Funded by the European Union within the
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Deliverable 2.1 - Four manuscripts on the multiple stressor framework

Part 1: Review of multiple stressors and their effects on European surface waters

Part 2: Cook-book for ecosystem service assessment and valuation in European water resource management

Part 3: Framework to select indicators of multi-stressor effects for European river basin management

Part 4: Report on the MARS scenarios of future changes in drivers and pressures with respect to Europe's water resources

Lead beneficiary and Contributors: **multiple partners (see each part for details)**

Due date of deliverable: **Month 12**
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Dissemination Level		
PU	Public	**x**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Overview

This deliverable is composed of four chapters describing products of the MARS project, which will contribute to harmonize the outcome of the experiments (WP3), of the catchment modelling (WP4) and of the large-scale data analysis (WP5). All these work areas address the effects of multiple stressors on water resources and aquatic ecosystems, but are using different approaches, targeting different stressor combinations and response variables. To ensure that the outcome is suited for a meta-analysis across approaches, scales, stressors and variables several underlying procedures were harmonized; that's what this deliverable is about.

Part 1: Review of multiple stressors and their effects on European surface waters

Part 1 reviews the effects of multiple stressors on rivers, lakes, groundwaters and coastal ecosystems, based on a thorough literature analysis. Despite the existence of a huge conceptual knowledge base in aquatic ecology, only few studies provide quantitative evidence on multiple stress effects. Two-stressor combinations were addressed most frequently. Over all biological groups analyzed, the strength of the pressure-response relationships increased with increasing number of stressors considered in lakes and rivers, but the response remained unclear in transitional and coastal waters. Biological groups responded generally very differently to increasing complexity of stress.

Part 2: Cook-book for ecosystem service assessment and valuation in European water resource management

Part 2 first addresses current approaches towards ecosystem service assessment and valuation and provides an overview of ecosystem services evaluated in the MARS experiments, catchment models and large-scale data analysis. Finally, a procedure towards ecosystem service assessment to be applied in MARS is described, which comprises four steps: Scoping of the analysis, development of the integrated assessment framework, biophysical quantification of ecosystem services, and economic valuation of ecosystem services. The procedure is exemplified for a number of case study catchments.

Part 3: Framework to select indicators of multi-stressor effects for European river basin management

Part 3 describes a set of "benchmark indicators", i.e. response variable to be addressed in the experiments, catchment modelling and large-scale data analysis. These indicators allow for a streamlined analysis of multi-stressor effects across the different spatial scales and environmental conditions targeted in MARS. The benchmark indicators mainly comprise simple metrics and indices of abiotic and biotic ecosystem properties, covering physico-chemical, hydrological and riparian features of the water body and selected attributes of its biological community. The indicators are known to respond to anthropogenic pressure. They are applicable in various geographical contexts and to different water categories and types of water bodies.

Part 4: Report on the MARS scenarios of future changes in drivers and pressures with respect to Europe's water resources

Part 4 describes storylines outlining future changes regarding (i) main drivers in the economy, (ii) economic growth, (iii) policies regarding the environment, and (iv) public concern about the environment and protection of ecosystem services. This contribution establishes the baseline for simulating future scenarios at both basin and European scale. Various future climatic and socio-economic scenarios were chosen to define three storylines at the European level. Several projects and modeling tools were reviewed with the aim of identifying quantitative data fitting the selected storylines. Suitable data were collated and can now be used by the subsequent MARS work packages to drive the simulations of the three storylines.

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MARS PROJECT

Managing Aquatic ecosystems and water Resources under multiple Stress

Deliverable 2.1 - Four manuscripts on the multiple stressor framework: Review of multiple stressors and their effects on European surface waters (1/4)

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Content

Non-technical summary

We have reviewed 219 papers and built an inventory of 532 items of ecological evidence on multiple stressor impacts in rivers, lakes, transitional and coastal waters, as well as groundwaters found in these papers. Our review revealed that, despite the existence of a huge conceptual knowledge base in aquatic ecology, only few studies provide quantitative evidence on multiple stress effects. Nutrients as main physico-chemical anthropogenic stress were involved in 71% to 98% of multi-stress situations in surface water ecosystems and in 42% of those in groundwaters; however, their impact was expressed differently along the groundwater-river-lake-transitional-coastal continuum determined mainly by hydro-morphological conditions. Two-stressor combinations were addressed most frequently. Over all biological groups analysed, the strength (R^2) of the pressure-response relationships increased with increasing number of stressors considered in lakes and rivers, but the response remained unclear in transitional and coastal waters. Biological groups responded very differently to increasing complexity of stress. Over all water categories the explanatory power of benthic macroinvertebrates and fish increased with the number of stressor groups taken into account in the analysis, showing them as useful holistic indicators in multiple stress situations. The explanatory power of phytoplankton and benthic flora decreased in multiple stress situations.

Highlights

- We reviewed 219 papers quantifying impacts of multiple stressors on aquatic systems
- Quantified relationships cover just a tiny part of common conceptual schemes
- Nutrient stress occurred in 71% to 98% of multi-stress situations in surface waters
- Hydro-morphology modifies the sensitivity of water bodies to nutrient stress
- R^2 of macroinvertebrate and fish equations increased with more stressors involved
- R^2 of phytoplankton and macrophyte equations decreased with more stressors involved

Keywords

Stressor combination, stressor interaction, biological group, freshwater systems, marine systems, nutrient stress, river, lake, fish macroinvertebrates, macrophytes, algae

Introduction

In our globalising world multiple stresses on surface and ground water systems from natural and man-made disturbances have become the rule rather than an exception. A stressor can be either an abiotic as well as a biotic factor (Cottingham 1999; Vinebrooke et al. 2004) that exceeds its range of normal variation and affects individual physiology, population performance or community balance in a significant way. Similarly, most other definitions of ecological stress (e.g. Barrett et al. 1976; Auerbach 1981; Underwood 1989; Hughes & Connell 1999) include the effects at individual and demographic (population or functional group) level. At the individual level, stress is considered as a sub-lethal effect on the physiology of an organism, e.g., a decline in feeding, growth, or fecundity, or a biochemical change. At the community or ecosystem level, stress denotes an acute or chronic disturbance that causes a decline in the number of organisms affecting biotic interactions and integrity (e.g, Hyland et al. 2003; Pilière et al. 2014).

Ecosystems as dynamic and self-organizing systems are continuously adapting to a multitude of disturbances (Connell 1978). Rapid increase in anthropogenic pressures has modified the types, frequency and magnitude of disturbances to an extent, which a number of species cannot keep up with, while others will take advantage of the freed-up or new resources (Halpern et al. 2008). At any organisational level, multiple stress situations include biological interactions (e.g. food chain interactions, resource competition), human pressures, which typically alter more than one environmental factor, and impacts of climate change (Ormerod et al. 2010).

A number of theoretical concepts in the field of multiple stress, partly originating from terrestrial ecology, back up the on-going research activities on multi-stress effects. The landscape filter concept (Tonn et al. 1990) explains the structure of river communities as a result of a set of environmental constraints filtering species that can be found at a place. The ‘control species’ concept (Downes 2010) advocates measuring the reaction of a group of ‘treatment species’, which are predicted to respond to a specific gradient against that of ‘control species’ not sensitive to the stressor of interest because of specific features of their biology or ecology. Simulating in this way the experimental conditions in field situation has a potential to improve our capacity to draw conclusions about causality. The species co-tolerance model (Vinebrooke et al. 2004) hypothesizes that positively correlating tolerance of species to multiple stressors increases ecosystem resistance, while negatively correlating tolerance results in additive or synergistic impacts, compared to situations where tolerances of each species are randomly distributed. A related hypothesis – the stress-gradient hypothesis highlighting a global shift towards positive species interactions with increasing environmental stress – has been tested so far mostly on vascular plants (He et al. 2013).

The dominating endeavour in multi-stress studies has been to disentangle the effects of confounding factors one-by-one (e.g. Vonesh et al. 2009; Battarbee et al. 2012) and specify the cause-effect chains lying at the bottom of these relationships. It requires careful hypothesis driven research, often combining field studies with experiments and modelling, to discover the intimate linkages between species and/or functional groups and their environment (Dowes 2010; Ormerod et al. 2010). By now, this massive and continuing effort has revealed: (i) a huge variation in impact-response relationships over water categories, seasons, climatic regions, and biotic communities; (ii) a domination of non-linear and often lagged responses in biotic reactions to stressors; (iii) dependence of a particular stress effect with perturbation history (Hughes & Connell 1999); and (iv) stressor's interactions amplifying or dampening each-other's effects (Folt et al. 1999; Micheli et al. 2013).

Given the complexity of the multi-stress issue and the urgent need for management advice in respect of the Water Framework Directive (WFD), a simplified approach has been implemented, known as assessment of ecological status. This approach does not explicitly focus on causal relationships at species level, but relates complex pressures (e.g. those created by land use change) to structural and functional parameters of the aquatic communities. This has created a large body of research dedicated to the assessment of 'ecological status', 'biotic integrity' or 'ecosystem health' (Karr et al. 1986; Karr 1996; Palmer & Febria 2012). In a review on pressure-response relationships in stream ecology, Friberg (2010) points out the sensitivity of macroinvertebrates to combinations of natural environmental factors and anthropogenic pressures and lists a number of approaches (sensitivity numbers, multi-metric indices, additive models) that are sensitive to more than one stressor. Despite being criticised for its inability to reveal fundamental causal relationships and, hence, to give scientifically sound management advice (Downes 2010), the integrative community or ecosystem level indices may gain importance in understanding non-equilibrium aspects of ecosystems, such as unpredictability, instability and stochasticity, which so far have not been satisfactorily integrated into practical application (Mori 2011). One of such applications is the use of certain statistics of biological response variables as early warning signals of regime shifts in ecosystems (Scheffer et al. 2009; Dakos et al. 2012).

Hence, the main aim of this review is to assess the quantity and quality of the described evidence base on multiple stress effects in aquatic ecosystems (rivers, lakes, transitional and coastal systems) and groundwaters as the basis for a diagnostic tool for water bodies in all these systems (see Hering et al. 2015). We expected to find knowledge gaps, i.e. multi-stress situations for which conceptual knowledge exists but the effects are not quantified. We hypothesised that the same drivers are responsible for the dominating stressor combinations in all water categories but the responses differ between categories due to diverging sensitivity. We questioned whether the different research traditions in rivers, lakes, transitional and coastal (TraC) waters are reflected in the methodological approaches used in multi-stressor studies.

Material and methods

Literature selection

For the literature survey, we used the ISI Web of Science citation databases. For surface water category specific queries, we used a combination of the water category ('lake*', 'river*' OR 'stream*', and 'coastal' OR 'transitional'; for further analysis, we grouped transitional and coastal waters as TraCs), coupled single stressors relevant for the given water category in various combinations (e.g. 'nutrient load' OR 'eutrophication' AND 'temperature', 'flow alteration' AND 'sediment transport' etc. for rivers), a biological indicator group for surface waters ('phytoplankton' OR 'zooplankton' OR 'phytobenthos' OR 'macrophyte*' OR 'invertebrate*' OR 'macroinvertebrate*' OR 'fish*'), a term showing the simultaneousness of stress or stressors ('multi-stress*' OR 'multiple stress*' OR 'multiple pressure*'), and a term showing the interaction ('interaction*' OR 'synergis*' OR 'antagonis*' OR 'additive'). Although zooplankton is not a mandatory biological group for the WFD, it was included as a search string for lakes because the central position of zooplankton in lake food webs renders a high indicative value to it in multi-stress situations (Altshuler et al. 2011; Jeppesen et al. 2011a). Since the aim was to find papers in which the multiple stress effects were quantitatively described, we screened the retrieved papers for that. Search was continued by a 'bottom up' approach looking through the references in relevant papers. We excluded ecotoxicological lab experiments with single species as test organisms.

Due to different traditions and prevailing hydrogeological paradigm in groundwater research, different search terms had to be used for literature search (e.g. a query including 'ground water*' OR 'groundwater*' AND 'multiple stress*' resulted in zero hits). We performed the search by a simplified list of stressors including 'climat*' OR 'water abstraction' OR 'seawater' OR 'nitrate*' OR 'pesticide*' as search strings to cover the main hydrological drivers and two main pollutants. Biological indicators, irrelevant for groundwaters, were skipped and the papers were screened for water quality and quantity indicators. From the initial list of >400 papers only 46 papers describing simultaneous effects of two or more stressors remained in the analysis. Since the behaviour of groundwater systems relies heavily on site-specific hydrogeological and also soil settings, the relationships were mostly of conceptual type and almost no quantifying equations could be found that would be valid anywhere else.

Given the extremely broad scope of the review covering the major part of aquatic ecology and groundwater research, the retrieved set of papers does not pretend to completeness, but is expected to give a relatively comprehensive cross-cut of prevailing stressor combinations, preferred indicators, and ways of quantification of complex stressor-interactions. Additional literature on simple (additive) stressor settings which are often not highlighted as multiple stressor impacts, is certainly available, but an attempt to include it all would be unfeasible work load wise.

Review table

Relevant information from the papers was extracted to an Excel table (provided as Supplementary Material (SM)) to enable further search by key-words and meta-analysis. According to the concept, each quantitatively described effect of combined pressures on a response variable forms an 'evidence item' (EI) which was described in a separate row of the table. Papers containing more than one EI covered several rows of the table (Table 1).

Table 1. Number of papers included in the review and number of multi-stress evidence items described for different water categories.

Water category	Rivers	Lakes	Transitional and coastal	Groundwaters	Total
Papers	75	65	33	46	219
Multi-stress evidence items	214	152	120	46	532

- The column structure was kept similar for all water categories to enable a common analysis. The table contained the following blocks:
- Water category.
- Bibliographic information.
- Narrative description of the EI and its implications for management or ecosystem services.
- Spatial and temporal scale of the study (number of water bodies, their geographic location and type, temporal scale of the data).
- Drivers (the main climatic and anthropogenic drivers).
- Stressors and covariates (climatic, hydrological, morphological, thermal/optical, chemical, trophic, toxic, and biological, each sub-divided into more specific direct stressors).
- Response variables including their type (structural or functional, snapshot or time-series) and quantitatively described impact-response relationship (equation, slope factor, or ANOVA results, strength (R^2)).
- Risks involved and ecosystem services impacted.

Three types of entries are used in different columns:

1) (Free) text columns are used for the full reference and the type of paper, for describing the multi-stress impact-response relationship (the 'Narrative statement'), management implications, study design, statistics used, comments, and for explaining the category of 'other' under water body type location, and driver of stress.

2) Numeric entries were used for publication year, the number of water bodies included in the study, temporal scale of the source data (in years), and strength of the described relationship (R^2).

3) Number 1 was used as a tick mark denoting ‘Yes’ for selecting one (or more) of the multi-choice columns under water categories, study scale, drivers, stressors, indicators, risks involved and ecosystem services impacted.

Cells were left empty, if the choices were ‘No’, ‘non-applicable’ or ‘not indicated’.

Effects on ecosystem services were assessed based on our expert opinion. For surface waters we used the MAES/CICES (Maes et al. 2014) conceptual framework, in which only ecosystem services (ES) provided by biota are considered. Hydropower and navigation are not considered as ecosystem services. For groundwaters two additional ES (strategic reserves and groundwater dependent ecosystems) were used.

Meta-analysis

The meta-analysis was carried out at two levels: (i) at the paper level we analysed the publication year, geographic distribution, time frame of data collection, number of water bodies analysed, and the broad types of metrics used; while (ii) at the evidence item level the pressure-response interactions were analysed in more detail. We carried out a descriptive comparison over different water categories based on the numeric values and numbers of entries (indicated by tick-marks) in different columns. As the numbers of both papers and evidence items differed by water categories, the comparison is mostly done in relative proportions.

Correlation analysis and Mann-Whitney test was carried out with STATISTICA 12 (StatSoft 2013). A Z-test to compare proportions in two populations was done with an online calculator available at http://www.socscistatistics.com/.

To analyse the broad types of metrics used as response variables in the four water categories, they were grouped as follows:

(i) Metrics of simple structure (SS) including e.g. stratification structure, water level, temperature, concentrations, taxon abundances and biomasses, size and age structure, species richness, diversity, evenness, macrophyte zonation, etc.

(ii) Metrics of functional structure (FS). For surface waters they include structural metrics with functional (tolerance, trophic, reproduction, habitat and migration related) attributes. Metrics of this group are sometimes termed ‘functional metrics’ (e.g. Hering et al. 2004; Pont et al. 2006). For groundwaters, metrics of functional structure included e.g. aquifer vulnerability factors such as soil properties, hydraulic conductivity, pressure or pathway parameters, and coastal topography.

(iii) Functional or process metrics (P) sensu Palmer & Febria (2012), i.e. metrics characterising matter fluxes or rates and equilibria of processes such as nutrient uptake, photosynthesis, growth rate, respiration rate etc. For groundwaters they include e.g. the water budget components, salt water intrusion or refreshing rate, base flow, etc. At least two point measurements are needed for most process metrics to capture the time dimension. Exceptions of this rule are e.g. the length of fish year classes including a hidden time dimension or the annual maximum biomass of macrophytes reflecting their productivity.

For each metric it was checked whether a snapshot measurement or a time series was used. Metrics which dynamics were measured as time series were marked with d (correspondingly, SSd, FSd and Pd). Multimetric indices composed of different types of metrics were decomposed and analysed based on the component metrics used.

SS and FS were summed up as static metrics while SSd, FSd, P and Pd as dynamic metrics.

Results

The selected 219 papers covered a period of 29 years from 1986 to 2014 with steadily increasing numbers of publications per year towards the end of the period (SM Fig. S1).The number of papers by water categories ranged from 33 for TraC waters to 75 for rivers (SM Table S1). For all water categories the largest number of papers was from Europe (53%) followed by North America (21%) and multi-continental studies (13%).

Highest median numbers of water bodies per study were analysed for rivers followed by TraC waters, lakes and groundwaters (SM Fig. S2). Case studies of single water bodies contributed with 5% of the river evidence base, about 30% of lake and TraC waters' evidence base, and nearly 50% of the groundwater evidence base.

The median time window for data collection ranged from 0.1 years for rivers to 7.5-9 years for other water categories (Fig. 1).

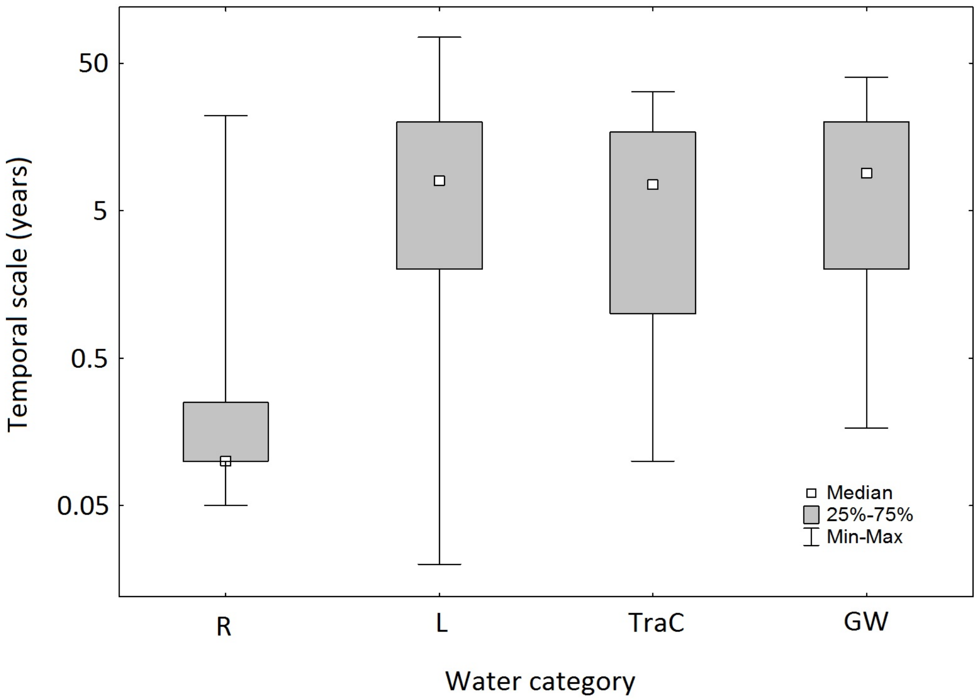

Fig. 1. Time scale of data collection used in studies of different water categories (W Cat). Time scale <1 year includes single surveys or sampling campaigns, short-time experiments, and studies covering some months or the vegetation period of a year. Temporal scale 1 year includes studies over one whole annual cycle (e.g. monthly sampling) even if data from two calendar years. For modelling studies temporal scale indicates the observed data used for building and/or validating the model. Note: R – rivers; L – lakes; TraC – transitional and coastal waters; GW – groundwaters.

Nutrient stress was a predominant stressor group occurring in more than 70% of multiple stress situations described in rivers, lakes and TraC waters (Table 2). Still hydrological stressors dominated in rivers (74%) and were overwhelming in groundwaters (83%). In TraC waters toxic stress sheared the 2nd and 3rd position with hydrological causes (i.e. 47% and 45% of cases, respectively).

Table 2. Stressor groups by water categories (number of EIs and % of total EIs). Note: R – rivers; L – lakes; TraC – transitional and coastal; GW – groundwaters; n – number; % – percentage.

	Rivers		Lakes		TraC		GW	
	nr	%	nr	%	nr	%	nr	%
Nutrient stressors	152	71	119	78	117	98	20	43
Hydrological stressors	159	74	61	40	54	45	38	83
Morphological stressors	64	30	21	14	46	38	0	0
Thermal/optical stressors	46	21	47	31	12	10	0	0
Chemical stressors	26	12	21	14	14	12	17	37
Toxic stressors	48	22	18	12	56	47	10	22
Biological stressors	21	10	42	28	33	28		
Total evidence items	214		152		120		46	

Nutrient and hydrological stressors in combination with others formed the bulk of most frequent stress situations in all water categories (Table 3).

Table 3. Three dominant stressor combinations (1, 2, 3) for lakes (L), rivers (R), transitional and coastal waters (TraC), and groundwaters (GW).

	Hydrological stressors	Morphological stressors	Thermal stressors	Chemical stressors	Toxic stressors	Biological stressors
Nutrient stressors	R(1), L(1), TraC(2)	R(2), TraC(3)	L(2)		TraC(1)	L(3)
Hydrological stressors			R(3), GW(1)	GW(3)		
Morphological stressors						
Thermal stressors				GW(2)		

A combination of hydrological and nutrient stressors was the most frequent two-stressor combination in rivers and lakes occurring, correspondingly in 53% and 27% of multi-stress situations described for these water categories. For TraC waters this combination was addressed only slightly less frequently (43% of EIs) than the combination of nutrient and toxic stress (45%). The frequency of occurrence of various two-stressor combinations in rivers correlated significantly ($p<0.05$) with those in lakes ($r=0.57$) and TraC waters ($r=0.63$), whereas the correlation between the stressor occurrence patterns in lakes and TraC waters was non-significant.

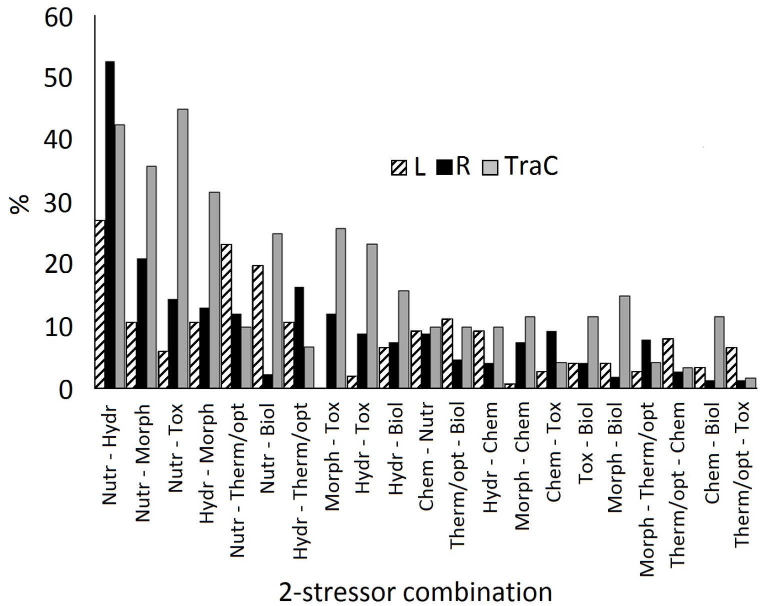

Fig. 2. Frequency counts for the occurrence of two-stressor combinations (% of EIs) among surface water categories. Note: R – rivers; L – lakes; TraC – transitional and coastal waters.

The number of simultaneously acting stressor groups ranged from one to seven, but two-stressor combinations were addressed most frequently (Fig. 3).

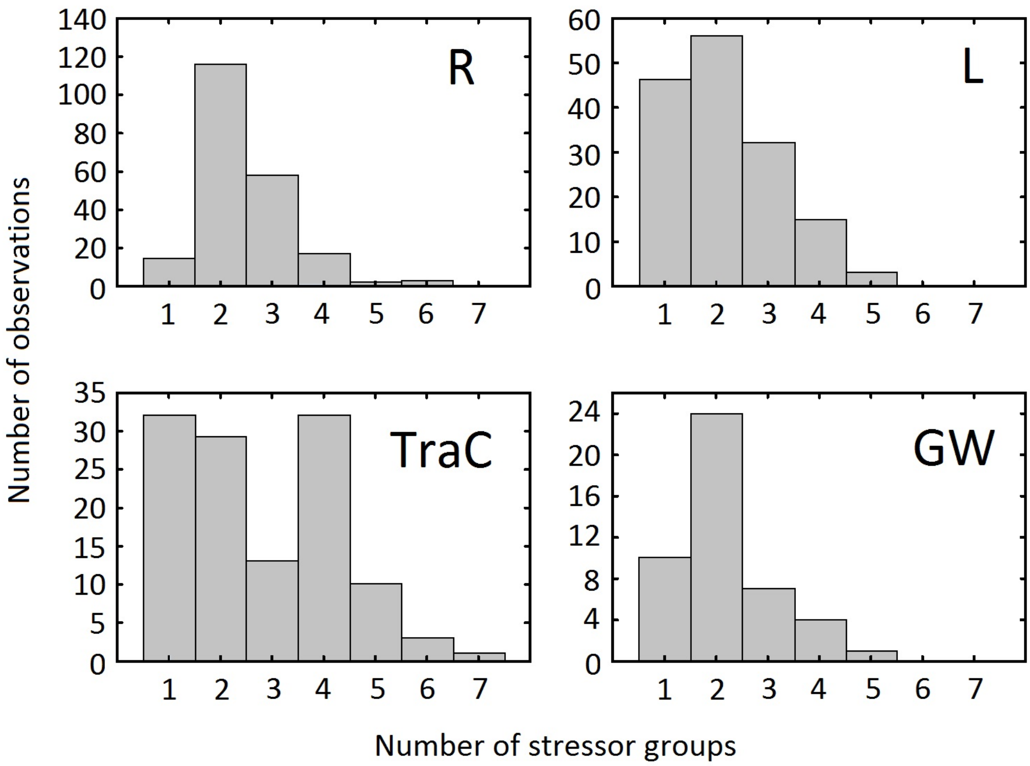

Fig. 3. Number of simultaneously acting stressor groups. Note: R – rivers; L – lakes; TraC – transitional and coastal waters; GW – groundwaters.

Among status and impact indicators, benthic macroinvertebrate metrics were most frequently used in river and TraC water studies, while fish, aquatic macrophytes, zooplankton and physico-chemical metrics were used almost equally as indicators to study multiple stress effects in lakes (not shown). Phytoplankton metrics occupied only the fifth position in lake studies. Among groundwater studies most evidence could be found on contamination with nitrates or toxic substances, while metrics describing groundwater quantity or salinity changes occurred also rather frequently.

The analysis of the broad types of metrics used as response variables revealed several peculiarities by water categories.

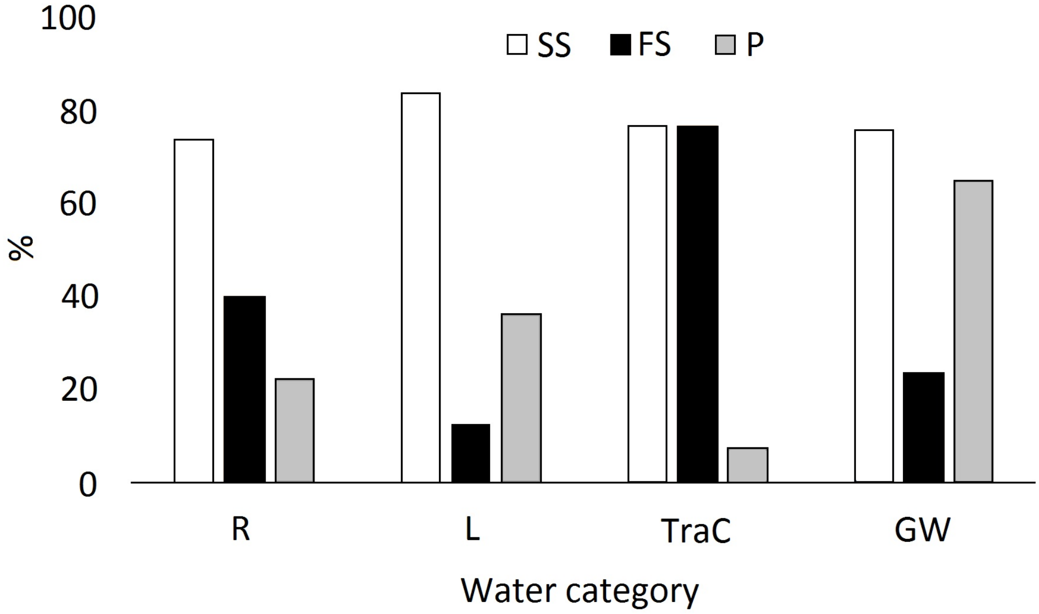

Fig. 4. Percentage of studies in different water categories using as response variables metrics describing simple structure (SS), functional structure (FS), and processes (P). For each metric type both single and time series measurements are included. Note that the sum of these percentages is >100% because several studies included more than one type of metric. R – rivers; L – lakes; TraC – transitional and coastal waters; GW – groundwaters.

Metrics of simple structure dominated in river, lake, and groundwater studies, showing a percentage between 72% and 83%. Metrics describing functional structure were equally represented in TraC studies (Fig. 4). Metrics of functional structure were significantly more often used in TraC studies than in all other water categories ($p<0.01$), and the frequency in rivers was significantly higher than in lakes ($p<0.01$). Process metrics were most frequently used in groundwater studies, followed by lake, river, and TraC water studies with all differences being significant ($p<0.01$).

Static metrics were significantly less often used in groundwater than in surface water studies ($p<0.05$; SM Fig. S3). Making snapshot measurements was almost similarly popular in all surface water categories, used in more than 70% of all studies. Dynamic metrics dominated in groundwater studies were equally used with static metrics in lake studies, and were significantly less frequent in river and TraC studies ($p<0.01$). Two thirds or more of lake and river studies used only one type of metric, while more than half of TraC and groundwater studies used simultaneously two types, often combined into indices (SM Fig. S4).

The median strength (R^2) of the described impact-response relationships for multiple stress situations in rivers (0.42) and lakes (0.47) was rather similar, but was significantly smaller in TraC waters (0.25; Mann-Whitney U-test, p<0.01) (Fig. 5). In groundwater studies the strength of the relationship was not given in most of the studies.

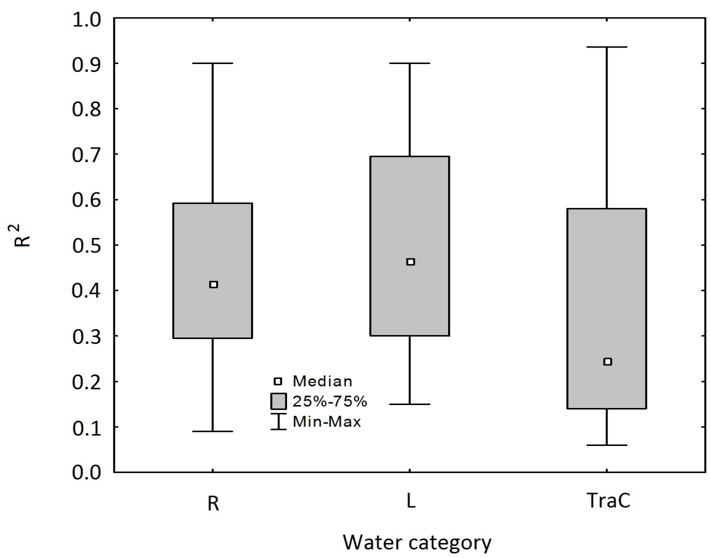

Fig. 5. Strength (R^2) of the described impact-response relationships for multiple stress situations in surface water categories. R – rivers; L – lakes; TraC – transitional and coastal waters.

Over all water categories the explanatory power of benthic macroinvertebrates and fish increased with the number of stressor groups taken into account in the analysis, whereas among primary producers – phytoplankton and benthic flora – the explanatory power decreased in multiple stress situations (Fig. 6). The data for zooplankton and multi-metric indices (including metrics from several biological groups) was too limited to see any pattern in their response (not shown).

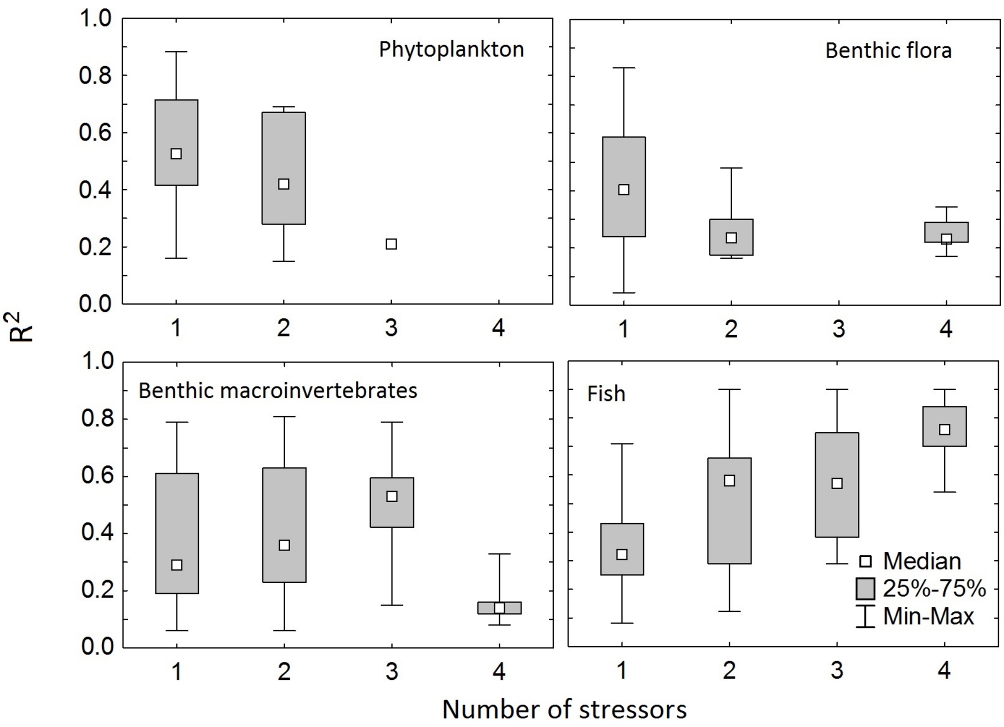

Fig. 6. Changes in explanatory power (R^2) of the pressure-response relationships by biological group with increasing number of stressors considered. Data on single pressure cases (N=84) were taken from the review of national assessment methods (Birk et al. 2012).

Over all biological groups the R^2 of the pressure-response relationships increased with increasing number of stressors considered in lakes and rivers, but the response remained unclear in TraC waters (Fig. 7)

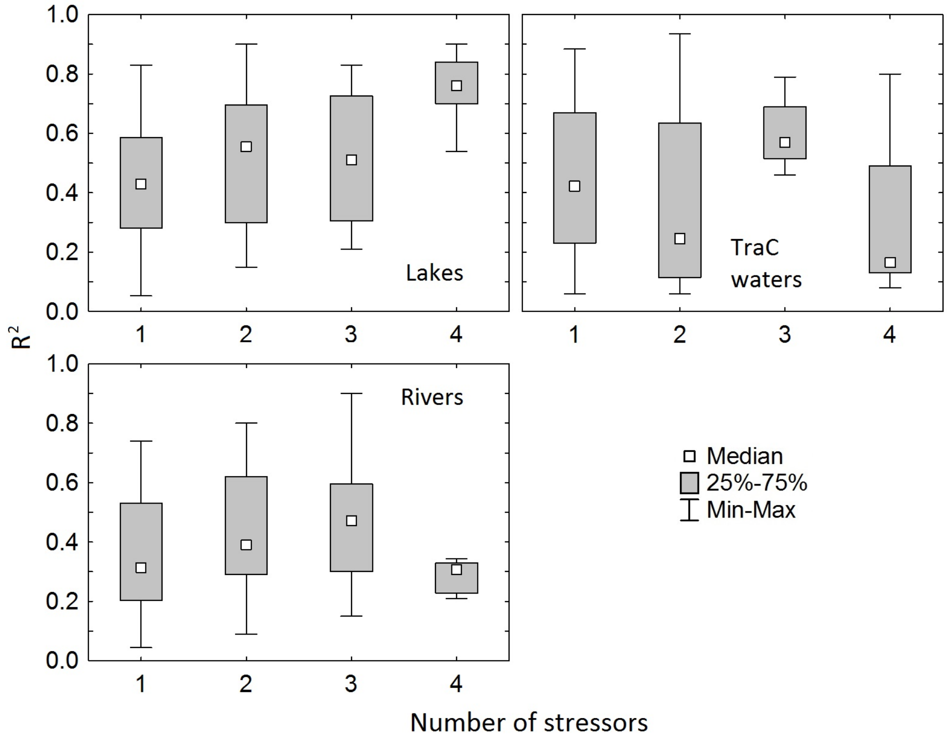

Fig. 7. Changes in explanatory power (R^2) of the pressure-response relationships by water categories with increasing number of stressors considered. Data on single pressure cases (N=84) were taken from the review of national assessment methods (Birk et al. 2012).

The type of interaction between stressors (whether additive, synergistic or antagonistic) was indicated in more than 50% of cases in river and groundwater studies, but only in 15% of cases in lake and TraC studies (Fig. 8). All types of interactions between stressors were represented in all water categories. Synergistic interactions dominated in groundwater studies, additive interactions in TraC water studies, whereas no clear dominance of any interaction type was found in lake and river studies.

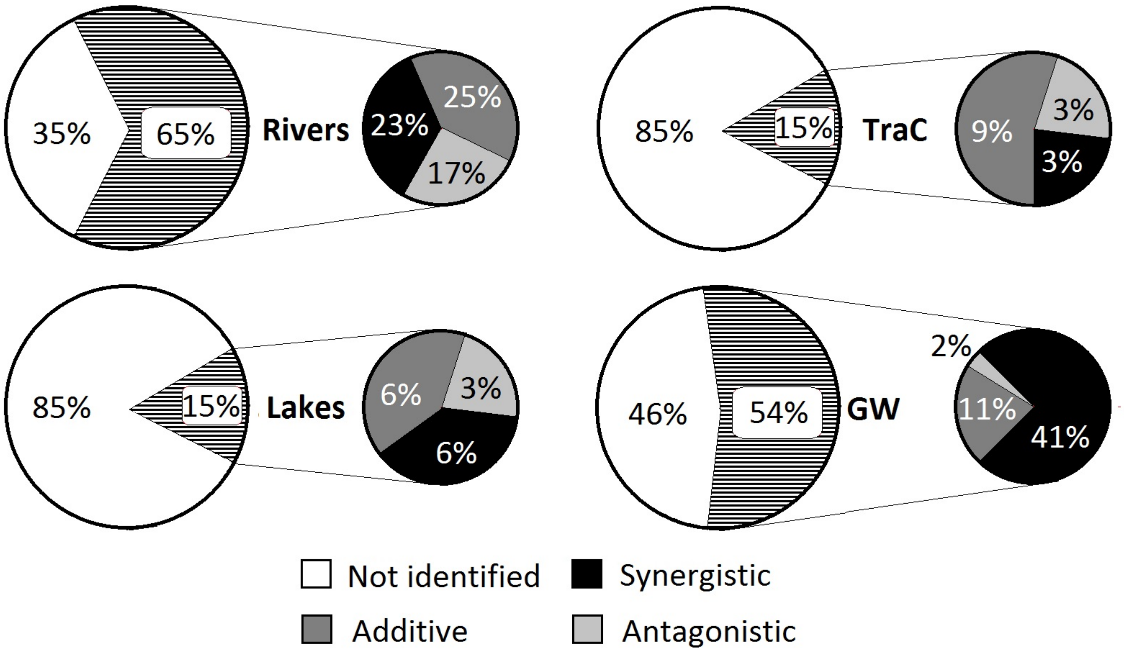

Fig. 8. Interactions between stressors in multiple stress relationships described for different water categories. TraC – transitional and coastal waters; GW – groundwaters.

River studies were clearly biodiversity oriented, whereas in lake and TraC studies biodiversity and water quality risks were equally addressed.

According to our expert opinion, all ten main types of ecosystem services (ES) provided by biota (Maes et al. 2014) were concerned by the multiple stress situations described. In river studies the maintenance of physical, chemical and biological condition was considered most affected while in other water categories the impact was assessed to distribute more uniformly between the different ES categories.

Discussion

Rivers

Rivers are impacted by different stressors and often several stressors are acting simultaneously, especially in Europe (Ormerod et al. 2010; Tockner et al. 2010; Schinegger et al. 2012). The meta-analysis identified hydrology with emphasis on sediment transport and nutrients as the major stressor combination studied in rivers. Each of the stressors is used in more than 70% of the studies as stressors (Table 2). Out of 21 two-stressor combinations identified by the review, the combination 'hydrology' and 'nutrients' occupies a quarter of all possible combinations (Table 3). In highland and mountainous rivers, the ranking of coarse stressor categories stays relatively constant but the importance of specific stressors within the stressor categories shifts. Within the category 'hydrology' the role of flow and water quantity as stressor in the system increases (entries indicating low or high flow as well as level regime as stressor) in comparison to sediment load which represents the second major hydrological stressor.

Flow is a major determinant of physical habitat in rivers which triggered species' life history adaptations (Bunn & Arthington 2002; Poff & Zimmerman 2010). However, those adaptations are linked to natural flow conditions with corresponding effects of flow alterations (Acreman & Dunbar 2004; Dewson et al. 2007) which basically applies to both, fish and macroinvertebrates. More than in lowland rivers, the physical roughness of the available habitats driven by hydrology affects the aquatic organisms and their life stages in high-energy rivers of highlands and mountainous areas. Furthermore, the amount of water in the system proportionally gains weight as discharge of small- and medium-sized rivers, mostly found in higher elevations, is generally lower. Thus, potential interactions of water quantity with other stressors of the chemo-physical environment come into play, like warming (interaction with climate change) or dilution of substances (interaction with pollution).

Not surprisingly, the literature review underlined the importance of flow in the field of river-ecological research in general (Bunn & Arthington 2002). However, looking at biological indicators, a split which aspect of hydrology is investigated occurs between fish and macroinvertebrates: the amount of available water is dominant in fish-based studies (e,g, Walters et al., 2013; Lange et al., 2014), whilst sediment transport is for macroinvertebrate-based studies (e.g. Matthaei et al. 2010; Wagenhoff et al. 2011, 2012). Focusing on the investigated co-stressors, the differences between the two biological groups even get more obvious. This paradigm is emphasised by Marzin et al. (2013) who compared the reactions of different biological groups to different stressors. They underline that fish reacted more to reach-scale anthropogenic pressures, which often affect local hydrology, than to large scale factors like land use, which triggers impairments like eutrophication or fine sediment input (Allan 2004). Obviously, the mode how drivers and stressors act on biota is related to the question of scale and ecosystem hierarchy (Frissell et al. 1986; Poff 1997; Stendera et al. 2012).

Land use is well known as a driver of sediment input into rivers (Wood & Armitage 1997). The role of fine sediment as stressor is intensively shown in different studies and for different aspects of the benthic community. Analyses cover the taxonomic (Matthaei et al. 2010; Molinos & Donohue 2010; Wagenhoff et al. 2011, 2012), assemblage (Molinos & Donohue 2010) as well as the trait level (Larsen & Ormerod 2010) reporting majorly negative effects of increased sediment loads. Especially, the interaction with nutrient levels as disturbance showed synergistic interactions with sediment load (Townsend et al. 2008; Molinos & Donohue 2010; Wagenhoff et al. 2011). In contrast to the studies on macroinvertebrates, interaction effects between the stressors 'fine sediment' and 'nutrients' were not observed for fish (Lange et al. 2014). Conclusively, the two stressors may differ in their mode of action for fish compared to invertebrates and therefore affect fish independently.

Alongside land use change and accompanying intensification of human uses, climate change acts as the second 'big player' as driver of habitat change in rivers (Palmer et al. 2009; Kingsford 2011). Mountain-range and highland rivers are evidently located in environments which impose investigations on climate change: cold thermal regimes and discharge conditions driven by precipitation, both factors which are prone to climate change impacts (Arnell 1999; Caissie 2006). Consequently, climate change per se establishes a multiple stressor setting with potential interactions, i.e. thermal as well as hydrological changes.

Our review identified several studies which aimed at the interaction effects of hydrologic and thermal changes in mountainous rivers on fish (Wenger et al. 2011a, 2011b; Jones & Petreman 2012; Walters et al. 2013) but none considering macroinvertebrates as biological indicator. One study focussed on the interaction of morphological homogenization and flooding events with scouring flows which impact benthic assemblages (Wooster et al. 2012).

As far as thermal regimes were investigated, climate change was addressed as a driver, too. Results-wise, the studies highlighted vulnerability of different life stages (Jones & Petreman 2012) or spatial exposure of distinct habitats (Roberts et al. 2013). The described interactions have been additive in most cases. Complex interactions of the stressors were not necessarily detected (Walters et al. 2013). Beside the interactions in between the chemo-physical factors, interestingly a focus was set on stress originating from biological interactions in climate change-related studies considering the role of competition and predation affects (Stefferud et al. 2011; Wenger et al. 2011a, 2011b). Stefferud et al. (2011) showed potentially increased predation effects during low flow conditions whereas Wenger et al. (2011, 2011b) indicated different sensitivities of salmonid species in a similar distribution range. Climate change will induce different biological reactions. A key aspect in this context is distribution shifts (Comte et al. 2012). Moreover, changes in thermal and hydrological regimes may promote species invasions (Britton et al. 2010). Conclusively, all three factors – thermal regime, hydrology and biotic interaction – will play a vital role in biological responses to climate change impacts.

Lakes

Nutrient stress was included in 78% of the multiple stress evidence items for lakes and was one component in the three most frequent stressor combinations (Table 2 and Table 3) which grouped together nutrient enrichment, stressors linked to climate change and the resulting stress from changed biotic interactions. In a review, Moss et al. (2011) describe how eutrophication and climate change impact on lakes. Both, nutrient loadings and temperature independently and strongly control lake functioning, but Moss et al. (2011) demonstrate also strong interacting effects of these factors on lake ecosystems. Nutrient enrichment of lakes by human wastes and agricultural activities disturbs lakes' natural functioning and, in worst cases, has cascading effects on physico-chemical parameters and communities. Warming increases energy input through enhanced primary production and modifies species dynamics and energy allocation. When both pressures act on lakes, synergistic effects may appear: warming increases the availability of nutrients entering the lakes; those stressors conjointly favour cyanobacteria, floating vegetation and fish biomass (Jeppesen et al. 2011b). When interacting, the increased nutrient load and warming reinforce each other effects and accelerate the vicious circles they trigger.

While Moss et al. (2011) comprehensively addressed the eutrophication-warming interaction, another important mechanism is caused by the interaction between eutrophication and water level fluctuation induced by climate change. Thomaz et al. (2006) studied the effects of a drought-induced temporary five-meter water level drawdown on the macrophyte community of a reservoir. They showed that free-floating species quickly recolonized re-flooded areas hence taking advantage of high nutrient concentrations. Floating vegetation was then replaced by a more complex rooted community. The authors compared these successional steps with what happens when artificial lakes are flooded for the first time, showing that these interacting pressures deeply shape communities. Coherently, Arthaud et al. (2012) showed that drought effects interact with eutrophication to structure macrophyte communities essentially through selection on resilience-traits to drought and light competition. However,in Europe the effects of warming and changes in precipitation are sometimes hard to disentangle as high temperatures are associated with low precipitation and high evaporation (IPCC 2014) while low water levels lead to faster warming-up of water (Reinart & Reinhold 2008).

In addition to climate change, eutrophication notably interacts with biological pressures (20% of the evidence items). Fisheries and fishermen associations manipulate lake fish communities to enhance the productivity of the species of interest. Stockings and introductions made for these purposes often consist of large bodied and often predatory species (Blanchet et al. 2010). Through cascading effects along the trophic chain, these manipulations may deeply modify the community structure and ecosystem functioning (Carpenter et al. 2001; Bucak et al. 2012). Fish community manipulations are expected to interact with nutrient enrichment (Jeppesen et al. 1997; Starling et al. 2002; Kronvang et al. 2005; Bucak et al. 2012) as they both have direct and indirect impacts on algal communities. Still these co-effects may be case-specific. In a whole-lake experiment, in which both the fish communities and nutrient intakes were manipulated, Carpenter et al. (2001) showed no interaction between those stressors as fish community modifications had coherent effects along the phosphorus gradient. However, in a microcosm experiment, fish presence was shown to have significant negative effect on ostracod proportion only in eutrophic ecosystems, indicating an interaction between stressors (McKee et al. 2002a). Reciprocally, abiotic stressors sometimes facilitate the establishment of invasive species (Strayer 2010), including lakes (McKee et al. 2002b; Rahel & Olden 2008).

Coastal and transitional waters

From the 33 papers collated and the 120 evidences of multi-stress gathered, most of the studies dealt with nutrients (97.5% of the cases), followed by toxic stressors (46.7%), hydrological (45.0%) and morphological stressors (38.3%). The bigger attention paid to nutrients in TraC studies is probably due to the large number of impacted water bodies by nutrient enrichment in these environments. For instance in the USA, 65% of the estuaries show eutrophication problems (Bricker et al. 2008), whilst in Europe >40% of coastal water bodies and around 30% of transitional ones are affected by this impact; in turn, hydromorphological pressures affect around 10% and 38% of the water bodies, respectively (EEA 2012).

From our study, the three most common pressure combinations in TraC are those in which nutrient pressures interact with toxic, hydrological, and morphological pressures. Brown et al. (2013) propose three prevailing views about interactions in the management of global stressors of ecosystems: (i) synergisms between stressors are prevalent, being the fact of concern because in this case future rates of ecosystem decline predicted on the basis of individual stressor effects will be underestimated; (ii) multiple stressors have cumulative impacts on ecosystems, implying that management that addresses the largest stressor will have the greatest benefit; and (iii) managing for ecological resilience to reduce the likelihood of ecological transitions to alternative degraded states. Although in our study the type of interaction between stressors was explicit in only 15% of cases, additive interactions were three times more frequent compared to synergistic or antagonistic ones which were equally represented.

However, none of the above three views addresses the prevalence of antagonistic interactions between stressors, assuming that managing a local stressor improves the ecosystem (Brown et al. 2013). As highlighted by these authors, antagonisms imply that local management actions cannot compensate for global stressors such as climate change impacts. Some authors, through meta-analyses of experimental studies from marine, freshwater and terrestrial systems, indicate that antagonisms are as common as synergisms (Darling & Cote 2008; Crain et al. 2008; Foden et al. 2010; Fukunaga et al. 2011; Ban et al. 2014; Strain et al. 2014), as it has been shown in our analysis.

From the analysis done, the most used indicators are macroinvertebrates and physic-chemical, and less frequently fish and macroalgae. This can be an artefact caused by our primary background; however, when analysing over 300 methods used to assess the ecological status in aquatic systems in Europe, Birk et al. (2012) determined that the most common biological groups used to assess the status was macroinvertebrates (27%), followed by phytoplankton (21%), fish (14%), macroalgae (9%) and others. As such, probably when studying the biological responses to multiple stressors, researchers used as indicators those for which assessment methods were more developed, validated and intercalibrated (Poikane et al. 2014).

The metrics used to determine the effects of multiple stressors are a bit more functional than structural, with very few process metrics. This is interesting, since in European marine waters, the methods used to assess the ecological status in TraC waters (within the WFD) are more based on structural metrics (e.g. richness, diversity, etc.), being one of the top 10 knowledge gaps the development of functional assessment tools for the WFD (Reyjol et al. 2014). In turn, the methods that are being developed to assess the environmental status in offshore waters (within the Marine Strategy Framework Directive (MSFD)) are more based on functional metrics (e.g. biological traits) (Borja et al. 2010).

The risks related to multiple stressors in TraC waters addressed biodiversity and water quality in equal proportions, with only one study concerning human health, and no studies concerning water quantity. Such emphasis could be related with the importance of the main stressors studied, i.e. nutrients and toxics, which affect directly the water quality, and the impacts exerted on the biodiversity of macroinvertebrates, fish, macroalgae, etc. Some of these biological groups, especially the benthic ones, act as indicators of cumulative changes in water quality variables, which tend to exhibit rapid and wide fluctuations when measured directly. This is because these components are continuously subject to multiple stressors and disturbances that are associated with changes in water quality along the land/sea interface (Philips & Durako 2000).

The ecosystem services affected by multiple stressors are maintenance of physical, chemical and biological conditions (119 cases), nutrition (113 cases), mediation of waste and toxics (107 cases) and mediation of flows (36 cases), which are in line with the ecosystem services provided by estuaries and coasts (Van den Belt & Costanza 2012).

Groundwaters

Groundwaters are impacted by various stressors leading to either depletion of groundwater quantity or/and quality, including groundwater dependent ecosystems. The review on multi-stressor effects in groundwaters identified climate and its change, water abstraction, sea water and pollutants the major stressors for the groundwater. A general review of the mechanisms and significance of three facets of aquifer degradation (depletion of aquifer storage and its effects on groundwater availability and dependent ecosystems; groundwater salinization arising from various different processes; and vulnerability of aquifers to pollution) is given, for example, by Foster & Chilton (2003).

Regarding natural stressors, the groundwater recharge as a key process securing a replenishment of groundwater is directly influenced by climate and hydrogeological settings. Since hydrogeological settings do not change in time, the climate predominantly affects the changes of groundwater recharge. Climate processes influence groundwater patterns in a complex way, with a number of direct and indirect effects. Climatic variables influence hydrological processes, so any change in precipitation, evapotranspiration, snow accumulation and snow melt impacts on recharge and groundwater formation (Kløve et al. 2014). Substantial reductions in potential groundwater recharge are uniformly projected in southern Europe, whereas increases are consistently projected in northern Europe (Taylor et al. 2013). A global analysis of climate change impacts on irrigation demand suggests that two thirds of the irrigated area in 1995 will be subjected to increased water requirements for irrigation by 2070 (Taylor et al. 2013). Excessive groundwater abstraction is a worldwide problem especially in regions of dry climate (Barron et al. 2012; Candela et al. 2009; Menció & Mas-Pla 2010; Wriedt et al. 2009). Increasing water demand, which in a drying climate is likely to be accompanied by high rates of groundwater abstraction, may pose a further risk to groundwater-dependent ecosystems including maintenance of environmental flow in rivers. The most extreme effects of combination of an excessive groundwater abstraction and dry climate leading to severe land subsidence were addressed by Tomás et al. (2005) and Giambastiani et al. (2007).

Hydrological modelling for various climate scenarios was used to assess an impact of climate change on groundwater resources in the Mediterranean region. Ertürk et al. (2014) showed the decrease of precipitation and subsequently the recharge and increase of evaporation. Almost 60% of precipitation is lost via evapotranspiration in the region. The groundwater levels are projected to decrease for considered climate change scenarios, even in the temperate climate. Drier summers will also likely cause increases in exploitation rate of groundwater. Intensification of irrigation practices by groundwater extraction will also induce an additional water volume leaving the system by evapotranspiration. Additionally, problems of contaminant accumulation within an aquifer (e.g. salts, pesticides, fertilizers) could also appear due to recirculation of water in a closed system (Goderniaux et al. 2009) as an effect of combination of up to three respective stressors.

Seawater intrusion occurs in coastal areas worldwide (Werner et al. 2013) and leads to a failure to achieve good chemical status of European groundwaters (Solheim et al. 2012). The limited number of studies conducted to date on groundwater quality has primarily addressed seawater intrusion into coastal aquifers, and some studies indicate that groundwater pumping is expected to have more of an effect than climate change and sea level rise on seawater intrusion in some coastal aquifers (Kløve et al. 2014). The phenomenon of seawater intrusion as a combined effect of climate (affecting a recharge and thus ground water table level) and water abstraction occurs mainly in arid and semi-arid areas i.e. in case of Europe in the Mediterranean (Demirel 2004; Giambastiani et al. 2007; Grassi et al. 2007; Lambrakis & Kallegris 2001; Petalas et al. 2009; Petalas & Lambrakis 2006; Vodouris 2006).

Changes in recharge rates and mechanisms may also increase the mobilisation of pesticides and other pollutants present in the unsaturated zone and reduce groundwater quality (Kløve et al. 2014) as an effect of combination of these two stressors. In addition to recharge, land use and management practices play an important role in contamination of groundwater, especially in case of agricultural activities such as irrigation, fertilization, pesticide application or even urban settings (Baran et al. 2008; Carlson et al. 2011; Kampbell et al. 2003; Köck-Schulmeyer et al. 2014; Masseti et al. 2008; Menció et al. 2011; Pasini et al. 2012; Stuart et al. 2011; Wick et al. 2012). Higher temperatures may also lead to lower nitrate pollution of groundwater, possibly as a result of increased evapotranspiration (Wick et al. 2012). Complex chemical mixtures of various natural and anthropogenic contaminants occur in groundwater (Loss et al. 2010; Tocallino et al. 2012), but little is known about their potential health effects (Toccalino et al. 2012). Bloomfield et al. (2006) and Stuart et al. (2011) both conclude that the indirect effects of climate-induced changes in demand for water and other natural, and agricultural resources and changes in land use may have a greater effect on fate and transport of pesticides and on nitrate concentrations respectively than direct effects of climate change itself.

General discussion

The need for quantitative evidence

The review underlines that despite the importance of multiple stressor issues, both for science and management, paradoxically poor elaboration of this field is mirrored by the existing research. Ormerod et al. (2010) and Downes (2010) already pointed out the poor capacity to predict correctly the effects of almost any human activity impacting aquatic ecosystems. This assessment is even more pessimistic if the effects of multiple stressors need to be disentangled.

The reasons why multi-stress effects have not been adequately assessed so far are manifold: (i) stressors descriptions are still not fully harmonised impeding large scale analyses; (ii) collected biological information is not appropriate (insensitive) for the combination of stressors; and (iii) collected data has insufficient temporal or spatial resolution to detect the impacts of relevant stressors. For instance, time series are still lacking for several biological groups in a lot of water bodies preventing long-term effect analyses. Sampling in lakes where time series exist to a certain extent is often limited to one pelagic sampling point overlooking warning signals in the more sensitive littoral areas.

Common principles are needed in order to coordinate the European Member States' efforts to improve the protection of waters or restore them in terms of both quantity and quality. Understanding the effect chain in multiple stress situations is evidently important for restoration ecology which is just emerging as a field in aquatic ecology and is a site-, time- and biological group-specific activity (Verdonschot et al. 2013). Here, the knowledge of quantifiable responses to multiple stressors serves as basis to recognise the risks and take adequate management measures. Recently, developed decision support systems for causal analysis, such as CADDIS (Norton et al. 2009) and Eco Evidence (Webb et al. 2011), use scientific literature to inform evidence-based decision making in environmental management. Both applications rely on literature databases containing information on stressor-response associations reported in the peer-reviewed scientific literature but then allow for implementing qualitative cause-effect relationships.

