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SCENES

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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 Food'.

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

This report, Volume B, discusses the Water for Food 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. The final chapter discusses the key findings that can be drawn from the analysis of the 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 7 is discussed in chapter 2 of Volume A.

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 Analysis of future trends in Water for Food

The main drivers that influence the water use for food are:

- Climate change (natural water availability, crop water deficit and temperature regime);
- Changes in cropped area, irrigated area, irrigation efficiency, crop choice and crop calendar.

In this chapter an analysis is given of the changes of the "agricultural" drivers: Irrigation efficiency, cropped area and irrigated area.

2.1 Irrigation efficiency

In general, the irrigation water use efficiency in 2050 increases due to the application of water saving techniques.

<u>The pattern over the different socio-economic scenarios</u>

Irrigation in the western countries is mainly a pressurized irrigation (sprinklers, pivots and micro-irrigation compared to other countries like Southern EU or Crimea Region where traditional irrigation by gravity is the most important.

Table 2.1 shows the irrigation efficiencies per country. The 2000 baseline irrigation efficiencies are on average 0.53 and range from 0.25 (Syria) to 0.79 (Croatia). For 2050 the efficiency increases or stagnates, except for Slovenia, where it decreases. Economy First is characterized by a stagnating efficiency (no change) except for Eastern Europe where it strongly increases, although not in Ukraine. Seen over the socio-economic scenarios the gains in efficiency increase from EcF, FoE, PoR to SuE and is 33 % average over the countries for SuE. The range in national efficiency values is between 0.45 (Moldova) and 0.85 (Croatia) in the Sue 2050 scenario. The scenarios PoR and SuE are similar in the changes in irrigation efficiencies (relative to the baseline) except for the West-, North and Central European countries under PoR where no efficiency gain is foreseen, like in EcF for many more countries. Another particularity of these West-, North and Central European countries is that the national efficiencies under FoE are higher than under SuE. Remarkably, the average efficiency under SuE for Germany and France does not improve compared to the baseline.

Table 2.1 Irrigation efficiencies per country (Center for Environmental Systems Research, University of Kassel)

irrigation efficiency PEP3 — **relative change in irrigation efficiency I**
country sorted by region — **country sorted by region**

2000	2050 EcF	2050 FoE	2050 PoR	2050 SuE	Country	2050 EcF	2050 FoE	2050 PoR	2050 SuE	region
0.41	0.41	0.57	0.73	0.73	Algeria	0.0%	39.4%	78.8%	78.8%	NA
0.33	0.33	0.49	0.65	0.65	Egypt	0.0%	48.0%	96.1%	96.1%	NA
0.49	0.49	0.65	0.81	0.81	Libya	0.0%	32.8%	65.6%	65.6%	NA
0.35	0.35	0.51	0.67	0.67	Morocco	0.0%	45.8%	91.7%	91.7%	NA
0.45	0.45	0.61	0.77	0.77	Tunisia	0.0%	35.2%	70.5%	70.5%	NA
0.62	0.62	0.72	0.62	0.69	Austria	0.0%	16.1%	0.0%	11.3%	WE
0.71	0.71	0.81	0.71	0.78	Belgium	0.0%	14.1%	0.0%	9.9%	WE
0.54	0.54	0.64	0.54	0.54	France	0.0%	18.6%	0.0%	0.0%	WE
0.62	0.62	0.72	0.62	0.62	Germany	0.0%	16.2%	0.0%	0.0%	WE
0.71	0.71	0.81	0.71	0.78	Luxembourg	0.0%	14.1%	0.0%	9.9%	WE
0.51	0.51	0.61	0.51	0.58	Netherlands	0.0%	19.5%	0.0%	13.6%	WE
0.71	0.71	0.81	0.71	0.78	Switzerland	0.0%	14.1%	0.0%	9.9%	WE
0.71	0.71	0.81	0.71	0.78	Denmark	0.0%	14.1%	0.0%	9.9%	NE
0.40	0.40	0.50	0.40	0.47	Estonia	0.0%	25.0%	0.0%	17.5%	NE
0.62	0.62	0.72	0.62	0.69	Finland	0.0%	16.2%	0.0%	11.3%	NE
0.40	0.40	0.50	0.40	0.47	Iceland	0.0%	25.0%	0.0%	17.5%	NE
0.40	0.40	0.50	0.40	0.47	Ireland	0.0%	25.0%	0.0%	17.5%	NE
0.71	0.71	0.81	0.71	0.78	Latvia	0.0%	14.1%	0.0%	9.9%	NE
0.62	0.62	0.72	0.62	0.69	Lithuania	0.0%	16.2%	0.0%	11.3%	NE
0.42	0.42	0.52	0.42	0.49	Norway	0.0%	23.8%	0.0%	16.7%	NE
0.71	0.71	0.81	0.71	0.78	Sweden	0.0%	14.1%	0.0%	9.9%	NE
0.62	0.62	0.72	0.62	0.69	UK	0.0%	16.1%	0.0%	11.3%	NE
0.56	0.56	0.73	0.78	0.79	Albania	0.0%	29.7%	38.5%	40.3%	SE
0.50	0.50	0.60	0.65	0.66	Bosnia Herzeg	0.0%	20.0%	30.0%	32.0%	SE
0.79	0.79	0.85	0.85	0.85	Croatia	0.0%	7.6%	7.6%	7.6%	SE
0.65	0.65	0.75	0.80	0.81	Greece	0.0%	15.4%	23.1%	24.7%	SE
0.54	0.54	0.64	0.64	0.64	Italy	0.0%	18.5%	18.5%	18.5%	SE
0.48	0.48	0.58	0.63	0.64	Macedonia	0.0%	20.8%	31.3%	33.3%	SE
0.48	0.48	0.58	0.63	0.64	Malta	0.0%	20.8%	31.3%	33.3%	SE
0.47	0.47	0.57	0.62	0.63	Portugal	0.0%	21.3%	32.0%	34.1%	SE
0.50	0.50	0.60	0.65	0.66	Serbia and Mo	0.0%	20.0%	30.0%	32.0%	SE
0.65	0.65	0.47	0.52	0.53	Slovenia	0.0%	-27.7%	-20.0%	-18.5%	SE
0.61	0.61	0.71	0.76	0.77	Spain	0.0%	16.4%	24.6%	26.3%	SE
0.64	0.64	0.74	0.64	0.71	Czech Republi	0.0%	15.5%	0.0%	10.9%	CEE
0.64	0.64	0.74	0.64	0.71	Hungary	0.0%	15.5%	0.0%	10.9%	CEE
0.44	0.44	0.54	0.44	0.51	Poland	0.0%	22.6%	0.0%	15.8%	CEE
0.65	0.65	0.75	0.65	0.72	Slovakia	0.0%	15.4%	0.0%	10.8%	CEE
0.62	0.78	0.78	0.78	0.78	Belarus	25.8%	25.8%	25.8%	25.8%	EEE
0.36	0.52	0.52	0.52	0.52	Bulgaria	45.1%	45.1%	45.1%	45.1%	EEE
0.29	0.45	0.45	0.45	0.45	Moldova	55.2%	55.2%	55.2%	55.2%	EEE
0.46	0.62	0.62	0.62	0.62	Romania	34.5%	34.5%	34.5%	34.5%	EEE
0.52	0.68	0.68	0.68	0.68	Russian Feder	30.8%	30.8%	30.8%	30.8%	EEE
0.52	0.52	0.68	0.68	0.68	Ukraine	0.0%	30.5%	30.5%	30.5%	EEE
0.67	0.67	0.67	0.85	0.85	Cyprus	0.0%	0.0%	27.6%	27.6%	WA
0.29	0.29	0.29	0.61	0.61	Georgia	0.0%	0.0%	110.3%	110.3%	WA
0.66	0.66	0.66	0.85	0.85	Israel	0.0%	0.0%	29.0%	29.0%	WA
0.42	0.42	0.42	0.74	0.74	Lebanon	0.0%	0.0%	76.9%	76.9%	WA
0.25	0.25	0.25	0.57	0.57	Syrian Arab Re	0.0%	0.0%	126.0%	126.0%	WA
0.29	0.29	0.29	0.61	0.61	Turkey	0.0%	0.0%	110.0%	110.0%	WA

<u>The regional pattern</u>

Northern Africa: Baseline efficiency is rather low, around 0.40. Zero increase in EcF, Very high increases in PoR and SuE, efficiencies range from 0.67 to 0.81. relative increases since 2000 are from 66 to 96 percent. The gain in FoE is halfway between EcF and the other two scenarios.

Western, Northern and Central Europe: Stagnation in EcF and PoR, modest increases (relative increase 10 – 25 percent) in FoE and SuE, (except zero change in Sue 2050 for Germany and France).

Southern Europe: No improvement in efficiency in EcF, some 18- 40% increase in efficiency in FoE, and 18-40 percent in PoR and SuE. Exceptions: no difference between FoE, PoR and SuE in Italy (all three 18.5% increase) and Croatia (all three 7.6% increase). Slovenia shows strong decrease in efficiency.

Eastern Europe: Strong increase in efficiency of 26 to 55%. Whole region moves from rather low to high efficiency. All scenarios are equal except EcF Ukraine (no change since 2000).

Western Asia: Stagnation (zero change) under EcF and FoE, while under PoR and SuE the whole region moves from mixed to high efficiency, strong improvements in Georgia, Turkey and Syria (over 100% increases).

2.2 Rainfed and irrigated cropland

The WaterGAP land use data sets distinguish area extents of land per crop, total crop land and irrigated cropland. These data do vary over the four socio-economic scenarios and in addition over the two climate scenarios. So there are eight realisations of land use scenarios. In relation with Food indicators an important factor to take into account is the development in the total extent of cropland. In some countries this may shrink, while the irrigated area increases.

