8

Gaps in knowledge and suggestions for further work

There is abundant evidence from observational records and climate projections that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change. However, the ability to quantify future changes in hydrological variables, and their impacts on systems and sectors, is limited by uncertainty at all stages of the assessment process. Uncertainty comes from the range of socio-economic development scenarios, the range of climate model projections for a given scenario, the downscaling of climate effects to local/regional scales, impacts assessments, and feedbacks from adaptation and mitigation activities. Limitations in observations and understanding restrict our current ability to reduce these uncertainties. Decision making needs to operate in the context of this uncertainty. Robust methods to assess risks based on these uncertainties are at an early stage of development.

Capacity for mitigation of climate change and adaptation to its impacts is limited by the availability and economic viability of appropriate technologies and robust collaborative processes for decision making among multiple stakeholders and management criteria. Knowledge of the costs and benefits (including avoided damages) of specific options is scarce. Management strategies that adapt as the climate changes require an adequate observational network to inform them. There is limited understanding of the legal and institutional frameworks and demand-side statistics necessary for mainstreaming adaptation into development plans to reduce water-related vulnerabilities, and of appropriate channels for financial flows into the water sector for adaptation investment.

This section notes a number of key gaps in knowledge related to these needs.

8.1 Observational needs

Better observational data and data access are necessary to improve understanding of ongoing changes, to better constrain model projections, and are a prerequisite for adaptive management required under conditions of climate change. Progress in knowledge depends on improved data availability. Shrinkage of some observational networks is occurring. Relatively short records may not reveal the full extent of natural variability and confound detection studies, while long-term reconstruction can place recent trends and extremes in a broader context. Major gaps in observations of climate change related to freshwater and hydrological cycles were identified as follows [WGI TS.6; WGII 3.8]:

- Difficulties in the measurement of precipitation remain an area of concern in quantifying global and regional trends. Precipitation measurements over oceans (from satellites) are still in the development phase. There is a need to ensure ongoing satellite monitoring, and the development of reliable statistics for inferred precipitation. [WGI 3.3.2.5]
- Many hydrometeorological variables e.g., streamflow, soil moisture and actual evapotranspiration, are inadequately measured. Potential evapotranspiration is generally calculated from parameters such as solar radiation, relative humidity and wind speed. Records are often very short, and available for only a few regions, which impedes complete analysis of changes in droughts. [WGI 3.3.3, 3.3.4]
- There may be opportunities for river flow data rescue in some regions. Where no observations are available, the construction of new observing networks should be considered. [WGI 3.3.4]
- Groundwater is not well monitored, and the processes of groundwater depletion and recharge are not well modelled in many regions. [WGI 3.3.4]
- Monitoring data are needed on water quality, water use and sediment transport.
- Snow, ice and frozen ground inventories are incomplete. Monitoring of changes is unevenly distributed in both space and time. There is a general lack of data from the Southern Hemisphere. [WGI TS 6.2, 4.2.2, 4.3]
- More information is needed on plant evapotranspiration responses to the combined effects of rising atmospheric CO_2, rising temperature and rising atmospheric water vapour concentration, in order to better understand the relationship between the direct effects of atmospheric CO_2 enrichment and changes in the hydrological cycle. [WGI 7.2]
- Quality assurance, homogenisation of data sets, and inter-calibration of methods and procedures could be important whenever different agencies, countries etc., maintain monitoring within one region or catchment.

8.2 Understanding climate projections and their impacts

8.2.1 Understanding and projecting climate change

Major uncertainties in understanding and modelling changes in climate relating to the hydrological cycle include the following [SYR; WGI TS.6]:

- Changes in a number of radiative drivers of climate are not fully quantified and understood (e.g., aerosols and their effects on cloud properties, methane, ozone, stratospheric water vapour, land-use change, past solar variations).
- Confidence in attributing some observed climate change phenomena to anthropogenic or natural processes is limited by uncertainties in radiative forcing, as well as by uncertainty in processes and observations. Attribution becomes more difficult at smaller spatial and temporal scales, and there is less confidence in understanding precipitation changes than there is for temperature. There are very few attribution studies for changes in extreme events.
- Uncertainty in modelling some modes of climate variability, and of the distribution of precipitation between heavy and light events, remains large. In many regions, projections of changes in mean precipitation also vary widely between models, even in the sign of the change. It is necessary to improve understanding of the sources of uncertainty.
- In many regions where fine spatial scales in climate are

generated by topography, there is insufficient information on how climate change will be expressed at these scales.

- Climate models remain limited by the spatial resolution and ensemble size that can be achieved with present computer resources, by the need to include some additional processes, and by large uncertainties in the modelling of certain feedbacks (e.g., from clouds and the carbon cycle).
- Limited knowledge of ice sheet and ice shelf processes leads to unquantified uncertainties in projections of future ice sheet mass balance, leading in turn to uncertainty in sea-level rise projections.

