Climate Change Adaptation and Mitigation Measures in the EU Water Environments

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1. Introduction

European water bodies are already suffering from a number of human activities, such as physical modifications, water abstraction, pollution with nutrients, heat and hazardous substances. Where their conditions allow, they are still being used for fisheries, transport, energy production, and recreational activities. The effects of climate change (CC) are already clearly manifested in some water related aspects like the seasonal flow patterns in rivers, stratification and water level regimes in lakes, frequency of extreme events (floods and low flow), or phenological changes in aquatic food chains and much bigger changes are expected in the near future. The last report by the International Panel on Climate Change (IPCC) declares it unequivocal that the world is heating up beyond any natural cyclical variations, and that there is 90 per cent certainty that the phenomenon of climate change is caused by humans. Mitigation and adaptation form a two-pronged strategy for dealing with climate change causes and consequences.

Climate mitigation is any action taken to reduce or eliminate the long-term risk and hazards of climate change to human life and property. The IPCC defines mitigation as: "An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases".

Climate adaptation refers to the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damage, to take advantage of opportunities, or to cope with the consequences. The IPCC defines adaptation as the "adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation."

Climate change represents a major challenge for the management of freshwater resources as water is the main channel through which the impact of climate change will be felt and the key to developing successful adaptation strategies (OECD 2013). The carbon balance of aquatic and terrestrial ecosystems is tightly linked with cycles of other nutrients, first of all with nitrogen and phosphorus, and with the CNP stoichiometry in food webs (Peñuelas et al., 2013). All these processes are sensitive to climate change (CC) and transform as a result of global trends. The recent study by Stips et al. (2016) unambiguously shows that greenhouse gases (GHG), and specifically CO_2, are the main causal drivers of the recent warming. Paradoxically, climate change itself could have a minor impact on water bodies compared to indirect pressures from human responses to climate change (both adaptation and mitigation) (WFD 2000, CIS 2009).

CC mitigation measures aim to reduce GHG emissions while adaptation measures should reduce the vulnerability of societies and ecosystems to adverse effects of CC. In respect of water resources and ecological status of water bodies, the two approaches are often disconnected that, instead of synergies, can create trade-offs between them. It is well-known that large-scale biofuel production increases water demand and contamination, hydro-electric power plants fragmentise the river ecosystem integrity and affect biodiversity, dams and water reservoirs can emit additional GHGs, and seawater desalination as a drought combating measure accelerates energy consumption. It is much less known that even afforestration/reforestation, wetland reconstruction, floodplain restoration or creating buffer strips, usually considered as win-win measures (Nixon, 2008), may locally become antagonistic to other adaptation and mitigation measures. Given that ecosystems can provide mitigation and adaptation services at the same time, policies and local initiatives related to ecosystem management have the potential to contribute to both climate change strategies and to avoid trade-offs between them (Locatelli 2016).

As the IPCC report shows, besides a slow change of parameters, climate change is characterized by increased frequency of extreme events. Another most sensitive indicator of climate change is the time shift of seasonal events, i.e. changes in phenology.

If a few degrees change in mean temperature may be not very noticeable (given that the annual amplitude in temperate regions ranges over 50-60 degrees Celsius), the unexpected heat waves and cold spells often have detrimental impact on ecosystems (Gómez & Souissi, 2008) and human mortality rates (Conti et al., 2005). Shifts in the timing of the snowmelt (Bayard et al., 2005) and ice breakup (Goulding et al., 2009) affect the seasonal pattern of runoff, may cause ice jams in rivers, and shifts in phyto- and zooplankton development (Nõges et al, 2010), and fish spawning (Mooij et al., 2008). There are already clear increasing trends in winter runoff and lowering of the spring flood peak in the northern Europe (Saarinen et al., 2010). Large hydrological changes have occurred in watersheds at the permafrost boundary (Wang et al., 2009).

Recent climate projections (Strandberg et al., 2015) indicate an increase of precipitation in Northern Europe and a decrease in Southern Europe. The intensity of single rainfalls, however, is predicted to increase even in regions where the overall amount of precipitation decreases. This will cause flash floods, which may cause great economic damage in densely populated areas. Urbanization as one of the globalization phenomena leads to a rapid growth of impermeable surfaces (buildings, streets and roads, industrial areas, parking places), which further accelerates the runoff from urbanized areas.

