Water and Climate Change Adaptation

Chapter 1

A changing and uncertain future for freshwater

This chapter provides an overview of the range of complex impacts on freshwater that can be expected in a changing climate. It also highlights the main sources of uncertainty and information gaps associated with climate change impact assessments on water systems that pose challenges for informing practical, on-site adaptation decisions. Finally, it examines the policy implications of the proposition that "stationarity is dead", or in other words, that the future for freshwater will not look like the past.

Key messages

- **Climate change is, to a large extent, water change.** Climate change affects all aspects of the water cycle and water is the main way through which the impacts of climate change will be felt. The consequence of these impacts will depend on their nature, where and when they occur, and the exposure and vulnerability of the populations, ecosystems, and physical assets they affect.
- Typical assessments of the impacts of climate change on freshwater are of **limited use when it comes to making practical, on-site decisions** about adaptation. In general, the level of confidence in climate change projections decreases as their potential utility for making decisions on how to adapt increases. Adaptation decisions need to accommodate considerable uncertainty.
- One trend appears predictable: **the future for freshwater will not look like the past.** This shift calls for a flexible, dynamic, future-oriented approach that takes into account climate variability on all timescales.

Climate change impacts on freshwater resources are already evident and are projected to become more significant and to accelerate over time (Bates et al., 2008). There is also a growing recognition that climate change presents a singular challenge for water systems[1] by rendering the historical assumption of stationarity[2] increasingly irrelevant (Milly et al., 2008). This means that a fundamental assumption upon which water management, infrastructure design and planning, and ultimately many economic and resource management decisions are founded will no longer be a reliable basis for future planning and management. Decisions made today may lock us into management strategies and infrastructure for many decades that will not match future climatic conditions. The unprecedented rate of change and potential novel changes outside of historical experience introduce a greater degree of uncertainty beyond what water managers have traditionally had to cope with.

Uncertainty and knowledge gaps

Despite an ever-expanding scientific basis, reliable information about the nature, magnitude and timing of hydrological impacts at the scale needed for water resources planning and management is generally lacking. Improving this information base to attain the required level of detail and confidence needed to inform practical, on-site adaptation decisions will take time. This is due to limitations in data, modelling capacity, and computational requirements. Moreover, by their very nature, climate and hydrological systems are hard to predict. Given the current state of knowledge and limits to predictability of climate change impacts on water, effective decisions to adapt to climate change will need to be made in the absence of accurate and precise climate predictions (Dessai et al., 2009).

Most climate change impact studies rely on projections from **global circulation models** (GCMs). These models were originally designed to assess the global impact of various emissions pathways in order to make the case for mitigation efforts. The extension of their use to adaptation decision-making is a relatively recent development. The current suite of climate models were not developed to provide the level of accuracy required to inform adaptation decisions for water resources management (Kundzewicz and Stakhiv, 2010). The utility of GCMs for adaptation decisions for water resources and the most promising approaches for addressing their shortcomings or developing alternatives are the subject of widespread debate (Kundzewicz and Stakhiv, 2010). Even if some of the limitations of current approaches can be addressed, adaptation decisions will still need to accommodate considerable uncertainty (Anagnostopoulos et al., 2010; Wilby, 2010; Bates et al., 2008).

Although is it becoming “standard” practice for climate change impact assessments for water to link the results of a climate change model for temperature and precipitation with a hydrological model for runoff, these assessments have several limitations (Rodríguez-Iturbe and Valdés, 2011). However, the emergence of a “standard” approach does not imply that there is consensus about the utility or effectiveness of this approach. Novel approaches, such as “decision scaling” (Brown and Wilby, 2012), are emerging as a promising way forward (see Chapter 2 for further discussion). The main sources of uncertainty and knowledge gaps associated with typical climate change impact assessments for water resources are highlighted below.

Uncertainty related to scenarios, emissions trends, and models

There is significant uncertainty associated with climate models' reproduction of the current climate and simulation of the future climate. These models simulate some climatic processes in only a rudimentary fashion (Bates et al., 2008). Other sources of uncertainty are the scenarios used to estimate emission trends and the way that climate models simulate the impact of those trends on the climate. Depending on the climate model, the same emission trend can produce a wide variation of climate change projections.[3] This is particularly acute in the case of precipitation and evapotranspiration. Hydrological models also add substantial uncertainty due to regional differences and limitations in the coverage of monitoring networks (Huntington, 2006).