Quantity and quality of the multi-stressor evidence base

Our review revealed that despite the existence of a huge conceptual knowledge base in aquatic ecology, only few studies provide quantitative evidence on multiple stress effects. Hence, the relationships quantitatively described so far cover just a tiny part of common conceptual schemes. While selecting the papers for this review, very often we were unable to find sufficient quantitative evidence in the literature regarding many of the linkages generally accepted as a common knowledge. Accordingly, this constitutes a valuable outcome by itself because it highlights the need for further research.

We see two risks related to quantitative multiple stressor approach. Firstly, the large proportion of single water body-based evidence items among lakes, TraC waters and groundwaters poses the risk of ‘confirming’ linkages on the basis of very little/poor evidence (even if the relationships are statistically strong). These problems can be avoided using a formal evidence synthesis method like Eco Evidence for decision making. Secondly, there may be a temptation to add more and more detail that finally will blur the picture and ‘dilute’ the research resources. To avoid this, one needs to identify a limited number of linkages of highest priority to investigate. The two to four simultaneous stressor groups addressed in the majority of studies reviewed could perhaps be optimal, but this depends on the local conditions.

Differential expression of nutrient stress along the river-lake-transitional-coastal continuum

In line with the recent review by Verdonschot et al. (2013), our analysis revealed that the same pressures originating primarily from human population growth and increases in land use and water use changes, affected all water categories, but the action mechanisms among water categories and, consequently, their impacts could be very different depending on the sensitivity of the systems. Nutrients representing the main physico-chemical anthropogenic stress were involved in 71% to 98% of multi-stress situations in surface water categories and in 42% of those in groundwaters; however, their impact was differently expressed along the groundwater-river-lake-transitional-coastal continuum, determined mainly by the different hydro-morphological characteristics of these ecosystems.

Rivers and partly transitional waters are characterised by (i) high benthal-to-pelagial ratio resulting in higher relevance of morphological stress, and (ii) directional flow and low retention time resulting in lower relevance of physico-chemical stress, and higher relevance of hydrological stress (especially when affecting the retention time). That implies that rivers may transport large inorganic nutrient loads without showing up strong impacts; however, the sensitivity to nutrients increases if flow conditions stagnate, e.g. during drought or manipulated flow (Lake 2003). Dynamic flow, temperature and salinity gradients in transitional waters create strong natural stress in the freshwater–saltwater transition zone resulting in lower species diversity when compared to higher salinity areas (e.g.Remane 1934). Morphometry and topography controlling the flow regime and water exchange determine also the sensitivity of these systems to other stressors. Nitrogen which may have passed the freshwater systems without visible impact may become the limiting nutrient in TraC waters.

Lakes and TraC waters are characterised by (i) low benthal-to-pelagial ratio resulting in lower relevance of morphological stress, which can be expressed only locally at shorelines or if water levels are strongly affected, and (ii) high retention time implying higher relevance of physico-chemical stress, and lower relevance of hydrological stress. In lakes the impact of inorganic nutrients, especially phosphorus, appears when the flow slows down at the river mouth. The effect is nonlinearly depending on retention time. Elliott et al. (2009) showed the importance of the phosphorus source (point vs. non-point) in determining the influence of retention time on phytoplankton. The sensitivity of lakes to nutrient loading and their ability to retain nutrients depends strongly on their morphometry determining the retention time. In TraC waters the local effect of nutrients entering from rivers depends strongly on the exposure and can be suppressed by the dilution effect of advection currents.

Abrupt changes in hydrological conditions at transition points from ground- to surface waters, from rivers to lakes or TraC waters (e.g. Neto et al. 2014), and from lakes to rivers need a harmonisation of quality assessments for adjacent water categories to avoid inconsistencies caused by differentially expressed nutrient impact, e.g. situations in which a high quality river forms a moderate quality lake. Similarly the status of outflow rivers may fall in a lower class compared to lakes from which they start due to high biochemical oxygen demand caused by autochthonous organic matter produced in the lake. Nitrogen fixed by cyanobacteria in lakes may also be transported downstream. Lakes and rivers are partly fed by groundwaters, which, as a rule, are poor in phosphorus but may be highly contaminated by nitrogen. Judging by biota and a Secchi depth of more than 7 m, for example, the karstic Lake Äntu Sinijärv in Estonia may look pristine (Reinart et al. 2003) because the impact of high (up to 5 mg l-1) nitrogen concentrations is not expressed due to the specific hydrological setting.

Strength of relationships

From a purely mathematical viewpoint, the explanatory power of a regression should increase with increasing number of factors taken into account. This is valid if the complexity of the system remains constant. However, the database analysed contained studies from a large variety of systems from rather simple ones with one dominant stressor to highly complex ones in which up to seven stressor groups are affecting systems simultaneously.

Over all biological groups, the R2 of the pressure-response relationships increased with increasing number of stressors considered in lakes and rivers, but the response remained unclear in TraC waters. The latter could perhaps be explained by the fact that two very different water categories – transitional and coastal waters – have been combined and the number of studies involving different numbers of stressors could be unbalanced.

Biological groups responded very differently to the increasing complexity of stress. Across all water categories the explanatory power of benthic macroinvertebrates and fish increased with the number of stressor groups taken into account in the analysis. This shows that the trait-based approach largely applied for these biological groups in which a number of functional attributes can be used to characterise complex habitat conditions, makes macroinvertebrates and fish especially useful as holistic indicators in multiple stress situations.

Among primary producers – phytoplankton and benthic flora – the explanatory power decreased in multiple stress situations. Phytoplankton is specifically sensitive to nutrient stress and benthic flora additionally to hydrology/water level changes. In more complex situations the responses to these primary stressors can be diversified resulting in drop in the explanatory power. However, more research on the interactions between nutrient loading and modification of the hydrological regime (e.g. residence time) is required.

Different paradigms in aquatic ecosystems' research

Our meta-analysis revealed a striking difference in the temporal resolution of data collected in rivers compared to other water categories: the bulk of river data is collected using single surveys. An obvious reason for that is the ambiguity of the water body concept for rivers (at least, compared to lakes) described as a continuum or sequence of individual sections of the running water (Vannote et al. 1980). Due to rotation of river stations in many monitoring schemes, or due to different lengths of river sections studied, no time-series for the same sites are built up. To compensate for the missing time dimension, a large variety of functional attributes of taxa have been developed showing the feeding type, reproduction biology, preferences for biocoenotical region, habitat, and flow velocity (Hering et al. 2004). Since the development of the saprobic system by Kolkwitz & Marsson (1902), a number of sensitive/tolerance indices have been routinely used as first-hand tools for ecological status classification in rivers, whereas the paper by Karr (1986) gave a strong impetus for creating multi-metric indices. Metrics of functional structure were used in 40% of the river studies analysed reflecting the long tradition, compared to only 8% in lake studies (see also Birk et al. (2012) for a review of metrics used in biological assessment methods).

The bulk of lake data in the papers analysed represented time-series of different length up to 85 years (Jeppesen et al. 2012). Leading theories in lake research such as the trophic cascades concept (Carpenter et al. 1985), the alternative stable states concept (Scheffer et al. 1993), the phosphorus limitation paradigm (Vollenweider 1968; review by Sterner 2008) or the microbial loop theory (adopted from marine research; Azam 1983) all study the dynamics of fundamental processes. Owing to the available long time-series on lakes extendable to thousands of years by palaeo-studies of sediments, lakes have been recently recognised as sentinels and integrators for the effects of climate change on watersheds, airsheds, and landscapes (Schindler 2009). Although process parameters reflecting nutrient dynamics, community metabolism, or food web processes were significantly more often described in lakes compared to rivers and marine waters, still the majority of 'dynamic' metrics was constituted by time series of simple structure metrics, while functional structure metrics were least developed for lakes.

The TraC water studies reviewed here pertain (with only one exception) to the last decade (2005-2014) and reflect mostly the new methods specifically developed to satisfy the European WFD requirements. By nature, transitional and coastal waters range by exposure or connectivity to the world's ocean from topographically open systems to semi-enclosed and enclosed systems (Lindgren & Håkanson 2007) that largely defines the water retention time. Due to this large topographic variability, the conditions in TraC waters range from as dynamic as in rivers to as stable as in lakes. Considerable salinity gradients in transitional waters add to the variability of habitat conditions. Assessment methods addressing multiple stressors in TraC waters are in most cases based on indices composed of a number of metrics of simple and functional structure.

We could not find studies quantitatively describing multiple stressor effects in groundwater ecosystems although qualitative studies exist and have been reviewed by Stendera et al. (2012). The reviewed groundwater studies addressed the abiotic side of groundwater research and were mostly based on physical models that explain the broadest use of process metrics among water categories. Functional metrics were represented by soil properties such as pressure and pathway parameters.

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Deliverable 2.1 - Four manuscripts on the multiple stressor framework: Cook-book for ecosystem service assessment and valuation in European water resource management (2/4)

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CO	Confidential, only for members of the consortium (including the Commission Services)	

Content

Non-technical summary

MARS aims to analyse the effects of multiple stressors on the status of European waters and on the ecosystem services provided by aquatic ecosystems. *Ecosystem services* refer to the benefits that people obtain from ecosystems, the direct and indirect contributions of ecosystems to human well-being.

This work proposes a methodological framework for the biophysical assessment and the economic valuation of water ecosystem services at the water body, the catchment and the European scale. It suits the intent of understanding how changes in pressures may affect the delivery and the value of these services.

To this end, we integrated the existing knowledge with experience and needs of the partners of the project (collected through a consultation), to propose practical methodologies able to address the project specific objectives.

This report is organized as follows. The first section analyses the objectives of the ecosystem services assessment in MARS, explains how and why we selected and designed the methodology proposed, and discusses the concepts of ecosystem services and their integrated assessment and valuation. The results of the consultation of the project partners are presented in the second section. The third section ("cook-book") exposes, in a concise and practical way, the approach and methodologies proposed to assess and value water ecosystem services in MARS. Finally, some major issues related to this methodology are discussed in the last section.

The work presented in this report tries to link the assessment and valuation of water ecosystem services to the ecosystem status and to the analysis of the impacts of pressures at different spatial scales (water body, catchment and European scale).

1. Introduction

1.1 Objective

The project MARS aims to analyse the effects of multiple stressors on the status of European waters and on the ecosystem services provided by aquatic ecosystems. While the *ecological status* expresses the quality of the structure and functioning of the aquatic ecosystems (Directive 2000/60/EC), *ecosystem services* refer to the benefits that people obtain from them (MA, 2005), the direct and indirect contributions of ecosystems to human well-being (TEEB, 2010). In MARS the analysis will be conducted considering three spatial scales: the water body, through field experiments, such as river flumes and mesocosms, where stressors changes are controlled; the catchment, studying the effect of multiple pressures across different climatic conditions in 16 European catchments, ranging from Southern to Nordic catchments; and the European scale, where the effects of multiple pressures will be assessed on the whole continent.

The purpose of the research presented in this report (MARS Task 2.2) is to develop a methodology to assess and value the ecosystem services provided by aquatic ecosystems, with the aim to study the effect of multiple stressors on ecosystem services at the three scales of interest for the project. The methodology will be then applied in the course of the project at the water body, the catchment and the European scale.

1.2 Strategy to design the assessment methodology

To develop the methodology we combined two approaches. On the one hand, we analysed the framework and concepts of ecosystem services to provide definitions, indicators and methods for assessing and valuing ecosystem services in water ecosystems for the specific application in MARS, based on literature review and on-going initiatives in Europe (MAES, Maes et al. 2014; EU FP7 OpenNESS and OPERAs projects). On the other hand, we collected the experience, knowledge, and needs of the MARS partners through a web questionnaire, to select the relevant ecosystem services and target the methodology. We considered this research as a learning process, where previous experiences in the MAES working group and information available through literature review had to be combined with the knowledge and expertise of the project consortium, independently from previous experience in ecosystem service assessments. We integrated the outcomes of our analysis and partners' consultation to propose a methodology that addresses the objectives of the project and can be applicable in practice.

In the development of the research, the interaction with the MARS partners that will apply the methodology at the different spatial scales (water body, catchment, European scale) has been organised around two major events. The first in May 2014, when the web questionnaire for partners' consultation was sent, and the second in October 2014, when we presented the results of the questionnaire and circulated a draft of the proposed methodology for partners' comments and feedback (Figure 1.1).

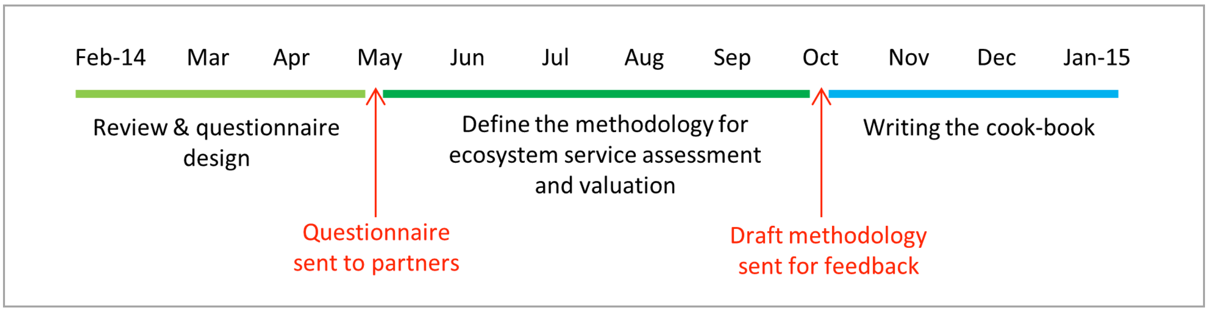

Figure 1.1 Main steps in the development of the MARS methodology for assessing and valuing ecosystem services.

This report presents the results of this research. It is organised in four parts. After a thorough analysis of the objectives of the assessment, the document explains how and why we selected and designed the methodology proposed (Chapter 2), discussing the concepts of ecosystem services and their integrated assessment and valuation in MARS. Then, the results of the consultation of the project partners are presented (Chapter 3). Chapter 4 (the cook-book) shows in a concise and practical way the methodology proposed to assess and value water ecosystem services for MARS. Finally, some major issues related to this methodology are discussed (Chapter 5).

To improve the readability of the document and the practical application of the methodology most of the results (data, information and tools) on which chapters 2-4 are based are presented in the Annexes 1-6, and Annex 7 provides definitions of some key terms used in the report.

2. Analysis

This section presents the results of the analysis and literature review conducted for developing the methodology for assessing and valuing ecosystem services in MARS. We start from the analysis of the purposes of the assessment in the project to shape the methodology and we then present and elaborate the concepts of ecosystem services (definition, classification) in the context of the project. We propose an integrated framework for the assessment of water ecosystem services and discuss the challenges of a valuation. Finally, the methodologies for the biophysical and economic assessment of water ecosystem services are presented.

2.1 Scope and scale of the assessment

The first step in developing the methodology for assessing and valuing ecosystem services is an attentive analysis of the purpose of this methodology in the project MARS. What do we want to achieve in the project? What should the methodology fulfil? Clearly identifying the objectives is essential for developing a suitable and targeted approach. It is also necessary as the field of "ecosystem services" is broad and in part undefined.

The overall objective of the project MARS is to study the effects of multiple-stressors on the ecological status and the delivery of ecosystem services in surface water and groundwater, to support managers and policy makers in the practical implementation of the Water Framework Directive (WFD, Directive 2000/60/EC). It will analyse and predict multiple stressor-impact relationships at three scales: water bodies (WP3), river basins (WP4) and Europe (WP5). The project will define overall concepts and methodologies for the assessment and valuation of ecosystem services with the aim of demonstrating the practical use in multiple-stressor problems for river basin managers (WP2). Specifically, the project refers to the **biophysical quantification** and **economic valuation** of ecosystem services. (Box 1 summarises the main research activities related to ecosystem services per different project work packages, as described in the DOW).

The ecosystem services of interest are those related to the water bodies covered by the WFD and relevant for the river basin management. The methodology should 1) address ecosystem services at different scales, 2) represent the effects of multiple stressors, and 3) support the integrated river basin management.

Box 1 - Ecosystem services in the DOW

WP2 will review existing approaches and methods of ecosystem service assessment and valuation at various spatial scales, and will provide guidelines for service valuation in WPs 3-6 and more generally for the use in river basin management. It will provide an overview of concepts and criteria for indicators (water quality, water quantity, ecological quality and ecosystem services) applicable in integrated river basin management and will select benchmark indicators to be applied within other WPs.

WP3 will assess the combined impacts of extreme climatic events (floods, low flow, thermal extremes, extreme mixing and pulsed DOM loading), nutrient loading and morphological alterations on selected core indicators, including ecological status, ecosystem structure, function and resilience in ecosystem service delivery.

WP4 will link catchment models, benchmark indicators and risk assessment to appraise how multiple stressors affect water quantity and quality, ecological status, ecological functions and ecosystem services under contrasting scenarios of water resource management, land use and climate change. The work interfaces directly with river basin and regional environmental management. It will demonstrate how the improved models can be used to guide River Basin Planning and Programmes of Measures through enhanced policy support related to EU water resources.

WP5 will describe patterns of multiple stressors, ecological status, water quantity, water quality and ecosystem services at the European scale for lakes, rivers, groundwater and transitional waters to be displayed in a series of maps; to analyse linkages between multiple stressors, status and services at the European scale for lakes, rivers, groundwater and transitional waters; in specific, Subtask 5.1.4 will carry out a spatial assessment of services delivered by European aquatic ecosystems.

WP6 will synthesise the results from WPs 3-5, enhance understanding of stressor interactions and stressor-response relationships across scales, including the sensitivity of particular species, water-body types, or ecosystem services to common stress combinations identify indicator and tool gaps for improving Integrated River Basin Management across Europe. Task 6.4 Integrated River Basin Management: evaluation of the MARS conceptual model. The benefits of sustaining ecological flows and the value of green infrastructure for natural water retention measures (flood regulation and drought mitigation).

WP7 will integrate the results from WP2-6 into practical, easy-to-use tools to support water resources management. The tools will contribute to designing cost-effective programmes of measures to extend and improve existing tools to detect and diagnose changes in chemical, ecological and quantitative status of water bodies, and to identify the risks for ecological functioning and capacity for provision of ecosystem services. A set of benchmark indicators addressing water quantity, water quality, ecological status, ecosystem functioning and ecosystem services will be presented

WP8. A set of benchmark indicators addressing water quantity, water quality, ecological status, ecosystem functioning and ecosystem services will be presented interacting with the most relevant WFD-CIS groups to provide timely inputs to guidance documents concerning impacts of multiple stressors on water status and related ecosystem services, and the best mitigation measures.

2.1.1 Address ecosystem services at different scales

Considering the case studies of the project at the three different spatial scales, water body, catchment and the European scale, we can identify specific objectives and opportunities of the assessment of ecosystem services (Annex 1).

At the water body scale (Annex 1 Table A1.1), in confined experimental conditions, the main focus is the analysis of specific functions of the ecosystem that support certain ecosystem services, and the study of their alteration under different combinations and changes of stressors (which in the experiments are controlled). In these experiments the functions supporting the ecosystem services can be assessed, while the demand side is not directly taken into consideration (preventing the full application of the ecosystem service assessment).

The case studies at the catchment scale offer the relevant spatial scale for the application of ecosystem services concepts in river basin management (possibly through River Basin Management Plans). Within the catchment, the aquatic ecosystems and their services can be further mapped at the water body scale or by sub-catchments or regions, depending on the data availability and the resolution desired for the assessment. The catchment is the appropriate scale to observe and quantify processes related to the water cycle, to implement monitoring and management plans, and to test and downscale scenarios of multiple-pressures. The 16 catchments of MARS represent a great variability of pressures and ecosystem services across Europe (Annex 1 Table A1.2). In addition, in these case studies the research will involve the local stakeholders, which is relevant for the application of ecosystem service concepts in the development of management plans.

The assessment and valuation of ecosystem services at the European scale allows to address regional trends, identify hot spots in the delivery or degradation of services, test the effectiveness of regional policies (such as EU Directives) and scenario analysis at the large scale (Annex 1 Table A1.3). Data issues are related to the availability of homogeneous and consistent data across Europe, which is possible when data are based on satellite images but more difficult when monitoring data are collected by national and regional agencies. In terms of resolution, aquatic ecosystems at the European scale can be mapped as water bodies, river basins or sub-catchments, or areas, and generally rely on the catchment as the meaningful spatial unit for processes related to the water cycle.

2.1.2 Represent the effects of multiple-stressors

The methodology developed by the project MARS should be able to describe the impacts of multiple-stressors on the delivery of ecosystem services, under different scenarios. Based on the description of the case studies at the different scales, we can summarise that the main pressures that affect the aquatic ecosystems are related to alterations of water quantity and quality, and to changes in the habitat and the biological components (Table 2.1).

An important aspect in this respect is that the excessive exploitation of ecosystem services can turn into a pressure for an ecosystem. It is important that the conceptual framework of the methodology correctly addresses the inherent link between ecosystem services and pressures. For this reason we would like to include the concept of sustainability in the assessment of ecosystem services (this will be discussed in Section 2.4).

Table 2.1 Main pressures that affect aquatic ecosystems. The pressures can be the consequence of different drivers, such as changes in population, economic activities, land use and climate.

<table>
<tr><th colspan="2">Alteration of:</th></tr>
<tr><td>Water quantity
Flow modifications (hydrological alterations):
• Quantity and frequency (dams, water abstractions, irrigation, transfers)
• Groundwater abstractions
• Changes in precipitation and temperature
• Changes in runoff</td><td>Water quality
Diffuse and point pollution:
• Nutrients
• Chemicals (pesticides, endocrine disrupting compounds, nanoparticles, etc.)
• Metals
• Pathogens
• Litter
Groundwater salinization
Sediments, increased turbidity and brownification</td></tr>
<tr><td>Habitat
Hydromorphological alterations (physical alteration of channels, bed disruption, dams, etc.)</td><td>Biota and biological communities
Alien species
Overfishing</td></tr>
</table>

2.1.3 Support integrated river basin management

The final aim of the project MARS is to support managers and policy makers in the practical implementation of the Water Framework Directive (WFD). With respect to the methodology for assessing ecosystem services two levels of objectives can be identified. A specific level of application for analysing the link between ecosystem services and multiple-stressors, and a more general level for assessing and valuing ecosystem services to support the development of River Basin Management Plans (RBMP) foreseen under the WFD, that is relevant for the catchment and European scale analysis.

Indeed, the ecosystem service approach could be appealing for policy makers and river basin managers to quantify and justify the cost of maintaining and restoring ecosystems (conservation), to set target of sustainable use of natural resources, to highlight co-benefits of certain measures, and to analyse trade-offs between different stakeholders' needs or different scenarios.

The application of the ecosystem service approach in river basin management means that the methodology should make use of appropriate data (such as data already available by monitoring) and tools for water management, such as hydrological models. It should be spatially explicit, to the extent possible, to support the spatial planning, and should include the interests and perspectives of all stakeholders involved.

Above all, to support the implementation of the WFD, the methodology should be applicable in practice. This means in several cases to opt for pragmatic solutions and delimit the context of application. We will discuss further the link between the ecosystem service approach and Integrated Water Resource Management (IWRM) in Section 2.2.

2.1.4 Characteristics of the methodology

To summarise, based on the previous analysis of the scope we can identify some requirements that the MARS methodology for assessing ecosystem services should fulfil:

- define the ecosystem services relevant for aquatic ecosystems and water resource management;
- provide quantitative information on the benefits people obtain from nature including economic value, with the focus on biophysical quantification and monetary valuation;
- be sufficiently simple and flexible to be applied for the analysis at the different spatial scales (water body, catchment, Europe) by different users across Europe (not site-specific);
- capture the effect of multiple stressors and scenarios on ecosystem services delivery;
- support the river basin management process, which means offering an approach that considers sustainability (and conservation) of natural resources, is sufficiently pragmatic (using data and tools that are available and suitable for river basin management), is linked to valuation (cost-benefit analysis, trade-off analysis) and proves effective in communication with stakeholders involved in river basin management planning.

We have considered these elements as guiding principles in the development of the methodology, which is discussed in the rest of the document.

2.2 Ecosystem services and water management

2.2.1 Ecosystem services

Ecosystem services are the benefits that people obtain from ecosystems (MA, 2005), the direct and indirect contributions of ecosystems to human well-being (TEEB, 2010) (for definitions of terms see also Annex 1 of Maes et al. 2014). One of the goals of the conceptualization of ecosystem services is to make more visible the key role that biodiversity and ecosystem functions play to support multiple human benefits, such as nutrition or safety. Understanding the linkages between the natural and socio-economic systems can lead to appreciation and, consequently, to an improved protection and management of ecosystems (Alahuhta et al., 2013).

Several classifications and **conceptual frameworks** have been proposed to analyse ecosystem services, such as the Millennium Ecosystem Assessment (MA, 2005a), the Economics of Ecosystems and Biodiversity (TEEB, 2010), and the Common International Classification of Ecosystem Services (CICES, Haines-Young and Potschin, 2013). The Working Group on Mapping and Assessment of Ecosystems and their Services (MAES), which was set up to support the implementation of the EU Biodiversity Strategy to 2020, has developed an analytical framework to ensure that consistent approaches are used by the EU and its Member States (Maes et al. 2013). The conceptual framework is based on the CICES v4.3 and has been tested in several pilot studies, including one on freshwater ecosystems and another on marine ecosystems. To be consistent with the assessments carried out in the EU we propose to use the CICES v4.3 as reference for the MARS methodology. In CICES, ecosystem services are considered through the ‘cascade model’, which links the structure and the functions (processes) of the ecosystem to the service, which can be translated into benefits and values associated to human well-being (Figure 2.1).

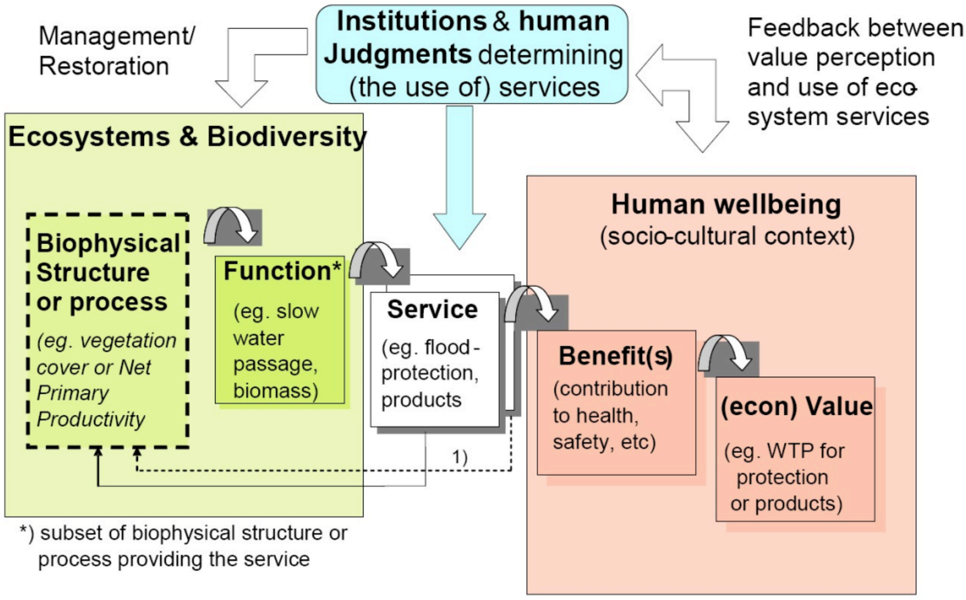

Figure 2.1 Illustration of the cascade model, a conceptual model to analyse ecosystem services, from De Groot et al. (2010).

2.2.2 Water related ecosystem services

A large variety of ecosystem services have been addressed by ecosystem services assessments such as MA, TEEB, MAES, and national assessments (Pereira et al., 2006; UK NEA, 2011). In MARS we are interested to study ecosystem services related to water and aquatic ecosystems. Maes et al. (2014) have analysed the **ecosystem services per typology of ecosystem**, considering the services delivered by rivers, lakes, groundwater and wetlands in the freshwater pilot study, and those provided by transitional waters, coastal waters, shelf waters and open ocean in the marine pilot study. With a slightly different approach, Brauman al. (2007) discussed the '**hydrologic ecosystem services**', defined as the ecosystem services that "encompass the benefits to people produced by terrestrial ecosystem effects on freshwater", each hydrological service being characterised by the hydrological attributes of quantity, quality, location and timing. Keeler et al. (2012) described in detail water-quality related ecosystem services. Recently, Guswa et al. (2014) have addressed more generally the 'water related ecosystem services', discussing the link between hydrological modelling and the ecosystem services relevant for river basin management. From these studies we can observe two approaches in the organisation of the analysis, one per ecosystem typology (Maes et al. 2014) and the other per hydrological relevant services (Brauman et al. 2007). Both approaches consider the integration of the processes, the first by accounting for all the ecosystems in the analysis, the second by integrating the processes in the river basin.

In the DOW of MARS, the ecosystem services of interest are referred as: ecosystem services at the water body, river basin and European scale; ecosystem services of surface and ground waters; ecosystem services for lakes, rivers, groundwater and transitional water; ecosystem services delivered by aquatic ecosystems; ecosystem services associated with riparian areas; ecosystem services relevant for water resource management. In MARS there is primarily a focus on the ecosystem services delivered by the aquatic ecosystems, which can be linked to the water body status, and secondary an interest in the hydrological ecosystem services relevant for river basin management, which may include processes related to the interaction of water and land in different ecosystems, such as forest, agriculture, riparian areas, wetlands, and water bodies.

To address the principal focus of the project, starting from the experience of MAES pilot studies, we developed a classification of ecosystem services based on the CICES v4.3 and we linked it to the classifications of the Millennium Ecosystem Assessment (MA, 2005a) and the Economics of Ecosystems and Biodiversity (TEEB, 2010) (for users more familiar with other classifications). The idea was to offer a coherent terminology relevant for MARS partners, sufficiently simple for stakeholders, and meaningful for river basin managers. The **list of ecosystem services** relevant for water systems we proposed for MARS is presented Annex 2 Table A2.1. In the analysis we considered the following aquatic ecosystems: lakes, rivers, transitional waters, coastal waters, groundwater, freshwater wetlands, coastal wetlands, riparian areas, floodplains. Providing a list of ecosystem services for the aquatic ecosystems can support the practical implementation of the methodology, but of course the list has not to be considered exhaustive and more services can be included, especially hydrological services relevant for river basin planning and decision making. We tested the list of ecosystem services in the partners' consultation. The results are discussed in Section 3 of this report.

The list of ecosystem services proposed in Annex 2 was developed to facilitate the analysis of the effects of multiple-stressors on the delivery of aquatic ecosystem services. If the objective is to carry out a comprehensive trade-off analysis using the ecosystem service approach at the river basin scale, we recommend using the original CICES v4.3 where a longer list of ecosystem services is provided (including terrestrial ecosystem services), considering the specific characteristics of the region under study.

2.2.3 Ecosystem services and water resource management

The interest of MARS in providing support to the implementation of the WFD and **River Basin Management Plans** (RBMP) brings in the discussion on the use of the ecosystem service approach in water management and the relationship between ecosystem services and Integrated Water Resource Management (IWRM).

IWRM is defined as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP, 2000). Before the ecosystem service approach (see definition in Annex 7), IWRM already insisted on the need of connecting environment and human well-being and proposed the integration of multi-disciplinary knowledge from different sectors and stakeholders in the water management.

There are significant similarities between the ecosystem services approach and IWRM. Cook and Spray (2012) argue that the two concepts are 'nearly identical'. Both aim at a management of natural resources that optimises the economic and social welfare and contemporary insure the ecological sustainability, integrating the knowledge of stakeholders and multiple disciplinary perspectives. As IWRM has a longer history in concepts development and in the implementation, they suggest that learning from the criticisms to IWRM would help improving the adoption of the ES approach.

These criticisms are related to several aspects. First of all the lack of a consistent definition and the difficulty of developing a holistic approach, for analysing all the links between sectors needed in the management and integrating all the range of knowledge involved. Similar criticisms on the lack of clear definitions have been moved to the ecosystem service approach, and considering the boosting of the scientific publications (and communities) now adopting the terminology there is also some confusion and the risk of an inconsistent use of terms (Jax et al. 2013). The concept of IWRM has also been considered quite broad, so that can be interpreted to suit opposite societal visions, from resisting to supporting neoliberalisation of water resources (Cook and Spray 2012). The Ecosystem Service approach aims at making explicit the value of ecosystem services, but this might involve the risk of creating economic markets for provisioning, regulating and cultural services. The challenge is to recognise the value of ecosystems and their services, especially for those not considered so far, without let them being managed only by the markets. The third main criticism to IWRM according to Cook and Spray (2012) is the failure to incorporate the principles in the governance, for the inherent difficulty in the implementation of concepts into practice, because of the barriers to change in the mentality of governments and water managers, and the inability to reconcile the social and ecological systems of water management. The 'implementation gap' is also an important challenge for the ecosystem service approach, and the main goal of entire research projects, such as MAES, OpenNESS, OPERAs, or current national assessments.

Ecosystem services and IWRM both share the goal of negotiating the trade-offs between different human and ecosystem needs, while supporting sustainability, and require the involvement of stakeholders for making explicit the whole range of values (not only economic values). The ecosystem service approach offers a framework for analysing the trade-offs among different services and the links to beneficiaries (Brauman et al. 2007). But importantly, in river basin management the main goal is the state of receiving waters, which have some target state to be achieved by a combination of measures to be implemented in the catchment in a cost-efficient way, while in the ecosystem services approach the emphasis is on ecosystems not specifically on target values, which however could be included in the analysis.

In our opinion IWRM used more the term "environment" while the ecosystem service approach used the term "ecosystem", with environment referring more to resources and physical conditions, and ecosystem inherently making more explicit the dimension of the relationships between physical conditions, biota, biodiversity and functions.

The concept of human-ecological system advocated by the ecosystem service approach is very powerful in linking biophysical processes and human benefits, and allows ecosystem services to be valued and integrated in the river basin decision making process. There are high expectations from the use of the ecosystem services approach to capture and integrate all the effects (economic, environmental and social) associated with new plans and investments (in a way similar to the Environmental Impact Assessment). Hydrological modelling can provide knowledge and tools to integrate the water related ecosystem services into the land management decisions, such as in scenarios analysis, payments for ecosystem services, and strategic spatial planning (Guswa et al. 2014).

Finally, we have also to notice that the WFD refers to economic valuation in decision-making to support the RBMP in the identification and selection of a cost-effective Programmes of Measures (PoM, WFD Article 11). The development of the PoM can be improved integrating all relevant ecosystem services, for example considering the co-benefits of different Natural Retention Measures on different ecosystem services. In addition, the WFD (under Article 9) requires Member States to implement the cost-recovery principle in the water supply system, and benefits of ecosystem services could be included in the Cost-Benefit Analysis. Some recent studies have been reflecting on the potential of the ecosystem service approach in the application of the WFD and RBMPs, highlighting the opportunity of the holistic system thinking to understand the co-benefits of measures (Vlachopoulou et al. 2014; COWI 2014; ESAWADI 2013).

2.3 Integrated assessment

The reflections on ecosystem services and water management reveal the potential of the ecosystem service approach for integrated analysis and the evaluation of trade-offs, and bring us to the next step of our analysis: the development of an integrated assessment framework and the discussion on the valuation of ecosystem services. In this context it is important to mention that there are two ongoing EU FP7 projects, OpenNESS[1] and OPERAs, both started in 2013, specifically dedicated to the study of the concepts of ecosystem services and natural capital and their operationalization. The approach proposed in this document is functional to the purpose of the project MARS and makes reference to the work developed so far by these projects, but has not the ambition to completely resolve the methodological issues relative to ecosystem services.

2.3.1 Linking pressures, status and ecosystem services

In MARS the methodology for assessing and valuing ecosystem services has to be able to capture the effects of multiple stressors on the delivery of the services, as well as to consider the relationship between aquatic ecosystem status and services.

The approach proposed by MAES for the pilot studies (Maes et al 2014) was based on the assumption that the delivery of ecosystem services depends on both the spatial accessibility of ecosystems and the ecosystem condition. Following this hypothesis, the working structure proposed in MAES consisted of four steps: 1) the spatial mapping of the ecosystems; 2) the assessment of the conditions of the ecosystems; 3) the quantification of the ecosystem services; and 4) the integration of these two components in an integrated assessment, considering the range of ecosystems and services and their relationships in space and time. MAES put a great emphasis on the spatial dimension of the analysis and on the use of data already collected through the current EU policy frameworks.

In the case of aquatic ecosystems this working structure corresponds to analyse on one side the (ecological) status of water bodies and on the other side the ecosystem services delivery. Multiple pressures and their changes can result in the alteration of both the status and the services. Analysing these variations is at the core of the project MARS, with scenarios of multiple stressors tested by experiments or modelling. The challenge is to disentangle the complex relationships between stressors, status and services, and correctly distinguish between indicators of condition and service.

Integrated assessment means as well analysing the synergies and conflicts between different services in the current situation and under different future scenarios (trade-offs). In addition to

[1] The authors of this report are participating to the project OpenNESS, supporting synergies and reciprocal learning between MARS and OpenNESS on the ecosystem services related to aquatic ecosystem and water resource management. They are also collaborating with the project GLOBAQUA on economic valuation of ecosystem services.

changes in pressures, MARS will investigate a number of scenarios of possible future development, which will involve specific combinations of multiple pressures. In this regard the possibility of quantifying the changes in the delivery of services by biophysical and hydrological models appears crucial.

To summarise, the working hypothesis of MARS that will be tested throughout the project is that the multiple stressors affect the status of the aquatic ecosystem (the ecological status and more generally the ecosystem status), which in turn could result in a change in the ecosystem services and in their economic value, schematically:

Change in Pressures[2] → Change in Ecosystem Status →Change in Ecosystem Services → Change in Value

The methodology for assessing and valuing ecosystem service in MARS should be able to explore the nature of these linkages. To this purpose, we developed a **conceptual framework for the integrated assessment** of water related services to support the users in making explicit the links between pressures (and scenarios) and ecosystem services. The framework is presented in Annex 3.

In the framework, we identify the main pressures affecting aquatic ecosystems (according to Table 2.1) and the possible links to the alteration of four ecosystem/hydrologic attributes: 1) water quantity (including seasonality); 2) water quality; 3) biological quality elements; 4) hydromorphological & physical structure. The attributes are different from those proposed by Brauman et al. (2007), to include in the analysis the biological and hydromorphological aspects and to make the link to the WFD elements explicit (so that the relationship to ecological status should be in principle more easy and the analysis based on similar data). For each attribute we selected a number of representative indicators and identified the possible relationships with the ecosystem services suggested for the methodology (taken from the list presented in Annex 2). The indicators of ecosystem status can be linked to the benchmark indicators proposed by the Task 2.3.

The purpose of this framework (Annex 3) is to support the users in describing the logical relationships in the assessment of ecosystem services and design a conceptual scheme of the research. The arrows are examples. Each case study could select the relationships under analysis and complete and adapt the framework to the specific case study.

2.3.2 Valuation

Once the assessment framework is established, the following step is the quantification and valuation of ecosystem services, and here there is another dimension of integration to be taken into account that regards the valuation. Before discussing the methodology for assessing and valuing ecosystem services we need to explore the concept of 'valuation' of ecosystem services.

The value is "the contribution of an action or object to user-specified goals, objectives, or conditions" (MA, 2005). Valuation is the process of attributing a value. The value of ecosystem

[2] See the definition of the terms *stressor* and *pressure* and their use in this report provided in Annex 7.

services is the relative contribution of ecosystem to the goal of supporting sustainable human well-being (Costanza et al 2014). Any decision involving trade-offs of ecosystem service implies valuation (Costanza et al 2014).

There are multiple values and multiple valuation languages (metrics). Drawing from environmental ethics, Jax et al. (2013) discuss the different values in the relationship of human and non-human nature, including inherent, fundamental, eudaimonistic and instrumental values. The values that are captured by the ecosystem service concept depend on how the concept is operationalised and implemented (approaches and methodologies used). Different stakeholders have different value systems and perspectives. Therefore involving all the stakeholders (not only politicians, managers and scientists) in the valuation process is necessary to consider the plurality of values, while neglecting some values would exclude the people who embrace these values (Jax et al. 2013).

The notion of value should not be restricted to the merely monetary value but embrace a larger range of values. If restricting the value of ecosystem services to economic value, we risk to fail accounting all value dimensions and environmental components (trade-offs) of policy decision (Keeler et al 2012). The criticism to the commodification of ecosystem services is that the non-monetary values of nature, such as inherent, fundamental and eudaimonistic values, can be neglected in the assumption that the natural capital can be substituted by other capital. Other valuation methods (non-monetary) should be adopted to account for values other than instrumental values (Jax et al 2013).

‘Value pluralism’ refers to the idea that there are multiple values, including economic (monetary), sociocultural and ecological values. An integrated valuation should endorse the value pluralism (Gomez-Baggethun et al. 2014). This is the approach currently developed in the project OpenNESS.

The valuation techniques vary with the typology of values to be elicited and the scope of the valuation exercise, the geographical scale, spatial resolution, and reliability and accuracy required. The purpose of the valuation can range from awareness raising, to accounting, priority setting, instrument design and litigation (Gomez-Baggethun and Barton 2013).

We recognise the importance of integrating the different dimensions of value. The challenge is the difficulty of integrating different valuation languages (metrics). Projects like OpenNESS are investigating the use of different techniques for valuation of ecosystem services, including non-monetary techniques and Multi Criteria Analysis, in addition to the traditional monetary methods. However, when the study is targeted on few services at the local scale and involves stakeholders (without the ambition to cover all ecosystem services and all possible value dimensions) the risks associated to neglecting the multiple values are lower (Jax et al 2013).

MARS will not perform integrated valuation studies, including economic, social and ecological values. The project will focus on the biophysical and the economic (monetary) dimensions of ecosystem services. In any case, we think it is important to consider the notion of value pluralism in the analysis and to interpret the economic valuation in monetary terms *sensu* Costanza et al. (2014), i.e. for awareness raising about relative changes over a period in time. This excludes the intent of treating all ecosystem services as substitutable. In the valuation in MARS we are interested mainly in the change of value as the result of the effects of multiple stressors changes.

What the MARS methodology should aim for is the integration between biophysical and economic valuation. This highly depends on the method used for the assessment. Economic models to value ecosystem services related to water quality are often poorly integrated with the biophysical models describing the underpinning natural processes (ecological and hydrological models) (Keeler et al. 2012). We will discuss how to improve the integration in the following section, which presents the methodology for biophysical and economic valuation of ecosystem services proposed for MARS (Section 2.4 and Section 4).

2.4 Biophysical and economic assessments

2.4.1 Biophysical assessment

Methodology and tools

There are several approaches to assess and map ecosystem services, from land cover maps combined with scoring factors (e.g. Burkhard et al. 2009) to specific ecosystem service models based on ecological production functions (Sharp et al. 2014). There are also some specific decision support tools, available in literature, for assessing and valuing ecosystem services, that follow specific methodology. Bagstad et al. (2013) reviewed 17 tools for assessing and valuing ecosystem services, including InVest (http://www.naturalcapitalproject.org/InVEST.html) and ARIES (http://www.ariesonline.org/). These tools usually combine ecology and economics, considering the spatial dimension.

The EU FP7 project OpenNESS (Dec 2012 - May 2017) is studying methodologies for mapping and modelling the biophysical control of ecosystem services and approaches for the valuation of the demand of ecosystem services. The application of a number of methods in 27 case studies is ongoing. The methods for assessing the biophysical control that are under study in OpenNESS are reported in Table 2.2. The approaches for the valuation of the demand of ecosystem services include monetary, non-monetary and deliberative methods (e.g. multi-criteria and Bayesian approaches).

Table 2.2 Methodologies for mapping and modelling the biophysical control of ecosystem services under study in the project OpenNESS (2013).

Name of the method	Reference
Spreadsheet/GIS methods	Burkhard et al. (2012); Vihervaara et al. (2012)
QUICKScan	http://www.quickscan.pro/
Bayesian Belief Networks (BBNs)	Bayesian Belief Networks: A Cross-Cutting methodology in OpenNESS: Briefing Note
State and transition models (STMs)	Bestelmeyer et al. (2011)
ESTIMAP	Zulian et al. 2013
InVEST	http://www.naturalcapitalproject.org/InVEST.html

Considering the current and impellent challenge of the implementation, i.e. being able to translate the concepts of ecosystem services into practice, the need to be operational constituted one of the leading criteria in the development of the methodology. This means as well to simplify and accept some compromise. We also wanted to assure the **flexibility and feasibility** to users, to be able to further apply/adapt the methodology to their specific case of application. For this, in developing the biophysical methodology, we focused on the concepts, while leaving the tools to the choice of the users.

The water quantity and quality, and the water related ecosystem services, are affected by the complex interactions of climate, topography and geology, land cover and management, and other anthropogenic modification of the landscape. Incorporating water related ecosystem services in the decision making process requires the capacity to predict the effects of land use changes on the water resources, which can be offered by the **hydrological models** (Guswa et al. 2014). Hydrological and biogeochemical catchment models are appropriate tools for dealing with water related ecosystem services (Guswa et al. 2014; Vigerstol and Aukema 2011; Brauman et al. 2007). They can represent the dynamic of the river basin and the temporal (lag time) and the spatial distance between beneficiaries and impacts, and they can be used in scenario analysis for testing multiple stressors (the core element of MARS). They also allow describing the connection to the hydrologic/ecosystem attributes presented in the integrated assessment framework (Annex 3), that are key for establishing any physical relationship between stressors, status and services.

Following this line and considering the wealth of knowledge in hydrological modelling available in the project MARS, we have featured a methodology that could profit and enhance this capacity. For this reason for the biophysical assessment we propose to base the assessment on **indicators of ecosystem services** rather than tools, proposing indicators of ecosystem services that are directly related to water bodies or to water-land interaction in the watershed (hydrologic ecosystem services). To assure the maximum flexibility and stimulate the creative application of different biophysical models and data analysis we leave the choice of the tool to the user, while we concentrate on the common methodology. Similar to Maes et al. (2014) and Layke et al. (2012), we propose the selection of appropriate indicators or proxies, as flexible and handy approach to measure ecosystem services. We started testing this option through the partners' consultation in May 2014, where we offered a list of indicators per ecosystem service type extracted from Maes et al. (2014) (see questionnaire template Annex A6.1).

Proposed conceptual framework for the indicators

To support the correct understanding and appropriate use of the indicators for ecosystem services, and more generally to structure the assessment, we have to analyse which dimension of the ecosystem service is captured by the indicators (this is particularly relevant in the project MARS, where indicators will be used also for the assessment of the status of ecosystems, and the relationship between conditions and services will be investigated).

To this purpose we propose a simplified conceptual framework based on the cascade model (shown in Figure 2.1) for structuring the analysis and the classification of indicators of ecosystem services to be used in MARS. The framework, presented in Figure 2.2, includes the **Capacity** of the ecosystem to deliver the service, the actual **Flow** of the service, and the **Benefits**. Capacity refers to the potential of the ecosystem to provide ecosystem services, while flow is the actual use of the ecosystem services. The capacity relies on biophysical data, while flow requires the acquisition of socio-economic data. Benefits are associated to the human well-being and the value system (other studies discussing the concepts of capacity and flow: Schroter et al 2014; Layke et al 2012; Villamagna et al 2013; Maes et al. 2013). This framework is coherent with the MARS conceptual model.

Services are often associated with high exploitation of the ecosystem; the risk is an unsustainable use of nature. For this reason we are interested in looking at the sustainable flow of services. This is considered in the conceptual framework by including indicators informing about the **sustainability**, i.e. indicator combining capacity and flow. In many cases, the information on capacity and flow is lacking, or the full capacity of the ecosystem is unknown or unaccountable. In these cases we can try to collect indicators about the **efficiency** of processes, for comparing two different scenarios or ecosystem performances in delivering services.

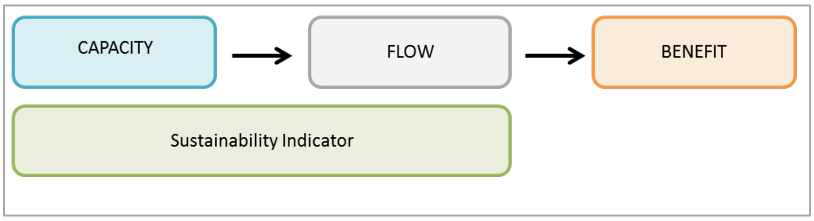

Figure 2.2 Conceptual framework to classify indicators of water ecosystem services in MARS.

Review of indicators for water ecosystem services

To help the partners selecting the best indicator for each situation, we compiled a list of potential proxies/indicators[3] for water ecosystem services and classified them according to the categories of the conceptual cascade model: capacity, flow and benefit (the category of 'sustainability' and 'efficiency' were not explicitly used in the classification, but the user is invited to consider when the proxies/indicators provide this kind of information). Here, we present some conclusions from our literature review.

The specific studies of the Millennium Ecosystem Assessment dealing with freshwater systems (MA 2005b, c) settle down the basis for the analysis and its interpretation, but they do not provide specific indicators to be monitored. Following the MA process, UNEP (2009) focuses on the relevance of water security and UNEP-WCMC (2011) collects the lessons learnt in sub-global assessments reviewing 137 indicators of ecosystem services. However, despite the valuable

[3] See Annex 7 for the definition of the terms *proxies* and *indicators*

information, the full list of indicators analysed in UNEP-WCMC (2011) is not publicly available. A similar situation (i.e. very good analysis without raw data access) is found in the studies of Feld et al. (2009, 2010). TEEB (2010) is a good introduction of indicators for many uses (not only ecosystem services) but it does not enter into the detail of listing them. Vigerstol and Aukema (2011) and Clerici et al. (2014) offer practical assessments of freshwater ecosystem services and evaluate different approaches, although they do not provide new indicators for ecosystem services.

Our compilation and classification of water ecosystem services indicators is presented in Annex 4 Table A4.1. It includes a total of 206 proxies and is based on Maes et al. (2014), Egoh et al. (2012), Layke et al. (2012), Russi et al. (2013) and Liquete et al. (2013). Minor modifications from the original authors like re-phrasing or re-allocation were required to avoid duplications and to respect our conceptual framework (and also our list of ecosystem services).

Table 11 of Maes et al. (2014) comprises all the indicators proposed in the deliberative process of implementation of the EU Biodiversity Strategy around the freshwater pilot. Since Maes et al. (2014) was the basis to build the MARS questionnaire, we include all their indicators except only few[4].Appendix 1 of Egoh et al. (2012) summarises an extensive literature review. The Ecosystem Service Indicators Database of the World Resources Institute (www.esindicators.org, Layke et al. 2012) compiles metrics and indicators from numerous sources that have been identified and applied by individuals from varied organizations. We reviewed a selection of over 400 indicators from this database. Russi et al. (2013) highlights the relevance of water and wetlands and links it to decision-making. It also provides a few examples of indicators for freshwater ecosystem services in Table 3.1 and Box 3.1. We reviewed also Liquete et al. (2013), which includes a systematic compilation of 476 marine and coastal ecosystem services' indicators, in order to cover additional aspects specifically related to transitional and coastal waters.

In the MARS cookbook, we will try to guide the user step-by-step in the process of assessing water ecosystem services (Section 4.3). However, whenever a new practitioner is presented with a list of indicators such as Annex 4, it is worthwhile to recall the key messages of UNEP-WCMC (2011):

- Ensure objectives are clear
- Adopt a small set of specific, policy-relevant indicators
- Go beyond provisioning services
- Utilise existing data and proxies (but recognise limits)
- Think about sustainability – include indicators for both ecosystems and benefits

[4] The proxies excluded are:

- Number and efficiency of treatment plants: this is human technology, not an ecosystem-based function.
- Waste water treated: it depends only on human, not natural, capabilities.
- Number of sites for CO_2 deep injections and volumes of CO_2 injected: this is human technology, not an ecosystem-based function.

- Include biodiversity
- Be sensitive to scale
- Assess trends and consider synergies and trade-offs
- Engage stakeholders early
- Focus on communication

2.4.2 Economic valuation methods

Valuation methods and policy instruments

To propose the methodology for the economic valuation of ecosystem services for MARS, we first reviewed the economic valuation techniques and consulted the project partners on their specific needs and knowledge in the field. In this phase it was important to understand the availability of trained economists in the consortium and the intention of the case studies to perform an economic valuation (case study research plan), as well as to target the suggested methodology.

There are several ways to estimate values of ecosystem services (see for instance Koundouri et al. (2014) for a recent implementation of the ecosystem service approach to valuing freshwater goods and services to humans). Broadly speaking, there are three categories of approaches: cost-based, revealed preferences and stated preferences approaches.

- **Cost-based approaches** consider the costs that arise in relation to the provision of services.
- **Revealed preferences** approaches refer to techniques that use actual data regarding individual's preferences for a marketable good which includes environmental attributes
- **Stated preferences** approaches refer to methods based on structured surveys to elicit individuals' preferences for non-market environmental goods.

Another practical way to value ecosystem services under non-availability of site-specific data or funding constraints is the **benefit transfer approach.** This approach consists in using economic estimates from previous studies to value services provided by the studied ecosystem (see Navrud and Ready, 2007).

Table A5.1 in Annex 5 provides a detailed list of methods for economic valuation, making the distinctions between the different approaches.

To mitigate the impact of multiple stressors, different policy instruments may be implemented or may be relevant. In Table A5.2 in Annex 5 we provide a list of the typical available policy instruments, making the distinction between economic instruments, voluntary approaches, regulations and information tools. Knowledge which policy instruments are to be implemented is important since it helps choosing among the different valuation approaches.

Tables A5.1 and Table A5.2 have been used in the partners' consultation for understanding their needs and research plan for the MARS case studies regarding economic valuation. The results of the consultation are presented in Section 3. The intention of performing economic valuation is also summarised per case study in Annex 1.

Based on further analysis and feedback from partners, we have developed the methodology to be applied in MARS, which is presented in details in Section 4.4 (Cook-book).

3. Partners' consultation

3.1 Approach

To inform and target the methodology for assessing and valuing ecosystem services (WP2.2) we included the consultation of the users in the process. We designed an on-line questionnaire to collect the needs, experience and knowledge of the MARS partners and consider them in the development of the methodology. The consultation took place in May 2014 through the questionnaire, which included some parts of the analysis presented in the previous section (Section 2). The questionnaire form is reported in Annex 6 (A6.1).

In MARS the effects of multiple stressors on the delivery of ecosystem services will be studied at three different scales: water body (WP3), catchment (WP4) and at the European scale (WP5). For this reason we designed the questionnaire in a way to receive input from the groups working on the different scales (case studies). The list of people that were contacted for each scale is reported in Annex 6 (A6.2), together with the names of the actual respondents.

The following part presents a critical analysis of the results of the questionnaire and provides some indications on the methodology for assessing and valuing ecosystem services based on the responses to the questionnaire. The complete statistics on the responses from partners are reported in Annex 6 (A6.3). It is important to notice that the answers to the questionnaire reflect the knowledge and research plan of the case studies in May 2014, which might change and evolve in the course of the project.

3.2 Results

3.2.1 Case studies in MARS: scale, ecosystems and their services

Respondents and scale of application

We sent 37 questionnaires: 9 to WP3 partners, 16 to WP4, 8 to WP5, and 4 to partners from other WPs. In total we received 27 responses (see Annex 6). In some cases the questionnaire has been filled referring contemporary to two different scales. Figure 3.1 presents the distribution of the respondents to the questionnaire according to the three different scale of study of the project.

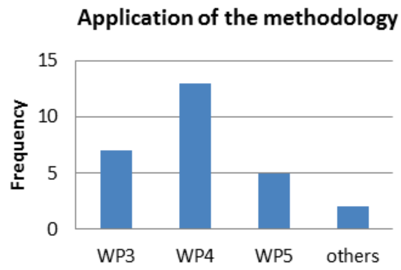

Figure 3.1 Distribution of the respondents to the questionnaire according to the three different scales of study of the project. Legend: water body (WP3), catchment (WP4), European scale (WP5), others (the partner was consulted but is not involved in the application of the methodology).

In MARS most of the users will apply the methodology at the catchment scale (WP4), while doubts were reported on the sense of applying ecosystem services approach to flume experiments (WP3) (Question 2.1). We consider that the most relevant scale for the methodology will be the catchment scale, as the European scale (WP5) can be considered as the aggregation of all the river basins in Europe.

Ecosystem types

The assessment of ecosystem services and their value under multiple-stressors will be focused mainly on rivers and lakes, with some interest as well for transitional waters, groundwater and riparian areas (Figure 3.2, Question 2.2). This is especially the case when considering only the response from the catchment scale (WP4) (Figure 3.3).

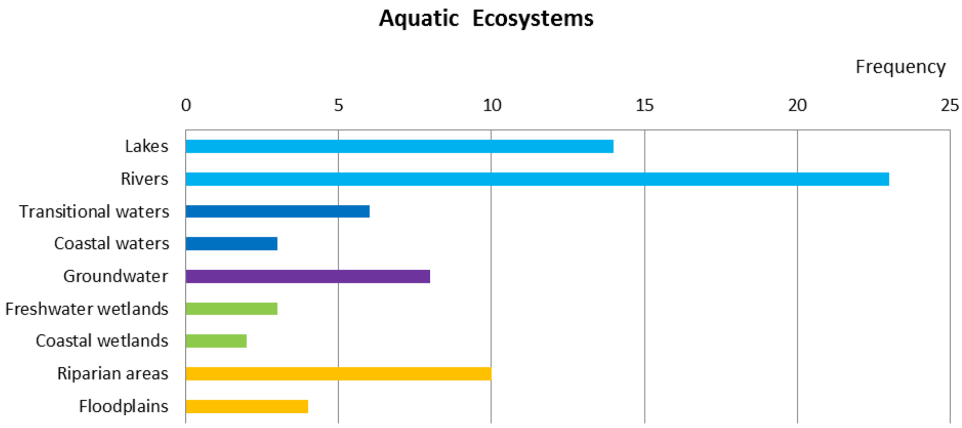

Figure 3.2 Aquatic ecosystems relevant for the delivery of ecosystem services that will be assessed in the project (all responses).

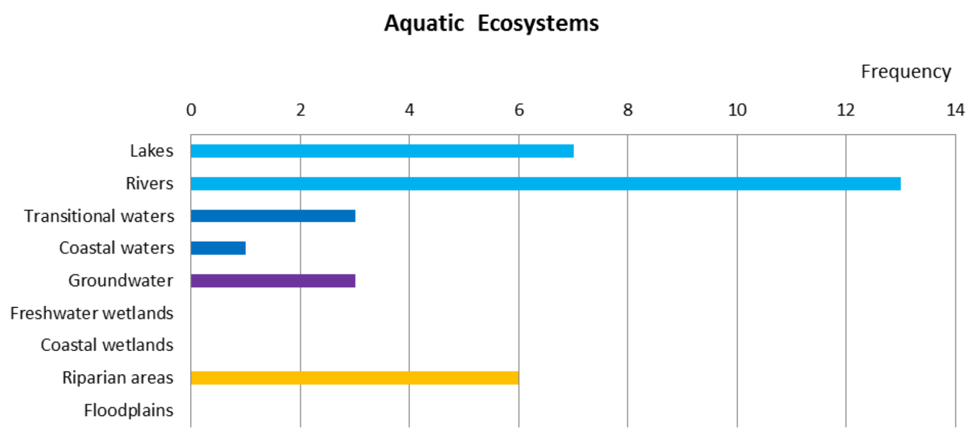

Figure 3.3 Aquatic ecosystems relevant for the delivery of ecosystem services that will be assessed in the project at the catchment scale.

