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# CLIMATE CHANGE AND WATER SUPPLY, MANAGEMENT AND USE: A LITERATURE REVIEW

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## ABSTRACT

There is evidence that atmospheric concentrations of $CO_2$, tropospheric $O_3$, and $CH_4$, among other gases that contribute to the greenhouse effect, have increased in recent decades, and that these changes may induce changes in global air temperatures and regional climate features in coming years. A literature review was conducted to sample the literature base on which our understanding of the water resource impacts of climate change rests. Water resource issues likely to be important include hydrologic response to climate change, the resilience of water supply systems to changing climatic and hydrologic conditions, and the effects of climate change on water quality and water uses (such as navigation and energy generation). A computer-assisted search of literature on the effects of climate change on these subjects was conducted. All studies were classified by type of paper (e.g., review, discussion, case study), region, water resource variable studied, and source of climate scenario. The resulting bibliography containing more than 200 references was largely annotated. Case studies of potential hydrologic impacts have been more common than studies of impacts on water management or water use, but this apparent research gap is decreasing. Case studies demonstrating methods of incorporating potential risks of climate change into water project planning and management have been performed. Considerable variability in regional coverage exists; the Great Lakes basin and California receive relatively more attention than such regions as New England and the Missouri River basin. General circulation model-based and hypothetical climate scenarios have been the dominant sources of climate scenarios used in case studies, although a variety of other methods for developing climate scenarios have been developed.

## 1. INTRODUCTION

Many water resource scientists and professionals believe that a change in climate due to increasing levels of certain gases, including $CO_2$ and $CH_4$, while of uncertain magnitude and sometimes direction, could have impacts on water resources that would be physically and economically significant (Revelle 1990). As an illustration, a recent study shows that changes in Great Lakes water levels with currently available estimates of near future climate scenarios would affect wetlands, fish, and wildlife; navigation and transportation; economics of coal and hydroelectric energy production; local economies; and fishery, agricultural, and recreational resources within the Great Lakes basin (Hartmann 1990). It was our objective to describe the literature base concerned with the effects of climate change on water resources in the United States.

## 2. METHODS

### 2.1 Water Resource Keywords

Several comprehensive reports on thé potential effects of climate change on water resources have been published (e.g., Waggoner 1990, Callaway and Currie 1985, Mugler and Rubino 1989). Specific hydrologic and water resource variables, such as streamflow, transpiration, water quality, urban drainage systems, and navigation, agriculture, recreation, and fishery water requirements, are identified as likely to be substantially affected by a climate change. A preliminary list of water resource keywords was developed to represent these issues. The list of keywords was used to execute a computer-assisted search of climate change literature on these topics. The keyword list was then supplemented with other applicable terms taken from the results of the preliminary search, a water resource management journal list of keywords (American Society of Civil Engineers 1986), and a report on national water use (Solley et al. 1988). The final list of keywords, as used in the computer-assisted search code, is in Appendix A.

### 2.2 Climate Change Keywords

The keywords we use for climate change are *climate change*, *global warming*, *greenhouse effect*, *climate variability*, and *sea level rise*. We specify general terms of climate change rather than specific climate variables, such as temperature, humidity, wind speed, and so forth, because we assume that a search for specific climate variables would yield large volumes of basic research. We are interested, however, in climate impact research, or the synthesis and application of basic research on the effects of temperature and other individual variables on water resources. Thus, we distinguish between climate impact research and basic climate variable research and restrict our search to the former.

### 2.3 Search Parameters

The DIALOG (DIALOG Information Systems 1990) computer-based information access and retrieval system was used to access eight selected data bases available from different data base vendors in the DIALOG system (these data bases and their contents are in Appendix B). The search was executed for the period 1985 to 1990 (references with year of publication from 1985 on and catalogued in DIALOG as of November 1990), using the above keywords and the search code in Appendix A. Our search was limited to papers published in English.

### 2.4 References Not Obtained Through DIALOG

The authors were aware of a substantial number of studies not catalogued by DIALOG (e.g., studies published before or after the date range we specified). These studies were also annotated and classified and are included in the annotated bibliography in this report.

### 2.5 Sorting of References

#### 2.5.1 By Subject

All titles extracted from the literature were grouped into three categories for ease of discussion and presentation. The three water resource subject categories in this report are hydrology, water use, and water management. The distinction between hydrologic and water resource studies has been made before (e.g., Beran 1986, Gleick 1989). Hydrologic studies examine the response of hydrologic variables, such as runoff or streamflow, to climate changes. Studies that were classified as hydrologic also include studies of coastal hydrology and groundwater response to climate change.

Water resource studies, on the other hand, examine implications of climate change for the ability of water supply, delivery, and management systems to function as required [although it has been suggested that hydrologic studies are an essential precursor to an understanding of possible climate change effects on the developed portion of available water, the portion considered the usable resource (Beran 1986, Klemes 1985, Gleick 1989)]. An example of a water resource study is Klemes's (1983) analysis of the consequences of several different sets of climate conditions on the ability of two southern U.S. reservoirs to deliver a reliable supply. The term water management was designated as a second category for this literature review. All studies related to any part of water supply systems (e.g., reservoir performance and reservoir operation), flood management, or urban water management (including urban drainage systems) were classified as water management studies.

It has also been pointed out that the impacts of climate change on water resources may be broken into two groups: those related to impacts on water supply and those related to impacts on water use requirements (Beran 1986). Thus, a third category, water use was defined. All research related to instream and offstream use, water quality (including lake and reservoir thermal and chemical structure), potential future conflicts in use, and water use policies were considered water use studies. Instream use, as defined in the U.S. Geological Survey (USGS) water use estimate series (Solley et al. 1988), includes fisheries, navigation, hydroelectric power generation, and recreation. Offstream use includes agricultural, industrial, domestic, commercial, and thermoelectric energy use.

### 2.5.2 By Geographic Region

Studies were also classified, when possible, by geographic region. For all studies on U.S. territories, standard USGS water regions (Seaber et al. 1987) were used to identify the U.S. water region with which the study was concerned. For non-U.S. regions and large portions of the United States, additional codes were used (Appendix C).

### 2.5.3 By Type of Paper

In order to better describe the nature of information provided by the literature base, all studies were classified by type of paper. Case studies, for instance, identify a specific region or resource and illustrate or demonstrate concrete new information regarding the potential effects of greenhouse climate change on the region or resource. A modeling study of changes in runoff resulting from changes in temperature and precipitation patterns and a study of specific social and economic consequences of past drought climates in a region are examples of case studies. Discussions on the other hand present issues and problems in research, management, or policy related to the potential effects of climate change but do not create concrete information about a well-defined water resources issue in a specified region. Reviews present the research literature about a specific topic, and critiques discuss an earlier case study or some aspect of the problem of understanding and dealing with the potential effects of climate change on water resources.

### 2.5.4 By Source of Climate Scenario

For all papers classified as case studies, the method for developing climate change scenarios or estimates was determined. A review of the literature indicates that climate scenarios are generally developed from general circulation models (GCMs) of the earth's atmosphere, derived from climate records from past epochs or periods believed to be analogous to greenhouse climate conditions, or hypothesized based on judgment or generalization from various sources. These approaches were designated as GCM-based, analogue, and hypothetical, respectively. GCMs simulate the dynamics of the earth's fluid atmosphere under specified initial conditions and produce output for parameters including surface air temperature, rainfall, specific humidity, wind speed, and solar radiation at the surface. Values for these parameters when the model is run with increased (typically, doubled) $CO_2$ concentrations are often used as inputs to resource modeling studies. Hypothetical estimates of changes in climate include estimates such as ± 2°C monthly air temperature, +1–3 m rise in sea level, or ± 20% monthly rainfall. A fourth type of study used past periods of climatic or other stress to define a period of interest for a variable (e.g., water system management) and examined the behavior of the variable during that period to develop insight regarding its response to possible climate stress. This type of study was designated as historical. In some instances other approaches to the development of climate scenarios were used and classified as other. For additional discussion of sources of climate scenarios, see Gleick (1989) or Lamb (1987).

## 3. RESULTS

The DIALOG-based search yielded 102 references published between 1985 and 1990 (i.e., catalogued in the DIALOG data bases before October 1990) on the potential effects of climate change on water resources.[1] Of these titles, 58 concern hydrology, 54 are about water management, and 39 focus on water use.

Among the 47 references that were classified as case studies, however, there seemed to be a more noticeable emphasis on hydrologic studies. Twenty-seven case studies cover some aspect of hydrology, whereas only 17 cover management and 18 cover water use.[2] It appears more recently that management and use issues have received more research attention (Fig. 1). In general, the number of case studies increased during the period 1985—1989 (Fig. 2 because the search was executed in the third quarter of 1990, 1990 is under-represented).

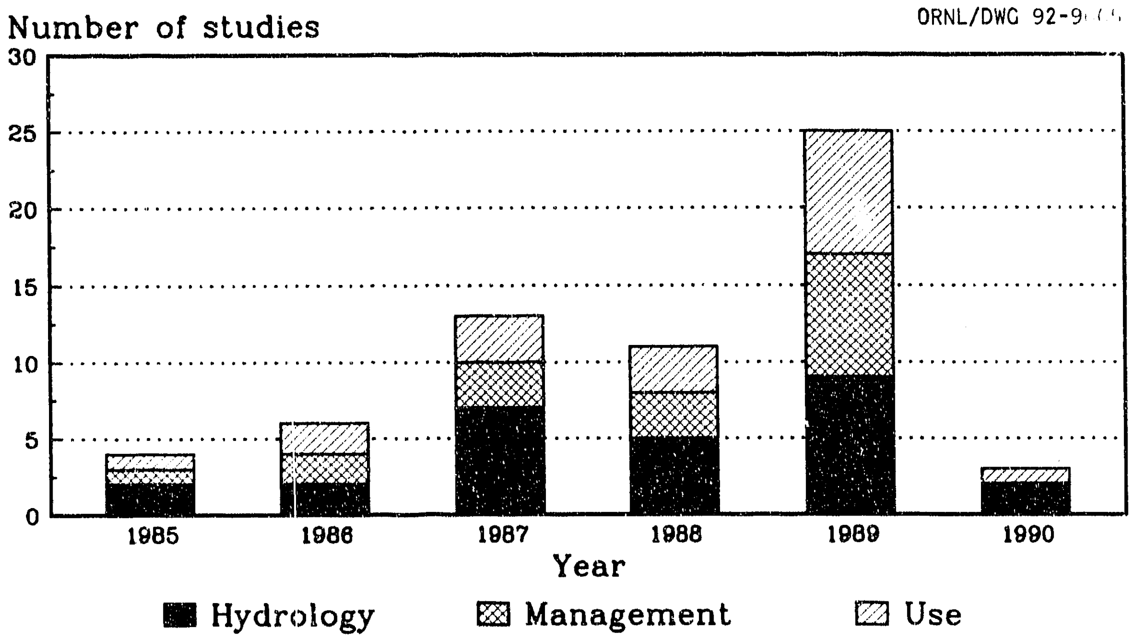


**Fig. 1. Subject of publication, by year (references from DIALOG search only).**

[1]Papers or abstracts published in conference proceedings are included among these references, and in some cases the same or similar research is presented in both a journal article and in a conference paper. Our total number of references may suggest a higher level of research activity than actually exists.

