Nordic Hydrology, 34 (5), 2003, 387-398
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Water and Climate – The IPCC TAR Perspective

Paper presented at the Nordic Hydrological Conference
(Røros, Norway 4-7 August 2002)

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The aim of the present contribution, opening a session on climate change and hydrology at the 2002 Nordic Hydrological Conference in Røros, Norway, is to discuss essential water-related findings of the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC), with particular reference to region-specific issues of the Nordic region. Discussion of impacts of climate variability and change embraces both already observed effects and projections for the future. After review of changes in hydrological processes, climate-related impacts on extreme hydrological events – floods and droughts – are outlined. Finally, adaptation and vulnerability are dealt with, including presentation of key water-related regional concerns in various parts of the World.

Introduction

Climate systems and water resource systems are intimately linked, so that any change in one of these systems induces a change in another one. The interplay between climate and water has been extensively tackled in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001, 2001a). In particular, its volume two (IPCC, 2001a), devoted to impacts, adaptation and vulnerability, contains ample material on water resources not only its Chapter Four on hydrology and water resources (Arnell and Liu 2001), but also in several other sectorial and regional chapters of the volume.

According to IPCC (2001, 2001a, 2001b), the Earth's climate system has considerably changed since the pre-industrial era. The atmospheric concentrations of greenhouse gases have considerably increased in the last 140 years, *e.g.* carbon dioxide by 31±4%, methane by 151±25%. Enhanced greenhouse effect has led to the increase of global surface temperature by 0.6±0.2°C over the 20th century, greater than during any other century in the last 1000 years, and 1990s are likely to be the warmest decade of the millennium. There is now new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities (therein, most notably, to emissions of greenhouse gases and land-use and land-cover change). It is projected that atmospheric CO_2 concentration in the year 2100 may range from 540 to 970 ppm (compared to 280 ppm in the pre-industrial era and 368 ppm in the year 2000). The foreseen increase in atmospheric concentrations of greenhouse gases is likely to result in an increase in globally-averaged Earth surface temperature of 1.4° to 5.8°C over the period 1990-2100. This is two to ten times larger than the 20th century warming and the projected rate will be without precedent during at least 10,000 years.

The present paper refers to both climate change and variability. It covers, in a compact way, both observed and projected changes. In principle, the already observed trends are likely to continue, and to become more pronounced. The convention assumed here is that since the "IPCC TAR Perspective" appears in the title, the extensive IPCC Third Assessment Report is the collective major source, in which thousands of detailed references can be found, thus shortcutting the need to refer to many original sources. Typically, every statement made in IPCC TAR has been backed by several autonomous references, hence the IPCC assessment reports are so extensive – from 762-1042 pages each. However, it is not easy to find hydrology-related information there, as it has been scattered throughout the monumental work. The rationale for writing the present short paper on climate change impacts on hydrology and water resources, in a nutshell, is: to provide service to community, conveying the main hydrology-related messages of IPCC TAR. The IPCC TAR is freely available on the web (www.ipcc.ch).

Climate-Change Impacts on Hydrological Processes

There are a variety of mechanisms, in which climate influences different processes of the hydrological cycle. A short review of impacts, mostly stemming from IPCC (2001a), follows.

Precipitation – A statistically significant (though neither spatially nor temporally uniform) increase of global land precipitation over the 20th century was observed (IPCC; 2001). Instrumental records of land-surface precipitation continue to show an increase of 0.5 to 1% per decade in much of the Northern Hemisphere mid- and high latitudes. Marked increase in precipitation in the latter part of the 20th century over Northern Europe and western Russia has been observed, being particularly pronounced in autumn and winter. Continuation of change – general increase of precipitation in Northern Hemisphere mid- and high latitudes (particularly in autumn and winter) and a decrease in the tropics and subtropics in both hemispheres has been projected for the future.

Regional precipitation scenarios developed under the ACACIA project (Parry 2000; IPCC 2001a) show a marked contrast between winter and summer precipitation change in Europe. Wetter winters are predicted throughout the continent, with two regions of highest increase being the northeastern Europe and the northwestern Mediterranean coast. In summer, it is likely that a strong difference in precipitation change between the Northern Europe and the Southern Europe will develop; the former getting wetter by 2% per decade, while the latter getting drier by 5% per decade. The forecast of increasing summer dryness is valid for most continental interiors. Yet, quantitative differences between scenarios and models are large.