Ecosystem services

The ecosystem services considered in the research will be mainly (Figure 3.4, Question 2.3):

- *Provisioning services*: fish provisioning, water provisioning for drinking and other purposes
- *Regulating services*: water purification, flood protection, maintaining population and habitats
- *Cultural services*: recreation

Some partners indicated the interest in considering also extra abiotic environmental services, such as extraction of reed for building roofs, navigation (transport and shipping) and hydropower.

Figure 3.5 presents the results specifically for the catchment scale. In most of the cases the ecosystem services that are considered relevant for the catchment will be studied in the project, except for recreation that, although is acknowledge as an important service by many partners, in half of the cases will not be assessed.

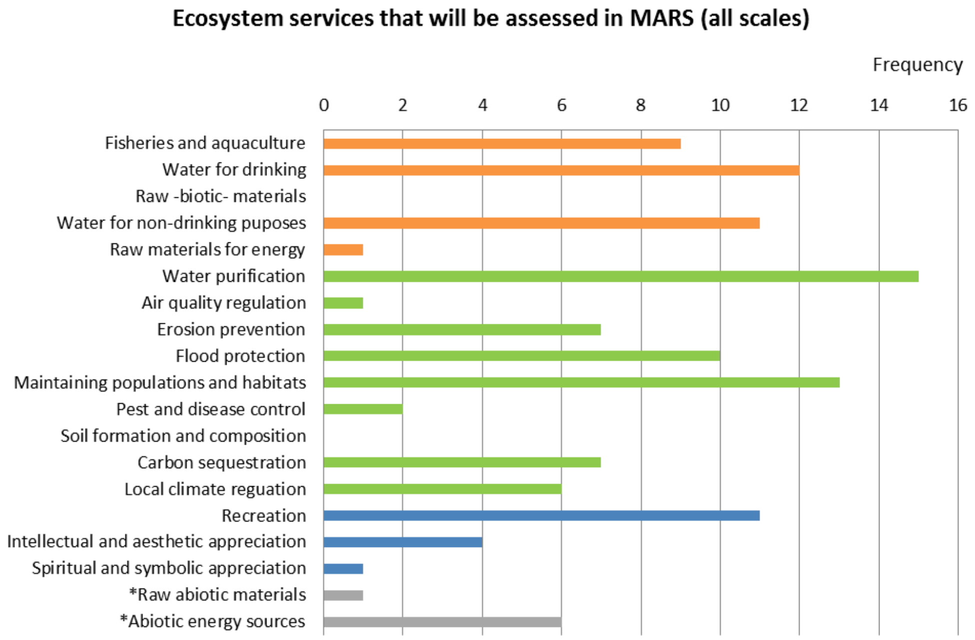

Figure 3.4 Ecosystem services that will be assessed in the project (according to the questionnaire results). *indicates extra abiotic environmental services.

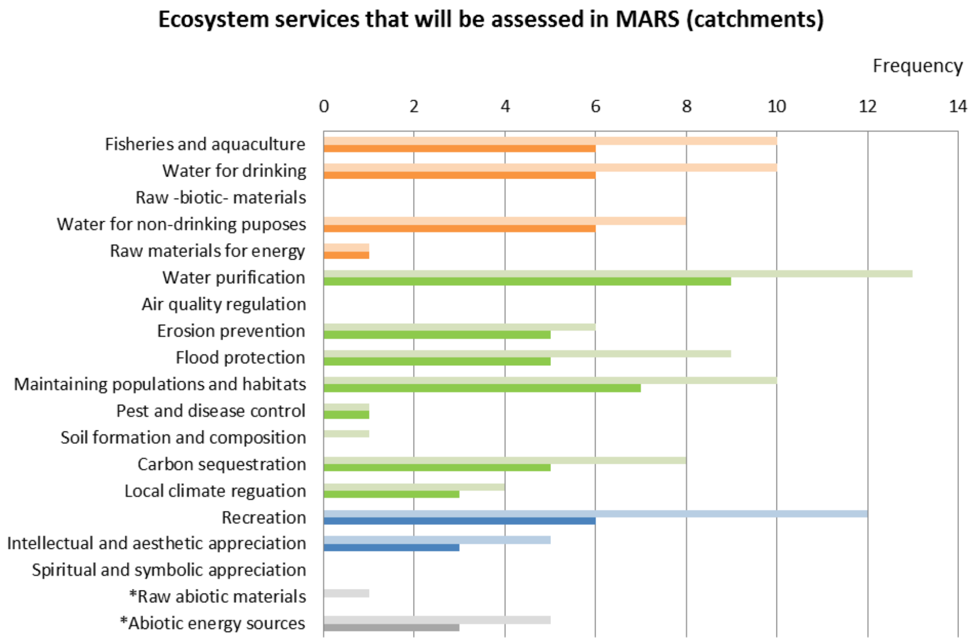

Figure 3.5 Ecosystem services that are considered relevant (light colours) and will be assessed (dark colours) in the project at the catchment scale. *indicates extra abiotic environmental services.

3.2.2 Needs and resources of the partners for the assessment

Indicators for ecosystem services

In the questionnaire, for the ecosystem services selected, the partners were asked if the proposed indicators were appropriate for assessing the delivery of the ecosystem services in their study, and if they had the possibility to assess them by data or modelling (Question 2.5). As list of indicators we provided those proposed by the MAES Working Group in the Freshwater Pilot (Maes et al. 2014; Maes et al. in preparation) with some revision. Considering that the respondents to the questionnaire represent the opinion of aquatic ecosystem experts across the whole Europe, the answers to this question offer a valuable feedback of MARS to the MAES WG.

As already discussed in Maes et al. (2014) that list includes both indicators of status (conditions) of water bodies and indicators of delivery of ecosystem services.

The results for provisioning services, regulating services and cultural services are reported in Figure 3.6, 3.7 and 3.8 respectively.

Considering all responses and all indicators together, on average 53% of the indicators provided are relevant and can be assessed in the project MARS (Question 2.5).

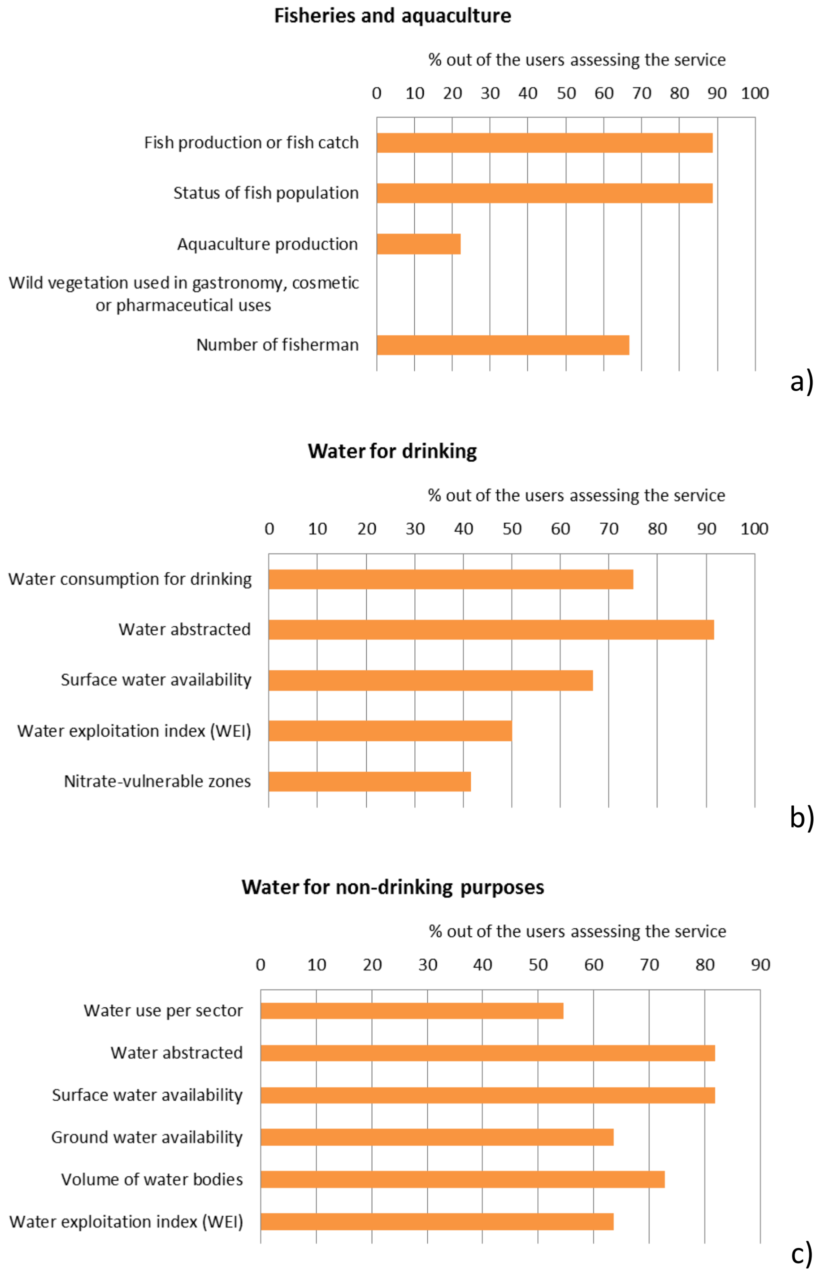

Figure 3.6 Percentage of responses that considered the indicator relevant for the assessment of the PROVISIONING ecosystem service: a) fish provisioning, b) water provisioning for drinking, c) water provisioning for non-drinking purposes. The percentage is calculated out of the total number of responses that declared the intention to assess the ecosystem service in the project.

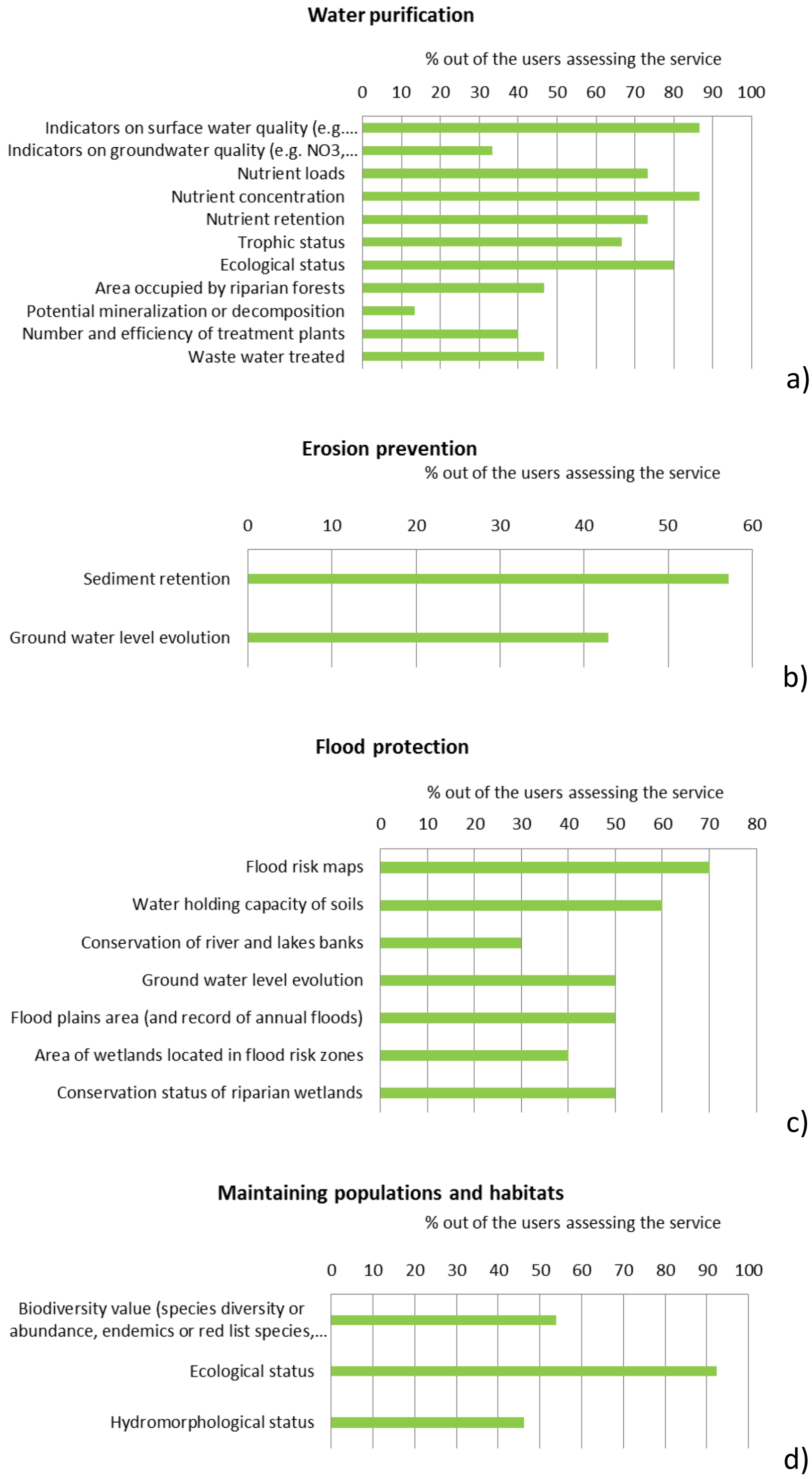

Figure 3.7 Percentage of responses that considered the indicator relevant for the assessment of the REGULATING ecosystem service: a) water purification, b) erosion prevention, c) flood protection, d) maintaining population and habitat. The percentage is calculated out of the total number of responses that declared the intention to assess the ecosystem service in the project.

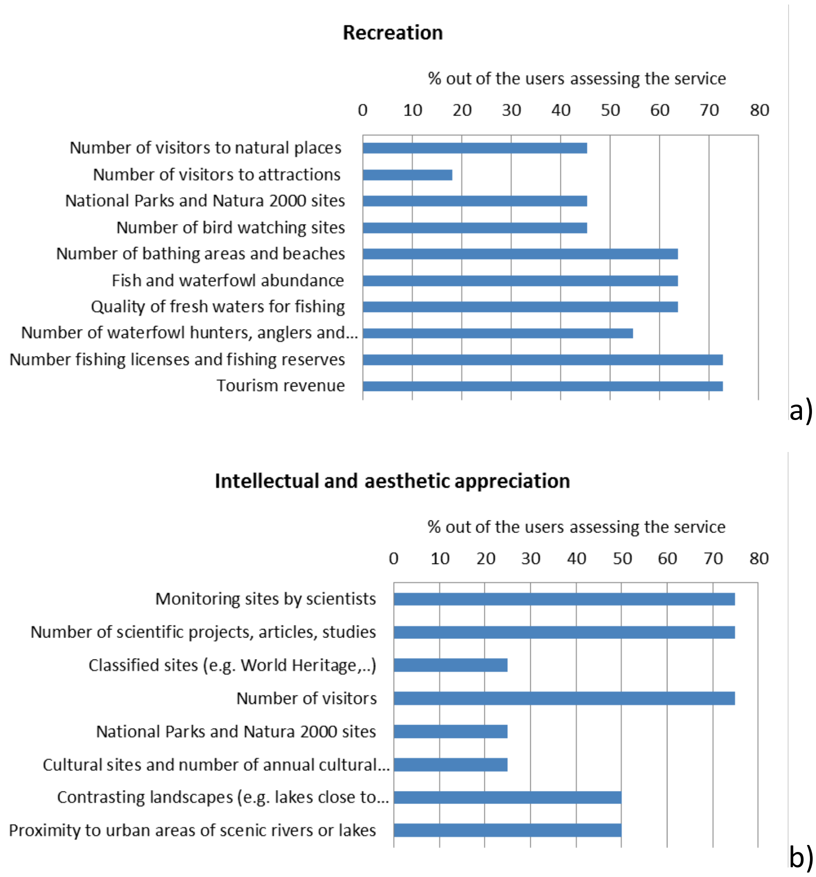

Figure 3.8 Percentage of responses that considered the indicator relevant for the assessment of the CULTURAL ecosystem service: a) recreation and tourism, b) Intellectual and aesthetic appreciation. The percentage is calculated out of the total number of responses that declared the intention to assess the ecosystem service in the project.

Economic assessment

In MARS, four partners will carry out an economic assessment at the catchment scale (AZTI-Tecnalia, Aarhus University, NIVA, Cardiff University) and one at the European scale (JRC).

The ecosystem services they will value are mainly "fisheries and aquaculture", "recreation" and "intellectual and aesthetic appreciation" (Figure 3.9, Question 2.7).

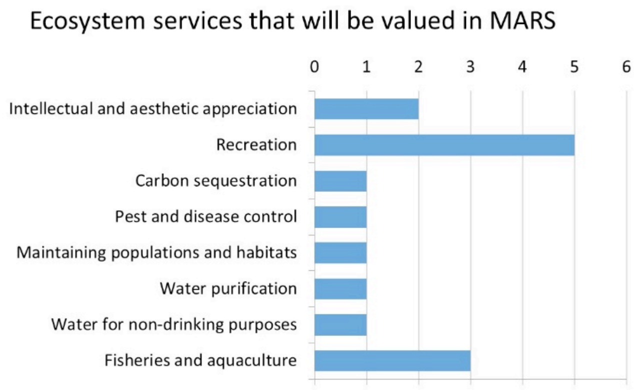

Figure 3.9 Ecosystem services that will be valued in the project (according to the questionnaire results)

Three partners (AZTI, NIVA and Cardiff) plan to collect economic data (e.g. conducting surveys) while the others (Aarhus University and JRC) will use existing databases (Question 2.9).

They will apply cost-based, stated preferences and benefit transfer approaches (no revealed preferences will be applied) (Figure 3.10, Question 2.10).

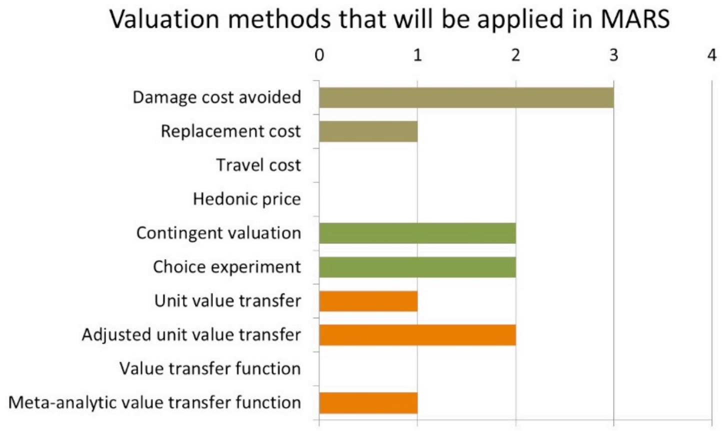

Figure 3.10 Economic methodologies that will be applied in the project (according to the questionnaire results)

The questionnaire also asked respondents which policy instruments (to face the impact of multiple stressors) have already been implemented / would be relevant to implement in their case study. Results show that there is no dominant instrument (Question 2.12 and 2.13).

Previous studies and expertise available in the consortium

The assessment and valuation of aquatic ecosystem services foreseen in the project will produce new knowledge, as studies already published on the topic relative to the MARS case studies were reported only in 37% of the responses (Question 3.1). At the same time, the fact that some studies are already available in some areas is an important knowledge base for the future development of the project and has to be taken into consideration.

Importantly, 44% of the respondents declared to have direct experience in mapping and assessing ecosystem services (Question 3.2) but the percentage falls to 33% regarding the specific experience in economic valuation. However, all partners (5/5) that will perform an economic assessment already have experience in the valuation of ecosystem services and they know which method to use in their case study.

Feedback from partners on the questionnaire

Feedback on the questionnaire was given by 93% of the respondents. The large majority considered the background information provided with the questionnaire useful and clear (Figure 3.11, Question 4.1).

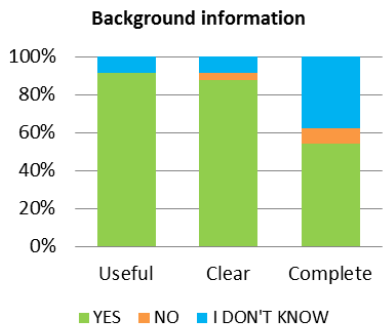

Figure 3.11 Feedback of the respondents on the background information document provided with the questionnaire.

A similar opinion was expressed regarding the list of ecosystem services, with almost 70% of the respondents also keen in using the list with their stakeholders (Figure 3.12, Question 4.3). This confirms that the list of ecosystem services was considered useful and clear not only for researchers (like the partners of the projects) but also for stakeholders involved in the river basin management. Some doubts were reported on the completeness of the list, highlighting the need to be more explicit about the services provided by groundwater and transitional/coastal waters, and on some conceptual aspects, such as the service “maintaining population and habitat” or the inclusion/exclusion of “hydropower and navigation”. The latter are not considered as ecosystem services in the framework, but rather as extra abiotic environmental services. In addition, there is a need to clarify to which extend the analyses of ecosystem services will be applied in flume experiments. The large majority of respondents judged also the list of indicators in the questionnaire as useful and clear, but about 20% think it is incomplete (Figure 3.12, Question 4.5). This is in part explained by the fact that new indicators also for ecosystem services will be developed in the course of the MARS project (such as indicators of the contribution of the groundwater baseflow to the surface water ecology, or for examples the use of the number of ships for transport and for tourism).

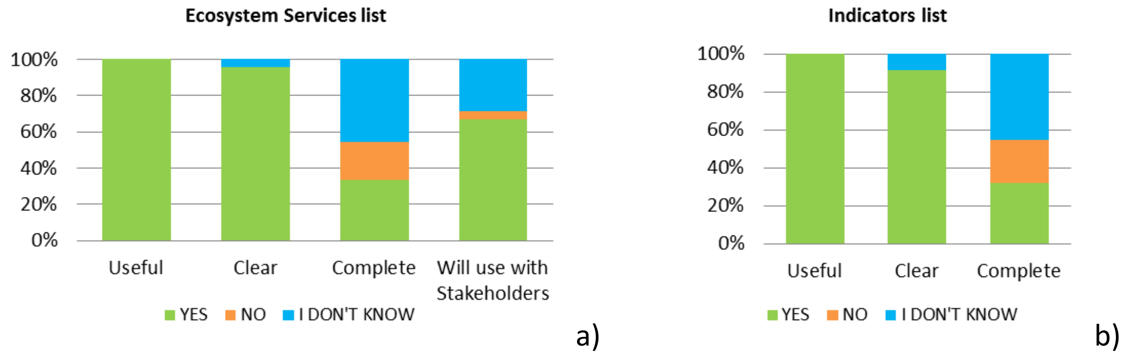

Figure 3.12 Feedback of the respondents on a) the ecosystem services list and b) the indicator list per ecosystem service provided in the questionnaire.

The questions on the economic valuation of ecosystem services were answered by 5 respondents (that will carry out the economic valuation in their case studies), and the feedback on this part was provided by 4 of them. All respondents on the economic part agreed that the list of economic valuation methods made available in the questionnaire was useful and clear, although half of them think it is incomplete. They suggested including market methods and multi criteria analysis. With regards to the policy instruments list, half of the respondents found it useful and clear, but most of them were not sure about the completeness, although no additional instruments were suggested.

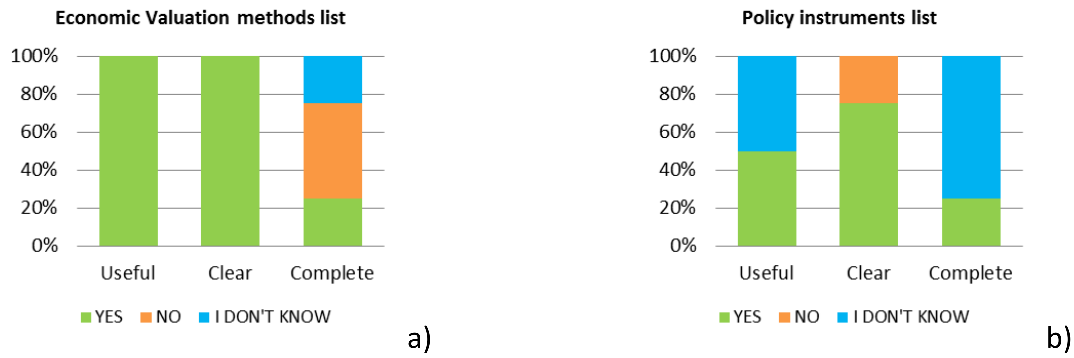

Figure 3.13 Feedback of the respondents on a) the economic valuation methods list and b) the policy instruments list provided in the questionnaire.

Finally, two important comments were reported. First, the WFD assessment of the quality status should not be questioned as an overall objective. Second, there is a need to reflect on the indicators used to measure ecosystem services, especially to avoid the use of state indicators for process-related ecosystem services. These points are completely taken into account in the methodology of Task 2.2.

3.3 Possible benchmark indicators for ecosystem services

Based on the responses to the questionnaire, some possible candidates for benchmark indicators (developed by Task 2.3 of MARS) for ecosystem services can be suggested at the time of writing this report. They are the following:

- Fish provisioning: fish production or fish catch;
- Water provisioning: water abstractions for different purposes; water availability;
- Water purification: nitrogen retention (mainly based on modelling); area occupied by riparian forests;
- Finally, an indicator based on e-flow statistics.

4. The cook-book for MARS

On the basis of the concepts and research analysis discussed in Section 2 and the consultation of the project partners presented in Section 3, we propose a methodology for the biophysical assessment and economic valuation of water ecosystem services to be applied in the MARS case studies at the water body, catchment and European scale.

The methodology, also called cook-book for is pragmatic intent, is organised in four main steps (Figure 4.1):

- Scoping of the analysis
- Development of the integrated assessment framework
- Biophysical quantification of ecosystem services
- Economic valuation of ecosystem services

In the following paragraphs we describe each step and the intermediate stages in the application.

(Notice that according to partners' consultation in May 2014 only five case studies will perform the economic valuation, the step 4 of the methodology. See Annex 1 for an overview of the analysis and economic valuations planned in MARS).

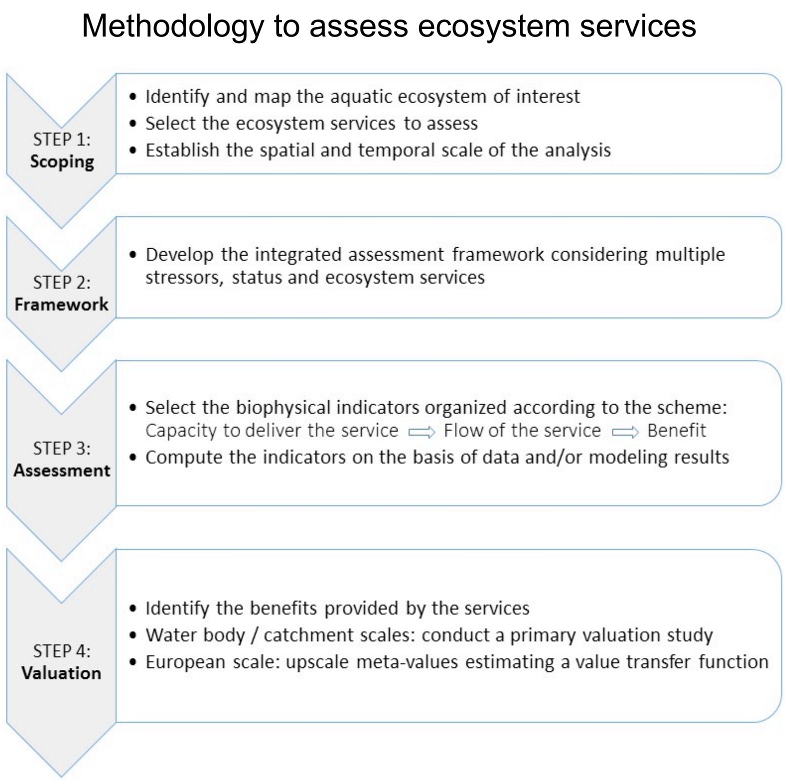

Figure 4.1 Schematic representation of the main steps of the methodology for assessing and valuing ecosystem services.

4.1 Scoping (Step 1)

First of all the scope of the assessment has to be clearly formulated. This clarifies the ambitions and limitation of the study and is needed to establish the scale of the analysis and select the appropriate methodology/tools. In MARS the final aim is analysing the effects of multiple pressures on the ecosystem service delivery at different scales but specific goals are established by each case studies (see Annex 1 for details). It is important to establish whether the case study plans to involve the stakeholders, reflect on RBMP and water management in general, and perform the economic valuation.

Overall, we noticed that in the field scale studies the focus will be on the biophysical functions responsible for the delivery of the services, while at the catchment and the European scale both the supply and demand sides of ecosystem services will be assessed, therefore including biophysical and socio-economic data, and in some cases also performing an economic valuation. At the three scales the research will focus on the relationships between multiple stressors and the delivery of ecosystem services, the outcomes from the catchment scale could be relevant for river basin management while at the European scale for understanding trends and effects of EU policies (see Section 2.1)

As a general indication the scheme proposed by Gomez-Baggethun and Barton (2013) or other can be used. According to this scheme the purpose of the valuation can be:

- awareness raising
- accounting
- priority setting
- instrument design
- litigation

The next elements of the scoping involve:

a) selection of the ecosystems of interest
b) selection of the ecosystem services of interest
c) temporal and spatial scale of the analysis

The order of these actions depends on the case study. For users working on specific aquatic ecosystems, probably it is easier to identify first the ecosystems and then the relevant services. On the contrary, for users focused on hydrological services (see discussion on water related services in Section 2.2 for definition) generally at the river basin scale, it might be simpler to select the ecosystem services first and then include the relevant ecosystems (in this case not only aquatic ecosystems).

a) Selection of the ecosystems of interest

The aquatic **ecosystems** of interests for the study are mainly those relevant for the WFD:

- Lakes
- Rivers
- Transitional waters
- Coastal waters
- Groundwater
- Freshwater wetlands
- Coastal wetlands
- Riparian areas
- Floodplains

The mapping is important for the catchment and the European scale, while for field experiments only a local analysis will be conducted.

b) Selection of the ecosystem services of interest

For each aquatic ecosystem a number of **ecosystem services** of interest have to be selected using the list of ecosystem services provided in Annex 2. This list is the same made available in the questionnaire, and was considered useful and clear by the respondents (93%).

With regard to hydropower generation, we classified it as extra abiotic environmental service, to be consistent with the CICES classification. However, some partners of the projects mentioned it as an ecosystem service (in the questionnaire), while others include it as a pressure. We suggest to consider dams as pressures and water provisioning for hydropower generation as the contribution of the ecosystem, therefore under the class water provisioning for non-drinking purposes.

If the objective of the analysis is to carry out a comprehensive trade-off analysis using the ecosystem service approach at the river basin scale, we recommend consulting also the original CICES v4.3 (Haines-Young and Potschin 2013), where a longer list of terrestrial and aquatic ecosystem is provided.

c) Temporal and spatial scale of the analysis

A crucial element for the assessment is to establish the **spatial and temporal scale** of the analysis. This strongly depends on general scope of the analysis, the availability and resolution of temporal and spatial data and modelling capabilities. The temporal and spatial scale has to be established taking into account the scenario analysis. A possible resolution could be for example the sub-catchment scale or main water bodies, and annual or seasonal temporal values.

4.2 Integrated assessment framework (Step 2)

After the scoping the following step is the development of the integrated assessment framework for the case study. In this step the users are invited to develop the expected links between multiple stressors, ecosystem status and services relevant for their case study, using the integrated assessment framework presented in Annex 3 as support (see Section 2.3 as rationale). The users have to select the stressors under study, consider the expected impacts on the ecosystem/hydrological attributes, check if the indicators of status under analysis capture the effects of the stressors, and link the attributes (and indicators) to the ecosystem services of interest.

All ecosystem services can be affected by multiple stressors. The users should attempt to describe the possible links between the stressors and the ecosystem services. In addition to the scheme of integrated assessment (Annex 3) Table 4.1 could inspire this reflection. The idea is to think about the relationships between the selected services and selected stressors as a matrix and reflect on the expected links. This will help in designing the assessment and the scenario analysis.

Table 4.1 Matrix of multiple stressors and expected qualitative effect on different ecosystem services.

	Ecosystem services proposed in MARS	Flow modifications	Diffuse and point pollution	Groundwater salinisation	Erosion/ Brownification	Hydromorphological alterations	Alien species	Overfishing
Provisioning	Fisheries and aquaculture	● high	● high	● low	● high	● medium	● high	● high
	Water for drinking	● high	● high	● high	● high	● medium	● low	● low
	Raw (biotic) materials	● medium	● high	● low	● medium	● high	● high	● medium
	Water for non-drinking purposes	● high	● high	● high	● high	● medium	● low	● low
	Raw materials for energy	● high	● high	● low	● low	● high	● medium	● low
Regulation & Maintenance	Water purification	● high	● high	● medium	● high	● high	● medium	● low
	Air quality regulation	● high	● high	● low	● low	● medium	● low	● low
	Erosion prevention	● high	● low	● low	● low	● high	● medium	● low
	Flood protection	● high	● low	● low	● low	● high	● medium	● low
	Maintaining populations and habitats	● high	● high	● low	● medium	● high	● high	● high
	Pest and disease control	● high	● high	● low	● medium	● high	● high	● high
	Soil formation and composition	● high	● medium	● low	● high	● high	● low	● low
	Carbon sequestration	● medium	● low	● low	● medium	● high	● medium	● low
	Local climate regulation	● high	● low	● low	● low	● high	● low	● low
Cultural	Recreation	● high	● high	● low	● high	● high	● medium	● high
	Intellectual and aesthetic appreciation	● high	● high	● high	● high	● high	● high	● high
	Spiritual and symbolic appreciation	● high	● high	● high	● high	● high	● high	● high

Legend: Expected impact of each pressure over the ESS ● high, ● medium, ● low.

4.3 Biophysical assessment (Step 3)

To ensure the flexibility of the methodology and the use of the wealth of hydrological models and data analysis techniques available in the project consortium, for the biophysical quantification of ecosystem services we propose to select ad hoc indicators. To this purpose we have prepared a **list of proxies/indicators** based on literature review. The list of indicators is presented in Annex 4 (see Section 2.4 for rationale).

In the list the indicators are classified (as much as possible) according to:

- Capacity
- Flow
- Benefits

This classification of indicators follows the conceptual framework developed in Figure 2.2 (Section 2.4). The user is also invited to consider if indicators of ecosystem services providing information on the sustainability or efficiency can be included (Section 2.4).

Notice that the biophysical assessment will probably include in most of the case **only indicators of capacity and flow**, while indicators of benefits might already be connected to the economic valuation, the forth step of the methodology (presented in Section 4.4).

In Table 4.2 we show an application of the proposed methodology to the European scale case study, showing which indicators can be proposed for capacity, flow and sustainability/efficiency.

Each partner is invited to:

- Select from Annex 4 the most significant and feasible proxy/indicator for the ecosystem service and category they want to measure,
- or get inspired by the list of proxies and re-interpret a new one (see Table 4.2 for an example).
- Apart from the ecosystem service characterisation, the estimation of sustainability/efficiency indicators and the temporal evolution are particularly interesting.
- Keep in mind that the final goal of this exercise is to compare the delivery of ecosystem services under multiple stressors, thus the effects of the stressors have to be captured by the selected indicators (the integrated framework - Annex 3 - should help in design the assessment correctly).
- Calculate the selected proxy/indicator with data coming from the best available sources (models, measurements, national statistics, scientific literature, etc.).
- Present the information stating clearly the ecosystem service analysed, the water body at stake, the type of information (capacity, flow, benefit or sustainability/efficiency) and, if possible, the scale and the time frame.

The users that have opted for specific tools for assessment of ecosystem services, such as Invest, will follow the methodology proposed by the tools but are prompt to integrate their results in the proposed conceptual framework (see discussion in Section 2.4 and Figure 2.2).

Table 4.2 Proposal of proxies/ indicators to quantify some relevant ecosystem services, using indicators of capacity, flow and sustainability or efficiency according to the cascade model proposed for MARS. The example is based on the research plan proposed by JRC at the European scale.

Ecosystem services	**Natural capacity**	**Service flow**	**Sustainability or efficiency**
Fisheries and aquaculture	Biomass of commercial species	Fish catch	% of catch within sustainable limits (catch below the Maximum Sustainable Yield)
Water for drinking	Surface runoff Groundwater recharge	Water used by different sectors	Water Exploitation Index +; Falkeman index
Water for non-drinking purposes	Surface runoff Groundwater recharge	Water used by different sectors	Water Exploitation Index +; Falkeman index
Water purification	Area or coverage of wetlands	Nitrogen removal Persistent Organic Pollutant degradation	Total mass removed vs. total input
Erosion prevention	Area or coverage of vegetated riparian areas	Sediment retention	Sediment retention vs. sediment yield
Flood protection	Natural retention capacity Area covered natural floodplains	Proportion of the water volume retained for a flood with 100 yr return time	Trend in flooding frequency
Maintaining populations and habitats	Mapping nursery areas (e.g. trout)	Minimum requirements like e-flow Habitat change	Recruitment rate
Carbon sequestration	Total carbon stored in a riparian zone or in wetland soils	Carbon sequestration (accumulation rate) per year	% of total carbon accumulated or emitted per year
Recreation and tourism	Mapping protected areas (national parks, Natura 2000…)	Number of visitors	Density of visits % of neighbour population (100 km) visiting the site

4.4 Economic valuation (Step 4)

4.4.1 A scale-specific approach

This section presents approaches and methodologies for monetary valuation of water ecosystem services in MARS. It shows how this value can be estimated in order to be integrated into the decision making process of the RBMP. Cost-efficient program of measures supposes to carry-out a cost-benefit analysis of these measures including benefits such as ecosystem services. In this respect, the monetary valuation exercise contributes to take into consideration the benefits the humans get from the ecosystems into the implementation of policies.

We limit our analysis to the ecosystem services that are planned to be valued in the project MARS. In the consultation carried-out among the MARS partners in May 2014, five research teams have expressed their interest for the valuation of 8 ecosystem services in their case study. The information is summarized in Table A1.2 and Table A1.3.

We propose an economic valuation of ecosystem services that is scale-specific, targeted at the water body/catchment scale and at the European scale. The steps of the economic valuation are outlined in Figure 4.2 and described in more detail in the following paragraphs. The first two stages of the assessment are common to both scales.

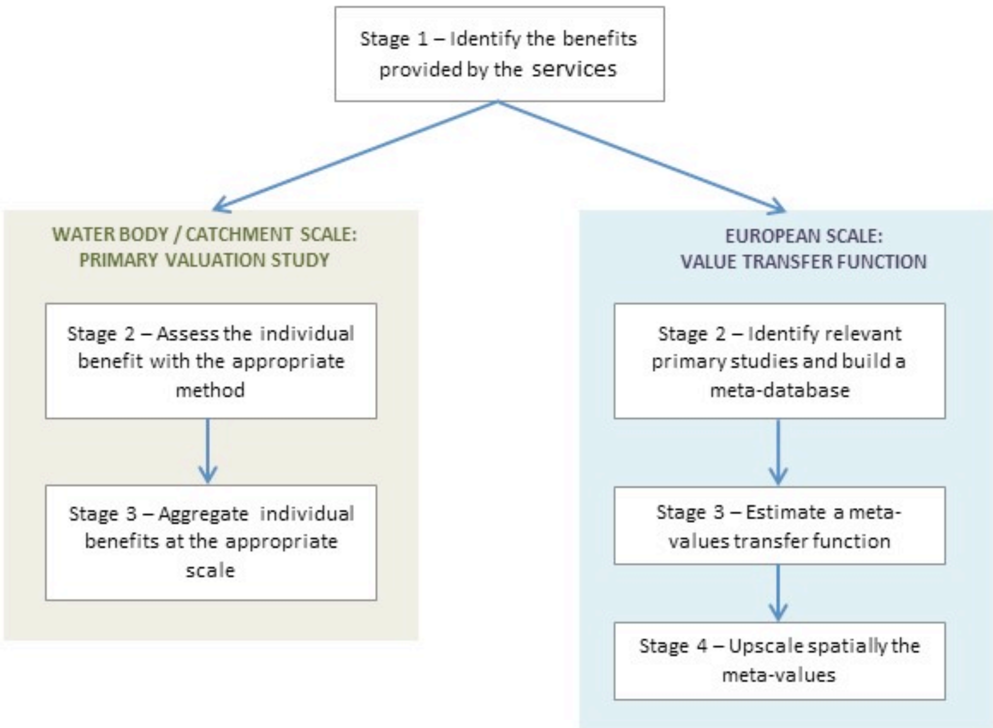

Figure 4.2 Steps of the methodology for the economic valuation of ecosystem services.

STAGE 1 – Identify the benefit provided by the service

The first step of an economic assessment consists in identifying the benefits provided by the ecosystem service to be valued. Fisher et al. have argued that it is the easiest way to perform a valuation exercise avoiding any double counting (Fisher and Turner 2008, Fisher et al. 2009). Following this approach, only the services that have a direct impact on welfare are valued.

In their seminal paper Potschin and Haines-Young propose a conceptual delineation between function, service, benefit and value:

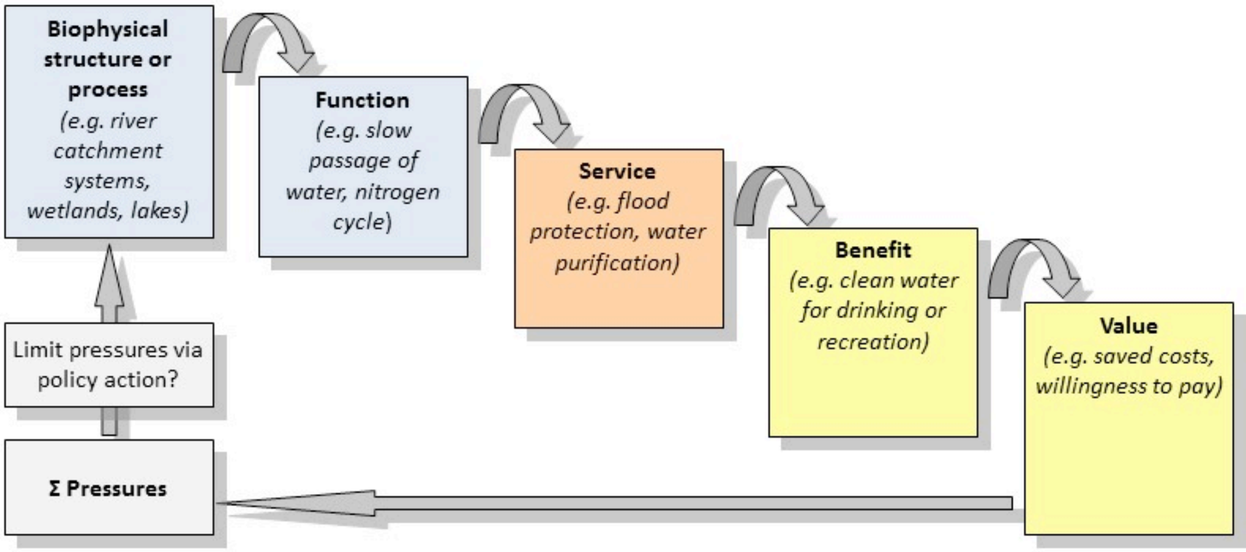

Figure 4.3 Relationships between ecosystem services, benefits and values (modified from Potschin & Haines-Young, 2011).

Services are separated from benefits because gains in welfare generated by ecosystems may vary depending on the final uses and users. An ecosystem service can provide different benefits depending on its location and the socio-economic characteristics of the environment. Figure 4.3 gives an example of the benefits provided by water purification service: clean water for swimming (recreation) or potable water for drinking (provision) are two different benefits. Benefits are created by the flow of services (even if the flow may depend on the size of the stock) while the value of the stock should be seen in the context of the natural capital concept. Therefore, we have limited the methodologies to the valuation of the flow of services. Within the MARS project, we aim to measure the change in economic benefits resulting from the effect of stressors. An assessment consists then in estimating the variation in the value of the flow of services resulting from the realization of a given scenario.

The benefits are obviously higher when more beneficiaries get advantage of it. It is therefore crucial to identify the beneficiary population. We examine this point later on (stage 2).

4.4.2 Economic assessment at the water body and catchment scales

This section presents various techniques that have been developed to value water ecosystem services at small or medium scales. A first subsection introduces the appropriate method to be used to assess the individual benefits (stage 2). A second subsection explains how to aggregate individual benefits at the appropriate scale (stage 3).

One should point out that there are other on-going initiatives related to the development of methodologies for the economic assessment of water ecosystem services. For instance, MARS works closely with the GLOBAQUA project which intends to incorporate valuation of ecosystem services into an approach for sustainable management of water-related resources (Koundouri et al., 2014). In line with the Driving forces, Pressures, States, Impacts and Responses (DPSIR) framework, they propose a methodology to assess the level of cost recovery of a water infrastructure that includes the costs associated with the depletion of water ecosystem quality. They suggest to use monetary valuation to transpose in economic terms the effects of ecological and biological characteristics of water on human welfare. The valuation technics delivered in MARS also offer a chain of tools to estimate the environmental damage resulting from a change in ecological conditions. This integrated approach for the management of freshwater resources, by monetizing environmental cost through valuation of ecosystem services, is an example of the mutual synergies that can benefit both projects.

STAGE 2 – Assess the individual benefit with the appropriate method

Water ecosystems provide a wide range of services, very different in their biophysical functions and in the way they impact human welfare. There are many valuation methods, the relevance of each depending on the service to be valued. An extensive overview of methods can be found in Annex 5.

They are usually classified into two main categories, namely *revealed* and *stated* preference methodologies. *Revealed* methods take into account observable market information, which can be adjusted and used for revealing the individual's preference and thus quantifying the associated welfare benefits. With *stated* preference methods, consumers are proposed some hypothetical markets for which they have the opportunity to pay or accept compensation for the environmental good or service in question (Bateman et al 2003).

In addition to these two main categories, *cost-based* methods and *benefit transfer* approaches may be considered. The *cost-based* methods include the damage cost avoided, the replacement cost, and the substitute cost methods. These methods do not provide strict measures of economic values. Instead, they assume that the costs of avoiding damages or replacing ecosystems or their services provide useful estimates of the value of these ecosystems or services. A *benefit transfer* takes pre-existing values from a study case (or cases) to develop a customized benefit estimate for a new policy case.

The choice of the primary valuation method to be applied is crucial. It depends both on the ecosystem service to be valued and on the beneficiary population. In the following, we give the correspondence between services and the appropriate valuation method to be applied for the ecosystem services valued in MARS.

The following tables provide the valuation method suggested per ecosystem service:

- Fisheries and aquaculture (Table 4.3)
- Water for non-drinking purposes (Table 4.4)
- Water purification (Table 4.5)
- Carbon sequestration (Table 4.6)
- Recreation (Table 4.7)
- Intellectual and aesthetic appreciation (Table 4.8)

Table 4.3 **Fisheries and aquaculture**

Potential case studies: Nervion-Ibaizabal catchment, Welsh basins, Vansjø-Hobøl and Otra catchments

Valuation method suggested	**Market-price**
Potential beneficiaries	Fishing industry (fishermen, commercial sector)
Approach	Use the (adjusted) market-price of fish as a proxy for the value of the fish provisioning service
Example	Assess the total value of the fish provisioning service through the revenue generated by fish sales net of the cost of fishing
Procedure	1. Collect information on fish price, fish demand (approximated by fish sales) and production costs of the fishing industry 2. Value the service as the total market value of catches minus the cost of production
Marginal change value	Net profit (value of sale minus cost of production) from an additional ton of fish
Data requirement	▪ Price of fish on the wholesale market (eventually by specie) ▪ Demand for fish (can be approximated by current fish catches) ▪ Production cost of the fishing industry
Benefit of the approach	▪ Market price and fish catch data are easily available
Limitation of the approach	▪ Market price may not reflect the economic value in case of market imperfections (e.g. disproportionate subsidies) ▪ The method is only valid if the fishery / aquaculture production is sustainable (for an unsustainable fishery, the value is higher than the market price)

Table 4.4 **Water for non-drinking purposes**

	Potential case studies: Vansjø-Hobøl and Otra catchments	
	Agriculture / Industry	***Hydropower***
Valuation method suggested	**Production function**	**Market-price**
Category	Revealed WTP	Market-based
Potential beneficiaries	Farmers, industries	Households, industries
Approach	Value the resource provisioning service as its impact on the production of a marketed output	Use the (adjusted) price of electricity as a proxy for the value of the abiotic energy provision service
Example	Assess the value of the water provisioning service for agriculture/industry as the change in the net value of the total output production resulting from the use of the resource	Assess the annual value of water produced by a watershed as the net value of the hydropower production generated by this quantity of water
Procedure	1. Estimate the agricultural / industrial production technology (production function, profit function or cost function) 2. Apply the marginal productivity approach to estimate the value of water	1. Estimate the annual quantity of water produced by a watershed (e.g. biophysical modeling, primary data) 2. Compute the amount of electricity generated at the dam for the water supplied by the watershed 3. Assess the annual value of the abiotic energy provision service as the market value of the energy generated by the dam, net of the annual cost of production
Marginal change value	Marginal profit resulting from the use of one additional cubic meter of water by the farm/industry	Market value of the energy generated by an additional cubic meter of water produced by the watershed, net of the average annual cost of production (cost per cubic meter per year)
Data requirement	▪ Quantity and cost of production factors (including water) ▪ Level of production (agricultural/industrial output), cost of production or profit realized ▪ Market-price of the produced good	▪ Annual average quantity of water produced by a watershed ▪ Price of electricity ▪ Building and operating costs of the dam ▪ Lifetime of the reservoir ▪ Power production technology of the dam
Benefit of the approach	▪ Well-know and applied methods ▪ Approach is grounded on reliable statistical and economical technics	Allows value mapping by attributing a specific value to the water yield in the different parcels of the water basin
Limitation of the approach	▪ Data can be difficult to obtain (amount of data needed is important) ▪ The method requires that a change in the use of water does not affect the market price of the final good	Seasonal variations in energy production and energy price are not taken into account

Table 4.5 **Water purification**

Potential case study: Welsh basins	
Valuation method suggested	**Replacement cost**
Potential beneficiaries	Population benefiting from clean water
Approach	Use the cost of a built infrastructure able to provide the water purification service as a proxy for the value of the water purification service provided by the ecosystem
Example	Assess the value of the water purification service through an estimation of the construction and operating cost of artificial wetlands
Procedure	1. Identify all the possible technical solutions for achieving the require pollution removal 2. Estimate the cost of all alternatives and select the cheapest one 3. Value the purification service as the unit cost of the cheapest alternative
Marginal change value	Cost of the purification process for one cubic meter of water
Data requirement	▪ Quantity of water purified by the ecosystem ▪ Beneficiary population from the clean water ▪ Cost of providing clean water (quantity purified by the ecosystem or quantity used by the beneficiaries) with an alternative built infrastructure
Benefit of the approach	▪ Allow to assess the value of the service through a technical-economic approach which is less time and resources demanding than measuring the value of the benefits
Limitation of the approach	▪ Do not consider individual or social preferences for clean water and cleaning systems ▪ Replacement cost is a poor proxy for the benefit value (cost of substitute is not a good measure of the benefit) ▪ Overestimate the value of the water purification service

Table 4.6 **Carbon sequestration**

Potential case studies: Vansjø-Hobøl and Otra catchments	
Valuation method suggested	**(Adjusted) market-price**
Potential beneficiaries	Society
Approach	Use the CO2 price on the emission trading markets as a proxy for the value of the carbon sequestration service
Example	Assess the total value of the carbon sequestration service applying the price of the emission permits to the amount of carbon sequestered by the ecosystem
Procedure	1. Determine the amount of carbon sequestered by the ecosystem (carried-out in the biophysical assessment) 2. Depending on the time scale of the assessment, choose the market price or an estimation of this price (e.g. European Union Emission Trading Scheme) for a one-ton emission permit 3. If necessary, select a value for the discount factor (when the time scale of the assessment is a long period, benefits of the sequestration service should be discounted on time) 4. Compute the value of the sequestration service as the discounted sum of the values of emission permits corresponding to the carbon sequestered each year within the assessment period
Marginal change value	Change in the amount of carbon sequestered (with respect to the Business as Usual case) x price of the corresponding emission permits on the market (for future emissions, the price is an estimation)
Data requirement	▪ Quantity of carbon sequestered by the ecosystem for each year of assessment period ▪ Market-prices of a one-ton emission permit for each year of the assessment period ▪ Discount factor to use for long term assessments
Benefit of the approach	▪ Carbon market prices and discount factors data are easily available
Limitation of the approach	▪ To date, carbon market-price has been very volatile ▪ Carbon price may be impacted by policies or subsidies

Table 4.7 **Recreation**

Potential case studies: Nervion-Ibaizabal catchment, Odense, Welsh basins , Vansjø-Hobøl and Otra catchments, Europe

Valuation method suggested	**Contingent valuation**	**Choice experiment**	**Travel cost**	**Hedonic prices**
Potential beneficiaries	Visitors	Visitors	Visitors	Residents
Approach	Survey-based technique in which respondents answer questions regarding their willingness to pay for an ecosystem service or a change in this ecosystem service	Survey-style technique in which respondents are asked to state their choice over different hypothetical alternatives ("alternatives" consist in a combination of attributes of an ecosystem and a price associated to this combination)	Survey-based technique that uses the cost incurred by individuals taking a trip to a recreation site as a proxy for the recreational value of this site	Method that estimates the value an environmental characteristic of an ecosystem by looking at differences in property prices
Example	Assess the value of recreational swimming in a lake by asking individuals how much they are ready to contribute for it (e.g. to have clean, swimmable water)	Assess the recreational value of a lake by the choice respondents make between different options (accessibility, possibility to practice activities such as swimming or boating, water quality) associated with different prices to be paid for each combination.	Assess the value of the recreational service of a lake based on the number of visitors and the money they spend to visit the lake	Assess the value of lake amenities by comparing real-estate prices located at different distances of this lake

Procedure	1. Design the survey (survey mode, target population, services valued, development of scenarios, questions and visual support, treatment of protest answers) 2. Implement the survey (selection of the population sample, realization of the survey) 3. Compile and treat data (apply appropriate statistical technics), analyze the results	1. Design the experiment (target population, choice sets, attributes, questions and visual support) 2. Implement the experiment (selection of the population sample, realization of the experiment) 3. Compile and treat data (apply appropriate statistical technics), analyze the results	1. Design the questionnaire that will be addressed to the visitors 2. Collect information from the visitors (see the row "data requirement" below) 3. Estimate by regression the relationship between the decision to visit, the travel cost and the ecosystem services variable 4. Estimate the demand function for the ecosystem (including the socio-economic characteristics of the visitors and biophysical features of the ecosystem) 5. Estimate the ecosystem services benefits from the (consumer) surplus of the visitors	1. Collect data on residential property sales in the area of the ecosystem for a given time period (price and property characteristics) 2. Estimate a function stating the relationship between the property price and its characteristics (including characteristics of the ecosystem) 3. Estimate the value of the amenities provided by the ecosystem (which is the change in real estate value resulting from a change in an attribute of the ecosystem)
Marginal change value	WTP of people to open the site one extra day / to open an extra site (e.g. a lake) to the public	WTP of people to improve the quality of water such that it can be swimmable one extra day in the year	Marginal (individual) travel expenses people are willing to spend when the water quality (e.g. of a lake) increase from a class to an upper one	WTP of a resident to live one meter closer to the ecosystem (e.g. a lake)
Data requirement	▪ Physical and ecological characteristics of the ecosystem ▪ Scenario of change of the ecosystem (e.g. change in the water quality or ecological status) ▪ (Declared) individual willingness to pay for the service ▪ Socio-economic characteristics of the respondents ▪ Socio-economic characteristic of the beneficiaries (e.g. population around the area)	▪ Physical and ecological characteristics of the ecosystem ▪ Scenario of change of the ecosystem (e.g. change in the water quality or ecological status) ▪ Choices made by the participants during the experiment ▪ Socio-economic characteristics of the respondents ▪ Socio-economic characteristic of the beneficiaries (e.g. population around the area)	▪ Visitors' travel costs (including the value of time spent travelling) ▪ Other travel expenses (e.g. accommodation) ▪ Visitors' socio-economic characteristics ▪ Distance from visitors' hometown to the ecosystem visited ▪ Other locations visited during the trip ▪ Distance of the site from substitute ecosystems ▪ Biophysical and ecological characteristics of the ecosystem	▪ Data on property sales (price, property characteristics, including location) ▪ Data on the ecosystem itself (size, quality, ecological status) ▪ Size of the beneficiary population

Benefit of the approach	▪ Allows to measure the value of non-market services ▪ Able to capture use and non-use values	▪ Allows to measure the value of non-market services ▪ Able to capture use and non-use values ▪ Allows to value separately the outcomes of one or several policy option ▪ Respondents do not directly state their WTP (values are inferred from hypothetical choices they made) which limits bias	▪ ESS value estimates are based on the actual choices of beneficiaries and not on what they declare (no strategic behaviour) ▪ Results can be easily interpreted	▪ ESS value estimates are based on the actual choices (and not on answers) of beneficiaries (no strategic behaviour possible) ▪ Allows to estimate separately the value of several non-market attributes (e.g. distance from the ecosystem, quality of the ecosystem)
Limitation of the approach	▪ Answers can be biased by respondents (they can lie) ▪ Values of non-use services are not consistent with those estimated through other approaches (e.g. hedonic prices or travel cost method)	▪ Discrete choice experiment cannot be used with too many attributes ▪ Designing the questionnaire requires a specific expertise	▪ ESS value may be overestimated if the visitors also travelled for other reasons (in addition to visit the ecosystem) ▪ The travel cost is only a lower-bound measure of the ESS value (value can be underestimated), e.g. for local visitors ▪ Value of some components of the travel cost are controversial (e.g. value of time)	▪ Housing prices may be explained by factors subject to bias the results (e.g. taxes, interest rates) ▪ Environmental benefits should be of common knowledge to be reflected in home prices

Table 4.8 **Intellectual and aesthetic appreciation**

Potential case studies: Welsh basins, Vansjø-Hobøl and Otra catchments

Valuation method suggested	**Contingent valuation**	**Choice experiment**	**Hedonic prices**
Potential beneficiaries	Visitors	Visitors, residents	Residents
Approach	Survey-based technique in which respondents answer questions regarding their willingness to pay for an ecosystem service or a change in this ecosystem service	Survey-style technique in which respondents are asked to state their choice over different hypothetical alternatives ("alternatives" consist in a combination of attributes of an ecosystem and a price associated to this combination)	Method that estimates the value of an environmental characteristic of an ecosystem by looking at differences in property prices
Example	Assess the value of a water environment landscape by asking individuals how much they are ready to contribute for preserving it	Assess the intellectual/aesthetic value of being in a protected wetland by the choice respondents make between different options (combinations of water quality, number of species and vegetation) associated with different prices to be paid for each combination.	Assess the value of lake amenities by comparing real-estate prices located at different distances of this lake
Procedure	1. Design the survey (survey mode, target population, services valued, development of scenarios, questions and visual support, treatment of protest answers) 2. Implement the survey (selection of the population sample, realization of the survey) 3. Compile and treat data (apply appropriate statistical technics), analyze the results	1. Design the experiment (target population, choice sets, attributes, questions and visual support) 2. Implement the experiment (selection of the population sample, realization of the experiment) 3. Compile and treat data (apply appropriate statistical technics), analyze the results	1. Collect data on residential property sales in the area of the ecosystem for a given time period (price and property characteristics) 2. Estimate a function stating the relationship between the property price and its characteristics (including the distance to the ecosystem) 3. Estimate the value of the amenities provided by the ecosystem (which is the change in real estate value resulting from a change in an attribute of the ecosystem)
Marginal change value	WTP of people to open the site one extra day / to open an extra site (e.g. a lake) to the public	WTP of people to improve the quality of water such that the frequency of alga bloom is reduced by one day in the year	WTP of a resident to live one meter closer to the ecosystem (e.g. a lake)

Data requirement	▪ Physical and ecological characteristics of the ecosystem ▪ Scenario of change of the ecosystem (e.g. change in the water quality or ecological status) ▪ (Declared) individual willingness to pay for the service ▪ Socio-economic characteristics of the respondents ▪ Socio-economic characteristic of the beneficiaries (e.g. population around the area)	▪ Physical and ecological characteristics of the ecosystem ▪ Scenario of change of the ecosystem (e.g. change in the water quality or ecological status) ▪ Choices made by the participants during the experiment ▪ Socio-economic characteristics of the respondents ▪ Socio-economic characteristic of the beneficiaries (e.g. population around the area)	▪ Data on property sales (price, property characteristics, including location) ▪ Data on the ecosystem itself (size, quality, ecological status) ▪ Size of the beneficiary population
Benefit of the approach	▪ Allows to measure the value of non-market services ▪ Able to capture use and non-use values	▪ Allows to measure the value of non-market services ▪ Able to capture use and non-use values ▪ Allows to value separately the outcomes of one or several policy option ▪ Respondents do not directly state their WTP (values are inferred from hypothetical choices they made) which limits bias	▪ ESS value estimates are based on the actual choices (and not on answers) of beneficiaries (no strategic behaviour possible) ▪ Allows to estimate separately the value of several non-market attributes (e.g. distance from the ecosystem, quality of the ecosystem)
Limitation of the approach	▪ Answers can be biased (respondents can lie or may have strategic behaviours) ▪ Values of non-use services are not consistent with those estimated through other approaches (e.g. hedonic prices or travel cost method)	▪ Discrete choice experiment cannot be used with too many attribute ▪ Designing the questionnaire requires a specific expertise	▪ Housing prices may be explained by factors subject to bias the results (e.g. taxes, interest rates) ▪ Environmental benefits should be of common knowledge to be reflected in home prices

STAGE 3 – Aggregate individuals benefits at the appropriate scale

The WFD requires to conduct some economic analyses and assessments of the associated environmental and resource costs and benefits. As the population who benefits from an improvement of aquatic ecosystem services may be spread across a wide geographical area, one of the key parameters when aggregating benefits of improved water ecosystem quality is the spatial distribution of these benefits.

