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Evaluation of the effectiveness of Natural Water Retention Measures

Support to the EU Blueprint to Safeguard Europe's Waters

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Contents

Table of figures

Table of tables

Abbreviations

DMI:	DMI-HIRHAM5-ECHAM5 – climate model from Danish Meteorological Institute
KNMI:	KNMI-RACMO2-ECHAM5 – climate model from The Royal Netherlands Meteorological Institute
METO:	METO-HadRM3Q0-HadCM3Q0 - climate model from UK Met Office
GCM:	General Circulation Model
RCM:	Regional Climate Model
DWD:	Deutscher Wetterdienst (German Weather Service)
LAI:	Leaf area index [m^2/m^2]
LISFLOOD:	Hydrological model used in this study
LUMP:	Land Use Modelling Platform
MARS:	Meteorological Archiving and Retrieving System
MLE:	maximum likelihood estimation
NWRM:	Natural Water Retention Measures
SCE:	Shuffled Complex Evolution
IA:	Impact Assessment
CAPRI:	Common Agriculture Policy Regionalised Impact Model

I. Summary

In the context of the impact assessment for the forthcoming policy document "Blueprint to safeguard Europe's waters", the European Commission has developed a common baseline scenario bringing together climate, land use and socio-economic scenarios and looking at the implications for water resources availability and use under different policy scenarios.

This study was carried out by the Joint Research Centre of the European Commission with the support of Stella Consulting SPRL, Brussels. It shows the impact of no-regret natural water retention measures on water quantity which can, in turn, be used to quantify ecosystem services related to water provision, water flow regulation and the moderation of extreme flows. It also contributes to the identification of multifunctional adaptation measures that reduce the vulnerability of water resources and related ecosystem services to climate change and other anthropogenic pressures. Within the context of this report “no-regret” is solely based on hydrological impact. The following report “A multi-criteria optimisation of scenarios for the protection of water resources in Europe” will also address co-benefits and costs.

The novelty of this study is in linking climate, land use and hydrological scenarios and models on a pan European scale and providing a first quantitative pan-European overview of the effects of ‘green’ measures on discharge. This should encourage Member States to further explore the use of efficiency measures and foster communication between stakeholders.

12 different policy scenarios were used, addressing changes in forest and urban areas, agriculture practice, and water retention. Locally some of these scenarios were estimated to change low flows and flood discharge up to 20%. For the 21 defined macro-regions in Europe there is a clear difference in the impacts of measures and for each region the effectiveness of each scenario has been ranked in terms of increasing low flow or reducing flood peaks.

It can be shown that:

- no-regret natural water retention measures can contribute to increased low flows and reduced flood peaks
- In each of the 21 macro-regions a different set of measures can be effective depending on the climate, flow regime, land use and socio-economics.

II. Introduction

Land use management is a vital tool for the regulation of both water quality and quantity. Water quality is adversely affected by relatively high surface runoff and erosion (Fiener et al 2011) and water quantity is manifested in both water scarcity and the flood events (Creed et al 2011). The implementation of appropriate Natural Water Retention Measures (NWRMs) have as main purpose a reduction in surface runoff following rainfall events in order to reduce flood risk. The related advantages are numerous, and include reduced erosion and leaching, as well as increased groundwater recharge and climate regulation (CRUE, 2009; Forest Research, 2010).

The effect that these measures will have on the local and regional hydrology can be evaluated using a modelling approach which takes into account the changes in land use involved and the related changes in soil hydraulic properties and area coverage of impermeable surfaces. Several NWRM scenarios are proposed below, most of which require a first run with the Land Use Modelling Platform (LUMP) to determine the spatial distribution of land use classes to be considered. The resulting maps are then used as input to the LISFLOOD hydrological model. Some scenarios only require the adjustment of specific parameters within LISFLOOD to determine the resulting impact on river regime.

The main aim of this study is the estimation of changes in low flow and average and peak discharge as a consequence of the implementation of a series of planned natural water retention measures. This report describes the methods and models used, the natural water retention measures themselves, the implementation of the measures within the models, and the results obtained.

The policy frameworks supporting this study are:

- The Water Framework Directive,
- The Floods Directive,
- Europe 2020 strategy – resource efficient Europe,
- Blueprint to safeguard Europe's waters (2012),
- The Biodiversity Strategy including the Green Infrastructure strategy
- CC Adaptation Strategy (2013)

Other studies showing the benefit of NWRM measures were assessed in different studies like:

- The STELLA 2012 study on natural water retention measures including their costs, complemented by JRC hydrological and landuse modeling (Stella Consulting, 2012)
- Environmental Effectiveness of Selected Agricultural Measures (Frelih-Larsen et al. 2012)
- River Basins network activity - WFD and Agriculture. (JRC, http://rbn-water-agri.jrc.ec.europa.eu)

- Comparative study of pressures and measures in the major river basin management plans in the EU funded by DG Environment.

- PEER Research on Ecosystem Services - A spatial assessment of ecosystem services in Europe - the Phase II Report – Synthesis (Maes et al. 2012)

III. Combining Models

1 Overview

The models and techniques used in this project can be divided into three lines (see Figure III-1). In the “Climate line” some combinations of climate simulations from the ENSEMBLE project were selected and bias corrected. In the “Land use – Scenario line” different models and data sources were used to drive land use claims and to build up a baseline land use scenario “2030”. The different natural water retention measures were analysed by changing the relevant land use settings.

Both lines were combined in the “Hydro line”. In a first step the land use parameter sets were translated into climatic-hydrological relevant parameters. The climatic parameters from the “Climate line” and the parameter settings from the “land use – scenario line” were then used to feed the hydrological model for 30-year runs. The resulting spatial time series were further processed using statistical methods such as extreme value fitting. A description of these models is given below.

Climate line	**Hydro line**	**Land use - Scenario - line**
Climate simulations General Circulation Models (GCMs)		CAPRI PE model, Eurostat data, CORINE Land Cover trends
Climate simulations Regional Climate Models (RCMs)		**Land Use Modeling Platform (LUMP)**
Selection of combinations of GCMs and RCMs		Selection of 2030 as baseline scenario
Bias Correction		Scenarios
	Pedo-transfer functions	
	Hydrologic Modeling LISFLOOD	
	Extreme value fitting	
	Analysis of results	

Outside the project, used as input

Figure III-1: Schematic Overview of the used models and techniques

2 Climate line

2.1 Climate models

Climate simulations have been obtained from the data portal of the ENSEMBLES project (van der Linden and Mitchell 2009, http://ensemblesrt3.dmi.dk/). Within the framework of ENSEMBLES, a large number of climate simulations using different combinations of state-of-the-art General Circulation Models (GCMs) and Regional Climate Models (RCMs) have been run for Europe. For this work, we employ three climate simulations obtained from a combination of two GCMs (HadCM3Q0 and ECHAM5) and three RCMs (HIRHAM5, RACMO2 and HadRM3) (see Table 1 for details). These climate simulations have been selected in order to cover as much as possible of the climate uncertainty, as suggested in the framework of the PESETA-II project. The latter, however, does not preclude that climate uncertainty is underestimated given the under-sampling of climate simulations used for this work. Further on only the acronyms DMI, KNMI and METO are used.

Climate simulations have a daily temporal resolution covering the period 1981-2010, whereas the lateral resolution is ca. 25 km (0.22° rotated lat-lon). All climate simulations are forced by the SRES-A1B scenario defined by the IPCC (Nakicenovic and Swart, 2000). Climate simulations from the ENSEMBLES project show three major advantages over simulations from previous projects (e.g. PRUDENCE project Christensen and Christensen 2007). First, the lateral resolution of the simulations is higher (25 km vs. 50 km). Second, the number of GCMs providing the lateral boundaries for RCMs is larger, thus resulting in a more realistic spread of the climate uncertainty. Third, the simulations cover the whole period 1961-2100, therefore giving continuity to the physical processes (Räisänen and Eklund, 2011). As target for the bias correction, we used the high-resolution gridded E-OBS data set (version 5.0) publicly available from http://eca.knmi.nl/ (Haylock et al., 2008). The aim of the E-OBS data set is to represent daily areal estimates of observed precipitation and maximum, average, and minimum surface temperature on grid boxes of 0.22° (ca. 25 km) in the period 1981-2010.

Table III-1: Climate simulations used to force LISFLOOD in the period 1981-2010

Model	Driving GCM	RCM	Institute	Acronyms
1	ECHAM5-r3[a]	HIRHAM5	Danish Meteorological Institute	**DMI**-HIRHAM5-ECHAM5
2	ECHAM5-r3[a]	RACMO2	The Royal Netherlands Meteorological Institute	**KNMI**-RACMO2-ECHAM5
3	HadCM3Q0b	HadRM3Q0	UK Met Office, Hadley Centre for Climate Prediction and Research	**METO**-HadRM3Q0-HadCM3Q0

[a] Represents a run of the ECHAM5 model using one out of three different sets of initial conditions defined as: "-r1", "-r2", and "-r3" (see Kendon et al., 2010).

[b] Represents one of three versions of the GCM HadCM3 with perturbed parametrization impacting the simulated climate response sensitivities: Q0 (reference), Q3 (low-sensitivity) and Q16 (high-sensitivity) (see Collins et al., 2006)

This dataset improves on previous products in its spatial resolution and extent, time period, number of contributing stations (increased station density in Spain, Germany, Norway and Eastern Europe) and attention to finding the most appropriate method for spatial interpolation of daily climate observations (Haylock et al., 2008). The E-OBS data set has been specially designed to represent grid box estimates instead of point values, which is essential to enable a direct comparison with climate simulations obtained from ENSEMBLES.

2.2 Bias correction – period 1981-2010

2.2.1 Procedure

Notwithstanding Climate simulations have considerably advanced in reproducing regional and local climate, they are known to feature systematic errors. These errors are likely explained by model errors caused by imperfections in the climatic model conceptualization, discretization and spatial averaging within cells, and uncertainties conveyed from the GCM to the RCM. Particularly, small-scale patterns of precipitation are highly dependent on climate model resolution and parametrization. At the same time, some RCMs show systematic biases with a clear tendency to enhance these biases in more extreme cold or warm conditions The presence of biases in the forcing data seriously limits its use in hydrological impact assessments. RCM outputs not corrected for biases tend to produce inaccurate probabilities for extreme events, thus rendering the extreme value analysis less reliable (Durman et al., 2001). Hence, some form of prior bias correction of the forcing data is required if a realistic description of the hydrology is needed.

The procedure for bias correction is based on the algorithms developed by Piani et al. (2010) and recently applied to correct climate simulations from ENSEMBLES by Dosio and Paruolo (2011) and Rojas et al. (2011). The BC method falls within the category “quantile mapping”. As described in Piani et al. (2010), a “transfer function” between climate observations and simulations can be obtained by calculating the cumulative distribution functions (cdfs) for each time series and, subsequently, associating to each simulated value an observed equivalent such that cdfsim(xsim) = cdfobs(xobs). To find such transfer functions we can use (computationally intensive) non-parametric methods or resort to parametric estimation. Following Piani et al. (2010), two parametric functional forms are used to correct for bias in precipitation at the grid-cell level:

$$x_{cor} = a + bx_{sim} \quad (1)$$

$$x_{cor} = (a + bx_{sim}) \times \left(1 - exp^{-\frac{x_{sim} - x_0}{\tau}}\right) \quad (2)$$

where x_{cor} is the corrected precipitation, x_{sim} is the simulated precipitation to be corrected, and a, b, x_0, and _ are parameters of the function to be fitted.

When the number of wet days (i.e. precipitation > 1 mm) is greater than 20 and the mean observed precipitation is greater than 0.01 mm/day, Eq. (1) is fitted. Equation (2) is fitted under two conditions: first, if a > 0 in equation (1), which is interpreted as ignoring dry days entirely and, second, when b in equation (1) is too extreme, with arbitrary values defined in the range b < 0.2 and b > 5. In the case of temperature, only the linear function (Eq. 1) is used to correct for bias, where xcor and xsim are replaced by corrected and simulated temperature, respectively.

Climate simulations from the 3 models (see Table III-1) and observations from the EOBS for the period 1981-2010 have been used to obtain the corresponding transfer functions employed for bias correction of daily precipitation and maximum, average, and minimum surface temperature. The fitted functions have then been applied to correct the same period. We note here the important assumption of stationarity, which means that the corresponding form of the fitted function and its associated parameters are invariant over time. Therefore, the fitted function estimated for present climate conditions is assumed to remain valid to correct biases in alternative time periods. The stationarity assumption, however, could be violated as biases can grow under climate change conditions and they depend on the values of the variables to be corrected (Christensen et al., 2008).

2.2.2 Results for temperature

A good correspondence between bias corrected and observed temperatures is obtained for daily average, maximum and minimum surface temperature with discrepancies in the range [-0.1; 0.1] °C for average temperature. For daily maximum temperature, a common feature for all bias corrected climate simulations is a slight cold bias [0.1; 0.5] °C during summer (JJA) in northeastern Europe and Great Britain. At the same time, few cells (<0.5%) show a considerable warm bias in the Carpathians. For winter (DJF) a tendency to a slight warm bias [0.1; 0.5] °C in some parts of Scandinavia is observed together with a weak cold bias in Great Britain. For the rest of Europe minor variations are observed. The remaining discrepancies after bias correction can be attributed to imperfections in the algorithm as daily maximum and minimum temperatures are corrected for indirectly through the diurnal temperature range and skewness (Rojas et al., 2011).

Some strong variations are observed when comparing the results of both sets of bias correction transfer functions. On average, the new set of bias corrected temperatures is higher than its 1961-1990 based counterpart for average daily temperature and maximum temperature during summer. For winter, in turn, a somewhat mixed pattern is observed. These variations are likely explained by the facts that in the period 1981-2010 station density increased, particularly, in Spain, Germany, Norway and Eastern Europe (as reported in http://eca.knmi.nl/ for the description of the new E-OBS data set v5.0), and that for the transfer functions calculated in the period 1961-1990, the period 1981-2010 constitutes purely an application period with only ten years of overlap with observed data.

Comparing bias corrected climate simulations for the period 1981-2010: the relevance of the stationarity assumption is highlighted. In this case, important variations are observed for both series of bias corrected simulations confirming that the transfer functions and their associated parameters are likely to be variable over time.

2.2.3 Results for precipitation

Figure III-2 and Figure III-3 show the assessment of bias corrected annual average of daily precipitation and the 5-days maximum precipitation in the period 1981-2010 for each climate simulation. On average, a good correspondence between bias corrected and observed precipitation is obtained for the annual average of daily values, with few cells showing a remaining bias after correction for the model DMI-HIRHAM5-ECHAM5. This is in agreement with the results of Rojas et al. (2011) who suggested that this remaining bias is potentially linked to a shifting between equations (1) and (2) for consecutive months, especially during winter, and to limitations in the observed data set due to under-catching of precipitation in mountain areas. At the same time, underestimation of the observed precipitation is obtained for the climate model METO-HadRM3Q0-HadCM3Q0 (see Figure III-3), which has been verified by Dosio and Paruolo (2011) and is common to all models driven by the GCM HadCM3. For the 5-days maximum precipitation, we observe a good agreement with a weak tendency to underestimation of the observed values, especially for central-north and north-eastern Europe. As discussed in Rojas et al. (2011), this might be related to the persistent underestimation of the wet day frequency for the majority of the models included in ENSEMBLES after performing the bias correction (see Dosio and Paruolo, 2011). At the same time, the bias corrected precipitation shows an overestimation of observed precipitation in south-south-eastern Europe. As for the average precipitation, the underestimation in the 5-days maximum precipitation is more significant for the climate model METO-HadRM3Q0-HadCM3Q0 (HadCM3-driven). A comparison for the bias corrected precipitation using transfer functions from the periods 1981-2010 and 1961-1990 is included in the right column of Figure III-2 and Figure III-3. In general, strong differences occur in central-north and southern Europe, which may be related to the increase in station density for the period 1981-2010.

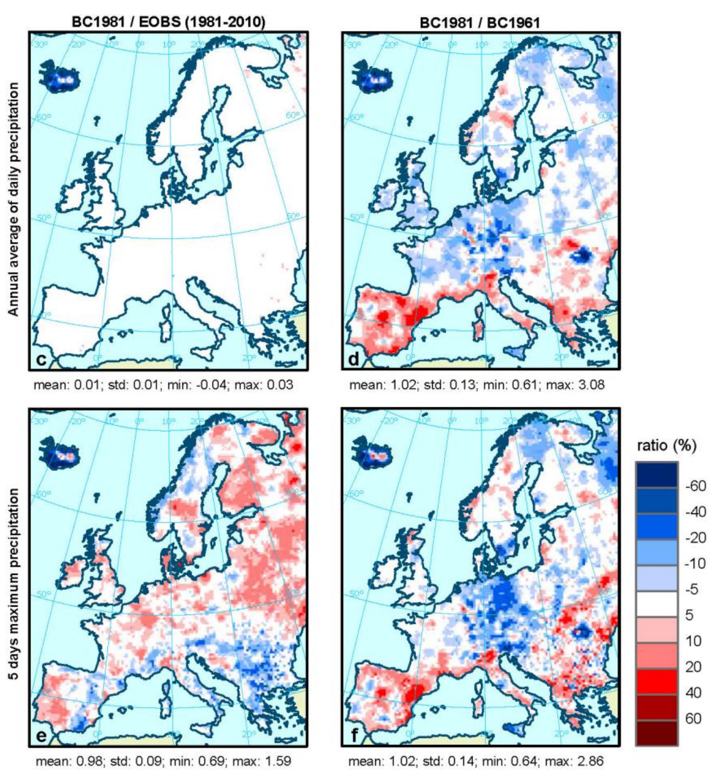


Figure III-2: Assessment of bias corrected daily precipitation in the period 1981-2010 for the climate simulation KNMI-RACMO2-ECHAM5. The left column shows the ratio between bias corrected precipitation and observations from the E-OBS data set. The right column shows the ratio between the current period (1981-2010) and the previous bias correction period (1961-1990). The first row shows the annual daily average precipitation whereas the second row shows 5-days maximum precipitation.

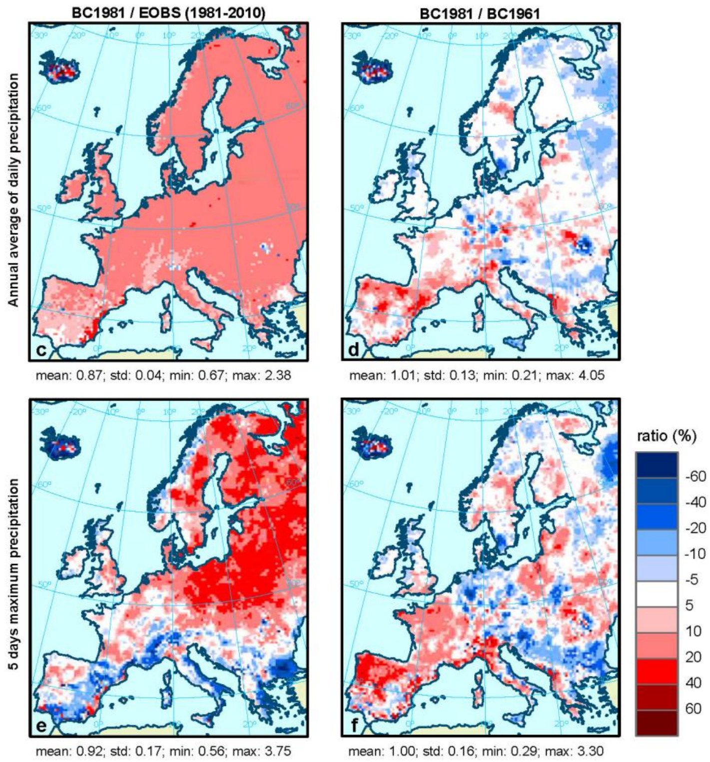


Figure III-3: Assessment of bias corrected daily precipitation in the period 1981-2010 for the climate simulation METO-HadRM3Q0-HadCM3Q0. Left column shows the ratio between bias corrected precipitation and observations from the E-OBS data set. The right column shows the ratio between the current period (1981-2010) and the previous bias correction period (1961-1990). The first row shows the annual daily average precipitation whereas the second row shows 5-days maximum precipitation.

3 Land use – Scenario line

3.1 The Land Use Modelling Platform (LUMP)

The Land Use Modelling Platform (LUMP) is being developed at JRC Ispra with the objective to support the policy needs of different services of the European Commission, such as the exploration of future policies and impact assessments of specific proposals. The land use/cover model EUClueScanner (EUCS100), developed in collaboration with DG Environment, is the core component of the platform which links specialized models and data within a coherent workflow (Lavalle et al. 2011).

This set of specialized models and data can be divided into two main categories: those which contribute to driving the land use model (*land use claims*); and those which contribute to the quantification of the impacts of land use change (*indicators*). For this study, we will exploit the LUMP through the application of specialized models in both the input and output stages. At the input and allocation stages, the CAPRI model (Common Agricultural Policy Regionalized Impact modelling System[1]), Eurostat data (EUROPOP2008[2]) and Corine Land Cover trends were used to drive land use claims. Crop suitability maps modelled by AGRI4CAST (JRC) and

[1] http://www.capri-model.org/
[2] Source: http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home.
[3] Distinguishment between mesoscale catchments and macroscale catchments, because of the different, scale
[2] Source: http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home.

a biomass potential map developed within the SOILS Action (IES, JRC) were used to help allocate those claims.
The CAPRI baseline (current legislation) for agricultural policies includes the following assumptions:

- The ‘Health Check’ of the Common Agricultural Policy (CAP)
- Agricultural premiums are largely decoupled from production levels
- Bio-fuels as projected by PRIMES
- Impacts of the Nitrates Directive

At the output stage, the maps computed by the EUCS100 model are further processed to produce the necessary input for the LISFLOOD model. This input is specific to the LISFLOOD parameters which are most sensitive to land use and land cover. The LISFLOOD hydrological model is configured to model hydrological response units and in order to do this, the input land use maps are processed according to the proportion sealed area, forest and water at a sub-pixel level. Thus the original land use maps undergo a sequence of elaborations through a ‘soft link’ developed in the WQM Action (IES, JRC), resulting in a series of 56 input maps to be ingested into the hydrological model. Water retention measurements and land use scenarios will therefore be fully integrated, even for the baseline scenario.

In some cases, the hydrological parameters associated with land use can be manipulated within LISFLOOD without the need to re-run the entire LUMP. The implementation of the scenarios requiring a LUMP run are described in detail in section III.

Simulated land use maps were produced on a yearly basis for the period 2006-2030, but only the final year, 2030, was provided to LISFLOOD. . Only EU27 member states were modelled due to the fact that the model was not calibrated for the remaining European countries and we also lacked the demand files that drive their land use change. Countries not modelled were mosaicked later (GIS post-processing) in order to be included in the final output which has Pan-European coverage.

4 Hydro line

4.1 Pedo-tranfer functions

Some of the land use transitions related to the implementation of water retention measures will directly affect the soil hydraulic properties. The influence of land use change on soil organic matter and bulk density has been widely studied, and relative changes in both parameters for different land use transitions can be adequately estimated from literature (Table III-2; Bormann, 2007; Laganiere et al., 2009).

Table III-2: Literature review on the influence of land use conversions on soil bulk density and organic carbon content.

Source	Study Area	Land use transition	Δ Bulk Density	Δ Organic Carbon
Bauer and Black (1981)	Northern Great Plains, USA	Grassland to crops	5-20% increase (depth dep.)	*decrease*
Bewket and Stroosnijder (2003)	Chemoga watershed, Blue Nile Basin, Ethiopia	Forest to crops	13% increase 0-22% increase)	13-89% decrease
		Forest to grazing land	11-17% increase	15-47% decrease
		Forest to eucalyptus	33-67% increase	22-84% decrease
Breuer et al (2006)	Lahn-Dill Highlands, Germany	Crops to grassland	No significant differences	No significant differences
Bronson et al. (2004)	West Texas, USA	Grassland to crops	3-21% increase (depth dep.)	32% decrease (depth dep.)
Franzluebbers et al. (2000)	Southern Piedmont USA	*Grassland to crops*	*3-17% increase (depth dep.)*	24% decrease (up to 200mm)
		Forest to grassland		12-15% decrease
Murty et al. (2002)	Literature review	Forest to grassland	9.5% (+-2%) increase	No significant trend in differences (-50% to +160%)
		Forest to crops	17% (+-2%) increase	22-30% decrease OC
Neill et al. (1997)	Rondonia, SW Amazon Basin, Brasil	Forest to grassland (pasture)	0-27% increase	20% decrease to 42% increase OC
Strebel et al. (1988)	Hannover, Germany	Grassland to crops	*15% increase (upper soil horizon)*	57% decrease OC (A-horizon)
Hajabbasi et al. (1997)	Lordegan, Iran	Forest to cultivated	almost 20% increase	50% decrease OM
Davidson et al. (1993)	Literature review	Untilled to cropland		20-40% decrease
Reiners et al. (1994)	Costa Rica	Primary forest to pasture	increase (~18%)	50% decrease OC
Laganiere et al. (2009)	Literature review	Croplands to forest		26% increase
		Pasture to forest		3% increase
		Natural grass. to forest		<10% increase
Saikh et al. (1998)	Simlipal National Park, India	OC highest in evergreen forests > deciduous forests > grasslands > cultivated areas		

Taking into account the conversion factor between soil organic matter and organic carbon (OM=58% OC), and based on the literature review, we compiled the following assumed percentage changes in both parameters for each land use transition considered (Table III-3).

Table III-3: Assumed literature-based changes in bulk density (BD) and organic carbon (OC) content used in the modelling exercise.

Land use change	Assumed change in BD	Assumed change in OC
Crops to grassland	6.5% decrease	*5% increase*
Crops to forest	15% decrease	15% increase
Grassland to crops	**7% increase**	**20% decrease**
Grassland to forest	9% decrease	*10% increase*
Forest to crops	**17% increase**	**35% decrease**
Forest to grassland	**10% increase**	**15% decrease**

The percentage changes in these parameters can be translated into an associated change in soil moisture and hydraulic conductivity (Wosten, 1998), which drive the soil model inside LISFLOOD. For this purpose, pedo-transfer functions (the Mualem-Van-Genuchten equations) were used from the HYdraulic PRoperties of European Soils (HYPRES) database (http://eusoils.jrc.ec.europa.eu/):

$$\theta_s = 0.7919 + 0.001691*C - 0.29619*D - 0.000001491*S^2 + 0.0000821*OM^2 + 0.02427*C^{-1} + 0.01113*S^{-1} + 0.01472*\ln(S) - 0.0000733*OM*C - 0.000619*D*C - 0.001183*D*OM - 0.0001664*topsoil*S$$

$$K_s^* = 7.755 + 0.0352*S + 0.93*topsoil - 0.967*D^2 - 0.000484*C^2 - 0.000322*S^2 + 0.001*S^{-1} - 0.0748*OM^{-1} - 0.643*\ln(S) - 0.01398*D*C - 0.1673*D*OM + 0.02986*topsoil*C - 0.03305*topsoil*S$$

Where θ_s is a model parameter, α^*, n^*, l^* and K_s^* are transformed model parameters in the Mualem-van Genuchten equations; C = percentage clay (i.e. percentage < 2 μm); S = percentage silt (i.e. percentage between 2 μm and 50 μm); OM = percentage organic matter; D = bulk density; topsoil and subsoil are qualitative variables having the value of 1 or 0 and ln = natural logarithm (Wosten et al., 1998).

The resulting values of saturated conductivity (K_s) and soil moisture content (θ_s) are shown in figure III-4. The sequence of changes crops → grassland → forest, for example, results in a substantial increase in θ_s, and an even larger increase in K_s.

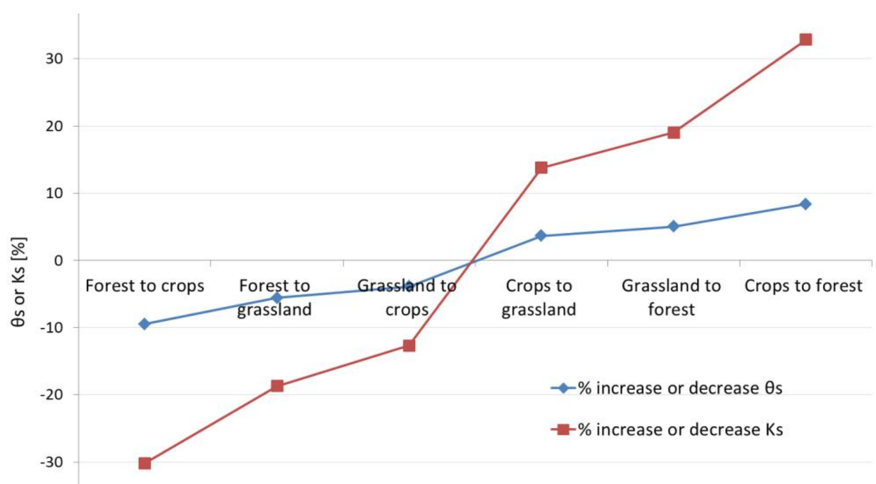
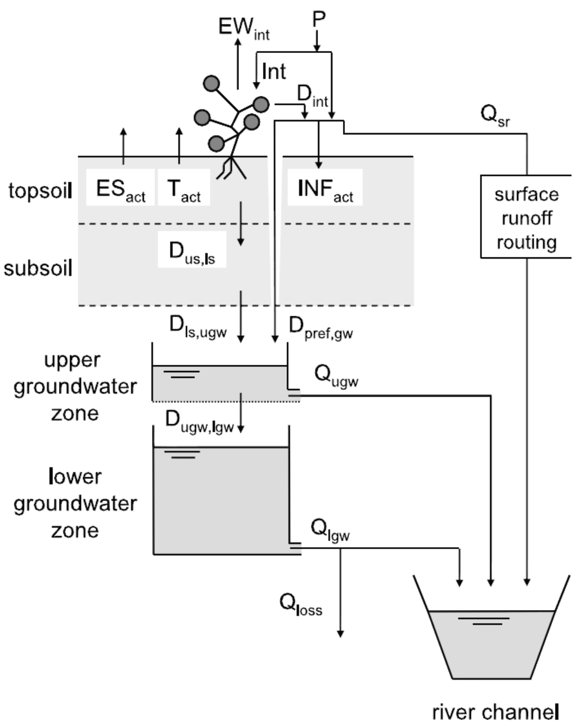


Figure III-4: Conversion of land use changes into change of hydraulic parameters based on the Mualem-van Genuchten equations

4.2 Hydrologic modeling - LISFLOOD

4.2.1 The LISFLOOD model used for land use scenarios

LISFLOOD is a GIS-based spatially-distributed hydrological rainfall-runoff model, which includes a one-dimensional hydrodynamic channel routing model (van der Knijff et al., 2010). Driven by meteorological forcing data (precipitation, temperature, potential evapotranspiration, and evaporation rates for open water and bare soil surfaces), LISFLOOD calculates a complete water balance for every (daily) time step and every grid cell (Figure III-5). Processes simulated for each grid cell include snowmelt, soil freezing, surface runoff, infiltration into the soil, preferential flow, redistribution of soil moisture within the soil profile, drainage of water to the groundwater system, groundwater storage, and groundwater base flow. Runoff produced for every grid cell is routed through the river network using a kinematic wave approach. Although this model has been developed aiming at operational flood forecasting at pan-European scale, recent applications demonstrate that it is well suited for assessing the effects of land-use change and climate change on hydrology (Feyen et al., 2007; Dankers and Feyen, 2008, 2009).



Abbreviations:

P, precipitation; Int, interception;
EWint, evaporation of intercepted water;
Dint, leaf drainage;
ESact, evaporation from soil surface;
Tact, transpiration (water uptake by plant roots);
INFact, infiltration; Qrs, surface runoff;
Dus,ls, drainage from upper to lower soil zone;
Dls,ugw, drainage from lower soil zone to upper groundwater zone;
Dpref,gw, preferential flow to upper groundwater zone;
Dugw,lgw, drainage from upper to lower groundwater zone;
Qugw, outflow from upper groundwater zone;
Qlgw, outflow from lower groundwater zone;
Qloss, loss from lower groundwater zone.

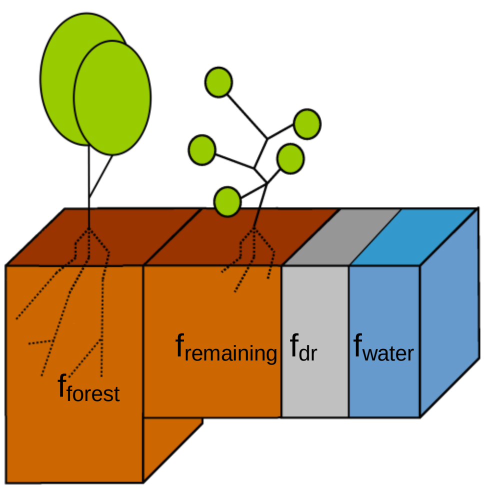
*Note that snowmelt is not included, even though it is simulated by the model.

Figure III-5: Schematic overview of the LISFLOOD model

Including land use sensitivity into the model

To account properly for land use dynamics some conceptual changes have been made to render LISFLOOD more land use sensitive. Combining land use classes and modelling aggregated classes separately is known in hydrology as the concept of hydrological response units (HRU) (e.g. Kumar et al., 2009). This concept is used in models such as SWAT (Arnold and Fohrer, 2005) and PREVAH (Viviroli et al., 2009). The hypothesis behind this approach is that areas with similar characteristics will react similarly and areas with diverse characteristics will react differently. Because of the nonlinear nature of the rainfall runoff processes this should yield

better results than running the model with average parameter values (Das et al. 2008). Therefore we have transferred the LISFLOOD model to an HRU approach on sub-grid level. To address the big sub-grid variability in land use, we model the within-grid variability by running some sub models (e.g. all soil processes) separately for fractions of land use. In this LISFLOOD version, a forest fraction map, water fraction and direct runoff fraction have been derived from the 100m resolution land use LUMP maps. The spatial distribution and frequency of each class is defined as a percentage of the whole represented area of the 5 x 5km pixel.
In the soil model, each of the aggregated land use categories is modelled separately. Figure III-6 shows the method of calculating evapotranspiration. In this example, water not available for runoff (evaporation and transpiration) is calculated differently for each of these four aggregated classes. The total sum of evapotranspiration for a pixel is calculated by adding up the fluxes for each class multiplied by the fraction of each class.



$$
\begin{aligned}
ET_{pixel} = \; & f_{forest} \cdot ET_{forest} + \\
& f_{dr} \cdot E_{dr} + \\
& f_{water} \cdot E_{water} + \\
& (1 - f_{forest} - f_{dr} - f_{water}) \cdot ET_{remaining}
\end{aligned}
$$

Figure III-6: Simulation of forested, impermeable, water and "remaining" category in LISFLOOD

In this version of LISFLOOD, the outputs of the soil model are a) three different surface runoff fluxes for forest, water and impervious and the category containing other land use classes; b) two outflows from the upper groundwater zone and c) two outflows from the lower groundwater zone. The difference between the two "soil classes" forest and remaining land use are the different parameter sets for leaf area index, crop coefficient, crop number, soil hydraulics and the upper and lower soil depth. For water bodies, the potential evaporation from an open water surface is subtracted from the total amount of available water. The result is the amount of surface runoff from water bodies. Impervious surfaces are treated differently in that the initial and depression loss is calculated and subtracted from the total amount of available water. The result is the amount of surface runoff from impervious surfaces. Each result is multiplied by the fraction of aggregated land use to get the real fluxes.

Simulating reservoirs and lakes

The model does have an option to simulate lakes and reservoirs (as described by van der Knijff et al. 2010), which can be relevant for this analysis as they tend to increase low flows. In the current setting 169 lakes and reservoirs are included, but due to the lack of relevant data about the steering mechanism of reservoirs and to a lesser extend also lakes, they are likely to underestimate the human influence on low flows.

Reservoirs are included in the natural water retention measures as points with various storage capacities (conservative, normal, flood and total storage volume), and outflow boundary conditions (minimum, normal, non-damaging, flood and spill-way outflow). Steering rules are assumed to be minimized only to prevent damaging. The outflow is based on the fraction of the reservoir filled and the boundary conditions.

Model input data

The current pan-European setup of LISFLOOD uses a 5 km grid and spatially variable input parameters and variables obtained from European databases. Elevation data were obtained from the Shuttle Radar Topography Mission (SRTM) (Farr et al. 2007) and river properties were obtained from the Catchment Information System (Hiederer and de Roo, 2003). Soil properties were obtained from the European Soil Geographical Database (King et al., 1994) whereas porosity, saturated hydraulic conductivity and moisture retention properties for different texture classes were obtained from the HYPRES database (Wösten et al., 1999). For different natural water retention scenarios the hydraulic properties were changed by using pedo-transfer functions as discussed in section 4.1. Vegetative properties and land use cover were obtained from the Land Use Modelling Platform (LUMP, section 3). Figure III-7 shows some examples of input maps from the European database.

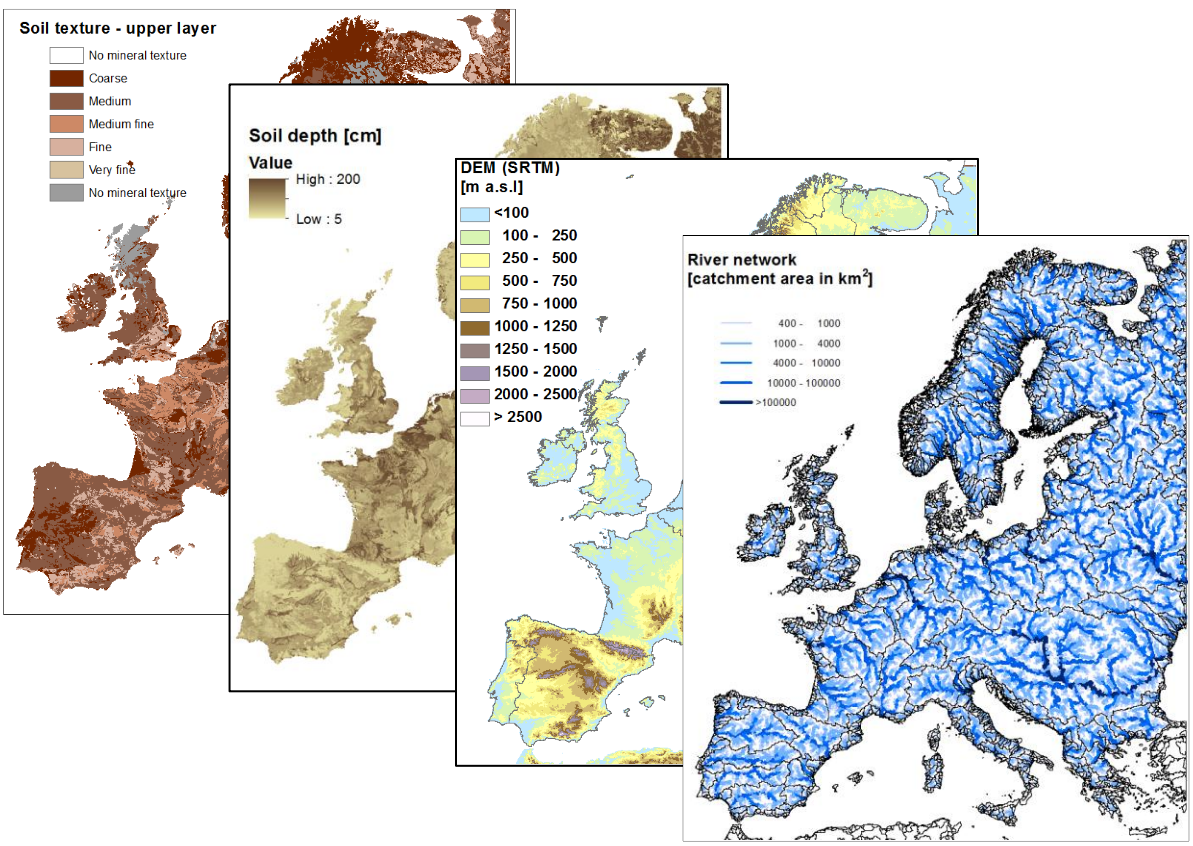


Figure III-7: Examples of input maps from the European data base used for LISFLOOD

Model output data

The LISFLOOD model output can be any internal variable calculated by the model, given either as time series, summary maps or stacked maps over the complete period of time. Examples of output are discharge hydrographs, summary maps of evapotranspiration, soil moisture or groundwater recharge. Results are can be analyzed further using statistical approaches like extreme value fitting.