Modelling uncertainty may be reduced to some extent by running an ensemble (several slightly different models of the climate system) or thousands of runs from a single model. Yet, in practice, this is a complex and resource-intensive task. Also, the results from an ensemble run may diverge significantly. Even multiple runs of a single model can show significant variation between projections at coarse spatial and temporal scales. Lack of agreement between climate models does not mean that there will be no impact, or that any given impact is unlikely. Instead, it may mean that there is a large range of possible futures, including significant potential increases or decreases in a given climate parameter.

Coarse resolution/scale mismatch

In general, the level of confidence in climate change projections decreases as their potential utility for adaptation decision-making increases. As the spatial scale decreases, projections become less consistent between models. Thus, it is widely recognised that findings from global assessments of climate and hydrological change are not directly usable by decision makers at regional, national and subnational levels for adaptation (UNFCCC, 2011).

The coarse "resolution" of global climate models means that outputs are insufficiently detailed for climate impact studies at finer geographic scales. While climate models have been able to reproduce broad features of the past climate at large geographic scales (continental and above), in general, they still cannot reconstruct the important details of the climate at finer scales (Kundzewicz and Stakhiv, 2010). Because of these limitations, outputs from GCMs are typically "downscaled". These techniques require significant information on the ground for calibration (Rodríguez-Iturbe and Valdés, 2011). However, efforts to address the scale mismatch of global models to provide more site specific information through downscaling also have serious practical limitations (Wilby and Dessai, 2010).

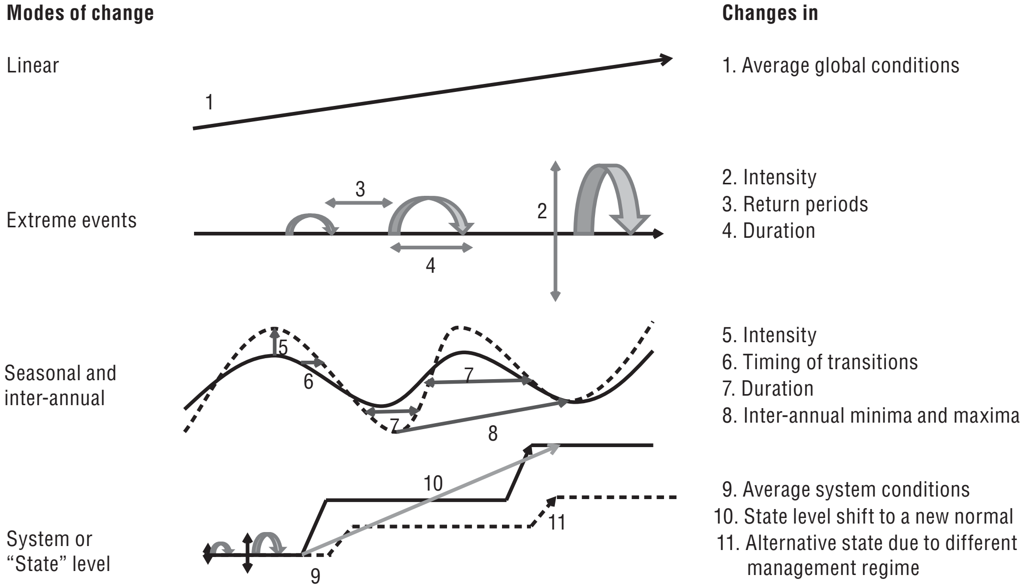
Low confidence for key climate parameters

There is a higher degree of confidence in estimates of shifts in temperature, than for changes in precipitation and evapotranspiration. Unfortunately, precipitation, the principal input to freshwater systems, is not adequately simulated in present climate models (Kundzewicz et al., 2008). With some exceptions, models generally disagree about the magnitude of precipitation changes and sometimes also the direction of the change. Low confidence in precipitation projections also precludes the reliable estimate of changes in flood frequency and magnitude.

