Water Resources Adaptation Strategy in an Uncertain Environment

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Abstract

Poland has an annual freshwater supply of only 1,500 m^3 per capita, resulting in a scarcity of water in much of the country. A recent impact analysis showed that, for some climate scenarios, the summer run-off from most of Poland's rivers, as well as the amount of soil moisture during the summer, may decrease. At the same time, irrigation water requirements may increase. This combination would increase water deficits in Central Poland. In the framework of the Country Studies Program, the Warta River basin was selected for analysis of possible adaptive measures to cope with adverse effects of climate change. Several alternatives were investigated: (1) reducing economic activities in regions particularly scarce in water, (2) investing in water storage, (3) transferring water among river basins, and (4) establishing a policy aimed at more rational water use. Taking into account the highly uncertain climatic future, the "minimum regret" approach is advocated in formulating a national water-resources strategy, which means that alternative 4 merits priority. Large new investments should be undertaken only when absolutely necessary, that is, when other measures prove insufficient.

Introduction

During an average year, Poland's rainfall and snowfall yield about 197 km^3 of water. Of this amount, 142 km^3 returns to the atmosphere via evaporation, and 55 km^3 feeds the Baltic Sea through the river systems. The spatial distribution of surface run-off is presented in Figure 1. Variations in the run-off from 1951 to 1990 are shown in Figure 2, where the values range between a low of 34.4 km^3 in 1954 and a high of 79.5 km^3 in 1981. An additional 5 km^3 of flow enters Poland from neighboring countries. The annual per capita freshwater supply is about 1,500 m^3, the lowest value in Europe. Because of the inter- and intra-

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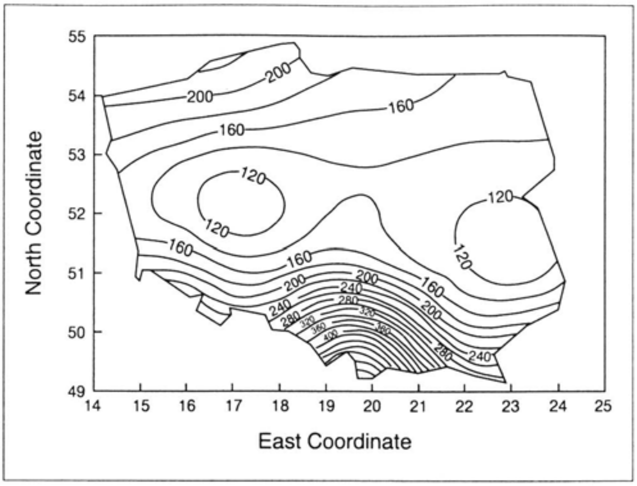

Figure 1. Mean Annual Run-off from Poland (mm yr^{-1})

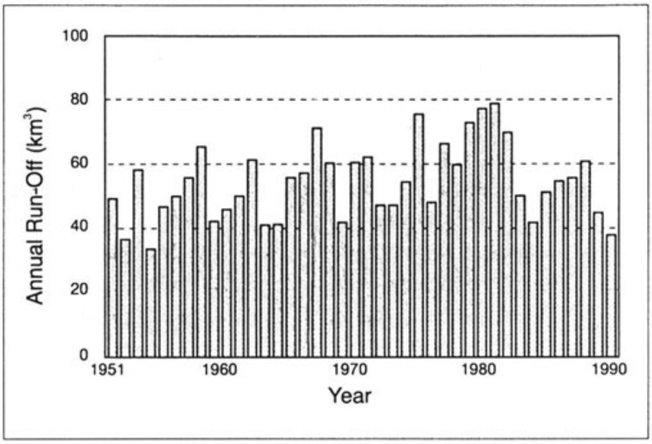

Figure 2. Variability of Annual Run-off from Poland

annual stochastic variability of climatic and hydrologic processes, reliable water resources (available about 95% of the time) equal approximately 22 km^3, but they are unevenly distributed throughout the country. Because of environmental constraints, only 30-40% of these surface-water resources may be effectively used for agricultural, industrial, or residential needs.

