen Laagwater Afvoer - OLA) (Rijkswaterstaat, 2009). The OLA can be defined as: local discharge which is not reached during 20 (ice-free) days a year ($\approx Q_{94}$). Table 3.1 gives the OLA for a number of locations along the Rhine.

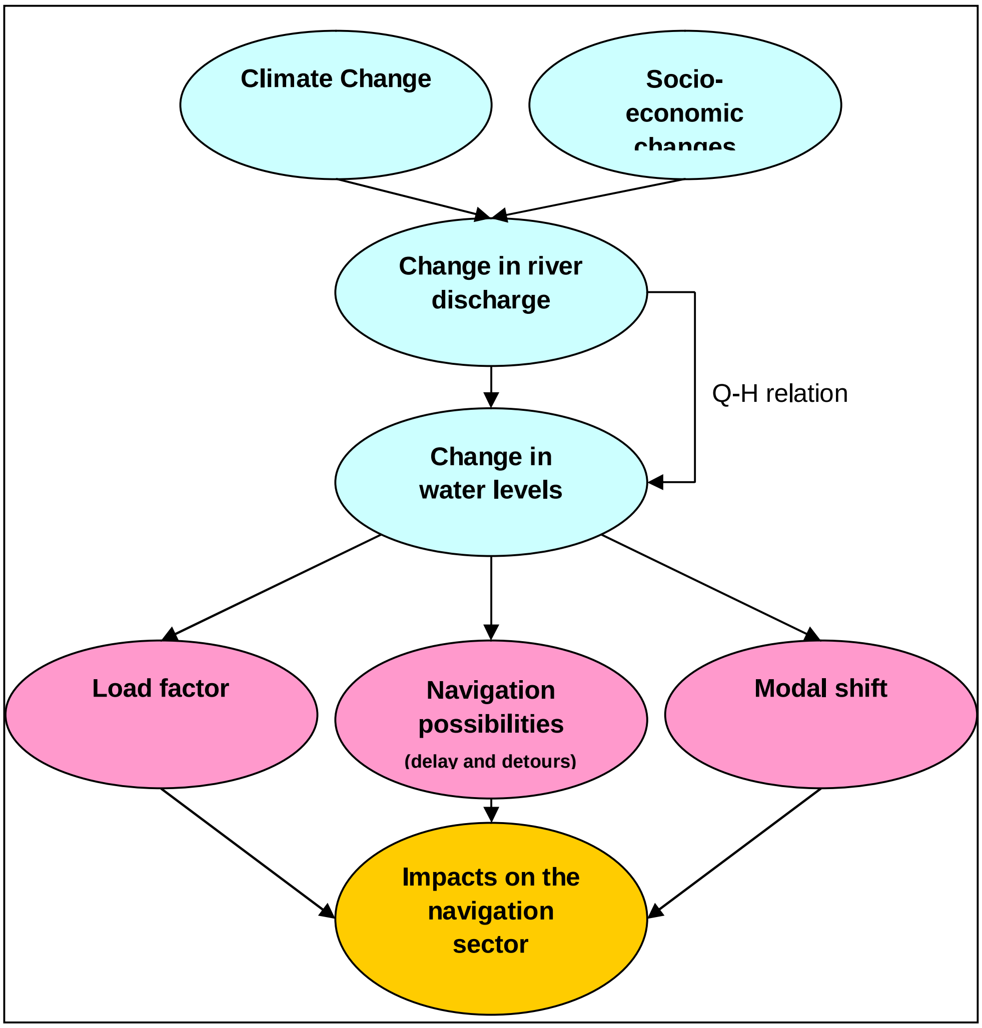

Figure 3.1 Effect chain of climate change on inland waterway transport

As an estimation of the duration of levels below navigable depth, the change in frequency of the discharge that is currently exceeded 90% of the time (Q_{90}) is selected to indicate impacts on the navigation sector.

Table 3.1 Flow conditions river Rhine

Location	**Agreed low flow (m^3/s)**	**Average flow (m^3/s)**	**Highest navigable flow (m^3/s)**
Maxau	585	1.050	3.180
Wesel	935	2.460	7.400
Lobith	1.020	2.200	-

Main waterways

The indicator computations focus on the major European navigation routes. In Europe several inland waterways can be distinguished. Figure 3.2 shows the European network of main waterways.

Figure 3.2 European network of waterways (source: wikipedia.com)

The main navigation channels in Europe are:

- Meuse
- Rhine
- Mittelland Kanal
- Elbe
- Danube
- Mosel
- Rhone
- Seine

In this list rivers near the sea (like the Thames) are not included, because not only the discharge of the river is limiting for navigation, the tide is as well.

The inland navigation routes in Europe are categorized in CEMT-classes to synchronize the dimensions of the waterways. The classification is done by the 'Conferénce Européenne des Ministres de Transport'. In total six main classes can be distinguished. Table 3.2 shows the different classes with accompanying characteristics.

For this indicator the focus is on main navigation routes, classes VI and VII, and therefore on the Rhine and Danube.

