Water Resources in the IPCC Fourth Assessment Report

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Abstract

The Intergovernmental Panel on Climate Change has recently published its Fourth Assessment Report. This presents an up-to-date assessment of the scientific literature on the physical basis of climate change (Working Group I), impacts, adaptation and vulnerability (Working Group II) and mitigation (Working Group III). Some 500 authors from around the world came together over a period of five years to write the three assessment reports, together with the Synthesis Report, each of which has undergone a rigorous process of review by experts and governments. The last publication of the Fourth Assessment will be a Technical Paper on 'Climate Change and Water'. This is a distillation of all the material in the IPCC Assessment and Special Reports which deals with the topic, although naturally it focuses primarily on the Fourth Assessment, since this is the most up to date. It is expected to appear in August 2008, and will be translated into all the official UN languages. This paper presents the major findings of the IPCC Fourth Assessment as these relate to climate change and water resources. It looks at the process by which Assessment Reports are written, reviewed and approved. It reports briefly on the decisions made to date on the Fifth Assessment.

Key Words: IPCC, climate change, water resources, water availability.

1. Background

The Intergovernmental Panel on Climate Change (IPCC) published its Fourth Assessment in 2007. This presents an up-to-date assessment of the scientific literature on the physical basis of climate change (the Working Group I Report), impacts, adaptation and vulnerability (Working Group II) and mitigation (Working Group III). Some 500 authors from around the world came together over a period of 5 years to write the three working group reports which, together with the Synthesis Report, comprise the Fourth Assessment. Each report has undergone a rigorous process of review by experts and governments.

As can be imagined, there is a great deal of material in the Fourth Assessment which relates to water resources and climate change. Therefore, the IPCC decided at its plenary meeting in 2002 that a Technical Paper would be prepared, drawing together the material in IPCC Assessment and Special Reports which relates to climate change and water. This was to be delivered by the writing team to the IPCC Bureau in spring 2008.

2. Introduction to the Technical Paper

The last publication of the Fourth Assessment is the Technical Paper 'Climate Change and Water' which became available on-line in August 2008, and which was published as a paper volume in the English language in the same month. It will ultimately become available in all the official languages of the United Nations. This is a distillation of all the material in the IPCC Assessment and Special Reports which deals with the interrelationships between climate change and water, although naturally it focuses primarily on the Fourth Assessment since this is the most up-to-date. The Technical Paper is available on the web site at www.ipcc.ch.

The objectives of the Technical Paper are:

1. To improve our understanding of the links of both natural and anthropogenically induced climate change, its impacts and adaptation and mitigation response options, with water issues; and
2. 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 and climate change response options, including associated synergies and trade-offs.

There were 29 authors in the writing team for the Technical Paper, drawn from some 20 different countries. The team was led by Bryson Bates from Australia, Zbigniew Kundzewicz from Poland and Shaohong Wu from China. The document underwent two stages of review, the first by experts and government representatives, and the second by government representatives only. The final step in the process of production was to place the document before the IPCC Bureau, whose members acted as an editorial committee as set out in the *Principles Governing IPCC Work*, and this took place at a meeting in Budapest in April 2008.

In this overview, we explore the major findings of the Paper, as these appear in the Executive Summary. There are 15 key statements in the Technical Paper Executive Summary.

3. Major findings of the Technical Paper

3.1 Statements related to the physical basis of climate change

Key statement 1: Observed warming over several decades has been linked to changes in the large-scale hydrological cycle. These changes include changes to precipitation amounts and intensity, changes to extremes such as droughts and floods, as well as changes to cryospheric components such as reduced snow cover and widespread melting of ice. During the 20th century, in general precipitation increased over land in high northern latitudes, but decreases dominated from 10°S to 30°N from the 1970s onwards. Extremes of both high rainfall events and of drought are expected to become more severe, where high rainfall events are measured as the proportion of total rainfall from heavy falls, and drought is measured by the area of land classified as very dry. There have been significant decreases in water storage in mountain glaciers and Northern Hemisphere snow cover.

