Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report

Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability

IPCC WGII Fourth Assessment Report – Final Draft for Government Review

Chapter 3: Freshwater Resources and their Management

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Chapter 6: Coastal Systems and Low-lying Areas

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Fresh water resources and their management

1. By mid-century, annual average river runoff and water availability are projected to increase by 10-40% at high latitudes and in some wet tropical areas, and decrease by 10-30% over some dry regions at mid-latitudes and in the dry tropics, some of which are presently water stressed areas. In some places and in particular seasons, changes differ from these annual figures.

1. Drought-affected areas will likely increase in extent. Heavy precipitation events, which are very likely to increase in frequency, will augment flood risk.

1. Adaptation procedures and risk management practices for the water sector are being developed in some countries and regions that have recognised projected hydrological changes with related uncertainties.

2. In the course of the century, water supplies stored in glaciers and snow cover are projected to decline, reducing water availability in regions supplied by meltwater from major mountain ranges, where more than one-sixth of the world population currently lives.

Coastal systems and low-lying areas

1. **Coasts are projected to be exposed to increasing risks, including coastal erosion, due to climate change and sea-level rise and the effect will be exacerbated by increasing human-induced pressures on coastal areas.**

2. **Corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surface temperature of about 1 to 3°C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatisation by corals.**

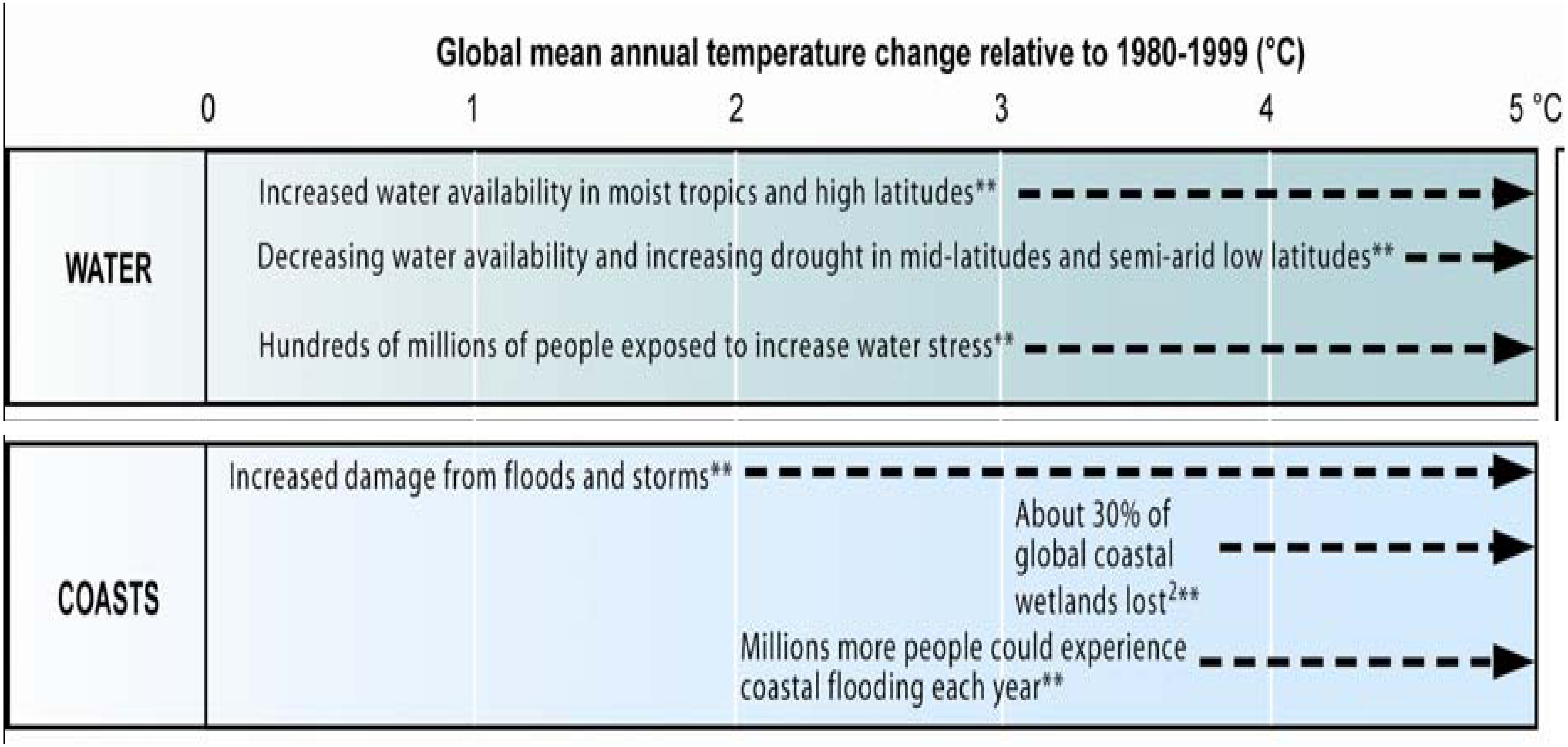
3. **Coastal wetlands including salt marshes and mangroves are projected to be negatively affected by sea-level rise especially where they are constrained on their landward side, or starved of sediment.**

4. **Many millions more people are projected to be flooded every year due to sea-level rise by the 2080s. Those densely-populated and low-lying areas where adaptive capacity is relatively low, and which already face other challenges such as tropical storms or local coastal subsidence, are especially at risk. The numbers affected will be largest in the mega-deltas of Asia and Africa while small islands are especially vulnerable.**

5. **Adaptation for coastal regions will be more challenging in developing countries than developed countries due to constraints on adaptive capacity.**

Illustrative examples of global impacts projected for climate changes (and sea-level and atmospheric carbon dioxide where relevant) associated with different amounts of increase in global average surface temperature in the 21st century.