Table 3.2 Classification Inland waterways

Class	Length	Width	Depth	Height	Tonnage
I	38,5	5,05	1,8-2,2	4	250-400
II	50-55	6,6	2,5	4-5	400-650
III	67-80	8,2	2,5	4-5	650-1.000
IV	80-85	9,5	2,5	5,25-7	1.000-1.500
Va	95-110	11,4	2,5-4,5	5,25-7	1.500-3.000
Vb	172-185	11,4	2,5-4,5	9,1	3.200
VIa	95-110	22,8	2,5-4,5	7-9,1	3.200-6.000
VIb	185-195	22,8	2,5-4,5	7-9,1	6.400-12.000
VIc	193-200	34,2	2,5-4,5	9,1	9.600-18.000
VIIb	195-285	34,2	2,5-4,5	9,1	14.500-27.000

Method

Calculation approach

The Q_{90} (the level at which flows are exceeded 90% of the time, can be derived from river discharge) is assumed to be representative for the effect on navigability on large rivers. For the scenario's the change in Q_{90} (in m^3/s) will be presented.

The frequency of the baseline Q_{90} magnitude for the scenarios is calculated for a number of locations along several rivers. This was done by sorting 30-year monthly results and taking the 0.1 percentile. In the scenario results the frequency of this discharge was determined, see also the indicator on frequencies of river low flow.

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. 590 dams from the European Lakes and Reservoir Database (ELDRED2, EEA) are included into WaterGAP in order to consider anthropogenic flow regulation. Thereby, all dams with a storage capacity higher than 0.1 km^3 have been taken into account from this database and the management scheme according to the algorithm of Hanasaki et al. (2006) is applied.

Input data

- monthly average discharge including consumptive use and regulation (output WaterGAP)

Spatial and temporal scales

The calculation are carried out a grid cell level for a selection of grid cells that are located on the main navigation routes in Europe.

Thresholds

The thresholds used to define the frequency of current low flow (Q_{90}) are:

Q_{100}-Q_{95} = 0- 18 days current low flow a year
Q_{95}-Q_{95} = 18- 36 days current low flow a year
Q_{90}-Q_{85} = 36- 55 days current low flow a year
Q_{85}-Q_{80} = 55- 73 days current low flow a year
Q_{80}-Q_{0} = 73- 365 days current low flow a year

When the frequency of the baseline Q_{90} is lower than 90 (red, orange and yellow dots), the area becomes drier. A drier area means a negative effect on navigation. When the frequency of the baseline Q_{90} is higher then 90 (light blue and dark blue dots), the area becomes wetter. A wetter area means a positive effect on navigation.

Uncertainties

Uncertainties follow from:

- WaterGAP computation of monthly average discharge
- For the navigation sector the number of days below navigable depth is of interest. The distribution of those days over the year is important: days in sequence are better than single days.

The Q_{90} is derived from monthly discharges. For a more accurate result, daily discharges are required. Furthermore, the discharges are determined on catchments scales, so local variations can not be distinguished.

Validation

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

3.2 Results

Figure 3.3 to 3.10 show the change in Q_{90} with respect to the baseline for the main navigation routes.

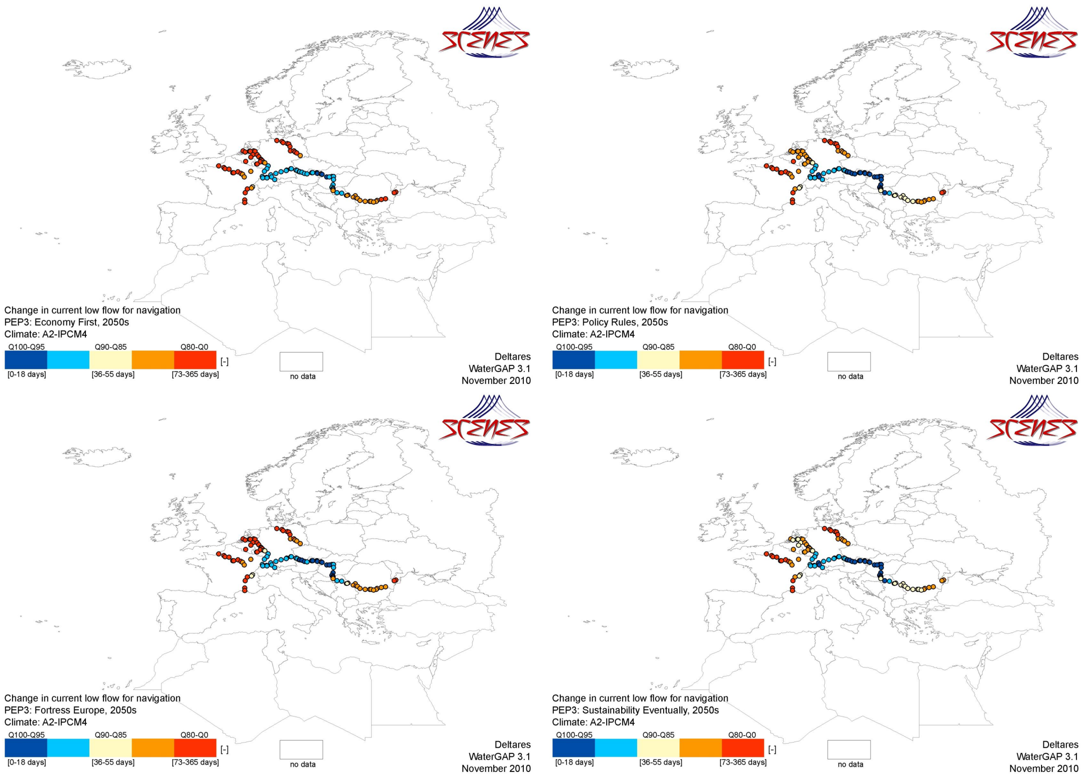

Figure 3.3 until 3.6 (left to right). Change in current low flow for navigation under the IPCM scenario. Economy First: Figure 3.3. Policy Rules: Figure 3.4. Fortress Europe: Figure 3.5. Sustainability Eventually: Figure 3.6.