<u>The baseline situation</u>

First of all, the irrigated area (or rather area equipped for irrigation) constitutes a very small part of the total cropland in Europe, and its neighbouring regions (Table 2.2). Egypt is a special case with nearly 50% of the crop land under irrigation. In southern Europe Greece has the highest fraction of the crop land irrigated (17%), while Italy, Spain, and Portugal are around 10% irrigated. The fractions irrigated crop land in Western Asia are in the same range (9-17%), only Cyprus is far lower. In Western and Northern Europe the highest fractions irrigated and irrigable areas are located in the Netherlands (20%) followed by Norway (12%) and Denmark, France and Sweden (close to 10%). Romania and Slovakia are at 6%. Most other countries are below 3%.

Table 2.2 Landuse data for baseline (data from Center for Environmental Systems Research, University of Kassel)

country name	region	base2000 rainfed crops	base2000 irrigated area	base2000 total cropland	fraction irrig cropland baseline
Algeria	NA	76759	2071	78830	2.63%
Egypt	NA	20573	20017	40589	49.32%
Lybian Arab Jamahiriya	NA	23939	1347	25286	5.33%
Morocco	NA	67856	6046	73902	8.18%
Tunisia	NA	42055	1889	43943	4.30%
Austria	WE	11752	410	12162	3.37%
Belgium	WE	7194	158	7351	2.15%
France	WE	115532	12571	128103	9.81%
Germany	WE	112160	3507	115667	3.03%
Netherlands	WE	6342	1607	7949	20.21%
Switzerland	WE	2956	64	3020	2.11%
Denmark	NE	15840	1601	17441	9.18%
Estonia	NE	4857	8	4866	0.17%
Finland	NE	12676	312	12988	2.40%
Iceland	NE	0	0	0	n.a.
Ireland	NE	7040	22	7063	0.32%
Latvia	NE	38215	29	38244	0.08%
Lithuania	NE	63912	49	63961	0.08%
Norway	NE	5465	730	6195	11.79%
Sweden	NE	12833	1235	14068	8.78%
United Kingdom	NE	52844	1364	54208	2.52%
Albania	SE	3611	1062	4673	22.73%
Bosnia and Herzegovina	SE	14129	103	14232	0.72%
Croatia	SE	10612	258	10870	2.38%
Greece	SE	45098	9513	54611	17.42%
Italy	SE	193701	22270	215971	10.31%
Macedonia	SE	3695	211	3906	5.41%
Malta	SE	847	14	861	1.67%
Portugal	SE	29321	3083	32404	9.51%
Serbia and Montenegro	SE	28965	1060	30025	3.53%
Slovenia	SE	2340	20	2359	0.84%
Spain	SE	278544	29968	308512	9.71%
Czech Republic	CEE	23277	569	23845	2.38%
Hungary	CEE	36068	872	36940	2.36%
Poland	CEE	99065	318	99383	0.32%
Slovakia	CEE	10046	671	10717	6.26%
Belarus	EEE	135334	373	135707	0.27%
Bulgaria	EEE	25804	984	26787	3.67%
Moldova	EEE	14401	2255	16656	13.54%
Romania	EEE	57106	3575	60681	5.89%
Russian Federation	EEE	455538	8439	463977	1.82%

country name	region	base2000 rainfed crops	base2000 irrigated area	base2000 total cropland	fraction irrig cropland baseline
Ukraine	EEE	125024	4540	129564	3.50%
Cyprus	WA	10070	221	10291	2.15%
Georgia	WA	12792	1325	14116	9.38%
Israel	WA	9137	1254	10391	12.07%
Lebanon	WA	7338	800	8138	9.82%
Syrian Arab Republic	WA	40528	8177	48706	16.79%
Turkey	WA	165950	25489	191439	13.31%

The share of irrigated crop land influences the crop production. As long as the fraction irrigated land is low, the bulk of the agricultural production comes from rainfed land and the influence of changes in irrigated area on national crop production volume remains low. Yet, changes in irrigated area have immediate effects on the irrigation water requirement and irrigation water stress. For example, even with 10% to 15% irrigation remains the first water consumer among all water services, even in Western EU.

<u>Future changes in irrigated area</u>

Table 2.3 shows the changes in irrigated areas upto 2050. In northern Africa (Algeria, Morocco, Tunisia), the irrigated area increases in 2050, most strongly in the EcF and FoE scenarios. The irrigated area also increases for western Europe (Germany, France). For the Mediterranean countries however (Italy, Spain, Portugal), a general pattern of decrease in irrigated area can be seen, except for the EcF scenario. The differences between IPCM2050 and MIMR2050 scenarios are rather small.

<u>The regional pattern: total crop area and irrigated fraction</u>

For northern African countries, the total crop land increases, while for most of the European countries the total crop area decreases (Table 2.4). In the European regions the tendency is that the total crop land shrinks considerably by proportions of commonly between 20 to 50% (impact on food production). The shrinkage of total cropped area is moderate in EcF and FoE (average approximately 20% less crop land), and clearly more strong in PoR and SuE (average approximately 30% less crop land).

Countries with decreases in irrigated area over all scenarios are Denmark, Greece, Italy, Portugal, Russia, Ukraine, Cyprus, Israel, Lebanon, Turkey. A few other countries have the same decreasing trend over most scenarios but with notable exceptions: Spain has irrigated area shrinkage of 15-38% in 7 scenarios except EcF-IPCM2050, which has a 70 percent expansion. Similar contrasts in 6 shrinkage versus 2 expansion scenarios for Norway, Slovenia, Slovakia. In some countries the number of both increasing and decreasing irrigated cropland scenarios equals 4: Cyprus, Macedonia and Poland.

Strong irrigated area expansion in Northern Africa and Malta, with a mixed pattern in Egypt. Very strong relative expansion (often two- to fourfold) in most countries of West, North and Central Europe, especially where the initial baseline situation had a low fraction irrigated area the area it may be ten-fold or more. In Romania the expansion is limited, not more than 11%. In West Asia the pattern is very contrasting: shrinkage in Cyprus, Israel, Lebanon, Turkey, and strong expansion in Georgia and Syria.

Table 2.3 Change in irrigated area for future scenarios (Center for Environmental Systems Research, University of Kassel)

increase in irrigated area since 2000

country name	EcF_2050 _IPCM increase irr area since 2000	EcF_2050 _MIMR increase irr area since 2000	FoE_2050 _IPCM increase irr area since 2000	FoE_2050 _MIMR increase irr area since 2000	PoR_2050 _IPCM increase irr area since 2000	PoR_2050 _MIMR increase irr area since 2000	SuE_2050 _IPCM increase irr area since 2000	SuE_2050 _MIMR increase irr area since 2000
Algeria	385%	355%	400%	361%	217%	213%	184%	179%
Egypt	-4%	-9%	36%	32%	27%	32%	-6%	-9%
Lybian Ara	36%	57%	42%	83%	7%	21%	13%	7%
Morocco	217%	189%	236%	245%	148%	160%	133%	135%
Tunisia	440%	425%	475%	524%	208%	187%	142%	119%
Austria	339%	251%	347%	298%	169%	159%	183%	190%
Belgium	180%	205%	321%	358%	171%	159%	219%	177%
France	225%	256%	213%	253%	5%	73%	16%	73%
Germany	439%	407%	564%	529%	300%	284%	319%	285%
Netherland	130%	120%	115%	124%	63%	59%	65%	61%
Switzerlan	353%	579%	321%	258%	354%	253%	127%	240%
Denmark	-31%	-36%	-12%	-14%	-36%	-37%	-48%	-50%
Estonia	1785%	765%	2666%	798%	1540%	672%	966%	667%
Finland	346%	264%	357%	298%	321%	278%	190%	141%
Iceland								
Ireland	1085%	1051%	1446%	1446%	887%	893%	860%	849%
Latvia	1387%	634%	2108%	527%	1319%	495%	1179%	576%
Lithuania	602%	484%	1034%	602%	461%	412%	304%	247%
Norway	13%	14%	-52%	-60%	-67%	-58%	-59%	-52%
Sweden	189%	202%	172%	147%	53%	74%	2%	-4%
United Kin	306%	285%	104%	72%	47%	4%	-20%	-31%
Albania	76%	63%	70%	69%	54%	58%	79%	71%
Bosnia an	342%	691%	266%	667%	365%	396%	334%	523%
Croatia	422%	241%	200%	210%	194%	219%	220%	257%
Greece	-25%	-30%	-38%	-38%	-34%	-37%	-30%	-35%
Italy	-10%	-9%	-15%	-17%	-13%	-14%	-10%	-9%
Macedonia	56%	70%	10%	-3%	-20%	-22%	20%	-13%
Malta	571%	921%	60%	352%	113%	464%	115%	121%
Portugal	-21%	-19%	-22%	-26%	-26%	-26%	-17%	-17%
Serbia and	146%	145%	117%	190%	107%	136%	68%	86%
Slovenia	-80%	-81%	-42%	-58%	-62%	-43%	220%	142%
Spain	70%	-19%	-27%	-38%	-29%	-36%	-15%	-33%
Czech Re	31%	33%	10%	4%	11%	29%	35%	20%
Hungary	139%	231%	91%	235%	-43%	29%	-38%	5%
Poland	131%	126%	167%	156%	-13%	-11%	-7%	-14%
Slovakia	-3%	-23%	31%	-12%	-19%	-43%	20%	-24%
Belarus	552%	523%	355%	304%	197%	171%	-11%	-18%
Bulgaria	33%	40%	23%	13%	21%	10%	12%	11%
Moldova	108%	114%	76%	78%	60%	70%	-26%	-22%
Romania	10%	7%	10%	11%	11%	8%	5%	-3%
Russian F	-4%	-34%	-27%	-42%	-43%	-52%	-54%	-61%
Ukraine	-1%	-28%	-11%	-44%	-37%	-60%	-50%	-60%
Cyprus	-33%	-47%	-41%	-18%	-48%	-19%	-13%	-9%
Georgia	190%	85%	70%	46%	2%	-16%	-9%	-25%
Israel	-35%	-35%	-44%	-37%	-31%	-43%	-28%	-23%
Lebanon	-30%	-22%	-20%	-5%	-5%	-10%	-28%	-26%
Syrian Ara	58%	64%	76%	74%	72%	68%	33%	32%
Turkey	-14%	-6%	-10%	-5%	-29%	-25%	-26%	-28%