The black lines link impacts, dotted arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left hand side of text indicates approximate onset of a given impact. Adaptation to climate change is not included in these estimations.



Phenomena[a] and direction of trend [WGI SPM]	Likelihood of future trend based on projections for 21st century using SRES scenarios [WGI SPM]	Examples of major projected impacts by sector			
		Impacts due to altered frequencies and intensities of extreme weather, climate, and sea level events are very likely to change			
		Agriculture, forestry and ecosystems [4.4, 5.4]		**Human health [8.2]**	**Industry/settlement/ Society [7.4]**
Warmer and fewer cold days and nights; warmer/more frequent hot days and nights over most land areas	Virtually certain[b]	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks		Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves: frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; wild fire danger increase		Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially-isolated	Reduction in quality of life for people in warm areas without appropriate housing; impacts on elderly, very young and poor.
Heavy precipitation events: frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land due to water logging of soils		Increased risk of deaths, injuries, infectious, respiratory and skin diseases, post-traumatic stress disorders	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures
Area affected by drought: increases	Likely	Land degradation, lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire		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		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
Increased incidence of extreme high sea level (excludes tsunamis)[c]	Likely[d]	Salinisation of irrigation water, estuaries and freshwater systems		Increased risk of deaths and injuries by drowning in floods; migration-related health effects	Costs of coastal protection *versus* costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above

Executive Summary (Chapter 3-Fresh water resources)

The impacts of climate change on freshwater systems and their management are mainly due to the observed and projected increases in temperature, sea level and precipitation variability (very high confidence).

Semi-arid and arid areas are particularly exposed to the impacts of climate change on freshwater (high confidence).
Many of these areas (e.g. Mediterranean basin, western USA, southern Africa and north-eastern Brazil) will suffer a decrease of water resources due to climate change. Efforts to offset declining surface water availability due to increasing precipitation variability will be hampered by the fact that groundwater recharge will decrease considerably in some already water-stressed regions

Higher water temperatures, increased precipitation intensity and longer periods of low flows exacerbate many forms of water pollution, with impacts on ecosystems, human health, and water system reliability and operating costs (high confidence).

Climate change affects the function and operation of existing water infrastructure as well as water management practices (very high confidence).
Adverse effects of climate on freshwater systems aggravate the impacts of other stresses, such as population growth, changing economic activity, land use change and urbanisation (very high confidence)

Executive Summary (Chapter 3-Fresh water resources)

The impacts of climate change on freshwater systems and their management are result of climate changes are likely (high confidence)

Current water management practices are very likely to be inadequate to reduce negative impacts of climate change on water supply reliability, flood risk, health, energy and aquatic ecosystems (very high confidence). Improved incorporation of current climate variability into water-related management would make adaptation to future climate change easier (very high confidence).

Adaptation procedures and risk management practices for the water sector are being developed in some countries and regions (*e.g.* Caribbean, Canada, Australia, Netherlands, UK,USA, Germany) that recognize the uncertainty of projected hydrological changes (very high confidence).

The negative impacts of climate change on freshwater systems outweigh its benefits (high confidence).

