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Introduction to climate change and water

1.1 Background

The idea of a special IPCC publication dedicated to water and climate change dates back to the 19th IPCC Session held in Geneva in April 2002, when the Secretariat of the World Climate Programme – Water and the International Steering Committee of the Dialogue on Water and Climate requested that the IPCC prepare a Special Report on Water and Climate. A consultative meeting on Climate Change and Water held in Geneva in November 2002 concluded that the development of such a report in 2005 or 2006 would have little value, as it would quickly be superseded by the Fourth Assessment Report (AR4), which was planned for completion in 2007. Instead, the meeting recommended the preparation of a Technical Paper on Climate Change and Water that would be based primarily on AR4 but would also include material from earlier IPCC publications.

An interdisciplinary writing team was selected by the three IPCC Working Group Bureaux with the aim of achieving regional and topical balance, and with multiple relevant disciplines being represented. United Nations (UN) agencies, non-governmental organisations (NGOs) and representatives from relevant stakeholder communities, including the private sector, have been involved in the preparation of this Technical Paper and the associated review process.

IPCC guidelines require that Technical Papers are derived from:
(a) the text of IPCC Assessment Reports and Special Reports and the portions of material in cited studies that were relied upon in these reports;
(b) relevant models with their assumptions, and scenarios based on socio-economic assumptions, as they were used to provide information in those IPCC Reports.

These guidelines are adhered to in this Technical Paper.

1.2 Scope

This Technical Paper deals only with freshwater. Sea-level rise is dealt with only insofar as it can lead to impacts on freshwater in the coastal zone; for example, salinisation of groundwater. Reflecting the focus of the literature, it deals mainly with climate change through the 21st century whilst recognising that, even if greenhouse gas concentrations were to be stabilised, warming and sea-level rise would continue for centuries. [WGI SPM]

The importance of freshwater to our life support system is widely recognised, as can be seen clearly in the international context (e.g., Agenda 21, World Water Fora, the Millennium Ecosystem Assessment and the World Water Development Report). Freshwater is indispensable for all forms of life and is needed, in large quantities, in almost all human activities. Climate, freshwater, biophysical and socio-economic systems are interconnected in complex ways, so a change in any one of these induces a change in another. Anthropogenic climate change adds a major pressure to nations that are already confronting the issue of sustainable freshwater use. The challenges related to freshwater are: having too much water, having too little water, and having too much pollution. Each of these problems may be exacerbated by climate change. Freshwater-related issues play a pivotal role among the key regional and sectoral vulnerabilities. Therefore, the relationship between climate change and freshwater resources is of primary concern and interest.

So far, water resource issues have not been adequately addressed in climate change analyses and climate policy formulations. Likewise, in most cases, climate change problems have not been adequately dealt with in water resources analyses, management and policy formulation. According to many experts, water and its availability and quality will be the main pressures on, and issues for, societies and the environment under climate change; hence it is necessary to improve our understanding of the problems involved.

The objectives of this Technical Paper, as set out in IPCC-XXI – Doc. 9[6], are summarised below:

- to improve our understanding of the links between both natural and anthropogenically induced climate change, its impacts, and adaptation and mitigation response options, on the one hand, and water-related issues, on the other;
- to inform policymakers and stakeholders about the implications of climate change and climate change response options for water resources, as well as the implications for water resources of various climate change scenarios and climate change response options, including associated synergies and trade-offs.

The scope of this Technical Paper, as outlined in IPCC-XXI – Doc. 9, is to evaluate the impacts of climate change on hydrological processes and regimes, and on freshwater resources – their availability, quality, uses and management. The Technical Paper takes into account current and projected regional key vulnerabilities and prospects for adaptation.

The Technical Paper is addressed primarily to policymakers engaged in all areas relevant to freshwater resource management, climate change, strategic studies, spatial planning and socio-economic development. However, it is also addressed to the scientific community working in the area of water and climate change, and to a broader audience, including NGOs and the media.

