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Climate Adaptation – modelling water scenarios and sectoral impacts

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- Floods
- Climate Change and Water

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2000/60/E	EU Water Framework Directive
2007/60/EC	EU Flood Directive
COM/2007/0414 final	European Commission's Communication on Water Scarcity and Droughts
2009/28/EC	regional development policies and European renewable energy directive
.dbf	database file
.shp	vector shapefile
.xls	excel file
A1B	see *A1B IPCC*
A1B IPCC	SRES scenario
	http://www.ipcc.ch/ipccreports/tar/wg1/029.htm#storya1
ACQWA	EU/FP7 project: Assessing climate impacts on the quantity and quality of water
	http://www.acqwa.ch
ADAM	EU/FP6 project: Adaption and Mitigation Strategies
	www.adamproject.eu
AGNA	a freeware application designed for social network analysis, sociometry and sequential analysis
	http://www.oocities.org/imbenta/agna/
AGRI4CAST	EU project from Monitoring Agricultural Resources (MARS)
	http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST
ALARM	EU/FP6 project: Assessing large scale risks for biodiversity with tested methods
	http://www.alarmproject.net/alarm/
AlienFish&ClimChange	EU/FP7 project: Modelling of non-native fish species responses to climate change
	http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ_RCN=10067396
Alp-Water-Scarce	EU project: Water Management Strategies against Water Scarcity in the Alps
	http://www.alpwaterscarce.eu/
AM	Analysis Matrix
AR4	IPCC Fourth Assessment Report: Climate Change 2007 http://www.ipcc.ch/
ARPEGE	Global climate model runs from IPCC AR4

ATEAM	EU project: Advanced Terrestrial Ecosystem Analysis and Modelling
	http://www.pik-potsdam.de/ateam/
B/C ratios	Benefit/cost ratios
BaltCICA	project: Climate Change: Impacts, Costs and Adaptation in the Baltic Sea Region
	http://www.baltcica.org/
BAU	business as usual
BCM	Bergen Climate Model
	http://www-2.nersc.no/~oddho/PhD_thesis/thesis_html_8.html
BLOOM	a generic deterministic phytoplankton module
BRAHMATWINN	EU/FP6 project: Twinning European and South Asian River Basins to enhance capacity and implement adaptive management approaches
	http://www.brahmatwinn.uni-jena.de/index.php?id=5314&L=2
C-Map	cognitive mapping tool
	http://i3s.aquastress.net/tools/cmap.aspx
C.C. mitigation	climate change mitigation
CAP	Common Agricultural Policy
CARPIVIA	EU project: Carpathian integrated assessment of vulnerability to climate change and ecosystem-based adaptation measures
	http://www.carpivia.eu/
cap.	capita
CBA	Cost Benefit Analysis
cc	climate change
CC-WaterS	project: Climate Change and Impacts on Water Supply
	http://www.ccwaters.eu/
CECILIA	EU/FP6 project: Central and Eastern Europe Climate Change Impact and Vulnerability Assessment
	http://www.cecilia-eu.org/
CEH	Centre for Ecology and Hydrology
	http://www.ceh.ac.uk/
CEMT	Conferénce Européenne des Ministres de Transport
CESR	Center for Environmental Systems Research
cf.	compare
CGE	Computable General Equilibrium
CGMS	Crop Growth Monitoring System
CHAOS	EU/FP7 project: Climate change and species invasions in aquatic systems: a comparative perspective

CHIND	China and India
CIRCA	Communication & Information Resource Centre Administrator http://circa.europa.eu/
CIRCE	EU/FP6 project: climate change and impact research: the Mediterranean Environment http://www.circeproject.eu/
CIS	Common Implementation Strategy
CLAVIER	EU/FP6 project: CLimate ChAnge and Variability: Impact on Central and Eastern EuRope http://www.clavier-eu.org/
CLIMALPTOUR	EU project: Climate change and its impact on tourism in the Alpine Space http://www.climalptour.eu
CLIMATECOST	EU/FP7 project: Full costs of climate change http://cordis.europa.eu/fetch?CALLER=FP7_PROJ_EN&ACTION=D&DOC=1&CAT=PROJ&QUERY=0131b338ec0a:9d1c:2445eb2c&RCN=89308
ClimateWater	EU/FP7 project: Bridging the gap between adaptation strategies of climate change impacts and European water policies http://cordis.europa.eu/fetch?CALLER=FP7_PROJ_EN&ACTION=D&DOC=1&CAT=PROJ&QUERY=0131b3379fbc:d66c:21a0c10b&RCN=88495
CLIMB	EU/FP7 project: Climate Induced Changes on the Hydrology of Mediterranean Basins http://www.climb-fp7.eu/home/home.php
CLIMSAVE	EU/FP7 project: Climate Change Integrated Assessment Methodology for Cross-Sectoral Adaption and Vulnerability in Europe http://www.climsave.eu
ClimWatAdapt	This project: Climate Adaptation – modelling water scenarios and sectoral impacts http://www.climwatadapt.eu/
CLIVAGRI	Climate Change and Variability on European Agriculture ESSEM COST Action 734 (http://www.cost734.eu)
CLIWAT	project: a transnational project in the North Sea Region http://www.cliwat.eu/
CLM	Climate Local Model
CMCC	Euro-Mediterranean Centre for Climate Change
cnt.	to be continued
CO2	carbon dioxide

COMBINE	EU/FP7 project: Comprehensive Modelling of the Earth System for Better Climate Prediction and Projection
	http://www.combine-project.eu/
CORFU	EU/FP7 project: Collaborative Research on Flood Resilience in Urban areas
	http://www.corfu-fp7.eu/
COST 734 Action	see *CLIVAGRI*
	http://www.cost734.eu/
CP	current protection
CzechRepubl	CzechRepublic
D	Driver
DB	database
Dec	December
DESERTLINKS	EU/FP5 project: Combating Desertification in Mediterranean Europe: Linking Science with Stakeholders
	http://www.kcl.ac.uk/projects/desertlinks/
DM	decision maker
DMPs	Drought management plans
DPSIR	Driving force-Pressure-State-Impact-Response
DSS	Decision Support System
EAFRD	European Agricultural Fund for Rural Development
EC	European Commission
ECA&D	European Climate Assessment & Dataset
ECCONET	EU/FP7 project: Effects of Climate Change On the inland waterway and other transport NETworks
	http://www.ecconet.eu/
EcF	SCENES scenario Economy First
ECHAM5	IPCC Climate Model: Atmospheric General Circulation Model
	http://www.mpimet.mpg.de/en/wissenschaft/modelle/echam.html
ECHAM5/MPI-OM	is coupled climate model consisting of atmospheric general circulation model (ECHAM5) and MPI-OM ocean-sea ice component developed at the Max Planck Institute for Meteorology (MPIM)
	http://www.mpimet.mpg.de/en/science/models.html
ECHAM4/OPYC3	a coupled global model: Atmospheric General Circulation Model (ECHAM4) and Ocean General Circulation Model (OPYC3)
	http://cera-www.dkrz.de/IPCC_DDC/IS92a/Max-Planck-Institut/echam4opyc3.html
EDs	Exogenous Drivers

EEA	European Environment Agency (www.eea.europa.eu/)
EDO	European Drought Observatory
e.g.	example given
ELDRED2	European Lakes and Reservoir Database as developed and provided by the European Environmental Agency (EEA)
ELECTRE	Decision rule used by mDSS
ELOISE	European Land Ocean Interaction Studies
	http://www2.nilu.no/eloise/
EM	Evaluation Matrix
EMODNET	European Marine Observation and Data Network
ENSEMBLES	EU/FP6 project: ENSEMBLE-based Predictions of Climate Changes and their Impacts
	http://www.ensembles-eu.org/
Eq.	Equation
ESF	European Social Fund
ESPON	EU project: ESPON project 2013/1/4 "Climate change and territorial effects on regions and local economies"
	http://www.espon-climate.eu/
et al.	et alia (and others)
etc.	Et cetera
EU-FP6	EU's Sixth Framework Programme for Research and Technological Development
	http://ec.europa.eu/research/fp6/index_en.cfm
EURATOM	European Atomic Energy Community
EUROCAT	project: European Catchments - Catchment changes and their impact on the coasts
	http://databases.eucc-d.de/plugins/projectsdb/project.php?show=168
EURO-LIMPACS	EU/FP6 project: Integrated Project to Evaluate the Impacts of Global Change on European Freshwater Ecosystems
	http://www.eurolimpacs.ucl.ac.uk/
FACE	free air CO_2 enrichment
FEEM	Fondazione Eni Enrico Mattei
	http://www.feem.it
FoE	SCENES scenario Fortress Europe
FP	future protection
FP5	EU's Fifth Framework Programme
	http://cordis.europa.eu/fp5/

FP6	EU's Sixth Framework Programme
	http://ec.europa.eu/research/fp6/index_en.cfm
FP7	EU's Seventh Framework Programme
	http://cordis.europa.eu/fp7/
FUME	EU/FP7 project: Forest fires under climate, social and economic changes in Europe, the Mediterranean and other fire-affected areas of the world
	http://cordis.europa.eu/fetch?CALLER=FP7_PROJ_EN&ACTION=D&DOC=1&CAT=PROJ&QUERY=0131996de46e:e223:23da843b&RCN=94659
GCM	General Circulation Model *or* Global Climate Model
GCM-RCM	General Circulation Model – Global Climate Model connected with Regional Climate Model (RCM)
GDM	group decision-making
GDP	Gross Domestic Product
GEV	Generalized Extreme Value
GHGs	Greenhouse Gases
GIS	Geographic Information Systems
	http://www.esri.com/what-is-gis/index.html
GMES	Global Monitoring for Environment and Security
GTAP 7 database	GTAP: Global Trade Analysis Project
	https://www.gtap.agecon.purdue.edu/databases/v7/
GTAP-E	an Energy-Environmental Version of the GTAP Model
	https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=923
GVA	Gross Value Added
HAB's	Harmful algal (cyanobacterial) blooms
HABITAT	spatial analysis tool to support the development of management plans
	http://public.deltares.nl/display/HBTHOME/Home
HadCM3	Hadley Centre Coupled Model
	http://www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/hadcm3
HIRHAM	formerly RACMO, Regional Climate Model
	http://www.dmi.dk
HadAM3H	A high resolution (~150 km) GCM a Regional Climate Model
IAM	Integrated Assessment Model
IAF	Integrated Assessment Framework

Ice2sea	EU/FP7 project: improving projections of the contribution of ice to future sea-level rise
	http://www.ice2sea.eu/index.html
ICES	Inter-temporal Computable Equilibrium System; Computable General Equilibrium model
i.e.	id est; in other words
IHA	Indicators of Hydrological Alteration
IKM	Information and knowledge management
IMPRINTS	EU/FP7 project: Improving preparedness and risk management for flash floods and debris flow events
	http://imprints-fp7.eu/
IPCC	Intergovernmental Panel on Climate Change
IPCC SRES scenario A2	SRES scenario
	http://www.ipcc.ch/ipccreports/tar/wg1/029.htm#storya2
IPCC SRES A1B	see *A1B IPCC*
IPCC-IS92a	Emission scenario IS92a, IPCC 1992
	http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml
IPCM4	*s. IPSL-CM4*
IPCM4-A2	*s. IPSL-CM4, output for IPCC SRES A2 scenario*
IPSL-CM4	Global Climate Model from the Institute Pierre Simon Laplace, France (IPCM4)
	http://icmc.ipsl.fr/model-and-data/ipsl-climate-models/ipsl-cm4
IR	Inception Report
Jan	January
JRC	European Commission Joint Research Centre
	http://ec.europa.eu/dgs/jrc/index.cfm
k	Criteria k
KnowSeas	EU/FP7 project: The Knowledge-based Sustainable Management for Europe's Seas
	http://www.knowseas.com/
LISFLOOD	a GIS-based hydrological rainfall-runoff-routing model that is capable of simulating the hydrological processes that occur in a catchment
	http://floods.jrc.ec.europa.eu/lisflood-model
M	Technical measure
MACIS	EU/FP6 project: minimisation of and adaptation to climate change impacts on biodiversity
	http://www.macis-project.net/
MAR	Managed Aquifer Recharge

MCA	Multi-Criteria Analysis
mDSS	mulino Decision Support System
MICE	EU project: Modelling the Impact of Climate Extremes
MICORE	EU/FP7 project: morphological impacts and coastal risks induced by extreme storm events
	https://www.micore.eu/
MICRO3.2	Global Climate Model from the Center for Climate System Research, University of Tokyo, Japan (MIMR)
	http://www.ccsr.u-tokyo.ac.jp/ehtml/etopindex.shtml
MIMR	*s. MICRO3.2*
MIMR-A2	*s. MICRO3.2, output for IPCC SRES A2 scenario*
mm	millimetre
MOS	Multiple Option Spatial
MS	Member States
MULINO	multi-sectoral, integrated and operational Decision Support System for sustainable use of water resources at the catchment scale
MWh	megawatt hour
MQD10	Minimum discharge of a 10-year drought
MQD50	Minimum discharge of a 50-year drought
n	Total number of assessment criteria
NetSyMoD	methodological framework for Social Network Analysis, Creative System Modelling and Decision support approach
NEWATER	EU/FP6 project: New Approaches to Adaptive Water Management under Uncertainty
	http://www.newater.info/
NGOs	non-governmental organisations
no.	number
NOSTRUM-DSS	Network on governance, science and technology for sustainable water resource management in the Mediterranean
	http://www.feem-web.it/nostrum/
NUTS	Nomenclature of Territorial Units for Statistics, a geocode standard for referencing the subdivisions of countries for statistical purposes basic regions for the application of regional policies
	http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction
OECD	Organization for Economic Co-operation and Development
Oil_Pcts	oil production

OLA	local discharge which is not reached during 20 (ice-free) days a year (≈Q94)
OURCOAST	EU project to support and ensure the exchange of experiences and best practices in coastal planning and management http://ec.europa.eu/environment/iczm/ourcoast.htm
OWA	Order Weighting Average
PBL	Netherlands Environmental Assessment Agency http://www.pbl.nl/en/
PDSI	Palmer Drought Severity Index
PESETA	EU project: Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis http://peseta.jrc.ec.europa.eu/
pg.	page
PIANC EnviCom (Task Group 3)	PIANC: The World Association for Waterborne Transport Infrastrucutre http://www.pianc.org/home.php
PoR	SCENES scenario Policy Rules
PPPs	Policies, Plans and Programs
PREPARED	EU/FP7 project: “PREPARED Enabling Change” http://www.prepared-fp7.eu/
PRUDENCE	EU/FP5 project: Prediction of regional scenarios and uncertainties for defining European climate change risks and effects http://prudence.dmi.dk/
Q5	river discharge which is exceeded 5% of the time
Q90	low flows: river discharge which is exceeded 90% of the time
Q95	low flows: river discharge which is exceeded 95% of the time
Q-H relationships	the relation between discharge and water height
R	response
RACMO2	Regional Atmospheric Climate Model
RBMP	River Basin Management Plan
RCA	Rossby Centre regional Atmospheric climate model
RCM	Regional Climate Model
REFRESH	EU/FP7 project: Adaptive strategies to mitigate the impact of climate change on European freshwater ecosystems http://www.refresh.ucl.ac.uk/
REMO	Regional Climate Model http://www.remo-rcm.de/

RoEU	Rest of Europe
RoOECD	Rest of OECD
RoW	Rest of the World
RVA	Range of Variability Approach
SA	Supporting actions
SAW	Simple Additive Weighting
SCENES	EU/FP6 project: Water Scenarios for Europe and for Neighbouring States
	http://www.environment.fi/default.asp?contentid=379147&lan=EN
sDSS	Spatial Decision Support System
SEA	Strategic Environmental Assessment
SEBI	Streamlining European 2010 Biodiversity Indicators
Sk	Component score of criteria k
SRES	Special Report on Emissions Scenarios
STARDEX	EU/FP5 project: Statistical and Regional dynamical Downscaling of Extremes for European regions
	http://www.cru.uea.ac.uk/projects/stardex/
Stowasus	EU/FP4 project: regional storm, wave and surge scenarios for the 2100 century
	http://web.dmi.dk/pub/STOWASUS-2100/
SUDS	Sustainable Drainage Systems
SuE	SCENES scenario Sustainability Eventually
sq. km.	square kilometres (km2)
SRES A1B	IPCC Special Report on Emissions Scenarios (SRES)
	http://www.ipcc.ch/ipccreports/tar/wg1/029.htm#storya1
Swavr	Measure’s weighted average score
SWOT	is a strategic planning method used to evaluate the Strengths, Weaknesses/Limitations, Opportunities, and Threats.
TCI	Tourism climatic index
temp.	temperature
TEP	thermal electricity production
TN	total nitrogen
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TRANSCAT	EU/FP5 project: Integrated Water Management of Transboundary Catchments
	http://transcat.vsb.cz/new/
UK	United Kingdom

UK UKCP09	UK Climate Projections http://www.ukcip.org.uk/ukcp09/
UNCD	United Nations and Commonwealth Department
UNECE	United Nations Economic Commission for Europe www.unece.org/env/water/water.and.climate
UNFCCC	United Nations Framework Convention on Climate Change
UK	United Kingdom
VI	vulnerability indicator(s)
w.t.a.	withdrawals-to-availability ratio, water stress indicator
WASA	EU project http://coast.gkss.de/staff/storch/projects/wasa.html
WasserMed	EU/FP7 project: water availability and security in southern Europe and the Mediterranean http://www.wassermed.eu/
WATCH	EU/FP6 project: water and global change http://www.eu-watch.org/
WaterGAP	Global water model WaterGAP (Water - Global Assessment and Prognosis) http://www.usf.uni-kassel.de/cesr/index.php?option=com_project&Itemid=143&task=view_detail&agid=47
WCAP	Water conservation and abstraction plans
WEATHER	EU-FP7 project, Weather Extremes: Impacts on Transport Systems and Hazards for European Regions
WEI	Water exploitation index
WFD	EU Water Framework Directive
WISE	Water Information System for Europe
WISER	EU/FP7 project: Water bodies in Europe: Integrative Systems to assess ecological status and recovery http://www.wiser.eu/
WIY	Water-limited yield
Wk	Weight assigned to criteria k (in %)
WSUD	Water Sensitive Urban Design (WSUD
WWD	Water withdrawals
XEROCHORE	EU/FP7 project: an exercise to assess research needs and policy choices in areas of drought http://www.feem-project.net/xerochore/

1 Introduction

Floods, Droughts and Water Scarcity have already affected large parts of the European Union and have an important impact on socio-economic developments (EEA 2010a). In the future, climate change is likely to change water availability and global warming will probably increase both the number and magnitude of hydrological extremes (Ludwig et al. 2009).

The maps in Figure 1, visualising projections for changes in precipitations as used in this study for the 2050s (2041-2070), show that there are areas where both substantial increase in precipitation during the frost season and decrease in the non-frost season occur. Furthermore, comparing the map of changes in non-frost season with the map of changes in the return period of a 100-year flood (Figure 2) indicates that many areas with a significant decrease in precipitation will encounter also a significant increase in the river discharge for the 100-year flood.

Further annual river flows are projected to decrease in many parts of southern and south-eastern Europe and increase in northern and north-eastern Europe. Strong changes in seasonal run-offs are projected with lower flows in the summer and higher flows in the winter. Consequently, droughts and water stress will increase in the summer season. The most drought prone areas are southern and south-eastern Europe.

This means that our environment (human and nature) has to be prepared for a decrease of water availability and for an increase of flooding severity simultaneously, and thus it should aim to build retention potential that can address them both. In addition to landscape retention areas and reservoirs, soil is one of the biggest water reservoirs at our disposal. The map of annual risk of soil erosion in Figure 3 demonstrates, however, that much of the area that will suffer simultaneously of increase of flooding and decrease of water availability have also high risk of soil erosion.

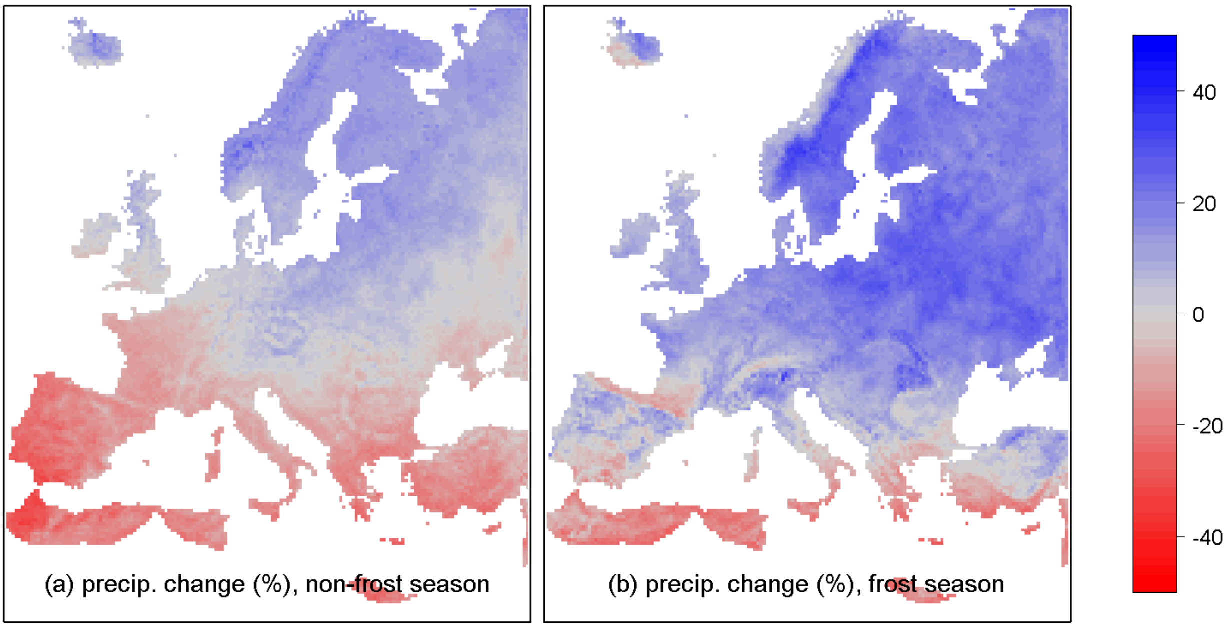


Figure 1 Change in average precipitation in the ensemble median of climate projections for the 2050s compared to the baseline for (a) non-frost and (b) frost seasons. (Non-frost season covers March-November, frost season covers December, January, and February.)

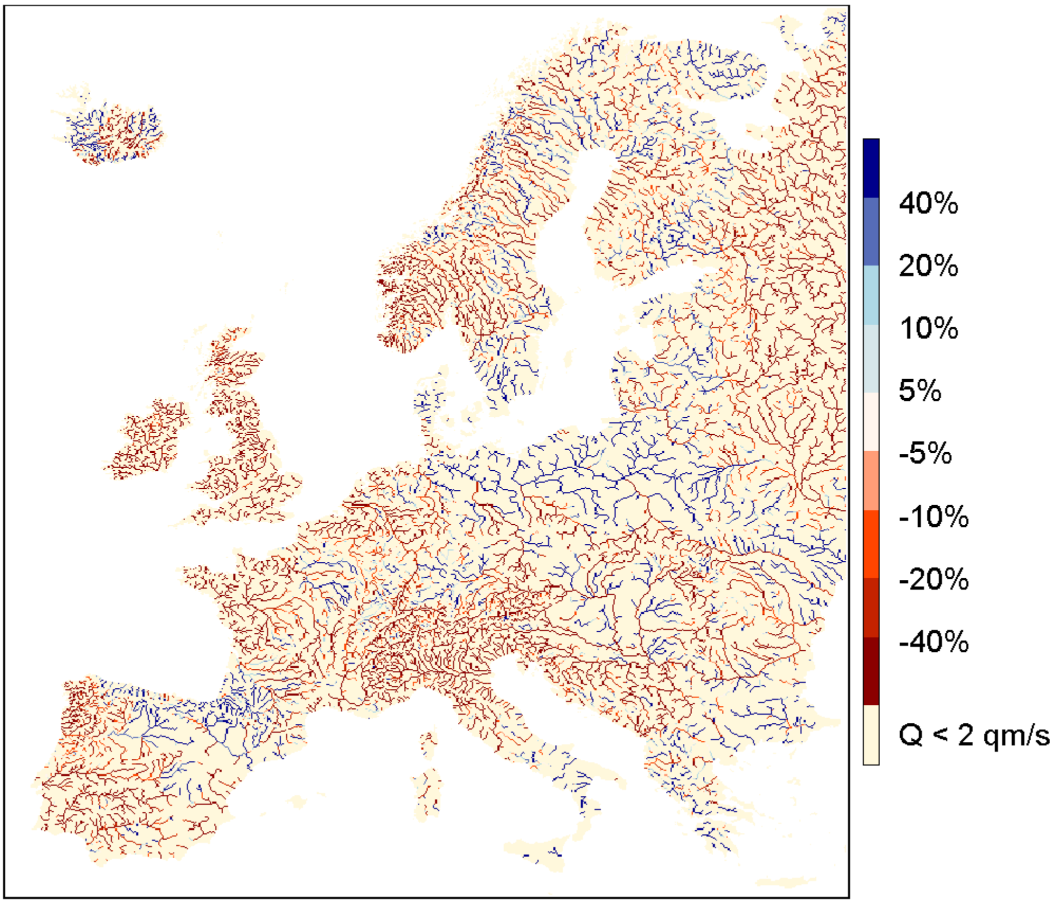


Figure 2 Projected change in the recurrence period of a current 100-year return level of river discharge between the 2050s and the reference period 1961–1990 based on the ensemble of 11 simulations with LISFLOOD.

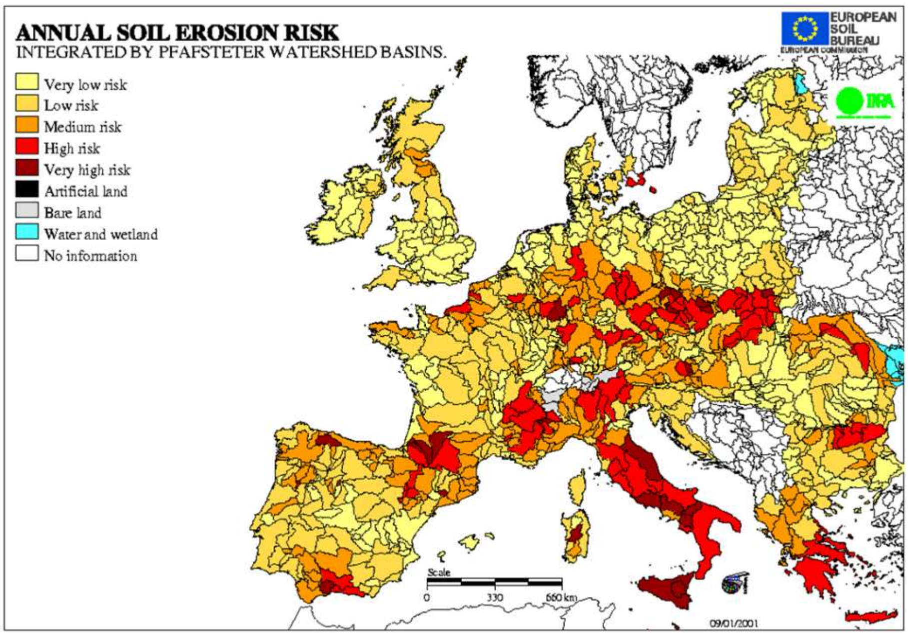


Figure 3 Annual risk of soil erosion (source: European soil bureau).

Future management of water of EU needs to take into account these changes in water availability, floods, and drought risks. Although most scientist and policy makers acknowledge Europe is potentially vulnerable to climate change there is need for more specific information about which regions and sector will be particularly affected by climate change. Even if Research and Development activities on climate change adaptation have rapidly expanded over the last decade, still many policy makers struggle with climate change adaptation. Especially the large uncertainty about the impact of climate change remains a high concern.

1.1 Objectives of this study

The main objective of this project is the assessment of vulnerability to climate change impacts and adaptation measures. Therefore, the main *aim* of this project was to set up an Integrated Assessment Framework (IAF), which allows to analyze which regions in Europe are potentially vulnerable to climate change and to identify which adaptation measures could potentially be promoted at the EU level.

In particular, the study focuses on

- the development of an Integrated Assessment Framework (IAF). The IAF is a conceptual framework for the assessment of vulnerability and adaptation measures that comes together with a comprehensive database integrating available information needed for the assessment, i.e., modelling results and generic data. In this way, the IAF enables the European Commission to carry out further in-house analyses by applying the principles of the conceptual framework to new aspects of climate change based on the information provided in the database. Moreover, the database facilitates modelling analyses with any simulation model that can use the information as input. Since the database is designed to be extendible with additional information and datasets that may become available in the coming years, the results of those modelling exercises can be integrated into the database as well. Furthermore, the technical implementation of the database allows for the integration into the Clearinghouse Mechanism on Adaptation (CHM) and the Water Information System for Europe (WISE).
- water related impacts from climate change and their potential implications for the European water depending sectors, such as agriculture, tourism, inland navigation, hydropower, energy, and, in the case of flooding, for the EU economies as a whole.
- "water for nature" by considering the changes in ecosystem conditions, which are influenced by climate change and in turn will affect other economic sectors. Changes in future water withdrawals are likely and will vary between the different sectors and regions. Global drivers such as climate change are likely to have an influence on water quality. The Intergovernmental Panel on Climate Change has pointed out that many changes expected in water quality may be negative, including reduced dilution capacity of rivers because of decreasing discharges or increased pollution loadings due to changes in rainfall patterns (Bates et al., 2008). Water quality issues will be taken into account to the extent available datasets allow.
- potential adaptation measures which should be promoted or prevented in order to increase the adaptive capacity of Europe.

1.2 To whom this report is addressed

This project addresses two target groups:

- **Policy makers on EU-level:** They get an overview of the most vulnerable regions in Europe, including information on why these regions are vulnerable to climate change is given. In addition, a database of adaptation measures has been developed. The measures in this database have been analyzed along several factors (see chapter 2.2.3) including an assessment of which measures should be promoted, and which could be prevented (see chapter 3.7).

  The review process of the Water Framework Directive (WFD) and the Water Scarcity and Drought policy can take advantage of synergy effects according to the analyses conducted. By providing results for medium- and long-term impacts of climate change on freshwater resources in terms of quantity and quality, the Commission is able to identify measures to be considered by Member States in the future WFD planning cycles. ClimWatAdapt builds a knowledge base on the impacts and consequences of climate change for the EU for preparing a comprehensive EU adaptation strategy within the framework of the White Paper "Adapting to climate change: Towards a European framework for action".

- **Water managers on river basin level:** These mangers get a set of tools containing vulnerability indicators related to climate change, adaptation measures, and evaluation instruments that they can use to develop specific adaptation actions or the next program of measures required by the WFD. In many cases, water managers will have to complement the available information and tools with specific local data and knowledge. The outcomes provided by ClimWatAdapt's IAF were performed by applying a top-down approach and cover all of Europe, which allows the comparison of results across all European river basins and NUTS levels. Using a scenario approach helps to evolve different pathways into the future and to be prepared for various developments. The scenarios may overstate the development of future water resources but they span a variety of possibilities that can be used as a basis for flexible management.

1.3 Structure of the study

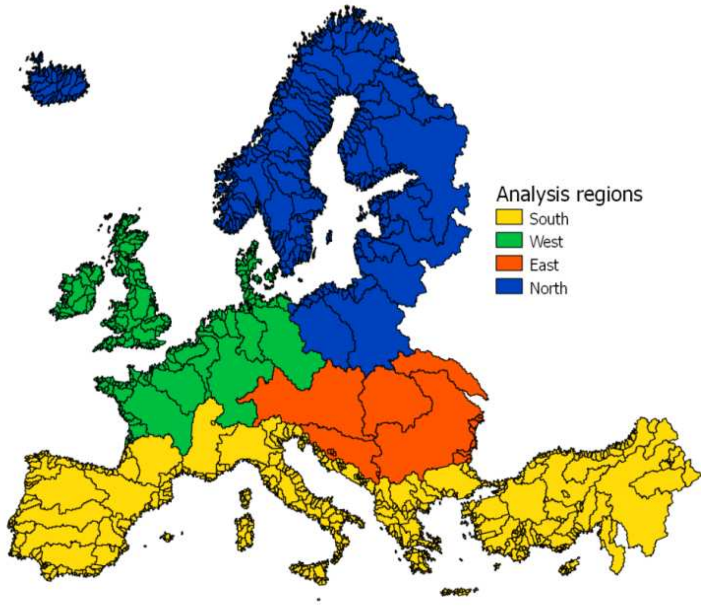
The report is structured as follows:

Chapter 1 presents the background to the study, the time period and the geographical area covered. The chapter also refers to the main data sources used and addresses the limitations of the study. In the following *Chapter 2*, a description of the methods used with the project how they relate to the Integrated Assessment Framework (IAF). This followed by a more detailed description of the different features of the IAF and two practical examples on how to use it. Chapter 2 also explains the link to WISE and the Clearinghouse and how third parties can use the IAF In *Chapters 3 and 4*, we present the results of the vulnerability and adaptation measures assessment. *Chapter 5* gives the main conclusion of the project including knowledge gaps and recommendations for future research. It also draws the key messages for policy makers. Please note that further and more detailed information with respect to chapter 2 to 4 can be found in the Annexes.

1.4 Geographical coverage

ClimWatAdapt covers the extent of the 27 EU Member States. However, due to a lack of hydrological information for Cyprus and Malta (both islands are not addressed by the LISFLOOD model) it was not possible to perform the vulnerability assessment for these countries. Therefore, both countries are not part of the IAF in terms of hydrological outcomes (this is also the case for Turkey). Spatial information at the river basin level has been used for data related to water resources. NUTS-2 level date has been used for other relevant data that can be linked to administrative units, like water withdrawals and socio-economic data.

If no information at NUTS-2 level was available for the assessment, a downscaling of coarser spatial data (e.g. national) has been performed using simple allocation rules (see Annex 1). In order to apply the assessment to the entire geographical region of the EU-27 Member States large-scale modelling results are primarily used to make a comprehensive assessment. Most model simulations are performed on grid cells or national level, which have to be aggregated or disaggregated to river basin and NUTS-2 levels. For water availability, the most appropriate hydrological unit is the river basin scale where water availability is defined as the accumulated runoff at the basin outlet cell. To merge data on water availability with water uses, to calculate for example water stress, national values have been downscaled to the basin level. In general, simple aggregation and disaggregation techniques are used to allocate coarser findings to a higher resolution like NUTS-2 or vice versa (see Annex 1). Another dimension next to river basin and NUTS-2 level is introduced for the performance of the vulnerability assessment related to water scarcity (see chapter 3.3), where the European area is subdivided into four regions. A geographical overview is given in the map below (see Figure 4).



	South	West	East	North	Total
Population in mill. people	**126 (84)***	**198 (9)***	**63 (26)***	**58 (18)***	**445 (137)***
Area in mill. km²	**1.3 (1.0)***	**1.0 (<0.1)***	**0.6 (0.3)***	**1.3 (0.9)***	**4.2 (2.2)***

Figure 4 European sub-regions for vulnerability assessment (*on non EU27 territory).

1.5 Time period covered by the study

The temporal specifications are set as follows: With respect to the hydrological modelling current conditions (baseline) are represented by the climate normal period (1961-90). In terms of water use modelling, the base year is 2005, except for agriculture (year 2000). Because of the enormous inertia built on the global climate system, climate policies implemented in the period 2000 to 2030 might have their greatest effect on global climate only after 2030. Therefore, for the coming decades differences between different climate change scenarios and their potential impacts may be of less relevance compared to the differences between socio-economic scenarios. Therefore, the potential impacts of climate change are assessed by comparing present conditions (baseline, base year) with reference scenarios for the mid-term (2025) and long-term (2050) future. Due to the amount of data and results performed in this study, the assessment described in this report focuses on the year 2050. All information for the time horizon 2025 is stored in the database.

1.6 Data sources and availability

In order to set up this study a huge assessment of finished and ongoing projects has been performed. In addition a broad literature review (including grey literature was performed. The following section gives a brief overview of the main sources that have been taken into account. Please note that several more sources of information are mentioned in the relevant chapter:

The IAF comprises numerical datasets that are available to the consortium and meet the requirements in terms of consistency. Here, the IAF is built on the latest results obtained in EU-FP projects ENSEMBLES and SCENES, i.e. hydrological outcomes as driven by high-resolution bias-corrected climate input and water demand calculations and socio-economic scenarios as based on recent scenario developments for Europe. To use this data for vulnerability analyses and to combine the information with potential adaptation measures is a big challenge and offers the opportunity to go a step beyond in the assessment of the future state of freshwater resources. On the other hand, it enables the identification of knowledge gaps and missing data and information.

In general, a lot of information is available from research and service projects, but mainly in reports and only seldom as numerical information. The application of different models and tools, different temporal and spatial resolution as well as different underlying model drivers and assumptions make the problem of using "foreign" datasets more complex. However, if "foreign" datasets would have been considered in the IAF, inconsistencies in underlying drivers and assumptions would reduce the significance of the outcomes produced. In case of vulnerability, other possible indicators are collected or developed and listed in Annex 3. These additional indicators cannot be calculated so far as the outcomes are not yet available by the models used in the consortium.

For the development of the set of indicators used in this study, the following information has been mobilized:

- *Exposure to climate change:* Water-related climate change has been subject of study of many of European projects. The most important data from these has subsequently been used by European Environmental Agency to develop and update EU indicators.

  Climate-related exposure indicators were studied by three European-funded projects: PRUDENCE, STARDEX (Statistical and Regional dynamical Downscaling of Extremes for European regions) and MICE (Modelling the Impact of Climate Extremes). These projects explored future changes in extreme events in response to global warming and assessed the impact of climate change on a number of sectors. The first of them, PRUDENCE, focused on the development and application of regional climate models. The objective of STARDEX was to identify robust downscaling techniques and to apply them to provide reliable and plausible future scenarios of temperature and rainfall-related extremes for European regions. MICE used the output of global and regional climate models to assess climate change impacts on agriculture, commercial and natural forestry, energy use, water resources, tourism and civil protection/insurance. All regional models, used in the cluster, were run at horizontal spatial scales of 50 km; some models were run at a higher resolution (20 km and 10 km). The FP6 project ENSEMBLES continued the research started with PRUDENCE and produced ensemble runs with projections for most important climate variables (including their extremes and seasonal changes) at higher resolution of 25 km. The climate modelling started in PRUDENCE and ENSEMBLES continues with the FP7 project COMBINE (Comprehensive Modelling of the Earth System for Better Climate Prediction and Projection) whose main goal is to produce more accurate climate projections and to work for reduction of uncertainty in the prediction of climate and climate change.

  Extended data sets on droughts and floods on different scales have been produced within the WATCH project (Van Lanen et al. 2008). WATCH also assesses the vulnerability of renewable groundwater resources to the impacts of climate change (Döll 2009) and river flow alteration due to water withdrawals and reservoirs (Döll 2009) on a global scale. Within the WATCH project, indicators were developed for a range of sectors, including agriculture, forests, biodiversity, coasts, water resources and urban development. The linkage of models for different sectors will enable stakeholders to see how their interactions could affect European landscape change.

  JRC has been studying river discharge under climate change (e.g., Danker and Feyen 2008, Feyen and Dankers 2008) and has produced high-resolution data sets with simulations with the LISFLOOD model.

  In XEROCHORE the focus is on droughts. The project identifies drought indicators, assesses the possible impacts of droughts in the Mediterranean and prepares guidance on appropriate responses for relevant stakeholders.

- *Climate change impacts on different sectors:* Climate change impacts on different sector have been studied in projects like ADAM, PESETA, SCENES, WATCH, and COST 734 Action (Impacts of Climate Change and Variability on European Agriculture - CLIVAGRI). ADAM assessed impacts on agriculture (Moriondo et al. 2010), risk of fires (Schelhaas et al. 2010), flooding (Kundzewicz et al. 2010), and landslides (Aaheim et al. 2010). PESETA estimates average regional changes in crop yield for different climatic zones, taking into account the future changes in these zones(Iglesias et al. 2009) and assesses impacts on tourism (Amelung and Moreno 2009;) health (Watkiss et al. 2009), coastal zones (Richards and Nicholls 2009), and flood risk (Feyen et al. 2007).

There are very few studies on impacts of climate change on interrelation between different sectors. The objective of CLIMSAVE is to fill this gap by linking models for different sectors, including agriculture, forests, biodiversity, coasts, water resources and urban development. This enables stakeholders to see how their interactions could affect European landscape change and explore adaptation strategies for reducing climate change vulnerability and possible cross-sectoral benefits and conflicts for different adaptation options.

The ESPON project “Climate change and territorial effects on regions and local economies” produced new climate scenarios for Europe and modelled multi-hazard impacts of climate change on the European regions and their economies, also considering mitigation and adaptation measures. For some of the most vulnerable areas, regional assessments are also carried-out. For example, ACQWA assesses the impacts of a changing climate on the quantity and quality of water originating in mountain regions; Alp-Water-Scarce is developing water management strategies and an early warning system to prevent the Alps from water scarcity; CLIMB and CIRCE focus on the Mediterranean; WasserMed on Southern Europe; CECILIA on Eastern Europe; CLAVIER on Central and Eastern Europe; CARPIVIA on the Carpathian region; BaltCICA on the Baltic Sea Region, and CLIWAT on future climate change effects on water quantity and quality in lowlands around the North Sea.

A number of studies also contribute to the in-depth understanding of climate change impacts on a single sector. For example, the impacts of climate change on availability and safety of public drinking water supply are studied in CC-WaterS project, on forest fires in FUME, on the management of water, wastewater and storm water in PREPARED, on flash floods in IMPRINT, and on urban flood management in CORFU.

The quantity and quality of drinking water is a powerful determinant of public health (WHO, 2008). The anticipated temperature increase due to climate change will change the fate and behaviour of pathogens (i.e., survival, growth, dilution, transport through soil), altering their concentration in source waters. The World Health Organization is leading research on the impacts of climate change on human health. (e.g., WHO, 2009)

The Current state of the quality of European Transboundary Rivers, Lakes and Groundwaters was assessed under the auspices of the Water Convention by UNCD and UNECE (2007). These studies conclude that climate change effects are becoming visible in almost all of the analyzed river basins and that water quantity issues cause upstream-downstream conflicts in Europe. As a result, UNECE (2009) published guidance on Water and Adaptation to Climate Change in Transboundary Watercourses and International Lakes.

PIANC EnviCom Task Group 3 (2008) reviews climate change impacts on maritime and inland navigation. In its report it includes the potential impact of sea level rise, wind conditions, wave action, tidal and surge propagation and range, ocean circulation, storms, coastal hydrodynamics, sea chemistry, environmentally protected areas, ice conditions, icing, water supply and quality in inland rivers, extreme hydrological conditions, and coastal, estuarine and river morphology and identifies potential adaptation and mitigation responses. Effects of climate change on the inland waterway and other transport networks are studied also by

ECCONET. The project WEATHER goes one step further and investigates the impact of climate change on the transport sector.

- *Impacts on coasts and seas:* The interactions between land, rivers and seas were studied in ELOISE (for European Land-Ocean Interactions) and EUROCAT (for European catchments, catchments changes and their impact on the coasts). KnowSeas aims to provide a comprehensive scientific knowledge base and practical guidance for the application of the Ecosystem Approach to the sustainable development of Europe's regional seas, taking into account also climate change. OURCOAST project developed extensive web database with case studies of adaptation measures, related to the Integrated Coastal Zone Management.

- *Impacts on ecosystems:* The ice2sea project is working on quantifying the contribution of continental ice to sea-level rise over the next 200 years, taking into account the contributions from mountain glacier systems and ice caps (e.g. Svalbard, Patagonia) and from Greenland and Antarctic ice sheets. Water-related climate change impacts on ecosystems have been studied in the ALARM project for reptile and amphibian species distribution in Europe (Miguel et al, 2006), in ATEAM for terrestrial ecosystem services, in MACIS for biodiversity and shifts in habitats (Hickler et al. 2009), in EURO-LIMPACS for freshwater biodiversity (Moss et al. 2004), in REFRESH for the future status of freshwater ecosystems; and International Arctic Science Committee for Arctic ecosystems (International Arctic Science Committee 2010).

  One of the known ecosystem impacts of climate change will be on invasive species. ALIENFISH and CLIMCHANGE and CHAOS are two EU projects studying this topic.

- *Impacts on water quality:* Less information is available from the European perspective, neither measured data nor the models for simulating climate and other global changes. For instance, there is no standard on water quality data available for the EU. This statement and further research gaps related to water quality (next to others) were identified during a workshop on "Science and Data Gaps in EU water-related Projects" within the ACQWA project.

  The Project ClimateWater is aimed as the first step on the analysis and synthesis of data and information on the likely water related impacts. One of the objectives is to identify research needs on climate change impacts. The project noticed several gaps related to field research associated with model development, in particular related to water quality. Research need is also needed for determining the cause and effect relations in terms of climate change.

1.7 Limitations of the study

It is important to note that this study has some overall limitations, which have to be taken into account when using the results in policymaking. These overall limitations are:

- As defined by the IPPC, vulnerability is defined as the degree to which a system is susceptible to, and unable to cope with, injury damage or harm. Vulnerable regions or sectors can be identified by linking the potential impacts and adaptive capacity. Since adaptive capacity is a very challenging concept and difficult to make operational as an indicator, we consider adaptive capacity as the ability of a system to implement measures that decrease its vulnerability.
- In order to provide an integrated assessment framework for entire Europe (or at least EU-27 region), large-scale modelling results available to the consortium are applied. It is worth noting that (i) data availability is rather limited not only by the models used, (ii) large-scale water quality results are not yet existent for the future (but SCENES started a first attempt),

(iii) water for nature is not yet defined on the large-scale, and (iv) the limitations of large-scale models (e.g. reservoirs not implemented; simple relations). Because the IAF also provides medium- and long-term outcomes based on future projections, the uncertainties related to the projections as well as to the models needs to be taken into account.

- The number of indicators that are quantified is limited by the model outcomes. Others are listed but not addressed by the IAF.
- The information on the different attributes, which are used to describe possible adaptation measures, is often very patchy. This relates in particular to cost information but also to the physical effect, a measure has (amount of water saved, geographical area of the effect). The existing information often just relates to local conditions, which are very different across the EU. So, up scaling of this information to the EU level is often impossible (e.g. the effects of giving rivers more space in a certain area). Therefore, there is a limitation of the IAF in terms of performance when it comes to the linkage of large-scale modelling results with location-specific adaptation measures. On other words the current version of the IAF cannot model several adaptation measures because of the locally embedment of these measures and the limits of up-scaling.