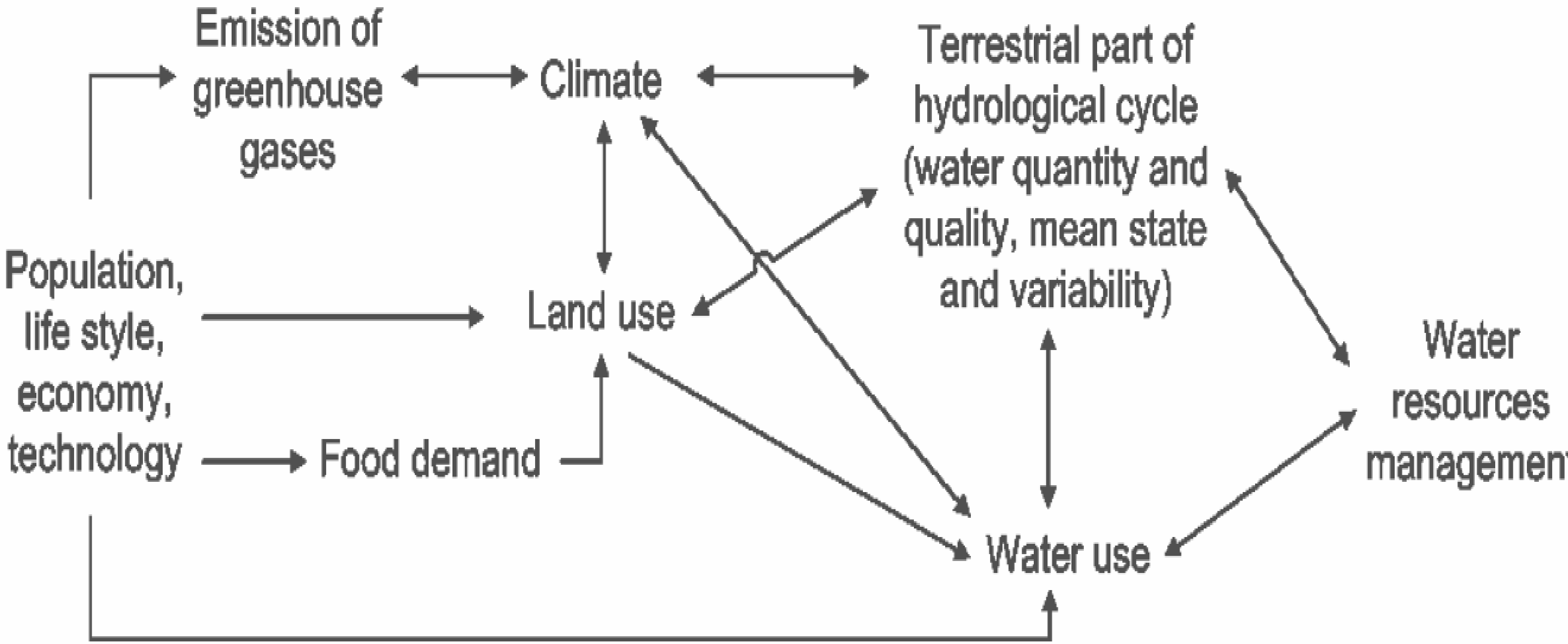


Figure 3.1: Impact of human activities on freshwater resources and their management, with climate change being only one of multiple pressures (modified after Oki (2005))

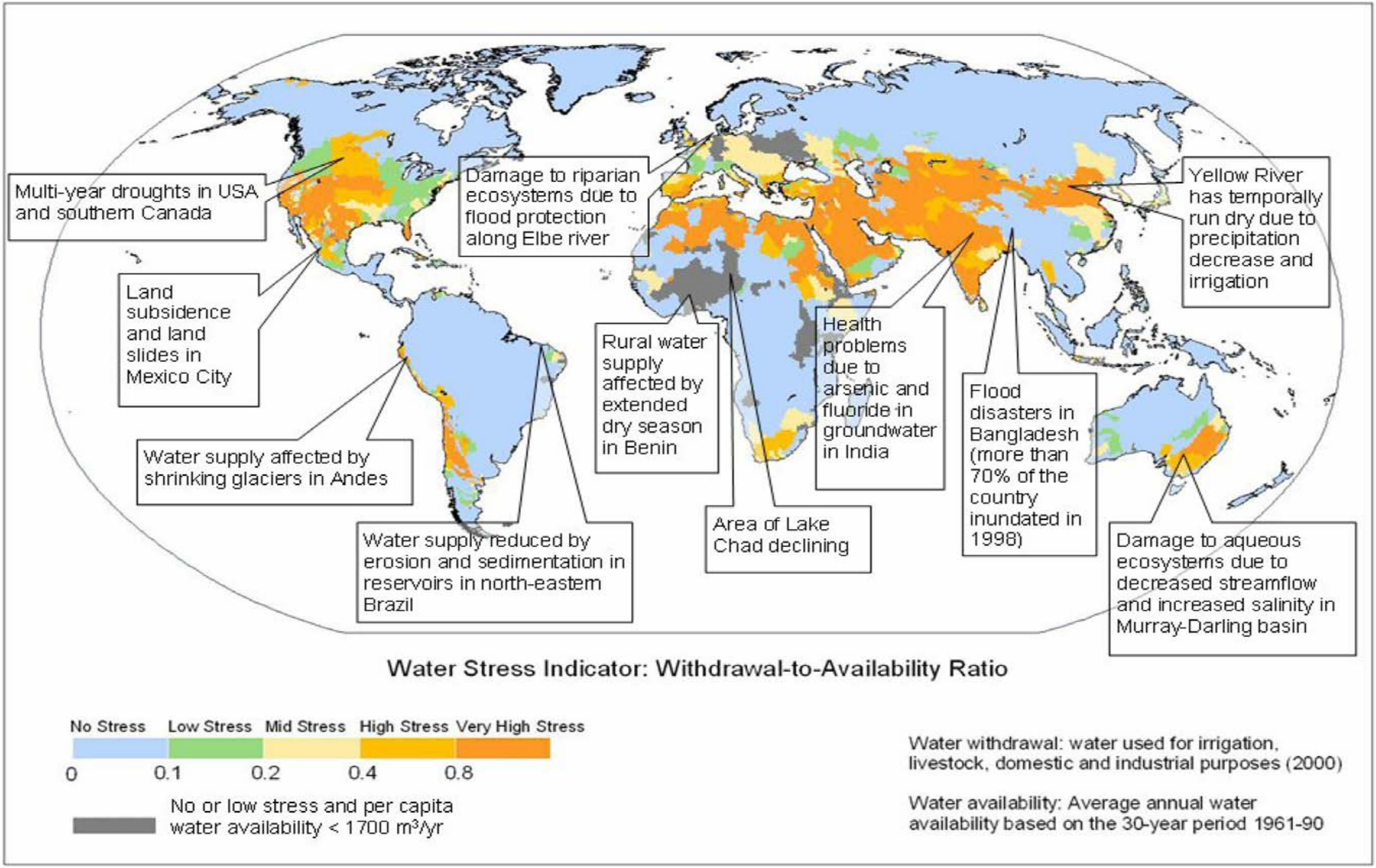


Figure 3.2: Examples of current vulnerabilities of freshwater resources and their management; in the background, a water stress map based on the 2005 version of WaterGAP (Alcamo et al., 2003a).