Extreme events and seasonality changes represent the major challenges the adaptation measures have to address most urgently. Sea level rise puts several low lying areas in Europe under risk and requires long-term spatial planning and implementation of specific adaptation strategies to guarantee the safety and welfare.

This paper reviews the information available in reports and scientific literature about potential or planned water related measures tackling climate change causes and consequences. In this context, measures are defined as practical steps or actions taken to: (i) reduce the sources or enhance the sinks of greenhouse gases, (ii) to decrease the vulnerability of water resources and aquatic ecosystems to climate change, or (iii) enhance the knowledge base on climate-water relationships and increase the capacity of the society to take right decisions on this matter. The span of measures is wide both by the main purpose (flood management, water scarcity, water quality, biodiversity, CC mitigation), type of intervention (legislative, administrative, financial, educational, hydrotechnical, technological, land use), and especially by the scale of generalization. This situation reflects the fact that there is no consistency in using the terms ’measure’, ’action’ or ’strategy’ in the climate change literature and their hierarchic position and linkages with other measures is often obscure. Given the overlapping character and the enormous scale differences among measures, to make a comprehensive overview, in this paper the measures are grouped under a limited number of general principles which follow the generally conservative spirit of the environmental sustainability concept.

The need for sustainability arose from the recognition that the profligate, extravagant, and inequitable nature of current patterns of development, when projected into the not-too-distant future, leads to biophysical impossibilities (Goodland, 1995). The resulting goal of environmental sustainability is the unimpaired maintenance of human life-support systems - environmental sink and source capacities. As both human activities and climate change have globally intensified the water cycle (Huntington, 2006) and the mobility of substances (Klee & Graedel, 2004; Holland & Turekian, 2007), combating of the adverse impacts must be conservative and knowledge based. The measures could be grouped by the following three simple principles that are introduced in the following sections:

1. Keep things in place
2. Keep things natural
3. Be informed and plan your actions

2. Keep Things in Place

The leading role of anthropogenic carbon emissions in the acceleration of climate change has been unequivocally proven by the IPCC (2007, 2013, 2018), however, the scientific understanding of biophysical linkages of climate change to water cycle and aquatic ecosystems is still weak. There is much uncertainty, and hence an undeniable need for the wide application of the precautionary principle.

2.1 Keep Carbon in its Present Pools

According to the review by Lal (2008), the fluxes among the five global C pools (Fig. 1) are strongly anthropogenically influenced by fossil fuel combustion (>7.5 Pg C y^{-1} during the 2000s), land use conversion (deforestation) and soil cultivation (about 1.6 Pg C y^{-1}). The total anthropogenic emission of about 9.1 Pg C y^{-1} is balanced by retention of 4.1 Pg C y^{-1} (45%) in the atmosphere, uptake of 2.5 Pg C y^{-1} (27.5%) by ocean, and absorption of 2.5 Pg C y^{-1} (27.5%) by an unidentified terrestrial sink.

The process by which carbon sinks remove carbon dioxide from the atmosphere is known as carbon sequestration. During the 1980s and 1990s, global terrestrial ecosystems took up carbon at a rate of 1–4 Pg y^{-1} offsetting 10–60% of the fossil-fuel emissions (IPCC, 2007; Houghton, 2007). Because growing vegetation absorbs carbon dioxide, the Kyoto Protocol allows countries with large areas of growing forests to issue 'removal units' to recognise the sequestration of carbon. In the Clean Development Mechanism, only afforestation and reforestation are eligible to produce certified emission reductions in the first commitment period of the Kyoto Protocol until 2012 (LeBlanc, 1999; Olschewski et al., 2005).

Currently, the magnitude of the terrestrial carbon sink is decreasing by expanding land use (House et al., 2003; Hese et al., 2005). Soils represent a short to long-term carbon storage medium, and contain more carbon than all terrestrial vegetation and the atmosphere combined (Fig. 1). Organic matter tends to accumulate in litter and soils of colder regions such as the boreal forests of North America and the Taiga of Russia. Peatland drainage results in substantial emissions of carbon dioxide and nitrous oxide. The global figures presented by Parish et al. (2008) show that from the 550 Gigatonnes of peat carbon pools 2 Gigatonnes per year are annually emitted as CO_2 from degraded peatlands (including fires). In sub-tropical and tropical climate conditions, leaf litter and humus are rapidly oxidized and poorly retained due to high temperatures and extensive leaching by rainfall (Powers & Schlesinger, 2002).

