European Commission

Multi-criteria hydro-economic optimisation of water resources in Europe

supporting the EU Blueprint to safeguard Europe's waters & the Danube Strategy

Prof. Dr. Ad de Roo[1,2], Dr. Giovanni Bidoglio[1], et al.

[1]European Commission, Joint Research Centre
[2]Faculty of Earth Sciences, Utrecht University

Fresh water: too much (floods), too little (droughts), but always essential

Germany: 8 Billion Euro (2013)
11.6 Billion Euro (2002)

Floods

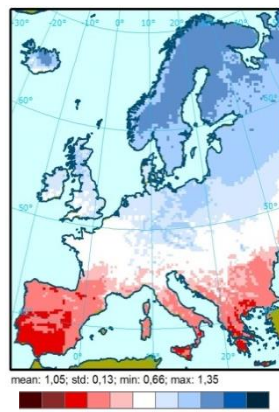
Droughts

Drought & Heatwave 2003:
13 Billion Euro

Agriculture

Industry & Transport

Climate change



Environment

Energy

Changing demands

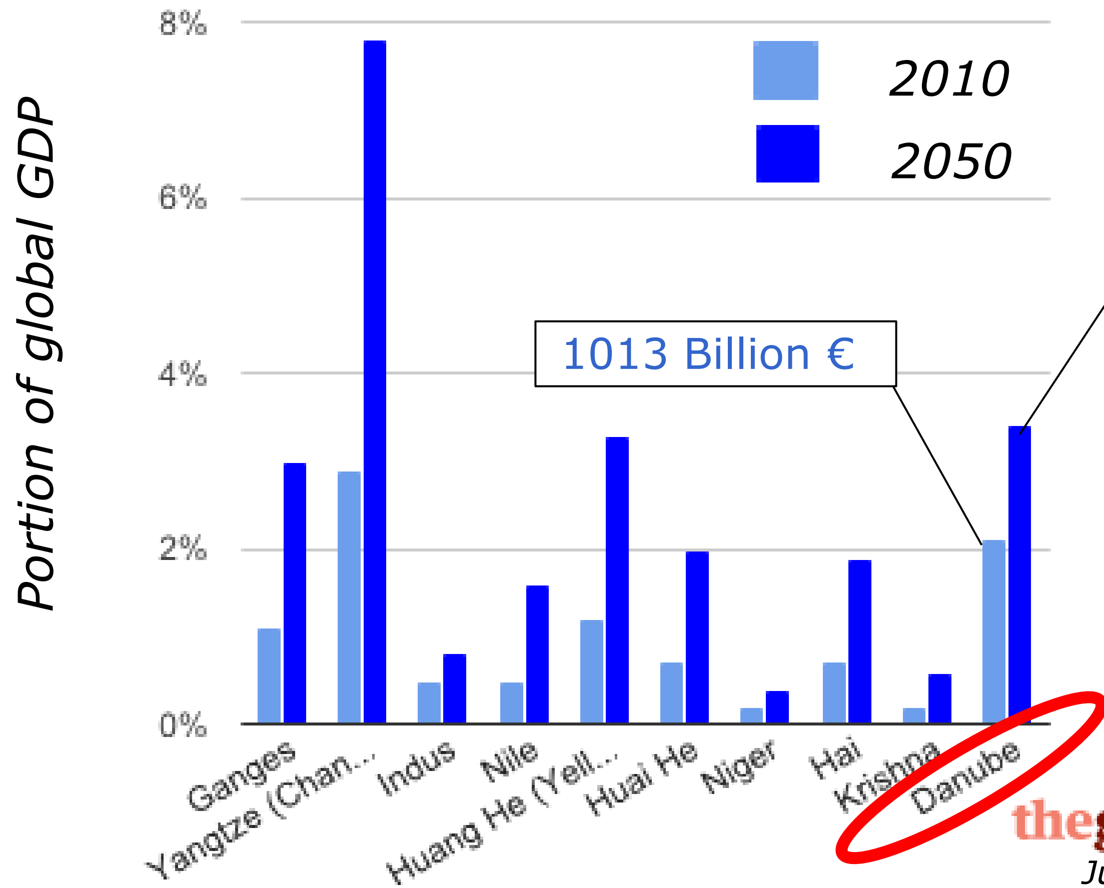
Recreation / Tourism

Human Consumption

Water as opportunity for growth

European Commission

By 2050, economic output of the 10 world's most populated river basins will exceed that of the USA, Japanese and German economies combined, but only if water scarcity is addressed



Sources:

HSBC

theguardian
June 2012

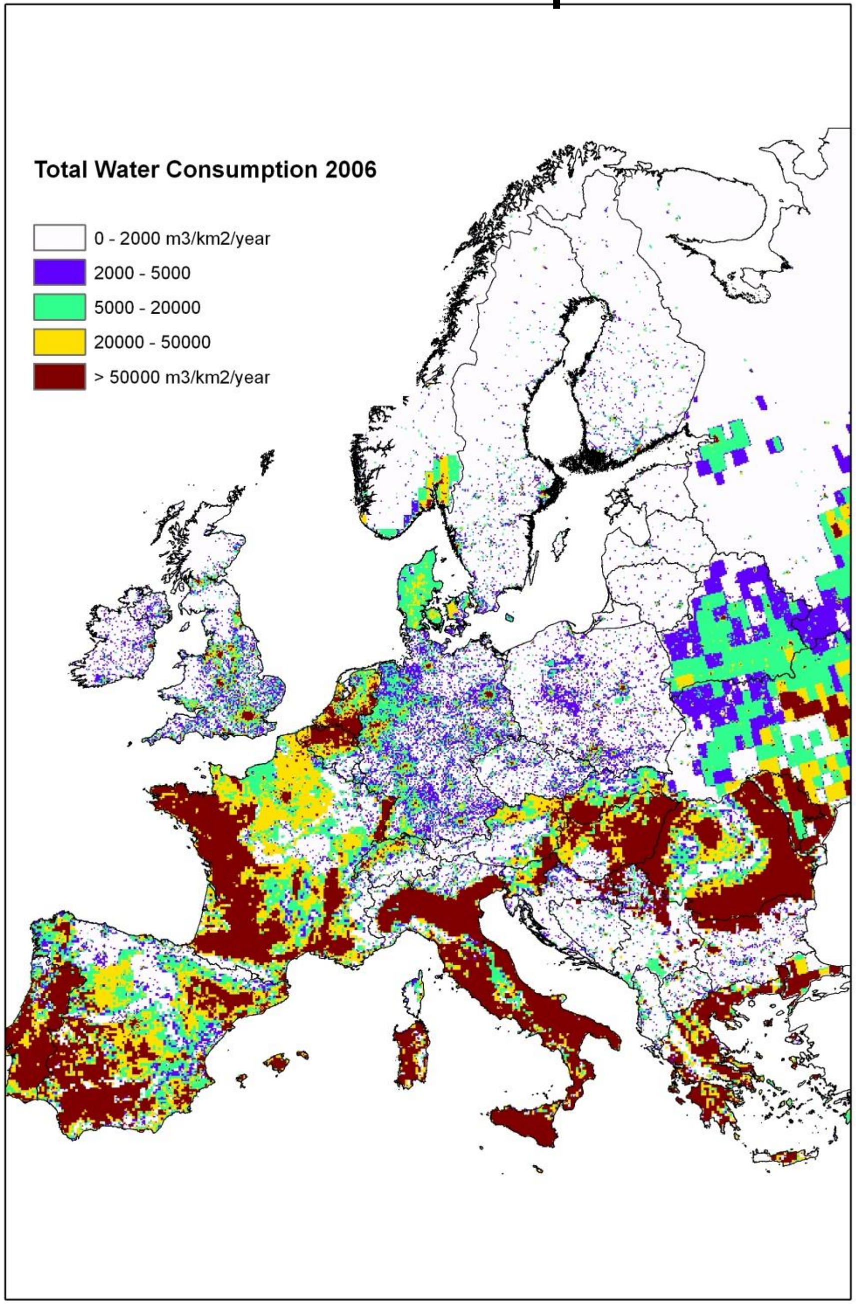
frontier economics

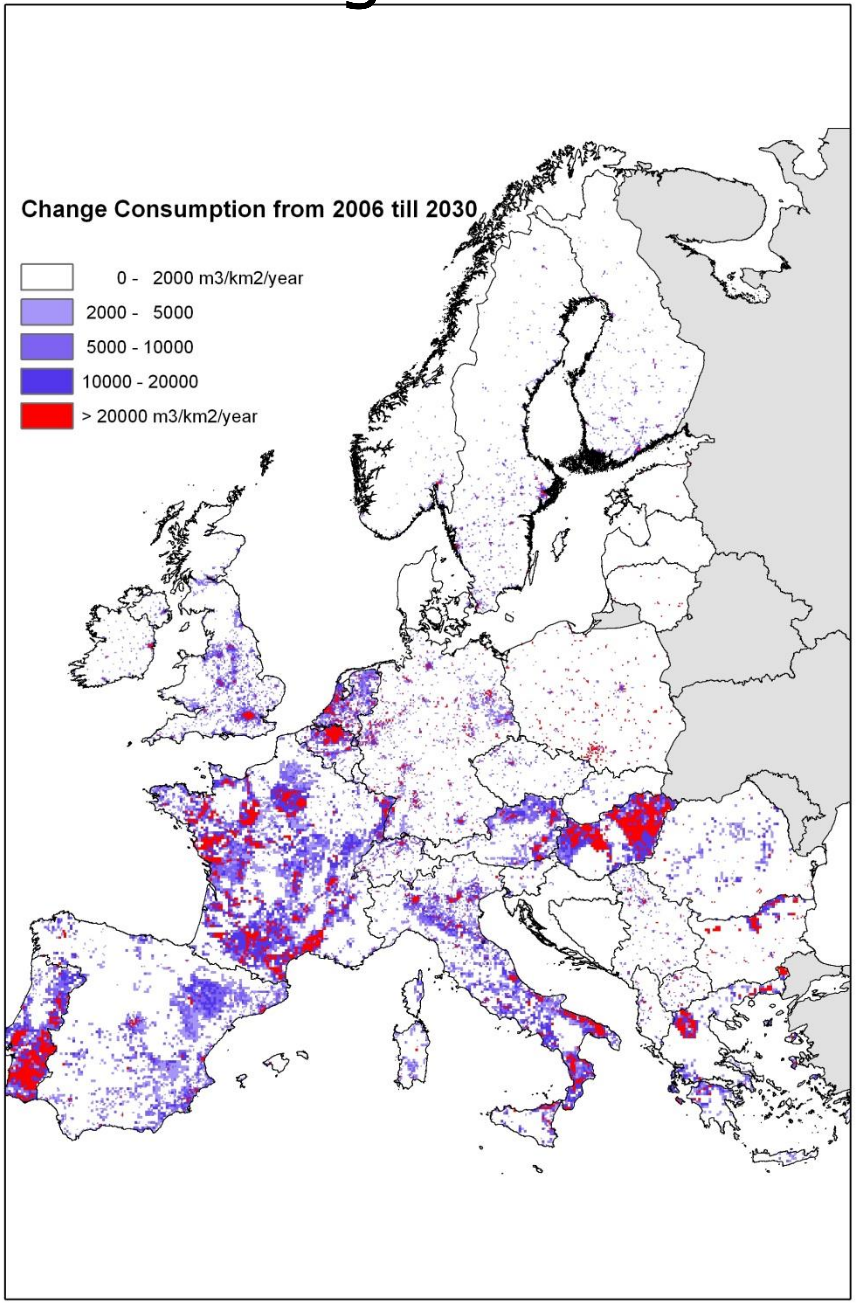
European Commission

Grand challenge:

Match water demand with supply

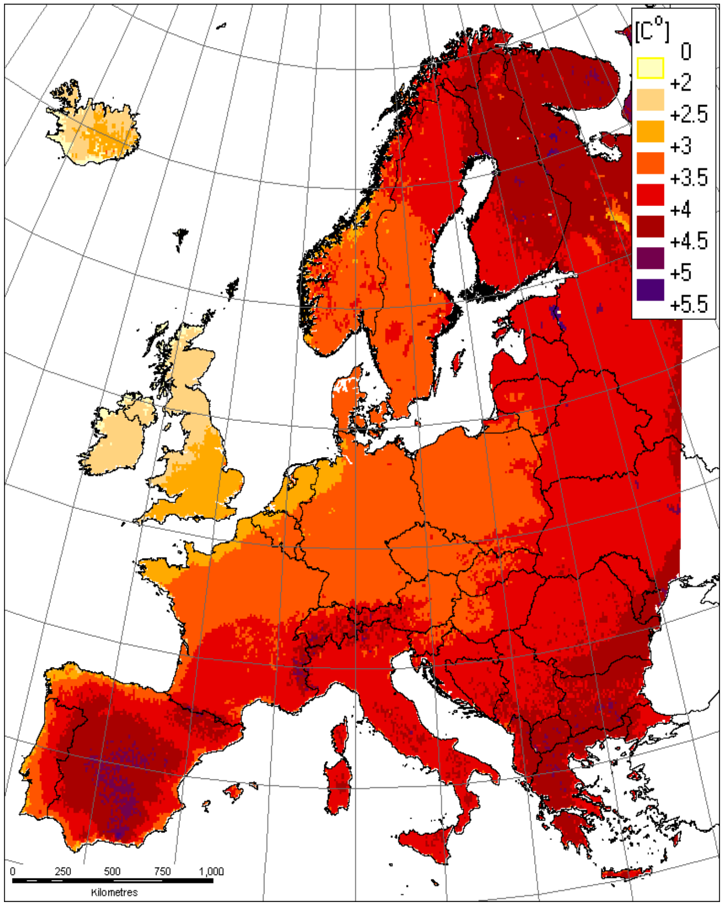
Water consumption 2006 and changes until 2030