2 The integrated assessment framework (IAF)

2.1 The main concepts and scenarios behind the IAF

The IAF has been built on three main concepts, which are framing the on-going scientific discussion on how to assess adaptation to climate change. These concepts are briefly summarized below:

2.1.1 Conceptual model for climate change impacts, vulnerability and adaptation

Vulnerability to climate change in its general meaning is a measure of potential future impacts (a function of exposure and sensitivity) and a range of political, institutional, socio-economic and technical components (adaptive capacity). The overall concept is displayed in the diagram below

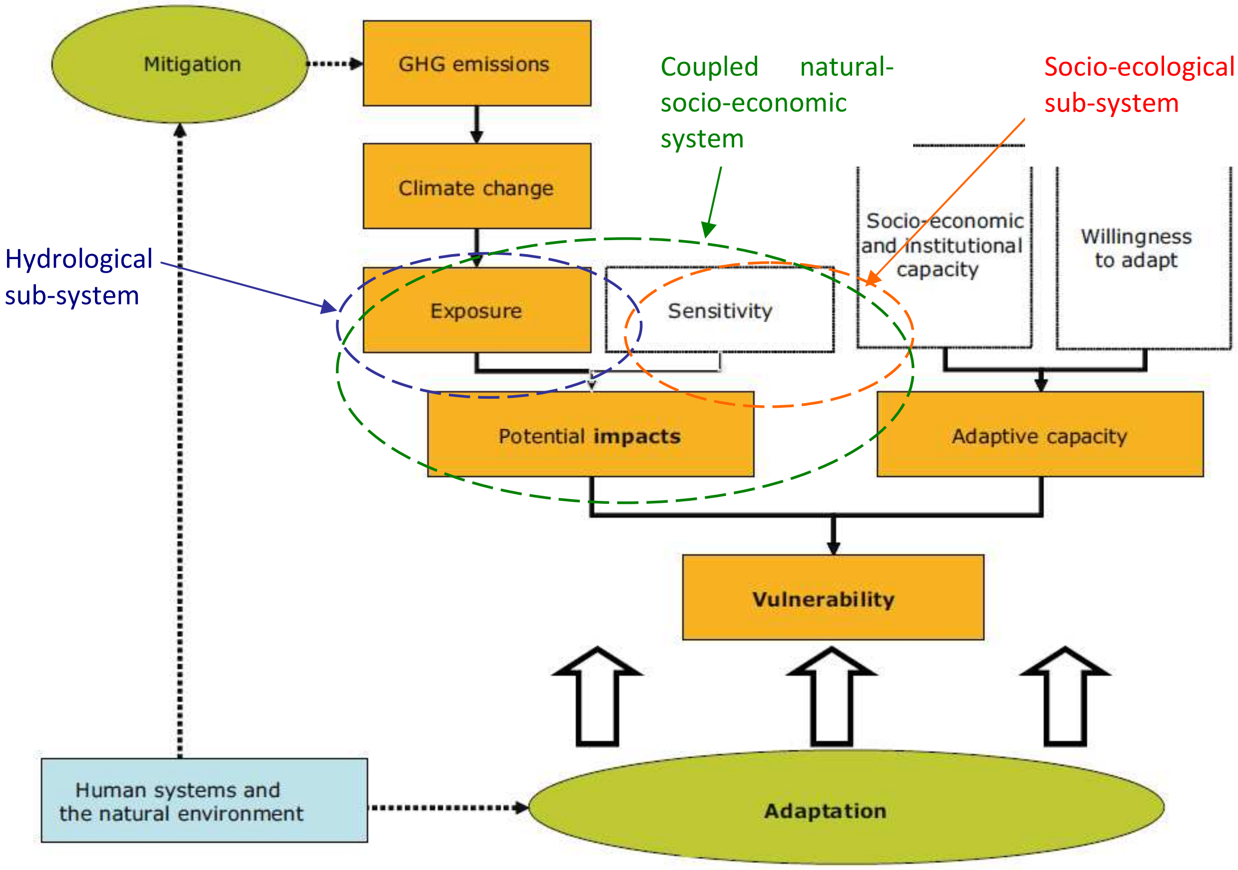


Figure 5 Conceptual model for climate change impacts, vulnerability and adaptation. Based on Isoard, Grothmann and Zebisch (2008).

In the simplest way, vulnerability can be described as a measure of possible future harm; however, the term vulnerability is still used in many different ways. For example, an extensive review by the ADAM project[1] on how vulnerability is defined and used in over 100 case studies showed rather inconclusive results, partly because the concepts it is based on are themselves vaguely defined (e.g. adaptive capacity). In order to identify adaptation options that serve to reduce vulnerability, many

[1] www.adamproject.eu

questions need to be answered: who or what is vulnerable, on which aspect, to what extent, and at which point of time? Obviously, there will be different vulnerabilities to different climate-driven changes and at different spatial and temporal scales. Therefore, there have been many European studies and projects, dedicated on these different aspects of water-related vulnerability to climate change (e.g., ADAM, SCENES, PESETA, WATCH, XEROCHORE, CIRCA, ACQWA, WASSERMed, DESERTLINKS). One of the aims of the current project is to use the results of these previous studies as a basis for developing a list of vulnerability indicators and guidelines that can be used to identify vulnerable areas in Europe as well as a benchmark for the effectiveness of the identified adaptation measures. These existing approaches have been systematically analyzed and used to build a basis for further development of indicators.

In literature, vulnerability is often referred to as having three components (see also Figure 5):

- ***exposure*** being the "nature and degree to which a system is exposed to significant climatic variations" (exposure to climate factors);
- ***sensitivity*** being the "degree to which a system is affected, either adversely or beneficially, by climate-related stimuli" (sensitivity to change); and
- ***adaptive capacity*** being the "ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences."

UNECE[2] considers exposure as an external dimension of vulnerability and sensitivity and adaptive capacity as internal dimensions. UNECE also distinguishes between current and future vulnerabilities, including adaptive capacities. Hence, future adaptation efforts should aim to reduce vulnerability by reducing exposure and sensitivity (potential impacts) and increasing adaptive capacity. In this project, we will use this general framework, but we will make it more operational. In our interpretation, adaptive capacity is considered as the capacity of the system (area, nation, and region) to plan and implement measures that will reduce vulnerability and will not be quantified.

In our interpretation, exposure is related to the effects of climate variability and change on the hydrological (biophysical) sub-system and sensitivity is related to the effect on the socio-economic sub-system (Figure 57). Biophysical and socio-economic sub-systems are in reality coupled and together form a natural-socio-economic system. Their interrelations result in impacts. The system will take some measures to reduce these impacts, and it will depend on its adaptive capacity to what extent the impacts will turn to vulnerabilities. Not all impacts will be negative, however, and the adaptive capacity will determine to what extent the system is able to utilize the opportunities.

2.1.2 The "Driver-Pressure-State-Impact-Response" (DPSIR) approach and its related indicators

The vulnerability assessment is structured by the DPSIR (Drivers, Pressures, State, Impacts, Response framework (DPSIR) that is commonly applied and widely adopted by the European Environment Agency (EEA) because of its simplicity, wide acceptance and its applicability for reporting environmental problems. For this project the DPSIR was operationalized in a dialogue with DG Environment, based on the definitions below (see also Annex 4A and B).

Driving Forces – Important large scale, slow changing processes influencing water availability, water demand and water quality

[2] www.unece.org/env/water/water.and.climate.

Pressures – Human activities directly affecting water demand and natural processes determining hydrological cycle

State Variables – The result of the interaction of natural and human pressures with the natural and socio-economic system.

Impacts – The outcome of the interacting natural and socio-ecological states,

Responses – Actions taken to prevent or alleviate vulnerabilities and take advantage of the opportunities. Responses play important role in determining the adaptive capacity of a system. In our interpretation, the ability of the system to act with adequate responses (to implement adequate measures) will decrease its vulnerability and increase its adaptive capacity. The increased adaptive capacity will lead to implementation of appropriate measures to deal with the resting vulnerability, will decrease again this vulnerability and further increase adaptive capacity in a continuing cycle (Figure 6).

In the context of this study, this approach has been developed further. For *Drivers*, *Pressures* and *State* the DPSIR approach is further divided into an exposure part and a sensitivity part which is combined again in the *Impacts* part (see Figure 6). The exposure part represents the natural resources and forces, or "supply" side while the sensitivity part represents the way people deal with or manage these resources and forces, or "demand" side. "Natural" is a relative term in this case, because these resources and forces are modified at each step by the humans. For example freshwater made available through desalination is still a natural resource and present the "supply" side, but is highly modified. In addition, "area prone to flooding" represents the natural side, but the existence of flood protection structures will modify its size.

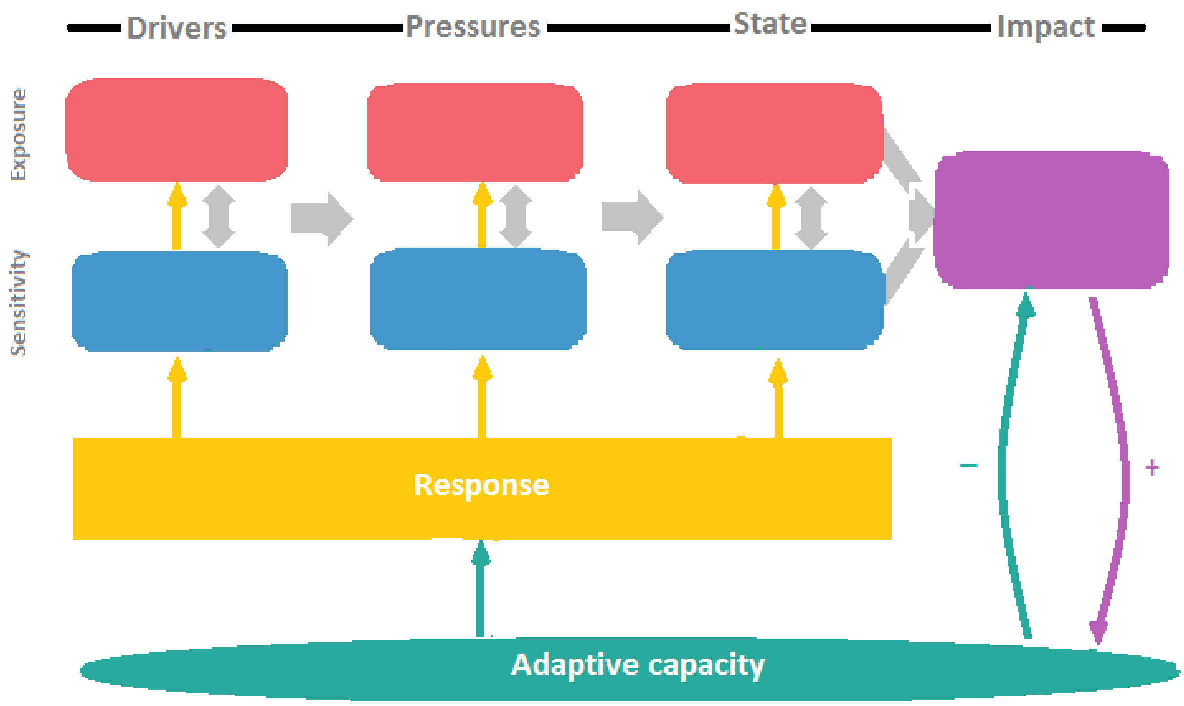


Figure 6 Conceptual Vulnerability Framework used in ClimWatAdapt, developed in cooperation with Jacques Delsalle, DG Environment.

In the *exposure* part, the following attributions are considered:

- *Driving force:* Climate change is considered as an exogenous driving force (and depends on climate scenario used).
- *Pressures*: Changes in hydrological and climate extremes and in long-term average climatic and hydrological variables, such as precipitation, river flow, and sea level rise.
- *State:* Water availability, river flow regime (including low flow, high flow, etc.), salt water intrusion, etc.

In the *sensitivity* part, the following attributions are considered:

- *Driving forces* are slowly changing variables such as demography, technology, preferences, etc.
- *Pressures*: Land use changes, change in resource efficiency, management practices, etc.
- *States*: Water demand, people and production in flooding zones, etc.

As mentioned above, exposure and sensitivity can be combined leading to *Impacts* such as water stress, and losses of life, wealth and biodiversity.

In our interpretation, DPSIR represents the casual chain leading to a given vulnerability. The vulnerability indicator stress, for example, is an outcome of the interrelations between the state exposure indicator Water availability and sensitivity state indicator Water use. Changes in natural Water Availability are a result of different climatic and hydrological processes such as changes in Precipitation and River flow measured with the respective Pressure indicators. These pressures are arise from changes in temperature (climate change) climate variability and measured with the exposure Driver indicators.

Water use arises, on the other hand, from changes in many human-driven processes such as changes in Land use and Resource use efficiency, measured with the respective sensitivity Pressure indicators. These pressures are the result of the preferences, knowledge and wealth of people and are measured with the corresponding sensitivity Driver indicators.

The modification of the DPSIR framework described above has been developed in such a way that it makes it possible to apply the main principles of the Integrated Water Resource Management (IWRM) paradigm. Global Water Partnership (2000) defined IWRM as “a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.” The DPSIR framework as used in this report reflects the holistic IWRM approach to water resource management and allows for systematic analysis from system point of view – taking into account not only one single indicator, but also its context and its interrelations with the other indicators.

The general criteria in the process of indicator selection are:

a) to be rigorously connected to the definitions,

b) to be selected on the base of a framework and policy relevance; and

c) to use available data and information.

The modified DPSIR framework has been developed for this project so as to comply with the second requirement for indicator selection: to be based on a framework. In order to comply with the first requirement, main definitions are provided below.

2.1.2.1 Indicators for exposure

Water resources managers are familiar with the variability of water quantity and quality parameters as planning and management of water resources systems requires knowledge about the statistical properties of hydrological events. Figure 7a depicts, for example, long-term, historical time series of precipitation. On its basis not only can long-term annual averages be estimated, but also rare extreme events such as frequency of occurrence of 1-in-50 years flooding and droughts (compare Figure 7a and b). The estimations are made on the basis of statistical analysis and can reveal processes such as the development of water scarcity conditions in the region of consideration (Figure 7c).

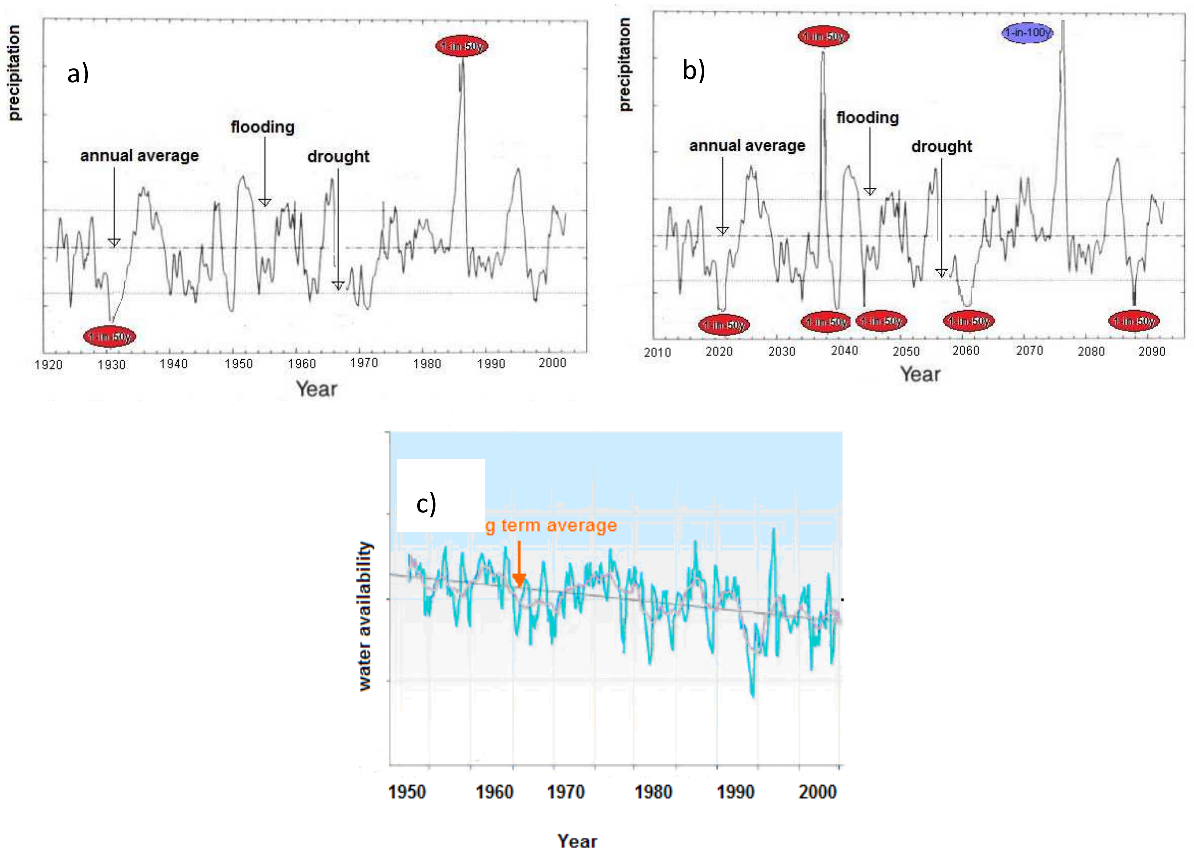


Figure 7 Long term precipitation time series: a) historical, b) future projections, c) long-term water availability series, indicating water scarcity.

The return period is one of the key characteristic of extreme events, defined as the frequency or recurrence interval of the event with given intensity and duration over an extended period of time (see red circles on Figure 7). The 1-in-100 years flood is not an event that may happen at the end of 100 years period, but rather demonstrates the particular flood level that has a 1% probability of occurrence each year. Return period is of particular interest for risk analysis. For example, it can be used for planning of structures able to withstand an event with a given intensity such as dykes and buildings or for building water reservoirs; its calculations are required by the Flood Directive[3] for flood risk estimation. Here, “flood risk" means the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event”.

[3] EU Directive 2007/60/EC on the assessment and management of flood risks

There are various ways in which hydrological events can be characterized statistically, but for the extreme, hazardous events such as flooding and droughts, the magnitude of the event (severity or intensity) duration and timing (time of the year) are of great importance. However, the importance of these characteristics differs for the different events and sectors. For example, magnitude is the most significant property for a flooding categorization, while for droughts it is the combination of magnitude and duration, representing the cumulative water deficit. The timing of an event such as delay in the start of the rainy season could have significant impacts on agriculture, depending on the seasonal phenology[4] of the crops, but could be irrelevant for industry.

Climate change is projected to have significant impacts on the hydrological cycle. Changes in temperature, evaporation and precipitation will affect the quantity and distribution of river flows, soil moisture and groundwater recharge. Current global climate change models indicate that the magnitude and frequency of extreme events may increase due to climate change. Seasonal patterns and return periods are projected to change as well (Kundzewicz et al. 2008). As a result, the main characteristics of the hydrological events, depicted in Figure 8a, may change as shown in Figure 8b or vice versa.

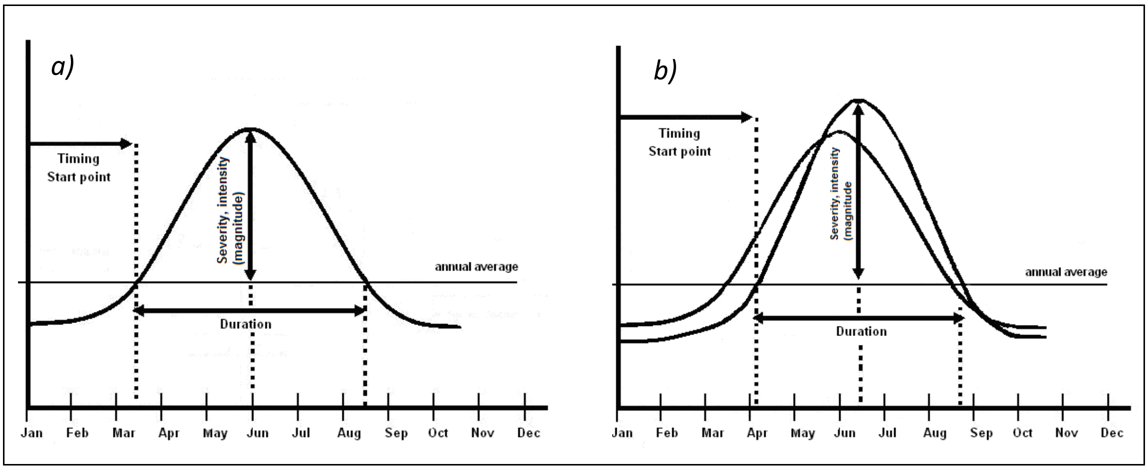


Figure 8 Main characteristics of hydrological events (a). Altered characteristics of hydrological events due to climate change (b).

Figure 8a suggests that although some of the main characteristics of one event might be altered, this does not necessarily correspond with changes in the average. One of the mechanisms that may lead to such a result is a simultaneous change in the magnitude and duration of one event, yielding shorter, but more intensive events. Figure 8 depicts another mechanism that may produce the same result on a longer time scale, where intensification and increase of the number of both droughts and flooding that does not change the annual average.

Significant changes in the return periods of flooding and droughts are likely occur, too: 1-in-100 years flooding may become 1-in-50 years flooding and 1-in-50 years drought may become 1-in-10 years drought (see chapter 3.4. In addition to these two mechanisms, the models may project a decrease in the availability of freshwater resources in some places and periods and an increase in other places and periods, implying that long-term annual averages will be altered in some places. The main consequences of change in annual averages are the possibility of augmentation of water scarcity and water logging conditions.

[4] Phenology studies periodic plant and animal life cycle events and how these are influenced by seasonal and interannual variations in climate

Exposure to water scarcity is defined as the degree to which a system is exposed to available long-term average water quantity. The exposure will affect long-term water availability and thus long-term water supply.

Examples of possible indicators: Changes in Average precipitation, average river discharge, average soil moisture, and groundwater recharge.

Exposure to droughts is the degree to which a system is exposed to climatic variations of the quantity, magnitude, frequency and seasonality of available water. The exposure will affect temporal water availability and thus temporal water supply.

Examples of possible indicators: Severity, duration, return periods and timing of drought events due to temporal decrease of precipitation, river discharge, soil moisture, Palmer Drought Severity Index (PDSI)[5], rechargeable groundwater and water stored in lakes and dams below some threshold level.

Exposure to flooding is the degree to which a system is exposed to climatic variations of the quantity, magnitude, frequency and seasonality of high waters and to sea level rise.

Examples of possible indicators: Severity, duration, return periods and timing of flooding events due to increase of precipitation and river discharge above some threshold level and sea level rise.

2.1.2.2 Indicators for sensitivity

Sensitivity to water scarcity is determined by the influence of water-related climate change effects on the functioning of the system - systems where water demand is high are more sensitive to water scarcity than systems where water demand is low. Climate change will not be the only stress factor on water demand, however. Population growth and changes in livelihoods and technology will have a more pronounced effect and therefore in the future projections are not separated from the effects of climate change. It should thus be noted that climate change is not the only one factor that determines sensitivity to future water changes and related indicators.

Examples of possible indicators: Changes in water demand, water productivity, and water accessibility, compared to some base period. These indicators could be further disaggregated according to different users and sectors: domestic, agriculture, industry, energy production, tourism. Some of these indicators are available from modelling work (e.g., WaterGAP calculates water withdrawals for different sectors, which can be used as a proxy for water accessibility in the future and these sub-indicators are included in the database). Each sector will have also a specific indicator, such as using a crop moisture index[6] for the agriculture sector.

Sensitivity to droughts is defined in this project similarly to sensitivity to water scarcity, but taking into account that the influencing factor is of natural, temporal origin as in accordance with the definition of drought.

Examples of possible indicators: Changes in water demand, water productivity, water accessibility and susceptibility to (production) losses due to these changes during drought events, compared to some base period. These indicators could be further disaggregated according to different users and sectors: domestic, agriculture, industry, energy production, tourism.

Sensitivity to flooding is mainly determined by the share of socio-ecological systems, located in the flood-prone areas and susceptible to flooding.

[5] Measures meteorological droughts. PDSI is based on the cumulative difference between normal precipitation and precipitation needed for evapotranspiration (Palmer, 1965). Alley (1985) adjusted it to measure the hydrological drought as well.

[6] Measured as the difference between the actual and expected weekly evapotranspiration (Palmer, 1968)

Examples of possible indicators: Susceptibility to flooding (fluvial, tidal/coastal, from surface and from groundwater) number of people, economic assets (property, agricultural production, industrial production, infrastructure, land, ecosystems), level of structural mitigation, and state of natural infrastructure (eco-services) located in flood-prone area.

Climate change is expected to have a significant effect on water quality: warmer climate and water will decrease oxygenation, extend algal blooms and change their timing and will increase the decomposition of pollutants. The increase in runoff will flush more contaminants and sediments into surface waters and thus will result in an increase of concentration of pollutions. At some places, rising sea level, combined with a decrease of river discharge will cause salt water intrusion in coastal aquifers and estuaries.

Water quality degradation can result in water scarcity even at areas with high fresh water availability. For example, a study of Vienna's water mountains suggests that the increased number of extreme events will cause water turbidity through high rates of mobilized sediments and that this will have negative impact on water availability (EEA, 2009b).

2.1.2.3 Indicators for impacts

Impacts of water scarcity: If water demand exceeds water availability, the difference between water supply and water demand will result in a water "gap", which will negatively influence socio-ecological systems. These influences we will label (potential) "impacts".

Examples of possible indicators: Potential changes in Water Exploitation Index, Water stress due to water scarcity, Loss of industrial production, Loss of agricultural production, of jobs, income and livelihoods, desertification and land degradation, and Tourism Climatic Index (TCI).

Impacts of droughts: If water demand exceeds water availability (supply) on a temporal, recurring basis (according to the definition of drought), the difference between water supply and water demand will result in a water "gap", which will influence negatively socio-ecological systems. These influences we will label "impacts".

Examples of possible indicators: Potential temporal Water stress, Loss of industrial and agricultural production, and loss of jobs and income. These temporal losses may become permanent if socio-ecological systems cannot recover from recurring droughts and a sequence of droughts leads to long term water scarcity.

Impacts of flooding are the impacts, emerging from the changes in the flood exposure parameters and the part of socio-ecological system, located in the flood-prone zone.

Examples of possible indicators: Potential loss of life and (temporal) loss of property, assets, infrastructure, jobs, land and livelihoods due to flooding.

2.1.2.4 Adaptive capacity

As it has been mentioned above, in this project we consider adaptive capacity as the ability of a system to implement measures that decrease its vulnerability. This has been done in order to avoid the existing methodological difficulties and to offer a practical approach in dealing with this challenging concept.

Adaptive capacity to cope with water scarcity is determined by the ability/possibility of regions or sectors to close the gap between water demand and supply. This could be achieved by enhancing the societal ability to increase water supply, decrease water demand or some combination of both.

Adaptive capacity to cope with droughts is determined by the ability/possibility of the sectors to close the gap between water demand and supply during recurring, temporal decreases of water availability due to drought. This could be achieved by enhancing the societal ability to temporarily increase water supply, decrease water demand or some combination of both.

Adaptive capacity to flooding is determined by the ability/possibility to protect the system against flooding.

Adaptive capacity is a very challenging concept and difficult to make operational as an indicator. There are a large number of factors, which contribute to adaptive capacity of one system such as GDP, education, social capital, infrastructure, technology, availability and accessibility of information, awareness, and equity. These factors are interrelated and very often scale-dependant. Therefore, we have modified them for a more practical approach, looking at the capacity of the system to implement measures necessary for the reduction of the identified vulnerability. In this way, the Water Stress Index, representing the gap between water supply and demand, as well as Losses due to flooding could be considered as proxies for adaptive capacity of the system. When measures are successfully implemented and the gap between supply and demand narrowed or losses from flooding are reduced, the adaptive capacity of the system increases. This approach has many limitations, but can at least give some first impressions of the adaptive capacity of the system under consideration. Further detailed research is needed for areas identified as having low adaptive capacity as identified by this approach.

2.1.2.5 Indicators for vulnerability

When climate change results in negative impacts, each system will attempt to adapt. If the adaptive capacity of the system is very high, it could offset these impacts through adaptation measures. If the adaptive capacity is not very high or the impacts are too severe, the system will not be able to offset them completely and potential vulnerabilities will become real.

Vulnerability to water scarcity: A system is vulnerable to water scarcity when its water demand exceeds water availability.

<u>*Examples of possible indicators*</u>: Changes in Water Exploitation Index, Water stress due to water scarcity, Loss of industrial production, Loss of agricultural production, loss of jobs, income and livelihoods, desertification and land degradation, and changes in Tourism Climatic Index (TCI).

Vulnerability to droughts: A system is vulnerable to drought if available water cannot meet demand due to occurrence of a drought event.

<u>*Examples of possible indicators:*</u> Temporal water stress, Loss of industrial and agricultural production, and loss of jobs and income. These temporal losses may become permanent if socio-ecological systems cannot recover from recurring droughts and a sequence of droughts leads to long term water scarcity.

Vulnerability to flooding: A system is vulnerable to flooding when it cannot prevent losses due to occurrence of flooding events.

<u>*Examples of possible indicators:*</u> Loss of life, (temporal) loss of property, assets, infrastructure, jobs, land and livelihoods due to flooding.

2.1.3 Indicators used in the IAF developed by ClimWatAdapt

Within this project a meaningful, transparent, and transferable set of indicators has been developed (Table 1), covering the environmental, social, and economic dimension. The definitions and the taxonomy of the indicators are given in chapter 2.1. The DPSIR tables with the indicators for this project are presented in Annex 3B.

Lessons learned from the 1st Expert Meeting
Vulnerability indicators: It was agreed to focus on exposure and sensitivity components. Adaptive capacity will be by-passed in the first step vulnerability assessment since it is very difficult to measure, and in practice does not provide much useful information. Adaptive capacity will instead be linked to adaptation measures. Thresholds: It is not clear if sufficient information on thresholds for intervention can be found. Therefore, the definition of thresholds was included as one topic to be discussed at the stakeholder meeting. Water quality issues mainly originate from water scarcity and floods and are mainly covered implicitly by measures related to those problems. For most of the water quality issues available water quality models have not yet been linked to climate change models. A literature review may help identify case studies for local situations that can be used to discuss water quality issues in the final report in a qualitative way.

Table 1 Vulnerability indicators used in the study and included in the IAF.

Vulnerability indicator (VI)	Description	Parameter name in ClimWatAdapt database
Water exploitation index (WEI)	Ratio of water withdrawals to water availability on river basin level	wei[_sector]_<season>[*,**]
c.t.a.	Ratio of water consumption to water availability on river basin level	cta[_sector]_<season>[*,**]
c.t.q90	Ratio of water consumption to discharge during low flow conditions Q90 (discharge exceeded in 90% of the days) on river basin level	ctq90[_sector][**]
c.t.q95	Ratio of water consumption to discharge during low flow conditions Q95 (discharge exceeded in 95% of the days) on river basin level	ctq95[_sector][**]
w.t.q90	Ratio of cooling water abstractions to discharge during low flow conditions Q90 on river basin level	wtq90[_sector][**]
w.t.q95	Ratio of cooling water abstractions to discharge during low flow conditions Q95 on river basin level	wtq95[_sector][**]
r.t.q95	Ratio of residual flow (water availability minus total water consumption) to Q95	rtq95_<season>[*]
Change in Q90	Relative change of Q90 between the baseline and a future time slice on NUTS2 level	rc_q90
Change in Q95	Relative change of Q95 between the baseline and a future time slice on NUTS2 level	rc_q95
Share of drought prone area	Area share of NUTS2-units potentially affected by severe droughts	sh_dpa
People affected by droughts	Number of people per NUTS-2 unit potentially affected by severe drought events	dp_pop

Vulnerability indicator (VI)	Description	Parameter name in ClimWatAdapt database
TEP affected by droughts	Thermal electricity production (MWh) per NUTS-2 unit potentially affected by severe drought events	dp_tep
Share of flood prone area	Area share of NUTS2-unit potentially affected by severe flood events	sh_fpa
People affected by floods	Number of people per NUTS-2 unit potentially affected by severe flood events	fp_pop
GVA affected by floods	GVA per NUTS2-unit potentially affected by severe flood events	fp_gva
Risk of saltwater intrusion	Risk of saltwater intrusion into transitional water due to sea level rise and change in river discharge (for 50 largest transitional water in Europe)	risk_saltwater_intrusion
Tourism overnight stays in water stressed areas	Number of tourism overnight stays per year and European analysis region under severe water stress (WEI>0.4)	nights
Change in maximum snow cover	Change in maximum snow cover between future period and baseline on NUTS-2 level	ch_snow_cover
Change in number of days with snow cover	Change in number of days with snow cover between future period and baseline on NUTS-2 level.	risk_winter_tourism
7-day minimum flow	Long-term average minimum flow during seven consecutive days	rc_av7qmin
Risk for navigation	Risk of more frequent disruption of navigability of the rivers Danube, Elbe, Rhine, Rhône, and Seine due to decreasing river discharge.	risk_navigation
Risk for hydroelectric dams	Risk of reductions in hydropower potential for hydroelectric dams due to changes in winter and summer water availability on river basin level	hydpow_risk_dam
Risk for run-of-the-river hydropower	Risk of reductions in hydropower potential of run-of-the-river stations due to changing Q95 and Q90 on NUTS2-level	hydpow_risk_ror

[*] Indicator defined for annual values or seasonal values. Placeholder <season> can be one of “ann”(=annual), “djf”(=winter) ,”mam” (=spring),“jja” (=summer), or “son” (=autumn). See DB documentation for details).

[**] Indicator defined for individual sectors or groups of sectors; [_sector] can be omitted (=all sectors, total), “tot” (=all secotors, total), “el” (=thermal electricity production), “dom” (=domestic), “irr” (=irrigation), “man” (=manufacturing). See DB documentation for details.

General DPSIR tables with possible exposure and sensitivity related indicators are presented in ANNEX 3A. In addition to the indicators calculated in this study, many other identified indicators are listed along with their relevance for different sectors and data sources for them, if available. The indicator list in ANNEX 3A is not complete, as the subjects of water and climate and their interrelations with human and natural systems are too broad to be able to include all of them in this study. The decision to include in the DPSIR tables indicators, for which data on EU scale still does not exist, was made because the existing information was so dispersed, that it became necessary to develop the conceptual taxonomy, described above, that was able to order the existing information in a systematic way. In the process of developing this taxonomy, we discovered that data describing important aspects of the system was missing for some indicators. However, we left them in our set of indicators, because firstly, they show the gaps in the current research, and secondly, they are necessary for the description of the system and its vulnerabilities. As Holling et al. (1998) notes, "understanding (but not necessarily complete explanation) of the combined system of humans and nature is needed to formulate policies". The missing indicators do not comply with the third requirement for indicator selection, but they do comply with the requirement for policy relevance and can guide policy in prioritization of further research.

2.1.4 Scenarios used

A scenario-based approach is used to provide options for the design of vulnerability indicators and to assess different adaptation measures and strategies. Scenarios offer the possibility to evolve plausible descriptions of how the future may unfold, based on a coherent and internally consistent set of assumptions about key relationships and driving forces. Scenarios provide alternative views of the future but they are not predictions nor should they be taken as the most likely of the numerous possible futures. At most, they draw pictures of a limited number of plausible futures, based upon a coherent and internally consistent set of assumptions about choices by key actors, the progression of social processes, and underlying system relationships (Robinson 2003). By using scenarios, possible future developments can be explored and strategies to influence those potential developments can be tested. Decision makers can use scenarios to think about the uncertain aspects of the future that worry them most and to explore the ways in which these might unfold.

2.1.4.1 Climate scenarios

For this project, the climate change scenarios developed in the ENSEMBLES[7] project (van der Linden and Mitchell 2009) were used. These scenarios are based on Regional Climate Model (RCM) runs driven by the outputs of different GCMs using the IPCC SRES A1B emission scenario (see Annex 4 for more detail). It is well known that large biases, either caused by the driving GCM or generated by the downscaling RCM, affect the modelled present day climate. This is also true for the future evolution of temperature and precipitation, which is discussed by Dosio and Paruolo (2011). They applied a statistical bias correction technique developed originally by Piani et al (2010 a,b) to correct the ENSEMBLES climate time series. In ClimWatAdapt we could make use of the bias-corrected climate datasets (provided by JRC) in a sense as JRC's hydrological rainfall-runoff-routing model LISFLOOD[8] (Annex 2) was forced by the bias-corrected output from 11 GCM-RCM model combinations (Annex 4). As a result, the vulnerability assessment performed in ClimWatAdapt is based on the best available high-resolution climate change input. More details on the climate multi-model ensemble are given in Annex 4.

The downscaling RCM simulations cover the period 1961-2100, with a domain covering the entire European continent at a resolution of about 25 x 25 km. The set of GCM-RCM simulations used in the study are listed in Table 2. However, it should be noted that this list does not represent the full set of the ENSMEBLES simulations, and the driving GCM runs do not cover the full CMPI3 range. RCMs data are stored on the ENSEMBLES database at the Danish Meteorological Institute (http://ensemblesrt3.dmi.dk/).

[7] http://ensembles-eu.metoffice.com/index.html

[8] http://floods.jrc.ec.europa.eu/lisflood-model

Table 2 List of regional-global climate model combinations used to drive the LISFLOOD model (climate simulations for the SRES A1B scenario from the ENSEMBLES project).

Acronym	Regional Climate Model	Global Climate Model
C4I_RCA_HadCM3	RCA	HadCM3
DMI_HIRHAM_ARPEGE	HIRHAM	ARPEGE
DMI_HIRHAM_BCM	HIRHAM	BCM
DMI_HIRHAM_ECHAM5	HIRHAM	ECHAM5
ETHZ_CLM_HadCM3	CLM	HadCM3
KNMI_RACMO2_ECHAM5	RACMO2	ECHAM5
MPI_REMO_ECHAM5	REMO	ECHAM5
SMHI_RCA_BCM	RCA	BCM
SMHI_RCA_ECHAM5	RCA	ECHAM5
SMHI_RCA_HadCM3	RCA	HadCM3
METO_HC_HadRM3_HadCM3	HadRM3	HadCM3

Precipitation changes between future projections and the baseline period as based on the ensemble of climate projections show an evident variability across the models in the magnitude of change, and at the local level, even the direction of change may alter between models. Figure 9 and Figure 10 illustrate the variation across the 11-member multi-model ensemble for the A1B scenario for the 2025s and 2050s.

Figure 9 Change in annual precipitation between the 2025s (2011-2040) and baseline period (1961-1990) for the SRES A1B scenario based on LISFLOOD simulations driven by various regional climate models. The maps represent the results for the 11 model combinations listed in Table 1 and the ensemble median.

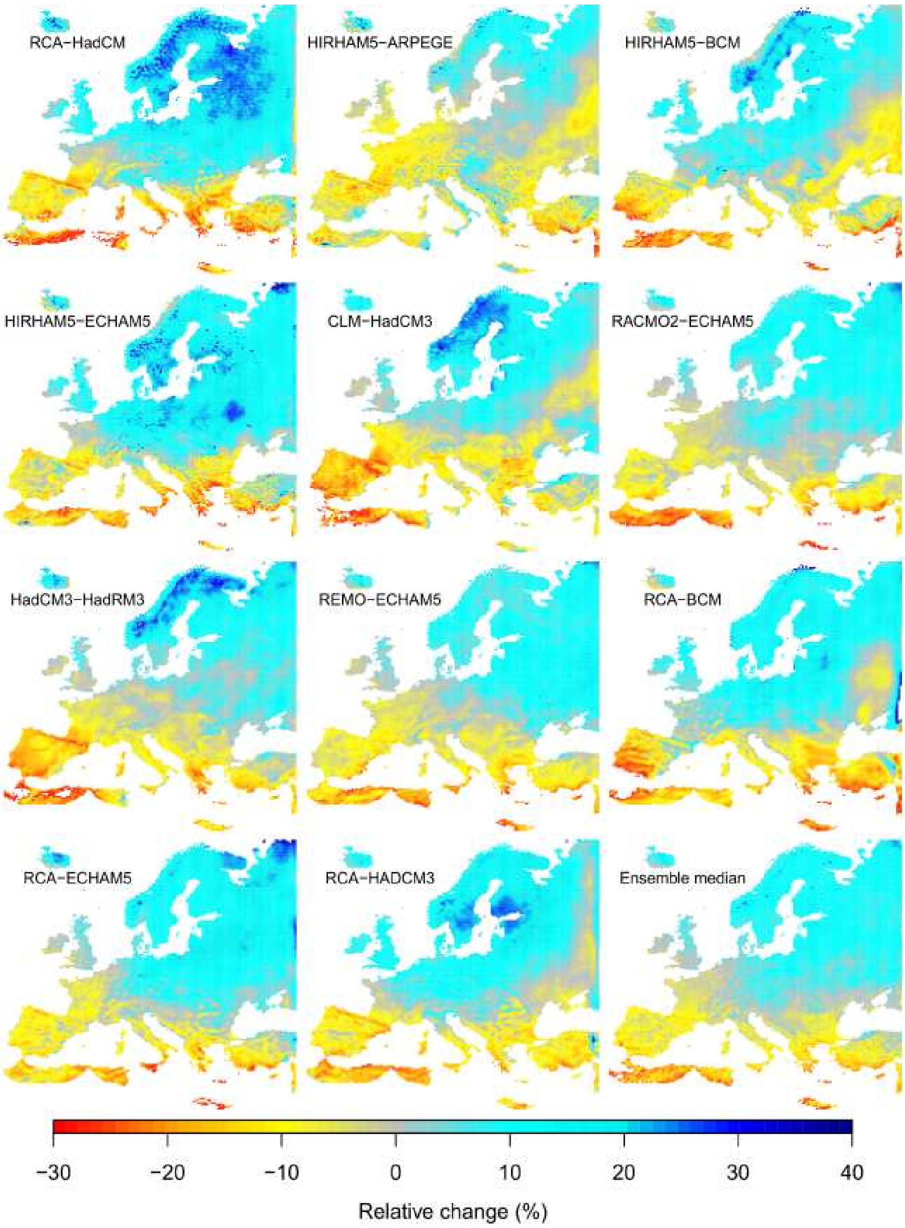


Figure 10 Change in annual precipitation between the 2050s (2041-2070) and baseline period (1961-1990) for the SRES A1B scenario based on LISFLOOD simulations driven by various regional climate models. The maps represent the results for the 11 model combinations listed in Table 1 and the ensemble median.

2.1.4.2 Socio-economic scenarios

Instead of downscaling regional scenarios from IPCC (IPCC 2000), the consortium made use of the SCENES[9] scenarios (see Annex 4) that are the latest water-related scenarios developed for Europe (Kämäri et al. 2008, Kok et al. 2011). This has an enormous advantage for the study since the main scenario drivers were developed by stakeholders and scientists on a sub-regional level (Europe was sub-divided into 6 sub-regions) and then downscaled to national scale. Future water uses have been

[9] http://www.environment.fi/syke/scenes

modelled by WaterGAP[10], considering the socio-economic and land use scenario input from SCENES, which ensures using of comprehensive and consistent information for the vulnerability assessment.

One of SCENES' major objectives is to develop and analyze a set of comprehensive scenarios of Europe's fresh waters up to 2050. This has been done by developing exploratory scenarios exploring specific trends into the future and providing an internally-consistent picture of how water resources in different parts of Europe will develop up to 2050 (to deal with longer term challenges such as climate change). Within SCENES, scenarios are developed that have the following characteristics:

1. They follow the SAS approach (Story-and-Simulation, Alcamo 2008), i.e. they consist of qualitative storylines; semi-quantitative system dynamics models and quantitative model runs and indicators.
2. They are developed at three different scales, pan-European; regional; and Pilot Area. Quantitative model runs were only performed at the pan-European level.
3. They are participatory, i.e. storylines are developed during stakeholder workshops. At the pan-European level, three pan-European panels (PEP) took place.

Four different scenarios were developed within the SCENES project:

"Economy First" (EcF) is a SCENES scenario where a globalised and liberalized economy pushes the use of all available energy sources and an intensification of agriculture where profitable. The adoption of new technologies and water-saving consciousness are low. Thus, water use increases. Only water ecosystems providing ecological goods and services for economies are preserved and improved. Curtailed infrastructure, poor treatment and intensified agriculture lead to increased pollution. Poisoning incidents catch the interest of media and public. This and social tensions lead to upheaval in the 2040s. This triggers new cooperation to restore economic prosperity and make ground for social coherence.

Fortress Europe (FoE) is a SCENES scenario in which a high number of crises (energy, financial, and climatic) result in an increasing instability and terrorist activities throughout the world, as well as in Europe. Subsequently, Europe closes its borders and concentrates on a series of security issues, including a central goal on self-sufficiency. Cooperation is difficult and alliances change, but perceived threats keep the EU together. The WFD becomes the Water Security Framework Directive with much less public participation, to tackle the increase and intensification of water conflicts. Water policies focus on water demand, which is largely satisfied by 2050.

Policy Rules (PoR) is a SCENES scenario where there is a stronger coordination of policies at EU level, but policies become slowly more ineffective. As a result, ecosystem services begin to deteriorate very significantly. Until 2030, EC becomes increasingly disappointed in the level of WFD compliance; issues of water quality and quantity are generally ignored; while there are emerging and increasing pressures on water resources. After 2030, climate change hits hard and changes public apathy, leading to WFD compliance that is higher than ever. By 2030, public participation increases, leading to local government support. By 2050, Europe is at the forefront of a new socio-economic paradigm of public/private partnerships and leads a global shift in this direction.

Sustainability Eventually (SuE) is a SCENES scenario that sketches the transition from a globalizing, market-oriented Europe to environmental sustainability, where local initiatives are leading and where the landscape becomes the basic unit. This fundamental change in human behaviour, governance structures, and level of decision making, is projected to come about through a phase of strong top-down policies ("quick change measures"), accompanied with a set of "slow-change" measures that bear fruit in the long run.

[10] http://www.usf.uni-kassel.de/cesr/index.php?option=com_project&task=view_detail&agid=47&lang

For the vulnerability assessment described in this report, only the EcF and SuE scenarios were analyzed because these two scenarios span the broad variety of the SCENES scenarios. Nevertheless, it should be noted that all data and information related to all scenarios is available in the database for further analyses.

Details of the zero-order and first-order draft as well as the final versions of the storylines can be found in project Deliverables of SCENES (Kok et al. 2008, Kok et al. 2009). Interesting observations include (Kok et al. 2011):

- Low population growth, but strong migration is assumed in most scenarios
- Water pricing is introduced as key instrument in all scenarios
- Technologies are important in all scenarios, but the type differs strongly, including water saving technologies, energy, or a broad spectrum of high-tech developments. Technology transfer and adoption rates differ likewise.
- The state of the environment improves only in Sustainability Eventually and Policy Rules.
- Climate change impacts are introduced that trigger nonlinear changes in all scenarios.
- The Water Framework Directive (WFD): the WFD regionally fails (EcF), is substantially modified into the Water Security Framework, with only minimal attention to water quality (FoE), is strengthened in response to heightened awareness of rising climate change impacts (PoR), or succeed regionally when accompanied with strong awareness campaigns and environmental taxes (SuE).

Within SCENES the projections of the main drivers (population, GDP, energy, land use change) were modelled at IIASA based on the storylines and quantitative information from the stakeholders. Figure 11 shows the scenario projections for the total population per SCENES region in connection to past trends (Northern Africa (NA), Western Europe (WE), Northern Europe (NE), Eastern Europe central (EEc), Eastern Europe eastern (EEe), Western Asia (WA, Southern Europe (SE)). For comparison, the range of UN scenarios is added to the diagrams. In most cases, the SCENES population projections are within the extremes of the UN projections. PEP members at the third meeting were satisfied that the results represented the intention of the scenarios, so the projections were finalized. More details on the drivers are given in Annex 4.

Figure 12 presents the GDP development between 1960 and 2050. Historic GDP data was not available for some countries in each region for the entire period since 1960 and the historic time series' show jumps in GDP as additional country data became available. Future developments follow the SCENES scenarios on a regional level. Again, negative GDP growth is projected for some regions in the SuE scenario. However, the working group for that scenario within the panel stated explicitly that GDP was not the focus of the society in the scenario and that it is anyway a poor indicator of quality of life, meaning that the GDP may be decreasing in some regions while quality of life still improves.