A focus on shifts in the mean

Changes in averages are easier to project than changes in extremes. However, projections of increasing average temperatures and changes in average annual rainfall are of limited use for adaptation decision-making. Reliable estimates of changes in the forms of precipitation (rain or snow), seasonal timing of precipitation, inter annual variability, shifts in runoff and river discharge are generally lacking. Moreover, most models do not even try to simulate shifts in extremes, often assuming that current levels of variability will continue relative to a shifting mean. This assumption may overlook some of the most severe, sudden, and costly impacts of climate change on water. Figure 1.1 illustrates several modes of climate change. Climate models tend to focus on changes in the "mean", which is not likely to be either the most likely mode of change (Le Quesne et al., 2010), nor the most relevant for adaptation decisions.

Figure 1.1. **Modes of climate change**



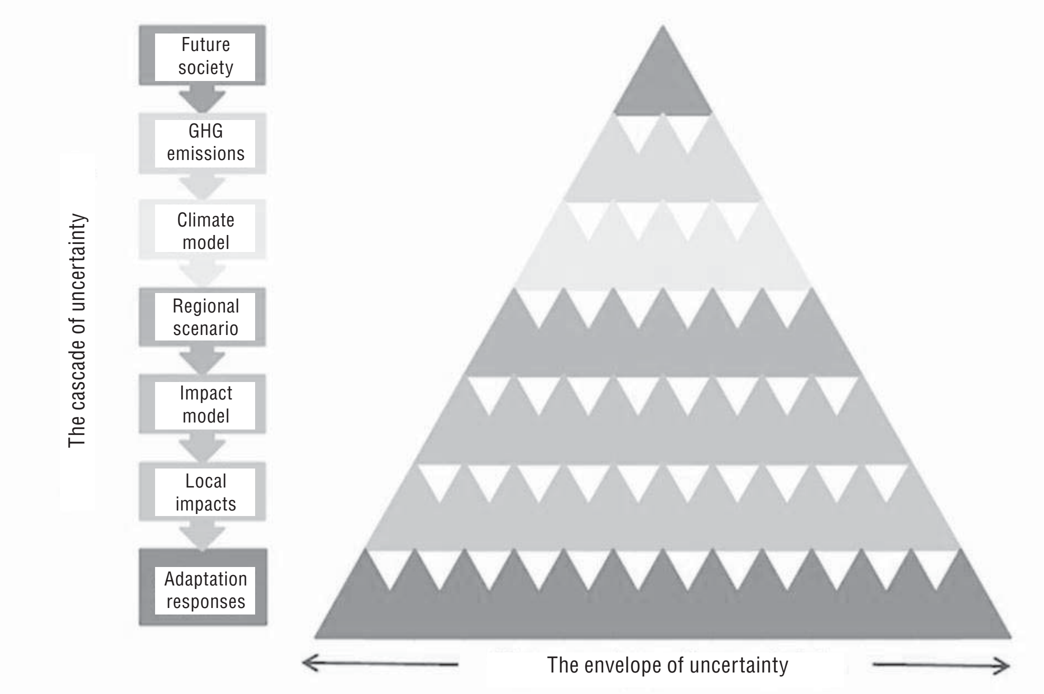
Source: A.J. and J.H. Matthews (2012), Adapted from "Vulnerability to What Change?", presented at the UNFCCC Technical workshop on water, climate change impacts and adaptation strategies, Mexico City, Mexico 18-20 July, World Wildlife Fund and Conservation International, *http://unfccc.int/adaptation/workshops_meetings/nairobi_work_programme/items/6955.php* (accessed 12 December 2012).

A widening range of possible futures

Uncertainties in climate change impact assessments for water resources arise in all stages of the impact assessment process. Figure 1.2 illustrates how the sources of uncertainties compound to multiply the range of possible futures.

Scientific advances can either reduce or expand the range of uncertainty. For example, as previously unknown processes are identified and described uncertainties about those processes may expand the existing range of uncertainty. Even if perfect climate models could be built, uncertainty about all the other non-climatic pressures means that regional hydrological projections would still be highly uncertain (Wilby, 2010).

Figure 1.2. **Cascade of uncertainty**



A cascade of uncertainty proceeds from different socio-economic and demographic pathways, their translation into concentrations of atmospheric greenhouse gas (GHG) concentrations, expressed climate outcomes in global and regional models, translation into local impacts on human and natural systems and adaptation responses.

Source: Wilby, R.L. and S. Dessai (2010), "Robust Adaptation to Climate Change", *Weather*, Vol. 65/7, Royal Meteorological Society, Reading, pp. 180-185, *http://dx.doi.org/10.1002/wea.543*.