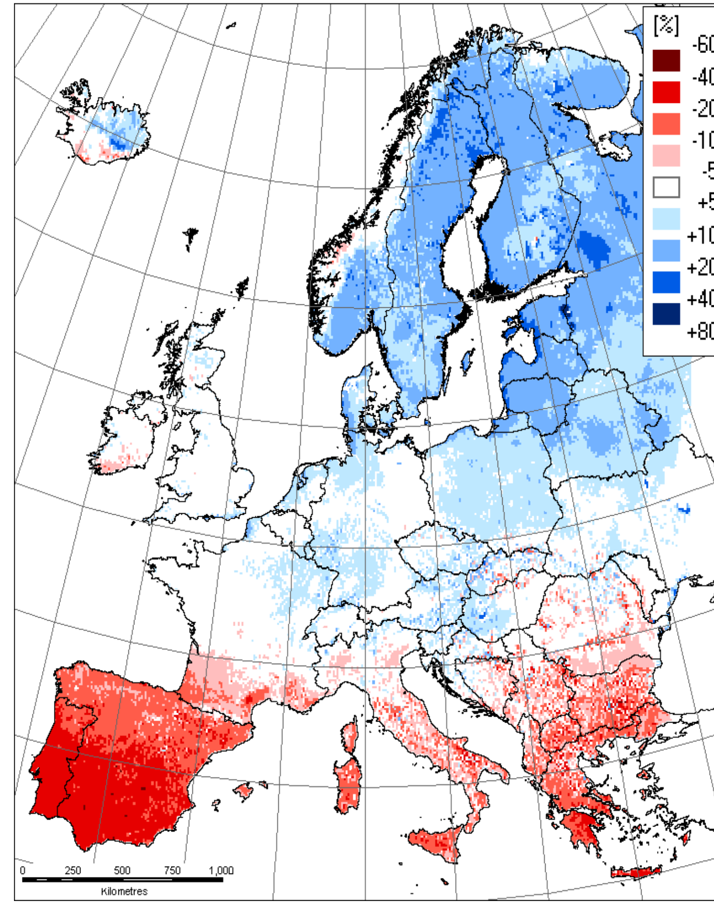


Not only society changes, but the climate changes as well....

Temperature: change in mean annual temperature [C°]

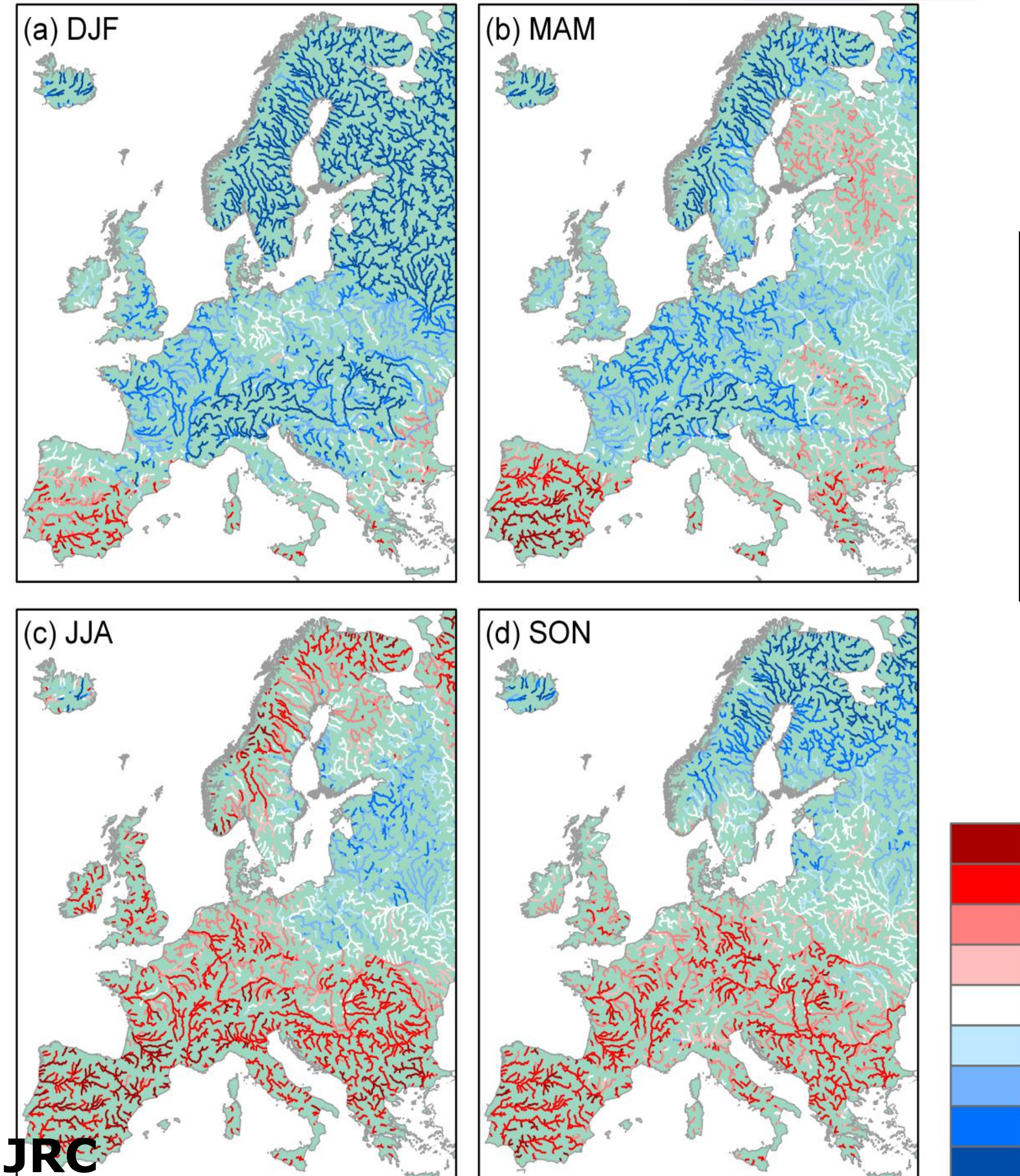


Precipitation: change in annual amount [%]



Expected changes in average temperature and annual precipitation 2070-2100 as compared to 1960-1990

Climate change effects on river flow:
hydrological model simulations with bias-corrected climate scenarios forcing



changing amounts of available water, with regional and seasonal variations

Increase of river flow in winter and spring in Central and N-NE Europe

Decrease of summer discharge, everywhere except NE Europe

Decrease in ALL seasons in Spain, Portugal, Southern Italy, Greece

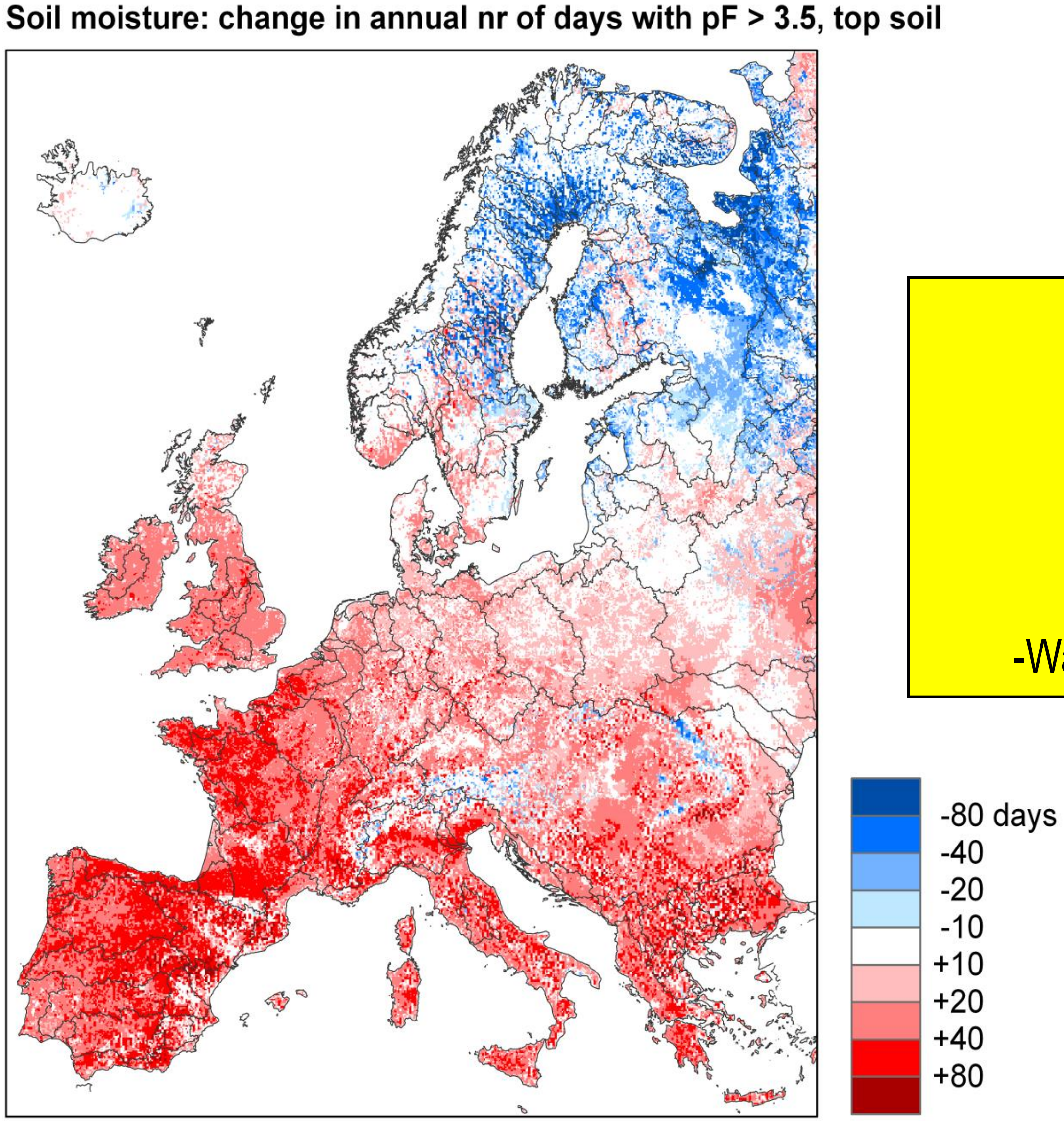
Consequences:

- Flood Hazard

- River Transport (low flows)

- Hydropower (energy production)

Climate change effects on soil moisture: changing # of days/year with extreme dry soils (pF >3.5)



Consequences:

-Agriculture

-Forest Fire Hazard

- Environment

-Water Availability (scarcity)

2012 EU Water Blueprint: The water milestone in the 2020 Roadmap to a Resource Efficient Europe


EUROPEAN COMMISSION

Brussels, 14.11.2012
SWD(2012) 381 final

COMMISSION STAFF WORKING DOCUMENT

EXECUTIVE SUMMARY OF THE IMPACT ASSESSMENT

Accompanying the document

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

A Blueprint to Safeguard Europe's Water Resources

Ensure sufficient availability of good quality water for sustainable and equitable water use

- Efficient water use
- Resilience to extreme events
- Good Ecological Status

- Integration
- Economic instruments
- Governance
- Knowledge base

https://dl.dropbox.com/u/21190688/EUR25551EN_JRC_Blueprint_NWRM.pdf

https://dl.dropbox.com/u/21190688/EUR25552EN_JRC_Blueprint_Optimisation_Study.pdf

European Commission

European Commission

JRC SCIENTIFIC AND POLICY REPORTS

Evaluation of the effectiveness of Natural Water Retention Measures

Support to the EU Blueprint to Safeguard Europe's Waters

Peter Burek, Sarah Mubareka, Rodrigo Rojas, Ad de Roo, Alessandra Bianchi, Claudia Baranzelli, Carlo Lavalle, Ine Vandecasteele

2012

Report EUR 25551 EN

Joint Research Centre

European Commission

JRC SCIENTIFIC AND POLICY REPORTS

A multi-criteria optimisation of scenarios for the protection of water resources in Europe

Support to the EU Blueprint to Safeguard Europe's Waters

Ad de Roo, Peter Burek, Alessandro Gentile, Angel Udias, Faycal Bouraoui, Alberto Aloe, Alessandra Bianchi, Alessandra La Notte, Onno Kuik, Javier Elorza Tenreiro, Ine Vandecasteele, Sarah Mubareka, Claudia Baranzelli, Marcel Van Der Perk, Carlo Lavalle, Giovanni Bidoglio

2012

Report EUR 25552 EN

Joint Research Centre

Aim of EC/JRC studies:

Aim is to stimulate EU countries to increase the efficiency of water use by 2020/2030, e.g:

- **Increasing irrigation water efficiency**
- **Increasing water savings in households**
- **Water re-use in industry/agriculture, etc**