At present, agriculture and associated land use changes emit about a quarter of the carbon dioxide (through deforestation and soil organic carbon depletion, machine and fertilizer use), half of the methane (via livestock and rice cultivation), and three-fourths of the nitrous oxide (through fertilizer applications and manure management) annually released into the atmosphere by human activities (Rosenzweig & Tubiello, 2007).

Because freshwater ecosystems cover only a small fraction of the Earth's surface area, lakes, rivers, and reservoirs have rarely been considered as important components of the carbon cycle at either global or regional scales. Inland aquatic systems are included in global models usually only for the transport of C through the riverine pipe. The review by Cole et al. (2007) on the role of inland waters in the global carbon cycle indicated that the 1.9 Pg C y^{-1} delivered from land to the freshwater exceeds the carbon finally delivered to the ocean by at least a factor of two. According to this review, lakes, reservoirs, large rivers, floodplains and estuaries are net sources of CO_2 to the atmosphere oxidising part of the carbon inflow from the watershed. Lakes contribution on average 0.11 Pg C y^{-1}, reservoirs 0.28 Pg C y^{-1}, the main channels of large rivers 0.23 Pg C y^{-1}, the inundated floodplains of the humid tropics 0.9 Pg C y^{-1}, and estuaries 0.12 Pg C y^{-1}. Ground water contributes a relatively small amount of CO_2 to the atmosphere (about 0.01 Pg C y^{-1} with large uncertainty). It is considered that wetlands still constitute a significant global net sink for CO_2 (Roulet, 2000; Roehm, 2005).

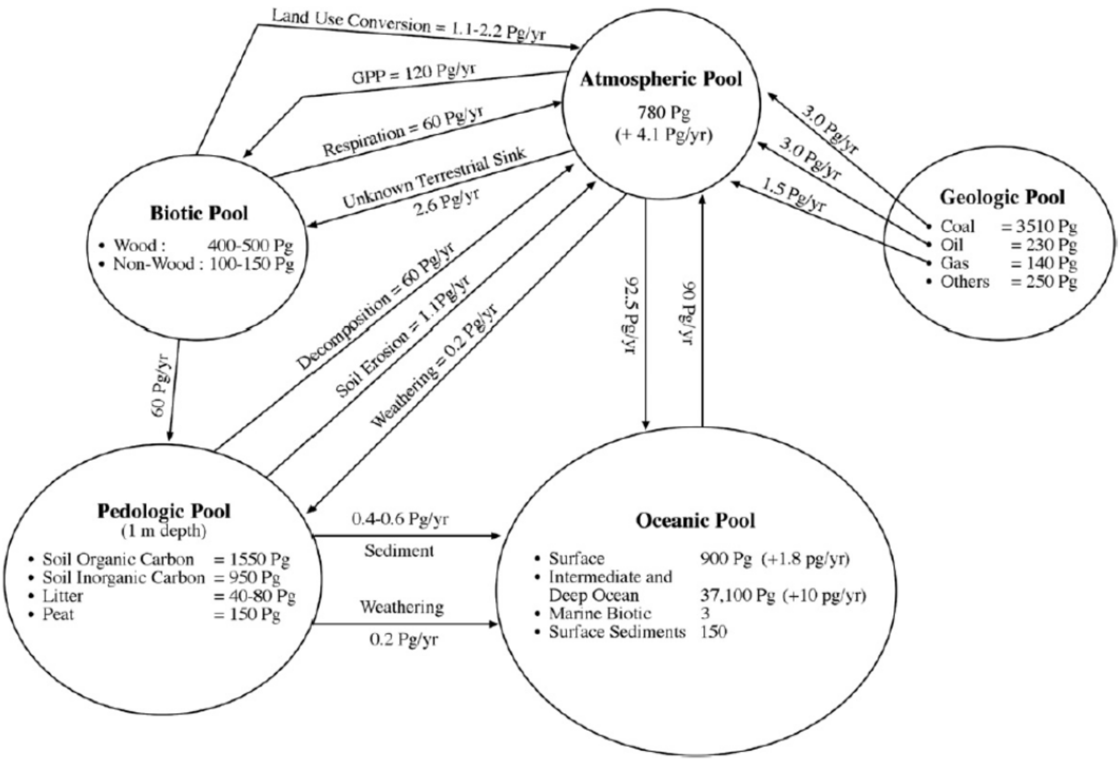

Figure 1. Estimates of the global carbon pools and fluxes between them (Lal, 2008)

