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Adaptive Strategies to Mitigate the Impacts of Climate Change on European Freshwater Ecosystems

Reporting

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REFRESH

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Final Report Summary - REFRESH (Adaptive Strategies to Mitigate the Impacts of Climate Change on European

Freshwater Ecosystems)

Executive Summary:
REFRESH had three overarching goals; i) to increase our understanding of how freshwater ecosystems will respond to the environmental changes driven by climate, land use, water use and pollution over the next 50-60 years; ii) to translate this knowledge into a form that can be used by water managers; and iii) To ensure uptake of REFRESH results by target stakeholders.

REFRESH adopted a multi-tiered approach to increasing understanding of how freshwater ecosystems will respond to global change drivers, how this might be managed practically and conceptually and how much management measures will cost. We collated existing knowledge from a wide range of sources and generated new knowledge using experimental and analytical approaches.

To increase our fundamental understanding of the mechanisms through which key global change-related drivers will affect freshwaters we used a series of co-ordinated field experiments to determine the impact of changing temperatures, changes in flow / water level and the interaction between these and nutrient concentration on rivers, lakes and riparian wetlands. The field experiments were supported by laboratory and mesocosm experiments, analysis of major databases and long-term time-series and by evidence from palaeoecological studies. All these approaches were combined to help develop the process-based models needed to run scenarios for adaptive strategies and improve the ecological parts of the models.

The ultimate objective of REFRESH was develop parsimonious integrated models to generate robust simulations of future water quantity, quality and ecology at the catchment scale. In REFRESH we ran a range of scenarios (for climate, land use, water resource use and atmospheric pollution) at a number of case study catchments to simulate hydrological and chemical response to future change and subsequently extrapolate ecological responses associated with temperature increases, altered hydrology and nutrient regimes at sites representative of the climate and land-use types of Europe. A key priority in REFRESH was to improve the ecological parts of the models and to couple the existing integrated models for flow and water chemistry to ecological models of appropriate complexity, so that the ecological response to climate and land-use management change can be predicted at the catchment scale, the feedbacks better understood and the connectivity between rivers, lakes and wetlands better represented. To assess the implications of model output for management we identified the most cost-effective ways of mitigating the adverse impacts of climate change and the impacts of these on achieving good ecological status under the WFD. This was achieved by coupling the ecological and economic outcomes to identify, through in-depth stakeholder dialogue and farm and sub-catchment modelling, the optimum combination of measures that need to be implemented at aggregate catchment scales to achieve WFD and HD compliance in the face of climate change. We also assessed whether the costs of the measures were proportionate and whether there were wider benefits following their implementation.

The stakeholder engagement effort in REFRESH had two main strands. For the first, REFRESH recognised that engaging stakeholders in a dialogue to identify problems, design solutions and address barriers to their uptake is an important element for successful implementation of the WFD and HD and for building adaptive capacity. Second, to maximise uptake of the results of the project, dissemination activities were targeted at specific stakeholder groups and organised to ensure that stakeholders were

aware of the project output, that the key messages for managers, practitioners and policy makers were expressed clearly and accessibly and that the stakeholders had the opportunity to feedback into the process. In REFRESH this work was carried from the very beginning to engage users and scientists together in the research process and to elicit stakeholder views that are needed to inform later stages of the Project. Further workshops were held to discuss outcomes of the research and to encourage stakeholders to disseminate the findings.

Project Context and Objectives:

Climate modelling studies indicate that even if greenhouse gases were stabilised at present levels, future climate change is inevitable as the climate system adjusts to emissions that have already taken place. Given the rate and magnitude of change projected it is important to ask what practical adaptation and mitigation steps can be taken to minimise the adverse effects of climate change on freshwater ecosystems over the next 50 years and what measures can be taken to ensure the success of freshwater restoration projects.

REFRESH is concerned with the development of a system that will enable water managers to design cost-effective management strategies for freshwater ecosystems at the local and catchment scales that account for the expected future impacts of climate change and land-use change in the context of the Water Framework and Habitats Directives. At its centre is a process-based evaluation of the specific adaptive measures that might be taken at these different scales to minimise the expected adverse consequences of climate change on freshwater quantity, quality and biodiversity. The Project considers how freshwater ecosystems (rivers, lakes, reservoirs, and riparian wetlands) in Europe will change over the next fifty years and it uses a combination of novel experiments and modelling to generate the understanding and tools needed to implement an adaptive management strategy. There are a number key concepts addressed in the projects which underpin the work programme.

Scenarios and storylines

Predicting how freshwaters will change in future is challenging, especially as they will respond in complex ways not only to climate change but also to change in other drivers acting separately and in combination with climate change. Hence, clearly defined scenarios for the future are required to enable experiments to be designed realistically and models to be run under expected combinations of future pressures. In REFRESH we developed realistic scenarios for future climate change, land-use/land management change, nitrogen deposition and water abstraction/water resource change and combined the scenarios to generate a range of storylines in the modelling and cost-effectiveness work at a number of case study catchments. In addition we engaged national and local stakeholders in the generation of storylines to develop a consensus view on the relevance and applicability of the various storylines when applied to the case study catchments.

Adaptation, mitigation and restoration strategies

Given the rate and magnitude of climate change projected over the next 50 years, it is necessary to minimise the adverse effects of climate change on freshwaters and to modify management and restoration targets to allow for shifts in the climate system. In REFRESH we focused on problems of increasing water temperature, changing hydrology (and salinity) and interactions between climate change and the behaviour of nutrients and organic matter as the principal climate-related threats to freshwater ecosystems. The overall principle is to improve the resistance and resilience of freshwater ecosystems to the adverse impacts of climate change by restoring ecosystem quality as required by the WFD. Specific adaptation strategies considered included: (i) the management of riparian areas to control water temperature by the establishment of woody riparian vegetation; (ii) the management of catchment hydrology to maintain flow in streams, water-level in lakes and regular flooding in wetlands; (iii) the re-creation of riparian floodplains to buffer against extreme precipitation events and to reduce nutrient flows and humic substances to water bodies; (iv) the management of catchment land-use to reduce diffuse nutrient loading and soil erosion; and (v) the management of water abstraction from, and effluent discharge to, surface waters.

Understanding processes

Adaptive management strategies need to be based on an understanding of the single and combined effects of the key climate-related drivers (temperature, hydrology and nutrients) on ecosystem structure, functioning and biodiversity. We focused primarily on the most vulnerable systems which are mainly those with small water mass (where warming will be highest and hydrological impacts most pronounced) in lowland regions (where the risks of eutrophication associated with nutrient loading and oxygen stress are greatest). Such systems are found throughout Europe in all climate zones. To increase our fundamental understanding of the mechanisms through which the key climate-related drivers will affect freshwaters we used a series of carefully designed, co-ordinated field experiments in which river, lake and wetland sites were selected to represent a gradient of climate conditions across Europe. For rivers the emphasis was on the impact of changing temperatures and low and variable flows under different nutrient conditions. For riparian wetlands the experiments were designed to study the processes involved in changing temperatures, drought regimes and reducing nutrient loading on wetlands. For lakes the experimental focus was on lake-level fluctuations and on ecosystem functioning especially with respect to carbon, nitrogen, phosphorus, oxygen and salinity dynamics. The field experiments were supported by laboratory and mesocosm experiments, analysis of major databases and long-term time-series and by evidence from palaeoecological studies All these approaches were combined to help develop the process-based models needed to run scenarios for adaptive strategies and which are required for up-scaling from local to river basin.

Identifying thresholds and reference conditions

A critical concern in the management of freshwater ecosystems is the attempt to prevent water bodies from crossing key thresholds, where systems may change abruptly and involve a switch to regimes that are difficult to restore. There is considerable uncertainty about how climate change may cause thresholds to be crossed, or may cause thresholds to move. In REFRESH we considered this problem for rivers, lakes and wetlands using analyses of existing long-term and palaeo-data time-series from sites distributed along the primary European climate gradients, from the results of the experiments and from extensive literature reviews. We evaluated how the threshold concept and knowledge of specific thresholds can be incorporated into adaptation, mitigation and restoration strategies needed to achieve the objectives of the WFD and HD. Climate change not only drives freshwater ecosystems across new thresholds but also changes the currently static concept of the reference state as defined by the WFD. Under climate change, reference conditions become dynamic and the definition of good ecological status becomes insecure. In REFRESH we examined how the use of reference conditions for lakes, rivers and riparian wetlands might be affected following climate change and how the concept of a dynamic reference state can be built into WFD and HD methodologies.

Indicators and vulnerability

Research funded by previous EU projects developed indicator systems for freshwater ecosystems under pressure from hydromorphological and pollution pressures, and subsequently from climate change. In REFRESH we focused on developing an effective system of indicators for freshwaters focussing essentially on ecological indicators sensitive to the functional response of rivers, lakes and wetlands to climate-induced changes in temperature, flow/water-level and nutrient/organic matter loading. Special attention was given to the use of species and assemblage traits as measures of functional response.

Developing and improving integrated catchment models

The ultimate objective of REFRESH was develop parsimonious integrated models that can generate robust simulations of future water quantity, quality and ecology at the catchment scale, the scale prescribed by the WFD for management decision-making and the scale at which adaptive measures will be most effective. In REFRESH we undertook integrated model development using the results from the reviews, analyses, experiments and local models of WP2-4 to extrapolate ecological responses associated with temperature increases, altered hydrology and nutrient regimes to the catchment scale at sites representative of the climate and land-use types of Europe. A key priority in REFRESH was to improve the ecological parts of the models and to link models between ecosystem types and couple the existing integrated models for flow and water chemistry to ecological models of appropriate complexity, so that the ecological response of freshwater ecosystems to climate and land-use management change can be predicted at the catchment scale, the feedbacks better understood and the connectivity between rivers, lakes and wetlands better represented.

Assessing the cost-effectiveness of adaptive management strategies

Successful implementation of the adaptive management strategies at the catchment scale requires the willingness of relevant stakeholders to adopt the measures proposed. A principal barrier to implementation is cost. There are two main aspects, first, the proportionality or disproportionality of compliance costs in relation to statutory European policy obligations under the HD and the WFD and second the specific costs of the alternative measures that might be introduced to achieve compliance.

Cost-effectiveness Analysis (CEA) has emerged as the preferred method for assessing the best means for water users or those whose behaviour impacts on water quality in order to achieve compliance with policy. Most established methods for assessing cost-effectiveness of water quality enhancement strategies fail to acknowledge fully the implications of the highly varied nature of land management systems and land manager behaviours, even at subcatchment scale. Cost-effectiveness studies of nutrient mitigation measures based on stylised or typical farm types do not take into account the inherent variability among farms caused by differences in farm size, land quality, spatial location, production techniques employed or managerial abilities. In REFRESH the intention was to identify the most cost-effective ways of mitigating the adverse impacts of climate change and the impacts of these on achieving good ecological status under the WFD or the favourable status of HD sites. This was achieved by coupling the ecological and economic outcomes to identify, through in-depth stakeholder dialogue and farm and sub-catchment modelling, the optimum combination of measures that need to be implemented at aggregate catchment scales to achieve WFD and HD compliance in the face of climate change.

Engaging with stakeholders and exchanging knowledge

Effective implementation of policy depends on the willingness and capacity of the various stakeholders to accept the policy and carry out the identified measures. Whatever the measures, there is likely to be some form of change required, ranging from awareness-raising to changing behaviour and practices. Given that climate variability may require rapid and far-reaching adaptation of practices, understanding the circumstances in which these changes might occur, and how to enable them, will be essential. Engaging stakeholders in a dialogue to identify problems, design solutions and address barriers to their uptake will assist with the implementation of the WFD and HD and build adaptive capacity. However, this requires a negotiated relationship between governments, relevant agencies, land managers and other water users and requires an understanding of the multiple perspectives, and potential conflicts of interest between the stakeholders to develop a constructive dialogue. In REFRESH this work was carried out throughout the duration of the project. Workshops with stakeholders were held to engage users and scientists together in the research process and to elicit stakeholder views that are needed to inform later stages of the Project. Further workshops were held to discuss outcomes of the research and to encourage stakeholders to disseminate the findings.

In these contexts, the Project has the following specific objectives:
• to generate scenarios and storylines for future climate, land-use, water resource demand and air pollution relevant to the future management of freshwater ecosystems;
• to review and assess measures that can be taken to mitigate the effects of temperature, changing hydrology (and salinity) and increased nutrient and organic matter loading expected under different future scenarios;
• to understand the processes that govern the relationship between temperature, hydrology (and salinity) and nutrient/organic matter loading and the structure, function and biodiversity of freshwater ecosystems;
• to develop methods for identifying thresholds and reference conditions for systems facing climate change;
• to develop new indicator systems and vulnerability assessment methods for systems facing climate change;
• to assess how climate change will alter species distribution patterns, especially those prioritised in the

HD, at the European scale;
• to develop and demonstrate effective methodologies to assess the cost-effectiveness of alternative adaptation/mitigation strategies in freshwaters;
• to develop and improve the performance of integrated catchment models for simulating the ecological response of freshwater ecosystems to climate, land-use and pollution change;
• to use the models to explore the ecological and cost-effectiveness of alternative adaptation, mitigation and restoration strategies to ensure long-term sustainable management; and
• to engage with stakeholders to develop scenarios and storylines and explore barriers to the implementation of adaptation and mitigation strategies at national and catchment scales.
• to disseminate the output of the project widely among the scientific and dtakeholder communities and translated this in a way that renders it accessible to policy makers and implementers.

There are thus three overarching goals

i) to increase our understanding of how freshwater ecosystems will respond to the environmental changes driven by climate, land use, water use and pollution over the next 50-60 years.

ii) to translate this knowledge into a form that can be used by water managers. This can then feed into the design of cost-effective restoration and management programmes that will account for the projected future impacts of climate, land use etc

iii) To ensure uptake of REFRESH results by target stakeholders – water managers, conservation bodies, policy makers, policy implementers etc

Project Results:
The main S&T results are broken down by work package for clarity.