& explore pro's and con's of other options:

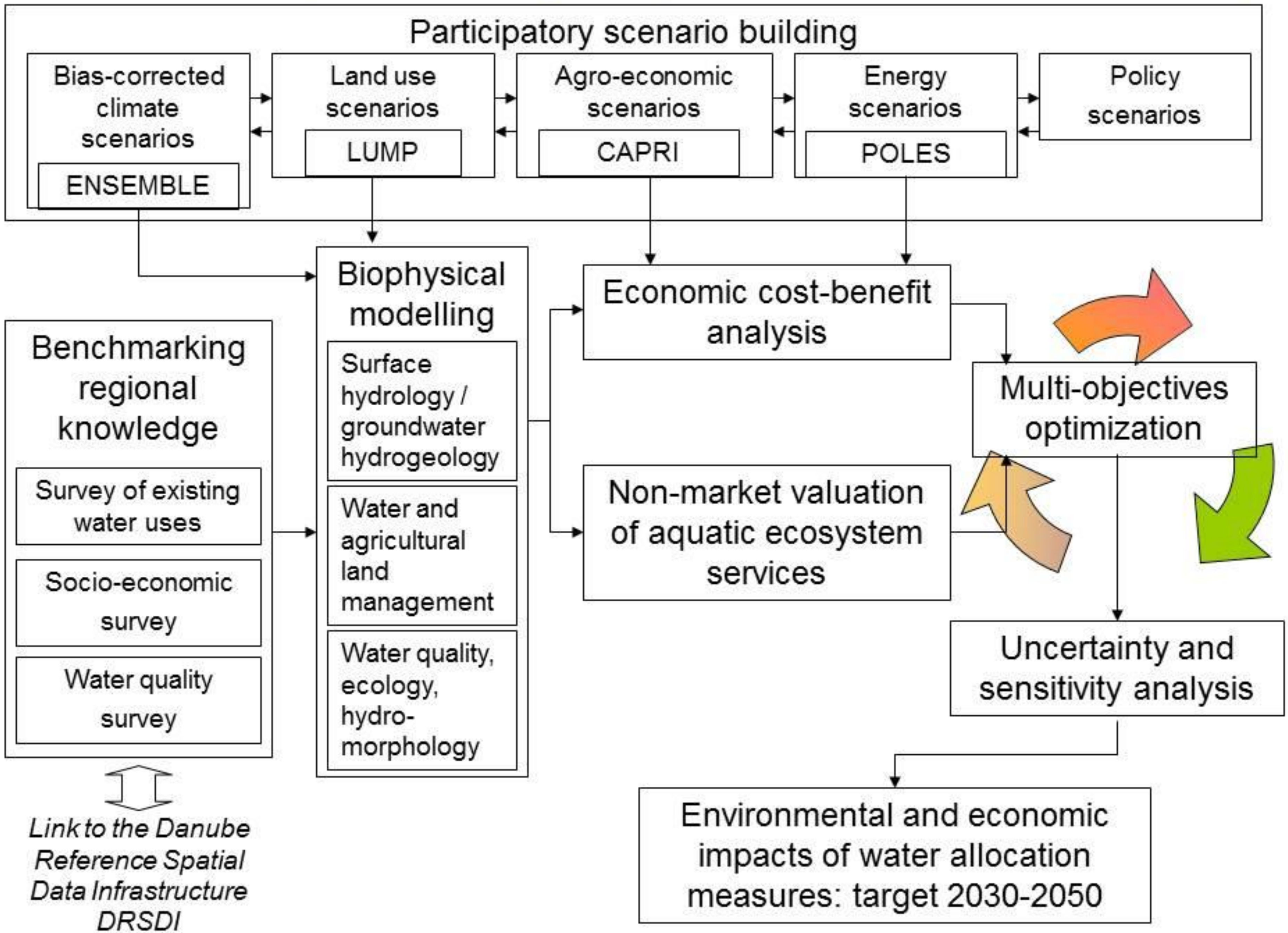
- **Desalination**
- **Reducing leakage from water supply**
- **Large distance water transfers between basins**
- **Water pricing**

& and at the same time:

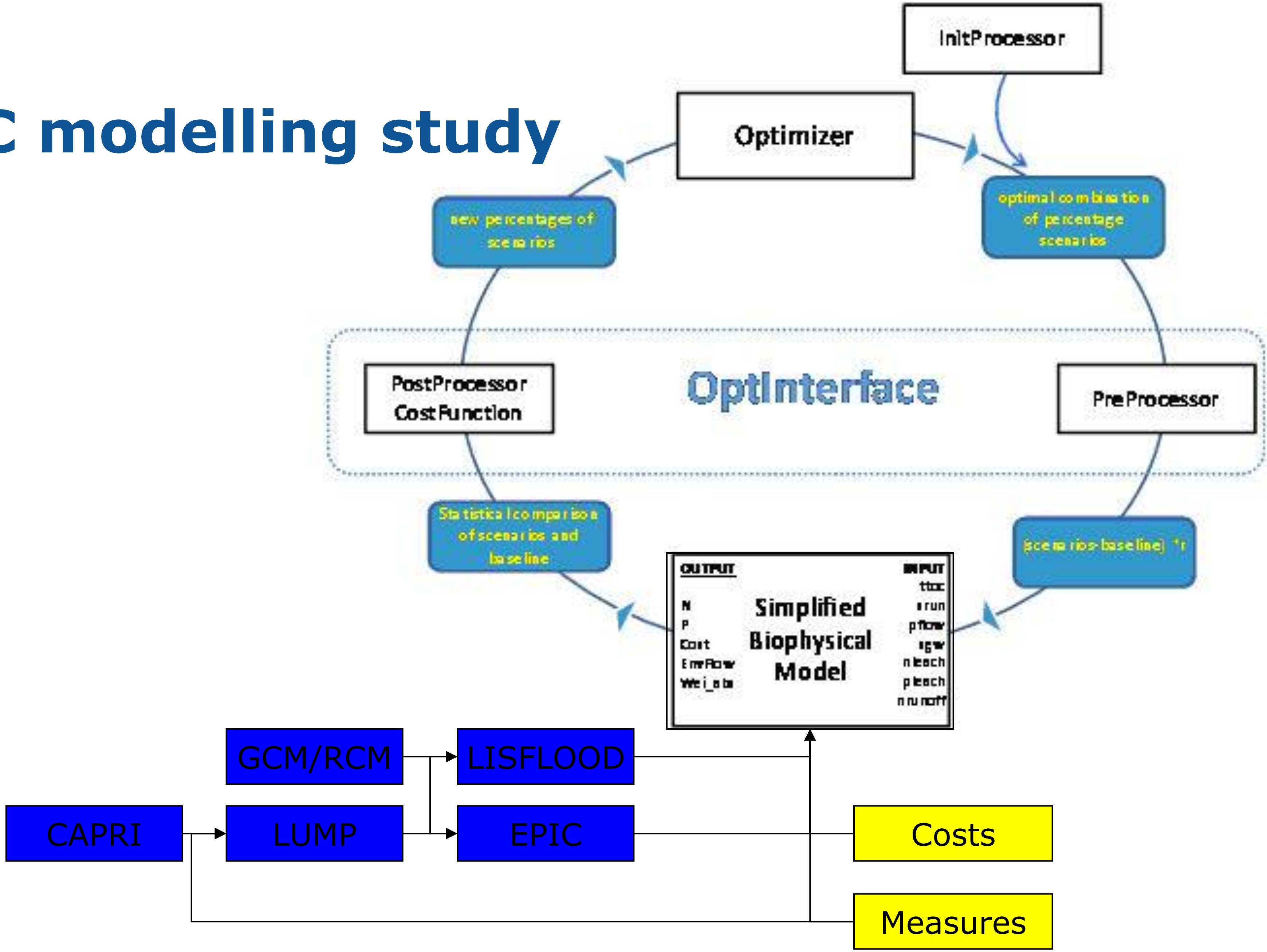
- **Reduce flood risk, if possible through natural water retention measures**
- **Have sufficient water for all economic sectors**
- **Respect 'environmental flow' conditions**
- **Maintain 'good ecological status' (WFD)**
- **Take into account costs & benefits**

& while respecting & taking into account:

- **Common Agricultural Policy & crop yield targets (CAPRI)**
- **Expected population growth and economic growth (LUMP)**


Participatory scenario building
Bias-corrected climate scenarios
ENSEMBLE
Land use scenarios
LUMP
Agro-economic scenarios
CAPRI
Energy scenarios
POLES
Policy scenarios
Benchmarking regional knowledge
Survey of existing water uses
Socio-economic survey
Water quality survey
Link to the Danube Reference Spatial Data Infrastructure DRSDI
Biophysical modelling
Surface hydrology / groundwater hydrogeology
Water and agricultural land management
Water quality, ecology, hydro-morphology
Economic cost-benefit analysis
Non-market valuation of aquatic ecosystem services
Multi-objectives optimization
Uncertainty and sensitivity analysis
Environmental and economic impacts of water allocation measures: target 2030-2050

JRC modelling study



JRC LUMP Land Use Modelling Platform

European Commission

using the land use model Eu-ClueScanner (JRC)

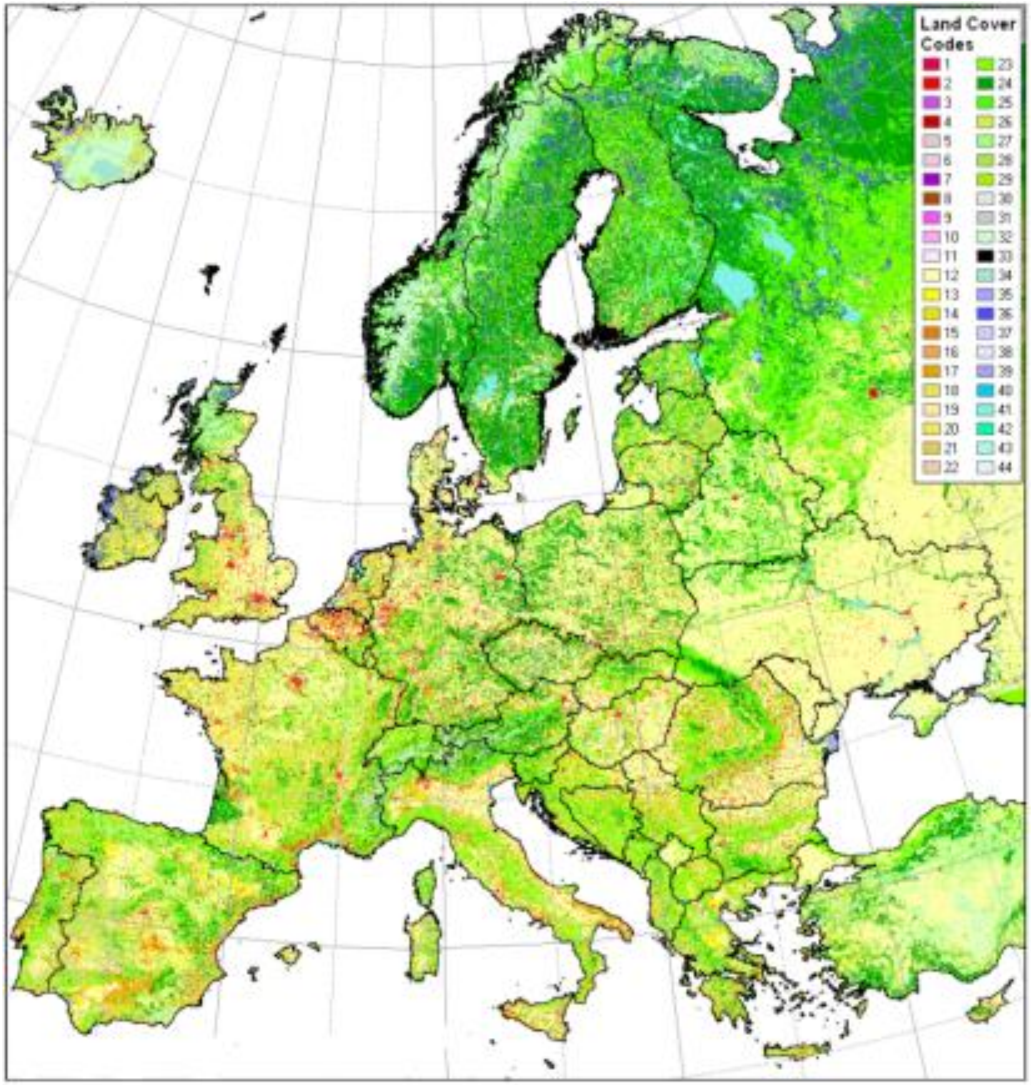
Land use / land cover change scenarios until 2030

Common Agricultural Policy (CAP) consistent (using CAPRI boundary conditions for 2030)

