SEVENTH FRAMEWORK PROGRAMME

THEME 6: Environment (including Climate Change)

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

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Deliverable 1.3: Review of the practical adaptation strategies adopted here in REFRESH for rivers (WP2.6), lakes (WP3.6) and wetlands (WP4.6)

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

Abstract

The focus of the REFRESH project is a process-based evaluation of the specific adaptive measures that might be taken to minimise the consequences of climate change on freshwater quantity, quality and biodiversity. The focus is on three principal climate-related and interacting pressures: increasing temperature, changes in flow regimes and increased excess nutrients, primarily with respect to lowland rivers and their riparian wetlands and shallow lakes because these often pose the most difficult problems in meeting both the requirements of the WFD and Habitats Directive.

In the WP2, WP3 and WP4 tasks 1-3 adaptation and mitigation strategies already under discussion at the European scale are experimentally tested with the objective to quantify how such strategies work and can be implemented.

The main objective of this Deliverable is to set the scene for the experiments performed in the REFRESH project by reviewing the available knowledge on some important adaptation and mitigation measures already being practised in Europe and argue why these experiments add to the knowledge needed to bring these measure further into practice.

The choice of experiments is based on the adaptation measures common for lowland streams, shallow lakes and riparian wetlands of lowland streams, respectively. The focus is to gather quantified knowledge on the effects of:

- the amount of shading needed to cool a lowland stream
- low flows and droughts in lowland streams
- combined effects of temperature, low flow/drought and nutrient load in lowland streams
- temperature in combination with different nutrient levels in lakes
- water level fluctuation on eutrophication in lakes
- combined effects of temperature, low flow/drought and nutrient load in lakes
- temperature on riparian wetland vegetation and soil processes
- flooding on riparian wetland vegetation and soil processes
- combinations of nutrients and flooding in riparian wetland vegetation and soil processes

Content

1. Introduction

1.1 Introduction to WP1 Task 1 Adaptation, mitigation and restoration strategies

Understanding how freshwater ecosystems will respond to future climate change is essential for the development of policies and implementation strategies needed to protect aquatic and riparian ecosystems. The future status of freshwater ecosystems is, however, also dependent on changes in land-use, pollution loading and water demand. In addition, the measures that need to be taken to restore freshwater ecosystems to good ecological health or to sustain priority species as required by EU Directives need to be designed either to adapt to future climate change or to mitigate the effects of climate change in the context of changing land-use. The focus of the REFRESH project is a process-based evaluation of the specific adaptive measures that might be taken to minimise the consequences of climate change on freshwater quantity, quality and biodiversity. The focus is on three principal climate-related and interacting pressures: increasing temperature, changes in flow regimes and increased excess nutrients, primarily with respect to lowland rivers and their riparian wetlands and shallow lakes because these often pose the most difficult problems in meeting both the requirements of the WFD and Habitats Directive.

Practical management strategies are urgently required by river basin managers either to adapt to future climate change or to minimise the effects of future change. In the WP2, WP3 and WP4 tasks 1-3 adaptation and mitigation measures already under discussion at the European scale are experimentally tested with the objective to quantify how such measures work and can be implemented.

The main objective of this Deliverable is to set the scene for the experiments performed in the REFRESH project by reviewing the available knowledge on some important adaptation and mitigation measures already being practised in Europe and argue why these experiments add to the knowledge needed to bring these measure further into practice.

WP2's field experimental studies focuses on small lowland streams to disentangle key (multiple) drivers and ecosystem responses to changes in temperature (Task 2.1), flow (Task 2.2) and nutrients (Task 2.3). The field experiments are repeated in six climate regions along the latitudinal climate gradient and under two levels of nutrient load (equivalent to two different land-use/management regimes with two lowland streams per climate region).

WP3's field experimental studies focuses on lakes

WP4's field experimental studies focuses on riparian wetlands along lowland streams to disentangle key (multiple) drivers and ecosystem responses to changes in temperature (Task 4.1), inundation regime (Task 4.2) and nutrients (Task 4.3). The field experiments are repeated in six climate regions along the latitudinal climate gradient and under two levels of nutrient load (equivalent to two different land-use/management regimes with two lowland streams per climate region).

The adaptation measures studied in the experiments are according to water/landscape type listed below.
In lowland streams:

- Planting trees to reduce temperature plus other effects of trees (Task 2.1 tests the amount of shading needed to cool a lowland stream).
- Water retention in upstream areas and riparian zones to prevent flow to pass critical thresholds (Task 2.2 tests the effects of low flows and droughts).

- Nutrient reduction to counteract multiple stress (Task 2.3 tests the combined effects of temperature, low flow/drought and nutrient load)

In lakes:

- A further reducing of the input of nutrients (Task 3.1 tests the link between temperature in combination with different nutrient levels).
- Control water level fluctuation to mitigate climate induced changes in precipitation (Task 3.2 tests the effects of water level fluctuation on eutrophication).
- Reduce the input of nutrients in lakes (Task 3.3 tests the combined effects of temperature, low flow/drought and nutrient load).

In riparian wetlands:

- Restoring riparian wetlands to reduce temperature rise (Task 4.1 tests the effects of temperature on wetland vegetation and soil processes).
- Water storage and retention in riparian wetlands (Task 4.2 tests the effect of flooding on riparian wetland vegetation and soil processes).
- Water storage and retention and de-eutrophication in riparian wetlands (Task 4.3 tests the combined effects of nutrients and flooding on riparian wetland vegetation and soil processes).

2. Temperature

2.1 WP2 Task 2.1: Temperature constraints on management success in rivers

The earth's surface dissipated solar energy or heat load by evaporation and condensation of water. This cooling function is one of the most important feedback mechanisms of the earth's ecosystem (Ripl & Hildmann 2000). A much smaller amount of this energy is dissipated by photosynthesis and mineralisation cycles of organic material. Vegetation place the crucial role in this feedback mechanism as it smoothens temperature gradients. Main drivers affecting atmospheric heat load are air temperature, solar angle, cloud cover, topographic shade, upland vegetation, precipitation, wind speed, and relative humidity. The solar energy entering streams controls the light availability for photosynthesis and the thermal regime of the stream. The thermal regime in its turn influences both instream chemical and biological processes.