Since material on water and climate change is scattered throughout the IPCC's Fourth Assessment and Synthesis Reports, it is useful to have a compact and integrated publication focused on water and climate change. The present Technical Paper also refers to earlier IPCC Assessment and Special Reports, where necessary. The added value of this Technical Paper lies in the distillation, prioritisation, synthesis and interpretation of those materials.

[6] 'Scoping Paper for a possible Technical Paper on Climate Change and Water'. Available at: http://www.ipcc.ch/meetings/session21.htm.

Text in the Technical Paper carefully follows the text of the underlying IPCC Reports. It reflects the balance and objectivity of those Reports and, where the text differs, this is with the purpose of supporting and/or explaining further the Reports' conclusions. Every substantive paragraph is sourced back to an IPCC Report. The source is provided within square brackets, generally at the end of the paragraph (except where parts of a paragraph are sourced from more than one IPCC document, in which case the relevant IPCC source is located after the appropriate entry). The following conventions have been used.

- The Fourth Assessment Report (AR4) is the most frequently cited IPCC publication and is represented by, for example, [WGII 3.5], which refers to AR4 Working Group II Chapter 3 Section 3.5. See IPCC (2007a, b, c, d).
- Where material is taken from other IPCC sources, the following acronyms are used: TAR (Third Assessment Report: IPCC 2001a, b, c), RICC (Special Report on Regional Impacts of Climate Change: Watson et al., 1997), LULUCF (Special Report on Land Use, Land-Use Change and Forestry: IPCC, 2000), SRES (Special Report on Emissions Scenarios: Nakićenović and Swart, 2000), CCB (Technical Paper V – Climate Change and Biodiversity: Gitay et al., 2002) and CCS (Special Report on Carbon Dioxide Capture and Storage: Metz et al., 2005). Thus, [WGII TAR 5.8.3] refers to Section 5.8.3 of Chapter 5 in the Working Group II Third Assessment Report.
- Additional sourcing acronyms include ES (Executive Summary), SPM (Summary for Policymakers), TS (Technical Summary) and SYR (Synthesis Report), which all refer to the AR4 unless otherwise indicated.

References to original sources (journals, books and reports) are placed after the relevant sentence, within round brackets.

1.3 The context of the Technical Paper: socio-economic and environmental conditions

This Technical Paper explores the relationships between climate change and freshwater, as set out in IPCC Assessment and Special Reports. These relationships do not exist in isolation, but in the context of, and interacting with, socio-economic and environmental conditions. In this section, we describe the major features of these conditions as they relate to freshwater, both observed and projected.

Many non-climatic drivers affect freshwater resources at all scales, including the global scale (UN, 2003). Water resources, both in terms of quantity and quality, are critically influenced by human activity, including agriculture and land-use change, construction and management of reservoirs, pollutant emissions, and water and wastewater treatment. Water use is linked primarily to changes in population, food consumption (including type of diet), economic policy (including water pricing), technology, lifestyle[7] and society's views about the value of freshwater ecosystems. In order to assess the relationship between climate change and freshwater, it is necessary to consider how freshwater has been, and will be, affected by changes in these non-climatic drivers. [WGII 3.3.2]

1.3.1 Observed changes

In global-scale assessments, basins are defined as being water-stressed[8] if they have either a per capita water availability below 1,000 m^3 per year (based on long-term average runoff) or a ratio of withdrawals to long-term average annual runoff above 0.4. A water volume of 1,000 m^3 per capita per year is typically more than is required for domestic, industrial and agricultural water uses. Such water-stressed basins are located in northern Africa, the Mediterranean region, the Middle East, the Near East, southern Asia, northern China, Australia, the USA, Mexico, north-eastern Brazil and the west coast of South America (Figure 1.1). The estimates for the population living in such water-stressed basins range between 1.4 billion and 2.1 billion (Vörösmarty et al., 2000; Alcamo et al., 2003a, b; Oki et al., 2003; Arnell, 2004). [WGII 3.2]

Water use, in particular that for irrigation, generally increases with temperature and decreases with precipitation; however, there is no evidence for a climate-related long-term trend of water use in the past. This is due, in part, to the fact that water use is mainly driven by non-climatic factors, and is also due to the poor quality of water-use data in general, and of time-series data in particular. [WGII 3.2]

Water availability from surface water sources or shallow groundwater wells depends on the seasonality and interannual variability of streamflow, and a secured water supply is determined by seasonal low flows. In snow-dominated basins, higher temperatures lead to reduced streamflow and thus decreased water supply in summer (Barnett et al., 2005). [WGII 3.2]

In water-stressed areas, people and ecosystems are particularly vulnerable to decreasing and more variable precipitation due to climate change. Examples are given in Section 5.