An example of the large-scale regional and persistent trend which have occurred over the last 80-90 years is shown in Figure 1 for the Sahelian region. The graph shows a persistent downward trend from around 1950 until about 1980. Since then there has been a levelling off, but no prolonged return to wetter conditions.

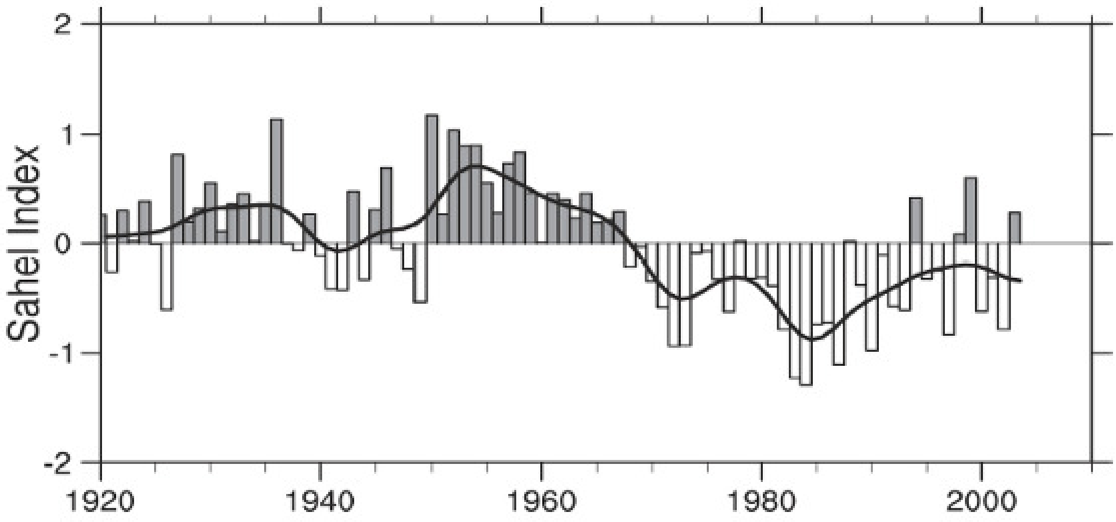

Figure 1. *Normalised rainfall index for the Sahelian region of West Africa.*

Key statement 2: Climate model simulations for the 21st century are consistent in projecting precipitation increases in high latitudes and parts of the tropics, and decreases in some subtropical and lower mid-latitude region. Outside these areas there is substantial uncertainty in precipitation projections.

Key statement 3: By the middle of the 21st century, annual average river runoff and water availability are projected to increase as a result of climate change at high latitudes and in some wet tropical areas, and decrease over some dry regions at mid-latitudes and in the dry tropics. Many semi-arid and arid areas (e.g., the Mediterranean basin, western USA, southern Africa and north-eastern Brazil) are particularly exposed to the impacts of climate change and are projected to suffer a decrease of water resources due to climate change. These projected changes in runoff largely mimic the projections for rainfall changes. Figure 2 shows the combined projected change in runoff from 12 climate models between 1980-99 and 2090-99.

Key statement 4: Increased precipitation intensity and variability is projected to increase the risks of flooding and drought in many areas. Heavy precipitation events are projected to become more frequent over most regions throughout the 21st century. This would affect the risk of flash flooding and urban flooding. Furthermore, it is likely that the area affected by drought will increase. Table 1 shows some potential impacts arising from these projected changes.

Key statement 5: Water supplies stored in glaciers and snow cover are projected to decline in the course of the century. This would have the effect of reducing water availability in regions supplied by melt water from major mountain ranges, where more than one-sixth of the world population currently lives. These reductions would be experienced through seasonal shifts in streamflow, increases in the ratio of winter to annual flows, and reductions in low flows.