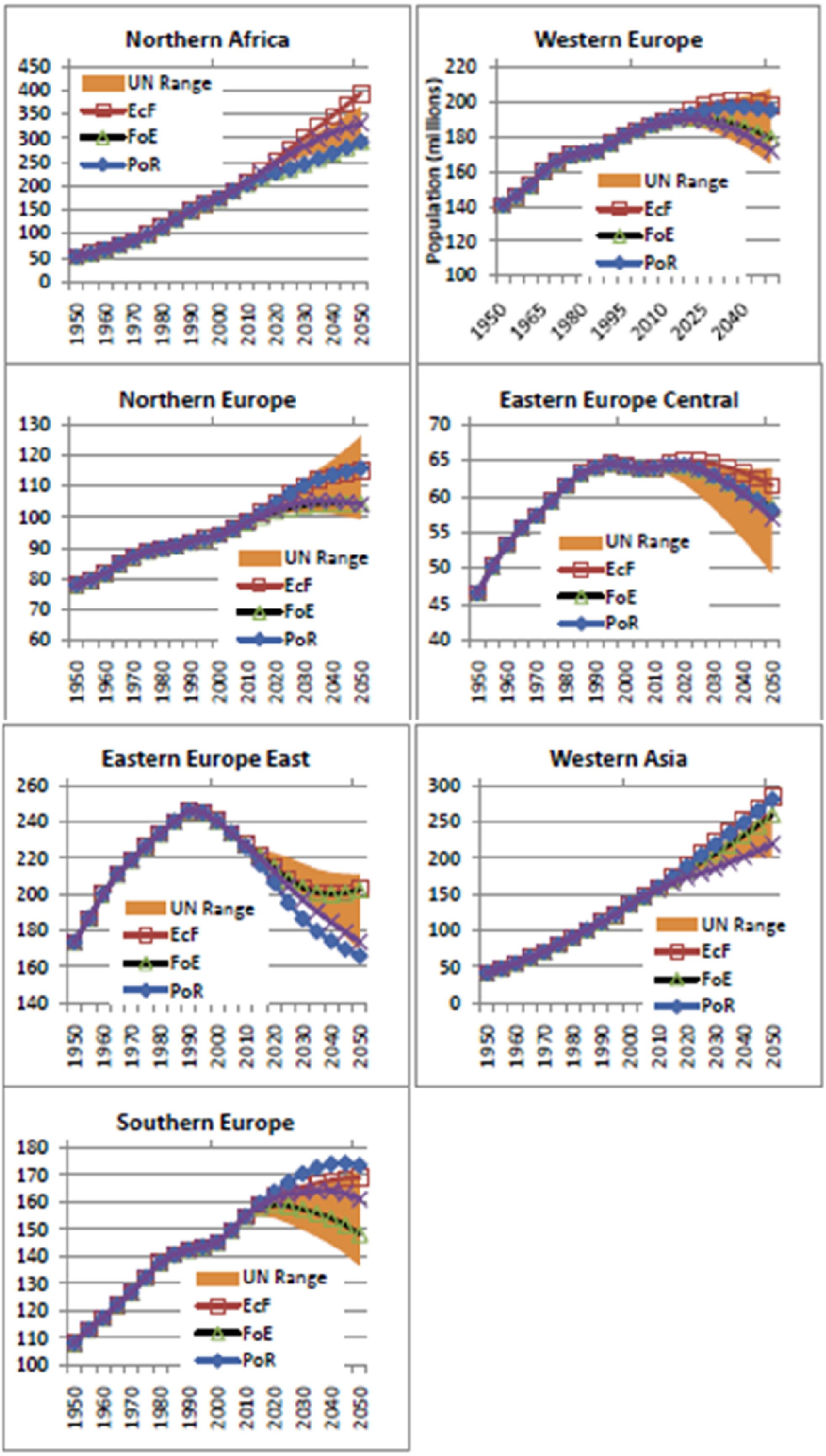


Figure 11 Total population projections for each of the SCENES scenarios and regions compared with UN projections. (Figures prepared by D. Wiberg, IIASA.)

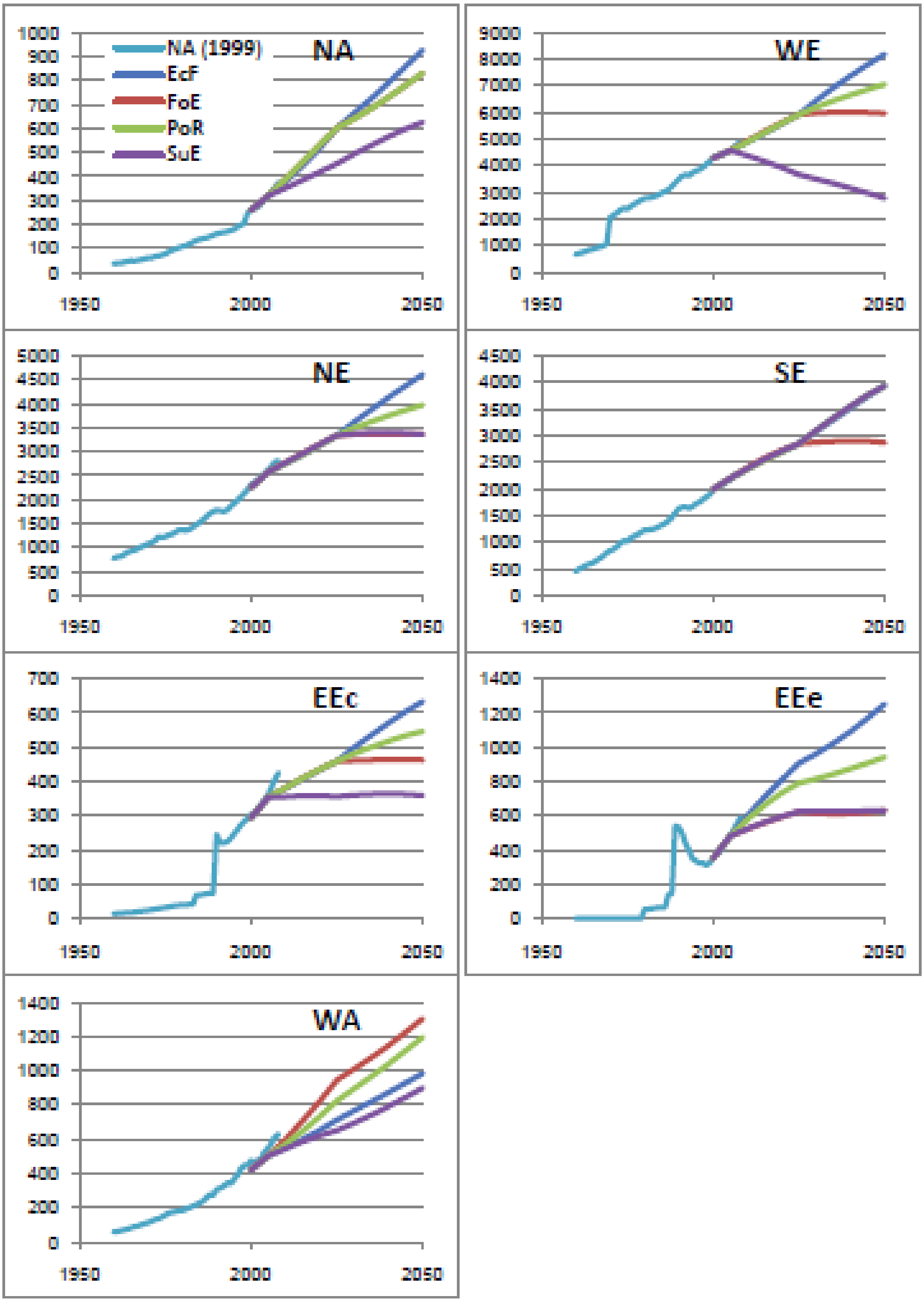


Figure 12 GDP projections after PEP3 for each scenario and region. GDP on the vertical access is in constant 2000 USD. (Figures prepared by D. Wiberg, IIASA.)

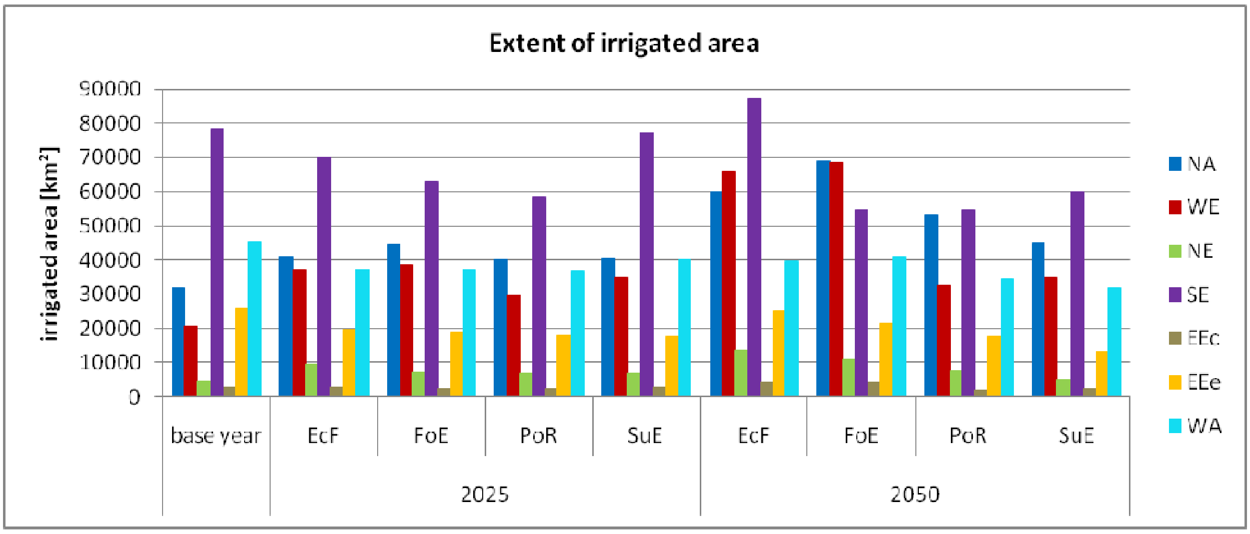


Figure 13 Future irrigated area for each scenario and region.

In SCENES, water-related scenarios were developed; therefore, the future development of irrigated areas was of interest. Figure 13 depicts the extent in irrigated area aggregated to the SCENES regions for 2025 and 2050. The extent of future irrigated area differs between the scenarios and the regions. Large increase in irrigated area (compared to the base year) is calculated for WE and NE due to intensification of agriculture. This intensification is partially the result of agricultural production moving from SE to WE and NE because of changing weather conditions and agricultural intensification on high productive land. Certain level of food-security is kept in all regions.

Technological changes are mainly leading to improvements in water use efficiency. This driving force is particularly important because it tends to reduce water use whereas the preceding driving forces in most cases increase water use. The impact of technological change on improving water use efficiency is taken into account in all sectors (except agriculture). In SCENES, technological changes were quantified by the PEP for two time periods (2005 – 2025 and 2025 – 2050) and for the seven different regions (Table 3).

Future projections for regional-specific project efficiencies were conducted according to the numbers quantified by the PEP (Table 4). WaterGAP data on project efficiency is used on a country level thus do not match the regional numbers as given in the table. However, to keep the direction and tempo of change, the regional changes as given by the PEP were taken and projected to national values.

Table 3 Technological change numbers as rate per year [%] for the SCENES regions.

Region	EcF		FoE		PoR		SuE	
Time	2005-2025	2025-2050	2005-2025	2025-2050	2005-2025	2025-2050	2005-2025	2025-2050
NA	0.3	0.3	-0.6	-0.6	0.3	0.6	0.6	1.2
WE	0.3	0.6	0.3	0.3	1.2	0.6	0.6	1.2
NE	0.3	0.6	0	0	0.6	0.6	0.6	1.2
SE	0.3	0.6	0.6	0.6	1.2	0.6	0.6	1.2
EEc	0.3	0.6	0.3	0.3	0.6	1.2	0.6	1.2
EEe	0.3	0.3	0.3	0.3	0.3	0.6	0.6	1.2
WA	0.3	0.3	0	0	0.3	0.6	0.6	1.2

Table 4 Results on the irrigation project efficiency [-].

Region	EcF		FoE		PoR		SuE	
Time	2025	2050	2025	2050	2025	2050	2025	2050
NA	0.37	0.37	0.53	0.53	0.53	0.69	0.53	0.69
WE	0.53	0.37	0.69	0.69	0.69	0.69	0.53	0.69
NE	0.53	0.37	0.69	0.69	0.69	0.69	0.53	0.69
SE	0.53	0.37	0.69	0.69	0.53	0.69	0.53	0.69
EEc	0.53	0.37	0.69	0.69	0.53	0.53	0.69	0.69
EEe	0.37	0.53	0.53	0.53	0.53	0.53	0.53	0.53
WA	0.37	0.37	0.37	0.37	0.53	0.69	0.53	0.69

2.1.4.3 Uncertainties of future projections

General sources

The immense complexity and the chaotic nature of the climate system seriously challenge the construction of reliable predictions about the magnitude and pace of climate change. Uncertainty about future changes falls generally in two main categories: aleatory and epistemic, or irreducible and reducible. The first arises from the inherent stochastic nature of some physical processes such as variations in atmospheric conditions and is also referred to as variability and random uncertainty. It will not decrease substantially with the development of new knowledge. The epistemic uncertainty can be reduced with the time, however, as it is a result of lack of knowledge of some processes and feedbacks, like ice sheet melting and flow. Below we summarize the main sources of uncertainty.

- Observed climate and hydrological characteristics are used to constrain climate model prediction and in model calibrations. High degree of agreement between model simulations and observations increases considerably the confidence in models capability to make future projections. All observations suffer from measurement errors, they are not spatially and temporally homogenous, consistent and complete, however. Differences between observational data sets could be very large (McAvaney et al. 2001). In addition, very often observations cannot be used directly, as the applications they were established for require much lower precision than needed for climate change estimations and projections (Wunsch et al. 2007).
- The projections for anthropogenic emissions are maybe the largest single source of uncertainty, because neither the quantity of these emissions nor the response of the climate system to this forcing is known. Projections concerning the first variable require many assumptions about future population, socio-economic development and technical changes and their relationships (e.g., Wigley et al. 1996; Nakicenovic and Swart 2000).
- Climate models are the most credible tools available to construct consistent future climate change projections. Yet, they are source of considerable uncertainties due to incomplete, missing or incorrect representation of some processes and poorly constrained parameters (e.g., Katz 2002; Murphy et al. 2004).

Model uncertainties can be partly resolved, using ensembles of simulations of one model with different scenarios and initial conditions or ensembles of simulations of different climate and hydrological models, forced with different scenarios. Projections based on the use of multi-model ensembles are considered more reliable than projections produced by single models alone, as the multi-model average or median can be expected to outperform individual ensemble members thus providing an improved 'best estimate' forecast (IPCC 2007). It should be noted, however, that a multi-model ensemble may share common systematic errors (Lambert and Boer 2001) because entire processes are omitted and there are gaps in understanding of the physics or models may compensate errors in one process or parameterization with errors in other processes or parameterizations (e.g. Murphy et al. 2007), simulating as a result realistic present climate. Therefore, these possible not-quantified uncertainties have to be taken into account in addition to quantified ranges in order to avoid overestimation of the capability of current state-of-the art models to make future projections.

In order to address uncertainty related to climate change projections in this project, bias-corrected transient time series of precipitation and temperature are used based on the ENSEMBLES projections. In this context, temperature and precipitation data from 11 different RCM-GCM combinations were selected to drive the hydrological simulations. The generated bias-corrected ensembles data sets are at the finest resolution available (25 x 25 km).

It is well known that the choice of the emission scenario is of less importance for the early decades of the 21st century (Déqué et al. 2007) than for the later ones since they start to diverge in the second half of the century. Moreover, it is a fact that ensemble runs of GCM simulations lead to regional differences. Thus, it is recommended good practice to use multi-model information to capture at least some of the uncertainties associated with climate modelling and projections.

However, for impact, vulnerability and adaptation analysis focussing on short and medium time scales, it is important to provide a meaningful combination of the climate change pathways with short- to medium-term scenarios for socio-economic development. For this study, one emission scenario (i.e., SRES A1B) was chosen for the climate scenarios, but to be in a better position to explore climate related uncertainties due to the choice of boundary conditions (i.e., the GCM) and model formulation (i.e., the RCM), the climate input simulated by an ensemble of models was considered (see Annex 4).

Most of important socio-economic assumptions and key characteristics were developed by a stakeholder driven process, initiated by questionnaires, which were then analyzed with Fuzzy Set methodology.

Sensitivity to uncertainty of climate projection

The robustness of the model results has been analyzed by selecting water stress results (WEI for summer, excluding cooling water; see chapter 3.3) with respect to the multi-model ensemble of hydrological input. The Box-Whisker-Plot (Figure 14) visualizes the respective results as calculated separately with all hydrological model results. Finally, this diagram highlights the climate variability given by the 11 GCM-RCM combinations and supports the significance of the water scarcity assessment for the different European regions. High agreement of the model results is demonstrated for Eastern and Northern Europe. A moderate to high variability is obvious for Southern and Western Europe, respectively. It can be concluded that the vulnerability assessment provides quite robust results for Eastern and Northern Europe; the outcomes for Western and Southern Europe are subject to higher uncertainties.

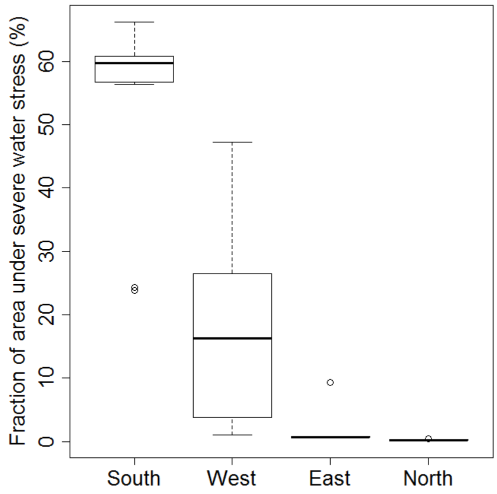


Figure 14 Box-Whisker-Plot of the fraction of area under severe water stress during summer (June, July, and August) under the SuE scenario for the four different European regions. Water availability was calculated with climate input from 11 GCM-RCM combinations representing the SRES A1B scenario.

Sensitivity to water use scenarios

EcF and SuE scenarios were chosen as they cover the largest range of the projections for e.g. WEI, where EcF results lead to higher and SuE to lower water stress. Figure 15 presents the fraction of Europe's area under severe, medium, and low water stress in a Whisker-Plot. Here, annual WEI is calculated in respect of the ensemble hydrological outcomes for the baseline and future scenarios. Under current conditions, approximately 10% of Europe's area is covered by river basins under severe water stress. According to the projections, this fraction increases until 2050 to more than 25% under EcF (+15%) while it decreases to below 5% under SuE. Since the hydrological conditions are the same for both, the EcF and SuE scenarios, substantial differences are related to the different water use projections.

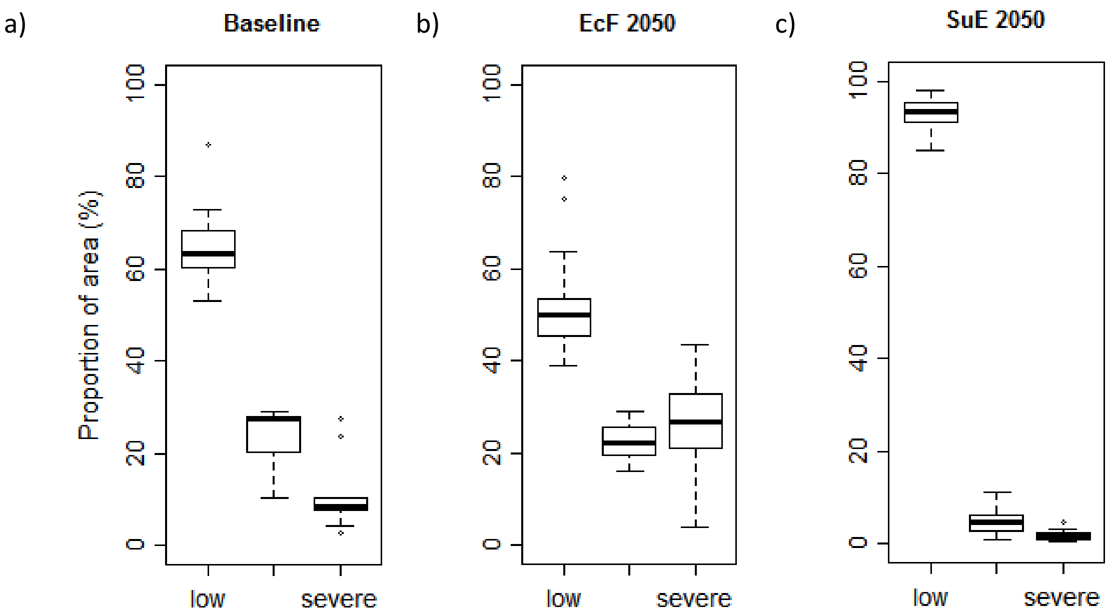


Figure 15 Box-Whisker-Plot of the fraction of Europe's area covered by river basins with low, medium and severe water stress represented by the water exploitation index WEI for a) the baseline and the scenarios b) EcF 2050 and c) SuE 2050.

When looking ahead into the future one has to deal with different kinds of uncertainties, related to the water availability (climate input) and water use scenarios (socio-economic scenarios), or to the models applied. Whether the uncertainty is higher for the water availability or water use cannot be illustrated. However, the uncertainty rising from the climate projections used is related to the GCM-RCM model combination since only one scenario (SRES A1B) was used, i.e. the background conditions are the same. A different picture is drawn for the socio-economic scenarios, which are based on the same past trends, but following different future pathways. These scenarios cannot be compared to a "real" scenario; therefore, no one is more likely than another is.

Assumptions and constrains of the models (available in the consortium and used in the assessment)

The results used in this study were produced by large-scale models and should be interpreted in this context, i.e. not focusing on local characteristics of river basins. Neither for hydrological modelling nor for the calculation of water withdrawals all information needed for assessing vulnerability or evaluating adaptation measures is available. Thus generic approaches are used for describing derivations or for performing downscaling rules. However, the results of the study can be used to draw several conclusions that constitute not only important findings but carry considerable policy relevance. Due to the inherent uncertainties of scenario studies covering 30 to 50 years into the future, we will attempt to qualify our conclusions by adding estimates of certainty based on expert judgment.

The scenario approach used in this report addresses uncertainty by showing different feasible pathways into the future based on different sets of input assumptions. However, we also know intuitively that some input assumptions and some scenario pathways are more feasible, or more uncertain, than others are. Here is a list of some of the factors determining water use that are particularly uncertain. In principle, reducing the uncertainties of these factors will increase the reliability of the scenarios and lead to better estimates of future water use.

a) Domestic sector: In most European countries, the relationship between future income and water use seems to be well defined. Another source of uncertainty in estimating future water use in the domestic sector is the future population and the distribution of water users. The differentiation between urban and rural water use is rather important in Central and Eastern European countries. For these countries, studies that are more detailed are needed to identify the factors that help explain historical and future trends in water use.
b) Manufacturing sector: The water intensity of different industries (m3 per gross value added) is a major uncertainty in most countries. However, perhaps more important is the water use of industries that are not now important but will become important over the next 30 years. Key questions are, what will these industries be, how much water will they use and where will they be located?
c) Thermal electricity production sector: Major uncertainties in this sector are the useful lifetime of power stations, the percentage of new power stations having tower versus once-through cooling, and their future geographic location. Also important is the uncertainty of future thermal electricity production as such.
d) Agriculture: Major unknowns in the agriculture sector are the future extent of irrigated crops, the types of crops to be irrigated, and future climate.
e) Technological change: The estimated rates of improvement of water use efficiency are very sketchy and by no means comprehensive.

f) Downscaling: National model results are allocated to river basin or NUTS-2 levels using simple downscaling techniques like population density or manufacturing industry density. An additional element of uncertainty is the static analysis of both maps over the entire scenario period.

g) Merging LISFLOOD and WaterGAP results: In general, hydrological-related outcomes from LISFLOOD were provided on a grid cell level (5 by 5 km resolution) but were aggregated to river basin as well as NUTS-2 levels to be combined with water use-related WaterGAP results for calculating indicators. To overcome this obstacle, the aggregation of hydrological results was carried-out following the routing system used in WaterGAP (Lehner et al. 2008).

2.2 The different modules of the integrated assessment framework in detail

In rounds of consultations among the partners and based on the feedback from the expert meetings, (see Annex 5) a conceptual model for the assessment of vulnerability and adaptation options was developed. After a long series of subsequent versions, a comprehensive conceptual map was released and a final agreement was reached, which is reported on below.

Concerning the vulnerability assessment as performed in chapter 3 most of the datasets used came from large-scale modelling, especially related to water quantity. Here, hydrological and water use-related model outcomes were merged. In this way, indicators were exclusively generated for describing the future of Europe’s freshwater resources. From the modelling perspective, 9 selected measures were evaluated by applying a model; the selected measures address water withdrawal s in a sense of changing technologies and efficiency rates and water supply in terms of desalination and waste water reuse. For the EU, direct economic costs of flooding and their final implications in terms of growth and wealth for the economic systems affected were estimated by using a Computable General Equilibrium model.

Huge literature review was undertaken to assess the measures as shown by the list provided in chapter 1.6 and the various references given in the factsheets and inventory of measures. In order to improve the inventory of measures and the associated factsheets, expert judgment was collected Water quality could not be modelled nor were modelled results available to the consortium to be further analyzed. Thus, all information used about water quality in the vulnerability assessment was taken from other sources, e.g. projects or literature.

In order to support the vulnerability assessment and to improve the inventory of measures and factsheets, two stakeholder workshops (Annex 12) and three expert meetings (Annex 13) took place during the project. Here, the objective was to compile stakeholder and expert knowledge and evaluations on aspects of individual adaptation measures and vulnerability indicators.

2.2.1 The IAF in a nutshell

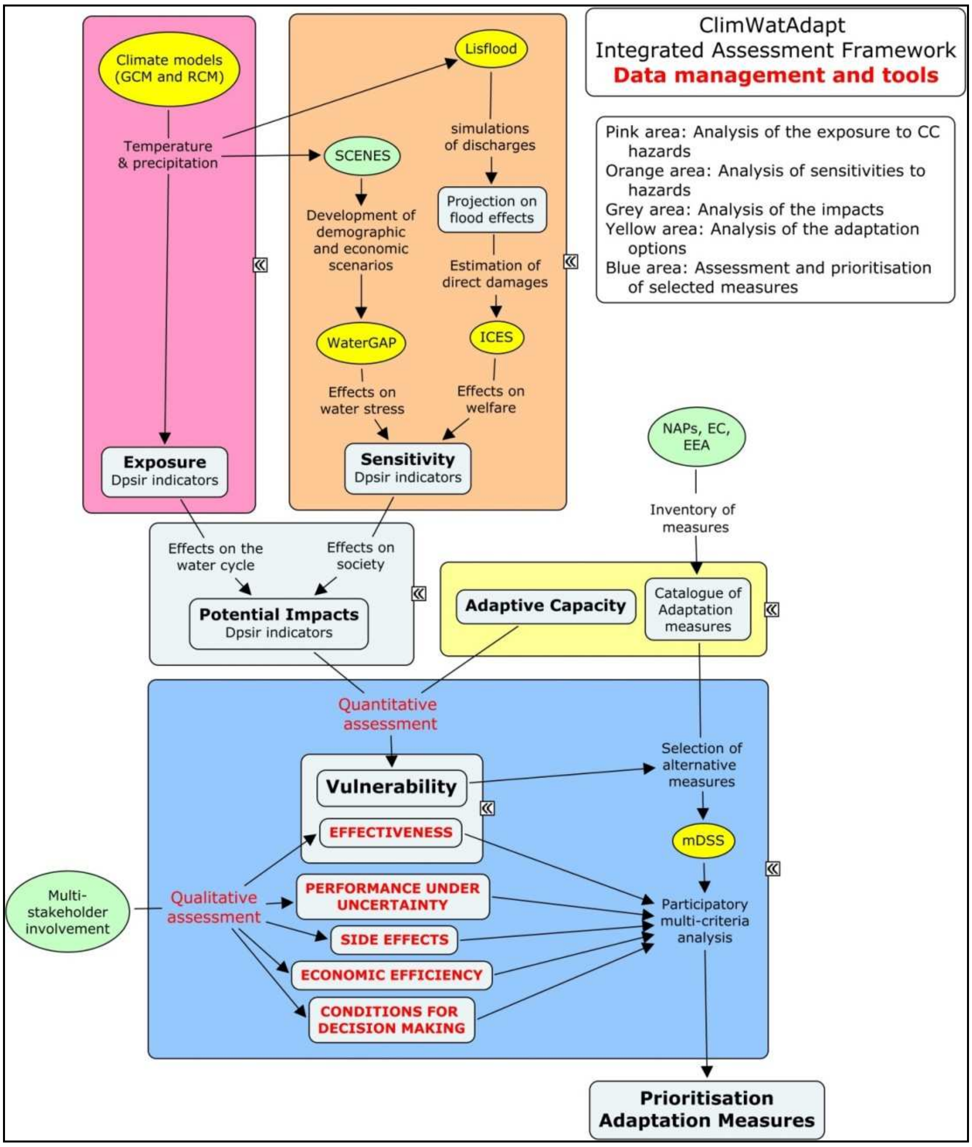


Figure 16 Detailed concept map of the project components and flows of the ClimWatAdapt Integrated Assessment Framework.

The consolidated IAF structure derived from the conceptualization presented above is shown in Figure 16: Detailed concept map of the project components and flows of the ClimWatAdapt Integrated Assessment Framework. The hierarchical structure is intended to guide users through methods, tools and data useful for the assessment. The use of the freeware Cmap enables expansion or compression of branches, as well as capabilities for creating a single interface with very different elements, such as software and databases. Such further developments of the project are seen to find their long lasting destination in the initiative for the Climate Change Adaptation Clearing House, with which the technical feasibility for integration have already been explored (see section 2.3).

In the first step of the integrated assessment, all information is collected into a comprehensive database. Subsequently, there is the assessment of vulnerability hotspots, vulnerable sectors, and the assessment of appropriate adaptation strategies. The central component in the first step is a database (DB) with the relevant parameters coming from the reference scenarios and other generic information. A set of vulnerability indicators (VI) is defined and the results are stored in the DB. Since these data are existent on different spatial levels across Europe, such as river basins, NUTS-2 units, or countries, a set of processing functions is needed, which allows geo-spatial analysis in order to evaluate the impact indictors and store the results in the DB. At this point, the basic information for the vulnerability assessment is prepared.

In order to provide the necessary information for the assessment of appropriate Adaptation Measures (AM), first a comprehensive inventory of AM reported in the literature is set up. A crucial step in the first part of the IAF is estimating the performance of individual AM with respect to individual river basins, NUTS-2 units, countries or the key European water related economic sectors. The performance of an AM is its likely effectiveness either to reduce vulnerability to climate change or to increase possible positive effects of climate change.

Finally, decision-makers and stakeholders can browse the database, analyze the performances expected for each measure, and select those that can be of interest for further assessment and comparative evaluation by means of the multi-criteria analysis methods provided by mDSS. The latter can subsequently be used for more in-depth assessment of selected adaptation measures and calculation of an overall score allowing for ranking and considering users' preferences in terms of weighing the evaluation criteria. In mDSS, multiple assessment paths carried out by stakeholders and decision makers can be combined by means of grouping procedure for facilitating participatory assessment and identification of common or compromise preferences.

The IAF can provide visualizations of the basic information in form of geographical maps and graphs. In case of qualitative information, coming from literature review and stakeholder and expert judgment, conceptual maps are used to illustrate the knowledge about specific issues.

2.2.2 Identification of vulnerable regions and sectors

In order to identify possible regions or sectors vulnerable to climate change impacts information on exposure and information on sensitivity are combined, which is based on comprehensive and consistent scenarios, e.g. merging hydrological scenarios based on climate change scenarios and water uses based on socio-economic scenarios. The list of vulnerability indicators is given in Table 1 above whereas the vulnerability assessment is described in chapter 3.

2.2.3 Analyses and assessment of adaptation measures

In the context of this study, we define an "adaptation measure" as *actions reducing vulnerability to climate change and climate variability by preventing negative effects or by enhancing the resilience to climate change*. Adaptation measures have been first divided into two main categories:

- "**Measures**": This refers to technical, hydro-technical and land-use based measures that bring about actual water savings and reduce droughts. Technical measures relate to grey infrastructure such as dykes, water supply systems and water saving devices. On the other hand, hydro-technical measures include "green" infrastructure, such as interconnecting the network of open spaces, preserving wetlands to store water, increasing natural water retention and sustainable drainage. Land-use based measures refer to changes in farm practices and changes in land use (e.g. afforestation).
- "**Support Actions**": 'This refers to administrative controls, financial instruments, policy actions, management plans, voluntary initiatives, and educational activities (research and awareness-raising) that support the implementation of "measures". The aim of administrative controls or financial instruments is either to trigger the implementation of the grey or green infrastructure measures or to change a certain behaviour (farming practices) or developments (e.g. land

reclamation). Policy actions combine several instruments and support actions (such as stakeholder participation processes) following a strategic direction to change a broader level of activities or sectors. These actions do not bring about concrete water savings themselves, but rather facilitate and support measures that do so.

Measures/support actions to adapt to climate change can be of different nature:

- **Preventing –** if the measure/support action reduces the risk and sensitivity of people, property or nature to WS&D events.
- **Preparatory** – if the measure/support action builds or enhances awareness about effects of WS&D in the region. (Includes carrying out studies, raising awareness and communication exchange activities.).
- **Reactive** – if the measure/support action includes the development of standards and processes to react to an extreme event.
- **Recovery** – if the measure/support action creates mechanisms such as establishing a funding instrument to support reconstruction or an insurance system.

The measures have been linked to the different indicators developed for the different phases of the DPSIR approach (see Figure 6). Deploying this system approach allows the user to decide where his intervention should focus on.

The Vulnerability Indicators (VIs) used in this project (Table 1, Annex 6) are linked with Driver (d), Pressure (p), State (s), and Impact (i) variables of the DPSIR framework. In the case of d, p, and s, the vulnerability indicator correlates with either Exposure to or with Sensitivity of a particular, water-relevant Driver, Pressure, or State. In contrast, the VIs related to Impact provide a metric whose change indicates an impact on the system; the link with Impact is simple.

Each of the 35 adaptation measures collected in this project's Inventory of Measures has been linked with this project's Vulnerability Indicators. The link can run either from the VI to the measure (i.e., for each VI there is a list with possible measure that are suitable to address it) or from measure to the VI (one measure can be applied to reduce different vulnerabilities, for example heightening a dike will decrease VI area flooded, people flooded, etc). One measure can be linked with different VIs which can belong to various components of the DPSIR framework. These links are collected within the project's database.

However, for some adaptation measures it has not been possible to establish a link with Vulnerability Indicators; this is the case with the measures that address aspects for which no indicators have been calculated within this project (due to a lack of data), for instance indicators for water quality.

The data measures and VI in the database can be filtered based on their link with particular aspects of the DPSIR framework.

In addition to the links within the Database, the Inventory of Measures (Annex 7) also makes explicit the links between adaptation measures and components of the DPSIR framework. The relevant columns in the inventory indicate the existence of a link (or its non-existence), without differentiating its type (i.e. in which direction the link runs). In the inventory, the adaptation measures can be filtered according to their linkages with the DPSIR framework.

2.2.3.1 A Catalogue of measures as a basis

The inventory of adaptation measures is another component of the IAF. The purpose of this database is to create a pool of measures that decision-makers from European, national, and regional levels can draw upon when looking for adaptation options in water management. The inventory of measures has been incorporated into the IAF and will, in a wider sense, contribute to the adaptation knowledge base.

The inventory is implemented in the form of a Microsoft Excel sheet, which can be filtered according to different criteria. Moreover, the inventory of measures is part of the ClimWatAdapt database that is searchable and linked to additional external information where relevant. All measures are inventoried through a code, name, and short description (basic attributes) and are tagged with three groups of attributes:

1. **Descriptive attributes** comprise e.g. the *category of measure* (support action or measure), the *climate event* that the measure is responding to (droughts, floods, etc.), or the *sector* it is designed for (agriculture, energy, etc.). These attributes can be used to search the database for a specific set of measures (e.g. measures to address water scarcity in the agricultural sector),
2. **Assessment attributes** are needed for the assessment exercise and include *urgency &priority, effectiveness, efficiency, side effects, performance under uncertainty*, and *conditions for decision making*.
3. **Additional information**, such as *case studies, policy areas that can integrate the measure, time needed to implement the measure*, and *referenc*es.

The operational definition of the different attributes is given in Annex 9. Figure 17 shows the structure of inventory of measures.

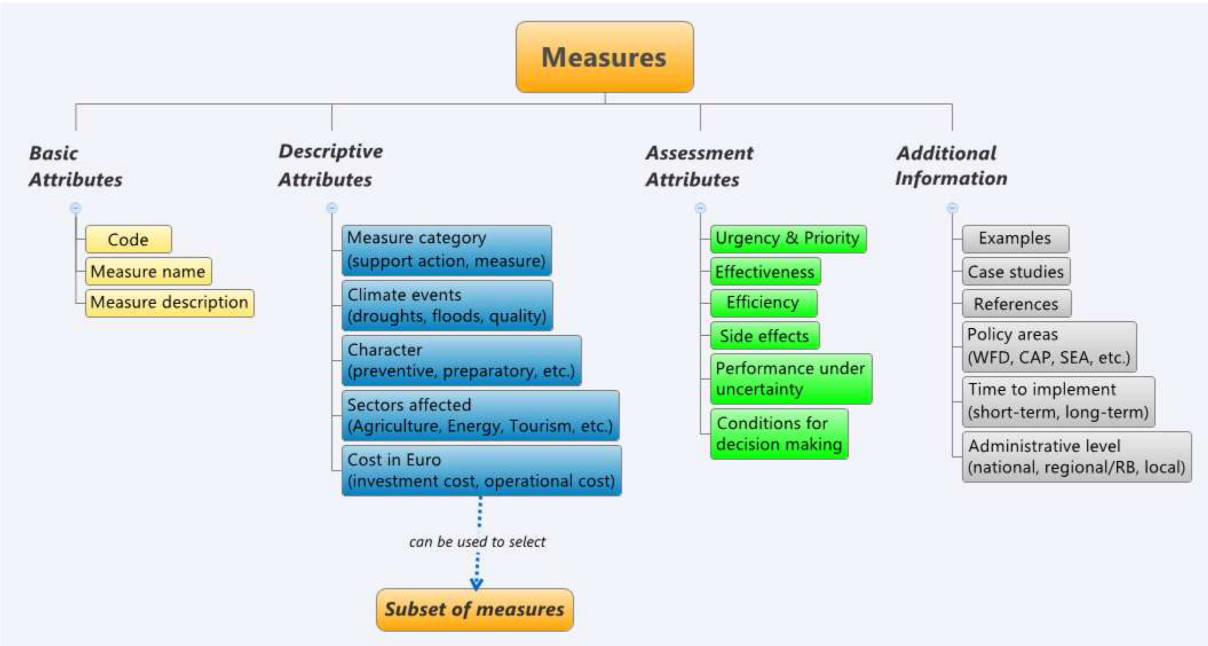


Figure 17: Structure of the inventory of measures

The database is based on the following sources of information:

- The call for evidence under the EU Water Scarcity
- The assessment of the River Basin Management Plans
- The input from the CIS expert groups on WS&D, Floods and personal contacts
- Various reports from the EEA, JRC and OECD, in particular the JRC report "Review of published climate change adaptation and mitigation measures related with water" (REFRESH project)

- General literature sources

The database contains a clear reference to where each of the measures has been found.

Measures/ support actions in the inventory are further subdivided into nine main categories:

- **Technical measures** relate to technical infrastructure such as dykes, water supply systems, water treatment systems, roads, and railways.
- **Measures related to "green" infrastructure**: Green infrastructure is the interconnected network of open spaces and natural areas that naturally accommodates storm water, reduces flooding risk and improves water quality.
- **Measures changing management or practices**: This refers in particular to changes in farming practice or changes in water management.
- **Risk prevention measures** are measures that aim to reduce the risk of economic damage due to non technical action. Early warning and risk maps are examples
- **Economic and financial measures**: Any economic incentive that changes the behaviour of certain people or sectors, such as water pricing.
- **Awareness/information measures** are aiming to make human society more aware of climate change and certain adaptation needs.
- **Land use change and allocation measures**: Measures that change how land is used, such as reallocation of buildings, afforestation of agricultural land.
- **Regulatory measures** are measures establishing or changing laws and regulations.
- **Long-term contingency planning measures** ("management plans") capture everything with "make a plan" and "develop a strategy"

2.2.3.2 Description and explanation of assessment criteria

Overview of the assessment criteria

For the purpose of the project, we have deployed five assessment criteria to analyze the outcomes and outputs[11] of the adaptation measures. These criteria include **effectiveness**, **economic efficiency**, potential **side-effects**, **conditions for decision making**, and **performance under uncertainties**. The five criteria are further refined using 12 sub-criteria as shown in Figure 18 and explained further down in this section.

[11] Outcomes are short or long term achievements brought about by the introduced policy. Outputs on the other hand are activities, straight achievements or milestones that anticipate the outcomes. For example, reduced residential water consumption (demand) is an outcome of a policy such as water efficiency standards or financial incentives to increase the use of water-conserving appliances. The outputs of these policies are a number of modern water appliances sold or a number of households/dwelling units that have been built in compliance with the water-sensitive building standards. Although better traceable, the outputs are imperfect proxies of the ultimate policy outcomes. The number of water saving appliances does not give immediate information about the total volume of water saved since that depends on the dwelling or household specific use of those appliances.

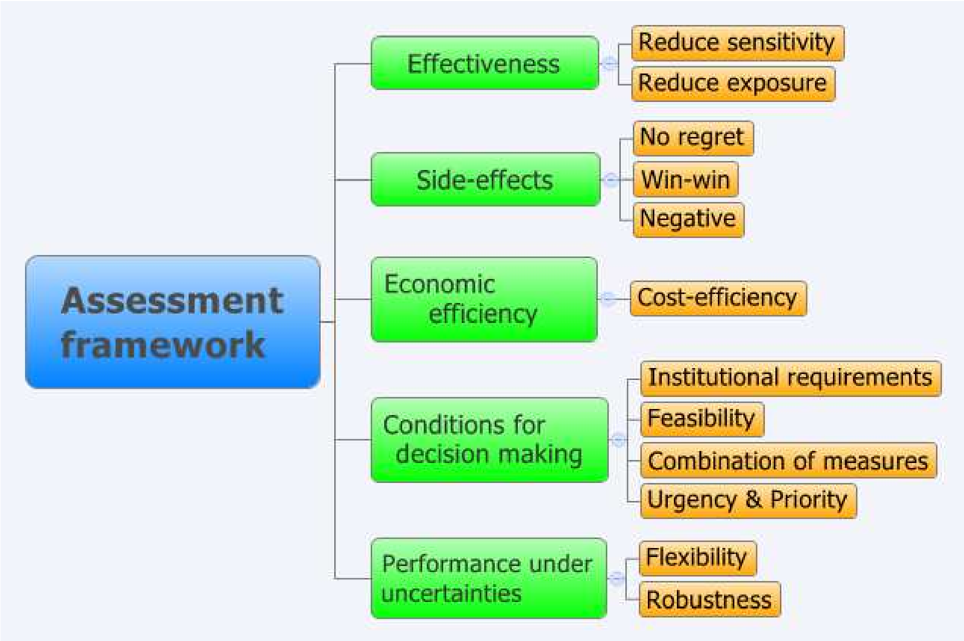


Figure 18 Framework for climate change adaptation assessment (Amended from EC, 2009).

General descriptions on assessment criteria

- ***Effectiveness*** is understood as the extent to which the adaptation measures contribute to reducing system's *vulnerability* to the expected impacts of climate change. Here we follow the conceptual scheme of vulnerability as defined in UNFCCC (2010a) and referred to in Isoard et al. (2008), according to which vulnerability is comprised by exposure, sensitivity and adaptive capacity. Exposure refers to "the nature and degree to which a system is exposed to significant climatic variations". Sensitivity represents "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli". Adaptive capacity is "ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences". The effectiveness of adaptation measures thus is expressed in terms of reduced exposure and/or reduced sensitivity and/or augmented capacity to adapt to climate change.
- ***Side effects:*** Even theoretically sound and efficient adaptation policy instruments and measures may fail to produce expected results, or worse, set off unintended consequences which further exacerbate the problems faced in practice. Side effects are unintended, both positive and negative, outcomes of the adaptation measures. The *negative side effects* (also referred to as maladaptation[12]) are indirect, negative outcomes set off by the adaptation measures outside of their target area. For example, the structural changes to river course may have as an unintended consequence higher water stages during the flood event and thus higher probability of floods. Wastewater treatment and increased pressurized irrigation increase energy demand which in turns lead to higher water abstraction/consumption. Application of water-efficient irrigation techniques may increase the extent of the irrigated

[12] 'action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups' (editorial note, journal of Global Environmental Change 20 (2010) pg. 211–213).

land and thus water demand/consumption. In addition, pressurized irrigation reduces the return flow and thus availability of water to down-stream users. Wastewater reuse may cause negative health effects. Increased water storage capacity may increase the number of accidents and people drowned. In tropics and sub-tropics, the methane release from the water reservoirs may offset the environmental benefits of hydropower and further exacerbate, rather than mitigate, climate change. Substantial subsidies for the production of bio-diesel and bio-ethanol lead to an increased production of energy crops. As energy crops compete with food crops for land and water, the increase in fuel crops is an important factor for the worldwide price increase of food crops, which has resulted in recent social upheavals in some parts of the world.

Positive side effects (ancillary effects) are additional beneficial outcomes delivered by the adaptation measures but not aimed at in the first place (e.g. new employment opportunities, innovation knock-on effects and new market potential, social capital accumulation). Full account of ancillary effects is important for identification of no-regret measures, which are interventions with positive outcomes for development even in situations in which the uncertainty surrounding the future impacts does not allow for better targeting of the policy responses.

Taking into account the above, we have introduced the following three sub-criteria:

- **No regret:** No regret measures are designed primarily for climate change adaptation whose other side-benefits are so extensive that their implementation is worthy for those side-benefits alone. Put differently, non-regret options are those, which bring non-climate related benefits exceeding the costs of implementation; hence, they will be beneficial irrespective of future climate changes taking place (Ierland et al. 2007). For example, prioritization of adaptation investment should pay attention to measures that solve existing water problems while also contributing to a more sustainable management of the resource.
- **Win-win**: Adaptation measures will lead to a win-win situation when they entail considerable benefits for other social, environmental and economic management objectives. For example, flood management by creating new floodplains will reduce vulnerability to flood hazard while also supporting biodiversity and conservation of natural habitats. In the context of the water sector, other management objectives that could benefit from climate change adaptation are disaster risk reduction, protection of economic assets, conservation of natural habitats and biodiversity, or supporting economic development by sustaining water supply. In practice, however, there are also adaptation options that can potentially hamper the achievements of other management objectives and in this sense lead to a win-lose situation. Consideration of this concern is also reflected in the assessment framework.
- **Negative side effects**: The extent to which the measure may contribute to increase vulnerability of other sectors (Agriculture, Energy, Industry, Tourism, Domestic and Environment) or agents or impact negatively on other policy or management objectives. For example, some measures may increase GHG emissions.

- ***Economic efficiency*** This criterion pays attention to the economic viability of adaptation measures by considering their costs and benefits. In short, an adaptation measure is considered cost-efficient if it brings higher benefits in comparison to its costs of implementation. Costs attached to an adaptation measure are comprised of construction/implementation costs, maintenance costs and transaction costs. Transaction cost is defined as costs associated with searching for information, searching for partners in collective action, drawing up and enforcing contracts, and building up networks and social capital (Adger et al. 2006).