One of the main difficulties in environmental economic valuation is then to decide on the size of the benefiting population (beneficiaries). This issue is important since aggregate benefits depend on estimates of both individual benefits and of the number of beneficiaries. As mentioned in Hanley et al. (2003), errors made in estimating the number of users and non-users affected by an environmental change can easily swamp errors in estimates of individual benefits (obtained in STAGE 2) when aggregate values are calculated.

The general rule is that the beneficiaries should be the households/persons aggregated at the relevant geographic scale. The beneficiaries should include both users and non-users impacted by the ecosystem service considered. For services which are only of local importance, the relevant population is the population of the site (e.g. the users). For ecosystems of national or global importance with a few substitute sites (e.g. protected area for endangered species), a larger population should be used (e.g. users and non-users).

When spatially aggregating individual benefits, it is usually considered that the willingness to pay decreases with the distance from water body providing ecosystem services. A first rationale behind distance decay is that the opportunities of taking advantage of improvements in ecosystem provision are greater the closer one lives considered water body, Jørgensen et al. (2013). A second rationale is related to the existence of possible substitutes. Indeed, as the number of available substitute sites is expected to increase with increasing distance to the site of interest, it is expected that individual values decrease as the distance to the water body increases.

There are a lot of empirical evidence supporting this view. Among others, Georgiou et al. (2000) have found a negative, significant relationship between the willingness to pay to clean up the River Tame in Birmingham (UK) and the distance respondents live from the river. Based on their estimates, the implied willingness to pay to clean up the River Tame declined to zero at a distance of 16 miles (for a ‘small’ improvement) and 36 miles (for a ‘big’ improvement). Bateman and Langford (1997) have measured the willingness to pay for protecting the Norfolk Broads (UK). They report that the willingness to pay declines from a mean value of £39/household/year at a distance of 20 km, to £13.90 at a distance of 110–150 km away from the Broads area.

The usual method to take into account the fact that the willingness to pay decreases with the distance to the water body providing ecosystem services is to use a *distance decay function* in order to weight the willingness to pay according to the distance to the ecosystem, Bateman et al. (2006). This distance determines the boundaries of the geographical area, or so-called economic jurisdiction, over which the individual WTP-values can be aggregated over the population of beneficiaries to calculate the total economic value of a proposed scenario of environmental change, Schaafsma et al. (2012)

The specification of the distance decay relations has been highly debated among economists. A number of studies have examined in particular how the distance decay relation differs between users and non-users of the ecosystem service. Among others, Bateman *et al.* (2006) find that distance decay is stronger for non-users than users, and Hanley *et al.* (2003) find that while distance decay is significant for both users and non-users, users of a water body show stronger distance decay than non-users.

4.4.3 Economic assessment at the European scale

For the valuation at the European scale, we propose a methodology consisting in upscaling values of primary studies (value transfer), accounting for the biophysical and socio-economic heterogeneity in the water environments.

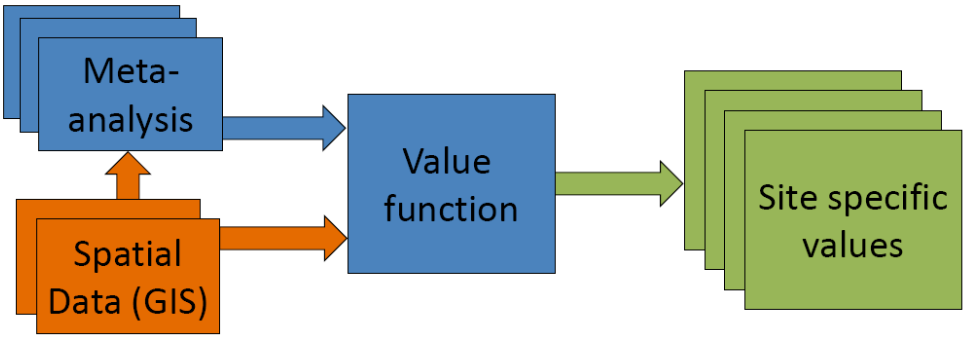

Figure 4.4 Methodology for economic assessment at the European scale

This approach first builds on a ***meta-analysis*** using the results of available past studies for various water bodies to estimate a function able to represent the relationship between the features of water ecosystems and the value of the services they provided. Ecosystem features include their geomorphological and ecological characteristics but also the characteristics of their beneficiaries such as income, distance to the ecosystem or to substitute ecosystems. From a methodological point of view, the meta-analysis is view as a mean to estimate benefit functions that synthesize information from multiple primary studies having valuated aquatic ecosystem. The interested reader may refer to Brander, Florax and Vermaat (2006) or to Brander, Beukering and Cesar (2007) for some examples of meta-analysis in the context of valuation of ecosystem services.

The second stage consists in ***upscaling*** the results of the meta-analysis. The economic values that have been estimated in the regression analysis must then be transferred and aggregated at larger geographic areas through a scaling-up procedure. This procedure allows to value multiples ecosystem sites at the continental scale, accounting for the change in the global stock of the resource. Recent examples of upscaling values of ecosystem services include Ghermandi *et al.* (2010) and Ghermandi and Nunes (2013).

STAGE 2 – Identify relevant primary studies and build of the meta-database

STAGE 2a – Identifying primary studies

This step consists in ***searching and selecting studies*** (most often in online databases) valuing services provided by ecosystems similar to those of the policy site[5] (this methodology will be applied in MARS at the European scale for valuing European lakes). The scientific references must be selected through systematic searches on various search engines and on the web sites of major publishers of academic journals. The grey literature must also be included, in particular to reduce the influence of a potential publication bias in the meta-regression analysis.

Validity tests have shown that studies closer spatially and in time tend to have lower transfer errors. However, relevant primary studies (in terms of ecosystem or ecosystem services) may not be available for the same area or countries as the policy site and gathering a sufficient amount of studies may require expanding the bibliography at a larger scale (worldwide).

STAGE 2b – Collect relevant information from primary sources in a meta-database

In stage 2b, all relevant information from primary sources must be ***collected into in a meta-database***. This stage consists in including in the database information on methods applied in the primary study, ecosystem services valued, biophysical characteristics of the ecosystem (water quantity, water quality, ecological status), and the characteristics of the beneficiaries (income, age, education level). All this information will serve as controls in the meta-regression.

STAGE 2c- Standardize primary values

Economic values have been reported in the literature in many different metrics (i.e. willingness to pay per unit of area or volume, marginal values, capitalized value), using different currencies and for different period of time. In order to enable a comparison across studies all these values must be standardized. As explained by Ghermandi et al. (2010), the standardization of different and heterogeneous metrics used to value ecosystem services is a difficult and controversial task.

Accounting for heterogeneity in space and in time. The observed economic values have been obtained for different countries and for different period of time. This requires some normalization procedures. First, to account for differences in purchasing power among countries, a purchasing power parity indexes has to be applied to the original values. Second, the problem of having different years of observation is usually solved by using appropriate price deflators, see Ghermandi and Nunes (2013) for a recent example.

Normalizing values for valuation studies. Economic values produced by various methods may be expressed in different metrics (currency, year, value, price) and cannot be directly compared. For example, some methods produce estimates of willingness to pay (e.g. contingent valuation) whereas

[5] *Policy site* is the site where the benefit transfer is applied based on the primary information from the *study sites*.

others produce estimates of capitalized value (e.g. hedonic prices). In order to make adjustments for a comparison across studies (common metric, currency and time period), a specific standardization procedure must be used. Two approaches may be followed. First, some previous studies have used a normalized value expressed in monetary units per unit of area per unit of time Ghermandi et al. (2010), Brander et al. (2012), Ghermandi and Nunes (2013). The second normalization procedure consists in expressing ecosystem service values in monetary units per visit per unit of time (Brander, Beukering and Cesar, 2007) or in monetary units per household/respondent per unit of time Brouwer et al. (1999), Johnston et al. (2005).

STAGE 2d - Augment the amount of information from secondary sources

This stage consists in including additional data for each primary study site from secondary sources (e.g. database or GIS files) with relevant information on population density around the ecosystem, income of the population or presence of substitute ecosystems (e.g. density of lakes).

STAGE 3 – Estimate a meta-values transfer function

Ecosystems features include their geomorphological and ecological characteristics but also the characteristics of their beneficiaries such as the income, the distance to the ecosystem or to substitute ecosystems. The data analysis of the meta-database does not allow for interactions between the various potential explanatory variables. Indeed, ***a meta-regression analysis*** allows to control for the variation in the characteristics of an ecosystem (e.g. biophysical surrounding, income, population density or availability of a substitute ecosystem) when conducting the value transfer. In order to attain marginal effect, we use a meta-regression analysis to assess the relative importance of all potentially relevant factors simultaneously. The regression technique allows accounting for the biophysical or socio-economical differences between the study sites and our case study (Europe).

This approach consists in using the results of available past studies for various water bodies to estimate a function able to represent the relationship between the features of water ecosystems and the value of the services they provided. The dependent variable in our meta-regression equation is the economic value of the ecosystem service considered. The explanatory variables are grouped in different matrices that include the ecosystem services provided (with potential interactions across ecosystem services), the water body characteristics (i.e., type of water body, size of water body, etc.), the study characteristics (i.e., survey method, payment vehicle, elicitation format, etc.) and context-specific explanatory variables.

There are two popular panel-data models which can be used for estimating the meta-regression model, e.g. the fixed-effect model and the random-effect model. The crucial difference between these two models lies on the assumptions used to define the error variance. In the fixed-effect model it is assumed that all studies included in the meta-analysis share a common true effect size, differences in observed effects arise only due to sampling error. However because studies commonly differ in implementation and underlying population, among others, the assumption of the fixed-effect model is often implausible. The random-effects model allows the true effect size to differ from study to study and this is the approach usually recommended.

STAGE 4 – Upscale spatially the meta-values

The values that have been estimated for localized changes by the regression analysis should then be transferred and aggregated at larger geographic areas through a scaling-up procedure. Scaling-up is value transfer across a larger geographic scale. This procedure allows to value multiples ecosystem sites at the continental scale, accounting for the change in the global stock of the resource (while the valuation of a specific water body is isolated from the rest of this stock).

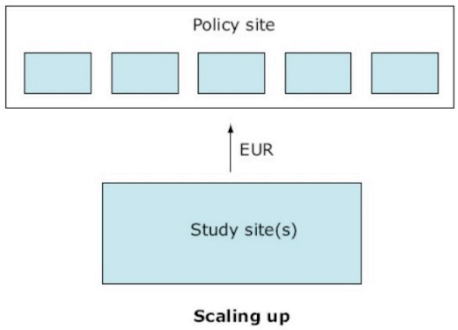

Figure 4.5 Schematic representation of the scaling up procedure (EEA, 2010)

The meta-database gathers studies at small scales (mainly water body scales). The information on value of services provided by these small ecosystems is synthetized by a meta-regression. The estimated meta-value function may then be used to scale-up the information at the European level, allowing to transfer and aggregate values of individual water bodies to the multiple-ecosystems European case study. However, the valuation of the flow of services provided by each ecosystem is not isolated from the other water ecosystem of the case study. The scaling-up procedure accounts for the abundance of ecosystem through the impact of the substitution effect on the individual value of the services they provide individually.

Following Germandhi and Nunes (2013), we propose the following steps. First, the most appropriate transfer function among the different meta-regression specifications must be selected. This choice may be based on explanatory power of the model, sign and significance of the coefficients estimated. Second, one must define the appropriate geographic scale for transferring values. Third, an ecosystem service grid must be built, each cell of the raster map being treated as a policy site, to which values are transferred by estimating the local value of the transfer function by means of map algebra. This requires an extensive use of GIS.

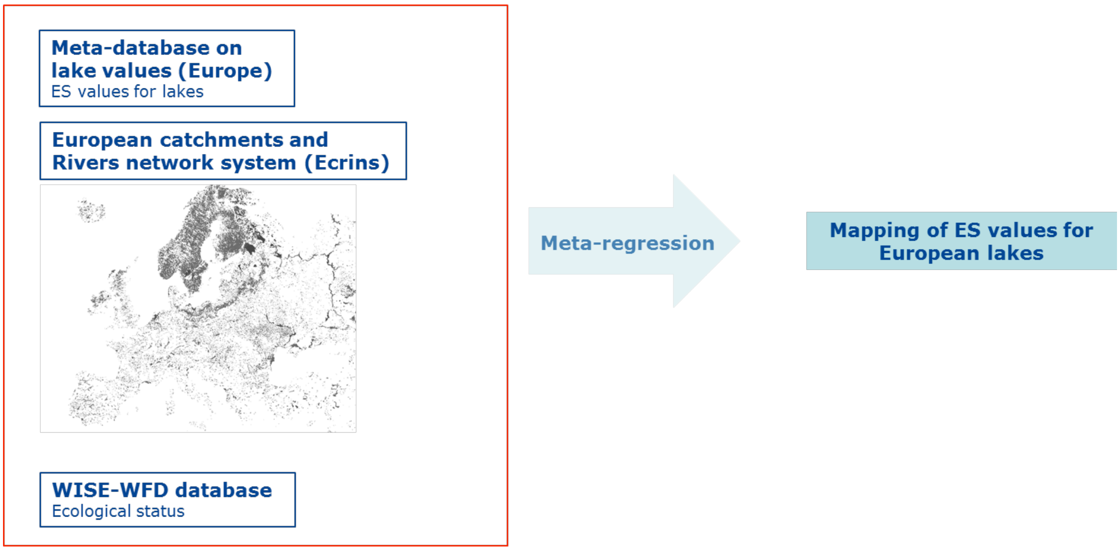

Figure 4.6 Example of scaling up procedure (upscaling of lake values at the European scale, on-going work at the JRC).

As discussed by Germandhi and Nunes (2013), when analyzing the results of the study, it is important to evaluate the accuracy of the value transfer model and to take into consideration the multiple sources of errors and uncertainties involved (uncertainty in the primary valuation data, uncertainty is involved in the estimation of the meta-analytic value transfer function, representativeness of the study sites).

4.5 Example of integration of biophysical and economic analyses

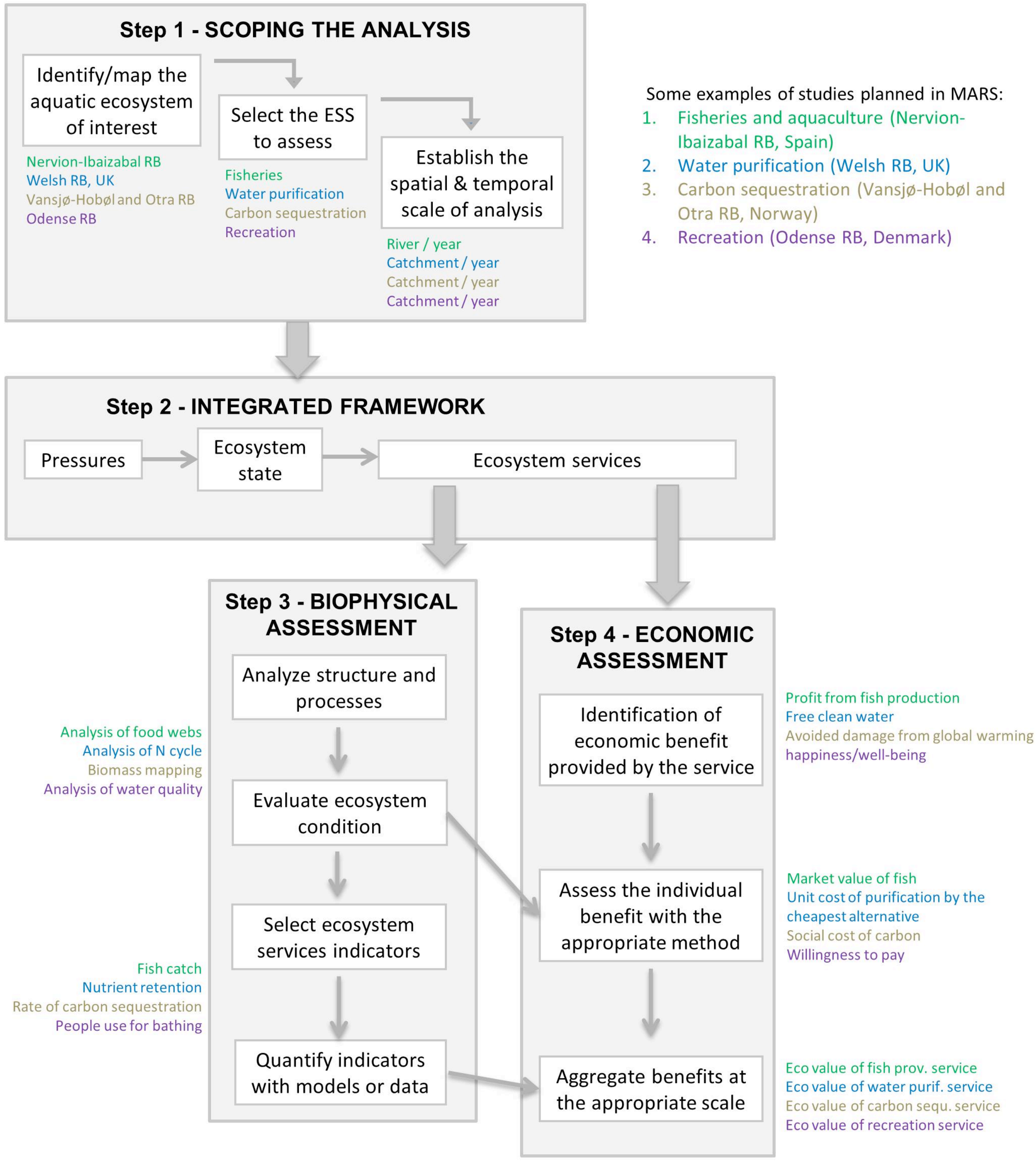

Figure 4.7 Scheme of integration of biophysical and economic analyses.

5. Discussion

In this report we have presented a pragmatic approach for assessing and valuing ecosystem services that builds on the expertise of the MARS partners, making use of the relevant knowledge on hydrological modelling, data analysis, monitoring and indicators, available in the MARS consortium (and in general in European research institutes). The methodology proposed fulfils the MARS main objective of analysing how multiple stressors may affect the delivery of ecosystem services. It is flexible and can be applied at different scales (experiments/catchments/continents) and in different locations in Europe, as required by the MARS project. It covers both the biophysical quantification and the economic valuation of water ecosystem services.

The methodology has been designed to be easy to follow. It presents the basic concepts and assumptions to be established before the analysis, and provides a “shopping bag” to select the appropriate tools to assess and value ecosystem services.

For the development and targeting of the methodology, a consultation of the project partners was carried out by a web-questionnaire in May 2014. The questionnaire was an opportunity for learning the main research issues of each case study, collecting knowledge and needs of partners, testing the ecosystem service list and having a preliminary discussion on indicators. Similarly, for partners the questionnaire requested reflecting on the definition and classification of ecosystem services (especially for those new to the topic) and writing a preliminary research plan. Touching upon ecology and economics, the questionnaire aimed to an interdisciplinary discussion in the research teams, which is necessary when working on ecosystem services.

The link between biophysical and economic assessments, which is an objective of the methodology, was challenging not only for the questionnaire but for the whole development of the methodology. The competence and knowledge needed to apply biophysical and economic methods are often in the hands of different experts. Similarly the valuation process, especially integrated valuation, which integrates ecological, social and economic values, is complex and requires an interdisciplinary team.

Therefore we recognise that the task of MARS is ambitious and the methodology proposed in this work has also some limitations. It simplifies and standardizes the objectives and tools to be used by the MARS partners. Still, a lot of research effort is needed to apply them, in particular to quantify the biophysical indicators and the economic values. For these reasons, most of the partners may select indicators and values easily calculated by their existing capabilities, without exploring the more complex or innovative ones.

The final aim of MARS is getting a holistic view of the aquatic environment in Europe. But in order to get a correct overview, this methodology requires compartmentalizing each natural or socio-economic factor at stake. The users of this methodology should be very clear about (1) what natural process or function they measure, (2) what are the feedbacks (pressure-state-service), and (3) what kind of ecosystem service assessment they accomplish (capacity-flow-benefit).

We have also to acknowledge that we (MARS consortium) are in the process of applying the methodology, but we had to develop the cook-book before completing testing the methodology, while it would have been better to adjust the methodology based on the implementation experience. This is what we expect happening in the course of the next years in the project MARS.

The scale of the analysis in the project involves several opportunities. The field scale studies will consider the effect of multiple stressors on the biophysical and the ecological processes underpinning the ecosystem services, the catchment scale will consider the ecosystem services integration and trade-offs, including management consideration. The European scale will address trends in regional changes and effects of EU policies. The barriers could be that when looking at the hydrological and ecological processes the relevant spatial scale are the catchment and the landscape, while data and statistics regarding the socio-economic development, needed for the studying the demand side of ecosystem services, are mainly available at the national and regional administrative scale.

Another risk that we can anticipate is the conceptual misunderstanding of the relationship between ecosystem services and anthropogenic pressures. High exploitation of the ecosystem can turn an ecosystem service into a pressure (ex. recreation, water use), this creates difficulties in identifying ecosystem services only as benefits. Confusion in the understanding and definition of ecosystem services could lead to a misuse of the concepts and be used against the objectives of protecting and enhancing the water ecosystem services.

We think that MARS and this work can contribute to the reflection on the use of ecosystem services in the water resource management. The application of ecosystem service concepts in RBMP is appealing and could reveal very powerful for the development of the green economy. A society that recognises the contribution of nature and the interest of protecting and restoring the environment is spending better and investing in green economy. The challenge is to integrate social equity and environmental elements in the management of the resources and the environment (Cook & Spray 2012).

Differently from ecosystem status, the concept of ecosystem service involves an anthropocentric perspective on nature and its resources, but at the same time recognises the fundamental interdependence between humans and nature (called the human-ecological system). Ecosystem services assessments look at the human benefits from nature. This approach could however be adopted with contrasting underpinning intentions. On the one hand to protect nature highlighting how precious and convenient are the services provided by nature; on the other hand to exploit nature, reducing nature to market goods. We adopt the first approach. Our working hypothesis is that ecosystem services do not substitute the information (indicators) of status of an ecosystem, but highlight the specific benefits that humans receive from it, with the intent of protect and enhance the ecosystem to continue assuring these natural benefits. Thus we consider status and services are complementary information for basin management.

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Annexes

Annex 1 – Scope of ecosystem service assessment in MARS case studies

Table A1.1 - Assessment at the water body scale

Experiments at the water body scale in the project MARS (WP3). *Indicates the research plan as reported in the partners' consultation in May 2014; - no answer to the questionnaire.

WP3 Task	Case study	Leading Institute	Brief description (based on the DOW text)	Ecosystem services*	Economic valuation*
3.1 Lake experiments	3.1.1 Extreme rainfall	NERC	(location UK) Study of the effects of extreme rainfall (32 mesocosms); mimic enhanced runoff into lakes. Ecosystem metabolism and biodiversity will be monitored. Biological and chemical analysis (bacteria by molecular methods, phytoplankton as clorophyll a, zooplankton, macroinvertebrates, macrophytes and fish)	No	No
3.1 Lake experiments	3.1.2 Extreme heatwaves	AU	(location DK) Study of the effect of extreme heatwaves (mesocosm). Biological and chemical analysis (bacteria, phytoplankton as clorophyll a, zooplankton, macroinvertebrates, macrophytes and fish)	-	-
3.1 Lake experiments	3.1.3 Extreme mixing and DOM loading	FVG-IGB	(location DE) Study of the effect of extreme mixing and DOM loading (24 mesocosms). Phytoplankton will be used as indicator of lake ecological status, in addition to physico-chemical indicators, including cyanobacterial toxins, Secchi depth, nutrients, and DOC. Variables capturing trophic and competitive relationships will serve to explain variation in phytoplankton and harmful algae.	-	-

3.2 River experiments	3.2.1 Extreme flow in Nordic rivers	NIVA	(location NO) Study of the effect of extreme flow (4 stream side flumes); effects on primary production and periphyton consumption in relation to trait composition of primary producers and consumers; combined effects of hydrology and nutrient loading; relative importance of primary production and allochthonous inputs for secondary production. Additional functional indicators include leaf breakdown rate and stable isotope signatures.	No	No
3.2 River experiments	3.2.2 Peak flow in Alpine rivers	BOKU	(location AU) Study of the effect of peak flow (HyTEC 2 large channels). Responses to hydraulic and other stressors will be habitat and behavioural shifts of larval and juvenile fish; drift of fish, macroinvertebrates and algae; water chemistry	Water purification, maintaining populations and habitats, abiotic energy sources	No
3.2 River experiments	3.2.3 Water scarcity in Mediterranean rivers	UTL	(location PT) Study of the effect of low flow in Mediterranean rivers (indoor flume). Responses addressed include hydraulic conditions, physico-chemical water quality, substrate composition, fish movement and behaviour, and invertebrate persistence, density and position in the substrate.	Maintaining populations and habitats	No
3.2 River experiments	3.2.4 Low flows in Nordic rivers	AU	(location DK) Study of the effect of low flow in Nordic rivers (12 outdoor flumes). Community composition of all biological elements, ecosystem functioning and food web structure will be determined.	Water for non-drinking purposes, water purification, maintaining populations and habitats	No
3.3 Analysis of time series	3.3.1 Lakes	EMU	Analyse existing time series from lakes in terms of multi-stressor effects on physico-chemical water quality parameters, biological quality elements, and measures of ecosystem functioning and services	Fisheries and aquaculture, water for drinking, recreation	No
3.3 Analysis of time series	3.3.2 Rivers	CU	Analyse existing time series from streams in terms of multi-stressor effects on physico-chemical water quality parameters, biological quality elements, and measures of ecosystem functioning and services	Fisheries and aquaculture, water for drinking, water for non-drinking purposes, water purification, erosion prevention, maintaining populations and habitats, pest and disease control, local climate regulation, intellectual and aesthetic appreciation	No

Table A1.2 - Assessment at the catchment scale

Figure A1.1 Location of the 16 catchments under study in the project MARS (WP4).

Table A1.2 - Case studies at the catchment scale in the project MARS (WP4). * Indicates the research plan as reported in the partners' consultation in May 2014.

WP4 Task	Case study	Leading Institute	Main pressures (from DOW)	Brief description (based on the DOW text)	Ecosystem services*	Economic valuation*
4.2 Southern river basins	Sorraia ($7,611\ km^2$, PT)	UTL	Widespread transfers, regulation and abstraction of surface and groundwaters climate change	Models of fluxes of water, nutrients, sediments and organic pollutants will be used to assess the impact of these multiple stressors on water resources and quality and focus on identifying optimal management solutions to water conflicts, restoration, and the effects of climate warning	Water for drinking; Water for non-drinking purposes; Raw materials for energy; Water purification; Flood protection; Maintaining populations and habitats; Carbon sequestration; Recreation	No
4.2 Southern river basins	Nervion-Ibaizabal ($1,755\ km^2$, ES)	AZTI	Water quality, morphological changes	Investigate how various discharge and morphological change scenarios may affect ecological quality, recreation (bathing) and estuarine biodiversity and what are the preferred management strategies to improve water resource and ecological status	Fisheries and aquaculture; Recreation	Yes. Ecosystem services that will be valued : Fisheries and aquaculture, Recreation Methods they want to apply: damage cost avoided, replacement cost.
4.2 Southern river basins	Pinios ($9,500\ km^2$, GR)	NTUA	Desertification agriculture	A hydrological model will link multiple water quality stressors to benthic macroinvertebrate data, and the consequences for management options related to the improvement of natural hydrological cycles, water supply and water purification will be appraised	Water for drinking; Water for non-drinking purposes; Erosion prevention; Flood protection; Carbon sequestration	No
4.2 Southern river basins	Beysehir ($4,080\ km^2$, TR)	METU	Abstraction for irrigation Climate changes eutrophication	Examine the conflicting demands of water use for crops, people and ecosystems in this setting, and investigate how these multiple stressors can be effectively reconciled with good water resource and ecological status outcomes. Particular attention will be given to surface water-groundwater interaction and the optimal use of all water resources within the catchment	Water for non-drinking purposes; Local climate regulation; Recreation	No

4.2 Southern river basins	Lower Danube (RO)	DDNI	Flood risk and water quality are already major problems, exacerbated by increasing urban land use, floodplain development, reduced river-bed capacity and deforestation. Hydro-morphological pressures include 255 reservoirs, 80% embankment on the lower reaches, regulation (6,600 km) and abstraction (138 significant abstractions).	Flow and quality alterations will be modelled, and land use change scenarios tested on order to evaluate the implications for ecosystem services within the Basin	Fisheries and aquaculture; Flood protection	No
4.3 Central river basins	Thames (9,948 km^2, UK)	NERC	Stressors include agricultural nutrients, organic pollutants, endocrine disrupting compounds, nanoparticles and metals, invasive species and pathogens, extensive regulation, high and growing water demand and regular droughts.	Linked abiotic and biotic models will be used to quantify response to multiple drivers using mechanistic and Bayesian approaches and so to characterise i.) the effects of climate change, land use changes and population growth on response surfaces describing nutrients stress, toxic compounds, temperature and pathogens, and ii.) the impact of a range of management scenarios on environmental services and outcomes under various multistressor conditions	Water for drinking; Water purification; Flood protection; Maintaining populations and habitats	No
4.3 Central river basins	Regge and Dinkel (1,350 km^2, NL)	DELTARES	Agriculture has caused large hydromorphological alterations, base flow reductions and water quality deterioration. Droughts and groundwater abstraction lead to water scarcity affecting biological quality	Work will focus on surface-groundwater interactions, ecological flows, drainage and irrigation strategies, Natural Water Retention Measures and HABITAT GIS assessment for selected BQEs	Water for drinking; Water for non-drinking purposes; Water purification; Maintaining populations and habitats	No

4.3 Central river basins	Odense ($1,100\ km^2$, DK)	AU	Agriculture has caused large hydromorphological alterations, base flow reductions and water quality deterioration. Droughts and groundwater abstraction lead to water scarcity affecting biological quality.	Mechanistic models will examine abiotic effects on phytoplankton, zooplankton, submerged vegetation and fish to understand consequences for key ecosystem services (water supply, nutrient retention, recreation and angling). Climate change and land use scenarios will be applied, and nutrient and sediment retention using new ten metre riparian buffers will be investigated as these will become mandatory from 2012 onwards	Fisheries and aquaculture; Water purification; Recreation	Yes Ecosystem service that will be valued: recreation Method used: Damage cost avoided, Contingent valuation
4.3 Central river basins	Elbe, Havel and Saale (DE)	FVB-IGB	Major stressors include eutrophication, hydromorphological alterations by damming, land use regulation structures, loss of bank vegetation and intensive shipping	Model applications will focus on services for flood risk reduction, fisheries, recreation and water purification (N and P-retention)	Water purification; Local climate reguation	No
4.3 Central river basins	Ruhr (DE)	UDE	Agriculture urbanisation	Models for nutrients and discharge will address ecosystem services including self-purification and biodiversity protection using empirical dose-response relationships to examine future scenarios of land use and restoration	Water purification; Erosion prevention; Maintaining populations and habitats; Carbon sequestration	No
4.3 Central river basins	Drava ($2,600\ km^2$, AT)	BOKU	hydropower and associated morphological alteration are key stressors affecting fisheries and recreation	Empirical models will link hydromorphology to fish, invertebrates and phytobenthos. Faced with new hydropower plants, scenarios will address the conflicting ecosystem service effects on fisheries, recreation and hydropower	Water purification; Maintaining populations and habitats; Abiotic energy sources (e.g. hydropower generation)	No

4.4 Northern river basins	Welsh basins (4,000 km^2, UK)	CU	Stressors combinations	Scenarios and modelling will explicitly address links between land-use, climate and ecosystem service resilience (fish production, water quality regulation, decomposition and cultural values)	Fisheries and aquaculture; Water for drinking; Water for non-drinking purposes; Water purification; Erosion prevention; Maintaining populations and habitats; Pest and disease control; Local climate regulation; Intellectual and aesthetic appreciation	Yes Ecosystem services that will be valued: Fisheries and aquaculture, Water purification, Maintaining populations and habitats, Pest and disease control, Recreation, Intellectual and aesthetic appreciation Methods they will use: Contingent valuation, Choice experiment
4.4 Northern river basins	Vansio-Hobol (690 km^2, NO)	NIVA	Diffuse agricultural pollution Flow regulation	Empirical studies will link macrophytes, macroinvertebrates and fish to nutrients and temperature, while lake process models will address consequences for chlorophyll a.	Fisheries and aquaculture; Water for drinking; Water for non-drinking purposes; Erosion prevention; Flood protection; Maintaining populations and habitats; Carbon sequestration; Recreation; Intellectual and aesthetic appreciation; Abiotic energy sources (e.g. hydropower generation)	Yes. For the Vansio Hobol and Otra catchments. Ecosystems services that will be valued: Fisheries and aquaculture, Water for non-drinking purposes, Carbon sequestration, Recreation, Intellectual and aesthetic appreciation. Methods applied: Damage cost avoided, Choice experiment, Unit value transfer, Adjusted unit value tranfer
4.4 Northern river basins	Otra (3,740 km^2, NO)	NIVA	hydropower, acidification, metals, invasive species and nuisance macrophytes	(Provides hydroelectric power, salmon habitat, recreation, and protected habitat for important biota). Long-term data on hydrology, hydrochemistry and biology allow empirical and mechanistic relationships between stressors and status of fish and benthic invertebrates.		

4.4 Northern river basins	Kokemaenjoki (27,040 km^2, FI)	SYKE	stressors combine eutrophication and pathogens from agriculture, hydromorphological change from hydropower and flood defence, climate change and brownification	Dynamic and hybrid modelling will assess stressor effects from forestry and agriculture on macrophytes, phytoplankton, concentrating particularly on 'brownification'.	Erosion prevention	No
4.4 Northern river basins	Vortsjarv (3,104 km^2, EE)	EMU	level fluctuations affecting ecosystem structure and CO2 emissions, while catchment agriculture results in eutrophication. Climate change is further affecting hydrology, water level, temperature, ice regime brownification and carbon balance. Large commercial fisheries are both ecosystem service and important pressures.	Modelling within MARS will focus on climate change effects on water temperature and ice regime, brownification and carbon balance alterations.	Fisheries and aquaculture; Water purification; Carbon sequestration; Recreation; Intellectual and aesthetic appreciation; Abiotic energy sources (e.g. hydropower generation)	No

Table A1.3 - Assessment at the European scale

Assessment at the European scale in the project MARS (WP5). * Indicates the research plan as reported in the partners' consultation in May 2014.

WP5 Task	Case study	Leading Institute	Brief description (based on the DOW text)	Ecosystem services assessment*	Economic valuation*
5.1 European matrix of stress and impact	5.1.4 Spatial assessment of services delivered by European aquatic ecosystems	JRC	We will assess the spatial distribution of both the biophysical and economic values of the services delivered by aquatic ecosystems (i.e. food provision, water regulation, water purification, recreation) and their changes under multi-stressor scenarios. Models will be applied to analyse scenarios on future land use, climate and mitigation / restoration. Models will be applied to analyse scenarios on future land use, climate and mitigation / restoration.	Fisheries and aquaculture, water for drinking, water for non-drinking purposes, water purification, air quality regulation, erosion prevention, flood protection, maintaining populations and habitats, carbon sequestration, local climate regulation, recreation, abiotic energy sources	Recreation
Task 5.2 Multiple stressors in large rivers		BOKU	This task will focus on the effects of multiple stressors on phytoplankton, macrophytes, macroinvertebrates and fish, and on ecosystem services. Though parts of the task will use data from a wide range of European rivers, a focus will be on the Danube, the largest river in Central Europe. We will survey the main historical waves of alterations related to overfishing, pollution, channelization, dam construction, navigation, invasive species and climate change, and we will relate the stressors to documented changes in the aquatic communities and ecosystem services.	-	-
5.3 Multiple stressors in lakes		NIVA	We will analyse the impacts of multiple stressors on lake ecosystems over large spatial scales. We will examine ecological responses of primary producers in large populations of lakes, assess the impacts of future multiple stressor scenarios. The biological responses examined (phytoplankton indices, macrophyte indices) will be selected as indicators of the quality of ecosystem services such as drinking water quality, bathing water quality and recreation.	-	-

5.4 Multiple stress effects on European fish assemblages		IRSTEA	We will comparatively analyse the effects of multiple stress on fish in rivers, lakes and transitional waters using statistical and modelling approaches and recent Europe-wide databases. The information can be used to identify the most threatened ecosystems across Europe with respect to services derived from fish (angling and fisheries), biodiversity (risk of local extinction due to increase of niche overlap), and ecosystem functioning (loss of function supported by endangered species). We will study the effects of multiple stressors on the establishment of exotic species and subsequent effects on native fish assemblages and services (e.g. recreational activities/angling and food resources, and management of fish communities dominated by exotic species)	-	-

Annex 2 - Ecosystem services classification

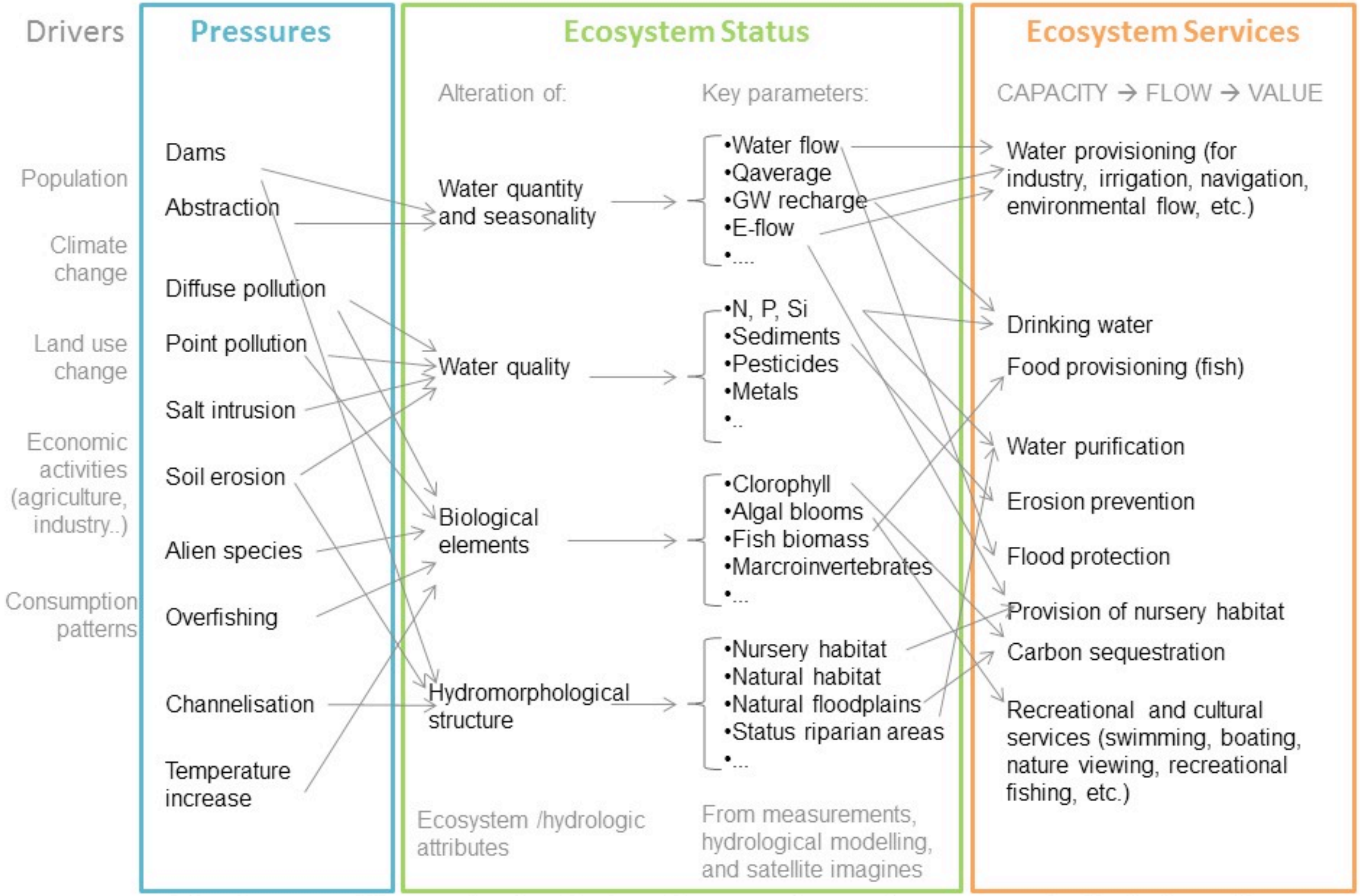
Table A2.1 – List of ecosystem services relevant for water systems

	Ecosystem services terminology proposed in MARS	**Examples**	**Ecosystem services from CICES**	**Ecosystem services from TEEB**
Provisioning	Fisheries and aquaculture	e.g. fish catch	Food - Biomass	Food
	Water for drinking	e.g. provision of water for domestic uses	Drinking water	Fresh water
	Raw (biotic) materials	e.g. algae as fertilisers, vegetal compounds for cosmetics	Materials - Biomass	Raw materials, Medicinal resources
	Water for non-drinking purposes	e.g. provision of water for industrial or agricultural uses	Non-drinking water	Fresh water
	Raw materials for energy	e.g. wood from riparian zones	Energy - Biomass	Raw materials
Regulation & Maintenance	Water purification	e.g. excess nitrogen removal by microorganisms	Mediation of pollution in water	Waste-water treatment
	Air quality regulation	e.g. deposition of oxides of nitrogen on vegetal leaves	Mediation of pollution in air	Local climate and air quality
	Erosion prevention	e.g. vegetation controlling soil erosion on river banks	Mediation of mass flows and erosion	Erosion prevention and maintenance of soil fertility, Moderation of extreme events
	Flood protection	e.g. vegetation or floodplains trapping and slowing down the water flow, coastal habitats protecting from inundation	Flood protection	Moderation of extreme events
	Maintaining populations and habitats	e.g. key habitats use as reproductive grounds, nursery, shelter… for a variety of species	Maintaining populations and habitats	Habitats for species, Maintenance of genetic diversity
	Pest and disease control	e.g. diseases and parasites are better controlled in the wild (by natural predation on weakened individuals)	Pest and disease control	Biological control
	Soil formation and composition	e.g. rich soil formation in floodplains or in wetlands borders	Soil formation and composition	Erosion prevention and maintenance of soil fertility
	Carbon sequestration	e.g. carbon accumulation in vegetation or sediments	Global climate regulation	Carbon sequestration and storage
	Local climate regulation	e.g. maintenance of humidity and precipitation patterns by wetlands or lakes, shading effect	Micro and regional climate regulation	Local climate and air quality
Cultural	Recreation	e.g. swimming, recreational fishing, sightseeing, boating	Experiential interactions with nature	Recreation and mental and physical health, Tourism
	Intellectual and aesthetic appreciation	e.g. subject matter for research, artistic representations of nature	Intellectual and aesthetic interactions with nature	Aesthetic appreciation and inspiration for culture, art and design
	Spiritual and symbolic appreciation	e.g. existence of emblematic species like *Lutra lutra* or sacred places	Spiritual and symbolic interactions with nature	Spiritual experience and sense of place

*Extra abiotic environmental services**	*Raw abiotic materials*	*e.g. extraction of sand & gravel from river bed or river banks*	*Abiotic materials*	
	Abiotic energy sources	*e.g. hydropower generation*	*Renewable abiotic energy sources*	

*See discussion in Section 4.1

Annex 3 – Integrated framework for water ecosystem services assessment



The list of pressures and the arrows describing the relationships are not exhaustive, the users are invited to develop the specific relationships at stake in their case study

Annex 4 – Biophysical assessment of ecosystem services: list of indicators

Table A4.1 - Biophysical indicators based on literature review

Potential proxies/indicators for water ecosystem services based on literature review (sources are listed below) and organised in three categories: natural capacity, service flow and social benefit, according to the type of information they provide. The proxies/indicators refer mainly to the ecosystem services delivered by lakes, rivers, groundwater, riparian areas, floodplains, wetlands, transitional and coastal waters.

Sources

[1] Maes et al. 2014 (Table 11)

[2] Egoh et al. 2012 (Appendix 1)

[3] Layke et al. 2012 (World Resources Institute database www.esindicators.org)

[4] Russi et al. 2013 (Table 3.1 and Box 3.1)

[5] Liquete et al. 2013 (Table S3)

Legend

- **in bold** = ecosystem services that will be assessed by the MARS partners according to the questionnaire of May 2014
- highlighted = indicators considered relevant by more than 6 respondents to the questionnaire of May 2014
- in red = this indicator is more appropriate for ecosystem condition or integrity than for the delivery of a particular service

References

Egoh B, Drakou EG, Dunbar MB, Maes J, Willemen L (2012) Indicators for mapping ecosystem services : a review. Publications Office of the European Union, Luxembourg.

Layke C, Mapendembe A, Brown C, Walpole M, Winn J (2012) Indicators from the global and sub-global Millennium Ecosystem Assessments: An analysis and next steps. Ecological Indicators 17: 77–87.

Liquete C, Piroddi C, Drakou EG, et al. (2013). Current status and future prospects for the assessment of marine and coastal ecosystem services: a systematic review. PloS one 8 (7): e67737.

Maes J et al. (2014). Mapping and Assessment of Ecosystems and their Services. Indicators and guidelines for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020. Publications office of the European Union, Luxembourg.

Russi D., ten Brink P., Farmer A., Badura T., Coates D., Förster J., Kumar R. and Davidson N. (2013) The Economics of Ecosystems and Biodiversity for Water and Wetlands. IEEP, London and Brussels; Ramsar Secretariat, Gland.

Ecosystem services	Natural capacity	Service flow	Social benefit
Fisheries and aquaculture	Status of fish population (species composition, age structure, biomass) [1,5] Abundance of fish [2,5] Relative fish abundance based on catch per unit effort (CPUE) [5] Condition of fish stocks [3] Food web structure and robustness [5] Number of wild species used for human food [3]	Fish catch [1,2,5] Aquaculture production [1,3] Sea food productivity [5] Wild vegetation used in gastronomy [1] Fish production from sustainable sources (e.g. proportion of fish stocks caught within safe biological limits, certified/viable fisheries…) [4,5]	Number of fishermen [1] Employment in fishing, mariculture and related sectors [3,5] Fish products as a percent of total animal protein in people's diet [3] Value of fish and sea food landings, or value of aquaculture sales [3,5] Marginal value of a change in fisheries management [5]
Water for drinking	Surface water availability [1,2] Total freshwater resources [1,4] Nitrate-vulnerable zones [1] River salinity [2] Renewable water supply accessible to humans [3] Water storage capacity [3]	Water consumption for drinking [1] Water abstracted [1] Water exploitation index [1] Consumptive water use by end user [3]	Proportion of population using an improved drinking water source [4] Proportion of cities obtaining water supplies from protected areas [4] Water-stressed population [3] Total water requirements [3]
Raw (biotic) materials	Land cover [2] (Wood) biomass production over stem diameter classes [5]	Wild vegetation used in cosmetic or pharmaceutical uses [1,5] Surface of exploited wet forests (e.g. poplars), coastal forests (e.g. mangroves) and reeds cutting [1,2,5] Timber produced by riparian forest [1] Timber from sustainable managed forests [4] Organisms from which drugs have been derived [3] Number of species that have been the subject of major investment or have become a commercial product [3]	Value of pharmaceutical products developed in natural systems or from marine organisms [3,5] Investment into natural products prospecting [3] Value of (wet or coastal) timber forest products [3,5] Net value added of raw materials: seaweed, fishmeal, fish oil, ornamental [5]

Ecosystem services	Natural capacity	Service flow	Social benefit
Water for non-drinking purposes	Surface water availability [1,2] Ground water availability [1,2] Total freshwater resources [1,4] Salinity levels [2,3] Renewable water supply accessible to humans [3] Water storage capacity [3]	Water use per sector [1,4] Water abstracted [1] Water exploitation index [1] Area water-logged by irrigation [4] Volume of water desalinated [3]	Cost of water and water delivery [3] Total water requirements [3] Net value added: desalinated water supply [5]
Raw materials for energy	(Wood) biomass production over stem diameter classes [5]	Production of peat [1] Surface of exploited wetlands for peat and biofuels [1] Firewood produced by riparian or coastal forests [1,5]	Net present value of clearance logging and of fuelwood under different management scenarios [5]
Water purification	Indicators on surface water quality (e.g. microbiological data, BOD, phosphate concentration, oxygen conditions, saprobiological status, suspended matter) [1,4,5] Indicators on groundwater quality (e.g. NO3, pesticide, trace metals, emerging pollutants) [1] Nutrient concentration [1,5] Trophic status [1] Ecological status [1] Area occupied by riparian forests [1] Presence of floodplains, wetlands, estuaries or mangroves [5] Presence/distribution of nitrophilous macroalgae or macrophytes [5]	Nutrient loads [1] Nutrient retention [1,2] Nutrient uptake by organisms [5] Removal of nutrients by wetlands [4] Amount of waste processed by ecosystems [3] Sedimentation and accumulation of organic matter [5]	Access to safe water [3] Value of ecosystem waste treatment and water purification [3] Cost of effluent treatment or nutrient abatement [5]

Ecosystem services	Natural capacity	Service flow	Social benefit
	Potential mineralization or decomposition [1]		
Air quality regulation	Tree cover [2] Pollutant concentration [2] Atmospheric cleansing capacity [3]	Deposition velocity [2] Flux in atmospheric gases [3]	
Erosion prevention	Ground water level evolution [1] Soil erosion rate by land use type [4] Geomorphology [2] Vegetation distribution and properties (of riparian or coastal zones) [2,5] Area affected by erosion [3] Presence of seagrass meadows or kelp [5]	Sediment accretion /soil retention [1,2,5] Siltation [3]	Willingness-to-pay of local residents [5] Loss in property values from declining shoreline protection [5]
Flood protection	Water holding capacity of soils [1,2,3,4] Conservation status of river banks, lake banks and riparian zones [1,2] Floodplain area [1,2] Area of wetlands located in flood risk zones [1] Ground water level evolution [1] Soil capacity to transfer groundwater [3] Infiltration capacity of an ecosystem [4] Floodplain water storage capacity [3,4] Area of intact wetlands, floodplains, coral reefs, mangroves, sandbars or barrier beaches [3,5] Vegetation distribution and properties (of riparian	Flood risk maps [1] Record of annual floods [1,2] Trends in number of damaging natural disasters [3,4] Probability of incident [4] Wave attenuation or surge reduction [5]	Percentage of population living in water hazard prone areas [4] Population in floodplain/coastal area [3] Spending on disaster assistance for floods [3] Construction and/or maintenance cost of sea defences [5] Avoided damage per storm condition [5]

Ecosystem services	Natural capacity	Service flow	Social benefit
	or coastal zones) [2,5]		
Maintaining populations and habitats	Biodiversity value (species diversity or abundance, endemics or red list species, spawning areas) [1,2] Ecological status [1] Hydromorphological status [1] Coverage, condition and structural complexity of nursery and feeding areas (e.g. coral, mangrove) [5] Macrophyte species richness [5]	Habitat suitability [2] Species abundance and richness [5] Habitat change [5] Juvenile density [5] Postlarvae production per hatchery [5]	Community perception on the importance of habitat provision [5] Economic value of the annual juvenile fish production based on the price of aquaculture growth [5]
Pest and disease control	Alien species introduced in aquatic environments and riparian zones [1] Disease vector predator populations [3]	Pest density [2] Control of aquatic disease bearing invertebrates and plants by fish [5] Occurrence of problems limiting crop and livestock productivity [3] Increase in disease vectors mosquitoes [3] Estimated change in disease burden as a result of changing ecosystems [3]	Population affected by water-related diseases [4] Waterborne and water related disease incidence [3]
Soil formation and composition	Presence of hydromorphic soils [1] Surface of floodplains [1] Potential mineralization or decomposition [1] Decomposition of dissolved and particulate organic matter by bacteria and funghi in the sediments [5]	Fluvisols surface [1] Nutrients stored in the sediments [5]	

Ecosystem services	Natural capacity	Service flow	Social benefit
Carbon sequestration	Organic carbon stored or carbon stock [1,4,5] Above and below-ground biomass [2,5] Carbon in soil or sediments [2,5] Dissolved organic matter [5]	Carbon sequestration or carbon change [1,4,5] Carbon uptake [3,5] Soil carbon accumulation [5]	Quantity of carbon fixed combined with the marginal damage costs of carbon emissions [5] Market value of carbon [5]
Local climate regulation	Riparian zone [2] Ground water level [1] Temperature & Precipitation [2] Evapotranspiration [3] Cloud formation [3] Canopy stomatal conductance [3]	Drought frequency [3]	
Recreation and tourism	National Parks and Natura 2000 sites [1] Number of bird watching sites [1] Number of beaches [1] Fish and waterfowl abundance [1,2] Condition of fish stocks [3] Quality of fresh waters for fishing [1] Accessibility [2] Footpaths [2] Size of marine leisure and recreation hotspots [5] Cover and smell of decomposing algae [5] Presence of coralligenous community or cetacean population [5]	Number of visitors to natural places (e.g. to National Parks, lakes, rivers, protected wetlands) [1,2,3,4] Number of visitors to attractions (e.g. thermal, mineral and mud springs and balnearies, speleology sites, species watching) [1,4] Number fishing licenses and fishing reserves [1] Beach closure due to bacteria limit, discolored or turbid water [5] Number of bathing areas[1] Number of waterfowl hunters, anglers and amateur fishermen [1,3]	Tourism revenue [1] Traffic census [2] Amount or spending on nature tourism [3,4,5] Beach visitors and travel cost [5] Tourists' perception in a marine protected area [5]

Ecosystem services	Natural capacity	Service flow	Social benefit
Intellectual and aesthetic appreciation	National Parks and Natura 2000 sites [1] Contrasting landscapes (e.g. lakes close to mountains) [1] Proximity of scenic rivers or lakes to urban areas [1,2] Monitoring sites by scientists [1] Fish studies as a source of information [5] Seabird populations [3]	Cultural sites and number of annual cultural activities organised [1] Classified sites (e.g. World Heritage, label European tourism) [1] Number of visitors [1,2] Number of scientific projects, articles, studies, patents [1,4] Number of educational excursions at a site [4] Number of TV programmes, studies, books etc. featuring sites [4]	Changes in the number of residents and real estate values [4] Comparative value of real estate nearer to nature/ cleaner water bodies [3,5] Price of a hotel room with sea views [5] Willingness to pay for improvement in the environment/ improved water quality [2,3] Taxes and subsidies that support maintaining open space [3] Financial expenditure in research [5]
Spiritual and symbolic appreciation	National species or habitat types [1] Rare species [2] Cultural landscape intactness [3]	Sacred or religious sites (e.g. catastrophic events, religious places) [1] Number of sites or species fundamental to performance of rituals [3] Number of visitors [1] Number of (environmental) associations registered [1]	Changes in the number of residents and real estate values [4] Incentives to maintain traditional cultural landscapes [3]

Annex 5 – Economic valuation of ecosystem services: list of techniques

Table A5.1 – Economic valuation methods

Approach	Valuation method	Description of the method	Examples of ESS value assessment
Cost-based	*Damage cost avoided*	Method that values an ecosystem service estimating the damage that might be incurred if this service disappears	Assess the value of the storm protection service provided by wetlands through an estimation of avoided damage in case of a storm
	Replacement cost	Method that uses the cost of a substitute for an ecosystem as a proxy for the value of services provided by this ecosystem	Assess the value of the water purification service through an estimation of the construction cost of artificial wetlands
Revealed preferences	*Travel cost*	Survey-based technique that uses the cost incurred by individuals taking a trip to a recreation site as a proxy for the recreational value of this site	Assess the value of the recreational service of a lake based on the number of visitors and the money they spend to visit the lake
	Hedonic price	Method that estimates the value an environmental characteristic of an ecosystem by looking at differences in property prices	Assess the value of lake amenities by comparing real-estate prices located at different distances of this lake
Stated preferences	*Contingent valuation*	Survey-based technique in which respondents answer questions regarding their willingness to pay for an environmental service or a change in this environmental service	Assess the value of an aquatic species by asking individuals how much they are ready to contribute for preserving it
	Choice experiment	Survey-style technique in which respondents are asked to state their choice over different hypothetical alternatives (alternatives consist in a combination of attributes of an ecosystem and a price associated to this combination)	Assess the value of services provided by a river by the choice respondents make between different options (combinations of water quality, number of species and vegetation) combined with different prices to be paid for each combination.
Benefit transfer	*Unit value transfer*	Method that values an ecosystem service by transferring a monetary value derived from another study (and from another site)	Assess the value of the recreational service of a lake applying a constant value per unit of ecosystem (e.g. the surface area) taken from another study
	Adjusted unit value transfer	Method that values an ecosystem service by transferring a monetary value derived from another study, this value being adjusted using an ad-hoc factor to account differences between the two sites	Assess the value of the recreational service of a lake applying a value per unit of ecosystem (e.g. the surface area) that depends on the income level of the local population
	Value transfer functions	Method that values an ecosystem service using a value function estimated from another site	Assess the value of the recreational service of a lake by plugging site-specific parameters into a value function estimated from another study
	Meta-analytic value transfer functions	Method that values an ecosystem service from a function estimated through statistical regression analysis of many primary valuation studies	Assess the value of the recreational service of a lake by plugging site-specific parameters into a value function estimated from a meta-analysis

Table A5.2 – Policy instruments relevant for ecosystem services

Category	Policy instruments	Examples / Explanations
Economic instruments	▪ *Taxes* ▪ *Markets* ▪ *Subsidies* ▪ *Payments for ecosystem services*	▪ Effluent taxes, water withdrawal fees. ▪ Tradable water pollution permits. ▪ Subsidies for low water consumption equipment. ▪ "Contract for services" i.e. voluntary payment for the delivery of specified ecosystem services. In France payment by the Vittel company to farmers who adopt less intensive farming techniques, in UK angler's payment for improvements to river water quality (angling passport).
Voluntary approaches	▪ *Private agreements* ▪ *Public voluntary schemes* ▪ *Negotiated agreements*	▪ Unilateral commitments made by polluters or resource users, multilateral agreements between polluters and pollutees or between resource users. ▪ Voluntary programs developed by public bodies such as environmental agencies, to which economic agents (individuals, farmers, firms) are invited to participate. ▪ Agreements usually created out of a dialogue between government authorities and economic agents (individuals, farmers, firms) typically containing a target and a timetable for reaching that target.
Regulations	▪ *Norms and standards* ▪ *Restrictions on use and access* ▪ *Liability rules*	▪ Minimum water flows, maximum pollutant concentrations in watersheds. ▪ Legal possibility for public authorities to restrict or to limit access or use of water resources. ▪ Legal obligations for the responsible party to bear the costs of restoring the environment.
Information tools	▪ *Education campaign* ▪ *Use of media* ▪ *Eco labelling of products*	▪ Campaigns to raise awareness of children about water issues. ▪ Use of any kind of media for informing populations about water issues. ▪ Water saving labelling program for products and services which are helping to reduce water use (Smart WaterMark in Australia).