Stream water temperature is dependent on both heat load and stream discharge; any process that influences heat load to the channel or discharge in the channel will influence stream water temperature and can be considered a driver of stream temperature (Poole & Berman, 2001). Moore et al. (2005) differentiated between:

- input of heat: solar radiation, long wave radiation, upstream temperature discharge, groundwater inflow (O'Driscoll & DeWalle 2006), tributary inflow and temperature (Poole & Berman 2001)
- output of heat: reflection, downstream temperature and discharge
- in- and output of heat: turbulent exchange (sensible and latent heat), bed heat conduction, hyporheic exchange

The riparian zone is the land area influenced by stream-derived moisture. Thus, the edge of a river is not its channel margin, but the edge of the riparian zone (Poole & Berman, 2001). Stream water temperature is determined by the interaction between the external drivers (such as solar radiation, air temperature, and wind speed) and the internal structure of the integrated stream system. Riparian shade is often an important component of a stream as (reviews by Poole & Berman, 2001; Moore et al., 2005; Quinn & Wright-Stow, 2008):

- it controls stream water temperature with large effects in small (1 and 2 order) streams (Anbumozhi et al. 2005), moderate effects in medium (3 and 4 order) streams, and low effects in in large (5+ order) streams
- it plays a role in protecting stream invertebrates from direct effects of UV radiation (Kelly et al. 2003)
- it reduces near-stream wind speed and in this way the convectional and advectional heat exchange at the water-atmosphere interface (Poole & Berman 2001)

Low stream water temperatures will reduce the mortality of fish and invertebrate species in mid-summer caused by temperature stress (Ghermandi et al. 2009), especially of cold-thermic species (Hendry et al. 2003). Furthermore, low temperature will reduce the risk for dissolved oxygen depletion.

Although there is convincing evidence about the importance of the riparian zone in stream water temperature control, especially from forestry research, only in few cases (e.g. Twery & Hornbeck 2001) the water goals have resulted in concrete management recommendations.

Besides the direct effect of the riparian zone on water temperature (Poole & Berman 2001; Moore et al. 2005; Quinn & Wright-Stow 2008) it also affects other ecosystem structures and processes, such as:

- creating a distinct terrestrial (Moore et al. 2005, Olson et al. 2007, Brooks et al. 2009) and instream microclimate (Hendry et al. 2003)

- stabilizing stream banks (Poole & Berman 2001)
- providing biotic connectivity (Rykken et al. 2007)
- supplying the stream with large wwod and coarse organic material
- providing intrinsic ecological value (Brooks et al. 2009)
- controlling water quality (Mander 2005, 2008)
- diminishing instream plant growth (Ghermandi et al. 2009, Kohler et al. 2010)
- reducing the light intensity (Boothroyd et al. 2004, Ensign & Mallin 2001, Kohler et al. 2010) and thus algae and macrophyte growth and nutrient uptake
- reducing surface and sub-surface inflow of nutrients and sediments

Riparian habitat rehabilitation is vital for a healthy stream ecosystem (Poole & Berman 2001; Davies-Colley & Rutherford 2005). The width of the riparian buffer width depends on the stream size to provide shading which maintains the moderated instream microclimate (Anderson et al. 2007). There is no consensus regarding the most effective buffer width to protect stream ecosystems although Olsen et al. (2007) indicated:

- ~10 m for retaining stream bank stability to reduce sedimentation
- ~15–30 m for maintaining instream habitat attributes such as water temperature, litter and wood inputs
- ~40– 100 m for a more conservative approach for provision of instream habitat conditions with benefits to riparian-dependent species.

Other authors indicated different widths such as 5-30 m (Meleason & Quinn 2004), 15-29 m (Lee et al. 2004), 30 m (Rykken et al. 2007) or >11 m (Wilkerson et al. 2006). Anderson et al. (2007) indicated that the strongest effects were expressed in the forst 10 to 15 m width.

But none discussed the effects of the length of the riparian buffer. In WP2 Task 2.1 this question is tackled.

WP2 Task 2.1: Shading experiment

Temperature constraints on management success in rivers are addressed in REFRESH WP2 Task 1. 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 are studied. 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. The temperature change effects on river ecosystem structure and functioning along a gradient from un-shaded to fully shaded lowland streams are studied.

Adaptation measure: Planting trees to reduce temperature plus other effects of trees.
Objective: To assess the overall effect of planting trees along streams in relation to the length of the stream.
Questions of managers:

- What length of wooded riparian zone is necessary for effective management?
- What about secondary effects such as habitat heterogeneity?

2.2 WP3 Task 3.1: Temperature constraints on management success in lakes

As in rivers solar radiation is the most important heat source in lakes. There is some exchange with air and sediment but most heat enters through absorption. In the majority of lakes, the vertical temperature distribution (thermal structure) and the intensity of vertical mixing are determined predominantly by meteorological forcing at the lake surface. A change in weather or climatic conditions affecting this local meteorological forcing will therefore alter both thermal structure and vertical transport by mixing, which in turn will affect the flux of nutrients and dissolved oxygen, as well as the productivity and composition of the plankton (Imboden 1990, Reynolds 1997).

More in detail the main physical mechanisms that determine the thermal structure of a lake act at the lake surface. In order of importance, these are: (i) the absorption of atmospheric long-wave radiation; (ii) the emission of long-wave radiation from the lake surface; (iii) the absorption of direct and diffuse short-wave solar radiation; (iv) the exchange of latent heat of evaporation/condensation; and (v) the convective exchange of sensible heat (Edinger et al., 1968). In addition to affecting the overall lake thermal structure, changes in in the above-mentioned mechanisms would also result in changes inthe vertical heat distribution within the water column.

Mostly, the temperature in lakes changes with seasonal changes in air temperature. Daily variation also may occur, especially in the surface layers, which are warm during the day and cool at night. In deeper lakes (>5 m for small lakes and >10 m for larger ones) during summer, by warming the water separates into layers of distinctly different density caused by differences in temperature (stratification). In winter inverse stratification can occur. Once the stratification develops, it persists until the air temperature cools again in fall. Because the layers don't mix, they develop different physical and chemical characteristics. For example, dissolved oxygen concentration, pH, nutrient concentrations, and species of aquatic life in the upper layer can be quite different from those in the lower layer. The most profound difference is usually seen in the oxygen profile since the isolated bottom layer consumes oxygen while in the upper layer it is produced. Because of their smaller volume and absence of stratification in summer, shallow water bodies are less influenced by meteorological conditions in the preceding winter than deeper water bodies, and respond more directly to the prevailing weather conditions (Gerten & Adrian 2000, 2001).

Lake water temperature also exerts influence on water chemistry. The rate of chemical reactions generally increases at higher temperature, which in turn affects biological activity. An important example of the effects of temperature on water chemistry is its impact on oxygen. Warm water holds less oxygen that cool water, so it may be saturated with oxygen but still not contain enough for survival of aquatic life. Some compounds are also more toxic to aquatic life at higher temperatures. Temperature is reported in degrees on the Celsius temperature scale

Most aquatic organisms are cold-blooded ("poikilothermic"), meaning they are unable to internally regulate their body temperature. Therefore, temperature exerts a major influence on the biological activity and growth of aquatic organisms. To a point, the higher the water temperature, the greater the biological activity will be. Fish, macroinvertebrates, zooplankton, phytoplankton, and macrophyte species all have preferred temperature ranges. As temperatures get too far above or below this preferred range, the number of individuals of the species decreases until finally there are few, or none. Changes in the growth rates of cold-blooded aquatic organisms and many biochemical reaction rates can often be approximated by the rule, which predicts that growth rate will double if temperature increases by 10°C within their "preferred" range.