Table 2.4 Change in total crop area (data from Center for Environmental Systems Research, University of Kassel)

increase crop area since 2000

country name	EcF_2050_IPCM increase crop area since 2000	EcF_2050_MIMR increase crop area since 2000	FoE_2050_IPCM increase crop area since 2000	FoE_2050_MIMR increase crop area since 2000	PoR_2050_IPCM increase crop area since 2000	PoR_2050_MIMR increase crop area since 2000	SuE_2050_MIMR increase crop area since 2000	SuE_2050_MIMR increase crop area since 2000
Algeria	130.3%	166.1%	142.4%	235.2%	51.1%	75.3%	67.5%	67.5%
Egypt	-14.9%	-36.2%	4.3%	-11.0%	23.0%	-2.0%	-15.9%	-15.9%
Lybian Ara	-10.9%	-13.5%	-3.4%	-3.7%	-22.0%	-22.3%	-19.8%	-19.8%
Morocco	95.7%	111.9%	94.9%	107.3%	34.0%	42.4%	52.5%	52.5%
Tunisia	47.5%	81.6%	59.6%	143.4%	7.5%	12.4%	11.9%	11.9%
Austria	-30.8%	-25.2%	-32.7%	-30.3%	-36.2%	-34.7%	-36.6%	-36.6%
Belgium	-22.0%	-18.7%	-32.9%	-32.0%	-31.0%	-29.9%	-38.9%	-38.9%
France	-8.2%	-5.5%	-9.1%	-6.8%	-27.2%	-22.0%	-31.7%	-31.7%
Germany	-31.8%	-30.2%	-35.0%	-31.4%	-33.8%	-33.8%	-35.6%	-35.6%
Netherland	-31.3%	-33.6%	-34.1%	-31.5%	-44.4%	-48.9%	-47.4%	-47.4%
Switzerlan	6.0%	15.6%	-0.3%	1.6%	-4.6%	-6.1%	-18.2%	-18.2%
Denmark	-40.5%	-42.5%	-31.0%	-33.8%	-43.2%	-45.5%	-52.9%	-52.9%
Estonia	-20.9%	-28.2%	-16.2%	-24.5%	-24.5%	-30.9%	-38.2%	-38.2%
Finland	-21.1%	-29.3%	-18.8%	-25.8%	-27.5%	-31.6%	-45.6%	-45.6%
Iceland								
Ireland	-1.8%	-5.1%	2.8%	-1.6%	-2.3%	-7.3%	-21.3%	-21.3%
Latvia	-29.1%	-12.4%	-32.8%	-14.7%	-25.9%	-15.8%	-18.3%	-18.3%
Lithuania	-18.0%	-20.5%	-20.2%	-18.9%	-20.6%	-21.0%	-21.6%	-21.6%
Norway	5.0%	-4.4%	-27.1%	-24.9%	-39.9%	-33.4%	-43.1%	-43.1%
Sweden	-16.3%	-16.1%	-17.9%	-24.1%	-37.3%	-33.7%	-50.9%	-50.9%
United Kin	-22.6%	-24.7%	-42.4%	-45.3%	-49.3%	-50.7%	-54.2%	-54.2%
Albania	2.0%	3.4%	-9.4%	-4.2%	-10.0%	-8.6%	-8.8%	-8.8%
Bosnia and	-24.5%	-9.7%	-32.5%	-21.4%	-33.0%	-13.2%	-22.5%	-22.5%
Croatia	-28.2%	-21.5%	-33.2%	-33.1%	-33.1%	-29.9%	-31.6%	-31.6%
Greece	-4.0%	-7.6%	-18.3%	-20.7%	-19.6%	-14.6%	-33.4%	-33.4%
Italy	-22.9%	-20.9%	-28.3%	-26.7%	-26.4%	-25.0%	-29.1%	-29.1%
Macedonia	-29.0%	-32.2%	-40.0%	-38.7%	-44.9%	-42.0%	-42.9%	-42.9%
Malta	-25.1%	-1.0%	-24.9%	-16.8%	-33.2%	-9.1%	-17.0%	-17.0%
Portugal	-19.2%	-4.8%	-20.6%	-6.4%	-19.5%	-4.7%	-11.1%	-11.1%
Serbia and	-31.8%	-25.5%	-47.9%	-39.5%	-46.2%	-39.0%	-40.6%	-40.6%
Slovenia	-35.1%	-32.5%	-53.2%	-47.9%	-47.9%	-50.5%	-48.2%	-48.2%
Spain	-14.7%	-33.4%	-41.6%	-42.5%	-37.1%	-38.5%	-51.3%	-51.3%
Czech Rep	-37.1%	-38.5%	-37.4%	-39.7%	-48.6%	-50.2%	-50.4%	-50.4%
Hungary	-36.7%	-34.9%	-37.7%	-35.4%	-51.5%	-44.6%	-43.2%	-43.2%
Poland	-41.6%	-40.4%	-36.7%	-37.1%	-45.2%	-45.3%	-47.1%	-47.1%
Slovakia	-35.1%	-36.5%	-34.8%	-37.2%	-47.9%	-48.0%	-48.2%	-48.2%
Belarus	-28.0%	-28.9%	-46.9%	-47.6%	-56.7%	-57.3%	-64.6%	-64.6%
Bulgaria	-43.2%	-38.0%	-37.5%	-32.2%	-45.9%	-39.8%	-48.1%	-48.1%
Moldova	-3.8%	-6.5%	-9.7%	-20.2%	-12.8%	-19.4%	-32.0%	-32.0%
Romania	-34.5%	-26.8%	-38.8%	-31.6%	-46.2%	-39.3%	-45.4%	-45.4%
Russian Fe	-31.5%	-34.7%	-39.4%	-41.3%	-51.1%	-52.2%	-55.9%	-55.9%
Ukraine	-42.5%	-42.8%	-49.1%	-50.1%	-55.0%	-56.0%	-59.9%	-59.9%
Cyprus	11.9%	4.4%	13.2%	13.9%	9.8%	3.7%	-3.1%	-3.1%
Georgia	-13.1%	-9.6%	-15.2%	-9.8%	-13.5%	-10.8%	-14.7%	-14.7%
Israel	3.6%	7.9%	5.1%	8.0%	4.1%	6.9%	-3.4%	-3.4%
Lebanon	-1.2%	-0.4%	-1.3%	1.3%	-1.2%	1.4%	3.9%	3.9%
Syrian Ara	12.3%	16.1%	20.7%	26.1%	12.2%	15.6%	-17.0%	-17.0%
Turkey	6.2%	10.4%	9.1%	13.9%	-0.3%	10.6%	-1.0%	-1.0%

Agricultural and irrigated area

The combination of shrinkage of agricultural crop area and increase of irrigated area leads to considerable increases in fraction of crop land that is irrigated (move to a more intensive agriculture and its resulting impacts on water quality).

In situations that both crop land and irrigated area increase, the change in fraction irrigated is less sharp, like in some countries in North Africa and West Asia. In general, the fraction irrigated crop land increases strongly, in Western Europe with a factor of about 3 to 5. In Northern Europe, the baseline values were very low, and the relative increase in fraction irrigated land is even larger. In the countries where both total crop land and irrigated are shrinking, the change in the fraction irrigated crop land is small. This holds for Greece, Portugal, Spain, Italy. Slovenia.

3 Water for Food 1 - Agricultural crop production

3.1 Definition of the indicator

The indicator "Agricultural crop production" addresses the current and future state of agricultural production in Europe. To demonstrate the effects of climate change and CO_2 concentration increase, the crop production is defined as the production per unit area.

The effects of water stress to agricultural production are quantified, and the regions that are most vulnerable in terms of production losses are identified.

For the calculation of the indicator, the CGMS (Crop Growth Monitoring System) model was used.

3.2 About the CGMS model

The Crop Growth Monitoring System (CGMS) version 8.1.2 as applied by the Joint Research Centre (JRC) of the European Commission (EC) was used to assess the crop production. Several previous studies have shown that crop simulation models can be applied to analyze impact of soil, climate, water availability on plant growth and crop production (Ewert et al. (2005), Parry et al. (2004), Easterling et al., (2001)). CGMS has been developed to monitor the year to year effects of weather on crop development and yield formation across Europe. It contains a pan-European weather data base and a crop simulation model and thereby constitutes a unique and independent tool to assess climate change effects. In CGMS crop growth simulations are executed with the WOFOST model (van Keulen & Wolf, 1986; van Diepen et al., 1989; Supit et al.,1994; Boogaard et al., 1998).

Two production situations are simulated: potential and water-limited. Simulation outputs are aggregated to sub-regional level (NUTS2), regional level (NUTS1) and finally to national level (NUTS0).