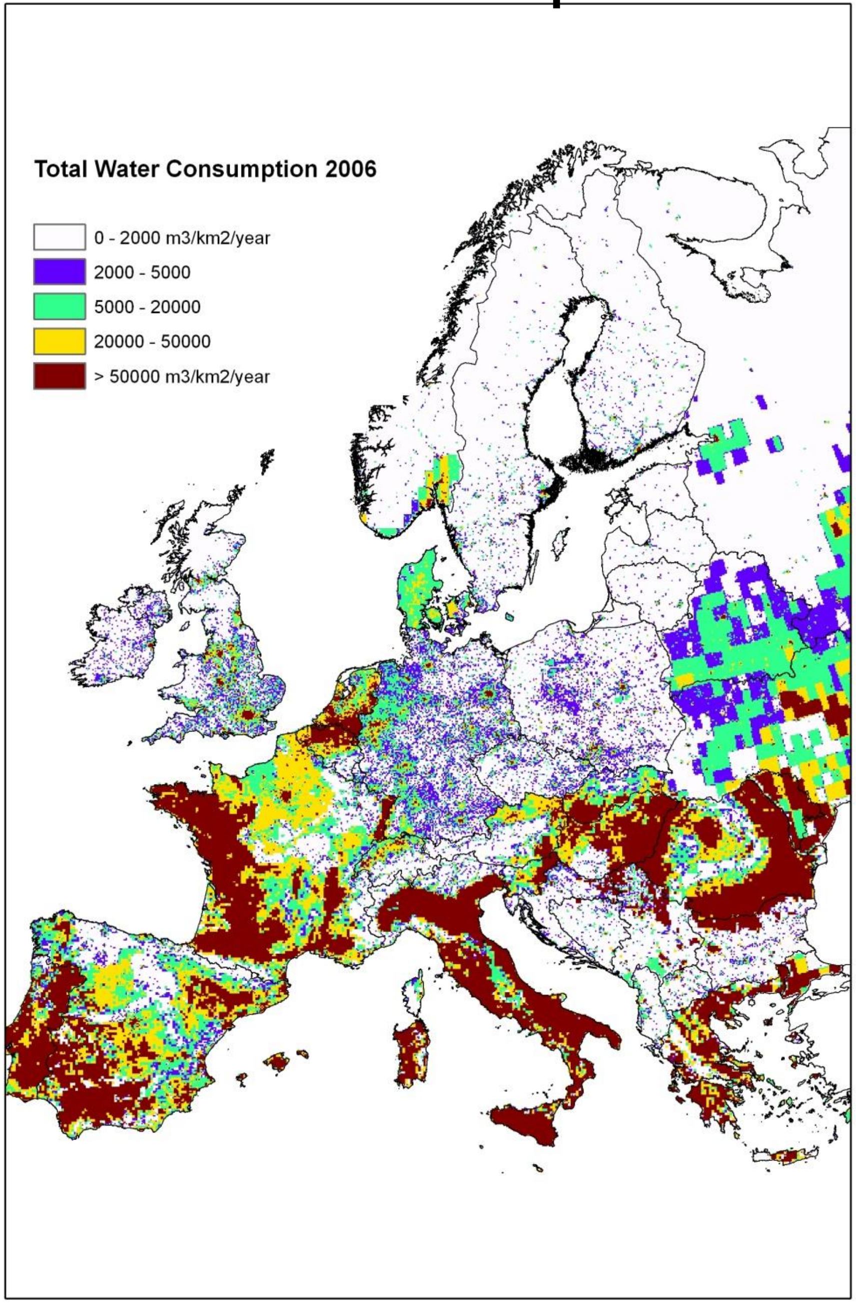
Socio-Economic data used from Eurostat

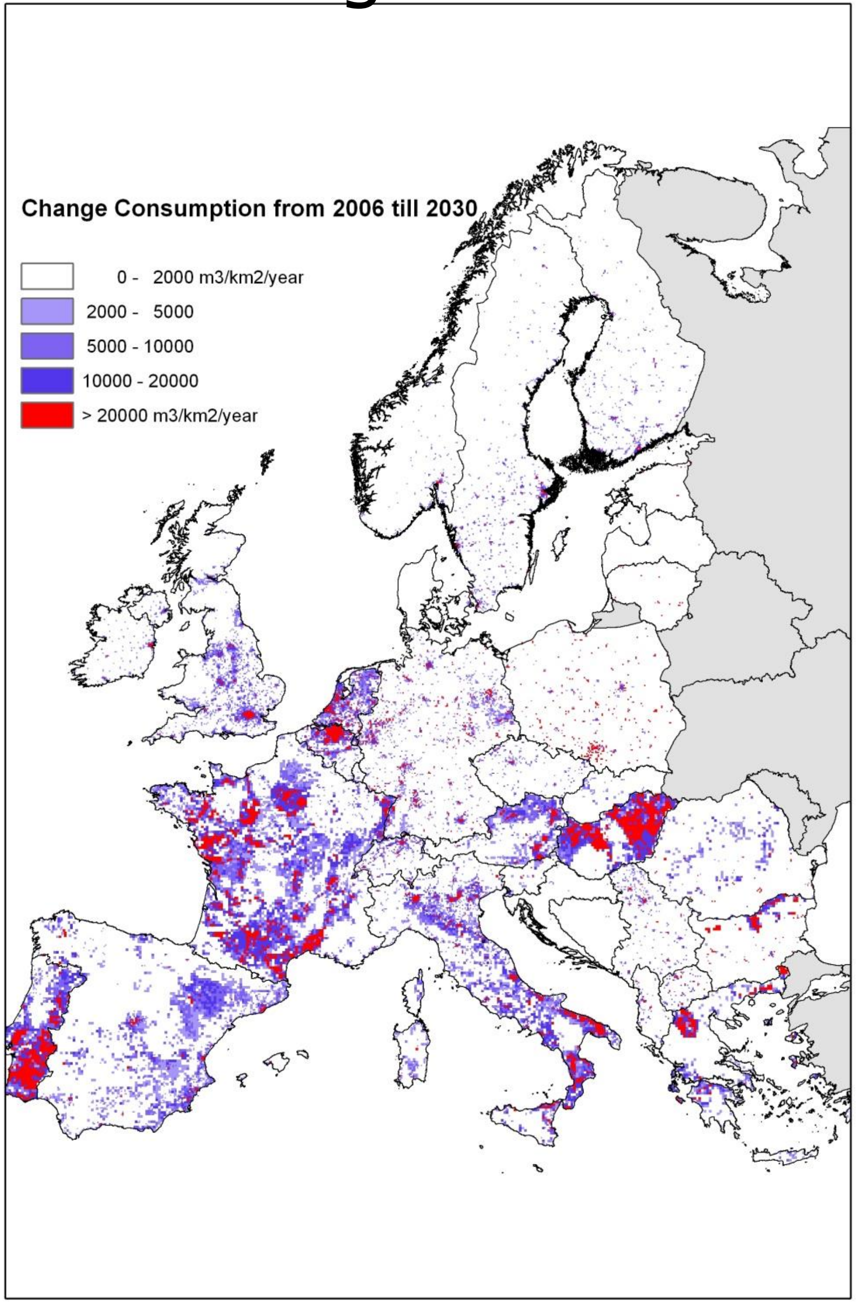
100m spatial resolution

Pan-European

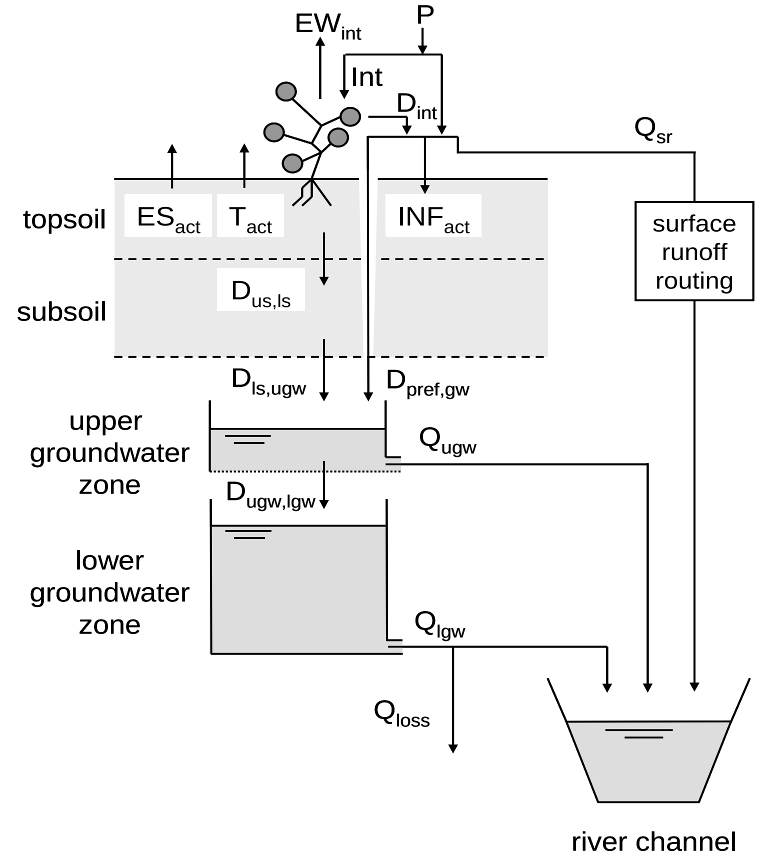


Water consumption 2006 and changes until 2030



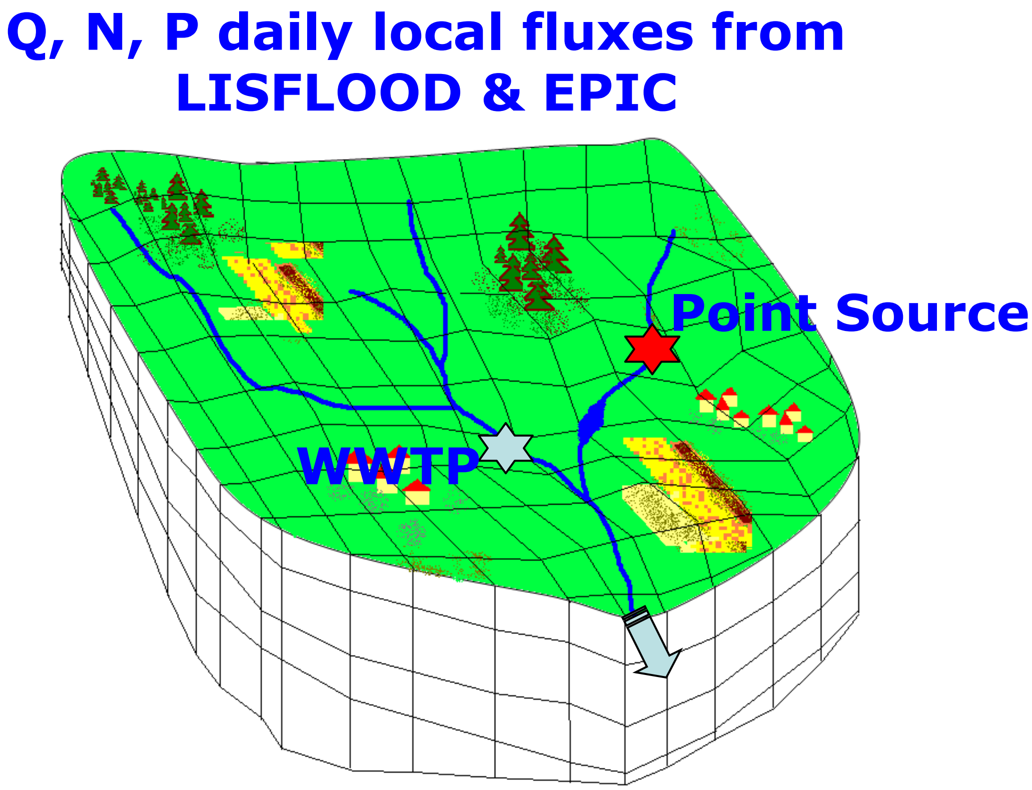


Hydrological model LISFLOOD



The LISQUAL model

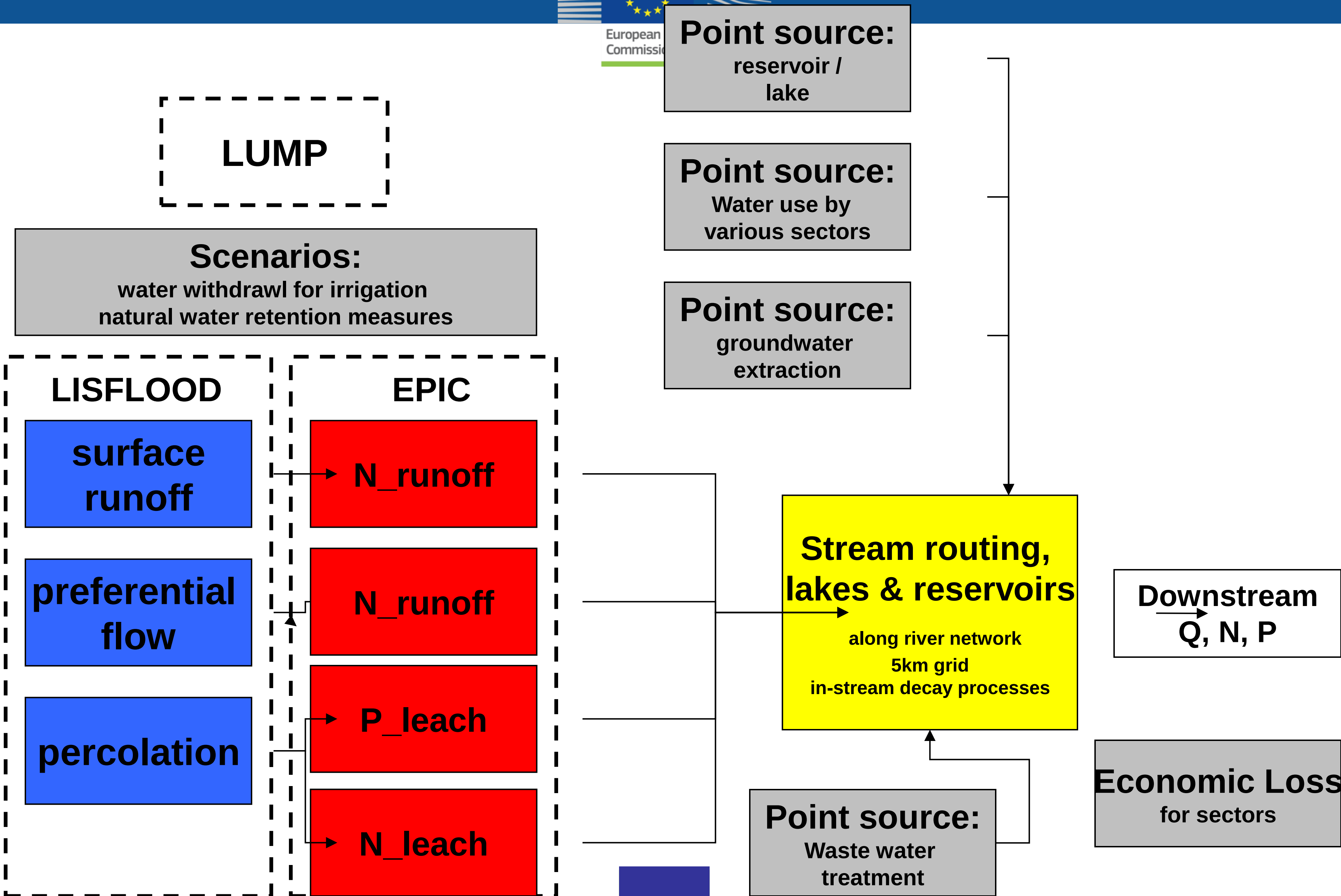
distributed routing model for Q, N and P, with decay functions and point sources, water scarcity indicators, and including functions to estimate monetary loss due to water scarcity



Spatial resolution : 5 x 5 km for Europe (with sub-grid info)

Calibration parameters are uniform over each sub-basin

LISQUAL bio-physical model



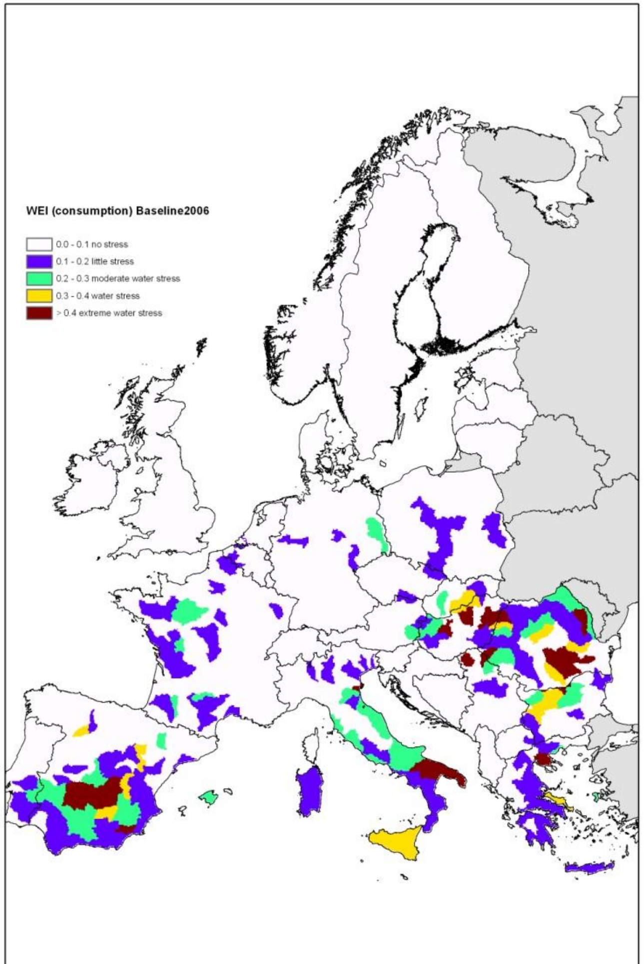
Example LISQUAL outputs

- **River discharge (daily, m3/s, spatial)**
  - flood damage (using 100m SRTM & landuse in post-processing)
- **Nitrate concentration (daily, mg/l, spatial)**
- **Phosphorous concentration (daily, mg/l, spatial)**
- **Environmental Flow indicator (daily, spatial)**
  - 10^{th} percentile monthly flows (spatial)
  - 25^{th} percentile monthly flows (spatial)
- **Water Exploitation Index (1 Oct – 1 Oct) (annual, regions)**
  - abstraction / available water
  - consumption / available water
- **Economic Loss (annual, million Euros, regions)**
  - domestic sector
  - industry/manufacturing sector
  - energy sector
  - irrigation

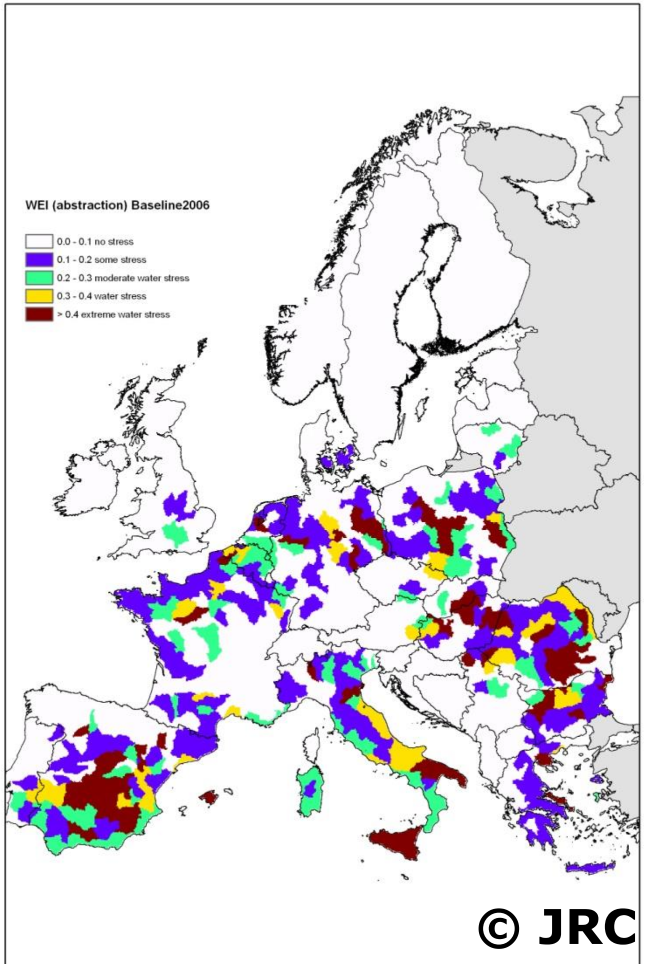
LISQUAL output: Water Exploitation Index

WEIcns= (Abstraction – ReturnFlow) / (Local runoff + Incoming runoff)

WEIcns (WEI+, consumption only)



WEIabs (abstraction only)



Scenarios (1)

Category	Scenario	Description
BASELINE2030	0.0 Baseline 2030	LUMP 2030, 2010 fertilisation application, 2010 point sources
BASELINE2006	0.1 Baseline 2006	As Baseline 2030, but with Landuse 2006
1-FOREST	1.1 Riparian Afforestation, CAP consistent	Afforest areas from LUMP-CAP scenarios
	1.2 Afforestation in mountainous areas	Afforest areas in mountainous areas (LUMP)
2-URBAN	2.1 50% Green	Green infrastucture, Green roofs, Rain Gardens, Park Depressions; For all urban areas: Direct Runoff Fraction << 50%, Evapotanspiration >> 50%
	2.2 25% Green	Green infrastucture, Green roofs, Rain Gardens, Park Depressions; For all urban areas: Direct Runoff Fraction << 25%, Evapotanspiration >> 25%