Model limitations

LISFLOOD with a grid size of 5 x 5 km is developed for simulating medium and large river basins. Combined with the climate scenarios with cell size of ca. 25 x 25 km good results can be obtained in basins of a few thousand kilometer up to the size of the entire Danube basin. On a pan-European scale you cannot expect a detailed flood routing approach (e.g. 1D full dynamic wave or even 2D dynamic wave). Here a double kinematic wave is used, which does not allow further analyses on the water level. Another limit is the availability of good, accurate and homogenous data for the entire pan European scale. For example soil data or measured discharge data. Human influence (e.g. steering of dams, reservoirs, polders, irrigation) is also hard to quantify and especially for low flows an important factor. The selection of three climate scenarios out of a combination of a huge number of GCMs and RCMs is a major source of uncertainty (see section 4.2.4 for a more detailed description).

4.2.2 Extreme value analysis

To estimate the probability of extreme discharge levels, a Gumbel distribution was fitted to the annual maximum discharges using the maximum likelihood estimation (MLE) method (Rojas et al. 2011). To obtain the 95% confidence interval for the return levels the profile-likelihood method is employed (e.g. Coles, 2001; Beirlant et al., 2004). By capturing non-symmetric behaviour of confidence intervals, especially for return levels associated to long return periods (e.g. 100 year), the profile-likelihood method is far more robust in assessing uncertainty compared to traditional approaches as the “Delta method” described in Coles (2001). The profile-likelihood method works through re-parametrization of the Gumbel model. Using the deviance function (Coles, 2001) confidence intervals for return level can be obtained.

4.2.3 Validation of the LISFLOOD model

The current European-wide model setup with a 5-km grid resolution uses spatially variable parameters on soil, vegetation and land use derived from European data sets. A set of 9 parameters that control infiltration, snowmelt, overland and river flow, as well as residence times in the soil and subsurface reservoirs, have been estimated in 435 catchments by calibrating the model against historical records of river discharge. The calibration period varied between the different catchments depending on the availability of discharge measurements, but all spanned between 3 and 6 years within the period 1998 - 2010. It may be argued that the selection of 3-6 years is too short for a long-term application, however, the selection of this period responded to a trade-off between computational time and the use of reliable and recent available information on discharges. The algorithm implemented for calibration corresponded to the Shuffled Complex Evolution (SCE) (Duan et al., 1992). A more detailed description of the calibration of LISFLOOD for different European catchments is given by Feyen et al. (2007, 2008).

The meteorological variables used to force the model in the calibration exercise were obtained from different sources (the Meteorological Archiving and Retrieving System (MARS) database, Meteoconsult Data, European Climate Assessment & Dataset, Synop data from the DWD). The locations of the stations used in the calibration and validation are presented by the black dots in Figure III-8. This overview shows that the coverage is sufficient in most parts of northern and central Europe. For the Balkan area, Greece, southern Italy and parts of the Iberian peninsula no discharge series were available at the time of the model calibration. For catchments where discharge measurements were not available simple regionalization techniques (regional averages) were applied to obtain the parameters.

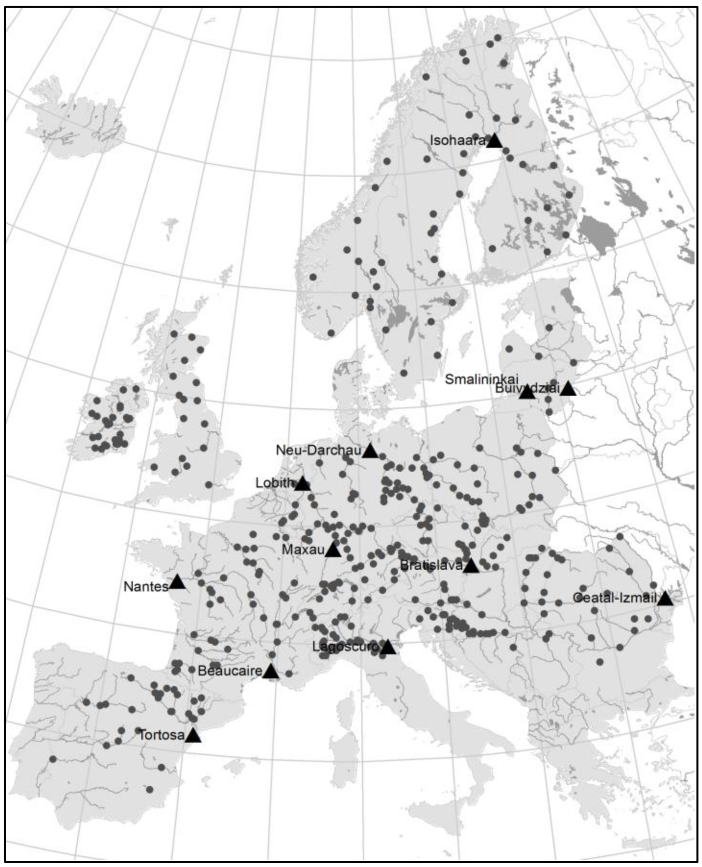


Figure III-8: Location of the 435 discharge gauging stations used in the calibration of the hydrological model and of the 12 stations mentioned in the report (triangles)

Figure III-9 shows observed versus simulated average, 95%, and 99% quantile discharge for each of the 435 calibration stations (Figure III-8) for a 3-year validation period. This period varied between the different catchments depending on the availability of discharge measurements but includes the most recent available data. Visual inspection and the values for the coefficient of determination (r^2) show that the observed flow statistics are reasonably well reproduced by the LISFLOOD simulation with a general tendency of better performance for average flows and with increasing catchment size.

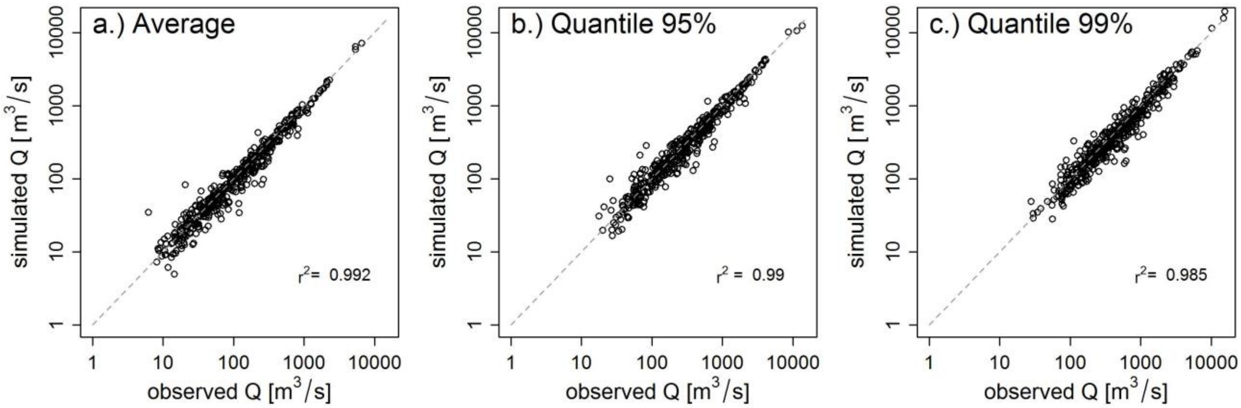


Figure III-9: Observed versus simulated average discharge (a), 95% quantile (b), and 99% quantile (c) for each of the 435 stations.

Table III-3 and Figure III-10 show some statistics and time series for the 3 year validation period for 12 gauging stations all across Europe from Zaragoza, Spain up to Isohaara, Finland. All stations show reasonable to good results looking at the Nash-Sutcliffe efficiency and the correlation coefficient.

Table III-3: Statistics for the 3 year validation period for the gauging stations depicted in Figure III-8

	Goodness of fit			Statistics [m^3/s]			
Station	**Neff**	**Pearson**	**Pbias [%]**	**Obs Avg.**	**Obs. q95**	**Sim. Avg.**	**Sim. q95**
Zaragoza, Ebro, ES	0.74	0.89	14.7	185	642	212	718
Lagoscuro, Po, IT	0.62	0.81	-10.5	896	1821	802	1552
Nantes, Loire, FR	0.78	0.91	-11.2	833	1947	740	1679
Beaucaire, Rhone, FR	0.75	0.88	-7.5	1607	3285	1486	2922
Maxau, Rhine, DE	0.66	0.92	-15.7	1252	2200	1055	1966
Lobith, Rhine, NL	0.81	0.93	2.3	2124	3977	2173	4296
Bratislava, Danube, SK	0.86	0.94	-7.0	2073	4141	1928	4180
Ceatal-Izmail, Danube, RO	0.55	0.81	8.5	6612	13500	7176	12474
Neu-Darchau, Elbe, DE	0.76	0.88	9.2	678	1510	740	1573
Smalininkai, Nemnus, LT	0.58	0.84	-14.5	409	906	350	901
Langnes, Gloma, NO	0.63	0.86	-14.4	702	1350	601	1131
Isohaara, Kemijoki, FI	0.72	0.91	-5.2	562	1376	533	1314

Neff: Nash-Sutcliffe efficiency
Pbias: Percent bias
Pearson: Person product moment correlation coefficient

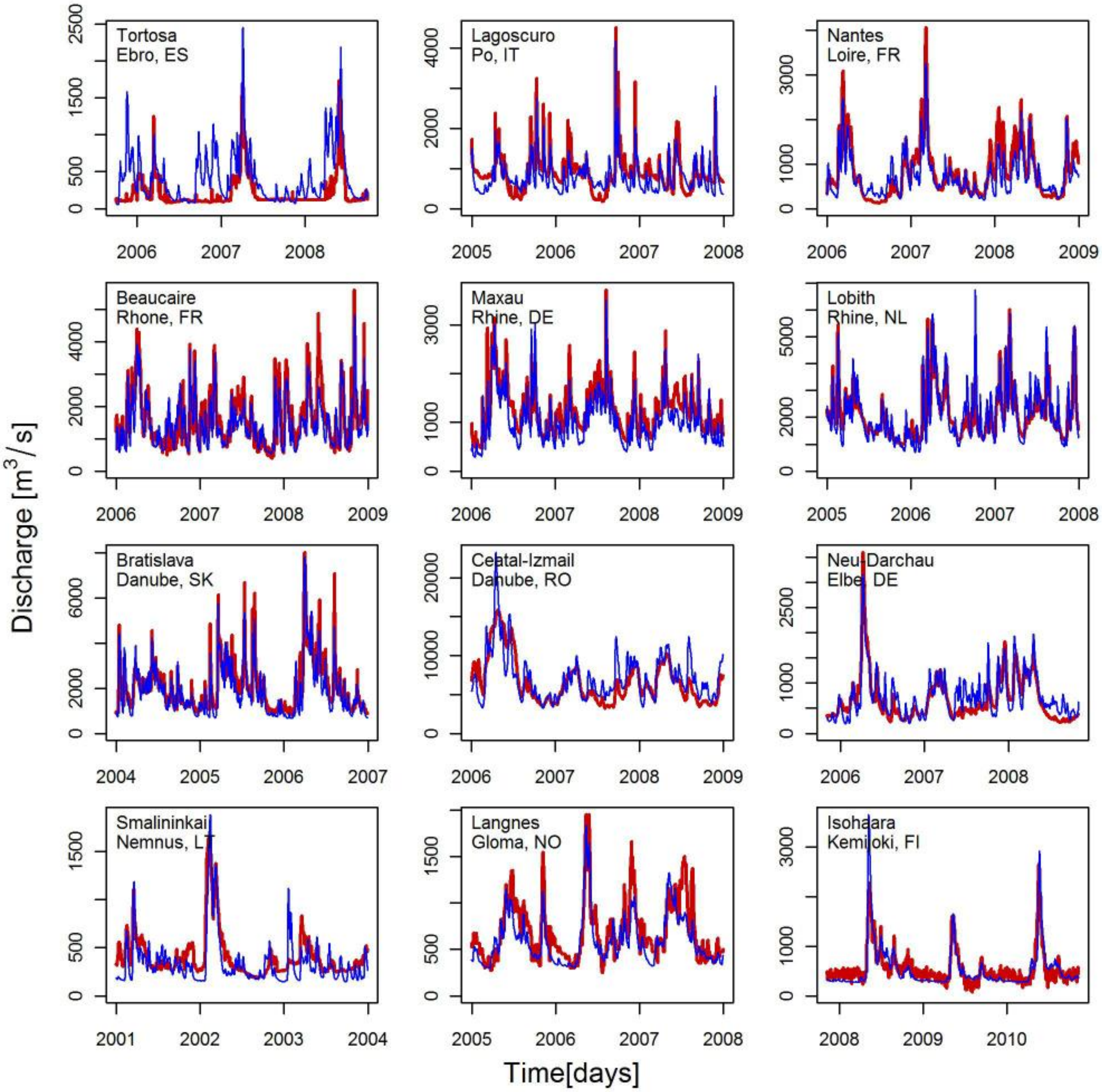


Figure III-10: Time series of observed and simulated discharge for 12 gauging stations

Notwithstanding the overall good agreement between the observed and simulated low-flow statistics, large discrepancies do occur at a small number of stations, where the relative error can be one order of magnitude and the Nash-Sutcliffe efficiency can be lower than 0.2. Deviations from the observation-based statistics can be attributed to errors in the climate data, the spatial interpolation of the climate data, as well as to errors in the hydrological model, its static input and in the calibration and regionalization of its parameters. Several studies, for example Wilby 2005, however, showed that uncertainty in the hydrological model is generally much lower than the uncertainty of the climate input. Some of the disagreements can also be linked with man-made modifications of low-flow regimes in many catchments in Europe that are not accounted for in the hydrological model. Lower observed flow levels can, for example, be due to an increased use of water for irrigation, whereas minimum flow requirements and river regulation may result in artificially higher flows than natural during low-flow periods. The relative impact of water extraction and river flow regulation can be considered to be higher in the low region of the flow spectrum, which renders low-flow regime analysis more susceptible to large errors introduced by unaccounted alterations than average or peak flow analysis (Feyen et al. 2009).

4.2.4 Uncertainty using climate simulations

This section shows the results of LISFLOOD runs aiming at quantifying the uncertainty arising from the use of climate simulations to force the hydrological model. Figure III-11 shows an example of the role climate uncertainty might play in the extreme value fitting. This figure shows, for a subset of 12 gauging stations (triangles in Figure III-8), the fitted Gumbel distribution for the three LISFLOOD runs (1990-2010) forced by bias-corrected climate scenarios (black lines). The darker gray areas therefore depict the range of variation arising from climate uncertainty solely. The lighter gray areas, in turn, show the (overlain) 95% confidence interval for the extreme value fitting, thus considering climate and fitting uncertainty together. The red lines show the extreme value fitting and the 95% confidence interval for the observed meteo data driven LISFLOOD run.

In general, an important range of uncertainty is obtained when performing extreme value analysis, which in some cases may span orders of magnitude (see, e.g., Ebro-Tortosa, Po-Pontelagoscuro or Nemnus-Smalininkai). At the same time, uncertainty increases for higher return periods, which is related to the high degree of extrapolation in the fitting procedure.

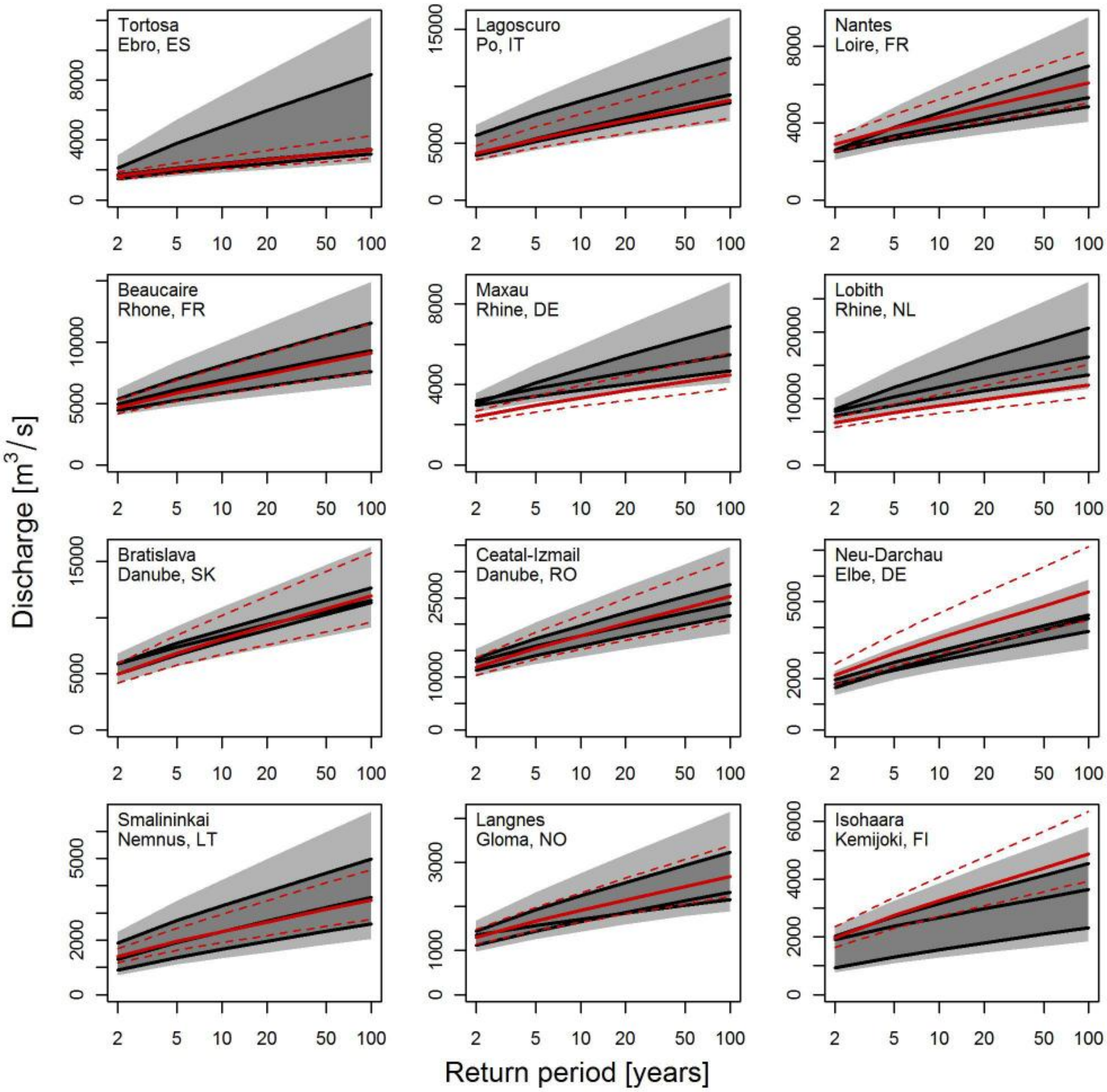


Figure III-11: Return level plots of simulated discharge levels for 120 gauging stations based on a Gumbel distribution fit to the annual maxima in the period 1990-2010.

IV. Scenarios

1.1 Overview

Based on the typology of Natural Water Retention Measures (NWRMs) presented by STELLA consulting (Stella Consulting, 2012) several scenarios were agreed upon as feasible to be modelled. The scenarios and their corresponding NWRMs are given in Table IV-1. Each scenario was simulated using the climate-land use-hydrology modelling framework described in section II to evaluate its impact on regional hydrology. In this section we describe how each scenario was interpreted and simulated. A summary of the processes involved for each scenario is given in Table IV-4. All scenarios were run with the 3 GCM-RCM combinations, and a bias-corrected 1981-2010 control run.

Table IV-1: Correspondence of the selected scenarios to the proposed NWRM measures

Category	Scenario	NWRM natural water retention measure
BASELINE2006	Baseline 2006	
BASELINE2030	0 Baseline 2030	
1-FOREST	1.1 Riparian Afforestation CAP consistent	M2 Maintaining and developing riparian forests M4 Afforestation of agriculture land
	1.2 Afforestation in mountainous areas	M1 Continuous cover forestry
2-URBAN	2.1 25% Green	M11 Filter strips and swales M12 Permeable surfaces and filter drains M13 Infiltration devices M15 Green roofs
	2.2 50% Green	
3-AGRICULTURE	3.1 Grassland	M3 Restoring and maintaining meadows and pastures Convert areas from LUMP-CAP scenarios to grassland
	3.2 Buffer strips	M5 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	M5 Buffer strips 10m wide grass-covered areas in valley-bottom; 1% of arable land converted to grassland, in valley-bottoms
	3.4 Crop practices	M6 Crop practices M7 Tillage M9 Green cover M10 Early sowing
4 STORAGE	4.1 Wetlands	M17 Wetland restoration Riparian wetlands along rivers
	4.2 Re-meandering	M22 Re-meandering Re-meandering of small and medium rivers
	4.3 Buffer ponds in headwater areas	M14 Basins and ponds Natural retention ponds in headwater areas
	4.4 Polders	M20 Floodplain restoration Flood retention polders along rivers

1.2 Description of the scenarios and translation into model parameters

Baseline scenarios

Both baseline scenarios for 2006 (refined CORINE land cover) and 2030 ('business-as-usual" run) were defined using the Land Use Modeling Platform (LUMP). The resulting maps were then used as input to the LISFLOOD model for 3 30-year runs from 1980-2010 on a 5km grid with a daily time step. Extreme value analysis of all 30 year time series of grid cells was carried out for both baseline scenarios.

Baseline 2006

Baseline land use 2006. The CLC land use/cover map for year 2006 (reference year for the simulations) was refined in both spatial and thematic resolution using additional sectorial datasets with continental coverage (Batista et al., 2011). Land use dependent parameters of LISFLOOD were calculated based on this scenario; the percentages of each land use were calculated as fraction maps (sub-grid information).

0 Baseline 2030

This is the reference scenario run, against which all following scenarios were evaluated. This baseline scenario represents the current socio-economic and environmental trends with current policy provision maintained (business-as-usual scenario). No further specific policy options were implemented. This scenario is consistent with the Status Quo scenario developed for the impact assessment of CAP post-2013. The policy provisions taken into consideration in the implementation of the baseline 2030 scenario are detailed as follows:

- Natura 2000: Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora and Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds;
- Nitrate Vulnerable Zones (NVZ): Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC);
- Erosion sensitive areas: the current GAEC framework (Council Regulation (EC) No. 73/2009, Annex III);
- Less Favoured Areas (LFA): this payment scheme promotes agriculture production in areas with natural handicaps (Articles 18 and 20 of Council Regulation (EC) 1257/1999).

The main assumptions used in the baseline 2030 scenario were:

- Future land claims for arable land and pasture were derived from the extended version of the Common Agriculture Policy Regionalised Impact Model (CAPRI) Baseline. Future land claims for urban land were derived from Eurostat data (EUROPOP2008).
- Land use change from forest or semi-natural vegetation to agricultural land, and from agricultural land to urban or industrial land was only allowed outside protected areas (i.e. Natura 2000).

- Abandoned land is driven by economic factors, i.e. emerges as a result of the decline in agricultural claims, and thus its definition does not take directly into consideration any other variable related with economic or demographic conditions (e.g. holdings with low income or proportion of farmers close to retiring age).
- Land use change to arable land and permanent crops is encouraged in less favoured areas and discouraged in environmental sensitive areas: potential riparian areas in currently designated Nitrate Vulnerable Zones; and in erosion sensitive areas (where erosion is between 20 and 50 ton/ha/year or higher than 50 ton/ha/year).

For the following scenarios, where additional LUMP runs were needed we have only highlighted the differences with respect to these baseline 2030 assumptions and the standard settings.

1 Forest

Studies show that extreme events such as floods are most prevalent in catchments where deforestation occurs, and that this is especially true in catchments that are already flood-prone (Solin et al., 2011). According to Creed et al. (2011), forest management strategies can be planned in order to preserve hydrological flows and therefore reduce extreme events. Two forest scenarios were simulated, both of which required an initial LUMP model run to determine the associated land use changes. Figure IV-1 shows an example of the resulting change in forest cover for a region in the Rhone basin.

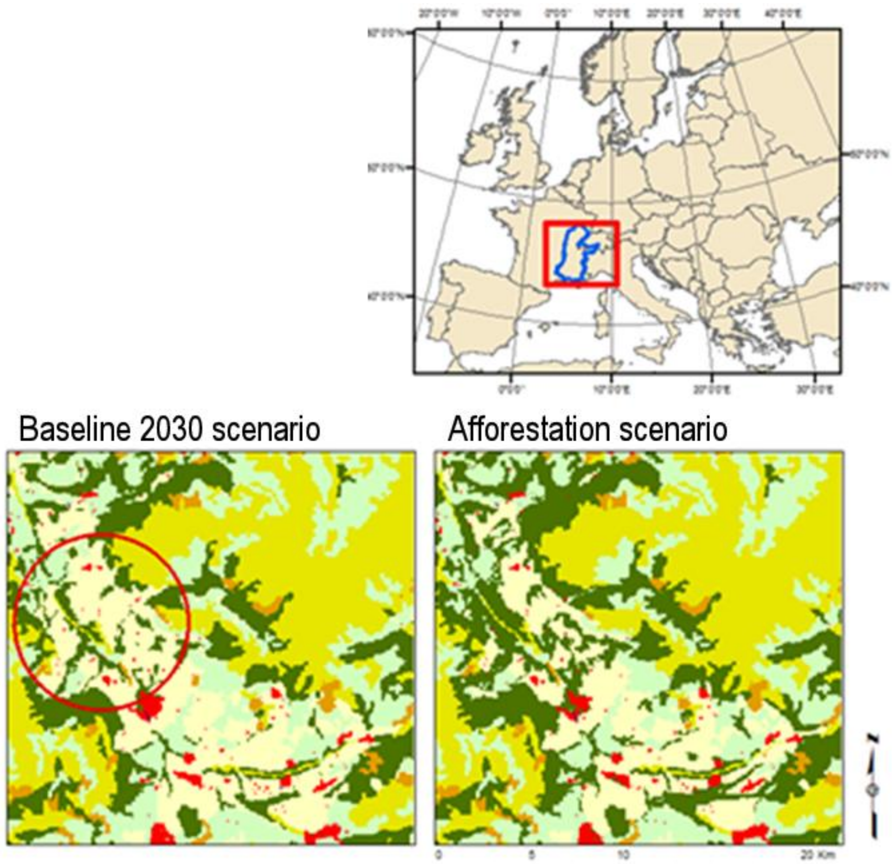


Figure IV-1: Example of land use changes modelled for the afforestation scenario in the Rhone basin

1.1 Riparian Forest

This scenario involves the afforestation of all potential riparian areas alongside rivers, consistent with CAP targets (e.g. demand for agricultural land is not modified at regional level, therefore not decreased because of the afforestation). A LUMP run is required. Taking as a reference the riparian zones identified by Clerici et al. (2011), the suitability for forest was enhanced within potential riparian areas. Since this dataset describes several degrees of probability of having riparian areas, the enhancement of forest might reflect these differences.

The output of the model was used in LISFLOOD as for the baseline runs. The land use transitions involved were translated into changes in hydraulic parameters using pedo-transfer functions.

Assumptions for this scenario were:

- The LUMP model was used with respect to the demand given by CAPRI
- Forest suitability was enhanced within riparian areas as defined by Clerici et al. (2011)

Figure IV-2 shows in blue columns the increase of forest within riparian areas per country. Because the demand given by CAPRI has to be fulfilled this will result in changes from forest to arable land or pasture in other areas. Therefore the green columns shows the real increase of forested areas which is effectively zero for some countries.

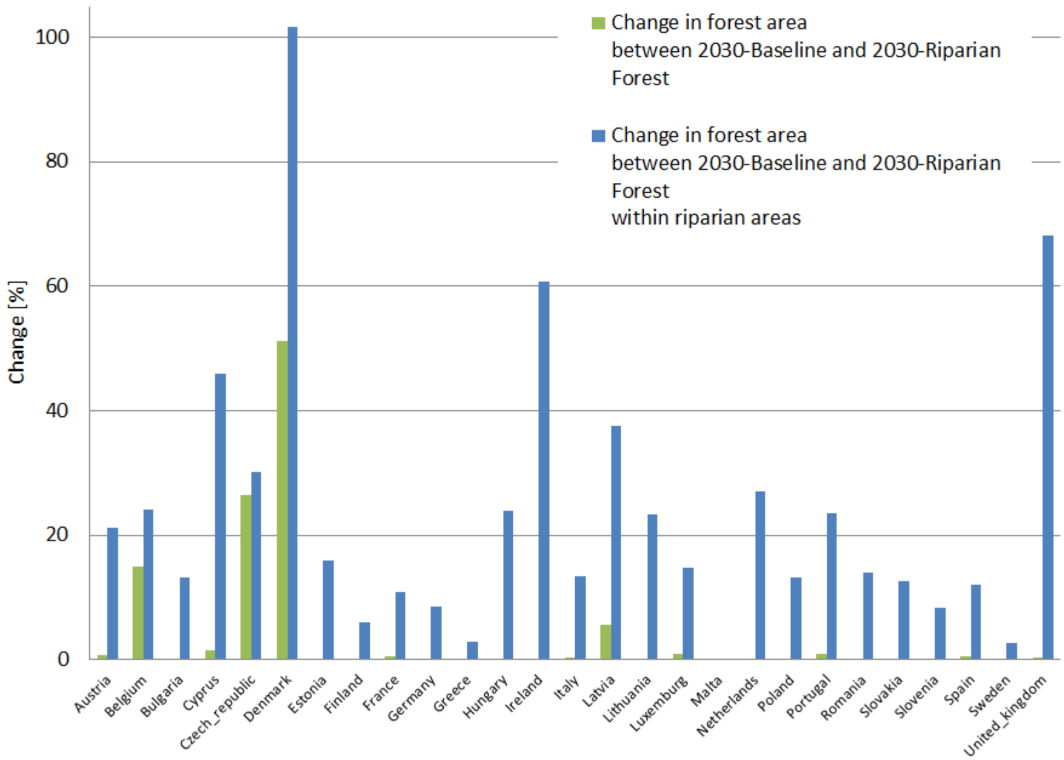


Figure IV-2: Change in forest area between Baseline 2030 and Riparian Forest Scenario 2030, as percentage of forest area in Baseline 2030

Translation into hydrological model parameters:
For each CORINE grid cell (~100m x 100m) it is checked, wether the CORINE land use type has to be changed according to the scenario assumptions. Each land use type is connected to vegetation parameters like leaf area index (LAI), different crop coefficients (see van der Knijff 2008) and to soil parameters like soil depth or surface runoff roughness. Furthermore hydraulic properties of the soil like porosity and hydraulic conductivity etc. (see van Genuchten, 1980) are also changed in relation to land use and soil type (Wösten et al., 1999).
For each 5x5km grid cell the new proportion of sealed area, forest and water is calculated and for each of this proportion the composite of the vegetation and soil parameter is calculated.

An example for a single 5x5km cell:
A 5x5km pixel contains 2500 100x100m cells. According to the scenario assumption 100 cells (+4%) are changed from arable land to mixed forest. The percentage of water stays the same but sealed area is reduced (-0.3%) because forest has less sealed percentage than arable land (less pathways). For the proportion of sealed, forest, water and other land use each parameter is calculated separately. I.e the area of forest has increased from 1000 cells to 1100. For this changed 100 cells the change in i.e LAI for January is included in the new average LAI for January for forest. At the end the LISFLOOD hydrological model is processed according to the proportion sealed area, forest, water and other land use with a new set of parameters for each proportion.

For the following scenarios this process is called:
- Vegetation and soil parameters were changed according to the different land uses

1.2 Afforest hilly and mountainous areas

Areas above 500m altitude, with slopes > 10% were afforested or reforested including the filling of gaps within existing forested areas, non-CAP consistent. A LUMP run was carried out with a strong enhancement of the conversion to forest from pastures, arable land, permanent crops and semi-natural vegetation in areas above 500m a.s.l and with slopes greater than 10%. It should be noted that this scenario is based on the configuration of the Baseline 2030. However, the encouragement of the land use change to arable land and permanent crops in Less Favoured Areas was not implemented, due to the conflict between art.18 (mountains) of Council Regulation (EC) 1257/1999 and the aim of this scenario. The LISFLOOD runs and post-processing were carried out in the same way as for the baseline scenarios.

Assumptions for this scenario were:
- The LUMP model was used with respect to the demand given by CAPRI
- Conversion to forest enhanced on areas above 500 m altitude,
- and slopes bigger than 10%

Translation into hydrological model parameters:

- Vegetation and soil parameters were changed according to the different land uses (see IV.1.1)

2 Urban

The urban “greening” runs were designed to show the impact of a lowered sealed surface and an increased leaf area index for selected urban areas. The urban areas were selected based on the configuration of their neighbouring areas. Only “core” urban regions, that is those completely surrounded by other urban areas, were selected for the greening measures. A 5x5 erosion filter was applied on the 2030 baseline map urban class to capture the core urban areas only (surrounded by 500m of urban on all sides). When overlain with the original 2006 map, 66% of what is called “highest density urban” in the CORINE land cover refined map for 2006; 37% of “medium density urban”; 7% of “low density urban” ; 1% industry ; 2% road and rail were captured. Figure IV-3 shows an example of the urban areas captured in this procedure for further analysis of greening urban areas.

Translation into hydrological model parameters:

- Vegetation and soil parameters were changed according to the different land uses (see IV.1.1)

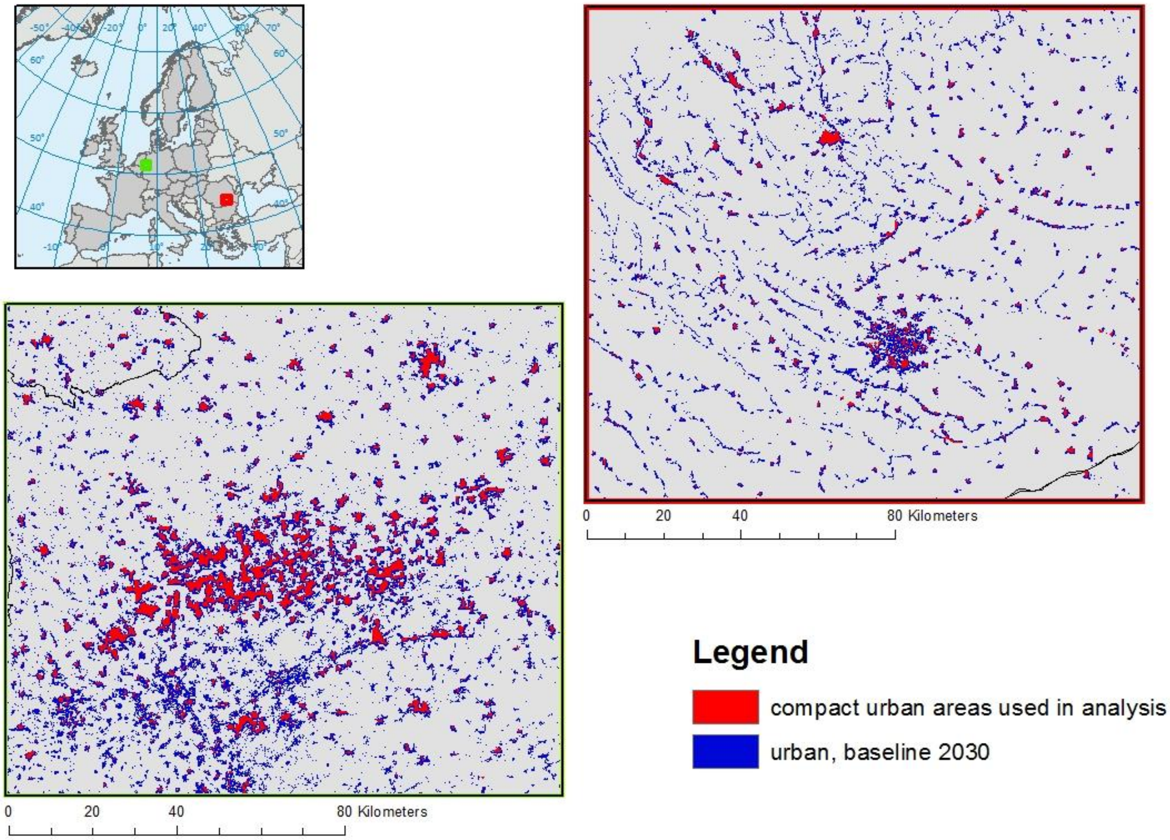


Figure IV-3: Two excerpts of the urban areas that were captured and retained for the analysis on greening urban areas.

2.1 25% Green

This scenario simulates the implementation of a combination of green infrastructure related measures in urban areas like open green spaces, green roofs, rain gardens, park depressions, and infiltration devices. The percentage of impermeable area within CORINE land use class 1 (continuous urban fabric) was reduced to 25% sealed area, using the methodology described above. The look-up table for land use was accordingly adjusted for impermeable area, and the leaf area Index for other vegetation was increased by 10%. The LISFLOOD runs were carried out as for the baselines.

Assumptions for this scenario were:

- The selection of only CORINE land use class 1 areas which are completely surrounded by other urban land

Effect on the hydrological model:

- The percentage of impermeable area of CORINE land use class 1 areas which are completely surrounded by other urban land was reduced by 25%. The new nonsealed areas got the soil and vegetation attributes of CORINE "Green urban areas" and vegetation and soil parameters were changed and aggregated according.

2.2 50% Green

The same methodology was applied as for 2.1, except that the percentage of impermeable area was reduced by 50%.

Assumptions for this scenario were:

- The selection of only CORINE land use class 1 areas which are completely surrounded by other urban land

Effect on the hydrological model:

- Vegetation parameters (i.e. leaf are index) were changed and the percentage of impermeable area was reduced by 50% for each single CORINE cell which fulfil the assumptions. To run LISFLOOD the parameters are averaged on a 5x5km grid for four different classes (see IV.1.1)

3 Agriculture

3.1 Grassland

The CAP-demand for grassland/pasture was increased by 10% on slopes larger than 10%. This required a LUMP run in which each NUTS2 region received an increase of 10% for grassland/pasture with respect to the demand given by CAPRI. Additionally, the presence of grassland/pastures was enhanced on land with slopes greater than 10%. If the current land use was already grassland/pasture its maintenance was enhanced. The conversion of forest/natural vegetation to grassland was prohibited to prevent increasing of flood risk.

The LISFLOOD runs were carried out as for the baselines. The influence of the conversion of cropland to grassland on the hydraulic parameters was calculated using the pedo-transfer functions (section III. 4.1).

Table IV-2: Change in bulk density and organic matter for scenario "grassland"

Land use change	Assumed change in bulk density	Assumed change in organic matter
Crops to grassland	6.5% decrease	5% increase

(Compiled from different literature e.g. Bormann et al. 2007; Breuer et al., 2006; Strebel et al., 1988)

Assumptions for this scenario were:

- Increased demand for pasture/grassland on slopes larger than 10%

  Slopes > 10% because:

  - replacing less productive arable fields with pasture/grassland

  - Generally hilly/mountainous area have higher precipitation

  The LUMP model is used with respect to the demand given by CAPRI

Translation into hydrological model parameters:

- Vegetation and soil parameters were changed according to the different land uses. For each single CORINE cell (100 x 100) it is checked if the assumptions are fulfilled. If the land use is changed this will influence the calculation of the average parameter values for either forest, water, sealed or other land use. These 4 subdivisions are than calculated separately in LISFLOOD. In general for grassland there is a higher leaf area index in spring, autumn and winter and less bulk density and more organic matter.

3.2 Buffer strips

5m wide grass buffer strips were simulated within arable fields, on slopes between 2% and 10%, every 200m slope length (ideally constructed along the contours). This involved GIS preprocessing, whereby the areas between 2% and 10% slope gradient were selected, overlain with the arable land defined by the land use maps, and the vegetation and soil parameter tables were recalculated assuming 2.5% of arable land converted to grassland. The LISFLOOD runs were carried out as for the baselines. Figure IV-4 shows the percentage of arable land for each $25km^2$ grid cell.