By averaging the published estimates, Cole et al. (2007) reported an annual global storage of 0.05 Pg C y^{-1} for lake sediments that is about 30–60% of the value that the oceans store, but lakes do this in less than 2% of the area of the sea. According to the estimate by Downing et al. (2008), lakes bury even more organic carbon in their sediments than the entire ocean. Lake carbon burial can represent an important part of the total carbon stored in the watershed at the regional scale.

Carbon storage in sediments may be enhanced by eutrophication, reservoir and small pond construction, which slow down the flow rate. As gross primary production (GPP; carbon uptake rate) in lakes is mostly limited by phosphorus, Hanson et al. (2003) suggested that lakes with high total phosphorus (TP) concentrations and low dissolved organic carbon (DOC) concentrations tend to function as net carbon sinks, whereas lakes with low TP and high DOC tend to emit CO_2. Cole et al. (2000) showed that a lake has a net heterotrophic C balance at the mean seasonal chlorophyll a concentration below 20 mg m^{-2} and at GPP less than 140 mmol C m^{-2} day^{-1} or, assuming a 200 day ice-free season, a GPP below 330 gC m^{-2} $year^{-1}$. In their review Andersson and Sobek (2006) showed that the switching from net sink to net source occurred at DOC concentrations higher than 4–6 mg l^{-1}. Smith et al. (2002) and Downing et al. (2008) suggest that also small farm ponds may be quantitatively significant.

Possible Climate Change Mitigation Measures in Water Management

Reduction of CO_2 atmospheric loading can be achieved by biological, chemical and technological options through either reducing or sequestering emissions.

Hydropower continues to serve as an important alternative energy source to fossil fuel and nuclear power in many parts of the world and is the cheapest way to generate electricity today. The rise of public awareness of environmental issues of the early 1970s narrowed public acceptance of hydropower as an energy source and reduced significantly its role in the energy matrix in numerous countries (Sternberg, 2008). Measures proposed by the EU Member States regarding hydropower production vary by their scopes implying development of large and micro-scale hydropower capacities, dam removal, research on future water needs, and establishment of rules for the minimum residual flows at hydropower plants (Nõges T. et al., 2010 a,b).

Similarly, growing biofuel crops on arable lands could be a significant alternative to fossil fuels (Falloon & Betts, 2010) that, in addition, could reduce nitrate losses (Powlson et al., 2001) and soil erosion (Börjesson & Berndes, 2006). The biggest concerns, however, are related with increased uses of water, fertilizers and pesticides (Prabhakar & Elder, 2009; de Vries et al., 2010) and the competition for land with food crops production (Koizumi, 2015; Rulli et al., 2016).

A review of mitigation strategies in agriculture (Rosenzweig & Tubiello, 2007) showed that over the next 40 years, "best practice" and conservation tillage alone could store about 8 GT C in agricultural soils. The "best practice'' agricultural techniques, such as use of catch and cover crops and/or nitrogen fixers in rotation cycles, mulching, optimal use of fertilizers and organic amendments; soil water management improvements to irrigation and drainage, as well as the conservation tillage evolved as means to enhance sustainability and resilience of agricultural systems to water scarcity rather than with carbon sequestration in mind. Soil carbon stocks can be increased also by converting cropland to grassland or forest to increase soil C sequestration (Ogle et al., 2003; Falloon et al., 2004; Ostle et al, 2009).

Afforestation and reforestation have a number of positive on-site hydrological effects but are also qualified as effective climate change mitigation measures due to carbon sequestration in growing biomass and forest soil. Also peatlands are storehouses of large carbon quantities, thus reducing atmospheric greenhouse gases. However, peatlands remain carbon 'sinks' only as long as they remain in good status. Protection of wetlands and their restoration can contribute to lowering carbon emissions (Nõges T. et al., 2010 a,b).