Long time series analyses of physical and biological characteristics of fresh water ecosystems in Northern Europe have shown that climate change affects:

- the winter concentration of nitrate nitrogen (George et al. 2004)
- the concentration of dissolved reactive phosphorus (George et al. 2004)
- the timing of seasonal succession events of phytoplankton and zooplankton (Muller-Navarra et al. 1997, Weyhenmeyer et al. 1999, George 2000, Gerten & Adrian 2000, Straile 2000, Straile & Adrian 2000; Straile 2002, Carvalho & Kirika 2003; George et al. 2004).

However, differences in lake morphometry and site specificity result in differences in the relative effect of climate change on ecosystem variables (Gerten and Adrian 2001; George et al. 2004). Several parameters are primarily and more specifically important in large, shallow lakes with changes in temperature (e.g. Mooij et al. 2005):

- mineralisation, de-nitrification, and sulphate reduction

- period of ice-cover
- wind effects

Secondary effects of temperature changes are changes in:

- nutrient loading and algal blooms
- oxygen regimes
- residence time
- water level (droughts)
- salinisation
- exoic species, diseases
- food web mismatches, changes in phenology, biomass
- disappearance of cold stenothermic species
- increase in terrestrialisation

Several recent studies suggest that temperature increase will enhance eutrophication symptoms in lakes and reservoirs. The mechanisms involved are complex and are also affected by temperature induced changes in physical conditions such as duration of stratification, oxygen content in the water and release of nutrients from the sediment. Little is known about the effect on metabolisms and biodiversity and how a climate change induced increase in temperature will counteract measures presently implemented worldwide to restore the lakes from eutrophication.

WP3 Task 3.1: Temperature experiments

Temperature constraints on management success in lakes are addressed in REFRESH WP3 Task 1. The effects of climate-driven changes in temperature regimes on structure and function of lakes and reservoirs across Europe are studied by: (i) longer-term field mesocosm experiments with a focus on metabolisms, including oxygen dynamics, nitrogen (N), phosphorus (P), and carbon (C) turnover and accumulation, and (ii) analysing the temperature effect on physical conditions, nutrient level, trophic structure, metabolisms, phenology and biodiversity using existing long-term data series and monitoring data. A special focus will be on lakes in recovery from eutrophication and subjected to lake restoration (e.g. biomanipulation, chemical treatment).

Adaptation measure: A further reducing of the input of nutrients.
Objective: To assess the overall temperature effect on eutrophication to both quantify climate proof nutrient thresholds and advice no-regret measures in nutrient input reduction.
Questions of managers:

- To what level do I have to reduce nutrient input to lakes?
- Can I counteract warming of lakes?

2.3 WP4 Task 4.1: Impacts of temperature change on wetland functioning and biodiversity

The riparian wetland encompasses the stream channel between the low and high water marks and that portion of the terrestrial landscape from the high water mark toward the uplands where vegetation may be influenced by elevated water tables or flooding and by the ability of the soils to hold water (Naiman et al. 1993, Naiman et al. 1997). The width of the riparian zone, the level of control that the streambed vegetation has on the stream environment, and the diversity of functional attributes (e.g. information flow, biogeochemical cycles) are related to the size of the stream, the position of the stream within the drainage network, the hydrologic regime, and the local geomorphology (Decamps 1996,Junk et al. 1989, Naiman & Decamps 1990, Rot et al. 1997, Salo et al. 1987). Vegetation outside the zone that is not directly influenced by hydrologic conditions but that contributes organic matter (e.g. leaves, wood, dissolved materials) to the floodplain or channel, or that influences the physical regime of the floodplain or channel by shading, may be considered part of riparian zones (Brosofske et al. 1997, Gregory et al. 1991).

Streams are dynamic ecosystems that have strong effects on the abiotic and biotic characteristics of riparian wetlands. The active stream channel and the floodplain are harsh environments for the establishment and survival of plants and animals (Naiman et al. 1997). Regularly, the riparian wetland is subjected to flood, erosion, abrasion, drought, freezing, and occasionally toxic concentrations of ammonia in addition to the normal biotic challenges. Therefore, the adaptation strategies of most riparian wetland organisms are such that extreme conditions are either endured, resisted, or avoided (Agee 1993, Grime 1979, Naiman et al. 1997). In general, riparian plant communities are composed of specialized and disturbance-adapted species (Naiman et al. 1997).

Complex interactions among hydrology, geomorphology, light, and temperature influence the structure, dynamics, and composition of riparian zones (Brinson 1990, Malanson 1993). The physical influence of temperature on the riparian wetland community is less well investigated than either hydrology or geomorphology. Riparian forests exert strong controls on the microclimate of streams, but there are few comprehensive studies of the riparian wetland microclimate itself. Stream water temperatures are highly correlated with riparian soil temperatures, and strong microclimatic gradients appear in air, soil, and surface temperatures and in relative humidity but not in short-wave solar radiation or wind speed (Brinson 1990). Riparian wetlands further influence stream discharge through evapotranspiration. Reduced stream flow increases water temperatures and as such causes physiological difficulties for cold water species (Hicks et al. 1991).

Weather, especially temperature and precipitation, exert a decided influence on most physical and biological processes of riparian wetlands. Regional weather factors interact with local conditions (topography, elevation, aspect, soil factors, and characteristics of surface water) to determine the types of vegetation in a given wetland or riparian area (Walters et al. 1980). More specific, precipitation controls the frequency and magnitude of major disturbances such as floods. Temperature directly influences the character of soils by controlling physical and chemical reactions and various biological processes (Buol et al. 1973).

Riparian wetland soil temperature influences the microbial activity (decomposition rate of organic material, denitrification rate). The activity further depends on the presence of phosphorus, nitrogen, carbon, moisture and the absence of oxygen. In riparian wetlands, anaerobic situations associated with decomposing organic matter fragments allow denitrification in otherwise well-drained soils. Decomposition and mineralization also return inorganic P to the soil solution or surface water. Rates of plant litter decomposition depend on substrate quality (including C:P ratios), physicochemical conditions such as pH, calcium content, redox potential, soil moisture, and temperature, and these are in turn related to the hydrological regime (Koerselman et al., 1990). Through microbiological processes sulphur is transformed and can occur in several oxidation stages. Reduction leads to changes in the redox potential scale and sulphides provide the characteristic 'bad egg' odour of some wetland soils. The redox potential is in fact a key parameter and decides on the reactivities and mobilities of elements, such as Fe, S, N, C and a number of metallic elements. Reactions involving electrons and protons are pH and redox potential dependent. The redox potential is further a measure of intensity and does not represent the capacity of the system for oxidation or reduction (Scholz & Lee 2005).