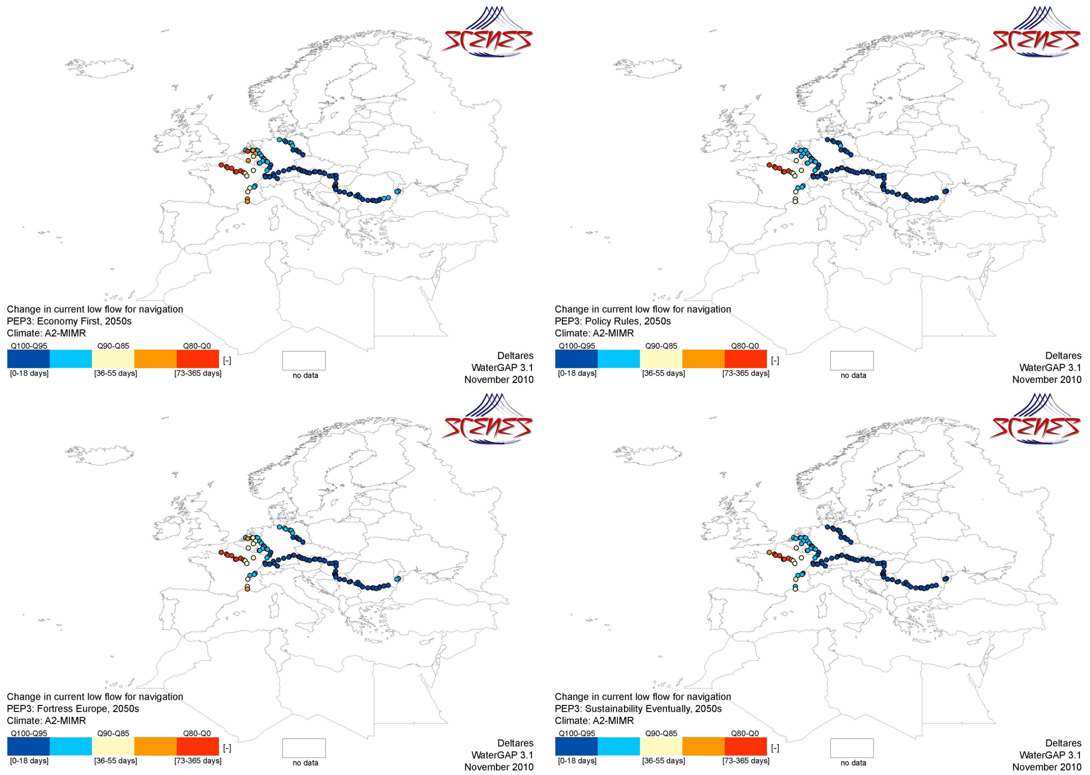

Figure 3.7 until 3.10 (left to right). Change in current low flow for navigation under the MIMR scenario. Economy First: Figure 3.7. Policy Rules: Figure 3.8. Fortress Europe: Figure 3.9. Sustainability Eventually: Figure 3.10.

Change in frequency of current low flows

Between the different socio-economical scenarios not many differences can be distinguished. For the IPCM climate scenario all rivers, except for the Danube, have a longer duration during which the current Q90 is exceeded compared to the baseline scenario. This means the river becomes drier. For the Danube, the largest part has a higher frequency of the low flow. Only the western part of the Danube has a lower frequency of the low flow.

For the MIMR climate-scenario only the rivers in France and Belgium have a lower frequency of the low flow. The other rivers have a higher frequency of low flow.

Change of the Agreed low flow

The agreed low flow (OLA) can be defined as: local discharge which is not reached during 20 (ice-free) days a year ($\approx Q_{94}$). The OLA has been defined for the river Rhine. For the indicator analysis 3 locations on the Rhine have been chosen. In theory, the OLA should be the same as the Q_{94} of the baseline. As shown in Table 3.3, this is not the case. The difference can be caused by the use of monthly discharges for the determination of the Q_{94} of the baseline instead of the use of daily discharges for the determination of the OLA.

Table 3.3 Results change in agreed low flow

	Maxau	**Wesel**	**Lobith**
Agreed low flow (Q_{94})*	585	935	1.020
Q_{94} Baseline	625	1.211	1.197
Q_{94} EcF- MIMR	709	1.255	1.262
Q_{94} FoE- MIMR	716	1.289	1.296
Q_{94} PoR- MIMR	724	1.328	1.333
Q_{94} SuE- MIMR	731	1.364	1.366
Q_{94} EcF- IPCM	626	999	996
Q_{94} FoE- IPCM	630	1.026	1.023
Q_{94} PoR- IPCM	641	1.088	1.090
Q_{94} SuE- IPCM	648	1.117	1.115

***Based on measurements

The table shows (nearly) all calculated Q_{94}'s are above the OLA. This will mean that there will be no negative effect on navigation due to the climate change and socio-economic developments. However, when assumed OLA and Q_{94} baseline are the same, the climate-scenario IPCM will have a negative effect on navigation.