Changes in glacier extent are occurring at the present day. Figure 3 shows the ice margin of the Gangotri glacier in the Himalayas, which is the source of the Ganges river. It is clear that the ice margin has retracted substantially since 1780. Although this retreat has been linked to anthropogenic climate change, no formal attribution studies have been carried out.

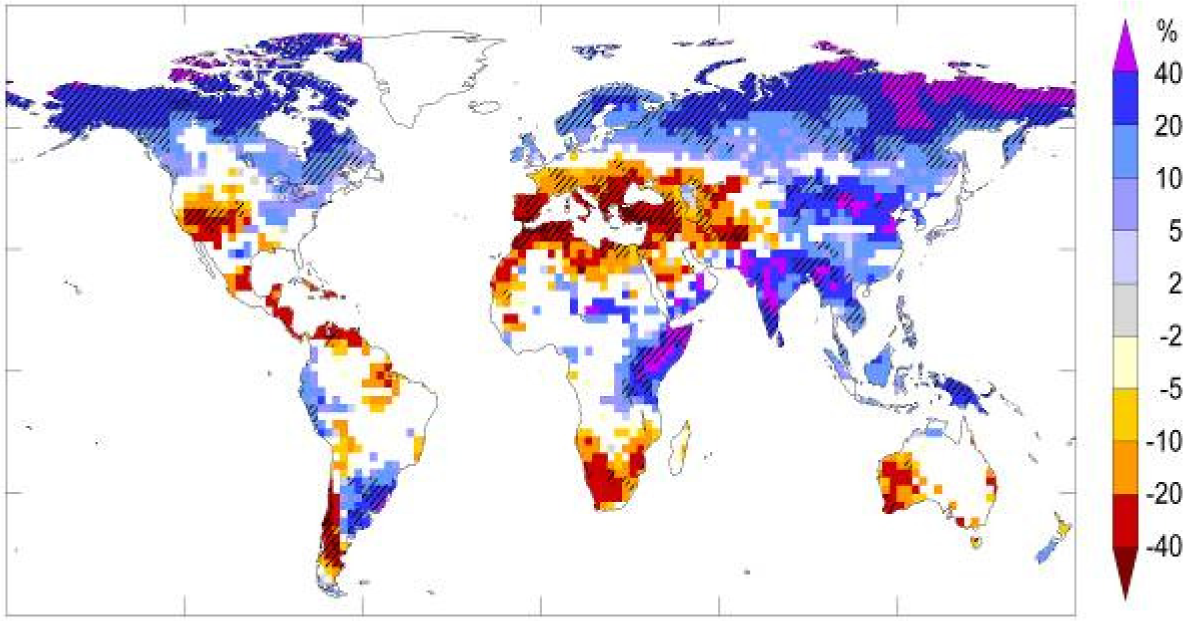

Figure 2. *Ensemble-mean percentage projected change in annual mean runoff between 1980-99 and 2090-99. Hatched areas indicate high model agreement (more than 90% of models agree), white areas are where there is low agreement between models fewer than 66% of models agree). (after Milly et al., 2005) [TP[1] Figure 2.10].*

3.2 Statements related to climate change impacts

Key statement 6: Higher water temperatures and changes in extremes, including floods and droughts, are projected to affect water quality and exacerbate many forms of water pollution. This water pollution will be derived from, for example, sediments, nutrients, dissolved organic carbon, pathogens, pesticides and salts, and thermal pollution. There are potentially negative impacts for ecosystems, human health, and water system reliability and operating costs. Moreover, in coastal areas, sea-level rise may extend areas of salinisation of groundwater and estuaries, resulting in a decrease of freshwater availability for humans and ecosystems. We have already discussed the potential for changes in extremes under Key Statement 4; Table 1 shows examples of the resulting impacts, including on water quality.

Key statement 7: Globally, the negative impacts of future climate change on freshwater systems are expected to outweigh the benefits. This statement overall summarises the impacts of climate change for water resources – that they will be predominantly negative.

