HOW CAN WATER HAVE A POSITIVE IMPACT ON CLIMATE CHANGE?

BOOK OF KNOWLEDGE

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WHAT POSITIVE IMPACT CAN WATER HAVE ON CLIMATE CHANGE?

Melting ice caps, droughts, and flooding, etc. the world must face up to the challenge of climate disruption, which is caused by man-made activities, while water is one of the first resources to be affected.

Water, which is precious and fragile, and a source of life for nature, Man, and all of his activities, is often only perceived via the risks that it may represent (flooding, droughts, and storms).
However, what we are less aware of is the fact that water also represents part of the solution for combating climate change, by helping to limit its effects, especially thanks to wetlands and their properties. In fact, wetlands can capture more carbon than any other ecosystem on earth, and therefore play a key role in maintaining the water cycle and biodiversity. They also slow the deterioration in water quality caused by climate change, while some wetlands, such as mangroves, are crucial for limiting the impact of rising sea levels.

Ahead of the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21) in Paris, we thought that it was important for the issue of water to be a focal point of the discussions, and of the commitments made, since it forms an essential part of the answer that needs to be provided to the climate challenge.

This issue is the entire focus of the work performed by scientists, on which we had the honor to rely, in order to draw up a review of knowledge about the essential links between water and the climate, and emphasize and investigate in greater depth this uncommon though very real assertion, namely that water forms part of the solution for combating climate change.

Danone's water businesses have focused on protecting their sources' regions for decades, and on exploiting them in a sustainable manner, in close consultation with their entire ecosystem. Accordingly, to us, protecting water goes beyond our products or our plants: it is in keeping with a global and collaborative approach aimed at managing the water cycle in a responsible manner.

evian is taking measures to protect natural water resources here and elsewhere, via its historical initiatives, and its involvement.

It is doing so ***here*** by working with local operators on protecting its impluvium, as well as via the sensible use of the resource.

It is doing so ***elsewhere*** by disseminating its expertise beyond its native Alps, in order to protect the Earth's wetlands. As the first company to enter into a partnership with the Ramsar Convention, evian is also involved in an international mangrove restoration program alongside the Livelihoods

Carbon Fund, which will soon have replanted 130 million trees in Africa, Asia, and Latin America.

Aside from its commitment to protecting resources and wetlands, evian, which is aware of the impact of its business activities on the climate, is taking action to reduce and offset its carbon footprint (packaging, production, transportation, and sorting & recycling), and has tangible goals for 2020.

This is why I am delighted to introduce this document on water and the climate, which forms a basis for knowledge and review; it is the result of a co-construction process between the Ramsar Convention, the Water Institute by evian and the Livelihoods Carbon Fund, and warns and encourages us to take even more action.

This booklet is the foundation for the initiatives that we will continue to implement in connection with our mission to protect natural water resources here and elsewhere, and which, I hope, will encourage anyone who can to join us in this commitment and contribute to it.

Véronique Penchienati
PRÉSIDENT EVIAN VOLVIC WORLD

IT IS SAID THAT WITH GREAT POWER, COMES GREAT RESPONSIBILITY AND HUMANITY HAS SHOWN THAT POWER HAS MADE SUCH IMPACTS THAT GLOBAL WARMING COULD INCREASE BY MORE THAN 2°C.

This would cause widespread problems and we need to recognize that climate change is a "clear and present danger". We are well aware of these risks, thanks to the evidence from the Inter-Governmental Panel on Climate Change (IPPC), and we now need to ensure that humanity changes its course and moderates its activities to prevent severe climate change.

As one of the many truths that are all too easily overlooked, wetlands deliver all our fresh water and are necessary for all parts of human life and development, and so we have been pleased to collaborate with Danone in seeking ways to increase knowledge about the importance of water and wetlands for humanity. Responsible management of wetlands as we have together shown with protection of the evian impluvium has secured water supplies and the livelihoods of the region and we hope to replicate this success.

However, as part of our development, since 1900, 64 % of the world's wetlands have been lost and degraded to make way for urban development and agriculture production for our growing population. An average of 40% has been degraded in the last 40 years according to the Wetland Extent Trend and this decline is continuing at an accelerated rate of 1.5% annually. This loss will affect availability of water in many countries that can least afford to have any reduction.

On the other hand, wetlands, if allowed to exist, have the potential to reduce climate change by capturing carbon and helping to adapt to change.

If we just look at peatlands occupying 3% of our planet, they contain twice the volume of carbon in all our forests. Currently 65 million ha of the peatlands have been degraded and estimates indicate this loss is responsible for 1,150 Gigatons of carbon dioxide emissions per year.

Fortunately, reversing these losses is possible and restoration of wetlands can have multiple benefits and guidance now exists from IPPPC to calculate carbon credits for restoration of drained wetlands.

Responsible companies can show us all the way forward to protect the future of our water and our wetlands and our results with Danone and IUCN can help all companies to reduce impacts of water in their supply chains and lead the path for sustainability. Already, the work of the Carbon Livelihoods Fund has shown how large scale restoration of mangroves can be done with profit for all, especially the environment.

In that light, we warmly welcome this scientific analysis to show the indelible linkages between water and climate and how water and wetlands are a key piece in the puzzle on how to regulate climate change and prevent further damage to our planet.

We see that the role of Parties is key in making positive changes to our climate, but if we work effectively with the private sector, the necessary impact and results will be more easily and speedily achieved across the globe.

Christopher Briggs
SECRETARY GENERAL
CONVENTION ON WETLANDS (RAMSAR, 1971)

1. WHAT IS AT STAKE, WHAT ARE THE CHALLENGES?

OUR PLANET,

the Earth is changing. This is nothing new. What is different today is the pace of change and the fact the majority of it is caused by a single species; Homo sapiens. In the era of the Anthropocene, human-induced changes are altering the face of planet and modifying the climate. The relative stability of the climate over the last 10,000 years (the Holocene), the period during which human civilizations flourished, is coming to an end. To survive and continue to prosper Homo sapiens must find ways to both mitigate the change that is to come, and adapt to that which is already locked in and for which no mitigation is possible.

The impacts of climate change will be felt primarily through impacts on water. Consequently better management of water has long been seen as the key to adaptation. **A famous saying is that "mitigation is about gases and adaptation about water". However, because of links with both energy and the carbon cycle, water management also has a key role to play in mitigation.** This paper is a brief synthesis of the critical role water management has to play in mitigation and adaptation.

GLOBAL CHANGE AND WATER

The extent of global change as a consequence of human activities has begun to match, or even exceed, that driven by the other forces of nature (Steffen et al. 2011). There is overwhelming evidence that the main drivers of global change come from the increasing demands from the growing human population, in particular, the demands for energy, food and freshwater, and the disposal of waste products (MEA 2005; Steffen et al. 2011).

Global change has resulted in major adverse outcomes in the Earth system, including ozone depletion, species extinctions, collapse of fish stocks, ocean acidification, widespread pollution, over-exploitation of water, desertification and large-scale shifts of biogeochemical cycles, including those which affect the composition of the atmosphere and hence the climate. These changes are individually and cumulatively far reaching with impacts evident across the atmosphere and terrestrial and aquatic ecosystems (MEA 2005; Bates et al. 2008; Vorosmarty et al. 2011). There is increasing evidence that human activities are now challenging the resilience of our planetary systems (Steffen et al. 2015).

EXAMPLES OF SUCH CHANGES ARE LISTED BELOW (TAKEN FROM MULTIPLE SOURCES).

- Close to 50% of the land surface has been adversely affected by direct human action, with adverse outcomes for biodiversity, nutrient cycling, soil structure, soil biology, and climate.
- Over 100 million tons of nitrogen from agriculture and sewage is discharged annually into our already stressed freshwater ecosystems, and nearly 50 million tons of nitrogen and 9 million tons of phosphorous is exported to coastal ecosystems every year, leading to eutrophication. More nitrogen fertiliser is now produced synthetically through fossil fuel combustion than is fixed naturally in all terrestrial ecosystems.
- An increasing proportion of fresh water is being appropriated by human purposes (primarily for agriculture), and in many places the surface and ground water resources are being overexploited. Groundwater extraction over the past 50 years has increased threefold.
- Up to 90% of wastewater in developing countries flows untreated into water bodies. 80% of Asia's rivers are in poor health threatening US$ 1.75 trillion in ecosystem services per year.
- In 2011, extreme climate events resulted in an estimated US$200 billion worth of damage globally affecting the lives and livelihoods of millions of people.
- Wetlands provide an essential role in maintaining the hydrological cycle. The extent of wetland loss during the 20th and early 21st Century averaged 64–71% and may have been as high as 87% since 1700 AD placing even more pressure on the remaining water resources.
- During the 20th century about 25% of the approximately 10,000 species of freshwater fish were either made extinct or their survival threatened.

Global change has exacerbated the pressures on water resources and the ecosystems associated with the water cycle. The impact of global change, including climate change, on the availability of fresh water for humans and biodiversity has been explored through the assessments undertaken by the Intergovernmental Panel for Climate Change (IPCC) and by others who have looked specifically at the consequences of climate change for water management. The IUCN more than a decade ago raised concerns about the consequences of climate change for the global water cycle, including the following statement:

> ***"We are faced with a great destabilization and reshuffling of the World's hydrological systems."***
>
> BERGKAMPF ET AL. 2003

The potential for water to be part of the solution to climate change has also been considered with adaptation and mitigation options being canvassed across many industry sectors, including water supply for urban (including peri-urban) and agricultural purposes, and through landscape-scale conservation initiatives. Given the importance of water for human wellbeing and the potential for mitigation and adaptation measures associated with water to be part of the "solution to climate change", an overview of the global water cycle and a summary of the importance of water for humans are provided below.

SUSTAINABLE DEVELOPMENT GOALS

The extent of global change and the resultant pressures on livelihoods and sustainability, such as the expectation that unsustainable use of water threatens the food security of 2.5 billion people, 40% of the world's grain production and 25% of the world's economy (Veolia Water and IFPRI 2014), have been increasingly recognised. The concerns about global change and the adverse consequences for people have resulted in the adoption by the United Nations of the Sustainable Development Goals (SDGs) (2015-2030). These build on the Millennium Development Goals (MDGs) (2000-2015) and represent a global commitment for eradicating poverty in all its forms and dimensions, an indispensable requirement for sustainable development. They further represent a commitment, by both rich and poor nations, to achieving economic, social and environmental sustainability in a balanced and integrated manner. There are 17 individual SDGs (Table 1) with a total of 169 aspirational and global targets; it is the responsibility of each government to establish its own national targets.