Still, the direct influence of temperature on the structure and functioning of riparian wetland is less well studied. It is clear that changes in temperature initiate a chain of responses in microbial soil processes as well as the role of the riparian wetland for the stream temperature regime but its direct links are not yet quantified.

WP4 Task 4.1: Temperature experiments

The impacts of temperature change on wetland functioning and biodiversity on the hydrology, chemistry, ecological functioning and biodiversity of riparian wetlands is addressed in Task 4.1. The effects of climate-driven changes in temperature regimes on the success of management measures in riparian wetlands, on structure and functioning of river ecosystems, and on changes in river biodiversity are studied. The re-creation or enlargement of non-wooded wetland area and increased frequency and duration of flooding aimed at increasing water storage capacity are studied as these comprise the main mitigation, adaptation and restoration strategies applied to these wetlands.

Adaptation measure: Restoring riparian wetlands to reduce temperature rise.
Objective: To assess impacts on the success of management strategies applied to riparian wetlands for the restoration and conservation wetland functioning and biodiversity of temperature rise.
Questions of managers:

- How do I have to re-create a streams riparian wetland to mitigate temperature rise?
- How wide a riparian wetland should be and what vegetation type best mitigates temperature rise?

3. Low flow and drought

3.1 WP2 Task 2.2: Low flows and drought constraints on management success in rivers

Stream flows resulting from the complex hydrological balance of the landscape undergo naturally large seasonal and inter-annual changes. During low flows that occur in summer and in soil frost areas also in winter, water is normally derived from groundwater discharge or surface discharge from lakes, marshes, or melting glaciers. Low flow periods are critical for the river ecosystems structure and functioning and are most vulnerable in these periods both to human impact and climate change.

Aquatic biota, by definition, are characterised by adaptations to an existence in water. Therefore, artificial or natural drying will stress or even eliminate these biota from aquatic environments. A more advanced view is that the impact of drought on the biota in different aquatic environments varies, influenced by factors such as hydrological history (did the site dry before?), the timing and severity (duration and intensity) of the drying disturbance, and the presence of drought refuges. Finally, climate change alter the timing or increase the severity of drought for sure impact most aquatic biota depending on the natural water regime of a specific environment.

In a stream or wetland, as stream flow reduces or drying commences, the littoral zone or riparian zone becomes isolated, reducing the habitat suitability for both many groundwater depend wetland plants and aquatic macroinvertebrates that feed, shelter or emerge in the littoral (Ormerod, Wade & Gee 1987, Wright et al. 1994, Harrison 2000). For example, roots or vegetation can offer refuge from current and fish predation, can provide complex habitat structure and food for a variety of herbivores and detritivores, offer attachment points for filter-feeding macroinvertebrates, and can function as exit points for emerging insects with aerial adult stages (Williams & Feltmate 1992). As the water level decline progresses and the flow ceases in a stream, it will become fragmented into wet and dry soil substrates and pools. The loss of current eliminates many rheophilous taxa almost immediately and prevents drift as a means of recolonisation (Williams 1977); pool formation will change the macroinvertebrate composition because of isolation and physic-chemical changes (Stanley et al., 1994). During declining flow water quality will deteriorate as dissolved oxygen concentrations decline, water temperature and major ion concentrations rise, and many animals will eventually die (Larimore, Childers & Heckrotte 1959). The disappearance of surface water is the most critical stage for most aquatic macroinvertebrates and fish, and occurs when the water table no longer breaks the surface or when the last water in a perched wetland evaporates. At this phase, numerous dead and dying invertebrates provide food for terrestrial consumers in a pulsed transfer of carbon and energy between ecosystems (Boulton & Suter 1986, Williams 1987). Saturated organic heaps or interstitial spaces below dried soil also constitute a refuge for some aquatic macroinvertebrates (Williams 1987). In many wetlands, where drying is a relatively common event, desiccation-resistant stages of many crustaceans and some insects can persist in the sediments (Crome & Carpenter 1988, Jenkins & Boulton 1998), remaining viable for decades (Hairston et al., 1995). Many insect taxa found in intermittent streams also have eggs or juvenile stages that can survive drying (Boulton 1989, Miller & Golladay 1996). In fact, droughts can be described as catastrophes that steadily get worse as droughts persist (Lake 2000, 2003).

Apart from the biological responses to low flow and droughts, these may result in changes of the abiotic environment by (e.g. Caruso 2002):

- increased sedimentation that changes the morphology of the stream channel and flood plain,
- aggravation of the effects of water pollution due to reduced dilution capacity,
- increase in water temperatures,
- bacterial contamination due to increased livestock use of streams and decreased dilution,
- increased concentrations of phosphorus, nitrogen and other soluble substances,
- increased conductivity due to evaporation.

Climate change will contribute to low flow conditions both due to temperature increase and decrease in precipitation in summer. The other principal activities by which flow regimes are modified include land-use changes such as drainage and agricultural/forestry practices, water abstraction and water transfer between catchments, impoundment and flow regulation, and hydroelectric power generation. The effects of the various human activities are to reduce flow, to increase flow, and to modify patterns of flow fluctuations. Human activities affecting flow processes include amongst other groundwater and surface water abstraction, floodplain drainage for agricultural or construction purposes, changes of the vegetation (including afforestation) in the stream valley through clearing or planting that modify the evapotranspiration loss from riparian soils, catchment urbanisation, river abstractions for industrial, agricultural or municipal purposes, and construction of dams and subsequent regulation of a river flow regime.

Despite the extended knowledge on the responses of stream ecosystems to drought under natural or re-occurring conditions, little is known about the effects of low frequent events of both low flow and drought in permanent lowland streams.

WP2 Task 2.2: Low flow and drought

Low flows and drought constraints on management success in rivers are addressed in REFRESH WP2 Task 2.2. The effects of climate-driven low flows and droughts on the management success in rivers, on structure and functioning of river ecosystems, and on changes in river biodiversity are therefore studied. The focus will be low flows and droughts in relation to completeness and naturalness of in-stream habitats (including the role of dryland river refugia) 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 are used as indicators. By the use of controlled field experiments low flow and drought is simulated.