Forest and peat fires release absorbed carbon back into the atmosphere, as does deforestation due to rapidly increased oxidation of soil organic matter. Creation of water retention reservoirs in forested landscapes could supply water for forest fire protection and thus be considered an emission reduction measure especially in the context of the projected increase in the forest fire frequency (Flannigan et al., 2000).

The guidance document on climate change issues in river basin management (CIS, 2009) suggests a 'climate checking' of the planned water management measures as a sensitivity analysis of the proposed measures to evaluate their long-term effectiveness and cost efficiency under changing conditions. This screening provides a good opportunity to assess also the carbon footprint of the measures. The SEPA, for instance, checked all proposed measures regarding the impacts on CO_2 emissions by putting the following questions (SEPA, 2009):

- Will the solutions lead to an increase or decrease in greenhouse gas emissions?
- Will the action help capture carbon in the soil or in vegetation?
- Will the action reduce energy use in the long-term?

2.2 Keep Water in the Catchment by Creating Retention Basins and Slowing Down the Run-off

The need to retain water in the catchment arises both in the case of excess water and when the water resources are scarce, the purposes, however, are totally different. In the case of floods, retaining the water in the upper catchment suppresses the peak flows while during drought periods, the retained water can be used for irrigation and other purposes (Nõges T. et al., 2010 a,b).

2.3 Keep Substances at Source Avoiding them Becoming Pollutants

Landscape ecological processes can be sustainable only if the necessary physical and chemical provisions of the site are maintained. Soil losses of carbon and/or inorganic matter through leaching and erosion degrade terrestrial ecosystems and create heavy loadings to aquatic ecosystems where these compounds, especially nutrients, become pollutants. Climate change altering the temperature regime and precipitation patterns accelerates also the cycling of toxic substances (Eisenreich, 2005). There are several, often rather simple ways to diminish the losses and support the resilience of ecosystems by keeping substances in place in the landscape (Nõges T. et al., 2010 a,b).

2.4 Keep Species Within Their Natural Habitats

The principle that species can effectively be protected only through protecting their habitats has been the basis for the EC Habitat Directive (EC, 1992). By the time this directive was adopted, Europe's natural habitats continued to deteriorate and an increasing number of wild species were seriously threatened mostly as a result of and agricultural intensification and urban development. These factors remain the leading factors threatening biodiversity, however, climate change starts adding to the pressures.

Hickling et al. (2005; 2006) showed that a wide variety of vertebrate and invertebrate species have moved northwards and uphill in Britain over approximately 25 years. Many species are potentially endangered (Hering et al., 2009) by climate change or, in contrary, are expected to expand their distribution areas in Europe (Ficetola et al., 2009).

Habitat and biodiversity protection in the context of climate change should include *inter alia* eventual restoration of habitats lost through sea level rise or increased flooding, monitoring and adjusting abstractions and other pressures which reduce river flows and groundwater levels for groundwater dependent and/or supported habitats and species, reducing of habitat fragmentation, protection and restoration of wetlands, rivers, and floodplains (Nõges T. et al., 2010 a,b).

3. Keep Things Natural

Keeping things natural means protecting and restoring the natural regulating function of catchments, rivers, floodplains and coasts in order to manage water quality and to alleviate flood and coastal erosion risk. This could involve diverse actions such as flow modification, floodplain reconnection instream and coastal habitat improvement, and riparian management. Restoring degraded peat bogs and reforestation will also help to slow run-off and increase infiltration. Sustainable urban drainage systems follow the same spirit of naturality in urban areas (Nõges T. et al., 2010 a,b).

Hydraulic modifications of rivers to reduce flood damages have a long history. Construction works were undertaken to prevent overbank waters and ensure unrestricted flow of flood volumes. For these purposes, rivers were straightened, channelized, and squeezed between embankments, disregarding the natural dynamics of the river and its ecosystem. According to a cartographic study in mid 1980s (Brookes, 1984), only about 900 km out of the 30,000 km of Danish watercourse of natural origin had retained their natural form. The main shortcomings of such river modification approach were summarized by Poulard et al. (2010) in the following three issues:

1. Acceleration the flow often results in aggravating floods downstream,
2. The disruption of the natural patterns can disrupt the sediment balance, hence causing erosion or deposits,
3. The consequences on ecosystems are often disastrous.