Assumptions for this scenario were:

- implementation on all arable land
- and with slope between 2% and 10% (in order to have an effect on discharge concentration)
- every 200m a 5m buffer strip, that is 2.5% of arable land converted to grassland

Translation into hydrological model parameters:

- Vegetation parameters (leaf are index), soil depth and overland flow roughness was changed

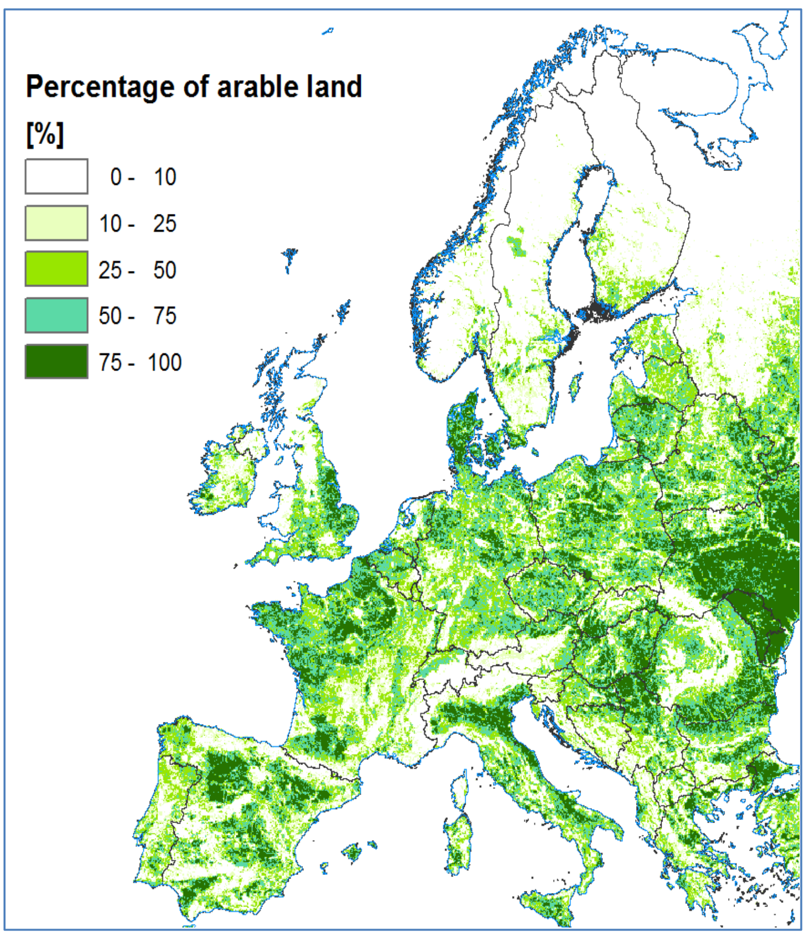


Figure IV-4 Percentage of arable land (derived from baseline 2030 scenario)

3.3 Grassed waterways

10m wide grass-covered areas were simulated in headwater valley bottoms. GIS preprocessing was used to select all areas equal 25km^2 upstream area (headwater areas). These areas were then overlain on the arable land defined by the land use maps, and the vegetation and soil parameter tables were recalculated assuming 5 % of arable land converted to grassland. This will result in changes of leaf area index, overland flow roughness and soil depth for the LISFLOOD run.

Assumptions for this scenario were:

- implementation on all arable land
- use of only headwater areas with a catchment size of 25km^2
- 5% of arable land converted to grassland - (50m grass strip every 1000m)

Translation into hydrological model parameters:

- Vegetation parameters (leaf are index), soil depth and overland flow roughness was changed

3.4 Crop practices

This scenario analyses the effects of the implementation of combined methods of improved crop practices on arable land. Modelled effects are reversed/reduced organic matter decline and increased mulching and tillage. Infiltration was increased by changing soil hydraulic parameters (e.g. bulk density/porosity). According to literature, improved crop practices should decrease bulk density and increase organic matter. The scenario "Crop practice" was applied to all arable land. Figure IV-4 shows the percentage of arable land for each 25km^2 grid cell.

Table IV-3: Change in bulk density and organic matter for the scenario "crop practice"

Land use change	Assumed change in bulk density	Assumed change in organic matter
Crop practices	10% decrease	10% increase

(Compiled from different literature e.g. Oquist et al., 2006; Goidts & Wesemael, 2007; Green et al., 2003)

Assumptions for this scenario were:

- implementation on all arable land

Translation into hydrological model parameters:

- hydraulic parameters were changed according to the assumed changes in bulk density and organic matter using the pedo-transfer functions.

4 Water retention in the river basin and along the rivers

4.1 Wetlands

The amount of riparian wetlands along rivers was increased. The same LUMP run was used as in 2.1 (Riparian areas). For the new riparian forest areas in scenario 2.1, the channel cross section was increased to match the size of the full riparian area. LISFLOOD was run as in the baseline, but with a changed channel width map. Figure IV-5 shows in which rivers this scenario was applied.

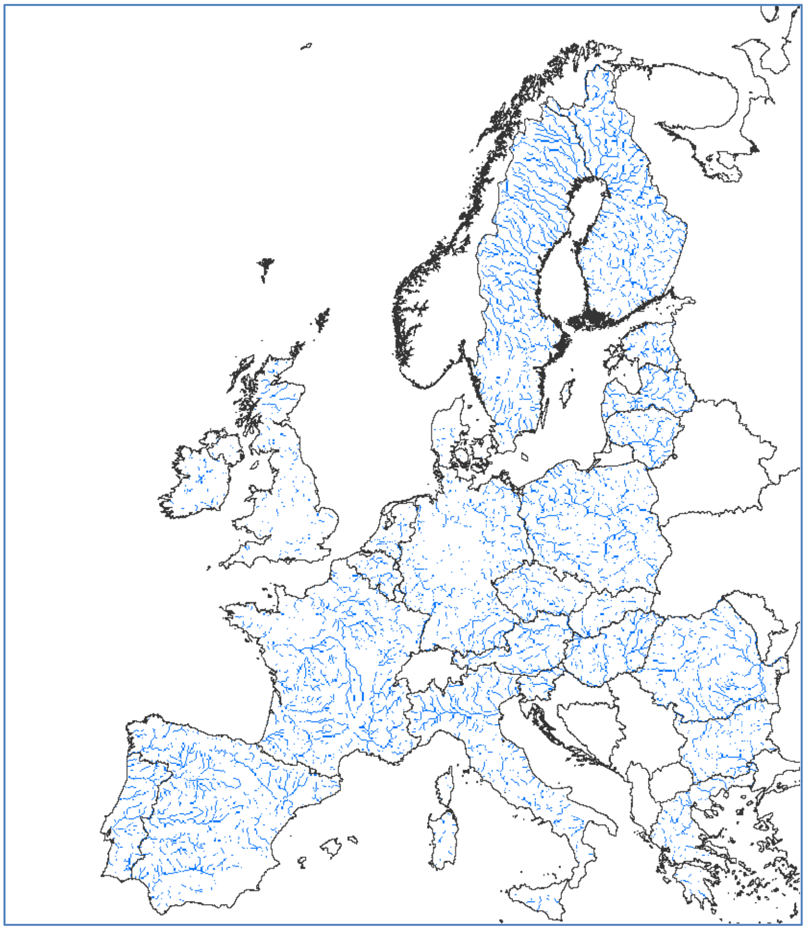


Figure IV-5 Rivers where the scenario "Wetlands" was applied

Assumptions for this scenario were:

- Implementation within riparian areas , see Clerici et al. 2011;
- Where slope of the channel was less than or equal to 1%;
- And upstream catchment area was larger or equal to 400 km^2

Translation into hydrological model parameters:

- flood plain width was increased by a factor of 1.2 for the rivers shown in Figure IV-5

4.2 Re-meandering

Small to medium rivers were selected to be used for re-meandering (Reinhardt et al., 2011). GIS preprocessing involved creating a buffer around the rivers of land with a gradient of ≤ 1%; for the remaining pixels, the channel length was increased by 20%. LISFLOOD was then run with the changed channel length map.

Assumptions for this scenario were:

- Implementation within riparian areas , see Clerici et al. 2011;
- Where slope of the channel was less than or equal to 1%;
- And upstream catchment area is between 100 km^2 and 5000 km^2

Translation into hydrological model parameters:

- river length was increased by a factor of 1.2 for the rivers shown in Figure IV-6

Figure IV-6 Rivers where the scenario "Re-meandering" was applied

4.3 Buffer ponds in headwater catchments

Natural retention ponds were introduced in headwater areas with a storage capacity of 86400 m^3. GIS preprocessing involved the selection of selected upstream areas 50 to 100km^2 (headwater areas), and the subsequent introduction of points with buffer ponds (excluding areas already having lakes & reservoirs). LISFLOOD was run simulating these points as ponds, or as lakes (with defined area 20000m^2 and outlet width equal to the channel width of the river network at this point). In total, 2213 natural retention ponds are introduced (see Figure IV-7).

Assumptions for this scenario were:

- Implementation in upstream area between 50 to 100 km^2;
- only if the percentage of urban settlement was between 10% and 40% (close to settlements but not inside cities)
- only between an elevation of 20m and 1000m (not in the coastal zones or mountainous areas)
- only if the soil texture was not sand
- only if it there is was not already a lake

Translation into hydrological model parameters:

- routing included the effects of natural retention ponds

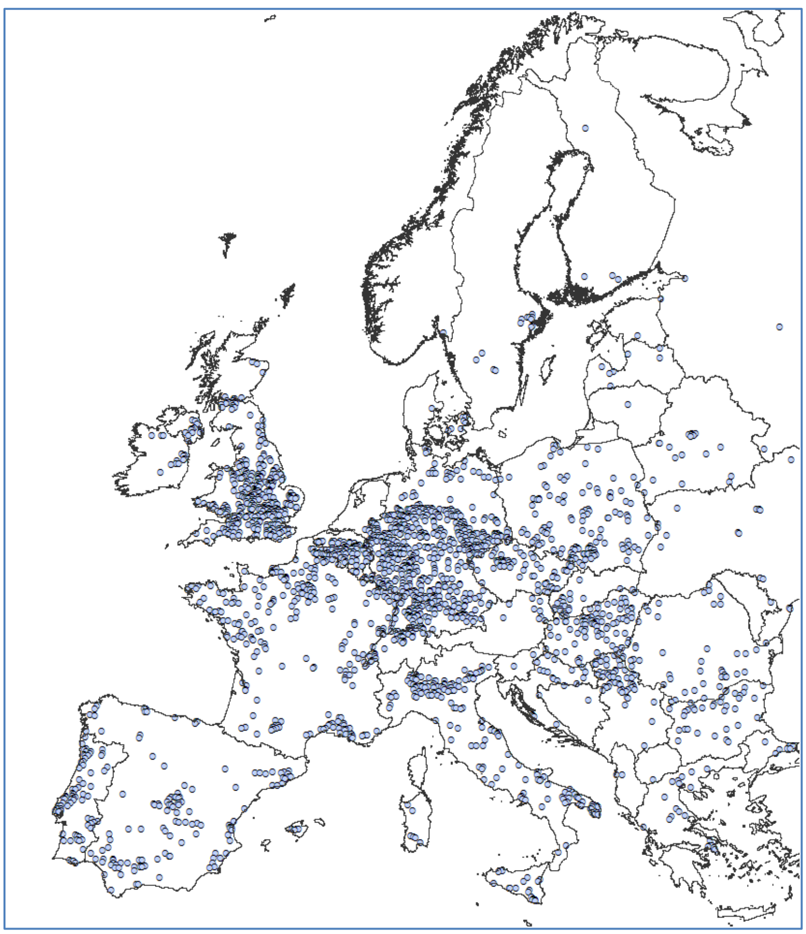


Figure IV-7 The location of natural retention ponds added for the scenario "Buffer ponds"

4.4 Polders

While floodplains (scenario Wetlands) are getting flooded with the rising waterlevel already during the initial phase of a flood, polders are flooded more or less suddenly after the waterlevel reaches a certain limit. Therefore in general a polder performs better to cut of the peak discharge of a flood. In the context of natural water retention measures we look here at polders without echnical steering of in- and outflow.

Natural polders were introduced along rivers. GIS pre-processing was used to find locations for the river polders. Catchments were selected with an area bigger than 10000km^2. The distance to the next polder was kept at approximately 50km. In LISFLOOD, the polders were implemented as lakes/reservoirs, so that the model was run with additional lakes with a defined area of 2 mio^2 and outlet width equal to the channel width of river network at this point. In total, 569 polder sites, each with a size of 200 ha were used in this scenario (Figure IV-8).

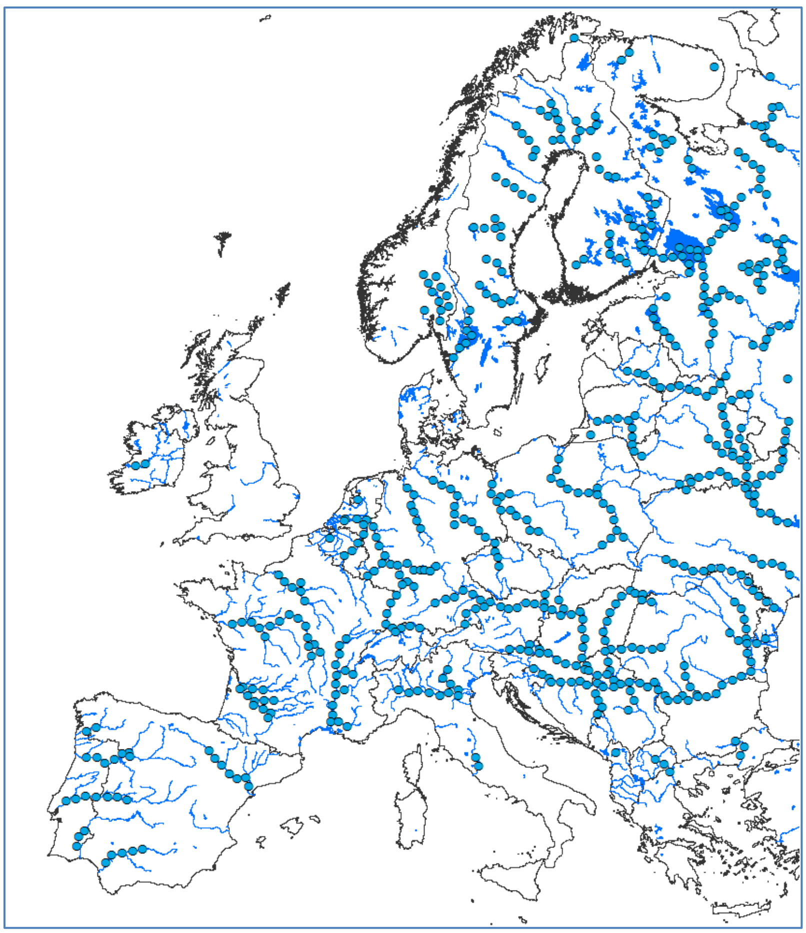


Figure IV-8 The location of polder sites added for the scenario "Polder"

Assumptions for this scenario were:

- Implementation where upstream catchment area was larger than 10000km^2;
- each polder at a distance of 50km from the next one;
- where the average discharge must be bigger than 100m^3/s

Translation into hydrological model parameters:

- routing included the effects of polders

Table IV-4: Summary of the scenarios simulated in this study

Scenario		Description	Pre-processing	LUMP	LISFLOOD Model
BASELINE 2006		LUMP Baseline 2006	-	Refined CORINE 2006	3 climate data sets, each 30-year run
BASELINE 2030		LUMP Baseline 2030	-	2030 baseline scenario	
1-FOREST					
1.1	**Riparian Forest**	Afforest areas alongside rivers, buffer of 100m	GIS & pedo-transfer	New run	change land use to forest for those areas
1.2	**Reforestation**	Afforest areas alongside rivers, buffer of 200m	GIS & pedo-transfer	New run	change land use to forest for those areas
2-URBAN					
2.1	**50% Green**	Green infrastructure, Green roofs, Rain Gardens	change of lookup tables	-	For all urban areas: Direct Runoff Fraction < 50%
2.2	**25% Green**	Green infrastructure, Green roofs, Rain Gardens	change of lookup tables	-	For all urban areas: Direct Runoff Fraction < 25%
3-AGRICULTURE					
3.1	**Grassland**	Convert areas to grassland	GIS & pedo-transfer	New run	change land use to grassland for those areas
3.2	**Buffer strips**	5m wide grass buffer strips within arable fields every 200m	GIS & pedo-transfer	-	2.5% of arable land converted to grassland
3.3	**Grassed waterways**	10m wide grass-covered areas in headwater valley bottom	GIS & pedo-transfer	-	2% of arable land converted to grassland
3.4	**Crop practices**	Reverse OM decline and increase mulching, tillage	GIS & pedo-transfer	-	increase infiltration by changing soil parameters
5-STORAGE					
4.1	**Wetlands**	Riparian wetlands along rivers	GIS	-	Change cross section
4.2	**Re-meandering**	Re-meandering of small to medium rivers	GIS	-	Change channel length
4.3	**Buffer ponds**	Retention ponds in headwater areas	GIS	-	Introduce ponds with 86000m3 storage
4.4	**Polders**	Introduce natural polders	GIS	-	Introduce polders along rivers

V. Results

1 Introduction

The results section looks especially at quantifying the scenario impacts on low flow and flood peaks as compared to the 2030 baseline. To assess the impact on flooding, the 20-year-return-period discharge was calculated as an indicator. The discharge of the Baseline 2030 20-year-return-period was taken as reference and compared to the ones for each scenario. To assess the impact on low flows, the 10th percentile of the daily discharge values was taken (i.e. for 10 percent of the days over the simulated domain of 30-years, discharge is lower than this value)

Results will be shown for 21 European macro-regions (figure V-1). Due to the resolution of the climate simulations (e.g. 25 km grid cells of the HIRHAM5-ECHAM5 model) the analysis is limited to catchments with an upstream area larger than 400 km^2.

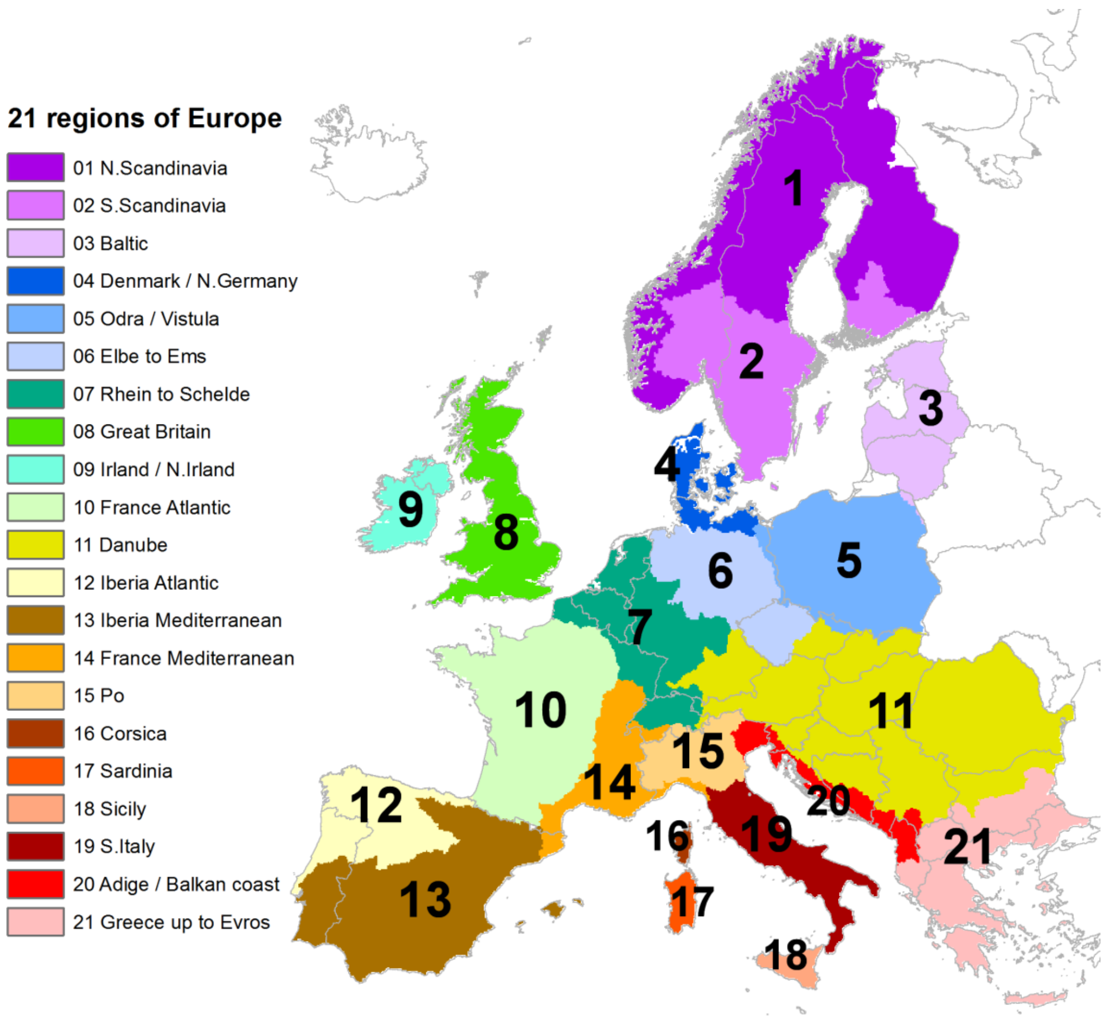


Figure V-1: The 21 regions of Europe used to represent the results, defined by river basins, climate zones and socio-economics

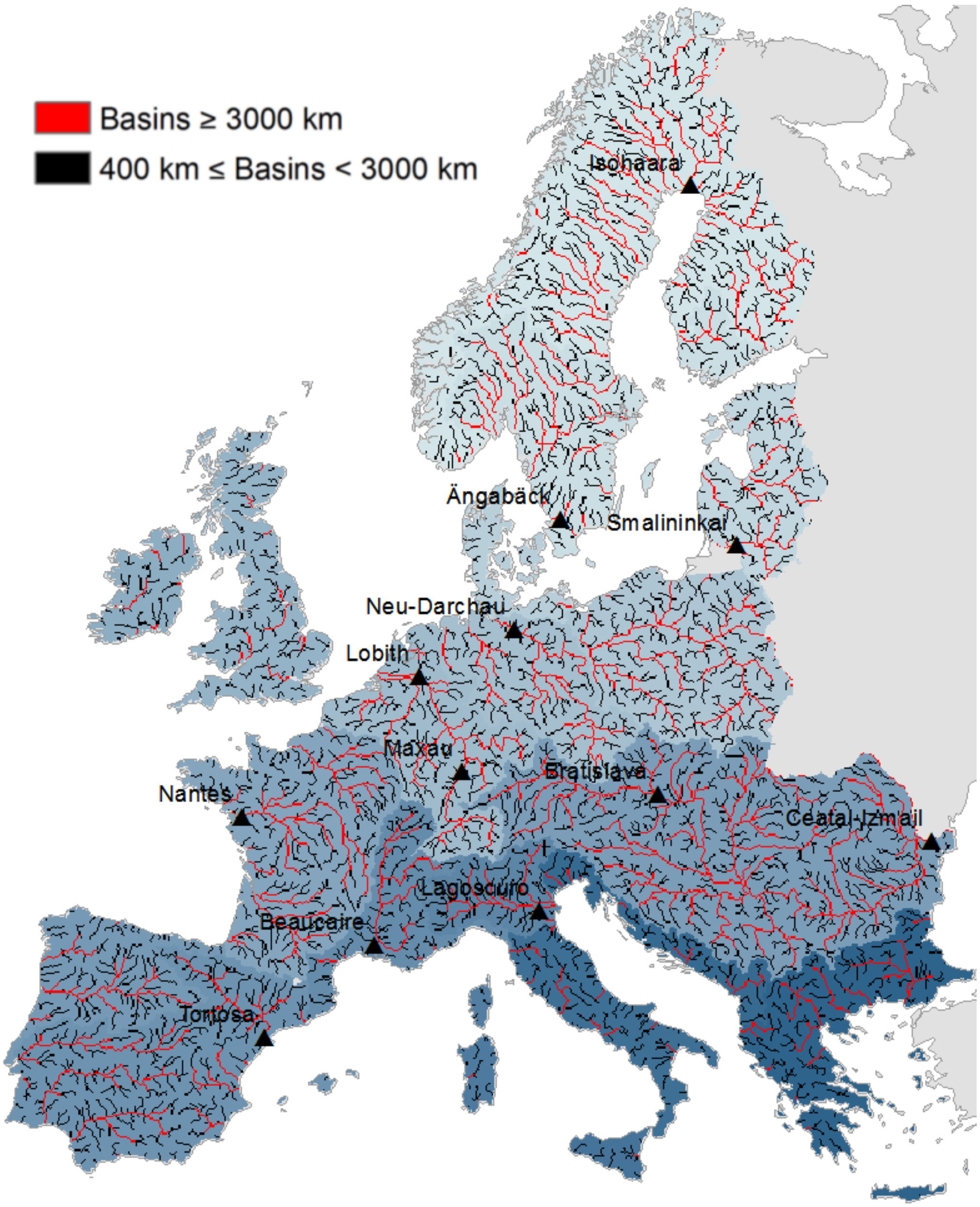


Figure V-2: The regions, river networks and gauging stations used to analyse the results

Addressing the uncertainty

Every model result in environmental sciences is uncertain and combining different models (e.g. here for climate, land use, hydrology, and extreme value estimation) will enlarge this uncertainty. A big if not major part of the uncertainty in this model chain originates from the climate scenarios. The way uncertainty was dealt with in this project was a compromise between a complex analysis procedure and computational effort. We tried to put some estimation of uncertainty in but we refrained from a complete evaluation like GLUE (Beven and Freir, 2001) mainly because this effort would require enormous computational effort. Instead of using a climate scenario ensemble we used three selected ensemble members. The spatial resolution of the Land use model is 100m, of LISFLOOD it is 5km but including sub-pixel information, but the spatial resolution of the climate simulations (e.g. 25 km grid cells of the HIRHAM5-ECHAM5 model) limits the analysis to bigger scales. Therefore the focus is on catchments with an upstream area larger than 400 km^2. Combined with the uncertainty of the extreme value estimation this resulted in differences between the lowest and highest value for the 100-year return period of a factor 2.

Furthermore we have to distinguish between mesoscale and macroscale catchments, because of the different, scale dependent, influence of different types of rainfall generation. Convective storm events in general have high precipitation intensities over a short period of time and cover a small area, as opposed to advective storms, which have lower intensities but for a longer period and covering a larger area. Convective storms will affect smaller areas and runoff due to the high rainfall intensity is highly correlated to land use and soil cover and less to the pre-condition of the soil (Bronstert et al. 2007), but mostly this kind of storm does not produce enough runoff to cause flooding in the larger rivers.

Advective storms can affect larger catchments entirely. The intensity is lower but due to the longer rain period and larger area covered the amount of runoff is sufficient to potentially cause major flooding of larger rivers. For these events the pre-condition of the soil (e.g. saturated, frozen) will have a greater effect on runoff than land use (Disse et al. 2007).

For further analysis the 21 regions were therefore split into catchments with an upstream area between 400 km^2 and 3000 km^2 and those with an upstream area equal to or larger than 3000 km^2.

Parameters used to describe the effect of scenarios

The hydrological model is able to quantify a wide range of parameters, describing snow, vegetation, soil, groundwater, runoff and discharge. For each of these parameters there are various statistical methods, which could be used to characterize the time series.

For discharge we used the following statistical characteristics:

- The 10th percentile of the whole 30 year period to describe the effect on low flows
- The average discharge to show the influence on the mean
- The 20 year return period derived from extreme value statistics to show the influence on flood peaks. The 20 year return period is the amount of discharge which can occur each single year with a probability of 1/20.

Three other parameters were selected to describe other aspects of the water cycle (fast runoff, evapotranspiration and groundwater recharge, see Figure V-3). For these parameters the average values from the 30 year period was calculated.

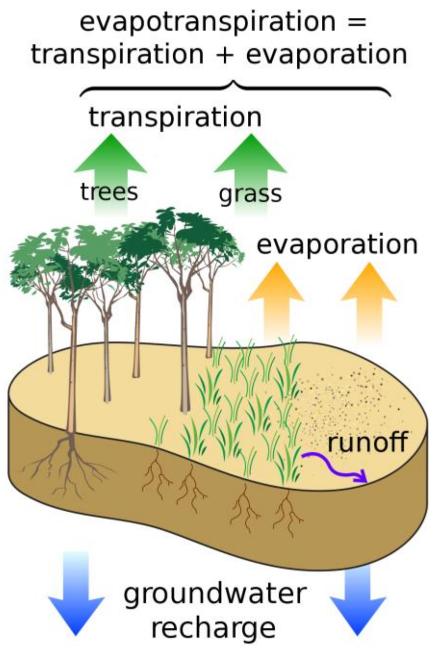


Figure V-3: Surface water cycle. © Mwtoews / Wikimedia Commons

- Fast runoff from surface and close to surface runoff (mostly through macropore flow). This part of the runoff reacts fast after a rainfall event and is the most important part of peak flows.
- Evapotranspiration is the sum of evaporation and plant transpiration from the surface to atmosphere.
- Groundwater recharge

In this study groundwater recharge is composed of soil water which percolates through the soil layers and preferential bypass flow, a flow that bypasses the soil matrix and drains directly to the groundwater. Ignoring this preferential flow would lead to unrealistic model behaviour during rainfall conditions, but the amount of preferential flow depends very much on the calibration of the model. Because of this more conceptional than physical approach, groundwater recharge can only be seen as an estimate.

All parameters except the water stress are expressed as a percentage change compared to a baseline scenario.
The parameter water stress is selected to describe the possible effect on arable plants. Water stress is the number of days where the amount of moisture is below the soil moisture at wilting point (soil moisture stress for plants). This parameter is calculated only for the arable parts of a pixel (no forest or sealed area is included).

2 Comparison of the baselines 2006 and 2030

2.1 Comparison of 12 reference stations

For the 12 reference stations (Figure V-4, Table V-1), the baseline 2006 and baseline 2030 results were compared (Table V-2). The results show a min. -2.0 % and max. 1.2 % difference between the two scenarios. The absolute values of the 3 different climate scenarios vary substantially, but the relative differences in relation to land use change are quite small. For the river Loire at station Nantes (France) we get the largest positive discrepancy especially for high flows (around 1% for all return periods and for all climate scenarios). For the river Lagan, Ängabäcks (Sweden) we get a reduction of discharge from low flows to high flows of around 0.8%.

Table V-1: An overview of the stations used for evaluation

Station	River	Country	Lat.	Lon.	Area [km^2][a]	Average Q [m^3/s][c]
Tortosa	Ebro	Spain	40.815	0.522	85001	276 (01/01/1990-30/09/2008)
Lagoscuro	Po	Italy	44.889	11.608	71650[b]	1450 (01/01/1990-31/12/2007)
Nantes	Loire	France	47.212	-1.539	115425[b]	824 (01/01/1990-31/12/2008)
Beaucaire	Rhone	France	43.805	4.651	95200[b]	1600 (01/01/1990-31/12/2008)
Maxau	Rhine	Germany	49.030	8.300	50196	1250 (01/01/1990-31/12/2008)
Lobith	Rhine	Netherland	51.840	6.110	160800	2230 (01/01/1990-31/12/2007)
Bratislava	Danube	Slovakia	48.140	17.100	131331	2064 (01/01/1990-31/12/2006)
Ceatal-Izmail	Danube	Romania	45.217	28.717	807000	6367 (01/01/1990-31/12/2008)
Neu Darchau	Elbe	Germany	53.230	10.880	131950	658 (01/01/1990-31/10/2008)
Smalininkai	Nemnus	Lithuania	55.070	22.570	81200	485 (01/01/1990-31/12/2003)
Ängabäck	Lagan	Sweden	56.490	13.510	5480	66 (01/01/1990-31/12/2003)
Isohaara	Kemijoki	Finland	65.792	24.549	50686	565 (01/01/1990-31/10/2010)

a: catchment area from GRDC or provider metadata
b: catchment area from LISFLOOD river network
c: calculated from the given time period (time series from GRDC or local provider)

Table V-2: Comparison of the Baseline 2030 – Baseline 2006 scenario simulations.
Negative (blue) values: Baseline 2030 < Baseline 2006
Positive (red) values: Baseline 2030 > Baseline 2006

[%]		Flow duration curve				Low flow		High flow			
Station	**Clima**	**p5**	**p10**	**p50**	**p95**	**Low7d**	**Low30d**	**AvgMax**	**rp2**	**rp20**	**rp100**
Tortosa, Ebro, ES	DMI	-0.3	-0.2	-0.4	-0.1	-0.5	-0.3	0.0	0.0	0.1	0.1
	KNMI	-0.2	-0.3	-0.2	-0.1	-0.5	-0.3	0.0	0.1	0.1	0.1
	METO	-0.3	-0.3	-0.1	-0.3	-0.2	-0.3	0.1	0.1	0.0	0.0
Lagoscuro, Po, IT	DMI	-0.2	-0.2	-0.1	-0.4	-0.2	-0.1	-0.4	-0.4	-0.4	-0.4
	KNMI	-0.3	-0.3	-0.3	-0.5	-0.3	-0.3	-0.5	-0.5	-0.5	-0.5
	METO	-0.3	-0.2	-0.2	-0.4	-0.3	-0.3	-0.7	-0.6	-0.8	-0.9
Nantes, Loire, FR	DMI	0.6	0.5	0.4	0.7	0.8	0.6	0.8	0.9	1.0	1.0
	KNMI	0.6	0.6	0.2	0.5	0.6	0.5	0.8	0.8	1.1	1.1
	METO	0.4	0.2	0.2	0.6	0.1	0.1	0.9	0.9	1.2	1.2
Beaucaire, Rhone, FR	DMI	-0.1	0.0	0.0	0.0	-0.1	-0.1	0.1	0.1	0.1	0.1
	KNMI	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	0.1	0.1	0.2	0.2
	METO	-0.1	0.0	0.0	-0.1	-0.1	-0.1	0.1	0.1	0.1	0.2
Maxau, Rhine, DE	DMI	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1
	KNMI	0.0	-0.1	0.1	0.1	0.0	0.1	0.2	0.2	0.1	0.1
	METO	0.1	0.0	0.0	-0.2	0.0	0.0	0.1	0.1	0.0	0.0
Lobith, Rhine, NL	DMI	-0.1	0.0	0.1	0.1	-0.1	0.1	0.2	0.2	0.1	0.0
	KNMI	-0.1	-0.2	0.1	0.3	-0.1	0.0	0.2	0.2	0.3	0.3
	METO	-0.1	0.2	0.1	-0.1	-0.1	0.0	0.2	0.2	0.1	0.1
Bratislava, Danube, SK	DMI	0.0	-0.1	0.0	0.0	0.0	-0.1	0.1	0.1	0.1	0.1
	KNMI	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.1	0.1	0.2	0.2
	METO	-0.1	-0.1	0.0	0.0	-0.1	-0.1	0.1	0.1	0.0	0.0
Ceatal-Izmail, Danube, RO	DMI	0.0	-0.2	-0.1	0.0	0.0	-0.1	-0.1	-0.1	-0.2	-0.2
	KNMI	-0.2	-0.2	-0.1	-0.1	0.0	-0.1	-0.1	-0.1	-0.1	-0.1
	METO	-0.2	-0.3	-0.2	-0.1	-0.4	-0.3	-0.1	-0.1	-0.1	-0.1
Neu-Darchau, Elbe, DE	DMI	0.1	0.1	0.5	0.3	0.2	0.7	0.5	0.5	0.4	0.4
	KNMI	0.4	0.1	0.5	0.1	0.0	0.2	0.5	0.6	0.5	0.4
	METO	0.0	0.3	0.6	0.3	-0.5	0.4	0.4	0.5	0.2	0.1
Smalininkai, Nemnus, LT	DMI	0.1	0.1	-0.6	-0.2	0.3	0.0	-0.4	-0.4	-0.3	-0.2
	KNMI	0.3	0.2	-0.8	-0.5	-1.0	-1.4	-0.5	-0.5	-0.2	-0.2
	METO	-0.6	-1.1	-1.4	-1.0	0.4	0.2	-0.5	-0.6	-0.1	0.0
Ängabäcks, Lagan, SE	DMI	-0.5	-0.5	-0.5	-0.2	-0.3	-0.7	-0.8	-0.8	-0.8	-0.8
	KNMI	-0.3	-0.7	-0.4	-0.3	-1.0	-2.0	-0.9	-0.9	-0.9	-0.9
	METO	-0.5	-0.8	-1.1	-0.1	-0.3	-1.3	-1.1	-1.1	-1.0	-1.0
Isohaara, Kemijoki, FI	DMI	0.5	0.5	-0.4	0.0	0.5	0.5	-0.1	-0.2	-0.2	-0.2
	KNMI	0.4	0.3	-0.3	-0.2	0.4	0.4	-0.1	-0.1	-0.1	-0.1
	METO	0.4	0.3	-0.6	-0.3	0.4	0.2	-0.2	-0.3	0.0	0.1

p5, p10, p50, p95: Percentage of the flow duration curve
Low7d, Low30d: Low flow analysis - average of yearly 7-day (30-day) minimum discharge
AvgMax: Average yearly flood (mean of yearly flood peaks)
rp2, rp20, rp100: Flood peaks with return period of 2, 20 and 100 years

2.2 Comparison of regions

Figure V-5 shows the comparison of the baseline 2030 vs. baseline 2006 scenario for the 21 regions. For low and average flows there are no significant differences between the two land use scenarios. For high flows we can see an increase for the Atlantic region and to a smaller extend for the South Europe region. This increase is larger for small catchment areas (400 to 3000 km^2) (see tables in the Annex I).

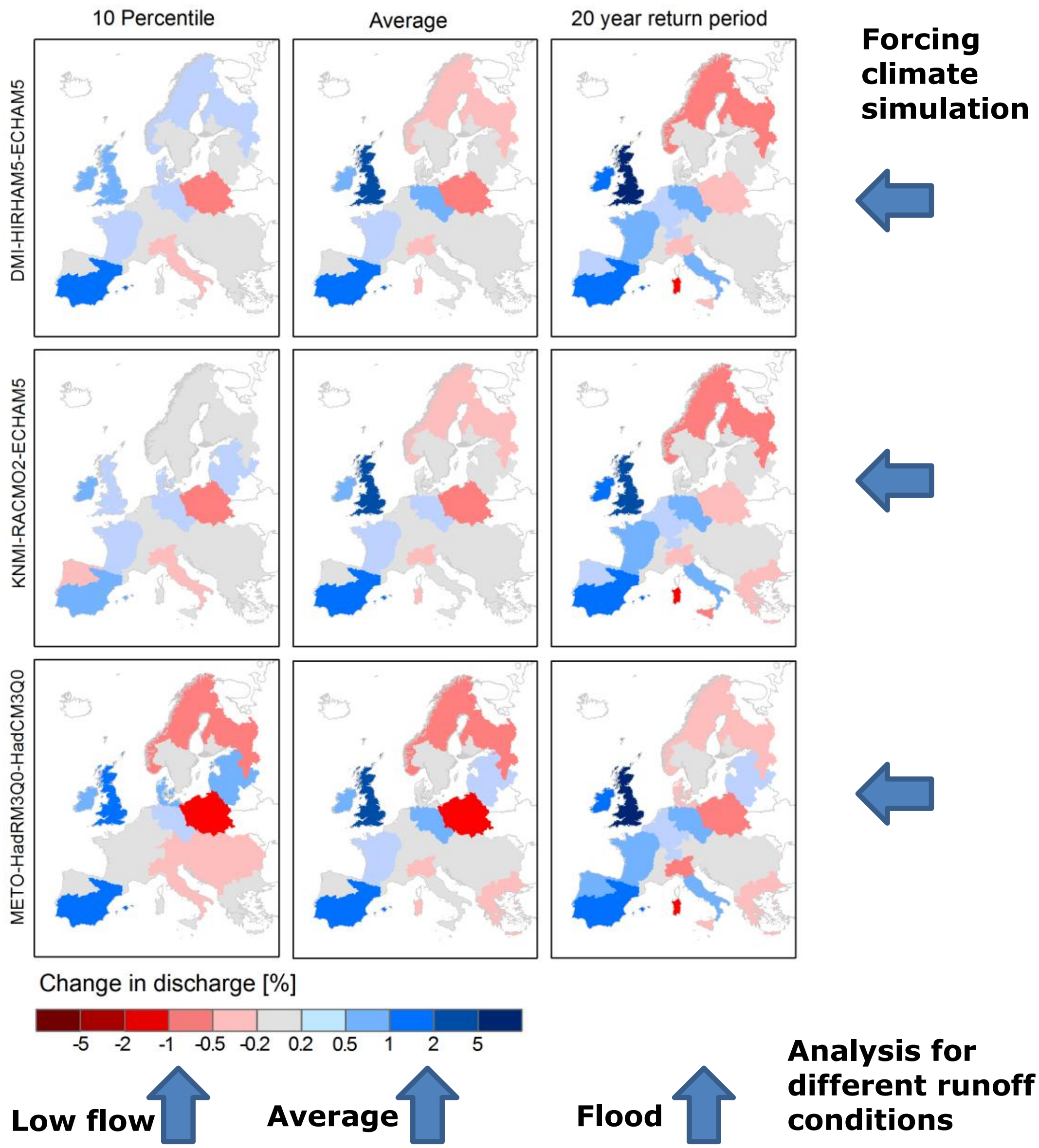


Figure V-5: Ratio between the baseline 2030 and baseline 2006 scenarios forced by 3 different bias corrected climate scenarios. The blue colour indicates underestimation of the baseline 2006 scenario; red colour indicates overestimation. Each column represents a LISFLOOD run forced by the corresponding climate scenario. Low to average flow: Average yearly 7-day minimum flow, 10% and 50% percentile

Comparison of fast runoff, evapotranspiration, groundwater recharge and water stress

All four parameters are averaged over the three forcing climate scenarios. Fast runoff, evapotranspiration and groundwater recharge are averaged over the 30 year period of simulation. The values are compared to the baseline scenario (here: Baseline 2030 vs. baseline 2006) and plotted as percentage of change in figure V-5. The blue colour indicates a positive change, red a negative change e.g. in Figure V-6 more fast runoff in Great Britain, and less fast runoff in Northern Scandinavia.