Water can become a barrier to social and economic development through several mutually dependent factors:

- Natural water scarcity caused by regional water supply and demand;

- Pollution of rivers, lakes, and groundwater aquifers;
- Technological and economic shortcomings; and
- Institutional impediments and low public awareness.

Only the first two factors are sensitive to climate change. The other two are subject to policy decisions that, if rationally applied, can help to adapt water-resource systems to changing geophysical processes.

Despite natural water scarcity, Poland's economy is water intensive. The water shortages observed in some years in certain regions are deeply rooted, not only in natural scarcity but also in inefficient water use and a high level of water pollution. When a nation's long-term economic future is considered, the issue of climate change cannot be neglected; scenarios of possible trends must be investigated. However, such assessment must be undertaken with the understanding that the main indicators of the water economy projected over the next century will be influenced not only by climate, but also by population processes, economic growth, and technological progress. Many factors can cause water to become a barrier to economic development, and some of these factors are far removed from the water resources themselves.

Possible Changes in Water Supply and Demand

Adaptation strategy must be based on projections of future water supply and demand. Because of the expected global change, such projections should take into account not only demographic and economic processes, but also possible changes of climatic and hydrological processes. In a water-resources impact study by the Institute of Geophysics of the Polish Academy of Sciences (Kaczmarek 1995), several General Circulation Model (GCM)-based climate scenarios were analyzed. Ultimately, the water-resources impact assessment was implemented on the basis of two GCMs (the Geophysical Fluid Dynamics Laboratory [GFDL] R-15 and the Goddard Institute for Space Studies [GISS] GCMs), which were selected because they best reflect two different climate conditions of Poland. For climate changes caused by a doubling of atmospheric concentrations of carbon dioxide (referred to as $2XCO_2$), the GFDL R-15 may be characterized as a "warm-dry" and the GISS as a "warm-wet" scenario. For both cases, data from the model output were interpolated to a grid with a resolution of one degree latitude by one degree longitude. To illustrate possible changes, monthly temperature and precipitation deviations from "historical" values for a station in Central Poland (at coordinates 18.67°E, 52.20°N) are shown in Figures 3 and 4.

To assess the impact of climate on water resources, a model of the hydrological processes is needed. For Poland, a conceptual water-balance model, CLIRUN3, has been applied with lumped input and output variables (Kaczmarek 1993). The model differs from other approaches commonly used

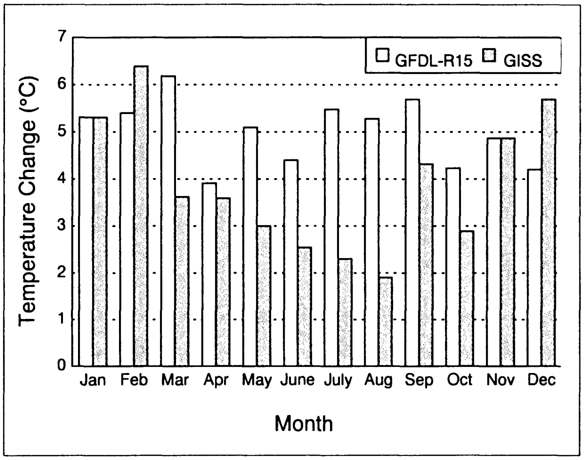

Figure 3. Projected Temperature Change in Central Poland: $2XCO_2$

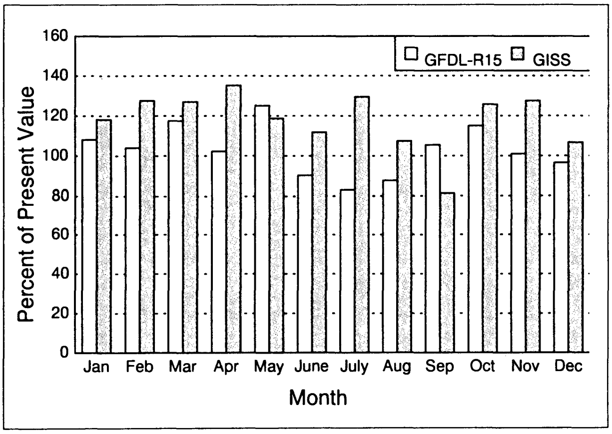

Figure 4. Projected Precipitation Change in Central Poland: $2XCO_2$

in that (1) this model is time-continuous (i.e., the water-balance components vary as continuous functions of time within certain assumed time intervals [e.g., months]); and (2) the stochastic properties of water-balance components are expressed either as a simulated time series or by a set of probabilistic matrices based on stochastic storage theory.

