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GLOBAL CLIMATE CHANGE AND WATER RESOURCES

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INTRODUCTION

The last years have seen a rapid growth in interest in the evaluation of possible future environmental changes due to global warming and their implications for society. There is much concern over the possible impacts of climatic changes on water resources. This paper is devoted to the discussion of selected problems connecting with the water balance response to climatic changes and its relation with the concept of the sustainable development.

IDENTIFICATION OF THE PROBLEM

Three main issues need to be addressed in considering the likely effects of climatic change on water resources: first, the nature of the expected changes in climate; second, the estimated impacts of these changes on water balance; third, the range of appropriate responses required to adopt to climatic change through adjustments both on the local (watershed) level and in regional policy.

Although the precise concept of sustainable development was explicitly introduced fairly recently [Our Common Future, 1987], it was elaborated in a number of scientific and political reports [see for instance Clark and Munn, 1986 and the references given there]. Loucks [1994] named three main components of its definition - justice to nature, justice to future generations and also justice within our own generation. This is the manner how it will be understood in the present paper.

The theory that the Earth is warming because of an enhanced greenhouse effect now commands wide support among scientists. Current best estimates suggest that if greenhouse gas concentration in the atmosphere continue to increase at present rates, then an increase in global mean annual surface air temperatures of approximately 3^{o}C by the end of next century can be expected. This is of course only a possible scenario loaded with a large degree of uncertainty. There are a number of possible and admissible estimates of projecting emission, gas concentration, global and local climatic response [Schneider, 1989]. Most of the climatic model forecasts are based on mathematical considerations and the General Circulation Models are referred most often. These models can be used either to simulate climate of chosen times in the geologic past, or for sensitivity tests of the unique influence of specific components of the climate system [Henderson-Seller, 1990; Ruddiman, 1990]. It is worth noting that the GCMs have in fact been unable to provide reliable projections of regional changes in climate. Although the broad-scale prediction is for a smooth increase in global temperature there may be rapid warming in some regions and possible even periods of cooling in others.

An important question is whether and how water systems can adopt to possible changes. For example a local increase in temperature can affect water supply and demand. Water quality can be depreciated if the same volume of wastes is discharged through decreased stream flow. In addition, irrigation demand (and thus pressure on surface and ground-water systems) may increase substantially if temperatures increase without concomitant offsetting increases in precipitation. The most often quoted danger is related to a possible sea level rise by 0.5 to 1.0 meter in next century.

Interrelation between climate and water resources seems to be an extremely complex problem and should be a challenge for the scientific community. We cannot share the opinion of Clark and Munn [1986] that the predictive efforts about future environmental impacts are naive on two counts: technical infeasibility and practical irrelevance. The role of scientific community is to make efforts to clarify the complex nature of the phenomenon and to give a reliable tool for decision-makers. The presented so far results are of disputable validity besides. New research sheds some new light on investigated problems. It was found that climate, characterized by various parameters, cannot be treated as stationary stochastic process any longer [IPCC Scientific Assessment, 1992; Mitosek, 1994]. Moreover, large problems arise because of the nonlinearity of the equations describing both climate and water dynamics. This is why the dynamics may evolve into aperiodic random looking behavior called deterministic chaos.

Kaczmarek and Krasuski [1991] named five main areas related to the climate/ water resources interface:

1. Studies aimed at detecting changes in atmospheric processes by means of hydrological indicators, including paleohydrological investigations;
2. Analysis of the sensitivity of water balance components to changes in climate characteristics;
3. Assessing the possible implications of climate fluctuations on water supply and demand, and consequently on water management;
4. Studies on the impact of climate change of physical, chemical and biological processes in rivers, lakes and reservoirs;
5. Research aimed at sound and more accurate parametrization of land surface processes in global and meso-scale atmospheric models.

We will touch only on a few aspects of the mentioned problems.

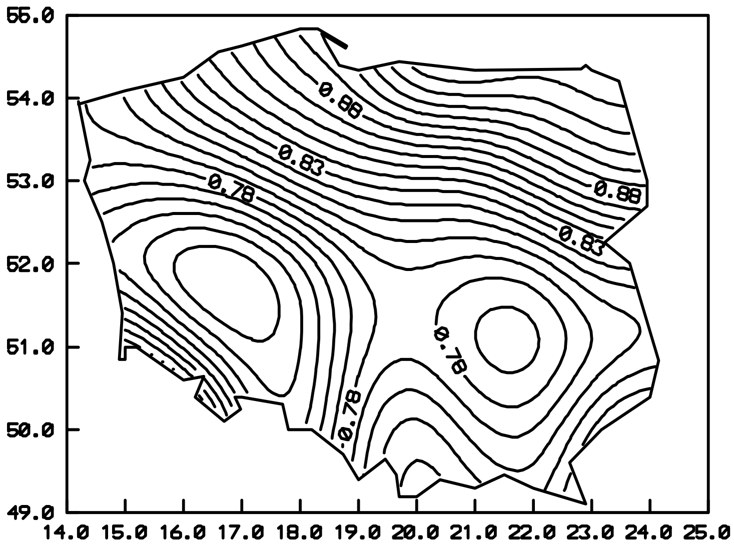
In the very long run, increased knowledge about the ways in which climate and water-resources interact may prove to be one of our most powerful tools for assisting politicians and decision-makers in managing sustainable development. It seems to be quite an easy answer what to do to remedy the future degradation of water resources in response to climate change. The answer is to impact on the grounds of climatic change, namely to achieve carbon dioxide and other gases reductions in spite of continued population growth and in a manner consistent with continued economic expansion. It is quite an abstract demand, and the question about the ways of achieving such progress in context of present and near future difficult political and economic situation in many regions, is far from being solved. The authors agree with Crosson and Rosenberg [1991] that adaptation and mitigation should be pursued jointly and that there are trade-offs between them. This approach will be briefly discussed further in the paper.