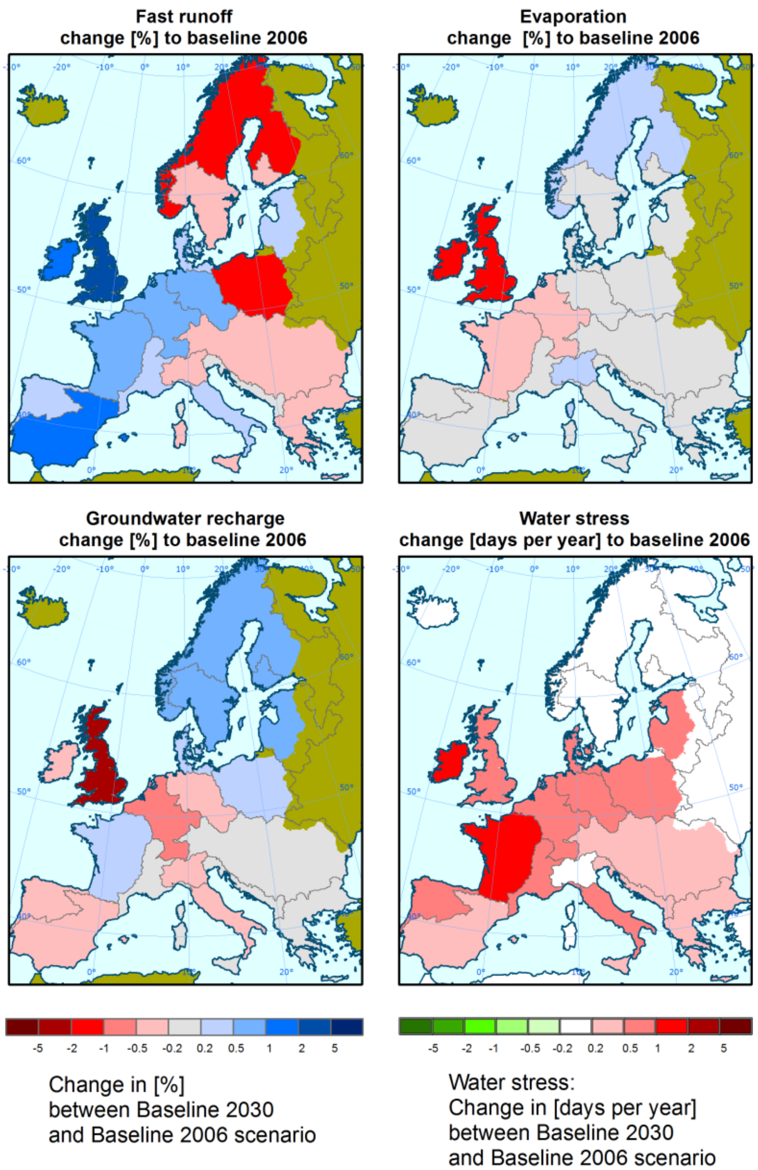


Figure V-6: Comparison between the baseline 2030 and baseline 2006 scenarios for fast runoff, evapotranspiration, groundwater recharge and water stress. The first three maps indicate the change in % between the baseline 2030 and baseline 2006 for averaged values. The last map shows the change of water stress in days per year.

Water stress is measured by the calculated number of days that plants are at soil moisture stress. The lower right map in Figure V-6 shows the difference between the scenarios in number of days per year. The red colour indicates an increase in water stress, green a decrease.
For Great Britain (region 8) you can see in Figure V-6 that the average fast runoff increases, while evapotranspiration and groundwater recharge decreases. This leads to more discharge (see Figure V-5) and to more water stress. For Atlantic France (region 10), fast runoff and groundwater recharge increases and evapotranspiration shows less decrease than Great Britain. This leads to even more days with water stress than for Great Britain.

3 Comparison of scenarios against baseline 2030

The following figures are built in the same way, separated into 4 single maps:

- The upper left map shows the spatial influence of the scenario (e.g. change of the forested area or where scenario the "Re-meandering" is applied)
- The upper right map shows the impact of the scenario on low flows. It shows the percentage of change in the 10% percentile low flow compared to the baseline scenario.
- The lower left map shows the impact on average discharge.
- The lower right map shows the impact on flood peaks with a 20 year return period.

Several other discharge conditions are put together in the tables of the Annex I as well as all information about mesoscale (400-3000 km^2) and macroscale (>3000km^2) catchments.
The colour scheme of the "change in discharge" maps is:

- A blue colour indicates an increasing discharge which is in general a positive effect for low flows and a negative effect for floods.
- A red colour indicates a decreasing discharge which is in general a negative effect for low flows and a positive for floods.

For some ecosystems a large range between low flows and flood discharge may be positive (e.g. for the biodiversity), therefore these statements are put in "in general".

3.1 Riparian forest

Discharge
Increasing the percentage of forest cover increases the soil's capacity to store water but also the amount of water which is evapotranspirated. In most of the 21 regions increasing riparian forest area leads to a more balanced situation during dry summer months, since the higher storage capacity of forest soil means that water still flows to the rivers during this period. For the Elbe to Ems catchment the effect of increased evaporation minimises the effect of contributing water from the soil to the rivers in summer.
The largest reduction in flood peaks occurs in the Elbe to Ems catchments, as this region has the largest introduction of riparian forest, according to the land use model. In some regions (GB,

Ireland, Iberia Atlantic, South Italy) an increase in flood peak discharge takes place. This is mainly because the land use model also reduces forest cover in some areas in order to be CAP consistent (note the red dots in the upper left picture).

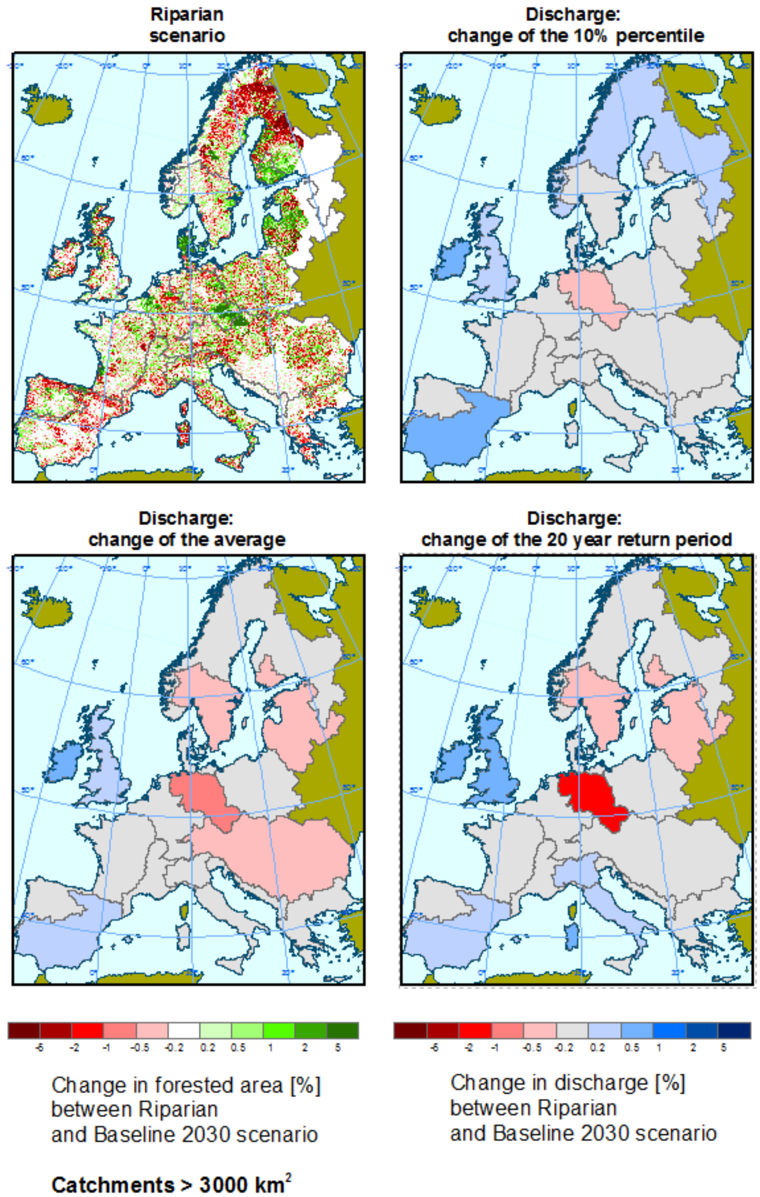


Figure V-7: Comparison between the "Riparian" and "Baseline 2030" scenarios

The presentation of data in Figure V-7 averages values for the 21 regions, which means that changes on a smaller scale are not noticeable. Figure V-8 shows the variability of results for the whole of Europe (upper picture) and for region 6 (Ems- Elbe) for all pixels where the Riparian scenario is implemented. Even if the average effect for region 6 on e.g. floods is only a 1-2% change, for 10% of all pixels the 20year return period is decreased by 4%, for around 3% of all pixels in this region the 20y return period is decreased by 10% (for the whole of Europe 2% of all pixels show a decrease of 4% and 0.4% of all pixels show a decrease of 10%).

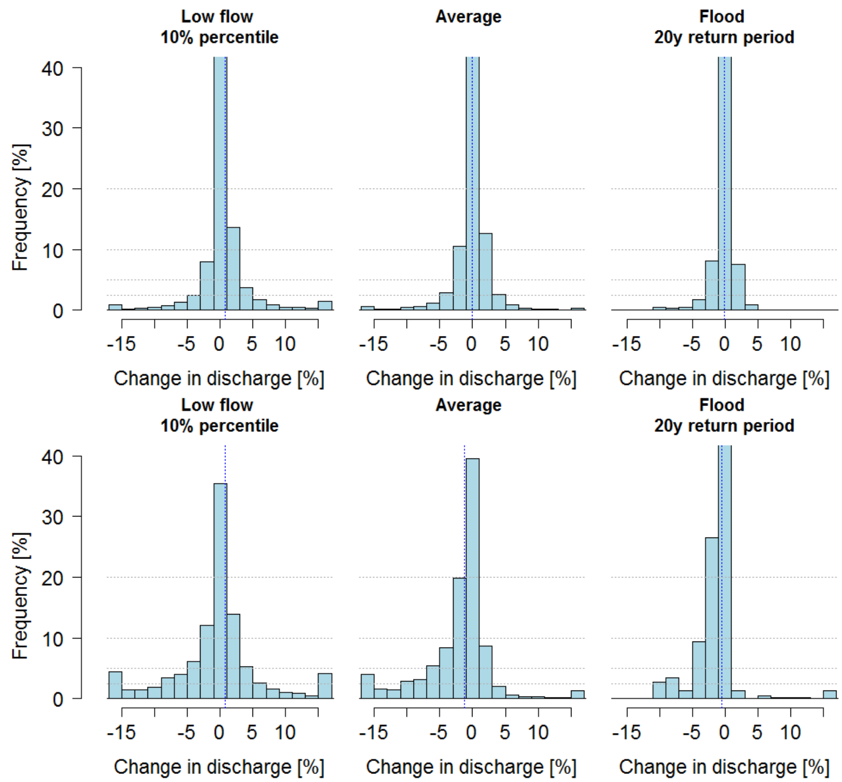


Figure V-8: Variability of changes (Riparian vs. Baseline 2030) for low flow, average and 20 year return period for a) whole Europe (top) and b) region 6 - Ems – Elbe (bottom)

Fast runoff, evapotranspiration, groundwater recharge and water stress

Figure V-9 left side shows the pixel values for fast runoff, evapotranspiration, groundwater recharge and water stress which can vary between -10 to +10 % respectively -10 to 10 days for water stress. On the right side the average values are shown. The largest reduction in fast runoff occurs in the Elbe to Ems catchments, as this region has the largest introduction of riparian forest. As the amount of forest cover increases, so does the evapotranspiration. The average amount of groundwater recharge decreases mainly because the flow which bypasses the soil matrix and drains directly to the groundwater is reduced significantly.

Water stress for arable land is increasing because the riparian areas with deeper soils have changed to forest land use, leaving the shallower, more prone to dry out soils for arable land use.

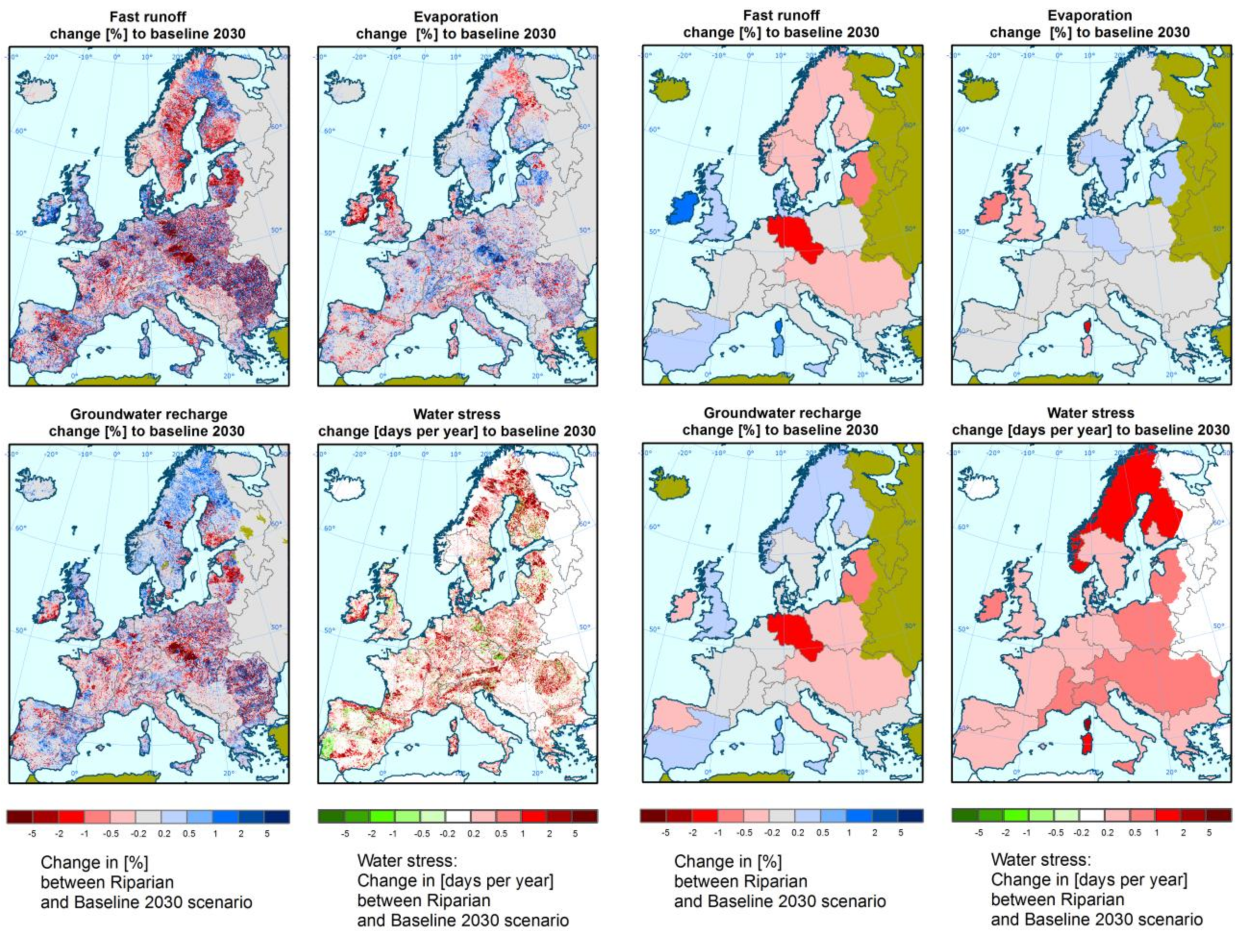


Figure V-9: Comparison between Riparian and baseline 2030 scenarios for fast runoff, evapotranspiration, groundwater recharge and water stress. Left picture: results on a pixel scale. Right picture: results averaged for the 21 reference regions.

3.2 Afforestation

Discharge

The impact of the afforestation scenario is similar to that of the riparian scenario, but its influence is greater since here afforestation is implemented specifically above 500m altitude, on slopes greater than 10%, where a greater percentage of precipitation falls (i.e. mountainous areas). For the Elbe to Ems catchments, Iberia, France, Southern Italy and the Greece/Evron catchment the effect of increased evapotranspiration overtops the effect of contributing water to the rivers in summer. Average discharge is reduced in most of the regions, due to increased evapotranspiration from more abundant vegetation and deeper soils in newly forested areas. Flood peaks are reduced in most of the 21 regions, except in a few regions where there is no increase in forest cover according to the LUMP runs.

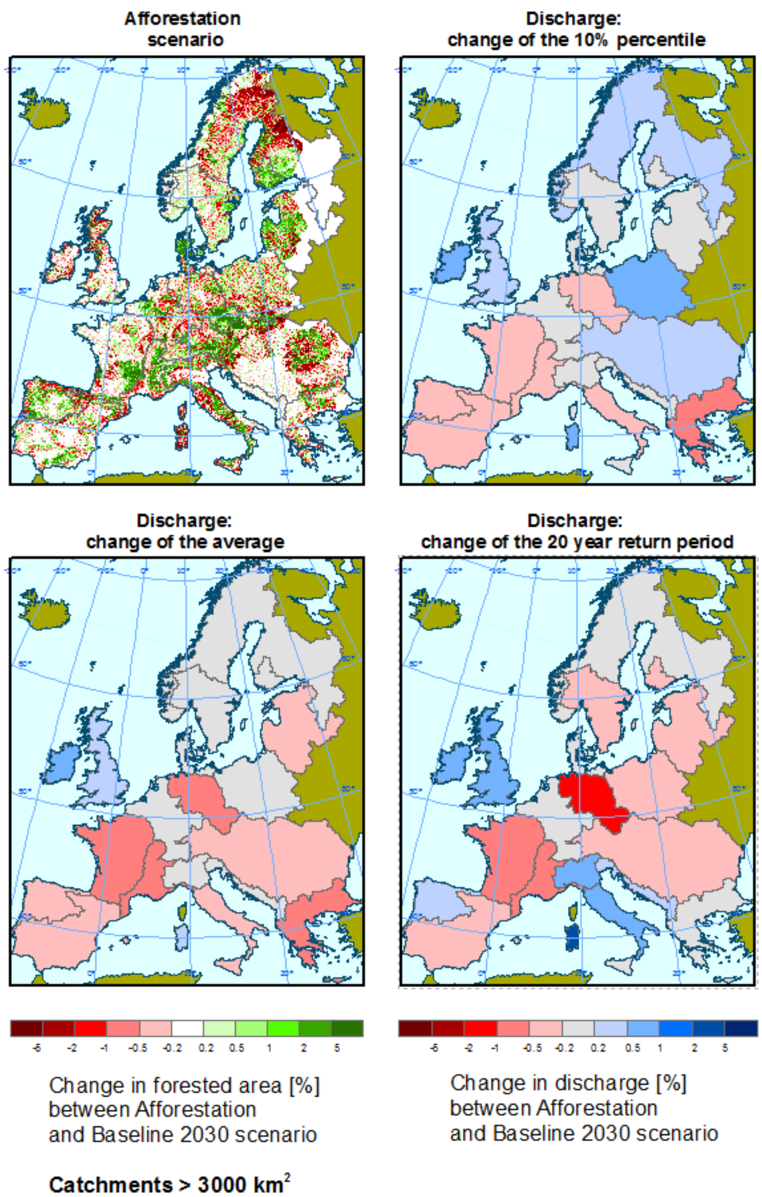


Figure V-10: Comparison between the "Afforestation" and "Baseline 2030" scenarios

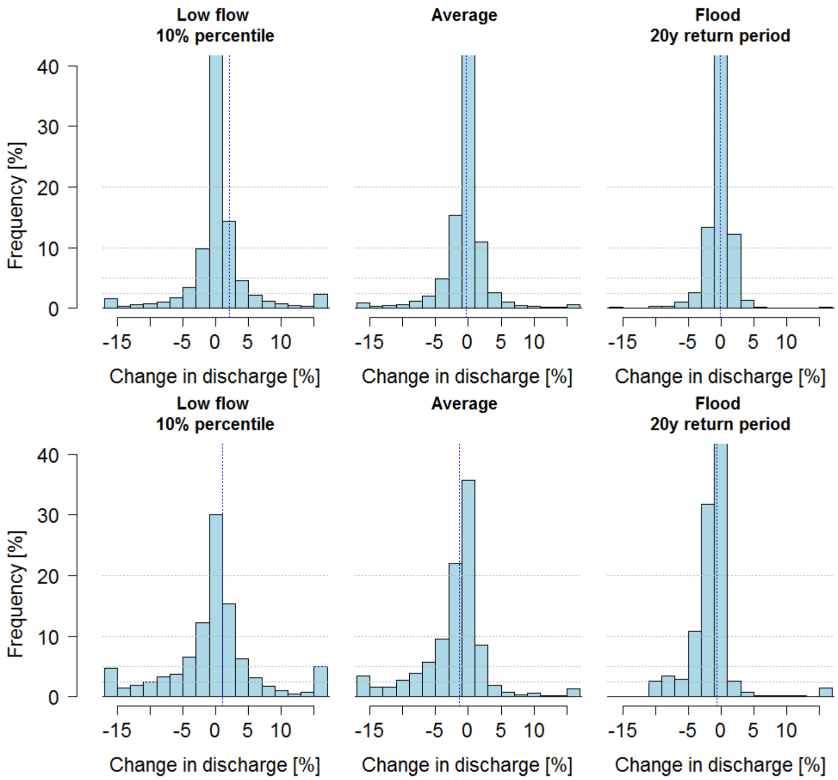


Figure V-11: Variability of changes (Afforestation vs. Baseline 2030) for low flow, average and 20 year return period for a) whole Europe (top) and b) region 6 - Ems – Elbe (bottom)

Figure V-11 shows the variability of changes comparing the Afforestation scenario against the baseline 2030 scenario. For Europe (upper picture) there is almost an equilibrium between negative and positive change. For the Ems-Elbe region this is shifted to the negative (decreasing) discharge part. For example up to 3% of the area inside region 6 may have a 10% decrease of the 20 year flood.

Fast runoff, evapotranspiration, groundwater recharge and water stress

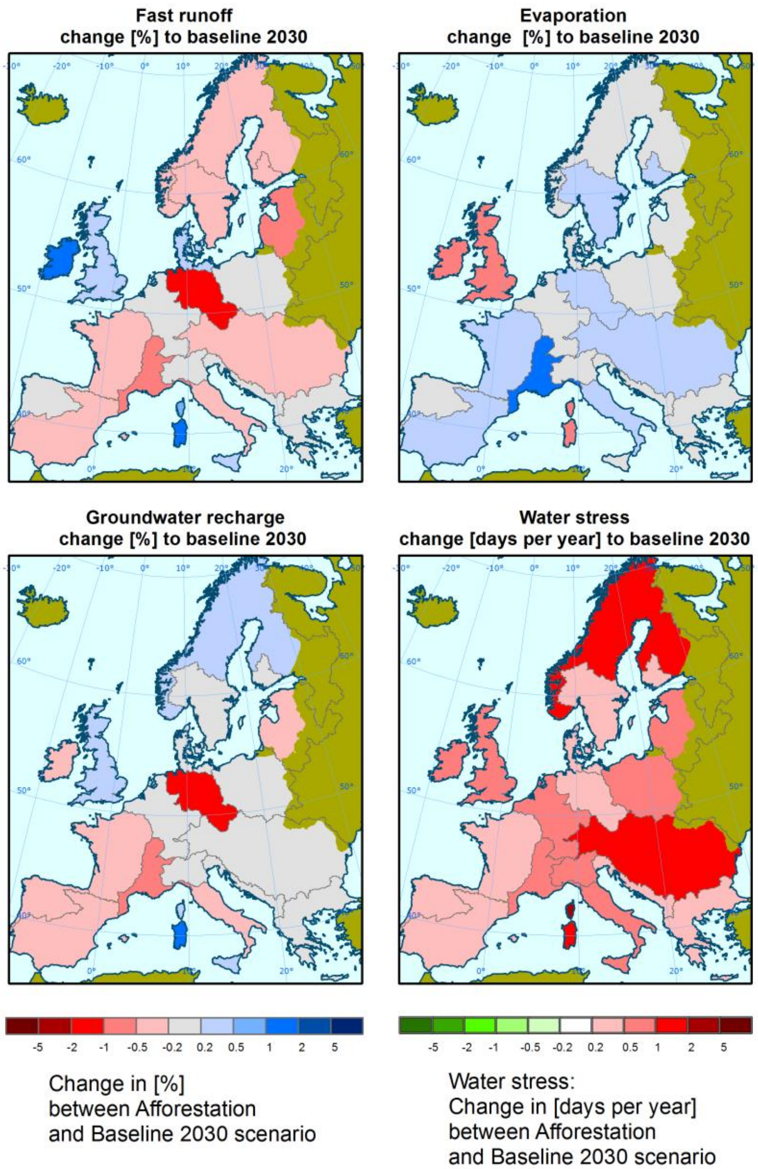


Figure V-12: Comparison between Afforestation and Baseline 2030 scenarios for fast runoff, evapotranspiration, groundwater recharge and water stress

The Ems-Elbe catchments is taken here as an example. Figure V-12 and Figure V-13 show a decrease in fast runoff and an increase in evapotranspiration due to a greater introduction of forest. The average amount of groundwater recharge decreases mainly because the flow which bypasses the soil matrix and drains directly to the groundwater is reduced.

Water stress for arable land increases because the areas afforested are at higher elevation with lower temperatures. If these areas are changed to forest land use, the arable land use is more concentrated on lower elevation and higher temperature and therefore more prone to dry out.

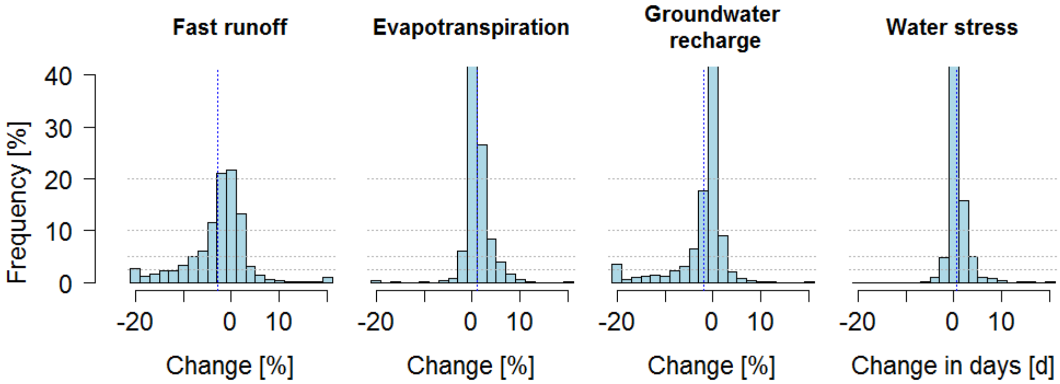


Figure V-13: Variability of average change (Afforestation vs. Baseline 2030) for fast runoff, evapotranspiration, groundwater recharge and water stress for region 6 (Ems – Elbe)

3.3 25% and 50% Green

Discharge

The reduction of sealed surfaces within urban areas resulted in a reduction of surface runoff. The 'green' areas introduced have a greater soil water storage capacity and therefore give a more balanced situation in dry summer months because the soil still delivers some water to the rivers. In Figure V-14 this can be seen in Paris and London where you get a local increase of low flows up to 20%. For average discharge and floods there is a decrease of up to 20% and 10% respectively. Figure V-15 shows the impact of the urban scenarios on low flows in the upper right map. The impact is more pronounced in the 50% green than in the 25% green scenario.

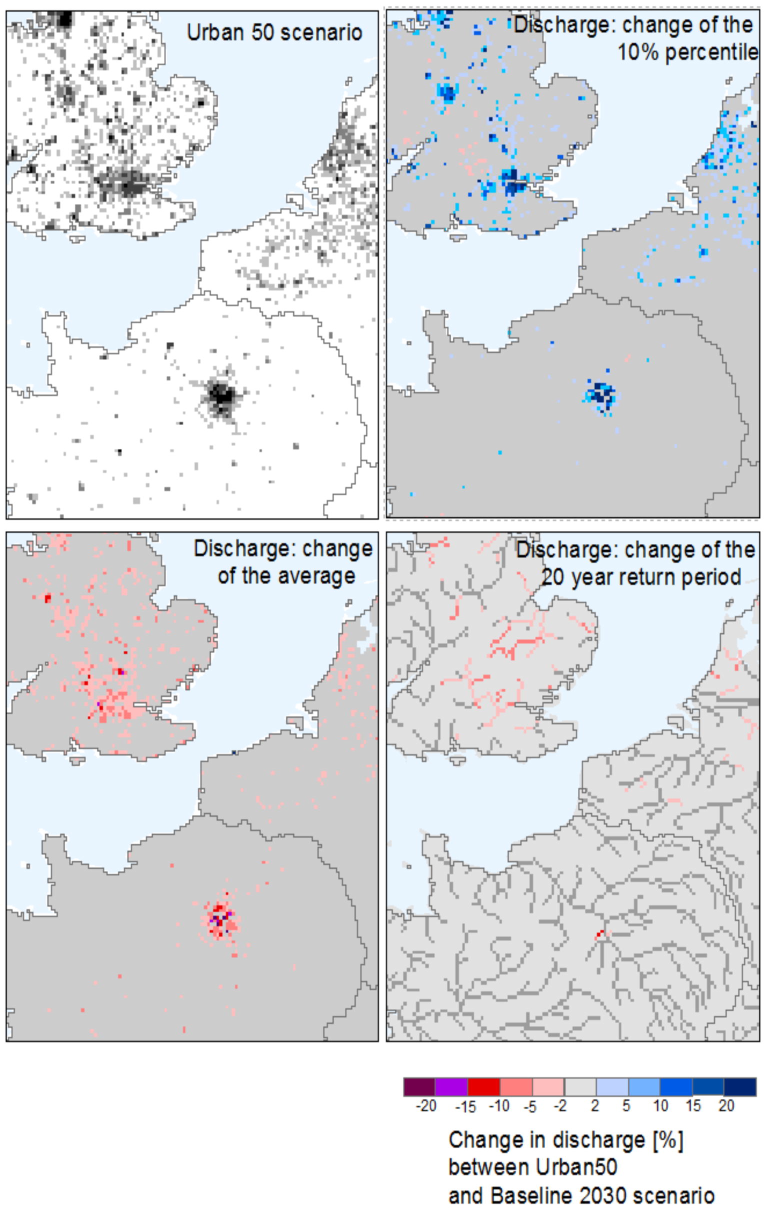


Figure V-14: Comparison between the "50% Green" and "Baseline 2030" scenarios – showing local changes

For Ireland, the Elbe to Ems, Vistula, Danube and Iberia Mediterranean regions this measure leads to a higher evapotranspiration rate, whose influence overtops that of having a greater storage capacity. Average discharge and flood peaks are reduced most prominently in Great Britain due to its high density of urban areas and the flow regime characterized by hilly regions. The Rhine to Schelde basins also have a high percentage of sealed urban areas but here the flow regime is characterized by the Alps and higher forelands. The effect of averaging can be shown on the example of the France Atlantic region. While there is a high local impact of the urban scenarios locally around Paris, there is no significant effect found at the regional scale.

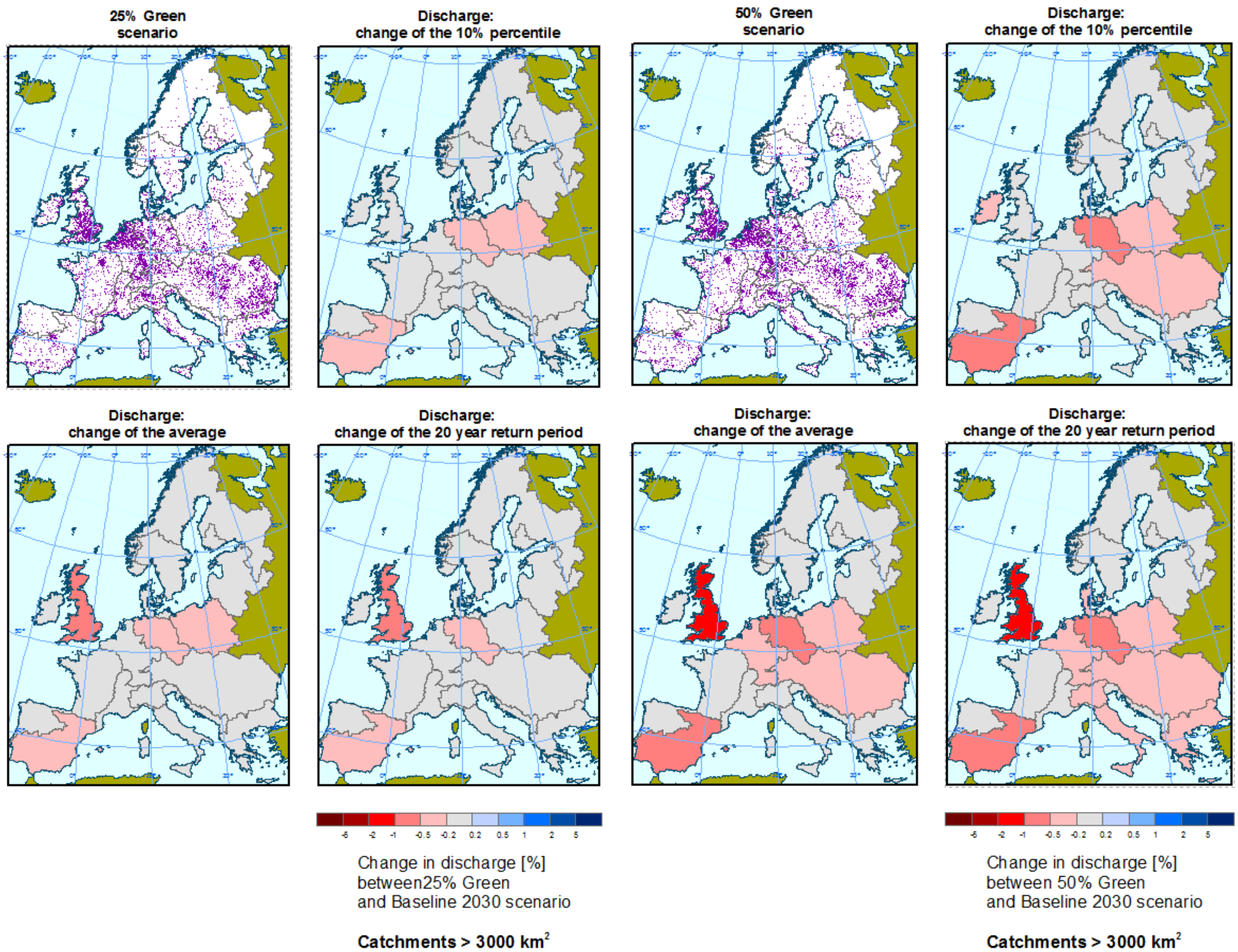


Figure V-15: Comparison between the “25% and 50% Green” and “Baseline 2030” scenarios

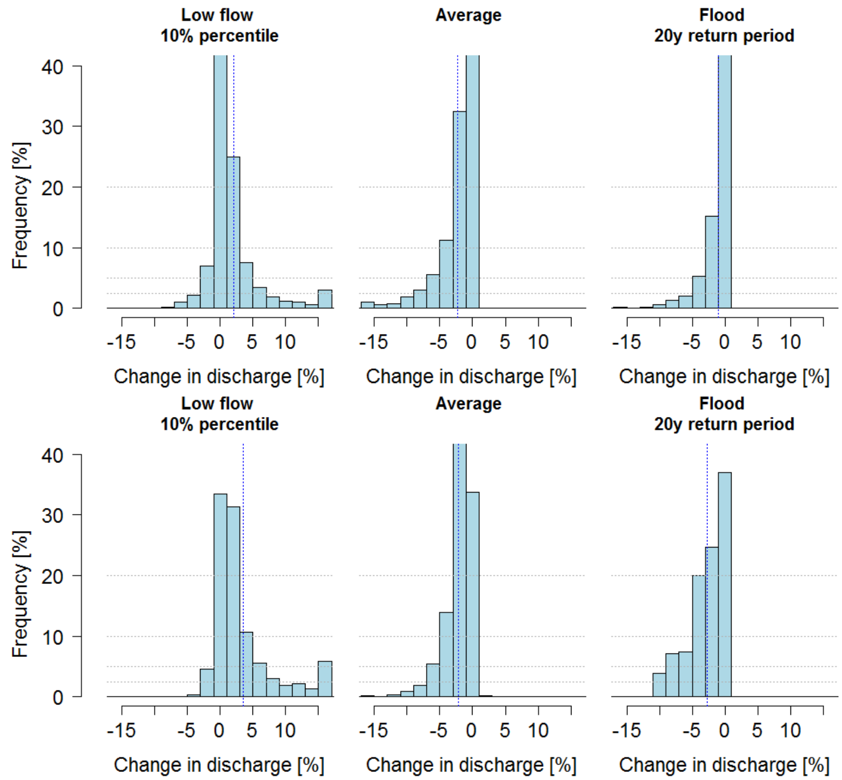


Figure V-16: Variability of changes (50% Green vs. Baseline 2030) for low flow, average and 20 year return period for a) whole Europe (top) and b) region 8 - Great Britain (bottom)

Figure V-16 shows the variability of changes for the 50% Green scenario for those pixels where it was implemented. You can see a slight increase in low flows but a decrease in average and flood discharge. This is even more prominent for the region of Great Britain (lower picture). For 10% of all pixels where the 50% Green scenario was implemented there is an increase in low flows of 10% and for 4% of all pixels there is a decrease in floods of 10%.