Water-balance components, run-off, evapotranspiration, and storage, were calculated by means of the CLIRUN3 model for 31 river catchments and 60 grid cells (Kaczmarek 1993). The study used climatic and hydrological data measured in 1951-1990 and GFDL R-15 and GISS equilibrium scenarios for $2XCO_2$

conditions. Estimated changes in monthly run-off for one grid box in Central Poland are shown in Figure 5. Possible changes in the surface-water supply estimated for the country as a whole are shown in Table 1. The table presents annual run-off values, as well as values for August, usually the driest month.

Trends in water demands caused by demographic and socioeconomic factors are identified without reference to possible changes in environmental conditions, including climate. The experience of water management agencies in various countries shows that socioeconomic processes influencing water use cannot be accurately predicted for long time periods. In most of the past studies formulating Poland's long-term water strategies, future demands were highly overestimated. Even more difficult to assess were possible implications of climate change on future water requirements.

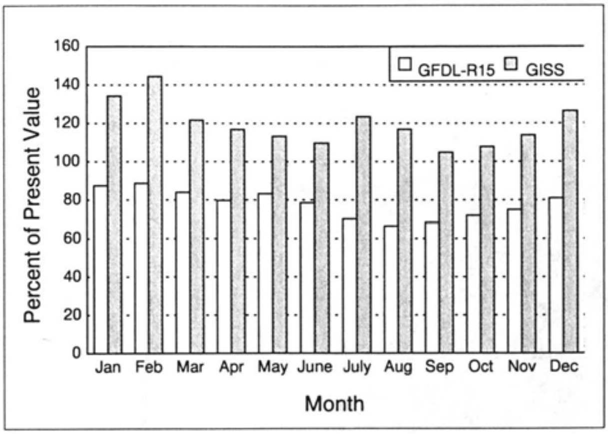

Figure 5. Projected Run-off Change in Central Poland: $2XCO_2$

Table 1. Projected Run-off from Poland

	Projected Run-off by Year and Model (km^3)				
Run-off	1990	GFDL 2020	GISS 2020	GFDL 2050	GISS 2050
Annual — mean	55.2	51.7	58.7	48.3	62.5
Annual — 90%	41.2	38.4	43.6	35.9	46.5
August — mean	3.3	3.0	3.3	2.7	3.2
August — 90%	1.9	1.7	1.9	1.6	1.8

In 1990, water withdrawal in Poland equaled 7.93 km^3, with the following distribution among sectors: domestic use, 2.54 km^3; industry (including water losses in cooling processes), 2.27 km^3; irrigation, 0.60 km^3; other agricultural water use, 1.52 km^3; and all other uses, 1.00 km^3. According to this study's estimates, water demands in mid-2000 may increase by 70% because of nonclimatic factors. Very little information is available on the effects of possible temperature and precipitation changes on water requirements in various sectors of Poland's economy. Preliminary estimates (based mostly on the literature) lead to the conclusion that a temperature increase may have only a moderate impact on industrial and domestic water use. An unknown factor is demand by Poland's agricultural sector, which at present uses a relatively small proportion of the total freshwater withdrawals for irrigation. According to the dry-warm climate scenario, however, the situation may change because the threshold between irrigated and nonirrigated agriculture may be surpassed in most of Poland's lowlands. In such a case, water demand for irrigation may increase substantially.

This study assumed that the area of irrigated agriculture in Poland will increase from the present value of 1.5% to about 4.0% in 2050. The latter figure corresponds to the current level of irrigation in West European countries, where the average air temperature is about 2°C higher than the present average air temperature in Poland. To estimate the unit water requirement for 1 ha of irrigated land, the IRDEM model was developed and applied in various regions. Estimated water demands for 2020 and 2050 are presented in Table 2.