Work package 1
Five reviews have been produced focusing on adaptation strategies in freshwater management;
Deliverable 1.1 a 'Report on climate change adaptation and mitigation strategies already in practice based on the 1st River Basin Management Plans of the Member States'
Deliverable 1.2 a 'Review of published literature for adaptation and mitigation measures including both scientific and policy papers.'
Deliverable 1.3 a' Review of the practical adaptation strategies adopted here in REFRESH for rivers (WP2.6) lakes (WP3.6) and wetlands (WP4.6)'
Deliverable 1.4 a report 'Integrating strategies at sub-catchment and local scale and strategies at catchment and European scales'
Deliverable 1.5 an 'Overview of practical climate adaptation strategies in European freshwaters at sub-catchment and local scales'

Climate change scenarios: At the outset REFRESH generated climate change scenarios (Deliverable 1.6) for each of the demonstration catchments together with an evaluation of the uncertainty in these scenarios. These have been generated using output from the FP6 ENSEMBLES project which generated an ensemble prediction system for climate change based on the principal state-of-the-art, high resolution, global and regional Earth System Models. The scenarios fed into subsequent modelling and storyline generation for modelling and cost effectiveness analysis.

Land use change scenarios: A review of scenario frameworks and previous large-scale land use scenario exercises for Europe was produced (Deliverable 1.7). Based upon this review, a generic socio-economic storyline framework for the REFRESH scenarios was developed with reference to the IPCC SRES framework. A specific case study implementation of quantitative land use change scenarios was then generated for the Dee catchment that linked the socio-economic drivers with climate change scenarios using the concept of 'land capability' to identify viable options for land use change (Deliverable 1.8). From this, a generic toolkit was then developed from the LandSFACTS software, complete with user-interface and guidelines, to allow it to be used for those other demonstration catchments that aim to investigate quantitative land use change (Deliverable 1.9).

Additionally, long-term nitrogen deposition scenarios (Deliverable 1.10) and, following a review of existing scenarios for water resources in Europe (Deliverable 1.11) water use scenarios, were developed for the REFRESH demonstration catchments were for the demonstration catchments.

Stakeholder engagement: A number of workshops involving stakeholders at different levels (from policy makers to farmers) were planned in REFRESH. A workshop was organised in London bringing together policy-makers and implementers from across Europe with scientists from REFRESH (Deliverable 1.13) focused on the future changes and challenges to WFD and HD implementation, as compared to those experienced at present. Two workshops were organised involving local stakeholders acting locally in the River Dee catchment in Scotland (Deliverable 1.14) and the River Louros catchment in Greece (Deliverable 1.15). The focus of these catchment scale meetings was to identify what constrains and influences actions to help the water environment and the workshops identified a series of potential barriers to implementation of water management legislation in two very different environments (Deliverable 1.16).

WORK PACKAGE 2

TASK 1 Temperature constraints on management success in rivers
We addressed the effects of climate-driven changes in temperature regimes on the success of management measures in rivers, on structure and functioning of river ecosystems, and on changes in river biodiversity. Shading, either by re-vegetation of wooded banks or by restoration of buffer strips or wooded riparian floodplain wetlands, can help to lower temperature, especially in smaller streams. Field experiments were used to investigate temperature change effects on river ecosystem structure and functioning along a gradient from un-shaded to fully shaded lowland streams.

Wooded riparian zones can mitigate stream water temperature rises induced by climate changes in north western Europe. Reducing stream water temperature can help maintain or restore the habitat for cold stenothermic stream organisms, among other benefits. Despite the large body of work on the effect of wooded riparian zones on water temperature, quantitative information on the magnitude of water temperature changes along open or shaded stretches of different lengths is scarce.

We measured stream water temperature year round along 1000- to 2000-m-long stretches of six streams in six countries with a shaded-to-open transition and with an open-to-shaded transition. We used the best-fitting regression models to describe the spatiotemporal changes in water temperature along these transitions. The derived data was compared among streams, and we evaluated the relationship between the magnitude of temperature changes and the stream physical properties.
The effect of the presence or lack of a canopy on water temperature was especially pronounced at relatively high stream water temperatures. During the spring and summer months, the water temperature increased by up to 1.9 °C after leaving a forested stretch, and cooled down by up to 2.3 °C on entering a shaded stretch. The magnitude of change in stream water temperature increased with the length of the stream stretch studied. The magnitude of temperature decrease along shaded stretches depended on the stream size and the LAI, with wooded riparian zones being especially effective as a temperature mitigation measure for small streams (width <3.5 m). The magnitude of the temperature increase along open stream stretches was mostly LAI dependent.
Synthesis and applications. These results provide a quantitative basis for ecologically successful stream temperature mitigation. The possible effects of stream temperature restoration through planting of wooded riparian zones, as well as stream temperature degradation along open stream stretches, are discussed.

The observed temperature changes are reflective of the stream physical properties, amount of shade, length of stream stretch, and the time of the year.

TASK 2 Low flows and drought constraints on management success in rivers

We addressed the effects of climate-driven low flows and droughts on management success in rivers, on structure and functioning of river ecosystems, and on changes in river biodiversity. The focus was on low flows and droughts in relation to completeness and naturalness of in-stream habitats and the construction of riparian buffer strips/floodplain wetlands to establish water retention along Atlantic, small-sized lowland streams. In such streams, periods of low flow and droughts will increase and extreme summer floods can wash away communities. Indicators (both structural and functional) reflecting key hydrological conditions were studied using controlled field experiments differing in intensity and periodicity of low flow. Algae, macroinvertebrates (in particular, oxygen sensitive groups) and macrophytes were used as biological effect parameters, and a number of ecosystem and physico-chemical parameters were monitored continuously.

As a result of hydromorphological degradation and climate change the number of low-order lowland streams transforming from perennial to intermittent flow increases in northwestern Europe. To understand the effects of such a regime shift on macroinvertebrate communities, field experiments were carried out in lowland streams in The Netherlands, Galicia and Denmark. Following a BACI design, flow was manipulated, resulting in two outcomes:

1.) a period of stagnation, with only minimal water loss;

2.) a period of drought, resulting in a dry streambed with water present only in scattered small pools.

We studied the degree to which the stagnant reach, isolated remnant pools, or the dry stream bed acted as refugia for macroinvertebrates and, where possible, to relate the observed changes to ecological preferences.

In the Danish and Dutch streams stagnation resulted in only minor changes in taxon composition. Most taxa remained present in the stagnant reach throughout the study period and overall richness even increased due to colonization by lentic taxa. However, the rheophilic taxa; they disappeared within one week after the flow ceased.

The stream fauna recovered in the pools and the dry bed overlapped almost completely with that of the stagnant reach, but contained only a subset of that found in the stagnant reach. Directly after the water disappeared a peak in taxon richness and abundance was recorded in the pools and in the wet surficial sediment, indicating a concentration effect of the receding water. This was followed by a steep decline in richness in the following weeks, coinciding with a deteriorating water quality in the pools and further drying of the surficial sediment. Nonetheless, several taxa were able to survive up to 25 days in the surficial sediment. The pool assemblage shifted towards one of lentic polysaprobic waters.

Our results indicate that although many macroinvertebrates are able to survive when only flow ceases, the characteristic rheofiles, disappear quickly after the onset of stagnation. Temporal loss of flow, even spanning only a short period of time, could have severe consequences for the composition macroinvertebrate assemblages of lowland streams.

In the Galician streams there was a significant overall effect of flow reduction on both abiotic and biotic stream components, although with different responses regarding streams and stretches. In the nutrient-poor stream, there was a marked decline of invertebrate densities in the stagnant stretch relative to the control, whereas in the nutrient-rich stream the strongest declines were found with invertebrate richness.

For the drought stretch, there were changes only in the nutrient-rich stream, where EPT richness was significantly reduced. Moreover, the experimental flow reduction produced changes on the invertebrate structure, mainly determined by the loss of sensitive, rheophilic and oxophilic taxa. Our findings indicate that even short-term water reductions have a significant impact on the structure of the stream invertebrate community, with potential ecological consequences for aquatic biodiversity and stream functioning.
In general, lowland streams are extremely vulnerable to climate change and anthropogenic impacts because of their position in the hydrological network and proximity to human populations. Our results highlight the need for better awareness of impairment to lowland streams, to be included in current management practices and development of adaptive strategies.

TASK 3 Nutrient and organic material constraints on management success in rivers
We addressed the effects of climate-driven changes in nutrient levels on the success of management strategies in rivers, on the structure and functioning of river ecosystems, and on changes in river biodiversity. The focus was on nutrients and organic matter in relation to the construction of riparian buffer strips/floodplain wetlands to establish water retention along small lowland streams. In the controlled field multiple stress experiments the combined effects on algae, macroinvertebrates and macrophytes were studied and the effects on a number of ecosystem and physico-chemical parameters were measured.

Temperature and shading
Streams without riparian forest are particularly vulnerable to increasing stream water temperature. Planting of riparian forest is considered a mitigation measure to reduce water temperatures for the benefit of stream organisms. However, no studies have investigated how long a forested reach is needed to obtain a significant temperature decrease. In 2010 and 2011 we therefore measured temperatures along a number of small lowland streams, all with a sharp transition between an upstream open reach and a downstream forested reach. In all stream reaches we also measured canopy cover and a range of physical variables characterizing the streams reaches. This allowed the analysis of differences in mean daily temperature and amplitude per month among forested and open sections, analysis of annual temperature regimes and analysis of the influence of the physical condition on temperature changes. Stream water temperature in the open reaches was affected by heating and in mid-summer we observed an increase in temperature over the entire length of these reaches. This resulted in temperatures even in Denmark above the incipient lethal limit for brown trout. Along the forest reaches we observed a significant decrease in mid-summer temperature immediately (100 to 500 m) after entering the forest. Sometimes stream temperature continued to decrease when moving further into the forested reach and the temperature decline did not reach a plateau indicating that the full cooling potential of the riparian forest was not reached. In other cases temperature was stabilised or appeared influenced by groundwater seepage. Even relatively short stretches (100-500 m) of forest alongside streams can thus act as mitigation measure to combat heating of stream water. However, the best (and cheapest) way may simply be reestablishment of the natural hydrology in the catchments. Flooding of riparian areas and natural succession leading to growth of smaller trees and bushes adapted to this environment would have the combined effects of reducing stream temperature and increasing biodiversity of both the stream and the riparian area.

Oxygen and flow reduction
Specific dissolved oxygen requirements of benthic invertebrates are rarely considered when evaluating impacts to streams, in spite of being the reason for the disappearance of many taxa with oxygen

availability as a direct effect of general flow reduction and other organic disturbances.
In an experimental study we tested the response of invertebrate species and communities to a complete reduction in flow created by longitudinally damming two streams with contrasting low and high nutrient levels. We sampled benthic invertebrates in control, and impact stretches (stagnant and drought) before and after the establishment of the dam over 10 weeks in summer. Oxygen daily values decreased and exhibited a strong daily fluctuation at the impacted stretches. The relationship between invertebrates and minimum daily DO values indicated the existence of differential sensitivity and tolerance of taxa to experimentally reduced oxygen concentrations, causing the decline of a high number of sensitive taxa in a synchronous way. We explored taxa resistance to minimum daily DO and different sensitivities and taxa reduction in resistance were evident as the minimum DO threshold diminished. The response of invertebrates was more evident in the impact stretches of the nutrient-rich stream, attributed to the greater and more sustained induced oxygen depletion.

Stagnation and drought
Small, permanent streams are at risk of becoming stagnant or intermittent due to climate change-induced hydrological changes, which can be further intensified by anthropogenic disruptions such as water abstraction. Macroinvertebrate communities are vulnerable to such changes due to their dependence on the stream hydromorphological regime. We conducted fully controlled field experiments in impacted and unimpacted lowland streams with contrasting nutrient availability; using dams and diversions to create short-term (2-10 weeks) stagnant and drought conditions. Furthermore, we installed pools in the drought area to test their value as refugia for benthic macroinvertebrates.
After 2 weeks, benthic macroinvertebrate community composition changed significantly in all treatments of all streams. In the pool treatments, diversity was significantly lowered (unimpacted stream) or not affected (impacted stream) compared to the drought treatment, indicating that pools did not act as a substantial refugium for benthic macroinvertebrates under extreme low flow conditions. Current velocity and amount of deposited organic material explained most of the change in the macroinvertebrate community. Nutrient availability did not influence the response of the benthic macroinvertebrate community to the treatments in Danish streams but it did in Dutch and Galician ones, probably in each case because the physicochemical changes were exacerbated in the impacted stream, thereby outweighing the expected higher resilience of this community in Denmark or not in the Netherlands and Spain.
Our results clearly demonstrate that short-term stagnation and drought events in lowland streams can result in a strong alteration of the species composition.

TASK 4 Thresholds and reference conditions: moving targets in river management
We identified temperature, flow and nutrient/organic matter load thresholds for rivers for application in adaptation, mitigation and restoration strategies. Long-term biological, hydrological and physico-chemical data series were analysed to determine if changes in ecosystem structure and functioning are occurring, whether these are linked to climate drivers and whether ecologically relevant thresholds can be identified (e.g. the transition from a permanent to a temporary system. This transition is already occurring in many European streams, not only Mediterranean systems). We focussed on functional indicators for this transition. We evaluated whether reference conditions in selected river types were changing and whether this was linked to climate drivers. Reference conditions were tested for climate vulnerability. We developed a concept of dynamic reference conditions (moving targets) as part of WFD methodologies (phytobenthos and macroinvertebrates).