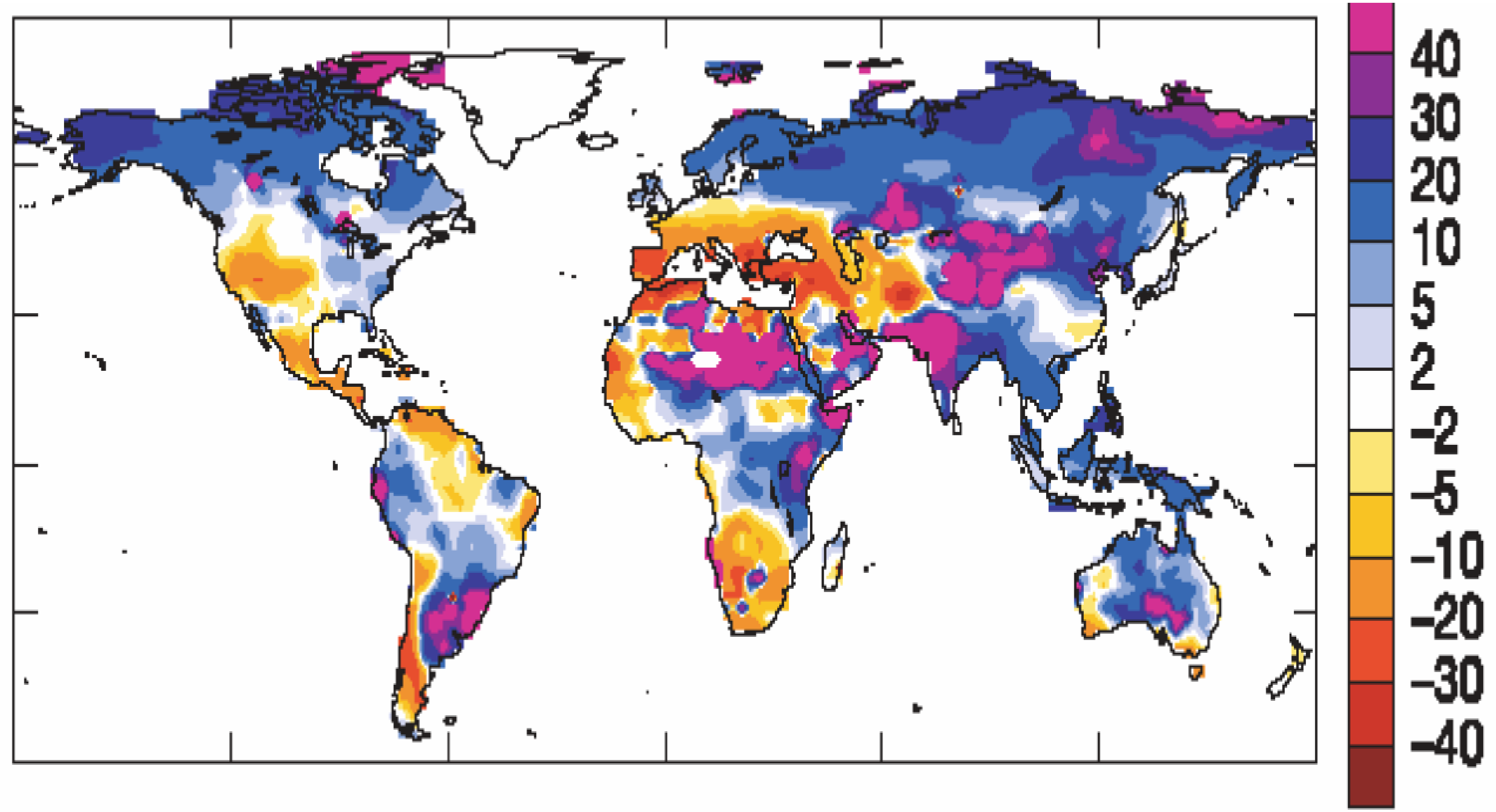


Figure 3.4: Ensemble mean change in annual runoff, in percent, by 2050 under the SRES A1B emissions scenario, based on an ensemble of 12 climate models (Milly et al., 2005).