By the 2050s, the area of land subject to increasing water stress due to climate change is projected to be more than double that with decreasing water stress. Studies have also been performed to estimate the numbers of people experiencing increased water stress. Of course, these numbers will not only depend upon the severity of climate change. They will also depend on how human societies, as well as technological and economic development, evolve over the coming years. A society with a very high population growth rate, but low levels of wealth, is likely to have a higher population exposed to increasing water stress than societies

[1] TP = Technical Paper

with lower population growth rates and greater wealth. This concept is clearly illustrated in Table 2 below. This shows the people at risk of increased water stress at three dates in the future, and for four scenarios of future human development. These are the SRES scenarios, as set out in the IPCC Special Report on *Emissions Scenarios*. Population growth is highest in the A2 scenario, and lowest in the B1 and B2 scenarios. Thus, the population at risk reflects not only the extent of climate change but also, to an equal or even greater extent, the influence of the socio-economic scenario.

Table 1. *Examples of possible impacts of climate change due to changes in extreme precipitation-related weather and climate events, based on projections to the mid- to late 21st century. These do not take into account any changes or developments in adaptive capacity. The likelihood estimates in column 2 relate to the phenomena listed in column 1. The direction of trend and likelihood of phenomena are for IPCC SRES projections of climate change. [TP Table 3.2]*

Phenomenon[a] and direction of trend	**Likelihood of future trends based on projections for 21st century using SRES scenarios**	**Examples of major projected impacts by sector**			
		Agriculture, forestry and ecosystems [4.4, 5.4]	**Water resources [3.4]**	**Human health [8.2]**	**Industry, settlements and society [7.4]**
Heavy precipitation events: frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures; loss of property
Area affected by drought increases	Likely	Land degradation, lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	Water shortages for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclone activity increases	Likely	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs.	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers; potential for population migrations; loss of property

Figure 3. *Changes in the extent of the Gangotri glacier since 1780. Reproduced courtesy of NASA EROS Data Center, 9 September 2001*

Table 2. *Millions at risk of increased water resources risk by 2080, estimated for four socio-economic scenarios by the HadCM3 climate model (Arnell, 2004)*

Scenario of human development:	**Millions at risk of increased water stress:**
A1FI	1256
A2	2583 – 3210
B1	1135
B2	1196 - 1536

Key statement 8: Changes in water quantity and quality due to climate change are expected to affect food availability, stability, access and utilisation. It is expected that these effects will be felt first by poor rural farmers, especially in the arid and semi-arid tropics and Asian and African megadeltas.

Figure 4 shows, for a range of published crop-climate modelling studies, the effects of climate change on wheat yields in mid to high latitudes, on the left, and low latitudes, on the right. Responses include those without adaptation (red dots) and with adaptation (green dots). The studies span a range of precipitation and CO_2 concentrations. The lines are best-fit polynomials, used to summarise the results. If we consider first the no-adaptation case (red dots and line), then for mid to high latitudes it is clear that moderate amounts of warming are projected to be beneficial for crop yields. The red best-fit line crosses the zero line at around

3.5°C, indicating that, up to 2-3°C, we may expect warmer temperatures and the associated changes in rainfall and CO_2 concentrations, to be beneficial for crop yields, whereas above this threshold yields will be reduced for global warming. The situation is different for low latitudes. In this case, the red (no adaptation case) best-fit line crosses the zero line at just above 1oC, indicating that even low levels of warming will have a negative effect on crop yields. Similar pictures are painted for other crops such as rice and maize (see the Working Group II Fourth Assessment Report, Chapter 5 Figure 5.2).