3-AGRICULTURE	3.1 Grassland	Convert areas from LUMP-CAP scenarios to grassland
	3.2 Buffer strips	5m wide grass buffer strips within arable fields, on slopes < 10%, every 200m; 2.5% of arable land converted to grassland, only on slopes < 10%
	3.3 Grassed waterways	10m wide grass-covered areas in valley-bottom; 1% of arable land converted to grassland, in valley-bottoms > 5%
	3.4 Crop practicies	Reverse OM decline and increase mulching; increased infiltration, porosity, modified hydraulic parameters
4-NATURAL RETENTION	4.1 Wetlands	Riparian wetlands along rivers; Change cross section
	4.2 Polders	Introduce flood retention polders along rivers
	4.3 Re-meandering	
	4.4 Buffer ponds in headwater areas 1	natural retention ponds in headwater areas with 5000 m3 storage per 25km2
	4.5 Buffer ponds in headwater areas 2	natural retention ponds in headwater areas with 10000 m3 storage per 25km2
5-NUTRIENTS	5.1 N-fixing winter crops	updated N & P fluxes
	5.2 optimum fertilisation application	updated N & P fluxes

Scenarios (2)

European

Category	Scenario	Description
6-POINT SOURCES	6.1 New wastewater treatment plants (WWTP)	updated point information
	6.2 Changing type of WWTP	updated point information
7. WATER SUPPLY	7.1 groundwater extraction	updated point water availability
	7.2 desalination	updated point water availability
	7.3 large-scale water-transfer infrastructures	transfer of water between river basins
8. TECHNICAL RETENTION	8.1 constructing dams and reservoirs	new dams/resoirvoir to temporarily store water
	8.2 hard infrastructure for flood risk	
9. EFFICIENCY	9.1 Irrigation management	optimizing crop water requirements
	9.2 Water efficiency in power generation	Save water in power generation, as compared to current use
	9.3 Water efficiency in industrial processes	Save water in industry, as compared to current use
	9.4 Water efficiency in Buildings/households	Save water in households, as compared to current use
	9.5 Leakage reduction 9.6 Wastewater reuse for irrigation	Fix all leakages 90% or 100% (reduce water abstraction) Reduce deep groundwater use for irrigation and replace by treated wastewater

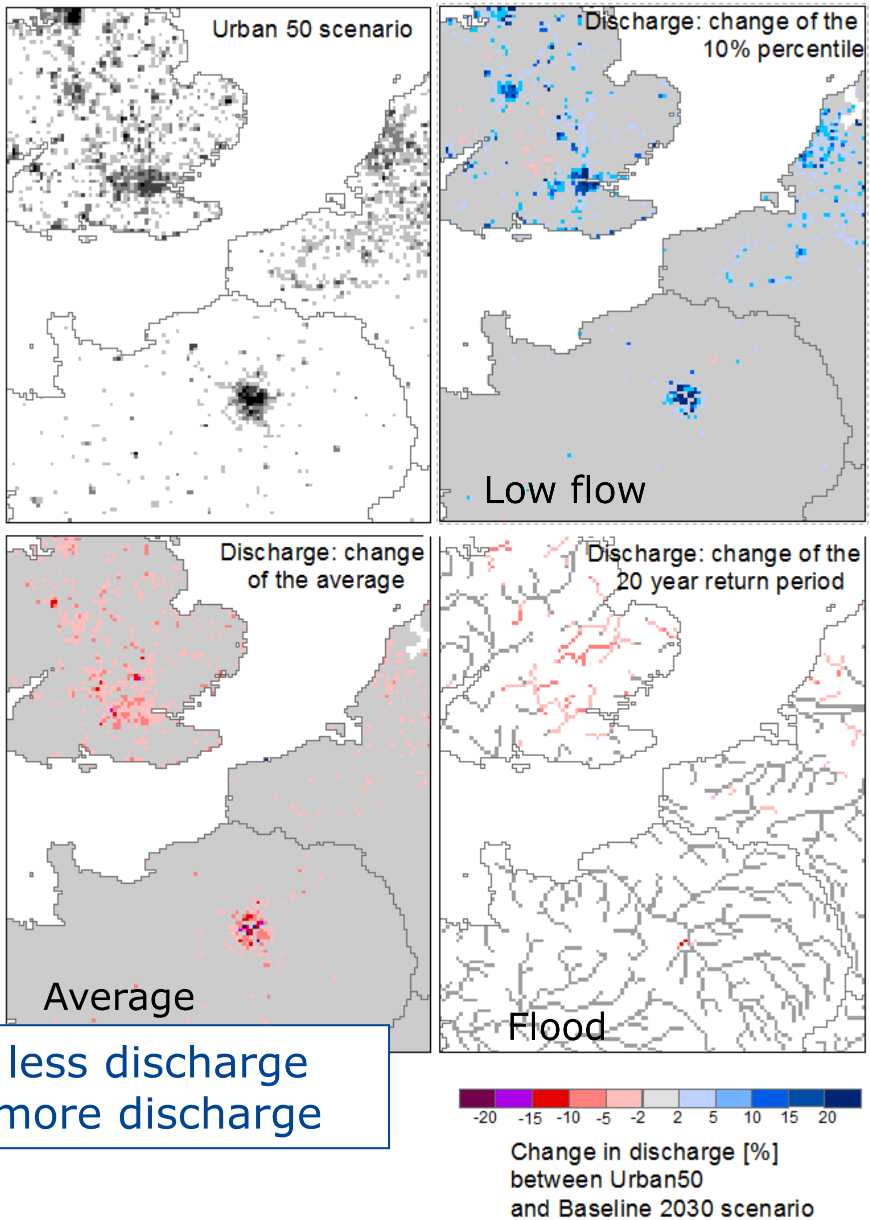
Scenario Green cities

Difference between green cities scenario and baseline 2030

Looking at the local impact:

- low flow increases locally up to 40%

- Average discharge and floods decrease locally up to 20%



Red color: less discharge
Blue color: more discharge

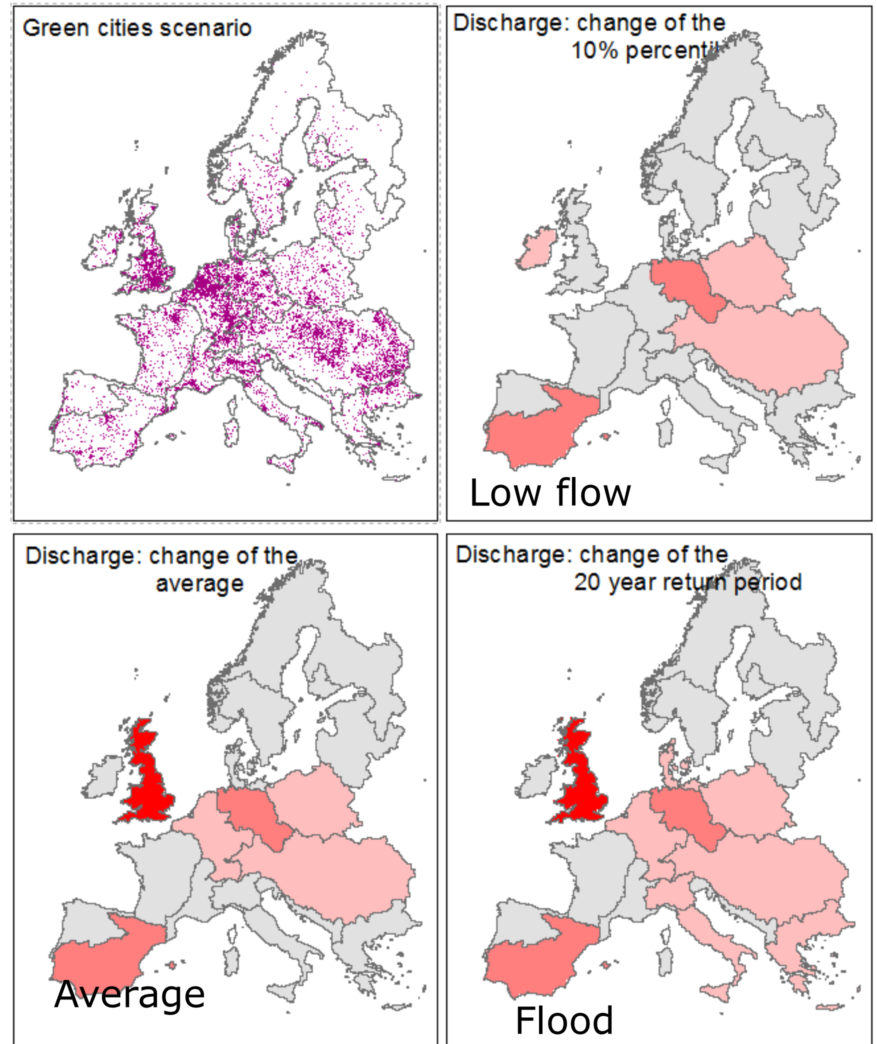
Scenario Green cities

Difference between green cities scenario and baseline 2030

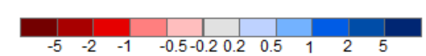
Looking at the average impact for 21 European regions:

•Discharge changes on river basin level due to measures are in the ±2% range

(local higher changes of up to 20% are averaged out)



Red color: less discharge
Blue color: more discharge

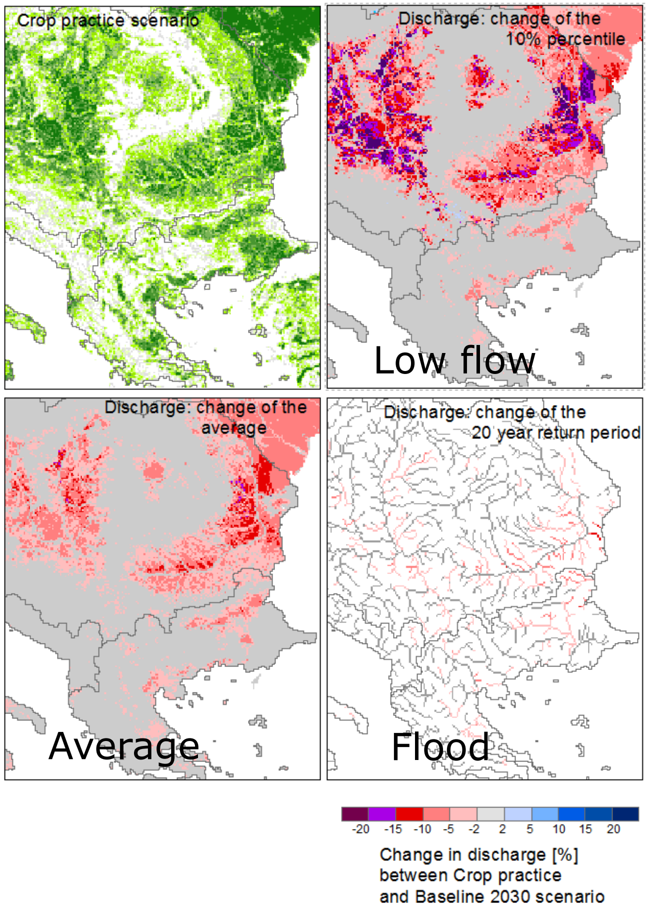


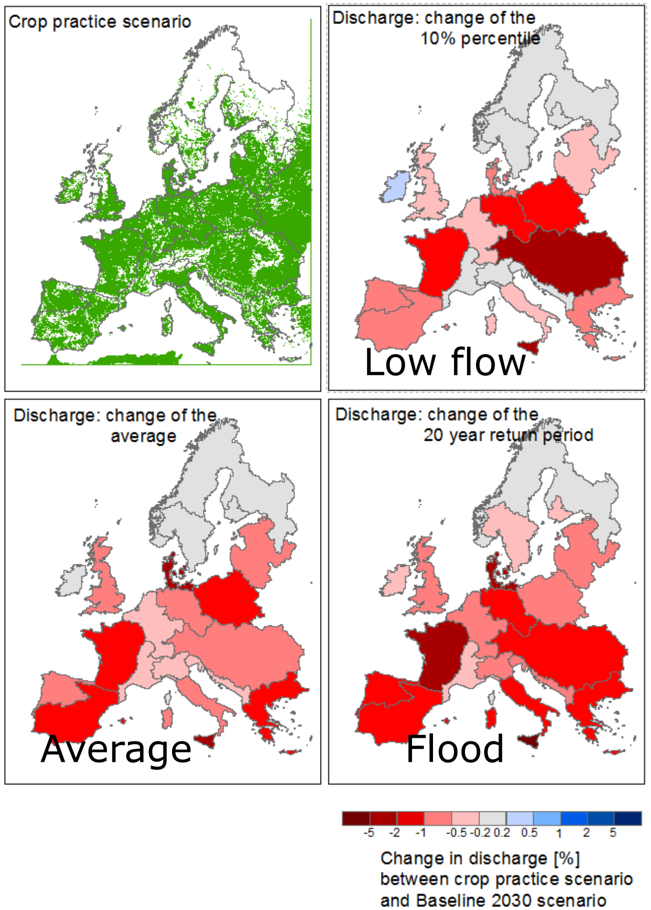
Change in discharge [%] between green cities scenario and Baseline 2030 scenario