- ***Conditions for decision making*** In climate change adaptation decision making, not only is the adaptation measure itself important, but the framework conditions in which the measures are selected and implemented play a crucial role. According to (EEA 2007, Ierland et al. 2007), the framework conditions for decision making consist of the following components:

    - **Institutional requirements:** As the selection and implementation of climate change adaptation measures are strongly linked with underlying institutional processes, its degree of success is, largely dependent on the current institutional settings. Addressing this aspect of adaptation, (Ierland et al. 2007) used the term 'Institutional complexity', which is operationalized as "the clashes between institutional rules; the organizational consequences of the option; the cooperative relations or associations which are necessary for the implementation; and the degree of renewal of the option in relation to existing arrangements". In this project, we follow this line of thinking by looking at the institutional requirements of adaptation measures to ensure successful implementations. These requirements focus mainly on the needed adjustments of current organizational procedures, arrangements and cooperation among management bodies at European level. Conversely, there might exist measures that either can weaken the institutional co-operation or would not overcome current settings, and therefore additional attention should be paid to their implementation.

    - **Feasibility:** Feasibility looks at the barriers that can potentially hamper the adaptation process. These barriers can be limited technical capacity, economic strength, socio-cultural acceptance and potential conflicts with current legal settings. Selection and implementation of adaptation measures should foresee these barriers, in order to guarantee the adaptation's success.

    - **Possibilities for combination of measures:** The principle underlying this criterion is that if a mix of adaptation measures is implemented, they can support each other and make the socio-ecological systems more resilient to uncertainties and climate impacts. To put it differently, a system's coping mechanisms are more diversified, thus having a greater chance to survive external impacts when it has a rich set of adaptation strategies. For example, a society is more vulnerable to flood events when it relies entirely on protection by dike systems. A combination of solid engineering and an evacuation plan in case of the protection system's failure is indeed much more efficient to cope with flood hazards.

    - **Urgency and priority:** These two sub-criteria are to a certain extent intertwined and considered very important when the society has limited financial resources for climate change adaptation. According to (Ierland et al. 2007), several questions need to be answered when assessing the relative priority and urgency of the adaptation needs: "How severe are the climate impacts that the adaptation measure would address relative to other impacts? When are the climate change impacts expected to occur, and on what timescales does action need to be taken?"

- ***Performance under uncertainties:*** The requirement is that adaptation measures should be able to maintain their performance under a wide range of changes in climatic and socio-economic conditions. Measures that meet this requirement are either robust to uncertainties or flexible in designing and implementation:
    - **Robustness to uncertainties:** Adaptation measures are considered robust to uncertainties if they can maintain their effectiveness under different climatic and socio-economic development scenarios. Design and implementation of adaptation interventions should consider this criterion in order to guarantee their success when facing the issue of uncertain climate and development projection in the future.
    - **Flexibility:** Flexibility criterion expresses to what extent the measures can be adjusted/ complemented or reversed when they turn out to be inadequate or inappropriate in practice. This is an important criterion for selection of adaptation measures, taking into account of the uncertainties about climate change projections and its impacts. In this sense, flexible adaptation measures should be able to be adapted to different climate scenarios as well as socio-economic development trends.

Sources of information and overall procedure

Three sources of information framed the basis for the assessment of adaptation measures, which are:

- The "Model based integrated assessment" which makes use of modelling activities carried out within the SCENES project. In the last phase of the project, the effectiveness of a selection of 5-6 adaptation measures, which are either related to water saving or the supply of additional water resources, were modelled with WaterGAP. The results are quantified indicators on the river basin / NUTS-2 scale that can be used to rank the measures according to their overall performance for all of Europe using mDSS (Annex 8).
  The economic consequences of adaptation measures can be addressed by using the economic equilibrium model ICES. It is important to clarify that the ICES model cannot measure the direct cost and benefit associated with a given adaptation measure. Rather, starting from a given implementation costs and effectiveness (measured by some impact or damage reducing potential) of given measures, it can provide an assessment of the effect of their implementation on the overall economic performance of a country. Thus, cost and effectiveness of a measure at the country scale are inputs to ICES. Outputs are the GDP and sectoral economic performance of the country consequential to the implementation of the measure. It has to be noted that such an analysis has not yet been done on the scale of this project and the necessary data are largely absent. Therefore, a single test run has been performed for adaptation to flooding (Annex 5 for the methodology in detail and chapter 0 for the results).
- For each of the measures, a broad literature review has been carried out. This literature review tried to compile the most recent information on all measures that is available in literature and the internet. Information sources in and outside the EU have been considered.
- Expert judgment was mobilized in a workshop where stakeholders assessed a selection of 31 adaptation measures in-depth. This second stakeholder workshop in Budapest 30-31 March 2011 was dedicated to the qualitative assessment of adaptation measures. More than 100 stakeholders from ministries, administrations, associations, NGOs, and research institutes

applied the evaluation criteria in an interactively moderated session to assess the 31 EU-relevant adaptation measures. Participants were spread over eight groups separating between climate change impact and geographic regions according to their background. All eight groups examined a core set of eight or nine measures, plus several more, depending on the available time. Two sets of measures were identified in relation to flood and two related to water scarcity and drought. Every set of measures was thus examined by at least two groups. The detailed results of the workshop can be found in Annex 12. In conclusion, the exercise showed substantial agreements in the evaluation of the measures by groups identified according to four geographical areas. Therefore, and even without any robust representativeness or statistical significance, the results from the second Stakeholder Workshop contributed significantly to refining and consolidating the catalogue of adaptation measures.

Each of these sources is used to “feed” the assessment criteria in a complementary manner. This way, every criterion listed above is judged for specific adaptation measures, using supporting information from either model outputs or literature. It is worth mentioning that the assessment framework is designed for handling both qualitative and quantitative data. The former category of data comes mainly from literature and expert judgments while quantitative data is gained from modelling outputs.

The research consortium provides default scorings for a set of most relevant adaptation measures based on literature and model outputs. This default scoring serves the role of a “pre-cooked” database for decision makers and stakeholders to facilitate exploration of the expected general performances of the adaptation measures considered and provide preliminary assessment for the latter evaluation phase of the procedure. Decision makers and stakeholders can browse the database, analyze the performances expected for each measure, and select those that can be of interest for further assessment and comparative evaluation by means of the multi-criteria analysis methods provided by mDSS. The latter can subsequently be used for more in-depth assessments of selected adaptation measures and calculation of an overall score, which allows for ranking and consideration of users’ preferences in terms of weighting of the evaluation criteria. In mDSS multiple assessment paths carried out by stakeholders and decision makers can also be combined by means of a group-making procedure for facilitating participatory assessment and identification of common or compromise preferences. The figure below (Figure 19) illustrates the assessment procedure and how three information sources contribute to the overall assessment process.

Members of the consortium combined the results of the quantitative modelling, the literature review, and the stakeholder consultation on measure factsheets. All partners revised and validated the results drawing on the expert knowledge available in the institutes of the consortium and their networks. A focused investigation of available literature was conducted where the other approaches had not found concluding results so far.

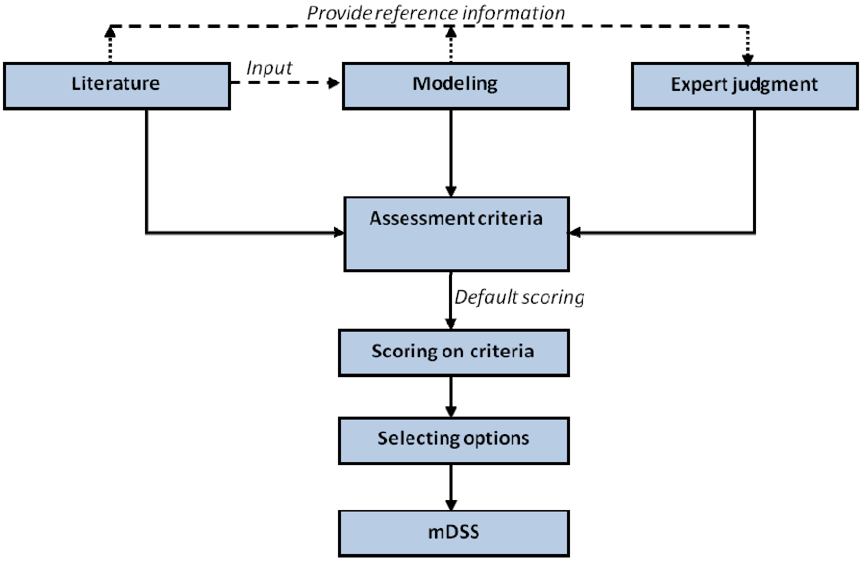


Figure 19: Assessment procedure with use of three information sources.

2.3 Link of the IAF to WISE and the Clearinghouse

In order to facilitate the communication of the study results for other users next to the consortium and, more importantly, even after finalizing the study, two possibilities were offered: i) the Clearinghouse Mechanism on Adaptation (CMA) and ii) the Water Information System for Europe (WISE). The CMA acts as an interoperable IT-tool accommodating information from multiple sources and providing unified geospatial information and as a knowledge service for the development of adaptation policies and a partnership for its development. The development of this platform is still in progress. WISE operates as a “Gateway to water” and contains previously unavailable data and information collected at the EU level by various institutions or bodies. The WISE project started in 2002.

As both CMA and WISE already provide a web-map service, our results can be displayed within their technical infrastructure. In this case, spatial datasets on vulnerability indicators and any other data (inventory of measures) can then be accessed online. The integration of the ClimWatAdapt database into CMA has already been successfully tested in a prototype version (see Figure 20). After the end of the project, all data and information stored in the ClimWatAdapt database will be integrated into CMA.

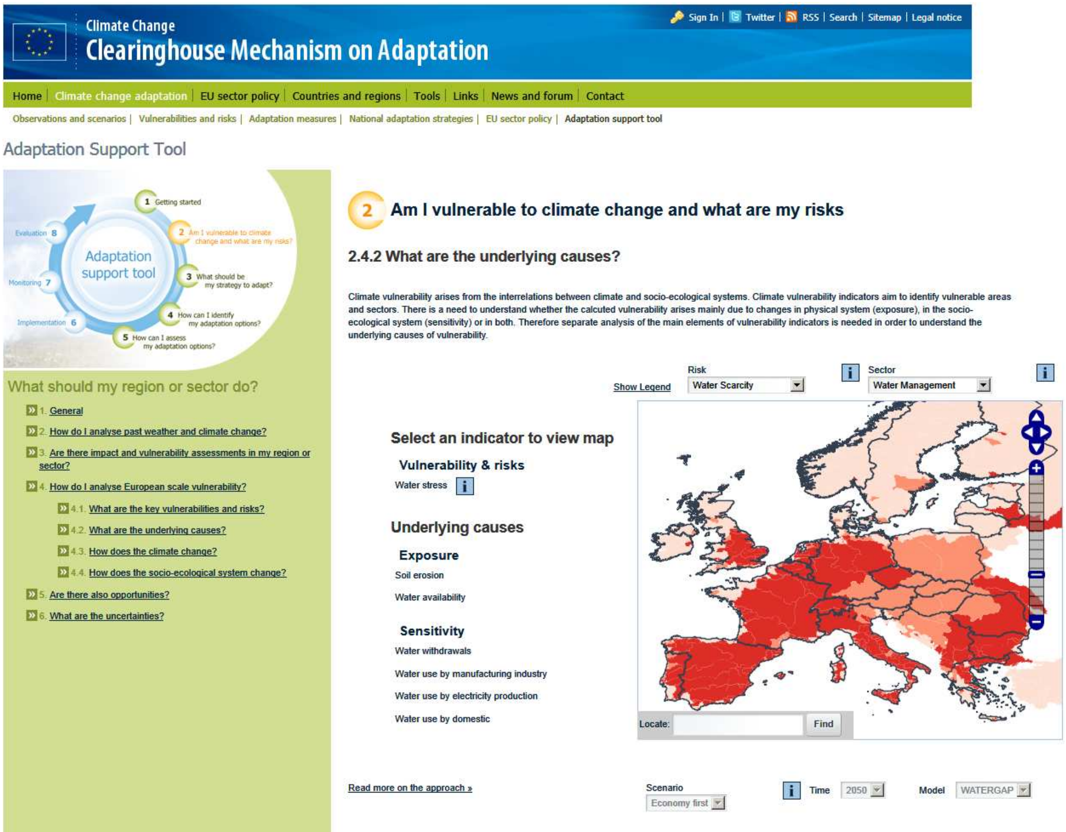


Figure 20 Screenshot from the CMA prototype including information from ClimWatAdapt.

2.4 Gaps of the IAF

The analytical platform of the IAF contains numerical information from the LISFLOOD and WaterGAP models, i.e. results of the hydrological modelling and water use modelling. All background information that forced these model simulations is stored in the database as well, for example, socio-economic developments and the extent of irrigated area or technological improvements. Hydrological scenarios from LISFLOOD are based on data from the EU-project ENSEMBLES, whereas the water uses have been calculated by WaterGAP based on socio-economic and land-use change projections from SCENES.

From the EU-27 perspective, less information is available for aquatic ecosystems (e.g. environmental flows) or water quality, especially with regard to future projections. The research gaps are, for example, highlighted and discussed in the EU-FP7 project ClimateWater. A first attempt to close this gap was made in the SCENES project, where large-scale water quality modelling results were further processed by different partners to obtain common findings for all of Europe. Because these model results are not available on the river basin or NUTS-2 levels, they are not part of the IAF. However, in order to provide these important outcomes, text boxes explaining the methodology and main findings are included in the report. Nonetheless, the key drivers behind those calculations are given in the database as they were developed in SCENES. Additional results from LISFLOOD concerning flood damages and population living in flood risk areas are given in the text and not implemented in the database since they are based on different socio-economic projections (EU-project ClimateCost). In this case, we explained the results in separate text boxes as previously described.

From the perspective of measures, the IAF does not allow for an analysis of a combination of measures. In particular, the link between support actions and technical measures is currently not reflected. This can be explained by some modelling constraints but also by the fact that the mechanisms between support action and measure are not fully understood.

Furthermore, the cost information on most measures is non-existent. So the user is not provided with a full monetary CBA. Only qualitative information on costs and benefits is available. This fact might influence decision-making.

3 Vulnerability Assessment

Currently, large regions of Europe suffer from water-related hazards and water scarcity (EEA 2010a). The expected changes due to global warming may further aggravate this situation, increasing the vulnerability of socio-ecological systems. Therefore, changes in the water cycle and their impact have to be studied, monitored, and assessed in order to reduce vulnerability and adapt successfully. Such assessments are usually carried out with the aid of indicators that allow current vulnerability to be compared with future vulnerability to climate change.

This section presents the current knowledge about European water vulnerability regarding water scarcity, droughts, and floods. In addition to information from the IAF, we needed other available sources of information for indicators that could not directly drawn from the IAF. Therefore, in addition to results from the IAF, we also present and describe results originating from other research projects, such as SCENES, ClimateCost, and CimateWater. This allows us to provide the most recent overview of water-related vulnerabilities possible. The information coming from literature is referenced.

Overall, chapter 3 is organized as follows: First, an introduction shows the status of the baseline (base year) water availability and water withdrawals in maps and diagrams. This is followed by demonstrating changes for 2050 under different scenario conditions. Based on the scenarios and drivers described in chapter 2.1.4, the two most diverging scenarios are selected to illustrate the vulnerability assessment: “Economy First” (EcF), a market-oriented scenario, and “Sustainability First” (SuE), a more sustainable scenario focusing on quality of life. In a second step, water scarcity indicators are presented, highlighting regional hot spots of water stress as well as sectors vulnerable to water scarcity under scenario conditions. Moreover, the causes and effects are analyzed. The same method is used with respect to droughts and floods. Water quality is addressed by literature review (qualitatively) as large-scale results are not yet available.

3.1 Introduction

The two main drivers in river runoff are precipitation and evaporation. Changes in precipitation will either increase or decrease the average volume of river runoff (Annex 2). Meanwhile, the expected higher atmospheric temperatures will increase evapotranspiration nearly everywhere, resulting in lower runoff values. These two effects interact differently at different locations and produce a net increase or decrease in future average annual water availability. Figure 21 shows the ensemble median of average annual renewable water resources in European river basins modelled for the 30-year climate time series 1961-90. The average annual water availability ranges between ~200 mm/year in Southern, Eastern, and Northern Europe and well above 1000 mm/year in coastal regions in Northern, Western, and even Southern Europe.

Water availability is especially predicted to decrease in Southern Europe, robustly signalling a decrease in average annual water availability for the Mediterranean countries (Figure 22). For example, 10 or 11 out of 11 model simulations predict reduced water availability for large parts of Spain, Portugal, and Greece. In Northern Europe, water availability is probably increasing, and none of the models project decreasing water availability in most parts of Northern Europe.

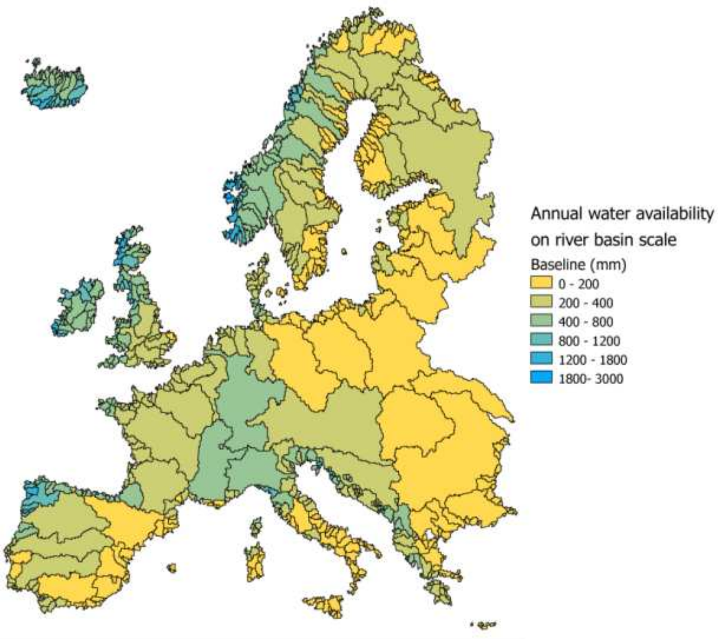


Figure 21 Annual average water availability for the multi-model ensemble median for the baseline (1961-90).

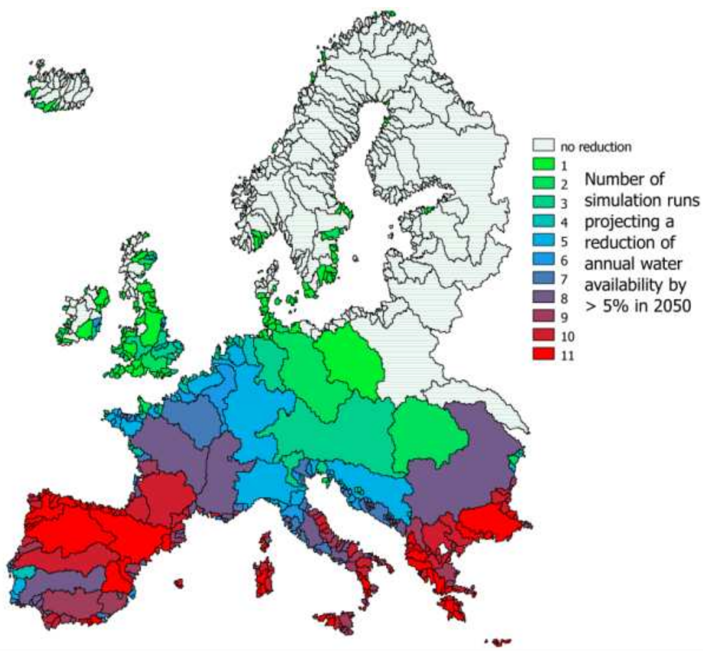


Figure 22 Agreement in the direction of change in the annual average water availability on a river basin scale for the 11 climate models forced by the A1B scenario used to drive LISFLOOD. The map shows the number of hydrological simulations that showed a considerable (more than 5% relative to the baseline) decrease for the year 2050.

On the other side, socio-economic, technological, and behavioural changes drive future water use and thus the amount of water that needs to be abstracted from freshwater resources for human activities. Figure 23 shows the total water withdrawals for the base year (2005) in Europe. Most intense abstractions of freshwater resources can be observed in the UK, the Benelux countries, Germany, northern Italy, and Turkey. For this report, two SCENES scenarios that cover a broad range of assumptions as to how the future may unfold, i.e., EcF and SuE, were chosen to demonstrate the possibilities for Europe's future freshwater use. According to these models, water withdrawals are expected to increase in Europe by 2050 under EcF scenario conditions, except in river basins in Denmark, the Iberian Peninsula, Italy, Greece, Cyprus, and Turkey (Figure 24a). For the SuE scenario, a decrease in total water withdrawals of more than 25% is simulated for all of Europe (Figure 24b). The main reason leading to a decline in total water withdrawals are technological innovations designed to use water more efficiently as well as an increasing commitment to conserve water.

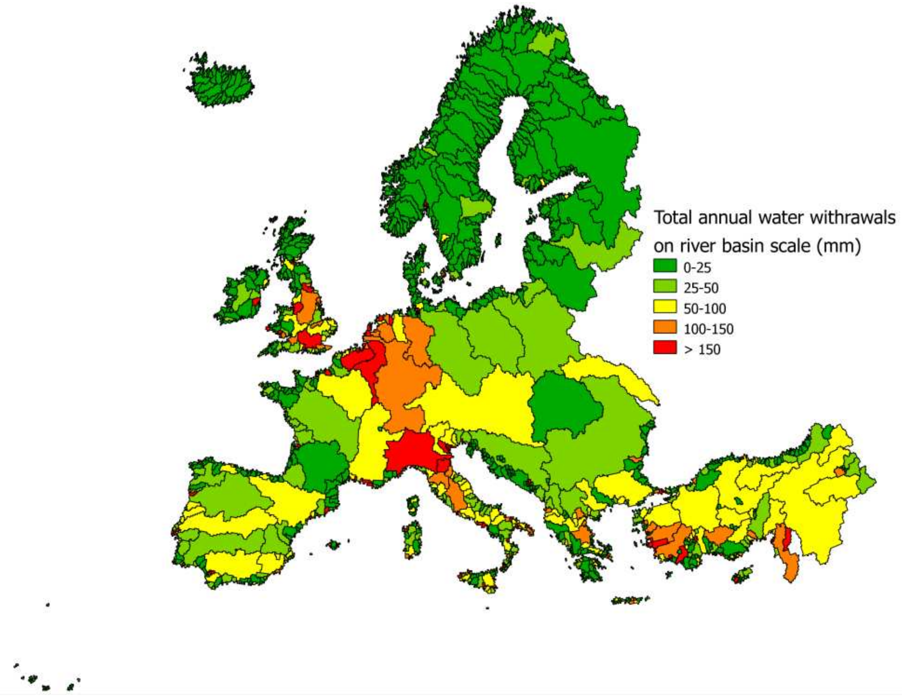


Figure 23 Total water withdrawals on the river basin scale for the base year.

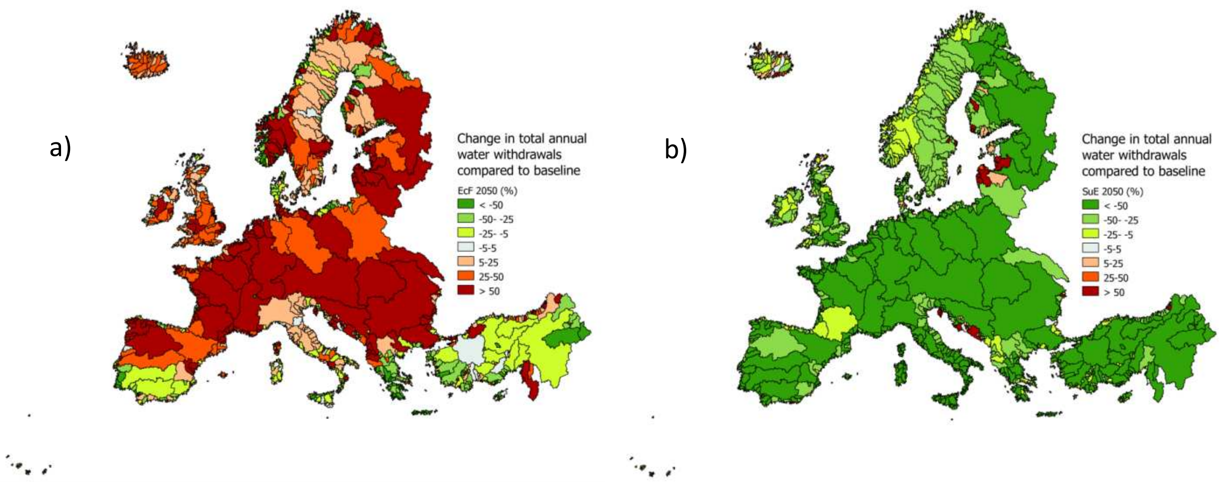


Figure 24 Change in total water withdrawals compared to the base year. (a) Ecf scenario and (b) SuE scenario in 2050.

Figure 25 depicts the amount of water abstracted by different water-related sectors for the base year and 2050 (EcF and SuE) for the different European regions (Figure 4). The agricultural sector is the dominant water use sector in Southern Europe for the base year and the future. Western Europe's freshwater resources are mainly used for cooling purposes. This share increases under the EcF conditions, whereas the cooling water proportion almost diminishes in SuE due to the assumption that all once-through cooling systems in Europe will be replaced by tower cooling. The same conclusions can be drawn for Eastern and Northern Europe, where in fact no dominant water use sector is apparent.

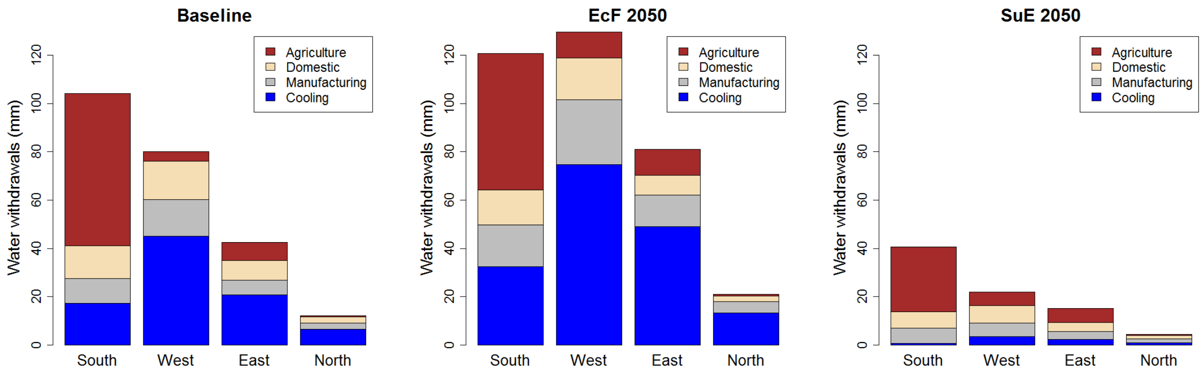


Figure 25 Area-specific water withdrawals (mm) in the European analysis regions sub-divided into sectoral shares

3.2 The impact of current EU policies on vulnerability

With the White Paper on Adapting to climate change, the European Commission presented a framework for adaptation measures and policies meant to reduce the European Union's vulnerability to the impacts of climate change. This document from April 2009 highlighted the need "to promote strategies which increase the resilience to climate change of health, property and the productive functions of land, inter alia by improving the management of water resources and ecosystems." Since then, action has been taken at the EU and MS levels.

On the EU level, efforts have been made to set up a Clearinghouse Mechanism on Adaptation (CHM) that combines the most recent knowledge to address climate change adaptation in one portal. Furthermore, several actions have been taken to streamline the integration of adaptation into existing policies, including water policies, which are especially important. Aside from developing guidance documents for water managers on how to include adaptation in the river basin management planning, several research and pilot projects have been started (such as ClimateWater).

On the MS level, most countries have already adopted or have started to develop national adaptation strategies (NAS) (see http://www.eea.europa.eu/themes/climate/national-adaptation-strategies). Neither the EEA nor the European Commission has developed an agreed, common definition or criteria for the content and scope of a national adaptation strategy, but a rough screening showed that the water sector is always included. No exhaustive comparison or evaluation of NAS across EU Member States has been performed so far, so it is impossible to judge the real effort put into these strategies to reduce vulnerabilities.

In addition, effort has been put into including climate change in the first cycle of the River Basin Management Plans required under the WFD. However most plans address the issue but do not build the bridge to taking action in the Program of Measures. This situation might change, as the Water Directors agreed that adaptation to climate change has to be considered in more detail in the second cycle of the plans.

With all this in mind, it becomes clear that the current effort taken can only be considered a starting point. Most actions taken relate to the identification of risks, potential adaptation measures, and possible vulnerability and aim to reduce the uncertainties regarding these issues. Concrete action and adaptation measures on the ground are less common. This should not be seen as major criticism of the White Paper because many MS have focused on building a sound knowledge base and raising awareness. At the same time, the current uncertainties regarding the impacts of climate change, the effectiveness of measures, and their costs are relatively high (see Altvater et al. to be published). Considering this fact, it becomes clear that efforts on the ground are rather rare.

In 2007, the European Commission published a Directive on the assessment and management of flood risks. Its aim is to reduce and manage the risks that floods pose to human health, the environment, cultural heritage, and economic activity. The Directive requires Member States first to carry out a preliminary assessment by 2011 to identify the river basins and associated coastal areas at risk of flooding. However, considering the issue of climate change is not required. For such zones they would then need to draw up flood risk maps by 2013 and establish flood risk management plans focused on prevention, protection, and preparedness by 2015. Again, at the current stage it is too early to say how these plans will influence vulnerability, as the decisions that might follow based on this risk mapping exercise are not known yet. Nevertheless, it is recommended to ensure that climate change is considered under the WFD in all subsequent plans.

Considering the current situation, the Commission plans to develop an EU adaptation strategy with the following main headings included:

- Objective 1: Furthering the understanding of adaptation, improving and widening the knowledge base, and enhancing access to adaptation-related information
- Objective 2: Developing adaptation action and mainstreaming the integration of adaptation into policies at EU level
- Objective 3: National implementation of climate adaptation requirements and support to and facilitation of exchange between Member States, regions, cities, and all other relevant stakeholders.
- Objective 4: Capturing the potential of the market, market-based instruments, and the private sector in strengthening adaptive capacity and climate impact preparedness and responses.

Currently, there are no details on the planned implementation of these objectives, but it can be assumed that several actions will be included to reduce vulnerability. However, at this stage it is impossible to estimate how actions/measures proposed by the strategy will reduce vulnerability.

In October 2011, the Commission published its proposal for the new Common Agricultural Policy. This proposal puts a focus on climate change adaptation and proposes several measures for adaptation (e.g., The SWOT assessments for the Rural Development Programs must consider adaptation to climate change and Art 12c of the proposed Rural Development Regulation would require including climate change adaptation in the Farm Advisory Service). On the other side, there is a risk of further intense water scarcity in many regions (e.g., there is the proposal of crop-specific payment for cotton in Bulgaria, Greece, Spain, and Portugal. Cotton accounts for less than 0.0025 % of the EU's UAA (utilized agricultural area) but main areas of growth can be found in Spain and Greece. As growing cotton requires a lot of irrigation water, this measure increases vulnerability. In this context, the Aral Sea gives a very good example of a case in which the irrigation of cash crops (cotton) resulted in enormous depletion of water resources (aus der Beek et al. 2011). However, as this proposal is subject to MS opinion and the final agreement of the CAP requires a co-decision by the European Parliament, it is impossible to predict which role adaption to climate change will play.

The main objective of the EU Cohesion Policy is to diminish the gap between different regions, more precisely between less-favoured regions and affluent ones. It is an instrument of financial solidarity and a powerful force for economic integration. The funds provided could easily be used for adaptation to climate change, even if this was not the main purpose so far. On 6 October, the

European Commission adopted a draft legislative package that will frame cohesion policy for 2014-2020. The new proposals are designed to reinforce the strategic dimension of the policy and to ensure that EU investment is targeted at Europe's long-term goals for growth and jobs ("Europe 2020"). This implies tackling the global economic crisis, unemployment, poverty, climate change, and other challenges that affect all EU regions. In the environmental field, the Cohesion Fund will support investment in climate change adaptation and risk prevention, the water and waste sectors, and the urban environment. The details of which kind of investments will fall under these categories are yet not known. Thus, there is a risk that investments leading to maladaptation (e.g., increasing irrigation) might be funded and vulnerability is increased in the long term. However, similar to the new proposal of the CAP, the policy discussions have only recently started and it remains unclear in which direction the final proposal will take us.

In order to mitigate climate change, the EU has set up an Energy Policy which focuses on the increase of renewable energy. Renewable energies often depend on the availability of water, either for hydropower or for growing biomass. As the total energy demand for Europe is growing and the policy targets for renewable are set as a percentage of the total consumption, this might increase the vulnerability of the energy sector. On the other hand, investing in nuclear or coal plants where less water-consuming cooling technologies exist might increase other risks (in particular related to nuclear power plants) or trigger climate change. In order to deal with this dilemma and find a way to reduce vulnerability and mitigate risks and climate change, resource efficiency and reductions in energy use might be the way forward.

To conclude, due to the current changes in policy making and the focus on building a knowledge base for adapting to climate change, it is impossible to quantify the impacts of current EU policies on vulnerability. In general, it can be stated that the awareness at EU and MS level on the issue is increasing and adaptation issues are becoming better recognized in decision making. Nevertheless, in some water-related sectors there is not enough attention paid to the issue; for example, the current proposal of the CAP suggests direct payments for cotton and reductions in spending on natural water retention measures.

3.3 Vulnerability to water scarcity

Water scarcity is both a natural and human-made phenomenon and defined as the point where there are insufficient water resources to satisfy long-term average requirements. In other words, it refers to long-term water imbalances, combining low water availability with a level of water demand exceeding the supply capacity of the natural system (EC 2011). Meaningful indicators can be used for identifying hot spots, i.e., whether the rates of abstractions in countries exceed a certain share of the freshwater resources available. Such indicators allow us to ascertain whether a country's abstraction rates are sustainable or causing water stress over the long term. However, the vulnerability assessment performed in ClimWatAdapt goes one step further by identifying what causes the difference in the water stress projections of the two scenarios. One has to go a step back to the adopted DPSIR framework and analyze the constituents of water stress – water availability (exposure) and water withdrawal (sensitivity) (Figure 26).

In the context of the DPSIR framework (Figure 26), the water exploitation index (representing water scarcity) is an impact indicator (I). The impact indicator is defined as the ratio of the environmental state variables (S) total water withdrawals and water availability. The numerator, total water withdrawals, results from the water demand for cooling, manufacturing, domestic use, and agriculture, i.e., pressures (P). The sectoral water demands depend on socio-economic drivers (D), e.g., population, GDP per capita, GVA, thermal electricity production, irrigated area, and climate. The main driver (D) of the denominator, water availability, is climate, represented by the key variables precipitation and temperature.

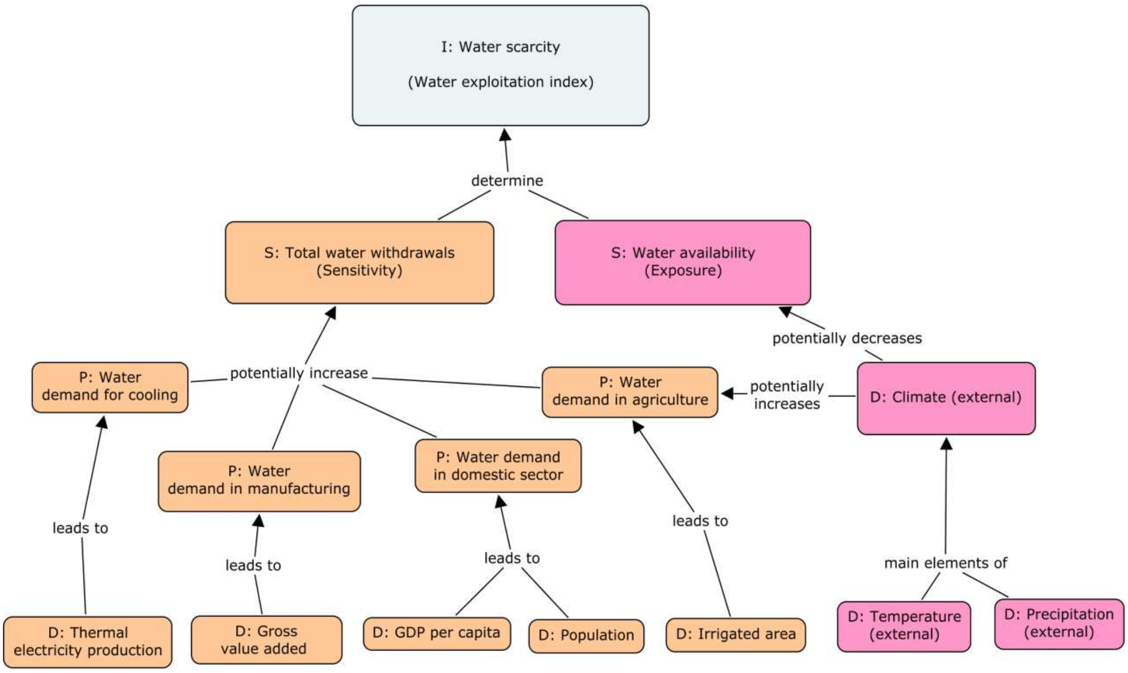


Figure 26 Composition of the water exploitation index (WEI) according to the DPSIR framework.

Water Exploitation Index (WEI, annual)

Among others, one of the most frequently used indicators for water scarcity or water stress is the water exploitation index (WEI), also known as water stress indicator (w.t.a.). WEI is defined as the total water withdrawals-to-water availability ratio within a river basin. Water scarcity can be the result of intensive water use, low water availability (climate driven), or a combination of these pressures. WEI values between 0.0 and 0.2 represent low water stress; WEI between 0.2 and 0.4 represents medium water stress, and a value greater than 0.4 represents severe water stress. To policy makers, the indicator provides a quick overview of areas that may encounter water shortage problems. It is widely used in scenario studies to address water shortage issues (Alcamo et al. 2007, Vörösmarty et al. 2000).

Figure 27a shows WEI on an annual basis as calculated for the baseline (see Annex 10 for details). Severe water stress occurs in Western and Southern Europe. On an annual basis, WEI increases under the EcF scenario conditions and appears at its highest in all European analysis regions in 2050. Northern Europe is the exception, where most river basins are at a low stress level (Figure 27b). Using the SuE scenario, a completely different development is estimated. Here, water stress is expected to be low for all of Europe, except in Southern Europe, where medium water stress is projected (Figure 27c). A more detailed examination of the projections shows still some hot spots of high water stress in Western, Southern, and Eastern Europe. However, the hot spots are smaller than the current ones (Figure 27a). Maps d) and e) of Figure 27 show the main reason of *increasing* water stress on an annual basis: *a change in classification from low or medium (baseline) to severe water stress in the 2050s* for EcF and SuE. It is obvious that for EcF, in almost all river basins affected, the sensitivity-related change is dominant (Figure 27 d), while exposure-related change is dominant only occasionally (e.g., in Italy). Under SuE, water stress decreases all over Europe. Hence, no river basin is affected by an aggravation of water stress from low/medium to severe, and consequently only “no data” is found in e).

a)

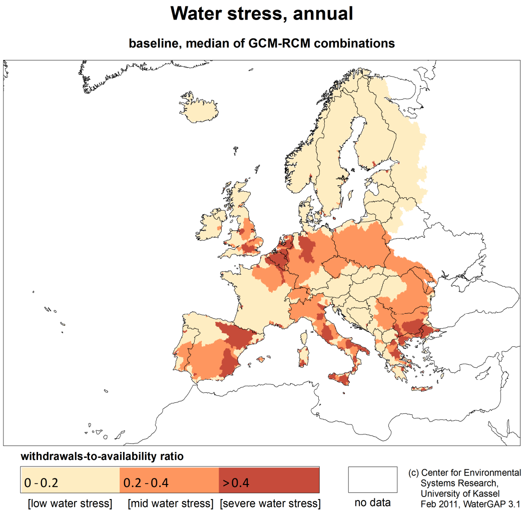


Figure 27 Annual average water stress indicator WEI on river basin level for the a) baseline, b) 2050 under EcF, and c) 2050 under SuE. Moreover, the main reason for an increase in water stress from "low" or "medium" to "severe" between the baseline and 2050 is shown for d) EcF and e) SuE. "Exposure" means that a decrease in water availability is most important while "Sensitivity" indicates that the increase in withdrawals is more important. Note: In d) and e) no data is shown for river basins with only minor changes in water stress or for river basins where water stress is already severe under baseline conditions.

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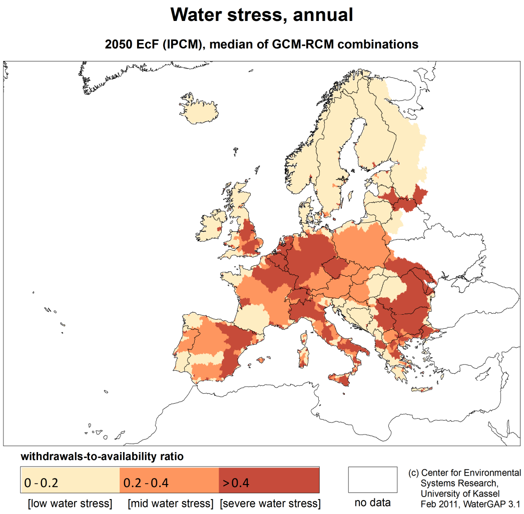

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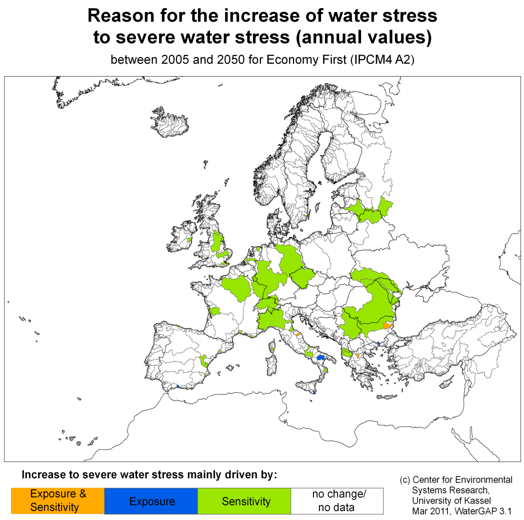

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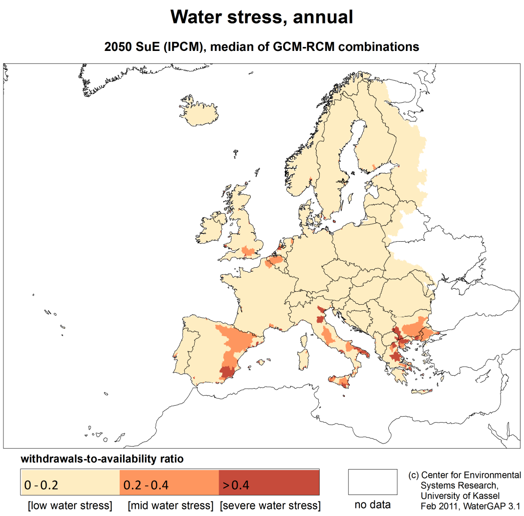

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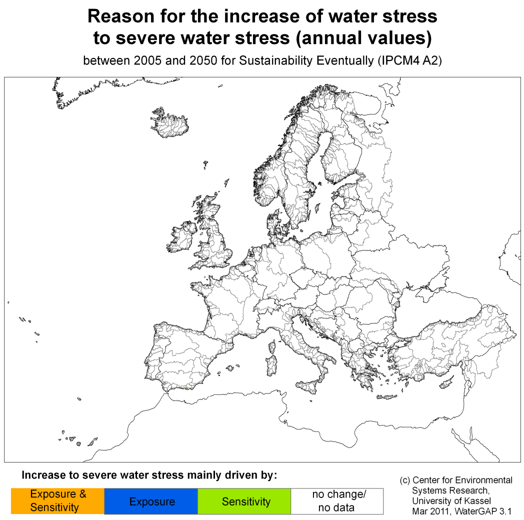

In order better to understand the main driving forces causing these high water withdrawals, a further disaggregation into water demand per sector (*Pressures*) is needed. Especially for water-intensive sectors, e.g., agriculture, we also need to take an additional step back in our DPSIR framework and determine the future development of the main drivers of water demand, i.e., population growth, economic development, technological progress, and changes in the extent of irrigated area (*Drivers*).

In the EcF scenario, total water withdrawals increase in each region (Figure 27b). Here, the increasing share of industrial water demand (cooling and manufacturing) is expected to play a major role, especially in Western, Eastern, and Northern Europe (Table 37 in Annex 10). This is driven by growing thermal electricity production in the energy sector and an increasing GVA due to a growing manufacturing output. Domestic water withdrawals, on the other hand, are of minor importance in all regions and stabilize or decrease due to declining population. Irrigation water requirements dominate in Southern Europe, which is a result of an increase in irrigated area and climate change impacts. Nevertheless, water withdrawals are somewhat dampened by increasing efficiencies. Looking at the net irrigation water requirements shows that in river basins in Spain, Italy, and Greece more than 30% of the annual water availability will be required solely for crop growing under irrigation (see Annex 10). It may be assumed that in these river basins groundwater will remain the ultimate source of freshwater when surface water sources have been depleted. The water demanded by the agricultural sector is expected to rise mainly in Western and Eastern Europe because of an increase in irrigated areas. But this causes no irrigation water stress compared to Southern Europe (Annex 10). Overall, a comparison with the baseline shows that the most important water use sector in all regions is unchanged because no big shifts in technology or consumption pattern were assumed.

If irrigation would not be taken into account, winter wheat yields are expected to increase until 2050 under water-limited yield (WIY) conditions. The higher CO_2 concentration has a strong positive effect on wheat yield, which more than compensates for the negative effects caused by higher temperatures. On the other hand, water-limited maize yields decrease almost everywhere in Europe due to warmer and drier conditions. Thus, it appears that winter C3-crops (like wheat) are likely to benefit from climate change, whereas yield losses are more likely for spring and summer and C4 crops like maize. Considering socio-economic scenario assumptions, crop production will be higher under the EcF conditions (compared to SuE, see Annex 4) due to intensification and extension of irrigated areas. However, the magnitude of variation for the same crop between the scenarios is small, i.e., and to maintain the current level should be taken into consideration, in particular for those crops with very low yields. These are findings from SCENES and are based on IPCC SRES A2 emission scenarios (more details in Annex 4 and 10).

SuE shows a different picture (Figure 27b). According to this scenario, the area under severe water stress is expected to drop in all regions and almost diminishes by 2050. Except for agriculture, sectoral water withdrawals decrease or remain constant in all regions. The reasons are moderate changes of the main driving forces accompanied by a more efficient use of water. Especially for electricity production, which is currently the most important use of water in Western, Eastern, and Northern Europe, the water-saving potential due to technological improvements is relatively high compared to other sectors. The assumption of replacing once-through cooling systems by tower cooling when power plants are retired after a lifetime of 40 years results in a high decrease in cooling water use. In comparison with the baseline, however, there is not just one sector in Western, Eastern, and Northern Europe sticking out as the most important water user. The differences between the sectoral water withdrawals are small. In Southern Europe, however, the agricultural sector remains the dominant water use sector although irrigation water requirements are expected to decrease sharply as a result of a shrinking irrigated area combined with increasing efficiencies.