Adaptation measure: Water retention in upstream areas and riparian zones to prevent flow to pass critical thresholds.
Objective: To establish the critical threshold for low flow (drought) in lowland streams.
Questions of managers:

- What minimum flow is acceptable to sustain WFD indicators in lowland streams?
- How long can a summer drought last without affecting the lowland stream community?

3.2 WP3 Task 3.2: Effects of water level fluctuations and salinity in lakes

Many lakes and reservoirs will undergo major changes in water level due to climate change, not least in southern and eastern Europe with major impacts also on nutrient state and salinity and consequently trophic structure, metabolisms and ecological state. The effect of enhanced drought will be reinforced by compensatory higher water abstraction for irrigation and water supply. Sea level rise and water level decline due to intensive irrigation may also enhance the risk of salt intrusion and salinisation of coastal lakes.

The functioning of lakes is partly controlled by the quantity and periodicity of the water resource independent of lake size, depth, basin origin and climate. Water level fluctuations are a decisive element of hydrology, especially in shallow lakes as these are particularly sensitive to any rapid change in water level and input. Therefore, water level fluctuations may have an overriding effect on the ecology, functioning and management of lakes. Water level fluctuations may occur on different time scales ranging from short-term (e.g. wind-driven oscillations) to annual, interannual and interdecadal (Blindow 1992, Gafny & Gasith 1999, Beklioglu et al. 2001). In particular, annual fluctuations may have a structuring role in spatial and temporal extension and functioning of littoral and aquatic-terrestrial transition zones. In undisturbed shallow-lake wetlands, this in turn may create great habitat diversity from fringing wet meadows towards open pelagic water, which should naturally support high species diversity. The amplitude of fluctuations, which is the difference between maximum and minimum levels, depends largely on climatic features of a given region and also on human use. The amplitudes of fluctuations in lakes seem to depend principally on local climatic conditions. On the other hand, anthropogenic factors, like global climatic change and human water use may strongly alter the amplitude, whereby it becomes far higher or lower than natural. This may become a strong disturbance and affect the state of shallow lakes (Coops et al. 2003).

The biological responses to water level fluctuations differ. Small changes of water level may result in a large shift in plant communities. For example, littoral helophytes can be completely dependent on slight fluctuations that expose substrate for germination and/or flooding seedlings. Analogously, desiccation and inundation tolerance determine the distribution of many species along the high and low water level zone. Furthermore, high water levels in spring may limit submersed plant expansion inducing a shift to a sparsely vegetated state, whereas a substantial reduction in spring lake level may encourage expansion of submersed plants (Coops et al. 2993).

Water level fluctuations can cause lakes to shift between clear-water and turbid states, shifts that are independent of nutrient enrichment and top-down effects (Wallsten & Forsgren 1989, Blindow 1992, Beklioglu et al. 2001). These shifts affect in turn species richness and diversity. Extreme fluctuations may exceed the physiological limits of biota. However, benthic invertebrate and to a lesser extent fish communities withstand periods of low water or desiccation provided their timing and extent are reasonably predictable. If invertebrates cannot time the emergence of adults to the beginning to the dry season, many taxa endure drought as larvae by becoming physiologically inactive or burrowing into the sediment profile to follow moisture gradients (e.g. Leslie et al. 1997, Chapman, 2001).

Climate is of great importance for lake water level as it determines the inputs, the outputs and the residence time of water. Hydrological extremes (floods and dry periods)

are predicted to take place through climatic change which may produce regionally different responses. Coops et al. (2003) listed the anticipated effects of climate-induced water-level change:
For semi-arid to arid climates (e.g. Mediterranean region):

- Reduced groundwater inputs (longer drought periods, higher contribution of surface water).
- Salinisation.
- Effects on nutrient retention capacity (enhanced denitrification, phosphorus mobility).
- Foodweb effects (e.g. increase in submerged plant cover-induced increased species diversity such as waterfowl).
- Intensity and duration of freezing (effect on oxygen concentrations and sedimentation).

For wet temperate regions:

- Increased ground water input.
- Increased phosphorus input through raised water table and surface water flux.
- Increased denitrification under waterlogged conditions.
- Decreased submersed plant coverage and species diversity.
- Increased water storage-flooding due to heavy precipitation conditions.

The role of water level fluctuations in lakes is far from being fully understood, since they respond in a non-linear way to disturbance. However, a limited number of studies have suggested that water level fluctuations may be a catastrophic disturbance for submersed plant communities since excessively high water level in the growing season reduces light availability, while a low water level may damage plants via ice and wave action during winter and desiccation during summer (Coops et al. 2003). To a certain extent, water level management can provide a useful tool for lake restoration (Coops & Hosper 2002) and climate change mitigation.

WP3 Task 3.2: Water level fluctuation experiments

The effects of water level fluctuations and salinity in lakes are addressed in WP3 Task 3.2. This task focuses on the direct and indirect (e.g. change in salinity) effect of water level change at low and high TP concentration on structure, function and metabolism of lakes and reservoirs. Special focus will be on shallow water bodies as they are most vulnerable to changes. In Task 3.2 joint field experiments were undertaken along an eastern latitude gradient in Europe to better understand how changes in water level (salinity) and nutrients affect trophic structure, function and metabolisms and the benthic-pelagic coupling in lakes.

Adaptation measure: Control water level fluctuation to mitigate climate induced changes in precipitation.
Objective: To provide the scientific basis for adaptive lake management to counteract the effects of changes in water level (salinity).
Questions of managers:

- What key ecological and functional response parameters and indicators can be used in lake management?

3.3 WP4 Task 4.2: The impacts of changes in flooding on wetland functioning and biodiversity.

The hydrological factors that control a riparian wetland also directly control the biological components. In turn, these biotic processes impact the hydrological conditions of this wetland. Furthermore, the hydrology directly affects the biochemical processes, nutrient availability as well as other physicochemical parameters, such as soil and water pH and anaerobiosis within the wetland soil. The net result of the in- and outputs of water, the hydroperiod, may show great seasonal variations but ultimately delineates wetlands from terrestrial and fully aquatic ecosystems. The hydrological regime definitely defines the species diversity, productivity and nutrient cycling of riparian wetlands. Water regime is a major determinant of plant community development and patterns of plant zonation in wetlands. It can be described by the depth, duration, frequency, rate of filling and drying, timing and predictability of flooded and dry phases in a wetland (Bunn et al. 1997).

