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Monthly hydrological indicators to assess impact of change on river ecosystems at the pan-European scale: preliminary results

Cédric L.R. Laizé[1*], M. Acreman[1], M. Dunbar[1], H. Houghton-Carr[1], M. Flörke[2], C. Schneider[2]
(1) Centre for Ecology and Hydrology, Maclean Building, Crowmarsh Gifford, OX10 8BB, UK
clai@ceh.ac.uk
(2) Kassel University, Germany

Abstract

The impact of change on river ecosystems at the pan-European scale under various climatological and development scenarios was assessed using a methodology based conceptually on the Range of Variability Approach (RVA) using Indicators of Hydrological Alteration (IHA), a desk-top technique for defining environmental flow requirements. The indicators are typically calculated from daily flows requiring extensive data storage and computing time when working at large spatial scales with multiple sites and scenarios. This paper presents an adaptation of the IHA approach using both daily and monthly flows. Modelled flows for nine scenarios (including baseline) and 664 sites from major rivers in contrasting European eco-regions were generated. IHA statistics based on daily and monthly data were calculated where appropriate (some daily IHA statistics cannot be calculated or are not meaningful at the monthly scale). Tailoring the RVA, acceptable baseline environmental flow ranges and departures from these of the projected hydrological regimes were aggregated via a traffic-light colour-coding. The results show spatial patterns of potential river ecosystem impacts across Europe and demonstrate that using monthly flows is a reasonable trade-off for broad-scale studies.

Introduction

Various factors determine the health of a river ecosystem (Moss, 2010; Norris and Thoms, 1999), including light, temperature, nutrient levels, water discharge, channel structure, physical barriers to connectivity, species interactions and the level of management, such as macrophyte cutting and dredging, fishing and stocking. Many of these factors are not independent; for example, discharge, channel structure and macrophyte growth interact to determine water depth and velocity, which in turn influence food delivery, light penetration and oxygen levels. Discharge (flow, measured in units of volume ÷ time) is a key variable, which changes naturally though time. Various authors have suggested that all elements of the flow regime influence freshwater ecosystems, including floods, average and low flows (Junk *et al.,* 1989; Richter *et al.,* 1996; Poff *et al*., 1997; Biggs *et al*., 2005; Arthington *et al*., 2006; Kennen *et al*., 2007). In many rivers, discharge is heavily influenced by anthropogenic activities, such as water abstraction, storage in reservoirs and effluent returns associated with public supply, agriculture and industry. The Millennium Ecosystem Assessment (2005) showed that many ecosystems were being degraded or lost, with aquatic systems suffering particularly from the withdrawal of water for direct human needs, many impacts directly resulting from fragmentation by dams (Nilsson *et al*., 2005). Thus, there is a pressing need to assess the degree of alteration of discharge to determine likely impacts on river ecosystems. The development of environmental flow regimes for rivers and associated systems is receiving increasing attention (Poff *et al*. 2010, Dyson *et al*. 2003). One approach to defining an environmental flow regime is to base it on an acceptable departure of the flow regime from a baseline. Normally the baseline is the natural flow regime and any departure signifies a degradation of the river ecosystem. One key area of current research is to envisage future impacts of climate change, rising populations, varying global markets and government policies on river ecosystems through alterations to the hydrological regime. This paper reports the results of research undertaken to assess hydro-ecological response(s) under future scenarios for Europe. The objectives are: (1) to define a method for assessing ecologically-relevant hydrological change based on monthly flows; (2) to test its validity at the pan-European scale; (3) to present preliminary analyses of scenarios to illustrate its application.

The SCENES project

SCENES, a four-year Integrated Project under the EU 6th Framework, is analysing a set of socio-economic storylines for Europe's freshwater futures up to 2050, covering all of 'Greater' Europe (EU countries and neighbours i.e. Iceland, Norway, Belarus, Ukraine, Moldova, Turkey, non-EU Balkan countries, Switzerland) and including the Mediterranean rim countries of north Africa and the near East (see map; Figure 1). The qualitative storylines are linked to quantitative methods (formal modelling and statistical analysis) methods. River flow scenarios, based on these socio-economic storylines have been defined using the WaterGAP (Water - Global Assessment and Prognosis) model for major rivers of Europe (Alcamo *et al.*, 2007). Within the 'Water for Nature' component of SCENES, indicators have been defined to quantify the impact on river ecosystems of these hydrological scenarios. The indicators quantify the difference between the natural flow regime and the flow regime resulting from a specific scenario at regular intervals along the major rivers of Europe.

This difference in flow regimes is determined by comparison of a set of nine parameters, covering different hydrological components calculated from flow time series. The greater the difference between the parameters for the pair of flow regimes, the larger the indicator value, which is displayed as traffic-light categories, where red is a large difference indicating the ecosystem is at high risk, amber is a medium difference indicating moderate risk, and green is a small difference indicating a low risk. The red/amber and amber/green boundaries are defined by how many parameters exceed thresholds for the differences between parameter values.

It is important to note that the impact indicator does not define an ecological status under the Water Framework Directive (WFD). River flow is a supporting element in the WFD. However, changes in the hydrological regime can put the river ecosystem at risk, hence the environmental flow indicator relates to risk to the ecosystem. Thus the indicator contains important information for policymakers, stakeholders and and river basin managers regarding the impacts of future use. It can, therefore, influence the development of policies to counteract the drivers and pressures causing non-beneficial changes to the ecosystem.