3.3 Synthesis

Between the different socio-economical scenarios not many differences can be distinguished. In general the IPCM-climate scenario shows more frequent low flow situations than the MIMR-climate scenario. For a summary of the observed changes in all regions, see Table 3.4. Climate change dominates this indicator; the effect of the socio-economic scenarios is small. Since the results per region do not vary much between scenarios, the trends indicated are relatively certain.

Table 3.4 Regional impacts as deviation from the baseline scenario - navigation

		Northern Africa	Western Europe	Northern Europe	Southern Europe	Central/Eastern Europe	Eastern Europe	Western Asia
IPCM	EcF	*no data*	- / +	*no data*	*no data*	+	-	*no data*
	FoE	*no data*	- / +	*no data*	*no data*	+	-	*no data*
	PoR	*no data*	- / +	*no data*	*no data*	+	-	*no data*
	SuE	*no data*	- / +	*no data*	*no data*	+	-	*no data*
MIMR	EcF	*no data*	- / +	*no data*	*no data*	++	++	*no data*
	FoE	*no data*	- / +	*no data*	*no data*	++	++	*no data*
	PoR	*no data*	- / +	*no data*	*no data*	++	++	*no data*
	SuE	*no data*	- / +	*no data*	*no data*	++	++	*no data*

3.4 References

Rijkswaterstaat, 2009. *Handreiking watertekorten scenario's watertekorten versie 2.1*. Ministry of Public Works, Transport and Water Management (*In Dutch).*

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

4 Water for Industry 3 – Cooling water stress

4.1 Introduction

On average, about 40% of total European water abstraction is used for cooling. Therefore together with agriculture it is one of the main drivers for water abstraction. Cooling water abstraction and discharges may be limited or prohibited during extreme dry and warm periods, whilst future electricity generation will increase cooling water requirements

Industry 3 looks at the cooling water topic from the water availability perspective and is defined as the water demand for cooling in relation to low flow conditions.

4.2 Method

Calculation approach

Water stress for cooling water is calculated by dividing withdrawals for energy generation by Q_{90} (the level at which flows are exceeded 90% of the time).

Input data

Input data is provided by WaterGAP output and based on grid cell-resolution. Q_{90} (and water stress for cooling water) are calculated per month. See for more information on calculation of Q_{90} based on natural flows the indicator Water 3 – Water Scarcity Index.

Thresholds and critical values

<10%	= No water stress
10-20%	= Low water stress
20-40%	= Water stress
>40%	= Severe Water stress

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 indicator is calculated through further post-processing of WaterGAP outputs. For further comments on the use of scarcity/stress indicators using Q_{90}, please see the reactions from the Pilot Areas included in the chapter on Water 3 – water scarcity index.

4.3 Results

4.3.1 Baseline scenario

In the baseline scenario medium cooling water stress can be observed in many parts of Europe, except the Northern region (Figure 4.1). Severe cooling water stress occurs in parts of Western Europe, Western Asia and most parts in Northern Africa.

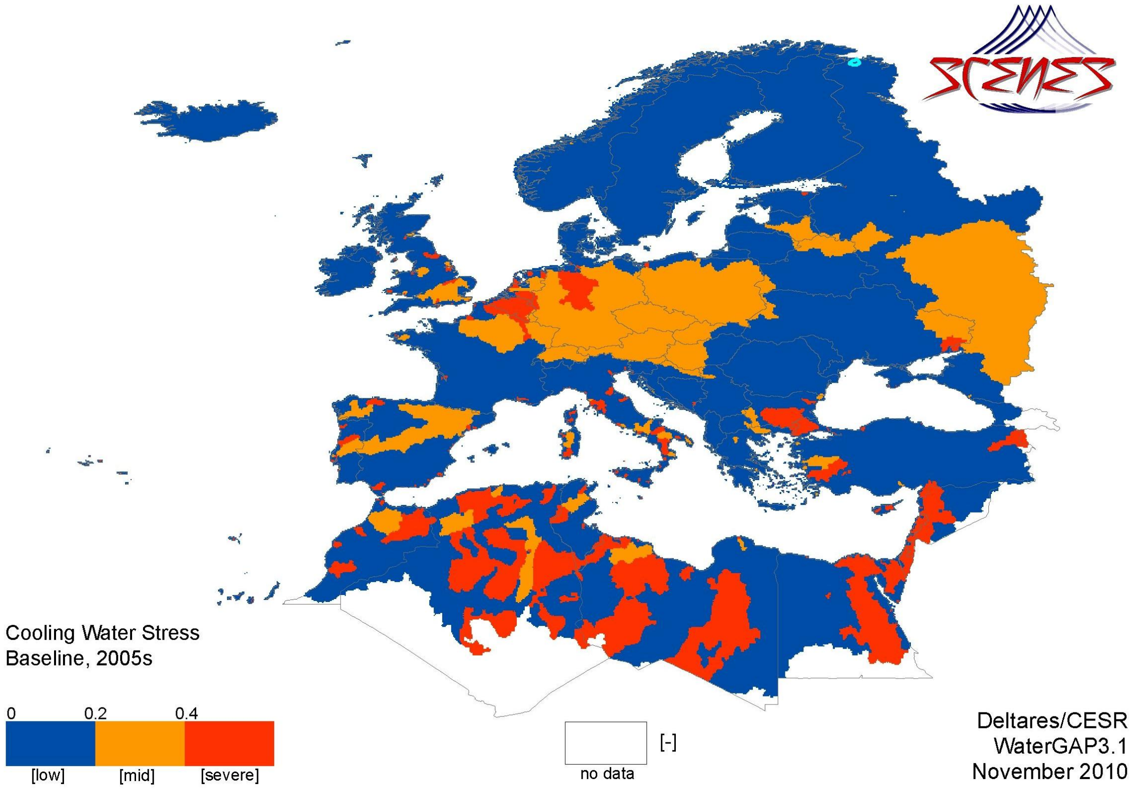

Figure 4.1 Cooling water stress for the baseline scenario expressed as the fraction of withdrawals over availability