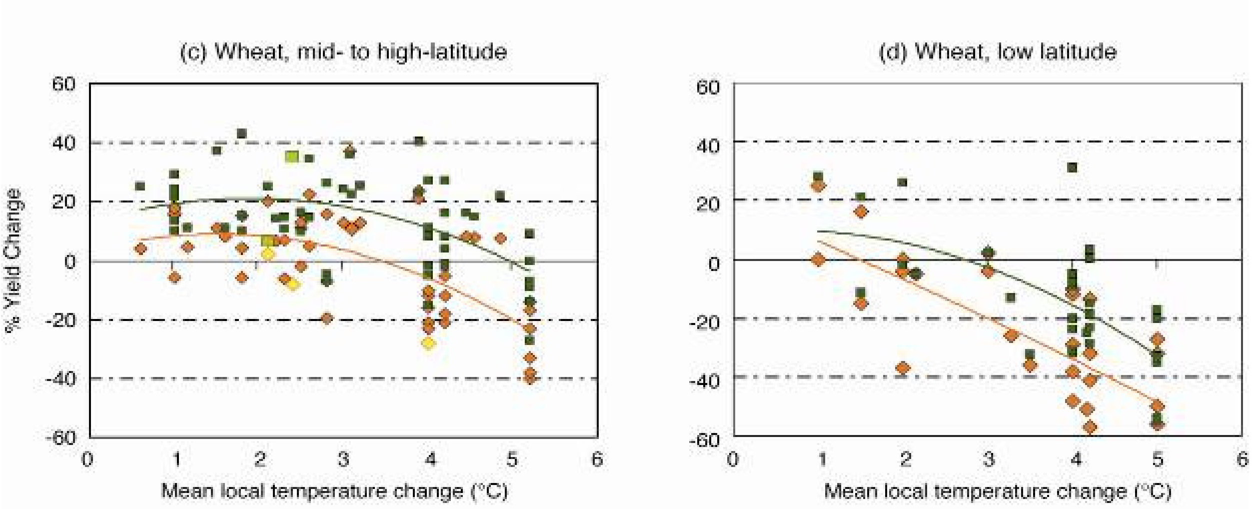

Figure 4. *Modelled relationships between temperature change (and associated rainfall and CO2 change) and wheat yields [Working Group II Fourth Assessment Report Figure 5.2]*

3.3 Statements related to infrastructure and water resources management

Key statement 9: Climate change affects the function and operation of existing water infrastructure—including hydropower, structural flood defences, drainage, and irrigation systems—as well as water management practices. At the present day, we already see the effects of climate change on existing infrastructure. Box 1 presents a case study of the Perth water supply. As we move into the future, these effects are expected to become more widespread and more severe, as the impacts of climate change on water resources interact with other stresses such as increasing population, changing economic activity and increased urbanisation. This is likely to lead to restrictions on water demand for all uses including public water supply and irrigation. This is in the context of a situation where, even ignoring the effects of climate change, irrigation demand in developing countries (with 75% of the global irrigated area) is projected to expand by 0.6%/year until 2030 (Bruinsma, 2003).

Key statement 10: Current water management practices may not be robust enough to cope with the impacts of climate change. In many locations, water management cannot satisfactorily cope even with current climate variability, so that large flood and drought damages occur. As a first step, improved incorporation of information about current climate variability into water-related management would assist adaptation to longer-term climate change impacts.

***Box 1:** Case study of the Perth water supply*

Figure 5 shows changes in the amount of water flowing into the supply system for Perth in Western Australia. It is clear that there has been a substantial downturn in the resource over time. In the eight years from 1997 stream flows had dropped to an annual average of 115GL compared with the 161GL/yr over the previous 23 years (1974–1997). The shortfall has been met through the construction of two dams and additional groundwater extraction. In addition, as part of a ‘security through diversity’ strategy, a desalination plant has been built which supplies 140,000m³/day with designed expansion to 250,000m³/day. The plant is the largest of its kind in the southern hemisphere and the biggest in the world to be powered by renewable (wind) energy. By 2010, around 107GL/year of new water will be needed to meet the rising demands of a growing population. Whereas additional groundwater extraction is the preferred strategy to meet this additional demand, the construction of a second desalination plant is a real possibility.