WaterGAP model and SCENES scenarios

WaterGAP calculates river discharge and water use on a 5’ x 5’ grid covering pan-Europe. It has two main components: a Global Hydrology Model (GHM) to simulate the terrestrial water cycle and a Global Water Use Model (GWUM) to estimate water withdrawals and water consumption of the following five sectors: domestic, electricity production, manufacturing industry, irrigation, and livestock; also built-in the model are 590 European dams and their management rules. The GHM calculates daily water balances for the land areas and open freshwater bodies for each individual grid cell; herein, the total simulated runoff of a grid cell is the sum of runoff from land and from open freshwater bodies. Runoff from each grid cell is routed as river discharge along the modelled drainage network. Natural cell discharge is then reduced by consumptive water uses as calculated by the GWUM.

SCENES storylines describe four different visions of Europe’s freshwaters up to the year 2050:

- Economy First (EcF), economy-oriented towards globalisation and liberalisation with intensified agriculture and slow diffusion of water-efficient technologies;
- Fortress Europe (FoE), closed-border Europe concentrating on common security issues with food and energy independence as the main focus of the European coalition;
- Policy Rules (PoR), stronger coordination of policies at the European level, driven in part by high energy costs and reduced access to energy supplies, expectation of climate change impacts and increasing water demand;
- Sustainability Eventually (SuE) transition from globalising, market-oriented Europe to environmental sustainability with quality of life as a central point.

To take into account climate change, the IPCC SRES A2 and B1 emission scenarios (IPCC 2007) were selected covering the whole time horizon up to the 2050s: SRES-A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change (global greenhouse gas emissions projected to grow steadily during the whole 21st century and possibly to double by 2050 compared to the year 2000); SRES-B1 describes a convergent world with a global population that peaks in mid-century and rapid changes in economic structures towards a service and information economy. The linkage of SCENES scenarios and climate change input is based on the information given in the storylines and the effects of the chosen Global Climate Model (GCM)-emission scenario combinations on precipitation and air temperature changes (see Table 1 for detail of used combinations).

Data

WaterGAP model runs

Modelled river flows ($m^3 s^{-1}$) for 664 sites were generated using the WaterGAP model (see Figure 1 for location of sites). The modelled locations include: (i) 136 gauging stations for which the Global Runoff Data Centre (GRDC) holds records, and (ii) sites spaced along all major rivers represented in the WaterGAP model (tributaries were ignored) so that there is one site for every 80 to 100 km stretch of river. Modelled monthly and daily mean flows were generated for nine different model runs corresponding to different climate models and socio-economic scenarios detailed in Table 1.

Table 1 WaterGAP model runs

Model run	*Period*	*Impacted flows?*[a]	*Climate data /model run*	*IPCC emission scenario*	*Socio-economic scenario*
1 - 1961-90 natural	1961-1990	No	CRU[b]		
2 - 1961-90 observed	1961-1990	Yes	CRU[b]		
3 - 2050 IPCM4 A2 natural	2040-2069	No	IPCM4[c]	SRES A2	
4 - 2050 IPCM4 A2 SuE	2040-2069	Yes	IPCM4[c]	SRES A2	Sustainability Eventually (SuE)
5 - 2050 MIMR A2 natural	2040-2069	No	MIMR[d]	SRES A2	
6.1 - 2050 MIMR A2 EcF	2040-2069	Yes	MIMR[d]	SRES A2	Economy First (EcF)
6.2 - 2050 MIMR A2 FoE	2040-2069	Yes	MIMR[d]	SRES A2	Fortress Europe (FoE)
7 - 2050 MPEH5 B1 natural	2040-2069	No	MPEH5[e]	SRES B1	
8 - 2050 MPEH5 B1 PoR	2040-2069	Yes	MPEH5[e]	SRES B1	Policy Rules (PoR)

[a] Impacts under the different socio-economic scenarios includes dam management and consumptive water use
[b] Climate Research Unit, University of East Anglia, UK
[c] GCM IPSL-CM4, Institut Pierre Simon Laplace, France
[d] GCM MICRO3.2, Center for Climate System Research, University of Tokyo, Japan
[e] GCM ECHAM5/MPI-OM, Max-Planck Institute for Meteorology, Germany

WaterGAP model efficiency

For the 1961-1990 period, monthly modelled observed flows (i.e. Run 2) were compared to the GRDC monthly mean gauged flows (115 out of 136 with complete records for that period were used) to assess the WaterGAP model performance. Model performance was assessed using the Nash-Sutcliffe criterion for model efficiency (Nash and Sutcliffe, 1970):

$$Efficiency = 1 - \frac{\sum_{i=1}^{n}(Qobs(i) - Qsim(i))^2}{\sum_{i=1}^{n}(Qobs(i) - Qbar)^2} \qquad \text{(Equation 1)}$$

Where:
Qobs is observed monthly mean flow
Qsim is modelled monthly mean flow
Qbar is mean of observed monthly mean flow over period of record

A perfect agreement between the observed and modelled flows yields an efficiency of 1. Results show that the average efficiency is 0.24 with 50% of the scores in the 0.39-0.82 range. Given the pan-European scale of the model, the overall efficiency is acceptable especially as the study focuses on the relative changes in flows rather their absolute magnitudes.

Methodology

The methodology used is based conceptually on the Range of Variability Approach (RVA) using Indicators of Hydrological Alteration (IHA), a desk-top technique for defining environmental flow requirements introduced by Richter *et al*. (1996, 1997). The IHA/RVA recognises that all characteristics of the flow regime (e.g. low and high flows and flood events) and their magnitude, duration, timing, frequency and rate of change are all ecologically important. First, the hydrological regime prior to an impact, whether due to, for example, the building of a structure, an abstraction point or climate change, is described by the IHA and constitutes the baseline against which post-impact conditions are assessed. The underlying assumption is that, if an ecosystem exists under the baseline conditions, then any departure from the baseline beyond some admissible thresholds will affect the ecosystem significantly. In the original approach, the flow regime was characterised by 32 parameters calculated from daily flow data for each year in the period of record (see Table 2; note: in this study, flow data (m^3s^{-1}) were converted to runoff (mm) to allow ready comparison across all catchment sizes). From these, acceptable ranges of flow are derived as the magnitude and variability of each parameter across the whole period of record. Magnitude could be described by the mean or the median, i.e. 50^{th} percentile, and the variability by the standard deviation or lower and higher percentiles, e.g. 25^{th} and 75th of annual parameters (Richter *et al*., 1997).