[2]Some case studies covered aspects of one or more subjects.

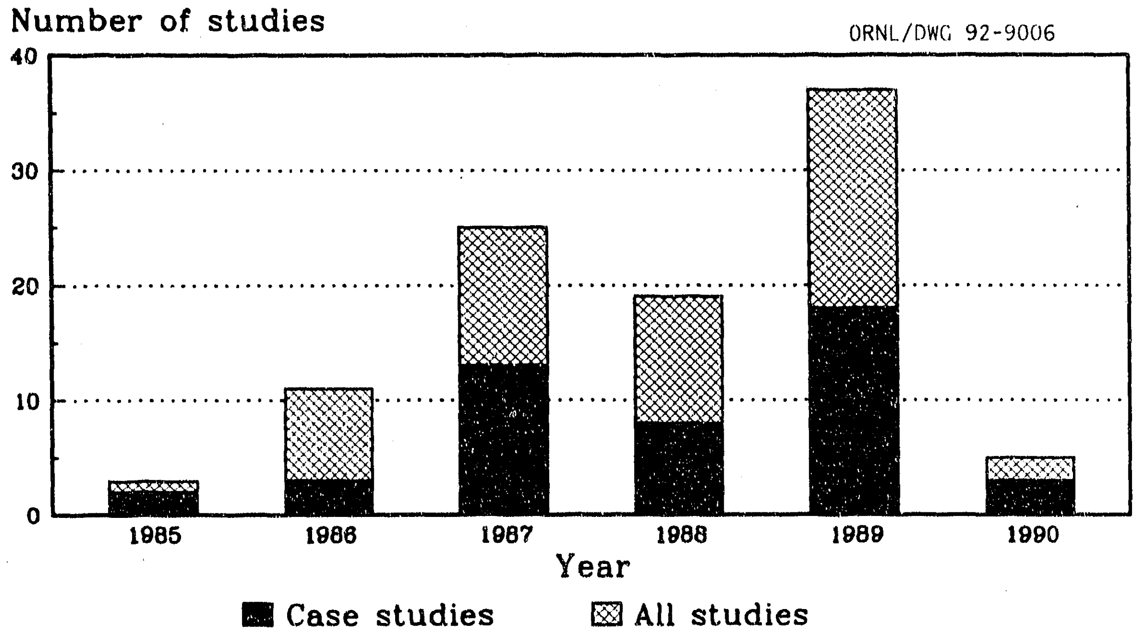


**Fig. 2. Number of studies, by year (references from DIALOG search and classified as case studies only).**

Also among the 47 case studies, several different methods for developing climate scenarios were used. Among hydrologic studies, GCM-based studies were clearly the most common. Hypothetical climate scenarios were also frequently used. Analogue climate scenarios were employed in three hydrologic studies. Management studies most frequently employed hypothetical climate scenarios; GCM-based scenarios and historical studies were somewhat less frequent. Among studies of water use, again, GCM-based scenarios were most frequently employed. Other climate scenario development approaches were used for only one water use study (Fig. 3).

Most of the case studies concern the U.S., Canadian, and European water resources. Within the United States, there is a considerable variability in the number of case studies produced by this search. There are more studies associated with the Great Lakes and California water resources regions than with all other regions; there are no studies associated with such regions as the Rio Grande, the Colorado, and the Souris-Red-Rainy (Fig. 4a).

Besides the classification of 47 references as case studies, 11 of the DIALOG references were classified as reviews, 3 as critiques, and 50 as discussions.[3] Consideration of all types of studies slightly changes the regional distribution of research; notably, the

[3]A number of references were classified both as discussions and as research studies (or any other combination of categories) when appropriate. Therefore, the sum of the references in each category will be greater than the total number of references in the data base.

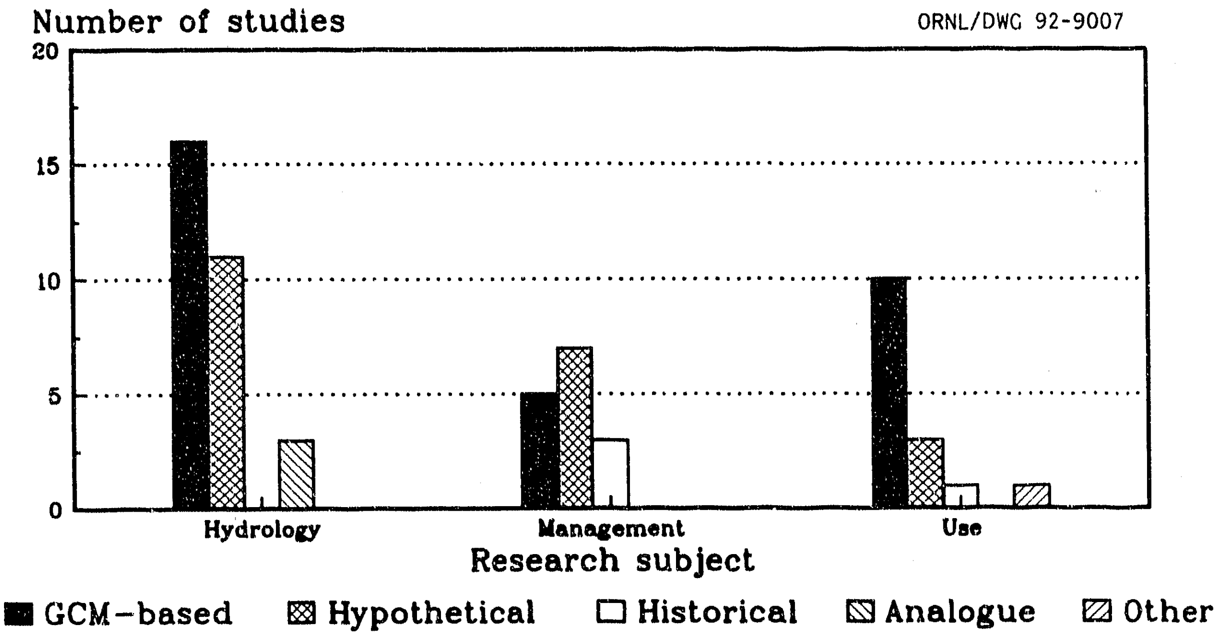


**Fig. 3. Climate scenario method used, by research subject (references from DIALOG search only).**

number of references associated with the Mid-Atlantic and South Atlantic/Gulf regions increases (Fig. 4b).

The bibliography in Appendix D contains not only references produced by an on-line search for the period 1985—90 but also references collected in the authors' efforts to follow research in the area of climate change and water resources. Therefore, graphical summaries for all references in the bibliography are provided (Figs. 5-8). Several points are worth noting. Several case studies performed prior to 1985 and a considerable number from 1990 and 1991 are included (Fig. 6). Several additional case studies using"other" climate scenario development approaches are included (Fig. 7). References associated with a greater number of water resource regions are included (Fig. 8).

## 4. DISCUSSION

The purpose of the following discussion is to draw specific examples from Appendix D of this report of the different types of studies described in Sects. 2—3 above. For this discussion, references from all sources are considered. References for all studies cited in the following section are found in Appendix D.

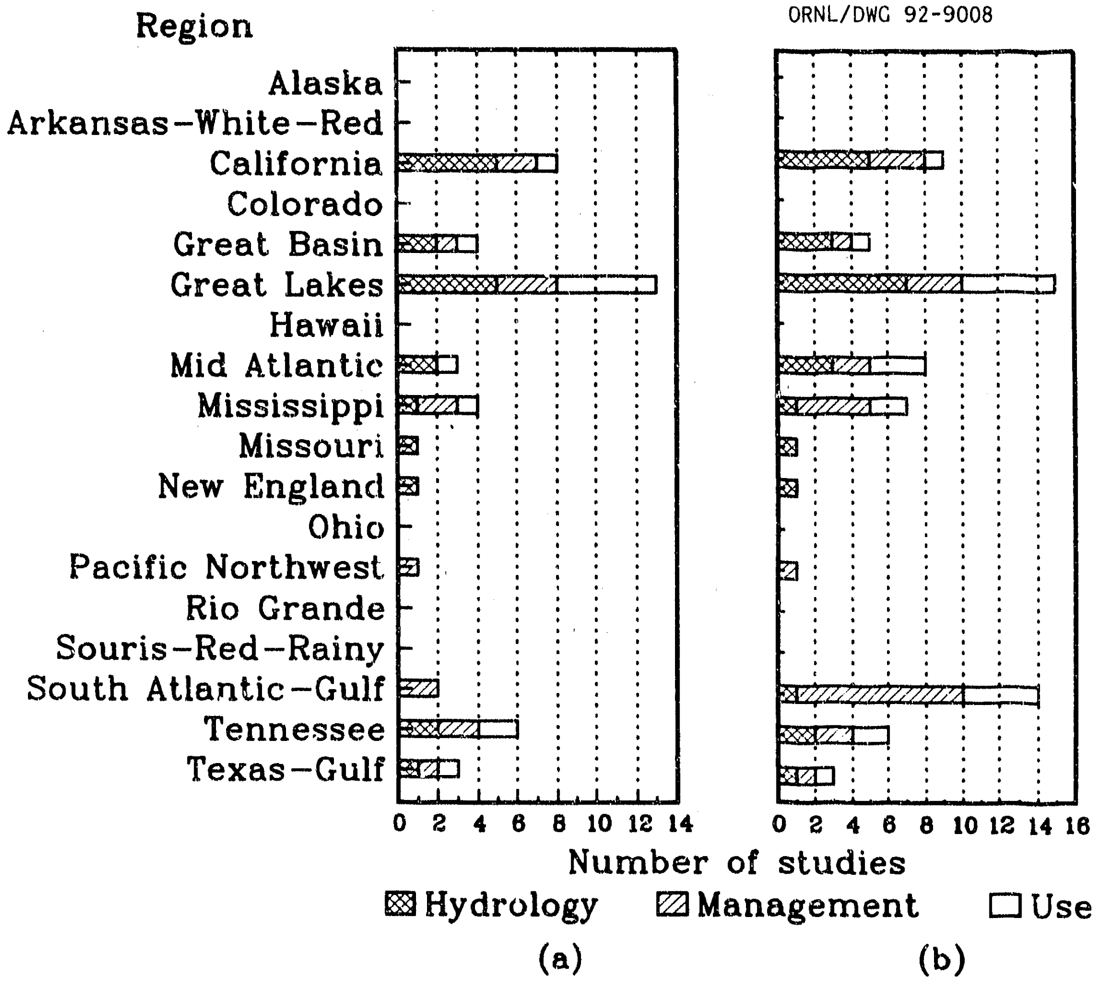


**Fig. 4. Number of references, by region. References from DIALOG search only, and (a) classified as case studies only, or (b) all references.**

### 4.1 General Discussions of Climate Change and Water Resources

Several institutional efforts to evaluate potential impacts of climate change on water resources have produced many important reports on this topic and should be noted (e.g., see references in Appendix D for Dracup 1977, Callaway and Currie 1985, Beran 1986, Askew 1987, and Waggoner 1990). Askew (1987) provides a brief comprehensive overview to the general topic; other general surveys are included in Waggoner (1990), Callaway and Currie (1985), and Gleick (1989).