Changes in ecological status at RIvPACS reference condition sites were studied to exemplify the objective of this work part. The WFD requires Member States to determine the ecological status of rivers and streams with respect to deviation from a type-specific reference condition. It is essential that Member States can demonstrate that the biological datasets used to define reference conditions meet the criteria of the WFD. The approach requires that reference sites be at their ecological optima, and are assumed to not change because by definition they are not impacted. We used RIvPACS reference site data and UK Environment Agency monitoring data to identify 81 RIvPACS reference sites that had subsequent monitoring data, and analysed seasonal patterns in ASPT and Ntaxa. Autumn ASPT increased over time in both data sets, but not Ntaxa, indicative of a shift in reference conditions and species replacement. The trend was site dependent, indicating that long term climatic cycles, or shifts in climate, are an unlikely cause. Deviation from the perceived reference condition was common for ASPT and Ntaxa at most sites, as a majority of subsequent samples did not fall within +/- 5% of the RIvPACS reference values. The ASPT and Ntaxa values of the RIvPACS reference samples for a site did not lie within the standard error range of the overall mean ASPT and Ntaxa for 70 and 80% of the sites respectively. ASPT was generally higher in upland areas of the UK and lowest in lowland agricultural areas. Rates of change in ASPT were highest at sites with intermediate ASPT scores. Low and high values of Ntaxa were more dispersed across the UK, though Ntaxa correlated to mean air temperature indicating a north/south gradient. Rates of change in Ntaxa were also highest at sites with intermediate Ntaxa scores, and rates of change were higher for spring samples. These results demonstrate that the fixed reference condition concept may not be realistic and that selection of reference sites should consider long term variability.

TASK 5 Indicators and vulnerability assessment in rivers
We derived innovative biological indicators (traits, functional response of benthic macroinvertebrates, algae, macrophytes and fish) for monitoring, assessment and evaluation of climate change impacts of temperature, flow (low flows, droughts and floods) and nutrients/organic material on adaptive management strategies in rivers. Existing large-scale data sets and species-specific ecological information were analysed by using different types of response models and bioclimatic envelope modelling, and also by using time-series data and space-for-time substitution with known environmental changes related to climate change. We developed response models for river habitats and new tools for vulnerability assessment incorporating connectivity and dispersal capacity. A database was produced.

The combined Deliverable 2.18/4.12 summarises the recent revisions of the freshwaterecology.info database including newly added ecological parameters and organism groups. It gives a short overview of the current state of the database and is supplemented by two case studies. The online database currently holds about 21,000 taxa from five different freshwater organism groups in Europe and provides approximately 72,000 ecological preferences and biological traits of fish, macro-invertebrates, macrophytes, diatoms and phytoplankton.
Within REFRESH we extended the database to encompass indicators, traits and functional response parameters relevant for river, lake and riparian wetland assessment. Additionally, the development of the database were summarised in a scientific paper “Life in European freshwaters – putting 20,000 species into boxes”

Task 6: Mitigation, adaptation and restoration in rivers under changing conditions

We evaluated the merits of various adaptation, mitigation and restoration methods to counteract effects of climate and land-use change on the structure and function of rivers. We reviewed existing strategies at the local scale in different European climate zones and assessed the success rate and cost-effectiveness of projects according to water type and measure. Differences in success rates for similar restoration methods across climatic zones, taking current land-use into consideration, were highlighted. The main drivers of recovery of biodiversity and ecosystem structure and functioning in rivers were identified.

Projected future climate change will undoubtedly result in even more dramatic shifts in the states of many aquatic ecosystems. Managing water resources and aquatic ecosystems in the face of uncertain climate requires new approaches. The focus of management and restoration will need to shift from (historic) references to potential future ecosystem services, and from reactive measures towards pro-active ones. Strategic adaptive management based on potential future climate impact scenarios will need to become a part of any action.
The objective of this task was to produce a practical guide to the most effective management strategies, applicable at sub-catchment and local scales, for use throughout Europe. Firstly, a list of sub-catchment and local scales adaptation measures was compiled for stream and rivers, and for lakes. It comprises measures that are normally being taken by local authorities/managers in different ecoregions and water types (for all kinds of purposes). To design a practical guide for water managers the scores were translated into a climate adaptation label per adaptation measure. Secondly, strategic adaptation measures aim to either improve resistance and resilience to stabilise aquatic ecosystems or to accept change and accommodate this. Therefore, three building blocks of a best practice framework for managing resilience in aquatic ecosystems were identified:
1. the principles from resilience concepts (nine basic principles)
2. the ecosystem approach (including the 5-S-Model and the DPSIRR chain),
3. strategic adaptive management.
The three together compose a practical guide for strategic adaptive management for aquatic ecosystems.
A list of sub-catchment and local scales adaptation measures was compiled for streams and rivers and also for small shallow and large deep lakes. The list was specified for climate regions (Atlantic, boreal,

alpine, continental and Mediterranean)

The list comprises common measures used by local authorities/managers in different ecoregions and water types (for all kinds of purposes). It includes only measures that mitigate direct and indirect effects of climate change. The measures are scored with the number(s) that corresponds to the one or more major climate change effects (Table 1).

Table 1. Score that relates each measure to a specific climate pressure.
score climate change induced pressure Example
0 no climate change related pressure
1 temperature rise direct, like warming, stratification
2 increase winter precipitation direct effects, like run off, water level fluctuation, spates, inundation
3 summer extremes direct effects, like droughts, spates
4 water quality indirect effects, like nutrient cycling, eutrophication, oxygen regime changes, salt seepage
5 others indirect effects, like exotic species, terrestrialisation

To design a practical guide for water managers the scores were translated into a climate adaptation label. For this label the scores 1 to 5 were taken into account. If an adaptation measures scores against all 5 climate change induced pressures then this measures contributes highly to climate adaptation. The fewer scores a measures has the lower its contribution. This approach resulted in the definition of climate adaptation labels (Table 2).

Table 2. Climate change adaptation labels.
colour code Colour number of climate induced pressures explanation
dark green 4-5 (+++) win-win measure
light green 2-3 (++) win-win measure
pale green 1 (+) no regret measure
yellow 0
red - regret measure

The list with adaptation measures (Verdonschot & Besse 2012) comprises measures that are commonly used by local authorities/managers in different ecoregions and water types (for all purposes). The scores in this list were used to design a practical guide for water managers and thus were translated into a climate adaptation label.

WORK PACKAGE 3
We have finished all 19 deliverables including several targeted at stakeholders. We have also published 91 scientific papers, including several comprehensive reviews and many more papers and reviews are in various stages of preparation. Some key outcomes are presented here:

Analysis of climate change effects using long-term data. Analyses of long-term data have been conducted for four lakes:

i) Lake Müggelsee, Germany: The effects of two recent Central European summer heat waves (2003 and 2006) on cyanobacterial blooms in eutrophic shallow Lake Müggelsee were evaluated. Critical thresholds of abiotic drivers were extracted from the available long-term (1993-2007) dataset on the lake using classification tree analysis to explain observations of cyanobacteria biomass. It was found that cyanobacterial blooms were especially pronounced when thermal stratification was critically intense and long-lasting. The study showed that extracting critical thresholds of environmental drivers from long-term records is a promising approach for predicting ecosystem responses to future climate warming. Changes in short-term meteorological variability will determine whether cyanobacteria will bloom rather than average temperature increases.

ii) Lake Võrtsjärv, Estonia: Long-term changes in phytoplankton composition in relation to hydrological, meteorological and nutrient loading data in large shallow Lake Võrtsjärv were analysed. All four calculated taxonomic indices showed a unidirectional deterioration of the lake's ecological status despite reduced concentrations of nutrients. The results suggest a non-linear response of phytoplankton to changing nutrient loadings and that the change observed between 1977 and 1979 was a regime shift triggered by water level change. High shade tolerance of the new dominants and their ability to create shade obviously stabilised the new status, making the lake resistant to restoration efforts.

iii) Lake Vansjø, Norway: A Bayesian Network model was developed for the shallow basin of Lake Vansjø in order to link biological response variables with the REFRESH scenarios and catchment and lake modelling. For variables with WFD status class boundaries (e.g. total phosphorus depth, chlorophyll a), the intervals of the discrete probability distribution are set by the WFD class boundaries "Good/Moderate" and "Moderate/Poor", which should ideally represent thresholds in dose-response relationships. For other variables, the intervals are based on the main breakpoints identified by the regression tree analysis.

iv) Lake Mjøsa, Norway: Analyses in Lake Mjøsa focused on two types of thresholds: (1) nonlinearities in the relationship between pressure (total phosphorus) and phytoplankton and effects of climatic variables on such relationships (e.g. cold vs. warm years; high vs. low stability) and (2) phenology: change in the timing of peak biomass of phytoplankton and zooplankton. For diatoms, the peaks in biomass are clearly lower in the 1990s-2000s compared to the 1970s-1980s. This reduction corresponds to the overall reduction of phytoplankton biomass, which is due to eutrophication abatement measures. The timing of the peaks also appears to have shifted, from June-July in the 1970s-1980s to smaller peaks in August-September in the 1990s-2000s. For peak biomass of chrysophytes, in contrast, the magnitude appears stable or slightly increasing across the decades. Moreover, the timing appears slightly earlier in the 2000s (mid-June) than in the preceding decades (June-July). The timing of the peaks also appears to have shifted, from June-July in the 1970s-1980s to smaller peaks in August-September in the 1990s-2000s.

Review of the effects of changes in temperature and net precipitation
The review provides strong evidence that climate change will enhance eutrophication in mesotrophic and eutrophic lakes as a result of physico-chemically and biologically induced higher internal loading and, in North temperate lakes, enhanced external nutrient loading as well. The effects on phytoplankton of such changes are ambiguous; most approaches indicate an increase in biomass, but the results generally point to a major increase in the risk of dominance and blooming of potentially toxic cyanobacteria species. If the biomass of phytoplankton and/or the amount of suspended matter increases, we can expect a shift in production within the ecosystem, from benthic and littoral processes to pelagic processes, as has also been found as a result of eutrophication. The role of macrophytes for maintaining clear water conditions will likely diminish, although water level reduction as in semi-arid lakes may counteract this effect. Enhanced salinity is to be expected in the Mediterranean lakes, which may reduce species diversity and adversely affect the provision of key ecosystem services.
Changes in species distribution due to climate warming are difficult to counteract. There may, however, be opportunities to compensate for some of the cascading effects of the changes in lake ecosystems as many of the symptoms of warming are similar to those following from enhanced nutrient loading. Measures should be aimed at increasing the natural resilience of ecosystems against external perturbations. For instance, measures taken to reduce the nutrient input to fresh waters, beyond those already implemented or planned, are straightforward and may include: i) application of fertilisers as determined by soil retention capacity and crop needs, leading to less intensive land use in catchments with sensitive fresh waters in order to reduce diffuse nutrient inputs; ii) (re)-establishment of riparian vegetation to buffer nutrient transfers to water bodies; iii) re-meandering of channelised streams to increase retention, decomposition and loss of organic matter and nutrients; iv) improvement in land management and agricultural practices to reduce sediment and particulate and dissolved nutrient export from catchments; v) improvement of the

design of sewage works to cope with the consequences of flood events and low flows in receiving waters; vi) more effective reduction of nutrient loading from point sources by proper sewage water treatments and from the atmosphere, the latter by reducing emissions from industry and agriculture; vii) in warmer regions, restrictions on alterations of natural hydrological cycles and water use, in particular for irrigated crop farming so as to reduce the risk of severe salinisation and eutrophication; viii) increased control of dispersal, arrival and establishment of exotic species. Some of these adaptation measures have been integrated in the River Basin Management Plans required under the European Water Framework Directive, but since they are largely qualitative (Nõges et al., 2010a,b) they will certainly promote discussion among different stake holders.

Cross-European mesocosm experiment
We conducted a simultaneous, standardised pan-European (six countries from Sweden to Turkey) mesocosm experiment to elucidate the effects of climate change on shallow lake community structure, functioning and metabolism at low and high nutrient levels crossed with contrasting depths. We used cylindrical fibreglass mesocosms. Nitrogen and phosphorus were dosed in monthly intervals and water was circulated continuously in the mesocosms from spring to autumn (Landkildehus et al., submitted). The mesocosms were inoculated with a mixed sample of sediment and plankton from lakes in each country with contrasting nutrient concentrations and stocked with macrophytes and planktivorous fish. Sediment was pre-equilibrated to the experimental nutrient concentration. During the experiment, the water level decreased with increasing temperature, and in the Mediterranean mesocosms the water level was reduced by 90 cm; in contrast, conductivity was more than doubled. The average chlorophyll a concentration in the deep mesocosms with high nutrients increased along the temperature gradient but peaked at intermediate temperatures in the shallow mesocosms. Average macrophyte PVI (% plant volume inhabited) increased with rising temperature in the shallow mesocosms, while oxygen saturation data suggest that net primary production peaked at intermediate temperature and was lowest in warm lakes, and overall lower in deep than in shallow mesocosms.

Scientific papers on nutrient balances, zooplankton, ecosystem resilience based on zooplankton,

periphyton, microbial communities are about to be submitted, followed later this year by papers on macrophyte, phytoplankton and metabolism.

Study of 31 Turkish lakes
A comprehensive study was conducted in Turkish lakes representing contrasting climate conditions. Numerous papers have been published or submitted. Highlights include:
• We found dominance of small-sized zooplankton in the warm and saline lakes. Physiological tests further showed that salinity controls Daphnia populations through increased mortality, decreased reproduction and slower growth. Loss of the keystone taxa Daphnia may have cascading effects in the lake ecosystem and lead to a higher risk of a shift to a turbid water state under warmer and drier conditions.
• Contrary to observations from temperate lakes, the submerged macrophytes in warm lakes did not act as a refuge for large-bodied grazers, such as Daphnia. Instead, when fish inhabited the plant beds, they avoided the plants and preferred to hide near the sediment when exposed to predation. Furthermore, also smaller-sized taxa among rotifers, cladocerans and copepods utilised the sediment as a hiding place depending on the intensity of the predation threat. However, only partial avoidance of predation was possible as zooplankton grazing was low (low zooplankton:phytoplankton biomass ratio) compared to the

situation in similar temperate lakes.

