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APPENDIX: A BRIEF ANNOTATED BIBLIOGRAPHY OF CLIMATE AND WATER RESEARCH

Beran, Max
1986 "The Water Resource Impact of Future Climate Change and Variability." In James G. Titus, ed., Effects of Changes in Stratospheric Ozone and Global Climate: Volume I. Washington, D.C.: U.S. Environmental Protection Agency.

This paper describes methods and models that have been used by hydrologists to forecast the effects of climatic change on water availability for uses such as irrigation, hydropower generation, and human consumption. The paper consists mainly of a survey of literature on both the hydrological and water resource impacts of climate change. A distinction between the two is drawn--hydrology being concerned with physical processes such as interception, runoff, and infiltration; water resources generally referring to the management of water available at the place and time required, in acceptable quality and quantity.

Beran also points to the relatively small amount of research that has been conducted on the impacts of climatic change on hydrology and water resources. Future research topics are suggested, and international organizations such as the World Meteorological Organization (WMO) and United Nations Environmental Programme (UNEP) are proposed as appropriate agencies to oversee this future research.

Changnon, Stanley A. Jr.
1977 "Climatic Change and Potential Impacts on Water Resources." In Living with Climatic Change, Phase II. McLean Virginia: Mitre Corp.

The impact of changing levels of precipitation on runoff is examined. It is shown that changes in precipitation amounts are magnified in the resulting changes in runoff. The implications of changes of lake levels in the Great lakes area (resulting from changing amounts of precipitation) for sectors of the regional economy are also explored. Due to benefits which would be enjoyed by the regional hydropower and navigation interests, a small (10-20%) increase in fall precipitation would result in a net benefit to the regional economy ($0.6--$1 million annually, in 1977 dollars). It is also suggested that decreases in precipitation would clearly result in sizeable economic "disbenefits."

The effects of urbanization on local meteorological and hydrological characteristics are also studied. An important change noted is an increase in the frequency of intense, short-duration rainfall events. An investigation of the impacts of additional urban-related summer rainfall on water quality

suggests that streamwater quality is reduced. It also appears that groundwater supplies may also be reduced in quality as a consequence of urban-induced precipitation increases.

Changnon, Stanley A., Jr.
1984 "Misconceptions About Climate in Water Management." Pages 1-8 in Water Resources Center, eds., Proceedings of Conference on Management Techniques for Water and Related Resources. Champaign-Urbana: University of Illinois.

In this paper, Changnon discusses areas of climate uncertainty which relate to water and its management. The notion of long-term climatic stability is refuted. The terms "average" and "normals" are sometimes used in hydrology with the belief that although climate fluctuates on an interannual basis, it has a long-term stability. Changnon points out, however, that the climate system is in a constant flux with varying periods (i.e., warmer or colder and wetter or drier) lasting from five years up to thousands of years. A critical aspect of climate change with regard to water management--changes in the frequency and magnitude of extreme events--is examined, as well. Climate change induced by human activities is also discussed. Due to the great deal of scientific uncertainty associated with such changes, it is suggested that effects attributed to large-scale climate changes (i.e., continental, hemispheric, or global) are misconceptions. Finally, recent research on climate and water management conducted by the Illinois State Water Survey is described.

Dracup, J.A.
1977 "Impacts on the Colorado River Basin and Southwest Water Supply." In National Research Council, eds., Climate, Climatic Change, and Water Supply. Washington D.C.: National Academy of Sciences

The Colorado River basin has more water exported from it than any other U.S. river basin and dominates the water resources of the Southwest. Dracup describes the legal framework governing allocation among its many users. Most of these allocation policies were established in the 1920s, a period of exceptionally high precipitation and runoff in the basin. Hence, the waters of the Colorado are often characterized as overallocated. This fact, coupled with increasing water demands in the basin, make the possibility of climatic change ominous. Possible future demands, several possibilities of augmenting the river's flow, and potential impacts of a future drought in the basin are briefly discussed.

Glantz, M.H., and T.M.L. Wigley
1986 "Climatic Variations and Their Effects on Water Resources." Page 625-641 in D.J. McLaren and B.J. Skinner, eds., Resources and World Development. New York: Wiley and Sons.

