Impacts of Climate Change and Climate Variability on Hydrological Regimes

This book examines the implications of possible climate change and variability on both global and regional water resources. Water is going to be one of the key, if not the most critical, environmental issue in the twenty-first century because of the escalation in socio-economic pressures on the environment in general. Any future climate change or climate variability will only accentuate such pressures.

The volume initially examines the subject from the perspective of the Intergovernmental Panel on Climate Change (IPCC), and infers possible changes in hydrological regimes and water quality based on the outputs from various scenarios of General Circulation Models (GCMs). In subsequent chapters, the possible effects of climate change on the hydrology of each of the continents is examined. The book concludes with an overview of hydrological models for use in the evaluation of the impacts of climate change. This is the first volume to provide a multidisciplinary framework for synthesizing many diverse trains of thought, research and practice in the assessment of the impacts of climate change on water resources. It will provide a valuable guide for environmental planners and policy-makers, and will also be of use to all students and researchers interested in the possible affects of climate change.

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Edited by

Jan C. van Dam

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Executive summary

It is now widely accepted that the increasing concentrations of greenhouse gases in the atmosphere are affecting the Earth's radiation balance, resulting in higher global air temperatures. However, there is still a great deal of uncertainty about the likely effects of such temperature rise on climate, and even more about the impacts of climate change and variability on the world's hydrological regimes and water resources. The interactions between climate change and hydrological conditions will also be affected, either directly or indirectly, by a number of socio-economic factors such as population pressure and changes in land use.

This final report of the Working Group of UNESCO's IHP-IV project H.2.1 provides an overview of ongoing activities in the 'trans-science' domain that involves climatologists, meteorologists, hydrologists, and water resource engineers. In recent years, a number of models of the world's climate have been developed to generate alternative scenarios of future climate conditions. The results of these scenarios are then used by hydrologists to assess the probable effects of climate change on hydrological regimes. Such information is in turn required by policy makers and water resources managers to enable them to formulate appropriate adaptive strategies.

This report is relevant to the international community of scientists and practitioners of hydrology and climatology. It gives an overview of the climatic and hydrological changes that are already occurring around the world, and surveys the variety of methods that are being used to forecast future changes. Such a survey can of course never be complete, but it summarizes the areas for which information was available and accessible.

The preparation of this report partly coincided with that of the second IPCC report, and some members of the Working Group and external assessors were involved in both processes. The two reports are quite different in nature, however. This report is restricted to the hydrological aspects of climate change and their consequences for water resources, and deals in particular with the various methods of 'trans-science' (hydrology and climate) research and their inherent problems. It therefore complements the IPCC report; there is little overlap and there are no major contradictions.

The report is structured as follows. After the Introduction, Chapter 2 provides an overview of the work of the IPCC in the period 1988–94. Chapters 3–7 review the work being undertaken in South America, North America, Europe, Africa, and Asia and Australia, respectively. Chapter 8 is unique in that it provides a concise overview of the models that are being used in the evaluation of the impacts of climate change on hydrology. Finally, Chapter 9 presents the conclusions and recommendations of the Working Group.

CONTINENTAL ANALYSES

Chapters 3–7 detail the results of the various modelling studies that have been undertaken to assess the possible impacts of climate change and variability on hydrological regimes. These continental analyses highlight a number of issues arising from the use of scenarios based on the results of general circulation models (GCMs), including the problems of downscaling the GCM results to provide the inputs for hydrological models at the catchment level, to produce the information required by water resources policy makers, planners and engineers.

South America (Chapter 3): The authors note that there have been few GCM-based studies of South America, except for the Uruguay basin. The results of different GCMs show some marked inconsistencies, particularly in terms of changes in precipitation, and their effects on river discharges. It is clear that GCMs have limited ability to describe accurately the convective precipitation process, and soil–water–plant interactions with the atmosphere in a tropical environment. However, a large-scale field experiment in the Amazon basin (LBA) is now in progress to improve the surface parameterization of GCMs to assess the impacts of deforestation on the Amazonian climate.

North America (Chapter 4): Many regional studies of climate–hydrology relations have provided insights into the potential sensitivity of water resources to climate change, and have also highlighted a number of shortcomings in the process of modelling in general. Such is the degree of uncertainty in the results of both hypothetical and GCM-based scenarios, that they could all be regarded as investigations of the sensitivity of water resources to changes in temperature and precipitation. More robust models are needed that can simulate atmospheric and hydrological processes over a broad range of conditions and spatial and temporal scales. The main obstacles to the development of such models include the limited understanding of many of the hydrological-atmospheric processes involved, and their interactions, and the lack of data with which to develop and test the models of such processes. For example, the temporal and spatial variations in seasonal precipitation, temperature and runoff in parts of North America have been shown to be related to large-scale atmospheric circulation patterns such as the El Niño–Southern Oscillation, which are still only poorly understood. There is also little consistency in the applied methodologies and assumptions. Resource managers will therefore have to continue to rely on scientists' 'best estimates' as the basis for their long-term plans, and must await improvements in the models and methodologies before more reliable estimates are available.