• Lakes located in southern lowlands (warmest) are the most eutrophic and saline with high nutrients and phytoplankton biomass, dominance of small planktivorous fish and low biodiversity. Northern upland lakes were characterised by low nutrients and chlorophyll a concentrations, dominance of large cladocerans and large proportions of piscivores. These results indicate that climate change may result in higher salinization and eutrophication with more frequent cyanobacteria blooms and loss of biodiversity in Mediterranean lakes if they do not completely desiccate.

A review of water level and salinity

We produced a comprehensive review of the ecological impacts of global warming and water abstraction on lakes and reservoirs due to changes in water level and salinity (Deliverable 3.11). The review is based on long-term data from seven lakes covering a geographical gradient of fifty two degrees of latitude and a literature review discussing how changes in water level and salinity related to climate warming and water abstraction impact the lakes' ecosystem structure, function, biodiversity and ecological state. Furthermore, we provided some guidelines for mitigation of the negative effects on the ecological state of lakes resulting from changes in climate and water abstraction and highlighted research gaps.

Both the case studies and the literature often showed profound negative (but not always) ecological effects of water level reduction – either due to climate warming or abstraction for irrigation, with potential synergistic effects, often followed by increasing salinity leading to reduced biodiversity in the Mediterranean region. Some of the negative cascading effects on lake ecosystems resulting from water level reductions and salinity increases may be counteracted. We emphasise the need for integrated water resources management, which includes reshaping of planning processes, coordinating land and water use, recognising water quantity and quality linkages, conjunctive use of surface water and groundwater, protecting and restoring natural systems, also to enhance inland water retention time. Win-win measures include those promoting sustainable water use such as water pricing and water use prioritisation; control over abstraction of surface and ground water; implementation of safety water technologies; efficient usage and conservation technologies; reduction of water loss and water friendly farming. Further win-win measures are those that improve the storage capacity of water in the drainage basin such as forest reforestation and controlled drainage, and in some areas use of desalinised sea water.

To compensate for enhanced eutrophication due to global warming, focus should also be on reducing external loading of nutrients and sediment to the lakes via changes in land management and agricultural practices, as discussed above. In-lake measures may include sediment removal, sediment capping (chemical treatment of the sediment) and/or biomanipulation.

Effect of increased dissolved organic matter input to lakes

An increase in dissolved organic carbon (DOC) in streams and lakes has been reported across the northern temperate region, but the effects of elevated DOC on whole lake ecosystems when combined with nutrient inputs are as yet unclear. In order to address this uncertainty, we performed a mesocosm study using twenty-four large outdoor mesocosms, each containing lake water and sediment together with one of three different levels of organic matter (added as filtered peaty water) (Deliverable 3.9). Identical amounts of nitrogen and phosphorus were added at intervals to all the mesocosms to simulate eutrophic conditions, but addition of the humic matter resulted in the highest total phoshorus and total nitrogen concentrations in the DOC-treated mesocosms. Light was particularly low in the high DOC mesocosms.

We found no significant difference between the organic matter treatments in terms of net ecosystem production, respiration or gross primary production. However, dissolved oxygen was lowest in the mesocosms receiving the highest level of added organic matter. In spring, mesocosms receiving high levels of organic matter exhibited the greatest increases in chlorophyll a among the treatment groups, whereas later in the year the high organic matter treatments showed the lowest phytoplankton biomass among the treatments. The highest phytoplankton biomass in summer, autumn and winter was observed in mesocosms receiving low organic matter level concentrations. A number of the mesocosms became turbid in summer as a result of cyanobacteria blooms. The concentration of cyanobacteria was highest and the duration of the bloom longest in the mesocosms receiving low levels of organic matter and lowest in those receiving high levels of organic matter. The concentration of organic matter concentration also affected higher trophic levels: total macroinvertebrate abundance increased with allochthonous carbon in spring and summer. However, fish abundance did not show consistent trends. The results of the study suggest that as cyanobacteria seemed to benefit from a low increase in humic substances in the mesocosms, eutrophic shallow lakes might be faced with increased pressures towards a turbid state with an increase of DOC in the near future.

A review of the effects of dissolved organic matter

The dissolved organic matter experiments were accompanied by a comprehensive review (Deliverable 3.14 concerning the current understanding of the effects of DOC and particulate organic carbon (POC) upon different elements of the lake food web and ecosystem-scale processes. We also considered the likely combined effects of increasing DOC loading, eutrophication and climate change upon lake ecosystems. The findings suggest that increases in DOM concentrations and in phytoplankton biomass, as a result of increases in nutrient concentrations, are likely to have additive effects on light attenuation and thus on the thermal structure of a lake. In addition, the influence of changes in algal biomass is likely to interact with climate change as well as DOC loading. Reduced mixed depths and warmer surface temperatures are anticipated through both climate change and loss of transparency by increases in DOC or algal biomass. These synergistic consequences may then result in further changes in algal communities, favouring the growth of buoyant cyanobacterial species, which may in turn further enhance light absorption near the surface.

Despite a growing body of literature on the effects of organic matter upon the structure and functioning of lake ecosystems, there is currently little knowledge of the implications of organic matter loading for the way lakes are managed. However, the need for this knowledge is becoming increasingly urgent due to observed increases in organic matter. In Europe, the Water Framework Directive (EC 2000) has been the major driver of lake management over the last ten years. Therein measures to reduce inputs of key limiting nutrients, specifically phosphorus, have been the focus of European lake management policy. The literature review suggests that measures to reduce phosphorus loading to lakes, in order to restore good ecological status, may also interact with changing organic matter loading in a way that affects the structure and functioning of lake ecosystems. Specifically, we may expect that measures to reduce phosphorus loading would reduce phytoplankton production in favour of bacterial production based upon external carbon sources. This change may be particularly pronounced for lakes experiencing elevated levels of DOC loading. Such a change would likely result in the re-structuring of phytoplankton communities (favouring mixotrophs) and would increase the relative importance of the microbial food chain as a conduit for energy flow to higher trophic levels. Ultimately, due to the energetic inefficiency of this pathway, we may expect that the productivity of higher trophic levels (zooplankton, fish) could be affected as an unintended consequence of lake management. In addition, high levels of DOC loading are known to impose light limitation upon phytoplankton and benthic algal communities. If, in humic systems, light is the primary limiting factor for phytoplankton growth then seeking to reduce primary producer biomass by cutting nutrient loads may not be as effective as anticipated.

In addressing the implications of organic matter loading for lake restoration and management, there is a clear need to think beyond the physical boundaries of lake ecosystems and consider landscape-scale processes and the management decisions that impact upon them. Land use can have significant effects on the loading of organic matter to lakes. In order to understand these impacts, it is therefore important to broaden the scope of scientific investigation to the catchment scale, including the stream network draining the catchment. Deforestation, agriculture and urbanisation can alter the quantity and quality of organic matter inputs to running waters and receiving water bodies.

Ensemble modelling
A global trend of increasing health hazards associated with proliferation of toxin-producing cyanobacteria makes the ability to project phytoplankton dynamics of paramount importance. Whilst ensemble (multi-)modelling approaches have been used for a number of years to improve the robustness of weather forecasts, this approach has until now never been adopted in ecosystem modelling. A REFRESH modelling study has shown that the average simulated phytoplankton biomass derived from three different aquatic ecosystem models is generally superior to any of the three individual models in describing observed phytoplankton biomass in a typical temperate lake ecosystem, and we simulate a series of climate change projections. Since this is the first multi-model ensemble approach applied to some of the most complex aquatic ecosystem models available, we believe that it sets a precedent for what will become a commonplace methodology in the future by enabling increased robustness of model projections and scenario uncertainty estimation arising from differences in model structures.

WORK PACKAGE 4
We designed a complementary framework of experimental studies and meta-data-analyses which, through experiments and reviews of existing data, assessed the potential impacts of future climate change on the hydrology, biogeochemistry, functioning and biodiversity of European riparian wetlands. The experimental manipulations of riparian hydrology (drought and flooding treatments) were carried out along a climatic gradient across Atlantic Europe. The objective was to simulate increased summer droughts and increased winter flooding periods by diverting stream water to dry out, or flood, stream riparian wetlands. The climatic gradient investigated runs North-South across Atlantic Europe, from Denmark, North Germany, the Netherlands, Atlantic Spain to Mediterranean Spain. Results on wetland biogeochemistry (N and P), biodiversity (plants and riparian beetles) and functioning (nutrient cycling, decomposition) are summarized.

Regarding plant species composition, a correspondence analysis suggests both climate components (temperature and precipitation/hydrology) could be major explanatory variables. Firstly, a clear gradient was found in the presence of species from North to South Europe (Figure: the first axis separates sites across a North-South gradient, with Danish sites to the left, Dutch/German sites in the centre and Spanish sites to the right). The main variable corresponding to the differences in species composition across all sites is air temperature. Secondly, for all sites, the most prevalent plant species found in the riparian zones all show adaptations to flood events. Thirdly, on the second axis, groundwater chemistry strongly differentiates sites. Most notably, the Groote Molenbeek site differs from all other stream riparian zones. The latter is probably due to the situation of the Groote Molenbeek in a highly intensively agricultural area. Overall, both climatic variables (temperature, precipitation-driven hydrology) and regional groundwater chemistry variables (NO3, SO4) correspond very clearly to the composition of the standing vegetation in the riparian wetland sites, suggesting that especially increasing temperatures and (loss of) flooding may have a dramatic effect on riparian zone species compositions, but that regional nutrient status is almost as important (certainly where nutrient loads are high).

In response to increased flooding, vegetation species composition, richness and biomass responded rapidly, even within the first year of applied flooding treatments. In the majority of the sites, flooding had a pronounced negative effect on species richness of the vegetation, while positively affecting standing biomass. Flooding also had a positive effect on springtime nutrient availability and species richness of the seeds deposited in the riparian zone. Nutrient release (measured as available phosphorus and nitrogen in the soil) following flooding and deposition of nutrient-rich sediments seems to mediate the major effect on the composition of the standing vegetation. The increased species richness of deposited seeds in the riparian zone indicates that flooding contributes to seed arrival, and may thus modulate species composition. In conclusion, winter flooding can have a negative effect on riparian species richness especially in already nutrient-enriched sites, by positively influencing the nutrient availability of the soil and plant biomass, while also potentially changing species composition due to the increased input of seeds.

In the first year, the flooding treatment acted as a heavy disturbance, with extensive die-back of the existing vegetation probably due to submergence and oxygen depletion in the root zone. Despite this die-back, there appeared very little effect on the functional trait characteristics of the community in the second and third year when comparing the functional characteristics of the treated plots with the control plots. However, linear regression coefficients indicated that changes took place, and that communities in both the dry and wet end of the hydrological gradient responded much faster than those under stable conditions. This result reveals the importance of following the functional response of the vegetation over a prolonged time period following a change in abiotic conditions.

The effects of increased drought on vegetation biomass and composition are less pronounced than for increased flooding, at least partly due to the fact that at some sites and in some years the drought treatment was not very effective due to high precipitation. As a consequence, for plant species the response is less clear than for flooding, although there are species shifts in some of the sites towards more terrestrial communities, indicating that increased drought leads to loss of riparian wetland habitat and species, and a narrowing of the riparian zone.

From a more detailed study carried out in the Danish, German and Dutch sites it appeared that only few species (range 1-22 species) were found in the sediment seed pool and mean richness was only slightly higher in the sediment seed pool deposited along the stream situated in the largest catchment compared to those of smaller catchments, indicating that the effect of catchment size on the richness of the sediment seed pool was minor. We also found very similar trait characteristics of the sediment seed pool when comparing seed (e.g. longevity, mass, physical dimensions) and canopy (e.g. SLA, height, leaf mass) trait characteristics from the four catchments. However traits associated with the height of the species and the average number of seeds produced by the species seemed to be influenced by land use characteristics e.g. the fraction of seeds from species being tall was higher in catchments with high percentages of forest and low percentages of agriculture. We conclude that the sediment species pool generally consists of few species sharing very similar functional trait characteristics and that differences in catchment size and land use characteristics seems to play a minor role in shaping sediment seed pool characteristics. Consequently flooding and sediment deposition, being processes that are expected to be intensified in a future climate, may not suffice to regain diversity in currently species poor riparian areas along lowland streams situated in agricultural landscapes.

Further, the seed pool tended to be more species rich compared to later successional stages in the vegetation (first and second years establishment and standing vegetation), in particular under dry conditions. Further, the seed pool and later successional stages of the vegetation differed in both species and trait composition. For all regions we found that the seed pool was characterized by a higher fraction and/or abundance of species forming tall canopies producing large amounts of seeds compared to later successional stages. The existing vegetation on the other hand was characterized by a higher fraction and/or abundance of species producing large seeds with a high floating capacity indicating that these traits can be associated with improved species fitness in riparian areas. In addition to differences found between the sediment seed pool and later successional stages, we observed differences in the response of community trait characteristics to the hydrological condition. The floating capacity of the seeds was higher in flooded sites and the canopies were taller compared to that found in control and dry sites, whereas the total mass of seeds produced was higher in the dry sites indicating that these sites were characterized by a higher fraction and/or abundance of ruderal species. Consequently, the functional characteristics of the riparian communities is likely to change with intensified flooding regimes towards a higher fraction and/or dominance of tall species producing seeds with a high floating capacity. We foresee that these traits may improve the fitness of the community under more frequent and/or prolonged flooding events and also that a higher floating capacity of the seeds of dominant and/or abundant species in the community we may also expect that species dispersal along rivers will be a more significant pathway for species dispersal under a future climate

In conclusion, a changing climate may very rapidly be followed by a change in riparian wetland species composition. Existing species not adapted to the new conditions may not survive, and are quickly replaced by better adapted species which arrive by simply migrating (clonally) downslope or upslope within the riparian zone or via seed dispersal. In the latter case, increased seed deposition, particularly of seeds from riparian species adapted to dispersal by water, following increased winter flooding may be expected to contribute to species turnover (with especially very common species arriving in great numbers). In situations of increased winter flooding, higher flood-related springtime nutrient availability is likely to mediate loss of species and species richness in the riparian zone, especially in areas with high nutrient loading. In situations of increased summer drought, the true riparian zone is effectively narrowed, with more terrestrial species coming in and loss of wetland habitat and species.