4.3.2 Future scenarios

General pattern

In Figures 4.10 to 4.11, a slight decrease in Southern Europe and Western Asia can be observed for Q_{90}, whereas small increase in Q_{90} is observed in Northern, parts of Central and Eastern Europe for all two climate scenarios. Western Europe and parts of Central Europe show either a decrease or increase in Q_{90} depending on the climate scenario. Water withdrawals for cooling water decrease significantly in the whole of Europe for both the Policy Rules and Sustainability Eventually scenarios. For the Fortress of Europe scenario there is little change and a small increase is observed for the Economy First scenario. The cooling water stress is reduced in the Policy Rules and Sustainability Eventually scenarios and unchanged or slightly increased in the Fortress of Europe and Economy First scenarios.

Socio economic and climate scenarios

There are large differences in cooling water stress between the eight scenarios. Compared to the baseline scenario the cooling waters stress slightly increases or remains the same for the Economy First and the Fortress Europe scenarios. Cooling water stress decreases drastically for the Policy Rules and Sustainability Eventually scenarios. In all cases the cooling waters stress is lower under the A2-MIMR climate scenario compared to A2-IPCM4, which is related to the change in Q_{90} (Figures 4.10 to 4.11). The most severe cooling water stress is observed under the Economy First A2-IPCM4 scenario. Under the Sustainability Eventually A2-MIMR scenario almost all river basins fall into the low risk class. However, some river basins in Northern Africa may still show a severe risk in cooling water stress.

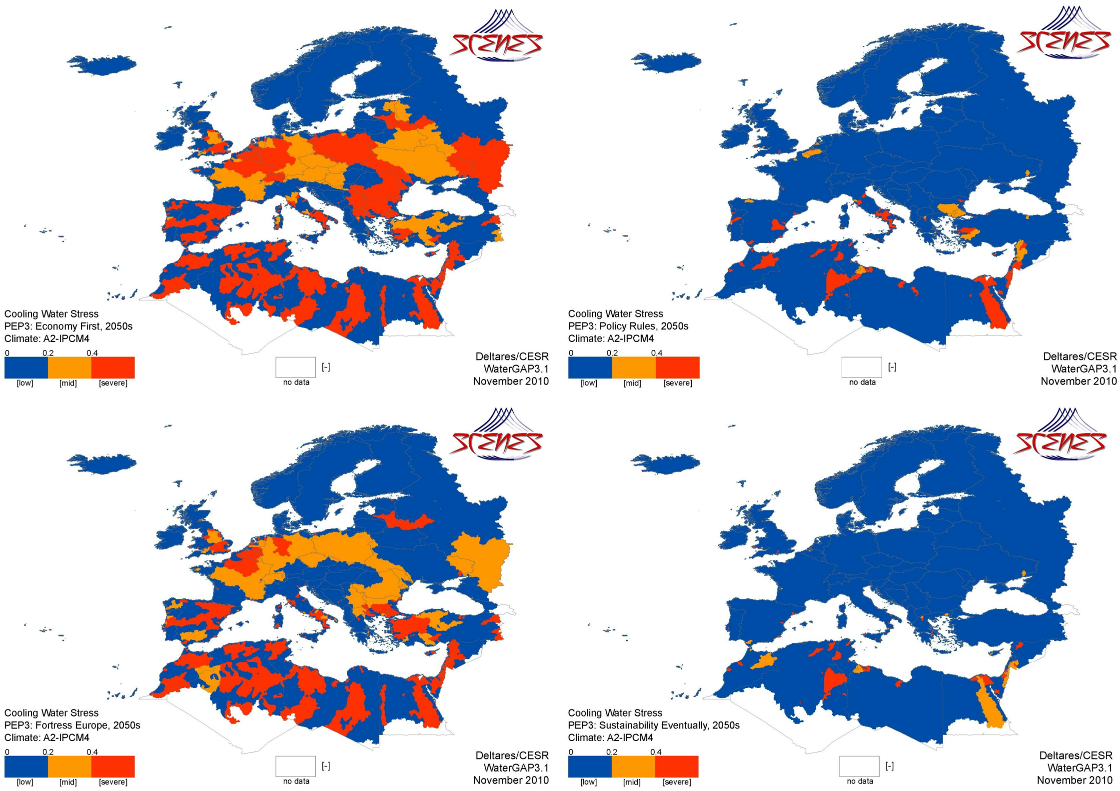

Figure 4.2 until 4.5 (left to right). Cooling water stress under the IPCM scenario. Economy First: Figure 4.2. Policy Rules: Figure 4.3. Fortress Europe: Figure 4.4. Sustainability Eventually: Figure 4.5.