Water Scarcity in summer (WEI, summer)

Since water scarcity is particularly high during the summer months (June, July, and August), a separate analysis of the summer WEI provides a more meaningful picture (Figure 28). For the baseline, summer high water stress occurs in Southern Europe and in the UK and Belgium. In the future, summer WEI is expected to increase in EcF and decrease in SuE (Figure 28 b, c). In the summer, decreasing water availability is of higher importance than in the analysis of annual averages. As a result, there are fewer river basins where sensitivity dominates the increase of water stress (d). Under SuE, some areas in France suffer from an increase in water stress during summer. Here, decreasing water availability is again dominant since water withdrawals are rather low in this scenario (Figure 28e).

It is obvious from the results that the areas under the most severe water stress are Southern and Western Europe in the EcF scenario (Figure 28). Approximately three quarters of the area of Southern and Western Europe is expected to be under severe water stress during summer. In Southern Europe, the area under water stress increases by 25% although the total water withdrawals decrease, driven solely by reduced irrigation requirements. At the same time, water availability also decreases (-28%) due to less rain and higher evaporation. Here, the decreasing water withdrawals cannot compensate for the reduction in water availability. A high increase in water-stressed area is expected for Western Europe, where both an increase in total water withdrawals and a decrease in water availability occur. In this region, especially the industrial and agricultural water abstractions increase. WEI increases in Northern Europe as well, but only a small part of the area is under severe water stress. In Eastern Europe, the summer water stress remains at the same level as the baseline conditions.

During the summer season, plants must be irrigated much more to ensure optimal crop growth. At the same time, water availability is low and expected to decrease in the future. Many river basins in Southern Europe and France will be facing severe water scarcity in the future (Figure 29; Annex 10). For the Iberian Peninsula, for example, it is expected in the EcF scenario that during summer more than 50% of the available water will be consumed by crops if optimal crop growing conditions are assumed; this value can increase up to more than 200%. Similar developments are also indicated for France, Greece, and Bulgaria, and in Italy mainly the Apulia region is affected. The reason for this high increase in consumptive irrigation use is related to the combination of an increase in irrigated area and higher plant water demands due to climate change. In this case, climate change impacts double: due to increasing temperature and reduced precipitation, more water is needed for irrigation, while at the same time less water is available.

The actual situation could be less severe due to the use of groundwater or water stored in reservoirs and dams. However, sustainable management of the surface and even groundwater bodies seems elusive and competition with other water use sectors is likely.

Figure 28 Water stress indicator WEI for summer (June, July, and August) on river basin level for a) the baseline, b) 2050 under EcF, and c) 2050 under SuE. Moreover, the main cause of an increase in water stress from "low" or "medium" to "severe" between the baseline and 2050 is shown for d) EcF and e) SuE. "Exposure" means that a decrease in water availability is most important while "Sensitivity" indicates that the increase in withdrawals is more important. Note: In d) and e) no data is shown for river basins with only minor changes in water stress or for river basins where water stress is already severe under baseline condition.

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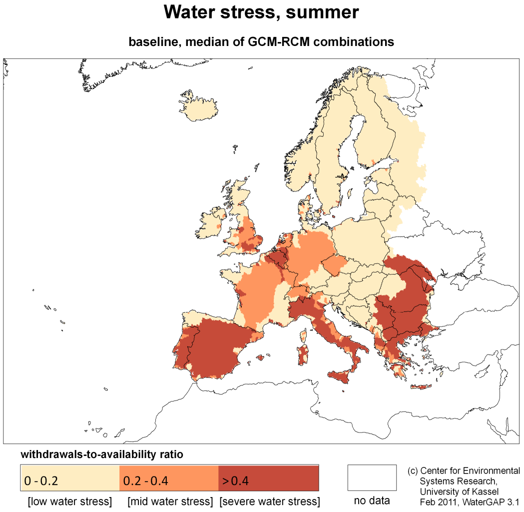

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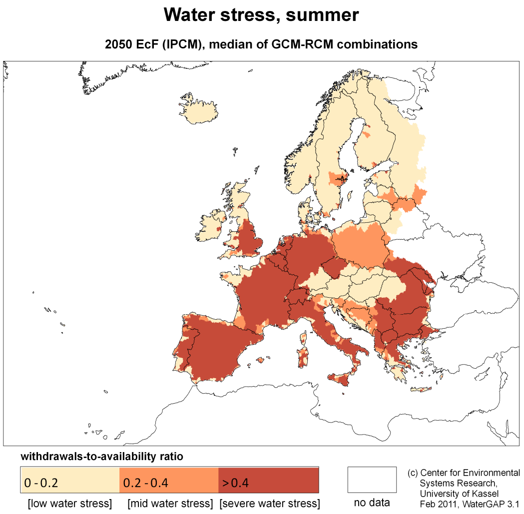

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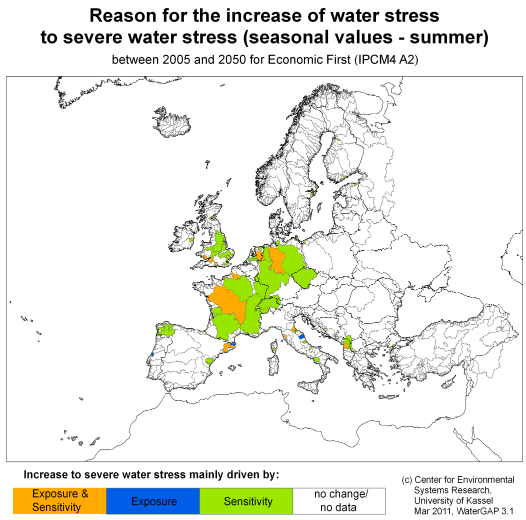

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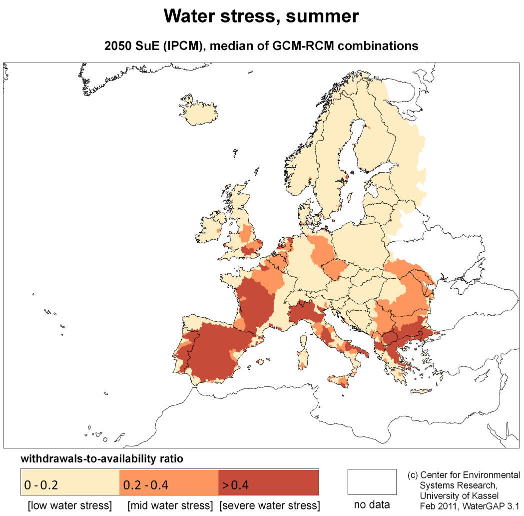

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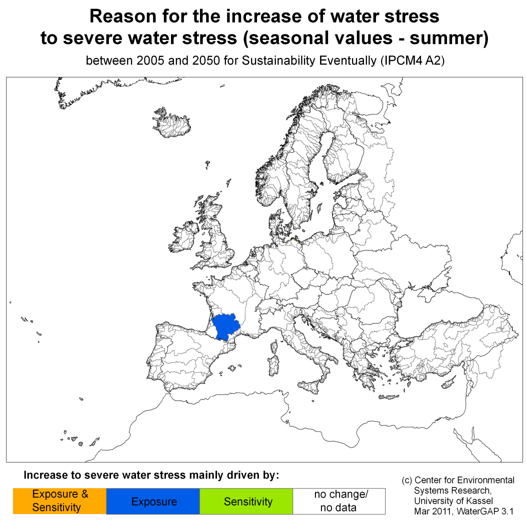


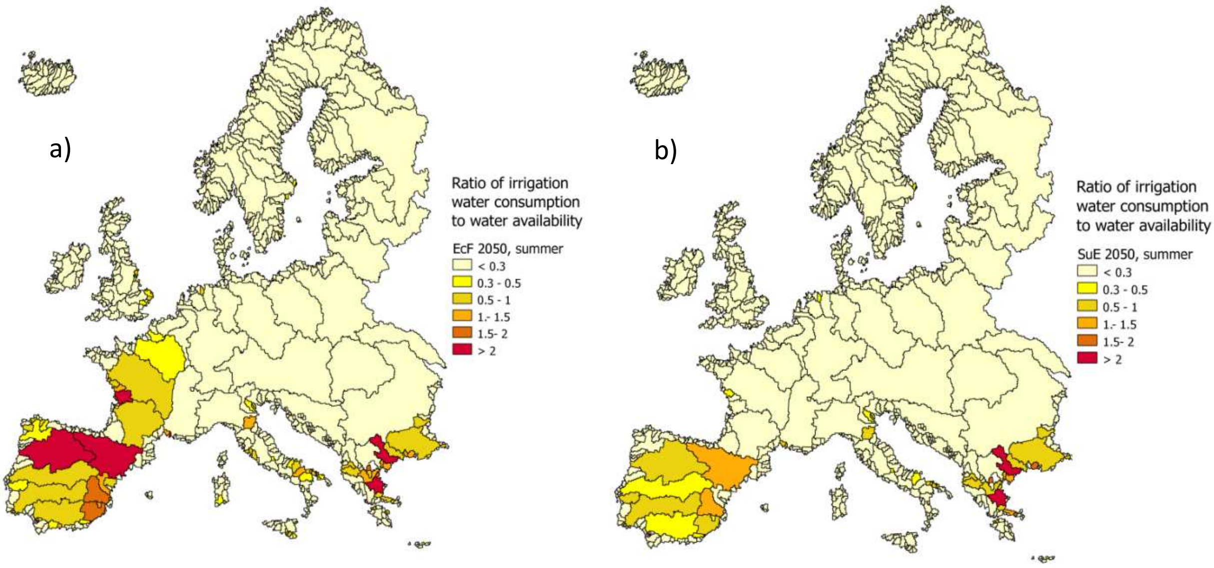


Figure 29 Irrigation consumption-to-availability ratio as calculated for the summer season for the baseline (a) and the Ecf (a) and SuE (b) scenarios in 2050.

Due to higher thermal electricity production, which doubles in the EcF scenario, the major water user in Eastern, Western and Northern Europe is the energy sector, resulting from increased cooling water demand (see Table "Summer WEI" in Annex 10 for comparison). Some of the water-scarce river basins also have large cooling water requirements for the thermoelectric industry. In Western Europe, for example, the percentage area under severe water stress will reduce by 19% if cooling water is not considered in the WEI calculation (Table "Summer WEI excluding cooling" in Annex 10). In this region, cooling water makes up a large fraction (50%) of total water withdrawals. In the relevant river basins, the thermoelectric power industry will have to compete with the other water-use sectors for scarce water resources. This industry will either win this competition or have to adapt to the situation by reallocating to a basin with more plentiful water or reducing their water requirements. An additional threat for the thermoelectric power industry is water temperature, since cooling water shortages may occur due to reduced river flows accompanied by water temperatures close to or above the threshold allowed for water intake in national legislation.

Water availability plays a major role in the thermoelectric power industry, as large volumes of water are used for cooling purposes and ongoing maintenance. The impact of climate change and water shortages on the electricity production sector are well known, in particular in the wake of the heat waves in 2003 and 2006, which are good examples of Europe's vulnerability to droughts, even in areas where water resources are not expected to be scarce. In this sense, Figure 30 indicates the river basins where future cooling water requirements will be difficult to meet (0.5 < ratio < 1) or cannot be fulfilled during low flow conditions (ratio >1). This may lead to conflicts with other water users that compete for the same resource. Low flows generally occur in summer and result in reduced water levels. Increasing air temperatures, which are expected for the summer months, will most likely lead to increases in river water temperature, and these increases impact the efficiency of once-through cooled power plants. In the EcF scenario, high ratios (>1) of cooling water abstractions-to-Q90 occur in Western Europe and in some river basins in Southern Europe due to the rise in thermal electricity production and a decrease in Q90 (Annex 10, Figure 34). The results are very different under SuE scenario conditions: although low flows will decrease in the future, cooling water needs will be met. This is due to expected technological improvements that save water in the thermoelectric sector, i.e., a shift in cooling systems, and a decline in thermal electricity production (in Western Europe). This indicator is highly recommended, e. g. by the ClimateWater project and developed in a similar application in Flörke et al. (2011).

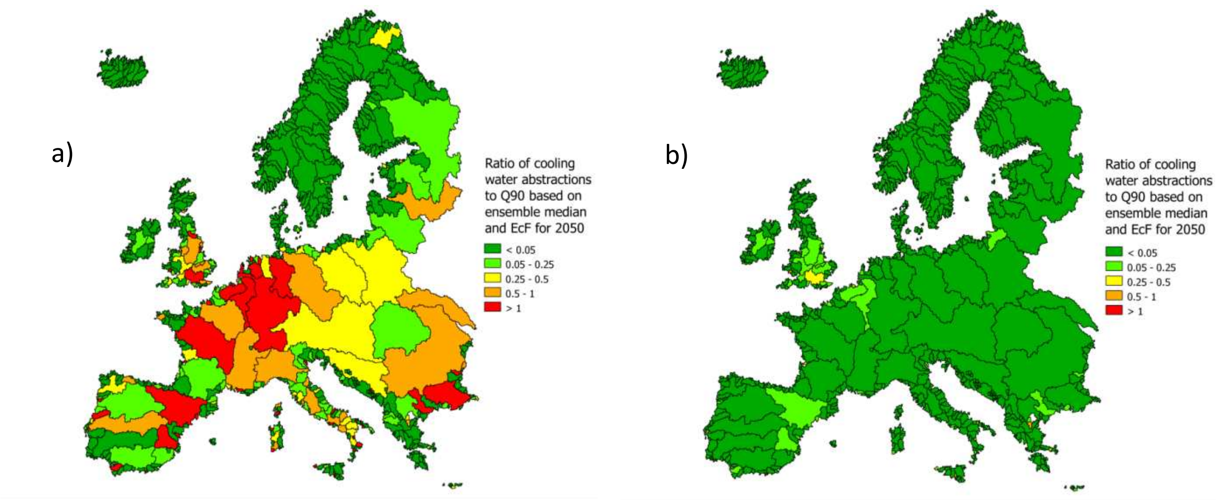


Figure 30 Maps indicating cooling water stress during low flow conditions in 2050. (a) EcF scenario, (b) SuE scenario.

Electricity demand is expected to further increase in the future in EcF. Another energy source that could fulfil this demand, next to thermal electricity production, is hydroelectricity, which can be expanded in water-rich areas with run-of-river plants (Annex 4). However, it is assumed that new large facilities will not be possible because of the lack of suitable remaining sites and expected public opposition to the social and ecologic impacts of large dams. Hydropower generation is likely to be impacted by climate change (Wilbanks et al. 2007), and in some regions negative effects on production in summer and positive effects in winter are expected. A loss in hydropower potential of "run-of-the-river" power plants is likely all over Southern and Western Europe (Figure 31) because operators must maintain a residual flow in the river which fulfils the minimum water requirements (Q95) for aquatic ecosystems (Stigler et al. 2005, Annex 10). In contrast, no risk of potential power losses was found for Eastern and Northern Europe. The analysis performed in this study shows also that reservoir stations are at risk, in particular in Southern Europe. This results because these stations are susceptible to insufficient water availability due to reduced precipitation (Figure 32).

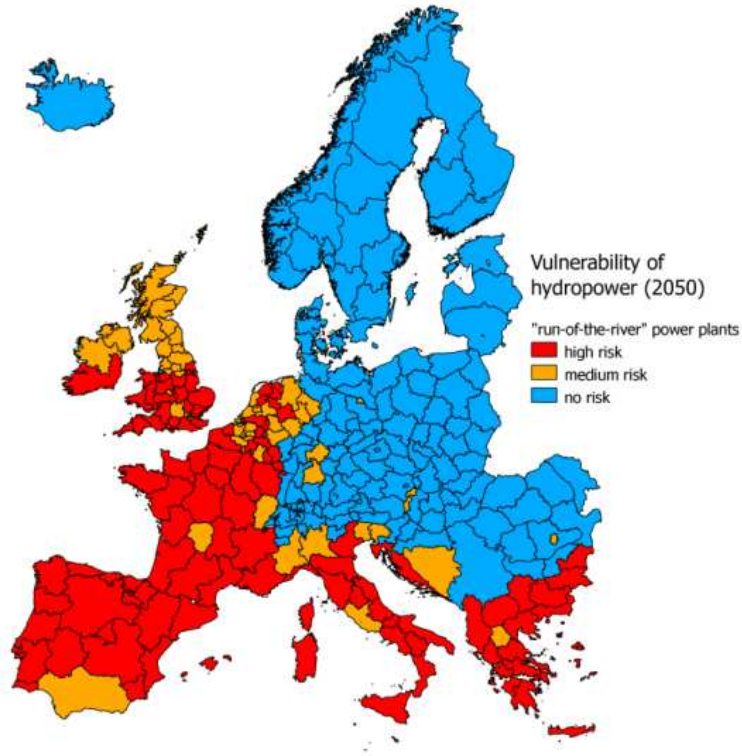


Figure 31 Climate change impact on the hydropower sector (run-of-the river power plants).

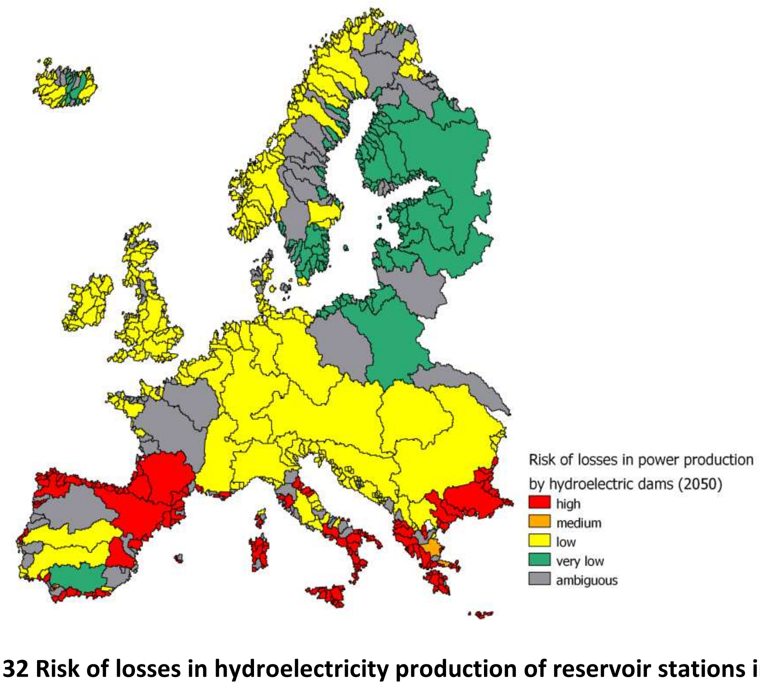


Figure 32 Risk of losses in hydroelectricity production of reservoir stations in 2050.

In Europe, the tourism sector is a multi-billion euro industry that is highly dependent on climate resources (Amelung and Moreno 2009). The tourism sector relies on large amounts of water, i.e., every tourist consumes between approximately between 300 and 850 litres of water per day depending on hotel facilities (WWF 2004). In fact, most popular tourism destinations are generally located in the Mediterranean region, especially in regions with warm climate and less water availability during the main tourist season (summer). We estimated 645 million overnight stays in water-stressed areas in Southern Europe under EcF conditions in 2050 (Figure 28b), provided that the number of overnight stays was kept constant according to the base year (Table 5). Thus, millions of tourist require water in the water-scarce regions and have to compete with other water-use sectors. Due to a smaller percentage of area under severe water stress, a fewer number of overnight stays is expected for the SuE scenario.

Table 5 Number of tourism overnight stays in water-stressed areas according to the four European regions.

	Overnight stays in water stressed areas (wei, annual > 0.4) in Mio. nights			Overnight stays in water stressed areas (WEI, summer >0.4) in Mio. nights		
Region	Baseline	EcF 2050	SuE 2050	Baseline	EcF 2050	SuE 2050
WE	167	565	22	232	645	45
SE	415	516	323	562	758	452
EE	2	40	0	2	40	2
NE	9	12	5	9	13	7

Possible physical and economic effects induced by climate change in Europe over the 21st century have been studied in detail by the PESETA (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis).

Summer tourism such as hiking, trekking, or biking in the mountainous regions will be impacted by more precipitation events or a higher fog level. Melting glaciers due to higher temperatures will affect summer skiing in the Alps and elsewhere. Additionally, more and stronger extreme weather events are another threat for tourism activities and tourism infrastructure (Bürki et al. 2003).

However, not only summer skiing is threatened by climate change; winter tourism also has to face significant changes which are likely to cause economic losses. Winter tourism depends on good snow conditions and is highly sensitive to snow-deficient winters and the length of the skiing season. Climate research findings show that there will be an increase in the number of winters with little snow due to climate change (Elsasser and Bürki 2002, IPCC 2007). In the Alps, for example, snow-reliability will rise from 1200 m up to 1800 m over the next few decades (Elsasser and Bürki 2002). Ski resorts at lower altitudes will disappear from the market sooner or later due to the lack of snow. The impact of climate change on winter tourism is probably most severe in countries such as Germany (for example resorts in the Black Forest or in Allgaeu) and Austria, due to the lower altitudes of their ski resorts (Bürki et al. 2003). Hantel et al. (2000) studied climate change impacts on the variation in snow cover duration. The authors found that in snow sensitive regions of Austria the period of snow cover may be reduced by approximately four weeks if temperature increases by 1°C.

The following two maps (Figure 33) show the changes in maximum snow cover (a) and number of days with snow cover (b) between the 2071-2100 (referred to as 2080s) and the baseline. Here, the snow cover is reported in mm snow-water-equivalent, which is the amount of water contained within the snowpack. Overall, maximum snow cover is expected to decrease in Europe due to higher temperatures, with maximal estimated reductions of more than 100 mm in the mountainous areas. An exceptional case is apparent in Norway, where an increase of maximum snow cover was simulated. The change in number of days with snow cover can also be large, i.e., a decrease of more than 60 days throughout the year is rather likely for mountainous regions. Although these results reflect the situation in the 2080s, the direction of change will be the same for the 2050s; however, it can be assumed that the differences are less pronounced. As a result, both indicators depict the impact of climate change threatening the winter tourism sector. (Please note, both indicators are available for the 2025s and 2050s and stored in the ClimWatAdapt database).

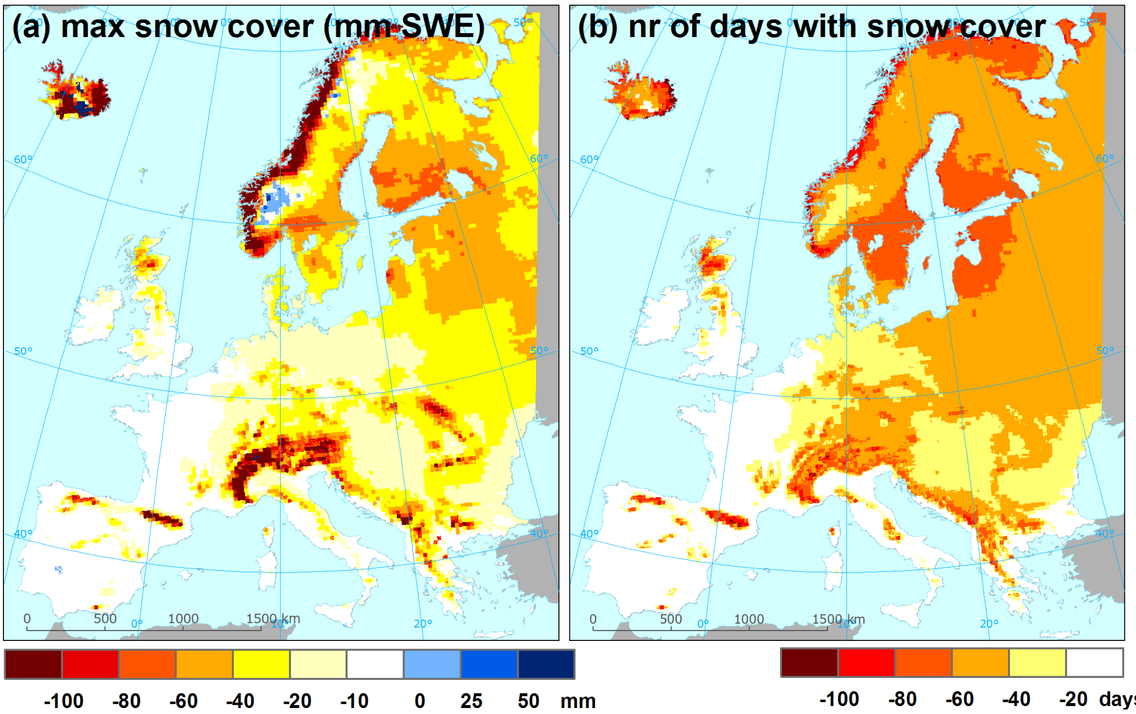


Figure 33 Ensemble average results derived from climate simulations by 8 regional climate models driven by A1B scenario, change between 2071-2100 (2080s) and 1961-1990 (source: JRC, LISFLOOD results)

As previously discussed in chapter 3.1, water withdrawals are expected to decrease under the SuE scenario. Considering the driver projections and assumptions made in the scenario, overall, the area under severe water stress is expected to decrease by 2050 (compared to the baseline, see Figure 28c). In Southern and Western Europe, the percentage of area under severe water stress is reduced by 3% and 4%, respectively, although in these regions total water withdrawals decrease by more than 60%. Since water availability decreases as well, this means, that the estimated reductions cannot compensate the pressure put on these river basins, and therefore are still overexploited. Positively, only a minor part of the Eastern and Northern European area remains in the severe water exploitation class (WEI > 0.4).

In Southern Europe, irrigation water requirements are reduced in comparison to the baseline, due to a decrease in the extent of irrigated area combined with increasing efficiency (Annex 4). Irrigation water stress as indicated in Figure 29b still occurs in some river basins in Southern Europe. Water scarcity is even worse in Southern Europe although, in addition, projected agricultural water withdrawals are reduced to one third of the amount in the baseline. Here, the water savings are not sufficient to reduce the water stress in summer significantly. The agricultural sector tends to be the dominant water user in all regions due to the expansion of irrigated area in Western, Eastern and Northern Europe. Nevertheless, declining water withdrawals prevent an additional expansion of the area under severe water stress. In order to safeguard freshwater requirements, the re-allocation of water use, waste water reuse or a further decrease in irrigated area seem to be more effective to cope with water shortages.

In the energy sector, where cooling water demands significantly decline until 2050, the water saving potential is especially high due to technological improvements. The emphasis on the efficiency of resource use, together with a shift to renewable energy sources lead to a reduction in thermal electricity production. Even less water stress is evident if cooling water is excluded from the sum of total water withdrawals. However, the effect is marginal and the impact of climate change on the thermoelectric power industry is less severe compared to the EcF scenario. The exclusion of cooling water demands does not change the picture much for SuE since the need for cooling water is diminished in this scenario. Still, in water stressed river basins thermal electricity plants have to compete for water with the domestic, manufacturing, and agricultural sectors. Electricity production from renewable energy sources increases in SuE, thus hydropower will play a more important role. The impact of climate change is described in the EcF-section above, since the analysis is solely based on the hydrological output (Annex 10).

During the summer period, water availability is expected to decrease in all regions in the future (until 2050) compared to the baseline conditions, though predominantly in Southern (-28%) and Western Europe (-21%) (see Table summer WEI in Annex 10). The projected decrease in water availability, even in combination with substantial reductions of water withdrawals, exacerbates water scarcity in Southern and Western Europe. Additionally, further river flow reduction can also aggravate the effects of water pollution, e.g. water temperature during low flow periods. The main climate change impact in relation to water scarcity is therefore likely to be increased water stress during the summer.

Environmental flows and transitional waters

The results discussed above are of importance for further analyses on environmental flows and transitional waters, which are both based on the hydrological projections. In order to maintain and improve the functions of European aquatic ecosystems, the Q95 has been used to set a critical threshold where no abstractions out of the river are allowed. This concept was recommended by Acreman et al. (2008) and is already applied in the UK. Resulting from the vulnerability assessment, climate is the primary driver of water availability (river discharge), setting the broad patterns at the European scale. Using the median of the 11 GCM-RCM simulations, Q95 is projected to decrease in Southern and Western Europe. For the North Eastern part of the EU an increase in low flows (Q95) is projected. In Southern and Western European regions, it is particularly important to reduce extraction during low flow periods to guarantee healthy ecosystems and maintain ecosystem functions.

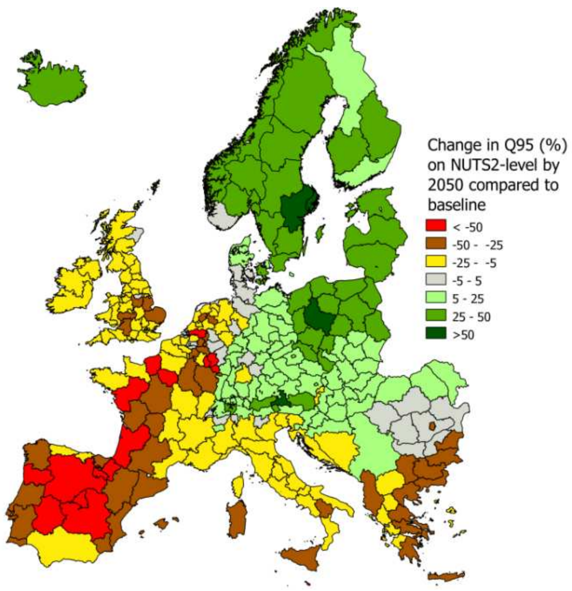
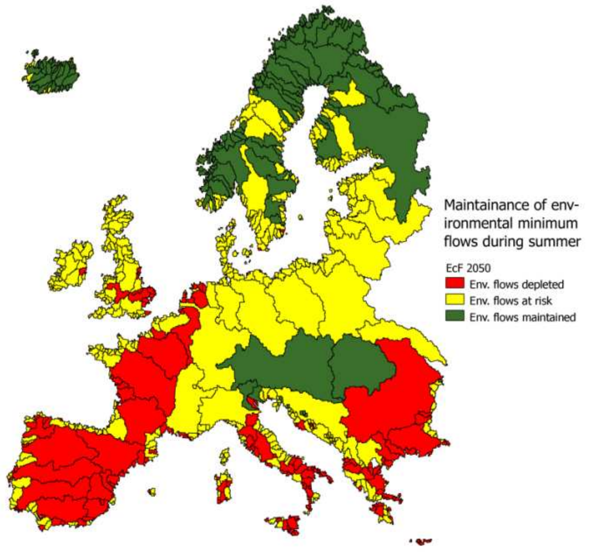


Figure 34 Change in Q95 on NUTS-2 level as compared to the baseline (1961-90), realized with the median of 11 GCM-RCM combinations for the 2050s.

a)



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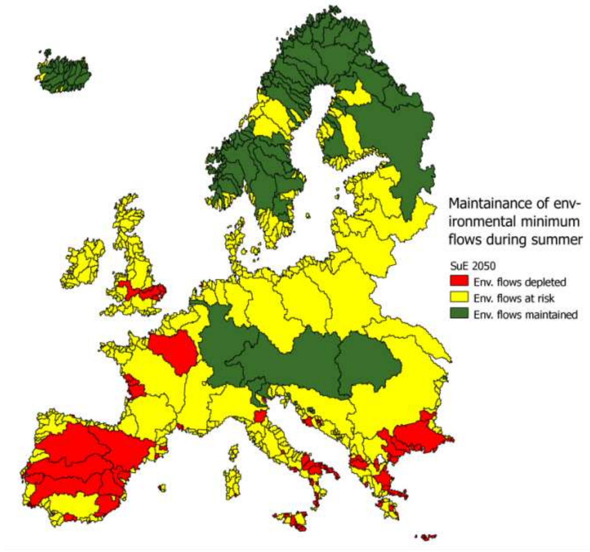


Figure 35 Maintenance of the environmental minimum water requirements (environmental flows) in the 2050s under (a) EcF and (b) SuE. "Env. Flows depleted" = residual flow equals 0-100% of baseline Q95, "Env. Flows at risk" = residual flow is 2-4 times larger than baseline Q95, "Env. Flows maintained"= residual flow is more than four times larger than baseline Q95.

In order to know whether or not environmental flows are met, changes in future water availability must be compared to future water consumption under different socio-economic scenarios. It is obvious from Figure 35a that under EcF environmental flows will be at risk throughout Europe, except in upper parts of the Danube basin and regions in the far north. In particular, in Southern and Western Europe the minimum flow requirements may even be partly depleted. Although reductions in water consumption, as under SuE (Figure 35b), improve the situation considerably, environmental flows are still projected to be at risk in about 75% of Europe's area.

Transitional waters are expected to be threatened by climate change impacts due to increasing saltwater intrusion caused by sea level rise and reduced freshwater inflows into the Sea. Estuaries of Southern European rivers are particularly endangered, and the situation becomes even more severe in summer when river discharge is even lower. During the low flow season, Europe's biggest rivers are affected, e.g. Danube, Rhine, Elbe, Tagus, and Loire. The risk in a shift in freshwater-seawater balance is highest in summer and lowest in winter (Annex 10), which increases the potential for saltwater intrusion into fresh groundwater in coastal aquifers. Highly urbanised coastal areas rely in particular upon aquifers sensitive to saline intrusion for domestic water supply, and are thus highly vulnerable. This is also an effect of sea level rise, which is expected to steadily increase due to climate change (Annex 10). The combined effects of human development and reduced river flow will also degrade water quality conditions, negatively affecting fisheries and human health through such changes as increased presence of harmful algal blooms and accumulation of contaminants in animals and plants (see Annex 10).

Water quality

Despite improvements in some regions, pollution from agriculture remains a major pressure on Europe's freshwater (EEA 2010b). As stated in the SOER (EEA 2010b), the implementation of the UWWTD has led to more households being connected to a municipal treatment works via a sewer network, and thus leading to a reduction in the wastewater discharge of some pollutants. However, the latest reporting under the WFD indicates that a substantial proportion of Europe's freshwaters are at risk of not achieving good status. There is already, not considering climate change impacts, a serious impact of diffuse pollution on aquatic systems because of the intensive farming over most of Europe (Sutherland et al., 2010). In this context, more water-related legislative provisions need to be realized to further improve water quality.

Some general conclusions from the analysis of many of the ClimateWater project documents and publications are as follows:

(i) Increasing frequency and intensity of rainstorms and accelerated melting of snow cover will result in additional pollutant loads of runoff-induced non-point source origin.

(ii) The weight of non-point sources is increasing with the increase of sewage and wastewater treatment investments

(iii) Non-point sources have dominated the overall pollutant budgets for many parameters.

(iv) It needs to be investigated whether drier climates are likely to experience reduced diffuse loads or increased diffuse event-based loads (due to a longer pollutant accumulation period and short heavy rainfall events); field based research should be initiated imminently (Delpla et al., 2009).

(v) Models are very useful for predicting the progression and severity of chemical or physical changes to water bodies, but too few are appropriately backed up with adequate field studies and continuous monitoring.

Data collection, as well as the development and improvement of tools and models to estimate current and future water quality from a large scale perspective, is of importance. The status of Europe's freshwater bodies in terms of water quality is generally well documented. Still, the effectiveness of measures to be implemented will depend upon the ability to account for driving forces that could affect water quality over the coming decades, e.g. climate, land-use, and socio-economic changes.

Finally, large-scale studies on the development of future in-stream water quality are not yet available, but a first attempt was undertaken in the SCENES project. Two water quality indicators developed are described in Annex 10. Please note, the underlying climate change data differ from those given in the IAF because two other GCMs in combination with the SRES A2 scenario were used.

Within SCENES, first attempts were made on large-scale water quality modelling and some results can be found in Annex 10. One of the impact indicators was the risk for harmful algal blooms in shallow lakes and reservoirs. There is no significant change between the EcF and SuE scenarios compared to the baseline since the risk for harmful algal blooms is already high all over Europe, except for Northern Europe. However, the SuE scenario gives the most positive results. The second indicator assesses the habitat suitability for river water temperature for fish. Here it could be shown that climate change (in SCENES A2 emission pathway was selected) leads to an increase in natural water temperature for European rivers between 2-4°C. Due to cooling water intakes, water temperature further increases. Therefore, there is a significant risk that future habitat suitability of river water temperature for fish will be reduced. Currently, many populated and industrialized areas in the Atlantic region and Southern Europe already show poor habitat suitability. For the scenarios, large parts of Europe show potential problems for regionally specific fish species with EcF showing the worst conditions for fish in all regions. SuE results in an estimated decrease in excess temperature, which is then compensated by the natural temperature increase (see Annex 10).

3.4 Vulnerability to droughts

Droughts can be considered as a temporary decrease of the water availability due to, for example, rainfall deficiency. Droughts can occur anywhere in Europe, in both high and low rainfall areas, and in any seasons. The impact of droughts may be exacerbated when they occur in a region with low water resources, or where water resources are not being properly managed resulting in imbalances between water demands and the supply capacity of the natural system (EC 2011).

As compared to floods, droughts are often perceived by society to play a less dominant role as a natural hazard. This may related to the fact that, unlike a flood, whose effects can be immediately seen and felt, droughts build up rather slowly, growing steadily. Droughts cause serious damage to economy, society, and the environment, both in the affected areas and further afield. For example, the serious drought of 2003 across Central and Western Europe caused an estimated economic damage of more than €12 billion (Lloyd's 2011). Agriculture and industry in southern Spain and Portugal were hit by severe drought in 2004. France and the UK suffered similar problems in 2006.

A decrease in summer precipitation in Southern Europe by 25% (Table summer WEI, Annex 10), accompanied by rising temperatures, will result in reduced summer soil moisture, and ultimately lead to more frequent and intense droughts in this region. The relative NUTS-2 area affected by severe drought events in the 2050s is shown in Figure 36. The analysis shows an increase in drought risks across almost all of Europe. The map presented in Figure 36 shows the median of LISFLOOD results of the 11-member multi-model ensemble for the A1B scenario. All models show strong agreements in their estimates that by the 2050s a 50-year drought of today's magnitude would return more frequently than once every 10 years. The occurrence of more severe droughts will entail losses of biodiversity, threats to human health, and damage to economic sectors, such as energy, agriculture, and tourism. Droughts affect rain-fed agricultural production as well as water supply for domestic, industrial, and agricultural purposes.

A relative share of more than 90% of the NUTS-2 area affected by droughts is expected to occur across Europe, except Northern Europe, Poland and Baltic States, where the area share is projected to be less than 50% in about half of the NUTS-2 units.

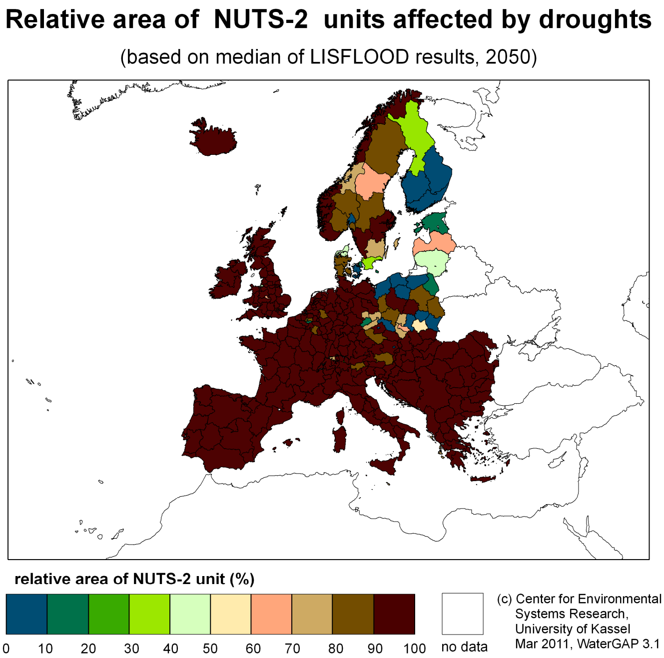


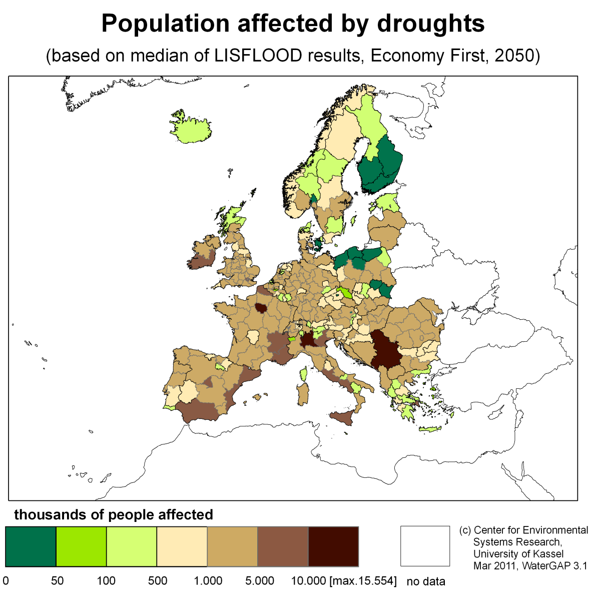
Figure 36 Share of NUTS-2 area affected by severe drought event; MQD10future < MQD50base in the 2050s. Median of ensemble drought results as calculated by LISFLOOD.

As almost all of Europe is affected by severe droughts, millions of people are affected under EcF scenario conditions (Figure 37a). NUTS-2 units where more than 90% of the area is affected by severe droughts result in more than one million people impacted by droughts per unit. These findings are in agreement with the regions vulnerable to 100-years flood events (chapter 3.5). Note that Serbia and Montenegro is particularly noticeable, since the population of the whole country is affected due to missing sub-national territory information (NUTS-2 classification).

Of economic importance are damages related to the energy sector, e.g. in terms of potential thermal electricity production, which may not be produced. The “damages in the energy sector” that could be caused by a severe drought event under different scenario perspectives are given in Figure 37b. Here, we defined damages as the potential thermal electricity production that could not be produced due to deficits in cooling water availability. Thermal electricity produced in power plants, which are cooled with salt water (seawater) are not included in this indicator. In the EcF scenario, high damages are expected because most of the electricity is produced using thermal power plants and cooling water is thus needed. In particular, Southern, Western and parts of Eastern Europe are affected. Cooling water intakes may also be impossible since water temperatures could be above the threshold. This will be especially true during summer.

Water shortages and droughts are the most severe climate change related threats in Southern Europe. In the agricultural sector, crop failures are more likely in the future due to increased frequency and duration of droughts. To overcome crop failure and economic losses, farmers could intensify field irrigation, which could worsen the water scarcity situation.

(a)



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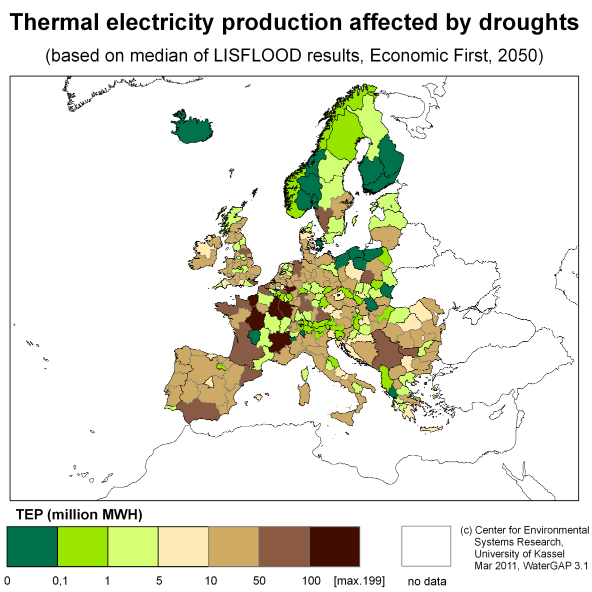


Figure 37 (a) Number of people affected by severe drought events in EcF for the 2050s. (b) Potential thermal electricity production (TEP) affected by severe drought in EcF for the 2050s. Calculation based on median ensemble results from LISFLOOD linked to projections for population and TEP from SCENES scenarios.

However, not only thermal power plants are at risk, but also hydropower plants, which are highly vulnerable to droughts. Run-of-the river plants are affected by low water levels (reduced river discharge) and dams may run out of water to generate electricity.

Overall, the differences between the numbers of people affected by a severe drought as calculated for the SuE scenario are small compared to the climate effects, which dominate the spatial distribution of expected drought events (Annex 10). Even the “ruralization” process as assumed in the SuE scenario is not reflected by the results.

Alternatively, under SuE, a high share of the electricity production will be generated by renewable energy sources, and hence, less impact is indicated concerning TEP. However, the hot spots where the production of thermal electricity production is high, like in France or Germany, are visible under these scenario assumptions as well (see Annex 10).

As stated in the IPCC report (Kundzewicz et al. 2007) increased flood periods in the future would disrupt navigation more often, and low flow conditions that restrict the loading of ships may increase. For example, restrictions on loading in the Rhine River may increase from 19 days under current climate conditions to 26–34 days in the 2050s (Middelkoop et al. 2001). Low water levels will force inland waterway vessels to use only part of their maximum capacity, which may considerably increase transportation costs. The estimated loss in 2003 was as high as € 91 million due to the very dry summer in that year (Koetse and Rietveld 2009). In 2010, the EU-FP7 project ECCONET[13] was launched, which aims to assess the effects of climate change on the inland waterway networks. A second project dealing with, for instance, inland navigation is the WEATHER[14] project, which aims at analysing the economic costs of more frequent and more extreme weather events on transport and on the wider economy, as well as exploring adaptation strategies for reducing them in the context of sustainable policy design. At the European level, the main transport route is the Rhine route, which represents more than 63% of the volume transported in Europe (Central Commission for Navigation on the Rhine 2008, CCNR). According to the CCNR, other transport routes, e.g. Seine, Elbe and Danube are main flows of inland waterways.

The multi-model ensemble median shows that the Rhine, Seine and Rhone are expected to experience a decrease in average lowest seven-day discharge, i.e. there is a risk of reduced low water levels in the future (Figure 38). Drought periods cause low water levels which leads to lower load factors of vessels, lower speeds, more fuel consumption and possibly a disruption of traffic (in particular for bigger vessels). Although for the upper reaches of Danube and Elbe, low flow discharge is projected to increase, a potential risk of decreasing low water levels is more likely in the downstream area of both rivers.

Water quality

Higher water temperatures are rather likely, due to declining river discharges and higher atmospheric temperatures. Increased water temperatures often affect water quality by exacerbating many forms of water pollution. Lowering of the water levels in rivers will lead to the re-suspension and lateral movement of sediments, which will deteriorate water quality (Kundzewicz et al. 2007). Patz et al. (2001) found out that a greater incidence of diarrhoeal and other water-related diseases occurs in regions suffering from droughts, i.e. mirroring the deterioration in water quality. Groundwater overexploitation is more likely during drought periods, leading to saltwater intrusion in (some) coastal regions.

[13] http://www.ecconet.eu/

[14] http://www.weather-project.eu

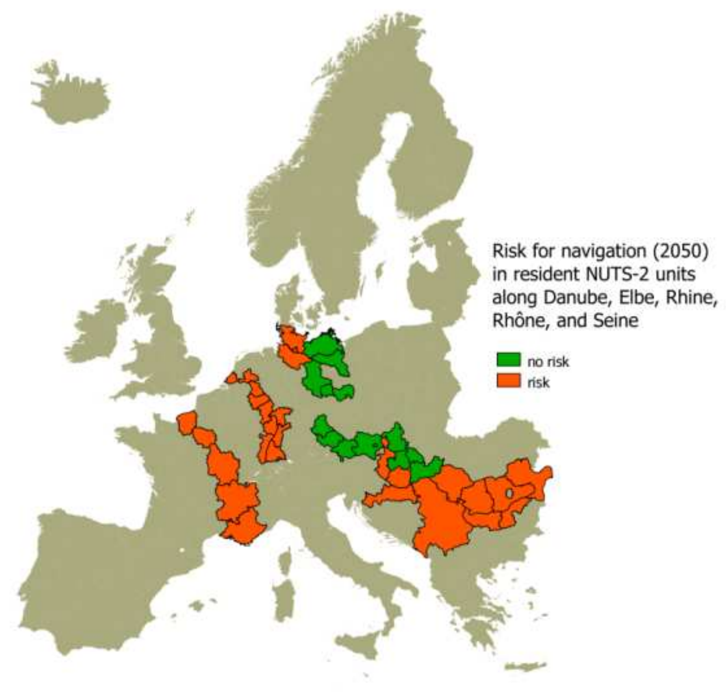


Figure 38 Impact of climate change on the inland navigation sector on a NUTS2-level in 2050s. Results are based on the ensemble median of 11 GCM-RCM combinations for the 2050s.