Water managers and policy-makers can contribute to the delivery of many of the SDGs through the close links to a range of water issues including *inter alia* human health and disease, the provision of food, water and sanitation. Furthermore, ecosystem services - especially those related to water - are at the core of sustainable development and adaptation to climate change. It is now widely recognized that only through careful stewardship of ecosystem services and the natural infrastructure that provides them can we build resilient and sustainable societies.

Goal 6 in particular seeks to ensure the availability and sustainable management of water and sanitation for all and, amongst others, has the specific target (6.6) of *protecting and restoring water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes* by 2020. A key point about target 6.6 is that while the aim is to protect and restore important ecosystems the overriding objective is to secure the provision of water-related services in order to safeguard development opportunities. Similarly, within Goal 15, which seeks to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss, wetlands receive a specific mention in the targets. Target 15.1 seeks to ensure that by 2020 the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements.

The development of the SDGs and their associated targets represents a global commitment to address the adverse outcomes from global change, including those associated with water and the maintenance of essential requirements for people and the maintenance or restoration of the many ecosystems associated with the global water cycle, in order to deliver a sustainable future for all.

The recognition of water as being central to sustainable development will be key to the success of the SDGs and our ability to cope with the looming consequences of global change.

TABLE 1: SUSTAINABLE DEVELOPMENT GOALS

1. End poverty in all its forms everywhere

2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture

3. Ensure healthy lives and promote well-being for all at all ages

4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

5. Achieve gender equality and empower all women and girls

6. Ensure availability and sustainable management of water and sanitation for all

7. Ensure access to affordable, reliable, sustainable and modern energy for all

8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

10. Reduce inequality within and among countries

11. Make cities and human settlements inclusive, safe, resilient and sustainable

12. Ensure sustainable consumption and production patterns

13. Take urgent action to combat climate change and its impacts

14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development

15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

17. Strengthen the means of implementation and revitalize the global partnership for sustainable development

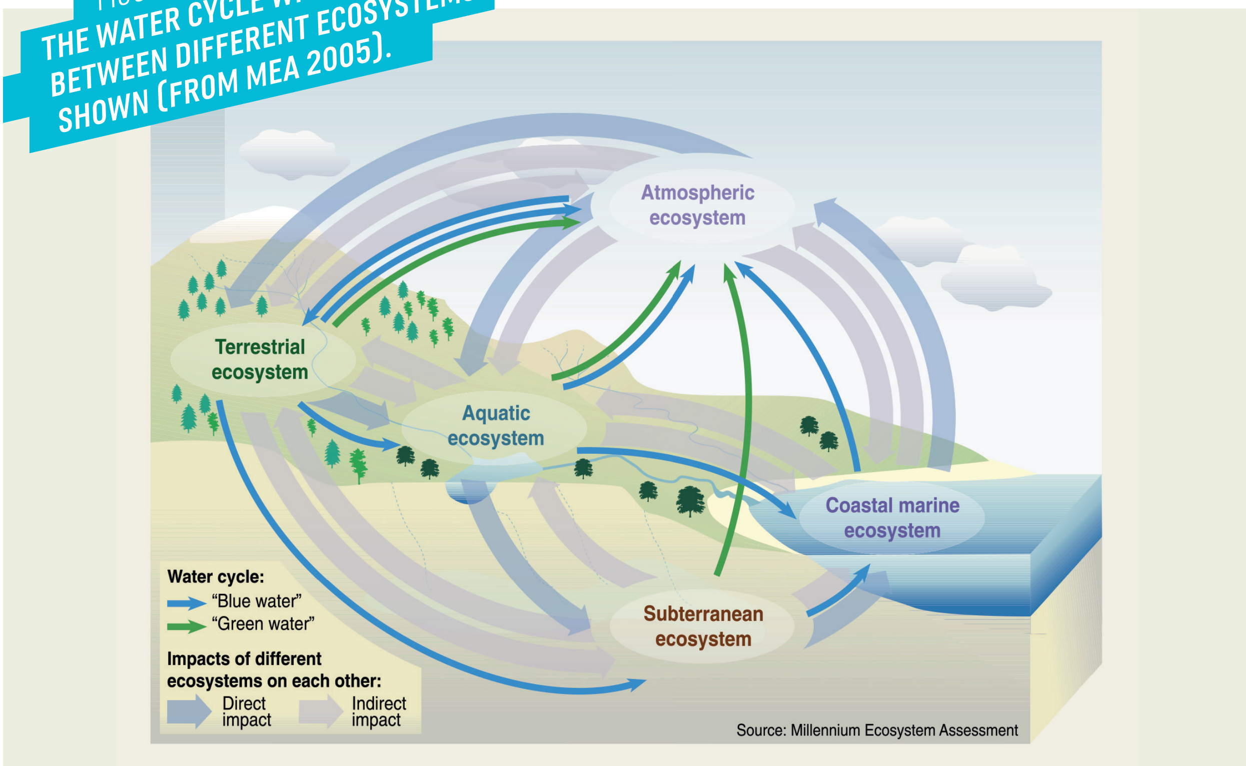





THE WATER CYCLE

The global water cycle comprises the movement of water in its different forms (vapour, liquid, and solid) between the atmosphere and marine and terrestrial ecosystems. The following diagram (Figure 1) provides a generalized picture of the major components of the cycle and the linkages that occur between them. Also shown are the aquatic and subterranean ecosystems that mediate the storage and movement of water through the terrestrial landscape. **Fresh water resources are linked to all parts of the broader terrestrial landscape, and support human wellbeing and livelihoods as well a large proportion of global biodiversity.**

FIGURE 1:
THE WATER CYCLE WITH THE LINKS BETWEEN DIFFERENT ECOSYSTEMS SHOWN (FROM MEA 2005).



The water within the fresh water cycle is often separated into two parts – "blue water" that comprises the water (surface and subterranean) that is controlled by physical processes, including evaporation, and "green water" that comprises the water that is influenced by biological processes such as transpiration by vegetation. A lot of attention has been focused on determining the extent and variation in water flows in the extensive river networks that distribute water across the landscape, including the amount that is now retained behind dams and barrages. There is less information about the extent and distribution of water in subterranean ecosystems (i.e. aquifers), and how this interacts with surface ecosystems. There is still a lot of uncertainty about many of the specifics, but climate change will, through changes in temperature and patterns of rainfall, have impacts on all parts of the water cycle. The impacts are projected to vary regionally with the implications for people and societies partly dependent on how water resources are managed in the face of increasing pressures from people and the expansion of agriculture and other industry. These changes are discussed below as are the opportunities to help in the mitigation of climate change through efforts to sequester carbon in particular through the management of aquatic ecosystems.

THE IMPORTANCE OF WATER FOR SUPPORTING HUMAN WELLBEING AND LIVELIHOODS

Recent global assessments, including the Millennium Ecosystem Assessment (2005), Global Environment Outlooks (2007, 2012), The Comprehensive Assessment of Water Management in Agriculture (2007) and UN World Water Development Report (2015) have highlighted the importance of water for supporting human wellbeing and livelihoods. In doing this they have drawn attention to the importance of the multiple functions of water **which represents a multi-faceted component of human wellbeing including the role of water in supporting the landscapes and ecosystems that provide so many services to people.**

1/ WATER AS A RESOURCE

Water is a vital resource for people, with the importance of a safe and reliable supply of fresh water for human consumption and sanitation being at the centre of human wellbeing through what is often known as the water-energy-food nexus. This includes the importance of groundwater which increasingly is used to supply drinking water for at least 50% of the world's population and 43% of the water used for irrigation (Groundwater Governance http://www.groundwatergovernance.org). In 2010, the United Nations General Assembly proclaimed access to safe water and adequate sanitation as a basic human right, creating inter alia policy and management implications. It is also essential for the production of food whether through agricultural or fisheries and aquaculture activities, and has attracted a lot of attention in terms of guaranteeing reliable supplies, including for industrial purposes. It is also a resource for energy production (through hydropower and geothermal sources, and also as a coolant for conventional and nuclear thermal power plants), as well as supporting tourism and recreational activities, for example in rivers, lakes and snowfields, as well as in coastal areas.

2/ WATER AS A LIVING ENVIRONMENT

Water is a major component of important ecosystems that support many plants and animals that support a large proportion of the global biodiversity. These aquatic ecosystems (wetlands which are defined in many ways and include a diverse range of ecosystems, including rivers, estuaries, lakes, marshes, swamps ad ground water systems) provide many benefits to people through the provision of ecosystem services. The importance of the benefits to people from the water contained in wetlands has been documented in the Millennium Ecosystem Assessment (MEA 2005) and in many subsequent investigations, such as that provided by Costanza et al. (2014) in a global review of the extent and value of ecosystem services. It is important to realise that both surface and ground water flows can sustain the base-flows of rivers and other aquatic ecosystems.

3/ WATER AS A HAZARD

Water can also be a hazard for people, from landslides, floods and erosion as well as from storm and tidal surges. Aquatic ecosystems also provide habitat for the vectors (e.g. insects and molluscs) of many diseases, some of which have caused huge amounts of human suffering. For example, anopheles mosquitoes which transmit malaria need shallow still water bodies for breeding habitat and schistosomiasis (bilharzia) is transmitted by snails that live in rivers and lakes.

4/ WATER AS VECTOR FOR POLLUTION

Water is an important carrier of pollutants, through the soil, and in surface and groundwater, from point sources, including urban, industrial, mining or infrastructure and transport, or from diffuse sources, such as agriculture. Surface water is generally more at risk of pollution than groundwater but the latter is more difficult to remediate and once polluted the impacts may last longer.

The catchment (or watershed/river basin) is the most relevant landscape unit for the management of the surface water components of the water cycle. It has been increasingly realised that the numerous functions supported by surface water need to be considered and/or managed at a catchment scale, which can range from a few hectares to millions of square kilometres. Management also needs to take into account the many interactions of water with ground water and other landscape units, such as those that support human settlements and agriculture, as well as those between ecosystems. Water policy, considered at the catchment scale, can consequently play a systemic and integrating role in order to maximize benefits from the multiple functions provided by water, and minimize adverse impacts.

WATER: A RESOURCE UNDER THREAT

Despite the importance of water, including past and ongoing investment in developing water infrastructure and in preventing degradation, the resource is under threat. It has been over used, polluted and diverted, often with adverse outcomes for people and ecosystems. Despite the many social and economic benefits that have accrued for humankind from the development of water resources and the construction of infrastructure there is widespread recognition that to ensure sustainability an alternative approach to water management is needed in future,, particularly in the face of global change.

Globally, 3,930 million people are dependent on freshwater provision from areas that are under persistent high threat including 2,175 million people in China and India, and 492 million in Africa (Green et al. 2015). The same authors have also pointed out that 52% (by volume) of the freshwater available in the upper reaches of catchments has been adversely impacted by measureable levels of catchment disturbance, pollution and water resource development. While 18% of this volume is reclaimed via infrastructure investments, a third of freshwater provided for human use is under threat (Green at al. 2015). Climate change will further affect the availability of water and water security for many people.