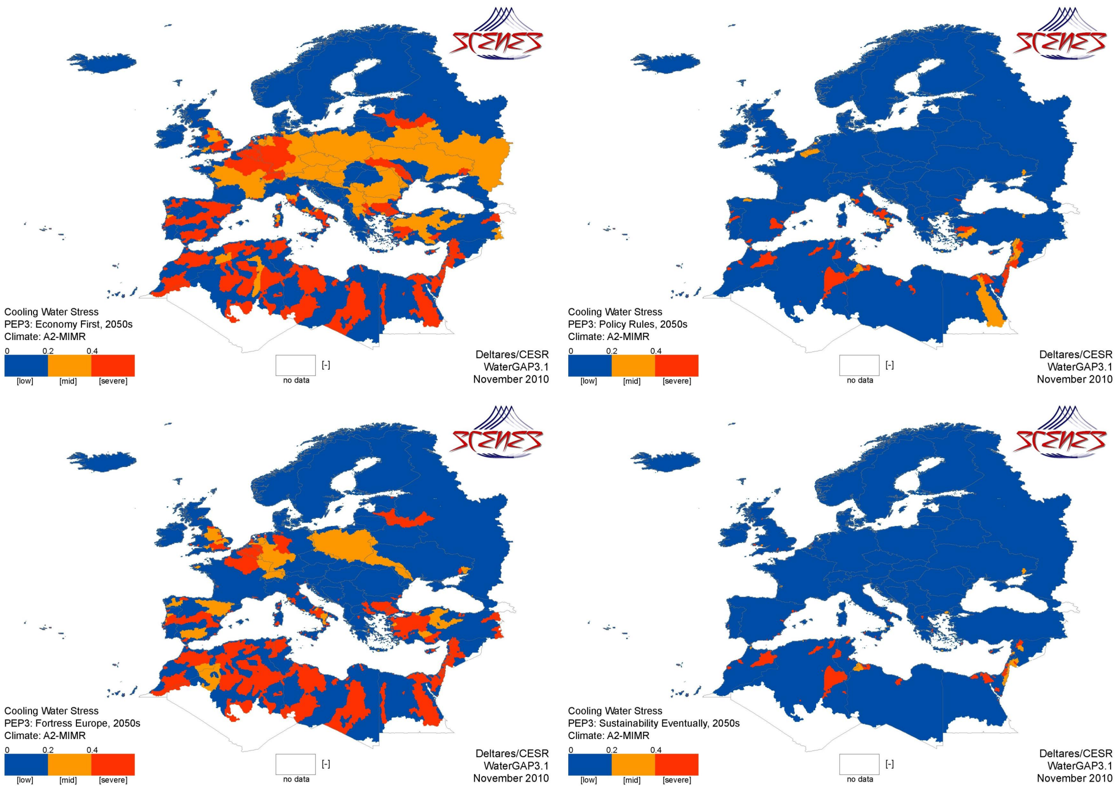

Figure 4.6 until 4.9 (left to right). Cooling water stress under the MIMR scenario. Economy First: Figure 4.6. Policy Rules: Figure 4.7. Fortress Europe: Figure 4.8. Sustainability Eventually: Figure 4.9.

The socio-economic scenarios have a large impact on the future cooling water stress. The changes in withdrawals for electricity generation (Figures 4.12 to 4.16) lead to increased cooling water stress for EcF. For FoE, the cooling water stress remains more or less unchanged under the A2-IPCM4 climate scenario and slightly decreases under the A2-MIMR climate scenario. The cooling water stress decreases for both PoR and SuE scenarios. The impact of the socio-economic scenarios is larger than the climate scenarios. However, in individual river basins the climate scenario can make the difference between the risk level.

Change in Q_{90}

A clear difference in change in Q_{90} can be observed between the two climate scenarios. Whereas for A2-MIMR in most parts of Pan-Europe, excluding the Iberian Peninsula and Western Asia, the natural low flow (Q_{90}) is increasing, for A2-IPCM4 most river basins in Western, Central and Eastern Europe show a strong decrease in Q_{90}. In general, the low flow periods in the A2-IPCM4 climate scenario get drier (Figures 4.10 to 4.11).

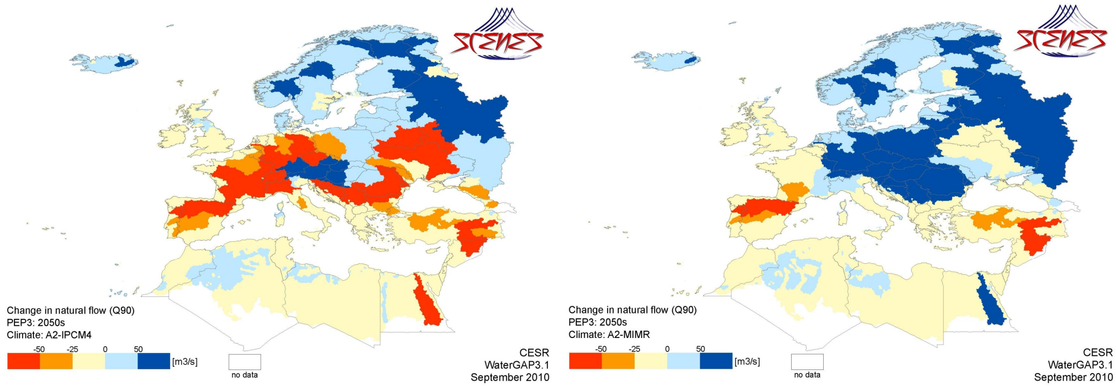

Figure 4.10 (left) and 4.11 (right) Change in natural flow (Q90) between the baseline and the IPCM (Figure 4.10) and MIMR (Figure 4.11) climate scenarios.