Fast runoff, evapotranspiration, groundwater recharge and water stress

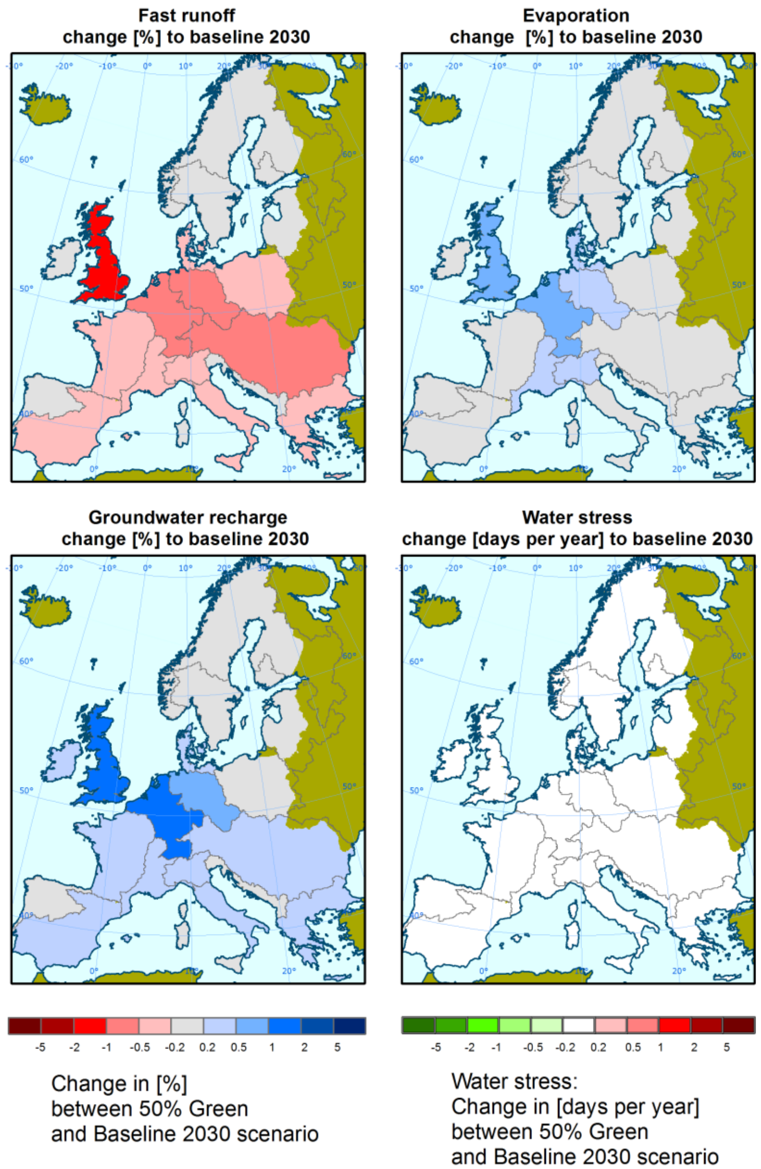


Figure V-17: Comparison between 50% Green and Baseline 2030 scenarios for fast runoff, evapotranspiration, groundwater recharge and water stress

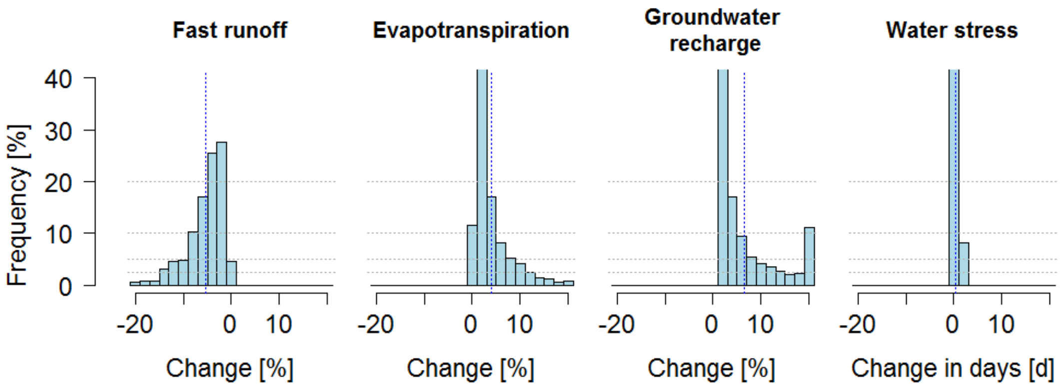


Figure V-18: Variability of average change (50% Green vs. Baseline 2030) for fast runoff, evapotranspiration, groundwater recharge and water stress for region 8 (Great Britain)

Figure V-17 shows that region 8 (Great Britain) reacts best on the 50% Green scenario. The effect of this scenario is less fast runoff, more evapotranspiration and more groundwater recharge, mainly because sealed surface is replaced by non-sealed surface which allows percolation of water into the soil. Water stress is not affected very much, because only a small percentage of sealed surface is turned into arable land. Figure V-18 shows that especially ground water recharge can be improved on those pixels where 50% Green is applied.

3.4 Grassland

Discharge

Increasing pasture leads in general to greater vegetation coverage and increased storage capacity of the soil. Higher storage capacity leads to a more balanced water household, with less water scarcity in summer and an improved capacity to buffer floods. For low flows the effect of a higher evapotranspiration (water taken out of the system) can overtop the effect of higher storage capacity, as in the Elbe to Ems catchment. Flood peaks are reduced in the Elbe to Ems, Danube, Baltic, and S. Scandinavia regions. Great Britain, Sardinia and Iberia Mediterranean regions show an increase of flood peaks, due to the constraints of the land use model.

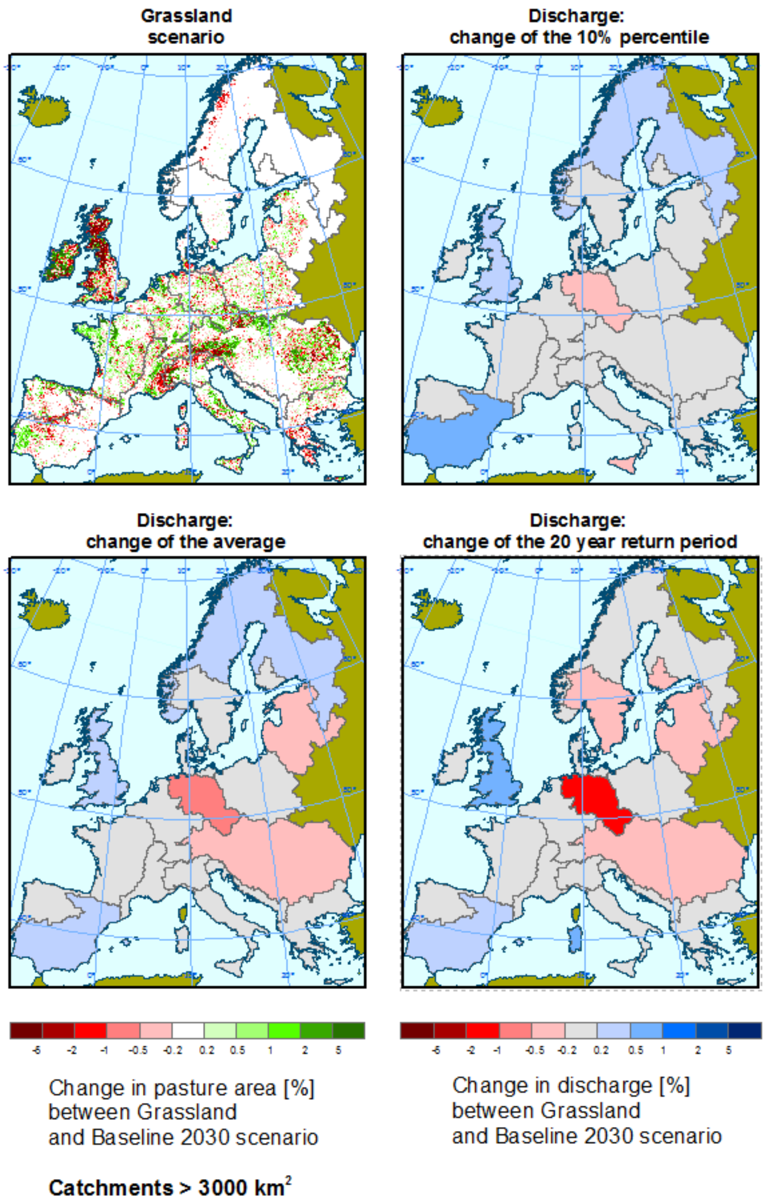


Figure V-19: Comparison between the "Grassland" and "Baseline 2030" scenarios

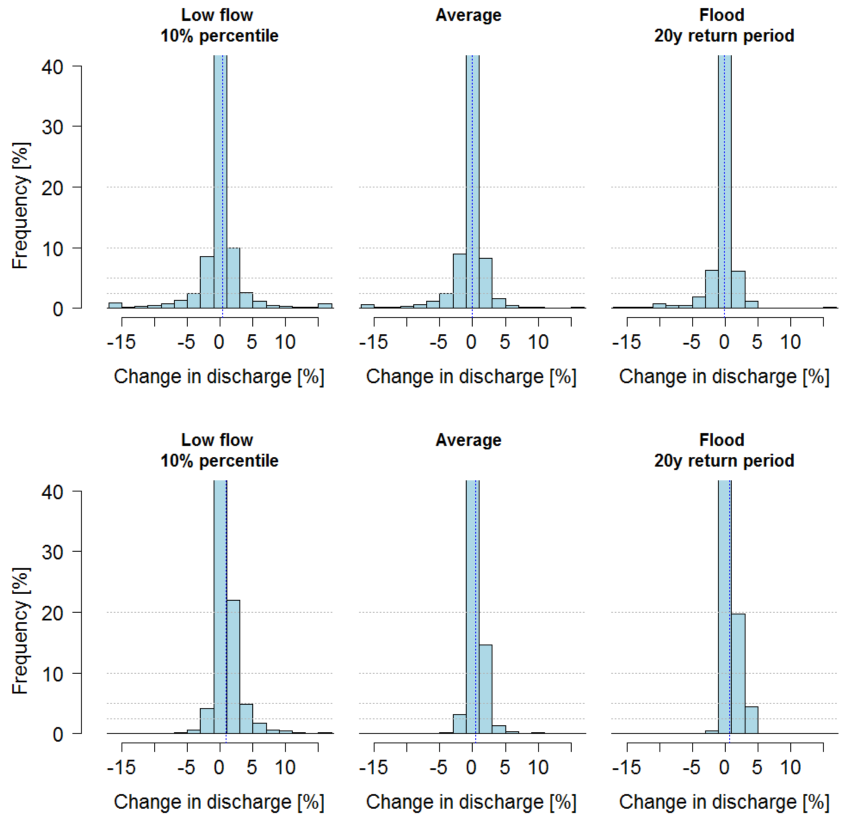


Figure V-20: Variability of changes (Grassland vs. Baseline 2030) for low flow, average and 20 year return period for a) whole Europe (top) and b) region 8 (Great Britain) (bottom)

The scenario Grassland almost leads to an equilibrium between negative and positive changes in discharge, due to an equilibrium in changes of pasture areas (see Figure V-19 upper left). In areas with less pasture in the Grassland scenario than in the Baseline 2030 scenario, there is an increase in discharge (see Figure V-19 and Figure V-20 lower picture). More pasture area leads to a decrease in discharge over all.

Fast runoff, evapotranspiration, groundwater recharge and water stress

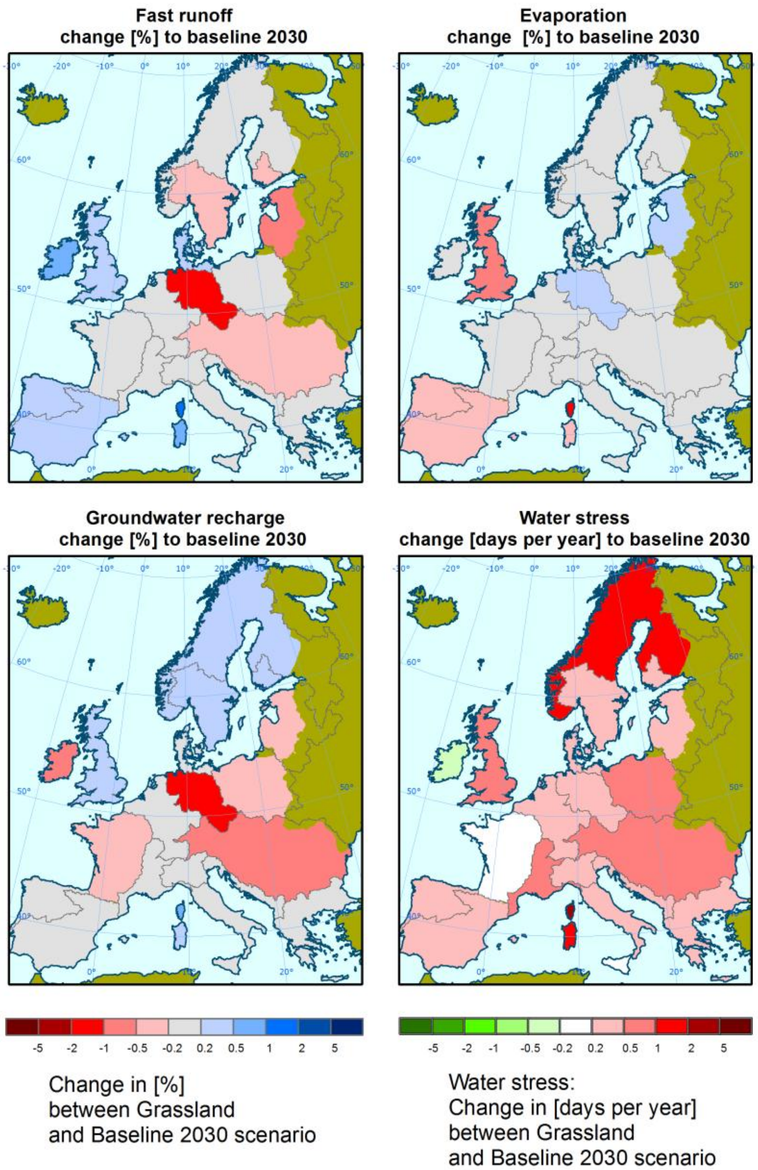


Figure V-21: Comparison between Grassland and Baseline 2030 scenarios for fast runoff, evapotranspiration, groundwater recharge and water stress

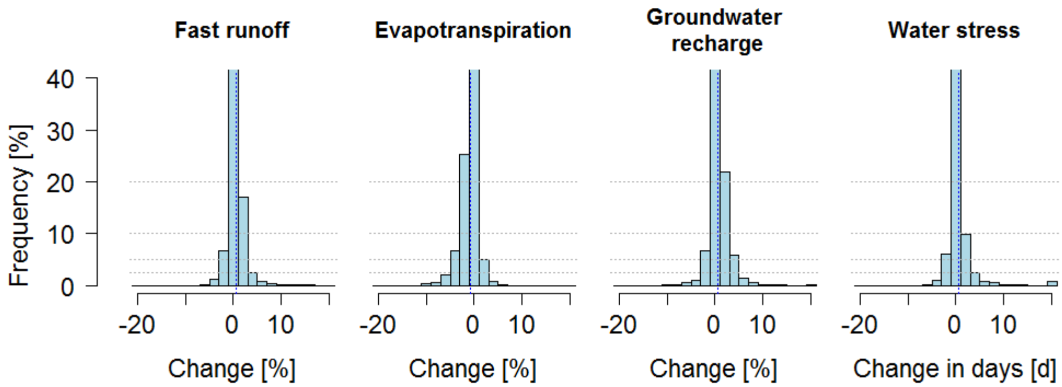


Figure V-22: Variability of average change (Grassland vs. Baseline 2030) for fast runoff, evapotranspiration, groundwater recharge and water stress for region 8 (Great Britain)

Replacing arable land with pasture leads to less fast runoff, more evapotranspiration and a higher groundwater recharge, mainly because of the changing soil properties (more organic matter, less bulk density) (Figure V-20). As the pattern of increasing/decreasing pasture is very inhomogeneous you will see histograms which are symmetrically distributed on the negative and positive sides (Figure V-21).

Water stress increases for almost all of Europe, because areas with a slope greater than 10% at high elevation are replaced by pasture. The remaining arable areas are in the lowlands, which are more prone to dry out because of higher temperatures.

3.5 Buffers strips and grassed waterways

Discharge

For the scenarios “Buffer strips” and “Grassed waterways” there is no significant impact on discharge (Figure V-22). These scenarios might have an influence on erosion and nutrient control, but at this scale of analysis (25x25km for the regional climate models) there is no significant impact to see.For flood peak reduction the amount of additional water stored due to additional vegetation or changed soil texture is to small and the possible delay of runoff is fading out because during an event runoff will bypass obstacles by using preferential flow paths.

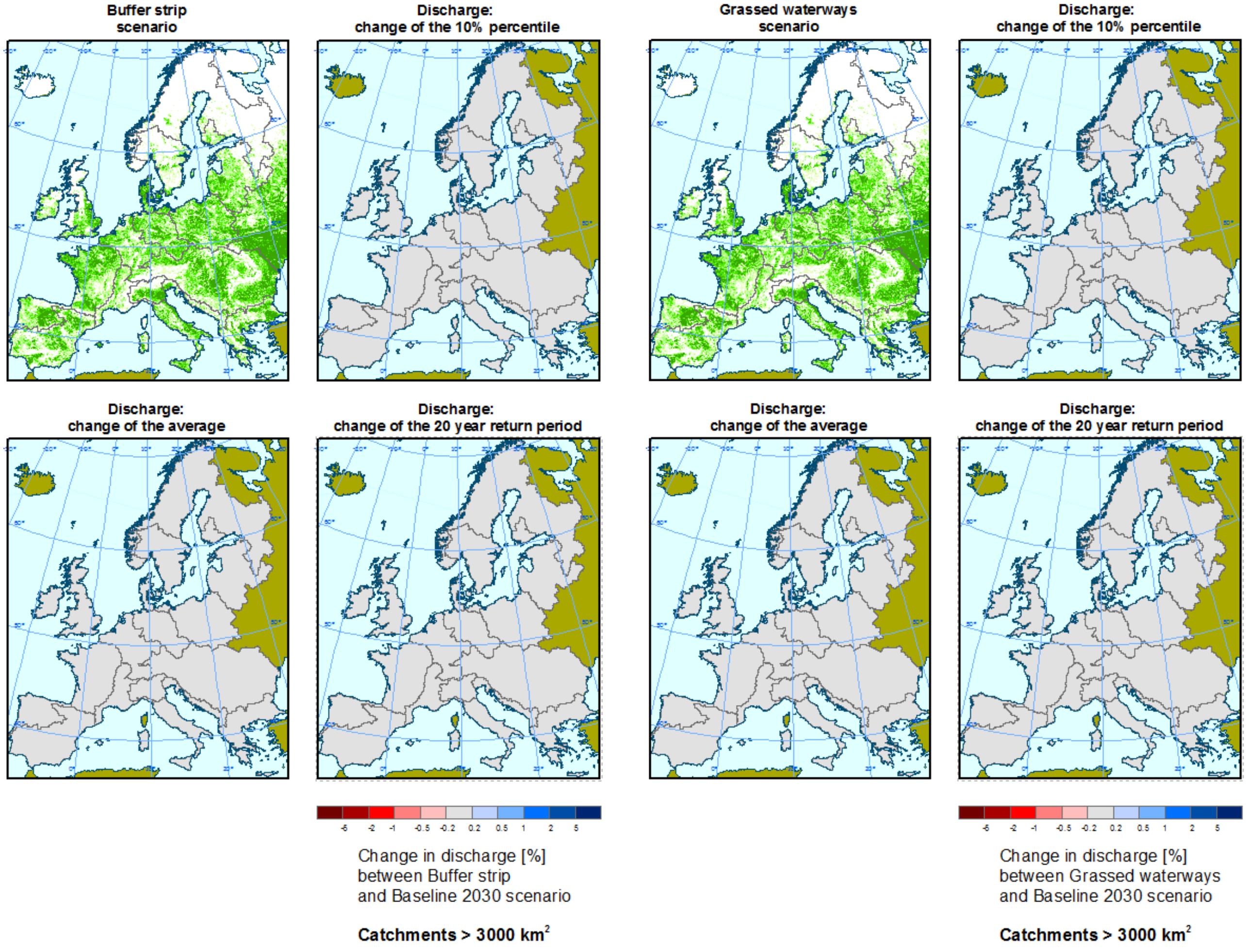


Figure V-23: Comparison between the“Buffer strips”,“Grassed waterways”and “Baseline 2030” scenarios

Fast runoff, evapotranspiration, groundwater recharge and water stress

Also for the parameters fast runoff, evapotranspiration, groundwater recharge and water stress there is no significant change visible.

3.6 Crop practice

Discharge

The upper left map in Figure V-24 shows where the "Crop practice" scenario is applied. The green colour indicates the amount of arable land use. This figure also shows the local impacts on discharge which can lead to a reduction in low flows of up to 15% (Danube catchment) but also to a reduction in flood peaks of up to 10%. Improved crop practices alter the hydraulic soil parameters, which on the one hand increases the storage capacity but on the other hand increases evapotranspiration and conductivity. This increase in evapotranspiration and conductivity leads to a reduction in water availability and faster drainage of water in summer. In case of floods the increased storage capacity of the soil leads to a delayed reaction and therefore to smaller flood peaks. This can be seen for almost all regions except Scandinavia and Ireland (Figure V-24), where there is less influence of the "Crop practice" scenario, and for the Alpine regions Rhine, Rhone and Po since there most of the discharge is generated in mountainous, non-arable areas.

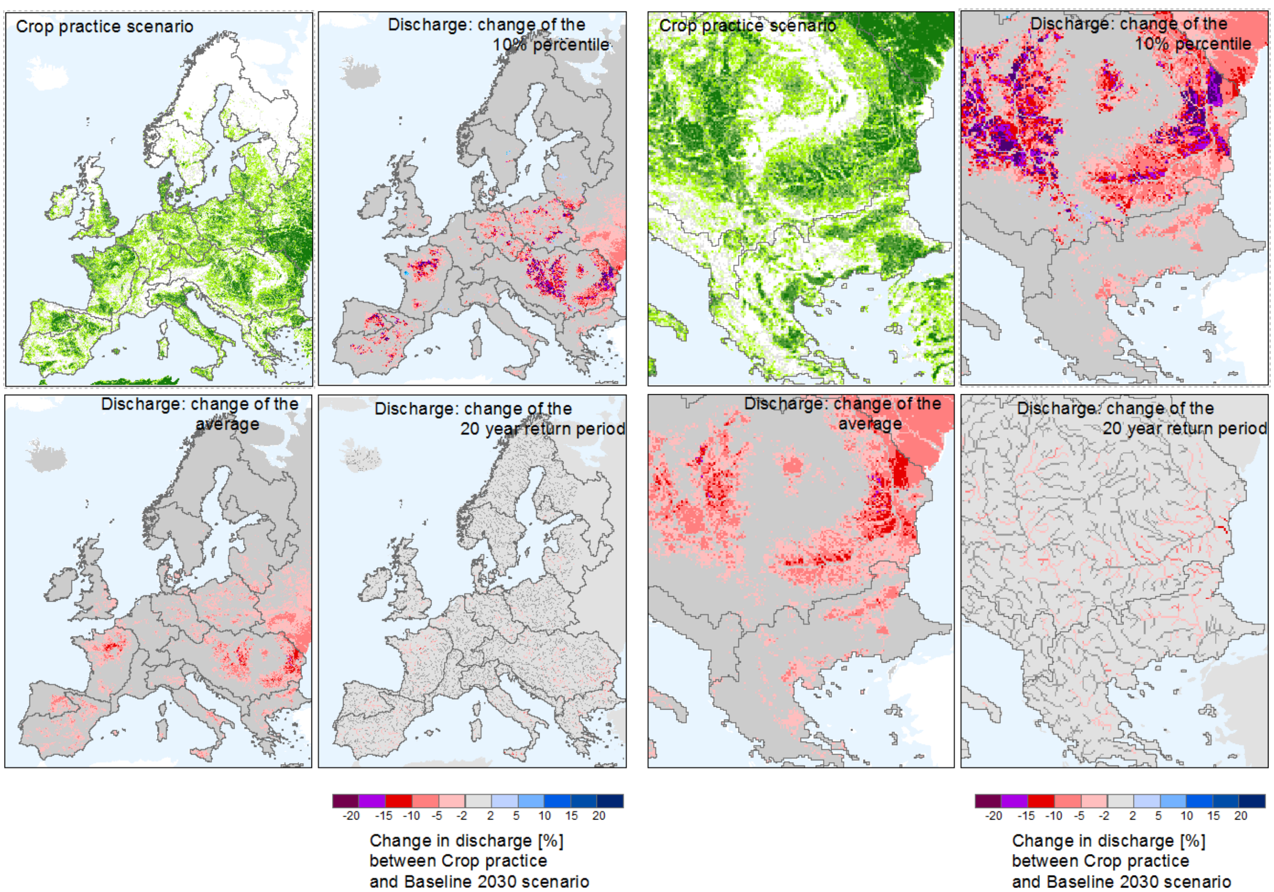


Figure V-24: Comparison between the "Crop practice" and "Baseline 2030" scenarios – local changes

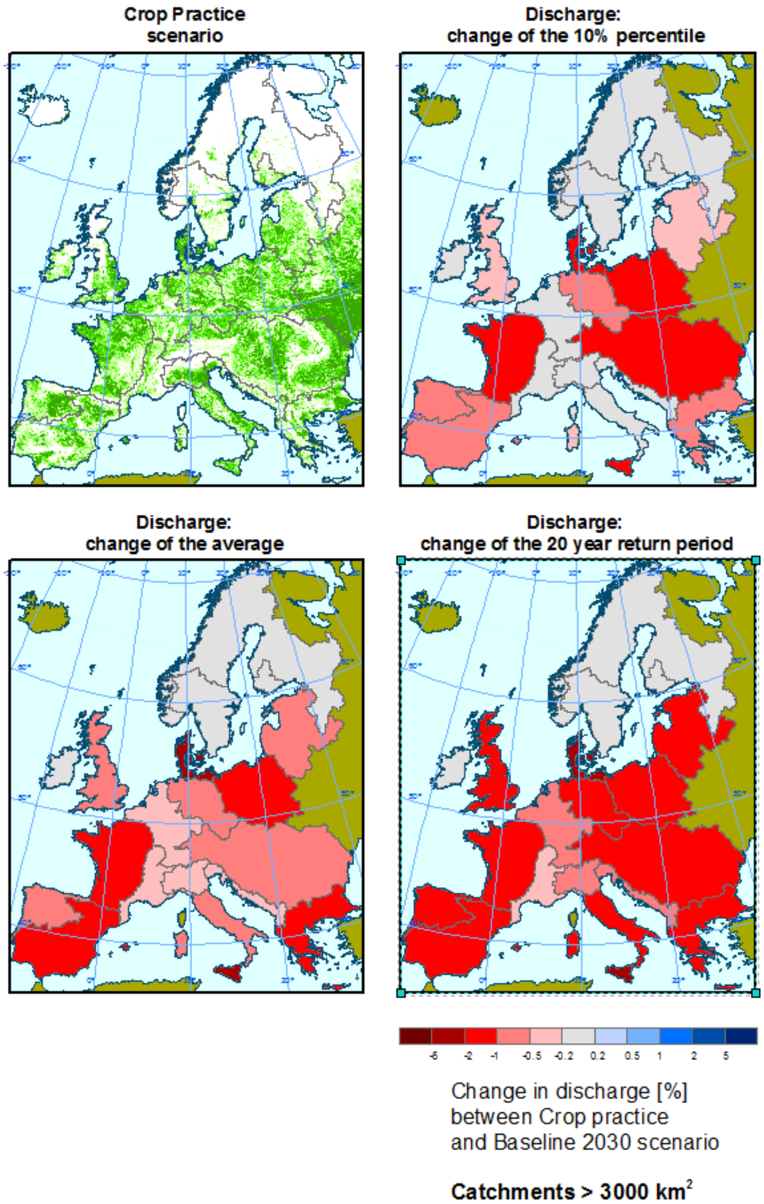


Figure V-25: Comparison between the "Crop practice" and "Baseline 2030" scenarios

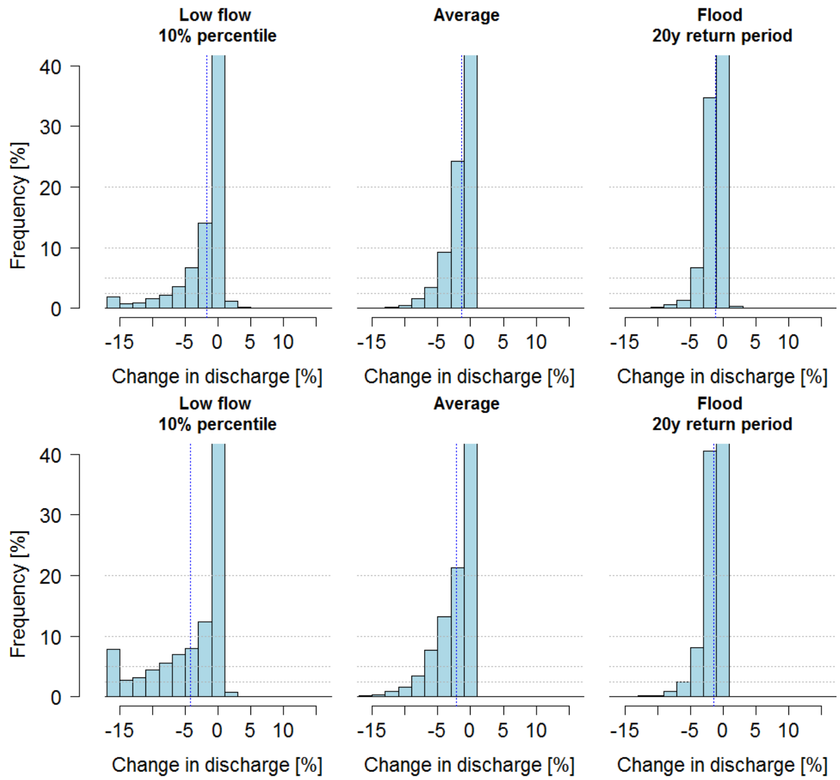


Figure V-26: Variability of changes (Crop practice vs. Baseline 2030) for low flow, average and 20 year return period for a) whole Europe (top) and b) region 11 (Danube) (bottom)

Especially in the Danube catchment improved crop practices can lead to decreasing discharge. On more than 50% off all pixels where crop practice is implemented the 20 year return period is decreased by at least 2%.

Fast runoff, evapotranspiration, groundwater recharge and water stress

Crop practice leads to decreased fast runoff and groundwater recharge and increased evapotranspiration. The aim of this scenario is to improve the conditions of arable areas. It can be shown in Figure V-27 (lower right) and Figure V-28 that water stress is reduced and therefore the conditions are improved.

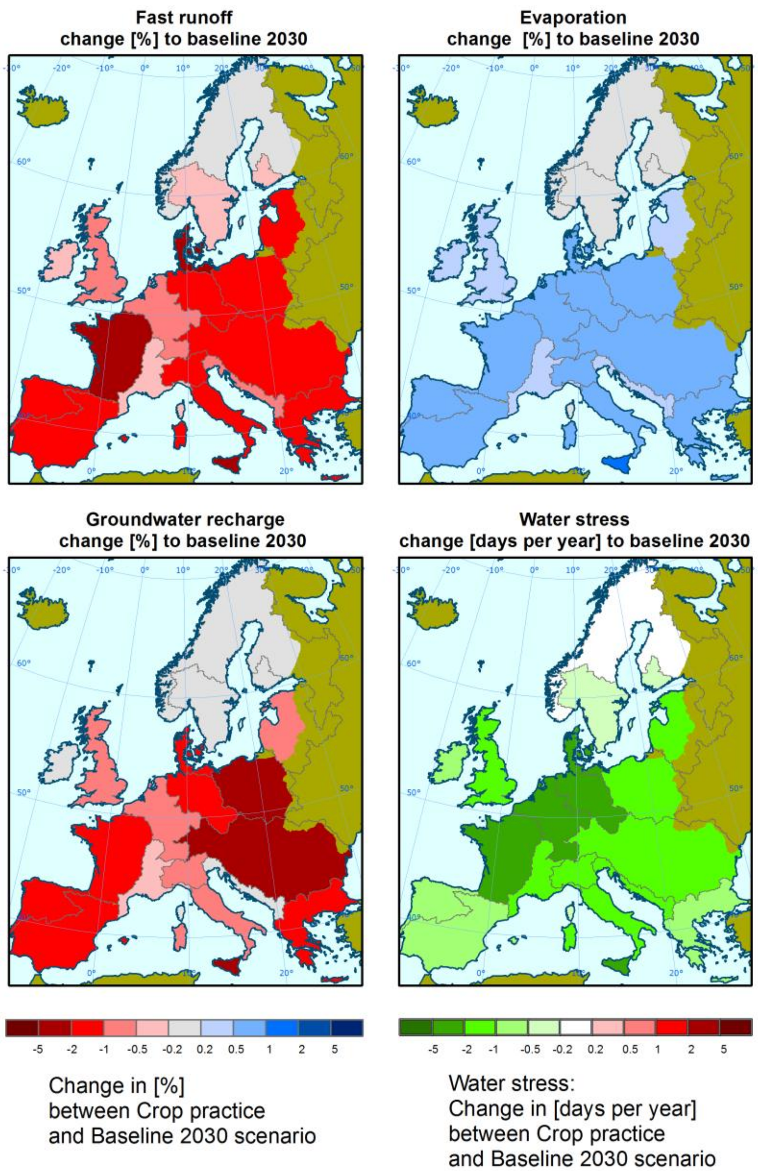


Figure V-27: Comparison between Crop practice and Baseline 2030 scenarios for fast runoff, evapotranspiration, groundwater recharge and water stress

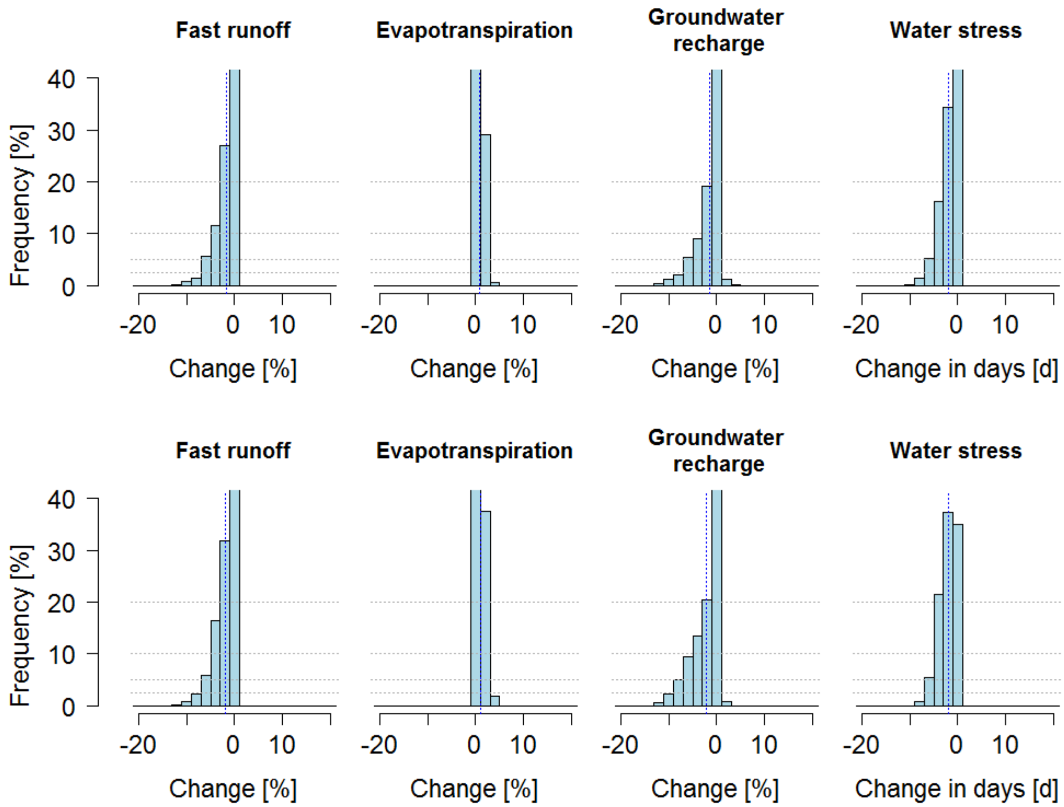


Figure V-28: Variability of changes (Crop practice vs. Baseline 2030) for fast runoff, evapotranspiration, groundwater recharge and water stress for a) whole Europe (top) and b) region 11 (Danube) (bottom)

3.7 Wetlands

The “Wetland scenario” has no influence on low flows and on the average discharge (Figure V-28), since only the flood plain area is increased. There is, however, a reduction in flood peaks for almost every region. The variation of changes is low (5% of all pixels where this scenario is introduced will have a reduction in the 20 year flood around 2%, Figure V-29). The effect is greater for those regions with larger low land streams, for example in the Danube catchment.

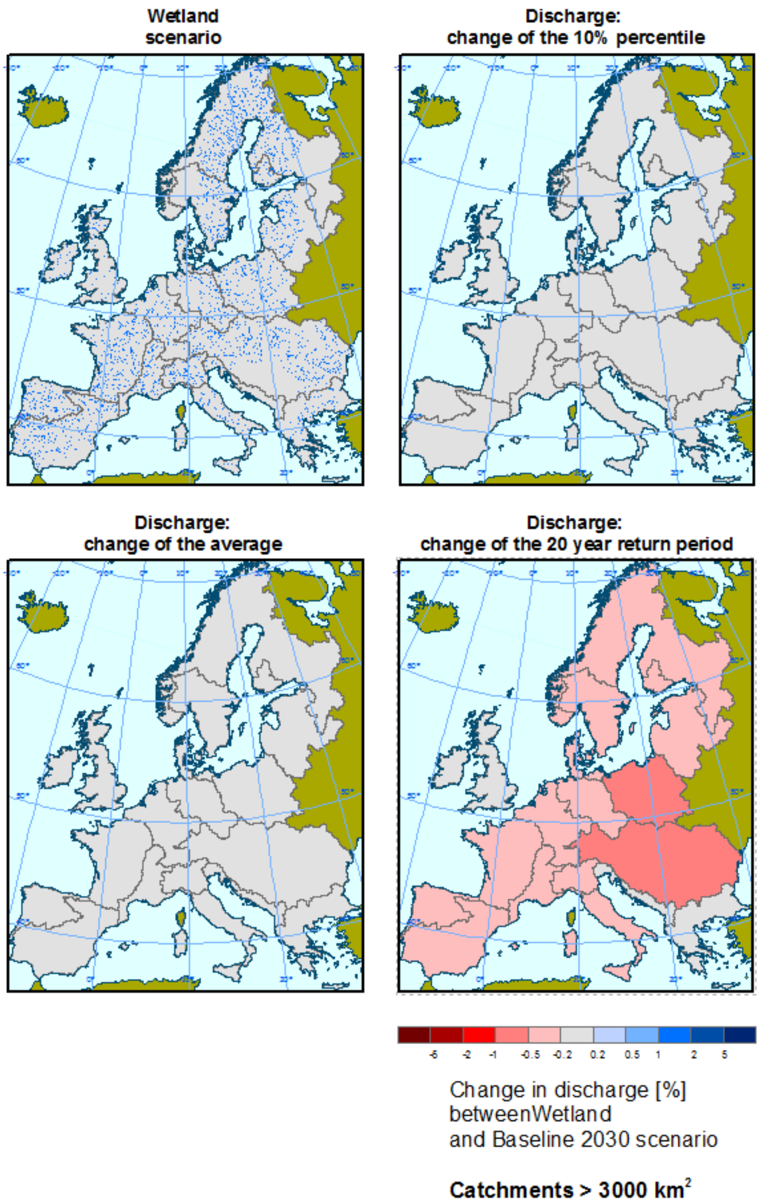


Figure V-29: Comparison between the “Wetland” and “Baseline 2030” scenarios

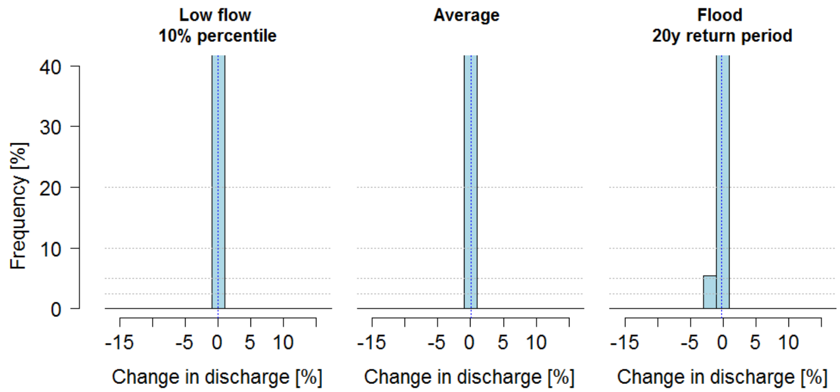


Figure V-30: Variability of changes (Wetland vs. Baseline 2030) for low flow, average and 20 year return period for Europe

In the Wetland and in the following scenarios the river channel parameters were changed to assess the effects of these scenarios. We did not include a sophisticated ground water model (e.g. a 2D groundwater model) to calculate the river-aquifer interaction. Therefore for these scenarios no assessment of groundwater recharge, water stress is given

3.8 Re-meandering

Re-meandering is applied for small to medium rivers and can locally increase low flows up to 15% and reduce flood peaks up to 15%.Figure V-30 shows the western Baltic Sea area and especially the lowlands of the Elbe and Odra catchment show significant low water increase and flood peak decrease. Re-meandering increases the river length which leads to longer travel times. This longer travel time can balance out the dry summer months and lower flood peaks. Also, since each single river branch has a longer travel time, there is a reduced probability of overlap of two flood peaks at river junctions. However, for single river stretches, there may actually be an increased probability of overlapping flood peaks.