Water Management in an Uncertain Environment

The fundamental problem in responding to possible consequences of global change is deciding what adaptive measures should be undertaken in the face of highly uncertain climatic threats. The choices must be made on the basis of incomplete knowledge of future water supply and demand, and the policy

Table 2. Projected Annual Water Demand in Poland

	Projected Annual Water Demand by Year and Model (km^3)				
Sector	1990	GFDL 2020	GISS 2020	GFDL 2050	GISS 2050
Domestic	2.54	3.25	3.22	3.78	3.71
Industry	2.27	4.09	4.09	5.84	5.84
Agriculture	2.12	3.00	2.77	3.81	3.19
Others	1.00	1.09	1.09	1.12	1.12
Total	7.93	11.43	11.17	14.55	13.86

alternatives must be analyzed with respect to the risks of assuming incorrect future scenarios. During the last century, water-resource management was planned on the assumption that variability of hydrological phenomena is governed by stationary stochastic processes. In the era of global environmental change, this concept has become questionable.

Water systems can be adapted to climate changes by three different approaches. In the first approach, decisions can be postponed until more reliable information on global processes becomes available. The existing water schemes remain unchanged, and new ones are designed in accordance with current procedures. The Commission for Hydrology of the World Meteorological Organization has adopted a "Statement on the Hydrological and Water Resources Impacts of Global Climate Change" (Commission for Hydrology 1988), which reads in part, "... given the added burden of uncertainty about climate change, it is certainly inappropriate at this time to discard available analytical procedures or to engage in expensive alterations to built facilities...." However, this first approach may lead to decisions being made too late to protect water systems from the negative consequences of climate change.

The second approach is the "minimum regret" approach, where decisions are made to solve current problems in the best possible way, while preparing water-resource systems for potential surprises and shocks. Waggoner (1990) describes this policy by saying, "So long as the future remains unsure, and that seems a long time ahead, rational people will make decisions that solve present problems and make water supply robust, resilient, and flexible for any future."

Finally, in the third approach, certain optimality rules are applied to a range of climate and water-resource scenarios. Decisions are made by comparing costs, benefits, losses, and risks for each scenario, partly on the basis of subjective interpretation of the scenarios and the results of the analysis. Some analysts advocate applying Bayesian theory in the decision-making process in an uncertain environment. However, this approach requires prior assignment of probabilities to assumed climate scenarios, which may only reflect different degrees of subjective belief about the accuracy of climatic models.

In Poland's present economic situation, the second policy approach seems to be the most rational. Not much can be done in Poland to reduce natural resource scarcity. Probably the best way of improving the supply/demand balance is implementation of rational demand-management and water-conservation strategies. Appropriate incentives of an economic nature must support these strategies.

Another possibility for coping with the consequences of climate change is to reduce the current variability of run-off by means of increased storage capacity. However, building new reservoirs requires a large investment of capital. In addition, those who favor protection of the environment disagree with those who advocate various kinds of water-resource investments.

If climatic and hydrologic conditions lead to temporal or regional water stress, it is crucial to protect available resources from contamination. The present level of pollution of water resources in Poland is very high, which is the main reason for the possible emergence of water as a barrier to growth. The program of water-quality improvement in Poland should provide for the construction of new wastewater treatment plants and for more effective use of the existing facilities.

Increased social awareness of the country's water problems and the possible negative consequences of changing the environmental conditions is needed. The present lack of perception is not caused by insufficient sensitivity of the population to water issues, but by the lack of belief in the multiplying effect of small, individual undertakings. The notion of "our water" must be given practical meaning, such as in the ongoing process of establishing self-governing regional water authorities in Poland. Water authority would be gradually transferred from the 49 regional administrations to the newly established river basin authorities. This important institutional change has been introduced within the framework of increased decentralized decision making in the entire country.

All of the measures discussed above, demand management, flow regulation, and water quality improvement, should be applied on the basis of rational economic principles, public participation, and more effective institutional arrangements to solve current national water-resource problems. These measures may, at the same time, help to prepare water systems to cope with possible shocks and threats caused by global changes.