Scenario: changing crop practices

European Commission

Reducing organic matter decline / mulching / tillage methods

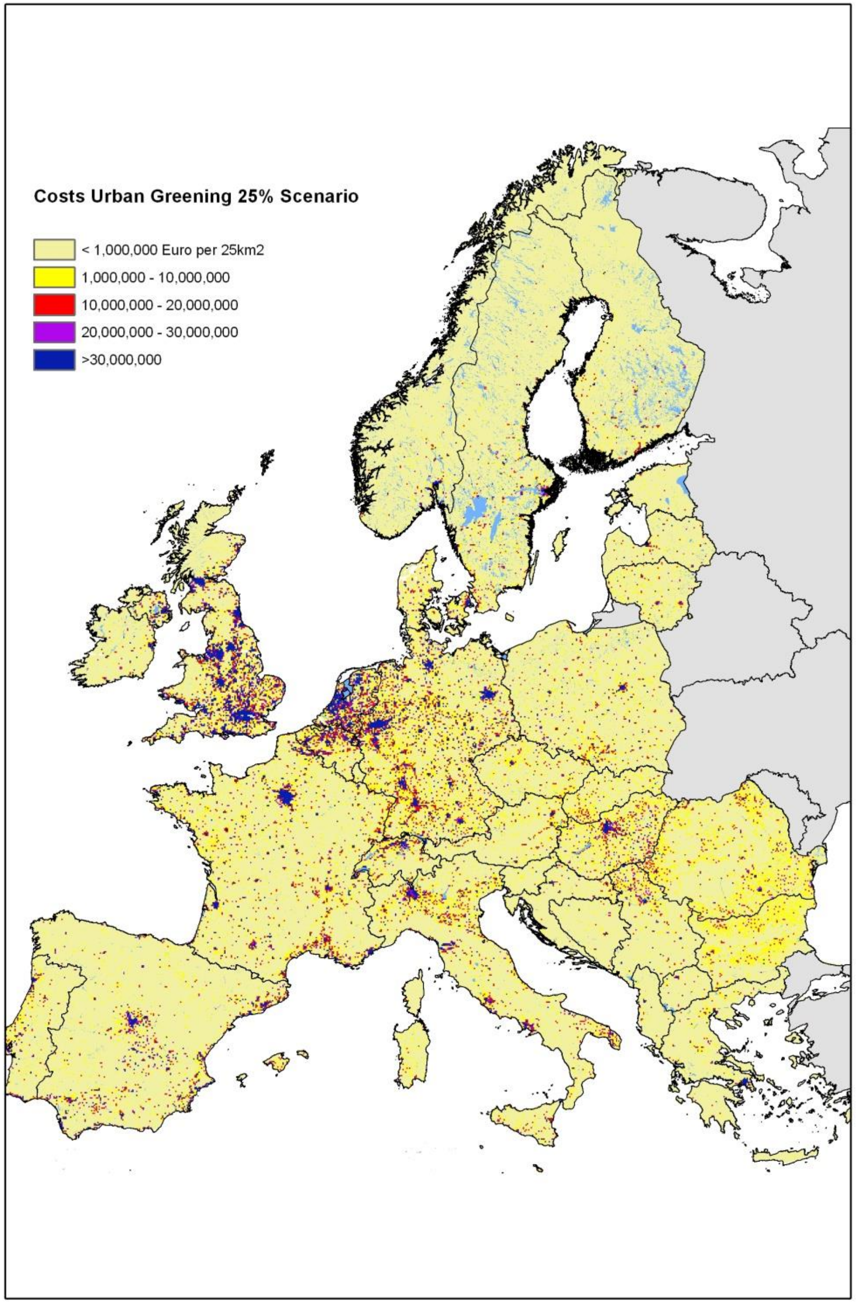


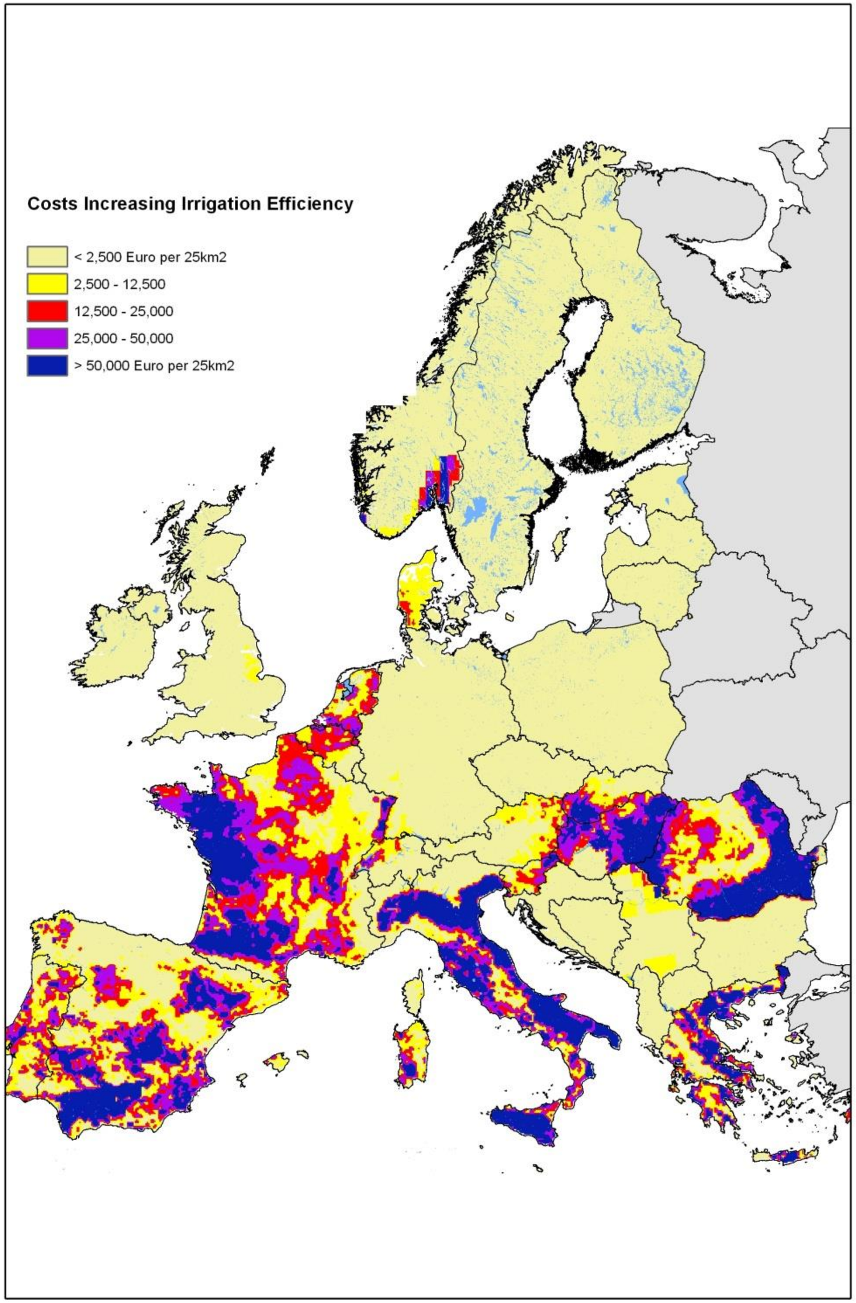


Low flows are reduced up to 40%
Floods are reduced up to 20%

On average discharge is reduced up to 5%

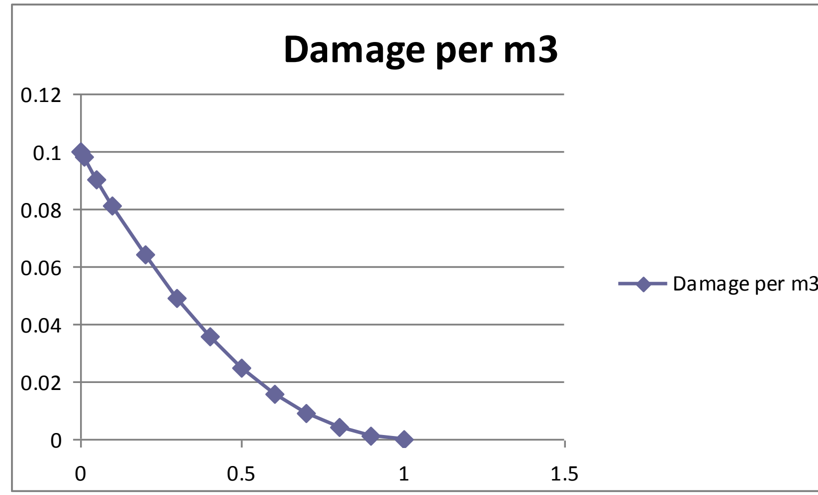
Cost of scenarios





Economic Loss model irrigation

Total water delivered	2.00E+06	m3	based on page 13 of C	
Total damage	200000	Euro		
Ratio	1.00E-01	Euro/m3	RealW	2.00E+06
Water delivered Fr	Damage per m3		Water(m3)	Damage(E
0	0.1		0.00E+00	2.00E+05
0.001	0.0998001		2.00E+03	2.00E+05
0.01	0.09801		2.00E+04	1.96E+05
0.05	0.09025		1.00E+05	1.81E+05
0.1	0.081		2.00E+05	1.62E+05
0.2	0.064		4.00E+05	1.28E+05
0.3	0.049		6.00E+05	9.80E+04
0.4	0.036		8.00E+05	7.20E+04
0.5	0.025		1.00E+06	5.00E+04
0.6	0.016		1.20E+06	3.20E+04
0.7	0.009		1.40E+06	1.80E+04
0.8	0.004		1.60E+06	8.00E+03
0.9	0.001		1.80E+06	2.00E+03
1	0		2.00E+06	0.00E+00



Assumptions:
- Ratio delivered water <> value is taken as 0.1
- Quadratic function

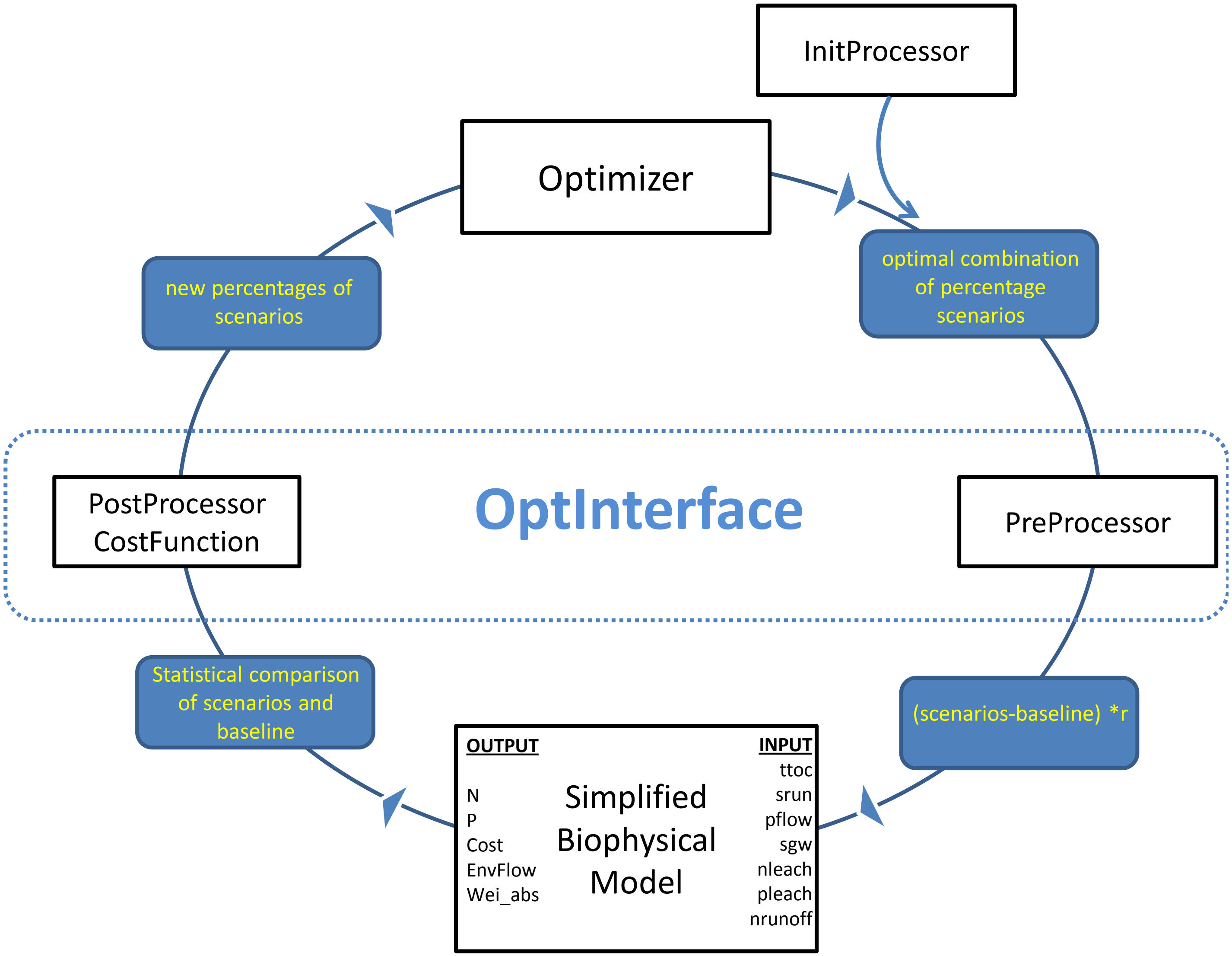
*This results in that for every m3 water that is not available for irrigation, the damage is maximally the **choke price** (0.1 euro in this example)*

So, e.g, if the required amount of water for irrigation area is 1 Mm3, and

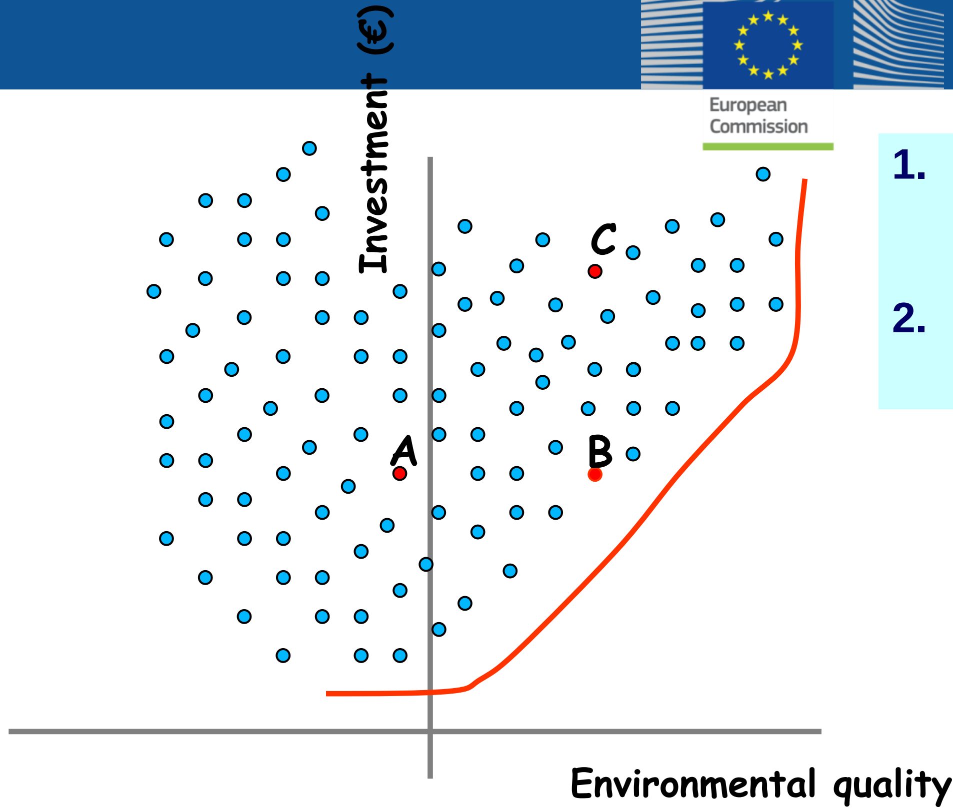
Available water (Mm3)	***Loss (MEuro)***
1.0	*0.0 MEuro*
0.5	*0.025 MEuro*
0.1	*0.081 MEuro*
0	*0.1 MEuro*

Choke price:
0.35 Euro/m3 (low value crops)
1.25 Euro/m3 (high value crops)

Optimization



Multicriteria Optimization



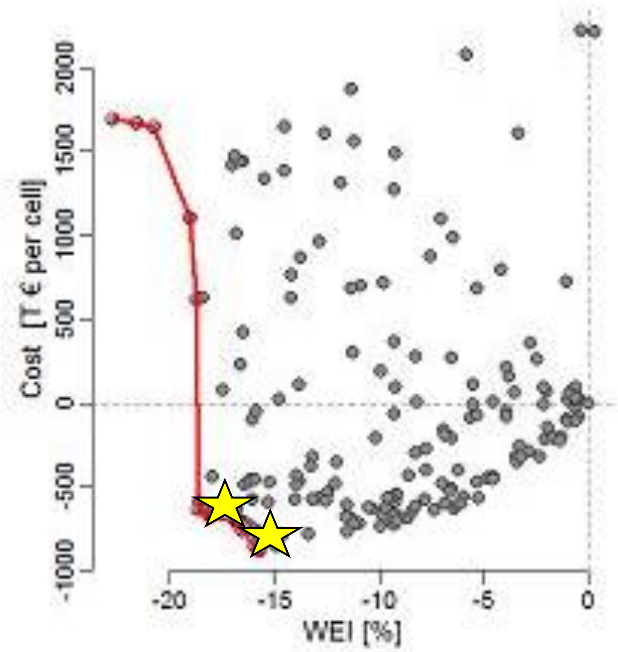
1. Point A and B same investment but point B has better Env. quality – I chose B
2. Point C and B same Env. quality but C needs higher investment – I chose B

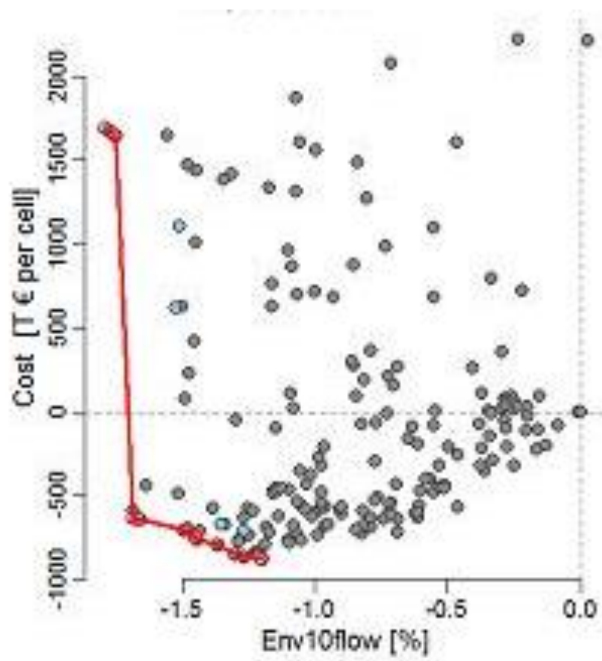
1. Point A is better choice compare with points B-C-D-E
2. The situation is less clear when you are looking to the point A and A'. A is lower Cost, but A' is better ENVIRONMENTAL quality…both options are valid choices.