Various authors have discussed hydrologic modeling concerns. Beran (1986) evaluates strengths and weaknesses in several hydrologic modeling approaches; Schaake and Kaczmarek (1979) discuss the use of hydrologic and climatic information in the planning

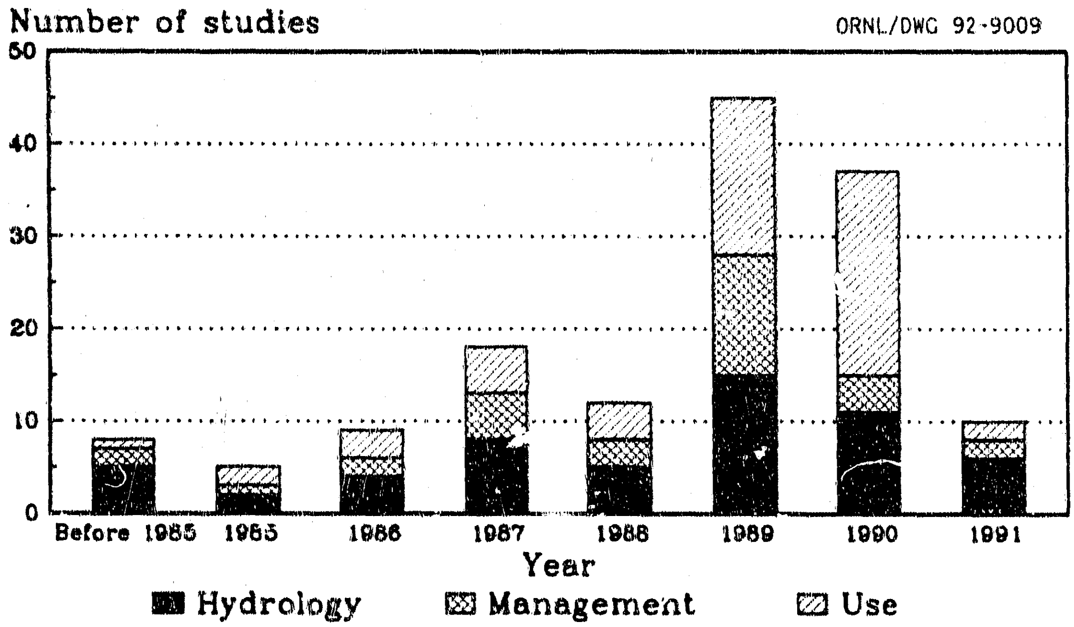


**Fig. 5. Subject of publication, by year (references from all sources included).**

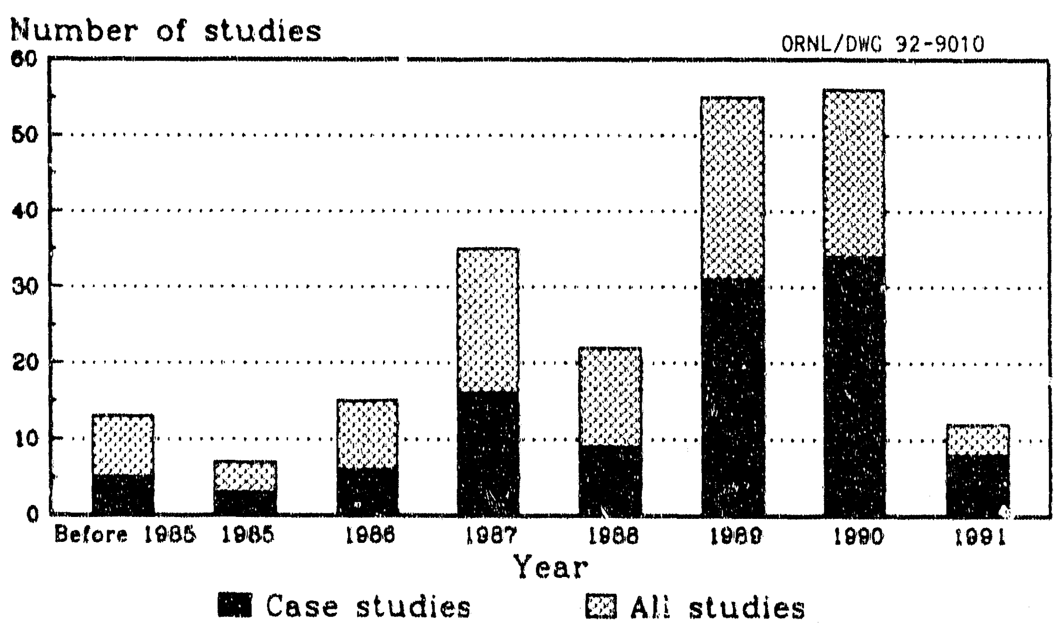


**Fig. 6. Number of studies, by year (references from all sources included).**

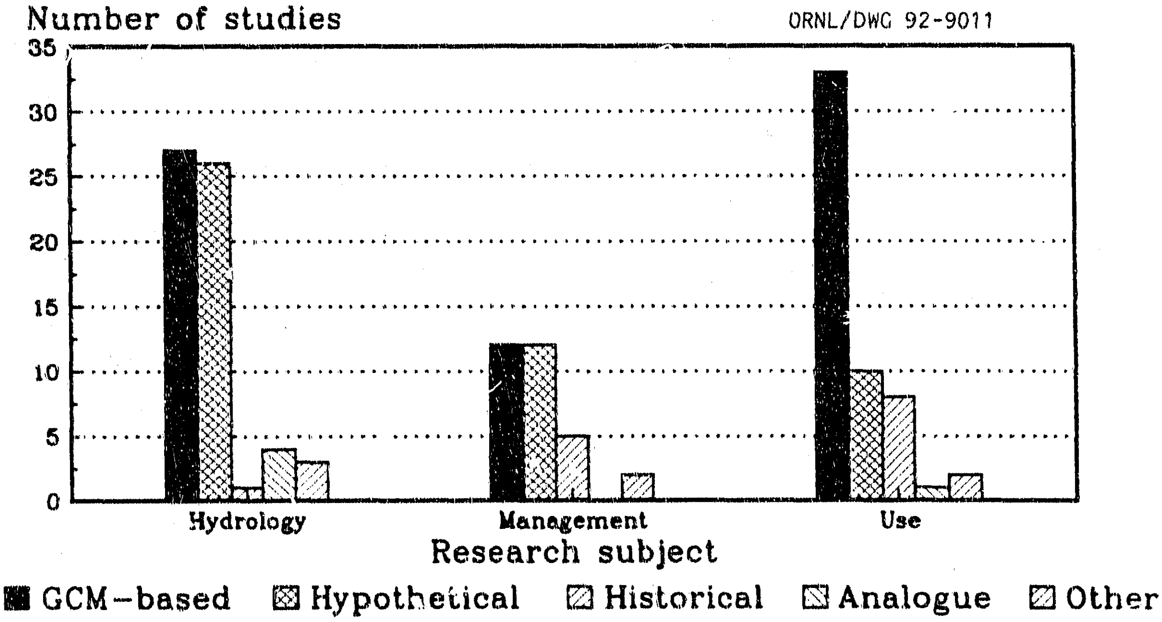


**Fig. 7. Climate scenario method used, by research subject (references from all sources included).**

and management of water systems as well as various hydrologic modeling approaches; Gleick (1986) compares various hydrologic modeling approaches for climate change studies and presents criteria for selecting between various approaches. The role of stochastic hydrologic techniques has been discussed by Lettenmaier and Burges (1977), Nemec (1988), Moss and Tasker (1987), and Matalas (1990).

A number of references also include discussions on water management ramifications of potential climate change. Schwarz (1977) (and other chapters in this book) discusses how water managers may evaluate water resource system sensitivities and difficulties in implementing climate change expectations into the water management process. Klemes (1985) suggests that there is little the water manager can do in anticipation of climate change impacts beyond the traditional measure of building safety margins in water management structures and procedures. Schwarz (1990) (and other chapters in this book) discuss implications of potential climate change and change in sea level on urban water management. Several researchers have described water management issues in a specific region: Hekstra (1986) for the Netherlands, Rhoads et al. (1987) for southern Florida, and Miller (1989) for large water resource systems in general.