8.2.2 Water-related impacts [WGII 3.5.1, 3.8]

- Because of the uncertainties involved, probabilistic approaches are required to enable water managers to undertake analyses of risk under climate change. Techniques are being developed to construct probability distributions of specified outcomes. Further development of this research, and of techniques to communicate the results, as well as their application to the user community, are required.
- Further work on detection and attribution of present-day hydrological changes is required; in particular, changes in water resources and in the occurrence of extreme events. As part of this effort, the development of indicators of climate change impacts on freshwater, and operational systems to monitor them, are required.
- There remains a scale mismatch between the large-scale climatic models and the catchment scale – the most important scale for water management. Higher-resolution climate models, with better land-surface properties and interactions, are therefore required to obtain information of more relevance to water management. Statistical and physical downscaling can contribute.
- Most of the impact studies of climate change on water stress in countries assess demand and supply on an annual basis. Analysis at the monthly or higher temporal resolution scale is desirable, since changes in seasonal patterns and the probability of extreme events may offset the positive effect of increased availability of water resources.
- The impact of climate change on snow, ice and frozen ground as sensitive storage variables in the water cycle is highly non-linear and more physically- and process-oriented modelling, as well as specific atmospheric downscaling, is required. There is a lack of detailed knowledge of runoff changes as caused by changing glaciers, snow cover, rain–snow transition, and frozen ground in different climate regions.
- Methods need to be improved that allow the assessment of the impacts of changing climate variability on freshwater resources. In particular, there is a need to develop local-scale data sets and simple climate-linked computerised watershed models that would allow water managers to assess impacts and to evaluate the functioning and resilience of their systems, given the range of uncertainty surrounding future climate projections.
- Feedbacks between land use and climate change (including vegetation change and anthropogenic activity such as irrigation and reservoir construction) should be analysed more extensively; e.g., by coupled climate and land-use modelling.
- Improved assessment of the water-related consequences of different climate policies and development pathways is needed.
- Climate change impacts on water quality are poorly understood for both developing and developed countries, particularly with respect to the impact of extreme events.
- Relatively few results are available on the socio-economic aspects of climate change impacts related to water resources, including climate change impacts on water demand.
- Impacts of climate change on aquatic ecosystems (not only temperatures, but also altered flow regimes, water levels and ice cover) are not understood adequately.
- Despite its significance, groundwater has received little attention in climate change impact assessment compared to surface water resources.

8.3 Adaptation and mitigation

- Water resources management clearly impacts on many other policy areas (e.g., energy projections, land use, food security and nature conservation). Adequate tools are not available to facilitate the appraisal of adaptation and mitigation options across multiple water-dependent sectors, including the adoption of water-efficient technologies and practices.
- In the absence of reliable projections of future changes in hydrological variables, adaptation processes and methods which can be usefully implemented in the absence of accurate projections, such as improved water-use efficiency and water-demand management, offer no-regrets options to cope with climate change. [WGII 3.8]
- *Biodiversity.* Identification of water resources needs for maintaining environmental values and services, especially related to deltaic ecosystems, wetlands and adequate instream flows.
- *Carbon capture and storage:* Better understanding is needed of leakage processes, because of potential degradation of groundwater quality. This requires an enhanced ability to monitor and verify the behaviour of geologically stored CO_2. [CCS, TS, Chapter 10]
- *Hydropower/dam construction:* An integrated approach is needed, given the diversity of interests (flood control, hydropower, irrigation, urban water supply, ecosystems, fisheries and navigation), to arrive at sustainable solutions. Methane emissions have to be estimated. Also, the net effect on the carbon-budget in the affected region has to be evaluated.
- *Bio-energy:* Insight is required into the water demand, and its consequences, of large-scale plantations of commercial bio-energy crops. [WGIII 4.3.3.3]
- *Agriculture:* Net effects of more effective irrigation on the GHG budget need to be better understood (higher carbon

storage in soils through enhanced yields and residue returns and its offset by CO_2 emissions from energy systems to deliver the water, or by N_2O emissions from higher moisture and fertiliser inputs). [WGIII 8.4.1.1]

- *Forestry:* Better understanding of the effects of massive afforestation on the processes forming the hydrological cycle, such as rainfall, evapotranspiration, runoff, infiltration and groundwater recharge is needed. [WGIII 9.7.3]
- *Wastewater and water reuse:* Greater insight is needed into emissions from decentralised treatment processes and uncontrolled wastewater discharges in developing countries. The impact of properly reusing water on mitigation and adaptation strategies needs to be understood and quantified.