3.5 Vulnerability to floods

Floods are among the most frequent and most costly natural catastrophes. Major floods caused economic losses exceeding US$ 200 Billion in the 1990s and the summer flood in Europe in 2002 generated costs exceeding 20 Billion Euro (MunichRe 2009). It is commonly agreed that climate change induces an enhanced climate variability, which is expected to increase the risks of flooding in many areas (IPCC 2007; Kundzewicz et al. 2007). Extreme precipitation is projected to increase until the end of the 21st century in those regions that are relatively wet under present climate conditions, such as middle and Northern Europe. Analogously, the number of consecutive dry days as indicator for dry extremes is projected to increase, particularly in those regions that are already relatively dry under present climate conditions, such as the Mediterranean Region (Sillmann and Roeckner 2008). Comparable results for total precipitation were found by a multi model simulation with global and regional climate models, which predict a precipitation increase in Northern Europe and a decrease in Southern Europe during all seasons, while in Central Europe precipitation is projected to rise in winter and decline in summer (Christensen and Christensen 2007). However, changes in extreme precipitation are not the only cause for changes in flood magnitudes. Floods often arise by snowmelt in snow-covered catchments. Due to increasing temperatures, the average snow pack decreases, which could result in lower snowmelt induced flood peaks. Snowmelt starts earlier within the year and leads to a temporal shift of the snow melt peak.

One of the most frequently used indicators for large floods is the discharge of a 100-year flood, defined as a flood that statistically returns once in 100 years. The 100-year flood is an extreme flood event, usually causing high economic damage. Therefore, the public interest is high in information about future changes in the magnitude of 100-year floods or in the recurrence interval of an event that is currently a 100-year flood. Furthermore, the 100-year flood magnitude is frequently used for the dimensioning of flood protection works.

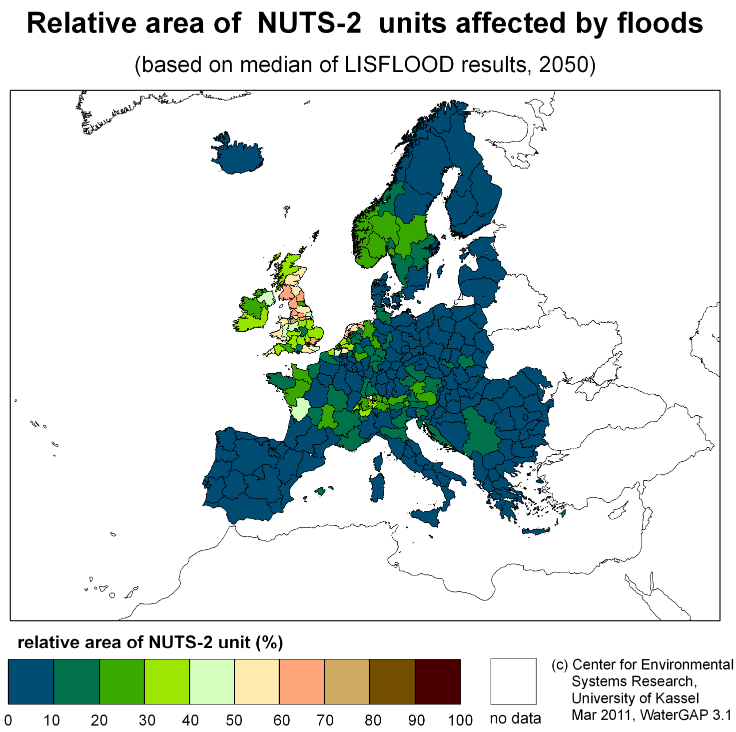


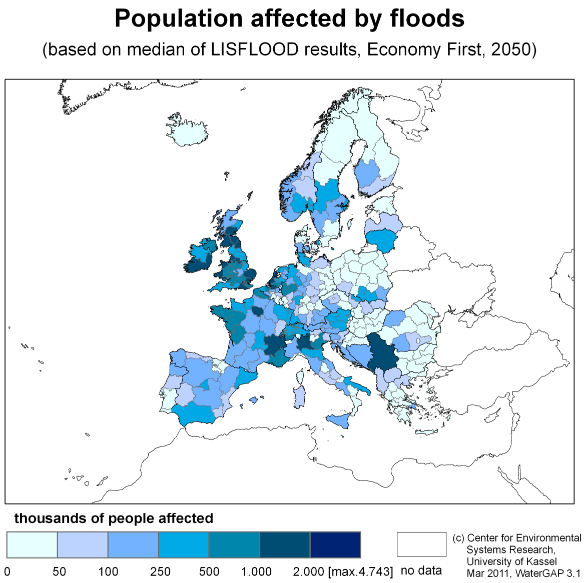
Figure 39 Percentage of NUTS-2 area affected by 100-year flood event in the 2050s. Median of ensemble flood results as calculated by LISFLOOD.

The relative NUTS-2 area affected by floods (see Annex 1 for details) in the 2050s is shown in Figure 39, which presents the NUTS-2 area affected for the median of the multi-model ensemble results. A relative share of NUTS-2 area larger than 60% is expected to occur in Northern UK and along the North Sea coast (Netherlands, and Belgium.

While the median area affected is a robust indicator for the analysis of the ensemble results, the pictures of the ensemble's minimum and maximum results show the broad variety of the overall GCM-RCM forced results (Annex 10). A broad heterogeneity is obvious due to the variety of precipitation patterns from the climate projections. Also, the uncertainties from climate change simulation related to precipitation extremes are much higher than the uncertainties in the change precipitation average. As the percentage of NUTS-2 area affected by 100-year flood events is defined, the impact on people living in these areas (Figure 40a) can also be estimated. The left map in Figure 40 shows the number of people living in areas strongly affected by flood events (100-year flood) for the EcF scenario in 2050. These are either NUTS-2 units where more than 60% of the area is affected by floods (e.g., in UK; compare to Figure 39) or where population (cities like Paris, Lyon) or population density is high (e.g., the Netherlands).

Next to the people affected by a 100-year flood, the damages related to the manufacturing sector in terms of manufacturing gross value added (GVA, Figure 40b) are estimated. The "manufacturing damage" that could be caused by 100-year floods under the EcF scenario perspectives is given in the right map of Figure 40. The highest damages are expected in the EcF scenario, compared to the other scenarios, because the scenario is globally market-oriented and quite a lot of money is made by the manufacturing sector. The NUTS-2 units affected are those where a large part of the area may be affected (e.g., North Sea coastline) or where a lot of manufacturing industries are located, like in France, Northern Italy, Netherlands or Western Germany. Damages are also significant in Serbia and Montenegro.

(a)



(b)

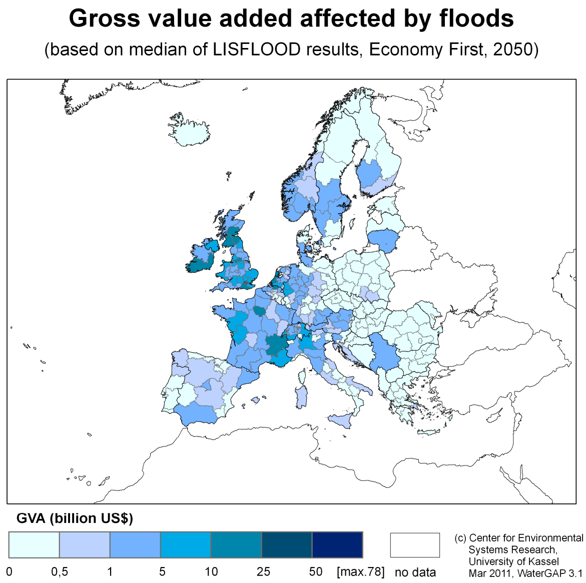


Figure 40 (a) Number of people affected by 100-years flood events in the EcF scenario for the 2050s. (b) Amount of manufacturing gross value added (GVA) affected by 100-year flood events in the EcF scenario for the 2050s. Calculations based on median ensemble results from LISFLOOD linked to population projections from SCENES scenarios.

Considering the number of people affected by the occurrence of 100-year flood events, the differences between the EcF and SuE scenarios are small compared to the climate effects, which dominate the spatial distribution (Annex 10). The "ruralization" given in the SuE scenario is not reflected by the results. Particularly noticeable is Serbia, as for this country no sub-national division (e.g. NUTS-2) exists and thus the total population is affected. The same applies for other western Balkan countries.

The amount of manufacturing output (in GVA) impacted by 100-year flood events is less pronounced in SuE compared to the EcF scenario. In SuE it is assumed that GVA decreases after 2025 in all European regions. Overall, this impact indicator is more sensitive to the SCENES scenarios compared to the indicator shown in Figure 11, because of large differences between the projections.

As an average over the SCENES socio-economic scenarios, JRC provided estimates on the number of people affected and the total adaptation costs, both reported in (Annex 10). Total adaption costs are deducted assuming they are ¼ of the avoided damages from adaptation itself. This estimate is an average extrapolated from the relevant literature. Under the assumption of current protection, 302 thousand people are expected to be affected by 100-year flood events in 2050, whereas the number is likely to reduce to 171 thousand if future protection is assumed. In LISFLOOD, current protection assumes that all EU countries are now adopting a full protection up to 100-year flood events and will be keeping the present protection expenditure constant till the end of the century irrespective of future changes in climatic conditions. Future protection, on the contrary, assumes that EU countries are increasing protection expenditures (when needed) to maintain the present level of protection. Thus, they are coping with a potential future increase in the frequency of flooding events (Annex 10).

Additionally, results for the number of people living in flood risk areas as obtained from the PESETA[15] project are given in Annex 10.

Obviously, the costs of adaptation in the LISFLOOD modelling exercise are by design lower than the benefits. However, the analysis becomes more interesting if instead of direct benefits, i.e. direct costs avoided, indirect benefits, i.e. lower GDP losses estimated by the ICES CGE model, are compared with the costs of protection. This cost-benefit analysis is performed in chapter 0 devoted to the quantitative assessment of adaptation measures. Table 6 reports the results of the ICES model once the information related to the current protection case have been processed.

Table 6 GDP losses induced by flooding in 2050 under current protection. Average across the four SCENES scenarios[16]

	Total cost of flooding (including those climate change induced) $ Million	Climate change induced cost of flooding (wrt current climate) $ Million	Total cost of flooding (including those climate change induced) % of GDP	Climate change induced cost of flooding (wrt current climate) % of GDP
Austria	-176.6	-78.5	-0.034	-0.015
Belgium	-129.3	-51.5	-0.021	-0.008
CzechRepubl	-90.1	-21.6	-0.044	-0.011
Denmark	-3.6	0.1	-0.001	0.000
Finland	-182.1	-90.3	-0.059	-0.029
France	-450.4	24.6	-0.014	0.000
Germany	-139.8	11.7	-0.003	0.000
Greece	-27.4	-4.6	-0.007	-0.001
Hungary	-150.0	-36.4	-0.091	-0.021
Ireland	-29.7	-15.4	-0.009	-0.004
Italy	-593.9	-201.2	-0.022	-0.008
Netherlands	-129.2	-17.4	-0.014	-0.002
Poland	-69.5	0.5	-0.018	0.000
Portugal	-9.0	-7.6	-0.001	-0.001
Spain	-144.6	-77.2	-0.008	-0.004
Sweden	-50.0	-12.6	-0.008	-0.002
UnitedKingd	-871.3	-476.1	-0.027	-0.015
RoEU	-274.1	-94.4	-0.046	-0.016
EU27	-3520.5	-1147.8	-0.017	-0.006

The vulnerability assessment thus confirms that the higher absolute costs are sustained by larger and richer EU countries (the biggest looser is UK with $ 871 million GDP losses on average in 2050, followed by Italy and France). This is due to the higher value and "density" of agriculture and capital assets at risk. Nonetheless, the highest costs in percent of GDP are sustained by Hungary, where direct impacts of flooding are the highest in the EU in all the macro-sectors concerned. Flooding damages could decrease the Hungarian GDP by 0.09% in 2050.

It is also interesting to note that flooding damages due to the climate-change component are important, but not the largest. At the EU 27 level they constitute roughly 1/3 of GDP losses. The

[1515] http://peseta.jrc.ec.europa.eu/

[16] Extended results, separated for each SCENES scenario are available upon request to authors.

other 2/3 would be experienced anyway (assuming current protection) independent of climate change.

Direct costs are significantly larger than final impacts on GDP. This is a typical result of CGE exercises, where factor and good substitution possibilities tend to smooth initial losses. For instance, land stock deterioration and capital productivity decline are partly compensated by higher labour use. In addition, demand re-composition plays a role. Agricultural commodities for instance become more expensive, as the land input is scarcer, but consumers can partly re-address their consumption preferences towards other goods and services, thus “buffering” the initial utility loss. More details are given in Annex 10.

Another economic sector affected is inland navigation. For example, an increasing frequency of flood periods will stop inland navigation on the Rhine river more often (Middelkoop et al 2001). This sector is at high risk in terms of extremes (floods and droughts, see chapter 3.4), and is under investigation in the EU-FP7 project WEATHER (Weather Extremes: Impacts on Transport Systems and Hazards for European Regions). Extreme weather events in terms of floods have a large impact on inland waterway transport, causing high water levels and possibly resulting in a lack of bridge clearance and, if critical values are exceeded, in a disruption of traffic. However, it can be expected that with an increase in 100-year flood magnitude, or decreasing recurrence interval of a current 100-year flood, the impacts on inland navigation increase as well. This will lead to additional costs from infrastructure closure (damages and suspension), followed by economic losses of providers, when navigation is interrupted. Cost estimates have been performed for the Rhine and its neighbouring rivers based on gauges and reports on ice days. Illustrative economic costs for floods in the Kaub area are estimated at 29.2 million Euros from 2003 to 2010 (Enei et al. 2011). The authors noticed that a lot of information (especially on floods and droughts) are available for public use, but there is not much information describing specific economic impacts on inland waterways and their operators.

Flooding can affect water quality due to overloaded storm and wastewater systems and an increased risk of damages at industrial sites, e.g., depots of harmful substances. In regions where intense rainfall is expected to increase, pollutants (pesticides, organic matter, heavy metals, etc.) will be increasingly washed from soils to water bodies (Boorman 2003; ClimateWater 2011,). It is expected that higher runoff will mobilize fertilisers and pesticides to water bodies in regions where application time and low vegetation growth coincide with an increase in runoff (Kundzewicz 2007).

The change in river discharge will alter the sediment entrainment into the rivers because of changes in soil erosion. An increase in soil erosion is related to an increase of effective precipitation (PIANC 2008). For the Rhine river, estimates for the increase of soil erosion range from zero up to 38 % until 2050 (Asselman 1997). Although there is considerable literature on flow alterations in the past in various rivers, either caused by human influences or natural climatic variability, or associated changes in morphology, there is very little on possible future channel changes (PIANC 2008). This may be attributed to a lack of physically based models of river channel form and sediment transport, resulting in little confidence in estimates of the effect of climate change on river channels (IPCC, 2001).

Changes in the timing of seasonal high flows and seasonal low flows may impact shipping and maintenance schedules. Next to navigation, these changes depict a potential threat to river ecosystems that depend on natural flooding patterns including inundation of adjacent floodplains (Junk et al. 1989). Schneider et al. (2011) showed that climate change most likely alters the average volume and timing of floodplain inundation over large regional scales in the future (see Annex 10). In snow affected catchments (i.e. in Eastern and Northern Europe as well as in mountainous areas) duration and volume of inundation are expected to decrease and inundation may appear earlier in the year. The timing of floodplain inundation is likely to be earlier in Southern Europe, but in some rivers, timing can be later within the year, too. Such alterations of the flow regime may lead to habitat change and possibly decreasing biodiversity.

3.6 Vulnerability – cross-sectoral and transboundary aspects

3.6.1 Transboundary aspects

European countries are naturally linked through the joint use of common water resources. This is reflected in the 71 international river basins, accounting for 54% of the total area (Wolf, Natharius et al. 1999). Therefore, the WFD has set an effort to increase the transboundary implementation but there is no doubt that transboundary water management is in essence more complex than national and sub-national water management because the water management regime (the principles, rules and procedures that steer water management) usually differ more between countries than within countries. Transboundary water management therefore requires coordination over different political, legal and institutional settings, as well as over different information management approaches and financial arrangements. Joint bodies are usually instrumental in achieving such coordination.

However, climate change will further increase the complexity of transboundary water management, as any change in the use and natural conditions at one point in a river catchment will affect the availability and quality of water resources for the other (downstream) users within a catchment. As climate change will alter the hydrological cycle (water supply) and water demand (e.g. crop water requirements), new transboundary challenges and opportunities will emerge. The list below provides examples of how climate change may lead to transboundary issues:

- Temporal, seasonal, or permanent decreases in river flow will cause a higher fraction of upstream water consumption that may endanger downstream water supply and navigation.
- Increasing irrigation water withdrawals due to rising temperatures may increase risks on environmental flows or water supply in the downstream neighbour country.
- Saltwater intrusion in deltas and estuaries will spur local communities to explore alternative sources of drinking water, which will most likely be located in upstream areas. In transboundary basins, this can intensify water conflicts with the upstream neighbour country.
- Increasing water temperature in rivers and increasing thermal loadings due to cooling may lead to decreasing cooling potential and deterioration of water quality in downstream regions.
- A typical conflict situation during flood events is that upstream communities are interested in a fast transmission of the flood wave, whereas flood retention in the upper reaches of the river would help to reduce damages downstream. The projected increase in the magnitude of floods will intensify those conflicts.

In particular, downstream countries might suffer more, as they could face more/new water scarcity caused by upstream countries, and increased flood risks due to depletion of ecosystems in the upstream part of the river or water pollution. In addition, water depending sectors in the downstream part of a river will become more vulnerable to upstream activities. If, due to a changing climate, upstream countries are required to increase water abstraction, allowing less water for downstream, then production patterns (agriculture, energy and industry) might deplete in downstream countries due to the lack of water. Such issues might cause new conflicts between MS, which not necessarily will only be discussed in the water sector.

As climate change alters the hydrological situation in many basins, increasing the number of extremes (such as floods and droughts), the need for transboundary management of these water resources has become very urgent, in order to prevent negative effects of unilateral adaptation measures and to choose the most effective measures (Timmerman, Koeppel et al. 2011). Furthermore, the long-term horizon that climate change imposes to planning can contribute significantly to the development of a more holistic and sustainable transboundary-water resource management, as solutions are required across borders. Nevertheless, a full assessment of all possible transboundary problems and opportunities is still lacking and it is advisable to carry out such an assessment in order to remove the barriers to sustainable water resource management.

The vulnerability assessment shows that under the EcF scenario many of the internationally shared river basins (transboundary) will be in the medium or severe water stress categories in 2050. The competition for the scarce water resources could be an ongoing source of tension between nations. However, the problems caused by climate and socio-economic changes are quite diverse and differ between the transboundary river basins. Western and Eastern European Member States are heavily dependent on water from upstream countries. The difference between the rivers shared in Southern Europe and those shared in Western or Eastern Europe is that in the first case it is a water scarcity (and drought hazards) and allocation problem, while in the second it is a water quality and flooding problem. Often the upstream area is affected by floods whereas downstream parts suffer from water scarcity (e.g. Elbe, Danube).

In shared river basins in Southern Europe, further river regulation (e.g., reservoirs) and increasing water abstractions in upstream areas will lead to reduced discharges available for downstream use, which in turn will trigger saltwater intrusion in coastal areas. Water allocation between different users is of importance since most of the water is required for agricultural purposes. The increase in hydropower potential may lead to a depletion of environmental flows downstream and, additionally, to losses in biodiversity.

Transboundary river basins located in Western and Eastern Europe have to face problems related to water quality, floods and water scarcity (drought periods). Adaptation to floods in upstream areas needs to be undertaken with consideration for downstream water scarcity, and consequently the implementation of measures requires a strong commitment to agreements (see factsheet "Transboundary Flood Management through Spatial Planning"). At the same time, downstream parts of transboundary rivers will be at risk for maintaining environmental minimum flows and navigation, and will probably face increased demands for water from upstream.

Furthermore, it is important that side effects of local adaptation measures need to be considered from a basin perspective in order to avoid negative impacts for downstream countries. Therefore, it is highly recommended to critically analyze and evaluate the planned measures from a transboundary perspective. In this context, the integration of cross-sectoral aspects and stakeholder cooperation, as well as the coordination of compatibility between monitoring, information and data management systems is of importance (Mostert 2003).

In its 2007 implementation report, the European Commission identified international coordination as one of the implementation issues suffering from the most serious shortcomings (Commission of the European Communities 2007). The currently published Fitness-Check (Deloitte 2011) confirms this lack, although some progress has been made due to the implementation of the Floods Directive.

Overcoming these deficits will play a major role in any successful implementation of adaptation strategies. Low levels of cooperation can lead to situations of high inefficiency when choosing adaptation measures, increasing administrative costs and producing little added value to the overall problem solution. Therefore, including adaptation strategies in the WFD should be seen as an essential need. As the WFD demands regular actualization of River Basin Management Plans, this could allow timely inclusion of new knowledge on climate change risks and adaptation needs in these plans. Such an approach should not only try to coordinate the different adaptation measures, it should also develop financial mechanisms that allow for burden sharing between down- and up-stream water users. Regarding the financial arrangements, riparian countries should focus on generating basin-wide benefits and on sharing those benefits in a manner that is agreed to be fair.

3.6.2 Cross sectoral aspects

Climate change impacts might intensify existing competition for water resources between the different sectors. The EEA (2009b) identified different fields of potential cross-sectoral water competition, which relevant for adaptation (Figure 41).

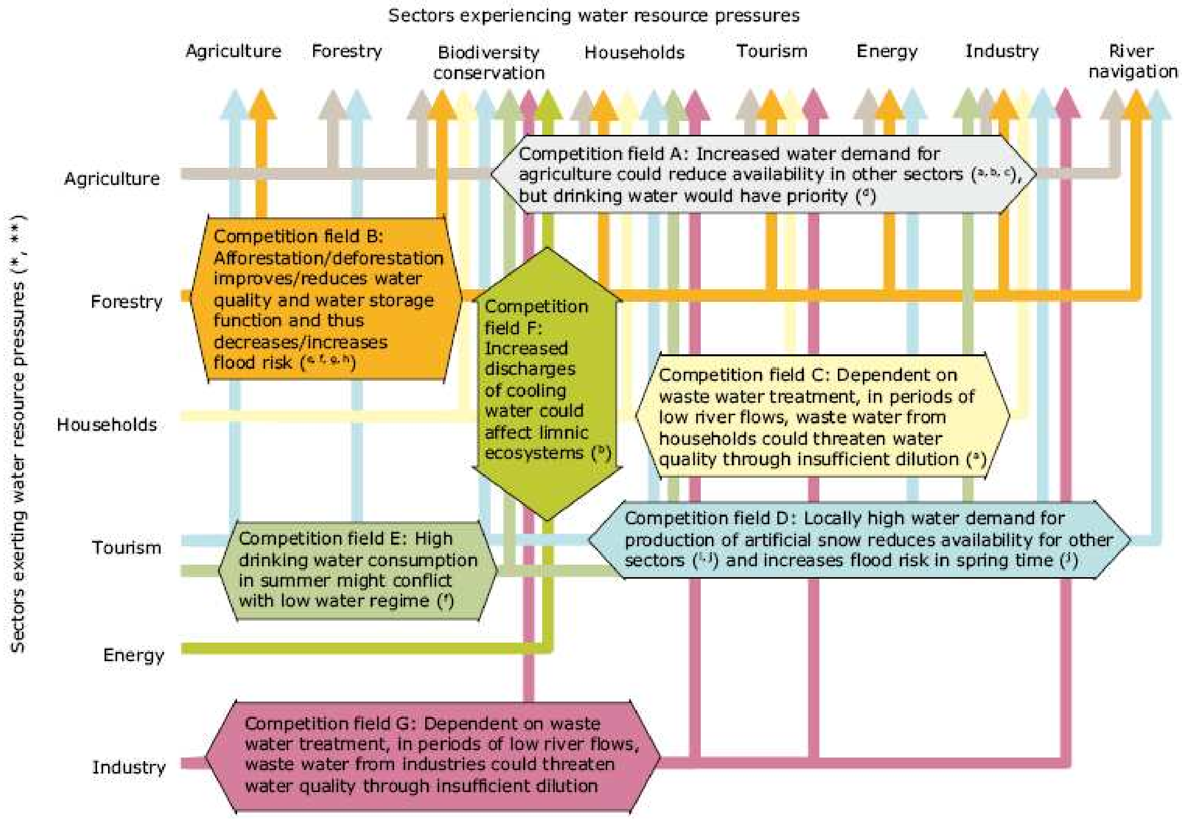


Figure 41 Fields of potential cross‑sectoral water competition relevant for adaptation (source: EEA 2009).* River navigation is not considered as a sector exerting water resource pressures as it uses but does not consume water. Biodiversity conservation is not considered as a sector imposing water resource pressures as it does not actively change water use pattern but rather can be considered as a sector exposed to water competition**

The EcF scenario shows that additional water stress in the future is expected to be triggered by human activities, which will be exacerbated by decreasing water availability due to climate change. Due to climate, the increased competition between the different water-related sectors will be particularly pronounced in the summer season. In most cases, drinking water will have the priority over other uses in the case of severe water scarcity. In Southern Europe, water use is dominated by agriculture, and this will remain the same in the future. Since the agricultural sector is not the only water use sector, domestic, tourism and industrial sectors compete for the same scarce resource. Overall, all water-related sectors indicate a strong demand increase, driven by growing population and income in conjunction with unchanged consumption patterns. However, the tendency of increasing water use will be dampened somewhat by continuing improvements in water use efficiency. Nonetheless, negative impacts on nature (aquatic ecosystems) can be expected because of the further reduction of minimum/low flows required for the maintenance of ecosystem functions. Finally yet importantly, an intensification of farming accompanied by increasing diffuse source loadings could lead to a further reduction of freshwater resources, creating an even worse situation. In this region, even under the SuE scenario in which a decrease in irrigated area is assumed, the region remains vulnerable to water scarcity caused by irrigation water requirements only. The storage of water in dams and reservoirs will help to ease the situation; however, according to our findings further drastic cuts or the replacement of freshwater by wastewater will be necessary to achieve a sustainable use of freshwater resources and for compliance of the WFD. It looks as if technological improvements are not sufficient in Southern Europe to manage freshwater resources in a sustainable way.

Overall, the water demand for cooling purposes in the energy sector is high and expected to further increase in Europe, and the influence of thermal power stations on river temperature can be considered as especially relevant. This will lead to a significant risk for future habitat suitability for fish in Western Europe (and Southern Europe). In addition, hydropower is a water-intensive energy source, which influences the temporal variability of the hydrological regime. A rising demand for (low carbon) electricity combined with increasing water use for electricity production thus falls within a period in which river flows are low. In particular, during this time, the power sector will be in direct competition with natural ecosystems or navigation. Moreover, in case of reservoirs and dams managed for hydropower production, competition arises during a period of higher water demand for summer tourists and water abstractions for irrigation. Water stress almost disappears under SuE scenario conditions due to a reduction in thermal electricity production, combined with a shift in cooling systems. Nevertheless, the decrease in cooling water abstraction has less impact on the environmental flows quantitatively, but a major impact on thermal pollution, which can be avoided (reduced).

Eastern European river basins are expected to be partly water stressed in EcF during summers. Under the SuE scenario assumptions, no water stress occurs. A moderate growth in income and changing consumption patterns together with increasing technological changes lead to this positive effect.

All sectors are vulnerable to water scarcity and drought hazards, but less vulnerable to floods. The allocation of water, i.e. who gets the water first, is often associated with economic aspects and often heavily subsidized. Integrated water resources management is important to balance water demand and supply and to manage flood risk.

3.7 Vulnerability – summary

The future water situation and developments in the water sector have been examined in Europe until 2050 in terms of “vulnerability to water scarcity”, “vulnerability to droughts”, and “vulnerability to floods”. Water quantity and water quality aspects were addressed, with water quality issues mainly addressed by literature review because of gaps in research, data collection, and observation. The sectoral level of detail involves the agricultural, energy, industrial, and tourism sectors, as well as navigation and aquatic ecosystems (environmental flows). Overall, one emission scenario (SRES A1B) using a multi-model ensemble of 11 GCM-RCM combinations and two socio-economic scenarios, particularly “Economy First” (EcF) and “Sustainability First” (SuE), were analyzed in this report.

Changes in future water scarcity are mainly driven by changes in water withdrawals. Under the EcF scenario, the percentage of area under severe water stress is expected to increase in all regions until 2050, with major changes in particular in Eastern, Western, and Southern Europe. Increasing water withdrawals are the main cause in Eastern and Western Europe. In Southern Europe a decrease in water availability due to climate change exacerbate the situation. No water stress occurs in Northern Europe. In river basins under severe water stress, there will be strong competition for scarce water resources between households, industry, agriculture, and nature. Overall, this situation is most severe during summer when river flows are low and are becoming lower due to climate change. Additionally, the water demands are highest during the summer due irrigation demands and tourism water use.

Under the SuE scenario, the water withdrawals are significantly reduced and as a result, the percentage of area under severe water stress is expected to decrease in all regions by 2050 and almost diminishes on an annual basis. Southern Europe and parts of Western Europe are still likely to suffer from water scarcity during summer, primarily caused by agricultural water use together with decreasing water availability because of climate change. The vulnerability of hydropower, navigation, and environmental flows is less affected by the water use scenarios since climate change is the dominant driver; however, water abstractions need to be considered to avoid further depletion and maintain the ecological function of the rivers.

In Western Europe, the energy sector in particular is extremely vulnerable to water scarcity and droughts under the EcF scenario conditions because of increased electricity production. This would lead on the one hand to cooling water stress during the low flow period, i.e. when cooling water requirements cannot be fulfilled, and on the other hand, to thermal pollution when water temperature is high and there is reduced cooling water intake. Alternative energy sources like hydropower are also at risk due to reduced river discharges, and growing biofuel crops may result in increasing diffuse source loadings. Hence, depending on the location, the expansion of hydropower might be critical. Irrigation water stress only occurs occasionally during the summer season, and maize yields are likely to decrease under rainfed conditions. Environmental flows are at risk or severe risk in the future and the same may be the case for the navigation sector.

Considering 100-year flood events, Western Europe is likely to be hit but these larger and richer EU countries can afford the rather high absolute costs. With respect to water scarcity and droughts, measures should preferably address the thermoelectric power sector. A shift in cooling systems reduces water stress as shown by the SuE scenario but increases water consumption, and therefore, a reduction in thermal electricity production as such or changing consumption patterns should be preferred. A special role is given to the navigation sector, which has to adapt to climate change impacts regardless of the water use scenario. Temperature increases and reduced snow cover will influence winter tourism in the Alps. In Western Europe, the different upstream and downstream-related vulnerabilities of transboundary river basins need to be carefully analyzed to avoid negative side effects of adaptation measures. Most of the transboundary river basins have been subject to water quality and flood problems so far, but in the future, they need to be better prepared to avoid, e.g., losses in the thermoelectric power sector due to water shortages during low flow periods or even droughts. This is obvious for the Rhine where the navigation sector will be affected, too.

For Eastern Europe, the results of the vulnerability assessment are not as clear as for Western or Southern Europe. Although the percentage of area under severe water stress is anticipated to increase due to higher water withdrawals no individual sector is particularly affected. Rather, the occurring water stress is caused by the cumulative water stress of the all sectors. An exception is the thermoelectric energy sector during low flow conditions when cooling water requirements are probably not met. The minimum flow for maintaining aquatic ecosystems is depleted under the EcF scenario and the navigation sector is affected in the lower Danube. In this area, the occurrence of severe droughts is rather likely. Extreme flood events are expected to increase in Eastern Europe, leading to higher flood damages. For example, among the European countries, Hungary is likely to suffer from the highest costs in percent of GDP due to direct impacts of flooding. Flooding damages might decrease the Hungarian GDP by 0.09% in 2050. In Eastern Europe, measures addressing floods and droughts should have highest priority; water scarcity seems not to be a major problem. However, the latter seems to be the case in the lower Danube where minimum environmental flows as well as navigation are expected to be at risk. This is an important result since the Danube, as a transboundary river basin, has to deal with a range of vulnerabilities affecting different sectors.

In Southern Europe, agriculture is the major water use sector and will remain so in the future. Irrigation water stress occurs throughout the year and especially during the summer. In some river basins much more water is consumed by crops than is available. Seasonal water shortage may be overcome by water stored in reservoirs. However, there is also a risk that the “water gap,” the imbalance between demand and supply, will be closed by over-exploitation of groundwater resources. Most prone to an increase in drought hazard is Southern Europe, which already suffers most from water scarcity. Due to reduced river discharge, aquatic ecosystems and transitional waters will be threatened. Saltwater intrusion along the coastline is most likely, polluting aquifers that are used for domestic water supply. Additional pressure is caused by the tourism sector, which increases demand during summer. With respect to the energy sector, losses in hydropower electricity production are most likely for run-of-the-river plants and for reservoir stations. In some river basins, thermoelectric power plants will also be at risk during the low flow season. Changes in flood hazards are expected to increase in parts of Southern Europe with a strong increase in Italy. Concerning adaptation measures, Southern Europe is mainly affected by water scarcity and droughts but also by (flash)floods. The imbalance between water supply and water demand is caused by increasing water withdrawals and decreasing water availability. For instance, a large portion of the agricultural land is intensively irrigated causing water stress and competition with other water users. A large decrease is necessary on the demand side to reduce water stress as could be shown with the SuE scenario. This cannot be reached only through technical measures addressing water use efficiencies. Instead, non-technical measures/actions that lead to a change in demand and water use are very important. Transboundary issues are mainly related to water scarcity and droughts and this will remain so in the future. However, in order to solve the problems between upstream and downstream user needs, integrated management is of high importance as well as cuts in agricultural sector water use by e.g., reducing the irrigated area or changing crop patterns. It is rather likely that downstream areas have to struggle with saltwater intrusion due to reduced freshwater intake but also sea level rise destructing wetland areas and reducing biodiversity.

In Northern Europe, no water stress occurs and only (locally) the thermoelectric sector may be at risk during low flow periods. However, average annual precipitation and temperature are expected to increase, leading to changes in snow cover during winter. This can lead to a shorter snow season and reduced snowmelt-induced flood peaks in the spring. Nevertheless, some areas are affected by an increase in flood hazards. Due to increased use of water in the agricultural sector, water quality problems may occur and resulting in an increase in diffuse source loadings.

With respect to water quality, less information is available on the European scale; however, some findings from SCENES are presented. The EU-FP7 project ClimateWater addresses water quality issues as well (but no modelling) and concludes with the urgent need for the development of a broad range of catchment models that are calibrated and verified against time series from catchment monitoring stations. Combining such models with long-term field monitoring allows the assessment of relationships between, e.g., diffuse pollution and its impacts. Hence, clear recommendations are given for the improved control of pollution with the increasing impact of climate change. Current management practices are inefficient in eradicating all pollution, the relative merits of which remain a contentious issue, therefore requiring the development of inter-disciplinary research.

However, water quality will deteriorate as a consequence of climate change, e.g. reduced runoff leading to lower dilution rates and higher runoff causing higher nutrient loads. It turns out that climate change-induced diffuse source pollution loadings would have a major impact on Europe’s water resources. According to ClimateWater, only general advice in terms of adaptation strategies is available so far. This statement is contradicted by the fact that diffuse source pollution is expected to grow to high levels due to catastrophic flooding and wash-off events after heavy rainfall. Finally, it becomes more important to consider both, the development of future water quantity and water quality to identify regions or sectors that are vulnerable to climate change.

3.7.1 Vulnerability of the European water sector

To draw a general picture of vulnerability of the European water sector we focused our analyses using the IAF on three main indicators on water scarcity, droughts and floods. The analyses show that climate change has a major effect on extreme events, i.e. the occurrence of droughts and floods. Our model results indicate that drought risks will increase throughout large areas of the EU, with the exception of Northern Europe, Poland and the Baltic States. A 50-year drought, such as the one that occurred at the end of the 20th century, is expected to occur more frequently in the future, approx. every 10 years, across the EU. In terms of 100-year floods, our analysis indicates that the most vulnerable countries are Ireland, the UK, Belgium and The Netherlands. Considering the impact of climate change on floods there are large differences between different climate models. On the other side, future vulnerability to water scarcity is more dependent on socio-economic development than on climate change impacts, i.e. changes in water use are likely to have more impact on water scarcity than changes in water availability resulting from climate change. Using the "Economy First Scenario" (EcF), water scarcity is foreseen to increase dramatically over the next 40 years. Using the "Sustainability Eventually" (SuE) scenarios, water scarcity will be reduced across Europe. In terms of water scarcity, Southern Europe is clearly the most vulnerable region in Europe. Using the low water demand SuE scenario, still more than 60% of the area in Southern Europe will be under severe water stress in summer, even without cooling water demand.

Key messages

- ☐ By comparing different scenarios, it can be concluded that socio-economic scenarios dominate the dynamics of water scarcity. Therefore, adaptation should not be discussed in isolation.
- ☐ Even a substantial decrease in water withdrawals would not prevent water scarcity in some regions. This is apparent during the summer season.
- ☐ Decreasing water availability exacerbates water stress, especially in Southern Europe.
- ☐ In Southern Europe, hotspots of vulnerability to water scarcity mainly occur in areas with intensive irrigation. Increasing irrigation efficiency reduces irrigation water withdrawals to some degree. However, technological changes will not be sufficient to save this region from water stress. A more profound change of agricultural practices is needed.
- ☐ Water withdrawals for cooling purposes are currently high in Western and Eastern Europe and will remain so in the future (EcF scenario). However, the energy sector has the highest potential to reduce water withdrawals through technological improvements; probably with the effect of increasing water consumption. Hence, it is important either to reduce the energy demand (increasing energy efficiency, behavioural change) or to decrease thermal electricity production (SuE scenario).
- ☐ The hydropower sector is vulnerable to climate change impacts, leading to potential losses in hydropower generation; this is particularly apparent in Southern and Western Europe.
- ☐ The manufacturing sector plays a minor role in terms of water use on the European scale but may be important in a number of intensive industrialized river basins. However, problems might occur due to insufficient dilution of pollutants in some stretches of rivers.
- ☐ The ensemble of hydrological model runs proves to be highly robust in Eastern, Northern and Southern Europe. High variability occurs in Western Europe.
- ☐ Extreme events are strongly impacted by climate change. For droughts, the ensemble

agrees remarkably well in Southern and South-East Europe. Nevertheless, uncertainties in spatial variability remain high in the case of floods.

- Environmental flows, which are important for the healthy maintenance of aquatic ecosystems, are threatened by climate change impacts and socio-economic developments. Although a Good Ecological Status is required by the WFD, RBMPs currently do not consider climate change impacts sufficiently. Mandatory water abstraction schemes are needed during low flow periods to protect ecosystems.
- When developing vulnerability assessments, cross-sectoral aspects should be considered as they influence the overall vulnerability of a River Basin/Region.
- Many of the transboundary river basins are expected to be in the severe water stress class in 2050. Competition for the scarce water resources could be an on-going source of tension between nations.

4 Result from the assessment of adaptation options

4.1 Introduction

Even with the most aggressive mitigation measures, the world is 'committed' to some degree of warming as a consequence of the current and past greenhouse gas (GHG) emissions (Solomon *et al.* 2010). Adaptation to climate change is thus a necessary accompaniment to the efforts to mitigate climate change by curbing the emissions of GHG. The climate adaptation efforts need to respond to a specific pattern of vulnerabilities resulting from either anthropogenic or environmental origin that vary across space and time. The vulnerability may be a result of unequal exposure to climate risk, human-made sensitivity to the given amplitude of perturbance, or insufficient coping or adaptive capacity. In previous chapters, we have discussed extensively the vulnerability indicators identified and analyzed for the scope of this project.

This chapter provides an overview about the adaptation measures identified and analyzed throughout the lifetime of the project, and the results of the assessment exercise conducted according to the framework outlined in chapter 2 of this document. We have identified, categorized, and collected knowledge about a high number of adaptation measures (M) and support actions (SA)[17].

The M/SA have been assembled into groups according to the mechanism through which the adaptation action is delivered (Table 7), thematic consistency, and the EU policies through which the adaptation action can be promoted or reinforced. The initial set of 95 specific M/SA has been organized in 35 factsheets, each providing a detailed explanation of the relative M/SA and complemented with supplementary information. The inventory database contains information fully consistent with the factsheets. Recall that the measures are technical, hydro-technical and land-use based measures meant to reduce the climate risk (see for more information). Supporting actions on the other hand are policy and regulatory actions, administrative controls, financial instruments, planning instruments, and educational activities. Sixteen out of the thirty-five factsheets explain in depth the supporting actions, which, in most cases, can and should be encouraged at the EU level. The SA foster climate adaptation action through improved knowledge management; risk prevention/management; economic and financial incentives and disincentives; improved management and planning practices; land use management; and regulatory decisions (Table 7) facilitating the implementation of the adaptation measures. The remaining nineteen factsheets address measures that are to be adopted preferably at the river basin scale. They include structural interventions (including green infrastructure), modified management practices across the water using sectors, and land use change and management.

Table 7 Sub-category of the climate adaptation measures (M) and supporting actions (SA) (see Table 9)

Supporting action	Sub-category
	Risk prevention/management
	Knowledge management, Awareness/information
	Changing management or practices
	Economic and financial instruments
	Land use management
	Regulatory actions

[17] For definition of measures and support actions, please see chapter 2.2.3.1

Measures
Land use change and management
Modification of production and/or management practices
Structural interventions and infrastructures (technical and green)

4.2 Summary of the assessment of measures and support actions

This section summarizes the links between the multiple vulnerabilities on the one hand and the climate adaptation actions on the other hand. Furthermore, we explain how the adaptation actions have been assessed. For an explanation of the assessment criteria please see chapter 2.2.3.2 of this document.

Initially, we have compiled a list of 95 individual and detailed adaptation measures (M) and supporting actions (SA). These M/SA have been subjected to an expert and stakeholder review and assessment, following the procedure described in chapter 2 of this document. During the second stakeholder workshop (Budapest, 30-31 March 2011, see chapter 2.2.3.2), the expert opinions of more than one hundred experts and stakeholders from government, governmental agencies, NGO and research institutes have been collected and analyzed. Some 30 adaptation actions have been subjected to a detailed assessment, including a whole range of assessment criteria (see chapter 2.2.3.2). The remaining 65 measures and supporting actions were subjected to a fast-track assessment using only two criteria: urgency/ priority for adaptation and EU relevance.

Following the suggestions expressed by experts and reviewers, the initial 95 individual M/SA have been aggregated in a form of 35 measures, which are addressed in the inventory and in the factsheets, each focusing a group of similar technical measures or supporting actions. The factsheets assemble knowledge gained from the IAF, literature review, and stakeholder/expert consultations. The factsheets are fully consistent with the inventory of adaptation measures (Annex 7) but provide additional information. Small differences between inventory and factsheets (e.g. the use of links) are due to the format of the respective final product/deliverable. The inventory provides information of a more quantitative nature, describing for instance the existence of a link, whereas the factsheets provide an analysis of these links.

Table 8 below describes the structure of the factsheets. The first part of a factsheet includes descriptive information and a categorization of the M/SA (category, sub-category, climate threat, link to vulnerability). The second part contains the assessment results. A quantitative assessment using the IFA (see example below) and a qualitative assessment were compiled for all measures based on the literature review, including costs where information was available. Other assessment criteria have been addressed based on expert knowledge and judgment. The third and last part contains information relevant for implementation. The relevance of different policy areas is addressed in each factsheet, focusing on the EU policies that can boost the implementation of the respective measure or supporting action. The table below (Table 8) shows cross references between the factsheets, inventory and this report.

Unlike a factsheet, the *inventory* of adaptation action contains a qualitative expression of the degree to which an adaptation action is suitable and appropriate for the identified **Climate Threat**, **Sectors affected**, and **Administrative level.** Again, this assessment is based on a literature review and expert evaluation.

Table 8 Attributes and data sources of categories selected from the factsheets.

Category	Attributes	Source
Measure category	(Technical Measure/Support Action)	See chapter 2.2.3
Measure sub-category	(Risk prevention / Awareness, Information / Changing management or practices /Land use change and management / Economic and financial/ Technical measure related to technical infrastructure / Technical measure related to green infrastructure / Management plans / Regulatory)	See chapter 2.2.3.1
Climate threat	Not enough water (scarcity & droughts), Too much water (flooding, sea level rise, coastal erosion), Deteriorating water quality & biodiversity, Snow	See chapter 2.1.2
Link to vulnerability	Vulnerability assessment of the measure regarding driver, pressure, state and impact	See chapter 3
Expert and stakeholder judgment	Assessment of measure regarding urgency & priority, conditions of decision making, side effects, efficiency	Stakeholder Workshop (ClimWatAdapt, 30-31/03/2011); REFRESH project
Quantitative results from using the IAF	Modelling results	Modelling results
Qualitative assessment based on literature review	Assessment of measure on literature basis	Literature review
Costs	Cost of implementing the measure (may vary considerably from one example to the other)	Literature review
EU Policies concerned and institutional process	Relevant policies in the following policy areas: Water, Agriculture, Biodiversity, Infrastructure and buildings, Renewables, Tourism, Coastal areas, Sustainable development, Cross-cutting	Literature review / Expert Evaluation
Character of measure	(Preventing / Preparatory / Reactive / Recovery)	See chapter 2.2.3
Sector(s) affected	(Water management, Agriculture, Energy, Industry, Forestry, Navigation, Domestic/Tourism)	
Time to implement	(Short term (5-25 yr) / mid- to long term (25+ yr))	Literature review / Expert Evaluation
Administration level	(National, Regional / River basin, Municipality/company)	Literature review / Expert Evaluation
Examples	Provided if available	Literature review
Case studies	Provided if available	Literature review
References		Literature review
Related to REFRESH-Measure		REFRESH project

For the purpose of illustration, let us consider the category **Climate Threat.** The 35 adaptation measures that make up the inventory have different potential for delivering adaptation to the different impacts of climate change ("climate threats"). For example, the Support Action SA13, "Water Conservation and Abstraction Plans", will have strong relevance as an adaptation measure addressing *Not enough water (water scarcity & droughts)*, will only have a weak relevance for the climate threat *Deteriorating water quality and biodiversity*, and will have no relevant effect regarding the climate threats *Too much water (flooding, sea level rise, coastal erosion)* and *Snow*.

The **Administrative level** is evaluated as having a ''high'' or ''low importance''. These evaluations describe whether an administration level has an especially important relation to the measure. Administration levels with a subordinated relevance are stated as "low importance".

Some current adaptation measures are the result of the merging of various sub-measures, originally evaluated separately at the stakeholder workshop. The current inventory shows the combined impact of the whole adaptation measure. This implies, for instance, that an adaptation measure showing a weak link to a climate threat can have a sub-measure, which presents a strong link to this same climate threat. When an adaptation measure presents no link to a certain climate threat, possible sub-measures will also present no relevant link to this particular climate threat.