Along with the pressure placed on water as a resource for humans the ecosystems that store or transport water are also severely threatened, possibly more than tropical rainforests, which are also an important part of the global water cycle, with species declines and the degradation and loss of wetlands, as well as the depletion and pollution of aquifers (MEA 2005; Davidson 2015). Much of this pressure has come from land-use change (e.g. for agriculture), the construction of dams and water infrastructure and the extraction of water for consumptive purposes including efforts to deal with the natural variability in the water cycle. The impacts of dams on aquatic ecosystems are well known, including adverse outcomes downstream and upstream of the dams (MEA 2005). The impact of the overexploitation of ground water on aquatic ecosystems, most notably rivers, is less well known, while the importance of groundwater(?)-dependent ecosystems has only in recent times been widely acknowledged (Ribeiro et al. 2013).

Water is at the centre of human wellbeing and livelihoods, but many of the ecosystems that sustain the water cycle, the rivers and wetlands, have been lost and degraded, as have catchments (both for surface and ground water). Additionally, changes to the water cycle as a consequence of climate change will exacerbate current threats, unless effective mitigation and adaptation measures, including remediation, and the avoidance of maladaptation, are adopted and implemented.

2. IMPACT OF CLIMATE CHANGE ON FRESH WATER

A SUMMARY

of observed and projected impacts on fresh water, as documented by the IPCC, based on published peer-reviewed literature, is given below (Jimenez Cisneros et al. 2014). As natural variability is often not well documented in many places, and the consequences of other drivers of change, such as water withdrawals and storage, land use practices, and pollution, can mask or interact with changes due to climate change, care is needed when trying to attribute changes in fresh water directly to changes in the climate.

PRECIPITATION, EVAPOTRANSPIRATION, SOIL MOISTURE

While variations in the worldwide global trend in precipitation from 1901-2005 is statistically insignificant there is evidence that changes in regional precipitation (e.g. the Asian monsoon) are attributable to variability in atmospheric circulation or to global warming. This includes observations that most droughts and extreme rainfall events of the 1990s and 2000s have been the worst since the 1950s. Information on changes in snowfall are also indeterminate, although it is consistent with observed warming and shorter snowfall seasons over much of the Northern Hemisphere, with snowmelt starting earlier.

Potential evapotranspiration over land areas is very likely to increase in a warmer climate, although long-term projections of actual evapotranspiration are uncertain. There are also increases in the number of dry days and prolonged dry periods since the 1960s that can be attributed to climate changes. Projections indicate that periods of severe declines in soil moisture will double in extent and frequency, and droughts longer than 12 months will become three times more common, between the mid-20th century and end of the 21st century.

PERMAFROST AND GLACIERS

Decreases in the extent of permafrost and increases in its average temperature have been observed in some regions, and the area of permafrost is projected to continue to decline over the first half of the 21st century. Additionally, in most parts of the world, glaciers are shrinking and are expected to continue shrinking with runoff in affected catchments reaching a peak in summer, although there are marked differences between regions. As the glaciers shrink, their relative contribution to runoff in the long-term declines and the annual peak shifts toward spring, although glacial melt also provides ground water that can contribute to summer runoff (Baraer et al. 2014).

STREAMFLOW

Trends in streamflow are generally consistent with observed regional changes in precipitation and temperature/evapotranspiration since the 1950s. In regions with seasonal snow storage, warming since the 1970s has led to earlier spring discharge maxima and has increased winter flows because more winter precipitation falls as rain instead of snow. There is evidence of earlier breakup of river ice in Arctic rivers, and where streamflow is lower in summer, decrease in snow storage has exacerbated summer dryness. Trends in streamflow must be interpreted with caution because of confounding factors such as land use changes, and changes in the use of water (including the volume used for drinking water supplies, irrigation and industry).

Average annual runoff is projected to increase at high latitudes and in the wet tropics, and to decrease in most dry tropical regions. For some regions there is considerable uncertainty in the magnitude and direction of change. Both the patterns of change and the uncertainty are driven largely by projected changes in precipitation. A global analysis shows a consistent shift to earlier peak flows, except in some regions where increases in precipitation are sufficient to result in increased, rather than decreased, snow accumulation during winter.

GROUNDWATER

Attribution of observed changes in groundwater level, storage, or discharge to climate changes is difficult owing to the influence of land use changes and groundwater extractions as well as data deficiencies (Taylor et al. 2012), although some case studies are well documented (see Treidel et al. 2011). Observed trends have been largely attributed to these other factors rather than to climate change with the extent to which the extraction of groundwater has been affected by climate change rarely demonstrated.

The range of projected groundwater changes is large, from significant decreases to significant increases. Furthermore, as the effective rainfall (rainfall minus evapotranspiration) is much lower than total rainfall, the range of groundwater recharge mostly exceeded the range of changes in precipitation. The areas where total runoff is projected to increase or decrease roughly coincide with the areas where groundwater recharge is projected to increase or decrease as, during most of the year and particularly during the dry season, groundwater outflows sustain the discharge of many rivers. Increased precipitation intensity may also not increase aquifer recharge in soils and aquifers with low hydraulic conductivity, such as those in granitic and metamorphic rocks (Lachassagne et al. 2011). However, increased precipitation intensity may increase aquifer recharge where there is faster percolation through the root zone or for some specific aquifers, such as those in karsts (Bakalowicz 2005). Decreasing snowfall may also lead to lower groundwater recharge. Changes in land use may also have greater effects on groundwater than climate change (see for example, Favreau et al. 2009).

WATER QUALITY

Most observed changes of water quality attributed to climate change are known from isolated studies. For lakes and reservoirs, the most frequently reported change is more intense eutrophication and algal blooms at higher temperatures, or shorter hydraulic retention times and higher nutrient loads resulting from increased storm runoff. Positive impacts have also been reported, including the risk of eutrophication being reduced when nutrients are flushed from lakes and estuaries by more frequent storms and hurricanes. For rivers, all reported impacts on water quality are negative. Greater runoff, instead of diluting pollution, can wash more pollutants from the soil into watercourses. In streams in semiarid and arid areas, temperature changes have a stronger influence on the increase of organic matter, nitrates, and phosphorus than precipitation changes. Groundwater quality is expected to be more impacted by human activities such as agriculture, waste water releases, etc. than from climate change, apart from aquifers with strong links with surface water, such as alluvial aquifers where the impacts of climate change will be similar to those observed for surface water.

In general, the linkages between observed effects on water quality and climate should be interpreted cautiously and at the local level. Projections of changes in water quality under climate change scenarios are difficult to perform and interpret. Most projections suggest that future negative impacts will be similar in kind to those already observed in response to change and variability in air and water temperature, precipitation, and storm runoff, and to many confounding anthropogenic factors. This holds for natural and artificial reservoirs, rivers and groundwater

SOIL EROSION AND SEDIMENT LOAD

There is limited evidence that climate change has made a significant contribution to soil erosion, sediment loads, and landslides. In most cases, the impacts of land use and land cover changes are more significant than those of climate change. A warmer climate may affect soil moisture, litter cover, and biomass production and can bring about a shift in winter precipitation from snow to more erosive rainfall or, in semiarid regions, an increase in wildfires with subsequent rainfall leading to intense erosive events. Potential impacts of climate change on soil erosion and sediment production are of concern in regions with pronounced glacier retreat. There is no clear evidence that the frequency or magnitude of shallow landslides has changed over past decades.

Projected increases in heavy rainfall and temperature will lead to changes in soil erosion and sediment load, but owing to the nonlinear dependence of soil erosion on rainfall intensity and its strong dependence on land cover there is low confidence in these projections.

EXTREME HYDROLOGICAL EVENTS

There is limited evidence that climate change has affected the frequency and magnitude of floods at a global scale and it is difficult to distinguish between the roles of climate and human activities. However, some projections under a future warmer climate demonstrate a large increase in flood frequency in Southeast Asia, Peninsular India, eastern Africa and the northern half of the Andes, although there is also uncertainty about the direction of change. Recent trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at regional scale with more locations having increases in heavy precipitation than decreases. Global flood projections show flood hazards increasing over about half of the globe, but with great variability at the catchment scale. Assessments of observed changes in rainfall and soil moisture droughts have become more frequent since 1950 in some regions, including southern Europe and western Africa, but in others (including the southern USA) there is no evidence of change in frequency. Very few studies have considered variations over time in streamflow drought, largely because there are few long records from catchments without direct human interventions.

3.WATER AS A SOLUTION: MITIGATION

ALTHOUGH THERE IS A DEGREE OF UNCERTAINTY ABOUT CLIMATE TRENDS

and the overall magnitude of change many of the impacts of climate change, and more generally of global change, are likely to be felt through impacts on water.

THE IPCC IN ITS FIFTH ASSESSMENT REPORT (IPCC AR5)

has defined mitigation as an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases. Actions that reduce emissions reduce the projected magnitude and rate of climate change and therefore reduce the risks of impacts on natural and human systems from climate change. Human and natural systems have the capacity to adapt to a changed climate, but ultimately the management of climate change will depend on the effectiveness of our mitigation actions. Mitigation actions are expected to delay or reduce damage caused by climate change. It is also expected that better management of terrestrial ecosystems, including wetlands, cannot provide the complete solution to climate change, but can buy time while steps are taken to reduce emissions from burning fossil fuels and other sources.

Further, over time, the net carbon sink rate may even decline in the living biomass of mature forests as the growth rate decreases relative to respiration rates and the system approaches a dynamic equilibrium. Consequently the climate mitigation value of such forested ecosystems resides in maintaining the carbon stored in the soils. Nonetheless, the carbon sink in almost all the world's forests suggest that favourable conditions remain for increasing carbon stocks with the larger threats to these stocks in both boreal forest soils and tropical forest being warming in the boreal zone, deforestation, and occasional extreme drought, coincident with fires in the tropics. Consequently a better understanding of the role of forests, including forested wetlands, in carbon fluxes and the mechanisms responsible for changes in the carbon sink function in forests is critical for guiding the design and implementation of mitigation policies.

THE CARBON CYCLE

The greenhouse gases, carbon dioxide and methane, are fundamental components of the global carbon cycle. **Understanding the potential to store and sequester carbon in the biosphere is essential for the development of anthropogenic climate change mitigation strategies.** If the goal is to mitigate climate change, it is important to consider the intrinsic linkages among carbon, soils, vegetation and water. In this manner the carbon and water cycles are intricately linked and provide the basis for developing mitigation measures.