Warta River Case Study

Within the framework of Poland's Country Studies Project, the Warta River basin was selected for more detailed analysis. The Warta River basin, located in western Poland, has a catchment area of 53,710 km^2, about 17% of the country's total area. The region is characterized by a moderate climate, a relatively low precipitation of 635 mm yr^{-1}, and an annual temperature of 8.1°C. Mean annual discharge at the mouth is estimated to be 216.7 m^3s^{-1}, which gives an average annual run-off equal to 130 mm or 6.8 km^3, while monthly discharges vary from 73.0 to 729.0 m^3s^{-1}. Spatial distribution of Warta annual run-off is shown in Figure 6.

More than 6.4 million people live in the basin, 33% in four major population areas. Annual per capita freshwater supply is 1,070 m^3, close to the 1,000 m^3 benchmark used as an indicator of water scarcity by The World Bank (Engelman and LeRoy 1993). The Warta basin represents one of the most critical water-resource regions in Poland because of water scarcity and the high level of industrial and agricultural development. Most of the region's agriculture is rain-fed, with irrigated arable lands covering only a small percentage of the entire basin. Estimated water supply and demand in the Warta basin for 1990, 2020, and 2050, based on projected future climate conditions, are shown in Tables 3 and 4. Comparison of these values shows that demand will barely be met in 2050.

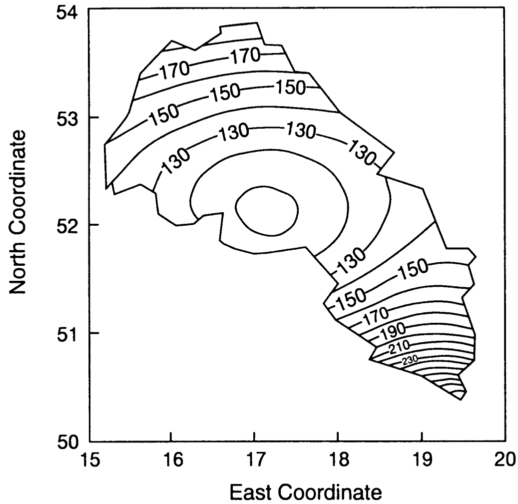

Figure 6. Mean Annual Run-off from the Warta River Catchment (mm yr^{-1})

Table 3. Projected Run-off from the Warta Catchment

	Projected Run-off from Water Catchment by Model and Year (km^3)				
Run-off	1990	GFDL 2020	GISS 2020	GFDL 2050	GISS 2050
Annual (mean)	6.8	6.1	7.0	5.6	7.6
Annual (90%)	4.7	4.2	4.8	3.9	5.3
August (mean)	0.39	0.35	0.37	0.30	0.37
August (90%)	0.21	0.19	0.20	0.16	0.20

The technical infrastructure of the Warta system is very modest. Two reservoirs, Poraj and Jeziorsko, are located along the river; only Jeziorsko has sufficient capacity to affect flow redistribution. The reservoirs together control only 3.2% of the catchment's run-off. Water transfers of limited capacity among various parts of the basin are possible, but their role in the catchment's water management is limited.

Table 4. Projected Annual Water Demands in the Warta Catchment

	Projected Annual Water Demands: Warta Catchment by Model and Year (km^3)				
Sector	1990	GFDL 2020	GISS 2020	GFDL 2050	GISS 2050
Domestic	0.42	0.54	0.53	0.62	0.60
Industry	0.41	0.74	0.74	1.06	1.06
Agriculture	0.36	0.50	0.46	0.63	0.54
Others	0.18	0.20	0.20	0.20	0.20
Total	1.37	1.98	1.93	2.51	2.40