Water use issues have also been the focus of numerous discursive papers. Meier (1977) described general concepts of water shortage focusing on utilities and illustrated economic and cultural impacts of water supply limitations in two U.S. cities. Hargreaves (1981) discusses possible climate change–induced changes in the needs and management of

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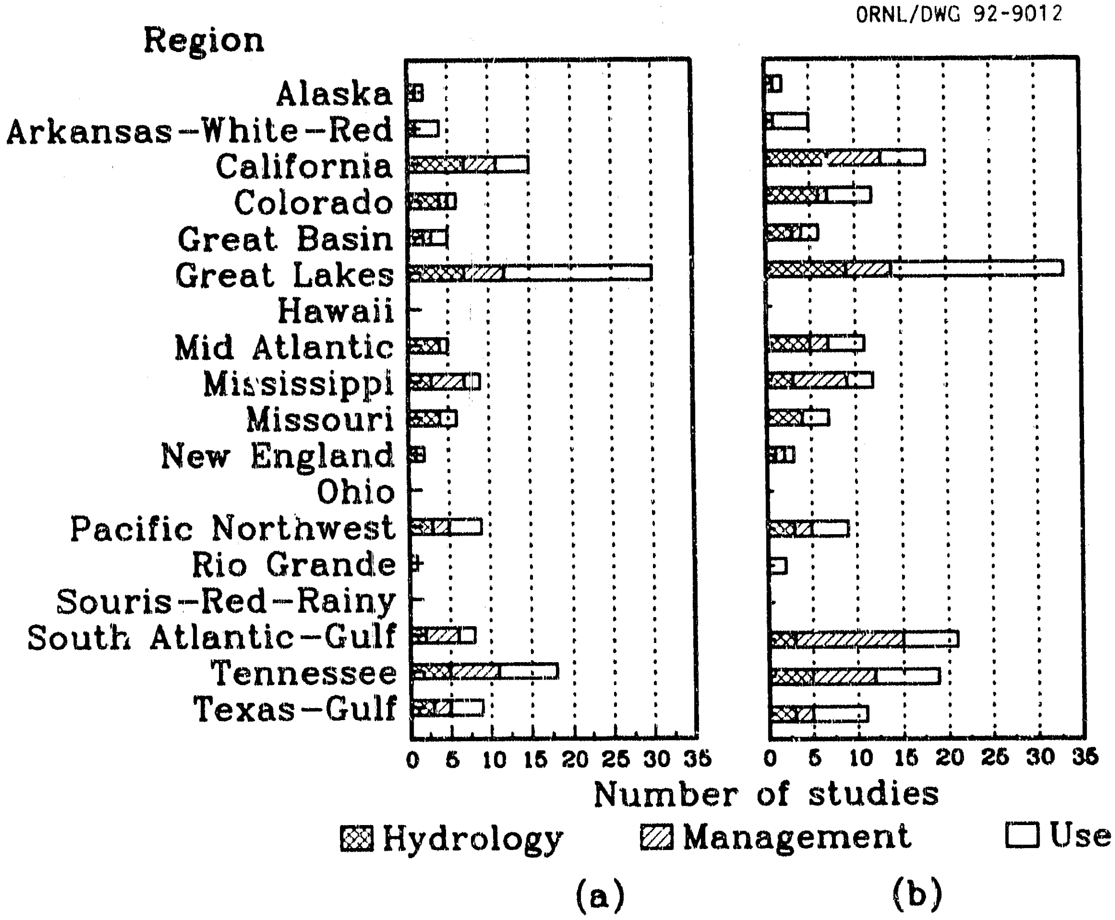


**Fig. 8. Number of references, by region. References from all sources included, and (a) classified as case studies only, or (b) all references.**

irrigated and dryland agriculture, concentrating on potential evapotranspiration. A number of authors have addressed implications of greenhouse climatic conditions on freshwater (Meisner 1987) and marine (Sibley and Strickland 1985) fisheries. Peterson (1987) considers relationships between anomalous climatic conditions and riverine chemistry. Gleick (1988) discusses possible climate change–induced changes in hydrology in arid basins in relation to political tensions among countries, using water supply in the lower Colorado River basin as an example of potential tensions between the United States and Mexico.

### 4.2 Reviews of Climate Change/Water Resource Literature

Several reviews have been conducted to cover research on hydrologic impacts of climate change. These include Beran (1986) and Gleick (1989). Lewis (1989) reviewed literature pertaining to Canadian water resources. Rosenberg et al. (1990) in their chapter include a review of research on the effects of increasing $CO_2$ on evapotranspiration. In the area of water management, reviews by both Beran (1986) and Gleick (1989) consider research on water management (e.g., reservoir and water supply systems). Da Cunha (1989) reviews the current understanding of future water requirements and potential climate change scenarios for the European Economic Community. Water use is covered in the review by Gleick (1989). Several reviews of research on potential fisheries impacts of climate change are available. For example, DeAngelis and Cushman (1990) review modeling work at the aquatic ecosystem, fish process, and fish population levels.

### 4.3 Critiques

The few critical discussions of other work or research problems found by this literature search mostly concerned hydrologic studies of potential climate change effects. For example, Klemes (1983) critically examines the statistical significance of hydrologic impacts of climate change simulated by Nemec and Schaake (1982). Idso and Brazel (1984) replicate the hydrologic simulations performed by Revelle and Waggoner (1983) but include an antitranspirant effect of $CO_2$ enrichment in the hydrologic model. Wigley and Jones (1985) continued the examination of the relative sensitivity of streamflow to the two processes of reduced evapotranspiration by plants and changes in rainfall associated with elevated atmospheric $CO_2$ concentrations.

### 4.4 Case Studies

Case studies of hydrologic responses to climate change cover many topics. Studies of such variables as streamflow and runoff, groundwater, and evapotranspiration have been performed. Management variables examined in case studies include coastal drainage systems, water supply systems, and water management decision making. Water use case studies include those concerned with water quality, fisheries, and irrigation.

#### 4.4.1 Hydrologic Case Studies

There are numerous investigations of climate change impacts on hydrologic variables. Nemec and Schaake (1982) used the Sacramento soil moisture accounting model to simulate streamflow under several hypothetical climate changes in three different basins. Aston (1984) used a distributed deterministic hydrologic process model to evaluate potential impacts of $CO_2$ enrichment on streamflow. Cohen (1986) applied a water balance model to the Great Lakes basin to examine potential changes in lake evaporation and basin runoff. Flashcka et al. (1987), also using a water balance model, examined hydrologic response in basins in Nevada and Utah. Gleick (1987) used a water balance model to evaluate hydrologic sensitivities in the Sacramento River basin in Northern California. Palutikof (1987) used an empirical streamflow model to estimate the effects of different assumptions about plant transpiration on hydrologic sensitivities to anomalous climates. Croley (1990) simulated the drainage into the Great Lakes system from the 121 surrounding watersheds with daily conceptual hydrologic models. Hains and Hains (1989) used both the Sacramento soil accounting model and an empirical correlation model to simulate hydrologic sensitivity in the Appalachicola–Chattahoochee–Flint system in the southeastern United States. Karl and Riebsame (1989) examined relationships in the instrumented record for areas in the United States among decadal fluctuations in rainfall, temperature, and runoff. McCabe and Ayers (1989) simulated potential hydrologic responses in the Delaware River basin with a water balance model. Rosenberg (1989) simulated the sensitivity of evapotranspiration to hypothetical climate changes using the Penman–Monteith evapotranspiration equation. Lettenmaier and Gan (1990) studied the simulated hydrologic response of small catchments in California to various scenarios of climate change. Schaake (1990) used a monthly water balance to examine hydrologic changes in basins in the southeastern United States to hypothetical climate changes. Wolock (1991) used a variable source area hydrologic model to explore the sensitivity of catchment runoff to assumptions about transpiration, storm characteristics, and air temperature change. Mimikou et al. (1991) simulated changes in mountainous catchment hydrology using a water balance model in an application in central Greece.

### 4.4.2 Water Management Case Studies

Case studies of potential effects of climate changes associated with an enhanced greenhouse effect have also been conducted for water management systems. Callaway and Currie (1985) used a series of models to estimate reservoir impacts of climate change in two basins in the Great Basin and Texas–Gulf regions. Cohen (1986) simulates runoff changes in the Great Lakes basin and discusses these in the context of regional social, economic, engineering, and water supply concerns. Miller and Brock (1989) model the sensitivity of the Tennessee Valley Authority (TVA) reservoir system to scenarios of climate change. Titus et al. (1987) demonstrate the planning of two southeastern coastal drainage systems under different assumptions of greenhouse–accelerated sea level rise. Riebsame (1988) analyzes actions of water managers in response to water supply stresses in the Sacramento River basin, California. Lettenmaier et al. (1989) examine the sensitivity of multipurpose reservoir management to a range of changes in annual air temperatures operating under two different operational decision making methods. Niemczynowicz (1989) estimated impacts to an urban sewerage system resulting from several scenarios of changes in precipitation regimes. Schwarz (1990) conducted interviews with water managers from several U.S. cities to develop an understanding of the urban water sensitivity to potential climate change and the attitude of urban water managers to the issues. Lettenmaier and Sheer (1991) modeled the performance of a California reservoir under different scenarios of climate change. Hartmann (1990) conducted a modeling study of potential impacts of climate change on water levels in the Great Lakes and suggested that because of possible water resource allocation conflicts new water management procedures may be required for scenarios of significant climate change.

### 4.4.3 Water Use Case Studies

Stockton and Boggess (1979) include estimates of water use (demand) limitations for each water resource region in the United States in their comprehensive survey of the sensitivity of U.S. water resources to hypothetical changes in climate. Cohen (1986) uses empirical relationships between water supply, population, and demand to project water supplies in the Great Lakes region under various climate scenarios. Cohen and Allsopp (1988) evaluated possible impacts on regional economic activities due to changes in lake levels and other variables in the Great Lakes region. Singh (1987) studied potential impacts to hydroelectric power production in Quebec resulting from changes in climate variables. Miller (1990) examining the behavior of a hydroelectric power company in response to a water supply stress, drew insights into possible industry responses to changing water supply conditions.

Several researchers have investigated potential impacts to water quality. Blumberg and DiToro (1989) simulated changes in water quality (dissolved oxygen concentrations) in Lake Erie under a set of climate change scenarios. Schindler et al.(1990) examined responses of many water quality and limnologic variables to past climatic fluctuations at a highly instrumented lake in Ontario. Henderson-Sellers (1987) examined lake level and water supply reductions using a lake surface energy budget model and estimates of perturbed earth surface energy flux resulting from increased atmospheric concentrations of greenhouse gases. Cooter and Cooter (1990) modeled stream water temperatures and water quality in the Southeast using a group of estimates of greenhouse climatic fluctuations. A number of studies on climate change impacts on fish habitat and fisheries have also been published. Magnuson et al. (1990) quantified fish habitat changes and changes in fishery yields under differing climatic conditions. Meisner (1990) estimated changes in regional brook trout habitat distribution under a GCM-generated climate scenario. Chang et al. (1992) examined changes in striped bass habitat in a southeastern reservoir.

Studies of climatic change impacts on other important water uses were fairly rare. Allen et al. (1991) simulated the changes in irrigation water requirements of alfalfa, corn, and wheat crops at a set of sites in the Great Plains to various estimates of greenhouse conditions. Peterson and Keller (1990) examined past U.S. irrigation trends and projected patterns under climate change scenarios. Frederick and Kneese (1990) studied dynamics of water supply, price, and water use, focusing in the western United States.

### 4.5 Methods of Cimate Senario Development

#### 4.5.1 Studies Using Scenarios from Multiple Sources

A number of investigators have used climate scenarios from several sources in resource impact studies. This approach can be useful in demonstrating robustness (or its lack) in estimates of greenhouse effect impacts on water resources. Cohen (1987) develops climate scenarios from both climatic analogues and from GCM output, and also hypothetical rainfall and temperature perturbations, and uses a water balance model to simulate impacts of these climatic conditions on Great Lakes basin streamflow. Gleick (1987) used a water balance model to simulate hydrology in the mountainous Sacramento River basin in Northern California applying both GCM-based and hypothetical climate scenarios. A resulting shift in the seasonal water balance patterns (increased winter runoff, decreased summer runoff, and decreased summer soil moisture) was observed with some degree of consensus in the basin. McCabe and Ayers (1989) modeled the hydrology in the Delaware River basin in the northeastern United States also using both GCM-based and hypothetical climate scenarios. It was noted that increased potential evapotranspiration, in the absence of increases in rainfall, may lead to reduced soil moisture in parts of the basin. Miller and Brock (1989) studied the response of the comprehensively managed TVA system of over 30 dams and reservoirs covering more than 41,000 square miles in the southeastern United States to both GCM-based and hypothetical future runoff conditions.