Europe (Chapter 5): In Europe, the seasonal distribution of runoff is more likely to be affected by climate change than the annual totals, especially in snowmelt-dominated catchments. In the milder regions of western Europe, climate change scenarios also indicate that the seasonality of flows will increase, with more frequent floods in winter and more persistent low flows in summer. In southern Europe, some studies have also investigated the possible effects of climate change on groundwater recharge rates. However, there have been few studies of the linkages between changes in land use and hydrological regimes, which may be more important than the impacts of climate change. In response to the uncertainties surrounding climate change scenarios, high-quality runoff data sets for Europe are now being compiled under the FRIEND programme in order to detect hydrological variability.

Africa (Chapter 6): Africa has a wide variety of hydrological regimes, but the Sahel is the most vulnerable to climate change. In both the Sahel and the Nile basin, changes in precipitation will be more important than changes in temperature: less rainfall will lead to less vegetation, leading to overgrazing, leading to less evaporation. The mechanisms of this downward spiral are still inadequately included in GCMs. The Nile basin contains a wide variety of sub-catchments, but such changes in vegetation and soils are still insufficiently included in the models. Southern Africa is now being studied under the FRIEND programme. Studies of the impacts of climate change in Africa are hampered by inadequate instrumentation, and time series data that are too short. HAPEX-type experiments should run for at least five years, and a catchment approach should be adopted. Analyses of satellite data have indicated the importance of the presence of aerosols in the atmosphere. The HAPEX-Sahel integrated database will be freely accessible in 1997.

Asia and Australia (Chapter 7): In a detailed case study of the Caspian Sea, the authors describe the dramatic rise in the level of the sea in recent years due to both climate change (increased precipitation in the Volga basin), and human factors (reduced water abstraction for irrigation and industry). In the cold and temperate regions of Asia, increased air temperatures would have a greater effect on runoff than changes in precipitation, particularly in cold regions. Long-term hydrometeorological data for the Yenisey basin show that so far, maximum warming has occurred in the southern part of the basin, and minimum warming in the north, on the Arctic Ocean coast. These observations are inconsistent with the results of both GCM and paleoclimate scenarios, all of which have forecast greater warming at higher latitudes. Surprisingly high air temperatures are predicted for the Yenisey basin. In the humid tropics, where runoff regimes depend mainly on precipitation, global warming would increase precipitation and runoff, particularly during the wet season. Runoff is thus much more sensitive to changes in rainfall than to changes in potential evaporation. With a 1–2°C increase in global air temperatures, total water resources are likely to increase; total runoff in Asia could increase by 20–30%, and in Oceania by 10–18%.

OVERALL CONCLUSIONS

The overall conclusions of the Working Group are presented in Chapter 9 under the following headings: (a) the use of paleoclimate scenarios; (b) the use of GCM scenarios; (c) hydrological models and climate change; (d) the uncertainties associated with GCMs and hydrological models; (e) field experiments to improve GCMs; (f) climate change and water resources management; and (g) the outcomes of the IPCC process. The main conclusions are as follows:

- The effects of climate variability and change on the hydrological cycle will be coincident with those of changes in land use, which could be of the same order of magnitude. It is therefore difficult to separate these two sets of effects in analysis and synthesis.
- Despite the considerable efforts that have been undertaken in research and modelling climate change and its impacts in recent years, the results are still highly uncertain, for a number of reasons: (1) the unpredictability of future emissions of greenhouse gases and the concentrations of aerosols; (2) the shortcomings in the capabilities of existing GCMs; and (3) the different levels of scale adopted in GCMs and hydrological models. There are two main sources of 'noise': (i) the noise in the GCM results, which can give rise to variable and even contradictory results; and (ii) the noise in the results of different hydrological methods. After more than 15 years of research, progress in reducing both of these sources of noise has been disappointing. A great deal of work is still needed to achieve adequate coupling between the results of GCMs and hydrological models.
- A number of multidisciplinary field experiments have been designed as a means of improving land surface parameterization from the hydrological perspective. However, most of these experiments have tended to focus on the vertical terrestrial–atmospheric exchanges of energy and water vapour, rather than on details of horizontal water fluxes.
- Hydrological models would be considerably improved if they incorporated a more physically based understanding of hydrological processes and their interactions, and if parameter measurement and estimation techniques were developed for applications over a range of spatial and temporal scales.
- Large-scale basin studies such as HAPEX, GCIP and LBA, which incorporate a nested drainage basin approach (NDBA), appear to be the key to improving our understanding of processes and for modelling the hydrological impacts of climate change.
- The inconsistencies in the model outputs mean that policy makers and water resource managers face equally high uncertainty in their task of formulating appropriate adaptive strategies. In the future, such strategic choices will be further complicated by socio-economic factors and the associated changes in the demand for water. In areas of rapid population growth, particularly in developing countries, the availability of water per capita will decrease, irrespective of climate change.
- In 1988 the IPCC was established to gather together and assess the results of research that has been conducted around the world on various aspects of climate variability and change. The Panel was then to use that information to evaluate the environmental and socio-economic consequences of climate change, to formulate realistic response strategies, and, above all, to publicize their findings to the scientific community, international organizations and decision-makers. The IPCC has fulfilled most of these objectives, and in this respect the process has been beneficial and useful to the international community in general. Nonetheless, the Panel has not been able to recommend one future climate change scenario or methodological approach for all assessments of the likely consequences of climate change. There has been little progress in improving the reliability of forecasts of climate change, nor of the probable impacts on water resources, the environment and society.

RECOMMENDATIONS

The recommendations of the Working Group are summarized in the following; the complete text can be found in Chapter 9. Depending on the message, these recommendations are addressed to individual nations, to the international organizations UNESCO-IHP, WMO, IPCC and international funding agencies, to policy makers, climatologists, hydrologists, modellers of climate and hydrology, water resources engineers and planners.

1. *Coordination*: Climate change scenarios and models should be selected so that the results will be directly comparable. This will require international coordination.
2. *Forecasts of future conditions*: More accurate forecasts of likely increases in greenhouse gas concentrations, and of changes in land use, are needed. Such forecasts require international cooperation.
3. *Adaptive measures*: Water resources engineers, planners and policy makers should be alert to any trends in climate as they become clearer, so that timely adaptive measures can be taken.
4. *Sensitivity analysis*: More accurate determination of changes in climate variables is needed, particularly in cases of high hydrological sensitivity and where the availability of water resources is low in relation to the demand.
5. *Water resources management studies*: UNESCO-IHP should frame a programme of water resource management studies and applications, including as inputs the

results of GCMs and subsequent analyses of data on climate variability and change.

6. *Anticipating extreme events*: Greater attention should be given to studies of the effects of extreme hydrological events such as floods, storms in urban areas, and droughts. For vulnerable locations, it may be useful to consider the transposition of existing data from other locations that are representative of the predicted changes in climate.
7. *Large-scale field experiments and modelling approaches*: In large-scale field experiments, greater attention should be paid to quantifying horizontal water fluxes in order to improve the effectiveness of the nested drainage basin approach (NDBA).
8. *Future large-scale field experiments*: Decisions as to whether new large-scale field experiments should be set up in other regions should be taken after weighing the value of the expected results against the inevitably high costs of such experiments.
9. *Freely accessible databases*: Future large-scale studies should include the compilation of complete and freely accessible databases, as is currently being done within HAPEX-Sahel.
10. *Data collection network*: It is important to have access to long-term data sets compiled both in the past and in the future. The WMO and individual nations should therefore recognize that a global network of climate and hydrological stations needs to be maintained at an adequate density. This is particularly the case in areas where data collection has been discontinued due either to natural disasters or political instability.
11. *Groundwater*: It is recommended that an inventory is made of the studies that have been undertaken so far of the impacts of climate change on groundwater regimes. Only then should areas for further study be selected, and appropriate research proposals formulated. Such an inventory and subsequent research proposals might be undertaken as a UNESCO-IHP project.
12. *Funding*: International funding agencies should focus on areas for which the data are scarce, and where the most serious problems, due to hydrological conditions and/or human impacts, are expected. North Africa, particularly the Sahelian region, should be given high priority. Because the process of climate change is slow, and water resources engineers need to pay particular attention to extremes, ongoing and new field experiments need to be established for periods of decades at least.

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Dr Bonell, Programme Specialist of the Division of Water Sciences at UNESCO, was appointed to organize the meetings of the Working Group and to provide secretarial support, which he did with great efficiency. He was always to the point and stimulating during the meetings. He also made substantial contributions to the final versions of the Conclusions, Recommendations and Executive Summary of this report.

Valerie Jones did an excellent job in editing the heterogeneous material of this report. Her familiarity with the subject enabled her to trace internal inconsistencies and, together with the Editor's comments, helped to improve the text. We benefited greatly from her input.

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J.C. van Dam
Editor