The stability of riparian wetlands is directly related to their hydroperiod or the seasonal shift in surface and sub-surface water levels. Within riparian wetlands flood duration and flood frequency give some indication of the time period involved in which the effects of inundation and soil saturation will be most pronounced. Of particular relevance to riparian wetlands is the concept of flooding pulses (Junk et al. 1989). These pulses cause the greatest difference in high and low water levels and benefit wetlands by the input of nutrients and washing out of waste matter that these sudden high volumes of water provide on a periodic or seasonal basis. This natural fluctuation and its effects is particularly important, since wetland management often attempts to control the level by which waters rise and fall. Such manipulation might be due to the overemphasis placed on water and its role in the lifecycles of wetland flora and fauna, without considering the fact that such species have evolved in such an unstable environment (Fredrickson et al. 1990).

Several components of the hydrological regime already have been examined to determine their effect on plant processes. In Australia season of inundation affects germination of wetland species, with highest germination and the greatest species richness in the autumn and spring, and least germination in the summer (Britton & Brock 1994). Tolerance of dry periods governed growth of emergent species, whereas reproduction is affected by both frequency and depth of fluctuations (Smith 1998). Species richness on river banks was highest where drawdown had occurred, and where there was low within year variation in water level (Roberts 1994). The duration and depth of flooding affected individual emergent species distribution on floodplains due to species tolerance of anoxia (van den Brink et al. 1995), and the frequency of flood disturbances can affect species richness when an intermediate frequency of flooding events creates establishment opportunities for species and prevents competitive exclusion (Bomette & Amoros 1996) consistent with the Intermediate Disturbance Hypothesis (Connell 1978). Prolonged flooding eliminates some species while favouring others (van der Valk 1981) and the depth of flooding can have a significant effect on species composition and biomass of establishing plants (Seabloom et al. 1998). Plant communities are more likely to respond to the history of water levels than the water level at the time of survey (Roberts 1994; Tabacchi 1995) and exotic species can be more sensitive to changes in hydrology than native species (Tabacchi 1995).

The vulnerability of riparian wetlands to changes in climate depends on their position within hydrologic ‘width’ in the stream valley. Hydrologic ‘width’ or hydrological influence zone is defined by the flow characteristics of surface water and ground water and by the interaction of atmospheric water, surface water, and ground water for any given locality or region. The vulnerability of riparian wetlands to climate change is primarily dependent on discharge. But there is not yet a quantified example of the magnitude of response to hydrological regime, especially flooding, available for riparian wetlands.

WP4 Task 4.2: Wetland flooding experiments

The impacts of changes in flooding on wetland functioning and biodiversity are addressed in WP4 Task 4.2. The effects of climate-driven changes in water level fluctuations on riparian wetlands, in particular the effects of changes in flooding regime (increased surface inundation) are studied. The experimental sites within the cross-European are expanded, within which the water flow is diverted along the experimental streams to create a gradient of increasingly dry wetland conditions during summer and increasingly inundated conditions during winter. Along hydrological gradients hydrological characteristics, biogeochemical and ecological functioning and biodiversity are quantified over several years.

Adaptation measure: Water storage and retention in riparian wetlands.
Objective: To provide the scientific basis for adaptive riparian wetland management to counteract the effects of changes in precipitation.
Questions of managers:

- How can I reconstruct a riparian wetland and combine it with water retention together without biodiversity consequence.
- What other role can such wetlands play?

4. Nutrients

4.1 WP2 Task 2.3: Nutrient and organic material constraints on management success in rivers

Phosphorus is an essential element which can be found in several biological macromolecules. The environmental hazards associated to the emission of phosphorus to the aquatic environment are related to its role as algae and plant nutrient. When phosphorus is the limiting factor and the environmental conditions favour the process, the algal or macrophyte growth rate increase associated to the phosphorus emissions may provoke an excessive development of algal or plant populations (or some opportunist species within the algal community) leading to structural changes in the ecosystem and, in some cases, extraordinary algal blooms resulting in fish kills, invertebrates impairment and even macrophytes mortality due to anoxic conditions derived from that. The phenomenon is known as eutrophication and phosphorus is just one of the factors involved in the process. Eutrophication compromises the beneficial uses of waters and can generally be perceived as an undesirable degradation of the environment; causing, in many cases, significant economic losses.

The external supplies of phosphorus and nitrogen, as the two most important nutrients, to aquatic ecosystems come from a wide variety of sources, including groundwater, fluvial, and atmospheric ones. This external load can originate both as point as nonpoint sources and their relative contributions can differ substantially from catchment to catchment, depending upon degreeof urbanisation and type and intensities of land use. Nutrients can have profound effects upon the quality of receiving waters (Carpenter et al. 1998, Correll 1998) and can result in enhanced plant growth. However, the environmental consequences of excessive nutrient enrichment can result in losses of their component specie and of the amenities or services that these systems provide (Postel & Carpenter 1996, US EPA 1996a, Carpenter et al. 1998).

Although the majority of freshwater eutrophication research during the past several decades has focussed on lakes and reservoirs, the nutrient enrichment of streams is also of great concern. Smith et al. (1997) for the US, Moss et al. (1989) for the UK and Kohler & Gelbrecht (1998) for Germany all reported significant eutrophication of the majority of streams and rivers. Despite, these findings the prevailing view still is that many rivers are insensitive to nutrient inputs (e.g. Hynes 1969). This view is based on the misconception that other physical, chemical, and biotic factors restrict the effects of eutrophication in rivers and streams. For example, light availability will limit biomass accumulation of benthic algae (periphyton) in low-order streams shaded by extensive forest canopies (Gregory 1980, Triska et al. 1983) or high concentrations of inorganic suspended solids (Hoyer & Jones 1983). Also the continuously presence of hydraulic flow forces that erode algae, the short water residence time that reduces growth potential as well as herbivore grazing that diminish algae population, all will reduce periphyton standing crops in flowing waters. Flowing waters thus were frequently perceived as nutrient saturated but this view does not stand anymore. Streams and rivers waters are proven to be sensitive to anthropogenic inputs of N and P, both by number of field studies (e.g. Huntsman 1948, Correll 1958, 1998, Elwood et al. 1981, Peterson et al. 1983, 1985, Gregory 1980)) and several laboratory experiments (e.g. Krewer & Holm 1986, Horner et al. 1990, Triska et al. 1983). Nutrient limitation of algal growth in streams and rivers is both common and widespread. The nutrient enrichment of streams and rivers typically is accompanied by increases in the biomass of suspended and/or benthic algae (Smart et al. 1985; Soballe & Kimmel 1987, Lohmann et al. 1991, Welch et al. 1992, McGarrigle 1993, Basu & Pick 1996, Van Nieuwenhuyse & Jones 1996, Dodds et al. 1997, 1998). Although the production of algae per unit total P often is significantly lower in rivers than in lakes and reservoirs due to higher washout loss rates (Soballe & Kimmel 1987, Van Nieuwenhuyse & Jones 1996).