### 4.5.2 Analogue Climate Scenarios

Case studies using an analogue approach to climate scenario development are relatively infrequent. Cohen (1987) and Palutikof (1987) both used analogue climate scenarios, among others, in hydrologic studies. Karl and Riebsame (1989) and Schertzer (1990) also identified and employed climatic analogues in evaluating potential climate change impacts on water resources.

### 4.5.3 GCM-Based Climate Scenarios

Many researchers in addition to those mentioned in Sect. 4.5.1 have used GCM output in impact studies. Among hydrologic studies are included Cohen (1986), Bultot et al. (1988), Croley (1990), and Lettenmaier and Gan (1990). Hay et al. (1991) demonstrate a new method for developing daily rainfall time series from GCM wind direction and cloud cover estimates.

There are several water management studies using GCM output. Cohen (1986) described interrelated water supply, water quality, engineering, social, and economic issues in the Great Lakes region. GCM climatic output with hydrologic and lake evaporation models was used to simulate potential hydrologic and lake level changes due to a greenhouse climate. Hartmann (1990), also studying the Great Lakes region, used GCM output and hydraulic routing models to simulate changing water supply conditions in the basin. Lettenmaier and Sheer (1991) modeled reservoir performance in a California water system under GCM-based climate scenarios. Sheer and Randall (1989) examined the performance of two different water resource systems (the Central Valley system, California and the system serving the Atlanta area) and the implications of changing conditions for system managers and clients.

A number of researchers have investigated potential impacts on water use issues using GCM-based scenarios. Particularly, numerous studies have been conducted on fisheries effects of climate change. Mandrak (1989) examined potential changes in species composition of Great Lakes fish communities using a Holdridge Life Zone climate classification scheme, as modified by GCM-based estimates of enhanced–greehouse climate changes. Coutant (1990) examined potential life-cycle changes and changes in the geographic distribution of *Morone saxatilis* (striped bass) in eastern North America associated with GCM-based estimates of climatic change; in the same journal issue devoted to studies on fisheries impacts of climatic change are included Hill and Magnuson (1990), Johnson and Evans (1990), Magnuson et al. (1990), and Meisner (1990). Chang et al. (1992) used a reservoir water quality box model with output from GCMs to simulate changes in daily striped bass habitat volumes in a southeastern reservoir. GCM-based studies on impacts of other uses of water have been conducted. These include Singh (1987) examining possible changes in hydroelectric production in Quebec, Blumberg and diToro (1990) modeling changes in water quality in Lake Erie, Byron and Goldman (1990) using empirical models to estimate impacts of GCM-generated double $CO_2$ temperature and rainfall on lake primary production, Cooter and Cooter (1990) modeling changing stream water temperatures and quality in the southeastern U.S., McCormick (1990) evaluating possible changes in lake thermal structure in Lake Michigan, and Allen et al. (1991) examining irrigation water requirements of three crops in the Great Plains region.

### 4.5.4 Historical Studies

No studies on hydrologic consequences of climate change employing a historical approach were found. However, a number of water management and water use papers have been written that use an examination of previous periods of water resource limitations to develop insight about possible response options and difficulties if future climate conditions should change. Riebsame (1988) selected a period of supply stress faced by water managers in the Sacramento River basin (California) and analyzed management actions during that period. Glantz (1990) describes responses of marine fisheries managers to periods of changing resource conditions and extracts lessons from these case studies. Similarly, Peterson and Keller (1990) review two case histories of responses to changing irrigation water supply and discusses guidance learned from these cases; and Miller (1990) examines a hydropower developer's response to water supply limitations in recent decades in Idaho. Schindler et al. (1990) studied chemical, biological, and physical changes in a highly instrumented Ontario lake corresponding with recent observed periods of climatic warming.

### 4.5.5 Hypothetical Climatic Change

Studies using hypothetical climatic perturbations to evaluate the climatic sensitivity of hydrology, water management, or water use have been fairly common. Stockton and Boggess's (1979) survey of hydrologic implications of climate change used hypothetical changes in rainfall and temperature to simulate runoff changes in regions throughout the United States. Other hydrologic studies using hypothetical changes include Nemec and Schaake (1982), Aston (1984), Idso and Brazel (1984), Flashcka et al. (1987), McCabe and Ayers (1989), and Mimikou et al. (1991). Management studies using hypothetical climate change estimates include Callaway and Currie (1985) and Lettenmaier et al. (1989). In the latter, multiple-use reservoir performance, under a range of hypothetical temperature changes, using two system decision-making methods, was explored. Some studies use estimates of sea level rise (classified in this literature review as hypothetical climate scenarios) to project possible coastal water management impacts. Titus et al. (1987) used estimates of future sea level increases to evaluate different current coastal drainage design plans. Water use studies incorporating hypothetical scenarios include Sibley and Strickland (1985).

### 4.5.6 Other Methods for Developing Climate Scenarios

Henderson-Sellers (1987) used estimates of the global change in surface energy flux due to changing concentrations of greenhouse gases directly in a modeling study of possible greenhouse effect–induced changes in lake levels.

### 4.6 Regional Coverage

Results presented in Sect. 3 suggest that three regions have been the subject of more published literature on the effects of climatic change on water resources. This section describes the research base that has developed in these regions.

#### 4.6.1 Great Lakes

Several researchers have studied possible Great Lakes basin hydrology under greenhouse conditions. These include studies by Cohen (1986, 1987), Croley (1990), and Sanderson and Wong (1987). Cohen (1986), Croley (1989), Sanderson (1989), and Hartmann (1990) have examined implications of changing water availability for the management of water resources in the basin. Cohen and Allsopp (1988) quantified potential impacts to resource-dependent activities such as shipping and energy use resulting from climate change estimates. Researchers including Meisner (1987), Assel (1989), Blumberg and diToro (1989), Hill et al. (1990), Holmes (1990), Johnson and Evans (1990), McCormick (1990), and Schertzer and Sawchuk (1990) have explored potential water quality, fish habitat, and fisheries implications of climate change in the Great Lakes.

#### 4.6.2 California

Gleick (1987) and Lettenmaier and Gan (1990) conducted studies of hydrologic sensitivities to climate changes in different California water basins. Riebsame (1988), Lettenmaier and Sheer (1991), Sheer and Randall (1989), and Williams (1989) have explored impacts of water resource changes on water managers and water systems in California. Byron and Goldman (1990) conducted research on potential water quality changes. Sheer and Randall (1989) and Williams (1989) include discussions of effects of climate change on water use in parts of California.

#### 4.6.3 South Atlantic—Gulf

Hains and Hains (1989) studied hydrologic responses in a southeastern river system to climate change scenarios. Schaake (1990) also simulated hydrologic changes across the southeastern United States with estimates of potential climate change. A number of researchers evaluated climate change and sea level rise concerns in the South Atlantic—Gulf region in a symposium [see Davidson et al. (1987), Gissendammer (1987), Hawxhurst (1987), Rhoads et al. (1987), Snedaker and deSylva (1987)]. Other studies on coastal water resources concerns that are related to climate change and sea level rise in the region include Titus et al. (1987). Kuo (1988), Meo (1989), Schaake (1990), and Sheer and Randall (1989) include discussions of water management impacts of climate change. Cooter and Cooter (1990) modeled stream temperatures and water quality in the southern United States; other studies including discussions of potential water quality or other water use impacts in the region are Davidson et al. (1987), Snedaker and deSylva (1987), Sheer and Randall (1989), and Schaake (1990).

## 5. CONCLUSIONS

A review of research literature concerning potential impacts of climate change on water resources for research through 1990 has been presented. Increasing coverage of water management and water use issues, and continued attention to hydrologic research, has been observed. GCM-based and hypothetical climate scenarios dominate among methods for developing greenhouse climate scenarios. There is considerable variability in the number of studies obtained through this exploratory literature search associated with different regions in the United States: such regions as the Great Lakes and California are the subject of numerous studies, and such areas as the Ohio and New England regions are associated with few or no studies. This document is intended as an introduction to literature through 1990 for investigators in the field of potential impacts of climate change on hydrology, water management, and water use.

## 6. REFERENCES

American Society of Civil Engineers (ASCE). 1986. ASCE Authors' Guide to Journals, Books, and Reference Publications. ASCE, New York. 25 pp.

Beran, M. 1986. The water resource impact of future climate change and variability. pp. 299–328, In J. G. Titus (ed.), Effects of Changes in Stratospheric Ozone and Global Climate. U.S. Environmental Protection Agency, Washington, D.C.

Callaway, J. M., and J. W. Currie. 1985. Water resource systems and changes in climate and vegetation. pp. 23–67, In M. R. White (ed.), Characterization of information requirements for studies of $CO_2$ effects—water resources, agriculture, fisheries, forests and human health. U.S. Department of Energy, Washington, D.C.

DIALOG Information Systems. 1990. User's Guide to Dialog. Dialog Information Systems.

Gleick, P. H. 1989. Climate change, hydrology, and water resources. Rev. Geophys. 27(3):329–344.

Hartmann, H. C. 1990. Climatic change impacts on Laurentian Great Lakes levels. Clim. Change 17:49–67.

Klemes, V. 1985. Sensitivity of water resource systems to climate variations. World Climate Applications Programme Publication No. WCP-98. World Meteorological Organization, Geneva, 17 pp. (plus 5 appendices).

Klemes, V. 1983. Climate change and the planning of water resource systems. pp. 485–500, In Sixth Annual Hydrotechnical Conference, June 2–3, 1983, Ottawa, Ontario. Canadian Society for Civil Engineering. As reprinted in Klemes, V. 1985.

Lamb, P. J. 1987. On the development of regional climatic scenarios for policy-oriented climatic-impact assessment. Bull. Am. Meteor. Soc. 68(9): 1116–1123.

Mugler, M. W., and M. C. Rubino. 1989. Chapter Nine: Water Resources. pp. 165–186, In J. B. Smith and D. Tirpak (eds.), The Potential Effects of Global Climate Change on the United States. EPA-230-05-89-050. U.S. Environmental Protection Agency, Washington, D.C.

Revelle, R. 1990. Preface. pp. ix–x, In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

Seaber, P. R., F. P. Kapinos, and G. L. Knapp. 1987. Hydrologic Unit Maps. U.S. Geological Survey Water-Supply Paper 2294. U.S. Geological Survey, Denver. 63 pp.