Table 2 Parameters for the Indicators of Hydrological Alteration

Parameter	*Units*
January mean flow	mm runoff
February mean flow	mm runoff
March mean flow	mm runoff
April mean flow	mm runoff
May mean flow	mm runoff
June mean flow	mm runoff
July mean flow	mm runoff
August mean flow	mm runoff
September mean flow	mm runoff
October mean flow	mm runoff
November mean flow	mm runoff
December mean flow	mm runoff
1-day minimum flow	mm runoff
3-day minimum flow	mm runoff
7-day minimum flow	mm runoff
30-day minimum flow	mm runoff
90-day minimum flow	mm runoff
1-day maximum flow	mm runoff
3-day maximum flow	mm runoff
7-day maximum flow	mm runoff
30-day maximum flow	mm runoff
90-day maximum flow	mm runoff
Julian date of 1-day minimum	Julian date
Julian date of 1-day maximum	Julian date
number of high pulses[a]	Number
number of low pulses[b]	Number
mean duration of high pulses	Day
mean duration of low pulses	Day
number of flow rises	Number
number of flow falls	Number
mean rise rate	mm runoff
mean fall rate	mm runoff

[a] number of times flow rises above 75th flow percentile
[b] number of times flow drops below 25th flow percentile

Redundancy analysis of IHA parameters

The 32 IHA parameters, and their derived indicators, duplicate some of the characteristics of the flow regime to some extent (Olden and Poff, 2003; Monk *et al*., 2007) depending on the data studied. For example, in Europe, January and February mean flows are often correlated. Due to some indicators being non-normally distributed, a correlation analysis was undertaken using the rank-based Kendall test (*tau;* Kendall, 1938) on the baseline modelled data (i.e. WaterGAP model Run 1; see above) for the 664 sites.

All parameters correlated by 55% or more were grouped and one parameter kept (this threshold was chosen as, although arbitrary, it corresponded to a natural cut-off in the dataset); this thinned down the list from 32 to 12. The monthly flows were peculiar in so far as the only three flow seasons were clearly differentiated (roughly winter, spring/summer and autumn). Despite the correlation results, it was decided to maintain a four-season structure, i.e. split spring and summer, because of: (i) the geographical coverage; (ii) it is intuitive from the perspective of climate, fauna and flora life-cycles; and (iii) climate change could induce change in a single season that could be critical to particular components of the biota.

The shortlist of parameters is thus: number of high pulses, number of low pulses, 1-day minimum flow, Julian date of 1-day minimum, 1-day maximum flow, Julian date of 1-day maximum, January mean flow, April mean flow, July mean flow, October mean flow, number of flow rises, mean rate of rise.

Monthly parameters

RVA/IHA is traditionally applied at small spatial and temporal scales. In the present study, the focus is on a pan-Europe scale rather than a catchment or a river reach, and the model produces daily and monthly data rather than sub-daily data. Given the broad spatial scale, and additionally the cost involved (staff and computing time) to generate model runs and then to derive IHA-style statistics at a daily time-step, the IHA approach was adapted to use monthly flows. In doing so, some of the 12 IHA parameters have to be necessarily excluded as they cannot be calculated (e.g. 1-day minimum or maximum flows), while others are less meaningful at the monthly scale. For example, rates of rise between months would most likely only show typical seasonal patterns year after year. Nine monthly time-step parameters were thus considered; a correlation analysis (following the same procedure as previously for daily time-step parameters) was undertaken and all nine parameters were kept (see list in Table 3).

Table 3 Environmental flow indicators

Regime characteristic	*Parameter monthly (one value per year)*	*Indicator (one value per record)*	*Analogue IHA daily*
Flood Magnitude & Frequency	Number of times that monthly flow exceeds threshold (all-data naturalised Q5 from 1961-1990)	25th, 50th, 75th Percentiles	Number of high pulses*
Flood Timing	Month (as number Jan=1, Dec=12) of maximum flow	Mode of month	Julian date of 1-day maximum
Seasonal Flow	January flow (mm runoff)	25th, 50th, 75th Percentiles	January mean flow (mm runoff)
	April flow (mm runoff)	25th, 50th, 75th Percentiles	April mean flow (mm runoff)
	July flow (mm runoff)	25th, 50th, 75th Percentiles	July mean flow (mm runoff)
	October flow (mm runoff)	25th, 50th, 75th Percentiles	October mean flow (mm runoff)
Low Flow Magnitude & Frequency	Number of months that flow is less than threshold (thresholds = all-data naturalised Q95 from 1961-1990)	25th, 50th, 75th Percentiles	Number of low pulses[a]
Minimum Flow Timing	Month (as number Jan=1, Dec=12) of minimum flow	Mode of month	Julian date of 1-day minimum
Low Flow Duration	Number of times that two consecutive months are less than threshold (all-data naturalised Q95 from 1961-1990)	25th, 50th, 75th Percentiles	Number of low pulses[a]

[a] the original IHA number of low and high pulses use the 25th & 75th percentiles as thresholds instead of 5th & 95th used here for the monthly parameters

Indicators, thresholds and traffic-light coding

From the parameters (one value per year of record per site), indicators (one value per period of record per site) were derived either as mean and standard deviation or percentiles. In this study, percentiles (i.e. 50th percentile to describe magnitude, and 25th and 75th to describe variability) were chosen because: (i) percentiles are less sensitive to outliers than mean and standard deviation; (ii) parameters are not necessarily normally-distributed, hence, percentiles would better describe skewed distributions. An exception was made for flood and minimum flow timing parameters. Indeed, these parameters are the months (i.e. integers ranging from 1 to 12) when flood and low flow events happen and are best summarised over the period of record by their mode.