Riparian beetle assemblages were investigated in summer in six of the study sites, in each case comparing the diverted (summer drought) section to the non-diverted (control) section of the stream riparian zone. The sites were located in Denmark (Sandemans baek and Voel baek), Germany (Boye), the Netherlands (Groote Moolenbeek) and Spain (Caselas and Pego). Beetles were sampled by pitfall traps, which were installed for one week in the drought experimental phase once per study site.

Drought has positive effects on the community composition and diversity of beetles in the riparian zone. The retreating water left unvegetated and muddy riparian areas open for colonization. Species who are bound to these environmental conditions immigrated and thus increased the richness in beetle families and genera. This applies also to carabid beetles. However, the drier wetland conditions and lack of aquatic areas typically benefited non-riparian beetle genera, and even reduced waterbound beetle genera (Fig. x). Although several studies emphasize that new habitats are directly colonized by macropterous carabid beetles, we could not find increased numbers in all drought sections. In contrast we found higher abundances and higher species richness of brachypterous specimen in the drought sections (Fig. 6). Those species prefer organic mud and wet detritus, which was released from the retreating water. They are eurytopic species relying on this wet substrate and migrated into the drought sections on search for food. No latitudinal gradient was detectable in the response to drought by beetles in general or carabid beetles. However, our results suggest general differences in beetle richness and compositions. The number of beetle families decreased with increasing latitude, which might be an artifact of the general climate association of the beetles. Southern control sections were characterized by a higher number of carabid species and higher diversity as particularly the Iberian Peninsula was a retreat for many species in the last glaciation and is currently a hot spot of beetle species diversity.

In contrast to other aquatic organism groups, for which negative effects of drought and climate change are expected in terms of decreased species richness and diversity (Boulton, 2003), beetle richness and diversity seem to (partly) benefit. This positive response has different reasons: First, the retreating water level opens new terrestrial patches for colonization and the order of the beetles is one of the species richest orders. Many species are adapted to riverine habitats and their strong flight ability supports a fast immigration in open spots. Second, many beetle species inhabit riparian areas and particularly the water edge utilizing food sources left behind from retreating water (e.g. carcasses, organic matter). Third, beetles are often habitat specialists and an increase in habitat diversity has direct effects for species to colonize those habitats while in terms of the very small size of many beetles their necessary patch size is extremely slight. Similar responses of arthropod communities to drought were found by Corti & Datry (2014). However, the greatest contribution to the increasing beetle richness and diversity was due to arrival of non-riparian beetles, and the lack of aquatic areas even reduced the number of waterbound beetles.

These results suggest that riparian beetles profit from summer drought and retreating summer stream water levels, but that maintenance of wet areas in the riparian zone, even during summer drought phases, is important for waterbound beetles.

We have generated important information regarding the effects of hydrological and temperature changes on wetland biodiversity and functioning, highlighting the important contribution of lateral aquatic habitats for species diversity and the sensitivity of riparian plants to the hydrologic regime. Our reviews emphasise the strong biological linkages between aquatic and riparian ecosystems, further suggesting that successful restoration and conservation of riparian zones require an integrative approach that operates across ecosystem boundaries. Additionally, we proposed practical indicators for assessing the state of wetland biogeochemical functioning relevant for managers, and generated publicly accessible information on the traits of important riparian species including Odonata and Carabidae. These are presented in a paper on riparian invertebrates and in the update of the www.freshwatercology.info website (Deliverable 4.12). A list of additional ecological parameters related to invertebrate traits relevant in wetland ecosystems was established and relevant references were identified to extract ecological information from these sources with special focus on Trichoptera (caddisflies), Plecoptera (stoneflies) and Ephemeroptera (mayflies). Data were codified and integrated in the testing environment of www.freshwaterecology.info and will go online with the next updated version of the database. Additional indicator groups for wetlands riparian beetles as well as Odonata, were chosen and a literature review on the autecology and European distributions was conducted. The data on riparian beetles will be available at www.freshwaterecology.info as downloadable file with the next online update of the database; the Odonata data will be integrated into the online database as soon as the expert check is finished.

The implications of threshold responses for the management and conservation of riparian zones were reviewed in a non-technical report aimed at policy maker and managers. We provided an overview of the concept of ecological thresholds and summarised recent case studies where riparian wetlands exhibited non-linear responses to abiotic drivers. Finally, we discussed the implication of threshold responses for the management of riparian zones and suggested future research directions. We developed a practical summary report on the experiments carried out, and on the species and habitats most vulnerable to climate change. These included red-listed species and habitats included in the Habitat Directive.

WORK PACKAGE 5

Beyond the State of the Art

The main results of workpackage 5 are the development of a method, applied at nine sites, based on new model chains to represent coupled river-lake-wetland ecosystems that includes key ecological indicators and uses integrated scenarios, a common modelling framework, and the testing of the latest sensitivity and uncertainty analysis techniques to determine the impacts of environmental change on flow and streamwater nitrogen and phosphorus concentrations and key ecological indicators. New models, based on Bayesian Belief Networks, were developed to describe the impacts of multiple stresses on streamwater macro-invertebrate biodiversity, riparian plant diversity, macrophyte status and algal-cyanobacterial interactions in lakes.

Overall evaluation of the impacts of environmental change on the WFD status of the demonstration sites
The general picture derived from the catchment-scale modelling is that the predicted effects of environmental change over the next 50 years on waters differ between the northern and southern sites. In the north and mid-latitudes, the projected increased temperatures are balanced to some extent by increased precipitation, leading to relatively small effects on water flows, though seasonal effects due to changes in winter precipitation and/or snowpack accumulation and melt may still be important. In the south, increased temperatures and lower precipitation act in the same direction to reduce water flows

considerably. In the case of Lake Beysehir, this may even lead to the lake drying up in the foreseeable future, and this effect would far outweigh any nutrient-related problems. In general, the effects of climate change alone on nutrient concentrations are rather small. The effects of credible land use changes are rather larger, and generally, the land use changes representing the “environmental” storylines (B1 and B2) reduce nutrient concentrations, and those from the “economic” storylines (A1 and A2) increase them. However, there are exceptions and considerable differences in response between sites. The responses seem more dependent on the mixture of nutrient sources (e.g. agriculture versus wastewater) than the degree of climate change. Modelled ecological changes are not generally proportional to the changes in nutrients. Ecological change can be less than the nutrient change (e.g. chlorophyll at Lake Beysehir and the Orlik Reservoir in the Czech Republic) or greater due to a complex set of reactions in the food web (e.g. at the IJsselmeer). Modelled mitigation options can reduce nutrients, and there is no evidence here that they are less effective under a future climate. With less certainty, mitigation options can affect the ecological status of waters at these sites in a positive manner leading to an improvement in Water Framework Directive status at some sites, such as Pyhäjärvi and Vltava. Uncertainty in the climate models, as represented by the differences between the three GCM-RCM combinations used in this study, does not affect this overall picture much, though there are differences at individual sites.

Climate drivers

Model predictions tend to show that Europe will become warmer, and also wetter in the north, but much drier in Mediterranean regions, and the modelling results used in REFRESH conform to this pattern. All three GCM-RCM models predict a rise in temperature over Europe, with the Had Model consistently and significantly higher than the others, with a mean rise of 2.2 °C, followed by KNMI (1.4 °C) and SMH (1.0 °C). This is the order generally observed for these models in Europe. The highest temperature rises are in Finland: apart from this site there is a north-south gradient with the greatest temperature rises in the south, though the differences between the models are generally greater than the differences between the sites. Predictably, there is also a north-south gradient in the actual temperature, though this is modified by the relatively high altitude of the southern sites. For precipitation, there is a distinct north-south divide, with small increases in the north and mid-latitude sites, and large decreases in the south. At Arbúcies in the Pyrenees, there is considerable variability between models, with the Had Model predicting a 17% decline in precipitation, and the SMH Model a 15% increase. Once again, the Had Model tends to give more extreme predictions. All models concur, however, in predicting substantial decreases in precipitation at the Greek and Turkish sites.

The increase in temperature increases evapotranspiration, thus reducing the water available for river flow. This has contrasting effects in the north and the south. The northern sites generally have a small increase in precipitation and the increase in temperature, and thus evapotranspiration almost cancels it out, leading to a smaller percentage increase in discharge, or even a slight reduction in some model - site combinations, reducing the magnitude of change in river flow. The southern sites have a large percentage decrease in precipitation, and here higher temperatures exaggerate the change, leading to an even larger percentage reduction in discharge, since the increased evapotranspiration is a larger percentage of the available water. The Hadley Model gives the largest decreases in discharge in the south, and the KNMI Model the smallest.

To understand the change in discharge pattern more completely, however, seasonal effects need to be taken into account. At Arbúcies, for instance, the KNMI Model predicts a 2% increase in precipitation, but a 14% increase in discharge. This is because under the KNMI model at Arbúcies the pattern of precipitation shifts to give less precipitation in summer and more in winter. The smaller evapotranspiration in winter means that winter precipitation is more effective in generating HER, hence the increase in discharge. Similar though less spectacular effects are probably occurring at all the sites. At the Tarland Burn on the Dee, for instance, the KNMI Model predicts a decreased summer flow and increased winter flow too, resulting in a slightly increased flow overall, but the SMH Model gives a year-round flow reduction. The difference between these behaviours may be of considerable ecological significance.

Nutrient Concentrations

Changes in total P due to climate change alone are mostly small, whereas changes in SRP are larger and more variable both between sites and between climate models. The differences seem due mostly to differences in the types of source present at each site. Where there is a substantial wastewater input, as at the Vltava site, reducing water volumes imply increases in nutrient concentrations as wastewater inputs are a reasonably constant volume. Where agriculture is the major source of nutrients, loads can decline in proportion to the declining water flux, and hence concentrations do not change or even decline, as at Beysehir, where the reduction in SRP is substantial. Nitrate shows little change due to climate change alone, the modelled changes mostly being small declines.

For total P, the modelled changes in nutrient concentrations due to land use change are greater than with climate change alone. Clearly the effects of the land use changes will depend on the magnitude of the change modelled, but both climate and land use changes are best estimates of the likely scenarios, so it seems valid to compare them. For SRP, this is also mostly the case, but at certain sites the changes due to climate alone are greater. At Beysehir, this is because the change in climate is substantial (less precipitation and higher temperatures), so the agricultural changes have relatively little effect. At the Vltava, the importance of wastewater inputs means that concentrations increase due to low flows, increasing the importance of climate change. Percentage changes in nitrate-N concentrations are generally somewhat smaller than those of SRP or total P concentrations, except at Yläneenjoki, which may be because the land use scenarios there involve quite large changes in agricultural practice. As with total P, the modelled changes are greater than when there is land use change as well as climate change, except at Beysehir and the Louros (where all changes are small). At these sites, nitrate concentrations decline in virtually all scenarios, whereas further north there is a mixture of responses depending on the scenario, with in general, the “Environmental” scenarios generating reductions. At the Vltava the B2 (LU4) scenario however generated an increase in N, as this scenario has a higher proportion of arable land.

The overall pattern of nutrient changes in rivers is that climate change alone does not cause a large proportional change in concentration, except for SRP at the Vltava (increase) and Beysehir (decrease). Generally, SRP and nitrate decrease due to climate change, while total P increases. Predicted changes in land use generally make a larger difference to concentrations, though SRP is more equivocal. The “Economic” land use scenarios generally increase concentrations while the “Environmental” scenarios decrease them, but the precise pattern depends on the predicted land use change in each case. In most cases the nutrient concentrations react in the same way independently of the climate model used, but in some instances (notably at the Louros) the differences between the predictions using different climate models are greater than those between the scenarios.

The changes in nutrient concentrations in lakes due to climate change are quite small, and are smaller than the relative concentration changes in the rivers that feed the lakes. Differences between the predictions of the GCMs are small too. This may be because lakes have mechanisms that buffer concentrations, such as transit times of water, P release from sediments or denitrification, and these reduce the differences between scenarios. Changes in discharge also tend to reduce the differences between scenarios, making lake loadings less variable than concentrations. The exception is Beysehir, where reductions in both discharge and concentration cause a large change in load.

Changes in chlorophyll concentration due to land use are generally considerably greater than those due to climate change alone. At Pyhäjärvi and Vansjø-Høbol, climate change leads to a small increase in chlorophyll concentrations, economic land use scenarios produce a further large increase, and environmental land use scenarios lead to a reduction. In both cases the changes closely mirror those of total P. Temperature-induced increases in algal growth and internal P loading cause an increase in chlorophyll at the IJsselmeer due to climate change, whereas land use change leads to a reduction due to decreased external nutrient loading. At the Orlik Reservoir (Vltava) a small decrease in chlorophyll due to climate change is attributed to increased P retention by the reservoir due to hydrological changes. Land use changes generally caused a decrease in chlorophyll, even when total P increased. This illustrates that changes such as in seasonal hydrological patterns can over-ride the responses expected from simple linear relationships. At Beysehir, changes in chlorophyll are largely negative due to reduced nutrient loading and water flux. The chlorophyll changes are however substantially smaller than the changes in water and nutrient inputs. At both Vltava and Beysehir, there are substantial differences in response to the GCM models – the KNMI Model had the smallest effect, the Hadley Model was intermediate, and the SMH Model led to the largest decreases in chlorophyll. This is a different response pattern to those in the driving variables.

Mitigation Strategies and Water Framework Directive Outcomes

Mitigation measures were generally effective in reducing nutrient concentrations in current climates.