A future for freshwater unlike the past

Despite all of the uncertainty, one trend appears predictable: the future will not look like the past. The notion that "stationarity is dead" (Milly et al., 2008) and is no longer an adequate guide for future water resources risk assessment and planning has gained widespread acceptance (Wilby, 2010). This marks a significant departure from the past, as much of the experience to date in managing water resources and infrastructure is based on the historical record of climate variability during a period of relatively stable climate.

Stationarity has served as a central, default assumption for water resources management. Probability-based design using historical climate data informs the construction and operation of levees, dams, spillways, and water supply and sewage treatment systems. Flood frequency characteristics, although meaningful under the assumption of stationarity, are questionable in the nonstationary environment (Kundzewicz and Somlyody, 1997). Water allocation regimes are oftentimes based on historical climate data, as are the basic tools that the insurance industry uses to communicate about water risks. Climate change alters the assumptions, data and modelling techniques required to develop information about water risks, such as flood zone maps and, ultimately, their utility as the basis for insurance (Ludwig and Monech, 2009).

The declining relevance of historical climate information to inform current and future planning presents a major challenge for water managers and policy makers. This shift signals the end of the static design paradigm for water resources systems, in favour of a dynamic response to changing conditions at all timescales (Brown, 2010). Such a dynamic approach would consist of periodically adjusting forecasts, building a flexible system focussed on robustness rather than optimisation, and taking a multidisciplinary approach to managing risk. A flexible, dynamic approach is required to minimise potential mismatches between water infrastructures and future climate (Matthews et al., 2011).

Climate change as water change

Despite the uncertainty and knowledge gaps, there is a significant and growing body of scientific evidence documenting the range of complex changes in the water cycle that can be expected in a changing climate. This evidence is useful to provide an overview of the broad range of changes that will present challenges for managing water systems in the future.

Climate change affects all aspects of the water cycle and water is the predominant means through which the impacts of climate change will be felt. Climate change is driving an on-going intensification (increases in evapotranspiration and precipitation) of the water cycle[4] (Huntington, 2006). In other words, in a warmer atmosphere, the water cycle is speeding up.

A certain amount of climate change is already unavoidable, regardless of future greenhouse gas emissions. Significant impacts have already occurred. The OECD *Environmental Outlook to 2050* projects that without more ambitious mitigation policies, the mean global temperature could increase by 3 °C to 6 °C above pre-industrial levels by the end of the century (OECD, 2012). Significant action is required to limit mean increases to 2 °C. Even if this target is achieved, it will only serve to slow the rate of climate change and there will still be considerable impacts.

Climate change impacts on freshwater include shifts in precipitation patterns, rising water temperature, deteriorating water quality, increases in evapotranspiration, and increases in the frequency and intensity of extreme events (Bates et al., 2008; IPCC, 2007). Impacts are expected to become more pronounced over time and the rate of change is expected to accelerate, with more severe impacts anticipated in the second half of the century. The range of impacts on water are summarised below.

Changing precipitation patterns and increased variability

Climate change is projected to shift the spatial and temporal distribution of precipitation, with some regions becoming wetter, others drier. In general, regions with high rainfall are projected to receive more precipitation, while arid and semi-arid regions are projected to become drier. Shifting precipitation patterns will affect runoff (see below), the rate of surface and groundwater recharge, and displace rainy seasons. More frequent and intense precipitation increases erosion and sediment loads in rivers, lakes and coastal zones with a negative effect on water quality. In arid and semi-arid regions, any reduction in rainfall has serious implications for rivers and lakes, even causing them to dry up, as seen in the case of Lake Chad (Ludwig and Moench, 2010).

Over the past several decades, increases in precipitation have been observed over land in high northern latitudes, while decreases have dominated in areas situated between 10 °S to 30 °N. Over the same period, land classified as very dry has more than doubled globally (Bates et al., 2008). Overall, the attribution of observed changes in global precipitation to climate change remains uncertain because precipitation is strongly influenced by large-scale patterns of natural variability.