Solley, W. B., C. F. Merk, and R. R. Pierce. 1988. Estimated Use of Water in the United States in 1985. U.S. Geological Survey Circular 1004, U.S. Geological Survey, Denver. 82 pp.

Waggoner, P. E. 1990. The issues. pp. 9–18, In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

# APPENDIX A

## Search Code

| Keyword | Data set created |
|---|---|
| Climate(3N)change[a] | S1 |
| Global()warming[a] | S2 |
| Greenhouse()effect[a] | S3 |
| Climate(3N)variability[a] | S4 |
| Sea()level(2N)rise[a] | S5 |
| Hydrology[b] | S6 |
| Groundwater[b] | S7 |
| Hydraulics[b] | S8 |
| Navigation[b] | S9 |
| Transpiration[b] | S10 |
| Irrigation[b] | S11 |
| Water()resources[b] | S12 |
| Stream()flow or streamflow[b] | S13 |
| Runoff[b] | S14 |
| Fish()habitat[b] | S15 |
| Water()quality[b] | S16 |
| Water()supply or Water()supplies[b]* | S17 |
| Economic*[b] | S18 |
| Policy[b] | S19 |
| Energy[b] | S20 |
| Recreation[b] | S21 |
| Drainage[b] | S22 |
| Water[b] | S23 |
| Fish[b] | S24 |
| S1 OR S2 OR S3 OR S4 OR S5 | S25 |
| S6 - S24/OR | S26 |
| S25 AND S26 | S27 |
| S27, LANGUAGE = ENGLISH | S28 |

[a]Climate change keywords.
[b]Water resource keywords.

## APPENDIX B

### Data Bases Accessed by DIALOG

| Data base | Contents |
|---|---|
| Compendex Plus | Machine-readable version of the Engineering Index, with abstracted information from major engineering and technological literature |
| Waternet | Index of all publications of the American Water Works Association (AWWA) and the AWWA Research Foundation |
| Water Resources Abstracts | Index of materials collected by over 50 water research centers and institutes in the United States. Covers hydrology, water resource economics, urban water management, and other topics |
| Fluidex | Index of all aspects of fluid engineering literature |
| Georef | Index of more than 4500 geological science journals and other publications |
| Oceanic Abstracts | Index of more than 3500 marine science journals and other publications |
| Aquatic Sciences and Abstracts | Index of more than 5000 marine and fisheries freshwater science, technology, and management journals and other publications |
| Chemical Abstracts | Index of publications related to chemical substances |

## APPENDIX C

### Dictionary of Classification Codes[1]

| Code | Definition |
|---|---|
| DIALOG | Obtained from DIALOG on-line search |
| F-ABSTRACT | Abstract only obtained |
| F-REPRINT | Reprint obtained |
| M-ANALOGUE | Analogue climate scenario used |
| M-GCM-BASED | Climate scenario from GCM output |
| M-HISTORICAL | Historical climate scenario used |
| M-HYPOTHETICAL | Hypothetical climate scenario used |
| M-OTHER | Other method of climate scenario development used |
| M-UNKNOWN | Method of climate scenario development not determined[2] |
| R-AFRICA | Region studied in Africa |
| R-ARCTIC | Region studied in Arctic |
| R-ASIA | Region studied in Asia |
| R-AUSTRALIA | Region studied in Australia |
| R-CANADA | Region studied in Canada |
| R-CARIBBEAN | Region studied in Caribbean |
| R-EUROPE | Region studied in Europe |
| R-GLOBAL | Study concerns global water resources |

[1]Classification codes appear in capital letters following reference in Appendix D.

[2]Generally results from limited time and information (e.g., abstract only) available.

**Dictionary of Classification Codes (continued)**

| Code | Definition |
|---|---|
| R-MEDITERRANEAN | Study concerns Mediterranean region |
| R-MIDDLE EAST | Region studied in Middle East |
| R-NONE | No region specified |
| R-SOVIET UNION | Region studied in Soviet Union |
| R-TROPICS | Study concerns tropics |
| R-UNKNOWN | Region not determined[1] |
| R-US | Study concerns U.S. water resources or large number of regions in U.S. |
| R-US-EASTERN | Study concerns water resources in eastern U.S. or large number of regions in eastern U.S. |
| R-US-WESTERN | Study concerns water resources in western U.S. or large number of regions in western U.S. |
| R-US-ALASKA | Region studied in Alaska water resources region (WRR)[3] |
| R-US-ARKANSAS/WHITE/RED | Region studied in Arkansas/White/Red WRR |
| R-US-CALIFORNIA | Region studied in California WRR |
| R-US-CARIBBEAN | Region studied in U.S. Caribbean WRR |
| R-US-COLORADO | Region studied in Upper or Lower Colorado WRR |
| R-US-GREAT BASIN | Region studied in Great Basin WRR |
| R-US-GREAT LAKES | Region studied in Great Lakes WRR |
| R-US-HAWAII | Region studied in Hawaii WRR |

[3]U.S. water resources regions after U.S. Geological Survey standard hydrologic unit maps (Seaber et al., 1987).

**Dictionary of Classification Codes (continued)**

| Code | Definition |
|---|---|
| R-US-MID-ATLANTIC | Region studied in Mid-Atlantic WRR |
| R-US-MISSISSIPPI | Region studied in Upper or Lower Mississippi WRR |
| R-US-MISSOURI | Region studied in Missouri WRR |
| R-US-NEW ENGLAND | Region studied in New England WRR |
| R-US-OHIO | Region studied in Ohio WRR |
| R-US-PACIFIC NORTHWEST | Region studied in Pacific Northwest WRR |
| R-US-RIO GRANDE | Region studied in Rio Grande WRR |
| R-US-S ATLANTIC/GULF | Region studied in South Atlantic–Gulf WRR |
| R-US-TENNESSEE | Region studied in Tennessee WRR |
| R-US-TEXAS/GULF | Region studied in Texas/Gulf WRR |
| S-HYDROLOGY | Subject of investigation hydrology |
| S-MANAGEMENT | Subject of investigation management |
| S-USE | Subject of investigation water use |
| T-CASE STUDY | Reference classified as case study |
| T-CRITIQUE | Reference classified as critique |
| T-DISCUSSION | Reference classified as discussion |
| T-REVIEW | Reference classified as review |
| T-UNKNOWN | Type of reference not determined[4] |

[4]Generally due to limited time and information (e.g., abstract only) available.

# APPENDIX D

## Annotated Bibliography

Ahmad, M. U. 1989. Hydrologist plan to combat greenhouse effect. Int. Geol. Congr. Abstr. 28(1):19.

DIALOG, F-ABSTRACT, R-AFRICA, R-ASIA, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-DISCUSSION

Alexander, E. C., S. C. Alexander, and R. S. Lively. 1987. Recharge of the Mt. Simon/ Hinckley aquifer; responses to climate change and water use. Trans. Am. Geophys. Union 68(44):1270.

Water temperature, pH, and water chemistry data from 60 wells in southeastern Minnesota are examined. Conclusions are drawn regarding groundwater movement and recharge in relationship to climate changes and withdrawals over the past 36,000 years.

DIALOG, F-ABSTRACT, M-ANALOGUE, R-US-MISSISSIPPI, S-HYDROLOGY, T-CASE STUDY

Allen, R. G., R. N. Gichuki, and C. Rosenzweig. 1991. Carbon dioxide-induced climatic changes and irrigation-water requirements. J. Water Resour. Plann. Manage. 117(2):157–78.

A crop irrigation-water requirement (IR) model was used to simulate the effects of general circu-lation model (GCM) estimates of climate conditions on alfalfa, corn, and wheat IR at 17 sites in the Great Plains for a 30-year period. The effects of different assump-tions of plant bulk stomatal resistance were examined, and it was noted that there is much variability in the literature regarding the expected response of stomatal resis-tance to a carbon-enriched atmosphere. Under most assumptions, increased IR was simulated by the model, induced largely by increases in plant evaporative demands and changes in precipitation patterns.

F-REPRINT, M-GCM-BASED, R-US-MISSOURI, R-US-TEXAS/GULF, S-HYDROLOGY, S-USE, T-CASE STUDY

American Geophysical Union. 1990. Abstracts. Chapman Conference on Hydrologic Aspects of Global Climate Change, June 12–14, 1990. Lake Chelan, Washington.

Papers and posters are presented on themes of (a) large-scale hydrologic-atmospheric interactions [10 presentations]; (b) land-surface process modeling [8]; (c) coupling of hydrologic and atmospheric models [9]; (d) case studies of the impacts of climate change on hydrology [9]; (e) paleoanalysis of the relationship between climate and hydrology [4]; (f) land- surface characterization and modeling [10]; and (g) climate characterization and modeling [5].

F-ABSTRACT

Askew, A. J. 1987. Climate change and water resources. pp. 421–30. In S. I. Solomon, M. Beran, and W. Hogg (eds.), The Influence of Climate Change and Climate Variability on the Hydrologic Regime and Water Resources. International Association of Hydrological Sciences Press, Wallingford, United Kingdom.

Climate change, climate variability, and water resources are defined and discussed. A research agenda for the issues is presented.

DIALOG, F-REPRINT, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-DISCUSSION

Assel, R. A. 1988. Climatic warming scenarios and Great Lakes ice cover. Trans. Am. Geophys. Union 69(44):1222.

F-ABSTRACT, M-GCM-BASED, R-US-GREAT LAKES, S-USE, T-CASE STUDY

Assel, R. A. 1989. Impact of global warming on Great Lakes ice cycles. pp. 5.1–5.30. In J. B. Smith and D. Tirpak (eds.), The Potential Effects of Global Climate Change on the United States. U.S. Environmental Protection Agency, Washington, D.C.

GCM output and transient temperature increases were used to simulate ice cover over the Great Lakes with a freezing degree day model. Simulated average winter ice cover decreased in $2xCO_2$ climates by 5–13 weeks. Daily spatial and temporal distribution of ice cover were also simulated.

F-REPRINT, M-GCM-BASED, R-US-GREAT LAKES, S-USE, T-CASE STUDY

Aston, A. R. 1984. The effect of doubling atmospheric carbon dioxide on streamflow: A simulation. J. Hydrol. 67:273–80.

A distributed deterministic hydrologic process model was used to quantify potential effect of atmospheric $CO_2$ enrichment on streamflow. An empirical equation that relates evapotranspiration to pan ratio and the difference between soil moisture content and plant wilting point, for given vegetation types, was also used. $CO_2$

enrichment led to increases in basin runoff and changes in the shape of the hydrograph. Agricultural areas with currently marginal water supplies may become increasingly productive under a $CO_2$-enriched atmosphere, given adequate nutrition. Urban and rural water supplies may also increase, which might encourage development and investment in additional water storage capabilities.