Mitigation strategies were generally aimed at improving ecological outcomes and hence tended to target P. Reductions in nitrate concentrations were therefore much lower than those of total P and SRP. Mitigation strategies continued to work with future climates, though in some cases the effects were small.

The initial status of the sites covered a wide range of WFD categories. Mitigation gives a general reduction in risk, and can cause sites to cross boundaries between WFD classes in a favourable direction. Of the 37 changes assessed, seven led to increases in WFD status, and three to crossing the moderate/good boundary, thus fulfilling the requirements of the Directive. Otherwise the WFD status stayed the same.

Publications and other dissemination activities

The number of outputs from workpackage 5 is substantial with 16 (of 16) deliverables produced, 22 journal articles already published in peer-reviewed, leading international journals, a further three submitted, with more to be produced as the new model development and applications of the models are written-up. Key papers will be those based on Deliverables 5.13 and 5.14 that will report on the REFRESH models and the synthesis of the modelling effort for the demonstration sites. Many of the papers are also collaborative with other workpackages. To date, the work done in WP5 has been presented at 27 national and international conferences.

WORK PACKAGE 6

Task 1 (Profiling the selected catchments)

The main anthropogenic activity identified in all demonstration catchments is primary production and more particularly agriculture. In some cases, livestock production and fisheries (Dee, Louros, Orlík) or forestry and timber harvesting (Dee, Pyhäjärvi, Vansjø-Hobøl) are also significant activities. Water demand for municipal use, mainly for drinking water and/or recreational activities constitutes a considerable issue in six cases and hydropower is important in two cases.

Diffuse pollution due to mainly farming practices is considered as a critical pressure, influencing landscape patterns, water abstraction and chemical/nutrient emissions. Moreover, high population density, industries and transport networks are associated with increased water demand and increased municipal wastewater discharges (Thames, Louros, Orlík). Hydrological and climate changes are reported as significant pressures as well, in Thames and Vansjø-Hobøl. Forestry is noted as a potential pressure in Pyhäjärvi, while fisheries and fish farming/breeding create pressure in Dee, Louros and Orlík.

The ecological water state of Thames is particularly compromised, since 77% of surface waters do not meet good ecological status. In Dee, WFD assessments have shown that the condition of 30 out of its 53 water bodies requires improvement. Intensive farming activities along with municipal wastes have also seriously degraded water quality in Louros. Excess amounts of nutrients resulting mainly from agricultural runoff and waste-water treatment plants are identified as the main threat in the water bodies of Pyhäjärvi and Vansjø-Hobøl catchments. In Orlík, intensive agricultural production along with the expansion of transportation networks and industrial zones has created significant pressure.

Overall, the impacts of the aforementioned pressures on water quality and quantity involve disturbances in biodiversity and aquatic ecosystem functioning, significant changes in natural landscape patterns, eutrophication and temporary water shortages. Impacts such as drought, flooding and disturbances in ecosystem functions are relevant to the Thames catchment due to various anthropogenic pressures, while eutrophication including harmful algae blooms is recorded in the cases of the Pyhäjärvi and Vansjø-Hobøl catchments and in one of the Dee sub-catchments. In Louros, agricultural practices, extensive land reclamation projects, hydrological regulation of the river and high water abstraction, impact on the landscape and the operation of lagoons that are supplied by Louros' waters. Similarly, pressures related to agricultural mass production, fish breeding, industry and households, along with drainage and technical adjustments of streams have caused significant changes to landscape and water functions in the Orlík.

Policy responses have been significnat in the Dee, where a variety of regulatory, voluntary and economic instruments/ measures and some general binding rules have been identified and some are already under implementation in the context of a management plan. In the Thames, a combination of incentive, advisory and regulatory mechanisms have been in place for a number of years to help farmers and other land managers protect the environment and significant water quality improvements have occurred in the last decade. With the exception of the CAP farm investment scheme and investments by municipalities on waste-water and solid waste treatment plans, response to date has been very poor in terms of the application of the WFD in Louros. On the contrary, response to the HD has been sensitive to environmental conservation needs. WFD action plans are under implementation in the Finnish catchment, while the Morsa project has introduced mitigation measures in Vansjø-Hobøl. Weak cooperation among municipalities and state authorities has resulted in the very low uptake of mitigation actions in Orlík.

The impact matrices constructed for the six sub-catchments show that the most severe impacts are relalted to hydromorphological characteristics and physical-chemical impacts on water quality. Also it is observed that the catchments of Morsa and Orlik have the highest number of “severe” impacts followed by Louros and Thames, while the catchments of Dee and Pyhäjärvi/Yläneenjoki have the highest number of “minor” impacts.

Task 2 (Selecting sub-catchments to represent variety of within-catchment compliance challenges):
Data available to inform choices of the sub-catchments varied considerably. In some cases there were only official data to draw on giving insufficient information with regard to some of the economically significant functions and ecosystem services provided by water. In other cases (e.g. Norway and Finland), there has been a great deal of scientific investigation already, which has provided a wealth of data.

Whereas the widespread nature of agricultural activity means that agricultural impacts on water quality through emissions of fertilizers, manures and pesticides over much of Europe are almost universal, impacts are nonetheless strongly shaped by intensity of agricultural practice, cropping regime and soil type. However other uses, such as commercial fishponds can also create very significant compromising conditions for water bodies in some sub-catchments.

Task 3 (Scoping the solutions)
Collaborative Scoping of Solutions Workshops were organized in order to engage stakeholders in the the scoping of solutions process. These workshops were designed to build on knowledge of the nature and sources of pressures at the sub-catchment level informing the stakeholder discussions and used to contrast local views with scientific findings.

The objectives of the workshops were addressed through three sets of activities: (1) discussion of water quality problems in the sub-catchment and the sources of these pressures, (2) discussion of measures to alleviate these problems and perceptions of their cost and effectiveness, and (3) discussion of climate change and its effect on water quality and adaptation measures.

Workshop discussions showed that nutrient pollution was the most widely cited problem, while agricultural activity and sewage treatment were identified as the major sources of pollution. Identified problems had often a contextual perspective, while other sources of pollution diverging from common trends include fishery management of ponds (CZ), housing developments and private septic tanks (Thames), forestry, quarries, septic tanks and the increase in the number of migratory geese (Dee). Divergences in contextual factors and in the feasibility, scope and perceived effectiveness of mitigation action, led to the specification of a significant variety of solutions, proving that there is not a common path to compliance. Workshop participants were able to develop a consensus on the potential effects of climate change. On the other hand (with very few exceptions), stakeholders seemed to have a rather contemporary perception of conditions and cannot project solutions in the form of “climate change proofing” of mitigation measures.

Also, in some cases, other issues (such as future developments in agricultural policy) were perceived as being more immediately important compared to climate change. This finding indicates the need for more coherent and rigorous efforts by policy makers (as all levels, i.e. international, national, regional, local) to raise awareness and initiate the detailed investigation of climate change response options.

Task 4 (Cost-effectiveness Analysis of Solutions):
In the case of the Dee, adaptation and mitigation measures considered focus mainly on agricultural land use and wastewater treatment works (WWTWs). Findings from the cost-effectiveness analysis indicate that: (1) the identification of key pressure sources and targeted measures are the best way to achieve cost-effective pollution mitigation, (2) livestock measures are more costly to implement than arable sector measures (in Tarland), (3) fertilizer reduction in the arable sector is the most cost-effective measure (in Tarland),(4) conversion of arable land to grassland is a costly option, (5) WFD targets in Tarland can be achieved at a relatively low total cost (compared to many other water bodies in Scotland), (6) investment in WWTWs appears to be the most effective and economically feasible strategy to deal with phosphorus loading problems, and (7) water quality standards for P can be achieved with modest total costs by implementing the combined measures of fertilizer input reduction and investment in WWTWs in the Loch of Skene catchment. Disproportionality analysis identified various non-market benefits of the improvement of water quality and the major beneficiaries. With the help of an extended CBA tool (using the NPV decision criterion), the key finding is that implementation of WFD measures in the study area is not disproportionately expensive in terms of comparison of the economic costs and societal benefits. However, economic efficiency analysis of mitigation/adaptation measures may not be the only environmental decision parameter; other non-economic factors and wider benefits may be taken into consideration in the decision making process.

Analysis in the Thame is focuses on phosphorous reduction from agriculture (arable and livestock) and sewage treatment works, which have been identified as the main pressures for the achievement of WFD and HD targets in the sub-catchment. Results indicate that the most cost-effective combination of measures to tackle phosphorous pollution includes establishing ten meter with riparian buffer strips, 20% P fertilizer reduction across all crop land, adoption of minimum tillage systems (over 50% of combinable crops), and establishment and maintenance of constructed wetlands and winter cover crops. Costs of implementation of these measures (including foregone benefits from agriculture) are outweighed by significant non-market benefits identified through existing stated preferences data, suggesting that the improvement of water quality can be achieved in a proportionate way from an economic viewpoint. Local stakeholders consulted throughout the project share this vision of proportionality, but acknowledge that a significant burden is placed upon farmers, while it is the public more generally who benefits from improved water quality. To address these distributional effects, it would be necessary to widen the decision criterion beyond purely cost-effectiveness, stimulating compensation mechanisms, increasing environmental regulation flexibility and awareness raising.

In the Louros, the mitigation measures proposed imitate the measures originally offered by the agri-environmental programme for Louros with two differences. First, we included, besides the cultivations of cotton and maize, the cultivations of medic and citrus fruit that could formulate potentially serious polluting activities. Second, we assumed different levels of abatement under two different production processes ("technologies"). The first production process allows for reductions in fertilizer application by means of set-aside land, reduction in fertilization to the cultivated land and reduction in irrigation. The second production process allows for equal levels of reductions in fertilizers but demands 5% set aside margins, allows the set aside land to be rain fed cultivated by nitrogen fixing legumes, and reduces irrigation. Climate change for the Louros catchment and its likely impacts on plant productivity and land use was drawn from a complete and coherent assessment study of climate change effects carried out by the Central bank of Greece under the supervision of the Academy of Athens. Following the IPCC story lines, four climate change scenarios were devised. For each climate change scenario the future costs for applying the mitigation measures were re-estimated. Costs of reducing N and P under climate change were again aggregated to the whole Louros catchment taking into account the distribution of cultivations in the catchment under climate change induced land use changes. Modelling of nutrients and sediment transport was based on INCA-N and INCA-P and was carried out by WP5. Modelling provided a baseline (calibrated) estimate of nutrient concentrations without any mitigation measures or land use and climate change. This showed very clearly, and in accordance to monitoring data, that the water quality of the Louros catchment was in good environmental status and under any definition of environmental standards. Thus, there was not a need to apply a catchment wide agri-environmental programme, or at least, this was not justified on the basis of non-point source pollution from agricultural activity. Modelling also produced simulated concentrations for nutrients under the mitigation measures and without any land use and climate change. These simulations showed that the application of mitigation measures marginally improve the water quality. The baseline scenario (i.e. no mitigation measures) also was simulated for climate change induced land use changes. Climate change, increases nutrient concentrations but not as much as it would have been expected from foreseen land use changes. This is due to the fact that climate change, and especially expected higher temperatures, lower precipitation and decrease runoff, reduce sediment and nutrient transport and increase the use of nutrients by plants. Thus, the quality of water at Louros remains, under any environmental threshold levels, at good status. When mitigation measures are applied to the climate change baseline scenario, the reduction in nutrient concentration is marginal for nitrogen and more significant (but still low) for phosphorous. Despite the fact that water quality in Louros is at good status under all environmental thresholds and all alternative simulations, it was decided to run the cost effectiveness analysis (CEA) and disproportionality analysis (DA) exercises assuming that the agri-environmental policy would have been applied, if recession had not occurred. So, instead of searching for the most cost effective solution we could search for the least ineffective solution. Disproportionality Analysis requires the estimation of aggregate benefits discounted over a time period. Budget constraints did not allow the estimation of benefits from a primary valuation study and the benefit transfer methodology was applied. Taking into account the high cost of even the most cost-effective mitigation measure, it is not surprising that we calculated a highly negative net present value at around -16 million euros. However, our estimations are based on the assumption that benefits accrue to locals due to the use of Louros water and thus refer mainly to use values. This argument misses the point that Louros water feeds the estuaries at Amvrakikos Gulf and that more and cleaner water has a direct impact on habitats and biodiversity to the adjacent Natura 2000 site. This implies that we may not restrict the benefits to Louros inhabitants only but allow other households (in Greece or Europe) to express non-use values for the Louros estuaries. To reach a breakeven position of zero net present values (i.e. with discounted costs equalling discounted benefits) the number of households should be tripled. Under any climate and land use change, benefit estimate or discount rate the net present value is negative, indicating that if such a project is undertaken, it would be highly disproportionate. For the benefits side, disproportionality is raised along two dimensions. First, the spatial dimension of benefits; second is the disproportionality to incomes. The distributional pattern of WTP estimates depends upon income elasticity. If income elasticity is less than one (as is the case with environmental services incorporating non-use values and certainly the case for biodiversity) WTP are distributed regressively among the beneficiaries. If the income elasticity is more than one, as it is sometimes the case for environmental goods such as water quality, WTPs are distributed progressively. If we assume that income elasticities are less than one and WTP is distributed regressively, this means that an agri-environmental project like the one that is proposed for Louros, has the possibility of benefiting poorer households more than rich households. This is due to the fact that the proportion of WTP to income is decreasing as income rises and thus the environmental improvement has proportionately higher benefits to poor groups than to rich groups among the general population. Costs are disproportional because are accrued only to the agricultural activity. Even within agriculture, costs are disproportionately distributed with the highest cost undertaken by cotton and maize producers. Cost, in the current economic situation, is not affordable by farmers and the imposition of such a policy without subsidisation for forgone income would force a part of the farming population out of business