Projections indicate increases in precipitation, average river runoff and water availability in high latitudes and in some parts of the tropics. Some dry regions at mid-latitudes and in the dry tropics are projected to become drier (Bates et al., 2008). Many semi-arid and arid areas (e.g. Mediterranean basin, western USA, southern Africa, and north-eastern Brazil) are particularly vulnerable to the impacts of climate change and are projected to suffer a decrease in water resources (IPCC, 2007). Higher temperatures will also alter the proportion of precipitation falling as rain and snow. The form of precipitation is extremely important for snowpack-dominated regions (e.g. the Sierra Nevadas, the Andes and the Himalayas). These areas depend on seasonal snowpack to meet water demand in dry seasons. The destruction of natural storage in the form of snowpack means that alternative storage will be required to ensure that winter precipitation continues to be an economically valuable resource during the summer when demand is high.

Changes in precipitation manifest at regional or local scales and are generally poorly described by climate models. These changes are among the least well-understood and least predictable aspects of climate change while at the same time, they are among the most important for making adaptation decisions for water resources management.

Shifts in runoff and river discharge

One of the most significant climate change impacts for water resources is the change in river discharge (Ludwig and Moench, 2010). Low river flows affect the functioning of freshwater ecosystems, navigation, hydropower generation, the availability and quality of water supply.

Observed changes in runoff and river discharge trends are not always consistent with changes in precipitation, although this may be due to data limitations. At the global scale, several studies suggest changes in annual runoff, with some regions experiencing an increase (e.g. high latitudes and large parts of the USA) and others experiencing a decrease (e.g. parts of West Africa, southern Europe and southernmost South America) (Bates et al., 2008). In regions where winter precipitation falls in the form of snow, there is more robust evidence that the timing of river flows has been significantly altered.

Projections indicate increases in runoff in high latitudes and the wet tropics, and decreases in mid-latitudes and some parts of the dry tropics. In some simulations, runoff is notably reduced in southern Europe and increased in south-east Asia and in high latitudes, where there is consistency among models in the direction of the change, although less so in terms of the magnitude of change (Bates et al., 2008).

Increasing frequency and intensity of extreme events[5]

Climate change leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events (IPCC, 2012). Extreme events have an impact on water quantity and quality and pose risks to populations, physical assets and ecosystems. Water quality is expected to be negatively impacted by extreme events via increasing sediments, nutrients, pesticides and salt loads. The risk of contamination of water supplies due to increased microbial loads spurred by both extreme rainfall and droughts could increase disease outbreaks.

Changes in extremes can be linked to changes in the mean, variance or shape of probability distributions, or a combination of all of these. Not all climate extremes are "tail events".[6] Some climate extremes, such as **drought**, may be the accumulation of weather or climate events that are not considered extreme when considered independently. Many extreme events continue to be the result of natural climate variability. Records in most places are patchy, which can mask extreme events, such as mega droughts in West Africa. A recent study of the paleoclimate record in Lake Bosumtwi, Ghana suggests that the most recent centennial scale drought took place only 200 to 300 years ago. This event was much more severe and longer than the multidecadal drought of the 1970s that had widespread ecological, political, and socioeconomic impacts (Shanahan et al., 2009). Natural variability will continue to be an important factor in shaping future extremes in addition to the effect of anthropogenic changes in climate[7] (IPCC, 2012).

Observations indicate that some regions, in particular in southern Europe and West Africa, have experienced trends toward more intense and longer **droughts** since the 1950s (IPCC, 2012). However, in some regions (e.g. Central North America and North Western Australia) droughts have become less frequent, less intense, or shorter. Recent studies project an increase in the duration and intensity of droughts in some regions, including southern Europe and the Mediterranean region, Central Europe, Central North America, Central America and Mexico, Northeast Brazil, and Southern Africa. These shifts may contribute to positive feedback mechanisms in ecosystems. For example, two recent droughts in the Amazon demonstrate mechanisms by which remaining intact tropical forests of South America can shift from buffering the increase in atmospheric carbon dioxide to accelerating it (Lewis et al., 2011).

Figure 1.3 depicts projections of changes in the frequency and intensity of water resources drought across Europe by the 2070s. Severe droughts are projected to become less frequent and intense in some areas of Northern Europe and more frequent and intense in some areas of Southern Europe (IPCC, 2012). The figure also illustrates that while the two models reflect broadly similar trends, at the finest level of resolution, there are significant differences in the projections.