Evapotranspiration – Higher temperature causes increase in potential evapotranspiration. Hence, increase in potential evapotranspiration has been determined, corresponding to the observed temperature rise, and this tendency is likely to strengthen in the future. Increases in potential evapotranspiration are largely related to increases in vapour pressure deficit resulting from higher temperature. Evaporation is driven by meteorological controls (*e.g.*, temperature, humidity, wind), mediated by characteristics of soils and vegetation and constrained by the availability of water. Plants exert control via changes in stomatal conductance. Climate change has the potential to affect all these factors (Arnell and Liu 2001). The actual evapotranspiration is constrained by water availability – if there is no water, evaporative demand will not be met.

Snow and Ice – In many areas, increasing temperatures lead to a smaller proportion of precipitation falling as snow, so that there is more runoff in winter and less in spring (lower snowmelt). In areas where currently snowfall is marginal, snow may cease to occur. On the other hand, as increase in winter precipitation is expected: snow cover may increase in areas where the temperature will still be below 0°C. Glacier fluctuations are a key indicator of climate variability and change. While glaciers in most parts of the world have been retreating (including a well-documented, and widespread, accelerated glacier retreat in the European Alps), some (*e.g.* in Scandinavia) have been advancing, following changes in regional climate. There have been clear links between glaciers balance and NAO variability in Europe. It has been observed that the NAO index correlates to a considerable extent with the snow cover in the European Alps. Strong positive phase brings more abundant snowfall and increase in snow cover in higher altitudes, while for lower altitudes there is less snowfall (hence decrease of snow cover) and more rain.

Soil Moisture – Global climate models, which directly simulate soil moisture (over a very coarse spatial resolution) for the future, give an indication of possible reduced soil moisture in Northern Hemisphere mid-latitude summers, due to reduced snow cover, higher evaporation, and lower summer rainfall. Climate change is likely to affect soil properties and its water-holding capacity (Parry 2000). It is likely that the warming will increase the rate of decomposition of soil organic matter, above the rate of carbon influx to soils arising from increased vegetation growth. Hence, the soil organic matter, of considerable importance in soil water storage, will diminish in many part of Europe, including its cooler regions. Drier climatic conditions will lead to increases in the frequency and size of crack formation in soils with large clay contents. Crack formation results in more rapid and direct downward movement of water and solutes from surface soil (bypass flow).

Groundwater – There have been relatively less research on potential climate change impacts on groundwater. Increased winter rainfall – projected under most scenarios for mid-latitudes – may result in enhanced aquifer recharge. However, increase in evaporation during the recharge season may lead to reductions in recharge.

Sea-level rise will cause saline intrusion into coastal aquifers. A reduction in precipitation coupled with sea-level rise would reduce the size of freshwater lenses. This is particularly critical where overpumping enhances seawater intrusion into freshwater aquifers. Sea-level rise, which is foreseen to continue, would worsen the situation.

Streamflow – Where data are available, changes in annual streamflow usually relate well to changes in total precipitation (IPCC, 2001). River flow changes have been observed in many records but typically no uniform, consistent and significant tendency has been identified. Part of this observation can be explained by human impacts superimposed on climate control.

Lakes – Lakes are vulnerable to climate change as their water storage is a result of a cumulative process, where small signals (if present for a sufficiently long time) can play a decisive role. Under adverse climate changes, some lakes may disappear, in particular small endorheic (closed) lakes.

Water Quality – Water quality is likely to be degraded by higher water temperature, leading to faster kinetics of reactions. Increases in oxygen-consuming biological activities are projected, leading to a rise of phytoplankton. This change is superimposed on controls related to water quantity, being moderated where flows increase, or amplified where flows decrease.

Seasonality – Distinct changes in timing of hydrological cycle have been observed, including delayed river freeze-up and earlier break-up. Changed river flow regimes have generally been noted with (largely snowmelt-controlled) high flows coming earlier in a year, shifting from spring towards winter.