Nutrient enrichment of flowing waters can cause a variety of water quality problems (Smith et al. 1999):

- Increased biomass and changes in species composition of suspended algae and periphyton
- Reduced water clarity
- Taste and odor problems
- Blockage of intake screens and filters
- Fouling of submerged lines and nets
- Disruption of flocculation and chlorination processes at water treatment plants
- Restriction of swimming and other water-based recreation
- Harmful diel fluctuations in pH and in dissolved oxygen concentrations
- Dense algal mats reduce habitat quality for macroinvertebrates and fish spawning
- Increased probability of fish kills

Efforts to restrict fluxes of N and P from the landscape into streams and rivers are necessary to improve the eutrophication-related water quality. The degree of nutrient loading control required to maintain satisfactory water quality varies from site to site, and the objective criteria used in judging acceptable versus non-acceptable water quality are not yet as well developed as for lakes and reservoirs, with a few exceptions (McGarrigle 1993, Miltner & Rankin 1998). Additional estimates of critical in-stream nutrient levels have been derived by Dodds et al. (1997) from a large comparative analysis of stream ecosystems. These authors concluded that maintenance of stream water total N concentrations <350 mg N m^3 and total P concentrations <30 mg P m^3 would be necessary to keep benthic algal biomass below nuisance levels of 100 mg m^2. Still, the knowledge base of eutrophication science for streams and rivers is far behind that for lakes and reservoirs, quantitative tools that link stream water nutrient concentrations and in-stream water quality are needed. Above this the combined effects of different stressors, like temperature rise and nutrients or low flow and nutrients are fully unknown.

WP2 Task 2.3: Nutrients

Nutrient and organic material constraints on management success in rivers are addressed in REFRESH WP2 Task 2.3. The effects of climate-driven changes in nutrient spiralling and organic material processing on the success of management strategies in rivers, on the structure and functioning of river ecosystems, and on changes in river biodiversity are studied. The focus will be on nutrients and organic matter in relation to the construction of riparian buffer strips/floodplain wetlands to establish water retention along small-sized lowland streams. Indicators (of both structure and ecosystem functioning) reflecting key nutrient and organic material conditions will be integrated in a shading – low flow/drought – nutrient/organic material load experiment. By the use of controlled field experiments the combined effects of nutrients on stream and on a number of ecosystem and physico-chemical parameters is tested.

Adaptation measure: Nutrient reduction to counteract multiple stress.
Objective: To establish the interaction effects of nutrients and low flows and droughts in lowland streams.
Questions of managers:

- What nutrient concentrations are acceptable under which (minimum) flow conditions in lowland streams?
- Do nutrients matter in lowland streams and if yes, what is the threshold acceptable?

4.2 WP3 Task 3.3: Nutrients and organic matter constraints on management success in lakes

In Europe, most lakes were once dominated by submerged plants (macrophytes) and had clear water. Several mechanisms stabilized these macropyte dominated state (Moss 1999), such as nutrient competition between macrophytes and algae and provision of refuges for invertebrate grazers on periphyton or phytoplankton. Increased nutrient loading as a result of various human activities converted lakes to turbid, algal dominated water bodies (Moss, Madgwick & Phillips 1996). Several processes, like damaging the macrophytes (vertebrate grazing, mechanical damage, herbicide run-off or treatment) or indirectly influencing the effectiveness of invertebrate grazers (changes in fish community, toxins, increased salinity), provided algal populations the opportunities to suppress plant growth and become dominant. The thresholds at which these changes acted have not been precisely quantified but appear to be influenced by nutrient availability (Jeppesen et al. 1997). The greater the nutrient load, the more likely it is that a turn over to phytoplankton dominance will take effect. Eutrophication is the key pressure impacting on lake ecosystem structure and functioning and there is a lot of knowledge on the eutrophication process, and restoration methods to combat it.

Another important pressure is climate change but on that pressure much less is known as well as about how climate change and eutrophication pressures interact, and specifically how global warming could potentially interfere with any recovery process. Much of the research on climate change impacts has focused on high altitude (Psenner & Schmidt 1992) or deep, stratifying lakes (George et al. 1990). Fewer studies have examined the impact of climate change on lowland, shallow lake systems (Carvalho & Moss 1999, Pettersson et al. 2003), and even fewer examine the response to climate change and eutrophication trends acting simultaneously (Scheffer 2001, Nõges et al. 2003). Climate, both directly and indirectly, affects lake physics (temperature, flushing), chemistry (DOC, pH, nutrients) and biology, therefore, climate-driven change can potentially obscure or exaggerate the eutrophication process.

Climate change will alter lakes but specific effects will vary among regions and lake types. In general, climate change will likely (Mooij et al. 2005) (i) reduce the numbers of several target species of birds; (ii) favour and stabilize cyanobacterial dominance in phytoplankton communities; (iii) cause more serious incidents of botulism among waterfowl and enhance the spreading of mosquito borne diseases; (iv) benefit invaders originating from the Ponto-Caspian region; (v) stabilize turbid, phytoplankton-dominated systems, thus counteracting restoration measures; (vi) destabilize macrophyte-dominated clear-water lakes; (vii) increase the carrying capacity of primary producers, especially phytoplankton, thus mimicking eutrophication; (viii) affect higher trophic levels as a result of enhanced primary production; (ix) have a negative impact on biodiversity which is linked to the clear water state; (x) affect biodiversity by changing the disturbance regime. Water managers can counteract these developments by reduction of nutrient loading, development of the littoral zone, compartmentalization of lakes and fisheries management.

WP3 Task 3.3: Experiments on lake de-eutrophication

Nutrients and organic matter constraints on management success in lakes are addressed in REFRESH WP3 Task 3.3. The effects of climate-driven changes in nutrient dynamics and organic matter processing are studied on (i) the structure, function and biodiversity of lake ecosystems; (ii) the successes of management measures in lakes; and (iii) interactions between temperature and multiple hydrological stressors in natural and eutrophied (restored) lakes.

Adaptation measure: Reduce the input of nutrients in lakes.
Objective: To better understand processes of eutrophication and other stressors, induced by climate and land-use/management change, upon managed and restored lake ecosystems.
Questions of managers:

- To what threshold do I have to reduce my nutrient levels to mitigate climate change?
- Can I take other measure to counteract climate change effects?