3.3 Calculation method and data input

Global Circulation Model (GCM) data

The IPCC AR4 GCM simulation results from 2 different models were used to establish future weather data (IPCM, MIMR). Note that the range of these simulation results is large and regionally dependent (NRC 2003; Giorgi and Bi 2005) and therefore we used data from two scenarios: the Special Report on Emissions Scenarios (SRES) A2 and B1 (Nakićenović et al. 2000) for the years 2050 and 2000. Each scenario represents different mixes of changes in population, economic output, land use, and energy and technology use, among others, but can be generally characterized by maximum atmospheric CO_2 concentrations (Sheffield and Wood, 2007). A2 represents the worst-case scenario. As a result of continuously increasing global population and limited technological change, CO_2 emissions in the period 2000–2099 will multiply 4-5 times and the atmospheric CO_2 concentrations will increase from about 350 to 850 ppm. In the B1 scenario environmental protection is emphasized and world population increases relatively slow. The atmospheric CO_2 concentrations will stabilize at 550 ppm by the end of the century. GCM outputs are extracted at a monthly time scale.

Differences between the year 2000 and the year 2050 are added to observed weather data to obtain future monthly data. Subsequently, daily climate series can then be produced for future climates using a weather generators (Semenov et al., 1998). In this study we constructed a weather generator that is based on a combination on the generators proposed by Richardson (1981) and (Semenov et al., 1998).

CGMS data

Weather data
Historical climate data are provided by the Monitoring Agricultural Resources (MARS) Unit of the Institute for the Protection and Security of the Citizen (IPSC) of the JRC of the EC at Ispra, Italy. These data consist of daily values of maximum and minimum temperature, wind speed, global radiation and vapour pressure, rainfall, interpolated from station data to a 50x50km climatic grid. These station data have been collected from the Global Telecommunication System (GTS) of the World Meteorological Organization as well as from national and sub national station networks. Presently, data from nearly 7000 stations is available. Of these stations about 2500 receive daily meteorological information. Missing global radiation values are computed automatically from data from the GTS: sunshine duration, a combination of cloudiness and the temperature range or only the temperature range. Other missing data are replaced by long term average values. From 1976 a more or less complete European coverage is available.

Crop data
Boons-Prins et al. (1993) constructed the initial crop files that describe the specific growth potentials of individual crops based on field trials executed in Belgium, United Kingdom and the Netherlands. In the framework of the MARS project these crop files were extended based on the research of Russell and Wilson (1994), Carbonneau et al. (1992), Fallisse (1992), Narciso et al. (1992), Bignon (1990), Falisse & Decelle (1990), Hough (1990) and Russell (1990). Since new crop varieties are constantly introduced, crop parameters that describe crop growth and development are regularly updated and calibrated (e.g. Gisat, 2003; Willekens et al., 1998). Region specific crop files have been constructed. For all crops the average planting date of the regional crop varieties have been collected and for some crops that may not reach maturity (i.e. sugar beet, potato, and maize) the end of season as well. Region and specific sowing dates are not available. For each crop-region combination a fixed sowing date and a fixed crop parameter set are assumed.

Soil data
Soil properties such as texture, rootable soil depth, slope and agricultural limiting phase are available from the 1 to 1 million soil map, version 3.1 (INRA, 1995; Le Bas, 1996; Jones & Buckley, 1996). Texture and rooting depth determine the water availability. Rooting depth, drainage conditions, salinity and alkalinity are derived from basic soil properties using pedotransfer rules (Lazar & Genovese, 2004). Detailed crop maps on the exact cultivated locations are not available. Therefore, the soil map is used to construct a proxy land use map, by assuming that in all regions where a given crop is grown this crop is cultivated on all suitable soils. In fact, CGMS considers a potential cropping pattern. In addition, each crop is assigned to one of the following groups: grasses, cereals and root crops, of which the root crops are the most demanding in terms of soil quality. The requirements per crop group with respect to soil related characteristics such as rootable soil depth, agricultural limiting phase, drainage, presence of stones, texture, alkalinity and salinity is accounted for and differ per crop group.
Missing weather data and missing planted area values for NUTS2 level (used in the aggregation procedure) are replaced with long term average values.

Incorporating CO_2

For C4 plants such as maize (and other tall tropical grasses) the photosynthetic response to CO_2 is only very steep for atmospheric CO_2 concentrations well below the current level. In the present and also the future range of atmospheric CO_2 concentrations (e.g., 300 to 1000 µmol/mol), the rate of CO_2 assimilation practically does not change at increasing CO_2, even under high light intensities (J. Wolf, personal communication, Goudriaan and Unsworth, 1990). The transpiration rate of the maize crop however, strongly decreases (J. Wolf, personal communication).

Direct effects of increasing atmospheric CO_2 concentration on the CO_2 assimilation and growth of the C3 crops are incorporated via the maximum and initial angle of the CO_2 assimilation-light response and a limited decrease in transpiration rate (J. Wolf, personal communication). Pot experiments demonstrated that doubling the CO_2 concentration resulted in yield increases of 40 to 60%. However, yield increases in free air CO_2 enrichment (FACE) studies are lower than for enclosure studies (Long et al. 2006) due to more plant interaction (e.g. shadowing in canopy). Yield increases of 25 to 40% for doubled CO_2 (De Temmermans et al.; 2002, Wolf & Van Oijen, 2002; Wolf & Van Oijen, 2003; Wolf et al., 2002) were found in such circumstances.

Socio economic irrigation scenarios

Crop production per unit area under the socio economic irrigation scenarios are calculated as follows:

$$Y_{scenario} = Y_{wl} + (1 - IW_{stress}) * (Y_{pot} - Y_{wl}) * f$$

Where $Y_{scenario}$ is the crop yield for a particular scenario, IW_{stress} is the average regional irrigation water stress provided by WaterGAP, Y_{pot} the potential yield from CGMS (i.e. assuming no limitations), Y_{wl} is the water limited yield from CGMS and f the fraction of the cropland that is irrigated.

3.4 Results

Figure 3.1 shows the water limited wheat and maize yields in 2050. This is an example of the CGMS crop production output.

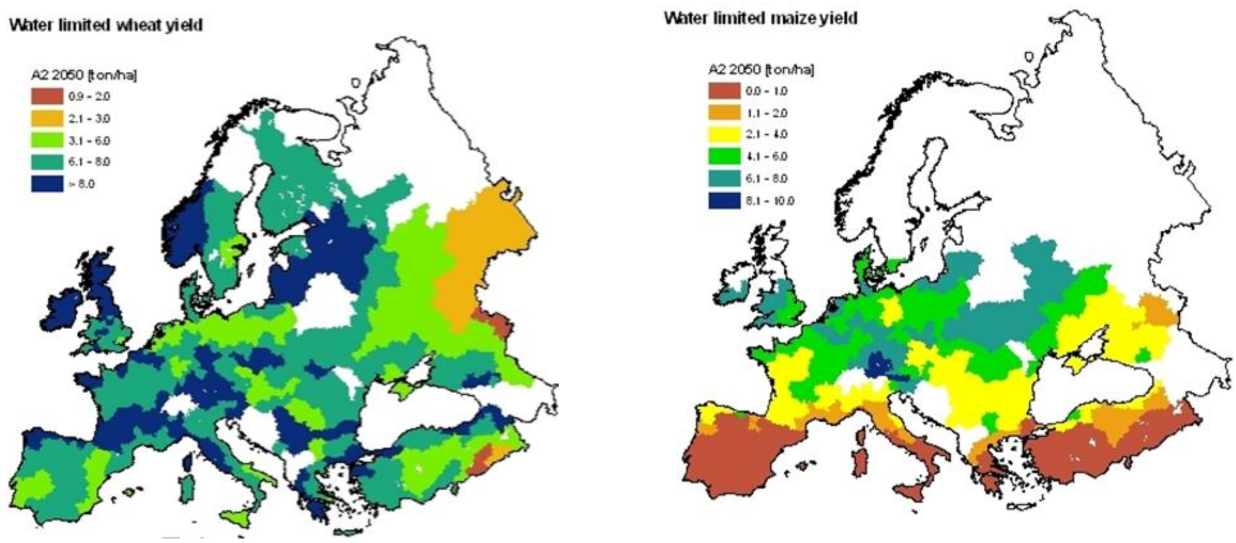

Figure 3.1 Water limited wheat and maize yield in 2050 for the A2 climate scenario (CGMS)

Table 3.1 presents the average crop production for wheat over the A2 and B1 scenarios per country. As can be seen in these tables the winter wheat yields increase in 2050 for both the water limited yield (WIY) as well as the potential yield (PotYI). The higher CO_2 concentration has a stronger positive effect on the winter wheat yields than the negative effects caused by the higher temperatures. The higher temperatures also decrease the length of the growing season and the droughts that occur in late spring and early summer can be avoided. These droughts may therefore have a limited effect on the production. Note that crop yields under the socio economic scenarios always are located between the potential and the water limited production. It can also be seen that the effect of irrigation on the national yield figures is limited. This is caused by the fact that only a limited fraction of the cropland is irrigated.

The situation for maize (not displayed in Table 3.1), a C4 summer crop, is different. Summer in 2050 will be warmer and dryer. As can be seen, the potential maize yields decrease in southern Europe, northern Africa and western Asia. Due to higher temperatures the respiration losses increase and the limited precipitation amounts during the growing season will further depress the maize yields. Since maize is a C4 crop the effects of increasing CO_2 concentrations on the crop production are limited.