F-REPRINT, M-HYPOTHETICAL, R-AUSTRALIA, S-HYDROLOGY, T-CASE STUDY

Becker, H. A. 1986. The Lower Countries and a higher Atlantic. pp. 95–103. In H. G. Wind (ed.), Conference on Impact of Sea Level on Society, Delft, the Netherlands, August 27–29, 1986. A. A. Balkema, Rotterdam.

DIALOG, F-ABSTRACT, R-EUROPE, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-DISCUSSION

Beran, M. 1986. The water resource impact of future climate change and variability. pp. 299–328. In J. G. Titus (ed.), Effects of Changes in Stratospheric Ozone and Global Climate. U.S. Environmental Protection Agency, Washington, D.C. and the U. N. Environment Programme.

Hydrologic modeling methods for assessing the impacts of climate change on hydrology are reviewed. Types of models discussed include causal models (e.g., the Briggs model for simulating evaporation), conceptual watershed models (e.g., the Sacramento model), empirical models (e.g., regression models), and water balance models. The published studies on climate change effects on water resources (e.g., water supply reservoirs) are surveyed. Identified research needs include better climate–hydrology transfer functions, better hydrology–water resource transfer functions, better understanding of the effects of elevated atmospheric $CO_2$ on plant transpiration, and systematic intercomparisons among hydrologic models.

F-REPRINT, R-NONE, S-HYDROLOGY, S-MANAGEMENT, T-DISCUSSION, T-REVIEW

Bishop, J. 1989. Climate change effects on Ontario's water quality. pp. 177–81. In S. A. Changnon (ed.), Report of the First U.S.-Canada Symposium on Impacts of Climate Change in the Great Lakes Basin. National Oceanic and Atmospheric Administration. National Climate Program Office, Rockville, Maryland.

DIALOG, F-REPRINT, M-UNKNOWN, R-CANADA, S-USE, T-CASE STUDY

Blumberg, A. F., and D. M. DiToro. 1989. Effects on Lake Erie water quality. p. 176. In S. A. Changnon (ed.), Report of the First U.S.-Canada Symposium on Impacts of

Climate Change in the Great Lakes Basin. National Oceanic and Atmospheric Administration. National Climate Program Office, Rockville, Maryland.

DIALOG, F-REPRINT, M-GCM-BASED, R-US-GREAT LAKES, S-USE, T-CASE STUDY

Blumberg, A. F., and D. M. DiToro. 1989. The effects of climate warming on Lake Erie water quality. pp. 7.1–7.28. In D. Smith and J. Tirpak (eds.), The Potential Effects of Global Climate Change on the United States. U.S. Environmental Protection Agency, Washington, D.C.

A coupled hydrodynamic and water quality model was used to determine the response of Lake Erie water quality to climate change. As with the other studies in this EPA report, outputs from GCMs were used as quantitative scenarios of greenhouse effect climate conditions. Lower dissolved oxygen concentrations were simulated under greenhouse climate conditions because of increased rates of bacterial activity. Changes in water quality may affect fish populations in Lake Erie.

F-REPRINT, M-GCM-BASED, R-US-GREAT LAKES, S-USE, T-CASE STUDY

Blumberg, A. F., and D. M. DiToro. 1990. Effects of climate warming on the dissolved oxygen concentrations in Lake Erie. Trans. Am. Fish. Soc. 119(2):210–23.

F-REPRINT, M-GCM-BASED, R-US-GREAT LAKES, S-USE, T-CASE STUDY

Breugdenhil, C. B., and H. G. Wind. 1986. Framework of analysis and recommendations. pp. 1–20. In H. G. Wind (ed.), Conference on Impact of Sea Level on Society, Delft, the Netherlands, August 27–29, 1986. A. A. Balkema, Rotterdam.

DIALOG, F-ABSTRACT, R-ASIA, R-EUROPE, S-MANAGEMENT, T-DISCUSSION, T-REVIEW

Brouwer, F., and M. Falkenmark. 1989. Climate-induced water availability changes in Europe. Environ. Monit. Assess. 13(1):75–98.

DIALOG, F-ABSTRACT, R-EUROPE, S-HYDROLOGY, T-REVIEW

Bultot, F., et al. 1988. Repercussions of a $CO_2$ doubling on the water cycle and on the water balance—A case study for Belgium. J. Hydrol. 99(3-4):319–47.

The IRMB hydrologic simulation model was used to estimate the effect of climate change on potential evapotranspiration, soil moisture changes, and other hydrologic

variables. Climate change scenarios were developed on the basis of literature reviews to obtain estimates for the following variables: net terrestrial radiation, solar radiation, sensible heat flux, flux of latent heat of evaporation, Bowen ratio, cloudiness, temperature, water vapor pressure, and precipitation. GCM "$4xCO_2$" experiments were examined for projections of possible temperature and precipitation changes. Model formulations were designed without a $CO_2$ enrichment effect, and justification was explained in paper. Implications of hydrologic modeling results for pollution risks, water supply, soil dryness, agricultural yield, hydraulic structure design, and other socially and economically important variables were discussed.

DIALOG, F-REPRINT, M-GCM-BASED, R-EUROPE, S-HYDROLOGY, T-CASE STUDY

Bultot, F., and D. Gellens. 1989. Simulation of the impact of $CO_2$ atmospheric doubling on precipitation and evapotranspiration— Study of the sensitivity to various hypotheses. pp. 73–92. In Conference on Climate and Water, September 11–15. Helsinki, Finland. Valtion Painatuskeskus, Helsinki.

DIALOG, F-ABSTRACT, M-GCM-BASED, R-EUROPE, S-HYDROLOGY, T-CRITIQUE, T-CASE STUDY

Byron, E. R., and C. R. Goldman. 1990. The potential effects of global warming on the primary productivity of a subalpine lake. Water Resour. Bull. 26(6):983–89.

Several empirical models are used to estimate the effects of GCM-estimated changes in temperature and precipitation on the primary productivity of a mountain lake. It was observed that climate changes led to increases in primary productivity. The authors state that the climate change effects may be different for lakes that do not freeze during the winter, since winter washout can have large impacts on primary productivity later in the year.

F-REPRINT, M-GCM-BASED, R-US-CALIFORNIA, S-USE, T-CASE STUDY

Byron, E. R., C. R. Goldman, and A. Jassby. 1988. Global climate change and the water quality of mountain lakes. Trans. Am. Geophys. Union 69(44):1203.

DIALOG, F-ABSTRACT, M-UNKNOWN, R-US-CALIFORNIA, S-USE, T-CASE STUDY

Byron, E. R., A. Jassby, and C. R. Goldman. 1989. The effects of global climate change on the water quality of mountain lakes and streams. pp. 2.1–2.42. In J. B. Smith and D. Tirpak (eds.), The Potential Effects of Global Climate Change on the U.S.,

Appendix E: Aquatic Resources. U.S. Environmental Protection Agency, Washington, D.C.

Empirical models for the relationship between lake annual primary productivity, lake heat storage, and climate were developed from long-term (29-year) data bases of water quality and climate for subalpine lakes and streams in Northern California. GCM-based scenarios of climate change were used with these models to assess potential effects of global warming on water quality in the lakes. Results included simulated increases in algal productivity under all scenarios of climate change for one modeled lake.

F-REPRINT, M-GCM-BASED, R-US- CALIFORNIA, S-USE, T-CASE STUDY

Callaway, J. M., and J. W. Currie. 1985. Water resource systems and changes in climate and vegetation. pp. 23–67. In M. R. White (ed.), Characterization of information requirements for studies of $CO_2$ effects—water resources, agriculture, fisheries, forests, and human health. U.S. Department of Energy, Washington, D.C.

This report has a dual objective: to define the issues involved in the impacts of climate change on water resources and to illustrate analysis methods and types of results through case studies of the sensitivity of water resources to climate change in the Great Basin and the Texas-Gulf areas. For the case studies, multiple regression rainfall-runoff models, a stochastic streamflow generation model, and a reservoir simulation model are used to estimate water resource levels in "base" and changed-climate conditions. Research recommendations presented include the following: improve the ability of ground and subsurface hydrologic models to incorporate climate model data; identify regions with highly sensitive water resources; focus research on climate change effects in these areas; and obtain improved information from climate models.

DIALOG, F-REPRINT, M-HYPOTHETICAL, R-US, R-US-GREAT BASIN, R-US-TEXAS/GULF, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-DISCUSSION, T-CASE STUDY

Canning, D. J. 1989. Sea level rise in Washington state: Technical issues and preliminary policy responses. pp. 231–35. In Oceans '89, Part I: Fisheries, Global Ocean Studies, Marine Policy and Education, Oceanographic Studies; September 18–21, 1989, Seattle, Wash. IEEE Service Center, Piscataway, New Jersey.

DIALOG, F-ABSTRACT, M-UNKNOWN, R-US-PACIFIC NORTHWEST, S-MANAGEMENT, T-CASE STUDY

Catallo, W. J., III, N. B. Theberge, and M. E. Bender. 1989. Sea level rise and hazardous wastes in the coastal zone: An ecological perspective. pp. 1407–20. In Coastal

Zone '89: Proceedings of the Sixth Symposium on Coastal and Ocean Management, Charleston, S.C., July 11–14, 1989, Vol. 2. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, R-US, S-MANAGEMENT, T-DISCUSSION

Chang, L. H., and S. F. Railsback. 1990. Predicting effects of global climate change on reservoir water quality and fish habitat. pp. 545–50. In R. M. Khanbilvardi and T. C. Gooch (eds.), Optimizing the Resources for Water Management, Proceedings of the 17th Annual National Conference of the Water Resource Planning and Management Division. American Society of Civil Engineers, New York.

F-REPRINT, M-GCM-BASED, R-US-TENNESSEE, S-USE, T-CASE STUDY

Chang, L. H., S. F. Railsback, and R. T. Brown. 1992. Use of a reservoir water quality model to simulate global change effects on fish habitat. Clim. Change (in press).

Results of a case study of climate change effects on water quality and fish habitat in a multipurpose reservoir in east Tennessee are presented. GCM output, a reservoir water quality model, and temperature and dissolved oxygen requirements for striped bass were used to simulate striped bass habitat for "base" and "greenhouse effect" conditions. Decreases in the volume of reservoir suitable for striped bass during the summer were simulated under greenhouse climate conditions, largely because of increases in lake water temperatures.

F-REPRINT, M-GCM-BASED, R-US-TENNESSEE, S-USE, T-CASE STUDY

Clark, R. A. 1987. Hydrologic design criteria and climate variability. pp. 545–51. In S. I. Solomon, M. Beran, and W. Hogg (eds.), The Influence of Climate Change and Climate Variability on the Hydrologic Regime and Water Resources. International Association of Hydrological Sciences Press, Wallingford, United Kingdom.