Lake Pyhäjärvi is presently in Good water status, but very close to the threshold between Good and Moderate. This means that the status is only Moderate during half of the years, and problems occur related to eutrophication. The protection objective in this study is to ensure the likelihood for the lake to remain in the good status. Measures are applied by farmers in the catchment area where, in a sense, the costs of protection are thus borne. The farmers are compensated for conducting mitigation measures, which makes the state and the tax-payers the actual cost-bearer. the analysis was based on a transdisciplinary approach, in which economic analysis for costs and benefits and catchment modelling to study effectiveness of protection measures are supplemented by input received from local stakeholders. Two stakeholder workshops discussed possible mitigation measures and potential benefits of water protection, respectively. To estimate cost-effectivenes, three different types of farming practices to increase winter-time vegetation coverage were considered in the case study. The actual CEA studied costs and effects of different combinations of these, namely, 1) Increasing the amount of winter cereals; 2) Changing from cultivator tillage to direct sowing; 3) Increasing the amount of nature management fields. The analysis of costs and effects of mitigation measures showed that there are cost-effective combinations of measures to reduce nutrient load. Some of the combinations could even reduce the costs of farming. In comparison to economic results of the farms, the combinations would lead to modest decrease or modest increase of economic result on a farm level. Only the most costly combinations of measures would mean a significant increase of costs of farming. It can be concluded that on the other hand affordability should not form an obstacle for applying the methods, but on the other hand the possible, modest reduction of costs of farming is not a strong incentive for adopting them. Choices that farmers make are strongly influenced by agri-environmental scheme of the EU CAP. Future agri-environmental schemes should be targeted for creating incentives for farmers to adopt more effective measures, but especially such that do not lead to unnecessary increase of costs, since there are cost-effective alternatives. A stakeholder workshop was organised to identify the types of benefits that can be gained by use of water and water areas of the Lake Pyhäjärvi. Five groups of main uses were identified: i) water as a resource, ii) recreational use by the local people, iii) professional fishing, iv) tourism and v) significance of good water quality for the reputation and living conditions in the area. A benefit transfer method was used to quantify the potential benefits that can be gained from reaching the set protection target. The analysis of potential benefits suggests that considerable benefits can be gained from meeting the protection goal. There is thus a social need to continue protection of the lake and high benefits to be gained. Comparison of costs of protection and potential benefits to be gained indicates that benefits are clearly higher than the costs.

Morsa (Vansjø-Hobøl) The analysis has focused on the reduction of total phosphorus, which is associated with eutrophication problems and the most cost-effective combination of measures included (ranked in order, with the most cost-effective measure first and the least last): i) Buffer zones with vegetation along creeks and rivers; ii) Sedimentation ponds; iii) Reduced tillage practices (leaving the fields in stubble during winter); iv) Reduction of sewage from scattered dwellings (stand-alone systems); v) Transfer of sewage to MSTPs outside the catchment. Caution needs to be taken when using these results in practice. Managers should for example not only consider the cost-effectiveness of the removal of total phosphorus, but also other concerns, such as the bioavailability of phosphorus from different sources, and risks of bacteria from sewage pollution. It must also be stressed that the cost-effectiveness figures for measures aiming to tackle diffuse runoff from agriculture are uncertain, and it may take several years before the effects of such measures are detectable in the river waters. Through stakeholder interactions, this analysis also identified a large range of wider benefits from these measures, ranging from improved cooperation across administrative borders to increased well-being of the local population. It is believed that such benefits may contribute to the continued motivation for implementing mitigation measures. The disproportionality analysis showed that the reduction of phosphorus in the case study catchment was proportionate and economically justified, but distributional effects and affordability considerations should be taken into account. Payment for ecosystem services, where beneficiaries contribute as well as polluters, may therefore be considered.

In the Vltava catchment, the analysis focused on phosphorus (P) reduction from its major sources in the catchment of the Orlík Reservoir, i.e. municipal wastewater discharges, fishpond fisheries, and agriculture (arable and livestock).The starting point of the CEA was an analysis of existing measures implemented in 2007-2015. Findings indicate that these measures would reduce the P inflow by approx. 22 tonnes (corresponding to 20% of the total necessary P reduction) at total costs of CZK 465 mil. (EUR 18 mil.) a year. CEA The then focused on creating a cost-effective scenario, the implementation of which would result in the total necessary phosphorus reduction, i.e. reduction of the P inflow to one half to prevent the massive algal bloom in summer months. Numerous measures for P reduction were identified in discussions with stakeholders and expert specifications. In total, 3,097 measure applications were analysed within the CEA (of which 1,654 qualified for the effective scenario). The total annual costs were CZK 369 mil (which equals to EUR 15 mil./year). CEA was followed by a benefit transfer analysis in order to calculate the benefits incurred by the water quality improvement. The focus was on recreational benefits for residents and tourists. Furthermore, due to a lack of available data, we assumed other benefits and the future tourism development through expert judgments. Benefits were calculated on different time scales corresponding to the cost analysis. The first scenario calculated benefits between 2007 and 2015 (amounting to CZK 256 million, i.e. EUR 10.23 million). The benefits in the case of the CEA scenario realisation were calculated in the second scenario (expected lifespan of the measures being 20 years); we calculated benefits between 2016 and 2035 (amounting to CZK 3,016 million, i.e. EUR 120.5 mil.). The cost-benefit calculations were then amended by stakeholder consultations sought for the acceptability of the proposed scenario, distributional effects and wider effects caused by its realisation. Qualitative methods (focused groups, questionnaires) were used to capture those features. It showed a problem of financing the implementation of proposed applications of measures (small municipalities do not have the money to build the infrastructure, fish producers and farmers require subsidies to change their practices above legal requirements). Furthermore, fish producers denied their contribution to P releases to a large extent.

Task 5 (Flagging the wider benefits to ecosystem services)
A combination of expert consultation and stakeholder participation was used to identify the wider benefits of measures to improve the water status in the six demonstration catchments.

Results indicate that identified costs and cost-bearers were mostly specific to the chosen mitigation measures and activities associated with them, while benefits and beneficiaries largely seem context-specific. Also, as probably expected, costs of protection measures are borne upstream and benefits are enjoyed downstream. Rather few anthropogenic sources of pressures exist, affecting the welfare of a rather large number of people.

Costs and cost-bearers identified and classified as important by local stakeholders include increased farm production costs and reduced yields, but also other sectors such as quarrying, fisheries and forestry. Water and drainage/sewage treatment authorities were also noted as significant cost-bearers in some catchments, while private households were expected to bear costs associated with septic tank management. Benefits and beneficiaries identified correspond to rather wider range than that associated with costs and cost-bearers. Recreational benefits were identified in all case studies and linked to economic welfare. Biodiversity benefits were also identified including those associated with species populations and wildlife health. Finally, an improvement of the quality of life was identified.

Regarding proportionality, it was argued that costs are more concrete and short term, while benefits were more abstract, subjective and longer term. In some cases this led to difficulties in the comparison of costs and benefits. However, there was a general opinion that benefits outweigh costs, despite their long term and “uncertain” nature.

Identified wider benefits were mostly non-water and non-strictly water ones. Main non-strictly water benefits identified for REFRESH demonstration catchments include biodiversity conservation, soil conservation, and increase of amenity and aesthetic values. Non-water benefits quoted include improvements in human health and wellbeing, gains in economic activity (including employment), educational resources and changes in attitudes towards environmental sustainability, and food security, but also pest control, climate change, retention of nutrients and organic material, air filtering, improvement of pollination, and generally, reduced environmental impacts.

We conclude that this exercise led to inference on the existence of a significant range of wider benefits associated with mitigation measures, which target the improvement of water quality. The existence of such benefits should play a fair role and be acknowledged in any holistic analysis of interventions to maintain water qualities to support sustainable and multifunctional management of European water catchments. Further, the link between these benefits and, rather complex factors such as perceptions on the state of the environment, development strategy capacity at the local level and economic factors influencing productive behavior should be taken into account when mitigation and adaptation actions are designed and implemented, in order to enhance policy efficacy. Finally, with the exception of the Louros case study, wider benefits identified in the context of Task 6.5 further support findings of Task 6.4 on the existence of

proportionality and confirm that the chosen mitigation/adaptation measures would generate social benefits.
Potential Impact:
REFRESH work on streams created a basis to apply knowledge on the effects of climate change and land use change on the structure, functioning and biodiversity in rivers and the effectiveness of adaptation and mitigation measures to restore rivers.
The shading experiments provided quantified insights in the role of temperature in rivers and the potential ecological gain to use shade to compensate temperature rise. The related shading and temperature reviews made a wider application and generalisation of the experimental results possible. Furthermore, shading also supplies organic material to rivers which improves the ecological functioning and thus adds to the objectives of the Water Framework Directive and the Habitat Directives. Shading as a measure is also of low cost. The indicators for temperature and wooded river banks were renewed and can improve the assessment techniques that accompany the WFD implementation.
The shading experiments were prepared and performed in about 48 streams spread over the Atlantic region of Europe, each in direct cooperation with local stakeholders (mostly regional water authorities). The results were communicated directly to the respective stakeholder and will help them in applying this type of measures.
The stagnation and drought experiments provided quantified insights in the role of low flow and drought in rivers and the potential ecological losses. The experiment provided thresholds for low flow and drought in Atlantic lowland rivers. The related low flow and drought reviews made a wider application and generalisation of the experimental results possible. Furthermore, flow and oxygen appeared crucial for rivers and decide the ecological functioning. Thus good oxygen regimes and healthy flow conditions are primary targets in any part of measures to reach the objectives of the Water Framework Directive and the Habitat Directives. The indicators for flow and oxygen were selected and can improve the assessment techniques that accompany the WFD implementation.

We have produced a comprehensive report on the implications of climate change for ecological reference conditions, thresholds and classification systems for European lakes (Del. 3-15-16). The aim of the report was to assess impacts of climate change on reference conditions and ecological thresholds in European lakes, to consider the implications for ecological classification systems (reference values, class boundaries and water body types), and to provide recommendations to river basin managers concerning monitoring programmes and programmes of measures. The EC guidance on river basin management in a changing climate (2009) states that "In general, reference conditions and default objectives should not be changed due to climate change projections over the timescales of initial WFD implementation (up to 2027) unless there is overwhelming evidence to do so" (section 5.4.4. Reference sites). Moreover, one should "avoid using climate change as a general justification for relaxing objectives" (EC 2009, section 5.5 Objectives setting), such as relaxing the Good/Moderate boundary.Nevertheless although national classification systems are already established and intercalibrated by most EU member states, the six-year River Basin Management planning cycle of the WFD offers an opportunity to review the methods for the adequate assessment of the ecological status of EU water bodies. Moreover, the programme of measures within the River Basin Management Plans should take account of climate change effects in order to achieve the WFD Good status target. In addition, impacts of climate change may affect lake ecosystem services and threaten the implementation of the EU Biodiversity Strategy 2020, especially target 2: Maintain and restore ecosystems and their services. Therefore, although not explicitly mentioned in the WFD, synergies between the WFD and the Biodiversity Strategy may contribute to both maintaining and restoring lake ecosystems and the services they provide.

The following key messages can be extracted from the literature review, new data analyses and case studies presented in this report as a basis for recommendations. In general, our results and recommendations support and expand on those given in the EC guidance (2009), by Moe et al. (2010a - see Fig. 7) and by Nõges & Nõges (2014). With respect to impacts of climate change on reference conditions: i) shifts in in lake type may occur, ii) changes in reference conditions for phytoplankton are expected for species composition, abundance and the onset and frequency of algal blooms, iii) an increase in reference concentrations of nutrients and cyanobacteria are likely to be required, iv) changes in reference conditions for fish, macroinvertebrate and macrophyte taxonomy based metrics are expected. With respect to impacts of climate change on thresholds and classification systems: i) the probability of exceeding the good/moderate boundaries for one or more biological quality elements will increase, ii) the current good/moderate class boundary for macrophyte metrics and the concentration of cyanobacteria will probably be reached at lower nutrient levels in the future, iii) fish metrics that include salmonids may need adjustment of class boundaries, iv) the current good/moderate boundaries for the BQEs could be retained but nutrient standards will need to be more stringent OR the good/moderate boundaries for the BQEs will need to be relaxed and the current nutrient standards retained.

Potential impacts of climate change on components of ecological status classification, for a biological metric (e.g. EQR based on amount of cyanobacteria) which responds to a nutrient pressure. Ecological status classes: H = high, G = good, M = moderate, P = poor, B = bad. Solid curves: present situation; stippled curves: impact of climate change (CC). (A) CC affects the level of local pressures. (B) CC affects the reference condition of the biological element (i.e. the baseline or condition found in sites with minimal impact of other anthropogenic pressures). (C) CC affects the biological element's response to increased local pressures, including thresholds used for defining boundaries between ecological status classes. (D) CC affects the biological element's ability to recover when local pressures are decreased due to measures. (From Moe et al. 2010a).

With respect to ecosystem services: i) the costs of treating drinking water supply are likely to increase, ii) water supply for drinking and irrigation will be threatened in Southern Europe, iii) the quality of bathing water will deteriorate, iv) the value of lakes for sportsfishing may be reduced, v) the overall value of lakes for recreation may be reduced. And finally with respect to recommendations for river basin managers: i) monitoring of biological quality assessment metrics in a set of reference lakes to assess the nature and degree of any change will be required, ii) improved monitoring of lakes impacted by eutrophication is crucial to assess whether the nutrient reduction measures and other restoration efforts are sufficient to achieve good status, iii) if only one BQE can be prioritised then phytoplankton should be selected as the BQE responding most strongly to eutrophication, iv) any change in lake type should be considered before the programme of measures is revised, v) climate change impacts on lakes are probably still small enough to be compensated with small to moderate additional restoration efforts in the 2nd RBMPs, vi) climate change impacts are expected to increase in the coming years and may thus require major improvements in nutrient reduction measures for the 3rd RBMP if good status and sufficient provision of ecosystem services are to be achieved in 2027.