Table 3.1 Crop production for wheat for the baseline and 2050 from CGMS, in t/ha
(PotYl=Potential Yield, WlY=Water limited Yield, Irr=Yield for irrigated conditions)

		Baseline			MIMR-2050					
		PotYl	WlY	Irr	PotYl	WlY	Ecf	FoE	Por	SuE
Western Europe	Austria	9.00	5.76	5.86	9.67	7.20	7.59	7.66	7.51	7.56
	Belgium	9.04	8.01	8.03	9.92	9.12	9.18	9.23	9.18	9.20
	Germany	8.76	6.55	6.75	9.75	7.66	8.11	8.23	8.03	8.03
	France	9.31	6.80	7.05	10.34	8.19	8.97	8.97	8.65	8.72
	Luxembourg	9.10	7.63	7.66	10.15	8.77	8.99	9.03	8.95	8.97
	Liechtenstein	8.44	6.16	6.23	9.54	8.46	8.54	8.61	8.54	8.57
	Netherlands	8.70	6.67	7.07	9.75	8.13	9.19	9.18	9.13	9.11
Northern Europe	Danmark	9.38	5.10	5.49	10.44	6.97	7.32	7.39	7.35	7.32
	Estonia	9.00	6.62	6.62	9.64	7.70	7.74	7.74	7.74	7.74
	Finland	8.78	5.77	5.83	12.17	9.99	10.08	10.10	10.06	10.08
	Ireland	10.27	7.30	7.30	9.54	6.99	7.30	7.32	7.32	7.27
	Lithuania	9.74	7.74	7.74	9.97	7.89	7.91	7.91	7.89	7.89
	Latvia	9.66	7.77	7.77	10.25	8.38	8.40	8.40	8.40	8.40
	Norway	8.55	6.58	6.82	10.13	9.04	9.19	9.11	9.12	9.15
	Sweden	9.56	5.05	5.46	10.57	6.91	8.08	7.97	7.75	7.53
	Uk	9.94	6.68	6.78	11.47	8.56	8.94	8.79	8.71	8.68
Southern Europe	Albania	8.59	6.54	6.94	10.44	8.72	9.23	9.28	9.29	9.35
	Spain	9.04	5.25	5.57	10.81	6.46	6.89	6.82	6.83	6.94
	Greece	7.55	6.20	6.40	9.29	7.77	7.93	7.94	7.94	7.99
	Croatia	7.87	7.43	7.44	9.38	8.98	9.01	9.02	9.02	9.02
	Italy	9.39	5.25	5.60	10.83	7.32	7.67	7.67	7.68	7.71
	Macedonia	5.86	5.50	5.52	7.55	7.23	7.27	7.25	7.25	7.25
	Portugal	9.98	5.06	5.48	11.13	5.36	5.74	5.74	5.70	5.80
	Slovenia	6.82	6.43	6.43	8.63	8.42	8.42	8.42	8.42	8.43
	San Marino	9.28	7.16	7.34	10.65	8.81	8.99	8.99	9.00	9.01
	Serbia & Mont	6.83	6.17	6.19	8.42	7.95	8.00	8.02	8.01	7.99
Central East. Europe	Czech Rep.	9.61	6.88	6.93	10.38	7.65	7.78	7.76	7.81	7.81
	Hungary	8.11	5.58	5.63	8.26	5.97	6.24	6.24	6.08	6.06
	Poland	8.86	6.02	6.02	9.33	6.54	6.57	6.57	6.57	6.57
	Slovakia	8.87	5.90	6.08	9.06	6.51	6.71	6.73	6.68	6.73
Eastern Europe	Bulgaria	6.34	5.90	5.92	7.71	7.28	7.31	7.31	7.31	7.31
	Belarussia	8.98	7.35	7.35	8.85	6.99	7.03	7.03	7.03	7.01
	Georgia	7.79	6.47	6.59	8.35	7.40	7.58	7.54	7.48	7.48
	Romania	7.97	5.54	5.68	8.27	6.47	6.63	6.65	6.65	6.65
	Russia	7.34	4.98	5.03	7.16	5.34	5.38	5.38	5.38	5.38
	Ukrania	7.93	6.19	6.26	7.83	6.42	6.48	6.48	6.46	6.46
Western Azia	Turkey	7.45	5.41	5.62	8.39	5.73	5.96	5.96	5.92	5.94
Northern Africa	Algeria	8.64	4.93	5.01	10.43	9.73	9.75	9.75	9.76	9.75
	Morocco	9.64	6.92	7.08	9.05	8.57	8.61	8.62	8.63	8.62
	Tunesia	9.56	4.23	4.39	11.51	8.78	9.04	9.02	9.02	8.97

<u>Socio-economic aspects</u>

The water limited yields (also known as rainfed yields) and yields under the socio economic scenarios are very low in Spain, Portugal, Morocco and Turkey due to the high water shortages during the growing season. In Slovenia, Croatia and the other countries on the Balkan the water shortages are less severe and consequently yields are higher. In general the water limited yields and scenario yield are in the same order of magnitude as the current yields.

At farmers level and with these yields, gross margin would be negative and maize will no more be cropped by farmers. This might induce a shift to winter crops.

In western and northern Europe (southern France excluded) maize may profit from the higher temperatures. In these region the temperature approaches the optimum temperature. The maize yield increases however, are limited.

Table 3.2 presents crop production for both maize and wheat at country and large basin level for France. Data or results are issued from:

- the French agricultural census (Recensement Général Agricole and a dedicated publication for irrigation, G. Gleyses, T. Rieu, 2004)
- calculation of actual agricultural production, as function of actual yields depending on water stress and the scenarios (irrigated acreage, irrigation efficiency…)

Calculation of crop production at basin level are made with a national average indicator of yields as this data is not available at basin level. Irrigated surfaces for wheat are restricted enough (less than 15 km2) to consider it as representative for a rainfed crop. It is reinforced by the fact that WaterGap doesn't consider durum wheat.

Looking at data, some deviations appear: the 2000 yields of maize in France (45% of the cultivated surface is irrigated), are higher and outside the range (potential, limited) considered for both IPCM and MIMR. For wheat, the 2000 yields are lower and within the range for IPCM 2050.

Results are expressed in volume of agricultural production (tons). For maize and all the scenarios, production and yields are reduced by approximately 60-70%. This impressive impact is coming first from scenarios variables (irrigated fraction, irrigated area), secondly from the climatic and water resources conditions. From an economic point of view it is obvious that with such a reduction in production, the net agricultural revenue for this crop is negative and that farmers won't cultivate it. So the maize area should be zero in these conditions. Looking at both the results for maize and wheat, a shift towards this last alternative crop or the collapse of cereal farms has to be considered.

Between scenarios for the same crop, the magnitude of variations is less important, in the range from 4% to 15%.

If we sum maize and wheat productions the value is nearly constant! The maximum range variation is about 4 to 5 %. That is an interesting output for policy makers that consider that food production has to be maintained to the present level. At micro economics we have to keep in mind the strong assumption that it will be valuable for farmers to crop with very low yields.

Table 3.2 Summary of maize and wheat production [tons] for both at country and large basin level for France

IPCM2050

	Maize				Wheat			
	EcF	FoE	PoR	SuE	EcF	FoE	PoR	SuE
France	64,543	64,017	54,722	57,352	389,971	390,460	368,442	372,845
Adour Garonne	26,344	26,129	22,335	23,409	37,198	37,244	35,144	35,564
Artois Picardie	687	682	583	611	38,611	38,660	36,480	36,916
Loire Bretagne	18,694	18,542	15,850	16,612	129,907	130,070	122,735	124,202
Seine Normandie	5,987	5,939	5,076	5,320	141,548	141,726	133,734	135,332
Rhin Meuse	5,311	5,267	4,503	4,719	21,051	21,077	19,889	20,126
Rhône Méditerranée Corse	7,520	7,459	6,376	6,682	21,656	21,683	20,460	20,705

MIMR2050

	Maize				Wheat			
	EcF	FoE	PoR	SuE	EcF	FoE	PoR	SuE
France	97,867	97,867	92,079	94,886	438,901	438,901	423,243	426,668
Adour Garonne	39,945	39,945	37,583	38,728	41,865	41,865	40,371	40,698
Artois Picardie	1,042	1,042	980	1,010	43,456	43,456	41,906	42,245
Loire Bretagne	28,347	28,347	26,670	27,483	146,207	146,207	140,991	142,132
Seine Normandie	9,079	9,079	8,542	8,802	159,308	159,308	153,625	154,868
Rhin Meuse	8,053	8,053	7,576	7,807	23,692	23,692	22,847	23,032
Rhône Méditerranée Corse	11,402	11,402	10,728	11,055	24,373	24,373	23,503	23,694

Conclusions and discussion

Seen from an ecological viewpoint a clear distinction should be made between the crops that are cultivated in winter and early spring and those that are planted in late spring and early summer. Winter crops such as winter wheat may "profit" from the climate change expected in the year 2050. Due to the higher temperatures the growing season will be shorter and drought periods later in the season can be avoided. Furthermore, the ample precipitation in winter in combination with the higher CO_2 concentration may result in higher crop yields.

For spring and summer crops the situation is different. Depending on the crop, only in northern and western Europe crops that have a high optimum temperature (maize, sugar beets) may profit from the higher temperatures. For the crops that have a lower optimum temperature than maize and sugar beet (such as for example potato), the temperature in 2050 may exceed the optimum temperature and yield losses should be expected. On the other hand, provided that precipitation is sufficient, the increased CO_2 concentration will reduce these losses.
In the other regions the extra production that can be attributed to the increased CO_2 concentration will be lost due to the higher crop maintenance respiration. The decreasing precipitation will further decrease the yields.

4 Water for Food 2 - Irrigation water withdrawals

4.1 Definition of the indicator

The indicator "irrigation water withdrawals" refers to the amount of water needed for irrigation, to compensate the rainfall deficit. The indicator is quantified in WaterGAP as water that is withdrawn from the river. The indicator depends on drivers like climate, crop type, overall project irrigation efficiency, and the irrigated area.