For the categories **Category of measure**, **Time to implement**, **Policy areas**, and **Link to Vulnerability,** only the existence of a link is indicated, without an indication of its strength.

The **Link to vulnerability** was assessed by looking at the connection, if one can be traced, between the measure and the associated drivers, pressures, state and impact vulnerability indicators. In the case of measures that resulted from the merging of various sub-measures, the existence of a link for one sub-measure was consequently maintained for the merged measure.

As discussed in previous sections, the **Quantitative assessment** was carried out for some adaptation actions under this project. The results are maps which indicate the relevance of these measures for the different EU countries.

The initial **Stakeholder and expert evaluation** (carried out during the Budapest Stakeholder Workshop in Budapest, March 31st, 2011) evaluated the categories on a scale of 1 to 5 (see Annex 12b). This scale was simplified to the following values: "low" (1-2.4), "middle" (2.5-3.4) and "high" (3.5-5). It was considered that providing numbers gave an impression of exactness and accuracy that was not intended to be conveyed, and that could be misleading.

a. *Urgency and priority* was evaluated for the initial list of 95 adaptation measures. Many of these measures were merged to provide the current list of 35 relevant adaptation measures (a few individual measures from the initial list were cut). The urgency and priority of merged measures was estimated by merging and calculating the average of the evaluations of the individual measures.

b. All other categories (the different sub-categories under *Conditions for decision-making*, *Performance under uncertainty*, *Side-effects*, and *Efficiency*) were only evaluated for a "short list" of 30 measures, of the initial list of 95. This evaluation is presented in the inventory in the following manner:

   When a current measure in the inventory was directly evaluated at the stakeholder workshop, or all the sub-measures which were merged to produce it were evaluated as part of the short list, the inventory shows a statement "high", "middle", or "low" (without brackets).

   When the current measure was only evaluated partially, because the evaluated measures were merged with others that were not included in the short-list evaluation at the workshop:

   - If half or more of the sub-measures were evaluated, the statement "high", "middle", or "low" is placed in brackets.

- If less than half of the sub-measures were evaluated, or if the measure was not evaluated at all, there is no statement for this aspect of the measure in the inventory.

The qualitative assessment is based on literature reviews and supplements the other results. The text is provided in the factsheet. **Examples** and **Case studies** from literature were selected to illustrate the measures. Furthermore, the results from the **REFRESH**-database were incorporated, linking with corresponding measures.

4.2.1 Overview of the assessed measures/support actions

The table below (Table 9) provides a brief overview of the assessed measures:

Table 9 Overview of the assessed measures differentiated into technical measures and supporting actions.

Technical Measures

Measure sub-category	Measure Code	Measure Name	Measure Description
Changing management or practices	M01	Water sensitive agricultural practices	Reduction of the water demand in agriculture by ways different from the irrigation techniques and efficiency.
	M02	Adaptation of Dredging Practices	The measure focuses on the adaptation of dredging practices to changes in erosion and siltation in rivers. Dredging methods or disposal options in use should be modified to ensure implementation with minimum environmental impacts.
	M03	Water sensitive urban design (WSUD)	Water Sensitive Urban Design (WSUD) is an emerging urban development paradigm aimed to minimize hydrological impacts of urban development on environment. In practice, the WSUD integrates storm water, groundwater water supply and wastewater management to protect existing natural features and ecological processes; maintains natural hydrologic behaviour of catchments; protects water quality of surface and ground waters; minimizes demand on the reticulated water supply system; minimizes wastewater discharges to the natural environment; and integrates water into the landscape to enhance visual, social, cultural and ecological values.
	M04	Managing Groundwater Recharge To Reduce Water Scarcity And Saltwater Intrusion Risk	MAR is a technique used in arid and semi-arid regions to recharge aquifers in a controlled way so that excess water can then be used later for water supply or environmental protection. A way of mitigating the threat of saltwater intrusion is systematically maintaining higher water table levels for groundwater, thus reducing the hydrological gradient from seawater.
	M05	Reducing freshwater demand for industrial cooling	Using recycled water for industrial cooling reduces freshwater demand, which will make power plants less susceptible to climate-induced changes to water availability.

Land use change and management	M06	Improved water retention	Increasing the water retention capability in rural areas aims either to increase the natural water retention capacity of a landscape or to increase the water storage capacity with man-made structures. Natural water retention can be improved by techniques like creating wetlands and increasing soil cover. Additional water storage capacity can be achieved with structures such as off-stream polders or flood retardation ponds. Winter water storage reservoirs reduce abstraction during the summer, increase flood storage capacity, and benefit wildlife. Compensation may facilitate implementation and operation.
	M07	Establishing wooded riparian areas	Vegetated and unfertilized buffer zones alongside watercourses act as a shield against overland flow from agricultural fields and reduce run-off from reaching the watercourse, thus decreasing erosion and the movement of pollutants into watercourses. Prevention of sea level rise and increased flooding, reduce potential for erosion in shore zones and lessen the impact on vegetation to worsen impacts of inundation.
Technical measures related to technical infrastructure	M08	Adaptation of existing dikes	The design of existing dikes can be modified to fulfil different purposes. Re-enforcing dikes and dams can increase their stability and resistance against dike breaching, e.g. by strengthening the inner core of the dike or improving the characteristics of the dike's surface that contribute to the overall stability of the dike. Dikes can also be re-enforced by heightening, broadening or by adding spatial components. Dike design can have the aim of allowing water in certain conditions to surpass them without breaching. This is usually achieved by strengthening the inner wall of the dike and by broadening the dike. Surplus water will be pumped away. Reallocation of dikes (spacing) will create a wider floodplain with an enclosed retention area.
	M09	Soft coastal defences	A new paradigm of giving space to water and using natural landscapes to aid coastal defence infrastructure is emerging. Example measures are: • Allowing the sea to invade former dune slacks in certain sections of the coast. • The strategic construction of reefs along a coastline to reduce the strength of waves and, thus, the erosion of the coastline by the sea. • Applying sand suppletion to maintain the amount of sand present in the “foundation” of the coast (beaches and underwater in the shallow bank zone). • Managed retreat of coastal defences. • Widening protection structures instead of making them higher and stronger. Introduction figure on alternatives for traditional coastal defence engineering solutions. (source: http://www.comcoast.org/)

	M10	Safe Havens In Inland Waters And Additional Temporary Moorings	Alter existing havens or construct new ones to address safety issues related to the increased frequency of strong stream conditions, floods and low water levels. Additional moorings address safety issues concerning the increased frequency of strong stream conditions as a result of high water levels or of periods with low precipitation and low water levels.
	M11	Leakage control in water distribution system	Controlling water leakage from extensive and aging municipal and agricultural water distribution systems.
	M12	Enhancing or increasing the water storage capacity of reservoirs	Reservoirs can contribute to redistributing available water resources in volume, time and space. Water that is stored during high flows can be distributed in dry periods to supply water for additional irrigation can make a region less vulnerable to droughts. At the same time, large reservoirs that have the capacity to store part of the high flows and release them during lower flow periods reduce peak flows and can prevent a region from flooding.
	M13	Recycling of treated water	Recycling of water for non-drinking purposes. Domestic water from baths, showers and sinks (grey water) can be re-used for toilet flushing, laundry/dish washing and garden and irrigation. Waste water can be used for irrigation, glasshouses; industrial processes can be designed to use water in closed circuits.
	M14	Desalination	Desalination is the process of removing salt from water to make it useable for a range of 'fit for use' purposes including drinking. Advancing technologies could render desalination more energy efficient and reduce operating costs. It could become a viable and weather independent alternative for urban drinking and non-drinking water supplies in the future.
	M15	Inter-basin water transfer	Shift of potentially large water volumes from a water abundant basin to areas outside of the donor basin where water resources endowment is low or very variable through year, limiting so economic growth.
	M16	Improving Irrigation Efficiency	A shift from gravity irrigation to modern pressurized systems (e.g. drip and sprinkler irrigation) and improved conveyance efficiency provide an opportunity for reduced water demand in irrigation.
Technical measures related to green infrastructure	M17	Water Sensitive Forest Management	Forest management measures can increase water yield, regulate water flow, and reduce drought stress for a forest e.g. during current and future low-flow conditions. Measures that address existing forests include (1) reduced density of stand stocking; (2) shorter length of the cutting cycles; (3) planting hardwood species; (4) regeneration from seedlings rather than sprouts (5). Afforestation, in particular near watercourses, brings benefits for the regulation of water flow and the maintenance of water quality, reducing the intensity of floods and the severity of droughts. The digital classification of forest sites can be used for analysis, consultation, and developing adaptation recommendations.

	M18	River restoration	The measure focuses on the increase of flow capacity of the river system during flood events, and/or the reduction of the speed of water flow. This also helps to increase habitat quality and groundwater recharge.
	M19	Sustainable Drainage Systems (SUDS)	Drainage systems can be improved by shifting to Sustainable Drainage Systems (SUDS), whose installation mimics natural drainage patterns to ease surface water run-off, encourage the recharging of groundwater, provide significant amenity and wildlife enhancements, and protect water quality.

Support Actions

Measure sub-category	Measure Code	Measure Name	Measure Description
Risk prevention	SA01	Spatial Decision Support System (sDSS)	A spatial decision support system (sDSS) can handle key tasks of water management such as administration, crisis management, and planning.
	SA02	Development and planning based on climate risk assessments	The Climate Risk assessment aims to assist authorities, investors, and planners in integrating the latest information on climate change impacts, possible adaptation response options, and investment selection criteria that take climate change into account into planning activities.
	SA03	Disaster risk reduction – emergency management	Emergency management comprises all activities to protect human life, property, cultural heritage and environment during hazard strikes, typically involving emergency response teams and facilities, and coordination mechanisms laid down in emergency plans.
Awareness/information	SA04	Information and knowledge management	Strategic monitoring on specific indicators and reporting activities provide baseline information that may indicate the inception of impacts. Early warning systems help decision makers and private individuals at all levels reduce the impacts on extreme climate events. The information should be reliable and timely available with a strong focus on the people exposed to risk in order to increase resource use efficiency. Information can be obtained from improved flood predictions and weather forecasts, from the state of waters and aquatic ecosystems in a region, from weather radar, and from satellites observations and can be collected and shared through related networks.
	SA05	Awareness and Capacity Building	This measure encompasses actions that promote awareness for the altered conditions under Climate Change. It strengthens the capacity of stakeholders affected by weather extremes from civil society groups and local and national governments to better address the impacts of climate change through their own involvement. Awareness and capacity building can address groups of people in a region

			affected by a particular climate change threat, groups of stakeholders, the general public, etc. The ultimate aim is to achieve behavioural changes. Actions which share information about ongoing impact assessments and adaptation activities will lead a wider range of organizations to think about climate-related problems.
Changing management or practices	SA06	Adapt the management of water levels in lakes, discharges in rivers, and inundation of wetlands to environmental needs	Human developments significantly alter water levels in lakes and wetlands and river discharge and this may cause significant environmental damage due to floods, water shortages, the accumulation of nutrients and toxins, and changes of habitats. Water level controls are management practices that may be the most socio-economically and environmentally balanced solution to protect threatened ecosystems and ecoservices. This management approach should be adapted on the basis of the best available information on climate variability and change and their impact on freshwater ecosystems in order to deal adequately with the increased flood and drought risks and improve the status of these ecosystems. In this process, substantial involvement of stakeholders in the formulation of the problems and their solutions should be envisaged, avoiding impasses in decision making, making water management as a guiding principle in spatial planning.
Economic and financial	SA07	Risk pooling and insurance	Risk pooling and insurance is the typical risk sharing/alleviating instrument. The insured pays a premium to the insurer that covers the risks regarding one or more variables and indemnifies only after the assessment of losses caused by climate change.
	SA08	Funding provision and subsidies	Provision of funding and subsidies (on products and practices) can spur behavioural change through incentives or disincentives, change conditions to enable economic transactions, or reduce risk. Rather than specifying a particular type of behaviour that the regulatee has to comply with, economic instruments create the economic incentives (e.g. price signals) to support drought and flood management.
Land use change and management	SA09	Transboundary flood management through spatial planning	Transboundary flood management projects bring representatives together from regional and national authorities, water boards, and other organizations. The goal is to decrease the impacts of floods through good spatial planning.
	SA10	Land use planning	Land use planning can be used in the case of droughts, scarcity, and flooding and can significantly affect the hydrological cycle of a region. Land use planning can influence water abstraction by particular sectors. Various measures, such as afforestation and sustaining wetlands, can reduce flood risk and make regions more resilient against droughts. Land use planning can also be used to reduce flood risks.
Management plans	SA11	Shoreline Management	Shoreline management has been introduced into coastal management practices since the 70ies of the past century (see for instance Washington State Shoreline Management Act adopted in 1971) giving

			way to holistic and sustainable practices of beach and shoreline management, including control of erosive processes and coastal flooding. Basic principles of shoreline management acquire an increased importance because of prospective of raising sea level rise under changing climatic conditions.
	SA12	Drought Management	Drought management and water conservation plans are planning instruments that contain measures aimed at the temporary and permanent reduction of water consumption or use. They help to identify and reduce societal vulnerability to drought by improving drought preparedness and reducing drought impacts. Drought and water scarcity knowledge systems capture, manage, analyze and display relevant meteorological, hydrological, agro-technical, social, and other data. This information can help to better forecast drought events and their associated impacts.
	SA13	Water conservation and abstraction plans	Water conservation and abstraction plans (WCAP) are multi-year plans that detail how the authorities responsible for granting water abstraction licenses will manage water resources at a catchment scale. The WCAP work by assessing the availability of water resources on a scientific basis and then taking stock of all water needs including the water demand of ecosystems in the future. The aim is to provide a framework for a licensing strategy which aids the sustainable management of water resources on a catchment scale. This can include consumptive (e.g. agriculture) and non- consumptive uses (abstraction for cooling purposes). Licenses are time-limited, requiring that WCAP are regularly updated and progressively integrated in other strategies and programs related to water. It is also important to elaborate a communication plan devoted to an efficient use of water consistent and coordinated with the organizations working on the issue.
	SA14	Implementation of a cross-sectoral adaptation and risk aversion strategy	The measure is aimed to establish national, state-wide or regional aversion strategy for all sectors that are related to climate change adaptation.
Regulatory	SA15	Water saving in building codes	New national standard for sustainable design and construction of new homes, which places strong emphasis on water conservation in households.
	SA16	Compulsory water restrictions and rationing	Water restrictions limit certain uses of water, for example, irrigation of lawns, car washing, filling swimming pools, or hosing down pavement areas. Water rationing includes a regular temporary suspension of water supply or a reduction of pressure below that required for adequate supply under normal conditions. Rationing is associated with equitable distribution of critically limited water supplies in a way that ensures sufficient water is delivered to preserve public health and safety. Both rationing and restriction that may be of a temporal or permanent character.

4.2.2 Summary of the assessment of the measures/factsheets

It is difficult to summarise the body of knowledge created from the results of the assessment exercise that is contained in the factsheets. All assessed measures and supporting actions are deemed pertinent and useful, whereas the urgency and priority of their adoptions depends on the specific pattern of vulnerability that varies across the geographic regions and sectors. In principle, all the measures and supporting actions can be adopted simultaneously and are complementary to one another.

The assessment results of the adaptation measures and supporting actions included in the 35 factsheets are presented in Figure 42 and Figure 43. The figures show the respective results of the full detailed assessment exercise. The assessment is consistent across all assessment criteria as discussed in chapter 2.3 and the expressed judgments are highly correlated. The three supporting actions *Drought Management*, *Awareness and Capacity Building*, and *Information and Knowledge management* received the highest ratings across the assessment criteria. These adaptation actions are worth pursuing independently of the magnitude of future climate change impacts, as they help tackle current vulnerabilities and risk. The measures are relatively easy to implement, provide significant benefits, and have a high benefit cost ratio. On the other hand, the supporting actions *Development and planning based on climate risk assessment*, *Water saving in building codes*, and *Risk pooling and insurance*, although pertinent and legitimate for tackling the future impacts of climate change, were perceived as more difficult to implement and precarious in terms of side-effects, performance, and benefit cost ratio.

			Assessment criteria										
code	type	title	Win-win	No-regrets	Spill-over	Negative	Flexibility	Robustness	Cost benefit	Effectiveness	Feasibility	Combinability	Institutional
031	SA	Drought Management	1	1	1	1	1	1	1	1	1	1	2
005	SA	Awarness and Capacity Building	1	1	1	1	1	1	1	2	1	1	1
004	SA	Information and knowledge management	1	1	1	1	2	1	1	1	1	2	1
003	SA	Disaster risk reduction – emergency management	2	2	2	2	3	2	2	1	2	2	2
011	SA	Adapt management of water levels in lakes, discharges in rivers	2	2	2	3	3	2	3	2	3	2	2
032	SA	Water conservation and abstraction plans	2	2	2	2	1	2	2	2	2	1	1
013	SA	Funding provision and subsidies	2	2	2	2	2	3	2	2	2	2	2
002	SA	Development and planning based on climate risk assessment	3	3	3	2	2	3	2	3	2	3	3
034	SA	Water saving in building codes	3	3	3	3	3	3	3	3	3	3	3
012	SA	Risk pooling and insurance	3	3	3	3	2	2	3	3	3	3	3

Figure 42 Assessment results of selected ten (group of) supporting actions (SA) according to all criteria (for the description of the criteria see chapter 2.2.3.2). The assessment results are displayed as tertiles (3-quantiles) of rank position; the most favourable SAs are highlighted in green (1), and least favourable in red (3).

The assessment results of the measures show a slightly higher variability, which we believe is the result of the different suitability or worthiness of the adaptation actions across the different geographic regions -as assessed during the stakeholder assessment- and the specific pattern of the vulnerabilities, which characterize these regions. Nevertheless, the three highest ranked measures – *River Restoration, Improved Irrigation Efficiency and Improved Water Retention in Rural Areas* – show a high degree of consistency across all assessment criteria.

River restoration embraces a great variety of measures that commonly restore natural functions of rivers that were lost or degraded by human intervention. Many European rivers were modified in past decades to serve only one dominant function. However, one-sided use, disregarding different functions, is no longer an optimal scenario. An integrated approach is viewed as a prerequisite for success. Achieving river restoration implies that apart from the technical and ecological considerations, raising support and creating public awareness are just as essential to obtaining results. There has been increasing interest in Europe in rehabilitation of watercourses and river valley ecosystems. An example is the spatial planning project "Room for the River" in the Netherlands, which includes a number of measures leading to improvement of stream morphology and floodplain restoration. Floods are among the most important weather-related loss events in Europe and can have large economic consequences (see chapter 3.5, Figure 40, Example 2 given below). Taking into consideration that both the recurrence and magnitude of a 100-year flood are expected to increase in 2050, spatial solutions try to take account of long-term developments and risks. However, concerning floods, climate uncertainty plays a major role because a wide range of results from different climate models exists (Annex 10). It becomes apparent that working with uncertainty requires an iterative and flexible approach for implementing adaptation measures.

Improved irrigation efficiency is of particular relevance in Southern Europe where irrigation is already an essential ingredient of agricultural production. The term 'efficiency' is used differently and sometimes, wrongly implies that the water that is not consumed in the transpiration is 'lost'. In truth, the portion of water applied to the field but not consumed through evapotranspiration – the return flow – remains available for use downstream (but is of reduced water quality). A shift from gravity irrigation to modern pressurized systems (e.g. drip and sprinkler irrigation) and improved conveyance efficiency, provides an opportunity for reduced water demand in irrigation, but at a high price. Increased irrigation efficiency does not always translate to reduced water consumption, as the extension of the irrigated land tends to increase as a consequence of higher application efficiency. However, the vulnerability assessment carried out in chapter 3.3 showed that an increase in irrigation efficiency may not lead to a reduction of water stress below a certain threshold (see chapter 3.3, Figure 29).

Increased water retention capability in rural areas can either aim to increase the natural water retention capacity of a landscape, or increase the water storage capacity with man-made structures. Natural water retention can be improved by techniques such as creating wetlands and increasing soil cover and soil structure. Additional water storage capacity can be achieved with structures such as off-stream polders or flood retardation ponds. Winter water storage reservoirs reduce abstraction during the summer, increase flood storage capacity, and benefit wildlife.

The measures that received least support from the expert and stakeholders include *Enhancing or Increasing Water Storage Capacity of Reservoirs*, *Desalination*, and *Water Sensitive Forest Management*. These measures show consistent evaluation results across the assessment criteria. Generally, they are associated with higher implementation costs and are less adaptable once put in place. We discuss desalination later in this document among the measures which should be handled with care. Desalination may be legitimate if no other adaptation measures are feasible, however we highlight the high energy consumption, negative environmental effects, and low social acceptance as the downsides.

code	type	title	Win-win	No-regrets	Spill-over	Negative	Flexibility	Robustness	Cost benefit	Effectiveness	Feasibility	Combinability	Institutional
			Assessment criteria										
028	M	River restoration	1	1	1	2	2	1	2	2	2	1	1
026	M	Improving Irrigation Efficiency	1	1	2	1	1	1	1	1	1	2	2
014	M	Improved water retention in rural areas	1	2	1	1	1	1	1	2	2	1	3
008	M	Water sensitive urban design (WSUD)	2	2	2	1	2	2	1	2	2	2	2
023	M	Reuse of treated water	2	1	1	2	2	2	2	1	2	2	3
015	M	Establishing wooded riparian areas	2	2	2	2	1	2	2	3	1	1	1
009	M	Managing Groundwater Recharge To Reduce Water Scarcity	2	2	2	2		2	2	2	1	2	1
010	M	Reducing freshwater demand for industrial cooling	2	2	2	2	2	2	2	1	2	2	2
022	M	Enhancing or increasing water storage capacity of reservoirs	3	3	3	3	3	3	3	2	3	3	2
024	M	Desalination	3	3	3	3	3	3	3	3	3	3	3
027	M	Water Sensitive Forest Management	3	3	3	3	3	3	3	3	3	3	2

Figure 43 Assessment results of selected eleven (group of) measures (M) according to all criteria (for the description of the criteria see chapter 2.2.3.2). The assessment results are displayed as tertiles (3-quantiles) of rank position; the most favourable Ms are highlighted in green (1), and least favourable in red (3).

Figure 44 and Figure 45, below, show the results of the fast-track assessment of all M/SA according to only two assessment criteria: *priority and urgency* for adoption, and *relevancy for EU* concerted action. The correlation between the two criteria is weaker than the correlation between the assessment criteria in the detailed assessment exercise. The supporting actions assigned both high priority/urgency and EU relevance were *Land Use Planning* and *Information and Knowledge Management*.

Oddly, the *Disaster Risk Reduction* (improved management of natural hazard under current climate conditions), although perceived as an urgent action with highest priority, was attributed a lower EU relevancy. EU action in the disaster risk reduction has already received high attention resulting from a striking increase in the losses caused by natural, particularly hydro-meteorological, disasters. We believe that the assessment results reflect this fact. Every year, large areas of Europe are hit by droughts and/or floods, directly or indirectly affecting many communities and economic sectors. The EU's efforts in disaster risk reduction intensified with the EC Communication on Disaster Response Capacity. This Communication highlighted the need for stepping up the Community's capacity and in responding to disasters, both within and outside the EU. To do so, the EC proposed several tangible means for a better coordination of various EU/Community policies, instruments, services, and players (at national, European, and international levels). While the Communication focuses on the response to disasters, it acknowledges that a comprehensive approach to disaster management is needed comprising risk assessment, forecast, prevention, preparedness, and mitigation.

code	type	title	Urgency/priority	EU relevancy
016	SA	Transboundary flood management through spatial planning	1	2
017	SA	Land use planning	1	1
004	SA	Information and knowledge management	1	1
003	SA	Disaster risk reduction – emergency management	1	3
030	SA	Shoreline Management	1	2
005	SA	Awarness and Capacity Building	2	2
031	SA	Drought Management	2	1
033	SA	Implementation of cross-sectoral adaptation and risk aversion strategy	2	2
002	SA	Development and planning based on climate risk assessment	2	2
001	SA	Spatial Decision Support System (sDSS)	2	1
011	SA	Adapt management of water levels in lakes, discharges in rivers	2	nd
035	SA	Compulsory water restrictions and rationing	3	3
013	SA	Funding provision and subsidies	3	nd
032	SA	Water conservation and abstraction plans	3	3
012	SA	Risk pooling and insurance	3	3
034	SA	Water saving in building codes	3	nd

Figure 44 The fast track assessment results of all sixteen (group of) supporting actions (SA). The assessment results are displayed as tertiles (3-quantiles) of rank position; the most favourable SAs are highlighted in green (1), and least favourable in red (3). (nd - no data, no replies obtained from stakeholders).

Transboundary flood management is an issue of particular relevance for Central and Northern Europe, home to large transboundary river systems such as Danube, Rhine, Tisza, and Elbe. In Southern Europe, river basins shared between Spain and Portugal are affected and future problems may arise due to reduced river discharge. In Europe, there are 71 international river basins, accounting for 54% of the total area. International cooperation in river basins with respect to climate change adaptation is very important, as measures in one country could have negative effects in another or country-by-country measures could be less effective or more expensive than measures designed to be optimized over the full river basin. Information related to the different aspects of vulnerability of transboundary basins is provided in chapter 3.6.1).

The *national adaptation strategies* are an effective tool to develop state-wide climate adaptation policy and to check effectiveness across sectors. Cross-sectoral aspects that should be considered are described in chapter 3.6.2. As such, these strategies are encouraged by the United Nations Framework Convention on Climate Change. National strategies are often based on the principles of cooperation, risk aversion, integration and sustainability. Although general objectives differ between Member States, common goals can be recognized: (i) identification and communication of dangers and risks, (ii) awareness creation; (iii) mainstreaming the climate change adaptation in private, business, and public planning activities; and (iv) assessment and planned implementation of adaptation measures. In Europe, some countries, including Denmark, Finland, Germany, France, Hungary, Netherlands, the United Kingdom, Sweden and Spain, have already adopted the strategies. Other should follow their lead.

code	type	title	Urgency/priority	EU relevancy
026	M	Improving Irrigation Efficiency	1	nd
028	M	River restoration	1	nd
029	M	Sustainable Drainage Systems (SUDS)	1	1
009	M	Managing Groundwater Recharge To Reduce Water Scarcity	1	2
025	M	Interbasin water transfer	1	2
010	M	Reducing freshwater demand for industrial cooling	2	nd
021	M	Leakage control in water distribution system	2	1
014	M	Improved water retention in rural areas	2	2
008	M	Water sensitive urban design (WSUD)	2	1
023	M	Reuse of treated water	2	nd
019	M	Soft coastal defenses	2	3
006	M	Water sensitive agricultural practices	2	1
022	M	Enhancing or increasing water storage capacity of reservoirs	2	nd
018	M	Adaptation existing dikes	3	3
015	M	Establishing wooded riparian areas	3	3
027	M	Water Sensitive Forest Management	3	2
007	M	Adaptation Of Dredging Practice	3	3
024	M	Desalination	3	nd
020	M	Safe Havens In Inland Waters And Additional Temporary Moorings	nd	nd

Figure 45 The fast track assessment results of all nineteen (group of) measures (M). The assessment results are displayed as tertiles (3-quantiles) of rank position; the most favourable M are highlighted in green (1), and least favourable in red (3). (nd - no data, no replies obtained from stakeholders).

The fast track assessment of the adaptation measures, particularly with respect to the EU Relevancy criterion, is compromised by the gaps in the assessment sheets, a high number of which were returned unanswered. Still, high interest for EU action is recognisable in case of *Sustainable Drainage Systems*, *Leakage Control*, *Water Sensitive Urban Design*, and *Water Sensitive Agricultural Practices*.

Leakage reduction is one of the main challenges in both municipal and agricultural water distribution systems and a worthwhile undertaking, considering the potential to reduce abstraction for public water supply is up to 50%. Minimum night flows in urban water distribution networks cause a higher leakage because pressures in the network are usually higher at night than during the daytime. Promising approaches for reducing water loss due to leakage are localization methods of leakage based on pressure sensitivity analysis and automatic pressure control using new management practices.

Inter-basin water transfer received relatively high marks with respect to the EU Action. The transfers redistribute the water across geographic space, from where it is abundant to places where economic and social development is obstructed by low natural availability of water or distribution in time. As the technological and engineering options of water transfer have become more sophisticated, large volumes of water have been conveyed from one basin to another. This practice is called inter-basin water transfer or trans-basin diversion. Despite the potential for large economic benefits in the receiving basin, inter-basin water transfers are controversial on environmental and social grounds. Inter-basin water transfers have contributed, among other factors, to shaping unsustainable water management practice. Therefore, despite high priority and EU relevance assigned to this measure by the stakeholders, we recommend treating the respective policies with care.

Managed aquifer recharge is a technique used in arid and semi-arid regions to replenish aquifers in a controlled way so that excess water can then be used later for water supply or environmental protection. At the same time, the measure can be applied for mitigation of risk of saltwater intrusion, by reducing the hydrological gradient from seawater. The flow path of the percolating water together with mechanical and chemical filtering processes, and a considerable travelling and residence time, provides an effective filtering mechanism so that the extracted water generally has a high quality. Groundwater recharge does not face losses due to evaporation, as opposed to other methods that store water on land surfaces, a particularly important feature in hot and dry climates. Groundwater recharge also maintains a higher groundwater level that serves agriculture as well as natural vegetation and ecosystem functions. Risks connected to groundwater recharge are predominantly related to the recharge of treated wastewater and uncontrolled use of groundwater.

Reduction of freshwater demand for cooling purposes can be achieved by different ways including: (i) using domestic wastewater, sea water, or brackish groundwater instead of freshwater; (ii) using cooling technologies that require less or no water; (iii) shifting to renewable energy technologies that do not need water for cooling such as wind and solar electric; (iv) introducing technologies to condense evaporation from cooling towers and to capture and re-use the water. Only a small part of the water used in the energy sector is actually 'consumed', the rest is returned to the source, usually with altered physical and chemical properties (thermal pollution). Close-looped evaporative cooling systems have far lower requirements on water withdrawal but consume up to twice as much water as open-loop cooling systems. A greater deployment of dry cooling – plants with cooling towers cooled by air – can reduce both water demand and plant efficiency; yearly plant output can be reduced by as much as 2 per cent compared to evaporative closed-loop cooling. This also means that more fuel is needed to deliver the current energy supply and as a result, more emissions are released. The comparison of the EcF and SuE scenarios showed that a shift in cooling water systems substantially reduces cooling water requirements (chapter 3.3, Figure 30).

Besides the summary of the assessment above and the full information for all measures assessed in Annex 9, a short summary of a full assessment is given below in order to demonstrate the IAF. Currently, it is impossible to quantitatively evaluate the measures in a comprehensive way. However, we used the tools available to the consortium to perform a partial analysis by. evaluating the effectiveness of some groups of measures. In this sense, we carried-out model simulations with (i) WaterGAP to modelling the effectiveness of some selected measures, mainly related to the demand-side and (ii) ICES to modelling the economic effects of a group of measures related to floods.

Example 1: Model simulations using WaterGAP

WaterGAP has been used to carry out model simulations considering selected adaptation measures. The selected measures address the water withdrawal side in terms of changing technologies and efficiency rates as well as the water supply side, in which desalination and wastewater reuse play a role. The implementation of adaptation measures is specific to local planning and therefore difficult to address from an EU-scale modelling perspective. While working on the assessment, it became clear that the assumptions made on the EU level would be too general, as different measures with varying targets cannot be compared. In order to provide close to realistic information used by policymakers and stakeholders, we performed an assessment that can be used to estimate the potential effectiveness of adaptation measures, i.e. information with regard to what can be done and what can be achieved. Nevertheless, the selected measures addressed by modelling are included in the fact sheets and listed below:

- Reducing freshwater demand for industrial cooling
- Improving irrigation efficiency
- Best management practices, efficient use of irrigation systems
- Water saving in building codes
- Water conservation plans
- Catchment abstraction management strategies (CAMS)
- Water restrictions and consumption cuts

- Desalinisation
- Recycling of treated water

Methodology

Overall, the modelled assessment of adaptation measures aims to provide EU-level information on water saving efforts from both the demand side and the supply side. In this context, we focus on the river basins where water is scarce, i.e. which are under severe water stress in summer (summer WEI > 0.4 (see chapter 3.3, Figure 28). The identification of vulnerable river basins facing water scarcity in the future is described in Annex 10. Based on the vulnerable river basins, the following steps were carried-out:

1) Identification of river basins that do not meet the target under EcF scenario conditions in the 2050s, which means summer WEI > 0.4. Water availability is represented by the ensemble median.
2) Calculation of water saving needed to meet the target.
3) Identification of the sector mainly contributing to the water saving. Here we assume that a sector could save a maximum of 25% (50%) of its water abstraction. If the required water saving cannot be reached by one sector solely an integrated multi-sectoral approach is needed in order to achieve the WEI target. Domestic, manufacturing, thermal electricity production (power), irrigation, and livestock sectors are considered.
4) Identification of the additional amount of water supplied for achievement of the assigned target.

Results

From the water demand perspective, it is necessary to know how much water must be saved in order to reach the assigned target. Figure 46 shows the results in terms of water saving efforts needed to reach the target (WEI ≤ 0.4) in the EcF scenario in summer 2050. The choice of adaptation measures implemented is left to responsible parties, e.g. water managers or policymakers. The left map (Figure 46a) is based on the results that the main sector is able to reduce water withdrawals by a maximum of 25%, the right map (Figure 46b) assumes a sectoral saving potential of 50%, respectively. Within the identified river basins, the livestock sector accounts only for a minimum share of the water withdrawn. Therefore, this sector cannot satisfy the water saving effort solely compared to the other sectors. When considering a maximum saving of 25% per sector, an integrated multi-sectoral approach is needed to prevent a river basin from vulnerability to water scarcity in the future. However, it is obvious from Figure 46a, that in fact in some river basins, the water savings required can be achieved with just one sector. Most water savings are related to irrigation (e.g. France, Spain, Greece, and UK) but manufacturing (Italy), power (France), and domestic (Spain) sectors play also a role. In a second case the maximum saving potential of 50% per sector is assumed. Here, the outcomes are higher compared to the water saving potential of 25%. The reduction of water withdrawals can especially be afforded by savings in the irrigation and thermal electricity production sectors and in smaller river basins, also by the manufacturing and domestic sectors. In approximately half of the vulnerable river basins, an integrated multi-sectoral approach is needed.

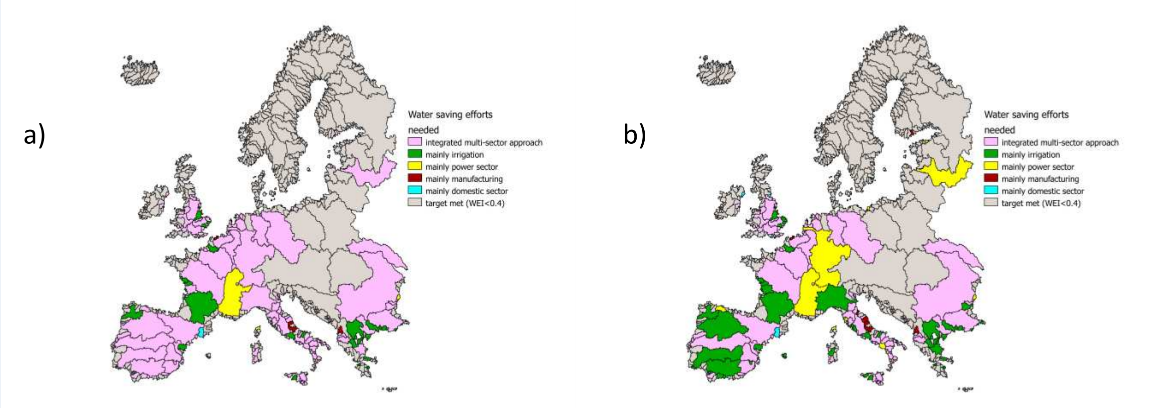


Figure 46 Water saving efforts needed to achieve the target (summer WEI ≤ 0.4) in the EcF scenario in 2050. Maximum saving per sector is assumed to be 25% (a) and 50% (b).

From the water supply side, the information about the amount of water needed to achieve the specified target is important. This information takes into account implementation of measures like desalination, water transfer, or replacing water abstractions by wastewater reuse. Figure 47a highlights the river basins that are expected to be vulnerable to water scarcity in summer 2050 considering the EcF scenario. The right map (Figure 47a) shows the volume that is needed to fill the gap between freshwater resources and water withdrawn, which is highest in a Danube sub-basin located in Bulgaria and Romania, followed by the Rhine basin. In these basins, approximately 8 million m³ of water is needed to maintain the balance in the sense of the required target. On the other hand, in most regions 3 to 5 million m³ is required to close the gap and to meet the assigned target. Figure 47b provides the same information as Figure 47a but in terms of percentages of total water withdrawals. Here it becomes obvious that in many river basins more than 100% of total withdrawals must be made available. This means that these river basins need particular attention as a sustainable water management is not feasible under the given scenario conditions. This applies for most river basins in Southern Europe but also in Western Europe.

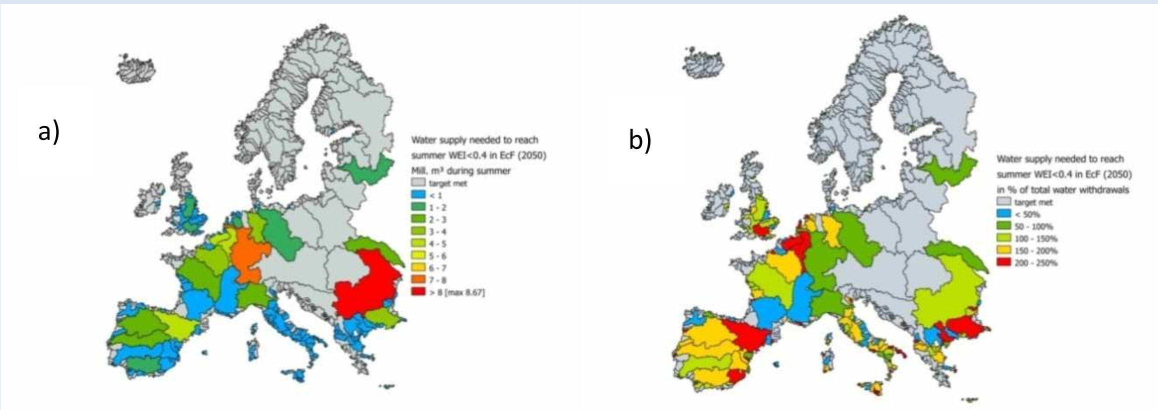


Figure 47 Water supply needed to achieve the target (summer WEI ≤ 0.4) in the EcF scenario in 2050. (a) With regard to the total volume and (b) in percentage of total water abstracted.

Synthesis

Within our analysis, we did not model specific adaptation measures, but instead present the water saving potential and the water supply needed to achieve the assigned target, which is set to summer WEI ≤ 0.4 in the EcF scenario in 2050. In this way, the information can be used for several adaptation measures, and in combination. Although some water-related sectors could capture the savings individually, the assessment shows that in many European river basins an integrated multi-sectoral approach is needed as already required by the WFD. This is of high importance for the future. Regarding supply side measures, it becomes obvious that in Southern and Western European river basins, sustainable management is not likely to be possible and that it will be a big challenge to supply desalinated water or the replace freshwater by treated wastewater.

Example 2: Modelling the impacts of adaption to flooding with ICES

This section compares the direct cost of adaptation to flooding estimated by the LISFLOOD model, along with benefits to derive some insights on benefit cost ratio. Benefits, however, are not measured by direct avoided costs, but by avoided GDP losses estimated with the ICES model. These two concepts are highly different. Specifically, measuring avoided GDP losses by adaptation implies assessing by how much adaptation safeguards countries' ability to produce their yearly stream of goods and services. This concept, the basic output of a CGE analysis, goes well beyond that of avoided property or human life losses as it considers how markets as a system react to impacts. As seen in chapter 3.5, this does not necessarily mean that avoided GDP losses are larger than avoided direct losses, making the current investigation particularly interesting. Table 10 shows GDP losses under "improved protection" and the effectiveness of adaptation (i.e. the percent difference of damages under improved and current protection). These are reported in chapter 3.5. Recall that improved protection assumes that the EU increases protection efforts to keep constant, under changing climate conditions, present safeguard levels protecting against flooding episodes with 1 over 100 years return period.

Table 10 Absolute GDP losses induced by flooding in 2050 ($ Million) under future protection (second and third column) and effectiveness of adaptation. Average across the four SCENES scenarios[18]

	Total cost of flooding Future protection ($ Million)	**Flooding losses due to climate change only Future protection ($ Million)***	**Eff.ness. of adaptation in reducing total cost of flooding (**% of damage reduction wrt current protection) **)**	**Eff.ness. of adaptaton in reducing CC induced cost of flooding (**% of damage reduction wrt current protection)
Austria	-87.1	-2.3	-51	-97
Belgium	-54.1	-6.3	-58	-88
Czech Republic	-59.0	1.5	-35	ns
Denmark	-4.0	0.4	12	ns
Finland	-74.8	-4.6	-59	-95
France	-310.8	1.8	-31	-93
Germany	-114.4	20.8	-18	ns
Greece	-10.0	1.6	-64	ns
Hungary	-115.5	5.1	-23	ns
Ireland	-12.8	1.3	-57	ns
Italy	-243.8	-18.6	-59	-91
Netherlands	-32.8	1.7	-75	ns
Poland	-63.7	11.8	-8	ns
Portugal	-3.8	-2.1	-58	-72
Spain	-66.8	-4.4	-54	-94
Sweden	-37.3	-0.9	-25	-93
United Kingdom	-309.3	-26.0	-64	-95
RoEU	-155.4	-4.8	-43	-95
EU27	-1755.6	-24.2	-50	-94

* In the third column, some entries are positive. Indeed, in some regions, climatic change actually reduces the cost of flooding as extreme conditions can change in ways that make flooding episodes less frequent.

[18] Extended results, separated for each SCENES scenario and the sectoral detail are available upon request to authors.

Adaptation is confirmed to be very effective in reducing negative impacts of flooding on GDP and not only on direct costs. By keeping protection at a level able to cope with flood events with a 100 year return period along the century, EU countries could decrease GDP losses linked to climate change-induced flooding by 72% in Portugal and by 97% in Austria in 2050. In absolute terms, this would mean avoiding an average yearly damage ranging from $ 5 million in Greece to $ 444 million in the UK. Improving adaptation against climate change-induced flooding also reduces the damages of flooding episodes unrelated to the changing climate. The total GDP cost of flooding under future protection reduces in a range from 8% in Poland to 75% in the Netherlands.

Still, if adaptation benefits were represented by the avoided negative impacts on GDP and related only to flooding induced by climate change, the benefit cost ratios of adaptation would be less than one (Table 11). This is different from the benefit cost ratios computed using avoided direct damages at the numerator.

Table 11 Benefit/cost ratios of adaptation: average across the four SCENES scenarios

	B/C ratios computed on avoided direct cost from CC-induced flooding	B/C ratios computed on avoided total direct cost of flooding	B/C ratios computed on avoided GDP losses from CC-induced flooding	B/C ratios computed on avoided total GDP losses from flooding
Austria	3.28	3.86	0.69	0.81
Belgium	2.35	3.93	0.56	0.94
Czech Republic	2.52	3.34	0.62	0.84
Denmark	0.82	-0.12	0.10	-0.18
Finland	2.94	3.69	0.66	0.83
France	-0.42	3.72	-0.12	0.72
Germany	0.02	2.12	0.20	0.55
Greece	1.07	3.67	0.36	1.02
Hungary	2.66	2.18	0.64	0.53
Ireland	3.67	3.79	1.51	1.53
Italy	2.13	3.98	0.59	1.14
Netherlands	0.75	3.99	0.16	0.79
Poland	2.20	0.96	0.57	0.29
Portugal	4.21	3.25	2.35	2.24
Spain	3.67	3.95	0.84	0.90
Sweden	3.19	3.46	0.60	0.66
United Kingdom	3.20	3.99	0.70	0.87
RoEU	2.72	3.57	0.65	0.87

Therefore, because of the avoided impacts on GDP from climate change-induced flooding, the chosen protection level is not clearly justified. This conclusion is potentially misleading. In fact, GDP is typically a flow measure: it neglects stock, or differently said, property losses. These, especially in the case of flooding, build up a relevant part of the economic damages. Therefore, in computing avoided damages it would be more appropriate to consider GDP losses additional to direct losses, even though from an accounting point of view, it is not very legitimate to combine flows with stocks.

Moreover, if the total costs of flooding are considered, and not only that part imputable to climate change, protection against future flood events with 100 year return period gives benefit cost ratios very close to one and sometimes larger even considering the avoided GDP losses.

4.3 Adaptation measures addressing regional vulnerabilities

Western Europe is identified as being vulnerable to water scarcity, droughts, and floods. The most vulnerable sector in terms of climate change is the energy sector. A shift in cooling system together with reduced thermal electricity production can help to overcome water shortages and prevent ecosystems from thermal pollution. Some minor irrigated agricultural areas may not suffer from water shortages due to increasing efficiencies. However, due to temperature increases, maize yields are expected to decline, meaning that either cropping calendars or cropping patterns need to be adapted. Due to climate change impacts and increasing future water abstractions, minimum water requirements for ecosystem maintenance and the hydropower sector are at risk. The navigation sector will suffer from climate change during either drought periods or flooding. The biggest unknown is the development of future water quality, which is expected to decrease resulting from diffuse source loadings released with floods and heavy rainfall or reduced dilution capacity of the rivers. Of specific interest are transboundary river basins that have to deal with many kinds of vulnerabilities.

In Eastern Europe, water scarcity can be reduced due to integrated water management. There is no major water user which is particularly threatened. The region is also vulnerable to floods, with the highest costs related to damages in percent of GDP. Similarly to Western Europe, transboundary rivers have to deal with high risk of flooding in the upstream part, whereas downstream vulnerability is related to water shortages and droughts. Navigation and ecosystems are threatened by climate change impacts, which will be exacerbated by increasing abstractions.

In Southern Europe, future freshwater resources will suffer from climate change impacts as well as socio-economic developments driving water uses. The region is highly vulnerable to water scarcity and drought and to flash floods that locally occur. The imbalance between water demand and supply needs to be solved by reducing water abstractions, mainly in the agricultural sector, which is the most vulnerable sector. Technological changes and raising awareness will not be sufficient to reduce water stress and reduction in irrigated areas and changes in cropping calendars or cropping patterns should be taken into consideration. Of specific interest are transboundary river basins shared between Spain and Portugal. High water abstractions upstream not only cause water shortages downstream but could also lead to deterioration of groundwater aquifers due to saltwater intrusion and reduced river discharges). In this case, additional pressure is put on the downstream country and the nature of the water shortage problem worsens due to a water pollution problem.

Projected vulnerabilities vary in character and magnitude across Europe and touch different sectors and levels of operation (see chapter 3.7). To respond to impacts, sets of measures should be selected and considered by Member States in the future. Slow or unfavourable developments could be prevented by using a variety of support actions. The link between measures, support actions, and relevant policies are described in the fact sheets and the inventory.

Descriptions of regional vulnerabilities and recommended adaptation actions are provided below.

Southern Europe

Vulnerability: Water scarcity is already critical in some places across Southern Europe and will only intensify in future. Water demands will increase significantly in less vulnerable areas under the EcF scenario and diminish under the SuE scenario, but water scarcity remains pervasive in Southern Europe, especially for agriculture. Changes in flood hazards are expected to increase in parts of Southern Europe, particularly flash flood-prone, rugged, mountainous, and landslide-prone areas. Efforts should address increased water demand in agriculture and safeguarding environmental flows. The energy generation sector, urban areas, and attractive areas for tourism face similar challenges. The fact that water demand for each of these sectors peaks in the summer only adds to the existing challenge.