Carbon is exchanged through the biosphere, soils and rocks, hydrosphere and the atmosphere (Figure 2) in a continuous cycle, including also from the Earth's crust and mantle (Kerrick 2001). Carbon is by far the most common element in living organisms and can account for more than 50% of the dry weight. Consequently, the carbon cycle is the most dominant cycle in ecosystems and is closely connected to the water cycle and also to that for oxygen and the plant nutrients, nitrogen and phosphorus. Leveque (2003) reports that global carbon stocks comprised the approximate following amounts (in Gigatonnes - Gt):

ATMOSPHERE :
750 Gt

OCEANS :
Surface waters : 1000 Gt
Deeper waters : 34,000 to 38,000 Gt

TERRESTRIAL VEGETATION :
500 to 600 Gt

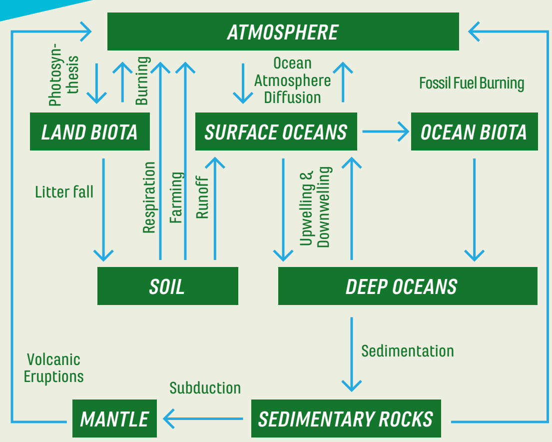
SOILS :
1500 to 1600 Gt

Carbon is also stored in the Earth's mantle and crust and interacts with the above components through geological processes. The exchange of carbon between these stocks occurs as the result of various chemical, physical, geological, and biological processes, with the natural flows between the atmosphere, ocean, and soils being balanced. The greatest exchange with the biosphere occurs through the stock in the atmosphere with the processes of photosynthesis (assimilation of carbon by plants) and respiration ensuring a constant storage and release of carbon.

All vegetation assimilates carbon dioxide from the atmosphere and converts it to organic carbon (Figure 3) with approximately half of it being oxidized by the plants as an energy source. Carbon is released as carbon dioxide through the leaves and returns to the atmosphere, or to the soils through the roots as dissolved inorganic carbon (DIC). Carbon that is not used for energy forms the cells, tissues and organs of the plants. This net primary production (NPP) forms the basis for almost all life on Earth. In more than half of the World's ecosystems primary production is limited by the availability of water. Hence local and global carbon cycles will be moderated by precipitation and other hydrological controls. Some of the carbon forming parts of plants may be subsequently released through the root system into the soil solution as dissolved organic carbon (DOC). The death of plants in autumn can release more carbon back to the soil as DOC and particulate organic carbon (POC). For annual plants, nearly all of the carbon fixed over the growing season can be returned to the soil.

Carbon in the earth's atmosphere exists in two main forms, carbon dioxide and methane, both of which absorb and retain heat in the atmosphere. Carbon dioxide leaves the atmosphere through photosynthesis and combustion. It can also be dissolved directly from the atmosphere into oceans, lakes, etc.. Most carbon in the terrestrial biosphere is organic, while about a third of soil carbon is inorganic. Carbon stored in soil can remain there for hundreds to thousands of years before being washed into rivers by erosion or released into the atmosphere through soil respiration

FIGURE 2: GENERALISED GLOBAL CARBON CYCLE



THE CARBON CYCLE AND LINKAGES WITH THE HYDROLOGICAL CYCLE

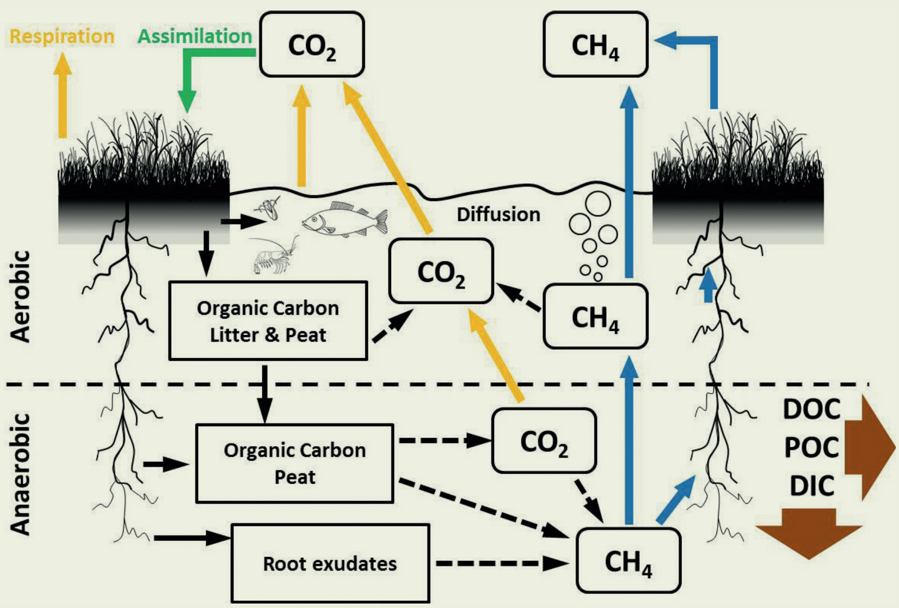
It is widely acknowledged that wetlands, in particular peat-based and forested forms, can lock up more carbon on a pro rata basis than any other terrestrial ecosystem through inactive exchange with the atmosphere. The production of organic matter by plants and the subsequent distribution, movement and decomposition of organic matter plays a major role in determining the structure and functioning of wetland ecosystems. The carbon cycle is central to understanding why certain wetland soils are anaerobic, how wetlands can store or sequester carbon, and why they release methane and carbon dioxide to the atmosphere. A general representation of the carbon cycle in wetlands is shown in Figure 3.

The carbon cycle in wetlands is closely linked to the water regime. A typical wetland system, such as a high latitude peatland, a temperate marsh or a tropical peat swamp forest, is characterized by vegetation that is adapted to long periods of waterlogging where the water is at, slightly above or slightly below ground surface. Changes in the water regime of a particular wetland can change the rate of carbon emission and storage.

Most ecosystems are not characterized by permanently saturated conditions, and some wetlands are dry at the surface for certain periods of the year. This unsaturated or aerobic zone can support a diverse community of decomposer organisms which decay and breakdown plant material using aerobic respiration.

The amount of carbon that will be released to the atmosphere through aerobic respiration will vary from ecosystem to ecosystem and under different local climatic conditions. However, the amount that is decomposed can vary depending on several factors including the amount of oxygen rich water flowing through the wetland and the depth and duration of any flooding or inundation. In some peatlands as much as 80% of the carbon produced by net primary production remains in the soil; whereas for some marshes, swamps and floodplain wetlands the proportion of carbon remaining may be as low as 5%. In general, the lower the proportion of carbon remaining in the soil, the higher the amount of carbon dioxide released back into the atmosphere. Under anaerobic conditions methane, which is a far more potent greenhouse gas than carbon dioxide, can be released. As it is present in much smaller concentrations and has a shorter atmospheric lifetime its direct effect is smaller, although it may have an understated effect due to its contribution to ozone formation (Shindell et al. 2005).

FIGURE 3:
REPRESENTATION OF THE CARBON CYCLE IN WETLANDS



(redrawn from van der Valk 2006). CO2 carbon dioxide; CH4 methane; DOC/POC dissolved/particulate organic carbon, DIC dissolved inorganic carbon.

HOW CAN CARBON BE RETAINED IN SOILS AND ECOSYSTEMS?

Reduced to its simplest form, the net amount of carbon accumulated in an ecosystem can be considered as the difference between the carbon gained through net primary production or the carbon used by plants to form their living parts, and the physical transport in an ecosystem, and the carbon lost through decomposition and the physical transport out of the system. These variables will differ for different ecosystems and will be influenced by the prevailing management interventions. Since the industrial revolution, land use change and soil cultivation account for approximately a third of the total global emissions of carbon. The export of carbon from ecosystems through land use changes includes those resulting from deforestation, by burning, conversion of natural systems to agricultural ecosystems, the drainage of wetlands and unsustainable cultivation of soils. Estimates of the depletion of soil organic carbon vary with a common range of 55 to 78 Gt lost since the mid-18th Century with carbon sequestration having the potential to offset 0.4-1.2 Gt of carbon per year, or 5-15% of the estimated emissions from fossil fuels (Lal 2004).

There is an intimate relationship among water and carbon cycles and climate and vegetation.

Water availability will influence a range of processes including net primary production, transpiration and respiration, and decomposition. Similarly, the import and export of carbon can be moderated by hydrological flows such as surface water flooding and runoff from adjacent uplands, as well as storage in the sediments, although most of the time only at the geological timescale. As the climate changes, altering temperatures and seasonal hydrological patterns, so too will the ability of an ecosystem to store and sequester carbon. Anthropogenic increases of carbon dioxide in the atmosphere are predicted to increase net primary productivity by plants, sometimes referred to as "CO2 fertilization". This can result in increased uptake of carbon into the biosphere and generate a negative feedback that slows the rate of increase of carbon dioxide in the atmosphere. Additionally, plant responses to increased atmospheric concentrations of carbon dioxide can also influence the water cycle. Plant stomata generally open less widely under levels of elevated carbon dioxide, which reduces transpiration to the atmosphere and maintains water at the land surface (Betts et al. 2007). However, there are conflicting views on whether the direct effects of carbon dioxide on plants have a significant influence on global evapotranspiration and runoff rates. There is evidence to suggest that the physiological effects of increased concentrations of carbon dioxide on plants means that less water is transpired per unit of carbon assimilated.

Due to the presence of waterlogged, anaerobic conditions, certain wetland ecosystems can act as effective sinks for carbon.

Wetlands from the equator to the high latitudes can retain and sequester carbon as long as the appropriate hydrological and sedimentation conditions prevail. For instance, mangrove ecosystems that occur along tropical and subtropical coastlines are among the most carbon-rich forests in the tropics, containing on average 1000 tonnes of carbon per hectare. The organic rich soils that have accumulated beneath these forested wetland systems can reach depths in excess of three meters and can account for between 49 and 98% of the carbon storage within a stand of mangroves (Donato et al. 2010). Additional carbon is stored above ground in the living and dead biomass making these important carbon storage systems. However, the survival of both mature trees and seedlings, and the overall integrity of mangrove systems, critically depends on the appropriate hydrological conditions. For instance, increased levels of salinity due to the reduction in fresh water availability or changes in anaerobic conditions can kill existing stands of mangroves. Consequently, any engineering works or built structures both in the vicinity of mangroves, but also in the wider catchment which drains into mangrove systems must be designed so as to allow sufficient free exchange of sea water with the adjacent coast or estuary, but equally must also ensure the continued supply of essential freshwater to the forest in order to prevent further degradation and loss of carbon stocks (Lewis 2005).