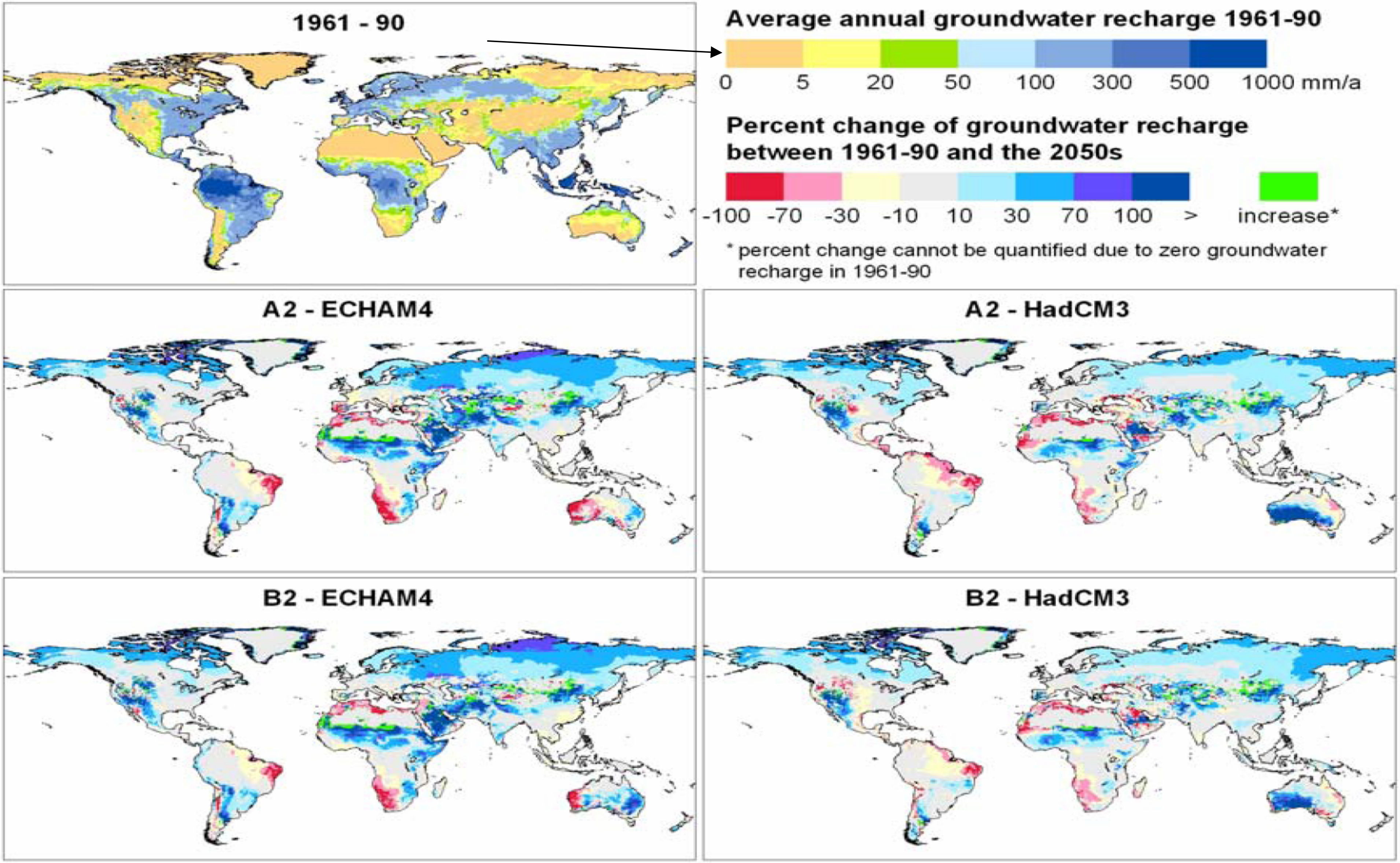


Figure 3.5: Simulated impact of climate change on long-term average annual diffuse groundwater recharge. Percent changes of 30-year averages groundwater recharge between 1961-1990 and the 2050s (2041-2070), as computed by the global hydrological model WGHM, applying four different climate change scenarios (climate scenarios computed by the climate models ECHAM4 and HadCM3, each interpreting the two IPCC greenhouse gas emissions scenarios A2 and B2 (Döll and Flörke, 2005).