4.3 WP4 Task 4.3 Impacts of nutrient loading on effects of increased temperature and flooding

The substances that play the key role in the soils of riparian wetlands are oxygen, carbon, nitrogen, phosphorus and (Scholz & Lee 2005). During flooding the soil becomes de-oxygenated and anaerobic processes prevail, while during dry periods oxygen will enter the soil pores and oxygenates the upper layers. As riparian wetlands are associated with temporarily dry and waterlogged to inundated soils, the concentration of oxygen within sediments and the overlying water is of critical importance for the biochemical processes. The latter will show great temporal variation. The state of reduction or oxidation of iron, manganese, nitrogen and phosphorus ions determines their role in nutrient availability and also toxicity. Anaerobic degradation of organic matter is less efficient than decomposition occurring under aerobic conditions. The duration of inundation and thus the level of reduction of riparian wetland soils is therefore important in understanding the chemical processes that are most likely to occur in the sediment and influence the above water column.

During flooding the soil becomes anaerobic and the following processes take place:

- Organic matter is usually degraded by fermentation and methanogenesis (Boon & Mitchell 1995).
- Sulphate is converted to to sulphide (Mitsch & Gosselink 2000).
- Release of gaseous nitrogen through denitrification (Mitsch & Gosselink 2000).
- Mineralisation of nitrogen to ammonium (ammonification).
- Reduction of ferric iron to the more soluble ferrous form whereby phosphorus as ferric phosphate (reductant-soluble phosphorus) is released into solution (Gambrell & Patrick 1978, Faulkner & Richardson 1989).
- Change of pH by organic, nitric or sulphuric acids produced by chemosynthetic bacteria causes phosphorus to be released into solution.
- Lowering of pH causes phosphorus sorption to clay particles (Stumm & Morgan 1996).

During the dry phase the soil becomes aerobic and the following processes take place:

- Mineralisation of ammonium to nitrite and subsequently to nitrate (nitrification).
- Denitrification (nitrate loss through N2) (Bachand & Horne 1999, Lund et al. 2000).
- Nitrogen fixation.
- Precipitation with ferric iron, aluminium (both under acid conditions) and calcium and magnesium (in alkaline soils) of insoluble phosphates.
- Dissolved reactive phosphorus levels peaks.

- Absorption of phosphates onto clay particles, organic peat and ferric/aluminium hydroxides and oxides.
- Uptake of phosphorus in organic matter by bacteria, algae and vascular macrophytes.
- Sedimentation of suspended solids during flooding causes phosphorus retention (Fennessy et al. 1994, Wang & Mitsch 2000).
- Oxidation of sulphides to elemental sulphur and sulphates (Scholz & Xu 2001, Rivera et al. 1995).

The physical, chemical and biological characteristics of a riparian wetland system affect the solubility and reactivity of different forms of phosphorus. Phosphate solubility has been shown to be regulated by temperature (Holdren & Armstrong 1980), pH (Mayer & Kramer 1986), redox potential (Moore & Reddy 1994), interstitial soluble phosphorus level (Kamp-Nielson 1974) and microbial activity (Gächter et al. 1998, Gächter & meyer 1993). Riparian wetland plants have consequently evolved to be able to survive in anaerobic soils. Furthermore, macrophytes assimilate phosphorus predominantly from deeper sediments, thereby acting as nutrient pumps (Carnignan & Kaill 1980, Smith & Adams 1986). There is an increase in total phosphorus in the water column in the presence of macrophytes mainly during the non-growing period, with little effect during the growing season. Most phosphorus taken from sediments by macrophytes is reincorporated into the sediment as dead plant material and therefore remains in the wetland indefinitely.

The general mass balance for a wetland, in terms of chemical pathways, uses the following main pathways: inflows, intrasystem cycling and outflows. There is great variation in the chemical balance from one wetland to another, but the following generalizations may be made:

- Wetlands act as sources, sinks or transformers of chemicals depending on wetland type, hydrological conditions and length of time the wetland has received chemical inputs. As sinks, the long-term sustainability of this function is associated with hydrologic and geomorphic conditions as well as the spatial and temporal distribution of chemicals within wetlands.
- Particularly in temperate climates, seasonal variation in nutrient uptake and release is expected. Chemical retention will be greatest in the growing seasons (spring and summer) due to higher rates of microbial activity and macrophyte productivity.
- The ecosystems connected to wetlands affect and are affected by the adjacent wetland.
- Upstream ecosystems are sources of chemicals, while those downstream may benefit from the export of certain nutrients or the retention of particular chemicals.
- Nutrient cycling in wetlands differs from that in terrestrial and aquatic systems. More nutrients are associated with wetland sediments than with most terrestrial soils, while benthic aquatic systems have autotrophic activity which relies more on nutrients in the water column than in the sediments.
- The ability of wetlands to remove anthropogenic waste is not limitless.

Riparian wetlands are ecosystems under the influence of adjacent streams or rivers (Scholz & Trepel 2004). There are four main reasons as to why the periodic flooding, which is typical of riparian wetlands, contributes to the observed higher productivity compared to adjacent ecosystems:

- There is an adequate water supply for vegetation.
- Nutrients are supplied and coupled with a favourable change in soil chemistry (e.g. nitrification, sulphate reduction and nutrient mineralization).
- In comparison to stagnant water conditions, a more oxygenated root zone follows flooding.

- Waste products (e.g. carbon dioxide and methane) are removed by the periodic ‘flushing’.

Nutrient cycles in riparian wetlands can be described as follows:

- Nutrient cycles are ‘open’ due to the effect of river flooding, runoff from upslope environments or both (depending on season and inflow stream or river type).
- Riparian forests have a great effect on the biotic interactions within intrasystem nutrient cycles. The seasonal pattern of growth and decay often matches available nutrients.
- Water in contact with the forest floor leads to important nutrient transformations. Therefore, riparian wetlands can act as sinks for nutrients that enter the system as runoff and/or groundwater flow.
- Riparian wetlands have often appeared to be nutrient transformers, changing a net input of inorganic nutrients to a net output of their corresponding organic forms.

As climate change affects both temperature as precipitation and thus riparian wetland flooding the combined effects need to be known to improve management and mitigation measures.

WP4 Task 4.3: Nutrients

Impacts of nutrient loading on effects of increased temperate and flooding are addressed in REFRESH WP4 Task 4.3. The interactions between climate-driven changes in temperature and flooding with land-use driven changes in nutrient loading are studied. The potential effects of climatic changes cannot be studied independently from predicted land-use change effects, in particular the effect of increased nutrient loading to aquatic and riparian systems. Sites in catchments with moderate and high levels of nutrient enrichment are compared along a climatic gradient. Differences in nutrient loading will help to identify interactions between changes in temperature, inundation regime and nutrient loading.

Adaptation measure: Water storage and retention and de-eutrophication in riparian wetlands.
Objective: To provide the scientific basis for adaptive riparian wetland management to counteract the effects of changes in precipitation and nutrient enrichment.
Questions of managers:

- How can I reconstruct a riparian wetland and combine it with water retention and nutrient reduction.
- What other role riparian wetlands can play in reducing nutrient effects of climate change?

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