In most countries, except for a few industrialised nations, water use has increased over recent decades, due to population and economic growth, changes in lifestyle, and expanded water supply systems, with irrigation water use being by far the most important cause. Irrigation accounts for about 70% of total water withdrawals worldwide and for more than 90% of consumptive water use (i.e., the water volume that is not available for reuse downstream). [WGII 3.2] Irrigation generates about 40% of total agricultural output (Fischer et al., 2006). The area of global irrigated land has increased approximately linearly since

[7] In this context use of water-hungry appliances such as dishwashers, washing machines, lawn sprinklers etc.
[8] Water stress is a concept describing how people are exposed to the risk of water shortage.

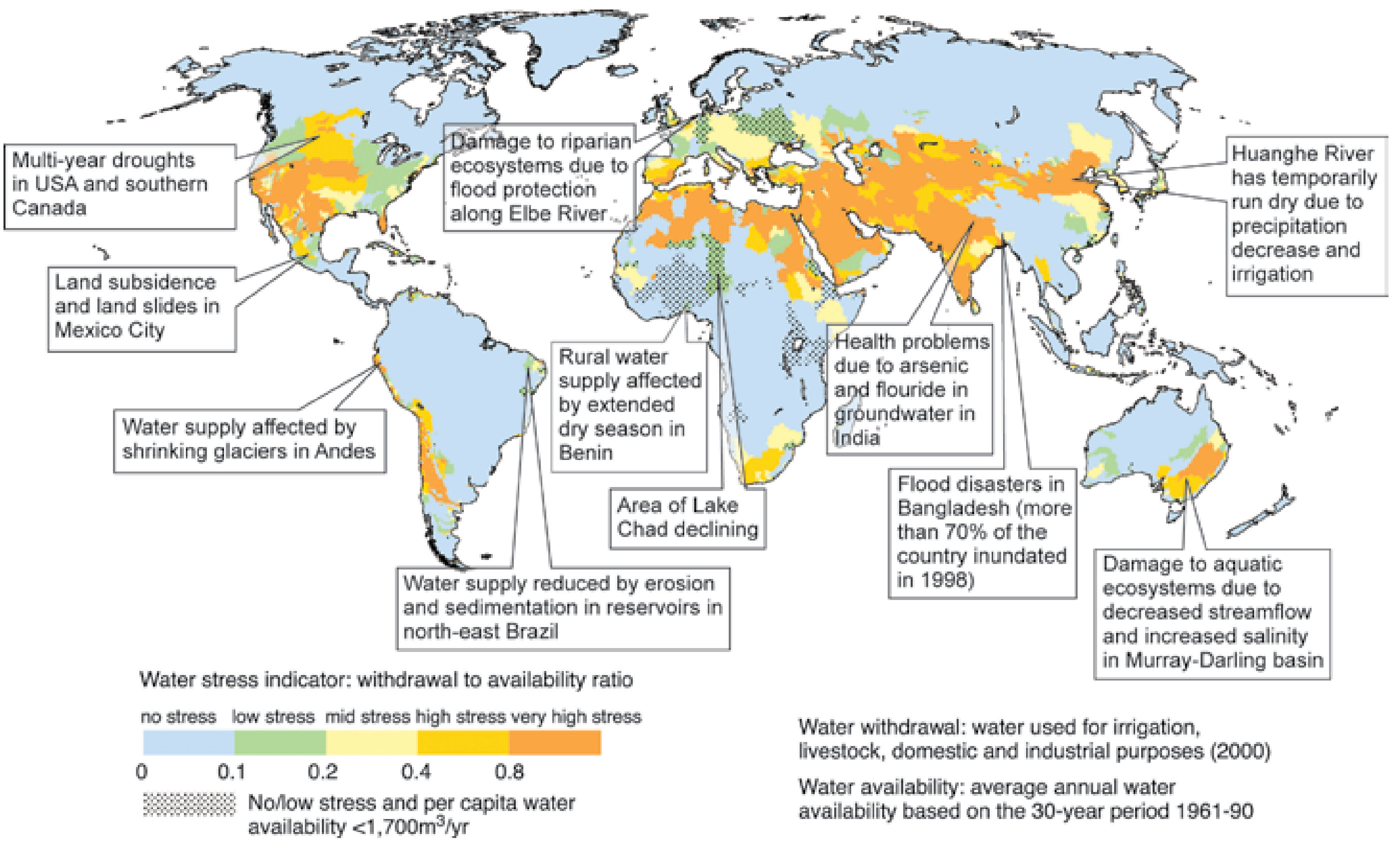

Figure 1.1: *Examples of current vulnerabilities of freshwater resources and their management; in the background, a water stress map based on WaterGAP (Alcamo et al., 2003a). See text for relation to climate change. [WGII Figure 3.2]*

1960, at a rate of roughly 2% *per annum*, from 140 million ha in 1961/63 to 270 million ha in 1997/99, representing about 18% of today's total cultivated land (Bruinsma, 2003).

Although the rates of regional population change differ widely from the global average, the rate of global population increase is already declining. Global water use is probably increasing due to economic growth in developing countries, but there are no reliable data with respect to the rate of increase. [WGII 3.2, 5.3]

The quality of surface water and groundwater has generally declined in recent decades due principally to growth in agricultural and industrial activities (UN, 2006). To counter this problem, many countries (e.g., in the European Union and Canada) have established or enforced effluent water standards and have rehabilitated wastewater treatment facilities (GEO-3, 2003). [WGII 3.3.2, Table 8.1]