Climate variability and change will have impacts on both water resource supply and demand; however, this paper examines only effects on supply. Although both precipitation and evapotranspiration are important factors in the response of the hydrologic cycle to climatic fluctuation or change, precipitation is by far the most important. One of the authors' main findings is that both precipitation and evapotranspiration can be magnified into larger changes in runoff, especially in areas with low runoff ratios. Hence, arid and semiarid zones are particularly sensitive to climatic variability. Three case studies in which existing climatic data were incorrectly used are also presented.

Gleick, Peter H.
1988 "The Effects of Future Climatic Changes on International Water Resources: The Colorado River, the U.S., and Mexico." Policy Sciences 21: 23-39.

Conflicts over international waters have been increasing in recent decades and will likely increase in frequency and intensity as future climatic changes alter the quality and/or availability of water resources. Unless agreements which allow for climatic changes in international water treaties can be implemented, international tensions in general could increase. The region which perhaps best exemplifies this type of potential political conflict in North America is the Colorado River basin of the United States and Mexico. Although past disagreements between the two countries over the waters of the Colorado have been largely resolved, changes in the Colorado's hydrologic regime could quickly revive such differences. Hydrologic changes would also exacerbate the intense competition for water from the Colorado within the U.S. This paper examines the possible political conflicts that might arise as a result of climatic changes. Recommendations for incorporating the issue of climatic change into international agreements are also put forth.

Karl, Thomas R. and William E. Riebsame
(in press) "The Impact of Decadal Fluctuations in Mean Precipitation and Temperature on Runoff: A Sensitivity Study Over the United States." Climatic Change.

The nature of climate variability is such that decadal fluctuations in average temperature (up to 1°C annually or 2°C seasonally) and precipitation (approximately 10% annually), have

occurred in most areas of the United States during the modern climate record (the last 60 years). The impact of these fluctuations on runoff is investigated, using data from 82 streams across the United States that had minimal human interference in natural flows. The effects of recent temperature fluctuations on streamflow are minimal, but the impact of relatively small fluctuations in precipitation (about 10%) are often amplified by a factor of two or more, depending on basin and climate characteristics. This result is particularly significant with respect to predicted changes in temperature due to the greenhouse effect. It appears that without reliable predictions of precipitation changes across drainage basins, little confidence can be placed in hypothesized effects of the warming on annual runoff.

Klemes, V.
1985 Sensitivity of Water Resource Systems to Climate Variations. World Climate Program Publication #98. Geneva: World Meteorological Organization.

This paper reviews a project which examined the sensitivity of water resource systems to variations in climate. The project was conducted by the World Climate Programme (WCP), a branch of the World Meteorological Organization (WMO). The project concentrated on two areas: simulation of changes in hydrologic parameters corresponding to climatic changes, and evaluation of the performance characteristics and design parameters of water-resource systems for the hydrologic regime simulated from changes in climate.

Two river basins in the U.S. were selected for the study: the Leaf River basin of Mississippi, located in a humid region, and the Pease River basin of north-central Texas, located in an arid region.

An important finding of the hydrologic impact analysis was that in the humid Leaf River basin, the percentage of runoff change was two-to-three times larger (depending on changes in evapotranspiration) than the runoff change. However, such a change in the arid Pease River basin was five-to-eight times as large.

A discussion on aspects and weaknesses of hydrological models, especially with regard to their ability to model changes in runoff resulting from changes in climate, is also included. Recommendations for improvements in hydrological modeling are given. The paper concludes with five studies, all regarding climatic variations and their impacts on hydrological-water resource systems.

Matalas, N.C. and M.B. Fiering
1977 "Water-Resource Systems Planning." Pages 99-111 in Climate, Climatic Change and Water Supply. Washington, D.C.: National Academy of Sciences.

The business of planning and designing water resource systems is subject to uncertainties imposed by the stochastic nature of climate and streamflow. In this paper, concepts of robustness, regret, and resilience are introduced as indicators of a system's ability to perform adequately in the event of climatic change. The authors also discuss some of the engineering, economic, and political considerations which contribute to the design selection process. Paretian analysis is presented as a potentially useful method for resolving conflicts of interest among groups with differing values in regard to project goals and different risk aversion characteristics. Matalas and Fiering emphasize that nontechnological factors, including political, institutional, military, social and other issues, can be pivotal in determining the course in the design process.