Recommended climate adaptation actions: Agriculture may adapt through water sensitive soil management techniques, extended irrigation, and improved irrigation efficiency. Land use management, river restorations, green infrastructure, and improved water retention in rural areas are beneficial for reducing water stress and maintaining environmental flow. The potential provided by technical structural measures may already be exhausted in many places and further development can be associated with negative side effects. River basin management plans required under the Water Framework Directive should pay attention to integrated land use planning at the river basin scale. The supporting action should prevent overexploitation of groundwater resources and ensure flood-risk sensitive development.

Eastern Europe

Vulnerability: Climate change-induced alteration of precipitation pattern may increase flood risk in the upper part of some extended basins, whereas the downstream part may be more affected by droughts and water scarcity. Land use changes and deforestation upstream may increase the risk of flooding. Low river flow downstream may negatively affect navigation, energy generation and water quality of transitional waters.

Recommended climate adaptation actions: Land use change and management in transboundary river basins should be addressed collectively. Green and technical infrastructure play a role in addressing both flood and drought risk. The Water Framework Directive can stimulate transboundary water management and cross-sectoral adaptation.

Western Europe

Vulnerability: Climate change may lead to more frequent and intense floods even under the Sustainability Eventually (SuE) scenario. Droughts may occur in summer and, less frequently, in winter, triggering low river flow and water shortage. Low summer flows may affect navigation and energy generation. Water quality will deteriorate due to higher temperatures, thereby exacerbating the already compromised environmental state in heavily modified water bodies.

Recommended climate adaptation actions: Reduced abstraction for cooling purposes may alleviate water stress to some extent. Existing flood protection measures should be strengthened to address the likely impacts of climate change.

Northern Europe

Vulnerability: Annual precipitation and temperature are expected to increase, likely change the temporal distribution of discharge. As a result, water levels may peak earlier in the spring, whereas low flows in summer may become a norm. River floods and droughts may become more frequent, the latter also in otherwise water-rich areas in the line Oslo – Stockholm and in the western fjords region. High concentration of thermo-electrical plants in the region may create water stress not experienced before. Reduced precipitation in the form of snow along with higher temperatures may affect winter tourism.

Recommended climate adaptation actions: Structural measures related to technical and green infrastructure may reduce climate change impacts on water flow. The energy sector may need to invest into less water-intensive cooling technologies such as tower cooling. Flood defence should be improved to deal with higher peak flows earlier in the season.

An overview of measures and support actions aimed at addressing vulnerability of different European sub-regions is provided in Table 12. It shows that regional specific vulnerability and response measures require a fine-tuning of European legislation, allowing a maximum initiative at the country level.

Table 12 Regional variation in adaptation responses (at subcategory level)

	Vulnerability to	Sectors / groups (Specific impacts)	Technical Measures	Support Actions
Southern Europe	Water scarcity Droughts (Flash) flooding	Agriculture (production) Tension in the water market Hydropower (demand for cooling water) Tourism (drinking water) Environmental flows Transitional waters (salt)	Changing management or practices Land use change and management Technical measures for technical and for green infrastructure	Awareness and information Economic and financial Management plans Regulatory measures
Eastern Europe	Flooding Water scarcity	River basin (floods and water shortage) Navigation Environmental flows (drinking water)	Changing management or practices Technical measures for technical and for green infrastructure Land use change and management (transboundary)	Awareness and information Risk prevention Economic and financial
Western Europe	Water scarcity Flooding	Energy Navigation Hydropower (demand for cooling water) Winter tourism People affected by floods Environmental flows (drinking water)	Technical measures for green infrastructure Land use change and management (transboundary)	Awareness and information Risk prevention Economic and financial
Northern Europe	No stress, no major floods	Water quality	Technical measures for technical and for green infrastructure	

5 Addressing EU vulnerabilities – recommendations for EU action

5.1 Introduction

The European water sector will be affected by a changing climate. The majority of the EU needs to prepare for more droughts. Floods are most likely to increase in North-West Europe, although other regions can be affected. Water scarcity is especially a problem in Southern and South-Eastern Europe. Therefore, climate change adaptation will be necessary throughout the entire EU and can in many circumstances significantly reduce vulnerability.

Currently, large areas of Europe, particularly in Southern and South-Eastern Europe, are vulnerable to water scarcity and drought events and this area is likely to increase in size in the future. Water scarcity and droughts have severe consequences for people living in water scarce (or water stressed) areas, for area economic activities, and for aquatic ecosystems. These consequences are likely to become more severe in the future, resulting in social, economic, and environmental losses.

At the same time, climate change will intensify the hydrological cycle and increase the magnitude and frequency of intense precipitation events in many parts of Europe, leading, for instance, to more frequent and intense floods. Over the last decade, floods have been among the most important natural hazards in Europe in terms of economic losses. Due to rising population, wealth, or number of industrial plants located in the affected areas, both the number of people affected by floods and monetary damages are expected to increase in the future.

Adaptation needs to happen at all levels of governance from international to local. Adaptation cannot be delivered in isolation and must be at the basis of all policies to ensure that they remain relevant as the climate changes. The main role of the EU in this context is to stimulate that process and to assure solidarity among EU Member States.

In order to do this, the EC launched its White Paper on Adapting to Climate Change in 2009. The White Paper outlines a two-phase pathway towards a European Adaptation Framework. Phase 1 (2009-2012) delineates an action plan towards the Adaptation Framework by 2012; Phase 2 (>2012) relates to defining and/or refining and implementing the Framework. Phase 1 comprises four pillars: 1) building a solid knowledge based on the impact and consequences of climate change for the EU; 2) integrating adaptation into EU key policy areas; 3) employing a combination of policy instruments (market-based instruments, guidelines, public-private partnerships) to ensure effective delivery of adaptation; and 4) stepping up international cooperation on adaptation. While the previous chapters of this report clearly contribute to the first pillar, the focus of this section is on the second and the third. This section lays a foundation for the four objectives that are most likely to be included in the EU adaptation strategy to be developed in the second phase (see also chapter 3).

The main objective of this project is the assessment of vulnerability to climate change impacts and adaptation measures. In order to carry out vulnerability and adaptation assessments, an Integrated Assessment Framework (IAF) has been developed. The IAF turned out to be an important tool that helps recognize the impacts resulting from climate change on different regions and the water-dependent sectors: agriculture, domestic use, manufacturing, electricity production, navigation, tourism, and aquatic ecosystems. A total of 21 indicators were defined to identify regions and water-related sectors such as water scarcity, drought, and flood hazards. Further, an in-depth analysis was conducted to identify the main driving forces of vulnerability next to climate change by using the DPSIR approach. After hot spot regions and vulnerable sectors are identified, the inventory of adaptation measures can be used to find relevant adaptation measures or support actions meeting respective needs. Nineteen measures and 16 support actions were identified as relevant at the EU level and assessed in many respects by either modelling, literature review, or expert and stakeholder judgment. Thus, the inventory of adaptation measures is complemented by these fact sheets, which provide all relevant information in order to find effective and responsible solutions.

This chapter provides recommendations on whether EU-relevant measures or support actions should be promoted or prevented in order to increase adaptive capacity in Europe. The section is structured along the four potential main objectives of the EU adaptation strategy in order to provide input to the starting discussion on the climate strategy. It also connects to the ongoing works for the EU 'Blueprint for Safeguarding Europe's Water'[19]. The blueprint will result from a review of the bloc's current strategy on water scarcity and droughts, a review of the implementation of the EU Water Framework Directive and a review of the vulnerability of water resources to climate change and other man-made pressures. It is expected to be published in late 2012 and will address seven key issues:

1. Land Use
2. Economic Incentives
3. Quantitative water resources use targets
4. Governance
5. Knowledge Base
6. Innovation
7. Global Dimension

As one can see, these seven issue are closely related to the objectives of the adaptation strategy (e.g. land use, governance, and targets are issues that can be covered under objective 2 - Developing adaptation action and mainstreaming of adaptation into policies at EU level, both policy actions address issues of knowledge).

In order to make recommendations for further EU actions in the context of the two above mentioned European Policy Actions it is important to understand the current policy framework and the possible actions that can be taken within it.

5.2 Existing EU initiatives to address vulnerabilities to climate change and how they cover current support actions

In the field of climate change policy, until recently, the EU legislative and regulatory actions concentrated on climate mitigation, that is reduction of greenhouse gas emissions. The **Directive 2009/28/EC** (Renewable Energy Directive) sets legally binding national targets for electricity and transport from renewable sources, adding up to a share of 20 % of total energy production in the EU as a whole. By June 2010, each EU Member State was required to adopt a national renewable energy action plan (NREAP) addressing national targets for the share of energy from renewable sources consumed in transport, electricity, heating and cooling in 2020. There is no doubt that achieving this targets will require sufficient water in particular for hydropower generation and also for growing enough crops for achieving sufficient yields of biomass.

In the field of climate adaptation, European Union has been slow in taking action. The 2009 EC White Paper on Climate Adaptation, **COM(2009) 147 final**, lays out a framework for adaptation measures and policies to reduce the EU's vulnerability to the impacts of climate change. A centrepiece of the framework, meant to enhance Europe's resilience to climate change impacts is a better management of water resources and ecosystems. Nonetheless, policy efforts in the field of natural hazards and civil protection mechanisms have prepared the stage for concerted action that takes into account the impacts of climate change that are unavoidable or unlikely to prevent by climate mitigation.

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[19] See http://ec.europa.eu/environment/water/blueprint/index_en.htm

The **Directive 2000/60/EC** of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (Water Framework Directive, WFD) commits the EU Member States (MS) to achieve good ecological status of all surface waters, including marine waters up to one nautical mile from shore, and good chemical status of groundwater by 2015. The **Directive 2008/56/EC** (Marine Strategy Framework Directive MSFD) pursues a similar goal but for marine environment. It creates a framework for marine waters and expands the approaches initiated by the Water Framework Directive (WFD), the Environmental Impact Assessment, the Strategic Environmental Assessment and the Birds and Habitats Directives, amongst others.

The **Directive 2007/60/EC** (Floods Directive) seeks to prevent and limit floods and their damages on human health, the environment, infrastructure, cultural heritage and property. The Directive obliges the Member States to assess risks posed by each Member State's water courses and coast lines, and to produce maps of areas subjected to floods of different intensity. The main aim of this assessment is to inform adequate and coordinated management measures to protect assets and humans in these areas. In order to address the issue of water scarcity and droughts in the EU, in 2007 the European Commission issued a Communication **COM/2007/0414 final** 'Addressing the challenge of water scarcity and droughts in the European Union'. The communication lists a set of policy options that are implementable as a concerted EU action to increase water efficiency and water savings, and to improve drought preparedness and risk management. At the heart of the policy options is the need to price water correctly with the "user pays" principle becoming the rule regardless of where water is taken from. Furthermore, as land and water resources are essential for farming, grazing, forestry, wildlife, tourism, urban development, and transport infrastructure it is now widely accepted that future land use and land planning in water scarce areas is a crucial factor for mitigating water stress. Autonomous farm level adaptation may find its limits as climate change impacts gradually become more drastic. Planned adaptation driven by public authorities, addressing the whole sector, and tailored to the diversity of regional and local agriculture will be needed to facilitate a broader range of responses. The second Pillar of the **Common Agricultural Policy**, which focuses on Rural Development, also includes climate adaptation measures targeted at the agricultural sector.

In the disaster response domain, EURATOM established the Community Civil Protection Mechanism (hereafter CCPM) in the European Council's **Decision 2007/779/EC**. More recently, the European Union intensified its efforts in disaster risk reduction with the EC Communication on Disaster Response Capacity (EC 2008). This Communication highlighted the need for stepping up the Community's capacity to respond effectively to disasters, within and outside the EU. To do so, the EC proposed several tangible means to improve coordination between various EU/Community policies, instruments, services and players (at national, European and international levels). While the Communication focuses on disaster response, it acknowledges the need for a comprehensive approach to disaster management that includes risk assessment, forecast, prevention, preparedness and mitigation.

This existing policy framework already allows including several support actions and measures. However, in order to identify existing gaps in this framework, the project examined the 16 support actions assessed in the context of the current policy framework. The project focuses on the support actions because these are the mechanisms through which the European Union can foster the uptake and implementation of technical measures. Furthermore, the adaptive impact of a technical measure is determined on a case-by-case basis. To this end, the EU's adaptive capacity is contingent upon the provision of adequate policy support for the assessed support actions; this is their primary method of ensuring that technical measures are implemented.

The following table (Table 13) maps the six subcategories of assessed support actions to existing EU policy. Where present, gaps are identified at the level of individual support actions.

Table 13 Overview of the measures addressed by European Policy on a subcategory level

	Water							Agriculture		Biodiversity			Infrastructures and buildings			Renewables	Soil	Coastal Areas	
Measure sub-category	Water Framework Directive	Marine Strategy Directive	Floods Directive	Communication on WS&D	Nitrate Directive	Urban Waste water	Direct payments (cc)	Rural Development Regulation	Birds Directive	Habitat Directive	EU Biodiversity Action Plan	Solidarity Fund	Council Reg (EC) N° 1083/2006	Eurocodes	Renewable energy	Biomass Action Plan	Proposal for a Soil Framework Directive	Commission Communi-cation Evaluation of ICZM	Assessed Support Actions with no direct links to EU policy areas
Risk prevention	x		x	x		x			x	x			x	x					SA01
Awareness/ information	x		x	x			x	x		x									
Changing management or practices	x	x	x	x				x		X		x	x	x					
Economic and financial	x		x	x			x	x				x	x						
Land use change and management	x		x	x	x		x	x	x	X	x	x	x		x	x	x		
Technical measure related to technical infrastructure	x	x	x	x		x	x	x					x	x				x	
Technical measure related to green infrastructure	x		x	x		x		x	x	X	x		x	x					
Management plans	x	x	x	x				x											SA14
Regulatory	x			x										x					

As is evident from Table 13 and the on-going activities to reduce vulnerabilities (see also section 3.2), the vast majority of the assessed support actions have a direct connection to existing EU policies. This indicates that the EU is well suited to implement the adaptation measures needed to meet its adaptive capacity needs. Only two of the assessed support actions have no direct link to existing EU policy. The first, 'Spatial Decision Support System (sDSS)' (SA01) cannot be linked to EU policies because it is a specific system to support decision-making that can have significantly different measures, aims and scope. However, the development of such systems can be supported by the Framework Program for Research. Additionally, the EEA might develop such a system for in-house modelling. The second support action with no link to EU policies is the 'Implementation of a Cross-Sectoral Adaptation and Risk Aversion Strategy' (SA14). It is part of the current policy developments in the area of climate change adaptation and will partly result in an EU Adaptation Strategy towards Climate Change in 2013 at the latest. It should be noted that a further support action, 'Transboundary flood management through spatial planning' (SA09), has a direct link to both the Water Framework Directive and the Floods Directive but the relevant text is minimal.

While the policy environment regarding the assessed support actions is favourable and there are few gaps, a limiting factor in terms of the EU's ability to enhance adaptive capacity lies with the degree to which the appropriate authorities at the national, regional and local level actually implement the measures. Implementation of EU policy can be uneven across and within Member States. One example is a Strategic Environmental Assessment (SEA). Climate change aspects can be incorporated into SEAs at different levels of policies, plans and programs, and since SEAs emphasize environmental and socio-economic conditions, they show cross-sectoral benefits for climate adaptation. A 2009 report by the European Commission highlights that application of the Strategic Environmental Assessment (SEA) Directive has varied in effectiveness "in terms of the institutional and legal arrangements of the SEA procedure, and in terms of how MS perceive its role" (EC, COM (2009) 469 final). Some MS have adopted clear guidelines (e.g. Environment Agency, 2007), but this is not uniform across all countries. A measurement of the EU's adaptive capacity will therefore be how clearly its policy provides guidance and assistance to all MS in the implementation of the identified support actions.

5.3 What still needs to be done?

To strengthen adaptation efforts further and reduce the vulnerabilities described in chapter 3, the following actions along the four potential objectives of the proposed EU adaptation strategy are proposed:

5.3.1 Increase the understanding of adaptation, improving and widening the knowledge base and enhancing access to adaptation related information (objective 1)

In general, it is important to accept that temporary lack of knowledge on climate impacts and societal change does not have to be a reason for delaying investments in response measures. Short-term actions may be possible as long as they do not hinder more strategic measures in the future and give special preference to no-regret measures. The following actions are recommended to bridge the current gaps:

1. Improve the EU's knowledge base with additional research: Climate and hydrological data and climate impact assessment methodologies are critical for scenario-based planning and capacity building. Adopting a 'no-regrets' precautionary approach of employing and expanding existing techniques should be part of any climate change adaptation portfolio in the water sector. However, as set out in chapters 1.6, 2.1.4.3 and 2.4, there are still important gaps in knowledge and data availability, in particular at the more local to regional levels where uncertainties remain high. To make better decisions, these data gaps need to be filled. To understand climate-water-land related processes and interactions better, for example, more reliable data and better

monitoring are needed. This relates to drought monitoring, ecosystem monitoring, and floods, water scarcity, and water quality. This could be achieved by establishing a common EU data set and a common set of indicators. While these indicators exist for floods, in the case of water scarcity and droughts the work has just started under the lead of the EEA. Furthermore, the EU should assure a sufficient level of data collection to ensure that the data baseline is built properly. The data should then be integrated into the Clearinghouse (CMA) and WISE (e.g. ClimWatAdapt, chapter 2.3). Furthermore, using ensembles and scenarios help identify a range of uncertainty; this should be strengthened by building ensembles for impact modelling.

Moreover, research should focus on regional aspects and needs to characterise the relationship in water management between and across governmental, administrative, and private levels (multi-level governance) as a key aspect of policy actions. It is necessary to consider European, national and sub-national levels to find a balance between interests, capacities and objectives.

Models and tools are needed to evaluate adaptation measures quantitatively. Therefore, research efforts should focus on how to improve the overall performance of one system/region instead of studying the effect of separate measures. This attention should focus especially on the water-energy nexus and on a more systematic mapping of the impact of measures and policies on water management in the agricultural, tourist and domestic sector. The modified DPSIR framework developed within this study could be more widely deployed. Research also needs to analyze conflicts and synergies between different actors and sectors and the measures they take in terms of implementation of adaptation measures. Better estimates of the economic costs of damages and adaptation strategies as well as the measures to address them are needed; this is still in a very early stage of development. Different viewpoints of the measures should also be combined; in other words, different time-dependent dynamics have to be brought together. Questions such as “what is the appropriate time frame for adaptation?” and ”how can different measures be combined in time and space?” need to be answered. Although their answer will depend on the local conditions, there is currently no guidance on how to approach these questions.

In this study, we adopted a practical approach to deal with adaptive capacity. However, adaptive capacity (and other related topics such as resilience and coping capacity) requires special attention in future research. Adaptive capacity should also be linked to migration dynamics, which might change certain production patterns, and to other human developments, such as urbanisation.

2. <u>Improve the knowledge base at the regional level by fully applying existing legislation:</u> Besides the more academic approaches to improve the knowledge base, River Basin Authorities need to explore their existing tools further in order to improve knowledge at the local level. For example, Annex III WFD Member States are required to make forecasts about their future water use and related investments. A few river basin management plans prepared under the WFD have included climate change in the initial characterisation of river basins and the economic analysis of water uses. Similarly, the Floods Directive made consideration of the future climate change optional until the first review of the preliminary flood risk assessment in 2018 (Article 14 and recital 14). The flood and drought risk management should be considered an integral part of the adaptation to ‘climate variability and change’, considering also the broader environmental changes and social trends. The stakeholders agreed that the re-evaluation of future water needs represents a highly valuable measure as it might lead to an increased understanding of potential future vulnerabilities. It also allows for a better understanding of the timeline in regional circumstances. Uncertainties in long-term projections may give rise to a combination of tactical and strategic measures.

3. Develop initiatives for further knowledge sharing: The European Clearinghouse on Climate Change Impacts, Vulnerability and Adaptation should fulfil a key role in this sharing and mobilization of knowledge and information regarding climate change adaptation. It is envisaged to help European policy makers at different levels of governance, as well as scientists and professionals, address real policy needs by using existing knowledge and information more effectively; currently, information use is fragmented. The Clearinghouse has a central web portal that allows people to combine plug-and-play information sources with analytical tools easily. Measures dealing with information gathering and provision but also linked to capacity building could be easily be covered by the Clearinghouse.

   Furthermore, the European Floods Alert System[20] (EFAS) provides an early warning system that is complementary to the national and regional forecast systems. Currently, the lead-time of the forecasts is limited to 3 or more days. Similarly, the European Drought Observatory provides useful information on droughts. We believe that the EU and national forecast systems could be embedded in a single one-stop portal such as the Clearinghouse. In addition, a continuous development of forecast methods is needed to further reduce uncertainties.

4. Define and agree on EU wide vulnerability indicators: Vulnerability indicators support the evaluation of the effectiveness of adaptation measures. Over the last decade, research has shown that a focus on vulnerability is necessary when studying the consequences of climate change. The question is, however, "the vulnerability of what?"
   Depending on which sector, region or issue the policy makers or water managers are interested in, they can select the appropriate indicator. However, focusing on only one indicator is not enough to identify proper adaptation measures. A system approach is often needed to identify the main issue causing the problem and the most effective/efficient way to adapt to climate change. Finding sustainable solutions also necessitates a systems approach, as demonstrated by using DPSIR tables. Although a single vulnerability indicator is not enough for the purposes of adaptation planning, the use of a limited set of indicators can be useful for the purpose of accountability--specifically, to measure the success of implemented adaptation measures.

   Currently there is no common set of indicators for Europe. Such a common set is needed in order to compare the vulnerability of different regions and to target measures in the best possible way. They are also needed to ensure that financial support by the EU goes to the most vulnerable areas (principle of solidarity). The selection of appropriate vulnerability indicators should be performed according to climate change impacts (water scarcity, drought, flood) or affected sectors (agriculture, domestic, manufacturing, electricity production, navigation, tourism, aquatic ecosystems, sea level rise). Using the DPSIR approach enables to examine the changes in both natural and human systems in a systematic way and helps identify the root cause(s) of vulnerability and the inter-linkages between different factors.
   To summarize, the vulnerability section shows that future research of water quality is especially necessary. Such research should entail developing models as well as collecting and providing appropriate measurements (parameters) and data.

5.3.2 Developing adaptation action and mainstreaming of adaptation into policies at EU level (Objective 2)

The focus of this objective is on strengthening existing adaptation efforts and mainstreaming adaptation into policies at EU level. Both aspects have to be discussed separately but should consider the following:

[20] http://floods.jrc.ec.europa.eu/

Although all actions that are implemented for adaptation to current climate variability can be used for climate change adaptation, there are some peculiarities. The most important of them is the uncertainty of the projections and the addition of the time dimension. Therefore, it is important that all climate change adaptation policies require that actions are chosen not only on the basis of their effectiveness to current climate variability and human pressures, but also on the basis of their ability to address future climate change and human pressures, while also taking into account the uncertainty in these future developments. This approach also requires that the actions implemented do not lead to path dependency, which would make the implementation of other actions at a later stage impossible. For example, a coastal zone can be protected by wetlands, by sand supplement, by dikes and by strengthening the dikes, in that order. If, however, dikes are built first, it is impossible to combine them with wetlands at a later stage. There should also be space for building and strengthening the dikes. Therefore, a detailed plan with the possible options, their order of implementation and their effectiveness is needed. This approach is called the "real options approach" and is used in the Thames Estuary (TE) 2100 project (Reeder and Ranger, 2011).

More concretely, the following actions are recommended:

1. <u>Strengthen and develop adaptation action</u>: The main focus behind all climate change adaptation activities should be to include adaptation needs in current land use management and practice and to strengthen the role of ecosystems. Land use change is one of the main drivers of the degradation of water resources and vulnerability to extreme events. Because of the close link between human activities and land cover, land use and river basin hydrology, there is a need to consider the long-term impacts of climate change. Harnessing nature's capacity to absorb or control the impacts of extreme events (by improving the soil's water storage capacity and conserving water in natural systems, for example), helps ameliorate the effects of droughts and helps prevent floods, soil erosion and desertification. This ecosystem-based approach is a more efficient way of adapting than simply focusing on physical infrastructure. Such changes in land use may be considered strategic. The implementation of land use may encounter much resistance and take a long time. If combined with other environmental goals steadily, progress may be expected. However, the potential of these measures has not been fully explored, mainly because the priorities for land use are set differently (e.g. housing, agriculture). These links need to be considered and constantly transferred into all EU policies targeting land use changes, such as the agricultural policy, transport policies, rural policies and energy policies (in particular in relation to renewable energy). In order to do so the following actions are recommended:

   Strengthen the role of ecosystems

   The development of floodplains and wetlands helps retain and slowly release (flood) water, facilitate groundwater recharge, provide seasonal aquatic habitats, support corridors of native riparian forests and create shaded riverine and terrestrial habitats. Using tidal wetlands as buffers help maintain functioning estuarine ecosystems and creates natural land features that act as storm buffers, protecting people and property from flood damages related to sea-level and storm surges. Reversal of delta island subsidence sediment and soil accretion is a cost-effective natural process that can help sustain the delta ecosystem and protect delta communities from inundation. During droughts, wetlands take on an even greater importance. As water resources become more and more scarce, wetlands provide a resource in an otherwise dry environment. As well as providing drought relief for stock, wetlands provide a habitat for a range of threatened plants and animals.

   These important functions of wetlands and other water retention systems need to be strengthened and further degradation should be prevented. However, initial assessments indicate that the application of green infrastructure measures to protect waters and adapt to climate change varies widely (Dworak et al. 2010). Also, the current and the proposed CAP describemany related measures in the Rural Development Programs but their overall uptake by farmers is limited because they are voluntary.

In order to increase the role of ecosystems in adaptation efforts, more land will be required. This land will have to come mainly from the agricultural sector. Securing this land could, therefore, be a difficult task. There are two options to overcome this problem: either a mandatory approach will be set up (which is most likely not going to be accepted) or a new approach that pays farmers for ecosystem services will be implemtented. These payments do not necessarily have to come from the EU. They could also come from those benefiting from a reduced risk (e.g. an urban area which has a reduced flood risk). The above mentioned measures could be promoted by amending the existing funding regulations for the next financial perspective. When doing so, specific funding lines in the main EU funding schemes, such as the Rural Development funding or the EU cohesion policy, are needed. The proposals for both policy areas will have such provisions. For example, the proposal for a regulation of the European Parliament and of the council on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) has several options in Articles 22 to 35 to include water retention measures. While funding is widely used across the EU, water pricing as a policy instrument to contribute to the cost recovery of water provisions/services is rarely fully exploited (Deloitte 2011). Another option to promote such measures could be included in the WFD. Similarly to how the requirements under Art 4.7 set mitigation measures in the case of new hydro-morphological degradation, a mitigation approach could be linked to abstraction that is reducing flows. In other words, new abstraction needs to be compensated by saving water somewhere else.

Spatial planning

Stakeholders showed high interest in reallocation of houses and infrastructures, but highlighted the potentially difficult implementation. The reallocation of infrastructure has been considered extremely costly and thus not feasible. However, the territorial development and urban master plans should clearly specify the areas prone to flood risk and restrict new developments in these areas.

The strategies aimed to the disaster contingency planning and business continuity have been considered important tools for dealing with whether related emergencies.

Including adaptation into the development of the next RBMP

In 2009 the Water Directors endoresed Guidelines on climate change adaptation and water and the available assessment of RBMPs and provide concrete recommendations on how to integrate the findings of the report into the production of next RBMPs. In the first cycle of the RBMPs only a few basins picked up the recommendation made in this guidance document. It is highly recomendet to strengthen the efforts to implement the recommendations from the guidance document in the second cyle in particular to ensure that measures taken are climate proof. However the guidance document should be developed further considering the information and knowledge gained over the last years.

In particular the section on Climate projections and scenarios should be strengthend in order to ensure that each RB develops its vulnerability assessment on future impacts from climate change. This is highly relevant as climate change impact and vulnerability analyses can be “simply” performed using a top down approach identifying potentially vulnerable regions at EU or even global scale. However assessing vulnerabilities on a regional or local level is much more difficult. One of the main reasons for this is that biophysical problems caused by climate change often have to be solved through implementing socio-economic measures for example water pricing or awareness raising. Although climate change is a global problem often, the solutions need to be found locally and many times adaptation is locally specific because it needs to be linked with the local cultural and socio-economic circumstances. As a result, it is not possible to find one-size-fits-all solutions, therefore, at the EU scale it is not possible to provide ready-to-use solutions for local policy makers. However, the tools and adaptation measures dataset developed in this project are an appropriate starting point for adaptation.

Based on this vulnerability assessment the development of river basin wide adaptation strategies - based on the WFD requirements - are recommended. Such strategies can allow addressing problems in a transboundary way reducing the risk of conflicts at a later stage. They also allow establish cross-sectoral approaches, which are based on a hierarchy of water use. As decision-making under increasing uncertainty is one of the greatest challenges posed by climate change, and a flexibility of approaches is needed when developing adaptation measures and strategies. Emphasis should be placed on no-regret and win-win measures that will deliver benefits under different scenarios. Further a link of these strategy to other plans (e.g. biomass action plan, renewable energy plan) is needed to reduce inconstancies and to prevent false expectations. These strategies should also include agreed disaster response action.

In order to finance adaptation measures, which are, included in river basin strategies the development of transboundary financing mechanisms that allow bordering countries to place measures in the basin where most appropriate should be discussed.

Prioritise demand management (in the EU funding schemes)

Historically, water shortages have been solved by increased supply. Building new storage capacities or increasing the capacity of existing facilities, inter-basin transfers and desalination are widely favoured ways to deal with water scarcity and droughts in many parts of Europe. There is a growing understanding though those demand-led approaches are indispensable for a long-term strategy to reduce water stress. Increased water supply may lead to a higher demand, as the incentive to use water more efficiently loose on appeal. So priority to regulation the demand side should be given. There are many ways that can be used to manage water demand, both directly, e.g., water restrictions and consumption cuts, leakage control in water distribution system, water sensitive urban design); or indirectly, via increasing the efficiency of water use, e.g., water saving in building codes, improved agricultural water management, reducing freshwater demand for industrial cooling, and water pricing, use of engineered crop varieties, incentive schemes to promote water efficient products, develop programmes to promote efficient use of water, share best practices to reduce water consumption of companies. When developing funding criteria for EU funds (e.g. Rural development or Cohesion funds) give a funding priority to “green” or “soft” measures. A further priority should be given to measures that address both water scarcity and droughts and flooding simultaneously. Desalination, water transfers and additional reservoirs should only be funded in exceptional causes. Other investments related to water infrastructure should be linked to vulnerability assessments as a prerequisite. So water infrastructure investments should be made “climate-proof”, i.e. it should be ensured that they will still be viable under changing climatic conditions

Start to consider more systematic changes

As shown in section 3, in some regions, more radical changes are needed to reduce vulnerability. The “extend of the radicalism” to shift to a new system needs to be evaluated. In some cases it is impossible or undesirable to continue a certain path of development and the replacement of one measure with another is not a solution. A measure which represents this radical shift is Managed retreat of coastal defence (M_020), for example—it can become unfeasible for some coastal segments to be defended; therefore the sea is allowed to inundate them. An example of a system that may have to be abandoned in a shift to a new one is the growing of water-intensive crops in dry lands. Some parameters of the old system can be optimised (for instance irrigation efficiency, increasing pumping of groundwater, importing water from elsewhere), but if the water stress increases beyond a certain threshold or the system becomes too unsustainable it should be abandoned completely. Such radical shifts should be considered from the beginning when evaluating adaptation measures, in order not to spend money on measures that will in the long run not prove to be sufficient. Further, in order to implement these radical changes, long stakeholder discussions will be needed, which normally take several years or even decades. These time requirements should be taken into consideration, and therefore again, such radical changes should be considered at as early a stage as possible.

2. <u>Mainstreaming of adaptation into policies at EU level:</u> The objective of mainstreaming is to ensure that the sectors covered by the policy areas are able to carry on with their core tasks even within the circumstances of a changing climate. In order words, adjustments in other policy areas will be necessary to achieve a sufficient level of adaptation (e.g. funding of green measures under pillar one of the CAP, new standards for cooling in power plants and industrial plants, new standards for buildings and infrastructure developments). This streamlining approach refers to climate change issues in general, but also to water related issues in particular, as water is a key issue for most sectors. The following actions are needed more concretely:
    a. Adaptation to climate change is not explicitly included in the text of the WFD or other water related sector policies. However several efforts in water management exist that aim to address the challenges posed by climate change. These efforts need to be strengthened and often brought to a broader level of application. This can be done by providing additional guidance or specific funding of measures. As well, any revision of EU water legislation should include the aspect of climate change (e.g. requiring climate proofing of any action that has to be taken under this Directive).
    b. Furthermore, the Strategic Environmental Assessment (SEA) is an effective review mechanism at the planning and programming level. The mechanism should be used for climate-proofing of new development projects. Climate change aspects can be incorporated into SEA at different levels of Policies, Plans and Programs (PPPs). As stated earlier climate change can have multiple effects on the water environment, and because water is the issue dealt with in the RBMPs, it is clearly relevant to incorporate into SEA considerations of how climate change will affect the issues dealt with in the RBMPs. On the basis of this, adaptation measures (like e.g. natural retention of flood water and coastal protection infrastructure) can be integrated into short and long-term plans of water management activities, and thus society's resilience to climate change can be improved. In order to do so, there is better guidance needed on how to consider adaptation issues better in the SEA.
    c. The Common Agricultural Policy, currently under review and revision, offers many opportunities to improve adaptation to future climate in agriculture. The stakeholders and experts agreed that these measures represent a tangible and risk free solution. Moreover, they pointed out to the high benefits of irrigation system data collection and delivery and of an improved agricultural water management, even in the case of less pronounced climate change impacts. However, the most important measure to be introduced in the next CAP is related to a mandatory risk assessment related to climate change for obtaining Rural Development funding, ensuring that adaptation measures are taken at an early stage.

d. Cohesion Policy: In the field of environment, the Cohesion Fund will support investment in climate change adaptation and risk prevention, investment in the water and waste sectors and the urban environment. The details, which kinds of investments will fall under these categories under the new proposed cohesion policy for 2014 to 2020, are yet not known. However, the focus should be on measures that strengthen the role of ecosystems.
e. Crosschecks should be made to assure that mainstreaming in one policy does not transfer the vulnerability of one sector or area to other sectors or areas. The assessment has to be supplemented, however, by a more detailed assessment for the specific regional circumstances where the measure should be implemented. The assessment criteria developed in this project can guide this process.

5.3.3 National implementation of climate adaptation requirements, and support to and facilitation of exchange between Member States, regions, cities and all other relevant stakeholders (Objective 3)

The implementation of adaptation measures and its facilitation by support actions at national level depends on the felt need of capabilities and available resources. From a technical perspective, the Clearinghouse is a supportive resource, as it collects and relates the relevant information on vulnerability and adaptation in an open, accessible environment. Local monitoring is supportive of the Clearinghouse and a confirmation of the national climate impacts and vulnerabilities.

At this stage, combinations of possible impacts have been applied already for some pilots considering measures for mid and longer term. An exchange of such experience between similar areas will be a successful form of capacity strengthening between the Member States through possible co-production on technological and process development. Most likely, the preferred support system and the selected measures will be country and site specific. Local situations always are extremer than Europe-wide. A good insight in future climate change impacts may provide the Member States better insight into their future, and even lead to the conclusion that existing systems can only be protected against extreme costs, and that new development goals need to be formulated for which short-term measures can even obstruct proper solution. This may provide new opportunities and bring adaptation in a new perspective that makes old technical solutions redundant. The development of such adaptation programs require substantial guidance and need for feedback from partner states.

At national level economic development, population growth and consumption pattern may change the effect of adaptation measures. This requires pro-adaptive monitoring and careful scenario planning. Important shifts may be possible, which may require a rearrangement of support action and policy priority.

Transboundary water management is already addressed in the WFD and can be used as a tool to support and facilitate exchange between Member States and regions. It is seen as a high priority and urgency issue, and a high importance at the EU level was assigned by the stakeholders. However, transboundary water management will also necessitate development of transboundary adaptation strategies.

Finally, is the EU capable of estimating the proper approach in relation to the various combinations of vulnerabilities and the various adaptive capacities in the Member States? To which extent is it possible to fine-tune support actions to certain regions, population groups or sectors, in order to initiate the required human and financial resources, considering the deregulation and subsidiary.

5.3.4 Capturing the potential of the market, market-based instruments and the private sector in strengthening adaptive capacity and climate impact preparedness and responses (Objective 4)

Many measures in our database of adaptation options are subject to the subsidiary principle (e.g. re-allocation of houses, measures related to urban development), or can be undertaken by private sectors. Even so, the European Commission may take action to ensure that the impacts of these measures are fully assessed and properly taken into account. The EU adaptation strategy is envisaged as a framework for coordinated climate adaptation efforts of the Member States and closer involvement of private sectors.

5.3.5 Adaptation measures that should be subject to a critical analysis at the European level

Some climate adaptation measures, at first sight potentially effective, may set off unintended consequences, which further exacerbate other problems or obstruct efforts to adapt to likely outcomes of climate change elsewhere. In chapter 4.3 we have discussed the issue of *unintended consequences*. Here we identify several measures whose potential unintended consequences raise serious concerns that in our opinion should be addresses at the European level, not least because of the solidarity principle. First, research conducted by Criss and Shock (2001) and earlier by Belt (1975) suggested that flood protection by increasing levees and other engineering works eventually increases the flood stages for the same discharges, thus increasing risk of flood downstream, all other factors being equal. The Directive 2007/60/EC on the assessment and management of flood risks (Floods Directive) interdicts measures 'which, by their extent and impact, significantly increase flood risks upstream or downstream of other countries in the same river basin or sub-basin,' unless these measures have been agreed on by the Member States concerned (Article 7 and recital 15). Increased structural flood defence measures are addressed in our factsheet "***Adaptation existing dikes***" in which we also call into attention the social acceptance and additional risks posed by the measure. We believe that apart from subjecting the structural flood defence work with substantial effects of flow regime to Environmental Impact Assessment (EIA), the European Commission should develop guidance and best practices for comprehensive risk assessment in the international river basins that should be made compulsory as a part of the negotiated agreement between the concerned Member States.

Second, ***desalination*** and ***water transfers*** are adaptation measures that are contested on various grounds. The full review of both measures is provided in the respective factsheets. In brief, desalination is highly energy-intensive in terms of both production and transport, and causes substantial environmental impacts. Water transfers also set off environmental impacts and encounter high social resistance. Because of these concerns, both measures should be considered with care. As limited water availability increasingly constrains the economic development of water scarce regions, both desalination and water transfers may become cost efficient, even with full environmental costs taken into account. We recommend that both measures are adopted only when all other adaptation measures have been exploited. In other words, it should be made compulsory to demonstrate that the welfare costs caused by additional water demand management options exceed the welfare costs of increased water supply, achieved by either desalination or water transfer.

Water transfers are partially addressed by the WFD, requesting in Article 4 that if the measure leads to deterioration from a high to a good ecological status, then the implied benefits to human health, safety or sustainable development need to outweigh the social benefits of preserving the initial higher ecological status. A similar requirement for desalination could be deduced from both from WFD and the Marine Strategy Framework Directive. We recommend though that specific assessment guidance and best practices be developed for all three of the above measures by the working groups established under the Common Implementation Strategy (CIS).

Mitigation measures have to be assessed in the light of adaptation. For example subsidies for the production of biodiesel and bio-ethanol can lead to an increased production of energy crops. Although subsidizing biofuels is not an adaptation measure, the support for biofuels can affect policies on adaptation. As energy crops compete with food crops for land and water, the increase in fuel crops is an important factor for the worldwide price increase of food crops. The 2008-2009 food crises, for example, are believed to be triggered by the incentives to produce biofuel. Food prices rose as many farmers sold their crops to biodiesel or ethanol refineries, instead of as foods. This has created incentives to turn additional forests into agricultural land, or to plant on marginal agricultural lands and land previously set aside for environmental reasons. At the same time food prices were influenced by large-scale droughts (e.g. by the eight-year-in-a-row drought in Australia) or floods (such as 2008 Midwestern United States floods). Under such complex interconnection, the extent to which biofuel incentives have contributed to price increases is difficult to assess and provides potential for disagreement and conflict. It is clear, however, that biofuel production will increase overall water demand; it is therefore important that biofuels policies link to water scarcity policies: for example, only promoting biofuels in regions where plenty of water (and land) is available.

Another example of how measures can be used in a wrong way is in tactical and strategic measures. In principle they can operate complementary to each other. However, if priority might be given to the easier short term measures they risk losing their effectiveness with increasing impacts. A more robust solution could have been an alternative solution but might appear to become over dimensioned under more moderate climate scenarios. A third approach is to analyse well the long-term scenarios and their threats and opportunities, possibly presenting new targets that can be accommodated by a combination of smaller and sustainable measures.

5.4 Discussing proposed measures/support actions in the context of the current EU adaptive capacity.

The needs for adaptive capacity are determined by the gap between the optimum set of measures required to adapt to climate change impacts and the set of measures that the EU or Member State is willing or able to implement. A variety of factors determine ability and willingness to implement these measures. These include: a lack of financial and/or technical resources, lack of knowledge and skills, insufficient leadership to take action, unclear responsibilities amongst authorities, expected resistance at a regional, MS or local level (as well as within different sectoral and interest groups), lack of conviction that implementation is necessary, and/or low priority compared to other issues (where non-implementation is a calculated risk). Similarly, measures may also be ineffectively implemented if they are too expensive or are poorly tailored (or inappropriate) for the local context.

To this end, the needs and adaptive capacities of different target groups must be identified as a prerequisite to provide effective guidance and capacity building. It is on this basis that the EU should orient its actions towards filling any identified gaps between required and implemented measures by support activities and policy.

As shown in chapter 3.2 and 5.4 the EU has already started to develop several efforts to address adaptation. The EU adaptation framework has established a multi-stage approach to addressing its climate change adaptation needs. However given the ongoing state of Phase 1, the final impact of this strategy on adaptive capacity cannot be precisely determined, but the EU is positioning itself well in terms of policy synchronization and planning. Hence, many existing gaps in adaptive capacity (in terms of policy) are in the process of being addressed.

Further, even in the context of the current financial crisis, the EU stands as one of the largest economies in the world. The EU's new growth agenda, 'the Europe 2020 Strategy', places climate change concerns as a key issue, and this emphasis is reflected in the capacity of the EU to address climate change adaption through budgetary means, as most of the budget is spent to influence how Europe's land and environment are used. For example, the Common Agricultural Policy (CAP) and Cohesion Policy (CP), which are key pillars of the EU budget, have direct coverage of the policy fields pertinent to water management. Agricultural land represents 40% of the EU total, and the CAP can consequently be an excellent financial tool for facilitating the implementation of adaptation measures to enhance adaptive capacity. Similarly, the focus of the Cohesion Fund on infrastructure in the new MS and Cohesion countries means that funds can be directed towards MS and regions with lower adaptive capacities, enhancing the adaptive capacity of the EU as a whole. The full extent to which climate change adaptation concerns are mainstreamed into EU policies like the CAP and CP, however, will depend upon the preparation of the upcoming multi-annual financial framework (MFF), which will set priorities for EU spending from 2013 onwards. However as the overall magnitude of costs of adaptation is currently not known in detail and the time when these costs might appear is also not fully known, it is difficult to judge if these funds are sufficient to reduce hardships to civil society and economic sectors. Further it should be acknowledged that in certain cases, such as the current economic crises, the EU has come up with additional efforts to combat these emerging threats. With this in mind, and considering that the cost of adaptation can be spread over the next 30 to 50 years, it can be assumed that there is the financial capacity to adapt the water sector (which is still a key sector) to a changing climate.

Another test of the EU's adaptive capacity is its ability to assist those who livelihoods are disrupted by the impacts of climate change. As impacts like water scarcity may lead to increased unemployment, EU policy to address social impacts will become increasingly important to meet adaptation needs. Existing policy has the potential to adequately meet the EU's adaptive capacity needs, but the extent to which it does so will depend upon the further mainstreaming of climate concerns. For example, Article 9 of the European Social Fund (ESF) Regulation could be adapted from its current form to ensure the provision of technical assistance and capacity building on climate adaptation, so as to limit the socio-economic impacts of climate change. As climate change is not presently an explicit focus, its ability to enhance adaptive capacity is less clear.

From a technical perspective, the capability of the EU is well supported by the establishment of the Clearinghouse, which collects and relates the relevant information on vulnerability and adaptation in an open accessible environment. To advance technical measures that were already effective as pilots and in some progressive countries, an exchange of knowledge needs to be facilitated between Member States and possibly through co-production. A less considered uncertainty is related to the effects of population growth and preferences on consumption and production. In addition, for adaptation programming, various scenarios need to be included and a monitored system needs to be in place. A hidden technical issue under increasing climate change impacts is the rigidity of systems based on short-term measures when in the long run, a more radical switch in measures may be needed. If long-term projections were considered, adaptation would be brought in a new perspective, which would make old technical solutions redundant. The implementation of an adaptation program may require substantial guidance and need for feedback, which may come from partner states as well. Such a network will strengthen adaptive capacity not only on single vulnerabilities but also as a whole.

Despite the good positioning and potential of the EU to meet the adaptive capacity needs of its Member States, a problematic issue might be the socio-cultural, institutional and political capacity to implement the measures. As shown by the Fitness check (Deloitte, 2011) there is often a clear lack of commitment or ambition to properly implement EU water legislation. For example, the Urban Waste Water Directive is not fully implemented even after two decades since it came into force.

Further, it is stated that greater efforts are needed to deliver improved coherence. For example, past reforms of the CAP have increased the importance of environmental protection within the overall policy framework of the CAP. Nonetheless, a number of key pressures and impacts arising from farming practice throughout Europe continue to influence the quality and availability of water. Considering these lessons learned, and the time horizon until climate change will outweigh socio economic impacts, it is most likely that the main barrier for adaptation will be due to socio-cultural, institutional and political capacity. This barrier can be partly overcome by increasing capacity in all areas of policy making and the general public. In addition, another option to overcome this problem is to develop a clearer hierarchy of policies that are consequently implemented. This hierarchy will ultimately determine the direction in which the EU will go—Economy First or Sustainability Eventually.

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Annex

The content of the Annex is as follows:

Annex 1 - Data processing

Annex 2 - Model descriptions

Annex 3 - DPSIR tables

Annex 3A is provided as a separate file: “Annex3A_DPSIR_for_IAF.xls”

Annex 3B is provided as a separate file: “Annex3B_DPSIR_total.xls”

Annex 4 – Scenarios and main drivers

Annex 5 - Applying a CGE methodology for the EU to assess GDP implications of flooding

Annex 6 - Documentation of the ClimWatAdapt databases

Annex 7 - Inventory of adaptation measures

Annex 7 is provided as a separate file: “Annex7_inventory_2011_10_28_final.xls”

Annex 8 – IAF for decision making. Applying mDSS

Annex 9 - Assessment criteria and evaluation of adaptation measures

Annex 10 – Vulnerability assessment. Methods and calculations

Annex 11 – Assessment of adaptation measures: fact sheets

Annex 12 - Minutes of the Stakeholder Workshops

Annex 12a: minutes of 1st stakeholder workshop

Annex 12b: minutes of 2nd stakeholder workshop

Annex 13 - Minutes of the Expert Meetings

Annex 13a: minutes of the 1st expert meeting

Annex 13b: minutes of the 2nd expert meeting

Annex 13c: minutes of the 3nd expert meeting

The “xls”-files are separated