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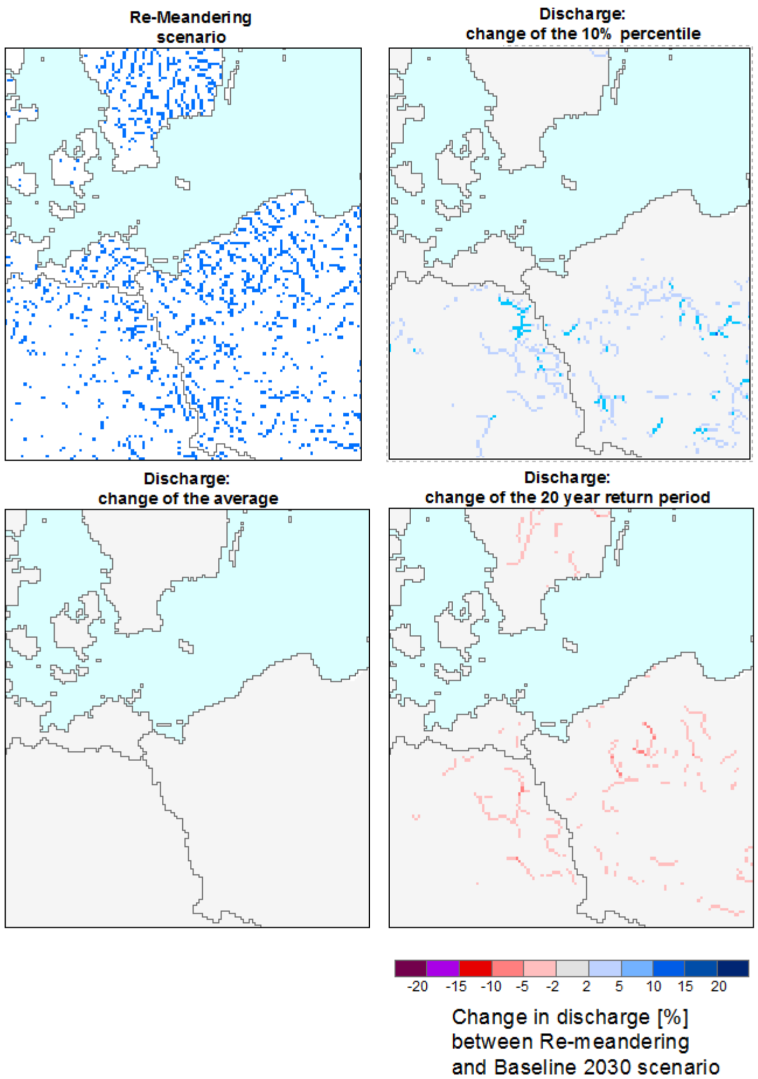


Figure V-31: Comparison between the "Re-meandering" and "Baseline 2030" scenarios – showing local changes

The "Re-meandering scenario" seems to result in a win-win situation for almost all regions; low flows are increased, while flood peaks are reduced (Figure V-31).

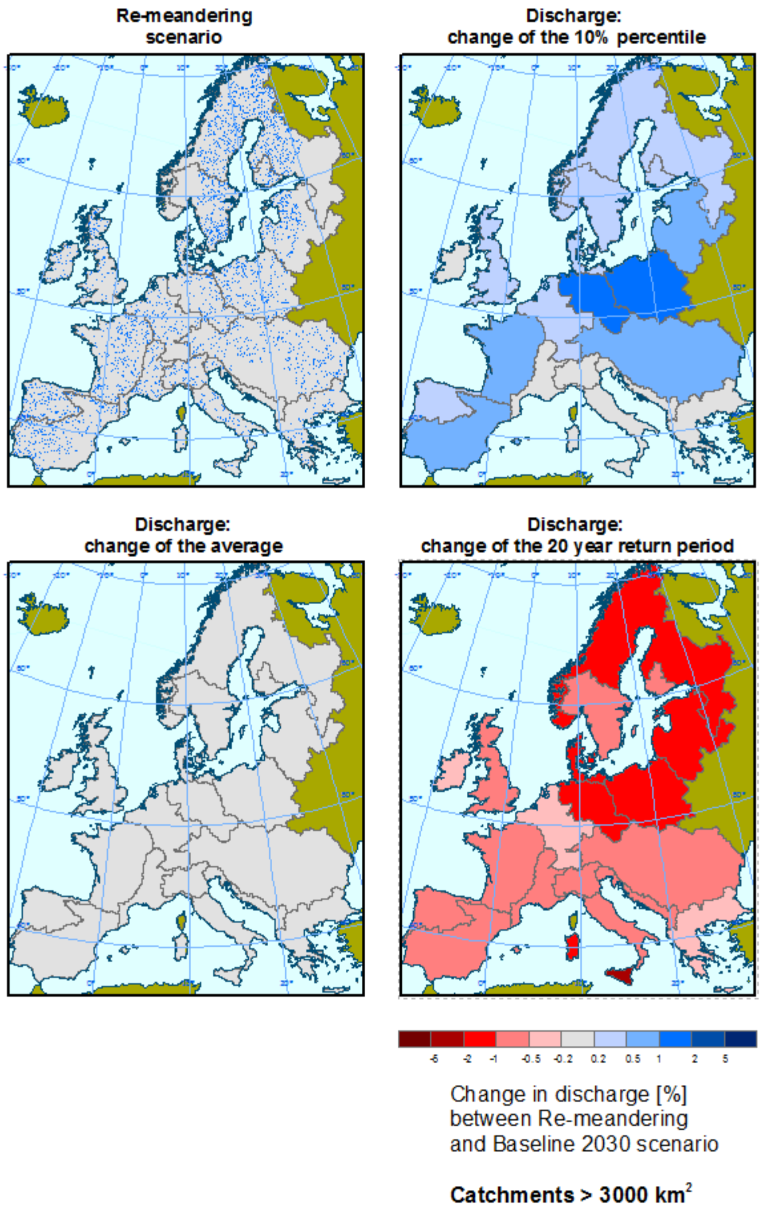


Figure V-32: Comparison between the "Re-meandering" and "Baseline 2030" scenarios

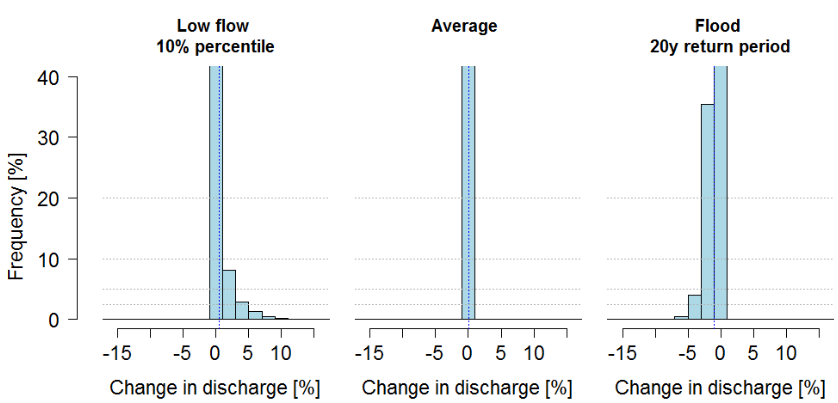


Figure V-33: Variability of changes (Re-Meandering vs. Baseline 2030) for low flow, average and 20 year return period

3.9 Buffer ponds

Introducing small "Buffer ponds" in headland catchments will increase low flows, since the storage capacity of the buffer ponds maintains a minimum discharge during dry periods. There is no change in the average discharge, since no water is added or removed. There is a reduction of flood peaks if there is a large concentration of ponds as in Great Britain, the Rhine or Elbe catchments (Figure V-33).

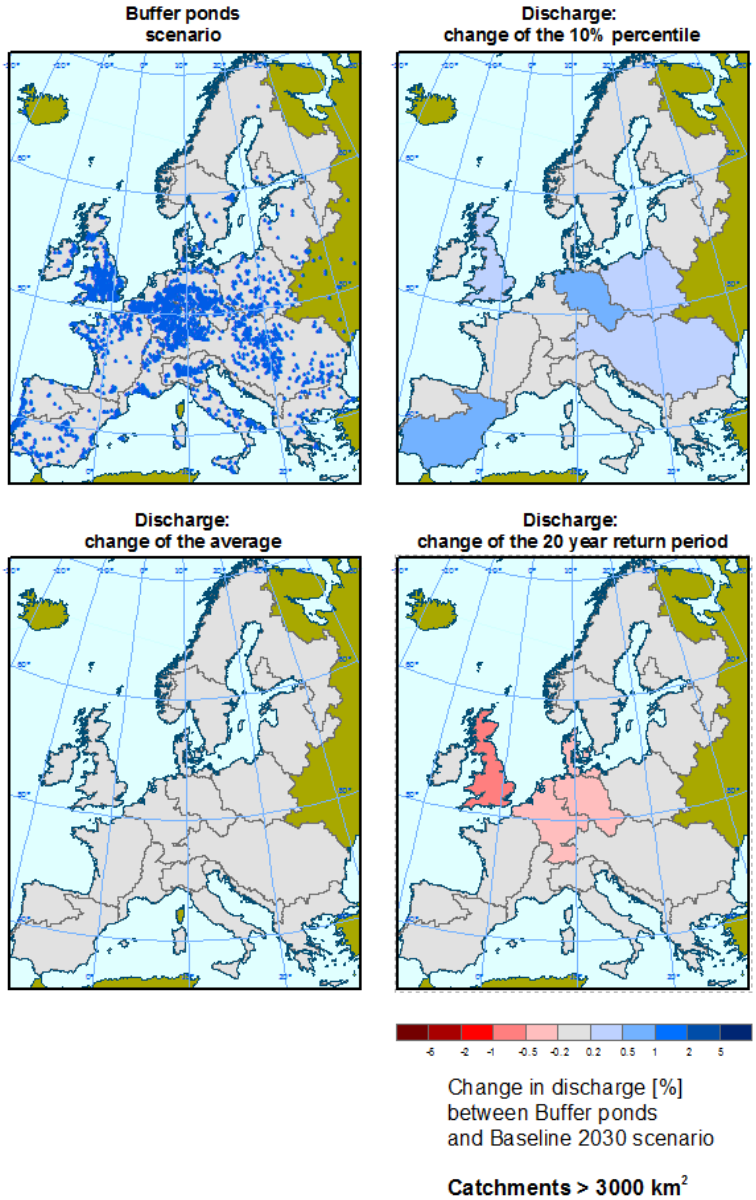
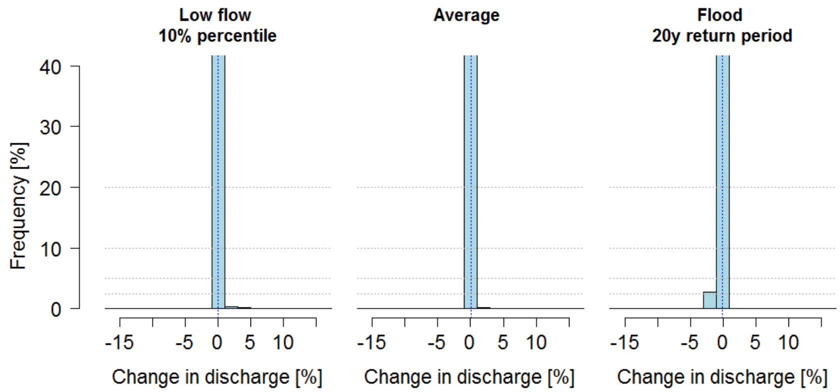


Figure V-34: Comparison between the "Buffer ponds" and "Baseline 2030" scenarios



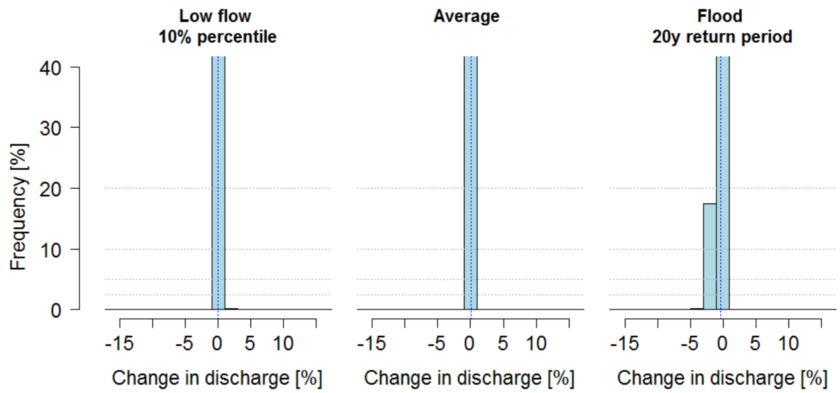


Figure V-35: Variability of changes (Buffer ponds vs. Baseline 2030) for low flow, average and 20 year return period for a) whole Europe (top) and b) region 8 (Great Britain) (bottom)

3.10 Polders

Polders were only placed in major rivers with a catchment area bigger than 10000 km^2. In large river systems like the Danube, Tisza, Elbe, and Rhine they are lined up one after the other with a distance of 50 km between them, therefore their effect will add up. To address this issue, each polder should be analysed based on the impact of the previous ones, which is not done in this study, but even without doing this analysis, this "add-up" effect can be shown here.

Polders show no effect on low flow and average discharge but reduce flood peaks for almost all regions, except Great Britain, Sicilia, Corsica, Sardinia and Southern Scandinavia where no or only a few polders were applied (Figure V-35).

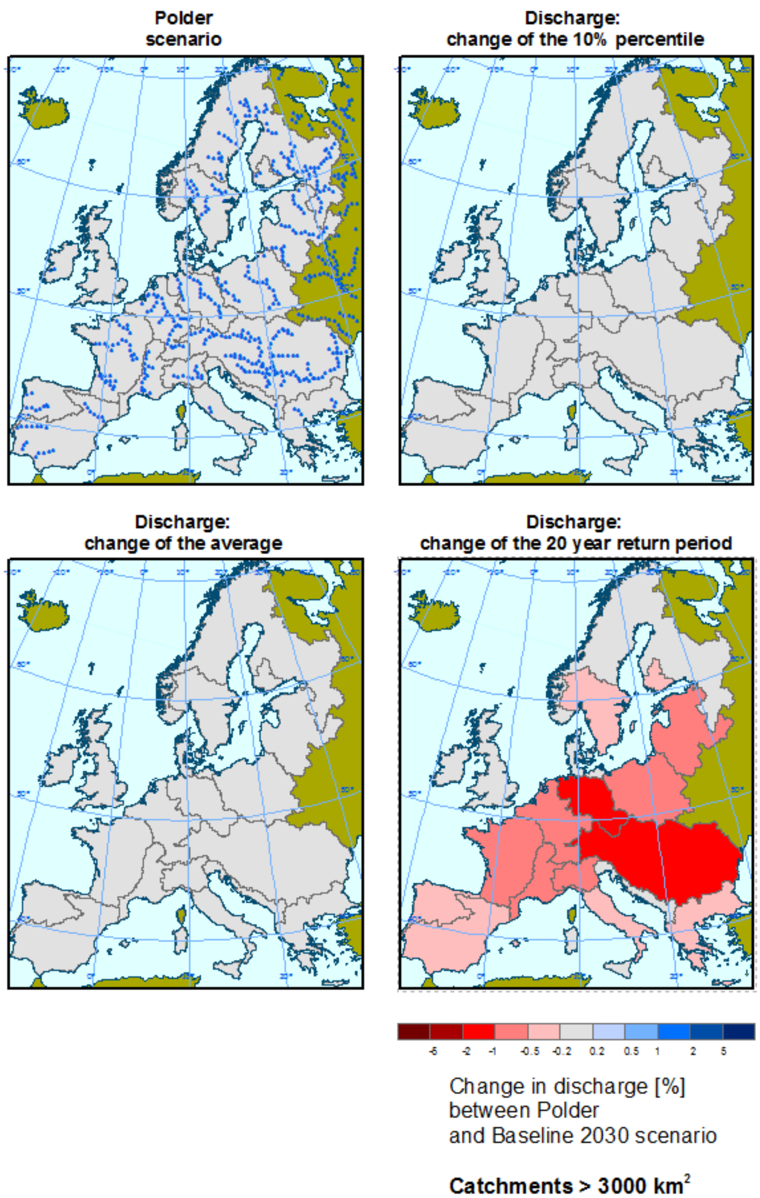


Figure V-36: Comparison between the "Polder" and "Baseline 2030" scenarios

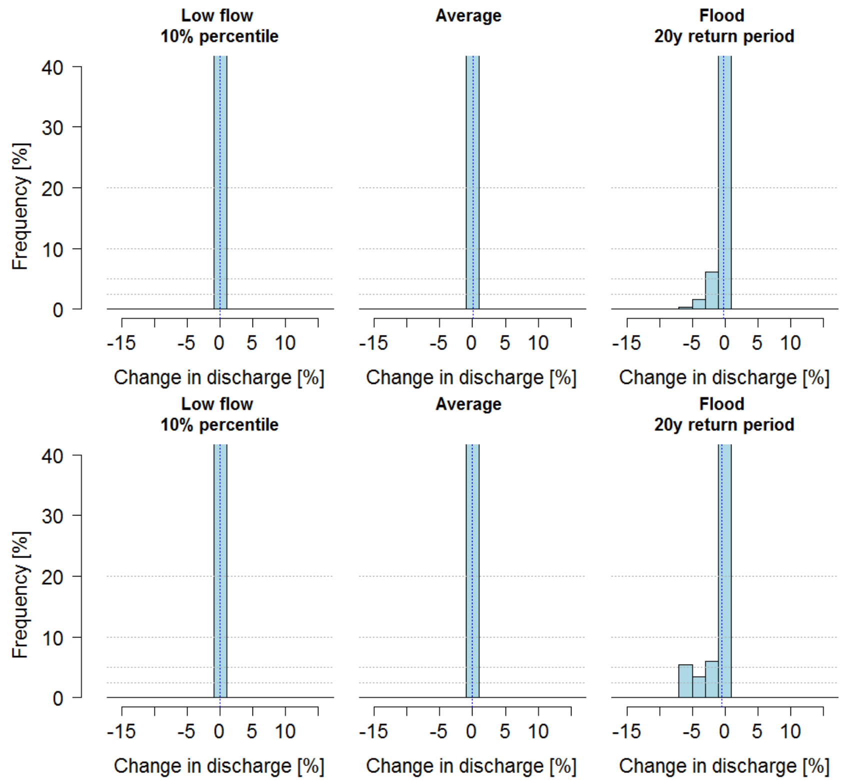


Figure V-37: Variability of changes (Polder vs. Baseline 2030) for low flow, average and 20 year return period for a) whole Europe (top) and b) region 6 (Ems-Elbe) (bottom)

VI. Discussion

Hydrological simulations were done for all 12 scenario measures (see Table IV-4) keeping the forcing climatic conditions from three different climate simulations (see Table III-1) stable in order to assess the impact of the scenarios only.

For each of the 21 European macro-regions, we assessed which scenario is the most effective to change high discharges (flood peaks) and low discharges (low flows). Values given are averages for the entire region. Local changes in discharge can reach up to 20% depending on the scenario and location, but are averaged out by looking at the 21 regions (see part IV of the report).

The hydrological output for each of the three different climate control runs differ in absolute terms, because the forcing input from the climate simulations (e.g. temperature, precipitation, evaporation) can be very different. However, the percentage of change is in the same range for each scenario (see part IV of the report), and therefore comparable. For the analysis of the results the percentage of change was averaged over the three different climate simulations.

To assess the impact on flooding, the 20-year-return-period discharge was calculated as an indicator. The discharge of the Baseline 2030 20-year-return-period was taken as reference and compared to the ones for each scenario. To assess the impact on low flows, the 10^{th} percentile of the daily discharge values was taken (i.e. for 10 percent of the days over the simulated domain of 30-years, discharge is lower than this 10^{th} percentile value).

The costs related to each scenario per region were calculated based on the costs per hectare estimated by Stella Consulting (2012) multiplied by the area for which the scenario was applied, and corrected for country price levels. Table VI-1 gives the summed costs for each region in in Millions of Euros. Note that costs for polders (scenario 44) were not provided by Stella, so could not be calculated.

Table VI-1: Estimated regional costs per measure (in millions of Euros)

Cost [M €] Region	11-Riparian	12-afforestation	21-urban25	22-urban50	31-grasland	32-bufferstrips	33-grassed	34-crop	41-wetlands	43-meander	44-buffer pond
01 N. Scandinavia	7945	6938	8499	17270	1	426	1206	7404	697	23	0
02 S. Scandinavia	4842	3572	17447	34778	3	1320	2383	13437	169	8	2
03 Baltic	4062	2549	7663	15374	8	1344	3043	15725	107	3	1
04 Denmark/N.Germany	5342	4156	10850	21991	2	861	2780	11942	9	1	3
05 Odra/Vistula	2378	2505	18389	37821	19	2174	4983	25534	165	3	11
06 Elbe to Ems	6751	5841	56965	117101	26	2358	3981	21771	125	2	31
07 Rhine/Meuse/Scheldt	4367	4330	111481	226878	51	2337	4438	23695	208	3	54
08 GB	2027	1997	141710	283421	48	1788	2613	13079	36	3	38
09 Ireland/N.Ireland	1009	671	9753	19506	281	259	827	4850	23	1	3
10 France Atlantic	4677	7584	51229	105660	108	5526	9158	47397	292	8	18
11 Danube	9739	14903	73456	146245	121	4379	9578	55209	754	9	29
12 Iberia Atlantic	1623	3267	7799	15614	27	1668	2728	15147	122	5	6
13 Iberia Mediterranean	1431	4760	40779	81558	25	5345	5421	31948	206	6	15
14 France Mediterranean	1218	4815	22745	46605	30	993	1298	8139	153	3	9
15 Po	840	1637	16199	33348	18	218	1595	8968	133	3	9
16 Corsica	15	47	69	143	1	15	23	149	1	0	0
17 Sardinia	108	450	761	1569	0	196	283	1793	3	0	1
18 Sicily	323	319	2071	4270	3	243	516	2773	3	0	2
19 South Italy	1151	2669	14047	28972	27	1073	2320	14198	45	3	8
20 Adige/Balkan	227	403	4071	8272	3	164	518	3101	13	1	2
21 Greece/Evros	656	990	16376	32834	7	1394	2394	14686	66	2	3

1 Reducing flood peaks

The most effective measures to reduce flood peaks for each region are shown in Figure VI-1, Figure VI-2 and Table III-1

- For Great Britain the most effective measures are the green scenarios, followed by improved crop practices. Investment and maintenance costs for the crop practice scenario are 10-20 times lower than the green city measures.
- For the Rhine and Rhone region the most effective scenarios are those that reduce the flood peaks along the river e.g. polders. Compared to Great Britain the alpine regime of the rivers produce most of the discharge and therefore the effect of the urban, agricultural and land use scenarios are weaker
- For the Elbe to Ems region afforestation, closely followed by crop practice and grassland are the most effective measures, since a lot of the area has a high potential for land use conversion according to our criteria. The grassland measure is the cheapest to implement,

followed by the afforestation measure. The crop practices are more expensive to implement in this region.

- For the Po and the Baltic regions re-meandering has the most potential to reduce flood peaks, but it is also quite effective for almost all the other regions. Re-meandering is a very cheap measure to implement compared to the other measures.
- Crop practice is by far the most effective measure for Iberia, France Atlantic, Danube, Balkan, South Italy, and Greece. For Sicily, using the crop practice scenario can reduce flood peaks of a 20 year return period by almost 4 % on average for the whole region. Crop practice is also a quite successful measure for Denmark/N. Germany. With the exception of the urban-greening measures, the crop practice scenario has higher total costs than all other scenarios, because of the size of the agricultural area.
- For Ireland/N.Ireland and Corsica there are no significant changes in discharge as a consequence of the scenarios.

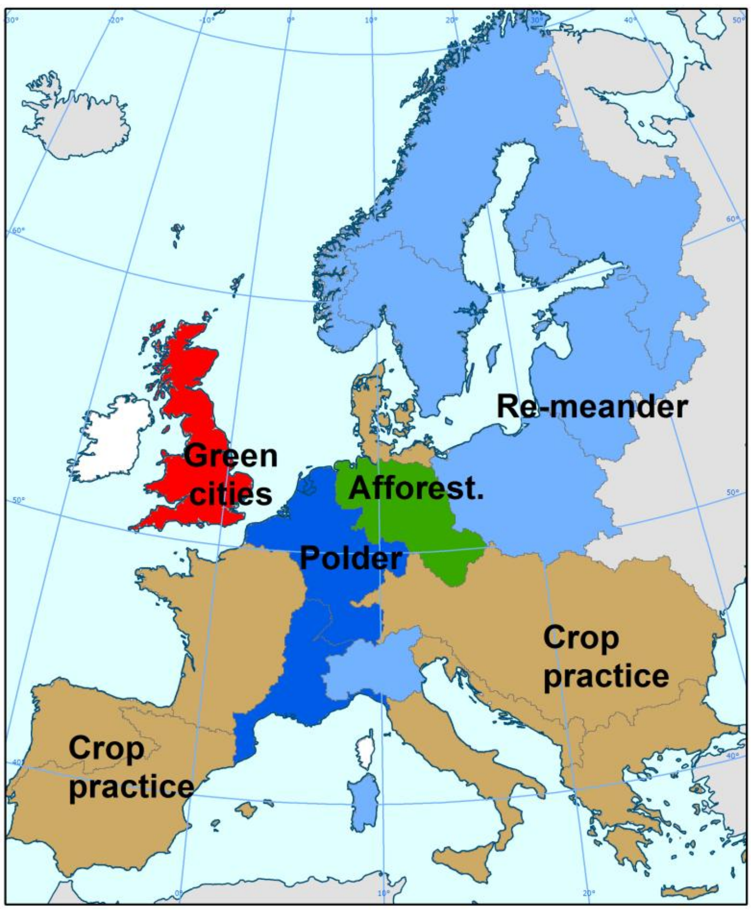


Figure VI-1: Most effective regional measures to reduce flood peaks (here: 20 year return period)

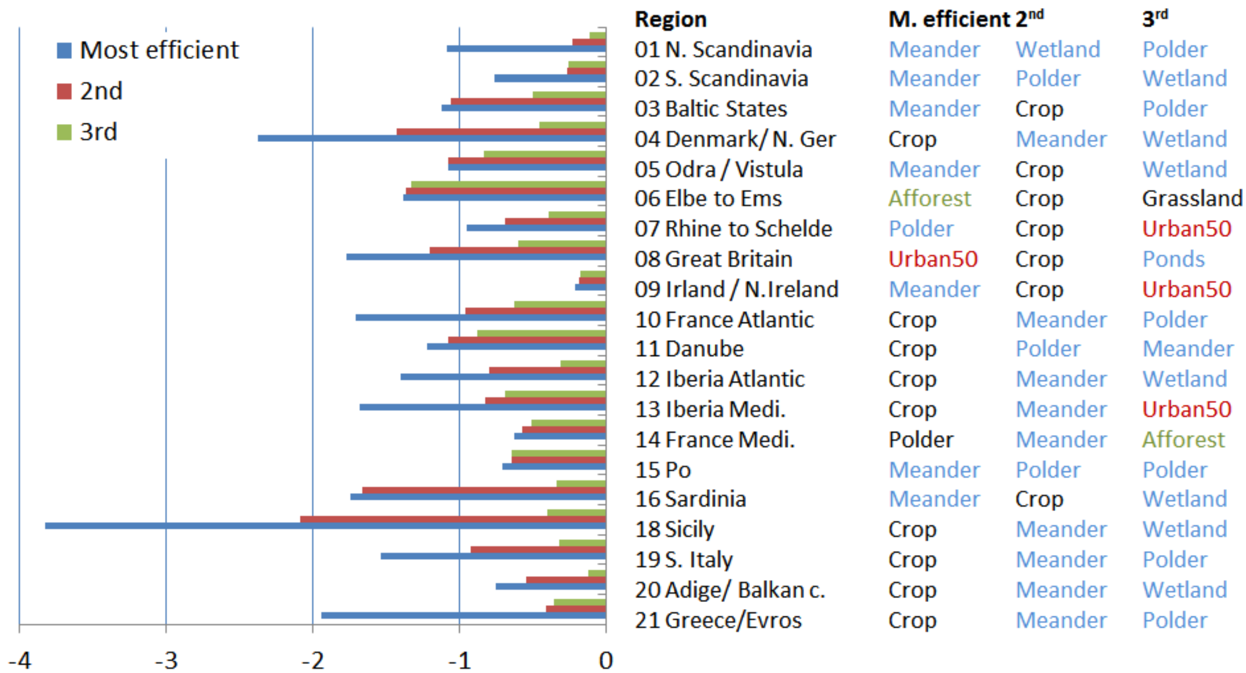


Figure VI-2: The three most effective measures to reduce flood peaks per region

Table VI-2: Most effective measure to reduce flood peaks

[%] change in discharge		Most efficient		2nd		3rd	
Region							
Region 01	N. Scandinavia	-1.1	Meander	-0.2	Wetland	-0.1	Polder
Region 02	S. Scandinavia	-0.8	Meander	-0.3	Polder	-0.3	Wetland
Region 03	Baltic	-1.1	Meander	-1.1	Crop	-0.5	Polder
Region 04	Denmark/N.Germany	-2.4	Crop	-1.4	Meander	-0.5	Wetland
Region 05	Odra/Vistula	-1.1	Meander	-1.1	Crop	-0.8	Wetland
Region 06	Elbe to Ems	-1.4	Afforest.	-1.4	Crop	-1.3	Grassland
Region 07	Rhein to Schelde	-0.9	Polder	-0.7	Crop	-0.4	50% Green
Region 08	GB	-1.8	50% Green	-1.2	Crop	-0.6	Buffer pond
Region 09	Irland/N.Ireland	-0.2	Meander	-0.2	Crop	-0.2	50% Green
Region 10	France Atlantic	-1.7	Crop	-1.0	Meander	-0.6	Polder
Region 11	Danube	-1.2	Crop	-1.1	Polder	-0.9	Meander
Region 12	Iberia Atlantic	-1.4	Crop	-0.8	Meander	-0.3	Wetland
Region 13	Iberia Mediterranean	-1.7	Crop	-0.8	Meander	-0.7	50% Green
Region 14	France Mediterranean	-0.6	Polder	-0.6	Meander	-0.5	Afforest.
Region 15	Po	-0.7	Meander	-0.6	Polder	-0.6	Polder
Region 16	Corsica	0.0	-	0.0	-	-0.0	-
Region 17	Sardinia	-1.7	Meander	-1.7	Crop	-0.3	Wetland
Region 18	Sicily	-3.8	Crop	-2.1	Meander	-0.4	Wetland
Region 19	South Italy	-1.5	Crop	-0.9	Meander	-0.3	Polder
Region 20	Adige/Balkan	-0.7	Crop	-0.5	Meander	-0.1	Wetland
Region 21	Greece/Evros	-1.9	Crop	-0.4	Meander	-0.4	Polder

No significant measures with effectiveness less than 0.1% are sorted out

The histogram in Table VI-5 shows the percentage of the considered area in Europe which belongs to the low flow change class per scenario, e.g. for the crop practice scenario 31% of the considered area decreases the 20year flood discharge by 1 to 3% compared to the Baseline scenario.
For Europe it seems that the crop practice and the meander scenarios are the most effective measures in terms of reducing floods.

Table VI-3: Histogram of changes in discharge for the 20 year return period

Flood	change in discharge [%] compared to Baseline										
	<-9	**-9 - -7**	**-7 - -5**	**-5 - -3**	**-3 - -1**	**-1 - 1**	**1-3**	**3-5**	**5-7**	**7-9**	**>9**
Baseline2030	0	0	1	2	8	76	9	2	1	1	0
Riparian	0	0	0	1	5	88	5	0	0	0	0
Afforestation	0	0	0	2	10	79	8	1	0	0	0
25% Green	0	0	0	0	3	97	0	0	0	0	0
50% Green	0	0	0	1	5	93	0	0	0	0	0
Grassland	0	0	0	1	5	88	5	1	0	0	0
Bufferstrip	0	0	0	0	0	100	0	0	0	0	0
Grassed	0	0	0	0	1	99	0	0	0	0	0
Crop	0	0	1	6	31	61	0	0	0	0	0
Wetland	0	0	0	0	4	96	0	0	0	0	0
Meander	0	0	0	2	23	74	0	0	0	0	0
Buffer pond	0	0	0	0	3	97	0	0	0	0	0
Polder	0	0	0	2	6	92	0	0	0	0	0

[1] Baseline2030 compared to Baseline 2006, all the rest compared to Baseline 2030

2 *Increasing low flow*

The most effective measures to increase low flow for each region are shown in Figure VI-3, Figure VI-4 and Table VI-4

- For Great Britain the most effective measure to increase low flow is the land use change scenario "Grassland", which is also a very low cost measure compared to other scenarios.
- For the Iberia Mediterranean region, buffer ponds are the most effective measure to increase low flow. This measure helps to store water during the rainy winter month in order to feed the rivers in the dry summer month, and has relatively low costs.
- For all central European regions implementing the re-meandering scenario increases low flow. Due to the extended river length the discharge recession curve during the dry summer months is less steep and it takes longer for the discharge to decrease. Re-meandering is also a relatively low cost measure to implement.
- For Ireland/N.Ireland, riparian forest is estimated to increase low flows. Costs are 1 billion Euro, covering investment and maintenance for a 30-year period.

- For Sardinia, afforestation is estimated to increase low flows. Costs are 450 million Euro, covering investment and maintenance for a 30-year period.
- For Southern Italy, the Green city scenario is the only scenario which has a slightly significant effect on increasing low flows. Costs are 14-29 Billion Euro, covering investment and maintenance for a 30-year period.
- For Sicilia, Corsica, the Balkan coast region, and the Greece/Evros region, the scenarios do not lead to significant changes in low flow.

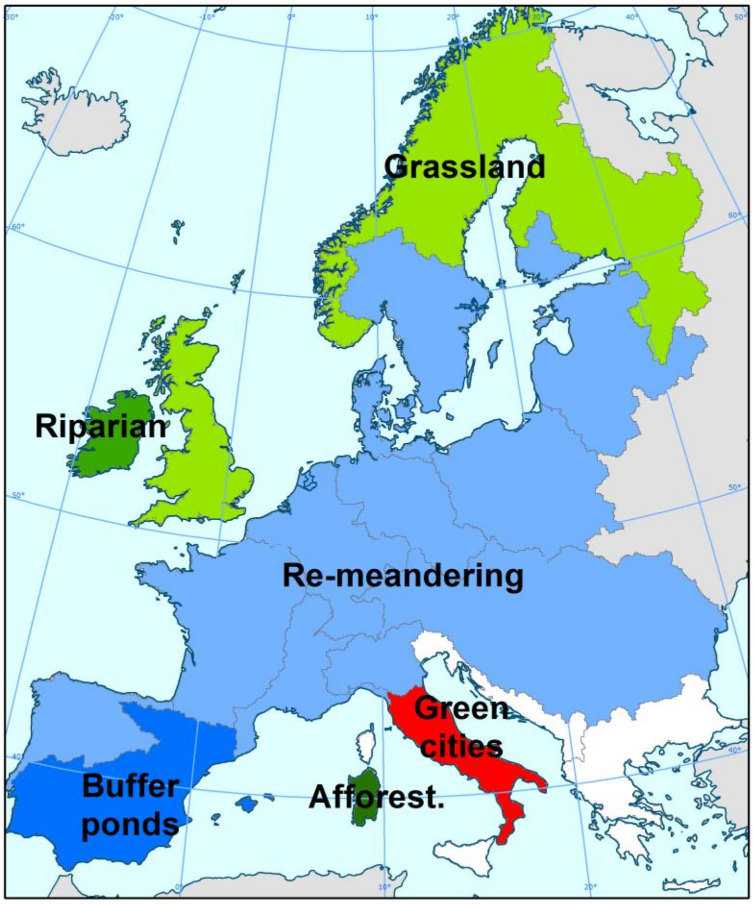


Figure VI-3: Most effective measures to increase low flow per region (here: 10% flow)

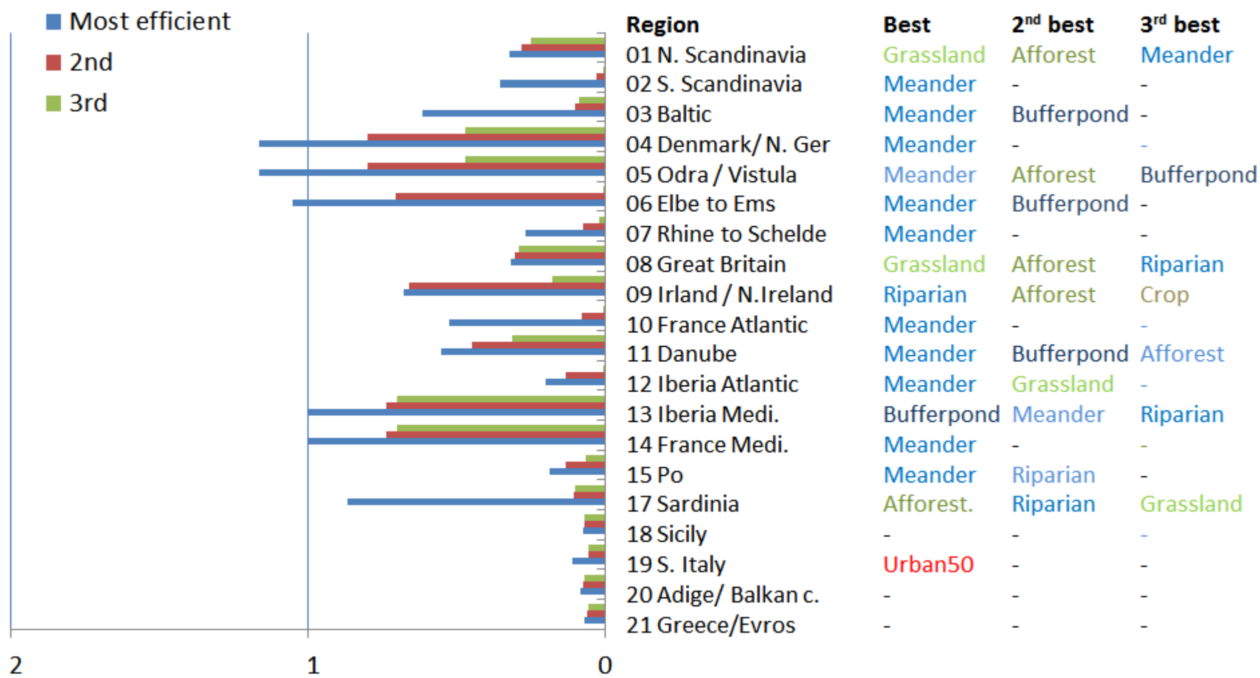


Figure VI-4: The three most effective measures to increase low flow (here: 10% flow)

Table VI-4: Most effective measure to increase low flows

[%] change in discharge		Most efficient		2nd		3rd	
Region							
Region 01	N. Scandinavia	0.3	Grassland	0.3	Afforest	0.3	Meander
Region 02	S. Scandinavia	0.4	Meander	0.0	-	0.0	-
Region 03	Baltic	0.6	Meander	0.1	Buffer pond	0.1	-
Region 04	Denmark/N.Germany	0.4	Meander	0.1	-	0.1	-
Region 05	Odra/Vistula	1.2	Meander	0.8	Afforest	0.5	Buffer pond
Region 06	Elbe to Ems	1.1	Meander	0.7	Buffer pond	0.0	-
Region 07	Rhein to Schelde	0.3	Meander	0.1	-	0.0	-
Region 08	GB	0.3	Grassland	0.3	Afforest	0.3	Riparian
Region 09	Irland/N.Ireland	0.7	Riparian	0.7	Afforest	0.2	Crop
Region 10	France Atlantic	0.5	Meander	0.1	-	0.0	-
Region 11	Danube	0.6	Meander	0.4	Buffer pond	0.3	Afforest
Region 12	Iberia Atlantic	0.2	Meander	0.1	Grassland	0.0	-
Region 13	Iberia Mediterranean	1.0	Buffer pond	0.7	Meander	0.7	Riparian
Region 14	France Mediterranean	0.1	Meander	0.0	-	0.0	-
Region 15	Po	0.2	Meander	0.1	Riparian	0.1	-
Region 16	Corsica	0.0	-	0.0	-	0.0	-
Region 17	Sardinia	0.9	Afforest	0.1	Riparian	0.1	Grassland
Region 18	Sicily	0.1	-	0.1	-	0.1	-
Region 19	South Italy	0.1	50% Green	0.1	-	0.1	-
Region 20	Adige/Balkan	0.1	Meander	0.1	-	0.1	-
Region 21	Greece/Evros	0.1	-	0.1	-	0.1	-

No significant measures with effectiveness less than 0.1% are sorted out

The histogram in Table VI-5 shows the percentage of the considered area in Europe which belongs to the low flow change class per scenario, e.g. for the crop practice scenario 11% of the considered area is decreasing 1 to 3% of the 10% low flow compared to the Baseline scenario.
For Europe it seems that the crop practice scenario is the most effective measure in terms of low flows.