Withdrawals for electricity generation

EcF shows a small increase in water withdrawals for electricity generation, FoE more or less equals the baseline scenario, both PoR and SuE show a large decrease in withdrawals.

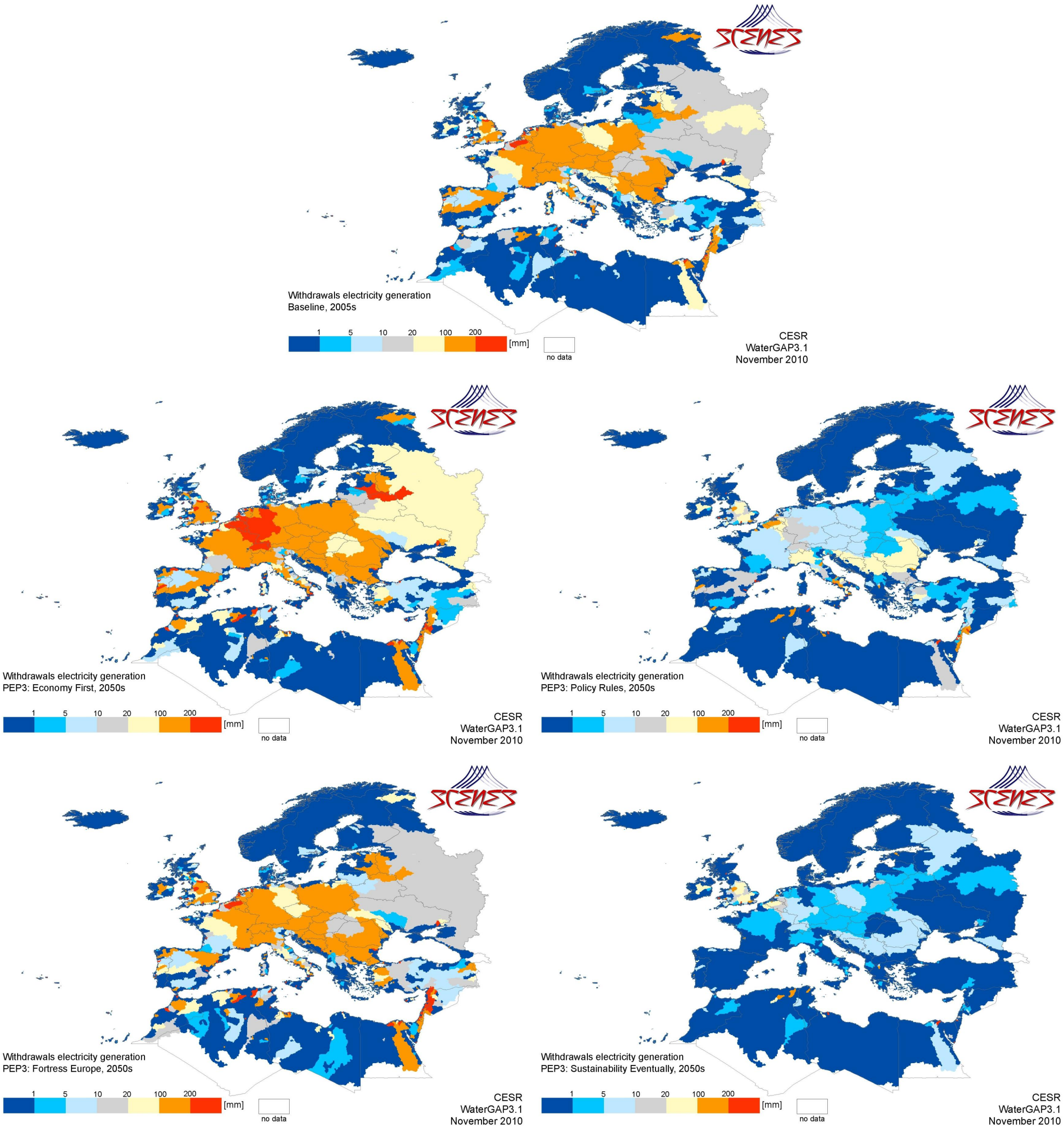

Figure 4.12 until 4.16 (left to right). Water withdrawals for electricity generation. Baseline: Figure 4.12. Economy First: Figure 4.13. Policy Rules: Figure 4.14. Fortress Europe: Figure 4.15. Sustainability Eventually: Figure 4.16.

4.4 Synthesis

Climate change plays an important role and shows significant differences between the Scenes Regions. Although the two climate scenarios show different patterns, in general the western part becomes drier, whereas more inland and in the northern parts the climate becomes wetter, which has a significant effect on low flows and related cooling water stress.

The industrial sectors are clearly impacted by changes in water availability and economic growth. This impact is not always negative, as a reduction of water stress for cooling water can be large, or in the worst case does not show a significant difference with the baseline scenario. Policies can make a big difference in cooling water withdrawals as can be seen from the socio-economic scenarios. However, in combination with temperature rise the cooling capacity in many rivers across Europe reduces and may therefore pose serious problems associated to cooling water needs in summer months. For a summary of the observed changes in all regions, see Table.