During the next stage, the indicators are computed for the baseline data and for all scenarios. Departure from the baseline can be due to any combination of change in magnitude (shift in 50th percentile) and/or variability (shorter or longer 25th-75th percentile span). Differences between baseline and scenarios relative to magnitude and variability are therefore summed. Whilst it is widely accepted that alterations to the flow will cause a change to the river ecosystem, the threshold point at which this occurs is often not clear. The functional relationship can take many forms (Arthington *et al.*, 2006), but normally fall into one of three general types: no relationship, linear (or curvilinear) response, and threshold response/step function (Poff *et al*. 2010); for example, where there are clear threshold responses such as overbanking flows needed to support riparian vegetation or to provide fish access to backwater and floodplain habitat. Where linear or curvilinear relationships exist, critical points need to be defined by professional judgement (Arthington *et al.*, 2004; Biggs & Rogers, 2003; Richter *et al.*, 2006). Based on common expert knowledge (e.g. WFD flow thresholds; Acreman *et al*., 2008), for a given parameter, scenarios are therefore considered not significantly different from the baseline if the total indicator difference is within 30% with the exception of the mode indicators (flood timing, minimum flow timing) for which a threshold of 1 month was retained (or 30 days for daily IHA). For practicality and ease of display and interpretation, differences are aggregated via a traffic-light colour-coding: a site was assigned green, amber, or red when when its number of parameters different from baseline by 0-2, 3-5, or >6, respectively (breakdowns for nine monthly parameters). For the selected daily IHA parameters, breakdowns were taken pro rata of 12, i.e. 0-3, 4-7, and >8.

Traffic-lights daily and monthly – comparison

The full analysis was undertaken on both monthly (9 parameters) and daily (12 parameters) data. For those daily parameters analogous to the monthly indices (see Table 3), values were similar (e.g. monthly mean flows) or in the same range (e.g. Julian dates tend to fall within the same period as the mode of month). Across all model runs, 50-65% of the sites obtain the same colour code. For 20-30% of sites, the daily assessment indicated more severe impacts, and for 5-15% a less severe impacts than the monthly assessment. Overall, the daily assessment tends to give slightly higher risks, which is consistent with daily parameters giving a more detailed description of the hydrological regime. However, for the majority of sites, the risk is the same regardless of time scale. Given the significant cost in computing time due to using the daily resolution and the relative closeness of assessments for both scales, it seems feasible and practicable to use the monthly scale.

Results

Primary analysis

The primary analysis sets Model Run 1 1961-90 naturalised ('natural') flows as the baseline and assesses Runs 2 to 8 against it. Results from selected traffic-light assessments are shown in Figures 1 to 4, and differences between assessments are summarised in Table 4 as the percentages of sites with different colour-coding. The assessment of Run 2, presented in Figure 1, reflects the influence of current water utilisation alone (including dams and human consumption; see Table 1); Europe is overall green except for some highly impacted areas. Model runs with the same climate model give similar impact patterns: (i) IPCM4 A2 Run 3 (natural; shown in Figure 2) has only 12% of sites differing from Run 4 (SuE); (ii) MIMR A2 Run 5 (natural; shown in Figure 3) has 21% of sites differing from Runs 6.1 (EcF) and 6.2 (FoE), themselves being only 1% different; (iii) MPEH5 B1 Run 7 (natural; shown in Figure 4) differs from Run 8 (PoR) by 21% (see Table 4). Overall the primary cause of departure from the baseline is the climate model, with the socio-economic scenarios bringing only localised changes.

Table 4 Summary of difference in traffic-light assessments of model Runs 2-8 against Run 1 (% of sites with differing colour-coding)

	1 v 2	*1 v 3*	*1 v 4*	*1 v 5*	*1 v 6.1*	*1 v 6.2*	*1 v 7*
1 v 3	90						
1 v 4	89	12					
1 v 5	87	41	45				
1 v 6.1	84	39	37	21			
1 v 6.2	83	39	37	21	1		
1 v 7	75	62	65	52	56	56	
1 v 8	73	60	61	50	50	49	21