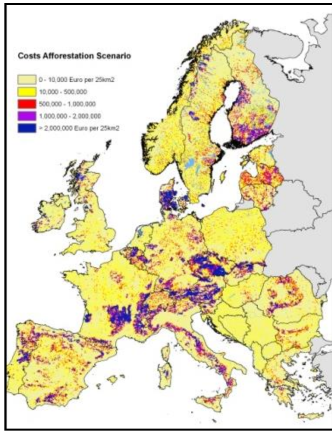
Example optimisation

European Commission

FLOOD	CROP	WATER SAVING
12afforestation	51Nfixing	71Desalination
21urban25	52OptFertilization	91Irrigation
34crop	53Combined	93Reuse
43meander	91Irrigation	94WaterSaving
31grassland	34crop	95Leakage
	93Reuse	21urban25







Region 11 "Water saving"	Scenario combination						Objective functions		
Scenario combination	21_UG	71_DS	91_IE	93_WRI	94_WSH	95_LR	Cost [T Euro per cell]	EnvFlow [per cell]	WEI [per cell]
C7	100	100	100	100	100	100	1696	-2	-23
C16	13	0	100	1	100	1	-877	-1	-16
C47	27	94	100	70	100	100	-635	-2	-19
C59	100	100	100	98	100	100	1643	-2	-21
C66	13	4	98	70	100	100	-639	-2	-18
C68	100	100	100	99	100	100	1673	-2	-22
C71	13	0	100	0	100	1	-879	-1	-16
C77	13	5	98	70	100	99	-706	-1	-17
C90	28	92	100	73	100	96	-762	-1	-17
C110	13	4	98	38	100	98	-743	-1	-16
C136	13	2	98	70	100	37	-865	-1	-16
C148	0	2	97	43	100	91	-790	-1	-16
C158	34	4	100	71	100	59	-847	-1	-16
C159	13	5	98	70	100	98	-740	-1	-16
C165	14	0	100	1	100	2	-871	-1	-16
C174	11	3	98	72	100	35	-865	-1	-16

Example optimisation: Danube

Region 11 "Water saving"	Scenario combination						Objective functions		
Scenario combination	21_UG	71_DS	91_IE	93_WRI	94_WSH	95_LR	Cost [T Euro per cell]	EnvFlow [per cell]	WEI [per cell]
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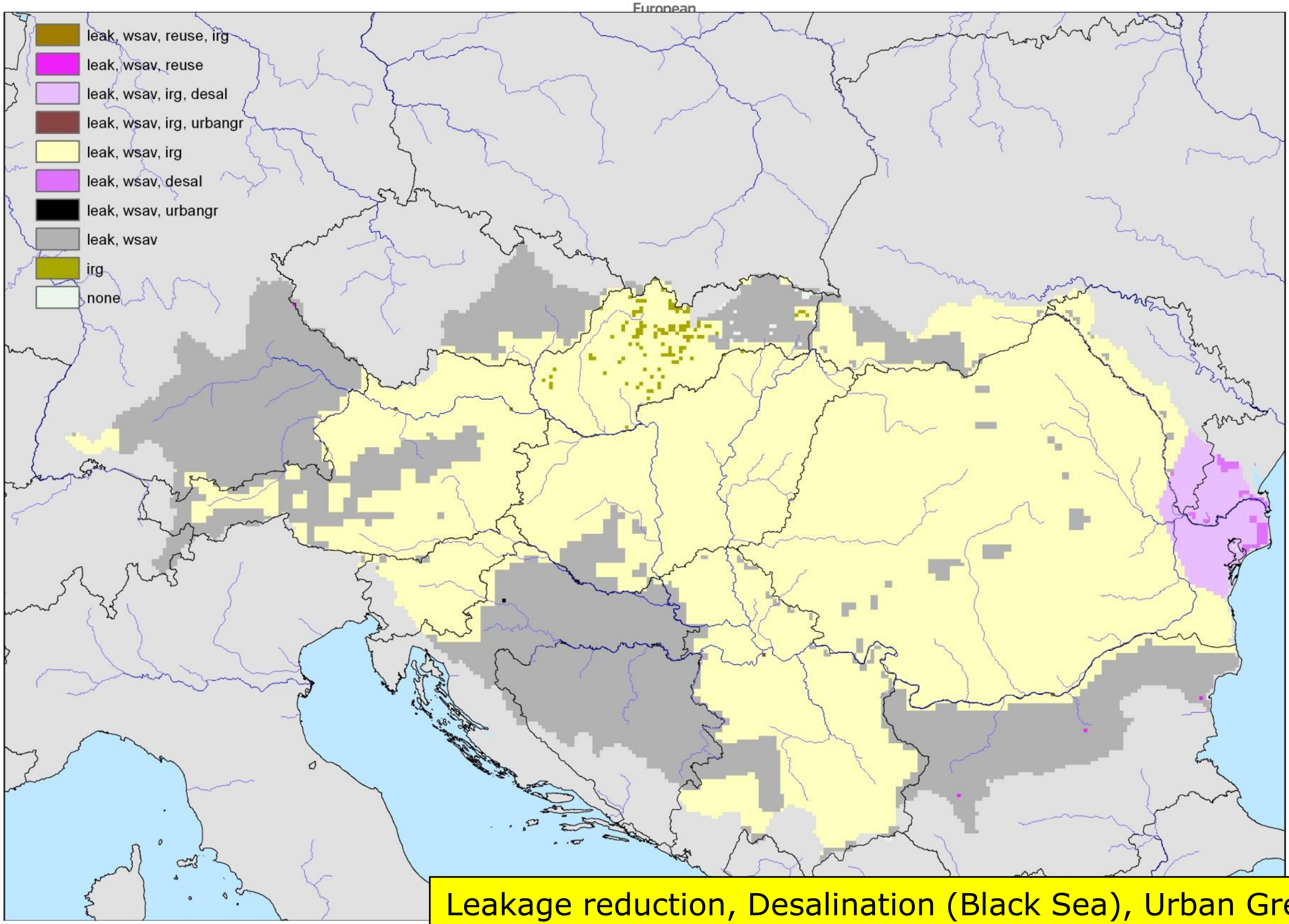
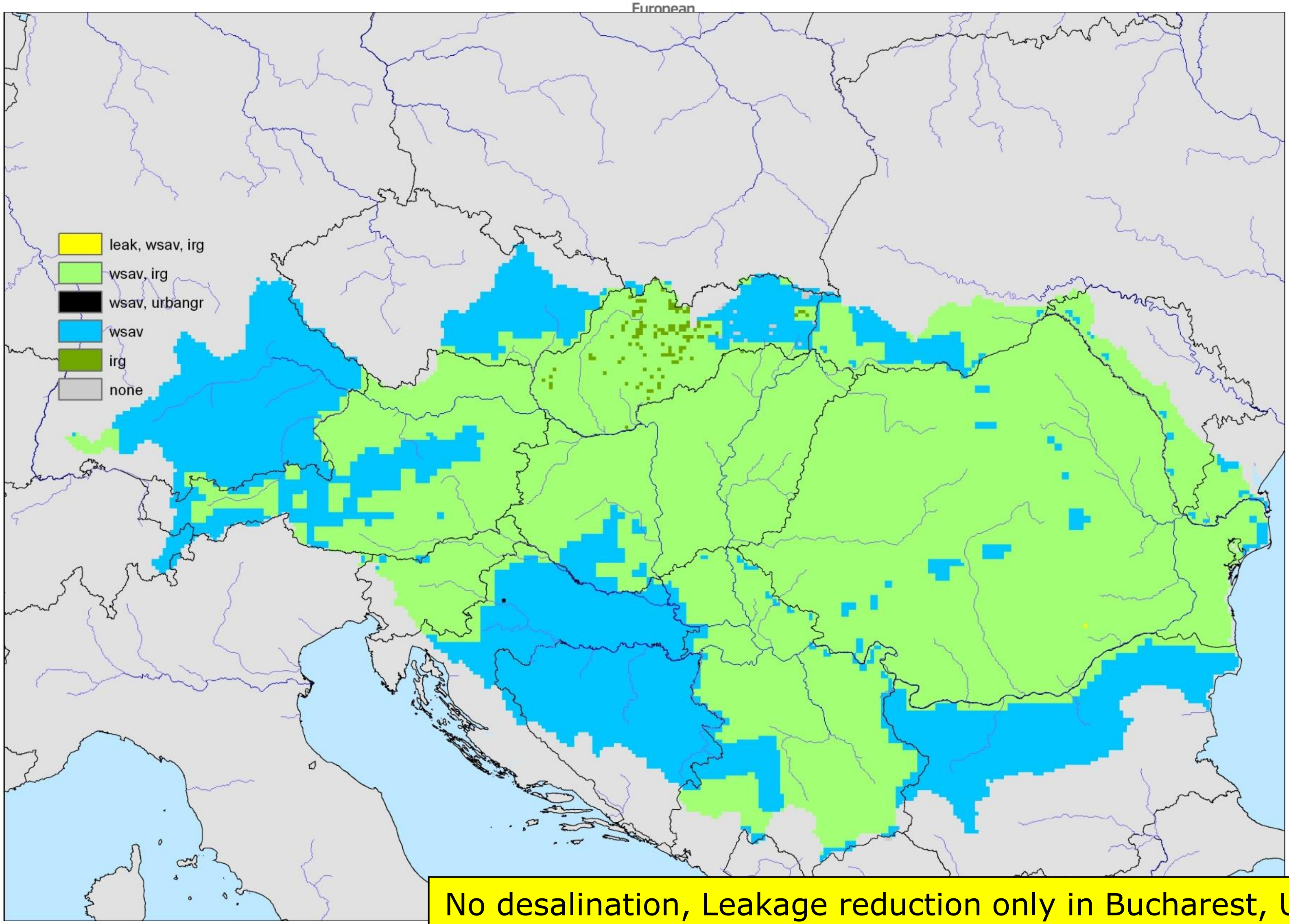
C16	13	0	100	1	100	1	-877	-1	-16
C47	27	94	100	70	100	100	-635	-2	-19
C59	100	100	100	98	100	100	1643	-2	-21
C66	13	4	98	70	100	100	-639	-2	-18
C68	100	100	100	99	100	100	1673	-2	-22
C71	13	0	100	0	100	1	-879	-1	-16
C77	13	5	98	70	100	99	-706	-1	-17
C90	28	92	100	73	100	96	-762	-1	-17
C110	13	4	98	38	100	98	-743	-1	-16
C136	13	2	98	70	100	37	-865	-1	-16
C148	0	2	97	43	100	91	-790	-1	-16
C158	34	4	100	71	100	59	-847	-1	-16
C159	13	5	98	70	100	98	-740	-1	-16
C165	14	0	100	1	100	2	-871	-1	-16
C174	11	3	98	72	100	35	-865	-1	-16

Danube: scenario-combination C47



Leakage reduction, Desalination (Black Sea), Urban Greening in Zagreb and Belgrade, Re-Use of Water in Industry in Bulgaria, irrigation water use efficiency, and water savings in households

Danube: scenario-combination C71



No desalination, Leakage reduction only in Bucharest, Urban Greening only in Zagreb, no water-re-use in industry in Bulgaria

Conclusions and further work

- **A multi-criteria tool has been built to optimize combinations of water efficiency measures**
  - Results are included in the forthcoming EC Blueprint to safeguard EU waters
- **The tool is further improved for Europe:**
  - **Include groundwater modelling in relevant areas in Europe**
    (linking LISFLOOD/LISQUAL/MODFLOW, SWAT/MODFLOW, or conceptual)
  - Economic Loss functions for Water Scarcity for all sectors (based on factual direct damage)
  - Selection of water regions that fit water supply areas
  - Water transfers between river basins
  - Improve underlying data: discharge (neg. WMO/ENV/JRC/EEA), precipitation, wastewater fluxes, groundwater use (for irrigation, drinking water) etc..
  - Costing other benefits, e.g. ecosystem services
  - Costs of measures from national and regional projects
  - Data on water price (industry, irrigation)
- **Specific case study started for the Danube, to support the Danube Strategy**
  - Two technical meetings already took place with Danube stakeholders
  - Budget available now for collaborating studies

Thanks for your attention

For further information, establishing collaborations

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