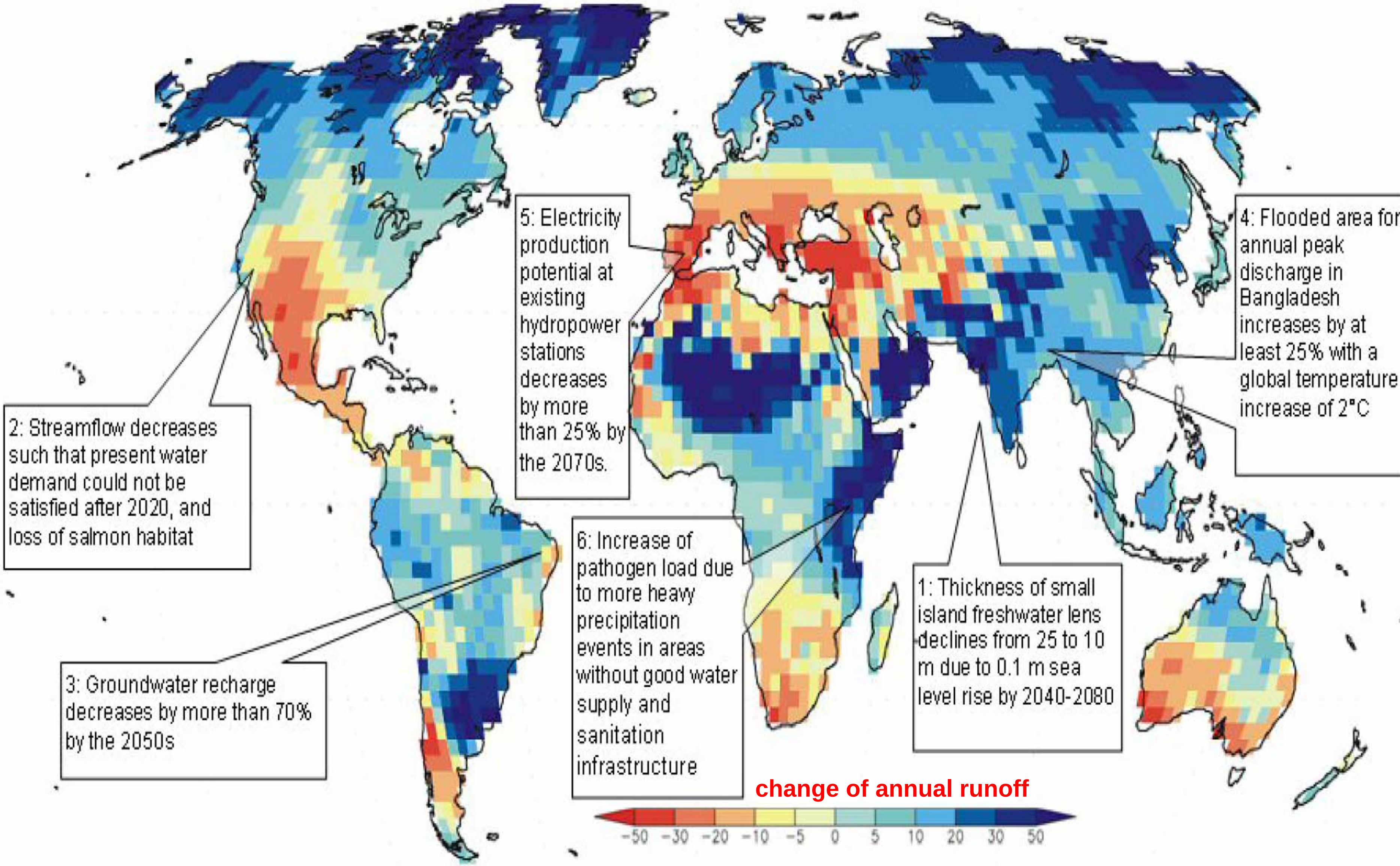


Figure 3.8: Illustrative map of future climate change impacts on freshwater which are a threat to the sustainable development of the affected regions. 1: Bobba et al. (2000), 2: Barnett et al. (2004), 3: Döll and Flörke (2005), 4: Mirza et al. (2003) 5: Lehner et al. (2005a) 6: Kistemann et al. (2002). Background map: Ensemble mean change of annual runoff, in percent, between present (1981-2000) and 2081-2100 for the SRES A1B emissions scenario (Nohara et al., 2006).

Research needs into water-climate interface is required:

- to improve understanding and estimation, in quantitative terms, of climate change impacts on freshwater resources and their management
- to fulfil pragmatic information needs of water managers who are responsible for adaptation.

Among the research issues related to the climate-water interface, where developments are needed, the following:

- improve understanding of sources of uncertainty in order to improve credibility of projections,
- There is a scale mismatch between the large-scale climatic models and the catchment scale,
- Impacts of change in climate variability need to be integrated into the impact modelling
- Climate change impacts on water quality are poorly understood.
- Relatively few results are available on economic aspects of climate change impacts and adaptation options related to water resources,
- Impacts of climate change on aquatic ecosystems
- Detection and attribution of observed changes in freshwater resources,
- There are challenges and opportunities posed by the advent of probabilistic climate changescenarios for water resource management.
- Despite its significance, groundwater has received little attention for climate change impact
- Water resources management clearly impacts on many other policy areas
- Impacts of climate change on soil water and water availability to plants

Executive Summary (Chapter 6)

Coasts are experiencing the adverse consequences of hazards related to climate and sea level (very high confidence).

Coasts will be exposed to increasing risks over coming decades due to many compounding climate-change factors(very high confidence).

The impact of climate change on coasts is exacerbated by increasing human-induced pressures (very high confidence).

Adaptation for the coasts of developing countries will be more challenging than for coasts of developed countries, due to constraints on adaptive capacity(high confidence).

Adaptation costs for vulnerable coasts are much less than the costs of inaction (high confidence).

The unavoidability of sea-level rise even in the longer-term frequently conflicts with present day human development patterns and trends (high confidence).