1.3.2 Projected changes

1.3.2.1 General background

The four IPCC SRES (Special Report on Emissions Scenarios: Nakićenović and Swart, 2000) storylines, which form the basis for many studies of projected climate change and water resources, consider a range of plausible changes in population and economic activity over the 21st century (see Figure 1.2). Among the scenarios that assume a world economy dominated by global trade and alliances (A1 and B1), global population is expected to increase from today's 6.6 billion and peak at 8.7 billion in 2050, while in the scenarios with less globalisation and co-operation (A2 and B2), global population is expected to increase until 2100, reaching 10.4 billion (B2) and 15 billion (A2) by the end of the century. In general, all SRES scenarios depict a society that is more affluent than today, with world gross domestic product (GDP) rising to 10–26 times today's levels by 2100. A narrowing of income differences between world regions is assumed in all SRES scenarios – with technology representing a driving force as important as demographic change and economic development. [SRES SPM]

1.3.2.2 Water resources

Of particular interest for projections of water resources, with or without climate change, are possible changes in dam construction and decommissioning, water supply infrastructure, wastewater treatment and reuse, desalination, pollutant emissions and land use, particularly with regard to irrigation. Irrespective of climate change, new dams are expected to be built in developing countries for hydropower generation as well as water supply, even though their number is *likely* to be small compared to the existing 45,000 large dams. However, the impacts of a possible future increase in hydropower demand have not been taken into account (World Commission on Dams,