For further information, see: www.water-technology.net/projects/perth/

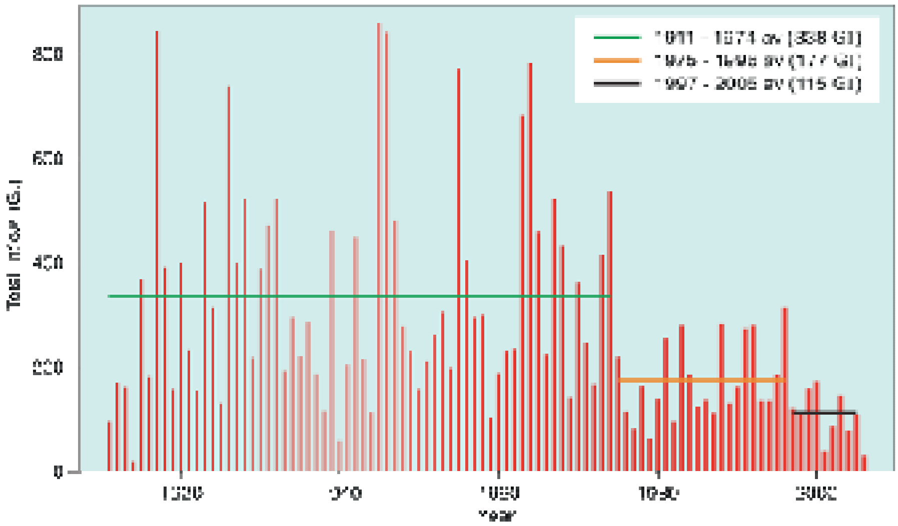

***Figure 5.** Annual inflow to Perth water supply system from 1911 to 2006. Horizontal lines show averages. [TP Figure 5.7]*

Key statement 11: Climate change challenges the traditional assumption that past hydrological experience provides a good guide to future conditions. The consequences of climate change may alter the reliability of current water management systems and water-related infrastructure. This situation is well illustrated for the present day by Figure 5 in Box 1. Although quantitative projections of changes in precipitation, river flows and water levels at the river-basin scale are uncertain, it can reliably be expected that hydrological characteristics will change in the future. Adaptation strategies and risk management practices that incorporate future changes with related uncertainties are being developed in some countries and regions.

3.4 Adaptation and mitigation measures

Key statement 12: Adaptation options designed to ensure water supply during average and drought conditions require integrated demand-side as well as supply-side strategies. On the demand side, potential strategies which hold promise for water savings and reallocation of water to highly valued uses include:

- improved water-use efficiency, e.g. by recycling water.
- expanded use of economic incentives, including metering and pricing to encourage water conservation and
- development of water markets and implementation of virtual water trade.

Supply-side strategies include:
- increases in storage capacity,
- abstraction from water courses, and
- water transfers.

Integrated water resources management provides an important framework to achieve adaptation measures across socio-economic, environmental and administrative systems. Successful integrated water management strategies include, among others, capturing society's views, reshaping planning processes, co-ordinating land and water resources management, protecting and restoring natural systems, recognising water quantity and water quality linkages and including considerations of climate change. In particular, an integrated approach to water management could help to resolve conflicts between competing water users. In several places in the western USA, water managers and various interest groups have been experimenting with methods to promote consensus-based decision making which takes into account the need for sustainable water use.

Key statement 13: Mitigation measures can reduce the magnitude of impacts of global warming on water resources, in turn reducing adaptation needs. Figure 6 shows, for a range of sectors, the expected impacts scaled against climate change. By plotting the unmitigated temperature change by 2100 (line a) on this figure, we can see the impacts likely to be experienced by that date if no efforts are made to reduce our emissions of greenhouse gases. Line b shows the temperature change by 2100 if mitigation measures are put in place, specifically a 50% cut in emissions by 2050. To explore further mitigation scenarios, the reader is referred to Parry et al. (2008).