SCIENTIFIC APPROACH TO CLIMATE IMPACT ON WATER RESOURCES ANALYSIS

There is a rich literature considering various approaches to the analysis of the possible results of the global warming in respect to water resources in various regions of the world [see for instance Dooge, 1992; Nemec and Schaake, 1982; Manabe et al., 1992]. We will focus here only on the investigations carried out in the Water Resources Division of the Institute of Geophysics, Polish Academy of Sciences. This research was conducted on the basis of the mathematical water balance model[1] developed in this Institute. For a deeper discussion of the

[1] The present version of the model is called CLIRUN 3 (climate/runoff model - 3rd version).

mathematical and physical bases of the model and the obtained results we refer the reader to Kaczmarek [1993,1994]. This conceptual model is based on the mass and energy conservation differential equations reflecting the water balance in a catchment (balance of precipitation, evapotranspiration, runoff and catchment storage). It allows to quantify the sensitivity of catchment runoff to changes in climatic characteristics, for example effective precipitation and mean temperatures. The input climatic data are evaluated based on the various equilibrium atmospheric versions of Global Circulation Models. The purpose of such investigations is to perform calculations for various case studies in different regions. We will only illustrate possible results obtained during the climate impact study aimed at evaluating changes in water supply in Poland. Figure 1 reveals, for example a possible percentage change of annual runoff by atmospheric CO_2 doubling assuming the scenario of GFDL (Geophysical Fluid Dynamics Laboratory in Princeton) model.



The research results illustrate the danger of serious water supply problems in Poland in case of the realization of the pessimistic scenario (simultaneous rise of the mean temperature and the decrease of the effective precipitation). This is a typical illustration of a likely climate change impact on sustainability (global warming as a significant threat for the economic productivity of water and damages to local environment water resources and consequently also for the integrity of regional ecosystems).

ADAPTING TO CLIMATE CHANGE

The study shows that the basin's water supply and demand are both sensitive to changes of climatic characteristics, and that the region is vulnerable to such changes. In the middle of next century the available freshwater supply may be insufficient to meet requirements. Optimal operation of existing reservoirs will not solve the problem in the basin as a whole, although may secure reliable supply for its upper part.

Burton *et al.* [1993] have listed a number of approaches for coping with negative effects of climate, like *prevention of losses*, *tolerating loss*, *changing activity or location*, etc. All such actions require a deep social and economic analyses and long-term planning. The list of possible adaptive responses that might be used in the one of the Poland's basins (Warta River Basin) to handle future water deficits includes [Kaczmarek and Napiórkowski, 1995]:

* conservation of water by various sectors of economy,

* improving management of resources,

* development of technical infrastructure, e.g., through constructing new storage reservoirs,

* transfer of water from other river basins,

It should be stressed that there is a strong opposition in Poland against new large-scale hydraulic investments. The reason is the relatively high density of population, lack of lands which could be eventually used for additional storage, environmental concerns, and insufficient investment funds. This leads to a conclusion that the most probable approach in adapting to future climate would be water conservation and improved management. One possible option is to reduce the acreage of irrigated lands, and to solve the food supply problem by introducing drought-resistant crops or by the food import. The key recommendation resulting from the Polish case study is to undertake an intensive research program on the vulnerability of the national agriculture to climate change, with particular emphasis on irrigation strategy. The experience of several European countries shows, that also in the domestic and industrial sectors water conservation may be an efficient and economically justified tools to cope with future water deficits.

CONCLUSIONS

It is difficult to formulate definite suggestions, unless more reliable information on future climate will be available. Based on the current knowledge, the following conclusions seem to be justified:

(a) Water supply and demand may be significantly affected in result of climate change.

(b) The current generation of GCMs does not offer the requisite degree of watershed-specific information on future climate states.

(c) Continuous adaptation of design criteria, development plans, operating rules and water allocation policies to the newly developed climate scenarios is required.

(d) The vulnerability of water systems to hydrologic nonstationarity decrease as the level of water system development and water management increase.

(e) Water supply and also water demand may be sensitive to climate change; this concerns first of all irrigation water requirements.

(f) Improved water demand management and institutional adaptation are primary components for increasing the robustness of water resources systems under increasing uncertainties due to climate change.

(g) Even countries scarce in water may effectively adapt to changed climatic conditions; cost of adaptation will, however, depend on the depth of expected water deficits.

(h) Lessons drawn out from a set of hypothetical case studies should be generalized as a guideline for adaptation strategies.

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