Climate Variability – Links between hydrological extremes and climatic variability (*e.g.*, oscillations in the Ocean-Atmosphere system, such as El Niño-Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), and the Arctic Oscillation (AO)) have been extensively studied. Since the mid 1970s, warm phase of ENSO episodes has become relatively more frequent, persistent and intense than the opposite cool phase, in comparison with the previous 100 years of instrumental records (IPCC, 2001). This is likely to have direct consequences related to changes in frequency of floods and droughts.

The variability of NAO has considerable influence on the regional climate in Europe, in particular in wintertime. Strong positive phase of the NAO, observed over more than decade (except for a short-lived minimum of 1995-1996), which corresponds to stronger westerly flow over the North Atlantic, coincides with mild and wet winters over a considerable part of Europe, including the Nordic region. Scientists raise the question – are the observed changes in ENSO and NAO perhaps consequences of global warming itself, which cannot be answered with confidence.

Extreme Hydrological Events

A question emerges as to the extent in which an apparent rise of hazard and vulnerability to extreme hydrological events – floods and droughts – can be linked to climate change. Characteristics of floods and droughts in several areas have changed or / and can change in the future climate (IPCC, 2001, 2001a). Table 1 presents projected changes in extreme events and associated water-related impacts.

As water holding capacity of the atmosphere, and thus its absolute potential water content, grows with temperature, the possibility of intensive precipitation also grows. In regions where total precipitation has increased, there have been even more pronounced increases in extreme precipitation events. The frequency of extreme precipitation events is projected to increase almost everywhere (IPCC, 2001). This is a sufficient condition, if other conditions do not change, of increase of flood hazard. Increases in "heavy and extreme precipitation" have been documented even in some regions where the total precipitation has decreased or remained constant.

Over the latter half of the 20th century, there has been a 2-4% increase in the frequency of heavy precipitation events reported by the available observing stations in the mid- and high latitudes of the Northern Hemisphere. The area affected by most intense daily rainfall is increasing and significant increases have been observed in both the proportion of mean annual total precipitation in the upper five percentiles and in the annual maximum consecutive 5-day precipitation total. The latter statistic has increased for the global data in the period 1961-1990 by 4% (IPCC, 2001, p.158). The number of stations reflecting a locally significant increase in the proportion of total annual precipitation occurring in the upper five percentiles of daily precipitation totals outweighs the number of stations with significantly decreasing trends by more than 3 to 1 (IPCC, 2001).

Changes in future flood frequency are complex, depending on the generating mechanism, *e.g.*, increasing flood magnitudes where floods result of heavy rainfall and decreasing magnitudes where floods are generated by spring snowmelt (IPCC; 2001, p.206). In some places, "[r]apid snowmelt from rain-on-snow events or warm periods in the middle of winter is a potential threat in a warmer world" (IPCC,

Table 1 – Examples of water-related impacts resulting from projected changes in extreme climate events in the 21st century (excerpt from IPCC, 2001a).

Projected changes in extreme events and their likelihood	**Examples of projected impacts (throughout: high confidence of occurrence in some areas)**
Simple extremes	
More intense precipitation events (*very likely, over many areas*)	Increased flood, landslide, avalanche, and mudslide damage Increased soil erosion Increased flood runoff could increase recharge of some floodplain aquifers Increased pressure on government and private flood insurance systems and disaster relief
Complex extremes	
Increase in tropical cyclone peak wind intensities, mean and peak precipitation intensities (*likely, over some areas*)	Increased risk to human life, risk of infectious disease epidemics, and many other risks Increased coastal erosion and damage to coastal buildings and infrastructure Increased damage to coastal ecosystems
Increased summer drying over most mid-latitude continental interiors and associated risk of drought *(likely)*	Decreased crop yields Increased damage to building foundations caused by ground shrinkage Decreased water resource quantity and quality Increased risk of forest fire
Intensified droughts and floods associated with El Niño events in many different regions (*likely*)	Decreased agricultural and rangeland productivity in drought- and flood-prone regions Decreased hydro-potential in drought-prone regions
Increased Asian summer monsoon precipitation variability (*likely*)	Increased flood and drought magnitude and damages in temperate and tropical Asia
Increased intensity of mid-latitude storms (*little agreement between current models*)	Increased risks to human life and health Increased property and infrastructure losses Increased damage to coastal ecosystems

2001a). Climate change is likely to cause an increase of the risk of riverine flooding across much of Europe.