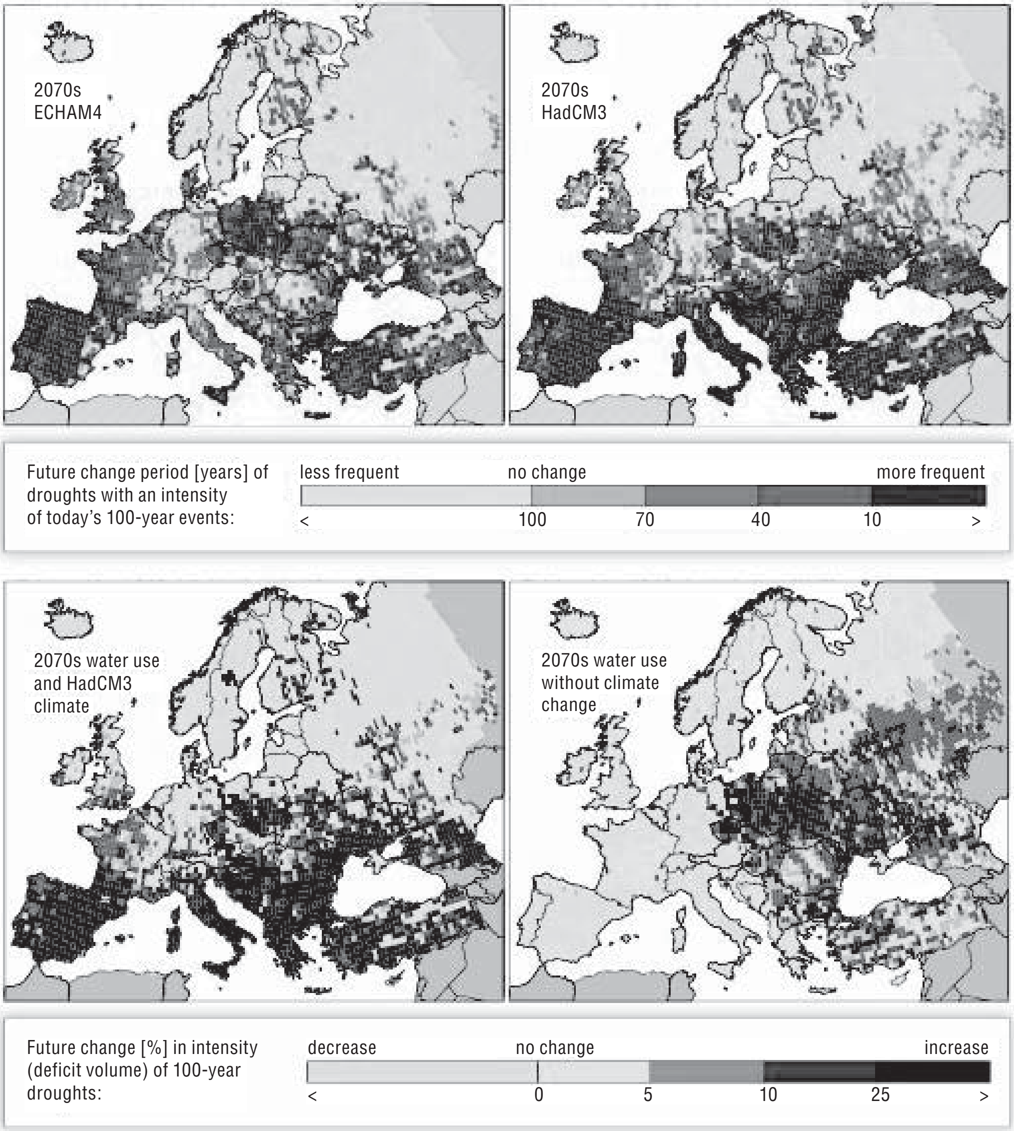
The number of **heavy precipitation** events has probably increased in many regions, but there are strong regional and sub-regional variations in these trends. North America exhibits the most consistent trends toward heavier precipitation. Projections indicate that it is likely that the frequency of heavy precipitation events will increase over many areas, especially in the high latitudes and tropical regions, and northern mid-latitudes in winter (IPCC, 2012).

As a result of increased frequency and intensity of rainfall events, **floods** are likely to become more frequent and potentially more severe in most regions around the world (Milly et al., 2002). It is difficult, however, to pinpoint the impact of climate change on observed changes in flooding, due to limited data and because of the importance of other factors that drive flood risk, such as changes in land use.