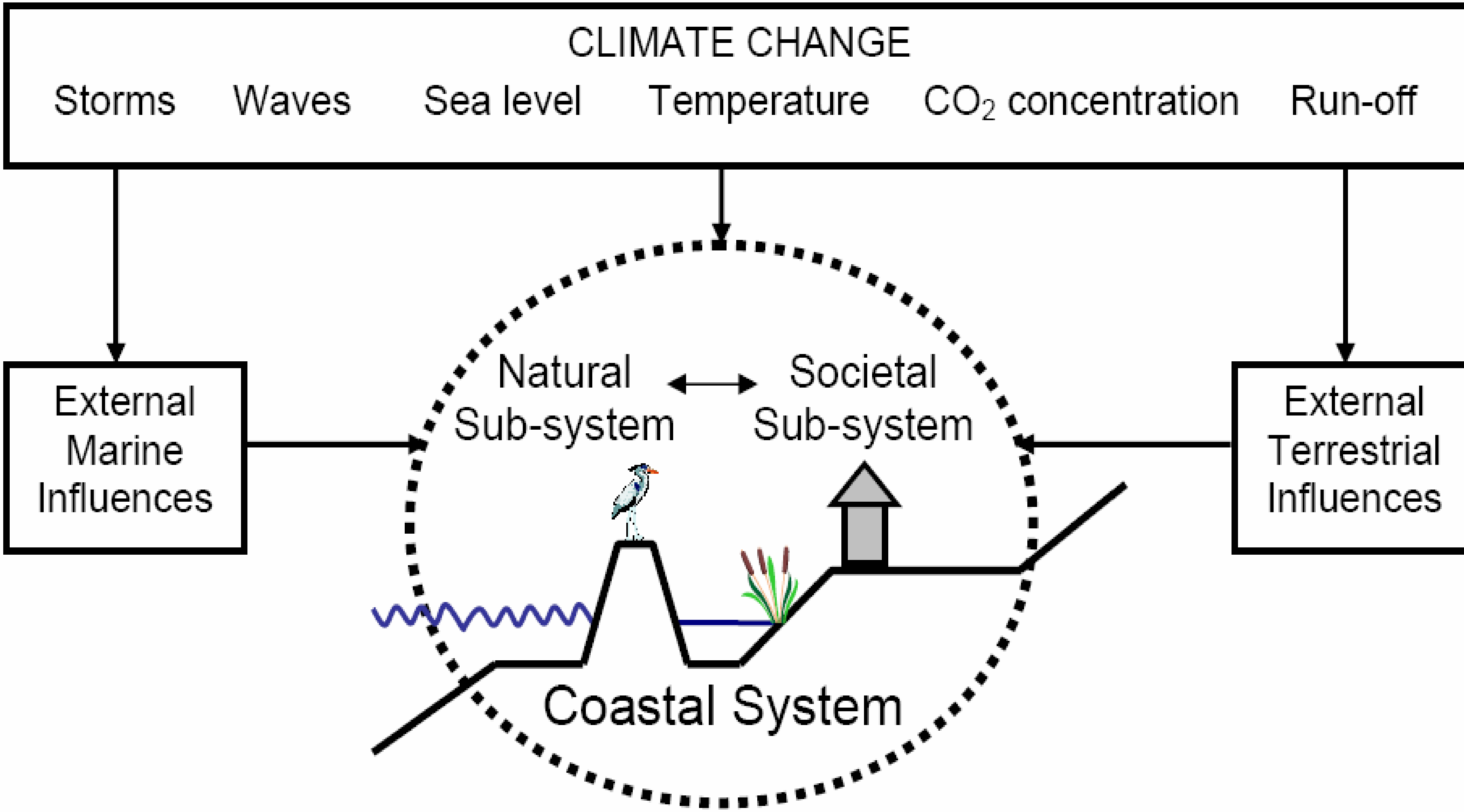


Figure 6.1: Climate change and the coastal system showing the major climate change factors, including external marine and terrestrial influences.

Table 6.4: Summary of climate-related impacts on socio-economic sectors in coastal zones

Coastal Socio-economic Sector	Climate-related impacts (and their climate drivers in Figure 6.1)						
	Temperature Rise (Air and seawater)	Extreme events (Storms, waves)	Floods (Sea level, run-off)	Rising water tables (Sea level)	Erosion (Sea level, storms, waves)	Salt water intrusion (Sea level, run-off)	Biological effects (All climate drivers)
Freshwater Resources	X	X	X	X	-	X	x
Agriculture and forestry	X	X	X	X	-	X	x
Fisheries and Aquaculture	X	X	x	-	x	X	X
Health	X	X	X	x	-	X	X
Recreation and tourism	X	X	x	-	X	-	X
Biodiversity	X	X	X	X	X	X	X
Settlements/ infrastructure	X	X	X	X	X	X	-

X = strong; x= weak; - = negligible or not established.