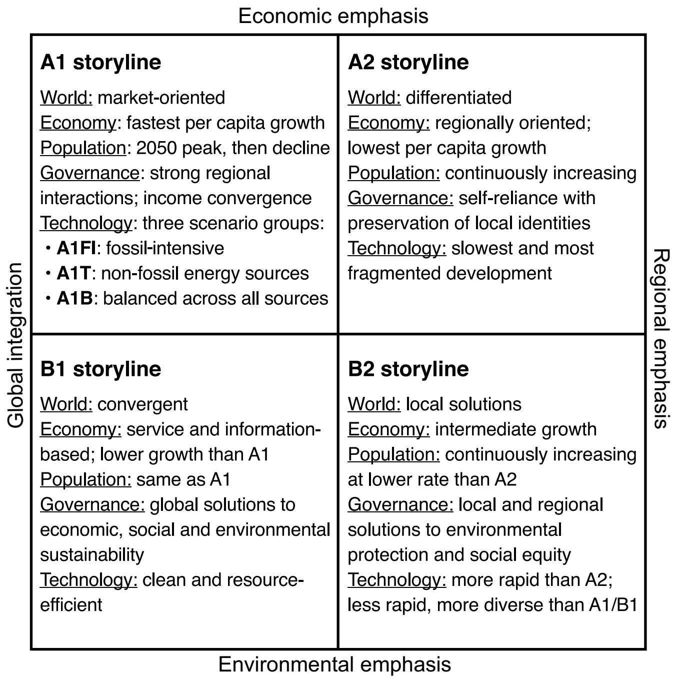

Figure 1.2: *Summary characteristics of the four SRES storylines (based on Nakićenović and Swart, 2000). [WGII Figure 2.5]*

2000; Scudder, 2005). In developed countries, the number of dams is *very likely* to remain stable, and some dams will be decommissioned. With increased temporal runoff variability due to climate change, increased water storage behind dams may be beneficial, especially where annual runoff does not decrease significantly. Consideration of environmental flow requirements may lead to further modification of reservoir operations so that the human use of water resources might be restricted. Efforts to reach the Millennium Development Goals (MDGs, see Table 7.1) should lead to improved water sources and sanitation. In the future, wastewater reuse and desalination will possibly become important sources of water supply in semi-arid and arid regions. However, there are unresolved concerns regarding their environmental impacts, including those related to the high energy use of desalination. Other options, such as effective water pricing policies and cost-effective water demand management strategies, need to be considered first. [WGII 3.3.2, 3.4.1, 3.7]

An increase in wastewater treatment in both developed and developing countries is expected in the future, but point-source discharges of nutrients, heavy metals and organic substances are *likely* to increase in developing countries. In both developed and developing countries, emissions of organic micro-pollutants (e.g., endocrine substances) to surface waters and groundwater may increase, given that the production and consumption of chemicals, with the exception of a few highly toxic substances, is *likely* to increase. Several of these pollutants are not removed by current wastewater treatment technology. Modifications of water quality may be caused by the impact of sea-level rise on storm-water drainage operations and sewage disposal in coastal areas. [WGII 3.2.2, 3.4.4]

Diffuse emissions of nutrients and pesticides from agriculture are *likely* to continue to be important in developed countries and are *very likely* to increase in developing countries, thus critically affecting water quality. According to the four scenarios of the Millennium Ecosystem Assessment (2005a) (‘Global orchestration’, ‘Order from strength’, ‘Adapting mosaic’ and ‘TechnoGarden’), global nitrogen fertiliser use will reach 110–140 Mt by 2050, compared with 90 Mt in 2000. Under three of the scenarios, there is an increase in nitrogen transport in rivers by 2050, while under the ‘TechnoGarden’ scenario (similar to the IPCC SRES scenario B1) there is a reduction (Millennium Ecosystem Assessment, 2005b). [WGII 3.3.2]

Among the most important drivers of water use are population and economic development, but also changing societal views on the value of water. The latter refers to the prioritisation of domestic and industrial water supply over irrigation water supply and the efficient use of water, including the extended application of water-saving technologies and water pricing. In all four Millennium Ecosystem Assessment scenarios, per capita domestic water use in 2050 is broadly similar in all world regions, at around 100 m^3/yr, i.e., the European average in 2000 (Millennium Ecosystem Assessment, 2005b). [WGII 3.3.2]