Annex 6 – Questionnaire on ecosystem services

A6.1 Questionnaire form

MARS Task 2.2 - Questionnaire on Ecosystem Services

Fields marked with * are mandatory.

The **aim** of this questionnaire is to collect the needs, experience and knowledge of the MARS partners to inform and target the methodology to be developed by Task 2.2 for assessing and valuing ecosystem services.

We ask you to carefully read the **background information** before taking the questionnaire.

Background information can be found here:
Background_information.pdf

A pdf copy of the questionnaire can be found here:
copy_questionnaire_Mars.pdf

The **questionnaire** is organized in four sections. We will ask information about:

1. the respondent (4 questions)
2. the ecosystem services of interest (13 questions)
3. previous experience and studies on ecosystem services (5 questions)
4. feedback on the questionnaire (6 questions)

You can save your answers anytime with the button "Save as Draft" at the bottom of the page.

This questionnaire has been prepared by Grizzetti B., Lanzanova D., Reynaud A., Liquete C., Cid N., Cardoso A.C.
(If you have any question about this questionnaire please contact denis.lanzanova@jrc.europa.eu)

1. Information about the respondent

In this section we ask you information about the **respondent** of the questionnaire and the involvement in the MARS project.

1.1 Name of the institution:*

1.2 Names of the respondents (people in your team that will be involved in assessing and valuing the ecosystem services in MARS. More than one name possible):*

1.3 Contact email:*

1.4 Type of involvement in Ecosystem Services in MARS (more than one option possible):*

- ☐ WP2
- ☐ WP3
- ☐ WP4
- ☐ WP5
- ☐ Other WP

Please specify (e.g. name of the study):*

2. Selection of relevant ecosystem services

In MARS we will study the effects of multiple stressors on the delivery of ecosystem services at three different scales: water body, catchment and the European scale. Task 2.2 will develop methodologies for assessing and valuing ecosystem services at these three scales. In this session we will ask you information about the ecosystem services that are of interest for you, considering first their biophysical assessment and then their economic valuation.

2.1 For which **scale** will you apply the methodology?*

- ○ I will apply the methodology developed by Task 2.2 at the water body scale (WP3)
- ○ I will apply the methodology developed by Task 2.2 at the catchment scale (WP4)
- ○ I will apply the methodology developed by Task 2.2 at the European scale (WP5)
- ○ I will not apply the methodology directly

In this case please specify for which scale you would like to take the questionnaire: water body, catchment, European scale.*

2.2 Within your study which **water bodies or ecosystems** (relevant for the delivery of ecosystem services) will you assess? (more than one option possible)

Please tick the relevant box(es)

	I will assess in MARS
Lakes	☐
Rivers	☐
Transitional waters	☐
Coastal waters	☐
Groundwater	☐
Freshwater wetlands	☐
Coastal wetlands	☐
Riparian areas	☐
Floodplains	☐

2.3 From the following list of **ecosystem services** which ones do you think are relevant (and you plan to assess in MARS) for your study? (more than one option possible)

Provisioning services

Please tick the relevant box(es)

	Are relevant for my study	I would like to assess in MARS
Fisheries and aquaculture *(e.g. fish catch)*	☐	☐
Water for drinking *(e.g. provision of water for domestic uses)*	☐	☐
Raw -biotic- materials *(e.g. algae as fertilizers, vegetal compounds for cosmetics)*	☐	☐
Water for non-drinking puposes *(e.g. provision of water for industrial or agricultural uses)*	☐	☐
Raw materials for energy *(e.g. wood from riparian zones)*	☐	☐

Regulation & Maintenance services

Please tick the relevant box(es)

	Are relevant for my study	I would like to assess in MARS
Water purification *(e.g. excess nitrogen removal by microorganisms)*	☐	☐
Air quality regulation *(e.g. deposition of oxides of nitrogen on vegetal leaves)*	☐	☐
Erosion prevention *(e.g. vegetation controlling soil erosion on river banks)*	☐	☐
Flood protection *(e.g. vegetation acting as barrier for the water flow, lakes or floodplains trapping and slowing down the water flow)*	☐	☐
Maintaining populations and habitats *(e.g. key habitats use as reproductive grounds, nursery, shelter... for a variety of species)*	☐	☐
Pest and disease control *(e.g. diseases and parasites are better controlled in the wild (by natural predation on weakened individuals) than in fish farms, biodiversity may control mosquito population and prevent malaria outbreaks)*	☐	☐
Soil formation and composition *(e.g. rich soil formation in floodplains or in wetlands borders)*	☐	☐
Carbon sequestration *(e.g. carbon accumulation in vegetation or sediments)*	☐	☐
Local climate reguation *(e.g. maintenance of humidity and precipitation patterns by wetlands or lakes, shading effect)*	☐	☐

Cultural services

Please tick the relevant box(es)

	Are relevant for my study	I would like to assess in MARS
Recreation *(e.g. swimming, recreational fishing, sightseeing, boating)*	☐	☐
Intellectual and aesthetic appreciation *(e.g. subject matter for research, artistic representations of nature)*	☐	☐
Spiritual and symbolic appreciation *(e.g. existence of emblematic species like Lutra lutra or sacred places)*	☐	☐

Extra abiotic environmental services

Please tick the relevant box(es)

	Are relevant for my study	I would like to assess in MARS
Raw abiotic materials *(e.g. extraction of sand and gravel from river bed or river banks)*	☐	☐
Abiotic energy sources *(e.g. hydropower generation)*	☐	☐

2.4 Are there any other ecosystem services not included in the list that you think are relevant and you plan to assess in MARS for your study?

2.5 For the ecosystem services you have selected in question 2.3, we would like to know which **indicators** you think are appropriate for assessing the delivery of the ecosystem service in your study and if you have the possibility to assess them by data or modelling (the list of indicators is also provided in the background document).

PROVISIONING SERVICES: Fisheries and aquaculture

Please tick the relevant box(es)

	Are appropriate	I can estimate
Fish production or fish catch	☐	☐
Status of fish population (species composition, age structure, biomass)	☐	☐
Aquaculture production (e.g. sturgeon and caviar production)	☐	☐
Wild vegetation used in gastronomy, cosmetic or pharmaceutical uses	☐	☐
Number of fisherman	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

PROVISIONING SERVICES: Water for drinking

Please tick the relevant box(es)

	Are appropriate	I can estimate
Water consumption for drinking	☐	☐
Water abstracted	☐	☐
Surface water availability	☐	☐
Water exploitation index (WEI)	☐	☐
Nitrate-vulnerable zones	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

PROVISIONING SERVICES: Raw (biotic) materials

Please tick the relevant box(es)

	Are appropriate	I can estimate
Timber produced by riparian forest	☐	☐
Surface of exploited wet forests (e.g. poplars) and reeds	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

PROVISIONING SERVICES: Water for non-drinking purposes

Please tick the relevant box(es)

	Are appropriate	I can estimate
Water use per sector	☐	☐
Water abstracted	☐	☐
Surface water availability	☐	☐
Ground water availability	☐	☐
Volume of water bodies	☐	☐
Water exploitation index (WEI)	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

PROVISIONING SERVICES: Raw materials for energy

Please tick the relevant box(es)

	Are appropriate	I can estimate
Production of peat	☐	☐
Surface of exploited wetlands for peat and biofuels	☐	☐
Firewood produced by riparian forests	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

REGULATION & MAINTENANCE SERVICES: Water purification

Please tick the relevant box(es)

	Are appropriate	I can estimate
Indicators on surface water quality (e.g. microbiological data, BOD, phosphate conc, oxygen conditions, saprobiological status)	☐	☐
Indicators on groundwater quality (e.g. NO3, pesticide, trace metals, emerging pollutants)	☐	☐
Nutrient loads	☐	☐
Nutrient concentration	☐	☐
Nutrient retention	☐	☐
Trophic status	☐	☐
Ecological status	☐	☐
Area occupied by riparian forests	☐	☐
Potential mineralization or decomposition	☐	☐
Number and efficiency of treatment plants	☐	☐
Waste water treated	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

For **air quality regulation**, if you want to suggest indicators for ecosystem services, please use this space:

REGULATION & MAINTENANCE SERVICES: Erosion prevention

Please tick the relevant box(es)

	Are appropriate	I can estimate
Sediment retention	☐	☐
Ground water level evolution	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

REGULATION & MAINTENANCE SERVICES: Flood protection

Please tick the relevant box(es)

	Are appropriate	I can estimate
Flood risk maps	☐	☐
Water holding capacity of soils	☐	☐
Conservation of river and lakes banks	☐	☐
Ground water level evolution	☐	☐
Flood plains area (and record of annual floods)	☐	☐
Area of wetlands located in flood risk zones	☐	☐
Conservation status of riparian wetlands	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

REGULATION & MAINTENANCE SERVICES: Maintaining populations and habitats

Please tick the relevant box(es)

	Are appropriate	I can estimate
Biodiversity value (species diversity or abundance, endemics or red list species, spawning areas)	☐	☐
Ecological status	☐	☐
Hydromorphological status	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

REGULATION & MAINTENANCE SERVICES: Pest and disease control

Please tick the relevant box(es)

	Are appropriate	I can estimate
Alien species introduced in aquatic environments and riparian zones (e.g. plants, invertebrates, vertebrates)	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

REGULATION & MAINTENANCE SERVICES: Soil formation and composition

Please tick the relevant box(es)

	Are appropriate	I can estimate
Fluvisols surface	☐	☐
Presence of hydromorphic soils	☐	☐
Surface of floodplains	☐	☐
Potential mineralization, decomposition, etc.	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

REGULATION & MAINTENANCE SERVICES: Carbon sequestration

Please tick the relevant box(es)

	Are appropriate	I can estimate
Carbon sequestration or carbon change (e.g. in riparian forests, Populus plantations)	☐	☐
Organic carbon stored or carbon stock (e.g. in fluvisols)	☐	☐
Number of sites for CO_2 deep injections and volumes of CO_2 injected	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

REGULATION & MAINTENANCE SERVICES: Local climate regulation

Please tick the relevant box(es)

	Are appropriate	I can estimate
Ground water level	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

CULTURAL SERVICES: Recreation

Please tick the relevant box(es)

	Are appropriate	I can estimate
Number of visitors to natural places (e.g. to National Parks, to lakes or rivers, to protected wetlands)	☐	☐
Number of visitors to attractions (e.g. thermal, mineral and mud springs and balnearies, speleology sites, etc)	☐	☐
National Parks and Natura 2000 sites	☐	☐
Number of bird watching sites	☐	☐
Number of bathing areas and beaches	☐	☐
Fish and waterfowl abundance	☐	☐
Quality of fresh waters for fishing	☐	☐
Number of waterfowl hunters, anglers and amateur fishermen	☐	☐
Number fishing licenses and fishing reserves	☐	☐
Tourism revenue	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

CULTURAL SERVICES: Intellectual and aesthetic appreciation

Please tick the relevant box(es)

	Are appropriate	I can estimate
Monitoring sites by scientists	☐	☐
Number of scientific projects, articles, studies	☐	☐
Classified sites (e.g. World Heritage, label European tourism)	☐	☐
Number of visitors	☐	☐
National Parks and Natura 2000 sites	☐	☐
Cultural sites and number of annual cultural activities organised	☐	☐
Contrasting landscapes (e.g. lakes close to mountains)	☐	☐
Proximity to urban areas of scenic rivers or lakes	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

CULTURAL SERVICES: Spiritual and symbolic appreciation

Please tick the relevant box(es)

	Are appropriate	I can estimate
National species or habitat types	☐	☐
Number of visitors (e.g. to places where springs and streams with groundwater origin made them historic and religious sites)	☐	☐
Sacred or religious sites (e.g. catastrofic events, religious places)	☐	☐
Number of wildlife associations registered	☐	☐

If you have additional comments on indicators, or you want to suggest indicators for ecosystem services not present in the list please use this space:

EXTRA-ABIOTIC ENVIRONMENTAL SERVICES - For **raw abiotic materials**, if you want to suggest indicators for ecosystem services, please use this space:

EXTRA-ABIOTIC ENVIRONMENTAL SERVICES - For **abiotic energy sources**, if you want to suggest indicators for ecosystem services, please use this space:

2.6 In your MARS study, will you carry-out an **economic valuation** of ecosystem services?*

- YES
- NO

Economic valuation

2.7 Which **ecosystem services will you value** in the MARS project?

Provisioning services

Please tick one box for each row

	I will value	I will not value	I don't know
Fisheries and aquaculture *(e.g. fish catch)*	○	○	○
Water for drinking *(e.g. provision of water for domestic uses)*	○	○	○
Raw -biotic- materials *(e.g. algae as fertilizers, vegetal compounds for cosmetics)*	○	○	○
Water for non-drinking puposes *(e.g. provision of water for industrial or agricultural uses)*	○	○	○
Raw materials for energy *(e.g. wood from riparian zones)*	○	○	○

Regulation & Maintenance services

Please tick one box for each row

	I will value	I will not value	I don't know
Water purification *(e.g. excess nitrogen removal by microorganisms)*	○	○	○
Air quality regulation *(e.g. deposition of oxides of nitrogen on vegetal leaves)*	○	○	○
Erosion prevention *(e.g. vegetation controlling soil erosion on river banks)*	○	○	○
Flood protection *(e.g. vegetation acting as barrier for the water flow, lakes or floodplains trapping and slowing down the water flow)*	○	○	○
Maintaining populations and habitats *(e.g. key habitats use as reproductive grounds, nursery, shelter... for a variety of species)*	○	○	○
Pest and disease control *(e.g. diseases and parasites are better controlled in the wild (by natural predation on weakened individuals) than in fish farms, biodiversity may control mosquito population and prevent malaria outbreaks)*	○	○	○
Soil formation and composition *(e.g. rich soil formation in floodplains or in wetlands borders)*	○	○	○
Carbon sequestration *(e.g. carbon accumulation in vegetation or sediments)*	○	○	○
Local climate reguation *(e.g. maintenance of humidity and precipitation patterns by wetlands or lakes, shading effect)*	○	○	○

Cultural services

Please tick one box for each row

	I will value	I will not value	I don't know
Recreation *(e.g. swimming, recreational fishing, sightseeing, boating)*	○	○	○
Intellectual and aesthetic appreciation *(e.g. subject matter for research, artistic representations of nature)*	○	○	○
Spiritual and symbolic appreciation *(e.g. existence of emblematic species like Lutra lutra or sacred places)*	○	○	○

Extra abiotic environmental services

Please tick one box for each row

	I will value	I will not value	I don't know
Raw abiotic materials *(e.g. extraction of sand and gravel from river bed or river banks)*	○	○	○
Abiotic energy sources *(e.g. hydropower generation)*	○	○	○

2.8 Are there any other ecosystem services not included in the list that you will value or for which you would like to add a comment?

2.9 Do you plan to collect by yourself **economic data** (that is conducting field surveys for instance by interviewing water users with specific environmental valuation technics) to conduct the economic valuation? (The alternative consists in using existing databases or economic valuation data from the literature)*

○ YES
○ NO
○ I DON'T KNOW

2.10 From the following **methods**, which one will you be interested to apply for the economic valuation? Please consider the background information document for an explanation of the methods

Cost-based approach

Please tick the relevant box(es)

	I know this method	I would like to apply this method
Damage cost avoided	☐	☐
Replacement cost	☐	☐

Revealed preferences approach

Please tick the relevant box(es)

	I know this method	I would like to apply this method
Travel cost	☐	☐
Hedonic price	☐	☐

Stated preferences approach

Please tick the relevant box(es)

	I know this method	I would like to apply this method
Contingent valuation	☐	☐
Choice experiment	☐	☐

Benefit transfer approach

Please tick the relevant box(es)

	I know this method	I would like to apply this method
Unit value transfer	☐	☐
Adjusted unit value tranfer	☐	☐
Value transfer function	☐	☐
Meta-analytic value transfer function	☐	☐

2.11 Are there any other methods not included in the list that you will be interested to use and for which you would like to add a comment?

2.12 To face the impact of multiple stressors which **policy instruments** have already been implemented in your case study? Please consider the background information document for the examples of policy instruments.

Category: economic instruments

Please one box for each row

	Already implemented	Not yet implemented	I don't know
Taxes	○	○	○
Markets	○	○	○
Subsidies	○	○	○
Payments for ecosystem services	○	○	○

Category: voluntary approaches

Please one box for each row

	Already implemented	Not yet implemented	I don't know
Private agreements	○	○	○
Public voluntary schemes	○	○	○
Negociated agreements	○	○	○

Category: regulations

Please one box for each row

	Already implemented	Not yet implemented	I don't know
Norms and standards	○	○	○
Restrictions on use and access	○	○	○
Liability rules	○	○	○

Category: information tools

Please one box for each row

	Already implemented	Not yet implemented	I don't know
Education campaign	○	○	○
Use of media	○	○	○
Eco labelling of products	○	○	○

2.13 To face the impact of multiple stressors which **policy instruments** would be relevant in your context for managing ecosystem services? Please consider the background information document for the definition of policy instruments.

Category: economic instruments

Please tick the relevant box(es)

	Would be relevant for testing in future scenario	I don't know
Taxes	☐	☐
Markets	☐	☐
Subsidies	☐	☐
Payments for ecosystem services	☐	☐

Category: voluntary approaches

Please tick the relevant box(es)

	Would be relevant for testing in future scenario	I don't know
Private agreements	☐	☐
Public voluntary schemes	☐	☐
Negociated agreements	☐	☐

Category: regulations

Please tick the relevant box(es)

	Would be relevant for testing in future scenario	I don't know
Norms and standards	☐	☐
Restrictions on use and access	☐	☐
Liability rules	☐	☐

Category: information tools

Please tick the relevant box(es)

	Would be relevant for testing in future scenario	I don't know
Education campaign	☐	☐
Use of media	☐	☐
Eco labelling of products	☐	☐

3. Previous experience and studies on assessing and valuing ecosystem services

In this section we would like to have some information about previous studies on assessing and valuing ecosystem services in your case study and on your personal experience in the field.

3.1 Have ecosystem services already been assessed in **previous studies in your case study** (literature review)?*

- ○ YES
- ○ NO
- ○ I DON'T KNOW

Could you please provide on or two references:

3.2 Do you (or somebody in your team who can contribute/be involved in the MARS project) have direct experience in MAPPING and assessing the delivery of ecosystem services (**biophysical quantity**) at the water body, catchment or the European scale?*

- YES
- NO

3.2.1 Please indicate which ecosystem services you have already assessed and which methodology you have used:

3.3 Do you (or somebody in your team who can contribute/be involved in the MARS project) have experience in **economic valuation** of ecosystem services at the water body, catchment or the European scale?*

- YES
- NO

Economic valuation

3.3.1 Please indicate which ecosystem services have you already assessed and which methodology you have used for the economic valuation:

4. Feedback on the questionnaire

In this session we would like to have your feedback on this questionnaire.

4.1 Do you think that the **background information** we have provided in this questionnaire was:

	YES	NO	I don't know
Useful	○	○	○
clear	○	○	○
Complete	○	○	○

Do you have any additional comments on the background information?

4.2 Do you think that the **ecosystem service list** we have provided in this questionnaire was:

	YES	NO	I don't know
Useful	○	○	○
clear	○	○	○
Complete	○	○	○
Could be used with your stakeholders	○	○	○

Do you have any additional comments on the ecosystem service list?

4.3 Do you think that the **indicator list** (also available in the background document) we have provided in this questionnaire was:

	YES	NO	I don't know
Useful	○	○	○
clear	○	○	○
Complete	○	○	○

Do you have any additional comments on indicators?

4.4 Do you think that the **list of methods for economic valuation** we have provided in this questionnaire was:

	YES	NO	I don't know
Useful			
clear			
Complete			

Do you have any additional comments on the methods for economic valuation?

4.5 Do you think that the **list of policy instruments** we have provided in this questionnaire was:

	YES	NO	I don't know
Useful			
clear			
Complete			

Do you have any additional comments on the policy instruments?

4.6 Do you have any specific **comments/suggestions/wishes** on the methodology for assessing and valuing ecosystem services in the project MARS what you would like to tell us?

A6.2 Contributors to the questionnaire

The project MARS analyses the relationship between multiple stressors and the delivery of ecosystem services related to the aquatic ecosystems at three different scales: water body (WP3), catchment (WP4) and the European scale (WP5). For this reason in the questionnaire we refer to studies at these three scales.

Through the questionnaire we collected relevant information from MARS partners to be considered in the development of the methodology. We received one questionnaire per each case study of WP4 and 7 out of 9 replies for the case studies of WP3. For the European scale (WP5), we asked the Task 5.2, 5.3 and 5.4 and all the partners of Task 5.1.4 to fill in the questionnaire. In addition, we were interested in the input of some partners of MARS who will not directly apply the methodology. These few partners not directly involved in WP3, WP4 or WP5 studies were asked to indicate for which scale they answered the questionnaire, according to their field of expertise (water body, catchment or the European scale).

The final list of contributors to the questionnaire is provided in the following table:

Table A6.1 - Contributors to the MARS questionnaire on Ecosystem services (Task 2.2).

Task	Sub task	PartNo.	Institute	Person contacted	Names of the respondents
WP3					
3.1 Lake experiments	3.1.1 Extreme rainfall, location UK	14	NERC	Heidrun Feuchtmayr	Heidrun Feuchtmayr, Stephen Maberly
3.1 Lake experiments	3.1.2 Extreme heatwaves, location DK	2	AU	Erik Jeppesen	
3.1 Lake experiments	3.1.3 Extreme mixing and DOM loading, location DE	10	FVG-IGB	Ute Mischke	Ute has filled a questionnaire for the Central RB (Elbe, Havel and Saale)
3.2 River experiments	3.2.1 Extreme flow in Nordic rivers, location NO	15	NIVA	Susanne Schneider	Susanne Schneider, Nikolai Friberg
3.2 River experiments	3.2.2 Peak flow in Alpine rivers, location AU	4	BOKU	Stefan Schmutz	Rafaela Schinegger, Stefan Schmutz
3.2 River experiments	3.2.3 Water scarcity in Mediterranean rivers, location PT	19	UTL	Paulo Branco	Teresa Ferreira, Paulo Branco
3.2 River experiments	3.2.4 River-low flow in Nordic rivers, location DK	2	AU	Annette Baattrup-Pedersen	Daniel Graeber, Annette Baatrup-Pedersen

3.3 Analysis of time series	3.3.1 Lakes	9	EMU	Peeter Nõges	Laurence Carvalho, Ian Winfield, Steve Thackeray (NERC-CEH) have filled a questionnaire for subtask 3.3.1 (analysis of time series for lakes)
3.3 Analysis of time series	3.3.2 Rivers	6	CU	Steve Ormerod	Steve Ormerod has filled a questionnaire for the Welsh basins (WP4)
WP4					
4.2 Southern river basins	Sorraia	19	UTL	Teresa Ferreira	Carina Almeida
4.2 Southern river basins	Nervion-Ibaizabal	3	AZTI	Angel Borja	Arantza Murillas, María C. Uyarra, Ángel Borja, Ibon Galparsoro
4.2 Southern river basins	Pinios	16	NTUA	Panagopoulos Yiannis	Yiannis Panagopoulos, Kostas Stefanidis
4.2 Southern river basins	Beysehir	13	METU	Meryem Beklioglu	Meryem Beklioğlu, Tuba Bucak, Jan Coppens, Eti Levi
4.2 Southern river basins	Lower Danube	7	DDNI	Jenică Hanganu	Jenica Hanganu, Adrian Constantinescu
4.3 Central river basins	Thames	14	NERC	John Bloomfield	John Bloomfield, Christel Prudhomme
4.3 Central river basins	Regge and Dinkel	8	DELTARES	Hans Peter Broers	Marijn Kuijper, Tom Buijse (one questionnaire filled for both 5.1 and 4.3)
4.3 Central river basins	Odense	2	AU	Hans Estrup Andersen	Hans Estrup Andersen, Dennis Trolle, Hans Thodsen, Shenglan Lu
4.3 Central river basins	Elbe, Havel and Saale	10	FVB-IGB	Ute Mischke	Ute Mischke, Markus Venohr, Christian Wolter
4.3 Central river basins	Ruhr	1	UDE	Alexander Gieswein	Alexander Gieswein
4.3 Central river basins	Drava	4	BOKU	Stefan Schmutz	Rafaela Schinegger and Stefan Schmutz have filled a questionnaire for WP3 (river experiments)
4.4 Northern river basins	Welsh basins	6	CU	Steve Ormerod	Steve Ormerod
4.4 Northern river basins	Vansio-Hobol	15	NIVA	Raoul-Marie Couture	Raoul-Marie Couture, Silje Holen
4.4 Northern river basins	Otra	15	NIVA	Raoul-Marie Couture	

4.4 Northern river basins	Kokemaenjoki	17	SYKE	Katri Rankinen	Katri Rankinen, Petteri Vihervaara, Martin Forsius, Seppo Hellsten
4.4 Northern river basins	Vortsjarv	9	EMU	Fabien Cremona	Sirje Vilbaste
WP5					
5.1 European matrix of stress and impact	5.1.4 Spatial assessment of services delivered by European aquatic ecosystems	12	JRC	Bruna Grizzetti	Bruna Grizzetti, Denis Lanzanova, Arnaud Reynaud, Camino Liquete, Nuria Cid
5.1 European matrix of stress and impact	5.1.4 Spatial assessment of services delivered by European aquatic ecosystems	10	FVB-IGB	Markus Venohr	Markus Venohr, Judith Mahnkopf
5.1 European matrix of stress and impact	5.1.4 Spatial assessment of services delivered by European aquatic ecosystems	14	NERC	Christel Prudhomme	Christel Prudhomme
5.1 European matrix of stress and impact	5.1.4 Spatial assessment of services delivered by European aquatic ecosystems	16	NTUA	Panagopoulos Yiannis	Yiannis Panagopoulos, Kostas Stefanidis
5.1 European matrix of stress and impact	5.1.4 Spatial assessment of services delivered by European aquatic ecosystems	8	DELTARES	Tom Buijse	Marijn Kuijper, Tom Buijse (one questionnaire filled for both 5.1 and 4.3)
5.2 Multiple stressors in large rivers		4	BOKU	Wolfram Graf	
5.3 Multiple stressors in lakes		15	NIVA	Jannicke Moe	
5.4 Multiple stress effects on European fish assemblages		11	IRSTEA	Mario Lepage	
Other					
2.3 Identification of benchmark indicators		1	UDE	Sebastian Birk	Sebastian Birk
2.4 Elaboration of the MARS model		14	NERC	Laurence Carvalho	Laurence Carvalho, Helen Woods
		1	UDE	Daniel Hering	
		AB	HMUELV	Stephan von Keitz	Stephan von Keitz

A6.3 Results of the questionnaire

This section provides the detailed results of the questionnaires that are discussed and displayed by graphs in the text of the report. The compilation of comments from partners has not been included here, but all comments have been taken into consideration in the analysis for the report.

1. Information about the respondents

Number of questionnaires sent out: 37

Number of questionnaire responses: 27

2. Selection of relevant ecosystem services

2.1 For which scale will you apply the methodology?

WP3	7
WP4	13
WP5	5
others	2

2.2 Within your study which water bodies or ecosystems (relevant for the delivery of ecosystem services) will you assess?

Lakes	14
Rivers	23
Transitional waters	6
Coastal waters	3
Groundwater	8
Freshwater wetlands	3
Coastal wetlands	2
Riparian areas	10
Floodplains	4

2.3 From the following list of ecosystem services which ones do you think are relevant (and you plan to assess in MARS) for your study?

Ecosystem Service		**Relevance**	**%**	**MARS**	**%**
Provisioning services:	Fisheries and aquaculture	20	74	9	33
	Water for drinking	21	78	12	44
	Raw -biotic- materials	3	11	0	0
	Water for non-drinking purposes	18	67	11	41
	Raw materials for energy	5	19	1	4
Regulation & Maintenance services:	Water purification	23	85	15	56
	Air quality regulation	2	7	1	4
	Erosion prevention	10	37	7	26
	Flood protection	17	63	10	37
	Maintaining populations and habitats	22	81	13	48
	Pest and disease control	5	19	2	7
	Soil formation and composition	3	11	0	0
	Carbon sequestration	15	56	7	26
	Local climate regulation	9	33	6	22
Cultural services:	Recreation	21	78	11	41
	Intellectual and aesthetic appreciation	10	37	4	15
	Spiritual and symbolic appreciation	3	11	1	4
Extra abiotic environmental services:	Raw abiotic materials	5	19	1	4
	Abiotic energy sources	12	44	6	22

2.4 Are there any other ecosystem services not included in the list that you think are relevant and you plan to assess in MARS for your study?

(Comments provided)

2.5 For the ecosystem services you have selected in question 2.3, we would like to know which indicators you think are appropriate for assessing the delivery of the ecosystem service in your study and if you have the possibility to assess them by data or modelling (the list of indicators is also provided in the background document).

Indicators on Provisioning services

Ecosystem services	Proposed indicators from MAES	ES will be assessed in MARS	Indicator is relevant	%	Indicator can be assessed in MARS	%
Fisheries and aquaculture	Fish production or fish catch	9	8	89	5	56
	Status of fish population (species composition, age structure, biomass)	9	8	89	7	78
	Aquaculture production (e.g. sturgeon and caviar production)	9	2	22	0	0
	Wild vegetation used in gastronomy, cosmetic or pharmaceutical uses	9	0	0	0	0
	Number of fisherman	9	6	67	4	44
Water for drinking	Water consumption for drinking	12	9	75	6	50
	Water abstracted	12	11	92	6	50
	Surface water availability	12	8	67	6	50
	Water exploitation index (WEI)	12	6	50	4	33
	Nitrate-vulnerable zones	12	5	42	3	25
Raw (biotic) materials	Timber produced by riparian forest	0	0		0	
	Surface of exploited wet forests (e.g. poplars) and reeds	0	0		0	
Water for non-drinking purposes	Water use per sector	11	6	55	3	27
	Water abstracted	11	9	82	6	55
	Surface water availability	11	9	82	8	73
	Ground water availability	11	7	64	4	36
	Volume of water bodies	11	8	73	4	36
	Water exploitation index (WEI)	11	7	64	4	36
Raw materials for energy	Production of peat	1	0	0	0	0
	Surface of exploited wetlands for peat and biofuels	1	0	0	0	0
	Firewood produced by riparian forests	1	0	0	0	0

Indicators on Regulation & Maintenance services

Ecosystem services	Proposed indicators from MAES	ES will be assessed in MARS	Indicator is relevant	%	Indicator can be assessed in MARS	%
Water purification	Indicators on surface water quality (e.g. microbiological data, BOD, phosphate concentration, oxygen conditions, saprobiological status)	15	13	87	9	60
	Indicators on groundwater quality (e.g. NO3, pesticide, trace metals, emerging pollutants)	15	5	33	3	20
	Nutrient loads	15	11	73	9	60
	Nutrient concentration	15	13	87	11	73
	Nutrient retention	15	11	73	8	53
	Trophic status	15	10	67	7	47
	Ecological status	15	12	80	9	60
	Area occupied by riparian forests	15	7	47	4	27
	Potential mineralization or decomposition	15	2	13	0	0
	Number and efficiency of treatment plants	15	6	40	2	13
	Waste water treated	15	7	47	4	27
Air quality regulation						
Erosion prevention	Sediment retention	7	4	57	1	14
	Ground water level evolution	7	3	43	0	0
Flood protection	Holding capacity flood risk maps	10	7	70	2	20
	Water holding capacity of soils	10	6	60	5	50
	Conservation status of river and lake banks	10	3	30	1	10
	Ground water level evolution	10	5	50	3	30
	Floodplain area (and record of annual floods)	10	5	50	1	10
	Area of wetlands located in flood risk zones	10	4	40	1	10
	Conservation status of riparian wetlands	10	5	50	1	10

Maintaining populations and habitats	Biodiversity value (species diversity or abundance, endemics or red list species, spawning areas)	13	7	54	5	38
	Ecological status	13	12	92	8	62
	Hydromorphological status	13	6	46	2	15
Pest and disease control	Alien species introduced in aquatic environments and riparian zones (e.g. plants, invertebrates, vertebrates)	2	1	50	0	0
Soil formation and composition	Fluvisols surface	0	0		0	
	Presence of hydromorphic soils	0	0		0	
	Surface of floodplains	0	0		0	
	Potential mineralization, decomposition, etc.	0	0		0	
Carbon sequestration	Carbon sequestration or carbon change (e.g. in riparian forests, *Populus spp.* plantations)	7	7	100	4	57
	Organic carbon stored or carbon stock (e.g. in fluvisols)	7	2	29	0	0
	Number of sites for CO_2 deep injections and volumes of CO2 injected	7	1	14	1	14
Local climate regulation	Ground water level	6	2	33	0	0

Indicators on Cultural services

Ecosystem services	**Proposed indicators from MAES**	**ES will be assessed in MARS**	**Indicator is relevant**	**%**	**Indicator can be assessed in MARS**	**%**
Recreation and tourism	Number of visitors to natural places (e.g. to National Parks, to lakes or rivers, to protected wetlands)	11	5	45	1	9
	Number of visitors to attractions (e.g. thermal, mineral and mud springs and balnearies, speleology sites, etc)	11	2	18	0	0
	National Parks and Natura 2000 sites	11	5	45	2	18
	Number of bird watching sites	11	5	45	1	9
	Number of bathing areas and beaches	11	7	64	5	45

	Fish and waterfowl abundance	11	7	64	3	27
	Quality of fresh waters for fishing	11	7	64	3	27
	Number of waterfowl hunters, anglers and amateur fishermen	11	6	55	2	18
	Number fishing licenses and fishing reserves	11	8	73	4	36
	Tourism revenue	11	8	73	5	45
Intellectual and aesthetic appreciation	Monitoring sites by scientists	4	3	75	2	50
	Number of scientific projects, articles, studies	4	3	75	3	75
	Classified sites (e.g. World Heritage, label European tourism)	4	1	25	0	0
	Number of visitors	4	3	75	2	50
	National Parks and Natura 2000 sites	4	1	25	0	0
	Cultural sites and number of annual cultural activities organised	4	1	25	0	0
	Contrasting landscapes (e.g. lakes close to mountains)	4	2	50	1	25
	Proximity to urban areas of scenic rivers or lakes	4	2	50	2	50
Spiritual and symbolic appreciation	National species or habitat types	1	1	100	0	0
	Number of visitors (e.g. to places where springs and streams with groundwater origin made them historic and religious sites)	1	1	100	0	0
	Sacred or religious sites (e.g. catastrofic events, religious places)	1	1	100	1	100
	Number of associations registered on animals, plants, environment, naturism, etc	1	1	100	1	100

2.6 In your MARS study, will you carry-out an economic valuation of ecosystem services?

5 respondents said YES (19%)

2.7 Which ecosystem services will you value in the MARS project?

Ecosystem Services		Will value	Will not value	Don't know	Sum of answers
Provisioning services:	Fisheries and aquaculture	4	1	1	6
	Water for drinking	0	3	1	4
	Raw -biotic- materials	0	4	0	4
	Water for non-drinking puposes	1	2	1	4
	Raw materials for energy	0	4	0	4
Regulation & Maintenance services:	Water purification	1	2	2	5
	Air quality regulation	0	2	1	3
	Erosion prevention	0	1	2	3
	Flood protection	0	1	2	3
	Maintaining populations and habitats	1	2	1	4
	Pest and disease control	1	2	1	4
	Soil formation and composition	0	2	1	3
	Carbon sequestration	1	1	1	3
	Local climate reguation	0	3	0	3
Cultural services:	Recreation	5	0	0	5
	Intellectual and aesthetic appreciation	2	1	1	4
	Spiritual and symbolic appreciation	0	3	0	3
Extra abiotic environmental services:	Raw abiotic materials	0	4	0	4
	Abiotic energy sources (e.g. hydropower generation)	0	4	0	4

2.8 Are there any other ecosystem services not included in the list that you will value or for which you would like to add a comment?

No answers

2.9 Do you plan to collect by yourself economic data (that is conducting field surveys for instance by interviewing water users with specific environmental valuation technics) to conduct the economic valuation? (The alternative consists in using existing databases or economic valuation data from the literature)

YES 3 respondents, NO 2 respondents

2.10 From the following methods, which one will you be interested to apply for the economic valuation? Please consider the background information document for an explanation of the methods

Economic valuation method	**know the method**	**know the method and will apply**	**would like to apply**	sum of answers
Cost-based approach: Damage cost avoided	1	3	0	4
Cost-based approach: Replacement cost	2	1	0	3
Revealed preferences approach: Travel cost	3	0	0	3
Revealed preferences approach: Hedonic price	3	0	0	3
Stated preferences approach: Contingent valuation	3	1	1	5
Stated preferences approach: Choice experiment	2	1	1	4
Benefit transfer approach: Unit value transfer	2	1	0	3
Benefit transfer approach: Adjusted unit value tranfer	1	2	0	3
Benefit transfer approach: Value transfer function	3	0	0	3
Benefit transfer approach: Meta-analytic value transfer function	2	1	0	3

2.11 Are there any other methods not included in the list that you will be interested to use and for which you would like to add a comment?

(Comments provided)

2.12 To face the impact of multiple stressors which policy instruments have already been implemented in your case study? Please consider the background information document for the examples of policy instruments.

		Already implemented	**Not yet implemented**	**Don't know**	**Sum of answers**	**Relevant for testing in scenario**
Economic instruments:	Taxes	4	0	0	4	3
	Markets	1	2	0	3	2
	Subsidies	5	0	0	5	3
	Payments for ecosystem services	3	2	0	5	3
Voluntary approaches:	Private agreements	2	0	1	3	1
	Public voluntary schemes	4	0	1	5	2
	Negociated agreements	0	1	3	4	1
Regulations:	Norms and standards	3	0	2	5	3
	Restrictions on use and access	3	0	2	5	2
	Liability rules	0	0	4	4	2
Information tools:	Education campaign	3	0	2	5	1
	Use of media	3	0	1	4	1
	Eco labelling of products	2	1	1	4	0

3. Previous experience and studies on assessing and valuing ecosystem services

3.1 Have ecosystem services already been assessed in previous studies in your case study (literature review)?

YES	10	(37%)
NO	14	(52%)
I DON'T KNOW	3	(11%)

(References provided)

3.2 Do you (or somebody in your team who can contribute/be involved in the MARS project) have direct experience in MAPPING and assessing the delivery of ecosystem services (biophysical quantity) at the water body, catchment or the European scale?

YES	12	(44%)
NO	15	(56%)
I DON'T KNOW	0	(0%)

(References provided)

3.3 Do you (or somebody in your team who can contribute/be involved in the MARS project) have experience in economic valuation of ecosystem services at the water body, catchment or the European scale?

YES	9	(33%)
NO	18	(67%)
I DON'T KNOW	0	(0%)

(References provided)

4. Feedback on the questionnaire

Feedback (any type) provided by 25 (out of 27) respondent (93%)

4.1 Do you think that the **background information** we have provided in this questionnaire was:

	Useful	Clear	Complete
YES	22	21	13
NO	0	1	2
I DON'T KNOW	2	2	9
blank	3	3	3
sum of answers	24	24	24
	% (out of sum of answers)		
YES	92	88	54
NO	0	4	8
I DON'T KNOW	8	8	38

4.2 Additional comments provided on the background information:

(Comments provided)

4.3 Do you think that the **ecosystem service list** we have provided in this questionnaire was:

	Useful	Clear	Complete	Will use with Stakeholders
YES	24	22	8	14
NO	0	0	5	1
I DON'T KNOW	0	1	11	6
blank	3	4	3	5
sum of answers	24	23	24	21
	% (out of sum of answers)			
YES	100	96	33	67
NO	0	0	21	5
I DON'T KNOW	0	4	46	29

4.4 Additional comments provided on the ecosystem service list:

(Comments provided)

4.5 Do you think that the **indicator list** we have provided in this questionnaire was:

	Useful	Clear	Complete
YES	23	21	7
NO	0	0	5
I DON'T KNOW	0	2	10
blank	4	4	5
sum of answers	23	23	22
	% (out of sum of answers)		
YES	100	91	32
NO	0	0	23
I DON'T KNOW	0	9	45

4.6 Additional comments provided on indicators:

(Comments provided)

4.7 Do you think that the **list of methods for economic valuation** we have provided in this questionnaire was:

	Useful	Clear	Complete
YES	4	4	1
NO	0	0	2
I DON'T KNOW	0	0	1
blank	23	23	23
sum of answers	4	4	4
	% (out of sum of answers)		
YES	100	100	25
NO	0	0	50
I DON'T KNOW	0	0	25

4.8 Additional comments provided on the methods for economic valuation:

(Comments provided)

4.9 Do you think that the **list of policy instruments** we have provided in this questionnaire was:

	Useful	Clear	Complete
YES	2	3	1
NO	0	1	0
I DON'T KNOW	2	0	3
blank	23	23	23
sum of answers	4	4	4
	% (out of sum of answers)		
YES	50	75	25
NO	0	25	0
I DON'T KNOW	50	0	75

4.10 Additional comments provided on the policy instruments:

(Comments provided)

4.11 Do you have any specific comments/suggestions/wishes on the methodology for assessing and valuing ecosystem services in the project MARS what you would like to tell us?

(Comments provided)

Annex 7 – Glossary of terms

We provide below some definitions that clarify the use of certain terms in this report. Different disciplines may use different definitions; the ones we propose reflect the meaning we agreed in this work.

Ecosystem approach	It is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. It is based on the application of appropriate scientific methodologies focused on levels of biological organization which encompass the essential processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of ecosystems (CBD, 2015)
Ecosystem service approach	It is a mechanism for integrating ecosystem services into public and private decisions. An ecosystem services approach seeks to integrate ecosystem services into decision-making by (a) using scientific c assessment tools to understand people's dependence and impact on the services provided by ecosystems and (b) applying policy mechanisms that incorporate ecosystem service values into the decisions made by governments, businesses, NGOs and individuals (McKenzie et al., 2008).
Integrated assessment	In the context of this report, it is a holistic evaluation of pressures, ecosystem state and ecosystem services in a certain case study, analysing in particular the links and interdependence among them. Here, ecosystem services can be quantified from a biophysical and/or economic perspective.
Ecosystem state or condition	The physical, chemical and biological condition of an ecosystem at a particular point in time (Maes et al. 2014)
Ecosystem service flow	*De facto* used set (bundles) of ecosystem services and other outputs from natural systems in a particular area within a given time period (Burkhard et al. 2014)
Inland waters	All standing or flowing water on the surface of the land, and all groundwater on the landward side of the baseline from which the breadth of territorial waters is measured (Directive 2000/60/EC). Depending on the position of that baseline in each country, inland waters may include transitional and coastal waters.
Water ecosystem services	In the context of this report, they are ecosystem services delivered by water bodies (the so-called aquatic ecosystem services) or water-dependant habitats (i.e. riparian zones, floodplains, wetlands)

Hydrologic ecosystem services	Ecosystem services that encompass the benefits to people produced by terrestrial ecosystem effects on freshwater (Brauman al. 2007). That is, they comprise all ecosystem services linked to a river basin or catchment area, thus joining water ecosystem services and some terrestrial ones.
Indicator	An indicator in ecology and environmental planning is a component or a measure of environmentally relevant phenomena used to depict or evaluate environmental conditions or changes or to set environmental goals (Heink and Kowarik, 2010)
Proxy	A figure that can be used to represent the value of something in a calculation (Oxford dictionary). Proxy data: data used to study a situation, phenomenon or condition for which no direct information - such as instrumental measurements - is available (EEA, 2015). Proxies are used as indirect indicators.
Stressors & Pressures	In MARS we refer to *stressor* as any environmental change in a factor that causes some response by the system of interest, e.i. organism, population, ecosystem (Odum, 1985). A *pressure* is the direct effect of a *driver*, which is any anthropogenic activity that may have an environmental effect (CIS guidance IMPRESS 2002). In this report we have used the terms *pressures* and *stressors* almost as synonymous, but we have tried to prefer the term *pressures* when the emphasis was on effects originated by anthropogenic causes (*pressures* are *stressors* originates by anthropogenic causes) or we wanted to make more explicit the link to the DPSIR scheme adopted by the WFD.

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MARS PROJECT

Managing Aquatic ecosystems and water Resources under multiple Stress

Deliverable 2.1 - Four manuscripts on the multiple stressor framework: Framework to select indicators of multi-stressor effects for European river basin management (3/4)

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Due date of deliverable: **Month 12**

Actual submission date: **Month 12**

Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Content

Note that this version does not contain benchmark indicators obtained from the questionnaire returns of Task 2.2 *Methodology for ecosystem service assessment and valuation*.

1. Introduction

To allow for a streamlined analysis of multi-stressor effects across the different spatial scales and environmental conditions targeted in MARS, we need to select "benchmark indicators". According to the DoW these indicators shall mainly address ecological status and ecosystem services. In terms of the DPSIR adaptive management cycle, we thus require '***state indicators***' for the ecosystem properties and functions, and '***impact indicators***' to assess the impact on ecosystem service capacity.

Based on questionnaire returns circulated to the MARS partners we have now concluded on a list of 15 indicators that meet determined selection criteria (see Annex 1) and were considered meaningful and practicable by the responders (see Annex 2). Most of the indicators represent 'classical' state indicators applied in EU Water Framework Directive (WFD)-related water management, some of which also cover abiotic state variables acting as direct pressures impacting on the biological state (e.g. total phosphorus concentration). Only two impact indicators are described here (toxic/nuisance phytoplankton, commercially-relevant fish), as we still intend to select suitable indicators from the questionnaire outcomes on ecosystem services (MARS Task 2.2) in the next weeks.

The benchmark indicators mainly comprise simple metrics and indices of abiotic and biotic ecosystem properties, covering physico-chemical, hydrological and riparian features of the water body and selected attributes of its biological community. The proposed indicators are known to respond to anthropogenic pressure. They are applicable in various geographical contexts and to different water categories and types of water bodies. They generally do not require acquisition of specific data, but refer to data already available.

We refrained from using multimetric indices to avoid the required standardisation of single metrics combined to multi-metrics. However, the benchmark indicators vary naturally across the gradients of environmental conditions studied in MARS (e.g. from Welsh upland brooks to Basque estuaries). We need to control for this natural variability in order to detect the effects of multiple stress on the indicators.

Most the benchmark indicators represent conventional (and approved) measures of single ecosystem properties. Innovations on multi-stress diagnosis and resilience will be addressed by the specific research done in other MARS work packages (e.g. WP6.2 on diagnostic indicators). Our selection of benchmark indicators is meant to support this research by covering a broad range of relevant ecosystem properties, allowing for the linkage of abiotic and biotic indicators, or indicators of different trophic levels; or relating state and impact indicators. WP6 on synthesizing stressors, scenarios and water management particularly needs the coherent application of the benchmark indicators across work packages and study areas (cf. WP6 Guidance document: Analysing stressor-response relationships and interactions in multi-stressor situations).

2. Details on the indicator profiles

This document presents the benchmark indicators by means of indicator profiles, i.e. concise characterisations of indicator background, context and rationale. The individual profile categories are outlined in the following.

Quality element: Refers to WFD specifications, distinguishing between physico-chemical (e.g. nutrient status), hydromorphological (e.g. morphology) and biological quality elements (e.g. fish).

Water category and water body types: Refers to WFD specifications, i.e. rivers, lakes and transitional waters. Lakes explicitly include reservoirs. Coastal waters are not addressed in MARS. Groundwaters are not covered by the selected indicators due to limited applicability and data availability.

The water body type represents an ecologically homogeneous unit characterised, for instance, by ecoregion, altitude, catchment size, background geology. In MARS we will refer to broad types established by the European Environment Agency (see Annex 3).

Selection rationale: Concise explanation highlighting the reason for indicator selection.

Indicator type (DPSIR): Refers to the adaptive DPSIR (Driver, Pressure, State, Impact, Response) management cycle, positioning the indicator in this conceptual framework.

Description: Brief summary on indicator background and features.

Spatio-temporal resolution: Specification of the spatio-temporal scope of information provided by the indicator.

Unit: Unit in which indicator is measured.

Standardisation: The benchmark indicators vary naturally across the gradients of environmental conditions studied in MARS (e.g. from Welsh upland brooks to Basque estuaries). We need to control for this natural variability in order to detect the effects of multiple stress on the indicators. This is especially relevant for studies using space-for-time substitution including different water body types. A viable option is to standardise the indicator using commonly defined, type-specific reference values, as established in the intercalibration exercise (cf. Annex 3 for the definition of broad European water body types).

Birk et al. (2013)[1] highlight that the peculiarities of differing sampling and analytical techniques also affect data comparability. These even outweigh any biogeographical differences when data are acquired based on differing protocols. A more preferred standardisation option thus includes modelling approaches disentangling the effects of biogeography and sampling protocols from the responses of multiple stress.

[1] Birk, S., Willby, N., Kelly, M., Bonne, W., Borja, A., Poikane, S., & van de Bund, W. (2013). Intercalibrating classifications of ecological status: Europe's quest for common management objectives for aquatic ecosystems. Science of The Total Environment, 454-455, 490–499.

Data requirements: Specification of data required to apply the indicator.

Other: Any other relevant information.

MARS spatial scale: Indicator applicability at MARS experimental, basin or European scale.

References: Relevant literature references.

3. Consolidated list of benchmark indicators

The 15 MARS benchmark indicators are listed in the table below. It contains the indicator short-code, indicator name and selection rationale. The table also specifies the water categories for which the indicator is applicable (Lak=lakes, Riv=rivers, Tra=transitional waters), as well as the relevant MARS scales (Exp=WP3 experimental scale, Bsn=WP4 basin-scale, Eur=WP5 European scale). Square symbols in brackets refer to partial applicability of the indicator (e.g. chlorophyll-a only at large rivers; invertebrate feeding groups only for river experiments sampling for invertebrates). ○=alternative indicator for transitional waters.

Code	Indicator name	Selection rationale	Water category			MARS scale		
			Lak	Riv	Tra	Exp	Bsn	Eur
BInd01	Ecological status of surface water body	General indicator of key relevance for WFD river basin management	■	■	■		■	■
BInd02	Total phosphorus concentration in the water column	Common water pollution factor driving primary production in aquatic systems, conditioning secondary pressures (e.g. oxygen depletion) and interacting with other pressures	■	■	■	■	■	■
BInd03	Total nitrogen concentration in the water column	Common water pollution factor driving primary production in aquatic systems, conditioning secondary pressures (e.g. oxygen depletion) and interacting with other pressures	■	■	■	■	■	■
BInd04	Mean duration of high pulses within each year	Indicator of extreme hydrological events related to flood risk		■			■	■
BInd05	Mean duration of low pulses within each year	Indicator of extreme hydrological events related to environmental flows and water supply		■			■	■
BInd06	Annual water-level fluctuations	Indicator of extreme hydrological events related to water supply and recreation	■				■	■
BInd07	Amount of naturally-forested land in the riparian corridor of water body	Indicator of riparian state of high relevance for water body status and ecosystem services	■	■	○		■	■
BInd08	Growing season mean of water column chlorophyll-a concentration	Commonly used water quality indicator with high data availability	■	(■)	■	■	■	■
BInd09	Chlorophyll-a to total phosphorus ratio (Chl:TP)	Simple measure of production efficiency	■	(■)	■	■	■	■
BInd10	Biovolume of toxic/nuisance phytoplankton species	Direct indicator of the functional quality of recreation and water supply services	■	(■)	■		■	■
BInd11	Abundance of submerged, emergent and floating-leafed macrophytic vegetation	Integrative indicator of hydromorphological and nutrient pressure, with relevance for habitat structuring	■	■	■	(■)	■	■
BInd12	Average Score per Taxon (ASPT)	All-round indicator of general pressure	■	■	○	(■)	■	■
BInd13	Abundance ratios of invertebrate functional feeding groups	Trait-based indicator of functional relevance linked to food web structure	■	■	■	(■)	■	■
BInd14	Relative abundance of invasive alien invertebrate species	Indicator of 'biopollution'	■	■	■		■	■
BInd15	Total fish abundance (incl. abundance of commercially relevant fish)	Simple and robust indicator responding to different pressures, relevant for assessing service provision (fish yield)	■	■	■	(■)	■	■

BInd01: Ecological status of surface water body

Quality element: Various

Water category and water body types: Rivers, lakes, transitional waters; all types

Selection rationale: General indicator of key relevance for WFD river basin management

Indicator type (DPSIR): State

Description: The ecological water body status is derived from worst case classification using bioassessment results of various biological elements. It represents the status classification based on national assessment methods, as stipulated by the Water Framework Directive. Classifying high and good status integrates non-biological assessment such as hydromorphological and physico-chemical parameters.

Spatio-temporal resolution: Water-body, single value

Unit: One out of five classes

Standardisation: Not necessary (type-specific assessment is implemented)

Data requirements: Official national WFD monitoring

Other:

Status classification to be provided according to governmental monitoring

! No classification of ecological potential !

MARS spatial scale: River-basin and European scale

Reference

ETC-ICM (2012). Thematic assessment on ecological and chemical status and pressures. ETC-ICM Technical Report 1/2012. Prague: European Topic Centre on Inland, Coastal and Marine waters.

BInd02: Total phosphorus concentration in the water column

Quality element: Physico-chemistry

Water category and water body types: Rivers, lakes, transitional waters; all types

Selection rationale: Common water pollution factor driving primary production in aquatic systems, conditioning secondary pressures (e.g. oxygen depletion) and interacting with other pressures

Indicator type (DPSIR): Pressure, State

Description: Phosphorus is an essential nutrient for plants and animals. The element is naturally limited in most fresh water systems. The concentration of total phosphorus in the water represents an indicator of the chemical ecosystem state, increased by discharge and runoff from urban and agricultural land (e.g. wastewater treatment plants, fertilized lawns and cropland, animal manure storage areas). Total phosphorus also represents a pressure causing eutrophication effects such as algal blooms, accelerated plant growth, and low dissolved oxygen as a secondary effect from the aerobic decomposition of vegetation biomass.

The indicator is a standard parameter of water quality: widely monitored, conceptually well-founded and empirically validated.

Spatio-temporal scale: Field data: sampling site, aggregated value of multiple measurements in time (e.g. annual average)

Unit: $\mu g\ L^{-1}$

Standardisation: To be standardised against type-specific background levels

Data requirements: Field data, modelled data

Other: none

MARS spatial scale: Experimental, river-basin and European scale

Reference: none

BInd03: Total nitrogen concentration in the water column

Quality element: Physico-chemistry

Water category and water body types: Rivers, lakes, transitional waters; all types

Selection rationale: Common water pollution factor driving primary production in aquatic systems, conditioning secondary pressures (e.g. oxygen depletion) and interacting with other pressures

Indicator type (DPSIR): Pressure, State

Description: Nitrogen is an essential nutrient for plants and animals. The concentration of total nitrogen in the water represents an indicator of the chemical ecosystem state, increased by discharge and runoff from urban, agricultural and industrial land (e.g. wastewater treatment plants, fertilized lawns and cropland, animal manure storage areas, industrial discharge). Total nitrogen also represents a pressure causing eutrophication effects such as algal blooms, accelerated plant growth, and low dissolved oxygen as a secondary effect from the aerobic decomposition of vegetation biomass. It is particularly relevant if the Chl:TP ratio is low (see also Bind09).

The indicator is a standard parameter of water quality, widely monitored, conceptually well-founded and empirically validated.

Spatio-temporal scale: Field data: sampling site, aggregated value of multiple measurements in time (e.g. annual average)

Unit: mg L^{-1}

Standardisation: To be standardised against type-specific background levels

Data requirements: Field data, modelled data

Other: none

MARS spatial scale: Experimental, river-basin and European scale

Reference: none

BInd04: Mean duration of high pulses within each year

Quality element: Hydromorphology

Water category and water body types: Rivers, all types

Selection rationale: Indicator of extreme hydrological events related to flood risk

Indicator type (DPSIR): Pressure, State, Impact

Description: Streamflow is the 'master factor' in stream ecosystems, establishing the physical mosaic of habitats and influencing the water quality conditions (e.g. temperature, dissolved oxygen, and nutrient concentration). The hydrological river regime is characterised by five general features: flow magnitude, frequency, duration, timing and rate of change, usually addressed within the 'range of variability approach' (Richter et al. 1997). Thus, a broad range of relevant streamflow indicators have been proposed (e.g. 32 Indicators of Hydrologic Alteration; Richter et al. 1996).

The 'mean duration of high pulses within each year' characterises the annual extreme streamflow conditions. High pulses are defined here as periods during which the daily mean flow exceeds the 75th percentile of the mean annual discharge.

The natural flow regime including high pulse magnitude, frequency, duration and timing represents an intrinsic hydrological feature of a river. Drivers influencing this feature include river regulation (e.g. damming, water abstraction and diversion), groundwater pumping, climate change (e.g. precipitation, evapotranspiration), catchment land use (e.g. impervious surface, deforestation) and river structure (e.g. straightening, embankment).

High pulses affect various hydraulic parameters (hydrodynamic forces, turbulence and shear stress) and impact on stream habitats and biota. High pulse magnitude and duration are related to flood risk.

Spatio-temporal scale: Field data: gauging station, representing upstream sub-catchment

Unit: Number of days per year

Standardisation: To be standardised against natural hydrograph (e.g. % deviation from natural hydrograph)

Data requirements: Field data, modelled data (e.g. JRC LISFLOOD model)

Other: none

MARS spatial scale: River-basin and European scale

References

Richter, B., Baumgartner, J., Powell, J., & Braun, D. (1996). A method for assessing hydrologic alteration within ecosystems. Conservation Biology, 10(4), 1163–1174.

Richter, B., Baumgartner, J., Wigington, R., & Braun, D. P. (1997). How much water does a river need? Freshwater Biology, 37, 231–249.

BInd05: Mean duration of low pulses within each year

Quality element: Hydromorphology

Water category and water body types: Rivers; all types

Selection rationale: Indicator of extreme hydrological events related to environmental flows and water supply

Indicator type (DPSIR): Pressure, State, Impact

Description: Streamflow is the 'master factor' in stream ecosystems, establishing the physical mosaic of habitats and influencing the water quality conditions (e.g., temperature, dissolved oxygen, and nutrient concentration). The hydrological river regime is characterised by five general features: flow magnitude, frequency, duration, timing and rate of change usually addressed within the 'range of variability approach' (Richter et al. 1997). Thus, a broad range of relevant streamflow indicators have been established (e.g. 32 Indicators of Hydrologic Alteration; Richter et al. 1996).