However, it should be noted that mitigation measures can in themselves have considerable negative side effects, such as increased water requirements for afforestation/reforestation activities or bio-energy crops, if these are not sustainably located, designed and managed.

3.5 Climate change, water resources, sustainability and knowledge

Key statement 14: Water resources management clearly impacts on many other policy areas, such as energy, health, food security, nature conservation. In designing adaptation and mitigation measures to address climate change, care must be taken to ensure that they interact favourably with the need for sustainable development. Low-income countries and regions are likely to remain vulnerable over the medium term, with fewer options than high-income countries for adapting to climate change.

As an example of the interrelationships between water resources management under climate change, and sustainable development, Table 3 shows how sustainable management of water can contribute to the achievement of the Millennium Development Goals.

Table 3. *Potential contribution of the water sector to attain the Millennium Development Goals. [TP Table 7.1]*

Goals	**Direct relation to water**	**Indirect relation to water**
Goal 1: Eradicate extreme poverty and hunger	Water as a factor in many production activities (e.g., agriculture, animal husbandry, cottage industry) Sustainable production of fish, tree crops and other food brought together in common property resources	Reduced ecosystem degradation improves local-level sustainable development Reduced urban hunger by means of cheaper food from more reliable water supplies
Goal 2: Achieve universal education		Improved school attendance through improved health and reduced water-carrying burdens, especially for girls
Goal 3: Promote gender equity and empower women	Development of gender-sensitive water management programmes	Reduce time wasted and health burdens from improved water service, leading to more time for income-earning and more balanced gender roles
Goal 4: Reduce child mortality	Improved access to drinking water of more adequate quantity and better quality, and improved sanitation, reduce the main factors of morbidity and mortality in young children	
Goal 6: Combat HIV/AIDS, malaria and other diseases	Improved access to water and sanitation supports HIV/AIDS-affected households and may improve the impact of health care programmes Better water management reduces mosquito habitats and the risk of malaria transmission	
Goal 7: Ensure environmental sustainability	Improved water management reduces water consumption and recycles nutrients and organics Actions to ensure access to improved and, possibly, productive eco-sanitation for poor households Actions to improve water supply and sanitation services for poor communities Actions to reduce wastewater discharge and improve environmental health in slum areas	Develop operation, maintenance, and cost recovery system to ensure sustainability of service delivery

Key statement 15: Several gaps in knowledge exist in terms of observations and research needs related to climate change and water. The following gaps were identified by the Technical Paper as the most pressing:

- Observational data and data access are prerequisites for adaptive management, yet many observational networks are shrinking.
- There is a need to improve understanding and modelling of changes in climate related to the hydrological cycle at scales relevant to decision making.

- Information about the water-related impacts of climate change is incomplete, especially with respect to water quality, aquatic ecosystems, groundwater, including their socio-economic dimensions.
- Finally, current tools to facilitate integrated appraisals of adaptation and mitigation options across multiple water-dependent sectors are inadequate.