However, the very issue of detecting a climate change signature in the available river flow data is complex due to strong natural variability and additional non-climatic factors, e. g., land-use changes, leading to growth of impervious areas and hence reduction in the storage volume and increase in the runoff coefficient. This leads to growth in amplitude and reduction of time-to-peak of a flood triggered by a "typical" intense precipitation. As indicated earlier, a "typical" intense precipitation event has been also changing due to climatic reasons.

Apart from the inherent complexity of the issue of detecting a greenhouse component in flow records, there are serious problems with the data with which to work, and also with the methodology to detect changes (restrictive assumptions).

Data should consist of long time series of good quality records. Because of strong climate variability, records of less than 30 years are too short for detection of climate change. At least 50 years of record are necessary for climate change detection (Kundzewicz and Robson 2000), but in case of very strong natural variability (*e.g.*, Australian river flow data) even this may not be sufficient (*cf.* Chiew and McMahon, 1993).

There are further problems related to the data. Baseline conditions are rare, typically human influence is strong (river regulation, deforestation, urbanization, dams and reservoirs). In order to detect a weak, if any, climate change component in river flow records, it is necessary to eliminate other influences and use data from pristine / baseline river basins.

Projections for the future indicate a likelihood of increased summer drying over most mid-latitude continental interiors and associated risk of drought in the vegetation season. As soil moisture is projected to decrease in several areas where it is already low, desertification enhancement is a serious concern.

Adaptive Capacity and Vulnerability

The climatic impact on water resource depends not only on changes in the characteristics of streamflow and recharge but also on such system properties, as: pressure (stress) on the system, its management (also organizational and institutional aspects), and adaptive capacity. Climate change is just one of several pressures facing water resources. Among other pressures are: overexploitation of water resources, general environmental degradation, water quality deterioration. Climate change may challenge existing water resources management practices by contributing additional pressure and additional uncertainty, but non-climatic changes may have a greater impact. Under such circumstances, improvement in efficiency, via integrated water management, is indispensable.

There is still a great deal of uncertainty in findings about climate change impacts on water resources. Part of it is due to scale mismatch between coarse-resolution climate models and hydrological (catchment) scale. Only in some, but not all, areas, the projected direction of change of hydrological processes is consistent across different models and scenarios.

Table 2 – Water-related issues referring to a regional adaptive capacity, vulnerability, and key regional concerns (excerpts from IPCC, 2001a, pp. 14-17). Confidence levels in Table 2 correspond to IPCC WG II classification (very high: 95% or greater, high: 67-95%, medium: 33-67%)

Region	***Adaptive capacity, vulnerability and key concerns***
Africa	Adaptive capacity of human systems in Africa is low due to lack of economic resources and technology, and vulnerability high as a result of heavy reliance on rain-fed agriculture, frequent droughts and floods Grain yields are projected to decrease for many scenarios, diminishing food security, particularly in small food-importing countries (medium to high confidence) Major rivers in Africa are highly sensitive to climate variation; average runoff and water availability would decrease in Mediterranean and southern countries of Africa (medium confidence) Increases in droughts, floods, and other extreme events would add to stresses on water resources, food security, human health, and infrastructures, and would constrain development in Africa (high confidence)
Asia	Extreme events have increased in temperate and tropical Asia, including floods, droughts, forest fires, and tropical cyclones (high confidence) Decreases in agricultural productivity and aquaculture due to ... water stress, ..., floods and droughts, and tropical cyclones would diminish food security in many countries of arid, tropical, and temperate Asia (medium confidence) Runoff and water availability may decrease in arid and semi-arid Asia but increase in northern Asia (medium confidence) Increased intensity of rainfall would increase flood risks in temperate and tropical Asia (high conficence)
Australia and New Zealand	Water is likely to be a key issue (high confidence) due to projected drying trends over much of the region and change to more El Niño-like average state Increases in the intensity of heavy rains and tropical cyclones (medium confidence), and region-specific changes in the frequency of tropical cyclones, would alter the risks to life, property, and ecosystems from flooding
Europe	Summer runoff, water availability, and soil moisture are likely to decrease in southern Europe, and would widen the difference between the north and drought-prone south, increases are likely in winter in the north and south (high confidence) Half of alpine glaciers and large permafrost areas could disappear by end of the 21st century (medium confidence) River flood hazard will increase across much of Europe (medium to high confidence)

Cont.