The 'mean duration of low pulses within each year' characterises the annual extreme streamflow conditions. Low pulses are defined as periods during which the daily mean flow falls below the 10^{th} percentile of the mean annual discharge.

The natural flow regime including low pulse magnitude, frequency, duration and timing represents an intrinsic hydrological feature of a river. Drivers influencing this feature include river regulation (e.g. damming, water abstraction and diversion), groundwater pumping, climate change (e.g. precipitation, evapotranspiration), catchment land use (e.g. impervious surface, deforestation) and river structure (e.g. straightening, embankment).

Low pulses lead to the loss of aquatic habitat availability and connectivity that generates a loss of biodiversity and biomass, poor water quality and riparian canopy die-back. Low pulse magnitude and duration are related to the concept of environmental flows and water supply.

Spatio-temporal scale: Gauging station, representing upstream sub-catchment

Unit: Number of days per year

Standardisation: To be standardised against natural hydrograph (e.g. % deviation from natural hydrograph)

Data requirements: Field data, modelled data (e.g. JRC LISFLOOD model)

Other: none

MARS spatial scale: River-basin and European scale

References

Poff, N.L., Richter, B.D., Arthington, A.H., Bunn, S.E., Naiman, R.J., Kendy, E., Acreman, M., Apse, C., Bledsoe, B.P., Freeman, M.C., Henriksen, J., Jacobson, R.B., Kennen, J.G., Merritt, D.M., O'Keeffe, J.H., Olden, J.D., Rogers, K., Tharme, R.E., Warner, A. (2010). The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. Freshwater Biology, 55(1), 147–170.

Roo, A. De, Burek, P., Gentile, A., Udias, A., Bouraoui, F., Aloe, A., Bianchi, A., La Notte, A., Kuik, O., Elorza Tenreiro, J., Vandecasteele, I., Mubareka, S., Baranzelli, C., Van der Perk, M., Lavalle, C., Bidoglio, G. (2012). A multi-criteria optimisation of scenarios for the protection of water resources in Europe. Support to the EU Blueprint to Safeguard Europe's Waters. Joint Research Centre, Ispra (IT): 134pp.

BInd06: Annual water-level fluctuations

Quality element: Hydromorphology

Water category and water body types: Lakes; all types

Selection rationale: Indicator of extreme hydrological events related to water supply and recreation

Indicator type (DPSIR): Pressure, State

Description: Lake water levels fluctuate naturally, caused by different amounts of water entering and leaving the lake. Water supply, hydropower generation or flood prevention can alter the natural hydrological regime towards more excessive fluctuation. In lakes used for recreation or navigation, water-levels are often more stable than natural ones. Climate change is an additional driver of a changed hydrological regime.

Especially the littoral zone, i.e. the belt of shallow water around the shoreline of a lake to the maximum depth at which light still reaches the bottom sediments, is affected by excessive water-level fluctuations. This zone is often more productive than the open water (pelagic zone) and provides important ecological functions (food resources, hiding places from predation, fish spawning sites). Anthropogenic fluctuations destabilize the littoral zone integrity, including the weakening of keystone species, proliferation of nuisance and invasive species, loss of biodiversity, and increased internal nutrient loading. The lake can become more eutrophic with large and more frequent cyanobacterial blooms occurring. In Mediterranean climates lake salinity may increase.

Modified water-level regimes are threats to the sustainable water supply and recreation services.

Spatio-temporal scale: Water level station, monthly measurements

Unit: Annual range of water-level fluctuation in centimetres

Standardisation: To be standardised against natural hydrograph (e.g. % deviation from natural hydrograph)

Data requirements: Field data, modelled data (e.g. JRC LISFLOOD model)

Other: none

MARS spatial scale: River-basin and European scale

References

Sutela, T., Aroviita, J., & Keto, A. (2013). Assessing ecological status of regulated lakes with littoral macrophyte, macroinvertebrate and fish assemblages. Ecological Indicators, 24, 185–192.

Wantzen, K. M., Rothhaupt, K.-O., Mörtl, M., Cantonati, M., G.-Tóth, L., & Fischer, P. (2008). Ecological effects of water-level fluctuations in lakes: an urgent issue. Hydrobiologia, 613(1), 1–4.

Zohary, T., & Ostrovsky, I. (2011). Ecological impacts of excessive water level fluctuations in stratified freshwater lakes. Inland Waters, 1, 47–59.

BInd07: Amount of naturally-forested land in the riparian corridor of water body

Quality element: Hydromorphology

Water category and water body types: Rivers, lakes, transitional waters[2]; all types

Selection rationale: Indicator of riparian state of high relevance for water body status and ecosystem services

Indicator type (DPSIR): Pressure, State, Impact

Description: Riparian corridors represent key habitats linking aquatic and terrestrial ecosystems. They can provide important natural and social services. Natural riparian zones encompass valuable natural habitats and are often characterized by high productivity and biodiversity. Riparian areas can reduce non-point-nutrient and pollution sources via plant uptake, physical filtering and chemical transformation (e.g. denitrification), together with trapping sediment-bound pollutants and waters coming from upstream. Riparian corridors play a major role in maintaining landscape connectivity, functioning as ‘dispersal corridors’ within fragmented landscapes. From a hydrological risk perspective, riparian environments supply river bank stabilization and provide resistance to runoff during flood events.

The amount of naturally-forested land in the riparian corridor of the water body quantifies the relative coverage of native woody riparian vegetation (e.g. deciduous forest in Central Europe) in the buffer zone bordering the river stretch, lake or transitional water. Areas of non-native vegetation (e.g. coniferous or eucalyptus plantations) are to be excluded. If access is granted by JRC to use the modelled map on the Maximum Potential Riparian Extent (Clerici et al. 2013), the land use data can be processed on the basis of functionally delineated riparian corridors. Alternatively, a fixed buffer width depending on the water body size is to be applied. Sweeney & Newbold (2014), for instance, postulate forest buffers ≥30 m wide are needed to protect the physical, chemical, and biological integrity of streams.

Spatio-temporal scale: Continuously mapped along riparian corridor (covering entire water body or area upstream of sampling site), single point in time

Unit: Percent naturally-forested land in the riparian corridor

Standardisation: none

Data requirements:

1. CORINE Land Cover (or comparable, higher resolution national databases)

2. Map on Maximum Potential Riparian Extent according to Clerici et al. (2013)
→ subject to data access granted by JRC

2. (*alternative*) Delineation of fixed buffer widths (50 metres)

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[2] **Alternative indicator for transitional waters:** Changes in intertidal areas measured by the ratio of intertidal to subtidal areas.

Other: none

MARS spatial scale: River-basin and European scale

References

Clerici, N., Weissteiner, C. J., Paracchini, M. L., Boschetti, L., Baraldi, A., & Strobl, P. (2013). Pan-European distribution modelling of stream riparian zones based on multi-source Earth Observation data. Ecological Indicators, 24, 211–223.

Feld, C. K. (2013). Response of three lotic assemblages to riparian and catchment-scale land use: implications for designing catchment monitoring programmes. Freshwater Biology, 58, 715–729.

Sweeney, B. W., & Newbold, J. D. (2014). Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. Journal of the American Water Resources Association, 50(3), 560–584.

BInd08: Growing season mean of water column chlorophyll-a concentration

Quality element: Phytoplankton

Water category and water body types: Lakes, large rivers, transitional waters; all types

Selection rationale: Commonly used water quality indicator with high data availability

Indicator type (DPSIR): State

Description: Chlorophyll-a has a long tradition as an indicator of the productivity and trophic condition of lakes and estuaries. It is a measure of phytoplankton biomass and reflects the net result (standing stock) of both growth and loss processes in pelagic waters. Chlorophyll-a is related to external nutrient loading, internal nutrient cycling, light availability, water residence time and grazing by zooplankton and benthic filter feeders.

The indicator is used to measure eutrophication pressure, featuring well-documented relationships with the water phosphorus concentration. As strong eutrophication leads to algal blooms, often followed by fish kills implying aesthetic and sanitary issues. The chlorophyll-a concentration is thus also relevant for provisioning and cultural services (water supply, recreation).

Spatio-temporal scale: Growing season mean, representative for water body

Unit: $\mu g\ L^{-1}$

Standardisation: To be standardised against type-specific reference conditions (e.g. Carvalho et al. 2008)

Data requirements: Field data

Other: none

MARS spatial scale: Experimental, river-basin and European scale

Reference

Carvalho, L., van Den Berg, M., Solimini, A., Phillips, G., Pietilainen, O. P., Solheim, A. L., Poikane, S., Mischke, U. (2008). Chlorophyll reference conditions for European lake types used for intercalibration of ecological status. Aquatic Ecology, 42(2), 203–211.

BInd09: Chlorophyll-a to total phosphorus ratio (Chl:TP)

Quality element: Physico-chemistry & phytoplankton

Water category and water body types: Lakes, large rivers, transitional waters; all types

Selection rationale: Simple measure of production efficiency

Indicator type (DPSIR): State

Description: The correlation of total phosphorus and chlorophyll-a is one of the best-communicated relationships in aquatic ecology. However, several factors can confound the response of surface waters to reductions in total phosphorus: zooplankton grazing, internal P-loading, climate and nitrogen limitation. Variation in the Chl:TP ratio can be used to infer the likely response of phytoplankton following phosphorus reduction. If the Chl:TP ratio is low (i.e. low amount of chlorophyll-a per unit of TP), it is likely that factors other than phosphorus availability are limiting phytoplankton productivity. Water bodies with a low Chl:TP ratio are less likely to respond to reductions in TP concentrations compared to water bodies with a high Chl:TP ratio (i.e. high TP to Chlorophyll-a transfer efficiency).

Spatio-temporal scale:

Chlorophyll-a: Growing season mean, representative for water body

Phosphorus: Annual mean, representative for water body

Unit: none

Standardisation: none

Data requirements: Field data

Other: none

MARS spatial scale: Experimental, river-basin and European scale

Reference

Spears, B. M., Carvalho, L., Dudley, B., & May, L. (2013). Variation in chlorophyll a to total phosphorus ratio across 94 UK and Irish lakes: Implications for lake management. Journal of Environmental Management, 115, 287–294.

BInd10: Biovolume of toxic/nuisance phytoplankton species

Quality element: Phytoplankton

Water category and water body types: Lakes, large rivers, transitional waters; except low alkalinity lake types (Northern Europe)

Selection rationale: Direct indicator of the functional quality of recreation and water supply services

Indicator type (DPSIR): State, Impact

Description: Many cyanobacterial species produce hazardous toxins, and high abundances of cyanobacteria threaten the use of recreational and drinking waters. In this regard the World Health Organisation established health risk thresholds for the densities of cyanobacteria in surface waters. Water retention time, water alkalinity and colour influence the presence of cyanobacteria, with low-alkalinity lakes particularly in Northern Europe naturally showing very low abundances of cyanobacteria. Nutrient enrichment, especially phosphorus, is responsible for cyanobacterial blooms, triggered by warmer and drier summer conditions. The biovolume of toxic/nuisance phytoplankton species is a direct indicator of the 'functional quality' of freshwater services regarding water supply and recreation.

Spatio-temporal scale: Growing season mean, representative for water body

Unit: $mm^3 L^{-1}$

Standardisation: WHO thresholds for cyanobacteria

Data requirements: Field data

Other: none

MARS spatial scale: River-basin and European scale

Reference

Carvalho, L., McDonald, C., de Hoyos, C., Mischke, U., Phillips, G., Borics, G., Poikane, S., Skjelbred, B., Lyche-Solheim, A., van Wichelen, J., Cardoso, A.C. (2013). Sustaining recreational quality of European lakes: minimising the health risks from algal blooms through phosphorus control. Journal of Applied Ecology, 50, 315-323.

BInd11: Abundance of submerged, emergent and floating-leafed macrophytic vegetation

Quality element: Benthic flora

Water category and water body types: Rivers, lakes, transitional waters; all types except mountainous headwater streams

Selection rationale: Integrative indicator of hydromorphological and nutrient pressure, with relevance for habitat structuring

Indicator type (DPSIR): State

Description: The categories of submerged, emergent and floating-leafed vegetation represent different growth form types of aquatic vegetation, distinguished on the basis of coarse-level vegetative, whole-plant traits. These growth forms constitute different components of the macrophytic 'set-up' of a water body, featuring distinct reaction to various pressures. The submerged component is part of the benthic community extending into the pelagic zone. Submerged plants are influenced by the physico-chemical conditions of both water and sediment (e.g. availability of light and nutrients), and are prone to hydrodynamic forces in lotic systems. Emergent vegetation demarks the land-water ecotone and thus responds to riparian quality status, including light conditions. The floating-leafed plant component is most competitive at high productivity due to optimal light yield (photosynthetic tissue above water surface), and favours lentic conditions.

The abundance of submerged, emergent and floating-leafed macrophytic vegetation represents an integrative indicator of hydromorphological and nutrient pressure, with relevance for structuring the habitat for other aquatic organisms. Light conditions, current velocity and habitat availability form the main factors influencing the abundance and ratio of these growth forms. Furthermore, the total abundance of macrophytic vegetation (derived as the sum of individual growth form abundances) relates to nutrient enrichment, structural degradation and riparian quality. Excessive macrophyte growth represents a nuisance for boating, swimming and by obstruction of water flow. The latter is relevant for flood control.

Spatio-temporal scale: Sampling site, single survey

Unit: Percent coverage; plant volume invested; abundance sum

Standardisation: To be standardised against type-specific reference conditions

Data requirements: Field data

Other: Generic growth form lists of most freshwater macrophytes relevant in Europe are available upon request

MARS spatial scale:
Experimental*, river-basin and European scale
* NERC lakes

References

Alahuhta, J., Kanninen, A., Hellsten, S., Vuori, K.-M., Kuoppala, M., & Hämäläinen, H. (2013). Environmental and spatial correlates of community composition, richness and status of boreal lake macrophytes. Ecological Indicators, 32, 172–181.

Steffen, K., Leuschner, C., Müller, U., Wiegleb, G., & Becker, T. (2014). Relationships between macrophyte vegetation and physical and chemical conditions in northwest German running waters. Aquatic Botany, 113, 46–55.

BInd12: Average Score per Taxon (ASPT)

Quality element: Benthic fauna

Water category and water body types: Rivers, lakes, transitional waters[3]; all types

Selection rationale: All-round indicator of general pressure

Indicator type (DPSIR): State

Description: The Average Score per Taxon (ASPT) is a water quality index rating benthic invertebrate families according to their sensitivity to dissolved oxygen depletion. The ASPT was primarily developed to detect water pollution caused by organic substances. Thus, the ASPT is also sensitive to the effects of eutrophication (decay of excess plant material causing oxygen depletion). Other pressures leading to changes in oxygen availability such as impoundment (decrease of flow velocity) or siltation generate changes in ASPT. Habitat degradation and toxic stress often impact on invertebrate families that are also most sensitive to oxygen depletion (e.g. mayflies, stoneflies, caddisflies).

The ASPT is a robust indicator of widespread applicability across Europe (and worldwide), mainly for rivers and also for lakes. It was extensively used in the intercalibration exercise as a common metric.

Spatio-temporal scale: Sampling site, single survey

Unit: Average score per taxon

Standardisation: To be standardised against type-specific reference conditions

Data requirements: Field data

Other: Calculated by the ASTERICS software (http://www.fliessgewaesserbewertung.de/download/berechnung/)

MARS spatial scale

Experimental*, river-basin and European scale

* all river experiments

References

Armitage, P.D., D. Moss, J.F. Wright & M.T. Furse, 1983. The performance of a new biological water quality score system based on macroinvertebrates over a wide range of unpolluted running-waters. Water Research 17: 333-347.

Šidagytė, E., Višinskienė, G., & Arbačiauskas, K. (2013). Macroinvertebrate metrics and their integration for assessing the ecological status and biocontamination of Lithuanian lakes. Limnologica - Ecology and Management of Inland Waters, 43(4), 308–318.

[3] Alternative indicator for transitional waters: Ratio of sensitive to opportunistic species.

BInd13: Abundance ratios of invertebrate functional feeding groups

Quality element: Benthic fauna

Water category and water body types: Rivers, lakes, transitional waters; all types

Selection rationale: Trait-based indicator of functional relevance linked to food web structure

Indicator type (DPSIR): State

Description: The benthic invertebrate community is often the taxonomically and functionally most diverse organism group in aquatic ecosystems. Abundance ratios of invertebrate functional feeding groups represent trait-based and process-related indicators, based on taxon-specific morphological-behavioural adaptations for food acquisition.

The indicator distinguishes between five feeding groups: (1) Shredders feeding on large particulate organic matter such as dead leaves, (2) Gatherers and Collectors feeding on sedimented fine particulate organic matter, (3) Grazers and Scrapers feeding on biofilms, (4) active and passive Filter Feeders acquiring suspended fine particulate organic matter, and (5) Predators feeding on prey organisms. Feeding group assignments are available from http://www.freshwaterecology.info.

The indicator is sensitive to detect functional changes in the biological community related to the nutritional resource base. Various ratios can be calculated, e.g.

- Grazers and Scrapers /to/ Shredders, Gatherers and Collectors
  → Dominant food source (autochthonous *versus* allochthonous)
- Shredders /to/ Gatherers, Collectors and Filter Feeders
  → Dominant food source (coarse particulate organic matter *versus* fine particulate organic matter)
- Predators /to/ Total of all other functional feeding groups
  → Top-down control of predators on prey

Shifts in these ratios allow for indicating the effects of multiple stressors (e.g. nutrient pollution, impoundment, siltation, riparian integrity) impacting on food availability.

Spatio-temporal scale: Sampling site, single survey

Unit: Dimensionless (abundances given as number of individuals; abundance classes; biomass)

Standardisation: To be standardised against rule-of-thumb values (e.g. Merritt et al. 2002)

Data requirements: Field data

Other: Calculated by the ASTERICS software
(http://www.fliessgewaesserbewertung.de/download/berechnung/)

MARS spatial scale
Experimental*, river-basin and European scale
* all river experiments

References

Merritt, R., Cummins, K., Berg, M., Novak, J., Higgins, M., Wessell, K., & Lessard, J. (2002). Development and application of a macroinvertebrate functional-group approach in the bioassessment of remnant river oxbows in southwest Florida. Journal of the North American Benthological Society, 21(2), 290–310.

Wooster, D. E., Miller, S. W., & Debano, S. J. (2012). An examination of the impact of multiple disturbances on a river system: taxonomic metrics versus biological traits. River Research and Applications, 28, 1630–1643.

BInd14: Relative abundance of invasive alien invertebrate species

Quality element: Benthic fauna

Water category and water body types: Rivers, lakes, transitional waters; all types

Selection rationale: Indicator of 'biopollution'

Indicator type (DPSIR): Pressure, State, Impact

Description: An alien species is defined as a taxon introduced outside its natural past or present distribution. According to the Millennium Ecosystem Assessment, invasive alien species are considered to be the third most important threat to biodiversity of inland waters (after hydromorphological degradation, and point source and diffuse pollution). Main cause for their spread in surface waters is the increasing international ship traffic and the connection of formerly separated river basins by canals (e.g. Rhine-Main-Danube Canal in Germany). Alien species also benefit from climate change effects. They are expected to be established as a prominent part of the communities of European surface water bodies in the near future.

Main impact of alien invasive species is the decrease or extinction of indigenous species populations, with effects on the entire food web, through (1) a change of the habitat quality (mostly resulting from other pressures) for native species, leaving an empty space for tolerant alien species, (2) an invasion of a new species which takes over the niche of a native or preys on them successfully and (3) an exploitation of a 'new', previously unexploited food resource (Orendt et al. 2009). Co-invasion describes the introduction of exotic diseases and parasites brought along with the invasion of aliens.

The relative abundance of invasive alien invertebrate species indicates the level of 'biological contamination' of the water body. It informs about the dominance structure of the community, assuming that impacts from invasive aliens on the native biota are proportional to their abundance in the system. The metric represents an indicator of pressure, state and impact, since alien species may also cause damage to economies, ecosystem services or human health.

The indicator is equal to the Abundance Contamination Index proposed by Arbačiauskas et al. (2008).

Spatio-temporal scale: Sampling site, single survey

Unit: Relative abundance (number of individuals *or* abundance classes *or* biomass)

Standardisation: none

Data requirements: Field data

Other: See Annex 4 for a list of alien invertebrate taxa relevant in German watercourses – the list needs to be adopted for the regional conditions

MARS spatial scale
Experimental*, river-basin and European scale
* all river experiments

References

Arbačiauskas, K., Semenchenko, V., Grabowski, M., Leuven, R., Paunović, M., Son, M., Csányi, B., Gumuliauskaitė, S., Konopacka, A., Nehring, S., van der Velde, G., Vezhnovetz, V., Panov, V. (2008). Assessment of biocontamination of benthic macroinvertebrate communities in European inland waterways. Aquatic Invasions, 3(2), 211–230.

MacNeil, C., Briffa, M., Leuven, R.S.E.W., Gell, F.R., & Selman, R. (2010). An appraisal of a biocontamination assessment method for freshwater macroinvertebrate assemblages; a practical way to measure a significant biological pressure? Hydrobiologia, 638(1), 151–159.

Orendt, C., Schmitt, C., Liefferinge, C., Wolfram, G., & Deckere, E. (2009). Include or exclude? A review on the role and suitability of aquatic invertebrate neozoa as indicators in biological assessment with special respect to fresh and brackish European waters. Biological Invasions, 12(1), 265–283.

von der Ohe, P.C., Apitz, S.E., Arbačiauskas, K., Beketov, M.A., Borchardt, D., de Zwart, D., Goedkoop, W., Hein, M., Hellsten, S., Hering, D., Kefford, B.J., Panov, V.E., Schäfer, R.B., Segner, H., van Gils, J., Vegter, J.J., Wetzel, M.A., Brack, W. (2014). Status and Causal Pathway Assessments Supporting River Basin Management. In J. Brils et al. (eds.), Risk-Informed Management of European River Basins. The Handbook of Environmental Chemistry 29. Springer, Berlin/Heidelberg: 53-149.

BInd15: Total fish abundance (incl. abundance of commercially-relevant fish)

Quality element: Fish fauna

Water category and water body types: Rivers, lakes, transitional waters; all types

Selection rationale: Simple and robust indicator responding to different pressures, relevant for assessing service provision (fish yield)

Indicator type (DPSIR): State, Impact

Description: Total fish abundance represents an integrative indicator sensitive to multiple pressures. The total abundance measured as catch per unit effort (CPUE), reacts to low dissolved oxygen concentrations and eutrophication effects (e.g. nutrient enrichment, algal blooms). Water clarity and macrophyte habitat can impact on CPUE, as well as wider catchment factors that affect fish abundance, such as the amount of non-natural catchment land use as well as habitat quality, barriers and water abstraction impacts in spawning streams. The metric is also considered a simple and robust indicator for describing the impacts of fishing intensity in aquatic ecosystems. Coupled with the information on fish species relevant for leisure or commercial fishing, the indicator allows for quantifying the service supply.

Spatio-temporal scale: Sampling site, single survey

Unit: Catch per unit effort expressed as fish number/weight caught per unit effort fishing (hours)

Standardisation: To be standardised against type-specific reference conditions

Data requirements: Field data

Other: none

MARS spatial scale

Experimental*, river-basin and European scale

* selected river experiments

Reference

Argillier, C., Caussé, S., Gevrey, M., Pédron, S., De Bortoli, J., Brucet, S., Emmrich, M., Jeppesen, E., Lauridsen, T., Mehner, T., Olin, M., Rask, M., Volta, P., Winfield, I.J., Kelly, F., Krause, T., Palm, A., Holmgren, K. (2013). Development of a fish-based index to assess the eutrophication status of European lakes. Hydrobiologia, 704(1), 193–211.

Annex 1: Criteria for selecting benchmark indicators

1. Reflecting the phenomenon of interest (concreteness & theoretical basis)

- The indicator relates to features representing ecosystem properties, functioning or services.
- The indicator is rooted in a sound conceptual framework linking anthropogenic pressures and their effects.

2. Responding to (multiple) pressure effects (responsiveness)

- The indicator responds to the effects of (multiple) pressures (including the effects of future climate change, changes in land use and water management).
- The indicator is validated based on conceptual and/or empirical models demonstrating a (significant) pressure-effect relationship.

3. General applicability

- The indicator is applicable in various geographical contexts and to different water categories and water body types.

4. Data availability

- The indicator does not require acquisition of specific data but refers to data already available (e.g. WFD monitoring, remote sensing).

5. Appropriate scaling

- The indicator addresses the relevant spatio-temporal scales to infer viable conclusions on the effects to be indicated.

6. Benchmarking

- The indicator can be standardised by referring to benchmarks (e.g. using biogeographically distinct, near-natural reference conditions) to allow for comparisons between spatially or temporally different conditions.

7. Management relevance

- The indicator provides insights applicable in water resource management.
- Indicators of specific management relevance are:
    - *Diagnostic indicators* diagnosing the cause of the effects indicated (capable of disentangling the effects of individual pressures);
    - *Recovery indicators* responding to abatement/mitigation measures (featuring an early and reliable response due to high indicator sensitivity and precision);
    - *Resilience indicators* informing about features preventing/buffering pressure effects on ecosystem properties, functioning or services (e.g. woody riparian buffer strips).

8. Policy and public awareness

- The indicator is comprehensible and accepted by decision makers, managers and the general audience.

Annex 2: Establishing the list of MARS benchmark indicators

Selecting the benchmark indicators presented above initially followed the specifications given in the DoW. Discussions during the MARS kick-off meeting in February 2014 allowed for outlining a more concrete concept for the indicator selection. On this basis, MARS Task 2.3 collated ideas for suitable benchmark indicators in March 2014. A preliminary indicator selection was circulated in form of a questionnaire to MARS partners in May 2014. This questionnaire aimed at evaluating if the different work package contributors consider the initial selection of benchmark indicators to be meaningful and practicable. The partners were asked if individual indicators are applicable in the context of their work task, and interrogated about the type and number of data available to process the indicator, and about their expert opinion on whether the proposed indicators are a reasonable choice. On the basis of 27 questionnaire returns completed by 49 responders (see below), we finalised the selection process and concluded on a consolidated and reduced list of benchmark indicators, as presented in this document.

We reduced the initially proposed 26 indicators to a final number of 15, excluding those indicators that most of the responders rejected (see Figure 1). In some cases we additionally omitted selected indicators, as their definition provoked ambiguous interpretation (e.g. *chemical water body status*). In other cases, we needed to adjust the indicator details to account for individual data availability (e.g. *total fish abundance* instead of *total fish biomass*).

List of responders

Adrian Constantinescu (DDNI), Alexander Gieswein (UDE), Ana Cristina Cardoso (JRC), Angel Borja (AZTI), Anne Lyche Solheim (NIVA), Arnaud Reynaud (JRC), Bruna Grizzetti (JRC), Bryan Spears (NERC), Camino Liquete (JRC), Christel Prudhomme (NERC), Denis Lanzanova (JRC), Dennis Trolle (AU), Elisabeth Bondar (BOKU), Ellis Penning (DELTARES), Erik Jeppesen (AU), Fabien Cremona (EMU), Florian Pletterbauer (BOKU), Francois Edward (NERC), Hans Estrup Andersen (AU), Hans Thodsen (AU), Heidrun Feuchtmayr (NERC), Henn Timm (EMU), Jannicke Moe (NIVA), Jenica Hanganu (DDNI), John Bloomfield (NERC), Katri Rankinen (SYKE), Kostas Stefanidis (NTUA), Laurence Carvalho (NERC), Lisa Schülting (BOKU), Marijn Kuijper (DELTARES), Meryem Beklioğlu (METU), Mike Bowes (NERC), Mike Hutchins (NERC), Nuria Cid (JRC), Paulo Branco (ULisboa), Peeter Nõges (EMU), Rafaela Schinegger (BOKU), Raoul Marie Couture (NIVA), Rein Järvrkülg (EMU), Shenglan Lu (AU), Stefan Auer (BOKU), Stefan Schmutz (BOKU), Steve Ormerod (CU), Susanne Schneider (NIVA), Teresa Ferreira (ULisboa), Tuba Bucak (METU), Ute Mischke (IGB), Wolfram Graf (BOKU), Yiannis Panagopoulos (NTUA)

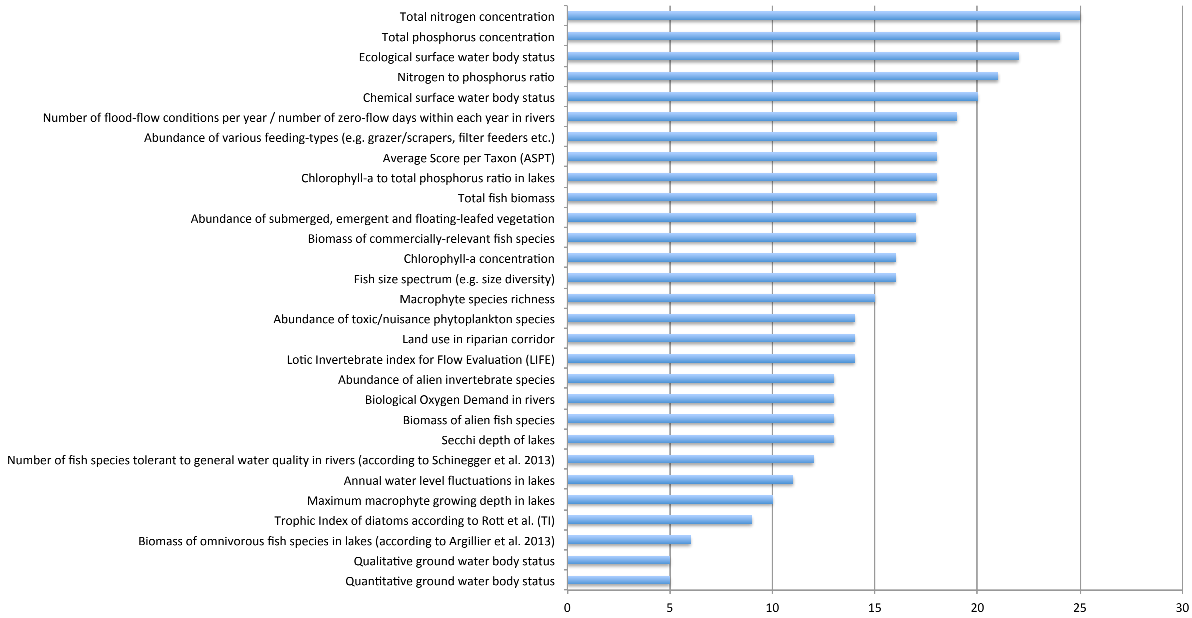

Figure 1: Number of positive votes indicating indicator applicability on the basis of 27 questionnaire returns

Annex 3: Broad river and lake types[4]

List of broad river types

Broad type name	Broad type number	Altitude (masl)	Catchment area (km²)	Geology
Very large rivers (all Europe)	1		>10 000	
Lowland, Siliceous/Organic, Medium-Large	2	≤200	100 - 10 000	Siliceous/Organic
Lowland, Siliceous/Organic, Very small-Small	3	≤200	≤100	Siliceous/Organic
Lowland, Calcareous/Mixed, Medium-Large	4	≤200	100 - 10 000	Calcareous/Mixed
Lowland, Calcareous/Mixed, Very small-Small	5	≤200	≤100	Calcareous/Mixed
Mid altitude, Siliceous, Medium-Large	6	200 - 800	100 - 10 000	Siliceous
Mid altitude, Siliceous, Small	7	200 - 800	≤100	Siliceous
Mid altitude, Calcareous/Mixed, Medium-Large	8	200 - 800	100 - 10 000	Calcareous/Mixed
Mid altitude, Calcareous/Mixed, Very small-Small	9	200 - 800	≤100	Calcareous/Mixed
Highland, Siliceous	10	>800		Siliceous
Highland, Calcareous/Mixed	11	>800		Calcareous/Mixed
Mediterranean, Lowland, Medium-Large	12	≤200	100 - 10 000	
Mediterranean, Mid altitude, Medium-Large	13	200 - 800	100 - 10 000	
Mediterranean, Very small-Small	14		≤100	

List of broad lake types

Broad type name	Broad type number	Altitude (masl)	Lake area (km²)	Geology	Mean depth (m)
Very large and deep*	1		>100		> 15
Lowland, Siliceous	2	≤200		Siliceous	
Lowland, Shallow, Calcareous/Mixed	3	≤200		Calcareous/Mixed	3 - 15
Lowland, Very shallow, Calcareous/Mixed	4	≤200		Calcareous/Mixed	≤ 3
Organic	5			Organic	
Mid altitude, Siliceous	6	200 - 800		Siliceous	
Mid altitude, Calcareous/Mixed	7	200 - 800		Calcareous/Mixed	
Highland, Siliceous	8	>800		Siliceous	
Highland, Calcareous/Mixed	9	>800		Calcareous/Mixed	
Mediterranean, Small-Very large	10		>0.5		
Mediterranean, Very small	11		≤0.5		

[4] According to: Lyche-Solheim, A., Persson, J., Stein, U., Kampa, E., Feher, J., Kristensen, P. (in prep.). Freshwater Ecosystem Assessment: Cross-walk between the WFD and Habitats Directive types, status and pressure information using broad types. EEA/ETC-ICM report.

Annex 4: List of alien invertebrate taxa relevant in German watercourses

Taxon	ID_ART
Astacus leptodactylus	4358
Atyaephyra desmaresti	9272
Barbronia weberi	8518
Branchiura sowerbyi	4494
Caspiobdella fadejewi	4563
Congeria leucophaeata	11585
Corbicula "fluminalis"	11177
Corbicula fluminea	11176
Corbicula sp.	11178
Cordylophora caspia	4743
Corophium curvispinum	4749
Corophium robustum	20515
Corophium sp.	4750
Crangonyx pseudogracilis	11227
Craspedacusta sowerbyi	19116
Dendrocoelum romanodanubiale	9363
Dikerogammarus haemobaphes	7854
Dikerogammarus sp.	8961
Dikerogammarus villosus	7517
Dreissena polymorpha	4999
Dreissena rostriformis	22042
Dreissena sp.	8965
Dugesia tigrina	5022
Echinogammarus berilloni	12328
Echinogammarus ischnus	4613
Echinogammarus sp.	8918
Echinogammarus trichiatus	10400
Eriocheir sinensis	5149
Eunapius carteri	19113
Ferrissia clessiniana	5271
Gammarus tigrinus	5294
Gyraulus parvus	5358
Hemimysis anomala	10597
Hypania invalida	5634
Jaera istri	8700
Limnomysis benedeni	8730
Lithoglyphus naticoides	5896
Menetus dilatatus	13673
Musculium transversum	16776
Obesogammarus obesus	9799
Obesogammarus sp.	12360
Orchestia cavimana	14241
Orconectes immunis	21742
Orconectes limosus	6199
Orconectes sp.	9121
Pacifastacus leniusculus	6272
Pectinatella magnifica	6353
Physella acuta	6396
Physella heterostropha	6397
Physella sp.	8661
Piscicola haranti	7855
Planorbella duryi	6432
Pontogammarus robustoides	10491
Potamopyrgus antipodarum	8251
Proasellus coxalis	8703
Proasellus meridianus	8696
Proasellus sp.	9166
Procambarus clarkii	10709
Rhithropanopeus harrisii	14412
Unio mancus	7136
Urnatella gracilis	19128
Viviparus viviparus	7158

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Deliverable 2.1 - Four manuscripts on the multiple stressor framework: Report on the MARS scenarios of future changes in drivers and pressures with respect to Europe's water resources (4/4)

Lead beneficiary: Deltares (8)
Contributors: Marta Faneca Sanchez (Deltares), Harm Duel (Deltares), Ana Alejos Sampedro (Deltares), Katri Rankinen (SYKE), Maria Holmberg (SYKE), Christel Prudhomme (NERC), John Bloomfield (NERC), Raoul Marie Couture (NIVA), Yiannis Panagopoulos (NTUA), Teresa Ferreira (UTL), Markus Venohr (FVB-IGB), and Sebastian Birk (UDE).

Due date of deliverable: **Month 12**
Actual submission date: **Month 12**

Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Contents

Preface

This document is part of task 2.6 Definition of future scenarios of the FP7 project MARS (Managing Aquatic ecosystems and water Resources under multiple Stress). The document includes the work done to define qualitatively and quantitatively the scenarios and storylines that will be used within MARS.

Abstract

Experiments and predictive models at local, basin, and European scale will be used in MARS to assess the combined impacts of multiple stressors affecting water quantity and quality, ecological status, ecological functions, and ecosystem services under contrasting scenarios. These predictive models will run several scenarios in order to predict future impacts. Fur such purpose, various future climatic and socio-economic scenarios were chosen to define three storylines at the European level, based on the latest versions of the Shared Socio-economic Pathways and the Representative Concentration Pathways. The combinations SSP5 and RCP8.5, SSP3 and RCP8.5 and SSP2 and RCP4.5 were selected through a participatory process as starting points. These storylines differ mainly in four main aspects; main drivers in the economy, economic growth, policies regarding the environment, and public concern about the environment and protection of ecosystem services. The storylines were downscaled to the three basin regions defined within MARS using the expert knowledge of the scientists working in the basins, and the stakeholders within those basin regions. In order to simulate the future scenarios at both basin and European scale, and to assess the impacts of multiple stressors, quantitative values for the input parameters and variables for each scenario are required. Several projects and modelling tools were reviewed with the aim of identifying quantitative data fitting the selected storylines. The data was derived mainly from previous projects and tools, including CLIMSAVE, ISIMIP, BASE, SCENES, and IMAGE. Values for diverse climate variables, runoff, water abstraction, potential flood plains, nutrient diffuse source emission, land use, population and GDP were collected. The result is a suite of quantitative values for diverse parameters and variables in gridded or vector format, which range from daily to yearly time steps at resolutions ranging from 5 by 5 arc minutes to a 0.5 by 0.5 degrees spatial resolution across Europe. These quantitative values can be used to drive the simulations of the three storylines defined within the MARS project.

1. Introduction

In MARS, experiments and predictive models at local, basin, and European scale will be used to assess the combined impacts of multi stressors affecting water quantity and quality, ecological status, ecological functions, and ecosystem services under contrasting scenarios of water resources management, land use and climate change.

The multiple combinations of drivers and pressures for a given aquatic system for the current situation are given by the historical and present climatic, managerial and socio economic conditions around the given system. Within MARS, the historical and present conditions will be identified by the stakeholders and scientists working on the system, and will be filled with data readily available such as historic and actual climate data, land use, or water abstractions and demand.

Future combinations of the drivers and pressures depend on the future climatic and socio-economic scenarios considered plausible for a given aquatic system. Various future climatic and socio-economic scenarios have been chosen within MARS to define three storylines at European level. Each storyline frames the conditions leading to certain combinations of drivers and pressures for Europe. These storylines have been downscaled to basin region level using the expert knowledge of the scientists working on the basins, and the stakeholders of those basin regions.

But what are storylines and scenarios within MARS?

A storyline is a narrative about a fictive sequence of events that could take place in the near future. Within MARS storylines describe several aspects of economic, environmental, political and climatic developments and are mainly defined focusing on the different fashions to manage and regulate drivers and pressures impacting aquatic systems.

A scenario is a coherent description of alternative hypothetical futures that reflects different perspectives on past, present and future developments, which can serve as a basis for action (Van Notten, 2005). Within MARS, we used climatic and socio-economic projections as scenarios that served as basis to define our storylines.

In this document we present the work done within this task to define storylines for MARS from a qualitative and quantitative perspective. The following chapters present a literature review of future storylines and scenarios (chapter 1), the approach taken to define the future scenarios and storylines for MARS (chapter 2), the description of the future storylines and scenarios for MARS (chapter 3), the process to acquire quantitative data for the storylines and a description of the data (chapter 4), and some conclusions and remarks on the work done regarding data availability (chapter 5).

2. Storylines and scenario review

This chapter summarizes the work done until date by different organizations and projects in the definition of scenarios and storylines for future scenarios. This review aims to give the reader a clear overview of the proponents and instigators of the first scenarios, the existing storylines and scenarios approaches, the last developments in this topic and the available knowledge.

Review of storylines and scenarios

Scenarios have been used for many organizations in the last years in order to describe possible futures for different variables such as climate, demography, politics, economy, land use, management of ecosystems and ecosystem services, etc. The first official report on scenarios was published by the Shell Scenarios Group in 1973. The Shell team saw the need to understand the factors affecting the business and the possible directions that these factors could take. The main drive was to help managers to be prepared to ensure the continuity of the business in different "what if?" situations. Since then, scenarios are a crucial planning part in the business of Shell. The success of the use of the scenarios encouraged others to work with those as well.

The International Panel of Climate Change (IPCC) has been coordinating the development of scenarios regarding the future anthropogenic climate change (AR 1990, SR 1994, and SRES 2000) since the nineties. Parallel to these development and often also in collaboration with the IPCC (as in the last Assessment Report), the scientific community has developed a series of scenarios and storylines some of them linked to specific projects. The project defined scenarios are often created keeping the main objectives of the project as a reference.

The most common methodology to define scenarios is a sequential stepwise approach starting by the definition of socioeconomic storylines, continuing with the match of the storylines with the green-house gas emission scenarios and the radiative forcing scenarios (as for example those of IPCC). Then the greenhouse emission scenarios are used as input for the Climate Models (CM) and the Integrated Assessment Models (IAMs). These models give the value ranges (sometimes with spatial resolution) for different climate variables such as precipitation and temperature, and the value ranges for other variables such as agricultural land use abandonment or expansion of cities.

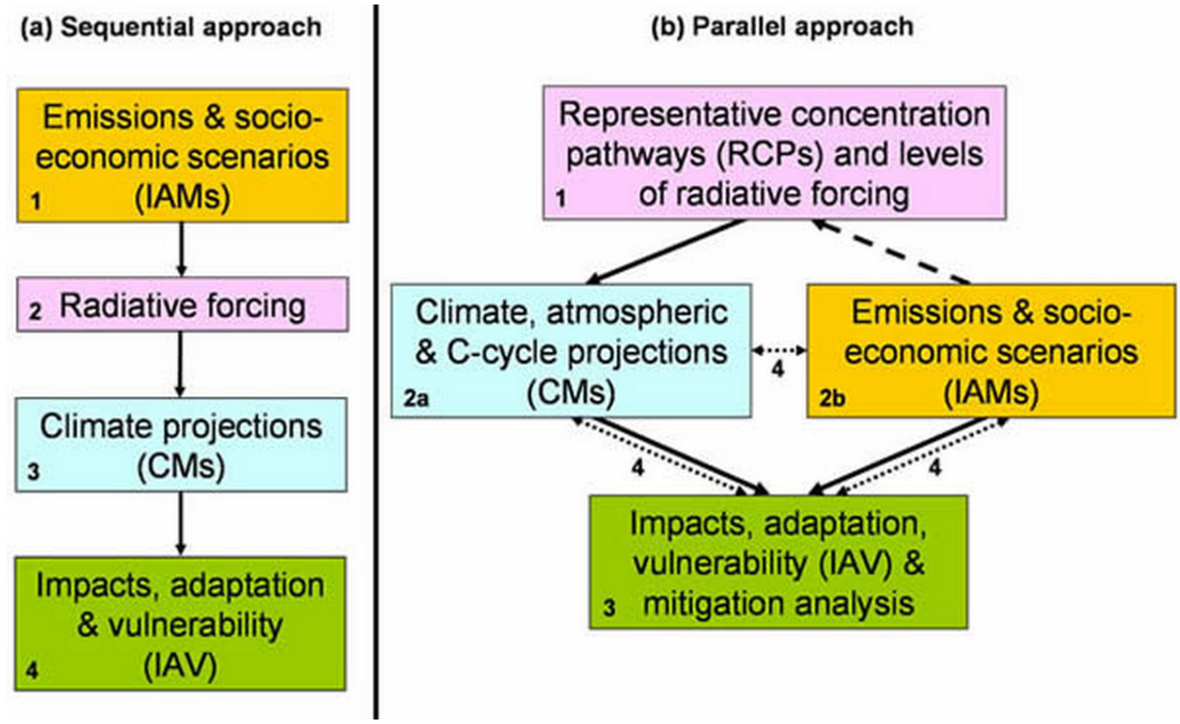


Figure 1 Approaches to the development of global scenarios: a) previous sequential approach; b) proposed parallel approach. Numbers indicate analytical steps. Arrows indicate transfers of information (solid), selection of RCPs (dashed), and integration of information and feedbacks (dotted). Source: Moss et al (2008)

The sequential approach (Figure 1a)) was used to create for example the scenarios of the Special Report on Emissions Scenarios (SRES) (Nakicenovic, et al 2000). However, the need for new scenarios as pointed out by Moss et al. (2010) induced the IPCC to request the scientific community to develop a new set of scenarios. The IPCC acted as a catalyst of the process and assessor of the scenarios. In the last Assessment Report of IPCC, the AR5, the approach to define the scenarios has been different and has not followed a sequential approach. Instead, the emissions and socioeconomic scenarios are developed in parallel (Figure 1b)). The starting points of the new scenarios are radiative forcing pathways that describe an emission trajectory and concentration by the year 2100. These radiative forcing trajectories are termed "Representative Concentration Pathways" (RCPs). The RCPs can either be or not be associated with unique socioeconomic and policy assumptions. They can also result from different combinations of economic, technological, demographic, policy, and institutional futures.

The new integrated scenarios framework

The new framework developed to define integrated scenarios (van Vuuren et al, 2013), takes the form of a matrix with 3 dimensions: climate and climate model projections, socioeconomic conditions and climate policies. The first dimension of the matrix is represented by the RCPs (van Vuuren et al 2011) ant the climate projections based on them. The second axis is determined by the Shared Socioeconomic Pathways (SSPs; O'Neill et al 2014), a set of socioeconomic future assumptions. The third dimension is the Share climate Policy Assumptions (SPAs; Kriegler et al 2013).

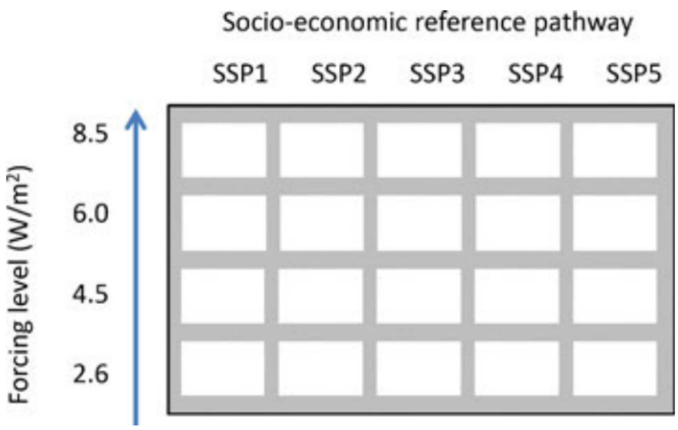


Figure 2 Scenario matrix. Every cell represents a possible scenario that combines policies of adaptation and mitigation.

The Representative Concentration Pathways (RCPs)

The radiative forcing scenarios are 4 and are defined depending on the total radiative forcing in year 2100 relative to 1750. The production of the RCPs resulted in a broad data set with high spatial and sectoral resolution. Land use and emissions of air pollutants and greenhouse houses are in its majority available at 0.5x0.5 degree spatial resolution. The four scenarios are:

Table 1 Representative pathways in the year 2100 (source van Vuuren et at 2013)

	Radiative forcing	CO_2 equivalent concentration	Rate of change in radiative forcing	Key reference
RCP 8.5	8.5 W/m^2	1350 ppm	Rising	(Riahi et al. 2011)
RCP 6.0	6.0 W/m^2	850 ppm	Stabilizing	(Masui et al. 2011)
RCP 4.5	4.5 W/m^2	650 ppm	Stabilizing	(Thomson et al. 2011)
RCP 2.6	2.6 W/m^2	450 ppm	Declining	(Van Vuuren et al. 2011b)

Scenario 2.6 is a mitigation scenario the emissions of which peak and decline before 2100. Scenarios 4.5 and 6.0 are stabilization scenarios and scenario 8.5 is a rising scenario with very high greenhouse gas emissions. Each of the scenarios provides a dataset of land use change, air pollutants per sector and greenhouse emissions.

These four RCPs are based on previous available in the literature scenarios, and they were built on specific socioeconomic assumptions. However, as these assumptions are not consistent in the 4 RCPs, they are further not used and can be substituted by the SSPs. Still, the socioeconomic assumptions behind the RCPs, can help understanding the scenarios (see references on Table 1 for more information on the predecessor scenarios of the four RCPs).

The IPCC has generated a new set of data based on the new climate simulations carried out with the climate model ensemble under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) and using as basis the RCPs.

Some of the outcomes are shown in the next figures:

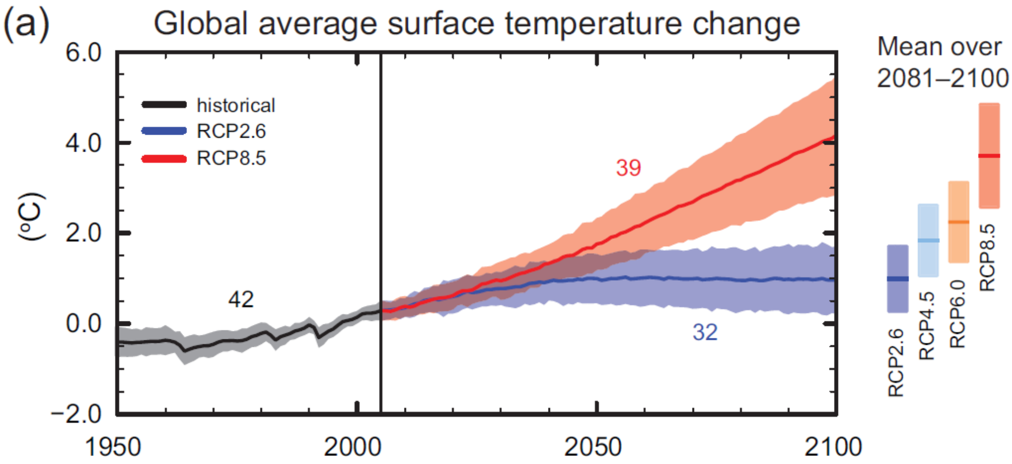


Figure 3 CMIP5 simulated global average surface temperature change from 1950 to 2100.

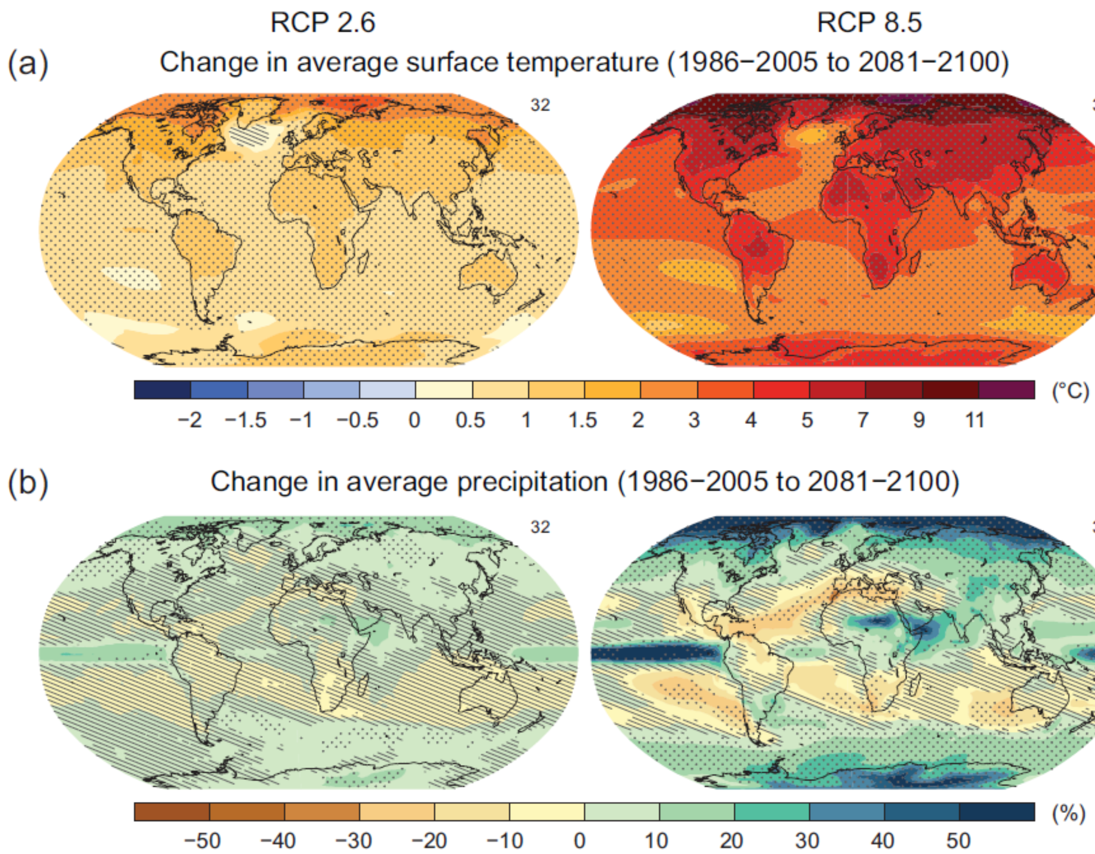


Figure 4 Spatial distribution of the change in average temperature (a) and precipitation (b) as calculated with the CMIP5 multi model projections.

		2046–2065		2081–2100	
	Scenario	Mean	*Likely* range[c]	Mean	*Likely* range[c]
Global Mean Surface Temperature Change (°C)[a]	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
	Scenario	Mean	*Likely* range[d]	Mean	*Likely* range[d]
Global Mean Sea Level Rise (m)[b]	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

Figure 5 Projected change in global mean surface air temperature and Source: Climate Change 2013 Summary for Policymakers, 2013

Regarding Land Use in the RCPs it is worth it to mention that the RCPs cover a broad range of land uses. The next tables give a coarse summary of the characteristics of the four RCPs with regards to the evolution of the land use (Table 2) and the situation of the land use in the world by the year 2100 (Table 3) as given in Van Vuuren et al 2011.

Table 2 Evolution of the land use up to the year 2100

RCP	Grassland	Cropland	Pasture
RCP8.5	Increase due to an increase of population	Increase due to an increase of population	
RCP6.0		Increase	Decrease
RCP4.5	Decrease due to reforestation programs	Decrease due to reforestation programs	
RCP2.6	Constant use	Increase as a result of bioenergy production	

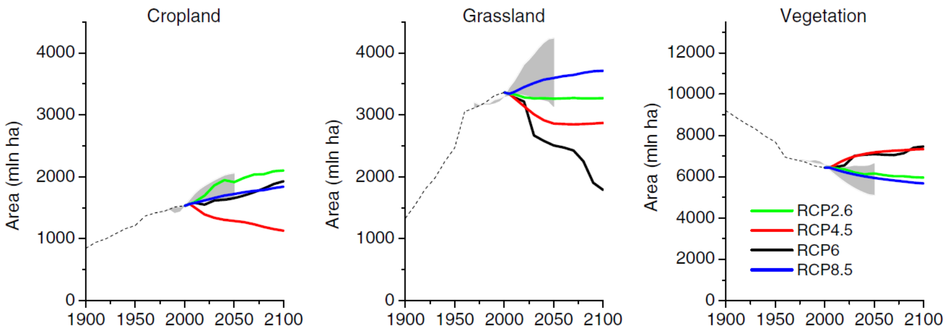


Figure 6 Development of primary energy consumption (direct equivalent) and oil consumption for the different RCPs. The grey area indicates the 98th and 90th percentiles (light/dark grey) (AR4 database (Hanaoka et al. 2006) and more recent literature (Clarke et al. 2010; Edenhofer et al. 2010). The dotted lines indicate four of the SRES marker scenarios

Table 3 Patterns for land use by 2100

RCP	Cropland	Pasture	Forest
RCP8.5	High density of cropland in United States, Europe, South-East Asia.	Western United States, Eurasia, South Africa and Australia.	Concentrated in northern high latitudes and parts of Amazonia. Secondary vegetation in United States, Africa, South America and Eurasia.
RCP6.0	Increase	Similar to RCP8.5 but less pasture in the United States, Africa, Eurasia an Australia	High density areas of secondary vegetation in United States, Africa and Eurasia.
RCP4.5	Less cropland than RCP2.6, RCP6 and 8.5		
RCP2.6	Similar to RCP8.5		

Shared Socioeconomic Pathways (SSPs)

The SSPs are defined by O'Neill et al as "reference pathways describing plausible alternative trends in the evolution of society and ecosystems over a century timescale, in the absence of climate change of climate policies". The approach followed to define the SSPs is an inverse approach combined with the complementary forward approach. It starts by defining the outcomes of interest for a climate change research and then finding the combination of socioeconomic elements that are likely to be the cause of those outcomes. Five SSPs have been defined as a function of different levels of challenge for mitigation and adaptation of a society to climate change. The level of the challenge to mitigation and adaptation is linked to the characteristics of the society to define and apply policies for mitigation and adaptation. The definition of policies for such matters is not included in the SSPs but in the SPAs.

The SSPs set the starting point for other scenarios that can be developed to meet specific objectives of its application. The scenarios or qualitative "narratives" that can be constructed need to cover the space of socioeconomic challenges to mitigation and adaptation that is set by the correspondent SSP. Currently initial starting points for SSP narratives have been set based on Kriegler et al 2012.

The next table shows a short description of the SSPs, the starting points for narratives, and the analogy to the SRES scenarios as described in O'Neill 2014.

Table 4 Initial starting points for the SSP narratives, based on Kriegler et at (2012)

SSP	Challenges	Illustrative starting points for narratives	Possible SRES analogue
SSP 1	Low for mitigation and adaptation	Sustainable development proceeds at a reasonably high pace, inequalities are lessened, technological change is rapid and directed toward environmentally friendly processes, including lower carbon energy sources and high productivity of land.	B1, A1T
SSP2	Moderate	An intermediate case between SSP1 and SSP3.	
SSP 3	High for mitigation and adaptation	Unmitigated emissions are high due to moderate economic growth, a rapidly growing population, and slow technological change in the energy sector, making mitigation difficult. Investments in human capital are low, inequality is high, a regionalized world leads to reduced trade flows, and institutional development is unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity.	A2
SSP 4	High for adaptation, low for mitigation	A mixed world, with relatively rapid technological development in low carbon energy sources in key emitting regions, leading to relatively large mitigative capacity in places where it mattered most to global emissions. However, in other regions development proceeds slowly, inequality remains high, and economies are relatively isolated, leaving these regions highly vulnerable to climate change with limited adaptive capacity.	No analogue
SSP 5	High for mitigation, low for adaptation	In the absence of climate policies, energy demand is high and most of this demand is met with carbon-based fuels. Investments in alternative energy technologies are low, and there are few readily available options for mitigation. Nonetheless, economic development is relatively rapid and itself is driven by high investments in human capital. Improved human capital also produces a more equitable distribution of resources, stronger institutions, and slower population growth, leading to a less vulnerable world better able to adapt to climate impacts.	A1FI

Besides this description of the SSPs as starting points, there is a larger process being developed with the collaboration between different communities including Integrated Assessment Model Communities and Impact Adaptation and Vulnerability communities to define SSP narratives and quantitative information. In the summary report of the Workshop on The Nature and Use of New Socioeconomic Pathways for Climate Change Research (O'Neill 2012), the international scientific community described the five SSPs. These descriptions include a qualitative part; the narratives, and a quantitative part; numerical pathways for important variables of the SSPs. The SSPs are built in 'blocks' containing 'elements' that are variables, processes or components that provide qualitative or quantitative information about the SSPs.