Table VI-5: Histogram of changes in discharge for the 10% flow

Low flow	change in discharge [%] compared to Baseline										
	<-9	**-9 - -7**	**-7 - -5**	**-5 - -3**	**-3 - -1**	**-1 - 1**	**1-3**	**3-5**	**5-7**	**7-9**	**>9**
Baseline2030	0	1	1	3	9	72	9	2	1	1	1
Riparian	0	0	1	1	6	78	8	2	1	0	1
Afforestation	0	1	1	2	7	73	9	2	1	1	1
25% Green	0	0	0	0	1	98	1	0	0	0	0
50% Green	0	0	0	0	1	96	2	0	0	0	0
Grassland	0	0	1	2	6	78	8	2	1	0	0
Bufferstrip	0	0	0	0	0	99	1	0	0	0	0
Grassed	0	0	0	0	1	96	3	0	0	0	0
Crop	5	2	2	4	11	76	1	0	0	0	0
Wetland	0	0	0	0	0	100	0	0	0	0	0
Re-meandering	0	0	0	0	0	98	1	0	0	0	0
Buffer pond	0	0	0	0	0	99	0	0	0	0	0
Polder	0	0	0	0	0	100	0	0	0	0	0

[1] Baseline2030 compared to Baseline 2006, all the rest compared to Baseline 2030

3 Groundwater recharge

The most effective measures to increase groundwater recharge for each region are shown in Figure VI-5 and Table VI-6. Mainly the scenario 50% Green is the most effective scenario in this catalogue of 8 scenarios. Wetland, re-meandering, buffer pond and polder scenarios are not included here, because in those scenarios only the routing is changed but not the runoff generation and concentration.

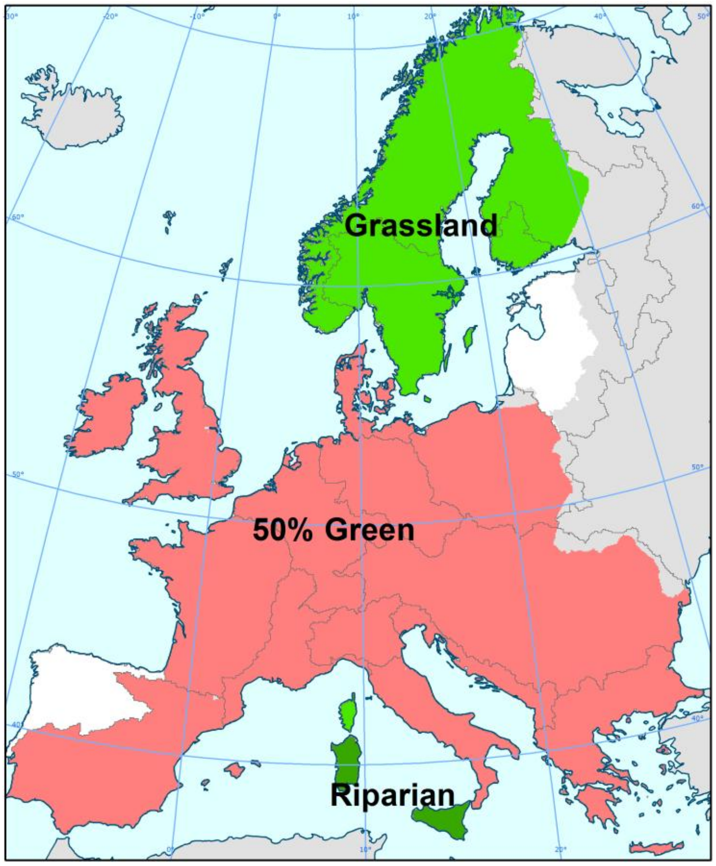


Figure VI-5: Most effective measures to increase groundwater recharge per region

Table VI-6: Most effective measures to increase groundwater recharge per region

[%] change in groundwater recharge		Most efficient		2nd	
Region					
Region 01	N. Scandinavia	0.5	Grassland	0.4	Riparian
Region 02	S. Scandinavia	0.2	Grassland	0.2	Riparian
Region 03	Baltic	-			
Region 04	Denmark/N.Germany	0.3	50% Green		
Region 05	Odra/Vistula	0.2	50% Green		
Region 06	Elbe to Ems	0.9	50% Green	0.4	25% Green
Region 07	Rhein to Schelde	1.1	50% Green	0.5	25% Green
Region 08	GB	1.7	50% Green	0.8	25% Green
Region 09	Irland/N.Ireland	0.3	50% Green		
Region 10	France Atlantic	0.4	50% Green	0.2	25% Green

Region 11	Danube	0.3	50% Green		
Region 12	Iberia Atlantic	-			
Region 13	Iberia Mediterranean	0.3	50% Green	0.2	riparian
Region 14	France Mediterranean	0.4	50% Green	0.2	25% Green
Region 15	Po	0.4	50% Green	0.2	25% Green
Region 16	Corsica	0.7	Grassland		
Region 17	Sardinia	0.5	Riparian	0.5	Grassland
Region 18	Sicily	0.3	Riparian		
Region 19	South Italy	0.2	50% Green		
Region 20	Adige/Balkan	0.2	50% Green		
Region 21	Greece/Evros	0.3	50% Green		

No significant measures with effectiveness less than 0.1% are sorted out

4 Water stress

The only effective measure to reduce water stress is the scenario Crop practice as shown in Figure VI-6 and Table VI-7. Especially for the regions France Atlantic, Rhine, Ems-Elbe and Denmark-Northern Germany a reduction of two days per year could be achieved. For Scandinavia the limiting factor for plants in general is low temperature and therefore soil moisture stress is not as important.

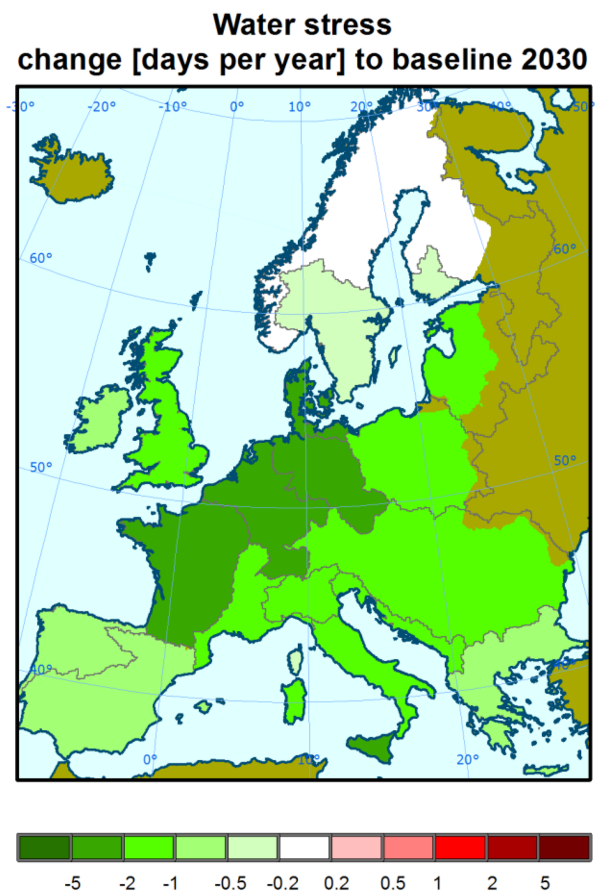


Figure VI-6: Comparison between the “Crop practice” and “Baseline 2030” scenarios for water stress

Table VI-7: Most effective measure to decrease water stress per region

[days per year] change in water stress		Most efficient	
Region			
Region 01	N. Scandinavia	-0.1	Crop practice
Region 02	S. Scandinavia	-0.5	Crop practice
Region 03	Baltic	-1.4	Crop practice
Region 04	Denmark/N.Germany	-3.0	Crop practice
Region 05	Odra/Vistula	-2.0	Crop practice
Region 06	Elbe to Ems	-2.0	Crop practice
Region 07	Rhein to Schelde	-2.0	Crop practice
Region 08	GB	-1.2	Crop practice
Region 09	Irland/N.Ireland	-0.9	Crop practice
Region 10	France Atlantic	-2.6	Crop practice
Region 11	Danube	-1.8	Crop practice
Region 12	Iberia Atlantic	-0.9	Crop practice
Region 13	Iberia Mediterranean	-0.7	Crop practice
Region 14	France Mediterranean	-1.0	Crop practice
Region 15	Po	-1.8	Crop practice
Region 16	Corsica	-0.5	Crop practice
Region 17	Sardinia	-1.2	Crop practice
Region 18	Sicily	-2.3	Crop practice
Region 19	South Italy	-1.8	Crop practice
Region 20	Adige/Balkan	-1.2	Crop practice
Region 21	Greece/Evros	-0.9	Crop practice

No significant measures with effectiveness more than -0.1% are sorted out

VII. Conclusion

In the context of the impact assessment for the forthcoming policy document "Blueprint to safeguard Europe's waters", the European Commission has developed a common baseline scenario bringing together climate, land use and socio-economic scenarios and looking at the implications for water resources availability and use under different policy scenarios.

This study was carried out by the Joint Research Centre of the European Commission with the support of Stella Consulting SPRL, Brussels. It shows the impact of no-regret natural water retention measures on water quantity which can, in turn, be used to quantify ecosystem services related to water provision, water flow regulation and the moderation of extreme flows. It also contributes to the identification of multifunctional adaptation measures that reduce the vulnerability of water resources and related ecosystem services to climate change and other anthropogenic pressures and also to the Green Infrastructure strategy. Within the context of this report "no-regret" is solely based on hydrological impact. The following report "A multi-criteria optimisation of scenarios for the protection of water resources in Europe" will also address co-benefits and costs.

The novelty of this study is in linking climate, landuse and hydrological scenarios and models on a pan European scale and providing a first quantitative pan-European overview of the effects of 'green' measures on discharge. This should encourage Member States to further explore the use of efficiency measures and foster communication between stakeholders.

12 different policy scenarios were used, addressing changes in forest and urban areas, agriculture practice, and water retention. Locally some of these scenarios were estimated to change low flows and flood discharge up to 20%. For the 21 defined macro-regions in Europe there is a clear difference in the impacts of measures and for each region the effectiveness of each scenario has been ranked in terms of increasing low flow or reducing flood peaks.

It can be shown that:

- The combination of climate scenarios, land use model and hydrological model shows the same relative changes regarding the used scenarios independent of the forcing climatology
- no-regret natural water retention measures can contribute to increased low flows, reduced flood peaks, improve ground water recharge and decrease water stress.
- In each of the 21 macro-regions a different set of measures can be effective depending on the climate, flow regime, land use and socio-economics.

This work is followed by "A multi-criteria optimisation of scenarios for the protection of water resources in Europe" which develops an optimisation model linked with dynamic, spatially explicit water quality and quantity models allowing the selection of measures affecting water availability and water demand based on environmental and economic considerations. The aim of this engagement is to seek the maximization of net social benefits from the use of water by economic sectors including a range of components, such as welfare impacts for water users, valuation of key ecosystem services provision, valuation of external costs from degradation of ecological and chemical status and energy consumption triggered by water abstraction and return.

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Annex I
Change in discharge

Abbreviations:

DMI:	DMI-HIRHAM5-ECHAM5 – climate model from Danish Meteorological Institute
KNMI:	KNMI-RACMO2-ECHAM5 – climate model from The Royal Netherlands Meteorological Institute
METO:	METO-HadRM3Q0-HadCM3Q0 - climate model from the UK Met Office
p5, p10, p50, p95:	Percentage of the flow duration curve
Low7d :	Low flow analysis - average of yearly 7-day minimum discharge
AvgMax:	Average yearly flood (mean of yearly flood peaks)
rp2, rp20, rp100:	Flood peaks with return period of 2, 20 and 100 years

Values are given for the average of the 3 climate runs (DMI,KNMI,METO)
The tables have the following structure:
Scenario

[3]Catchments ≥ 3000 km^2

[4]Change in percentage of discharge between scenario and baseline

Catchments ≥ 400 km^2 and < 3000 km^2

Change in percentage of discharge between scenario and baseline

[3] Distinguishment between mesoscale catchments and macroscale catchments, because of the different, scale dependent influence of different types of rainfall generation

[4] Red highlighted = less discharge than baseline scenrario
Blue highlighted = more discharge than baseline scenario

0 Baseline 2030

Catchments ≥ 3000 km^2

Change in [%] discharge from the baseline **2006** scenario

[%]			Low flow		Median	High flow			
Region		Clima	Low7d	p10		AvgMax	rp002	rp020	rp100
Region 01	N. Scandinavia	Avg.	-0.4	-0.2	-0.6	-0.7	-0.7	-0.5	-0.5
Region 02	S. Scandinavia	Avg.	0.1	0.1	-0.2	-0.2	-0.2	-0.1	-0.1
Region 03	Baltic	Avg.	0.5	0.5	0.2	0.1	0.1	0.2	0.2
Region 04	Denmark/N.Germany	Avg.	0.6	0.5	0.2	-0.4	-0.5	-0.2	-0.1
Region 05	Odra/Vistula	Avg.	-0.6	-0.9	-1.0	-0.7	-0.8	-0.4	-0.3
Region 06	Elbe to Ems	Avg.	0.1	0.3	0.6	0.8	0.9	0.8	0.7
Region 07	Rhein to Schelde	Avg.	-0.1	0.0	0.1	0.4	0.4	0.4	0.3
Region 08	GB	Avg.	-0.6	0.8	3.4	5.8	5.8	5.0	4.8
Region 09	Irland/N.Ireland	Avg.	0.2	0.9	1.1	1.5	1.5	1.5	1.5
Region 10	France Atlantic	Avg.	0.2	0.2	0.2	0.6	0.6	0.6	0.6
Region 11	Danube	Avg.	-0.2	-0.2	-0.2	0.0	0.0	0.1	0.1
Region 12	Iberia Atlantic	Avg.	-0.3	-0.2	-0.1	0.5	0.5	0.5	0.4
Region 13	Iberia Mediterranean	Avg.	0.3	0.9	1.5	1.7	1.8	1.4	1.4
Region 14	France Mediterranean	Avg.	-0.1	-0.1	-0.1	0.1	0.1	0.1	0.1
Region 15	Po	Avg.	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Region 16	Corsica	Avg.	-	-	-	-	-	-	-
Region 17	Sardinia	Avg.	0.1	0.1	-0.2	-1.8	-1.8	-1.8	-1.7
Region 18	Sicily	Avg.	0.0	0.0	-0.1	-0.4	-0.5	-0.5	-0.5
Region 19	South Italy	Avg.	-0.3	-0.3	-0.1	0.6	0.6	0.6	0.6
Region 20	Adige/Balkan	Avg.	-0.1	-0.2	-0.3	0.0	0.0	0.0	0.0
Region 21	Greece/Evros	Avg.	-0.1	-0.1	-0.2	-0.2	-0.3	-0.2	-0.2

Catchments ≥ 400 km^2 and < 3000 km^2

Change in [%] discharge from the baseline **2006** scenario

[%]			Low flow		Median	High flow			
Region		Clima	Low7d	p10		AvgMax	rp002	rp020	rp100
Region 01	N. Scandinavia	Avg.	0.1	0.2	-0.3	-0.6	-0.7	-0.5	-0.5
Region 02	S. Scandinavia	Avg.	0.3	0.2	-0.2	-0.4	-0.4	-0.3	-0.3
Region 03	Baltic	Avg.	0.6	0.6	0.4	0.2	0.2	0.3	0.4
Region 04	Denmark/N.Germany	Avg.	0.2	0.3	0.2	0.0	0.0	0.1	0.1
Region 05	Odra/Vistula	Avg.	-0.1	-0.4	-0.9	-1.1	-1.3	-0.8	-0.7
Region 06	Elbe to Ems	Avg.	0.0	0.3	0.3	0.6	0.6	0.5	0.5
Region 07	Rhein to Schelde	Avg.	-0.4	-0.3	0.3	1.2	1.2	1.2	1.1
Region 08	GB	Avg.	-1.5	-0.8	1.2	4.2	4.2	4.1	4.0
Region 09	Irland/N.Ireland	Avg.	0.3	0.9	1.2	1.5	1.5	1.4	1.4
Region 10	France Atlantic	Avg.	0.4	0.4	0.4	0.9	0.9	0.9	0.9
Region 11	Danube	Avg.	-0.1	-0.1	0.0	-0.1	-0.1	0.0	0.0
Region 12	Iberia Atlantic	Avg.	-0.3	-0.2	-0.1	0.5	0.5	0.5	0.5
Region 13	Iberia Mediterranean	Avg.	-0.3	0.0	0.4	1.2	1.3	1.0	1.0
Region 14	France Mediterranean	Avg.	-0.3	-0.2	-0.2	0.3	0.3	0.3	0.3
Region 15	Po	Avg.	-0.4	-0.4	-0.3	0.0	0.0	0.0	0.0
Region 16	Corsica	Avg.	-0.2	-0.2	-0.3	-0.4	-0.4	-0.3	-0.3
Region 17	Sardinia	Avg.	0.0	-0.1	-0.1	-1.2	-1.2	-1.2	-1.1
Region 18	Sicily	Avg.	0.0	0.0	0.0	-0.9	-0.9	-0.9	-0.9
Region 19	South Italy	Avg.	-0.2	-0.2	0.0	0.4	0.4	0.4	0.4
Region 20	Adige/Balkan	Avg.	-0.2	-0.2	-0.3	0.1	0.1	0.1	0.1
Region 21	Greece/Evros	Avg.	-0.1	-0.1	-0.1	-0.2	-0.2	-0.1	-0.1

1.1 Riparian afforestation

Catchments ≥ 3000 km²

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		Clima	Low7d	p10		AvgMax	rp002	rp020	rp100
Region 01	N. Scandinavia	Avg.	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Region 02	S. Scandinavia	Avg.	-0.1	0.0	-0.3	-0.3	-0.3	-0.3	-0.2
Region 03	Baltic	Avg.	0.1	0.0	0.0	-0.5	-0.5	-0.4	-0.3
Region 04	Denmark/N.Germany	Avg.	0.0	0.0	0.1	0.1	0.1	0.1	0.1
Region 05	Odra/Vistula	Avg.	0.1	0.1	0.1	-0.1	-0.1	-0.1	-0.1
Region 06	Elbe to Ems	Avg.	-0.2	-0.3	-0.5	-1.3	-1.3	-1.3	-1.3
Region 07	Rhein to Schelde	Avg.	-0.1	0.0	0.0	-0.1	-0.2	-0.1	-0.1
Region 08	GB	Avg.	0.3	0.3	0.5	0.5	0.5	0.5	0.5
Region 09	Irland/N.Ireland	Avg.	0.2	0.7	0.8	0.6	0.6	0.6	0.6
Region 10	France Atlantic	Avg.	-0.1	0.0	0.0	0.0	0.0	0.0	0.0
Region 11	Danube	Avg.	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2
Region 12	Iberia Atlantic	Avg.	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0
Region 13	Iberia Mediterranean	Avg.	0.6	0.7	0.4	0.3	0.3	0.3	0.3
Region 14	France Mediterranean	Avg.	0.0	0.0	-0.1	-0.2	-0.2	-0.1	-0.1
Region 15	Po	Avg.	0.1	0.1	0.2	0.3	0.3	0.3	0.3
Region 16	Corsica	Avg.	-	-	-	-	-	-	-
Region 17	Sardinia	Avg.	0.1	0.1	0.0	0.8	0.8	0.7	0.7
Region 18	Sicily	Avg.	0.1	0.0	0.0	0.1	0.1	0.0	0.0
Region 19	South Italy	Avg.	-0.1	-0.1	-0.1	0.2	0.2	0.2	0.2
Region 20	Adige/Balkan	Avg.	0.0	0.1	0.0	0.1	0.1	0.1	0.1
Region 21	Greece/Evros	Avg.	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.1

Catchments ≥ 400 km² and < 3000 km²

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		Clima	Low7d	p10		AvgMax	rp002	rp020	rp100
Region 01	N. Scandinavia	Avg.	0.2	0.4	0.2	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	Avg.	0.1	0.0	-0.3	-0.5	-0.5	-0.4	-0.4
Region 03	Baltic	Avg.	0.1	-0.1	0.1	-0.6	-0.6	-0.4	-0.3
Region 04	Denmark/N.Germany	Avg.	-0.2	-0.1	0.3	-0.8	-0.7	-1.0	-1.1
Region 05	Odra/Vistula	Avg.	0.2	0.2	0.1	-0.1	-0.1	-0.1	-0.1
Region 06	Elbe to Ems	Avg.	-0.1	0.0	0.2	0.1	0.0	0.0	0.0
Region 07	Rhein to Schelde	Avg.	-0.1	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 08	GB	Avg.	0.6	0.5	0.4	0.6	0.6	0.6	0.6
Region 09	Irland/N.Ireland	Avg.	0.3	1.1	1.3	1.0	1.0	1.0	1.0
Region 10	France Atlantic	Avg.	-0.1	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 11	Danube	Avg.	0.1	0.2	0.0	-0.1	-0.1	0.0	0.0
Region 12	Iberia Atlantic	Avg.	0.0	0.0	0.1	0.2	0.2	0.2	0.2
Region 13	Iberia Mediterranean	Avg.	0.4	0.4	0.3	0.4	0.4	0.4	0.4
Region 14	France Mediterranean	Avg.	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Region 15	Po	Avg.	0.1	0.1	0.1	0.2	0.2	0.3	0.3
Region 16	Corsica	Avg.	0.2	0.2	1.1	1.1	1.3	0.7	0.6
Region 17	Sardinia	Avg.	0.2	0.2	0.1	0.8	0.8	0.7	0.7
Region 18	Sicily	Avg.	0.2	0.2	0.2	0.3	0.3	0.3	0.3
Region 19	South Italy	Avg.	-0.1	-0.1	-0.1	0.2	0.2	0.2	0.2
Region 20	Adige/Balkan	Avg.	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Region 21	Greece/Evros	Avg.	-0.1	-0.1	0.0	0.2	0.2	0.2	0.2

1.2 Afforestation in mountainous areas

Catchments ≥ 3000 km^2

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		**Clima**	**Low7d**	**p10**		**AvgMax**	**rp002**	**rp020**	**rp100**
Region 01	N. Scandinavia	Avg.	0.1	0.3	0.1	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	Avg.	-0.1	-0.1	-0.3	-0.3	-0.3	-0.2	-0.2
Region 03	Baltic	Avg.	0.1	0.0	0.0	-0.4	-0.4	-0.3	-0.3
Region 04	Denmark/N.Germany	Avg.	0.0	0.0	0.1	0.2	0.2	0.2	0.2
Region 05	Odra/Vistula	Avg.	0.9	0.8	0.3	-0.4	-0.4	-0.3	-0.3
Region 06	Elbe to Ems	Avg.	0.0	-0.3	-0.6	-1.5	-1.5	-1.4	-1.4
Region 07	Rhein to Schelde	Avg.	0.1	0.1	0.0	0.0	-0.1	0.0	0.1
Region 08	GB	Avg.	0.3	0.3	0.5	0.5	0.5	0.5	0.5
Region 09	Irland/N.Ireland	Avg.	0.2	0.7	0.8	0.6	0.6	0.6	0.6
Region 10	France Atlantic	Avg.	-0.3	-0.3	-0.3	-0.8	-0.8	-0.5	-0.4
Region 11	Danube	Avg.	0.4	0.3	-0.2	-0.5	-0.6	-0.4	-0.3
Region 12	Iberia Atlantic	Avg.	-0.5	-0.5	-0.5	0.0	0.0	0.2	0.3
Region 13	Iberia Mediterranean	Avg.	-0.5	-0.4	-0.4	-0.4	-0.4	-0.3	-0.3
Region 14	France Mediterranean	Avg.	-0.3	-0.4	-0.9	-0.8	-0.8	-0.5	-0.4
Region 15	Po	Avg.	0.1	0.0	-0.1	0.4	0.3	0.5	0.6
Region 16	Corsica	Avg.	-	-	-	-	-	-	-
Region 17	Sardinia	Avg.	0.7	0.9	0.6	1.6	1.5	2.1	2.3
Region 18	Sicily	Avg.	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0
Region 19	South Italy	Avg.	-0.3	-0.3	-0.6	0.8	0.8	1.0	1.0
Region 20	Adige/Balkan	Avg.	0.1	0.1	-0.1	0.3	0.3	0.3	0.3
Region 21	Greece/Evros	Avg.	-0.6	-0.6	-0.5	-0.2	-0.3	-0.2	-0.1

Catchments ≥ 400 km^2 and < 3000 km^2

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		**Clima**	**Low7d**	**p10**		**AvgMax**	**rp002**	**rp020**	**rp100**
Region 01	N. Scandinavia	Avg.	0.3	0.4	0.2	0.0	-0.1	0.0	0.0
Region 02	S. Scandinavia	Avg.	0.1	0.0	-0.3	-0.5	-0.5	-0.4	-0.3
Region 03	Baltic	Avg.	0.0	-0.1	0.0	-0.5	-0.5	-0.3	-0.2
Region 04	Denmark/N.Germany	Avg.	-0.2	-0.1	0.3	-0.8	-0.7	-1.0	-1.1
Region 05	Odra/Vistula	Avg.	0.9	0.8	0.4	-0.3	-0.4	-0.2	-0.2
Region 06	Elbe to Ems	Avg.	0.1	0.1	0.3	-0.1	-0.1	0.0	0.0
Region 07	Rhein to Schelde	Avg.	0.1	0.1	0.1	0.0	-0.1	0.0	0.1
Region 08	GB	Avg.	0.7	0.5	0.5	0.6	0.6	0.7	0.7
Region 09	Irland/N.Ireland	Avg.	0.3	1.1	1.2	1.1	1.1	1.0	1.0
Region 10	France Atlantic	Avg.	-0.1	-0.1	-0.1	-0.4	-0.5	-0.3	-0.2
Region 11	Danube	Avg.	0.3	0.3	-0.2	-0.4	-0.5	-0.2	-0.1
Region 12	Iberia Atlantic	Avg.	-0.2	-0.2	-0.2	0.3	0.2	0.4	0.5
Region 13	Iberia Mediterranean	Avg.	-0.5	-0.4	-0.4	-0.2	-0.2	-0.1	-0.1
Region 14	France Mediterranean	Avg.	0.0	0.1	-0.7	-0.5	-0.5	-0.2	-0.1
Region 15	Po	Avg.	0.1	0.0	-0.4	0.5	0.4	0.7	0.7
Region 16	Corsica	Avg.	0.1	0.2	0.9	1.2	1.3	1.0	0.9
Region 17	Sardinia	Avg.	0.8	0.9	0.7	1.1	1.0	1.4	1.5
Region 18	Sicily	Avg.	0.2	0.2	0.2	-0.1	-0.1	0.0	0.1
Region 19	South Italy	Avg.	-0.4	-0.4	-0.7	0.5	0.4	0.6	0.7
Region 20	Adige/Balkan	Avg.	0.0	0.0	-0.1	0.3	0.3	0.3	0.3
Region 21	Greece/Evros	Avg.	-0.4	-0.4	-0.5	0.0	0.0	0.1	0.1

2.1 25% Green

Catchments ≥ 3000 km²

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		Clima	Low7d	p10		AvgMax	rp002	rp020	rp100
Region 01	N. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 03	Baltic	Avg.	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0
Region 04	Denmark/N.Germany	Avg.	0.0	0.0	-0.1	-0.2	-0.2	-0.1	-0.1
Region 05	Odra/Vistula	Avg.	-0.1	-0.2	-0.3	-0.2	-0.2	-0.1	-0.1
Region 06	Elbe to Ems	Avg.	-0.1	-0.3	-0.5	-0.5	-0.5	-0.4	-0.4
Region 07	Rhein to Schelde	Avg.	0.1	0.0	-0.2	-0.2	-0.2	-0.2	-0.2
Region 08	GB	Avg.	0.2	-0.1	-0.8	-1.1	-1.1	-0.9	-0.8
Region 09	Irland/N.Ireland	Avg.	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Region 10	France Atlantic	Avg.	0.0	-0.1	-0.1	-0.1	-0.1	0.0	0.0
Region 11	Danube	Avg.	0.0	-0.1	-0.2	-0.2	-0.2	-0.1	-0.1
Region 12	Iberia Atlantic	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 13	Iberia Mediterranean	Avg.	-0.1	-0.3	-0.4	-0.4	-0.4	-0.3	-0.3
Region 14	France Mediterranean	Avg.	0.0	0.0	-0.1	-0.1	-0.1	0.0	0.0
Region 15	Po	Avg.	0.0	0.0	-0.1	-0.2	-0.2	-0.1	-0.1
Region 16	Corsica	Avg.	-	-	-	-	-	-	-
Region 17	Sardinia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 18	Sicily	Avg.	0.0	0.0	0.0	-0.1	-0.2	-0.1	-0.1
Region 19	South Italy	Avg.	0.1	0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Region 20	Adige/Balkan	Avg.	0.0	0.0	0.0	-0.1	-0.1	0.0	0.0
Region 21	Greece/Evros	Avg.	0.1	0.0	-0.1	-0.2	-0.2	-0.1	-0.1

Catchments ≥ 400 km² and < 3000 km²

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		Clima	Low7d	p10		AvgMax	rp002	rp020	rp100
Region 01	N. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 03	Baltic	Avg.	0.0	0.0	-0.1	0.0	0.0	0.0	0.0
Region 04	Denmark/N.Germany	Avg.	0.1	0.0	-0.1	-0.2	-0.2	-0.2	-0.2
Region 05	Odra/Vistula	Avg.	0.0	-0.1	-0.2	-0.2	-0.2	-0.1	-0.1
Region 06	Elbe to Ems	Avg.	0.0	-0.1	-0.3	-0.5	-0.5	-0.4	-0.4
Region 07	Rhein to Schelde	Avg.	0.2	0.1	-0.2	-0.4	-0.4	-0.3	-0.3
Region 08	GB	Avg.	0.3	0.2	-0.3	-0.9	-0.9	-0.8	-0.8
Region 09	Irland/N.Ireland	Avg.	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1
Region 10	France Atlantic	Avg.	0.0	0.0	-0.1	-0.1	-0.1	-0.1	0.0
Region 11	Danube	Avg.	0.0	-0.1	-0.3	-0.3	-0.4	-0.3	-0.2
Region 12	Iberia Atlantic	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 13	Iberia Mediterranean	Avg.	0.0	0.0	-0.1	-0.3	-0.3	-0.2	-0.2
Region 14	France Mediterranean	Avg.	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1
Region 15	Po	Avg.	0.1	0.0	-0.1	-0.2	-0.2	-0.2	-0.2
Region 16	Corsica	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 17	Sardinia	Avg.	0.0	0.0	0.0	0.0	-0.1	0.0	0.0
Region 18	Sicily	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 19	South Italy	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 20	Adige/Balkan	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 21	Greece/Evros	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1

2.2 50% Green

Catchments ≥ 3000 km^2

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		**Clima**	**Low7d**	**p10**		**AvgMax**	**rp002**	**rp020**	**rp100**
Region 01	N. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	Avg.	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0
Region 03	Baltic	Avg.	-0.1	-0.1	-0.3	-0.1	-0.1	0.0	0.0
Region 04	Denmark/N.Germany	Avg.	0.1	0.1	-0.1	-0.3	-0.4	-0.2	-0.2
Region 05	Odra/Vistula	Avg.	-0.2	-0.4	-0.6	-0.3	-0.4	-0.2	-0.2
Region 06	Elbe to Ems	Avg.	-0.1	-0.5	-1.0	-1.0	-1.1	-0.8	-0.8
Region 07	Rhein to Schelde	Avg.	0.2	-0.1	-0.4	-0.5	-0.5	-0.4	-0.4
Region 08	GB	Avg.	0.5	-0.1	-1.6	-2.2	-2.2	-1.8	-1.6
Region 09	Irland/N.Ireland	Avg.	0.0	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
Region 10	France Atlantic	Avg.	0.0	-0.1	-0.2	-0.1	-0.1	-0.1	-0.1
Region 11	Danube	Avg.	0.0	-0.2	-0.4	-0.4	-0.4	-0.3	-0.3
Region 12	Iberia Atlantic	Avg.	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1
Region 13	Iberia Mediterranean	Avg.	-0.3	-0.6	-0.8	-0.8	-0.9	-0.7	-0.6
Region 14	France Mediterranean	Avg.	0.1	0.0	-0.1	-0.1	-0.1	-0.1	-0.1
Region 15	Po	Avg.	0.1	0.1	-0.1	-0.3	-0.3	-0.3	-0.3
Region 16	Corsica	Avg.	-	-	-	-	-	-	-
Region 17	Sardinia	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 18	Sicily	Avg.	0.1	0.1	-0.1	-0.3	-0.3	-0.2	-0.2
Region 19	South Italy	Avg.	0.1	0.1	-0.1	-0.2	-0.2	-0.2	-0.2
Region 20	Adige/Balkan	Avg.	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1
Region 21	Greece/Evros	Avg.	0.1	0.1	-0.2	-0.3	-0.4	-0.3	-0.3

Catchments ≥ 400 km^2 and < 3000 km^2

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		**Clima**	**Low7d**	**p10**		**AvgMax**	**rp002**	**rp020**	**rp100**
Region 01	N. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	Avg.	0.0	0.0	-0.1	0.0	0.0	0.0	0.0
Region 03	Baltic	Avg.	0.0	0.0	-0.2	-0.1	-0.1	-0.1	-0.1
Region 04	Denmark/N.Germany	Avg.	0.1	0.1	-0.3	-0.4	-0.4	-0.3	-0.3
Region 05	Odra/Vistula	Avg.	-0.1	-0.2	-0.5	-0.4	-0.5	-0.3	-0.2
Region 06	Elbe to Ems	Avg.	0.0	-0.2	-0.6	-0.9	-1.0	-0.8	-0.8
Region 07	Rhein to Schelde	Avg.	0.4	0.2	-0.4	-0.7	-0.8	-0.7	-0.6
Region 08	GB	Avg.	0.7	0.4	-0.7	-1.8	-1.8	-1.6	-1.6
Region 09	Irland/N.Ireland	Avg.	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1
Region 10	France Atlantic	Avg.	0.0	0.0	-0.2	-0.1	-0.1	-0.1	-0.1
Region 11	Danube	Avg.	0.0	-0.3	-0.5	-0.7	-0.7	-0.5	-0.5
Region 12	Iberia Atlantic	Avg.	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1
Region 13	Iberia Mediterranean	Avg.	0.0	0.0	-0.2	-0.5	-0.5	-0.4	-0.4
Region 14	France Mediterranean	Avg.	0.1	0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Region 15	Po	Avg.	0.1	0.1	-0.1	-0.4	-0.4	-0.3	-0.3
Region 16	Corsica	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 17	Sardinia	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 18	Sicily	Avg.	0.1	0.0	0.0	-0.2	-0.2	-0.1	-0.1
Region 19	South Italy	Avg.	0.1	0.1	-0.1	-0.2	-0.2	-0.2	-0.1
Region 20	Adige/Balkan	Avg.	0.1	0.1	-0.1	-0.2	-0.2	-0.1	-0.1
Region 21	Greece/Evros	Avg.	0.1	0.1	-0.1	-0.2	-0.2	-0.2	-0.2

3.1 Grassland

Catchments ≥ 3000 km^2

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		**Clima**	**Low7d**	**p10**		**AvgMax**	**rp002**	**rp020**	**rp100**
Region 01	N. Scandinavia	Avg.	0.2	0.3	0.2	0.1	0.1	0.1	0.1
Region 02	S. Scandinavia	Avg.	0.0	0.0	-0.3	-0.3	-0.3	-0.2	-0.2
Region 03	Baltic	Avg.	-0.1	-0.2	-0.2	-0.4	-0.5	-0.3	-0.3
Region 04	Denmark/N.Germany	Avg.	0.0	0.0	0.1	0.2	0.2	0.2	0.2
Region 05	Odra/Vistula	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 06	Elbe to Ems	Avg.	-0.2	-0.3	-0.5	-1.3	-1.4	-1.3	-1.3
Region 07	Rhein to Schelde	Avg.	-0.1	0.0	-0.1	-0.2	-0.2	-0.2	-0.1
Region 08	GB	Avg.	0.4	0.3	0.4	0.6	0.6	0.5	0.5
Region 09	Irland/N.Ireland	Avg.	-0.1	0.2	0.3	0.2	0.2	0.2	0.2
Region 10	France Atlantic	Avg.	-0.1	-0.1	0.0	0.0	0.0	-0.1	-0.1
Region 11	Danube	Avg.	-0.2	-0.2	-0.2	-0.3	-0.3	-0.3	-0.2
Region 12	Iberia Atlantic	Avg.	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Region 13	Iberia Mediterranean	Avg.	0.6	0.7	0.5	0.3	0.3	0.3	0.3
Region 14	France Mediterranean	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 15	Po	Avg.	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Region 16	Corsica	Avg.	-	-	-	-	-	-	-
Region 17	Sardinia	Avg.	0.1	0.1	0.0	0.7	0.7	0.7	0.7
Region 18	Sicily	Avg.	-0.2	-0.2	-0.2	0.0	0.0	0.0	0.0
Region 19	South Italy	Avg.	-0.1	-0.1	-0.1	0.1	0.1	0.1	0.1
Region 20	Adige/Balkan	Avg.	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Region 21	Greece/Evros	Avg.	-0.2	-0.2	-0.1	0.0	0.0	0.0	0.0

Catchments ≥ 400 km^2 and < 3000 km^2

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		**Clima**	**Low7d**	**p10**		**AvgMax**	**rp002**	**rp020**	**rp100**
Region 01	N. Scandinavia	Avg.	0.3	0.4	0.3	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	Avg.	0.1	0.0	-0.3	-0.5	-0.5	-0.4	-0.4
Region 03	Baltic	Avg.	-0.1	-0.3	-0.2	-0.5	-0.6	-0.3	-0.3
Region 04	Denmark/N.Germany	Avg.	-0.2	-0.1	0.2	-0.8	-0.7	-1.0	-1.0
Region 05	Odra/Vistula	Avg.	0.0	0.1	0.0	-0.1	-0.1	-0.1	0.0
Region 06	Elbe to Ems	Avg.	-0.1	0.0	0.2	0.0	0.0	0.0	0.0
Region 07	Rhein to Schelde	Avg.	0.0	0.0	-0.1	-0.4	-0.4	-0.4	-0.4
Region 08	GB	Avg.	0.6	0.5	0.4	0.6	0.6	0.7	0.7
Region 09	Irland/N.Ireland	Avg.	-0.1	0.4	0.3	0.0	0.0	0.0	0.0
Region 10	France Atlantic	Avg.	-0.2	-0.2	-0.1	-0.2	-0.2	-0.2	-0.2
Region 11	Danube	Avg.	-0.1	-0.1	-0.1	-0.2	-0.2	-0.1	-0.1
Region 12	Iberia Atlantic	Avg.	0.2	0.2	0.3	0.2	0.2	0.1	0.1
Region 13	Iberia Mediterranean	Avg.	0.4	0.5	0.3	0.4	0.4	0.4	0.4
Region 14	France Mediterranean	Avg.	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Region 15	Po	Avg.	0.1	0.0	0.1	0.2	0.2	0.3	0.3
Region 16	Corsica	Avg.	0.2	0.2	1.2	1.1	1.3	0.7	0.6
Region 17	Sardinia	Avg.	0.1	0.2	0.1	0.8	0.8	0.7	0.6
Region 18	Sicily	Avg.	-0.1	-0.2	-0.1	0.1	0.1	0.2	0.2
Region 19	South Italy	Avg.	-0.1	-0.1	-0.1	0.1	0.1	0.2	0.2
Region 20	Adige/Balkan	Avg.	0.0	0.0	0.0	0.1	0.1	0.1	0.0
Region 21	Greece/Evros	Avg.	-0.1	-0.1	-0.1	0.1	0.1	0.1	0.1

3.2 Buffer strips

Catchments ≥ 3000 km^2

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		Clima	Low7d	p10		AvgMax	rp002	rp020	rp100
Region 01	N. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 03	Baltic	Avg.	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Region 04	Denmark/N.Germany	Avg.	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Region 05	Odra/Vistula	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 06	Elbe to Ems	Avg.	-0.1	0.0	0.0	0.0	0.0	0.0	0.0
Region 07	Rhein to Schelde	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 08	GB	Avg.	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0
Region 09	Irland/N.Ireland	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 10	France Atlantic	Avg.	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0
Region 11	Danube	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 12	Iberia Atlantic	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 13	Iberia Mediterranean	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 14	France Mediterranean	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 15	Po	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 16	Corsica	Avg.	-	-	-	-	-	-	-
Region 17	Sardinia	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	0.0
Region 18	Sicily	Avg.	0.1	0.1	0.0	0.1	0.1	0.2	0.2
Region 19	South Italy	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 20	Adige/Balkan	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 21	Greece/Evros	Avg.	0.1	0.1	0.0	-0.1	-0.1	-0.1	-0.1