Impacts on freshwater ecosystems

Changes to the freshwater flow regime will be the most significant and pervasive of the impacts of climate change on freshwater ecosystems (Le Quesne et al., 2010). The integrity of flowing water systems depends largely on their natural dynamic character, with stream flow quantity and timing being the critical components (Poff et al., 1997). As such, changes in the timing of flows, as much as changes to total annual runoff, are likely to have the most significant consequences on freshwater ecosystems (Le Quesne et al., 2010). Although all ecosystems are threatened by climate change, freshwater ecosystems are especially vulnerable, with one of the highest numbers of threatened species (Ludwig and Monech, 2009).

Figure 1.3. **Projected change in indicators of water resources drought across Europe by the 2070s**



Top panel: projected changes in the return period of the 1961-90 100-year drought deficit volume for the 2070s, with change in river flows and withdrawals for two climate models, ECHAM4 and HadCM3. *Bottom panel:* projected changes in the intensity (deficit volume) of 100-year droughts with changing withdrawals for the 2070s, with climate change (*left*, with HadCM3 climate projections) and without climate change (*right*).

Source: Lehner, B. et al. (2006), "Estimating the Impact of Global Change on Flood and Drought Risks in Europe: A Continental, Integrated Analysis", *Climatic Change*, Vol. 75/3, Springer, pp. 273-299, *http://dx.doi.org/10.1007/s10584-006-6338-4*. Reprinted with kind permission from Springer Science + Business Media B.V.

Ecosystems respond to changes in hydrology in complex and often non-linear ways. Climate change impacts on ecosystems will occur through dramatic state shifts as "tipping points" are crossed as well as through gradual deterioration (Le Quesne et al., 2010). Evidence from recent studies by paleoecologists suggests that climate change may not simply result in mass migration of species, but instead, reshuffle into novel "no analog" ecosystems unknown today (Fox, 2007).

Rising sea level

Global mean sea level has been rising and there is high confidence that this has occurred at an increasing rate between the mid-19th and the mid-20th centuries (Bates et al., 2008). The spatial distribution of changes is uneven. For example, in the period 1993-2003, some regions experienced sea level rise up to several times the global mean, while sea level fell in other regions (Bates et al., 2008). In Hudson Bay, for instance, there is sea-level retreat, caused by the buoyancy of the land surface following the end of the last glacial period. The destruction of coastal wetlands or the modification of flow volume or speed can accelerate the rate of sea level rise. Changes in sea level tend to be very gradual (e.g. measured in millimetres annually), then may increase suddenly during storms, as weakened coastal defences give way.

In coastal areas, sea level rise will extend areas of salinisation of groundwater and estuaries, reducing the availability of coastal freshwater supplies. Sea-level rise also obstructs drainage in deltas.

Changes in glaciers, snow, ice and permafrost

The majority of glaciers and ice caps worldwide have shrunk, leading to significant declines in water storage in mountain glaciers and snow cover and very likely making a contribution to observed sea-level rise (Bates et al., 2008). In most regions, snow cover has decreased, especially during spring and summer. Warming has also shifted the timing and amplitude of runoff in glacier- and snowmelt-fed rivers and of ice-related phenomena in rivers and lakes. The degradation of permafrost and seasonally frozen ground negatively affects drainage systems. These changes have implications for reservoir storage, water supply, drainage systems, hydropower generation and flood management. The methane emissions from defrosting decayed plant matter also constitute a positive feedback mechanism for climate change, as methane is a very powerful greenhouse gas.

Climate change is expected to further reduce water supplies stored in glaciers and snow cover. Shifts in the flow regimes of rivers and streams of snow and glacier-fed basins (especially the timing of melt water) are projected, reducing water availability during warm and dry periods. Projections indicate widespread reductions in snow cover throughout this century, despite some projected increases at higher altitudes. Glaciers and ice caps are projected to shrink, with an eventual reduction in glacial melt water, with the possibility that some glaciers may disappear altogether. Glacial retreat may also result in glacial lake expansion, flooding from melting of glaciers and bursting of glacial lakes (Bates et al., 2008).