We have furthermore established a number of guiding principles concerning various aspects of the WFD such as the risk assessment, status assessment of lakes, objective setting, and the programme of

measures (Del. 3.21). These include:
Principle 1 assures that reducing external nutrient loading to lakes remains the key for successful lake restoration and meeting water quality targets also in CC conditions. Based on studies made in REFRESH it is shown that critical nutrient loading to achieve and maintain good ecological status in lakes has to be lowered in a future warmer climate as natural mechanisms that support zooplankton grazing weaken. Although in most studies, P is considered the most important limiting nutrient in lakes, several authors advocate consideration of both N and P.
Principle 2 suggests that water managers consider the dominant cascading effects in lake food chains and advocates for using zooplankton in lake monitoring schemes. A number of studies within REFRESH have demonstrated that increasing pressure exerted by planktivorous fish on zooplankton in warmer climates may cause rapid and dramatic increase in phytoplankton including cyanobacteria. Understanding the trophic cascade of a lake is the key for interpreting changes in variables characterizing the WFD ecological status, making future predictions and selecting effective restoration measures.
Principle 3 emphasizes the importance of geographic, and type-specific differences of lakes for selecting appropriate conservation, adaptation and restoration measures and distinguishes between three types of lake sensitivity: fast reaction, "memorizing" of past conditions, and proneness to system shifts exemplified by a number case studies.
Principle 4 stresses the importance of developing clear prioritization principles in order to diminish potential conflicts and trade-offs between management measures. Uncoordinated sectoral responses can be ineffective or even counterproductive, because a response in one sector can increase the vulnerability of another sector and/or reduce the effectiveness of its adaptation responses.

Results of the experimental work on riparian wetlands have been (and are being) disseminated to the broader scientific community via peer-reviewed publications and presentations at conferences and other (scientific) meetings. In addition, a summary report on the experimental results for a more general audience has been produced (Del 4.4) with a special focus on putting the results in a perspective relevant to riparian wetland management, conservation and restoration. This Del is available on the REFRESH website and its contents can be translated and used by all partners in national communications. All partners have been in intensive contact with local stakeholders such as water boards and landowners through their experimental sites, and have disseminated knowledge also through tv presentations and talks addressing a more general public. In addition, its contents form the basis of brief communications on REFRESH results targeting specific, relevant audiences. Finally, during the past four years of research on riparian wetlands a great number of junior researchers and PhD students (>8), MSc students (>10) and BSc students (>10) have been trained in scientific research, riparian wetland ecology, freshwater management, conservation, and restoration, and their education and skills will hopefully contribute to better European wetland management. This not only contributes to the growing population of skilled workforce able to deal with climate change effects on freshwaters, but also to awareness raising.

A modelling framework has been developed that takes integrated scenarios of climate, land management, water use and atmospheric deposition change as input to biophysical catchment models that represent connected river-lake-wetland systems, and determines the long-term, and is some cases, seasonal changes in flow and water quality and key ecological indicators. This framework is applicable on a catchment-by-catchment basis and thereby considers the nuances of each and is compatible with the basic management unit on which the Water Framework Directive is based: the river catchment. The parameter sets from the model applications will be made available allowing others to use the models with some idea of parameters that can be left ‘as factory settings’ and suggested parameter ranges for certain catchment types. The biophysical modelling framework has been used in conjunction with cost-effectiveness analysis to identify which measures will best help reduce nutrient pollution today and fifty years hence when set against the background of projected environmental change. A new generation of models, based on Bayesian Networks, have been trialled to incorporate multiple stresses on key ecological indicators.

The catchment biophysical monitoring highlighted a paucity of baseline flow, water quality and biological data in southern Europe. It is recommended that the EU provide the resources to support environmental monitoring in this region which is most at risk from the direct impacts of climate change. In REFRESH case studies for these regions, nutrient water quality appears of secondary importance to flow and other water quality elements, such as salinity and water temperature.

The general picture presented from the catchment modelling is that the predicted effects on waters differ between the northern and southern sites. In the north and mid-latitudes, the increased temperatures are balanced to some extent by increased precipitation, leading to relatively small effects on water flows, though seasonal effects may still be important. In the south, increased temperatures and lower precipitation act in the same direction to reduce water flows considerably. In the case of Lake Beysehir, this may even lead to the lake drying up in the foreseeable future, and this effect would far outweigh any nutrient-related problems. In general, the effects of climate change alone on nutrient concentrations are rather small. The effects of credible land use changes are rather larger, and generally, the land use changes representing future “environment-focussed” storylines (B1 and B2) reduce nutrient concentrations, and those from the “economic, market driven” storylines (A1 and A2) increase them. However, there are exceptions and considerable differences in response between sites. The responses seem more dependent on the mixture of nutrient sources (e.g. agriculture versus wastewater) than the degree of climate change. Modelled ecological changes are not generally proportional to the changes in nutrients. Ecological change can be less than the nutrient change (e.g. chlorophyll at Lake Beysehir and the Orlik Reservoir in the Czech Republic) or greater due to a complex set of reactions in the food web (e.g. at the IJsselmeer). Modelled mitigation options can reduce nutrients, and there is no evidence here that they are less effective under a future climate. With less certainty, mitigation options can affect the ecological status of waters at these sites in a positive manner leading to an improvement in Water Framework Directive status at some sites. Uncertainty in the climate models, as represented by the differences between the three GCM-RCM combinations used in this study, does not affect this overall picture much, though there are differences at individual sites.

Mitigation measures were generally effective in reducing nutrient concentrations in current climates. Mitigation strategies were generally aimed at improving ecological outcomes and hence tended to target P. Reductions in nitrate concentrations were therefore much lower than those of total P and SRP. Mitigation strategies continued to work with future climates, though in some cases the effects were small. The initial status of the sites covered a wide range of WFD categories. Mitigation gives a general reduction in risk, and can cause sites to cross boundaries between WFD classes in a favourable direction.

The socio-economic work has involved collating large amounts of material from disparate sources in selecting sub-catchments. Significant networks have been built with local stakeholders and national experts and it is clear that there is strong interest in the thematic challenges that WP6 in particular and REFRESH in general, set out to address. More important, the intensive consultation of stakeholders promotes an important aim of the project, namely to co-construct water management solutions which are not only effective (in terms of compliance and costs), but are also feasible both economically and socially, and thus have a strong chance to be actually adopted in the demonstration catchments. This particular analysis of WP6 is expected to promote a new approach on the selection of mitigation and adaptation interventions at local scale across Europe.

Furthermore, the policy implications of WP6 findings are considered important for agricultural policy and especially for Pillar 2 agri-environmental measures, which represent a very significant proportion of EAFRD funds dedicated to rural development. WP6 findings point out to four important policy rules, which if applied, are expected to enhance policy efficacy.

The first policy rule is to “express policy targets in the units used by the targeted environmental standard”. This will force policy makers to an ex-ante assessment of their proposed policy with science based nutrient transport models.

The second policy rule is to “climate change proof” the policy. Policy designers should ensure that, due to the long term commitments of agri-environment programmes, the proposed measures will continue to achieve compliance under expected changes such as climate and land use changes, and will continue to be cost effective, i.e. they will continue to achieve compliance with the lowest possible cost. This will force policy designers to proposed mitigation measures that are “climate change proofed”, i.e. will achieve cost efficient compliance under changing future conditions. Thus, measures would be designed in a way to allow transition to a stricter abatement level if changes are unfavourable or to looser abatement if changes are favourable with the lowest cost. This can be achieved by using science based nutrient transport models that simulate nutrient concentrations under changed environmental conditions. Thus, farmers would be a priori informed that, if conditions change, they will have to adopt transitional measures.

The third policy rule is to “unravel and flag all wider and associated benefits”. If a proper benefit assessment is carried out, especially for WFD related agri-environment programmes, the habitats and biodiversity non-use values should be measured and the target population should be expanded outside the limits of the local population and the benefits due to use values.

The fourth policy rule is to “take account of disproportionality and affordability effects” and establish firm grounds for possible departures from the Polluter-Pays-Principle.

The main socio-economic and wider societal impacts of work done under WP7 to date is that stemming from the dissemination of Project results to the stakeholders concerned with management of freshwaters. In the final year of the project a major effort was undertaken to ensure that the research output reached target stakeholders in an accessible way (during stakeholder meetings, science-policy interface events, through policy briefs, newsletters and summary leaflets) to maximise potential uptake and therefore impact. With the key messages for management and policy delivered directly to those responsible for making and implementing policy we believe we the work done in REFRESH has the potential to provide managers with ways to improve implementation of the Water Framework Directive and policy makers with suggestions as to how the design of the Directive might be improved during the next stage of its revision. More detailed dissemination are described below.

Dissemination activities

The Project web was developed and updated throughout the course of the Project. It provides an introduction to the Project aims, objectives and work programme, access to the REFRESH publication bibliography, links to related projects and organisations and includes a section giving access to publications and deliverables from the Euro-limpacs Project. A list of deliverables is provided in the public part of the Web site and clicking a deliverable that has been submitted links to an abstract describing the deliverable. All publically available deliverables can be downloaded from this part of the web site without the need for a restricted login. It also served as a management tool providing news, information, access to documents, work package resources and a means of communicating with different groups within the consortium. REFRESH news items were continually updated. The Web site was continually updated with news from REFRESH. Stakeholder meetings in key case study catchment were summarised with links to reports and publicity fliers. Details about project meetings and the activities of other freshwater projects (e.g. WISER and BioFresh) were provided. Reports from the REFRESH regional stakeholder meetings in the UL, Norway, Estonia and Turkey were added along with an account of the joint REFRESH / BioFresh Science Policy Symposium in Brussels. Links to presentations and video footage from the meetings were included. The results section of the Web was expanded to highlight the key messages from the project with links to more detailed output. A separate section on Policy Briefs from REFRESH was added to the main menu as part of the REFRESH commitment to disseminate output to stakeholders as well as the scientific community. This has been achieved both at the local level (in REFRESH case study catchments) and at the pan-European level (e.g. Joint Science / Policy symposium).

A series of dissemination materials has been produced for use by the consortium. These include a generic poster and Powerpoint presentation and a REFRESH flier. Three REFRESH newsletters were produced in the final reporting period and circulated widely via the REFRESH Stakeholder Database and the networks of contacts of RERESH scientists all over Europe. The Newsletter is also publicly accessible on the REFRESH web site. The first of these provided a general introduction to the REFRESH work programme highlighting the experimental work and the modelling case studies. The second focused on the outputs of the four regional stakeholder meetings in Norway, Estonia, UK and Turkey. The final newsletter showcased work undertaken at each of the modelling / cost-effectiveness case studies. In the case of the Thame study, this was supplemented by a leaflet providing more detail of the stakeholder activities undertaken in this sub-catchment of the Thames. This was circulated locally but also held up as an example of the successful stakeholder engagement underpinning REFRESH work in the case study catchments

REFRESH has been represented at numerous national and international workshops and meetings. These have included policy oriented meetings, national and local stakeholders meetings and international conferences. REFRESH established links with the CIS:SPI community and the SPI Water Cluster Projects

(STREAM, Water DISS 2.0 and WISE-RTD) with the intention of strengthening the effectiveness of the REFRESH dissemination activities. This led to a review of the REFRESH dissemination strategy and much of this was guided by the recently published 'Roadmap for uptake of EU water research in policy and industry'

Five regional stakeholder meetings were held in Estonia (two meetings), UK, Turkey and Norway. A report from each of these (Deliverables 7.7-7.10) in additional to one in Australia organised by Griffith University. A summary of each of the European meetings was included on the REFRESH web site with links to the presentations and to video footage (for the UK and Turkish meetings) of these.

The final reporting period saw continuing development of the Climate-and-freshwater.info web site. This now includes case studies from REFRESH as well as a section on restoration practices and guidelines, particularly in the context of global change.

The modelling and cost-effectiveness/disproportionality analyses undertaken at each of six REFRESH case study sites were synthesised and presented as a Deliverable for each catchment. These syntheses have been added to the Project Web site.

In partnership with the EU FP7 project BioFresh, REFRESH organised a Science Policy Symposium for Freshwater Life with the aim of bringing together policy makers and stakeholders from the water, energy and conservation sector, NGOs, the scientific community and selected experts to discuss challenges in implementation of the 2020 Biodiversity strategy and the EU Water Framework Directive and to agree on recommendations for policy making and future research. The scientific advances of BIOFRESH and REFRESH were presented (along with those of a number of other FP7 projects), and the implications of these for the freshwater management in the EU were discussed with the aim of highlighting clear recommendations for policy making. The Symposium sought to support the implementation of the Biodiversity Strategy 2020 and the EU Water Framework Directive (and its potential revision) and to create synergies across them building on the best recent knowledge on the current and future status of freshwater ecosystems and their inherent biodiversity. REFRESH has increased understanding of freshwater ecosystem response to climate and land use change and develops tools to support adaptive management.

BIOFRESH delivered policy relevant data and results on the current status, trends, pressures and conservation priorities of freshwater biodiversity.

The symposium aligned key research findings with the needs of policy making and generate policy-relevant messages relating to:
• Conservation planning and management of freshwater biodiversity in the context of Green Infrastructure and Natura 2000.
• Future protected area networks considering environmental scenarios and policy targets
• Freshwater biodiversity data and information to contribute to recent activities in ecosystem assessments by JRC, EEA and the European Commission
• Achievements of WFD good ecological status under climate and land use change scenarios
• Interlinkages between biodiversity, water related policies and other policy sectors (e.g. energy,

agriculture and cohesion) to infer recommendations on synergies for their implementation.

A series of policy briefs were produced toeards the end of the project highlighting some of the policy and management implications of REFRESH output. These focused on;
i) Zooplankton-an integrative Biological Quality Element for assessing the Ecological Status of lakes
ii) Riparian Forest can help mitigate climate warming effects in lowland temperate streams
iii) Stricter nutrient loading limits help lake ecosystems to withstand climate change pressures
iv) Stronger need for maintaining environmental flow in streams in a changing climate

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Related documents

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