Catchments ≥ 400 km^2 and < 3000 km^2

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		Clima	Low7d	p10		AvgMax	rp002	rp020	rp100
Region 01	N. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 03	Baltic	Avg.	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Region 04	Denmark/N.Germany	Avg.	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Region 05	Odra/Vistula	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 06	Elbe to Ems	Avg.	-0.1	0.0	0.0	0.0	0.0	0.0	0.0
Region 07	Rhein to Schelde	Avg.	-0.1	0.0	0.0	0.0	0.0	0.0	0.0
Region 08	GB	Avg.	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0
Region 09	Irland/N.Ireland	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 10	France Atlantic	Avg.	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0
Region 11	Danube	Avg.	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Region 12	Iberia Atlantic	Avg.	-0.1	0.0	0.0	-0.1	-0.1	-0.1	0.0
Region 13	Iberia Mediterranean	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 14	France Mediterranean	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 15	Po	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 16	Corsica	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 17	Sardinia	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 18	Sicily	Avg.	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Region 19	South Italy	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 20	Adige/Balkan	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 21	Greece/Evros	Avg.	0.1	0.1	0.0	-0.2	-0.2	-0.2	-0.2

3.3 Grassed waterways

Catchments ≥ 3000 km^2

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		Clima	Low7d	p10		AvgMax	rp002	rp020	rp100
Region 01	N. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 03	Baltic	Avg.	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Region 04	Denmark/N.Germany	Avg.	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Region 05	Odra/Vistula	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 06	Elbe to Ems	Avg.	-0.1	0.0	0.0	0.0	0.0	0.0	0.0
Region 07	Rhein to Schelde	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 08	GB	Avg.	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Region 09	Irland/N.Ireland	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 10	France Atlantic	Avg.	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0
Region 11	Danube	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 12	Iberia Atlantic	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 13	Iberia Mediterranean	Avg.	0.0	0.0	0.0	0.0	-0.1	0.0	0.0
Region 14	France Mediterranean	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 15	Po	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 16	Corsica	Avg.	-	-	-	-	-	-	-
Region 17	Sardinia	Avg.	0.0	0.0	0.0	-0.2	-0.2	-0.1	-0.1
Region 18	Sicily	Avg.	0.0	0.1	0.0	0.0	0.1	0.0	0.0
Region 19	South Italy	Avg.	0.0	0.0	0.0	-0.2	-0.2	-0.2	-0.2
Region 20	Adige/Balkan	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 21	Greece/Evros	Avg.	0.1	0.1	0.0	-0.2	-0.2	-0.2	-0.2

Catchments ≥ 400 km^2 and < 3000 km^2

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		Clima	Low7d	p10		AvgMax	rp002	rp020	rp100
Region 01	N. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 03	Baltic	Avg.	0.1	0.1	0.0	-0.1	-0.1	-0.1	-0.1
Region 04	Denmark/N.Germany	Avg.	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Region 05	Odra/Vistula	Avg.	0.0	0.1	0.0	-0.1	-0.1	-0.2	-0.2
Region 06	Elbe to Ems	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 07	Rhein to Schelde	Avg.	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0
Region 08	GB	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 09	Irland/N.Ireland	Avg.	0.0	-0.1	0.0	0.0	0.0	0.0	0.0
Region 10	France Atlantic	Avg.	-0.1	-0.1	0.0	0.1	0.1	0.1	0.0
Region 11	Danube	Avg.	0.1	0.2	0.1	0.0	0.0	0.0	0.0
Region 12	Iberia Atlantic	Avg.	-0.1	-0.1	0.0	-0.2	-0.2	-0.2	-0.2
Region 13	Iberia Mediterranean	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 14	France Mediterranean	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 15	Po	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 16	Corsica	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 17	Sardinia	Avg.	0.0	0.0	0.0	-0.3	-0.3	-0.2	-0.2
Region 18	Sicily	Avg.	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Region 19	South Italy	Avg.	0.0	0.0	0.0	-0.3	-0.3	-0.3	-0.3
Region 20	Adige/Balkan	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
Region 21	Greece/Evros	Avg.	0.1	0.1	0.0	-0.3	-0.3	-0.3	-0.3

3.4 Crop practices

Catchments ≥ 3000 km^2

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		**Clima**	**Low7d**	**p10**		**AvgMax**	**rp002**	**rp020**	**rp100**
Region 01	N. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	Avg.	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1
Region 03	Baltic	Avg.	-0.3	-0.5	-0.4	-1.2	-1.3	-1.1	-1.0
Region 04	Denmark/N.Germany	Avg.	-1.5	-1.8	-1.8	-2.0	-2.0	-2.4	-2.5
Region 05	Odra/Vistula	Avg.	-1.0	-1.0	-1.0	-1.2	-1.3	-1.1	-1.0
Region 06	Elbe to Ems	Avg.	-0.8	-0.8	-0.7	-1.4	-1.3	-1.4	-1.4
Region 07	Rhein to Schelde	Avg.	-0.1	-0.1	-0.3	-0.8	-0.8	-0.7	-0.7
Region 08	GB	Avg.	-0.4	-0.4	-0.5	-1.1	-1.1	-1.2	-1.3
Region 09	Irland/N.Ireland	Avg.	0.2	0.2	-0.1	-0.2	-0.2	-0.2	-0.2
Region 10	France Atlantic	Avg.	-1.2	-1.1	-1.1	-1.9	-2.0	-1.7	-1.6
Region 11	Danube	Avg.	-1.0	-1.0	-0.9	-1.2	-1.2	-1.2	-1.2
Region 12	Iberia Atlantic	Avg.	-0.8	-0.7	-0.8	-1.3	-1.3	-1.4	-1.4
Region 13	Iberia Mediterranean	Avg.	-0.9	-0.8	-0.7	-1.6	-1.5	-1.7	-1.7
Region 14	France Mediterranean	Avg.	0.0	0.0	-0.1	-0.4	-0.4	-0.4	-0.4
Region 15	Po	Avg.	-0.1	-0.2	-0.2	-0.6	-0.6	-0.6	-0.7
Region 16	Corsica	Avg.	-	-	-	-	-	-	-
Region 17	Sardinia	Avg.	-0.2	-0.3	-0.2	-1.7	-1.7	-1.7	-1.6
Region 18	Sicily	Avg.	-1.2	-1.6	-1.1	-3.7	-3.9	-3.8	-3.8
Region 19	South Italy	Avg.	-0.1	-0.1	-0.1	-1.5	-1.5	-1.5	-1.5
Region 20	Adige/Balkan	Avg.	0.0	0.0	-0.2	-0.7	-0.7	-0.7	-0.8
Region 21	Greece/Evros	Avg.	-0.7	-0.8	-0.8	-1.8	-1.8	-1.9	-2.0

Catchments ≥ 400 km^2 and < 3000 km^2

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		**Clima**	**Low7d**	**p10**		**AvgMax**	**rp002**	**rp020**	**rp100**
Region 01	N. Scandinavia	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 02	S. Scandinavia	Avg.	0.1	0.0	-0.1	-0.3	-0.3	-0.3	-0.3
Region 03	Baltic	Avg.	-0.3	-0.5	-0.3	-1.1	-1.2	-1.0	-0.9
Region 04	Denmark/N.Germany	Avg.	-0.4	-0.6	-1.0	-2.7	-2.6	-2.9	-3.0
Region 05	Odra/Vistula	Avg.	-1.5	-1.5	-1.0	-0.8	-0.9	-0.7	-0.7
Region 06	Elbe to Ems	Avg.	-1.1	-1.2	-0.8	-1.2	-1.2	-1.3	-1.3
Region 07	Rhein to Schelde	Avg.	-0.1	-0.2	-0.4	-1.0	-1.0	-1.0	-1.0
Region 08	GB	Avg.	-0.4	-0.4	-0.5	-0.9	-0.8	-0.9	-0.9
Region 09	Irland/N.Ireland	Avg.	0.3	0.3	-0.1	-0.5	-0.5	-0.4	-0.4
Region 10	France Atlantic	Avg.	-1.5	-1.5	-1.3	-2.2	-2.3	-2.0	-1.9
Region 11	Danube	Avg.	-2.5	-2.6	-1.7	-1.6	-1.6	-1.6	-1.6
Region 12	Iberia Atlantic	Avg.	-1.0	-0.7	-0.6	-1.0	-1.0	-1.1	-1.1
Region 13	Iberia Mediterranean	Avg.	-1.0	-0.9	-0.7	-1.5	-1.5	-1.6	-1.6
Region 14	France Mediterranean	Avg.	0.1	0.0	-0.1	-0.5	-0.5	-0.5	-0.5
Region 15	Po	Avg.	0.0	0.0	-0.1	-0.6	-0.6	-0.6	-0.6
Region 16	Corsica	Avg.	0.0	0.0	0.1	-0.2	-0.2	-0.2	-0.2
Region 17	Sardinia	Avg.	-0.2	-0.3	-0.1	-1.7	-1.7	-1.6	-1.6
Region 18	Sicily	Avg.	-1.5	-2.0	-1.3	-5.8	-5.9	-6.2	-6.3
Region 19	South Italy	Avg.	-0.2	-0.3	-0.2	-2.0	-2.0	-2.0	-1.9
Region 20	Adige/Balkan	Avg.	0.0	0.0	-0.1	-0.6	-0.6	-0.6	-0.6
Region 21	Greece/Evros	Avg.	-0.5	-0.7	-0.5	-1.7	-1.6	-1.8	-1.8

4.1 Wetlands

Catchments ≥ 3000 km²

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		**Clima**	**Low7d**	**p10**		**AvgMax**	**rp002**	**rp020**	**rp100**
Region 01	N. Scandinavia	Avg.	0.0	0.0	0.0	-0.2	-0.2	-0.2	-0.2
Region 02	S. Scandinavia	Avg.	0.0	0.0	0.0	-0.2	-0.2	-0.3	-0.3
Region 03	Baltic	Avg.	0.0	0.0	0.0	-0.4	-0.3	-0.4	-0.4
Region 04	Denmark/N.Germany	Avg.	0.0	0.0	0.0	-0.3	-0.4	-0.5	-0.5
Region 05	Odra/Vistula	Avg.	0.0	0.0	0.0	-0.7	-0.6	-0.8	-0.9
Region 06	Elbe to Ems	Avg.	0.0	0.0	0.0	-0.4	-0.4	-0.5	-0.5
Region 07	Rhein to Schelde	Avg.	0.0	0.0	0.0	-0.2	-0.2	-0.3	-0.3
Region 08	GB	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.2	-0.2
Region 09	Irland/N.Ireland	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 10	France Atlantic	Avg.	0.0	0.0	0.0	-0.4	-0.4	-0.5	-0.5
Region 11	Danube	Avg.	0.0	0.0	0.0	-0.4	-0.4	-0.5	-0.5
Region 12	Iberia Atlantic	Avg.	0.0	0.0	0.0	-0.3	-0.3	-0.3	-0.3
Region 13	Iberia Mediterranean	Avg.	0.0	0.0	0.0	-0.2	-0.2	-0.3	-0.3
Region 14	France Mediterranean	Avg.	0.0	0.0	0.0	-0.3	-0.3	-0.4	-0.4
Region 15	Po	Avg.	0.0	0.0	0.0	-0.3	-0.3	-0.3	-0.4
Region 16	Corsica	Avg.	-	-	-	-	-	-	-
Region 17	Sardinia	Avg.	0.0	0.0	0.0	-0.3	-0.3	-0.3	-0.3
Region 18	Sicily	Avg.	0.0	0.0	0.0	-0.3	-0.3	-0.4	-0.4
Region 19	South Italy	Avg.	0.0	0.0	0.0	-0.2	-0.2	-0.3	-0.3
Region 20	Adige/Balkan	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 21	Greece/Evros	Avg.	0.0	0.0	0.0	-0.2	-0.2	-0.2	-0.2

Catchments ≥ 400 km² and < 3000 km²

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		**Clima**	**Low7d**	**p10**		**AvgMax**	**rp002**	**rp020**	**rp100**
Region 01	N. Scandinavia	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 02	S. Scandinavia	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 03	Baltic	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.2	-0.2
Region 04	Denmark/N.Germany	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 05	Odra/Vistula	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.2	-0.2
Region 06	Elbe to Ems	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 07	Rhein to Schelde	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 08	GB	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 09	Irland/N.Ireland	Avg.	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1
Region 10	France Atlantic	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 11	Danube	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 12	Iberia Atlantic	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.2	-0.2
Region 13	Iberia Mediterranean	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 14	France Mediterranean	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 15	Po	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 16	Corsica	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 17	Sardinia	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 18	Sicily	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 19	South Italy	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 20	Adige/Balkan	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 21	Greece/Evros	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1

4.2 Re-meandering

Catchments ≥ 3000 km²

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		**Clima**	**Low7d**	**p10**		**AvgMax**	**rp002**	**rp020**	**rp100**
Region 01	N. Scandinavia	Avg.	0.3	0.3	0.3	-1.1	-1.1	-1.1	-1.1
Region 02	S. Scandinavia	Avg.	0.4	0.4	0.2	-0.7	-0.7	-0.8	-0.8
Region 03	Baltic	Avg.	0.6	0.6	0.3	-1.1	-1.1	-1.1	-1.1
Region 04	Denmark/N.Germany	Avg.	0.2	0.4	0.4	-1.7	-1.9	-1.4	-1.3
Region 05	Odra/Vistula	Avg.	1.2	1.2	0.4	-1.2	-1.2	-1.1	-1.1
Region 06	Elbe to Ems	Avg.	1.1	1.1	0.3	-1.1	-1.1	-1.0	-1.0
Region 07	Rhein to Schelde	Avg.	0.3	0.3	0.1	-0.3	-0.3	-0.3	-0.3
Region 08	GB	Avg.	0.2	0.2	0.1	-0.5	-0.5	-0.6	-0.6
Region 09	Irland/N.Ireland	Avg.	0.1	0.1	0.0	-0.2	-0.2	-0.2	-0.2
Region 10	France Atlantic	Avg.	0.6	0.5	0.2	-1.0	-1.0	-1.0	-0.9
Region 11	Danube	Avg.	0.5	0.6	0.3	-0.9	-0.9	-0.9	-0.9
Region 12	Iberia Atlantic	Avg.	0.1	0.2	0.2	-0.8	-0.8	-0.8	-0.8
Region 13	Iberia Mediterranean	Avg.	0.6	0.7	0.4	-0.9	-0.9	-0.8	-0.8
Region 14	France Mediterranean	Avg.	0.1	0.1	0.1	-0.5	-0.5	-0.6	-0.6
Region 15	Po	Avg.	0.1	0.2	0.1	-0.7	-0.7	-0.7	-0.7
Region 16	Corsica	Avg.	-	-	-	-	-	-	-
Region 17	Sardinia	Avg.	0.0	0.0	0.1	-1.5	-1.4	-1.7	-1.8
Region 18	Sicily	Avg.	0.0	0.1	0.2	-1.8	-1.7	-2.1	-2.1
Region 19	South Italy	Avg.	0.0	0.1	0.1	-0.8	-0.7	-0.9	-1.0
Region 20	Adige/Balkan	Avg.	0.0	0.1	0.1	-0.5	-0.5	-0.5	-0.6
Region 21	Greece/Evros	Avg.	0.0	0.0	0.1	-0.4	-0.4	-0.4	-0.4

Catchments ≥ 400 km² and < 3000 km²

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		**Clima**	**Low7d**	**p10**		**AvgMax**	**rp002**	**rp020**	**rp100**
Region 01	N. Scandinavia	Avg.	0.3	0.3	0.3	-0.9	-0.9	-0.9	-0.8
Region 02	S. Scandinavia	Avg.	0.6	0.5	0.2	-0.9	-0.9	-0.9	-0.9
Region 03	Baltic	Avg.	0.3	0.5	0.3	-0.8	-0.8	-0.8	-0.8
Region 04	Denmark/N.Germany	Avg.	0.0	0.1	0.1	-0.4	-0.4	-0.4	-0.5
Region 05	Odra/Vistula	Avg.	1.5	1.8	0.6	-1.3	-1.3	-1.2	-1.2
Region 06	Elbe to Ems	Avg.	0.7	0.8	0.3	-0.7	-0.7	-0.7	-0.6
Region 07	Rhein to Schelde	Avg.	0.2	0.3	0.1	-0.3	-0.3	-0.3	-0.3
Region 08	GB	Avg.	0.1	0.2	0.1	-0.5	-0.5	-0.6	-0.6
Region 09	Irland/N.Ireland	Avg.	0.2	0.2	0.0	-0.3	-0.3	-0.3	-0.3
Region 10	France Atlantic	Avg.	0.4	0.4	0.1	-0.5	-0.5	-0.4	-0.4
Region 11	Danube	Avg.	0.3	0.6	0.3	-0.7	-0.7	-0.6	-0.6
Region 12	Iberia Atlantic	Avg.	0.2	0.3	0.2	-0.9	-0.8	-0.9	-1.0
Region 13	Iberia Mediterranean	Avg.	0.4	0.6	0.3	-0.8	-0.8	-0.8	-0.8
Region 14	France Mediterranean	Avg.	0.1	0.2	0.1	-0.7	-0.7	-0.7	-0.7
Region 15	Po	Avg.	0.4	0.5	0.3	-0.7	-0.7	-0.7	-0.7
Region 16	Corsica	Avg.	0.0	0.0	0.0	-0.6	-0.6	-0.6	-0.7
Region 17	Sardinia	Avg.	0.0	0.0	0.1	-0.6	-0.6	-0.6	-0.6
Region 18	Sicily	Avg.	0.0	0.0	0.1	-0.6	-0.6	-0.7	-0.7
Region 19	South Italy	Avg.	0.0	0.0	0.1	-0.8	-0.8	-0.9	-1.0
Region 20	Adige/Balkan	Avg.	0.0	0.0	0.0	-0.2	-0.2	-0.2	-0.2
Region 21	Greece/Evros	Avg.	0.0	0.0	0.1	-0.5	-0.5	-0.5	-0.5

4.3 Buffer ponds

Catchments ≥ 3000 km²

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		Clima	Low7d	p10		AvgMax	rp002	rp020	rp100
Region 01	N. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 03	Baltic	Avg.	0.1	0.1	0.2	0.0	0.0	0.0	0.0
Region 04	Denmark/N.Germany	Avg.	0.0	0.0	0.1	-0.1	-0.2	-0.2	-0.2
Region 05	Odra/Vistula	Avg.	0.6	0.5	1.5	0.5	-0.1	-0.1	-0.1
Region 06	Elbe to Ems	Avg.	1.0	0.7	1.6	0.2	-0.3	-0.3	-0.3
Region 07	Rhein to Schelde	Avg.	0.0	0.0	0.1	-0.1	-0.2	-0.2	-0.2
Region 08	GB	Avg.	0.3	0.2	0.6	-0.4	-0.6	-0.6	-0.6
Region 09	Irland/N.Ireland	Avg.	0.1	0.0	0.1	-0.1	-0.1	-0.2	-0.2
Region 10	France Atlantic	Avg.	0.1	0.1	0.2	0.0	0.0	0.0	0.0
Region 11	Danube	Avg.	0.6	0.4	1.2	0.5	0.0	-0.1	-0.1
Region 12	Iberia Atlantic	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 13	Iberia Mediterranean	Avg.	2.7	1.0	1.3	0.0	0.0	0.0	0.0
Region 14	France Mediterranean	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 15	Po	Avg.	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.1
Region 16	Corsica	Avg.	-	-	-	-	-	-	-
Region 17	Sardinia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 18	Sicily	Avg.	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.1
Region 19	South Italy	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 20	Adige/Balkan	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 21	Greece/Evros	Avg.	0.1	0.0	0.2	0.0	0.0	0.0	0.0

Catchments ≥ 400 km² and < 3000 km²

Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		Clima	Low7d	p10		AvgMax	rp002	rp020	rp100
Region 01	N. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 03	Baltic	Avg.	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Region 04	Denmark/N.Germany	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 05	Odra/Vistula	Avg.	2.8	1.6	2.8	-0.1	-0.1	-0.1	-0.1
Region 06	Elbe to Ems	Avg.	3.0	1.8	2.2	-0.3	-0.3	-0.3	-0.3
Region 07	Rhein to Schelde	Avg.	0.0	0.0	0.1	-0.2	-0.3	-0.3	-0.3
Region 08	GB	Avg.	0.1	0.0	0.2	-0.3	-0.3	-0.3	-0.4
Region 09	Irland/N.Ireland	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 10	France Atlantic	Avg.	0.4	0.2	0.5	-0.1	-0.1	-0.1	-0.1
Region 11	Danube	Avg.	1.1	0.7	1.5	-0.1	-0.1	-0.1	-0.1
Region 12	Iberia Atlantic	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 13	Iberia Mediterranean	Avg.	1.3	0.2	0.7	0.0	0.0	0.0	0.0
Region 14	France Mediterranean	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 15	Po	Avg.	0.0	0.0	0.1	-0.1	-0.1	-0.1	-0.1
Region 16	Corsica	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 17	Sardinia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 18	Sicily	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 19	South Italy	Avg.	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Region 20	Adige/Balkan	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 21	Greece/Evros	Avg.	0.0	0.0	0.1	0.0	0.0	0.0	0.0

4.4 Polders

Catchments ≥ 3000 km² (polders only in catchments > 10000km²)
Change in [%] discharge from the baseline **2030** scenario

[%]			Low flow		Median	High flow			
Region		**Clima**	**Low7d**	**p10**		**AvgMax**	**rp002**	**rp020**	**rp100**
Region 01	N. Scandinavia	Avg.	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Region 02	S. Scandinavia	Avg.	0.0	0.0	0.1	-0.2	-0.2	-0.3	-0.3
Region 03	Baltic	Avg.	0.0	0.0	0.1	-0.5	-0.5	-0.5	-0.5
Region 04	Denmark/N.Germany	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 05	Odra/Vistula	Avg.	0.0	0.0	0.1	-0.5	-0.5	-0.5	-0.5
Region 06	Elbe to Ems	Avg.	0.0	0.0	0.1	-0.9	-0.9	-1.3	-1.4
Region 07	Rhein to Schelde	Avg.	0.0	0.0	0.1	-0.7	-0.7	-0.9	-1.0
Region 08	GB	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 09	Irland/N.Ireland	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 10	France Atlantic	Avg.	0.0	0.0	0.1	-0.5	-0.6	-0.6	-0.6
Region 11	Danube	Avg.	0.0	0.0	0.2	-0.8	-0.8	-1.1	-1.1
Region 12	Iberia Atlantic	Avg.	0.0	0.0	0.0	-0.2	-0.2	-0.2	-0.3
Region 13	Iberia Mediterranean	Avg.	0.0	0.0	0.0	-0.3	-0.4	-0.4	-0.4
Region 14	France Mediterranean	Avg.	0.0	0.0	0.1	-0.5	-0.5	-0.6	-0.6
Region 15	Po	Avg.	0.0	0.0	0.0	-0.6	-0.6	-0.6	-0.6
Region 16	Corsica	Avg.	-	-	-	-	-	-	-
Region 17	Sardinia	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 18	Sicily	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 19	South Italy	Avg.	0.0	0.0	0.0	-0.2	-0.2	-0.3	-0.3
Region 20	Adige/Balkan	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 21	Greece/Evros	Avg.	0.0	0.0	0.0	-0.3	-0.3	-0.4	-0.4

Annex 2

Change of fast flow, evapotranspiration, groundwater recharge and water stress

Abbreviations:

Fast flow: Fast runoff (surface runoff and swallow groundwater runoff)
In percentage of change (scenario – baseline)/baseline) [%]
Evapotrans. : Evapotranspiration of plants and soil [%]
Groundw. recharge : Ground water recharge through percolation through soil and preferential flow [%]
Water stress: Number of days with soil moisture stress (amount of moisture below the soil moisture at wilting point). Here: the difference of days between scenario and baseline per year

Values are given for the average of the 3 climate runs (DMI,KNMI,METO)

No values from scenario 4.1 onward, because those scenarios are influencing only discharge routing, not discharge concentration.

0 Baseline 2030

Change in [%] from the baseline **2006** scenario
For water stress change in [days per year] from

Region		Fast flow [%]	Evapotrans. [%]	Groundw. recharge [%]	Water stress [d per year]
Region 01	N. Scandinavia	-1.2	0.2	0.8	0.0
Region 02	S. Scandinavia	-0.4	0.1	0.5	0.0
Region 03	Baltic	0.3	-0.2	0.6	0.8
Region 04	Denmark/N.Germany	0.3	-0.1	0.2	0.7
Region 05	Odra/Vistula	-1.2	0.2	0.2	0.7
Region 06	Elbe to Ems	0.9	-0.1	-0.2	0.7
Region 07	Rhein to Schelde	0.8	-0.4	-0.6	0.8
Region 08	GB	4.2	-1.2	-2.4	0.6
Region 09	Irland/N.Ireland	1.5	-1.2	-0.3	1.2
Region 10	France Atlantic	0.9	-0.3	0.4	1.2
Region 11	Danube	-0.4	0.1	0.0	0.4
Region 12	Iberia Atlantic	0.3	0.0	-0.2	0.7
Region 13	Iberia Mediterranean	1.3	-0.2	-0.3	0.3
Region 14	France Mediterranean	0.2	-0.1	-0.1	0.7
Region 15	Po	-0.3	0.3	-0.4	-0.1
Region 16	Corsica	-0.1	0.2	-0.2	0.0
Region 17	Sardinia	-0.5	0.2	-0.2	0.2
Region 18	Sicily	-0.3	0.1	0.1	0.4
Region 19	South Italy	0.3	-0.2	-0.3	0.6
Region 20	Adige/Balkan	-0.1	0.1	-0.2	0.3
Region 21	Greece/Evros	-0.2	0.1	-0.1	0.4

1.1 Riparian afforestation

Change in [%] from the baseline **2030** scenario
For water stress change in [days per year] from

Region		Fast flow [%]	Evapotrans. [%]	Groundw. recharge [%]	Water stress [d per year]
Region 01	N. Scandinavia	-0.2	0.0	0.4	1.1
Region 02	S. Scandinavia	-0.5	0.2	0.2	0.4
Region 03	Baltic	-0.6	0.2	-0.5	0.7
Region 04	Denmark/N.Germany	0.3	0.0	0.0	0.4
Region 05	Odra/Vistula	0.0	0.1	-0.3	0.5
Region 06	Elbe to Ems	-1.0	0.4	-1.2	0.4
Region 07	Rhein to Schelde	0.0	0.1	-0.2	0.5
Region 08	GB	0.4	-0.5	0.4	0.4
Region 09	Irland/N.Ireland	1.5	-0.8	-0.3	0.6
Region 10	France Atlantic	0.0	0.0	-0.2	0.3
Region 11	Danube	-0.3	0.2	-0.5	0.8
Region 12	Iberia Atlantic	0.1	0.0	-0.3	0.3
Region 13	Iberia Mediterranean	0.3	-0.2	0.2	0.4
Region 14	France Mediterranean	-0.2	0.2	-0.1	0.5
Region 15	Po	0.1	-0.1	0.0	0.7
Region 16	Corsica	1.1	-1.2	0.7	2.4
Region 17	Sardinia	0.6	-0.4	0.5	1.6
Region 18	Sicily	0.4	-0.2	0.3	0.6
Region 19	South Italy	0.0	0.1	-0.2	0.4
Region 20	Adige/Balkan	0.0	0.0	0.0	0.5
Region 21	Greece/Evros	0.0	0.0	0.0	0.4

1.2 Afforestation in mountainous areas

Change in [%] from the baseline **2030** scenario
For water stress change in [days per year] from

Region		Fast flow [%]	Evapotrans. [%]	Groundw. recharge [%]	Water stress [d per year]
Region 01	N. Scandinavia	-0.2	0.0	-0.1	1.0
Region 02	S. Scandinavia	-0.5	0.2	-0.2	0.4
Region 03	Baltic	-0.5	0.2	-0.6	0.6
Region 04	Denmark/N.Germany	0.2	0.0	-1.3	0.4
Region 05	Odra/Vistula	-0.1	0.1	-0.3	0.6
Region 06	Elbe to Ems	-1.1	0.4	-0.9	0.4
Region 07	Rhein to Schelde	0.0	0.0	-0.2	0.6
Region 08	GB	0.4	-0.5	0.0	0.6
Region 09	Irland/N.Ireland	1.5	-0.8	0.1	0.6
Region 10	France Atlantic	-0.3	0.2	-0.4	0.3
Region 11	Danube	-0.3	0.2	-0.4	1.2
Region 12	Iberia Atlantic	-0.1	0.1	-0.3	0.4
Region 13	Iberia Mediterranean	-0.4	0.2	-0.3	0.3
Region 14	France Mediterranean	-1.0	1.3	-0.3	0.5
Region 15	Po	0.0	0.1	-0.1	0.7
Region 16	Corsica	0.9	-1.0	-0.1	2.2
Region 17	Sardinia	1.2	-0.5	0.1	2.0
Region 18	Sicily	0.3	-0.1	0.0	0.6
Region 19	South Italy	-0.2	0.3	-0.3	0.8
Region 20	Adige/Balkan	0.0	0.1	0.0	0.3
Region 21	Greece/Evros	-0.2	0.1	-0.1	0.4

2.1 25% Green

Change in [%] from the baseline **2030** scenario
For water stress change in [days per year] from

Region		Fast flow [%]	Evapotrans. [%]	Groundw. recharge [%]	Water stress [d per year]
Region 01	N. Scandinavia	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	0.0	0.0	0.0	0.0
Region 03	Baltic	-0.1	0.0	0.0	0.0
Region 04	Denmark/N.Germany	-0.2	0.1	0.1	0.0
Region 05	Odra/Vistula	-0.2	0.1	0.1	0.0
Region 06	Elbe to Ems	-0.4	0.2	0.4	0.0
Region 07	Rhein to Schelde	-0.4	0.3	0.5	0.1
Region 08	GB	-0.7	0.5	0.8	0.1
Region 09	Irland/N.Ireland	-0.1	0.1	0.1	0.0
Region 10	France Atlantic	-0.2	0.1	0.2	0.0
Region 11	Danube	-0.4	0.1	0.1	0.0
Region 12	Iberia Atlantic	0.0	0.0	0.1	0.0
Region 13	Iberia Mediterranean	-0.2	0.1	0.1	0.0
Region 14	France Mediterranean	-0.1	0.1	0.2	0.0
Region 15	Po	-0.2	0.1	0.2	0.0
Region 16	Corsica	0.0	0.0	0.0	0.0
Region 17	Sardinia	-0.1	0.0	0.0	0.0
Region 18	Sicily	-0.1	0.1	0.1	0.0
Region 19	South Italy	-0.1	0.1	0.1	0.0
Region 20	Adige/Balkan	-0.1	0.1	0.1	0.0
Region 21	Greece/Evros	-0.1	0.1	0.1	0.0

2.2 50% Green

Change in [%] from the baseline **2030** scenario
For water stress change in [days per year] from

Region		Fast flow [%]	Evapotrans. [%]	Groundw. recharge [%]	Water stress [d per year]
Region 01	N. Scandinavia	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	-0.1	0.1	0.1	0.0
Region 03	Baltic	-0.2	0.1	0.1	0.0
Region 04	Denmark/N.Germany	-0.4	0.2	0.3	0.0
Region 05	Odra/Vistula	-0.4	0.1	0.2	0.0
Region 06	Elbe to Ems	-0.8	0.4	0.9	0.0
Region 07	Rhein to Schelde	-0.9	0.6	1.1	0.1
Region 08	GB	-1.4	0.9	1.7	0.1
Region 09	Irland/N.Ireland	-0.2	0.1	0.3	0.0
Region 10	France Atlantic	-0.4	0.2	0.4	0.0
Region 11	Danube	-0.9	0.2	0.3	0.0
Region 12	Iberia Atlantic	-0.1	0.1	0.1	0.0
Region 13	Iberia Mediterranean	-0.4	0.2	0.3	0.0
Region 14	France Mediterranean	-0.3	0.2	0.4	0.0
Region 15	Po	-0.4	0.3	0.4	0.0
Region 16	Corsica	0.0	0.0	0.0	0.0
Region 17	Sardinia	-0.1	0.0	0.1	0.0
Region 18	Sicily	-0.3	0.1	0.1	0.0
Region 19	South Italy	-0.2	0.2	0.2	0.0
Region 20	Adige/Balkan	-0.1	0.1	0.2	0.0
Region 21	Greece/Evros	-0.3	0.1	0.3	0.0

3.1 Grassland

Change in [%] from the baseline **2030** scenario
For water stress change in [days per year] from

Region		Fast flow [%]	Evapotrans. [%]	Groundw. recharge [%]	Water stress [d per year]
Region 01	N. Scandinavia	-0.1	-0.1	0.5	1.4
Region 02	S. Scandinavia	-0.4	0.2	0.2	0.5
Region 03	Baltic	-0.6	0.2	-0.5	0.5
Region 04	Denmark/N.Germany	0.2	0.0	0.0	0.4
Region 05	Odra/Vistula	0.0	0.1	-0.4	0.5
Region 06	Elbe to Ems	-1.1	0.4	-1.2	0.3
Region 07	Rhein to Schelde	-0.2	0.2	-0.1	0.4
Region 08	GB	0.4	-0.5	0.5	0.6
Region 09	Irland/N.Ireland	0.9	-0.1	-0.6	-0.2
Region 10	France Atlantic	-0.1	0.1	-0.2	0.1
Region 11	Danube	-0.4	0.2	-0.6	0.6
Region 12	Iberia Atlantic	0.3	-0.2	0.0	0.4
Region 13	Iberia Mediterranean	0.3	-0.2	0.2	0.4
Region 14	France Mediterranean	-0.1	0.0	0.0	0.5
Region 15	Po	0.1	0.0	-0.1	0.5
Region 16	Corsica	1.1	-1.2	0.7	2.4
Region 17	Sardinia	0.6	-0.4	0.5	1.6
Region 18	Sicily	0.0	0.0	0.0	0.2
Region 19	South Italy	0.0	0.1	-0.2	0.3
Region 20	Adige/Balkan	0.0	0.0	0.0	0.5
Region 21	Greece/Evros	0.0	0.0	0.0	0.3

3.2 Buffer strips

Change in [%] from the baseline **2030** scenario
For water stress change in [days per year] from

Region		Fast flow [%]	Evapotrans. [%]	Groundw. recharge [%]	Water stress [d per year]
Region 01	N. Scandinavia	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	0.0	0.0	0.0	0.0
Region 03	Baltic	0.0	0.0	0.0	0.1
Region 04	Denmark/N.Germany	0.1	0.0	0.0	0.2
Region 05	Odra/Vistula	0.0	0.0	0.0	0.1
Region 06	Elbe to Ems	0.0	0.0	0.0	0.1
Region 07	Rhein to Schelde	0.0	0.0	0.0	0.1
Region 08	GB	0.0	0.0	0.0	0.1
Region 09	Irland/N.Ireland	0.0	0.0	0.0	0.0
Region 10	France Atlantic	0.0	0.0	0.0	0.2
Region 11	Danube	0.1	0.0	0.1	0.1
Region 12	Iberia Atlantic	0.0	0.0	0.0	0.0
Region 13	Iberia Mediterranean	0.1	0.0	0.1	0.0
Region 14	France Mediterranean	0.0	0.0	0.0	0.0
Region 15	Po	0.0	0.0	0.0	0.0
Region 16	Corsica	0.0	0.0	0.0	0.0
Region 17	Sardinia	0.0	0.0	0.1	0.0
Region 18	Sicily	0.1	0.0	0.1	0.0
Region 19	South Italy	0.0	0.0	0.0	0.0
Region 20	Adige/Balkan	0.0	0.0	0.0	0.0
Region 21	Greece/Evros	-0.1	0.1	0.2	0.0

3.3 Grassed waterways

Change in [%] from the baseline **2030** scenario
For water stress change in [days per year] from

Region		Fast flow [%]	Evapotrans. [%]	Groundw. recharge [%]	Water stress [d per year]
Region 01	N. Scandinavia	0.0	0.0	0.0	0.0
Region 02	S. Scandinavia	0.0	0.0	0.0	0.0
Region 03	Baltic	0.1	0.0	0.1	0.2
Region 04	Denmark/N.Germany	0.2	0.0	0.1	0.3
Region 05	Odra/Vistula	0.1	0.0	0.1	0.3
Region 06	Elbe to Ems	0.0	0.0	0.0	0.2
Region 07	Rhein to Schelde	0.0	0.0	0.0	0.2
Region 08	GB	0.0	0.0	0.0	0.2
Region 09	Irland/N.Ireland	0.0	0.0	0.0	0.1
Region 10	France Atlantic	0.1	0.0	0.0	0.3
Region 11	Danube	0.1	0.0	0.2	0.1
Region 12	Iberia Atlantic	0.0	0.1	0.1	0.0
Region 13	Iberia Mediterranean	0.0	0.0	0.1	0.0
Region 14	France Mediterranean	0.0	0.0	0.0	0.0
Region 15	Po	0.1	0.0	0.1	0.1
Region 16	Corsica	0.0	0.0	0.0	0.0
Region 17	Sardinia	0.0	0.0	0.2	0.0
Region 18	Sicily	0.2	0.0	0.2	0.0
Region 19	South Italy	0.0	0.1	0.1	0.0
Region 20	Adige/Balkan	0.0	0.0	0.0	0.1
Region 21	Greece/Evros	-0.1	0.1	0.3	0.0

3.4 Crop practices

Change in [%] from the baseline **2030** scenario
For water stress change in [days per year] from

Region		Fast flow [%]	Evapotrans. [%]	Groundw. recharge [%]	Water stress [d per year]
Region 01	N. Scandinavia	0.0	0.0	0.0	-0.1
Region 02	S. Scandinavia	-0.3	0.1	0.0	-0.5
Region 03	Baltic	-1.1	0.4	-0.8	-1.4
Region 04	Denmark/N.Germany	-2.5	1.0	-1.9	-3.0
Region 05	Odra/Vistula	-1.1	0.6	-2.1	-2.0
Region 06	Elbe to Ems	-1.2	0.7	-1.4	-2.0
Region 07	Rhein to Schelde	-0.9	0.6	-0.5	-2.0
Region 08	GB	-0.9	0.5	-0.7	-1.2
Region 09	Irland/N.Ireland	-0.3	0.2	0.0	-0.9
Region 10	France Atlantic	-2.2	1.0	-1.6	-2.6
Region 11	Danube	-1.9	0.8	-2.4	-1.8
Region 12	Iberia Atlantic	-1.1	0.7	-1.1	-0.9
Region 13	Iberia Mediterranean	-1.4	0.6	-1.7	-0.7
Region 14	France Mediterranean	-0.5	0.3	-0.3	-1.0
Region 15	Po	-1.2	0.7	-0.8	-1.8
Region 16	Corsica	-0.2	0.1	0.0	-0.5
Region 17	Sardinia	-1.5	0.7	-0.6	-1.2
Region 18	Sicily	-3.4	1.3	-2.5	-2.3
Region 19	South Italy	-1.7	0.9	-0.7	-1.8
Region 20	Adige/Balkan	-0.5	0.4	-0.1	-1.2
Region 21	Greece/Evros	-1.8	0.8	-1.4	-0.9

Picture credit:
Cover: Doon lake, Co. Clare, Ireland 2010 / Photographer:D.McInerney

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Title: Evaluation of the effectiveness of Natural Water Retention Measures

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Abstract

In the context of the impact assessment for the policy document "Blueprint to safeguard Europe's waters", the European Commission has developed a common baseline scenario bringing together climate, land use and socio-economic scenarios and looking at the implications for water resources availability and use under different policy scenarios. This study was carried out by the Joint Research Centre of the European Commission with the support of Stella Consulting SPRL, Brussels. It shows the impact of no-regret natural water retention measures on water quantity which can, in turn, be used to quantify ecosystem services related to water provision, water flow regulation and the moderation of extreme flows. It also contributes to the identification of multifunctional adaptation measures that reduce the vulnerability of water resources and related ecosystem services to climate change and other anthropogenic pressures. Within the context of this report “no-regret” is solely based on hydrological impact. The additional report “A multi-criteria optimisation of scenarios for the protection of water resources in Europe” (EUR25552) addresses co-benefits and costs.

The novelty of this study is in linking climate, land use and hydrological scenarios and models on a pan European scale and providing a first quantitative pan-European overview of the effects of ‘green’ measures on discharge. This should encourage Member States to further explore the use of efficiency measures and foster communication between stakeholders.

12 different policy scenarios were used, addressing changes in forest and urban areas, agriculture practice, and water retention. Locally some of these scenarios were estimated to change low flows and flood discharge up to 20%. For the 21 defined macro-regions in Europe there is a clear difference in the impacts of measures and for each region the effectiveness of each scenario has been ranked in terms of increasing low flow or reducing flood peaks.

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