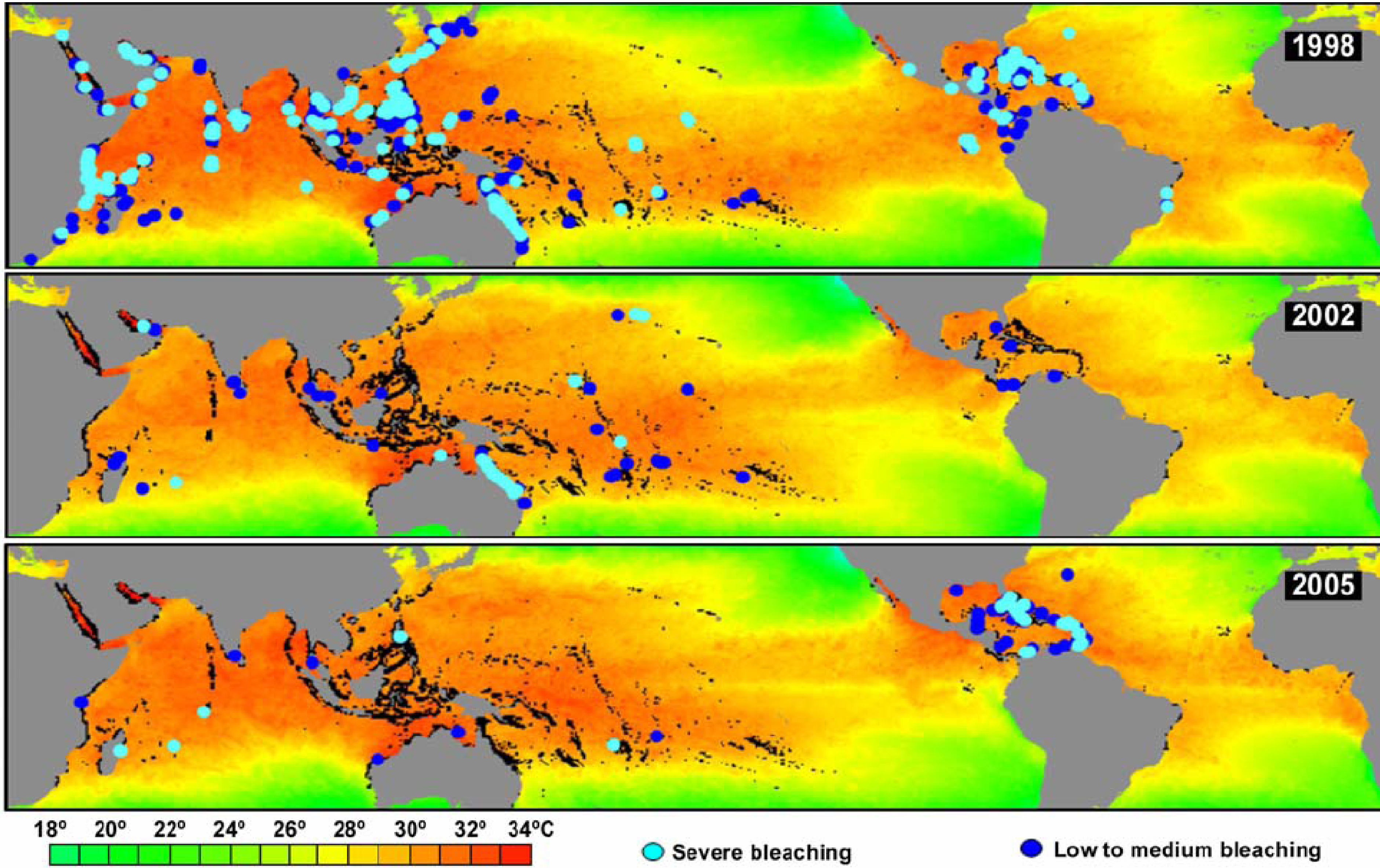


Figure 6.2: Maximum monthly mean sea surface temperature for 1998, 2002, and 2005 and locations of reported coral bleaching (data source, NOAA Coral Reef Watch (coralreefwatch.noaa.gov) and Reefbase (www.reefbase.org)).

Table 6.1: Selected global non-climatic environmental and socio-economic trends relevant to coasta[l] areas for the SRES storylines. Regional and local deviations are expected.

Environmental and Socio-economic Factors	Non-climatic changes and trends for coastal and low-lying areas (by SRES Future)			
	"A1 World"	"A2 World"	"B1 World"	"B2 World"
Population (2080s) (billions)[1]	1.8 to 2.4	3.2 to 5.2	1.8 to 2.4	2.3 to 3.4
Coastward migration	Most likely	Less likely	More likely	Least likely
Human-induced subsidence[2]	More likely		Less likely	
Terrestrial freshwater/sediment supply (due to catchment management)	Greatest reduction	Large reduction	Smallest reduction	Smaller reduction
Aquaculture growth	Large increase		Smaller increase	
Infrastructure growth	Largest	Large	Smaller	Smallest
Extractive industries	Larger		Smaller	
Adaptation response	More reactive		More proactive	
Hazard risk management	Lower priority		Higher priority	
Habitat conservation	Low priority		High priority	
Tourism growth	Highest	High	High	Lowest

[1] Population living both <100 m elevation above sea level and <100 km distance of the coast – uncertainty depends on assumptions about coastward migration (Nicholls 2004).

[2] Subsidence due to sub-surface fluid withdrawal and drainage of organic soils in susceptible coastal lowlands.

Relative vulnerability of coastal deltas

Figure 6.6: Relative vulnerability of coastal deltas as indicated by the indicative population potentially displaced by current sea-level trends to 2050 (Extreme > 1 million; high =1 million - 50,000; medium 50,000 – 5000; following Ericson et al. (2006)).

Table 6.8: *Key hotspots of societal vulnerability in coastal zones.*

Controlling factors	Examples from this Chapter
Coastal areas where there are substantial barriers to adaptation (economic, institutional, environmental, technical, etc.)	Venice, Asian megadeltas, Atolls and small islands, New Orleans
Coastal areas subject to multiple natural and human-induced stresses, such as subsidence or declining natural defences	Mississippi, Nile and Asian megadeltas, Netherlands, Mediterranean, Maldives
Coastal areas already experiencing adverse effects of temperature rise	Coral reefs, Arctic coasts (USA, Canada, Russia), Antarctic peninsula
Coastal areas with significant flood-plain populations that are exposed to significant storm surge hazards	Bay of Bengal, Gulf of Mexico/Caribbean, Rio de la Plata/Parana delta, North Sea
Coastal areas where freshwater resources are likely to be reduced by climate change	W. Africa, W. Australia, Atolls and small islands
Coastal areas with tourist-based economies where major adverse effects on tourism are likely	Caribbean, Mediterranean, Florida, Thailand, Maldives
Highly sensitive coastal systems where the scope for inland migration is limited.	Many developed estuarine coasts, Low small islands, Bangladesh

The following research initiatives would substantially reduce these uncertainties and increase the effectiveness and science base of long-term coastal planning and policy development:

- **Establishing better baselines of actual coastal changes, including local factors and sea-level rise, and the climate and non-climate drivers, through additional observations and expanded monitoring.**

- **Improving predictive capacity for future coastal change due to climate and other drivers, through field observations, experiments and model development.**

- **Developing a better understanding of the adaptation of the human systems in the coastal zone.**

- **Improving impact and vulnerability assessments within an integrated assessment framework that includes natural-human sub-system interactions.**

- **Developing methods for identification and prioritisation of coastal adaptation options.**

- **Develop and expand networks to share knowledge and experience on climate change and coastal management among coastal scientists and practitioners.**