The blocks used to build the SSPs are the following: Demographics, Economic development, Welfare, Environmental and ecological factors, Resources, Institutions and governance, Technological development, broader societal factors, and Policies.

In the next lines, the narratives of the SSPs are summarized (O'Neill 2014):

SSP1 – Sustainability – Taking the Green Road: *The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. Increasing evidence of and accounting for the social, cultural, and economic costs of environmental degradation and inequality drive this shift. Management of the global commons slowly improves, facilitated by increasingly effective and persistent cooperation and collaboration of local, national, and international organizations and institutions, the private sector, and civil society. Educational and health investments accelerate the demographic transition, leading to a relatively low population. Beginning with current high-income countries, the emphasis on economic growth shifts toward a broader emphasis on human well-being, even at the expense of somewhat slower economic growth over the longer term. Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. Investment in environmental technology and changes in tax structures lead to improved resource efficiency, reducing overall energy and resource use and improving environmental conditions over the longer term. Increased investment, financial incentives and changing perceptions make renewable energy more attractive. Consumption is oriented toward low material growth and lower resource and energy intensity. The combination of directed development of environmentally friendly technologies, a favourable outlook for renewable energy, institutions that can facilitate international cooperation, and relatively low energy demand results in relatively low challenges to mitigation. At the same time, the improvements in human well-being, along with strong and flexible global, regional, and national institutions imply low challenges to adaptation.*

SSP 2 - Middle of the Road: *The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Most economies are politically stable. Globally connected markets function imperfectly. Global and national institutions work toward but make slow progress in achieving sustainable development goals, including improved living conditions and access to education, safe water, and health care. Technological development proceeds apace, but without fundamental breakthroughs. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Even though fossil fuel dependency decreases slowly, there is no reluctance to use unconventional fossil resources. Global population growth is moderate and levels off in the second half of the century as a consequence of completion of the demographic transition. However, education investments are not high enough to accelerate the transition to low fertility rates in low-income countries and rapidly slow population growth. This growth, along with income inequality that persists or improves only slowly, continuing societal stratification, and limited social cohesion, maintain challenges to reducing vulnerability to societal and environmental changes and constrain significant advances in sustainable development. These moderate development trends leave the world, on average, facing* *moderate challenges to mitigation and adaptation, but with significant heterogeneities across and within countries.*

SSP 3 – Regional Rivalry – A Rocky Road: *Growing interest in regional identity, regional conflicts, and concerns about competitiveness and security push countries to increasingly focus on domestic or, at most, regional issues. This trend is reinforced by the limited number of comparatively weak global institutions, with uneven coordination and cooperation for addressing environmental and other global concerns. Policies shift over time to become increasingly oriented toward national and regional security issues, including barriers to trade, particularly in the energy resource and agricultural markets. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development, and in several regions move toward more authoritarian forms of government with highly regulated economies. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time, especially in developing countries. There are pockets of extreme poverty alongside pockets of moderate wealth, with many countries struggling to maintain living standards and provide access to safe water, improved sanitation, and health care for disadvantaged populations. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions. The combination of impeded development and limited environmental concern results in poor progress toward sustainability. Population growth is low in industrialized and high in developing countries. Growing resource intensity and fossil fuel dependency along with difficulty in achieving international cooperation and slow technological change imply high challenges to mitigation. The limited progress on human development, slow income growth, and lack of effective institutions, especially those that can act across regions, implies high challenges to adaptation for many groups in all regions.*

SSP 4 – Inequality – A Road Divided: *Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that is well educated and contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labor intensive, low-tech economy. Power becomes more concentrated in a relatively small political and business elite, even in democratic societies, while vulnerable groups have little representation in national and global institutions. Economic growth is moderate in industrialized and middle-income countries, while low income countries lag behind, in many cases struggling to provide adequate access to water, sanitation and health care for the poor. Social cohesion degrades and conflict and unrest become increasingly common. Technology development is high in the high-tech economy and sectors. Uncertainty in the fossil fuel markets lead to underinvestment in new resources in many regions of the world. Oil and gas prices rise and volatility increases. Energy companies hedge against price fluctuations partly through diversifying their energy sources, with investments in both carbon-intensive fuels like coal and* *unconventional oil, but also low-carbon energy sources. Environmental policies focus on local issues around middle and high income areas. The combination of some development of low carbon supply options and expertise, and a well-integrated international political and business class capable of acting quickly and decisively, implies low challenges to mitigation. Challenges to adaptation are high for the substantial proportions of populations at low levels of development and with limited access to effective institutions for coping with economic or environmental stresses.*

SSP 5 – Fossil Fueled Development – Taking the Highway: *Driven by the economic success of industrialized and emerging economies, this world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated, with interventions focused on maintaining competition and removing institutional barriers to the participation of disadvantaged population groups. There are also strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary. While local environmental impacts are addressed effectively by technological solutions, there is relatively little effort to avoid potential global environmental impacts due to a perceived trade off with progress on economic development. Global population peaks and declines in the 21st century. Though fertility declines rapidly in developing countries, fertility levels in high income countries are relatively high (at or above replacement level) due to optimistic economic outlooks. International mobility is increased by gradually opening up labor markets as income disparities decrease. The strong reliance on fossil fuels and the lack of global environmental concern result in potentially high challenges to mitigation. The attainment of human development goals, robust economic growth, and highly engineered infrastructure results in relatively low challenges to adaptation to any potential climate change for all but a few.*

The Shared climate Policy Assumptions (SPAs)

These assumptions are defined by Kriegler et al 2014 as assumptions that "capture key policy attributes such as the goals, instruments and obstacles of mitigation and adaptation measures". Kriegler et al 2014 defined two groups of SPAs, a first group of SPA which includes the "full SPAs" with all mitigation and adaptation policy targets (embeds RCP and SSP), and a second group of "reduced SPAs" that excludes the mitigation policy goals, so it has to be used if policy assumptions can vary for a given RCP-SSP combination.

The next table shows key components of the narratives for the SPAs. These narratives include information on the nature of climate policies, the participation of regions and countries, the constraints for setting policies, etc. In the rows the policy attributes are summarized and in the columns, the reduced SPAs are listed.

Policy attribute	Reference policy	Cooperation and moderate adaptation	Middle road and aggressive adaptation	Fragmentation and moderation adaptation
Mitigation: level of global cooperation	low	high	medium	Low
Mitigation: start of global cooperation	never	early	Mid term	Late
Mitigation: sectorial coverage	Focus on electric and industry sectors. No significant inclusion of land use based mitigation options	Carbon pricing on land. Full coverage of energy supply and end use sectors	Forest protection and bioenergy constraints. Energy supply, transport and industry covered	Limited forest protection, no limitation on bioenergy use. Electricity and industry covered
Adaptation: Capacity building	small	moderate	large	moderate
Adaptation: International insurance	Only via international markets, with limited access for some countries	Insurance available for least developed countries	Global insurance provided	Only via international markets, with limited access for many countries

Scenarios prior to the RCPs, SSPs and SPAs

Most projects until now have used the older approach of the IPCC SRES scenarios; the sequential approach. They based their scenarios on storylines that were defined along two axes in most cases (IPCC SRES, GEO3/4, SCENES, REFRESH, etc) and more axes in other cases (PRELUDE scenarios EEA, 2007).

IPCC SRES scenarios were defined based on two axes; axis 1 global versus local and axis 2 economic versus environmental. Within IPCC SRES, four storylines were defined (A1, A2, B1, and B2).

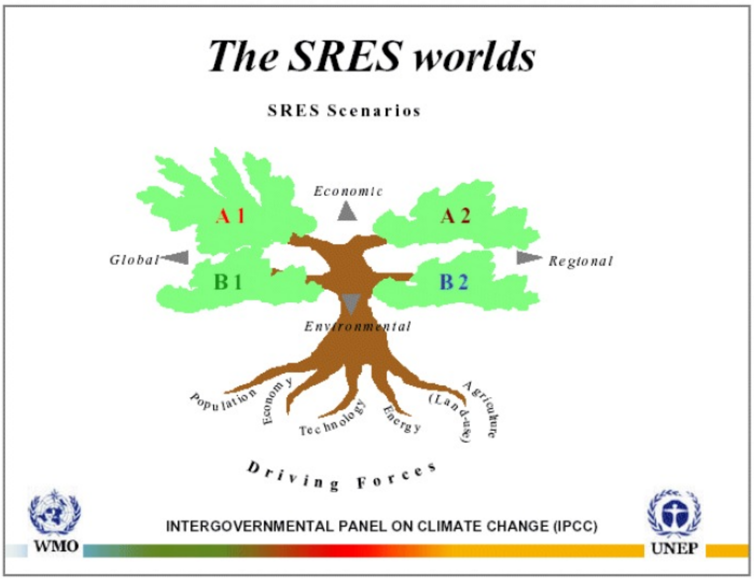


Figure 7 IPCC SRES scenarios

The UNEP's third and four global environmental outlook (GEO3 and 4), are based the same axes and include four storylines termed *markets first*, *policy first*, *security first* and *sustainability first*.

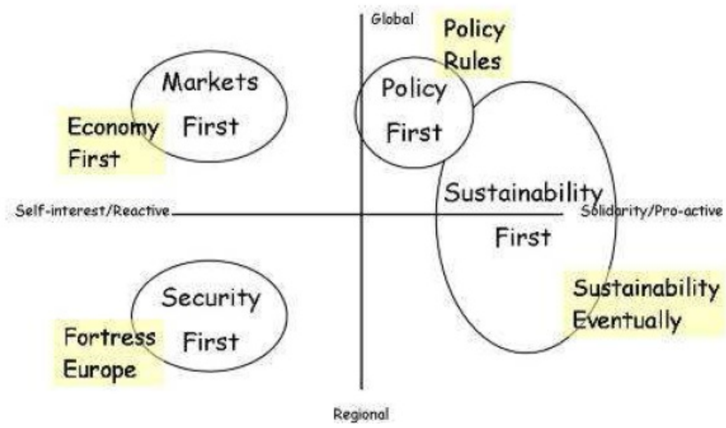


Figure 8 The GEO scenarios

Projects SCENES and REFRESH created own scenarios based on the SRES and GEO scenarios.

The next table summarizes the scenarios used in previous projects.

Classification	IPCC SRES	GEO3/4	SCENES	Millennium Ecosystem Assessment
The Global Market	A1	Markets First	Economy First	Global Orchestration
Continental Barriers Fortress	A2	Security First	Fortress Europe	Order from Strength
Continental Barriers Collapse				
Global Sustainability Policy	B1	Policy first	Policy Rules	(elements of Order from strength)
Global Sustainability Technology		Sustainability First (global)	Sustainability Eventually (global)	Techno Garden
Regional Sustainability	B2	Sustainability First (regional)	Sustainability Eventually (regional)	Adapting Mozaic

Besides, the UN has developed a set of scenarios described within the document "World Water Scenarios to 2050, exploring alternative futures of the world's water and its use to 2050". In this work, Gallopin (2012), present five scenarios build on a multi-axis approach which evaluates the evolution in the futures of drivers such as economy, demography, technology, etc., and the interaction between these drivers. The five scenarios are: Conventional World, Conflict World, Techno-world, Global Consciousness, and Conventional World Gone Sour.

Water Management Scenarios

Water management scenarios are often site specific. Therefore in the literature there is little information available about water management scenarios with global data. Instead, water demand and availability data and projections for the next 30 and 50 years are available (SCENES, 2011).

At basin level, the following water management scenarios are proposed:

- Change in technologies for irrigation. Impact on water use efficiency
- Change in river discharges due to increase of the water use
- Change in pesticides use. Impact on chemicals released to the water bodies
- Adaptation measures such as the ones described in BASE ?
- Building dikes for flood protection
- Building dams for hydroelectric power
- Measures regarding water use for industry and energy

- Conjunctive use of surface and groundwater sources through:
    - Use of groundwater if low flows
    - Artificial recharge of groundwater if high flows or small flooding
- Environmental flows to improve riparian zones and ecosystems
- Increase use of groundwater

3. MARS scenario framework

Introduction to the chapter

This chapter summarizes the approach taken to choose the scenarios and to define the storylines for MARS.

The Framework

MARS scenarios and storylines are used within MARS to calculate the impacts of multiple stressors on aquatic ecosystems. Therefore they must deliver a qualitative framework and where possible, quantitative data that modellers can use to run simulations.

The process followed to define the storylines and quantify them is described in Figure 9 and Figure 10. As a first step and through a participatory internal process we developed the storylines. A workshop was held in Helsinki with representatives of several works packages of MARS in which scenarios are relevant. During the workshop the main features of the storylines were defined and the first draft of the storylines was produced. Those storylines were sent to other MARS team members who were asked to share them with the stakeholders at basin scale. In order to get some idea of the acceptance of the defined storylines by the European stakeholders, we will send out some questionnaires asking for feedback. The objective is to understand the vision of the stakeholders on the utility of these storylines in policy building for aquatic ecosystems at European scale. The results of the questionnaires will be added to this report as an addendum as soon as they are available. Parallel to that process, we explored which projects and modelling tools could be used to extract data from socio-economic and climate variables (See chapter 4). After choosing the most suitable data sets according to MARS storylines and MARS modellers' needs, the data was pursued and provided to MARS team members for its use in the simulations. This data will be used within packages 3 to 7 to run the predictive models.

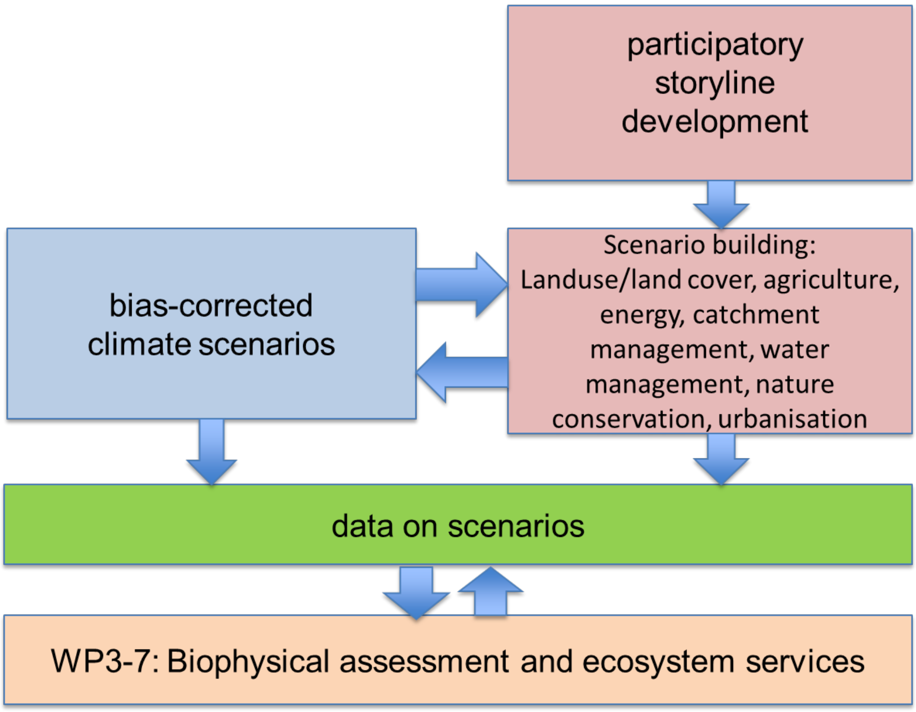


Figure 9 MARS scenario framework

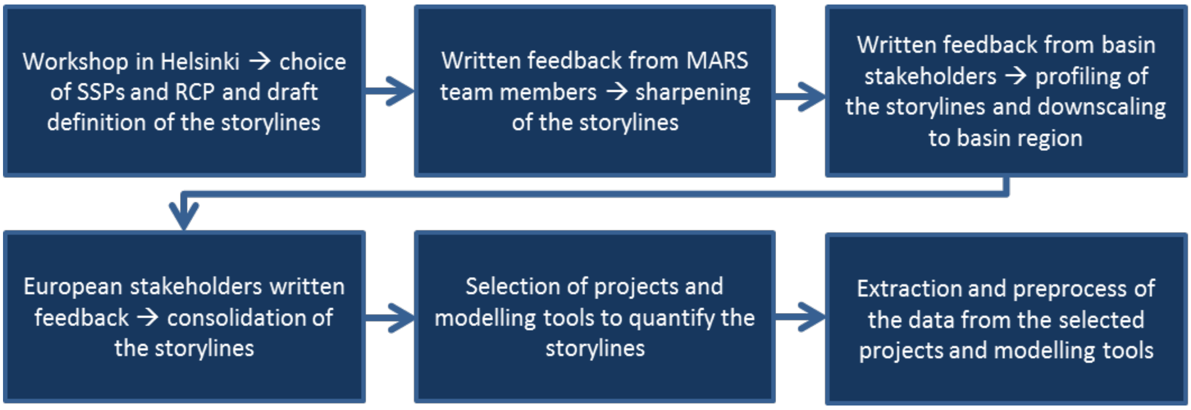


Figure 10 MARS storylines creation process

The choice of the storylines

Storylines in MARS are built on scenarios. The combination of certain climate scenarios and socio-economic scenarios set the basis for the narratives. The criteria used to select the scenarios were the following:

Scenarios must be plausible, but not desirable per se.

- The time horizon for the scenarios is 2030 and 2060. The reason for these horizons the update of the Water Framework Directive on 2027. One of the objectives of MARS is to support managers and policy makers in practical implementation of the WFD, therefore our predictions need to cover the period between now and the next update of the WFD. 2060 is chosen to show the impacts of climate change, as by 2030 climate projections show little change of climate variables in comparison with the now.

- Scenarios should represent future worlds of Europe where the impacts of the relevant stressors are showing significant differences.
- Water management measures, land use changes and the policy framework, are the main drivers to choose a scenario. The reason is the time horizon (2030 and 2060); by then the differences between climate scenarios are minimal and fit within the range of uncertainty.
- In order to identify the effect of socio-economic changes, the use of the same climate scenario might be desirable.
- Mitigation[1] and adaptation[2] challenges need to be in all storylines; however there will be significant differences between the storylines.
- Scenarios do not need to be extremes, but changes should be strong enough to cause effects for stressors studied in MARS.
- Stakeholders must support the choice of the scenarios.

In order to choose the scenarios and define the storylines, we made some assumptions (What is the current situation in EU?):

- Europe already cares to a certain extent about environment and tries to balance economic developments with a sustainable use of environmental resources. Policies are strong to protect the environment and biodiversity, and to promote sustainable and efficient use of resources available.
- Economic development goes along with environmental protection up to a certain level – world-wide: poorest countries- bad environmental quality problems vs. rich countries – high quality standards.
- Mitigation measures in Europe will only influence global climate change to a minor extent – In spite of mitigation measures in Europe we might end up with considerable climate change.
- We live in an economic driven world – farmers and industries operate within regulatory frameworks and focus on maximizing financial benefits.

In an internal workshop with MARS partners, 3 storylines were chosen and defined. The process to choose and define the storylines included intensive discussions on how to make the storylines unique, characteristic, suitable for MARS objectives, and different enough between them. The chosen storylines differ mainly on three main aspects: main driver in the economy

[1] Mitigation: measures to reduce climate change (basically reduction of CO2-emissions)
[2] Adaptation: measures to reduce the impacts of climate change
o Local reactive measures, to prevent direct damages: dikes, reservoirs, …
o Decentralized, extensive, provident measures: unsealing cities, increasing water holding capacity of soils, floodplains, riparian zones, restoration of rivers, water saving irrigation, natural water retention measures, …

(markets, Europe centrally, or Europe state members), economic growth (fast, same pace as now, unequally within Europe), policies regarding the environment (poor in Europe as a unit, strong and continuing current trends, or unequally within Europe), and concern about the environment and protection of ecosystem services (local and people driven, government driven and as much as now, or unequally in Europe).

The option of choosing a storyline in which both the economy and the environment are first priority and in which both are highly stimulated and protected, has been discarded for MARS. The main reason is that this future is not considered plausible. Besides, a society that needs and stimulates ecosystem services (through high technological and economic development), can probably not achieve a good development of the ecosystems at the same time. Figure 11 is a graph showing the relation between ecosystem services level and ecosystem development. It shows that the more use we make of ecosystem services, in the long run, the less they develop and are preserved. By maximizing the provisioning services, we can expect a decrease of regulating services.

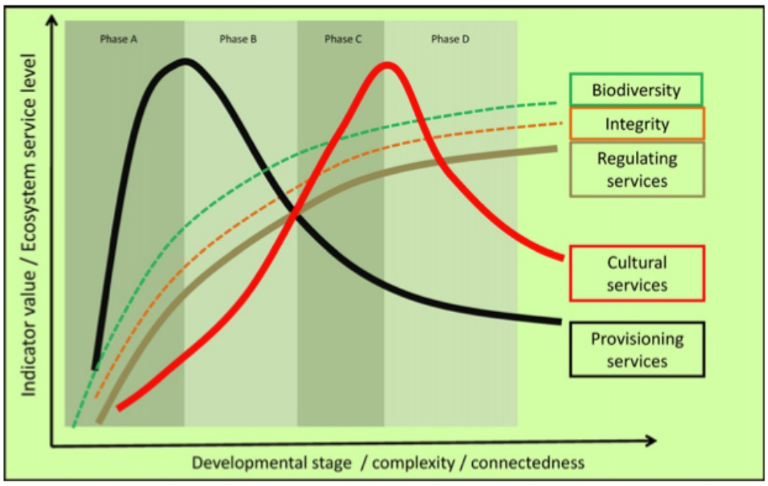


Figure 11 Hypothetical developmental traits of integrity, biodiversity and ESS (Kandziora et al. 2013)

The defined storylines are based on combinations of the SSPs and the RCPs. Annex1 shows the tables containing information on the climate change effects for the different RCPs.

Storyline 1 – Techno world - or Economy rules

Economy: the economy is growing fast. The main objective of the government and the citizens is an economic growth. Governments and EU are stimulating and facilitating companies and industries in developing innovative technologies and solutions to increase the capital. There are plenty of economic resources available; however they are invested mostly to generate more economic resources.

Energy: due to high economic development, energy demands are high; extended use of fossil fuels; oil and gas resources that are currently difficult to exploit are exploited in near future due to technological innovations. As a consequence of the use of more resources, there is an increase of CO2 emissions. In addition, increasing energy demand is fulfilled due to increase in energy production by hydropower and other alternative energy sources such as biofuel crops. The development of renewable energies is not because of environmental regulations, but because of financial stimulation programs to develop innovative technological solutions.

Environment: high awareness on society but poor regulation of environmental protection by the governments. Most actions to protect or improve the environment are taken ad hoc. Individuals and NGO's are active as there are enough resources available. Most actions are the result of individual or commune interest on protecting the environment, but they are not regulated strongly by the government. Some provisioning services are of high priority (e.g. biofuel crops, hydropower). Cultural services are locally important (recreation opportunities close to the cities). Regulating services (requiring basin-wide regulation) are neglected.

Policies: the current environmental policies and guidelines are not renewed after they expire in the next decade and no new environmental policies are set. The governmental focus is on enhancing trade and benefitting the economic growth. Therefore there are almost no policies regarding environmental flows, protection of nature areas, ecological status, etc. With respect to nature conservation, governments focus on assigning projects that aim at increasing the recreation potential of current nature conservation and protection areas.

Water management strategies: most strategies to protect against flooding and droughts or to minimize human health risks are based on technological solutions. Water resources management is focusing on getting the water needed for economic development and production of drinking water. Little effort is done to apply long term sustainable measures; measures are rather focused on the current need and development.

This world is based on a combination of SSP5 and climate scenario 8.5.

Storyline 2 – Consensus world

Economy: the economy and the population are growing at the same pace as now. The main objectives of the government and citizens are to stimulate economic growth on the one hand and to promote sustainable and efficient use of resources on the other hand. The focus is not per se on innovation, but assuring that everything keeps on moving and there is no recession. The available resources are limited and no risky investments are made.

Energy: mix of use of fossil fuels and renewable energies, including bio-energy crops (production level increases significantly). There are regulations to save energy in favour of reducing emissions.

Environment: awareness and interest for preservation, but mostly due to the existing and extended strong regulations. Greening measures being discussed within the EU take shape in this scenario.

Policies: the current guidelines and policies are continued after 2020 (EU strategy on Adaptation to Climate Change, EU Biodiversity Strategy to 2020, EU Habitats and Birds, Directive on industrial emissions, Regulation on European Pollutant, Flood directive, Directive on Environmental Quality Standards and Dangerous Substances, Water Framework Directive, etc), but in a more integrated manner. As a result policy objectives and targets are integrated as well, and therefore realistic to achieve.

Water management strategies: most strategies are set to comply with the regulations. Cheap solutions sustainable at mid-long term are the first choice, but there is a trend towards building with nature solutions (green infrastructure by benefiting from natural processes and structures).

This world is based on a combination of SSP2 and climate scenario 4.5.

Storyline 3 – Fragmented world

Economy: the economy grows in some countries (especially in Northern and Western – Central Europe) and decreases in others (Southern part). There is a high difference between the developments of the different countries because of no international trade agreements. The focus is set to survive as a country instead of as Europe. Each country chooses a different way to achieve that. A consequence is that Europe in general suffers from a lack of resources, and mostly the countries with current debts suffer from real scarcity of resources.

Energy: extended use of fossil fuels, investments in renewable energy to meet increased energy demands, only there where enough financial resources are available and no other alternatives are available.

Environment: no attention is paid to the preservation of the ecosystems. Both government and citizens are too busy with other issues. In rich countries there is awareness and resources, so some measures are implemented, especially local scale solutions. No attention for transboundary issues.

Policies: the current environmental policies and guidelines are broken in 2020-2025. Each country sets its own rules. But national institutions focus on economic development and forget about the environment. Rich countries do support local scale solutions.

Water management strategies: there are no strategies but actions. Actions are set just looking at short term effects and make sure that the current generation will have enough water and food and that the regions/locations with high economic value are protected against floods.

This world is based on a combination of SSP3 and climate scenario 8.5.

Ranking of the criteria to define scenarios

In the following table a set of criteria that will be used to shape the scenarios is shown. These criteria have been chosen based on 1) the input parameters of different models used in MARS (see Annex2), and 2) the discussions during the MARS workshop in Helsinki.

The scores that each criterion gets in each scenario is fruit of the description of the storyline above, the respective SSP, the description of other scenarios such as those of Climsave and SCENES (which partly can be comparable to the MARS scenarios), and the discussions during the MARS workshop in Helsinki.

The scores go from 3+ to 3- and include the 0. This range of scores gives the possibility to distinguish between significant, moderate, slight and no change in comparison with the current situation:

Table 5 Explanation of the scores given to the criteria used to define the storylines

Score	Description
+++	Significant increase compared to the current situation
++	Moderate increase compared to the current situation
+	Slight increase compared to the current situation
0	No change compared to the current situation
-	Slight decrease compared to the current situation
--	Moderate decrease compared to the current situation
---	Significant decrease compared to the current situation

Table 6 Ranking of the criteria used to define the storylines

Criteria	Element	Techno World - MARS ad hoc World	Consensus World - MARS World	Survival of the fittest - No MARS World
Environment, Biodiversity and Ecosystems	Protection of environment	+	+++	---
	Protection of coastal zones	+	+++	---
	Building with nature solutions	+	+++	---
	Preservation of natural habitats	+	+++	---
	Fish passages	0	++	---
	Loss of riparian zones in favour of touristic areas, agriculture, etc	+	0	+++
	Habitat loss	++	+	+++
	Desertification	++	+	+++
	Sediments in water due to erosion	++	+	+++

	Prevention of invasion alien species	-	+	---
	Shift of ecoregions	+	0	++
	Risk of superweeds	+	0	++
Land use change	Growth of non-native plantations	++	+	+++
	Urbanization	+++	++	+++
	deforestation	++	+	+++
	Landscape greening	-	++	---
Agriculture	Sustainable meat production	+	++	---
	Use of pesticides	+++	+	+++
	Use of new pesticides (less env. effects)	+	+++	0
	Nutrient load	++	+	+++
	Efficient use of resources	+++	++	---
	Reuse of manure and byproducts	++	++	---
	Abandonment of land	-	++	+++
	Recovery of eroded/degraded soils	-	++	---
	Control drainage	+	++	---
	Agricultural areas for crops	-	0	--
	Organic farming	0	++	---
	Genetically modified crops	+++	+	+++
	Crop rotation	0	+	0
	Use of crops to prevent erosion	0	++	---
	Efficient irrigation	++	++	---
	Production level	+++	++	+++
	Industrialization	+++	++	+++
	Use of fertilizers	+	++	+++
	Salinization of soils	+	+	+++
	Water pollution	+	+	+++
	Local agriculture	++	+	+++
Water management	Environmental flow needs covered	+	++	---

	Water transfer from water rich to water poor	++	+	0
	Natural flood retention	+	++	---
	Considerable difference in water levels in different seasons	+++	+	+++
	Water level extremes	+++	+	+++
	Increase water reservoirs and weirs	+++	+	+++
	ASR (Aquifer storage and recharge)	+	+++	---
	Use of dikes	+++	++	+++
	Overexploitation of water resources	++	+	+++
	Water use efficiency	+++	+	---
	Waste water reuse	+	++	---
	Green roofs	+	++	---
	more water use in touristic areas	+++	++	+++
Hydropower energy	Less and bigger hydropower plants	+++	-	+++
	Bigger reservoirs	+++	-	+++
	Small and more hydropower plants	-	++	---
	Compromise between hydropower and maintenance of environmental flows	+	+++	---
Water pollution control: eutrophication and water treatment	Water treatment plants	++	++	+
	Restoration of riparian zones	-	++	---

4. Data availability

Introduction to the chapter

The aim of this chapter is to provide an overview of the data available to run predictive models of the three future storylines developed within MARS.

In order to simulate the future scenarios, quantitative values for the input parameters and variables for each scenario needed to be assigned. The required data comprises mainly climate and socio-economic data as these parameters are the ones that vary most with each scenario. Specific data to set up each model that is not dependent on the MARS scenarios (elevation models, river network etc.) is outside the scope of work of this task and will need to be determined by the modellers.

The quantitative values of the inputs for the predictive models provided were derived from existing projects and modelling tools.

The variables and parameters needed as an input for the European scale and river basin level models were identified by the different participants; the focus was set on the main drivers and pressures impacting the modelled area.

It was prioritized to find data for the three European scale models, MONERIS, GREEN and PCR-GLOBWB, for which quantitative ranges of input variables and parameters have been identified. This data can also be used at river basin scale for the 16 catchments of MARS, as the data provided geographically covers all the catchments and in some cases has a high resolution. Table 7 summarizes the input parameters and variables required for each of the European models for which this task provides quantitative data.

Table 7: Input parameters/variables for each European model

Input parameter/variable	MONERIS	GREEN	PCR-GLOBWB
Surface air temperature			x
Precipitation	x	X	x
Evapotranspiration	x		
Runoff	x		
Water abstraction	x		
Water addition	x		
Potential flood plain	x		
Atmospheric deposition (NOx and NH4)	x		
Nutrient point source emissions	x	x	

(N and P)			
Nutrient diffuse source emissions (N and P)		X	
Nitrogen surplus	x		
Phosphorous accumulation	x		
Land use/cover classes	x		x
Population and GDP	x		

The next paragraphs briefly describe the models used in MARS at European Scale.

MONERIS

MOdelling Nutrient Emissions in RIver Systems (MONERIS) was developed by the Leibniz Institute for Freshwater Ecology and Inland Fisheries (IGB) in order to perform watershed and water quality-based studies. The model addresses three objectives: to identify the source of nutrient emissions on a regional basis, to analyse transport and retention of nutrients in river systems and to provide a framework for examining management alternatives.

MONERIS is an empiric model, which allows the quantification of nutrients emissions via various point and diffuse pathways into river basins (see Figure 12). The model has successfully been applied for diverse river basin studies such as the Danube (Schilling et al., 2005), the Elbe (Behrendt et al., 2002) or the Baltic sea (Schernewski et al., 2011).

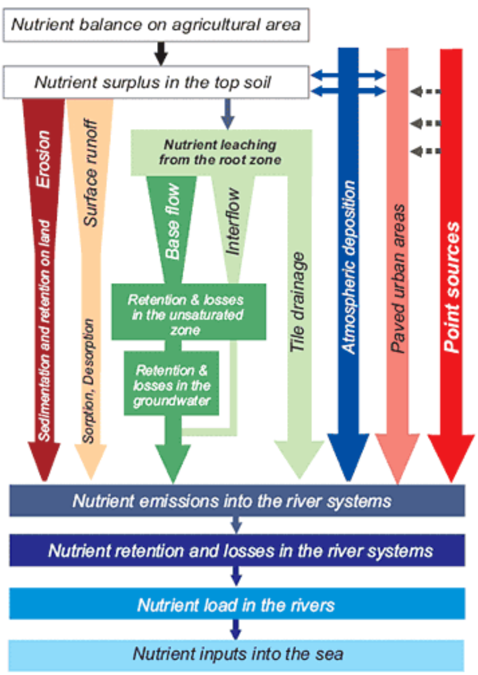


Figure 12: Pathways and processes in MONERIS (Source Behrendt et al., 2007)

GREEN

The model GREEN (Geospatial Regression Equation for European Nutrient losses) is a simplified empiric model which relates the nutrient loads to spatially referenced nutrient sources and river basin characteristics.

It was developed at the European Commission's Joint Research Centre, inspired from the SPARROW model (Smith et al., 1997). The goal was to provide a modelling tool that can be readily applied to medium and large river basins using data routinely collected; in particular, to quantify the nutrient emissions to surface water, quantify the contribution by different sources to the total nutrient export to the rivers and to estimate the retention of nutrients in the river systems.

GREEN has already been used to analyse nutrient pressures at the European scale (Grizzetti & Bouraoui, 2006).

PCR-GLOBWB

PCR-GLOBWB is a large-scale hydrological model intended for global to regional studies and developed at the Department of Physical Geography, Utrecht University (Netherlands).

The model PCR-GLOBWB (Sperna Weiland et al. 2010) is a leaky bucket type hydrological model that provides a grid-based representation of terrestrial hydrology with a spatial resolution of 0.5 by 0.5 degrees and 10 by 10 arc minutes on a daily basis. For each grid cell, PCR-GLOBWB uses process-based equations to compute moisture storage in two vertically stacked soil layers as well as the water exchange between the soil and the atmosphere and the underlying groundwater reservoir. Exchange to the atmosphere comprises precipitation, evapotranspiration and snow accumulation and melt, which are all modified by the presence of the canopy and snow cover (Figure 13).

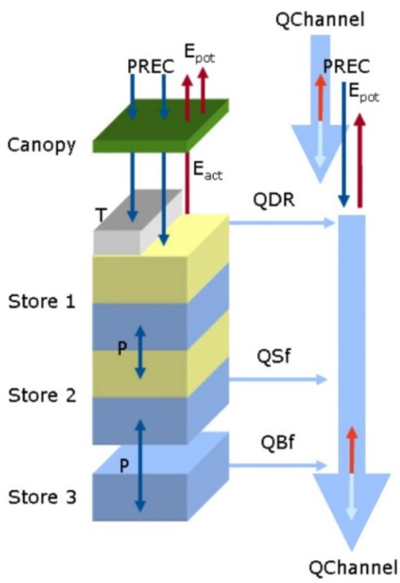


Figure 13: Model concept of PCR-GLOBWB (Source: PCRaster, 2014)

PCR-GLOBWB has successfully been used in recent years for such different purposes as to estimating groundwater recharge (Wada et al., 2010) or specification of wetland hydrological conditions (Petrescu et al., 2010). Some of the projects/modeling tools reviewed for this reports, including ISI-MIP, IMAGE and BASE, make use of PCR-GLOBWB to perform hydrological modeling.

PCR-GLOBWB has a double application in MARS since it will be one of the European scale models employed and it will also provide runoff data as input for the other two European-scale models; although the data won't be accessible until end-2015.

Economic model

An economic model at European scale is also planned to be built within the scope of MARS. However, it will employ a statistical modelling approach and run had-hoc scenarios on water quality and change in ecological status of lakes that are different from the storylines developed for MARS.

Models at river basin scale

The models that are going to be used at the river basin level are very diverse and include, among others, SWAT, PhytoFluss, QUESTOR, PROTECH, Persist, INCA, MyLake, MAGIC, PCLake, DYRESM-CAEDYM, Delft 3D, SOBEK, MOHID etc.

The variables and parameters needed as input for the river basin level models are, in many cases, the same as the ones for the European models. Those parameters that have not been quantified in this task will need to be calculated by the modellers of each river basin, based on the qualitative criteria used to shape each MARS storyline (refer to the MARS Storylines Memo from the scenario workshop held in Helsinki in May 2014) and their expert knowledge .

Literature Review

In order to evaluate existing data on the selected parameters and variables for the predictive models, a review of literature and on-going projects that assess possible futures of Europe was carried out. The following projects/modelling tools were revised:

- ISI-MIP
- CLIMSAVE
- SCENES
- IMAGE
- GLOBAQUA
- REFRESH
- BASE

According to its suitability, data and information on a range of parameters and variables was derived from the above mentioned literature as a starting point for analysis and assessment of the impacts of future multistressor conditions on water quantity, chemical and ecological status of Europe's water bodies at EU and river basin level.

The criteria used to assess the suitability of the data of the different projects and models was:

- similarities of the storylines and scenarios used in the projects/models with the storylines and scenarios defined for MARS
- novelty of the used scenarios and storylines and match with the last IPCC report, SSPs and RCPs
- temporal and spatial resolution
- use of the data in previous successful projects

A summary of the specifications of the projects and modelling tools that were reviewed is given in Table 8, followed by a more detailed description below.

Table 8: Summary of specifications of reviewed projects and modelling tools

Project/ modelling tool ID	Is it a project or a modelling tool?	Emission scenario used	Socio-economic scenario used	Climatic model used	Impact model used
ISI-MIP	Project	RCP's	SSP's	GFDL-ESM2M[3] HadGEM2-ES IPSL-CM5A-LR MIROC-ESM-CHEM NorESM1-M	Various (LPJmL, ORCHIDEE, WaterGAP, PCR-GLOBWB, PEGASUS etc.)
CLIMSAVE	Both	A1 A2 B1 B2	We are the world Icarus Should I Stay or Should I Go Riders on the Storm	HadGEM GFCM21 IPCM4 CSMK3 MPEH5	Various (WaterGAP, CFFlood. SFARMOD, GOTILWA+ etc.)
SCENES	Project	A2	Economy First Fortress Europe Policy Rules Sustainability Eventually	IPSL-CM4 (IPCM4) MICRO3.2 (MIMR)	WaterGAP HABITAT and CGMS
IMAGE	Modelling tool	Any	Any	MAGICC	Various (LPJmL, GLOBIO, PCR-GLOBWB etc.)
GLOBAQUA	Project	Not defined yet	Not defined yet	RCA4	Various (RWQM,

[3] ISI-MIP is the only project reviewed that has run the specified climate models to obtain data; the rest of the projects and modelling tools have employed existing data from the different climate models.

Project/ modelling tool ID	Is it a project or a modelling tool?	Emission scenario used	Socio-economic scenario used	Climatic model used	Impact model used
					InVEST, SWAT, LISFLOOD, LISQUAL etc.)
REFRESH	Project	A1B	World Market National Enterprise Global Sustainability Local Stewardship	ECHAM5-KNMI HadRM3-HadCM3Q0 SMHIRCA-BCM	SWAT, INCA-N, INCA-P and PERSiST
BASE	Project	RCP4.5 RCP8.5	SSP2 SSP5	A set of models from CMIP5 (or CMIP3)	AD-WITCH, Climate-Crop, WAPA, PCR-GLOBWB and PRIMATE.

ISI-MIP

The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) is a community-driven modelling effort bringing together impact models across sectors and scales to create consistent and comprehensive projections of the impacts of different levels of global warming. ISI-MIP uses a common set of input data and a common modelling protocol to provide the basis for a cross-sectoral integration of impact projections. The project is coordinated by the team at PIK (Potsdam Institute for Climate Impact Research) (Warszawski et al., 2013).

The ISI-MIP models are based on the RCP's and SSP's used in the IPCC's Fifth Assessment Report and five of the CMIP5 Global circulation models (GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M). Different impact models (LPJmL , WaterGAP, MPI–HM, Hybrid4, MAgPIE etc.) are being used to produce different simulation data that can be used for cross-sectoral comparison (Davie et al., 2013 and Schewe et al., 2013)

Climate data such as surface air temperature and precipitation for MARS was extracted using the ISI-MIP approach as it provided the best temporal and spatial resolution.

CLIMSAVE

CLIMSAVE or Climate Change Integrated Assessment Methodology for Cross-Sectoral Adaptation and Vulnerability in Europe, is a pan-European project that is developing a user-friendly, interactive web-based tool that will allow stakeholders to assess climate change impacts and vulnerabilities for a range of sectors, including agriculture, forests, biodiversity, coasts, water resources and urban development (Harrison et al., 2012). CLIMSAVE is coordinated by the University of Oxford and funded by EU FP7.

The CLIMSAVE Integrated Assessment Platform (IAP) allows the user to set specific future scenarios by selecting among five CMIP3 climate models (HadGEM, GFCM21, IPCM4, CSMK3 and MPEH5), four SRES emission scenarios (A1, A2, B1 and B2) and four socio-economic scenarios, specifically developed for the project (We are the world, Icarus, Should I Stay or Should I Go and Riders on the Storm). Among the various linked impact models that CLIMSAVE is able to run WaterGAP, CFFlood and SFARMOD-LP are the most relevant to water related issues (see Figure 14).

WaterGAP (Water – Global Assessment and Prognosis) is a global water assessment model developed at the Centre for Environmental Systems Research of the University of Kassel (Alcamo et al., 2003, Döll et al., 2003). WaterGAP consists of two main components: a Global Hydrology Model to simulate the terrestrial water cycle and a Global Water Use Model to estimate water withdrawals and water consumption of different sectors

The CFFlood (Coastal Fluvial Flood) meta-model within CLIMSAVE provides estimates of the socio-economic and environmental impacts of future flooding, such as potential flood plains, that are attributed to climate change and sea-level rise in Europe's coastal and fluvial floodplains.

SFARMOD-LP is a land-use model able to produce outputs on environmental burdens such as nitrate leaching, pesticide use or nitrogen use. SFARMOD-LP (also known as the Silsoe Whole Farm Model) is a mechanistic farm-based optimising linear programming model of long-term strategic agricultural land use that is based on profit maximisation, subject to the constraints of soil, precipitation and sound agronomic practice (Annetts & Audsley, 2002).

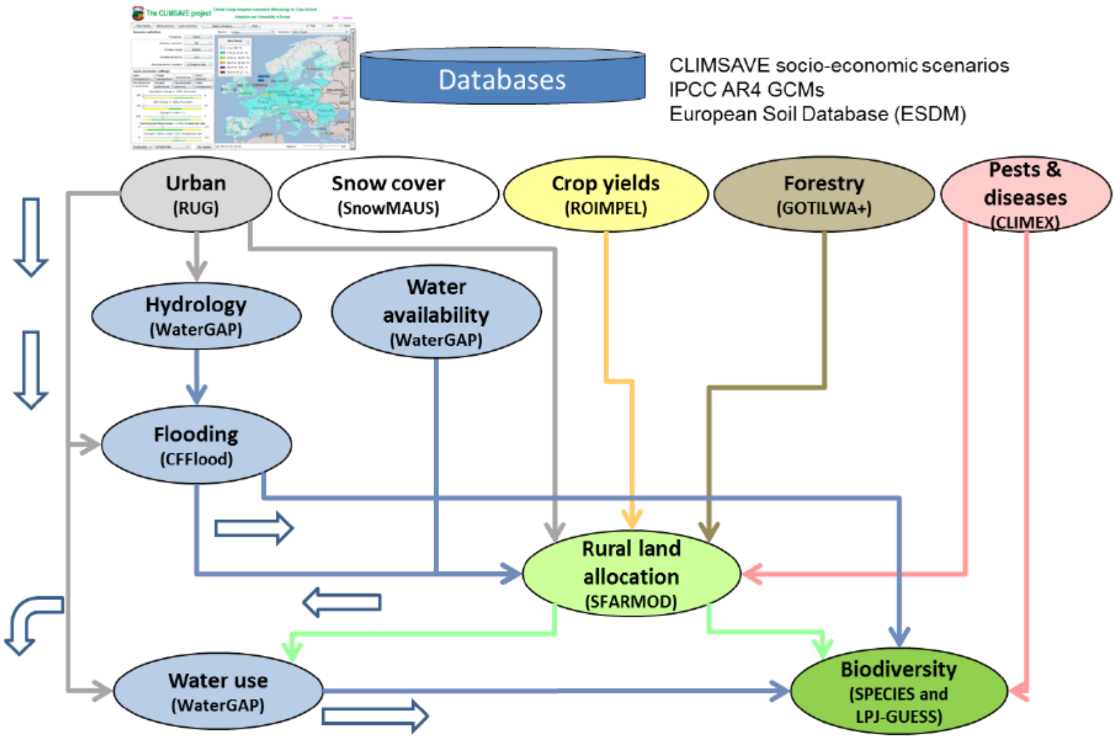


Figure 14: Simplified structure of the linked models within the CLIMSAVE IA Platform (Source: Holman et al., 2013)

CLIMSAVE has already been put into practice for measuring impacts in water resources (Wimmer et al., 2014) or evaluating robustness of climate change adaptation measures (Jäger et al., 1014).

Input data for the European scale models on potential floodplain and nutrient diffuse sources was derived from CLIMSAVE as it was the only project/modelling tool that could readily provide such information.

SCENES

SCENES (Water Scenarios for Europe and for Neighbouring States) was a European FP6 research project developing scenarios on the changes in the quantity and quality of fresh water resources in pan-Europe due to climate change, land use change and socio-economic development (Kämäri et al., 2008). SCENES aimed to provide relevant results directly to the science-policy interface that would allow a better management of water resources.

The project's approach was to combine the IPSL-CM4 and MICRO3.2 climatic models with the SRES A2 emission scenario (worst case emission scenario) and four purpose-built socio-economic scenarios (Economy First, Fortress Europe, Policy Rules and Sustainability Eventually). The project was coordinated by The Finnish Environment Institute (SYKE).

In order to compute the impact of climate change and water use by different sectors on future water resources, the WaterGAP3 version (Verzano, 2009) was applied in SCENES. This is the same model used in CLIMSAVE.

Indicators such as water abstraction, runoff and land use have been extracted from SCENES.

The rationale and assumptions behind the calculations of water abstraction data in SCENES were the most comprehensive and documented ones among all the projects/modelling tools reviewed and therefore, it was decided to derive that information from this project.

Runoff data will be extracted from PCR-GLOBWB as it is the most comprehensive hydrological model but since that data won't be available until the end of 2015, SCENES was also used to derive the information.

Land use data was also extracted from SCENES as it provided the most detailed spatial resolution.

IMAGE

IMAGE is an Integrated Model to Assess the Global Environment developed under the authority of PBL Netherlands Environmental Assessment Agency. The IMAGE model (version 3.0, released in 2014) has three main objectives: to analyse large-scale and long-term interactions between human development and the natural environment to gain a better insight into the processes of global environmental change, to identify response strategies to global environmental change based on assessment of options for mitigation and adaptation and to indicate key interlinkages and associated levels of uncertainty in processes of global environmental change.

IMAGE is an Integrated Assessment Modell (IAM) characterized by relatively detailed biophysical processes and a wide range of environmental indicators but it has less detail on economics and policy instruments than other IAM models.

Figure 15 shows the components of the IMAGE framework. Multiple models representing dynamics and impacts on a wide range of systems/sectors are interlinked within IMAGE.

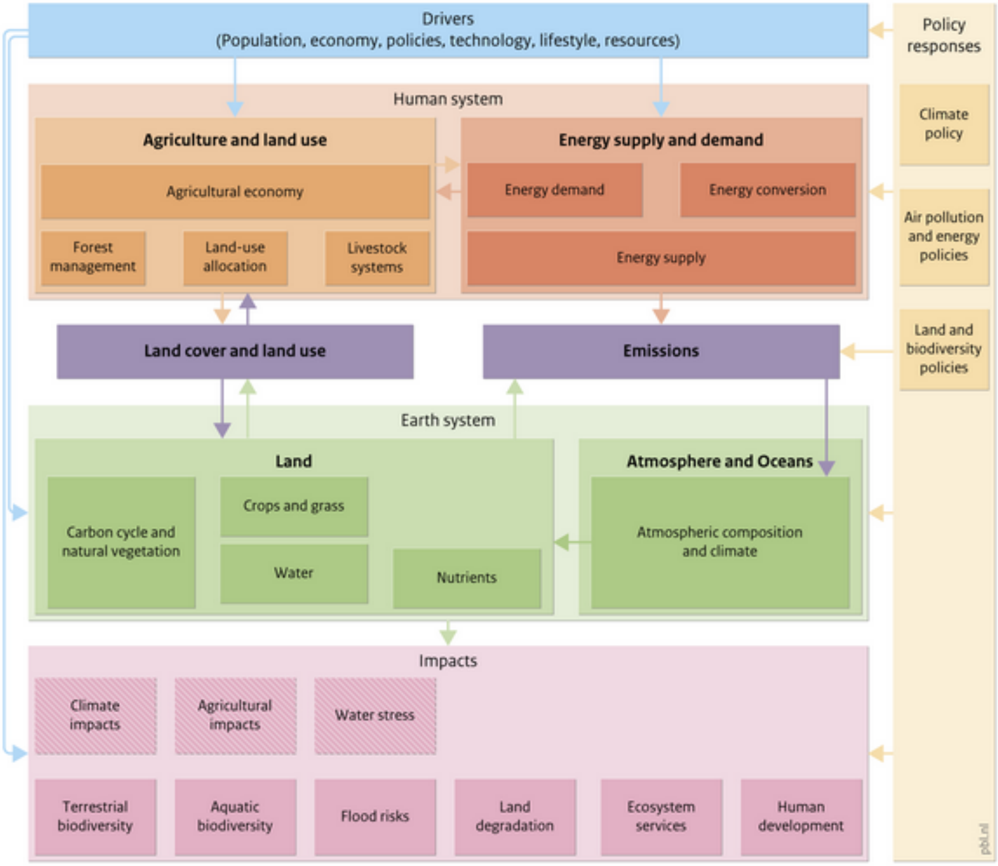


Figure 15: IMAGE 3.0 framework (Source: PBL, 2014)

IMAGE has progressively been developed since the 1980's and it has been used for a vast variety of purposed and studies: The Millennium Ecosystem Assessment project, where IMAGE framework was used to focus on the role of ecosystem services to support human development (Millennium Ecosystem Assessment, 2005), to develop the RCP2.6 for the IPCC's Fifth Assessment Report (Van Vuuren et al., 2011), the Eururalis project which assessed alternatives to the current EU Common Agricultural Policies (Eickhout et al., 2007) etc.

It's worth noting that IMAGE has participated in the ISI-MIP project; it was used to measure the effect of climate change on crop yields (Rosenzweig et al., 2013).

At the moment of the publication of this report, data derived from IMAGE has not been available for this project. However, quantitative values for atmosphere deposition, nutrient point source emission, nitrogen surplus, phosphorous accumulation and land use changes could be extracted with this modelling tool.

GLOBAQUA

The GLOBAQUA project (Managing the effects of multiple stressors on aquatic ecosystems under water scarcity) has assembled a multidisciplinary consortium in order to study the interaction of multiple stressors within the frame of strong pressure on water resources. The aim of GLOBAQUA is to identify the prevalence, interaction and linkages between stressors, and to assess their effects on the chemical and ecological status of freshwater ecosystems affected by water scarcity in order to improve water management practice and policies (Navarro-Ortega et al., 2014).

The main objectives of GLOBAQUA match those of MARS, and as such it was identified as a project of special importance. A framework for collaboration between both projects has been agreed and, if possible, the same scenarios will be used in GLOBAQUA and MARS.

GLOBAQUA is an EU FP7 funded project that started in February 2014. Since it's still on its early stages of development it hasn't yet generated any data that could be used in MARS.

REFRESH

Adaptive Strategies to Mitigate the Impacts of Climate Change on European Freshwater Ecosystems or REFRESH builds on a previous EU FP6 Project; Euro-limpacs. The key objective of this EU FP7 project is to develop a framework that will enable water managers to design cost-effective restoration programmes for freshwater ecosystems. This will account for the expected future impacts of climate change and land-use. REFRESH will evaluate a series of specific adaptive measures that might be taken to minimise adverse consequences of climate change on freshwater quantity, quality and biodiversity.

Six different catchment case studies across Europe were chosen to undertake scenario analysis. In all the catchment modelling activities the output from three Global Circulation Model-Regional Climate Model combinations derived during the ENSEMBLES project were used (ECHAM5-KNMI, HadRM3-HadCM3Q0 and SMHIRCA-BCM), as well as the A1B emission scenario which was also used in ENSEMBLES. Additionally, four different storylines were produced; each one linked to a different quadrant of the IPCC SRES scenarios: World Market (A1), National Enterprise (A2), Global Sustainability (B1) and Local Stewardship. The storylines were further adapted to local conditions based on the expert knowledge of modellers of each catchment.

Different impact models were utilized in each catchment case study depending on the anticipated impact to be analysed (Lepistö et al., 2013).

No input parameters to be used in the European models of MARS were derived from REFRESH as the data utilized in this project was specific for the selected catchment case studies.

BASE

BASE (Bottom-Up Climate Adaptation Strategies Towards a Sustainable Europe) aims to foster sustainable adaptation in Europe by improving the knowledge base on adaptation and making this information easier to access, understand and act upon. It will do so by undertaking an interdisciplinary assessment of costs, benefits, effectiveness, challenges and opportunities of adaptation across diverse sectors.

BASE is an ongoing EU project funded under the FP7 and coordinated by Aarhus University (AU). A natural precursor of BASE is the CLIMATECOST project which analysed the cost of long-term mitigation policies and the costs of inaction in the EU, but only dealt with the costs and benefits of adaptation to a limited extent; BASE thus complements CLIMATECOST.

In order to gather insights from the local level, the BASE project will examine climate change adaptation case studies from across Europe. There will be a common study methodology were all case study models will be run for a set of climate scenarios (CMIP5, if available, otherwise CMIP3) and employ RCP4.5 and RCP 8.5 and SSP2 and SSP5 from the IPPC's Fifth Assessment Report for the emission and socio-economic scenarios. BASE also foresees to develop narratives (storylines) of a plausible future including climate change, socio-economic developments and adaptation pathways with the participation of a stakeholder panel (Bosello et al., 2013).

Within BASE different types of impact models will be used: the AD-WITCH economy model to describe EU-wide economic implications of different climate strategies, diverse sector models (Climate-Crop, WAPA and PCR-GLOBWB) which will provide the direct damages and effects of climate adaptation by sector and finally, the decision support tool PRIMATE (interactive software for Probabilistic Multi-Attribute Evaluation).

The BASE project is currently generating scenario's data such as flooding recurrence times, but due to timing, the data/information could not be adapted for MARS.

In summary, among the literature examined, PCR-GLOBWB and IMAGE are the only strictly modelling tools revised; PCR-GLOBWB focuses on the hydrological cycle, while IMAGE covers a wider range of systems/sectors. CLIMSAVE has also developed a modelling tool that allows assessing climate change impacts associated with different sectors. The ISI-MIP project brings together diverse impact models in order to perform inter-sectorial comparisons. SCENES, GLOBAQUA and REFRESH (as well as MARS) are all projects which aim to support sustainable water resource management under varying water stress and climate change scenarios. BASE also deals with future climate change scenarios but focuses on adaptation strategies across diverse sectors, including the water sector.

Selected climate models and scenarios

The scenarios and climate models employed in the projects/modelling tools that were used to derive data from, namely, ISI-MIP, SCENES and CLIMSAVE, differ from each other and from the ones specifically developed for MARS in some cases. In order to be able to employ data extracted from the different projects/modelling tools, an approximation between their scenarios and the ones from MARS needed to be done. The following table provides a summary of the scenarios and climate models selected as best match to MARS:

Table 9: Summary of selected climate models and scenarios

MARS				ISI-MIP			SCENES			CLIMSAVE		
Storyline	**Climate model**	**Emission scenario**	**Socio-economic scenario**	**Climate model**	**Emission scenario**	**Socio-economic scenario**	**Climate model**	**Emission scenario**	**Socio-economic scenario**	**Climate model**	**Emission scenario**	**Socio-economic scenario**
Storyline 1	GFDL-ESM2M[4] HadGEM2-ES IPSL-CM5A-LR MIROC-ESM-CHEM NorESM1-M	RCP8.5	SSP5	GFDL-ESM2M HadGEM2-ES IPSL-CM5A-LR MIROC-ESM-CHEM NorESM1-M	RCP8.5	NA	MIMR	A2	Economy First	CSMK3	A1	Icarus
Storyline 2	GFDL-ESM2M HadGEM2-ES IPSL-CM5A-LR MIROC-ESM-CHEM NorESM1-M	RCP4.5	SSP2	GFDL-ESM2M HadGEM2-ES IPSL-CM5A-LR MIROC-ESM-CHEM NorESM1-M	RCP4.5	NA	MIMR	A2	Policy Rules	CSMK3	B1	Riders on the Storm
Storyline 3	GFDL-ESM2M HadGEM2-ES IPSL-CM5A-LR MIROC-ESM-CHEM NorESM1-M	RCP8.5	SSP3	GFDL-ESM2M HadGEM2-ES IPSL-CM5A-LR MIROC-ESM-CHEM NorESM1-M	RCP8.5	NA	MIMR	A2	Fortress Europe	CSMK3	A1	Should I Stay or Should I Go

[4] It has yet to be decided data from which climate model(s) will be employed in the MARS predictive models.

In relation to the climate data, ISI-MIP is the only project evaluated within MARS that has run climate models to obtain data; SCENES and CLIMSAVE employed existing data from diverse climate models. Since all three project/modelling tools applied different climate models, it was not possible to use data from the same climate model to extract the required parameters.

All available climate models were used in ISI-MIP to derive data from. Regarding the use of this data within MARS, it has not been decided yet if an ensemble with all the data will be employed in all the models or each participant will be free to choose the data from the model they consider more appropriate. From the models used in SCENES, MIMR was chosen as it produced precipitation projections across Europe that best corresponded to the RCP4.5 and RCP8.5 used in MARS. As for CLIMSAVE, from all the available climate models, the Global Circulation Model (GCM) that was closest to the multi-GMC mean was selected; this is CSMK3.

The emission scenarios were again different in each project/modelling tool. In ISI-MIP it was possible to select the same emission scenarios as in MARS. But both SCENES and CLIMSAVE utilised emission scenarios from the IPCC's Special Report on Emission Scenarios (SRES) instead of the RCP's of the Fifth Assessment Report, as they were developed beforehand. However, they are believed to still be valid. According to Rogelj et al., 2012, although RCP's were not developed to mimic specific SRES scenarios, pairs with similar temperature projections over the twenty-first century can be found between the two sets. RCP8.5 would yield temperature projections close to those of SRES A1(F1) scenario, RCP6 temperature projections are similar to those of SRES B2 and, likewise, RCP4.5 temperature projections of those of SRES B1.

As for the socio-economic scenarios, they were not considered in ISI-MIP as only climate data was derived from this project and both SCENES and CLIMSAVE employed specifically develop scenarios. Some of the socio-economic scenarios have similar characteristics to the storylines developed for MARS and consequently it was possible to match them as indicated in Table 9.

The time horizons considered in SCENES and CLIMSAVE for the future scenarios were 2025 and 2050 and 2020 and 2050 respectively, which vary slightly from the ones chosen in the storylines developed for MARS (2025-2030 and 2050-2060).

Input parameters

Surface air temperature

Surface air temperature values have been obtained from ISI-MIP as provided the best spatial and temporal resolution.