Geilen et al. (2004) and Poulard et al. (2010) have analysed effective flood-protection solutions with alleviated impacts on the ecosystems and advocate a close cooperation between biologists and hydraulic practitioners for finding best measures. The best practice document on flood prevention, protection and mitigation (EU, 2004) includes as the first basic principle: *As far as possible, human interference into the processes of nature should be reversed, compensated and, in the future prevented. It is necessary to promote and harmonise changes in water policies and land-use practices, as well as environmental protection and nature conservation, in order to improve flood management in the frame of Integrated River Basin Management.*

4. Be Informed and Plan Your Actions

A large and heterogeneous group of measures deals with administrative issues, planning, and capacity building in the sense of research, education and stakeholder involvement. According to temporal scale, these issues can be divided into long-term (most of strategic planning, research and education measures), medium-term (adaptive planning in the RBMP cycles) and short-term or operative issues, such as flood alert systems.

In a global change context, several recent advances in the field of hydrology and biogeochemistry suggest that a move from a riparian to a river drainage basin perspective is necessary to reframe research and thus provide a more integrated scientific understanding to inform water- and land-use management and policy (Pinay & Hannah, 2009; Lundqvist et al. 2012). Watersheds have been considered useful and globally applicable management units in which context to analyze and debate issues related to social and inter-generational health and equity, environmental change and social–ecological resilience (Parkes et al., 2010). Proposed measures like 'Implementation of river basin management plans', 'Integrated coastal zone management' or 'Development of management plans water resources in drought conditions' may sound too complex to be called measures, but this characterises the real situation with adaptation measures in Europe.

Community based adaptive management is the preferable way of watershed governance as it integrates social and ecological suitability to achieve conservation outcomes by providing landowners the flexibility to use a diverse set of conservation practices to achieve desired ecological outcomes, instead of imposing regulations or specific practices (Habron, 2003).

4.1 Uncertainty and the Precautionary Principle

Biophysical linkages in complex self-regulating systems are inherently uncertain that makes important considering the precautionary principle while making management decisions in these conditions. Adaptive management approach thrives on information collection and use, but it also enables action in the face of information shortage identifies uncertainties and establishes methodologies to test hypotheses concerning those uncertainties (Nõges T. et al., 2010 a,b).

4.2 Long-Term Capacity Development

Pinay & Hannah (2009) showed that uncertainties in predicting impacts may be attributed to limitation of historical data (in terms of duration, spatial coverage, homogeneity and so on) for model parameterisation, calibration, and validation; incomplete knowledge of complex process nonlinearity and feedbacks; general circulation model (GCM) scenarios; downscaling of GCM data to basin scale; and hydrological models. Although the future-oriented nature of any planning process remains uncertain, research can to some extent decrease the uncertainty by filling knowledge gaps. All climate change and adaptation strategies contain as a basic principle the research needs: to improve the temporal and spatial resolution of climate projections and to advance our knowledge on the relationships between climatic variations and water resources, ecosystems, flood risk, and pollution spreading. There is a need to develop methodologies for assessing potential damage of flood risk areas. Better climate change projections are especially important for planning large infrastructures like dams (Nõges T. et al., 2010 a,b).

Adaptive management uses management as a tool not only to change the system, but as a tool to learn about the system. It is concerned with the need to learn and the cost of ignorance, while traditional management is focused on the need to preserve and the cost of knowledge (Xue et al., 2018). If in Europe the need for education and advice to ensure efficient adaptation is stressed mostly at farm and regional scales, education in issues related to water saving and protection from pollution becomes vital in arid and drought prone areas. Environmental educational programmes such as the Worldwide Water Education Project WET[1], which publishes water resource materials in several languages, provides training workshops on diverse water topics (i.e., watersheds, water quality, water conservation), and organizes community water events for children, parents, teachers and community members, turns water education into a water management tool (Nõges T. et al., 2010 a,b).