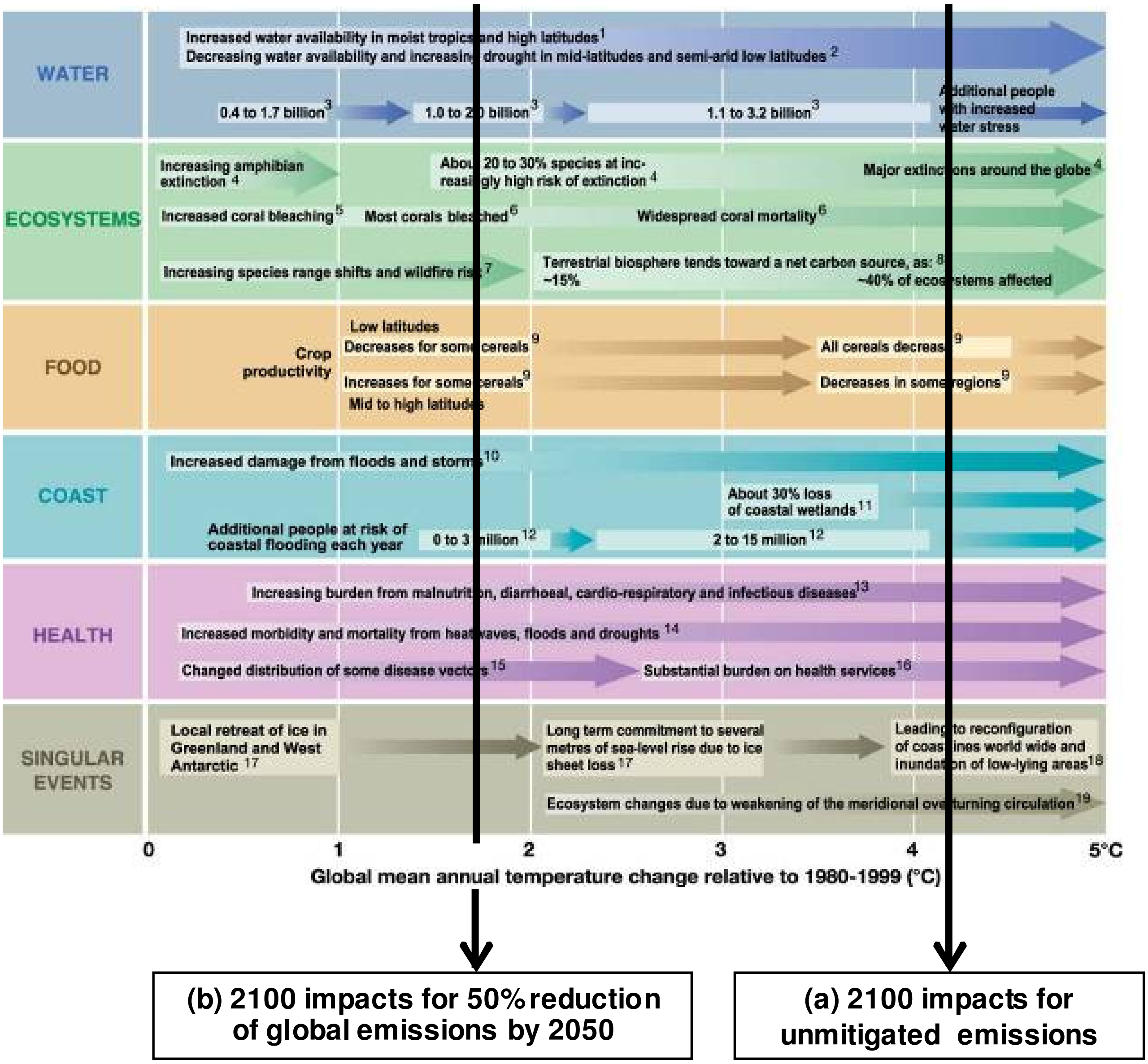

Figure 6. *Projected impacts, for different sectors, of projected changes in climate associated with different amounts of increase in global average surface temperature in the 21st century [Working Group II Fourth Assessment Table 20.8]. The vertical lines show (a) the amount of temperature change projected for unmitigated emissions up to 2100, and (b) the amount of warming by 2100 if emissions were cut by 50% by 2050. For further explanation, see Parry et al. (2008).*

4. Conclusions

As its headline statement, the Technical Paper concludes that:

> *Observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences on human societies and ecosystems.*

The 180-page Technical Paper is a compact and integrated publication focussed on water and climate change, which summarises and synthesises the latest results from all IPCC Working Groups on Climate Change and Water. It is targeted not only at policymakers in government, but also at the science community, NGOs and the media. As such, the language is crafted to be accessible to the general reader with an interest in climate change. It will be printed and distributed by the IPCC Secretariat free of charge, and translated into all UN languages, making it a readily-available primer on the current knowledge of climate change and water.

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The Technical Paper should be cited as:

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