Table 2 – Cont.

Region	***Adaptive capacity, vulnerability and key concerns***
Latin America	Loss and retreat of glaciers would adversely impact runoff and water supply in areas where glacier melt is an important water source (high confidence) Floods and droughts would become more frequent with floods increasing sediment loads and degrading water quality in some areas (high confidence) Increases in intensity of tropical cyclones would alter the risks to life, property, and ecosystems from heavy rain, flooding (high confidence) Yields of important crops are projected to decrease in many locations in Latin America (high confidence)
North America	[Effects on crops include] declines due to drought in some areas of Canada's Prairies and the U. S. Great Plains (medium confidence) Snowmelt-dominated watersheds in western North America will experience earlier spring peak floods (high confidence) Weather-related insured losses and public sector disaster relief payments in North America have been increasing: insurance sector planning has not yet systematically included climate change information, so there is potential for surprise (high confidence)
Polar	Changes in climate that have already taken place are manifested in ... permafrost thawing, coastal erosion, changes in ice sheets and ice shelves (high confidence)
Small Island States	The projected sea-level rise of 5 mm yr-1 for the next 100 years would cause ... saltwater intrusion into freshwater resources (high confidence) Islands with very limited water supplies are highly vulnerable to the impacts of climate change on the water balance (high confidence)

Adaptation to climate change in the water sector can be either structural (increasing reservoir capacity, structural flood defenses – levees, bypass channels, *etc.*) or non-structural (*e.g.* demand management – economic instruments: pricing, taxes or subsidies; legislation, institutional practices).

The Nordic region is likely to experience overall positive agricultural effects of climate change, whereas, in some production systems to the south, a decrease of productivity can be observed, due to water deficits. Changes in water-limited yield for wheat are likely to be generally positive in the Nordic region.

The demand for water is increasing worldwide as a result of population growth and economic development. The 21st century has been baptized "the age of water scarcity". In addition, the projection of climate-related increase in severity of drying in continental interiors during a vegetation season exacerbates the future irrigation water demands.

Table 2 indicates that several water-related issues have been identified on a short list of key regional vulnerabilities and concerns in all parts of the World. As vulnerabilities are high in those regions, where adaptive capacity is low, equity concerns occur: poor people are likely to suffer most. This is of considerable concern to the community of donors of international assistance.

Concluding Remarks

Changes in availability (quantity and quality aspects) and use of water resources, associated with climate variability and change, could have significant impacts across many sectors of economy, society and environment (IPCC, 2001a). Water-related vulnerability issues, associated with climate change, have been identified among key regional concerns in all regions of the World. Hazards related to extreme hydrological events are likely to rise in the future. Plausible climate change scenarios indicate the possibility of increases in both amplitude and frequency of flooding events, while drying in continental interiors in the vegetation season is a robust result from models. Yet, the degree of uncertainty in water-related projections is still high. There has been no conclusive and general proof as to how climate change affects the flood behaviour, in the light of data observed so far. Results of some studies, indicating that high floods are becoming more frequent, is challenged in other studies, based on contradictory evidence.

Acknowledgements

The work reported in the present contribution has been a background activity within a research project *"Detection of Change in Hydrological Data: Can One Observe A Greenhouse Signature?"* financed by the Scientific Research Committee of the Republic of Poland (research grant no. 6 P 04 E 05 520). The author wishes to acknowledge an anonymous referee, whose constructive criticism has helped to improve presentation of material.

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Received: 4 November, 2002
Revised: 29 September, 2003
Accepted: 20 October, 2003

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