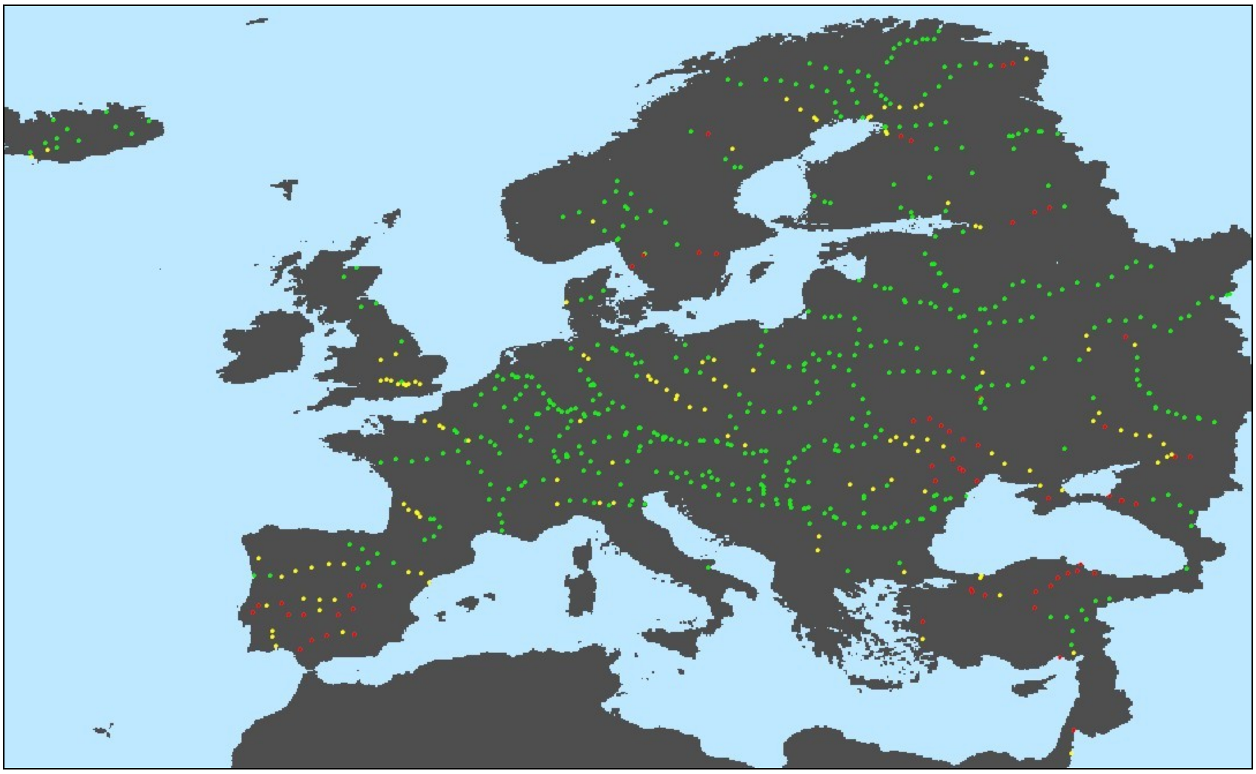

Figure 1 Baseline Run 1 1961-90 natural v Run 2 1961-90 observed

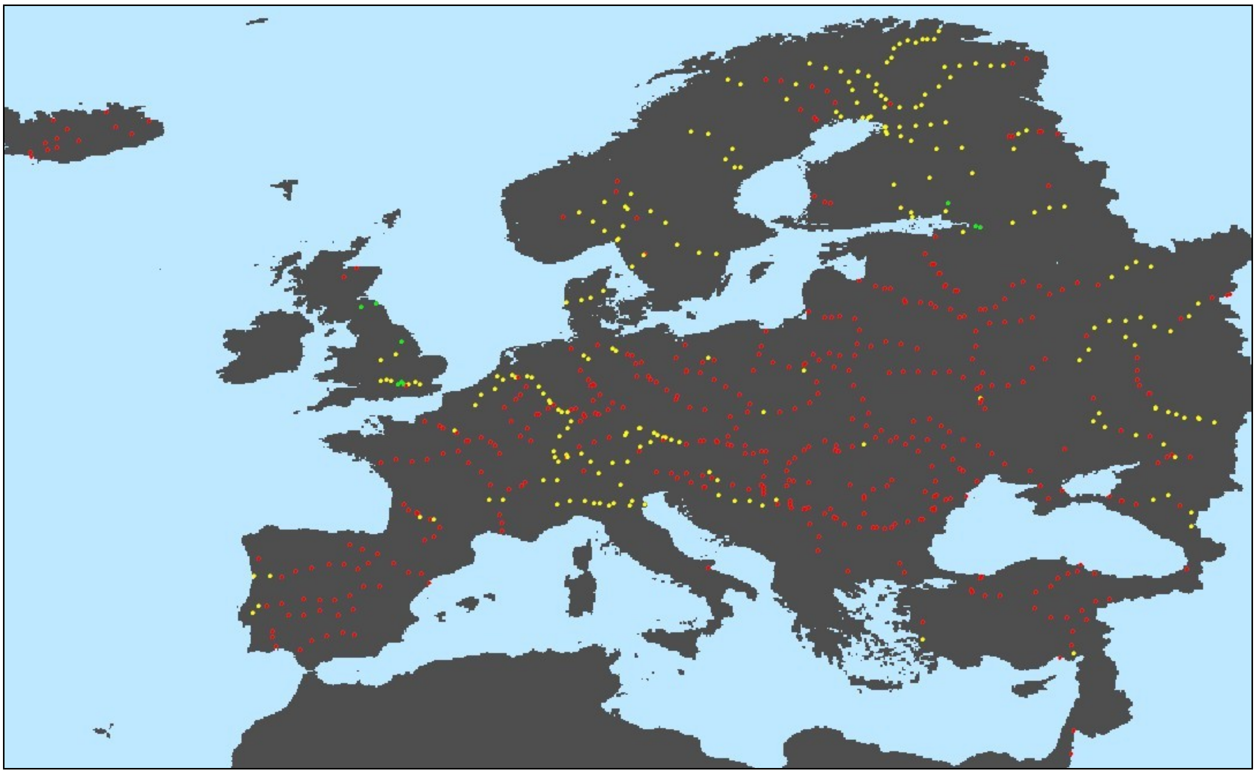

Figure 2 Baseline Run 1 1961-90 natural v Run 3 2050 IPCM4 A2 natural

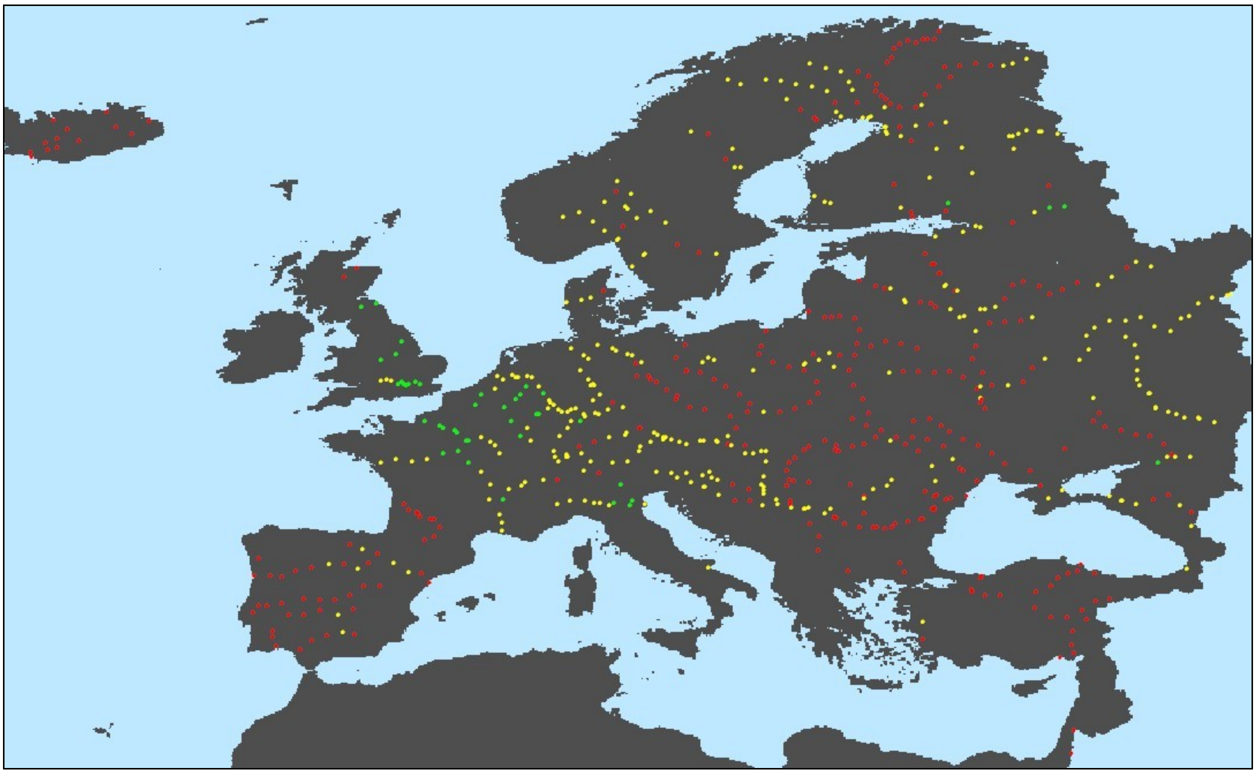

Figure 3 Baseline Run 1 1961-90 natural v Run 5 2050 MIMR A2 natural

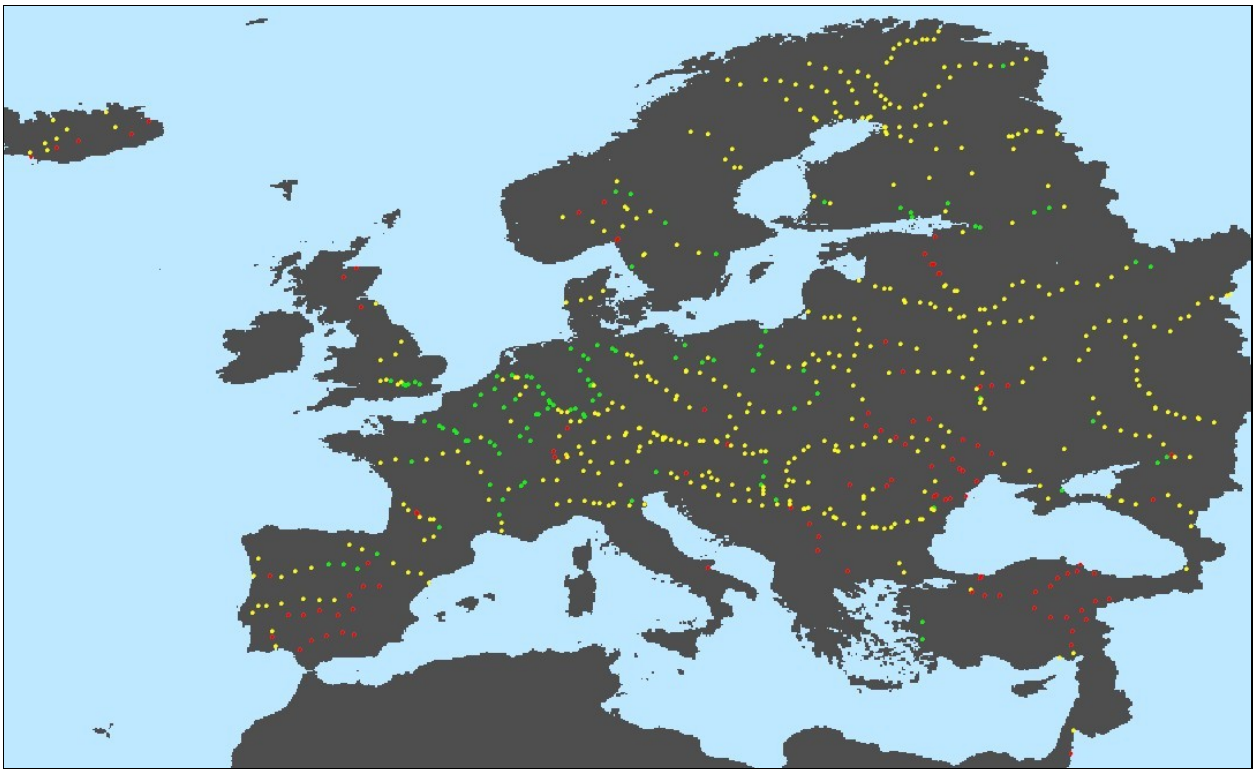

Figure 4 Baseline Run 1 1961-90 natural v Run 7 2050 MPEH5 B1 natural

Secondary analysis

From the above results, the influence of the socio-economic scenarios seemed to be masked by the overall climate-induced patterns. The analysis has been re-run using each natural model run as baseline and assessing the corresponding scenarios against it: Runs 2, 4, 6.1 and 6.2, and 8 against baseline Runs 1, 3, 5, and 7, respectively. This was done using the same threshold of 30%. By doing so, one attempts to isolate the influence of water utilisation alone under the conditions imposed by the climate model. Results for 1 v 2, i.e. baseline Run 1 1961-90 natural v Run 2 1961-90 observed, are necessarily the same as previously (see Figure 1). The overall patterns for all other assessments are very similar to that of 1 v 2, with patterns only differing by 17-19% of sites (see Table 5). As seen above, much of Europe is unaffected by water usage patterns except some regions at risk, e.g. southern Spain.