CARBON STORED IN WETLANDS

Numerous estimates exist regarding the global extent of wetlands and the amount of carbon stored in their soils. However, providing definitive summary values on the amount of carbon stored is an ongoing scientific challenge due to a range of factors including variations in carbon density, estimations of the depth of organic soils and the variability and gradation of wetland boundaries. This is shown by the information summarised from multiple sources by Zheng et al. (2013) with global wetland soil containing 154 to 550 Gt of carbon from a total surface area of wetlands in the world ranging from 2.40 to 17.45 million km2. Greater consistency is required both for determining the amount of carbon in wetland soils and the area of wetlands. With these limitations on the data in mind, the carbon stock in wetlands is 10 to 30% of that in soils, which are about 1500 to 1600 Gt (see above discussion).

The estimates of carbon in peatlands from Zheng et al. (2103) ranged from 120 to 500 Gt. Across large areas of Southeast Asia extensive peatlands represent a significant store of carbon. In Indonesia, conservative estimates suggest that at least 55 ±10 Gt of carbon are stored in the soils of peat swamp forests. However, anthropogenic impacts through, for example, deforestation, conversion to other land uses, and especially for the creation of oil palm and pulpwood tree plantations, and persistent, uncontrolled forest fires have caused the release of significant amounts of carbon to the atmosphere (Jaenicke et al. 2008). The drainage that accompanies these land use changes exacerbates the loss of carbon, accelerates the lowering of ground surface elevation through oxidation of the peat material and can in coastal environments results in seawater invasion and in some cases saltwater intrusion in the streams and the aquifers.

In northern latitudes, extensive boreal and subarctic peatlands are common across vast areas of Canada, the USA, northern Europe and Russia. These systems are characterized by permanent waterlogging and cool, anaerobic conditions with peat deposits often extending to several meters in depth. The importance of these systems as carbon stores has been recognized for a considerable period, as have concerns regarding the impact of drainage, melting permafrost and fires on fluxes of both carbon dioxide and methane (Gorham 1991). Estimates on the amount of carbon stored in the soil are still being refined, especially as improved information is established within the northern circumpolar permafrost region (Tarnocai et al. 2009), but what remains clear is that anthropogenically induced changes are altering these carbon stores. However, due to the relatively low rates of carbon accumulation, moderated by cool climatic conditions and low net primary production the overall impact on the global carbon cycle may be low (Mitsch et al. 2013).

Estimates suggest that up to 30% of the Earth's soil pool of carbon is stored in wetlands (Roulet 2000; Bridgham et al. 2006). These estimates are uncertain given gaps in our understanding of the extent of wetlands and the variable amounts of carbon stored in different types of wetlands. Forested wetlands may account for a considerable percentage of the total wetland area in any country or region. For example, in the conterminous United States of America, approximately 16% of the total forest area is also classed as wetland. Furthermore, it has been estimated that this 16% area contains over 50% of the USA's total soil carbon (Trettin & Jurgensen 2003). Whilst uncertainties exist associated with large-scale estimates, Robertson (1994) estimated that of the approximate peatland area of 7 million hectare in Central and South America, some 57% was forested.

Mangroves are recognized as among the most carbon-rich forested wetland ecosystems

Physical and biogeochemical conditions in coastal mangroves are highly favorable to long-term carbon retention with estimates that mangroves contain on average in excess of 1 tonne of carbon per hectare with 49–98% of the carbon stored in organic-rich soils (Donato et al. 2011); among other reasons, these areas are more prone to subsidence, and thus to the natural geological sequestration of carbon. Consequently, mangroves have been considered as possessing a very high potential within carbon offsetting programmes through protection and restoration. In comparison to terrestrial forested systems the contribution of vegetated coastal habitats per unit area to long-term carbon sequestration is much greater (Mcleod et al. 2011) (Figure 4). Furthermore, in contrast to other freshwater wetlands, salt marshes and mangroves release negligible amounts of greenhouse gases and store more carbon per unit area (Chmura et al. 2003).

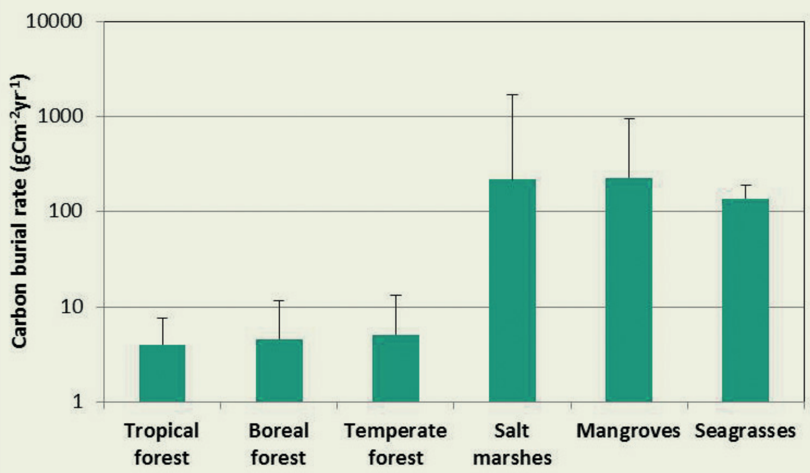
A best estimate undertaken for tropical peatlands indicates that 88.5 Gt of carbon (range 81.5-91.8) equal to 17-19% of the global peat carbon pool, is stored in this wetland type (Page et al. 2011). Forested peatlands of south east Asia are widely recognised as representing significant carbon stores, for instance in Central Kalimantan, South Sumatra and West Papua the total carbon storage of Indonesian peatlands is estimated to be in the region of 42 Gt (Hooijer et al. 2010) and may be as much as 55±10 Gt of carbon (Jaenicke et al. 2008).

However, other non-forested wetland types are also significant stores of carbon in both their soils and standing vegetation. For instance, the organic carbon pool of China's wetlands, including both forested, such as Larix gmelinii and Rhizophora sylosa mangrove systems, and non-forested systems, including communities dominated by Phragmites australis, Glyceria acutiflora and Scirpus mariqueter, is between 5.39 and 7.25 Gt, accounting for 1.3%–3.5% of the global carbon pool (Zheng et al. 2013).

In the UK, moss-dominated upland peatland systems, comprising mainly Sphagnum species, have been estimated to contain over 3.2 billion tonnes of carbon (Worrall et al. 2010), approximately twenty times that of UK forests, despite covering an area equivalent to approximately 7% of the total forested land. Euliss et al. (2006) estimated that across Canada and the USA agricultural conversion of prairie pothole wetlands has resulted in a loss of 10 tonnes per hectare of soil organic carbon over an area of 16 million hectares. However, the same authors also note that wetland restoration of these former prairie pothole systems, to non-forested and aquatic systems, has the potential to sequester a maximum of 0.4 Gt of organic carbon, or approximately 17 tonnes per hectare, over a ten-year period.

FIGURE 4: MEAN LONG-TERM RATES OF C SEQUESTRATION (GCM-2YR-1)

in soils of vegetated coastal wetland ecosystems and terrestrial forests. Error bars indicate maximum rates of accumulation.



Note logarithmic scale on y axis. Data from Mcleod et al. (2011).

HOW CAN ECOSYSTEM RESTORATION HELP TO MITIGATE THE IMPACTS OF CLIMATE CHANGE?

While maintaining carbon within intact ecosystems should remain a priority, along with maintaining catchment hydrology to ensure changes in land use and water management do not have negative effects on greenhouse gas emissions, the restoration of ecosystems and catchment hydrology should also be considered within a strategy to mitigate the effects of climate change.

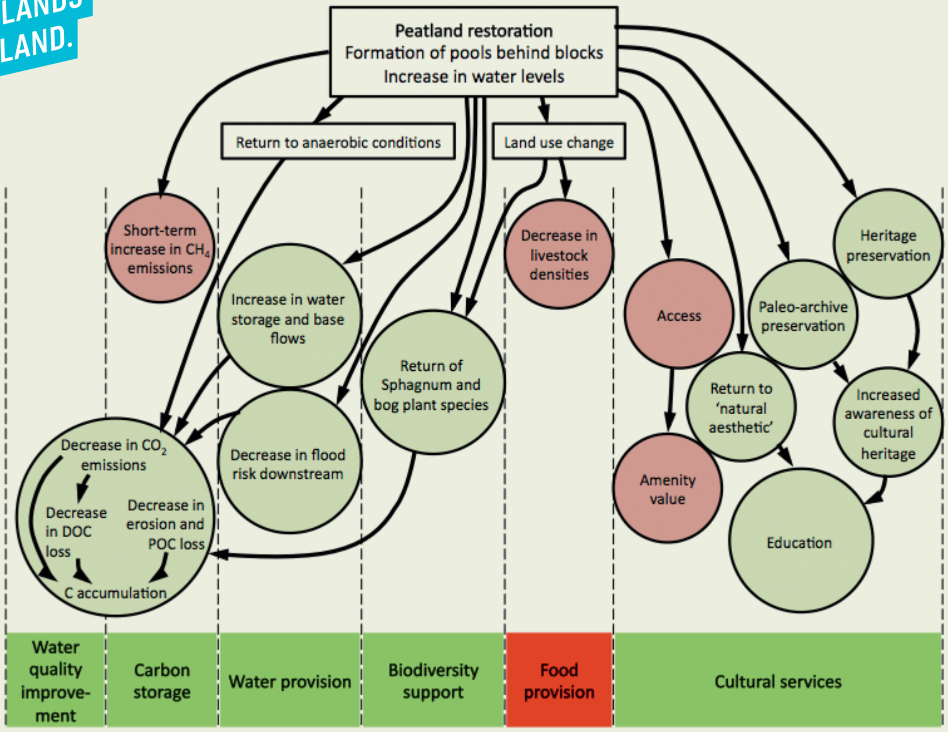
However, it is essential, when considering ecosystem restoration as a mitigation measure, that a systemic approach to water management, which considers the multiple benefits and disbenefits (Everard and McInnes 2013), is considered, and that the implications for wider elements of the hydrological cycle are considered adequately.

For instance, afforestation and reforestation are known to increase evapotranspiration rates and decrease aquifer recharge and total runoff, potentially leading to widespread decreases of the long-term average runoff within wider freshwater systems (Trabucco et al. 2008). However, in general afforestation which has adequately considered the availability of water is considered to have beneficial impacts on other ecosystem elements such as reducing soil erosion, reducing flood risks downstream, improving surface water quality (in terms of reducing nitrogen, phosphorus and suspended sediment concentrations) and improving the quality of in-stream habitats. Therefore, attention must be given to the potential trade-offs that exist between increased carbon sequestration and storage through afforestation initiatives and the wider benefits and disadvantages of such approaches.