Novaky, Bela, C. Pachner, K. Szesztay, and D. Miller
1985 "Water Resources." In R.W. Kates, J. Ausubel, and M. Berberian, eds., SCOPE 27, Climate Impact Assessment. New York: John Wiley and Sons.

In this chapter from the SCOPE volume on climatic impact assessment, the authors describe the many ways in which climatic fluctuations might alter the water resources of a river basin, region, or nation. In addition to addressing impacts over this spatial range, the temporal variety of climatic fluctuations and the correspondingly diverse impacts (e.g., soil moisture and storm flow on short time scales, and groundwater and base flow on longer time scales) is discussed.

The authors put forth major reasons why assessments of water-related climatic impacts are needed, and suggest lines along which such assessments might proceed. A section examining the "climate-water resources-water management-society" pathway is followed by a section which examines the elements of the "water resources-water management-society and economy" sequence. Finally, aspects of assessment integrated over this entire sequence are addressed.

Phillips, D.H. and D. Jordan
1986 "The Declining Role of Historical Data in Reservoir Management and Operations." Pages 83-88 in Proceedings of the Conference on Climate and Water Management. Boston: American Meteorological Society.

This paper examines the problems associated with the operation of Arizona's Salt River Project (SRP) in the face of growing urbanization and the attendant need to minimize flood damage. Historically, the primary function of the SRP has been storage; however, the present-day need to also provide flood control has decreased flexibility of reservoir operations. Recent studies which have updated the hydrometeorological records of the Salt and Verde River watershed (which provides roughly two-thirds of SRP supply) yielded dramatic results: the probable maximum floods on each river were recalculated to be several times larger than estimates used in original dam design. Phillips and Jordan point out that such climatologically derived statistics do not adequately address complex management problems, such as balancing water conservation against concerns of dam safety and mitigation of downstream flood damages. The authors go on to discuss advances made in methods for long-term forecasting and planning, such as the modeling of seasonal runoff and demand, as well as long-range weather forecasting.

Revelle, R.R. and P.E. Waggoner
1983 "Effects of a CO_2-Induced Climate Change on Water Supplies in the Western U.S." In Carbon Dioxide Assessment Committee, ed., Changing Climate. Washington, D.C.: National Academy Press.

Empirically-derived relationships between mean annual precipitation, temperature, and runoff are used to predict the impacts of a CO_2-induced climate change on water supplies in seven western U.S. watersheds. The authors assume a change--a "convenient increment"--of a 2°C increase in temperature and a 10% decrease in precipitation. Impacts on the Colorado River basin are emphasized due to its preeminence in the region. The authors point out that the 30-year or longer planning and construction horizon for major water projects normally proceeds under an assumption of climatic stability which is being challenged by a growing body of scientific evidence. It is suggested that the possibility of a CO_2-induced climate change should be accounted for in planning processes.

Riebsame, William E.
1988 "Adjusting Water Resources Management to Climate Change." Climatic Change 13: 69-97.

Some of the factors which hinder smooth adjustment to climatic change are highlighted. Among them are assumptions of long-term climatic stability and increasing environmental and economic constraints which inhibit the traditional strategy of using over-sized storage, thereby creating a comfortable "buffer" between supply and demand.

A case study of water resource managers' possible response to

climatic change in the Sacramento basin is presented. Increases in precipitation variability in the basin in the last 10-15 years illuminate possible problems water managers may face in adjusting to long-term climatic change. This increasing variability effected a change in the state's water delivery policy (its "rule curve"), and drastically reduced the RDF (reservoir design flood) return interval of Folsom Dam, a facility of the federal Central Valley Project. The case study shows the interaction of changing climate sensitivity and climate fluctuation as systems mature, as well as the effect of growing constraints on traditional adjustments to climate stress.

Rind, D. and Lebedeff, S.
1984 Potential Climatic Impacts of Increasing Atmospheric CO_2 With Emphasis on Water Availability and Hydrology in the United States. Washington, D.C.: U.S. Environmental Protection Agency.