Table 5 Summary of difference in traffic-light assessments of model runs against varying baseline, grouped by climate model (% of sites with differing colour-coding)

	1 v 2	*3 v 4*	*5 v 6.1*	*5 v 6.2*
3 v 4	19			
5 v 6.1	18	11		
5 v 6.2	18	11	3	
7 v 8	17	9	11	10

Discussion

In order to identify broad-scale patterns, the percentages of sites falling within the three impact risk levels were compiled for both for both primary and secondary analyses (Table 6). First, in regards to the primary analysis, under all three climate models (i.e. not considering Run 2), Europe would be mildly or highly impacted (green sites only amount to a maximum of 16%). By order of impact severity, IPCM4 A2 (Runs 3 and 4) leads to the most impacted pattern with at least two thirds of the sites flagged as red, followed by MIMR A2 (Runs 5, 6.1, and 6.2) with about half red, half amber, and MPEH5 B1 (Runs 7 and 8) more than two thirds amber.

Then, focusing on the secondary analysis, the influence of the socio-economic scenarios are not easily discriminated as they are all very similar to the modelled current water usage (77-80% of green sites for all four secondary assessments compared to 73% for 1 v 2). However, even if differences are small at a broad pan-European scale, it could still be significant at a more local scale. Indeed, in this study, 1% difference in 664 sites still represents 6 or 7 sites so potentially up to 500-700 km of river if they are contiguous.

Table 6 Percentages of sites assessed as green, amber, or red in primary and secondary analyses

	Green	*Amber*	*Red*
1 v 2	73	18	9
1 v 3	1	33	66
1 v 4	0	29	70
1 v 5	6	46	48
1 v 6.1	3	43	54
1 v 6.2	3	44	53
1 v 7	16	69	15
1 v 8	10	68	22
3 v 4	77	14	10
5 v 6.1	78	13	9
5 v 6.2	78	13	9
7 v 8	80	11	9

A visual inspection of the maps for all assessments showed that some sites are most often, and some always, flagged with the same impact risk level. This is summarised in Figures 5 and 6. In Figure 5, the coloured sites are allocated their respective colour in six to eight out of eight assessments (except for green as no site is flagged as such in more than six assessments). Some regions appear particularly impacted, e.g. southern Spain and the western and southern Black Sea region. Figure 6 follows a similar principle except that coloured sites have their impact level in all four secondary assessments. Interestingly, it confirms southern Spain and the southern Black Sea area as highly impacted.