Relevance (policies, stakeholders)

The agricultural sector is by far the biggest user of freshwater, and the sector continues to grow. To meet the growing water demands to produce food for the eight billion people expected to populate the earth by 2025, agricultural water consumption needs to be monitored. Several strategies are possible to cope with water shortages, e.g. re-allocation of water over sectors or water saving technologies in the agricultural sector.

Driving forces and pressures (cause-effect relationships)

The irrigation water withdrawals can be related to the crop choice, the rainfall deficit over the crop growing season, the irrigated area and irrigation project efficiency. These data are specified partially at watershed level and partly at country level. Irrigated area and changes in it are shown as maps, which gives a qualitative indication. The rainfall deficit is related inversely with the water availability.

4.2 Calculation method

Irrigation water withdrawals is a direct output from WaterGAP, and is quantified using the following equation:

WR = Irrigation water consumptive use / water use efficiency

The irrigation water withdrawals per unit area is the depth of the water layer (in mm) needed to compensate the rainfall deficit).The value depends on climate, cropping pattern, crop calendars and soil physical properties.

Data sources
WaterGAP3 is used to calculate the water required for irrigation based on irrigated area, crop type, and climate. The irrigation module in WaterGAP has been further developed to account for 18 different crop types.

4.3 Results

Baseline

Figure 4.1 shows the irrigation withdrawals for the baseline situation in mm. the highest withdrawals are seen in Spain, northern Italy, Turkey and the Nile basin.

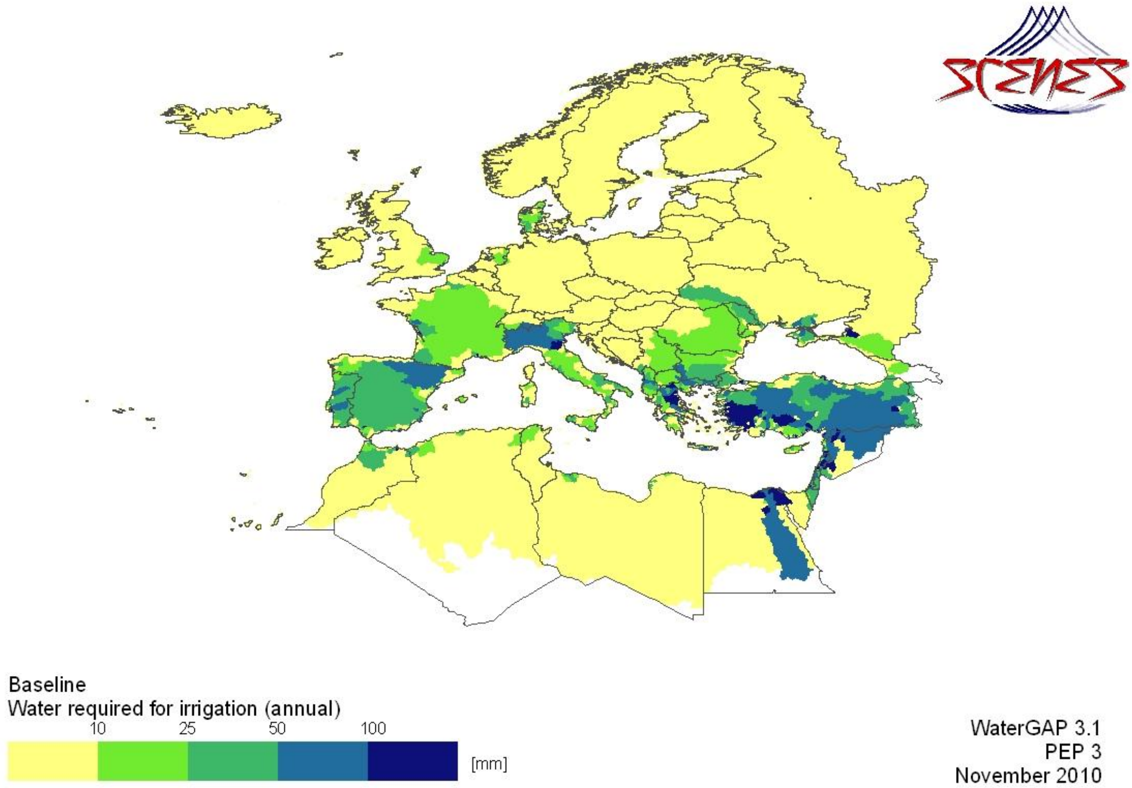

Figure 4.1 Annual withdrawals for irrigation for baseline (WaterGAP, University of Kassel)

Scenarios

For the 2050 scenarios (Figure 4.2 and Figure 4.3), highest withdrawals can be seen in northern Spain, southern France, central Turkey, the Nile basin and delta, the North African coast (Morocco, Lybia, Tunisia), and Israel for all socio-economic scenarios.

Differences in withdrawals are caused by different scenario assumptions: The Economy First scenario shows the highest withdrawals, mainly in areas with high population densities (western Europe, the Benelux and northern Italy). Policy rules shows the lowest withdrawals.

Changes in irrigation water withdrawals depend on crop choice, the rainfall deficit over the crop growing season (which is potential evapotranspiration minus rainfall), the irrigated area and irrigation efficiency.

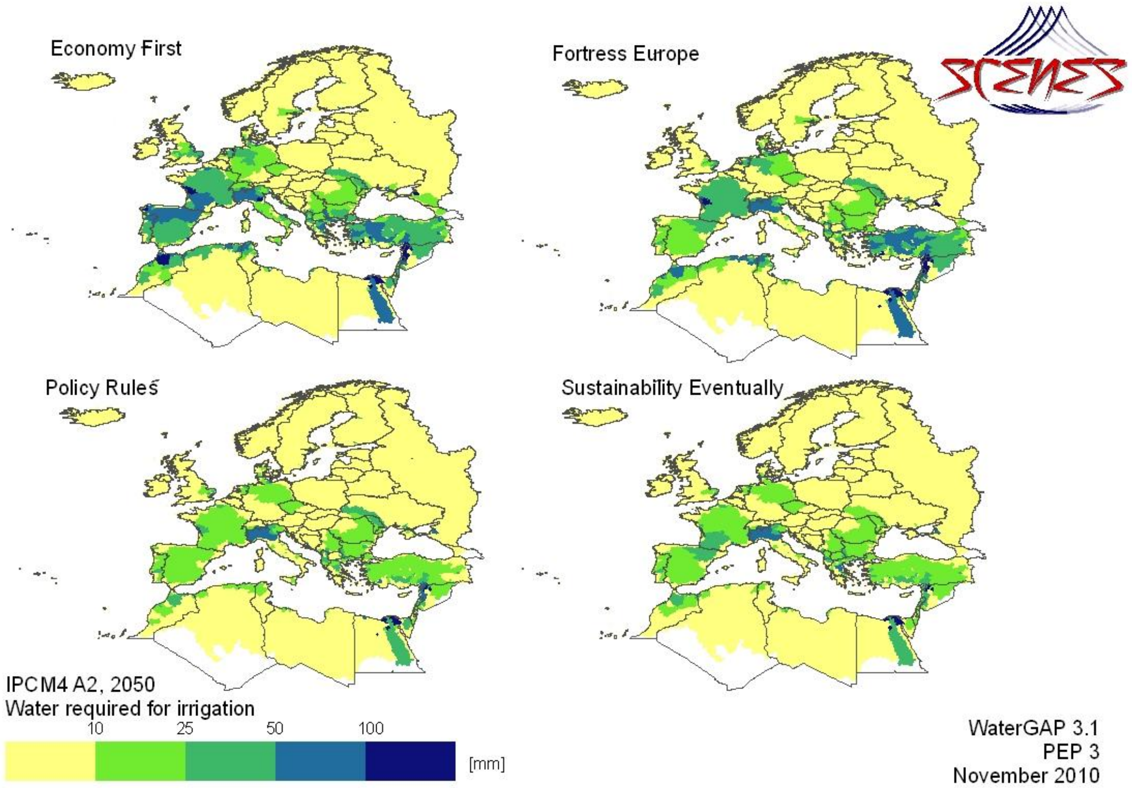

Figure 4.2 Irrigation water withdrawals 2050 (WaterGAP, GCM: IPCM4, University of Kassel)