Table. Regional observations on changes with respect to the baseline scenario

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

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.

5 Key messages

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

- What are the key messages?
- 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 5.1

In Table 5.1, the indicators are grouped slightly differently and the main input data are included as well:

- Climate-driven input:
    - Natural river water temperature
    - Low flows (Q90)
- Socio-economic driven input:
    - Excess river water temperature
    - Withdrawals for electricity production
- Indicators in which climate change and socio-economic change have been combined:
    - Extra demand for cooling water
    - Navigability of rivers
    - Cooling water stress

What are the key messages?

- Although lows flows may increase in some regions in Europe, especially under the A2-IPCM4 climate scenario, this does not directly pose a large pressure on the navigability in terms of Agreed low flow.

- Also the climate related increased low flows are in most socio economic scenarios compensated or even over-compensated by reduction in water withdrawals for electricity production, in general leading to reduced cooling water stress.

- However, climate induced temperature rise poses a clear risk for reduced cooling water capacity.

- Therefore, building of new power plants with cooling water requirements should be discouraged.

- Also, the energy sector should anticipate to longer periods where water temperature levels exceed critical values.

What is the overall image per region?

Northern Africa
Overall result: not much improvement, stress remains in many parts of NA, but as for this region for 2 drivers and 2 indicators values are missing, it is not possible to draw further conclusions from this result. It is therefore also not possible to determine whether for the total result CC or S-E is dominant.

Western Europe
Overall result: The development of water availability in this region is highly uncertain. In western Europe results for different scenarios range from negative impacts for the entire region to positive impacts for the entire region. The emphasis is however slightly on negative impacts.

Northern Europe
Overall result: The results for northern Europe show that this area becomes wetter: reduced low flow, but natural temperature rise leads to increased stress in parts where demand is high. Data on navigability is missing for this region.

Table 5.1 Aggregation of generic indicator results

Region	**Climate**				**Socio-economic**				**Impacts**					
	Natural river water temperature		**Low flow (Q90)**		**Excess river water temperature**		**Withdrawal for electricity generation**		**Extra demand for cooling water**		**Navigability of rivers**		**Cooling water stress**	
	Focus	**Uncertainty**	**Focus**	**uncertainty**	**Focus**	**uncertainty**	**Focus**	**uncertainty**	**Focus**	**uncertainty**	**Focus**	**uncertainty**	**Focus**	**uncertainty**
N. Africa			-/+	M			-/+	M					- or ++	H
W. Europe	-	L	-/+	M	-- or +	H	- or ++	H	--	L	- or +	M	- or ++	H
N. Europe	--	L	+	L	- or o	L	o or +	L	- or o	L			- or +	H
S. Europe	-	L	-	L	-- or o	M	o or ++	H	--	L			-- or +	H
C/E. Europe	-	L	+	L	-- or +	H	o or ++	H	--	L	++	L	+	H
E. Europe	-	L	+	L	- or +	H	- or +	H	-	L	- or ++	H	- or +	H
W. Asia	-	L	-	L	-- or +	H	o or +	M	--	L			- or ++	H

Southern Europe

Overall result: Water availability in this region in the future is likely to decrease. Also, natural water temperature is increased. Even though excess water temperature is reduced, water stress for cooling purposes is mainly expected to increase. Data on navigability is missing for this region.

Central/Eastern Europe
Overall result: Water availability during low flows in this region in the future is likely to increase. Even though this reduces the (cooling) water stress increased temperature lead to higher demands and stress is expected to grow. Navigability is independent of temperature and therefore expected to improve.

Eastern Europe
Overall result: Water availability in this region is likely to increase. With increasing temperature and highly uncertain withdrawals and excess temperatures stress is likely to increase. The change in navigability conditions is highly uncertain, with a slight tendency for improvement.

Western Asia
Overall result: availability during low flows in this region in the future is likely to decrease. With slightly reduced withdrawals cooling water stress is expected to decrease. However due to increasing temperature the water demand should increase leading to an overall increased water stress. Data on navigability is missing for this region.

Are there big differences between regions?
Table 5.1 shows that for some indicators, such as extra demand for cooling water, most regions experiences high stress. This is largely due to increased natural water temperatures. Even though the excess temperature is much more uncertain, this does not compensate for the increase in natural temperature in any scenario or region.
Navigability of rivers is only analysed for regions with a likely increase of water availability and therefore all tend to have better navigability in the future. For cooling water stress the changes are highly uncertain, and also the differences between regions are more pronounced. This is directly related to the large differences in withdrawals between regions as well as the scenarios. It is prominent that the stress is higher under the IPCM climate scenario for all regions. As a result of the relative small amount of withdrawals, low population densities and a high latitude, Northern Europe is not expected to have high stress for the energy sector in future. In southern regions where temperatures are already high and expected to increase in future scenarios and where low flows are expected to increase as well, the energy sector will most certain be impacted especially in drier periods.

Can socio-economic changes or climate changes be identified as dominant driving force of these changes?
Table 5.2 summarises whether climate change (CC) or socio-economic change (SE) seems dominant.

Table 5.2 Dominant driving force per indicator

Indicator/driver	**CC or SE?**
Extra demand for cooling water	CC
Navigability of rivers	CC
Cooling water stress	SE/CC