The appropriate management and restoration of soil carbon can mitigate climate change and also deliver food and water security benefits. There is a strong correlation between levels of soil organic carbon in the root zone and the yields of major food crops such as wheat, barley and maize. The implementation of farming methods that enhance and restore carbon sequestration in soils can also be effective at delivering numerous co-benefits in addition to enhancing crop yields. These include improving the efficiency of overall inputs (such as reducing inputs of industrially produced fertilizers), decreasing erosion and consequently sedimentation in downstream water systems, reducing the non-point source pollution and the consequential impacts on freshwater and groundwater ecosystems, and increasing soil biodiversity (Lal 2010). Given that worldwide, greenhouse gas emissions from agriculture (including both crop production and animal husbandry) are estimated to exceed those from power generation and transport. Consequently efforts to offsets these impacts and to manage and restore soil carbon should be seen as a priority, along with the need to stabilize rates of global

FIGURE 5:
CONCEPTUAL MODEL OF THE IMPACT OF RESTORING PEATLANDS IN SOUTH WEST ENGLAND.

Relative impact on ecosystem services given by circle sizes (small, medium, large). Green circles indicate positive impact, red circles indicate negative impact on ecosystem services. (Redrawn from Grand-Clement et al. 2013).



meat consumption which currently have negative impacts on both human health and water resource demands (McMichael et al. 2007).

In recent years the importance of mangroves as a carbon store has been increasingly recognized, with large amounts being stored, often for long periods of time, below ground in the soil and roots of mangrove species (Alongi 2012).

In addition to their very high carbon sequestration potential, mangroves also provide other benefits for people, such as protecting shorelines from storms, and from sea level rise, and can limit the landward ingress of saline water, and also provide valuable nurseries for several marine species, and thus contributing to productivity of coastal and marine ecosystems (Alongi 2008; Donati et al. 2011). The importance and quality of the ecosystem services provided by mangroves varies greatly in relation to the biophysical characteristics of the mangrove, taking into account many differences in tidal ranges and inundation patterns, the substrates, and the species assemblages and structure.

In addition to considering afforestation and appropriate soil management within agricultural systems, considerable attention is being paid to specific wetland restoration initiatives in order to reverse the rates of carbon loss and to deliver on multiple hydrological benefits. The total value of the benefits that flow from a restored wetland, including their role in climate change mitigation and moderating hydrological regimes, can often be several times higher than the cost of restoration when added to the value of the benefits lost due to degradation (Alexander and McInnes 2012). The restoration of forested wetland ecosystems can lead to reduced emissions and increased carbon sequestration and although these ecosystems represent only a small percentage of the world's forests, they are some of the most productive in terms of carbon storage and delivery of co-benefits.

Many wetland restoration projects, including those that seek to mitigate the impacts of climate change, are considered in isolation, or on a project-by-project basis, and fail to be integrated within wider river basin planning. Such an approach often fails to truly understand or reflect the multiple benefits, and especially those associated with maintaining water resource integrity and enhancing water quality. Work on restoring peatlands in south-west England, has developed a wider reaching conceptual model which demonstrates the range of benefits and disadvantages associated with site-based restoration activities (Figure 4). Motivated by a water company's desire to reduce operating costs associated with treating discoloration as a result of high dissolved organic carbon concentrations in surface water and the need to achieve wider water and environmental policy objectives, investment in peatland restoration was considered the most viable option. The restoration of upland peatlands, through relatively simple, low-cost interventions, has the potential to reduce water treatment costs but also to sequester carbon, store water and enhance species and habitats of conservation concern (Grand-Clement et al. 2013). However, by taking a broader catchment-based approach to the conceptualization, the potential disadvantages, such as reductions in food production and short-term increases in methane emissions, can be identified and factored into decision-making processes. Within such a decision-making framework and, as said above, considering the catchment as a whole and taking into account the different functions of water (resource, ecosystems, risks, etc.), a systemic approach to management is favoured. Such approaches are considered as being more beneficial than sectoral approaches for both human well-being and the environment.

4.WATER AS A SOLUTION: ADAPTATION

IRRESPECTIVE OF OUR FUTURE EFFORTS IN MITIGATING GLOBAL/ CLIMATE CHANGE,

significant changes in future climates are already locked in. Whether climate change is limited to a global average increase of 2˚C or rises to 4˚C or more, water flows, availability and demand will be affected. All organisations that are significant suppliers, managers or users of water will need to consider how they will respond, i.e. adapt, to these changes. **The IPCC in its Fifth Assessment Report (IPCC AR5) defined adaptation in human systems "as the process of adjustment to actual or expected climate and its effects in order to moderate harm or exploit beneficial opportunities". In natural systems, adaptation "is the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate".**

A whole language around the different types of adaptation has developed over recent years, which is often used inconsistently leading to confusion rather than clarification. Some important points about adaptation in human systems is that it can involve actions either in response to the experience of climatic events or in anticipation of future climates. Most of these actions will be to reduce the risk of damaging outcomes, but there are circumstances where climate change may offer opportunities. People responsible for planning for future climates are often confused and concerned by the plethora of scenarios and projections for future climates. Clearly better information about the climates of the future will assist better planning, but we cannot expect to have precise projections of future climates, 'or use the imprecision as a justification for inertia or slow responses to climate change. Moreover, the uncertainty associated with a parameter such as air temperature is less than that associated with rainfall which is important when considering changes in the water cycle.

Most adaptation activities are not stand-alone, but are modifications of normal planning processes to take into account future climate risks.

Adapting water management to climate change requires interventions that increase our ability to cope with more erratic rainfall and greater frequency of droughts and floods. In planning processes we must recognise that the past is no longer a good guide to the future, but experience from the past enhanced with the best estimates of broad descriptors of change such as the direction and trends in climate, changes in seasonality or variability etc. can help direct current decisions along paths that are more compatible with climate change. In many cases adaptation will require modifications that are needed even in a no climate change scenario in order to enhance socio-economic development and to respond to the impacts from wider global change.

Depending on local contexts, needs and interests, there are opportunities for improving water management that can significantly contribute to peoples' livelihoods and make them more resilient to the adverse impacts of climate change.

Many of the challenges that rural communities face to adapt to climate change relate to capturing and storing uncertain rainfall, managing variable water resources, enhancing soil moisture retention and improving water use efficiency. Some surface or underground compartments of catchments, such as flood plains or specific aquifers, can be used to re-establish hydrological regimes that have been disturbed either by climate change or other human activities. Many choices relate to the range of storage and use options, including water conservation or recycling measures, and the artificial recharge of aquifers. Groundwater has an important role in adaptation to global change as in many regions it provides a secure and cost-effective water supply (UNESCO-IHP 2015) and can be used to sustain potable water supplies when surface water may not be available as a consequence of drought. It is also a key resource for human development that has often been neglected in development strategies and projects. Some surface or underground compartments of catchments, such as flood plains or specific aquifers, can be used to re-establish hydrological regimes that have been disturbed either by climate change or other human activities. The sustainable management of groundwater and adaptation to global change is an issue for national and international water

ACTIVE MANAGEMENT AND ARTIFICIAL RECHARGE OF AQUIFERS

Some specific aquifers, such as those in karst or limestone rocks, and in certain cases some volcanic aquifers, may, under favourable geological conditions, combine, among other properties, huge water reserves and the hydraulic conductivity that allows them to be quickly recharged. The Lez aquifer, near Montpellier, France, is an example of an aquifer that is subject to "active management" by hydrogeologists (Jourde et al. 2013; Ladouche et al. 2014, Maréchal et al. 2014). Since the 1970s, this karstic aquifer has been heavily pumped during the dry season (about 1100 L/s on average) to provide potable water to the present 340,000 permanent inhabitants of Montpellier city. Part of this water is returned when necessary (under low water conditions) to the Lez river to maintain its ecological character.

The pumping of water from the aquifer ensures a yearlong supply of water to people in the city. It also draws down the reservoir of water in the aquifer. Consequently, in autumn, floods are necessary to ensure the groundwater reservoir. The recharging not only ensures the potable water supply for the following years (sustainable management of the groundwater resource), but can also attenuate the flood risk. This illustrates how groundwater ecosystems, with their huge natural storage capacity, can contribute to the active management of the water resource and thus attenuate the impacts of climate and/or anthropogenic changes on water supplies. More widely, the artificial recharge of aquifers (for instance with Managed Aquifer Recharge – MAR – and Aquifer Storage and Recovery – ASR – techniques), but also the use of non-conventional water resources, such as treated wastewater, for example provides a mechanism for reducing the stresses on freshwater resources.

security as some aquifers are transboundary (UNESCO-IHP 2015). Improved governance is needed, including the revision of legislation and regulations that do not promote adaptation measures. Political commitment and leadership are essential to create an adequate basis for the governance, as well as financial and human resources needed to manage ground water resources. Integrated Water Resource Management has been promoted as a framework that can be used to build resilience and support the consumptive use of surface and ground water in a combined manner (UNESCO-IHP 2015)/

Building resilience is not just about direct water management for human use, but also protecting and enhancing the ecosystem services on which we all depend. The ability of people to adapt to climate change is inextricably linked to the condition of ecosystems. Healthy, well-functioning ecosystems enhance natural resilience to the adverse impacts of climate change and reduce the vulnerability of people.

ECOSYSTEM-BASED ADAPTATION

There is increasing interest in the use of ecosystem-based adaptation (EbA) in responding to climate change. EbA is the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change (CBD 2009).

EbA is usually consistent with the management of ecosystems to assist their adaptation to future climates, but it is not identical as the focus of EbA is on supporting people's lives and livelihoods. For example the protection of forested water catchments by increasing fire-protection measures as the climate warms and dries is a good example of where EbA and the adaptation for humans and for natural ecosystems are fully consistent. Similarly the protection of natural wetlands as aquifer recharge areas is consistent with increasing ecosystem resilience and human adaptation through increased groundwater supply. However, restoring coastal deltas to improve protection of human communities from storm surges may require maintaining or even increasing the rates of coastal silt deposition that may not be consistent with the best management of the coastal and upstream ecosystems themselves.

EbA is often an attractive adaptation option as it can also contribute to local community livelihoods in ways not directly associated with climate change (e.g. by maintaining multiple ecosystem services from healthy and resilient forests). **It can also incorporate indigenous knowledge and respect indigenous and local values and sites of importance.**

EbA is often most effective when integrated with 'hard' infrastructural approaches. For example, flood management planning can integrate both physical barriers to water flow along with natural floodplains and wetland buffers. The example given in the Box below illustrates how floodplain management can have multiple benefits for local people, including in this instance, flood control, and biodiversity outcomes. Such examples may become more important when also adapting to the impacts of climate change.