Increasing water temperature

Higher water temperatures are projected to aggravate water pollution by increasing pathogens, dissolved organic carbon, and thermal pollution. Algal blooms will occur more frequently in a warmer climate and higher temperatures will also increase microbial activity and bacterial and fungal populations (Ludwig and Monech, 2009). These effects compound with negative impacts on water quality from more frequent extreme events and lower flow conditions during some seasons, which can increase the concentration of pollutants. These changes are projected to exacerbate many forms of existing water pollution, with potentially detrimental effects on freshwater ecosystems, human health, and the operation of water systems. However, in some regions with increasing precipitation (e.g. northern Europe), water temperatures are declining, given the greater mass in water bodies.

Groundwater

Climate change will affect the depth of groundwater tables and the amount of groundwater available through changes in recharge rates. Both changes in annual rainfall amount and extremes will impact on groundwater recharge rates (Ludwig and Moench, 2009). Groundwater recharge may also be affected by increasing evapotranspiration. Although research on this topic has improved in recent years, much uncertainly remains as to how climate change will affect groundwater.

Impacts on evapotranspiration and soil moisture

Climate change has the potential to affect evapotranspiration and soil moisture. In some areas, the rate of evapotranspiration can be quite high, driving dry season scarcity. Yet, in general, there are very limited direct measurements of actual evapotranspiration, and hence, sparse information on observed trends (Bates et al., 2008). In principle, as temperatures rise, the capacity of the atmosphere to hold water increases, thus "potential evaporation" is projected to increase almost everywhere, yet other climate factors may exaggerate or offset this effect (IPCC, 2007).

Changes in evaporation and the amount and timing of precipitation will have an impact on soil moisture. However, data on changes in soil moisture are very sparse and the magnitude of projected changes is uncertain. Decreases are projected in some areas (e.g. sub-tropics, the Mediterranean, and high latitudes) while increases are projected in others (e.g. East Africa, central Asia) (Bates et al., 2008).

Concluding remarks

The scientific evidence of the range and complexity of climate change impacts on freshwater resources is compelling and growing. Given that water is an essential resource as well as a potential threat, climate change impacts on freshwater will affect not only water and flood management *per se*, but also a number of key policy domains (e.g. energy, agriculture, infrastructure, biodiversity, and health). Despite the ever-expanding scientific basis, reliable information about the nature, magnitude and timing of impacts on freshwater at the scale needed for practical, site-specific adaptation planning is lacking. Adaptation decisions need to accommodate significant uncertainty.

Effective and timely adaptation can lower the cost of climate change impacts by improving the management of water risks and enhancing resilience. In both the near and longer term, adaptation to climate change calls for flexible, dynamic, and future-oriented approaches that take into account climate variability on all timescales along with associated changes in human and natural systems. In the absence of accurate and precise climate predictions, a risk-based approach can explicitly accommodate a range of possible futures to inform adaptation decision making. It can also be used to identify priorities and options to manage water risks and enhance resilience at least cost to society. Chapter 2 explores such an approach, in the broader context of achieving water security.

Notes

1. "Water systems" refer to natural and man-made systems used to manage water resources and floods, and to provide water supply and sanitation. This report focuses on freshwater. Climate change impacts such as sea-level rise are only considered to the extent that they impact on coastal freshwater supplies, e.g. through the salinisation of groundwater.
2. As expressed in Milly et al. (2008), stationarity is the idea that natural systems fluctuate within an unchanging envelope of variability. It is a foundational concept that permeates training and practice in water-resource engineering.
3. This difference is often more significant than differences arising from the same model run with different emission scenarios.
4. The theoretical basis for this intensification is summarised in the Clausius-Clapeyron relation that implies that specific humidity would increase approximately exponentially with temperature.
5. This section is based largely on the IPCC (2012) *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*.
6. "Tail events" are those with a very low probability in a typical probability distribution curve ("bell curve").
7. Extreme events are rare, which means there are few data available to make assessments regarding change in their frequency or intensity. The more rare the event, the more difficult it is to identify long-term changes.

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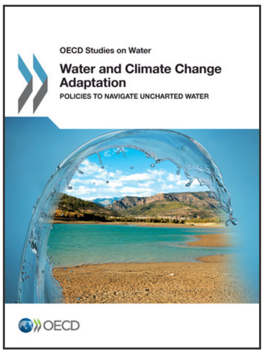

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