The dominant non-climate-change-related drivers of future irrigation water use are: the extent of irrigated area, crop type, cropping intensity and irrigation water-use efficiency. According to FAO (UN Food and Agriculture Organization) projections, developing countries, with 75% of the global irrigated area, are *likely* to expand their irrigated areas by 0.6% per year until 2030, while the cropping intensity of irrigated land is projected to increase from 1.27 to 1.41 crops per year and irrigation water-use efficiency will increase slightly (Bruinsma, 2003). These estimates exclude climate change, which is not expected by Bruinsma to affect agriculture before 2030. Most of the expansion is projected to occur in already water-stressed areas such as southern Asia, northern China, the Near East and northern Africa. However, a much smaller expansion of irrigated area is assumed under all four scenarios of the Millennium Ecosystem Assessment, with global growth rates of only 0–0.18% per year until 2050. After 2050, the irrigated area is assumed to stabilise or slightly decline under all scenarios except ‘Global orchestration’ (similar to the IPCC SRES A1 scenario) (Millennium Ecosystem Assessment, 2005a). In another study, using a revised A2 population scenario and FAO long-term projections, increases in global irrigated land of over 40% by 2080 are projected to occur mainly in southern Asia, Africa and Latin America, corresponding to an average increase of 0.4% per year (Fischer et al., 2006). [WGII 3.3.2]

1.4 Outline

This Technical Paper consists of eight sections. Following the introduction to the Paper (Section 1), Section 2 is based primarily on the assessments of Working Group I, and looks at the science of climate change, both observed and projected, as it relates to hydrological variables. Section 3 presents a general overview of observed and projected water-related impacts of climate change, and possible adaptation strategies, drawn principally from the Working Group II assessments. Section 4 then looks at systems and sectors in detail, and Section 5 takes a regional approach. Section 6, based on Working Group III assessments, covers water-related aspects of mitigation. Section 7 looks at the implications for policy and sustainable development, followed by the final section (Section 8) on gaps in knowledge and suggestions for future work. The Technical Paper uses the standard uncertainty language of the Fourth Assessment (see Box 1.1).

Box 1.1: Uncertainties in current knowledge: their treatment in the Technical Paper [SYR]

The IPCC Uncertainty Guidance Note[9] defines a framework for the treatment of uncertainties across all Working Groups and in this Technical Paper. This framework is broad because the Working Groups assess material from different disciplines and cover a diversity of approaches to the treatment of uncertainty drawn from the literature. The nature of data, indicators and analyses used in the natural sciences is generally different from that used in assessing technology development or in the social sciences. WGI focuses on the former, WGIII on the latter, and WGII covers aspects of both.

Three different approaches are used to describe uncertainties, each with a distinct form of language. Choices among and within these three approaches depend on both the nature of the information available and the authors' expert judgement of the correctness and completeness of current scientific understanding.

Where uncertainty is assessed qualitatively, it is characterised by providing a relative sense of the amount and quality of evidence (that is, information from theory, observations or models, indicating whether a belief or proposition is true or valid) and the degree of agreement (that is, the level of concurrence in the literature on a particular finding). This approach is used by WGIII through a series of self-explanatory terms such as: *high agreement, much evidence*; *high agreement, medium evidence*; *medium agreement, medium evidence*; etc.

Where uncertainty is assessed more quantitatively using expert judgement of the correctness of the underlying data, models or analyses, then the following scale of confidence levels is used to express the assessed chance of a finding being correct: *very high confidence* at least 9 out of 10; *high confidence* about 8 out of 10; *medium confidence* about 5 out of 10; *low confidence* about 2 out of 10; and *very low confidence* less than 1 out of 10.

Where uncertainty in specific outcomes is assessed using expert judgement and statistical analysis of a body of evidence (e.g., observations or model results), then the following likelihood ranges are used to express the assessed probability of occurrence: *virtually certain* >99%; *extremely likely* >95%; *very likely* >90%; *likely* >66%; *more likely than not* >50%; *about as likely as not* 33% to 66%; *unlikely* <33%; *very unlikely* <10%; *extremely unlikely* <5%; *exceptionally unlikely* <1%.

WGII has used a combination of confidence and likelihood assessments, and WGI has predominantly used likelihood assessments.

This Technical Paper follows the uncertainty assessment of the underlying Working Groups. Where synthesised findings are based on information from more than one Working Group, the description of uncertainty used is consistent with that for the components drawn from the respective Reports.

[9] See http://www.ipcc.ch/meetings/ar4-workshops-express-meetings/uncertainty-guidance-note.pdf.