This report focuses specifically on possible shifts in a range of hydrologic conditions that would accompany a doubling of atmospheric carbon dioxide. The significance of this report is that it represents the initial attempt to provide detailed regional hydrologic effects that would attend a CO_2 doubling.

Output from the GISS GCM is used to simulate future climatic and hydrologic changes. These changes are forecast at the "grid cell" level of the GCM, in this case roughly 17,000 square miles. This resolution prompted the authors to attach an important caveat to their study: the simulated values for a grid cell are only averages and, due to factors such as diverse topography within a grid cell, conditions at a specific location within the cell may differ considerably from the average value for that cell. Findings of the study include:

- A general pattern of increased runoff over the northwestern and extreme southwestern portions of the continent (i.e., +20-60%). Some areas in the central and eastern U.S. recorded decreases of 15-20%.
- Small reductions in upper-level soil moisture for most areas, with a larger reduction in the extreme northeast.
- Roughly similar increases in both precipitation and evaporation--both increased 11% globally--for a doubled CO_2 world. In the U.S., the northern and western U.S. recorded the greatest increases for both these values, each showing increases of 15-20% or more.

Russell, C.S., D. Arey, and R.W. Kates
1970 Drought and Water Supply: Implications of the Massachusetts Experiences for Municipal Planning. Baltimore: Johns Hopkins University Press.

This volume presents an intensive field study of the water supply system during a record four-year drought in the state of Massachusetts utilizing questionnaires, public documents, intensive interview surveys of 48 communities, newspaper files, and several special studies. The book is divided into five parts: water supply and demand: the level of system adequacy; climatic variation, the level of shortage, and the nature of short-run adjustments; the economic impact of water shortage; a planning model for municipal water supply systems; and practical system planning.

Timmerman, Peter, and A.P. Grima
1985 Climate Impact Assessment in the Great Lakes Basin: Overview and Research Recommendations. Environmental Monograph #7. Toronto: Institute for Environmental Studies, University of Toronto.

This small volume contains an overview paper and a set of research recommendations for research on the potential impacts of CO_2-induced climate warming in the Great Lakes Basin. The book summarizes the proceedings of a Canadian Climate Program workshop held February 8-9, 1985 at Seneca College, King City, Ontario.

Wigley, T.M.L., and Jones, P.D.
1985 "Influences of Precipitation and Direct CO_2 Effects on Streamflow." Nature, 314 (14): 140-152.

Wigley and Jones examine changes in streamflow which would occur in response to changes in precipitation and direct CO_2 effects on vegetation. CO_2-induced changes in vegetation--the closing of plant stomata, a decrease in transpiration rate, and an increase in water use efficiency--could make more water available for runoff and greatly complicate the impact of precipitation changes on the hydrologic cycle. For instance, reduced plant evapotranspiration would tend to offset any CO_2-induced reductions in precipitation.

Runoff ratios--present-day runoff/streamflow divided by present-day precipitation--are compiled for 27 of the world's major rivers. Rivers with lower runoff ratios, which usually flow through arid regions, generally had values of 0.1 or less, indicating a high sensitivity of runoff to precipitation (and, to a lesser extent, evapotranspiration) changes. The converse applies to rivers in more humid regions. Typical values for rivers in temperate regions were roughly 0.4, while tropical rivers were assigned values of roughly 0.6.

In addition to compiling these runoff ratios, the "direct effects" (on vegetation) of CO_2 on basins possessing various runoff ratios were assessed. It was shown that those direct effects are magnified in river basins possessing small (i.e., less than 0.2) runoff ratios.

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6 Avoidance-Response to the Risk Environment, Stephen Golant and Ian Burton, 1969, 33 pp.

7 The Meaning of a Hazard--Application of the Semantic Differential, Stephen Golant and Ian Burton, 1969, 40 pp.

8 Probabilistic Approaches to Discrete Natural Events: A Review and Theoretical Discussion, Kenneth Hewitt, 1969, 40 pp.

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13 Perception and Awareness of Air Pollution in Toronto, Andris Auliciems and Ian Burton, 1970, 33 pp.

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