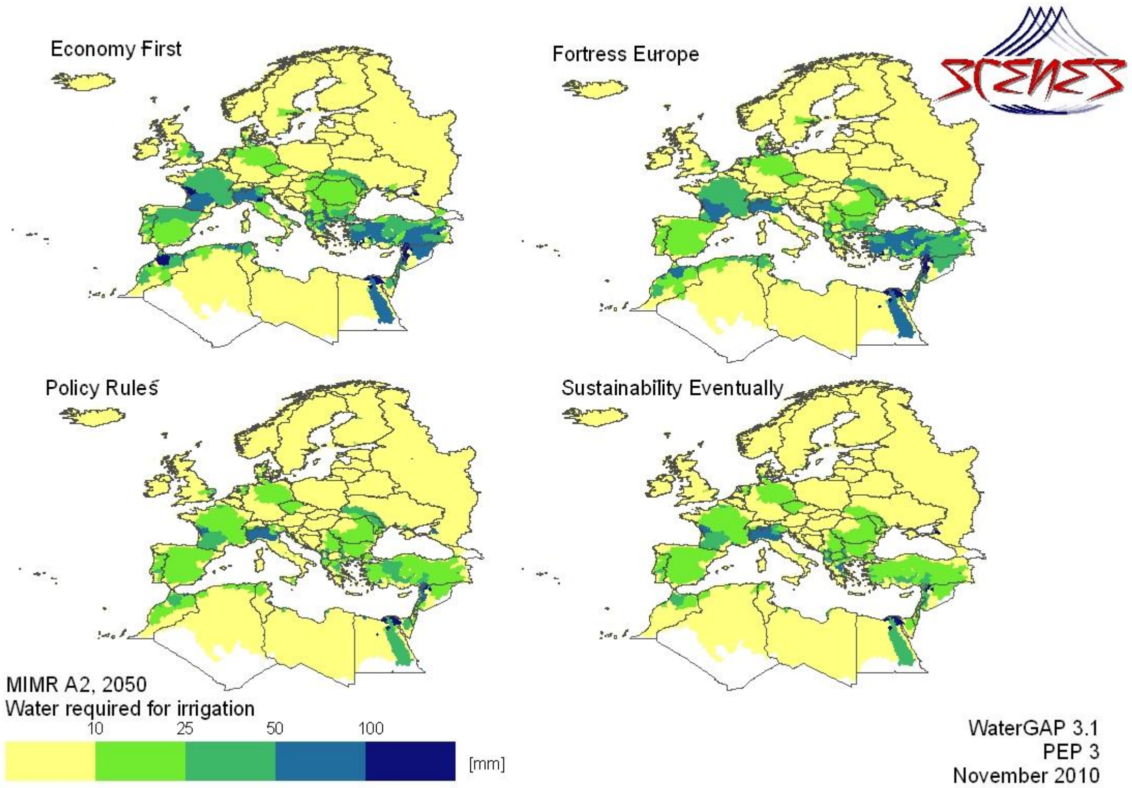

Figure 4.3 Irrigation water withdrawals 2050 (WaterGAP, GCM: MIMR, University of Kassel)

Table 4.1 presents the change in withdrawals for several Pilot Areas for the baseline compared to the scenarios in 2050. It can be seen from the table that the irrigation withdrawals decrease in 2050 for almost all scenarios, compared to the baseline.

Table 4.1 Irrigation withdrawals (mm) for baseline & scenarios for pilot areas (WaterGAP)

Basin	**Baseline**	**Scenarios (IPCM)**			
		Economy First	**Fortress Europe**	**Policy Rules**	**Sustainability Eventually**
Candelaro	41.8	43.5	19.5	14.3	18.2
Guadiana	39.0	34.9	15.3	13.5	16.2
Crimea (Salhir)	25.2	5.5	3.4	1.7	0
Seyhan	32.6	17.1	21.8	10.7	10.7
Upper Tisza (Danube)	14.7	18.7	16	15.5	11.2

Conclusion

In general, the following regional changes can be seen for 2050:

For the different regions, an increase in irrigation water withdrawals can be seen for northern Africa and western Europe; a decrease can be seen for southern Europe and western Asia. The main reason for the decrease is the enhanced irrigation technology, lowering the withdrawals from rivers. The increase in irrigation withdrawals in northern Africa and western Europe is due to the expansion of irrigation area.

5 Water for Food 3 - Water stress in irrigation

5.1 Definition of indicator

The indicator "water stress in irrigation' compares the amount of water needed for irrigation, to the available water. The indicator is used to detect crop water-shortage (temporal, spatial). This is useful because this gives an indication of the possible loss in biomass.

About 40% of all food is produced through irrigation. Since water becomes increasingly scarce, the productivity of water (with respect to input resources water, land, labour and funds) needs to be improved. The water stress indicator provides information needed to identify ways of optimum water use in case water stress occurs. Several strategies can be proposed based on the outcome of the indicator:

- Options for increasing water use efficiency
- Management decisions on reducing water use in irrigation sector
- reduce irrigated area
- reduce water gifts over entire area

5.2 Calculation method

The indicator is defined as the ratio of water withdrawal to water availability. The water withdrawal refers to the irrigation water extracted from rivers or groundwater.

The input data are:

Irrigated area map (based on national statistics)
Water required for irrigation (WaterGAP3)
Water availability (WaterGAP3)

Scaling issues

Cross scale analysis: This indicator was evaluated by the Guadiana, Candelaro, Crimea and Seyhan pilot areas. The indicator was evaluated as being a bit of a black box: It is not clear exactly where changes come from. It would be more practical to evaluate the drivers and input maps: Changes in irrigated area, water use efficiency, water availability and climate changes should be evaluated as in-between-indicators to understand changes in certain regions.

Thresholds and classes

The outcome is presented as a ratio where:
<0.1 indicates no water stress
0.1-0.2 indicates low water stress
0.2-0.4 indicates reasonable water stress
>0.4 indicates severe water stress

5.3 Results

Baseline

The annual water stress is the most generic expression of water stress. In the case of irrigated agriculture it makes sense to quantify the water stress over the growing season, either over spring and summer season together, or specifically over the crop growth period.

Figure 5.1 shows the water stress in irrigation for the baseline situation. Moderate water stress can be seen in Spain during spring, and severe water stress is visible during summer for Spain, northern Africa, Turkey and the Nile.

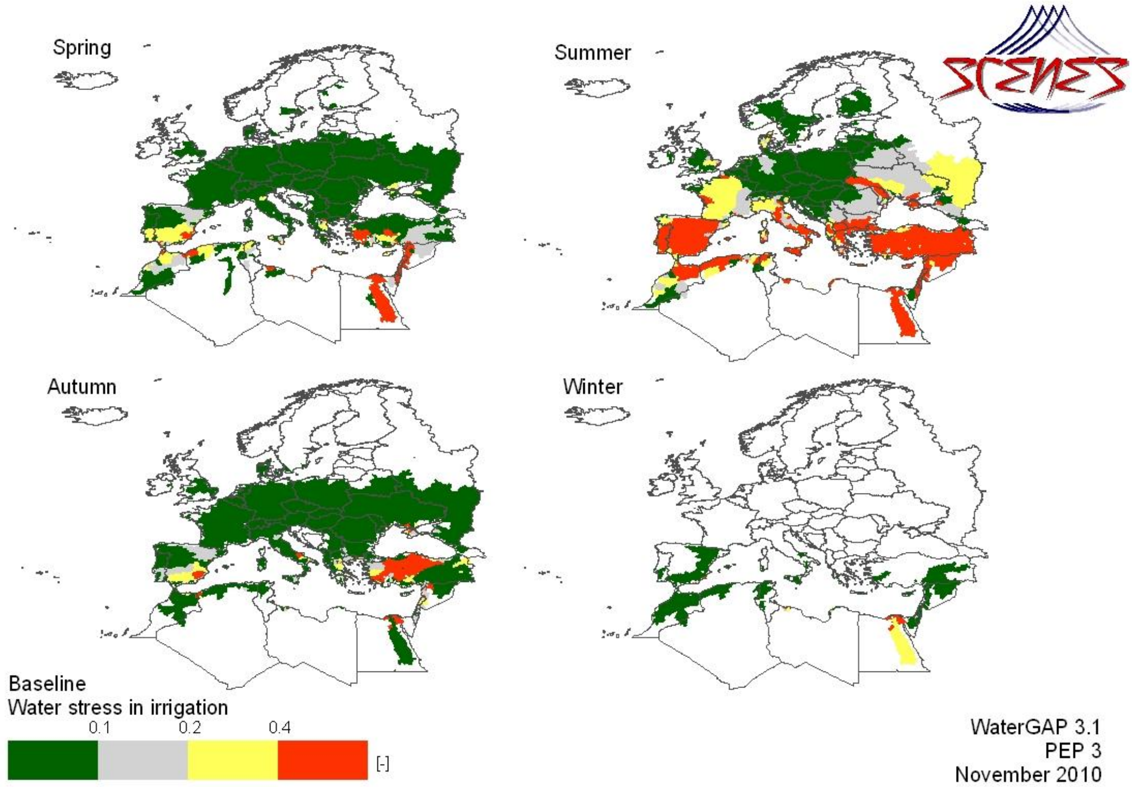

Figure 5.1 Water stress in irrigation for baseline (WaterGAP3, University of Kassel)

Scenarios

Figure 5.2 and Figure 5.3 present the water stress for the future scenarios. Highest water stress can be seen under the Economy First and Fortress Europe scenario.