YOLO BYPASS, CALIFORNIA, USA

The Yolo Bypass comprises a 24,000 hectare floodplain on the western side of the lower Sacramento River that was specifically constructed to carry floodwaters from several northern California rivers around several low-lying communities, including the state capitol, to the Sacramento—San Joaquin River Delta.

It is nationally recognized as an outstanding example of how public land can provide multiple public benefits, including flood conveyance for the Sacramento Valley, agricultural land for a variety of farming uses, and riparian and managed wetland habitats that are home to a wide range of species and serve as a stopover for migratory waterbirds along the along the Pacific migratory flyway. It includes embankments to channel floodwater away from the flood prone urban areas and the 6500 hectare Yolo Bypass Wildlife Area where wildlife, agriculture, and seasonal floods coexist. In the future, this type of multi-purpose, adaptive management will be increasingly important as we cope with the effects of climate change, particularly more frequent and intense flooding.

http://pacinst.org/wp-content/uploads/2013/02/managing_for_multiple_benefits3.pdf

AVOIDING MALADAPTATION

The possibility of creating or increasing unintended threats under future climates through adaptation actions is a concern for adaptation planners. Maladaptation, as it is called, may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change, or diminished human wellbeing or ecosystem resilience, now or in the future. Maladaptation can have negative impacts on areas distant from the intended target of the adaptation measures. For example, the cumulative impact of increasing small-scale water retention dams in an upper catchment may reduce and/or change the seasonality of downstream water availability. Maladaptation can also come about through actions that, although beneficial now, will have adverse outcomes in the future; for example, heavy investment in improved irrigation techniques in an area where water for irrigation will become unavailable in the relatively near future can result in stranded assets. Similarly, improved flood management may encourage further settlement and investment in infrastructure in an area that is ultimately going to be severely damaged by floods under a changing climate.

Fear of maladaptation should not become a rationale for inaction. Every adaptation decision has risks and its effectiveness will depend on future mitigation actions, risk factors other than those related to climate change, or to wider global change, and simple misfortune in the occurrence of extreme events.

In many situations there can be differences in opinion about how maladaptive an action might be because the impacts, negative and positive, of a particular action will vary between individuals; people have different attitude to risks, and often adaptation to climate change is only one of many issues facing a community and the maladaptive risks may be regarded as tolerable with the broader context. The application of environmental flows or the construction of engineering works and measures in order to restore ecosystem services and support ongoing irrigation from river systems in south-eastern Australia (Murray–Darling Basin) under climate change is an example where both negative and positive outcomes may occur (Lukasiewicz et al. 2015).

ENGINEERING WORKS AND MEASURES

Small-scale engineering works and measures have been used in Australia's Murray—Darling Basin for diverting water across floodplain wetlands as a part of a wider water and wetland conservation program. Pittock et al. (2013) consider that the governments that have promoted these approaches have embraced "the beguiling notion that scarce water supplies can be divided further, while conserving the environment and maintaining agricultural production." It was further expected that the difficulties associated with these measures would increase under climate change. These measures were though welcomed by irrigation communities who were reluctant to give up further water for restoring the floodplain wetlands that have been adversely affected by the diversion of water for irrigation purposes. Some of these measures were found to be beneficial, such as the construction of fishways; however, the measures that were assessed would only enable < 1% of the Basin's wetlands to be inundated while carrying significant risks of maladaptation including desiccation of non-target wetlands and possibly even further reductions in water allocations for the environment. In response they recommended that trade-offs between alternative strategies were assessed as a basis for minimising perverse impacts under changing climatic and hydrological conditions.

CONSTRAINTS OR BARRIERS

As planners consider the options for adaptation within the context of other societal goals and the possibility of climate change that may exceed the 2°C goals there is increasing concerns about the constraints (also referred to as barriers or obstacles) to adaptation and even the limits to adaptation. Adaptation options can be constrained by a range of biophysical, institutional, financial, social and cultural factors. Biophysical and financial constraints tend to be foremost in many planning situations, but increasingly institutional weaknesses, lack of information and understanding of the risks involved, and inappropriate legal instruments are often the most significant constraints to effective adaptation. Differing social perceptions of climate risk, differing priorities and differing valuation of nearer-term versus longer-term risks can further constrain adaptation actions.

Another form of constraint can arise from path dependency; i.e. where earlier decisions close later options or make them more difficult to implement or more expensive. A number of approaches have been developed to avoid this type of constraint. These include no-regret options and 'adaptive management' (or ”flexible pathway") approaches that use ongoing adjustments to the management plan, avoiding irreversible actions and trialling multiple options in poorly understood situations. 'Real option analysis' is a formal analytical framework to assist in deciding the relative merits of different paths and the risks and benefits of delaying or committing to action where information is limited.

In some circumstances there are real limits to adaptation in that the risks from climate change are unacceptable to those exposed and consequently adaptation is not acceptable. These situations require acceptance of losses, withdrawal from areas at risk, or "transformative adaptation", such as changing livelihoods from high water dependency agriculture to pastoralism. Failure to foresee and deal with limits to adaptation can contribute, along with other social factors, to community breakdown, forced migration and physical insecurity and conflict.

ADAPTIVE WATER MANAGEMENT

Although there is limited evidence, there is more and more agreement that an adaptive approach to water management can be used to address uncertainty due to global change, including climate change. Many practices that have been identified as adaptive to climate change have been used to address change and uncertainty due to climate variability. Many of these are seen as "low-regret" opportunities as they can provide social and/or economic benefits to both climate variability and climate change. A number of adaptation approaches for managing water under climate change are shown in Table 1. Adaptive techniques involve experimental approaches based on learning from experience, based on the collection of relevant data and information, and the development of flexible solutions that can cope with uncertainty. These are often associated with scenario planning and typically contain a mix of "hard" or infrastructural measures with "soft" or institutional measures.

TABLE 1: CATEGORIES OF CLIMATE CHANGE ADAPTATION APPROACHES FOR THE MANAGEMENT OF FRESHWATER RESOURCES

CATEGORY	OPTIONS	ASSIST IN MITIGATION
INSTITUTIONAL	Support integrated water resources management, including the integrated management of land considering specifically negative and positive impacts of climate change	X
	Promote synergy of water and energy savings and efficient use	X
	Identify "low-regret policies" and build a portfolio of relevant solutions for adaptation	X
	Increase resilience by forming water utility network working teams	
	Build adaptive capacity	
	Improve and share information	X
	Adapt the legal framework to make it instrumental for addressing climate change impacts	X
	Develop financial tools (credit, subsidies and public investment) for the sustainable management of water, and for considering poverty eradication and equity	
DESIGN AND OPERATION	Design and apply decision-making tools that consider uncertainty and fulfill multiple objectives	
	Revise design criteria of water infrastructure to optimize flexibility, redundancy and robustness	
	Ensure plans and services are robust, adaptable or modular, give good value, are maintainable, and have long-term benefits, especially in low-income countries	X
	Operate water infrastructure so as to increase resilience to climate change for all users and sectors	
	When and where water resources increase, alter dam operations to allow freshwater ecosystems to benefit	
	Take advantage of hard and soft adaptation measures	X
	Carry out programs to protect water resources in quantity and quality	
	Increase resilience to climate change by diversifying water sources and improving reservoir management	X
	Reduce demand by controlling leaks, implementing water-saving programs, cascading and reusing water	X
	Improve design and operation of sewers, sanitation and wastewater treatment infrastructure to cope with variations in influent quantity and quality	
	Provide universal sanitation with technology locally adapted, and provide for proper disposal and reintegration of used water into the environment or for its reuse	
REDUCE IMPACT OF NATURAL DISASTERS	Implement monitoring and early warning systems	
	Develop contingency plans	
	Improve defenses and site selection for key infrastructure that is at risk of floods	
	Design cities and rural settlements to be resilient to floods	
	Seek and secure water from a diversity (spatially and source-type) of sources to reduce impacts of droughts and variability in water availability	
	Promote both the reduction of water demand and the efficient use of water by all users	
	Promote switching to more appropriate crops (drought-resistant, salt-resistant; low water demand)	X
	Plant flood- or drought-resistant crop varieties	
AGRICULTURAL IRRIGATION	Improve irrigation efficiency and reduce demand for irrigation water	
	Reuse wastewater to irrigate crops and use soil for carbon sequestration	X
INDUSTRIAL USE	When selecting alternative sources of energy, assess the need for water	X
	Relocate water-thirsty industries and crops to water-rich areas	
	Implement industrial water efficiency certifications	X

(IPCC 2014 and multiple references therein)

FRAMEWORK FOR ASSESSING ADAPTATION OPTIONS AT A CATCHMENT LEVEL

In line with natural resource management approaches that have encouraged planning at a catchment scale, a Catchment Assessment Framework (CAF) for assessing the potential of climate change adaptation options was developed in the Murray-Darling Basin in south-eastern Australia (Lukasiewicz et al. 2013). The Framework is a process-based tool that is used to assess the climate change adaptation potential of natural resource management actions through a series of tables that are used to summarise discussions around seven key components (Table 2).

The CAF was used to assess the effectiveness of a number of "low-regret" ecosystem management options in a basin that was undergoing major transformation in the way in which water was allocated for irrigation and environmental purposes. In this respect the issues around water conservation and use were intimately interlinked with maintenance and restoration of ecosystems throughout the riverine system. The options that were assessed included the use of environmental flows, the construction of engineering works and measures, control of thermal pollution from water releases from dams, restoration of riparian vegetation, including the removal of exotic species, maintaining or re-establishing habitat connectivity and the geomorphic features of the ecosystems, and maintenance of river reaches connected to aquifers.

The assessment was based on knowledge provided through stakeholder participation and analysis of future climate scenario(s?). The stakeholders were provided with locally relevant climate scenario and asked to assess the opportunities and risk associated with the range of adaptation options, based on their expertise and experience in the catchments. First, the outcomes further showed that as many of the adaptation options were already being undertaken in the catchments for non-climate related management it was possible to extend and link them to form a substantial ecosystem-based approach to adaptation Second, the assessment also confirmed the need to look at a suite of complementary actions that spread the risk associated with adaptation rather than investing in one or two perceived best actions. Third, the adoption of an ecosystem-based approach was recognized as advantageous but possibly constrained by institutional complexity and socioeconomic considerations. Finally, the assessment and in particular the uncertainty associated with the climate scenarios reinforced the value that an adaptive approach would provide when implementing an ecosystem-based approach to climate change adaptation.

This example also illustrated the importance of tapping into local expertise, knowledge and experience when assessing adaptation options – expertise and experience that came from familiarity with the ecosystems and institutional practices for managing the water and riverine ecosystems.