4.3 Medium-Term Management

Measures within the time frame of a river basin management cycle of 6 years can be based on rather solid climate projections, although unpredictable extreme situations may divert their efficiency. These measures deal with rather concrete targets aiming at certain water resources regulation schemes, prioritization, water saving, metering, abstraction and discharge licencing and pricing. According to the guidance on river basin management in a changing climate (CIS, 2009), 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 monitoring reveals long term coherent changes in the status of reference water bodies over large geographical areas. This eventual adjustment of reference conditions and setting the quality objectives in some water body types is also possible within the RBM planning cycle.

4.4 Operative Measures

Difficulties with flash flood observations, inefficient hydrometeorological data transfer and lack of an archive of flood events hinder the development of a coherent framework to analyze flood hazard and vulnerability at the pan-European scale (Barredo, 2007). According to the estimate of Handmer (2001), between five and ten percent of Western Europe's population lives or works in floodplains and even more people are exposed to flood risks because recreation and transportation facilities are also flood prone. This makes the need to develop and apply efficient flood-warning systems a need. A number of measures aim at development and modernization of information systems of the flood forecasting and warning service and early warning systems in areas with low slope stability, and at training of the use of the early warning systems (Nõges T. et al., 2010 a,b).

4.5 Streamlining of Strategies and Avoiding Potential Cross-Sectoral Trade-offs in River Basin Management

Climate change affects nutrient and carbon losses from terrestrial ecosystems and their loads into aquatic ecosystems. For mitigating nutrient losses/loads, river basin management should plan better matching of nutrient supply with plant demand. Climate change mitigation

[1] http://projectwet.org/

measures aim to reduce greenhouse gas (GHG) emissions while adaptation measures should reduce the vulnerability of societies and ecosystems to adverse effects of climate change. In respect of water resources and ecological status of water bodies the two approaches are often disconnected that, instead of synergies, can create trade-offs between them (Nõges T. & Nõges P., 2017). It is well-known that large-scale biofuel production increases water demand and contamination, hydro-electric power plants fragmentise the river ecosystem integrity and affect biodiversity, dams and water reservoirs can emit additional GHGs, and seawater desalination as a drought combating measure accelerates energy consumption. It is much less known that even reforestation, wetland reconstruction, floodplain restoration or creating buffer strips, usually considered as win-win measures (Nixon, 2008), may locally become antagonistic to other adaptation and mitigation measures (e.g., Jackson et al., 2005). Careful spatial planning should avoid trade-offs between mitigation and adaptation, and make it possible to combine the reduction of vulnerability with mitigation of GHG emissions. Environmental impact assessment and strategic environmental assessment should be applied to analyze the environmental effects of proposed measures and to find an optimal prioritisation of the Multiple Uses and Functions of Water Services (MUFS).

5. Conclusions

Climate change represents a major challenge for the management of freshwater resources. Paradoxically, climate change itself could have a minor impact on water bodies compared to indirect pressures from human responses to climate change, both adaptation and mitigation. As both human activities and climate change have globally intensified the water cycle and the mobility of substances, combating of the adverse impacts must be conservative and knowledge based. There is much uncertainty involved in both the climate change projections and reactions of aquatic ecosystems, and hence an undeniable need for the wide application of the precautionary principle.

The need to retain water in the catchment arises both in the case of excess water and when the water resources are scarce, the purposes, however, are totally different. In the case of floods, retaining the water in the upper catchment suppresses the peak flows while during drought periods, the retained water can be used for irrigation and other purposes.

Landscape ecological processes can be sustainable only if the necessary physical and chemical provisions of the site are maintained. Losses of carbon and/or inorganic matter from soils through leaching and erosion degrade terrestrial ecosystems and create heavy loadings to aquatic ecosystems where these compounds, especially nutrients, become pollutants. Restoring degraded peat bogs and reforestation will help to slow down run-off and increase infiltration.

Watersheds have been considered useful and globally applicable management units. Community based adaptive management is the preferable way of watershed governance as it integrates social and ecological suitability as the conservation target. Biophysical linkages in complex self-regulating systems are inherently uncertain that makes important considering the precautionary principle while making management decisions. Careful spatial planning should avoid trade-offs between climate change mitigation and adaptation.

All climate change mitigation and adaptation strategies contain as a basic principle the research needs to improve temporal and spatial resolution of climate projections and to advance our knowledge on the relationships between climatic variations and water resources, ecosystems, flood risk, and pollution spreading.

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