A two-layer optimization technique developed in the framework of the Polish Country Studies (SYMOPT software package) was used to analyze the operation of the Jeziorsko reservoir (Kaczmarek et al. 1995). The reservoir is characterized by a catchment area of 9,063 km^2 (arable land of 1,967 km^2), total storage capacity of 202.8 million m^3, and dead storage of 30.2 million m^3. The optimal storage levels and reservoir outflow were simulated for 40 different hydrologic and water demand monthly time series (each for 1990-2050) for both the GISS and the GFDL climate scenarios. To determine the agricultural water demands, the current irrigation level of 1.5% of the arable land was assumed to increase to 4.0% in 2050. To estimate water requirement per hectare of irrigated land, the IRDEM model was applied for each summer month of all 40 hydrological series. Industrial needs were evaluated according to the expected growth of the gross national product, with some rationing of water use. Domestic water use was assumed to increase proportionally with population growth. In addition, the possibility of water transfer up to 15 m^3s^{-1} from Jeziorsko reservoir to the lower part of the basin was analyzed. A minimum reservoir outflow was assumed to meet hydrobiological criteria ($Q_o = 10.3\ m^3s^{-1}$) and ecological criteria (from 25.3 m^3s^{-1} in March-June to 22.8 m^3s^{-1} in July-October).

The results show that, for the GISS scenario, the impact of climate change on the operation of Jeziorsko reservoir may be negligible. For the GFDL scenario series, water deficits may arise after 2020, particularly in 2030-2050. The results of the simulation for a representative year are shown in Figures 7 and 8, and the results generalized for all 40 runs are shown in Figures 9 and 10.

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 mid-2000, the available freshwater supply may be insufficient to meet requirements in the summer months. Optimal operation of existing reservoirs will not solve the problem in the basin as a whole, although such operation may secure a reliable supply for the upper part.

Burton et al. (1993) listed a number of approaches for coping with negative effects of climate (e.g., prevention of losses, tolerating loss, changing activity or location, etc.). All such actions require comprehensive social and economic analyses and long-term planning.

The list of possible adaptive responses that might be used in the Warta basin to handle future water deficits includes the following:

- Conservation of water by various sectors of the economy;
- Temporary limitation of water use for irrigation in dry years, accompanied by import of food products;
- Improved management of resources through efficient operation of water-resources facilities;
- Development of technical infrastructure (e.g., constructing new storage reservoirs); and
- Transfer of water from other river basins.

The possible role of new water-resources investments in coping with expected water deficits will be investigated in the next phase of the Country Studies Project. Strong opposition exists in Poland to new large-scale hydraulic investments because of the relatively high density of population, lack of lands for additional storage, environmental concerns, and insufficient investment funds. Thus, the most probable approach for adapting to the future climate is water conservation and improved management. An option is to reduce the acreage of irrigated lands and to solve the food supply problem by introducing drought-resistant crops or by importing food. The key recommendation resulting from the Warta study is to undertake an intensive research program on the vulnerability of national agriculture to climate change, with particular emphasis on irrigation strategies. The experience of several European countries also shows that, in the domestic and industrial sectors, water conservation may be an efficient and economically justifiable tool for coping with future water deficits.

Conclusions

It is difficult to formulate definite suggestions until more reliable information on the future climate is available. On the basis of current knowledge, the following conclusions are justified:

- Water managers should be concerned because water supply and demand may be significantly affected as a result of climate change.
- Current-generation climate models do not offer the requisite degree of watershed-specific information on future climate states.
- Design criteria, development plans, operating rules, and water allocation policies must continually be adapted to the newly developed climate scenarios.

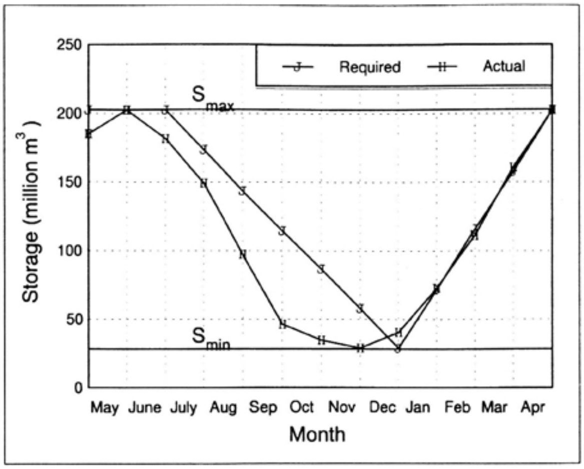

Figure 7. Optimal Storage Path for Jeziorsko Reservoir for a Representative Year (hydrological year begins May 1)