TABLE 2:
CATCHMENT ASSESSMENT FRAMEWORK (CAF) USED TO ASSESS CLIMATE CHANGE ADAPTATION FOR RIVERS AND WETLANDS IN AUSTRALIA'S MURRAY-DARLING BASIN*

* from Lukasiewicz et al.2015. NRM = Natural Resource Management

1. CATCHMENT RELEVANCE	Establishes specific projects that are either undertaken or considered by the managing body. Specifying actual projects or programs allows the evaluation to be more practical.
2. CLIMATE CHANGE ADAPTATION This part is further divided into 3 parts :	Consideration of whether the NRM action contributes to reducing non-climate change stressors or to increasing resilience to climate change shocks.
	Assessment of the effectiveness of NRM actions under different climate change scenarios.
	Consideration of the potential for maladaptation (unintended consequences).
3. ECOSYSTEM SERVICES BENEFITS	Looks at the ecosystem benefits provided by the NRM actions. The ecosystem-based approach to climate change adaptation highlights the need to have healthy, functioning ecosystems to build resilience to climate change impacts, sequester carbon (in itself a climate change mitigation strategy)v, attenuate natural disasters and meet other human needs.
4. COMPATIBILITY Highlights how the actions interact with one another. This aspect is qualitative but assessments can include listing actions that :	Must be done together to gain the greatest positive effect
	Will positively enhance the effects of others
	Will negatively affect the effects of others
5. CONSTRAINTS TO IMPLEMENTATION	Constraints can either prevent or limit the adoption of individual adaptation actions. These can be physical, financial, social and institutional.
6. SOCIO-ECONOMIC CONSIDERATIONS	Assesses the positive and negative socio-economic implications of individual projects.
7. RISK OF FAILURE	Looks at the risk (probability x consequence) of the action failing to achieve its goals under different climate change scenarios. While similar to the assessment of action effectiveness under different climate change scenarios, the risk of failure considers not just the bio-physical risks but the added institutional or socio-economic risks that may be overlooked in assessments.

5. SOLUTIONS AND CALL FOR ACTION

THE IMPACTS

of global change, including climate change, on the global water cycle have been increasingly assessed and recognised yet the fresh water resources that are critical for human wellbeing and livelihoods have been degraded, and are under further pressure.

Water is at the centre of human wellbeing and livelihoods, and many of the ecosystems that sustain the water cycle, the rivers and wetlands, have been lost and degraded, as have both surface and groundwater catchments; all parts of the water cycle are threatened by climate change that will exacerbate current threats.

Water supports numerous functions: it is a resource for people, agriculture, industry, energy production, etc.; it forms ecosystems, such as rivers, lakes, marshes, and groundwater, that contain habitats for plants and animals; it is a hazard, directly in the form of floods, for example, or indirectly by triggering erosion, soil degradation, landslides, etc.; it transports pollutants, through the soil, and in surface and groundwater; and it also supports disease vectors. Consequently water, and more particularly, freshwater, is at the centre both of human wellbeing and livelihoods, and of ecosystems.

The numerous functions supported by water are best considered and/or managed at a catchment scale, which can range from a few hectares to millions of square kilometres. Management also needs to take into account the many interactions of water with other landscape units, such as those that support human settlements and agriculture, as well as other ecosystems, and as such water management can often be considered a land use management issue

Global change, including climate change, has numerous impacts across the different parts of the water cycle. Many parts of the water cycle have been affected by such change and the ecosystems that sustain the water cycle have been lost or degraded. In most catchments, climate change will exacerbate current anthropogenic threats.

NEVERTHELESS, IN THE FACE OF GLOBAL CHANGE, AS DESCRIBED IN THIS BOOK, WATER CAN BE PART OF THE SOLUTION

1/ IN TERMS OF THE MITIGATION OF CLIMATE CHANGE

As the carbon and water cycles are intricately linked, water is key to retaining and storing carbon in ecosystems and their soils. Consequently, among other actions that don't directly target water management (including for example, farming methods that ensure the management and restoration of soil carbon), preserving and restoring wetlands (in particular by maintaining or restoring the water regime) in freshwater as well as in coastal zones, is a key issue. Coastal wetlands such as salt marshes and mangroves release lower amounts of greenhouse gases and store more carbon than many freshwater wetlands. Moreover, they also provide a number of very important ecosystem services that benefit society, in particular local communities. Freshwater-forested wetlands also deliver high mitigation benefits, and co-benefits for local communities. Their conservation or restoration, integrated within wider catchment-scale planning, should be a priority.

2/ IN TERMS OF ADAPTING TO THE IMPACTS OF CLIMATE CHANGE

Many wetlands, in particular mangroves, constitute key areas to limit the consequences of sea level rise. Mangroves can help stabilise coastal sediments and protect shore-lines from erosion, and, under some circumstances, can limit the salinization of upstream soils, surface water and aquifers.

3/ IN TERMS OF ADAPTATION TO GLOBAL CHANGE

Some surface or underground components of catchments, such as flood plains and some specific aquifers, can be managed advantageously to regulate hydrological regimes. Consequently it is possible to implement active management of the water cycle, and thus to mediate the impacts of global change. This particularly applies to managing flooding from rivers, to protect human settlements and infrastructure, and also to the attenuation of low flows, for the conservation of aquatic ecosystems or the dilution of water-vectored pollutants. Extreme hydrological regimes, such as significant flooding or periods of excessive low flows, can be natural but increasingly they are a consequence of disturbance by human activities, including by climate change. Moreover, water storage in flood plains or aquifers provides a resource that can be accessed during the dry season when there may be less water available in the rivers.

As vegetation can transpire around 50% (+/- 20%) of the rainwater input to any catchment, land and vegetation management practices can efficiently help reduce water scarcity, and encourage adaptation to global change. Conversely, afforestation and reforestation policies, which among other advantages can increase carbon storage, must be considered with care, and on a catchment by catchment basis, due to their potential impact on the water resource at the catchment scale.

More widely, the use of water recycling, or the artificial recharge of aquifers with non-conventional water resources, such as treated wastewater, and the multiple consecutive uses of water in closed loops are also means of reducing pressure on freshwater resources, and adapting to global change.

Appropriate agricultural soil management not only favors carbon storage but also increases capillary water storage in soils, and thus reduces the need for blue water for irrigation. It thus tends to reduce the pressure on freshwater resources with some positive side effects such as an increase in crop yield, and the reduction of soil degradation or erosion risk;

In terms of water quality, the conditions that often prevail in water saturated media, particularly those in wetlands and aquifers, promotes the improvement of water quality, or reduces its degradation due to global change. The conditions that prevail in waterlogged media are particularly efficient for removing agricultural nitrogen and also remediating industrial and mining contaminants, including some trace and heavy metals;
Numerous wetlands, in diverse environments, constitute biodiversity hotspots. Those that are effectively conserved can act as biodiversity reservoirs favoring future adaptation to global change.

4/ IN TERMS OF POLICIES FOR ADDRESSING GLOBAL CHANGE

A systemic and integrated approach that takes into account the whole water cycle, implemented at the pertinent scale for the catchment or landscape of concern and covering all of the above described water functions, presents an opportunity to combine and align different sectorial policies including land use and planning, agriculture, industry, energy, etc. As water is at the crossroads of many of these policies the design and adoption of appropriate integrated policies is a key for successful management. Such policies will help in implementing practices for mitigating and adapting to global change.

They will also help in implementing policies that have not only a global positive impact, but also local impacts, with visible benefits in particular catchments that will help with raising and maintaining the awareness of both the general public and local decision makers, and consequently the effectiveness of these policies.and adapting to global change. They will also help in implementing policies that have not only a global positive impact, but also local impacts, with visible benefits in particular catchments that will help with raising and maintaining the awareness of both the general public and local decision makers, and consequently the effectiveness of these policies.. Managing current climate variability is the best indicator of the ability to manage future variability. Water smart interventions that reduce the risks associated with climate variability already exist. However, there are no simple generic solutions and all possible interventions must be assessed within the context of the catchment in which they are proposed. Given the high levels of uncertainty they must also "work" regardless of the direction of hydroclimatic trends.

This being said, the following steps are proposed for consideration by water and land managers and decision makers in order to increase the resilience and sustainability of communities in the face of ongoing changes.

1. Improve the information resource to inform the choice and implementation of measures needed to stop and reverse the factors responsible for past degradation to enable ecosystems to recover from the impacts of further global change. Sustained effort is needed by multiple levels of government, communities and with industry at a national and global scale to ensure that adaptation and mitigation options are effectively assessed and implemented, as well as monitored to ensure an adaptive approach is possible.

2. Robust methods to assess the vulnerability of fresh water resources and ecosystems to climate change are needed as a first step in identifying priorities for adaptation.

3. A key component of such activities includes the supply of information to support better understanding of the water cycle, including the blue and green components, to identify the importance of particular components and places for people, and opportunities for their protection or restoration.

4. Global and regional data are needed to assess the importance of specific ecosystems or specific wetland types for mitigating climate change, and for determining priorities for restoration. Ecosystems and/or wetlands with high potential for carbon sequestration need to be identified and steps taken to ensure these are protected and measures to ensure sequestration implemented.

5. Adaptation measures for specific sites need to be assessed and the opportunities and risks identified in order to prioritise management activities, and to avoid maladaptation. Constraints to adaptation need to be identified and addressed and decisions made about the balance between hard or soft options.

6. Ecosystem based adaptation provides an opportunity to link the outcomes for people with those for the environment and as such opportunities should be explored in order to deliver win-win solutions.

7. The capacity to support mitigation and adaptation activities across the water cycle is needed, including the capacity to make locally relevant assessments and implement mitigation or adaptation measures.

The above actions should be developed or extended in collaboration with existing programs, and wherever possible synergies should be established. Case or demonstration studies act as powerful communication tools and should be used to develop the capacity needed to implement both ongoing and further activities with governments, local communities and business enterprises.

Above all, the imperative of global change demands leadership at many levels across our societies, including from government, non-governmental and community-based organisations, local communities and from industry to champion the importance of mitigation and adaptation to ensure the global supply of fresh water is maintained and the benefits to humans and biodiversity are realised. As water, through its various functions, connects people with ecosystems a multi-faceted approach is needed to ensure on-ground activity in response to the adverse outcomes of global change, including climate change, on society and its many values.

THE ENGAGEMENT OF COMMERCIAL ENTERPRISES ALONG WITH WIDER SOCIETY IS AN ESSENTIAL PART OF THE PROCESSES NEEDED TO ADDRESS THE CAUSES AND CONSEQUENCES OF GLOBAL CHANGE, ESPECIALLY THOSE RELATED TO WATER WHICH IS AT THE VERY HEART OF HUMAN WELLBEING AND THE HEALTH AND RESILIENCE OF THE EARTH SYSTEM.

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