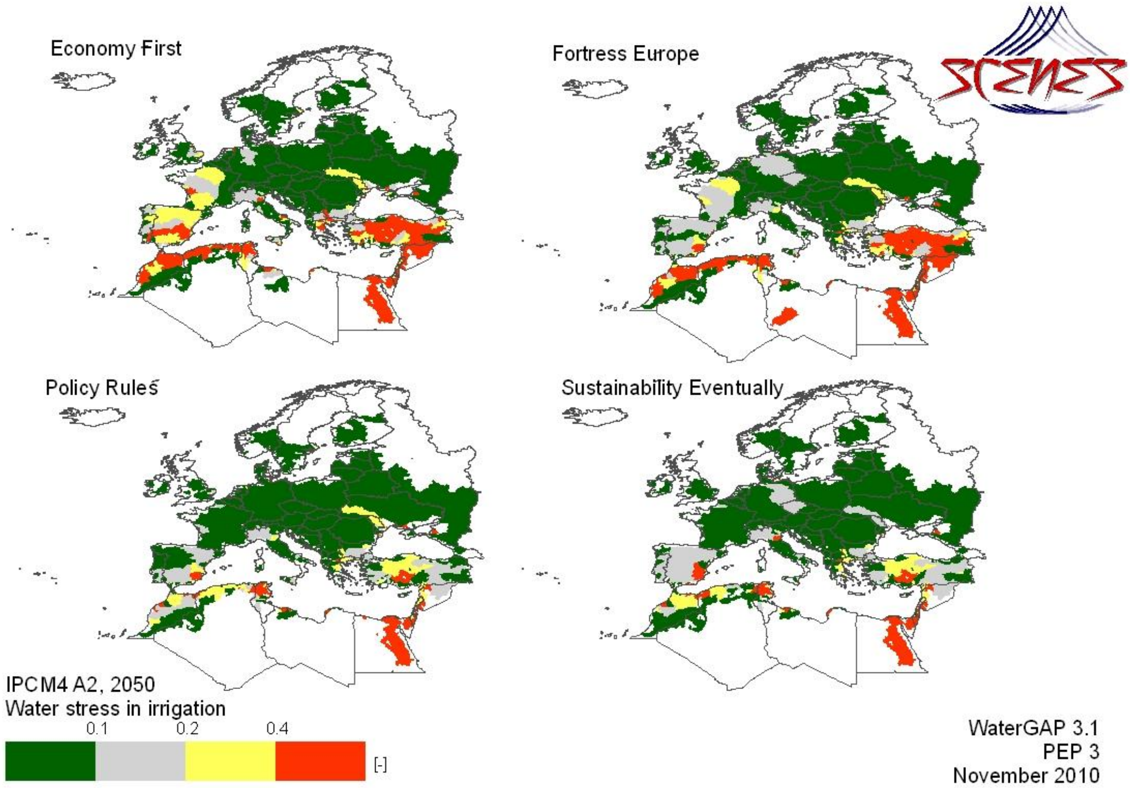

Figure 5.2 water stress in irrigation for 2050 scenarios, IPCM4 (WaterGAP, University of Kassel)

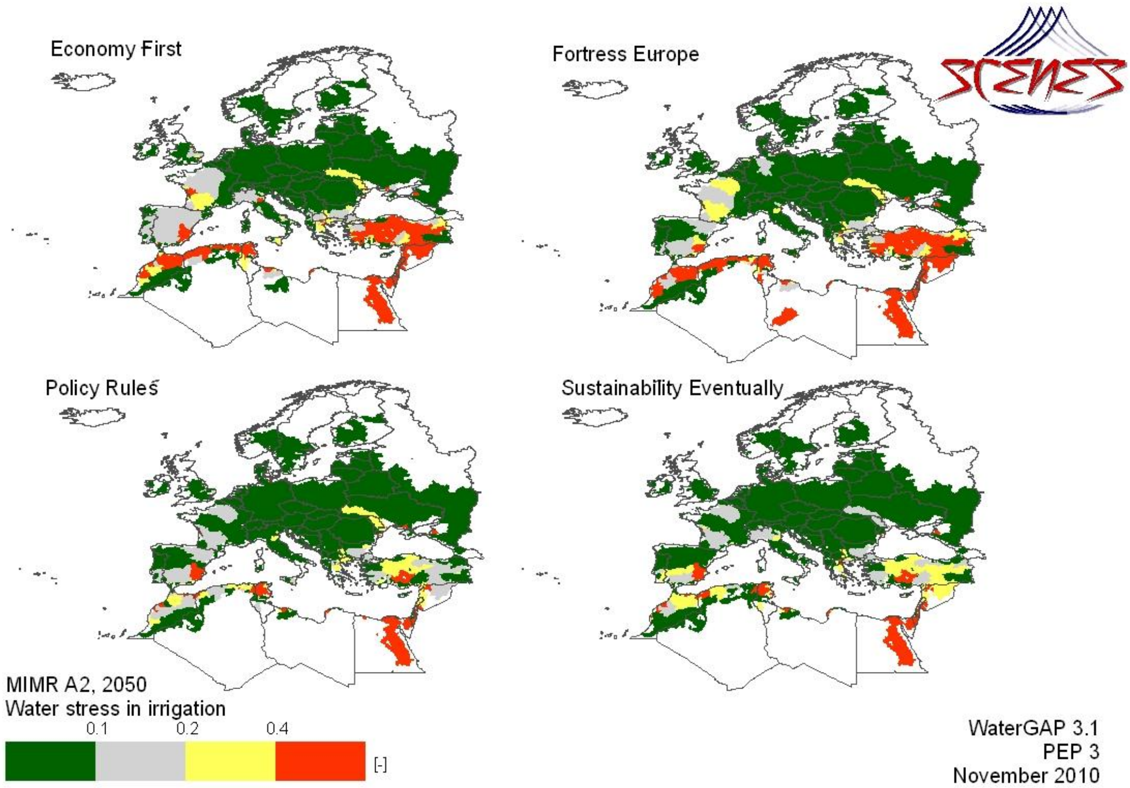

Figure 5.3 water stress in irrigation for 2050 scenarios, MIMR (WaterGAP, University of Kassel)

Water stress in irrigation depends on withdrawals as well as water availability. Water availability is driven by climate. In general, the same patterns can be seen under different climate scenarios. The differences in water stress in irrigation 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 values in the North African coast for the MIMR scenario and higher values in the Iberian Peninsula for the IPCM scenario.

Looking at water stress in summer (Figure 5.4) it can be seen that for Spain, France, and northern Italy, water stress will increase for the future scenarios.

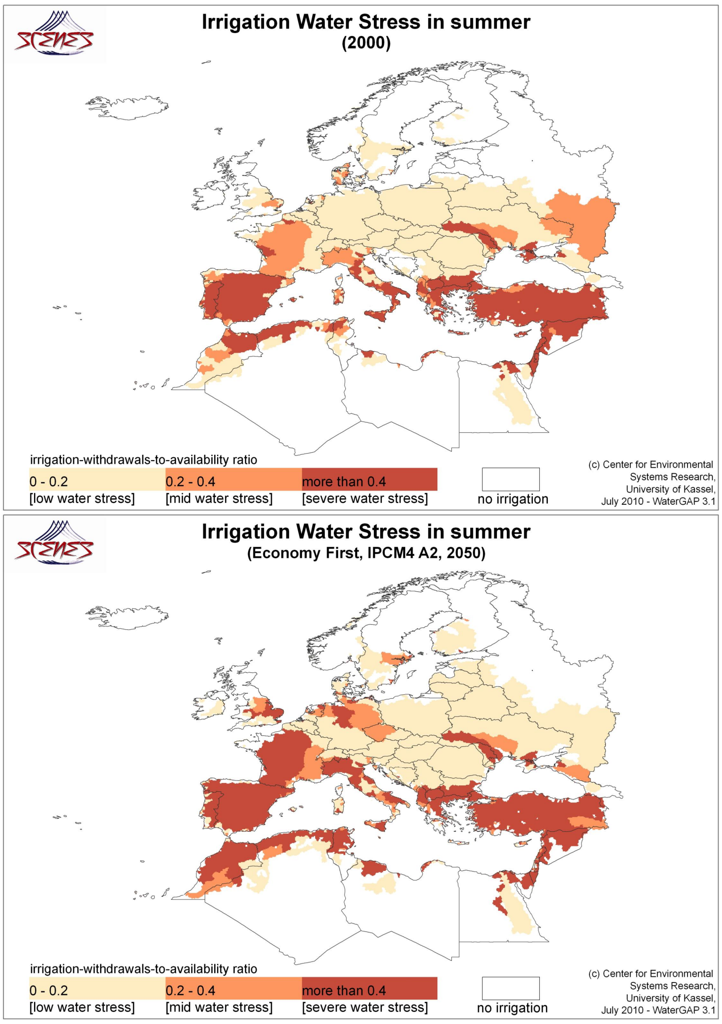

Figure 5.4 Water stress in irrigation in summer (WaterGap, University of Kassel)

Conclusion

For 2050, *annual* water stress for agriculture does not change substantially compared to the baseline. Summer water stress will slightly decrease in the Mediterranean region but significantly increases in northern Africa and western Europe (e.g. France), where the irrigated area increases. The decrease of summer water stress in the Mediterranean is due to the decrease in irrigated area in the Mediterranean (less water required) and the increase in irrigation technology.

6 Key messages

The overall conclusions for water for food can be summarised as:

The bulk of the total agricultural production in Europe is produced without irrigation, and climate adaptation strategies should include both irrigated and rain fed agriculture.

Socio-economic drivers, technological development and agricultural policies are more important than climate change as factor influencing irrigation water withdrawals and water stress. Technology innovation can compensate climate change impacts.

The irrigated area in western Europe (e.g. France) increases in 2050, while irrigated areas in the southern Mediterranean region (Greece, Spain, Portugal and Italy) decrease. There appears to be a shift in irrigated area from the southern Europe to western Europe. This is due to the better climatic conditions expected in 2050 for western Europe.

Water availability in southern Europe decreases in 2050:

- In the Mediterranean there is an annual decrease of 15-35 % compared to climate normal (baseline conditions)
- In western Europe there is an annual decrease of 10-20 % compared to climate normal (baseline conditions)

For 2050, irrigation water withdrawals decrease for southern Europe (Mediterranean) as compared to the baseline condition. This is due to a combination of improved irrigation technology (higher efficiency), a decrease in irrigated area and the effect of climate change (shorter growing season).

For 2050, annual water stress for agriculture does not change substantially. Summer water stress however will slightly decrease in the Mediterranean region, due to the decrease in irrigated area and the increase in irrigation technology. Summer water stress in northern Africa and western Europe (e.g. France) will increase significantly.

Crop growth simulation results show that due to climate change the growing season shortens and crops mature earlier (higher temperatures) in 2050. Depending on the crop, higher CO_2 concentration may result in higher crop yields. The yield increase is not always ensured due to moisture limitation. Summer crops (i.e. maize) planted in spring may suffer from droughts, while winter crops (i.e. wheat) can profit from higher precipitation in winter, and a faster crop development due to higher temperatures.

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