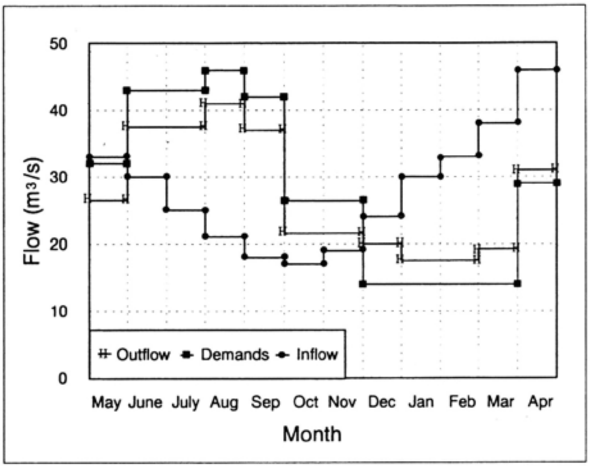

Figure 8. Optimal Outflow Values for Jeziorsko Reservoir for a Representative Year (hydrological year begins May 1)

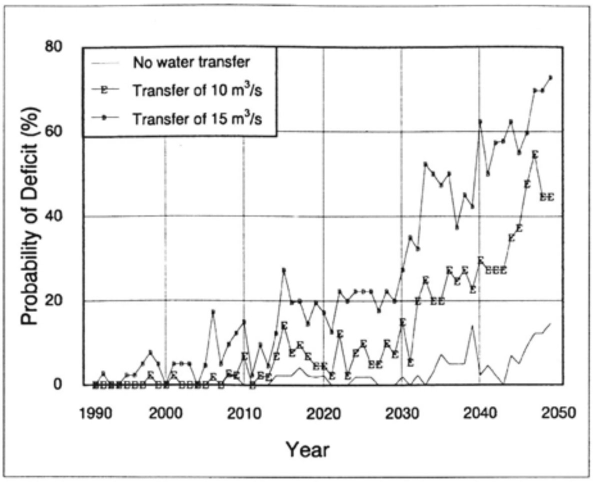

Figure 9. Probability of Water Deficits for Jeziorsko Reservoir: 1991-2050

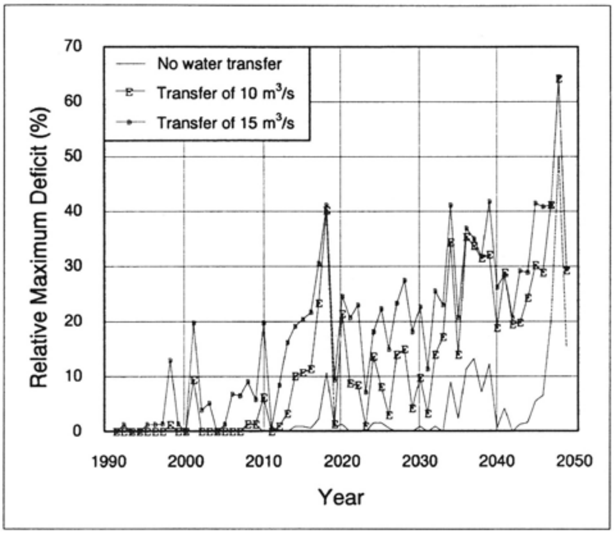

Figure 10. Relative Maximum Deficit (percent of demand) for Jeziorsko Reservoir: 1991-2050

- Vulnerability of water systems to hydrologic change decreases as the level of water-system development and water management increases.
- Water demand, as well as water supply, may be sensitive to climate change, which will affect irrigation-water requirements.
- Primary components for increasing the soundness of water-resources systems under increasing uncertainty due to climate change are improved water-demand management and institutional adaptation.
- Even countries scarce in water may effectively adapt to changed climate conditions, but the cost of adaptation will depend on the extent of the water deficits.
- Lessons drawn from a set of hypothetical case studies should be generalized in the form of guidelines for adaptation strategies.

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