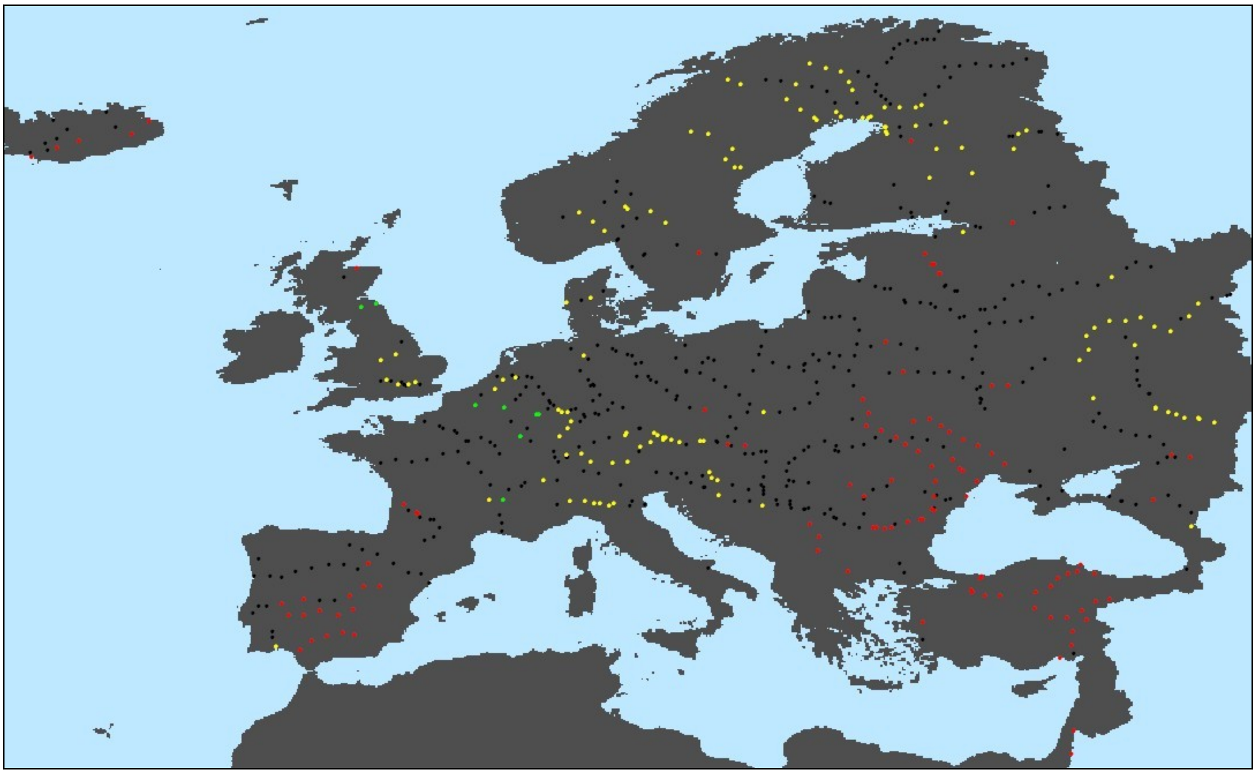

Figure 5 Primary analysis (baseline Run 1, assessments of Runs 2-8); colour-coded sites are those that are of the corresponding risk level in at least six out of eight assessments; remainder of sites showed in black

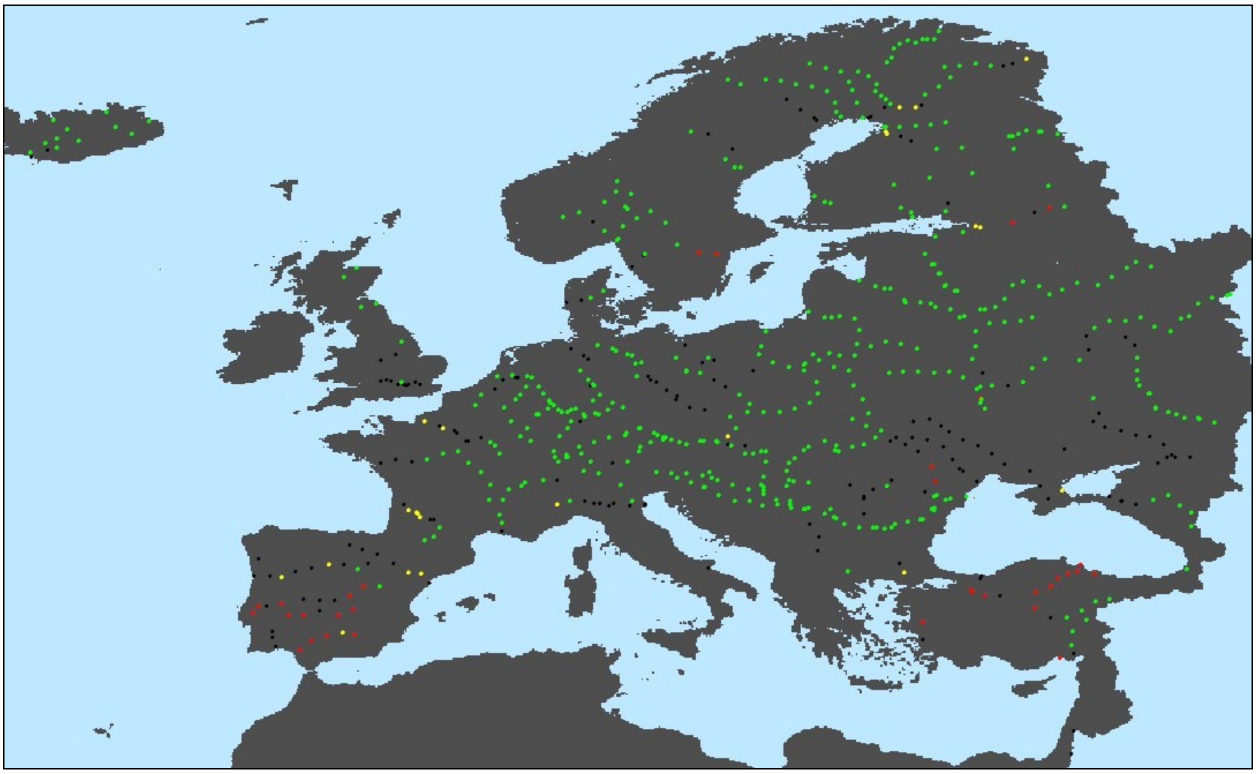

Figure 6 Secondary analysis (baseline and assessed runs grouped by climate model); colour-coded sites are those that are of the corresponding risk level in all four assessments; remainder of sites showed in black

Concluding remarks

At this stage, it would be inappropriate to make further inferences on the patterns shown in the results section as the analysis relied on a provisional set of climate and socio-economic scenarios. The final round of SCENES model runs will standardise the climate scenarios so as to focus on the influence and impact of the different socio-economic scenarios. The preliminary results however suggest that (1) the method does manage to flag potential impacts (not all rivers are flagged green) while being discriminating enough (they are not all red),and (2) using parameters based on monthly flow data is a sensible trade-off as similar overall assessments are obtained compared to using daily data.

To help in the interpretation of the results, i.e. why a given site is amber or red, one would also require additional data (detailed water consumption, i.e. not lumped at the catchment scale and location of major urban areas). It would also be necessary to link results, which are based on hydrological data, to ecological data to confirm the hypothesis that departure from the baseline hydrological regime actually relate to an ecological impact. However, this is complicated by the fact flow regulation is one of many potential reasons for failure to achieve good ecological status.

In a previous European Commission work on a groundwater and river resources management programme at a European scale (GRAPES; Acreman *et al*, 2000; Acreman, 2001), the impact of current anthropogenic pressures, such as water abstraction, outweighed the then predicted impacts of climate (this was partly due to the focus on case studies of heavily impacted catchments in the UK, Spain and Greece) and the difference between climate change predictions at the time and current scenarios. In contrast, this study shows that climate change impacts dominate over current water use impact at a general level across Europe.

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