The following table summarizes the data provided:

Table 10: Temperature data specifications

Units	Spatial Resolution	Time Step	Format
K	0.5 by 0.5 degree	Daily (2006 to 2099)	Grid

The surface air temperature data was extracted with the GFDL-ESM2M climatic model for RCP4.5 and RCP8.5 as the three storylines developed in MARS are based on those emission scenarios.

Climate data from the rest of the models available in ISI-MIP (HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M) will be distributed shortly.

For all data provided by ISI-MIP, the geographic coverage is the following:

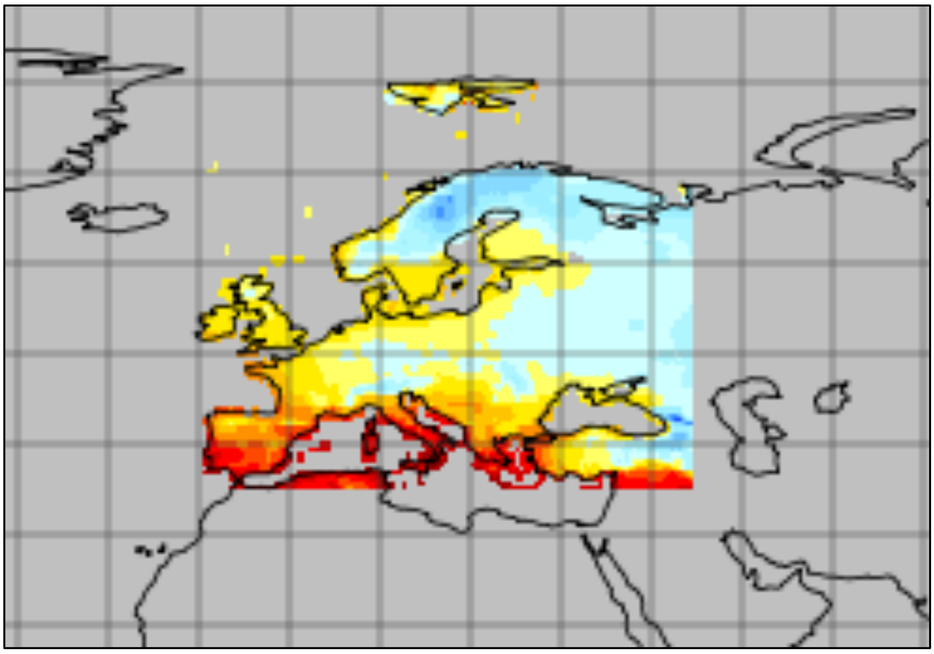


Figure 16: ISI-MIP data geographical coverage

Precipitation

Precipitation data, just as the surface air temperature data, was derived from ISI-MIP as it provided the best spatial and temporal resolution.

The following table summarizes the data provided:

Table 11: Precipitation data specifications

Units	Spatial Resolution	Time Step	Format
Kg/m2/s	0.5 by 0.5 degree	Daily (2006 to 2099)	Grid

Rainfall and snow precipitation data for RCP4.5 and RCP8.5 was derived with the GFDL-ESM2M climatic model.

Climate data from the rest of the models available in ISI-MIP (HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M) will be distributed shortly.

Additional atmospheric data

Together with temperature and precipitation, values for the following variables were also extracted from ISI-MIP and are available for the European scale and river basin level models:

- Surface radiation
- Near-surface wind speed
- Surface air pressure

The data can be employed to estimate evapotranspiration values.

The following table summarizes the data provided:

Table 12: Other climate data specifications

Variable	Units	Spatial Resolution	Time Step	Format
Surface radiation	W/m2	0.5 by 0.5 degree	Daily (2006 to 2099)	Grid
Near-surface wind speed	m/s	0.5 by 0.5 degree	Daily (2006 to 2099)	Grid
Surface air pressure	Pa	0.5 by 0.5 degree	Daily (2006 to 2099)	Grid

All values were extracted with the climate model GFDL-ESM2M for RCP4.5 and RCP8.5 emission scenarios.

Climate data from the rest of the models available in ISI-MIP (HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M) will be distributed shortly.

Water abstraction

Quantitative values for this indicator have been extracted from SCENES.

The following table summarizes the data provided:

Table 13: Water abstraction data specifications

Variable	Units	Spatial Resolution	Time Step	Format
Total abstraction	Million m3/ and million m3/km2	5 by 5 arc minutes	2025 and 2050	Vector
Abstraction for domestic use	Million m3	5 by 5 arc minutes	2025 and 2050	Vector
Abstraction for electricity	Million m3	5 by 5 arc minutes	2025 and 2050	Vector
Abstraction for irrigation	Million m3	5 by 5 arc minutes	2025 and 2050	Vector
Abstraction for livestock	Million m3	5 by 5 arc minutes	2025 and 2050	Vector
Abstraction for manufacturing	Million m3	5 by 5 arc minutes	2025 and 2050	Vector
Abstraction for agriculture	Million m3	5 by 5 arc minutes	2025 and 2050	Vector
Abstraction for industry	Million m3	5 by 5 arc minutes	2025 and 2050	Vector

All the parameters were calculated with WaterGAP3 which computes both water availability and water uses by sectors on a 5 by 5 arc minutes grid (longitude and latitude; 6 x 9 km in Europe), covering the whole Europe. In SCENES, water abstraction only accounts for water withdrawn from the rivers (both for consumptive use and the return flows), thus groundwater abstraction is not represented in the model.

Figure 17 to Figure 19 show the projected surface water abstraction at catchment level for the proposed MARS scenarios.

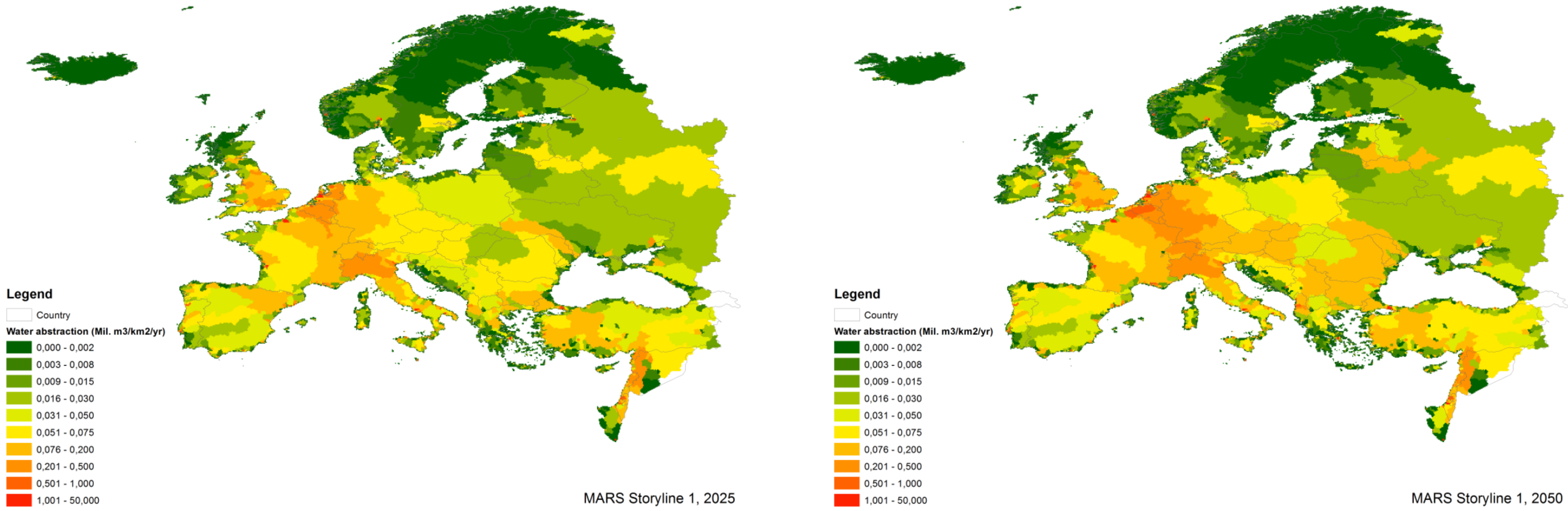


Figure 17: Water abstraction across Europe for MARS Storyline 1

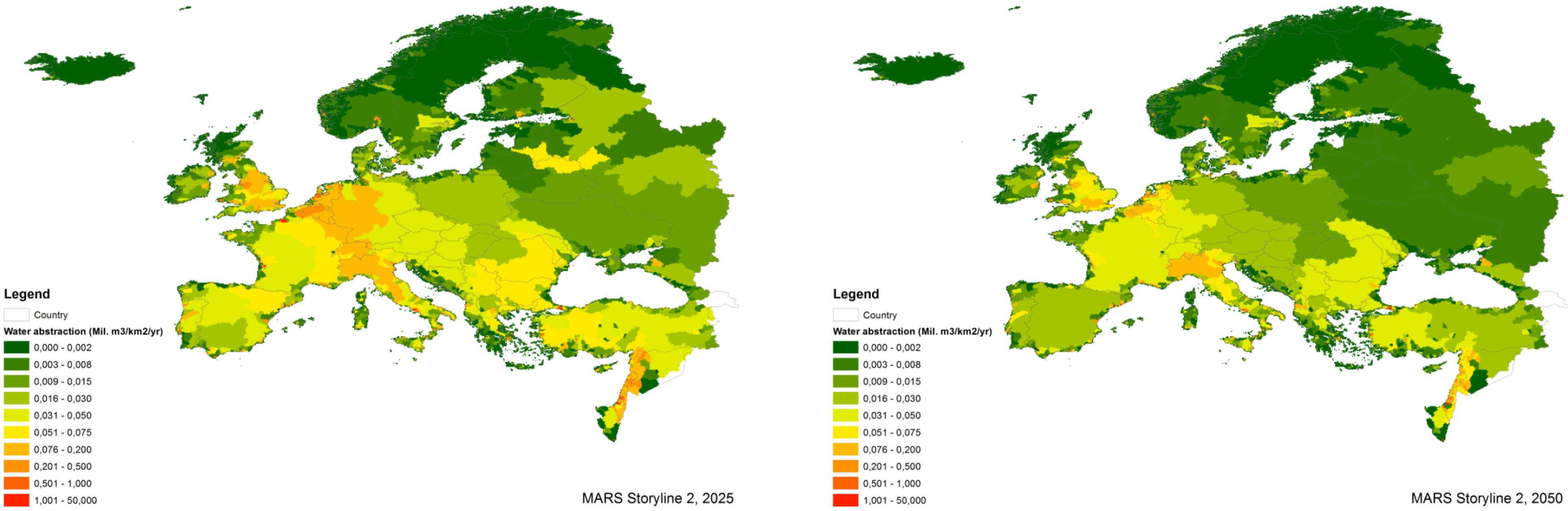


Figure 18: Water abstraction across Europe for MARS Storyline 2

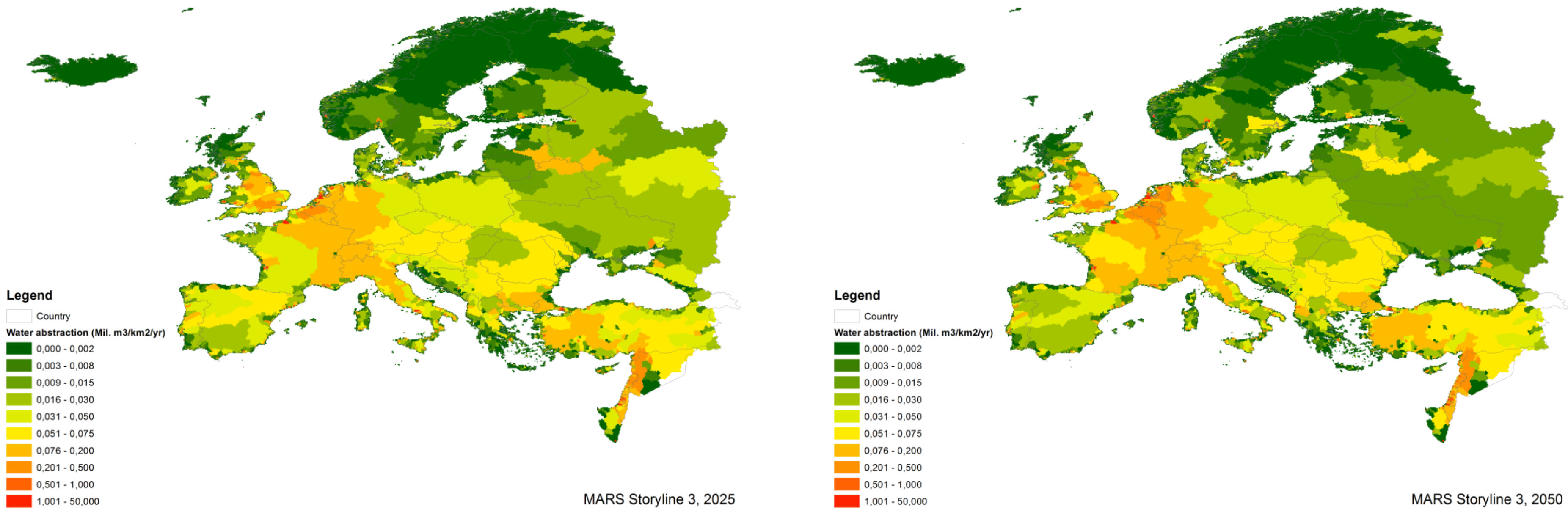


Figure 19: Water abstraction across Europe for MARS Storyline 3

Storylines 1 and 3 show greater impacts on water abstraction in the 2050's time horizon, while in Storyline 2 there is a slight decrease on water withdrawal with time. The highest water abstraction rates are presented in the 2050's of Storyline 1 which is consistent in a scenario based on a fast growing economy.

Regional differences are noticeable in all scenarios. The Scandinavian Peninsula is the area where impacts are less clear.

Water addition

No quantitative values were found for water addition and as such, the indicator will need to be determined by the modellers of each river basin, based on the qualitative criteria used to shape each MARS scenario (refer to the MARS Storylines Memo from the scenario workshop held in Helsinki in May 2014) and their expert knowledge .

Runoff

The most accurate runoff data can be obtained from PCR-GLOBWB. This data will be available after publication of this report and therefore it is not included here.

CLIMSAVE also calculates runoff; since both SCENES and CLIMSAVE employ the same model for the calculation (WaterGAP) but SCENES provides a better spatial resolution (5 by 5 arc minutes grid versus 10 by 10 arc minutes grid) it was decided to derive the runoff data from SCENES.

The following table summarizes the data provided:

Table 14: Runoff data specifications

Units	Spatial Resolution	Time Step	Format
Million m3/ and million m3/km2	5 by 5 arc minutes	2025 and 2050 (monthly and total annual)	Vector

The total runoff is defined in SCENES as the sum of surface runoff and groundwater recharge.

Runoff data at catchment level for the proposed MARS scenarios for 2025 and 2050 is shown in Figure 20 to Figure 22.

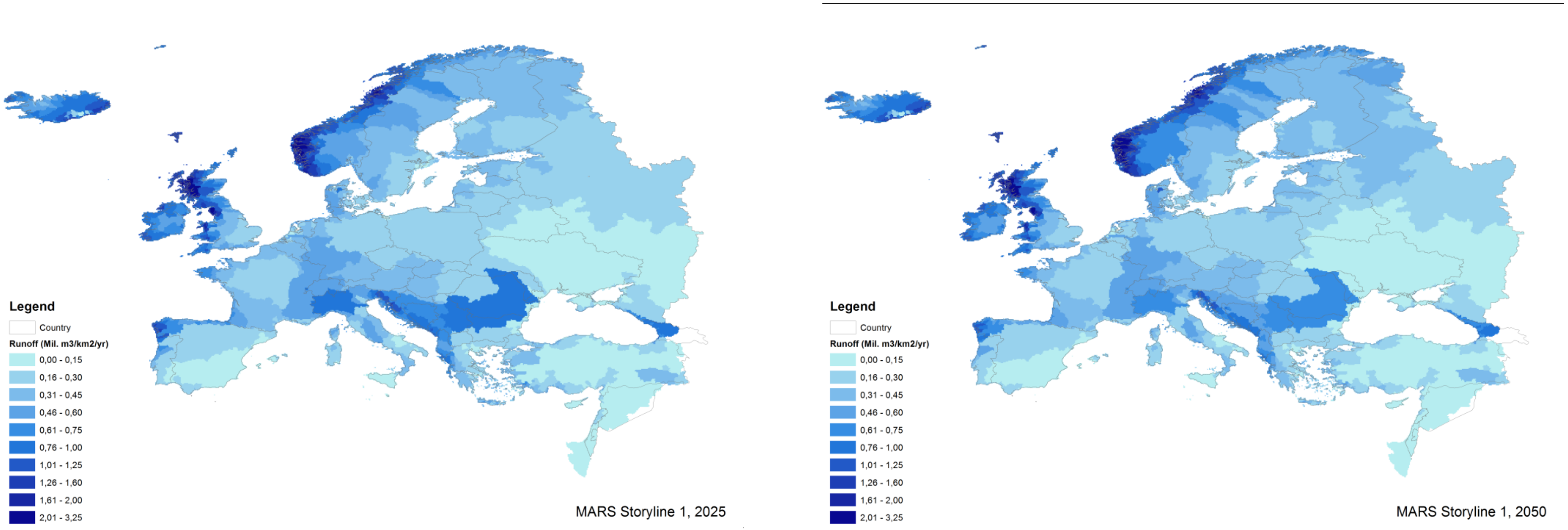
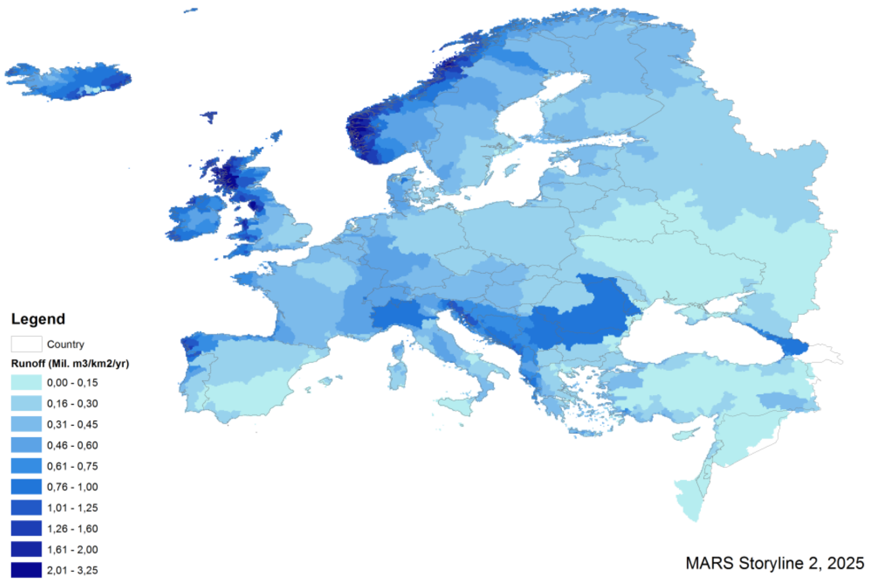


Figure 20: Runoff across Europe for MARS Storyline 1



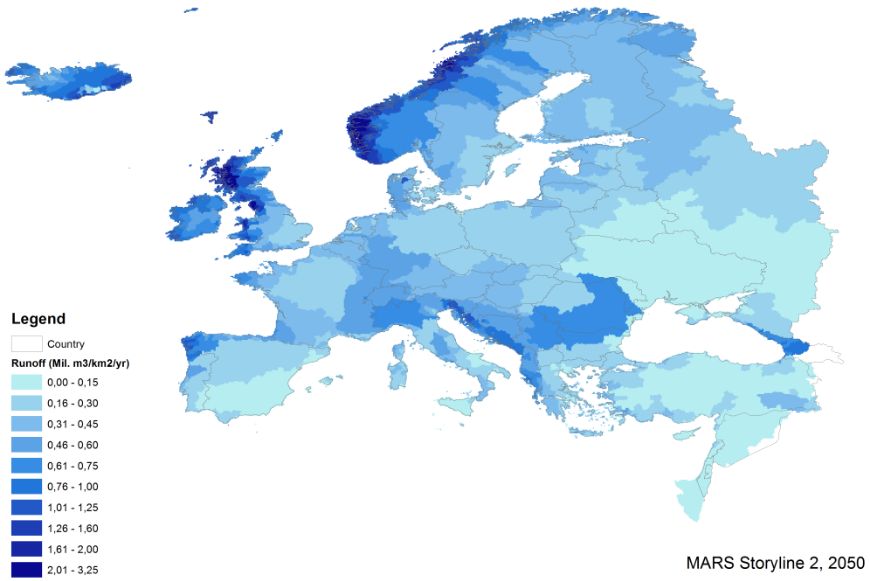


Figure 21: Runoff across Europe for MARS Storyline 2

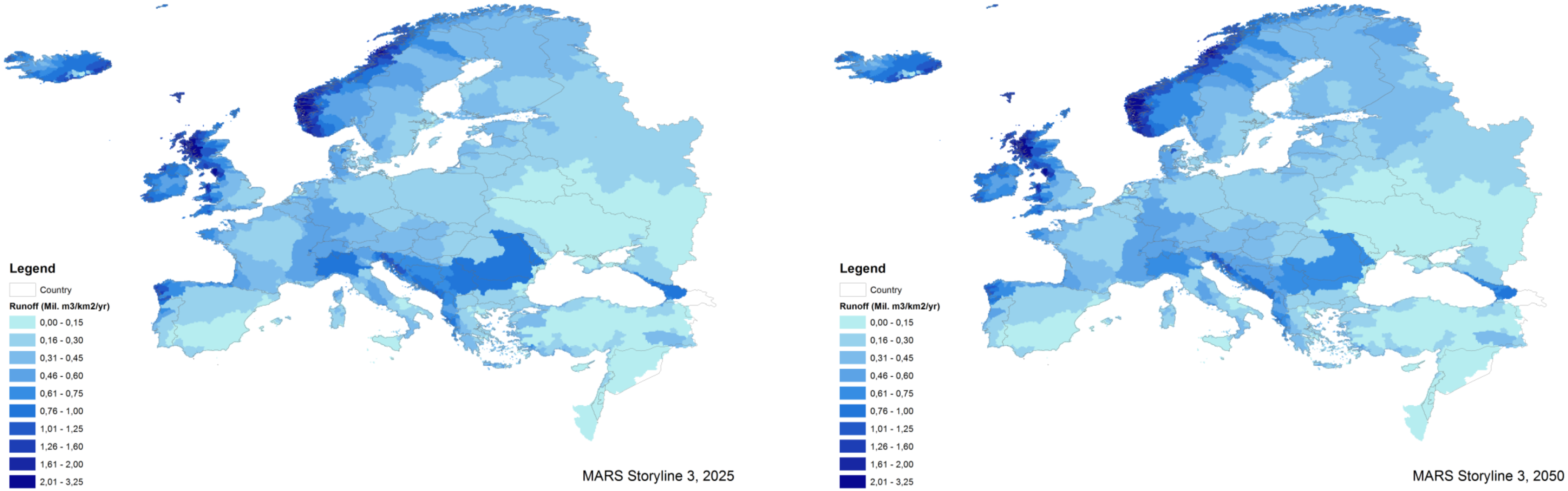


Figure 22: Runoff across Europe for MARS Storyline 3

In relation to water runoff, all scenarios are very similar.

The differences between storylines in the 2025's time horizon is almost negligible, although a slight decrease in total runoff across southern Europe and a slight increase in northern Europe can be detected with time (2050) in all three storylines.

Potential flood plain

Quantitative values for this indicator have been extracted from CLIMSAVE as it was the only modelling tool that quantified the parameter as such.

The following table summarizes the data provided:

Table 15: Potential flood plain data specifications

Units	Spatial Resolution	Time Step	Format
Ha	10 by 10 arc minutes	2020 and 2050	Vector

The parameter was calculated with the CFFlood (Coastal Fluvial Flood) model. The CFFlood model consists of three main components: coastal flood, fluvial flood and habitat changes/loss. Potential flood plain data is derived from the fluvial flood sub-model, which uses the European fluvial flood maps produced by the JRC Institute using LISFLOOD simulations at 100 m resolution (Feyen et al., 2011). These simulations provide flood maps for fluvial catchments assuming no flood defences. These maps, gridded at the 10 arc minutes (longitude and latitude; 12 x 18 km in Europe) spatial resolution, have been used as indicative maps of the flood risk zones in the CLIMSAVE project.

Figure 23 to Figure 25 show the potential flood plain or areas at risk of flooding for the projected MARS scenarios in 2020 and 2050.

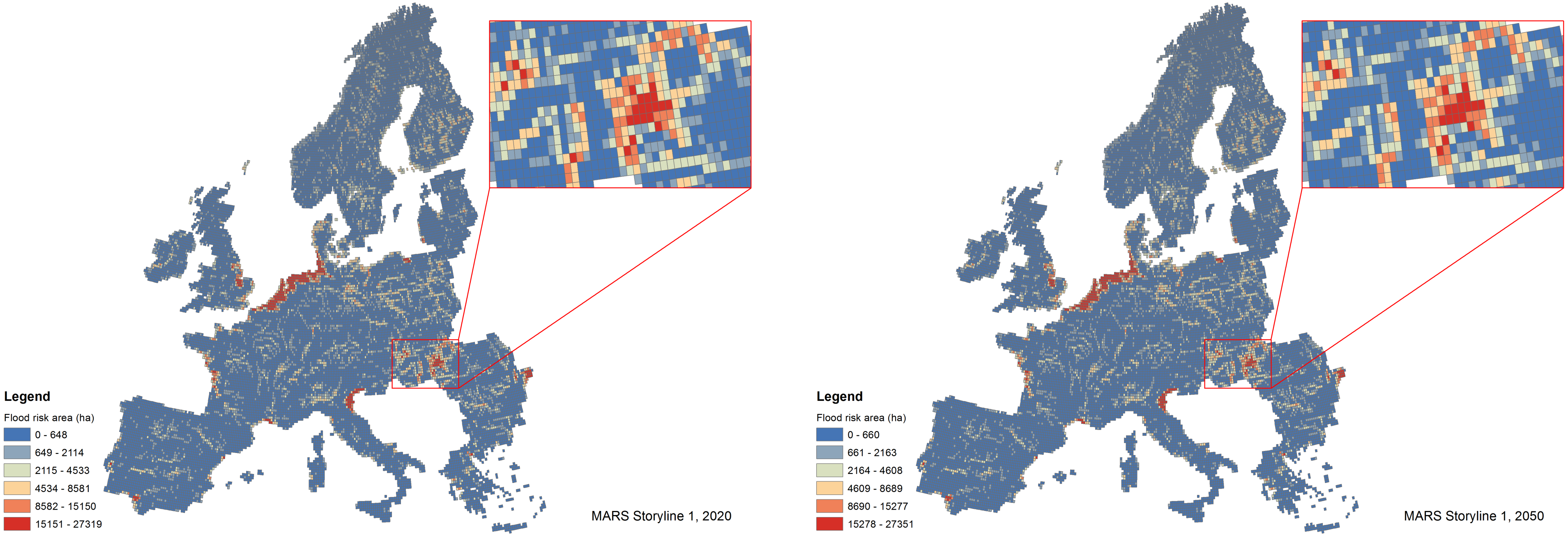


Figure 23: Flood risk areas across Europe for MARS Storyline 1

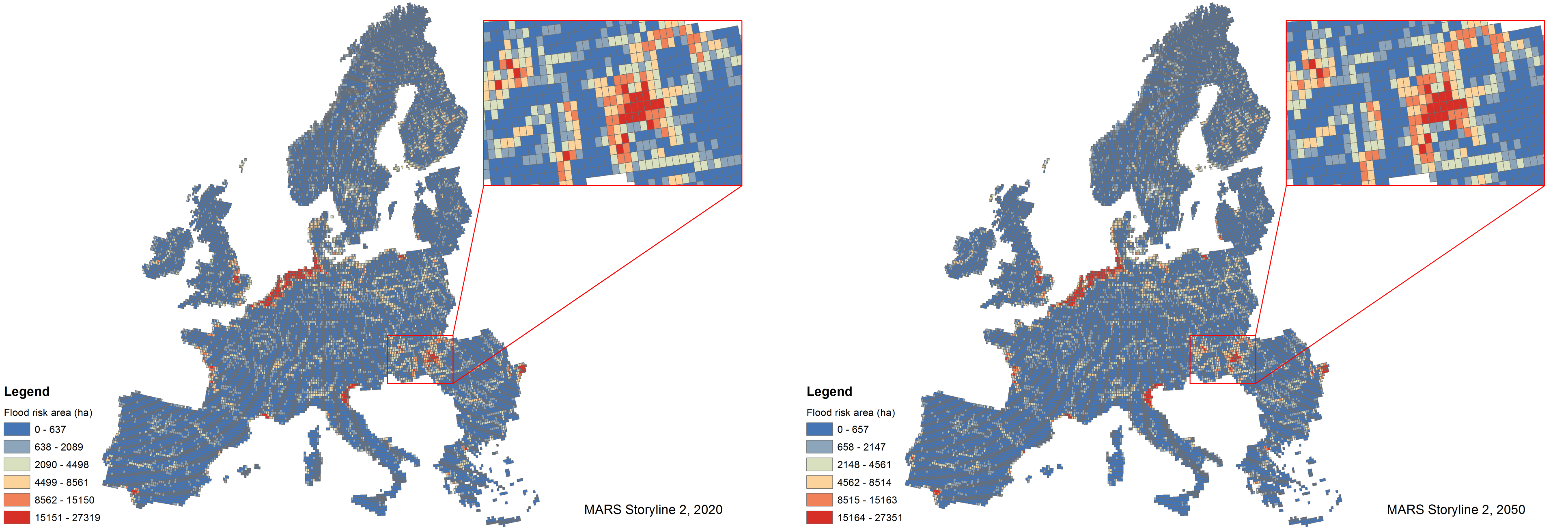


Figure 24: Flood risk areas across Europe for MARS Storyline 2

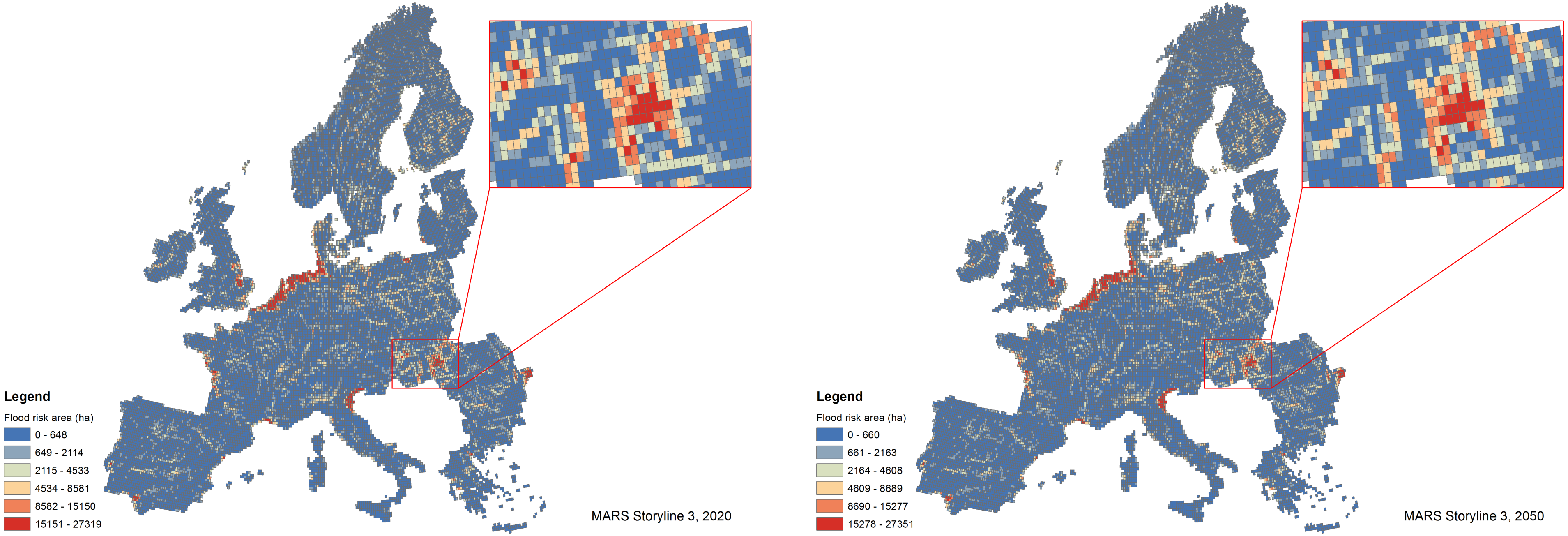


Figure 25: Flood risk areas across Europe for MARS Storyline 3

Areas at risk of flooding across Europe show very limited and localized changes. A detail around Hungary is shown in the figures in order to belter illustrate the minor variations.

Atmospheric deposition

Atmospheric deposition data can be extracted from IMAGE but access to this data has not been confirmed at the moment of the publication of this report.

Nutrient diffuse source emissions

Quantitative values for this indicator have been extracted from CLIMSAVE as it was the only project/modelling tool that quantified the parameter as such.

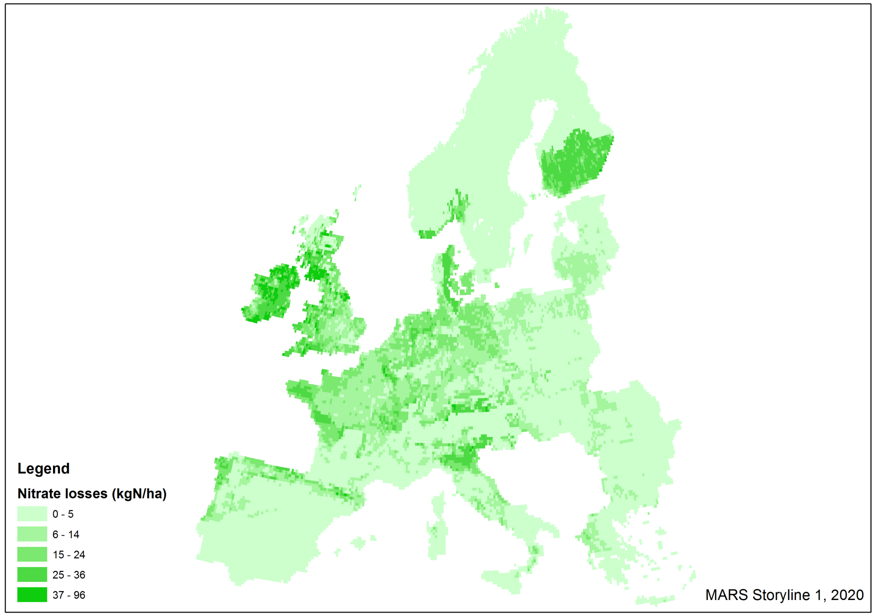
The following table summarizes the data provided:

Table 16: Nutrient diffuse source emissions data specifications

Units	Spatial Resolution	Time Step	Format
kg N /ha	10 by 10 arc minutes	2020 and 2050	Vector

The SFARMOD-LP model within CLIMSAVE calculates nitrate losses from agricultural activities in a 10 by 10 arc minutes (longitude and latitude; 12 x 18 km in Europe) spatial resolution.

Figure 26 to Figure 28 show nitrate losses for the projected MARS scenarios in 2020 and 2050.



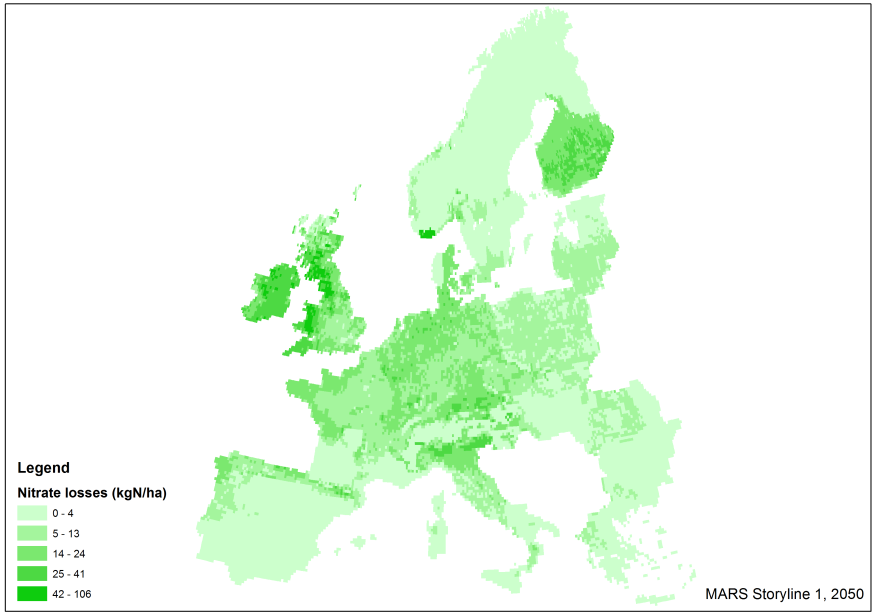


Figure 26: Nitrate losses across Europe for MARS Storyline 1

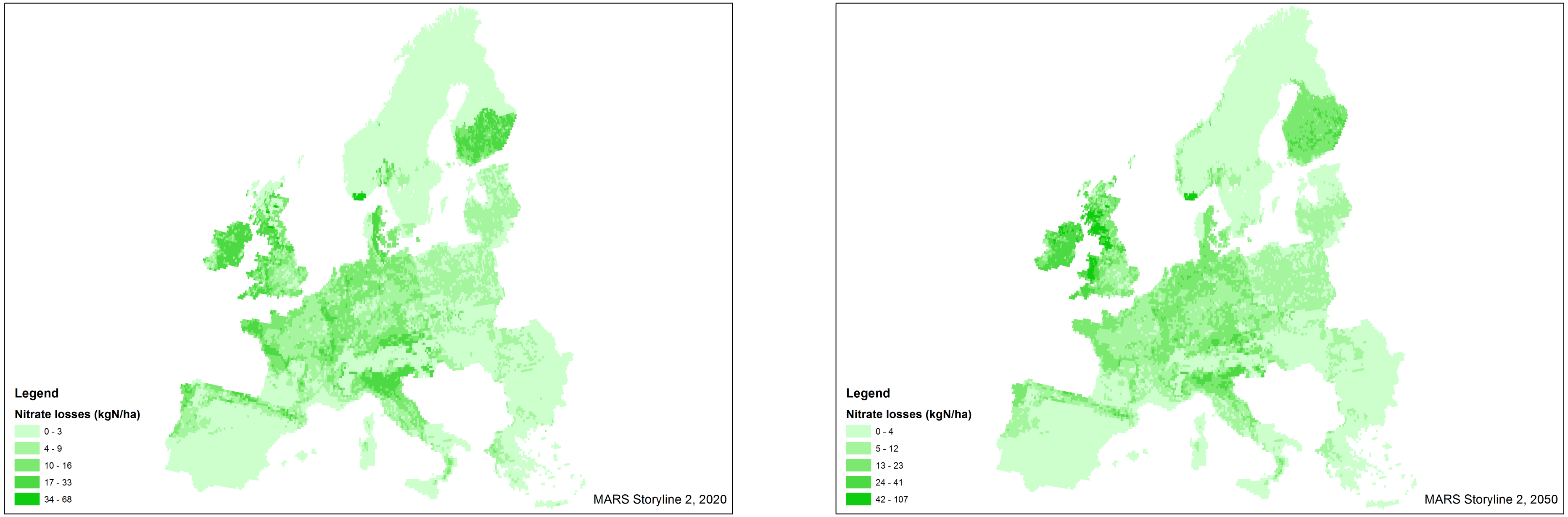


Figure 27: Nitrate losses across Europe for MARS Storyline 2

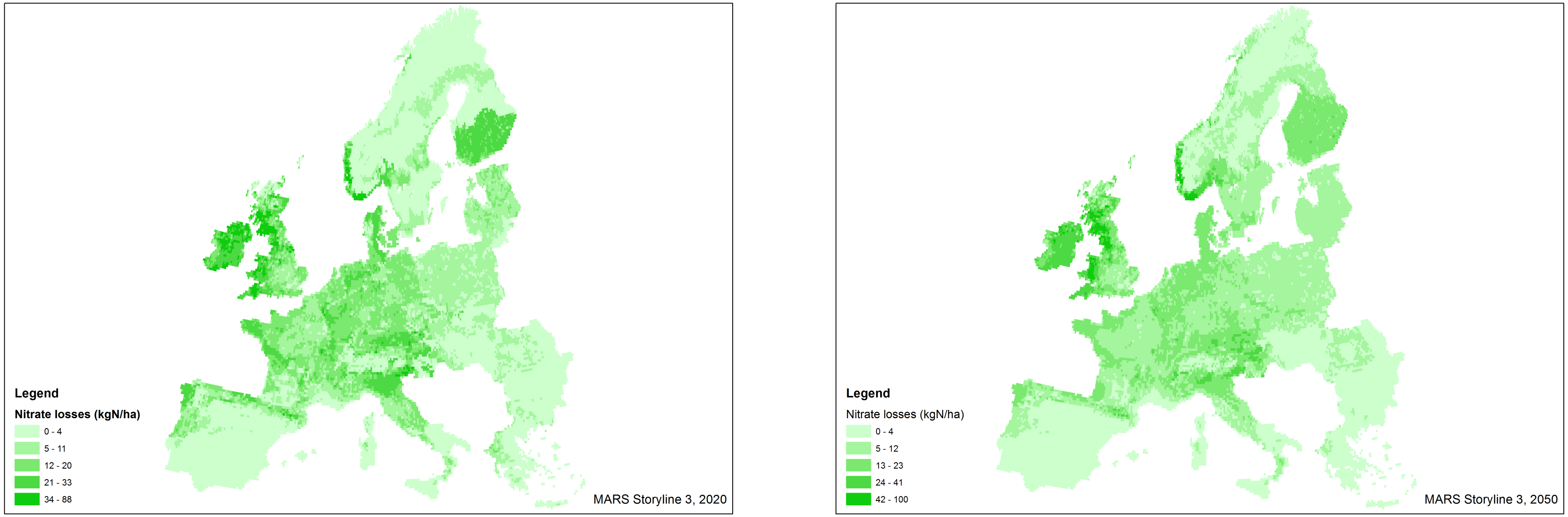


Figure 28: Nitrate losses across Europe for MARS Storyline 3

In general, in all three scenarios nitrate losses across Europe appear to extend further with time and the total amount slightly increase.

The biggest variations are detected in the central area of Europe where agriculture is one of the main economic sectors.

Nutrient point source emissions

Quantitative values for this parameter can be obtained from IMAGE but access to this data has not been confirmed at the moment of the publication of this report.

Nitrogen surplus

Nitrogen surplus data can be extracted from IMAGE but access to this data has not been confirmed at the moment of the publication of this report.

Phosphorous accumulation

Quantitative values for phosphorous accumulation can be obtained from IMAGE but access to this data has not been confirmed at the moment of the publication of this report.

Land use change

Changes on land use were derived from SCENES as it provided the most detailed spatial resolution from all the modelling tools/projects reviewed.

IMAGE could provide improved land cover and land use information but access to this data has not been confirmed at the moment of the publication of this report.

The following table summarizes the data provided:

Table 17:Land use data specification

Units	Spatial Resolution	Time Step	Format
Ha	5 by 5 arc minutes	2025 and 2050	Vector

Figure 29 to Figure 31 show land use across Europe for all three MARS storylines.

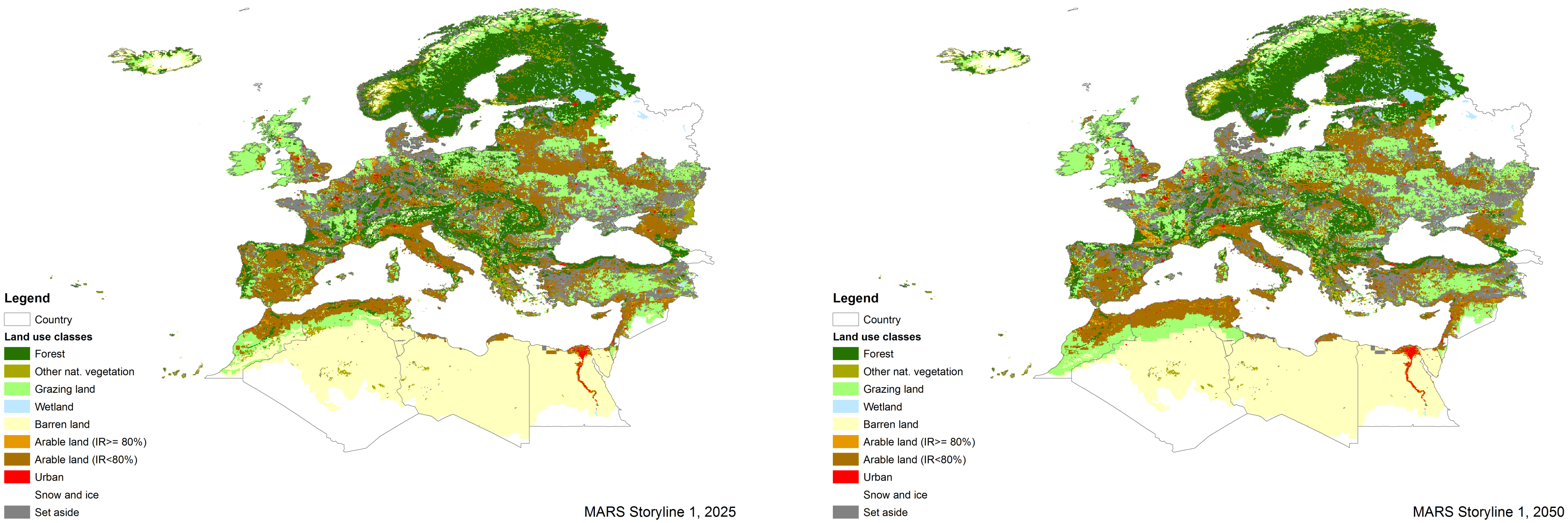


Figure 29: Land use across Europe for MARS Storyline 1

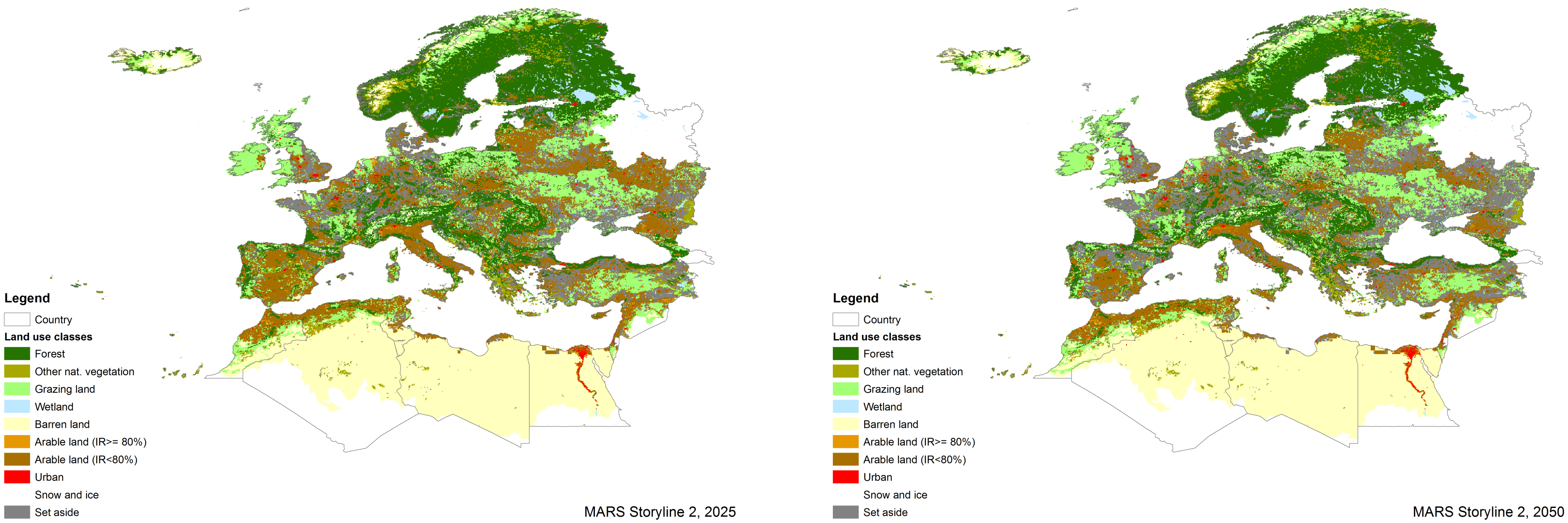


Figure 30: Land use across Europe for MARS Storyline 2

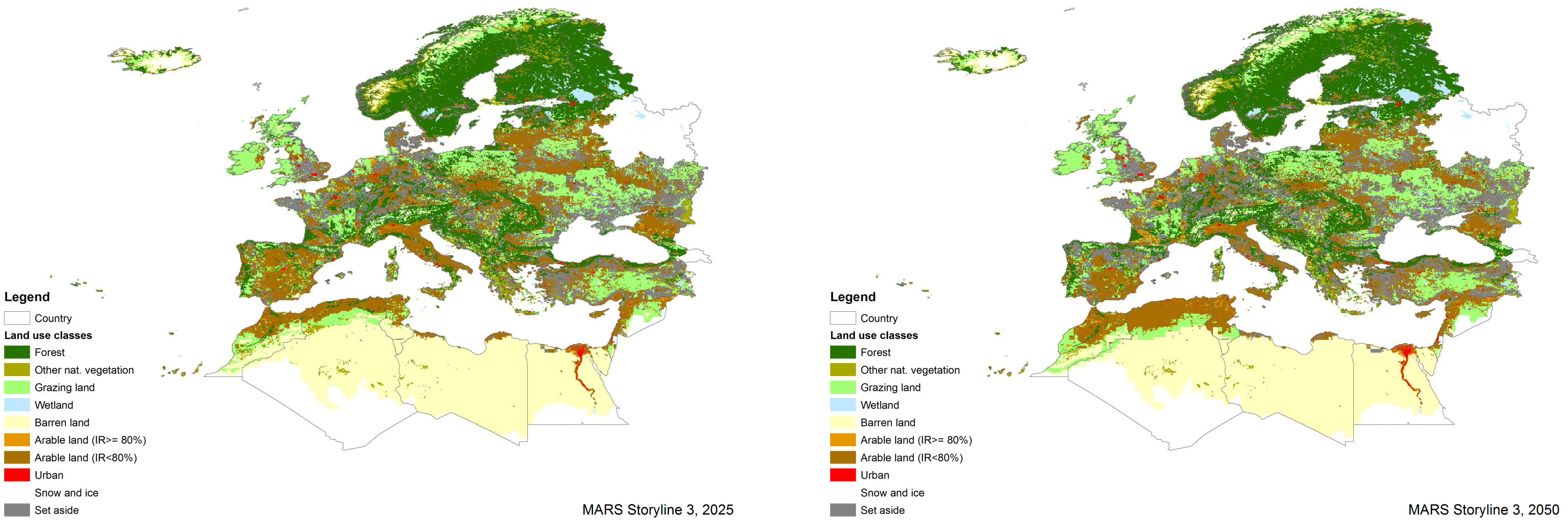


Figure 31: Land use across Europe for MARS Storyline 3

Land use changes across Europe seem to be quite localized. In general, more set aside land is observed in the 2050's time horizon in all three scenarios.

All three storylines show a decrease of non-irrigated arable land with time (2050); Storylines 1 and 3 indicate a shift to irrigated arable and grazing land, while in Storyline 2 the area of grazing land augments but the irrigate-arable land does not.

There are no noticeable changes in the Scandinavian Peninsula.

Population and GDP

Population and GDP data have been extracted from the IIASA (International Institute for Applied Systems and Analysis) SSP database.

The following table summarizes the data provided:

Table 18:Population and GDP data specification

Variable	Units	Spatial Resolution	Time Step	Format
Population	billion US$2005/yr	Country	2010 to 20100 (every 5 years)	Spreadsheet
GDP	Million inhabitants	Country	2010 to 20100 (every 5 years)	Spreadsheet

Data was extracted for SSP2, SSP4 and SSP5 as the three storylines developed in MARS are based on those socio-economic scenarios.

Conclusions on the chapter

In order to provide an overview of the data available to run the predictive models under the three future scenarios developed for MARS a literature review was carried out. Seven concluded and on-going projects and modelling tools that assess possible futures and impacts on Europe's freshwater were examined.

The aim was to assess the possibility of extracting suitable quantitative values for the parameters and variables required as input data for the models. The required data included principally climate and socio-economic data for each MARS scenario. The focus was put on finding data for the European scale models, which in many cases coincide with those necessary at river basin scale.

Although it was not possible to find data for all the required parameters, values for diverse climate variables, runoff, water abstraction, potential flood plains, nutrient diffuse source emission, land use, population and GDP were collected. It is expected that data for a few more parameters will soon be available. Those parameters that have not been quantified in this task will need to be calculated by the modellers of each area, based on the qualitative criteria used to shape each MARS storyline and their expert knowledge .

ISI-MIP, SCENES, BASE and CLIMSAVE were selected to extract the data from. Since the climate models and emission and socio-economic scenarios of these projects/modelling tools are different from each other and from the ones specifically developed for MARS, some comparison and approximation exercises had to be carried out.

The result is a suite of quantitative values for diverse parameters and variables on grid or vector format, which range from daily to yearly time steps and 5 by 5 arc minute to 0.5 by 0.5 degree spatial resolution, that are readily available to be distributed to the MARS modelling partners.

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6. Annex1

Projected changes of the climate parameters (IPCC WGII AR5 Chapter 23).

Table SM23-2: Projected changes of selected climate parameters and indices for 2071-2100 with respect to 1971-2000 spatially averaged for European sub regions based on RCP 4.5 and RCP 8.5. Numbers are based on 9 (RCP8.5) and 8 (RCP4.5) regional model simulations. The "*likely* range" defines the range of 66% of all projected changes around the ensemble median. The definition of indices is described below.

	Climate Para-meters	Measure	Alpine		Southern		Northern		Continental		Atlantic	
Scena-rios			RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
2071-2100 minus 1971-2000	Mean annual tem-perature in K	*Median*	*2.4*	*4.6*	*2.0*	*4.2*	*2.9*	*5.2*	*2.1*	*4.1*	*1.7*	*3.2*
		Lower bound	1.8	3.8	1.9	3.8	2.0	4.1	1.6	3.6	1.3	2.5
		Likely in the range	1.9 to 3.4	3.9 to 6.0	1.9 to 2.7	3.9 to 5.4	2.0 to 4.2	4.1 to 6.2	1.6 to 3.2	3.7 to 5.2	1.4 to 2.1	2.7 to 3.6
		Upper bound	3.6	6.3	3.2	5.7	4.3	6.5	3.2	5.3	2.9	4.2
	Frost days per year	*Median*	*-40*	*-70*	*-22*	*-43*	*-40*	*-68*	*-34*	*-62*	*-28*	*-40*
		Lower bound	-47	-93	-31	-51	-52	-93	-41	-73	-33	-60
		Likely in the range	-41 to -26	-85 to -57	-29 to -11	-51 to -23	-43 to -26	-83 to -60	-40 to -18	-65 to -50	-30 to -15	-50 to -26
		Upper bound	-25	-55	-10	-22	-24	-58	-16	-46	-12	-21
	Summer days per year	*Median*	*8*	*19*	*27*	*54*	*4*	*13*	*20*	*37*	*11*	*24*
		Lower bound	3	10	21	43	2	5	11	27	6	17
		Likely in the range	4 to 14	12 to 24	25 to 33	46 to 60	2 to 16	6 to 22	13 to 24	30 to 46	6 to 14	22 to 28
		Upper bound	18	25	37	67	23	28	28	49	33	38
	Tropical nights per year	*Median*	*1*	*4*	*20*	*45*	*1*	*1*	*9*	*22*	*3*	*7*
		Lower bound	0	1	7	23	0	0	2	11	0	3
		Likely in the range	1 to 3	2 to 5	11 to 24	25 to 57	0 to 5	1 to 3	9 to 27	17 to 31	1 to 5	3 to 12
		Upper bound	8	6	41	58	7	13	30	37	18	17
	Growing season length in days per growing season	*Median*	*31*	*61*	*27*	*49*	*23*	*55*	*26*	*58*	*39*	*58*
		Lower bound	23	52	16	34	17	37	17	52	24	41
		Likely in the range	23 to 39	52 to 83	17 to 33	38 to 53	19 to 33	41 to 60	20 to 38	53 to 71	27 to 43	47 to 68
		Upper bound	45	95	38	58	42	78	41	75	45	75

Warm spell duration index in days per year	*Median*	*34*	*96*	*34*	*124*	*35*	*82*	*23*	*73*	*20*	*65*
	Lower bound	26	73	28	90	22	64	16	52	17	46
	Likely **in the range**	**29 to 55**	**77 to 136**	**32 to 69**	**98 to 177**	**23 to 42**	**75 to 114**	**18 to 42**	**58 to 93**	**20 to 31**	**49 to 87**
	Upper bound	69	162	83	186	63	130	54	106	55	102
Cold spell duration index in days per year	*Median*	-5	-5	-5	-5	-7	-6	-6	-6	-5	-5
	Lower bound	-7	-6	-6	-6	-8	-7	-7	-8	-6	-6
	Likely **in the range**	**-7 to -4**	**-6 to -4**	**-5 to -3**	**-5 to -4**	**-8 to -6**	**-7 to -5**	**-7 to -4**	**-8 to -5**	**-6 to -3**	**-5 to -4**
	Upper bound	-3	-3	-3	-4	-4	-4	-3	-5	-2	-4
Annual total precipi-tation in %	*Median*	*4*	*11*	*-3*	*-11*	*10*	*22*	*9*	*10*	*1*	*4*
	Lower bound	3	4	-10	-23	7	17	0	0	-2	-2
	Likely **in the range**	**3 to 7**	**6 to 13**	**-9 to 1**	**-19 to -3**	**8 to 17**	**18 to 32**	**1 to 12**	**4 to 18**	**-1 to 6**	**1 to 7**
	Upper bound	9	15	2	-1	21	33	13	24	8	9
Annual total precipi-tation where RR>99p of 1971/2000 in %	*Median*	*34*	*70*	*27*	*35*	*31*	*69*	*35*	*55*	*29*	*60*
	Lower bound	14	29	14	20	22	57	11	29	15	42
	Likely **in the range**	**17 to 55**	**32 to 85**	**18 to 40**	**26 to 46**	**22 to 58**	**59 to 98**	**24 to 41**	**37 to 65**	**17 to 64**	**43 to 97**
	Upper bound	56	99	62	51	63	107	59	90	65	107

7. Annex2

Input parameter/variable European Models
Precipitation
Nitrogen diffuse sources
Nitrogen point sources
Phosphorus diffuse sources
Phosphorus point sources
Temperature
Water Quality Index
Land use change
Water abstraction
Water addition
Runoff
River network
Discharge
DEM
Planned potential flood plain
Human Influence index

Input parameter/variable Basin Models
Precipitation
Temperature (max and min)
Insolation
Discharge (inflow/outflow)
P and N deposition
Land use type
Number of animals
Air pressure
Relative humidity
Wind speed
Cloud coverage
Inflow P, DOC, chlorophyll, No3, NH4, S
Acid deposition
Soil map
Water level
Irrigation
Topography / digital elevation
Water abstraction (ground and surface)
Fertilization
Water use
Evapotranspiration
Nutrient concentration
bathymetry
Nutrient concentration sewage treatment work
Lake temperature profiles

Lake algal concentrations
Drainage level
Agricultural management (Crop rotation)
Population
Dams and weirs
Trees in riparian strip
Volume per water body
Sediment input