The sensitivity of the "probable maximum precipitation" (PMP), a climate statistic, to climate is evaluated. Precipitation mechanisms involved in PMP and how PMP may change with precipitation-related variables are discussed. The author concludes that a global warming could elevate sea surface temperature and therefore increase the PMP. Failures of hydraulic structures (e.g., dam accidents) designed with old PMP values could result. It is suggested that future planning based on the past climate record may be unwise.

DIALOG, F-REPRINT, R-NONE, S-MANAGEMENT, T-DISCUSSION

Cohen, S. J. 1986. Impacts of carbon dioxide–induced climatic change on water resources in the Great Lakes Basin. Clim. Change 8(2):135–53.

Water balance (for the basin hydrologic component of study) and mass transfer (for the lake evaporation component) models were used with GCM projections of change in climate parameters to examine potential changes in lake evaporation and basin runoff in the Great Lakes region. Also examined and defined are important social and economic issues related to climate change and its potential impacts on the Great Lakes region. A flow diagram of regional socieconomic, engineering, water supply, and water quality effects of changes in climate is included, and past resource effects of climate fluctuations (e.g., losses in hydroelectric power production, lake shipping, and shoreline erosion) are discussed, demonstrating that the regional economy is concretely and complexly related to the regional water resources in the lakes.

DIALOG, F-REPRINT, M-GCM-BASED, R-US-GREAT LAKES, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-CASE STUDY

Cohen, S. J. 1986. Climate change, population growth, and their effects on Great Lakes water supplies. Prof. Geogr. 38(4):317–23.

Possible future water supplies in the Great Lakes are projected with the use of relationships among water supply, population, and water demand, and GCM-based estimates of changes in regional climate. The author concludes that climate change may lead to water supply problems within the Great Lakes region.

M-GCM-BASED, R-US-GREAT LAKES, S-USE, T-CASE STUDY

Cohen, S. J. 1987. Influences of past and future climates on the Great Lakes region of North America. Water Int. 12(4):163–69.

DIALOG, F-ABSTRACT, R-US-GREAT LAKES, S-HYDROLOGY, T-DISCUSSION

Cohen, S. J. 1987. Sensitivity of water resources in the Great Lakes region to changes in temperature, precipitation, humidity, and wind speed. pp. 489–99. In S. I. Solomon, M. Beran, and W. Hogg (eds.), The Influence of Climate Change and Climate Variability on the Hydrologic Regime and Water Resources. International Association of Hydrological Sciences Press, Wallingford, United Kingdom.

This report constructs 140 climate change scenarios from GCM output, "analogue" climate records, and hypothetical changes. A water balance model for the Great Lakes region was run under two different sets of assumptions: first, including only temperature and precipitation as the climatic factors influencing hydrology in an elevated-$CO_2$ world; second, including not only temperature and precipitation but also

humidity and wind speed as forcing factors. The results under the two sets of assumptions were significantly different, and this difference points to the importance of lake evaporation to water supply in the Great Lakes region.

DIALOG, F-REPRINT, M-ANALOGUE, M-GCM-BASED, M-HYPOTHETICAL, R-US-GREAT LAKES, S-HYDROLOGY, T-CASE STUDY

Cohen, S. J. 1987. Projected increases in municipal water use in the Great Lakes due to carbon dioxide-induced climatic change. Water Resour. Bull. 23(1):91–101.

This report presents a regression model of annual per capita water use as a function of monthly potential evapotranspiration for May through September in the Great Lakes region. Two sets of GCM temperature and precipitation estimates for a double-$CO_2$ climate are used to estimate water use in a changed climate. Results indicate that if only summer (May through September) water use changes, GCM-projected climate change may have a minor effect on Great Lakes water supply and lake levels. The frequency of regional-scale summer dry periods expected in a $2xCO_2$ climate, which was not considered, could lead to more substantial increases in water demand.

DIALOG, F-REPRINT, M-GCM-BASED, R-US-GREAT LAKES, S-USE, T-CASE STUDY

Cohen, S. J., and T. R. Allsopp. 1988. Potential impacts of a scenario of $CO_2$-induced climatic change on Ontario, Canada. J. Clim. 1(7):669–81.

The impacts of a climate change on the Great Lakes basin are investigated from an interdisciplinary perspective. Climate output from the Goddard Institute for Space Studies GCM was used to simulate potential scenarios of future lake levels, outflow, snowfall, length of snow season, and other variables. Impacts on natural resources and resource-dependent activities such as shipping and energy use resulting from changing environmental conditions were then estimated. Economic impacts were quantified when data were available. The need for improved methodologies for integrated regional studies of potential impacts of climate change was illustrated.

DIALOG, F-ABSTRACT, M-GCM-BASED, R-CANADA, S-HYDROLOGY, S-USE, T-CASE STUDY

Cooper, C. F. 1990. Recreation and wildlife. pp. 329–339. In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

This chapter discusses nonmarket values associated with water resources and their potential vulnerability to changing climatic conditions. These values include water-based recreation, fish and fisheries, and freshwater wetlands.

F-REPRINT, R-US, S-USE, T-DISCUSSION

Cooter, E. J., and W. S. Cooter. 1990. Impacts of greenhouse warming on water temperature and water quality in the southern U.S. Clim. Res. 1:1–12.

GCM outputs were used as inputs to a water temperature and water quality model to estimate stream water temperatures for a warmed southeastern United States. The GCM climate scenarios all produced increases in stream water temperatures. The Streeter-Phelps waste load allocation model demonstrated that water quality, expressed in terms of dissolved oxygen content, is highly sensitive to water temperature, and therefore water quality may be highly sensitive to changes in regional climate. The authors suggest that more stringent levels of wastewater treatment may be necessary to maintain water quality standards. It is also suggested that riparian vegetation management may be an important mitigative measure for potential global warming–induced problems with water quality.

M-GCM-BASED, R-US-ARKANSAS/WHITE/RED, R-US-MISSISSIPPI, R-US-S ATLANTIC/GULF, R-US-TENNESSEE, R-US-TEXAS/GULF, T-CASE STUDY, S–USE

Coutant, C. C. 1990. Temperature-oxygen habitat for freshwater and coastal striped bass in a changing climate. Trans. Am. Fish. Soc. 119(2):240–53.

Specific water temperatures and dissolved oxygen concentrations tolerated by the striped bass are defined. Climate change scenarios from GCMs are used to estimate changes in water temperatures through the year at sites along the eastern North American range of the striped bass. The water temperature changes are used to estimate changes in the fish's geographic distribution and changes in the timing of spawning. An illustrative example (Chesapeake Bay) is used to discuss potential habitat changes in estuaries. Habitat, as defined by suitable temperatures and dissolved oxygen concentrations, is also examined during base and climate change scenarios in a southeastern reservoir.

F-REPRINT, M-GCM-BASED, R-CANADA, R-US, S-USE, T-CASE STUDY

Croley, T. E., II, and H. C. Hartmann. 1989. Effects of climate changes on the Laurentian Great Lakes levels. pp. 4.1–4.34. In J. B. Smith and D. Tirpak (eds.), The Potential Effects of Global Climate Change on the United States. U.S. Environmental Protection Agency, Washington, D.C.

A series of models (basin hydrologic, limnologic, hydraulic routing, and operational) is used to estimate basin meteorology and lake hydrodynamics with and without climate change. Results indicated increased evapotranspiration, altered seasonal distribution of runoff with net annual decreases, decreased soil moisture, altered lake hydrodynamics and ice formation, and changed lake levels. Possible consequences include allocation conflicts, decreases in hydropower output, wetlands effects, impacts to shipping industry, problems related to lake dredging and disturbance of toxins, impacts to aquatic ecology, and implications for lake regulation plans.

M-GCM-BASED, R-US-GREAT LAKES, S-HYDROLOGY, S-MANAGEMENT, T-CASE STUDY

Croley, T. E., II, and H. C. Hartmann. 1989. Climate change effects on Great Lakes levels. pp. 653–58. In M. A. Ports (ed.), Proceedings of the 1989 National Conference on Hydraulic Engineering, New Orleans, La., August 14–18, 1989. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, M-GCM-BASED, R-US-GREAT LAKES, S-HYDROLOGY, S-MANAGEMENT, T-CASE STUDY

Croley, T. E. 1990. Laurentian Great Lakes double carbon dioxide climate change—hydrological impacts. Clim. Change 17:27–47.

The "net basin supply," or runoff, from the 121 watersheds covering an area of 770,000 $m^2$ draining into the Laurentian Great Lakes, was obtained with a large basin runoff model, a daily conceptual model of watershed hydrology. Lake evaporation was also modeled under baseline and double-$CO_2$ climate conditions projected by GCMs. Reductions from 23 to 51% in net basin supply were projected for all the Great Lakes. Considerable variation in the components of net basin supply existed among different modeled scenarios.

M-GCM-BASED, R-US-GREAT LAKES, S-HYDROLOGY, T-CASE STUDY

Cuthbert, D. R. 1989. Effects on water resources. pp. 160–61. In Report of the First U.S.-Canada Symposium on Impacts of Climate Change on the Great Lakes Basin. National Oceanic and Atmospheric Associaton (NOAA) National Climate Program Office, Rockville, Maryland.

DIALOG, F-ABSTRACT, R-US-GREAT LAKES, S-HYDROLOGY, T-DISCUSSION

da Cunha, L. V. 1989. Water resources situation and management in the EEC. Hydrogeologie 2:57–69.

An overview of potential economic impacts from climate-induced water resources changes in Europe is provided. The current water situation in Europe is evaluated using population statistics and various climate change scenarios. The report concludes that a climate change may bring undesirable effects to European water resources (e.g., saltwater intrusion). The author recommends that an improved quantitative understanding of the hydrologic cycle be developed, temporal variations (interannual and intrannual) be better understood, the relationship between future water use in relation to future economic and social development be studied, better water management practices be developed (e.g., changed regulatory procedures), and water quality and pollution be considered in estimates of future water demand. Many water management policy points are presented for consideration.

DIALOG, F-REPRINT, R-EUROPE, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-DISCUSSION, T-REVIEW

Davidson, M. A., W. W. Dreyfoos, and W. K. Prause. 1987. Local responses to sea level rise, Charleston, South Carolina. pp. 223–35. In M. Meo (ed.), Proceedings of the Symposium on Climate Change in the Southern United States: Future Impacts and Present Policy Issues, May 28–29, 1987, New Orleans, La. Science and Public Policy Program, University of Oklahoma, Norman.

DIALOG, F-REPRINT, R-US-S ATLANTIC/GULF, S-MANAGEMENT, S-USE, T-DISCUSSION

Day, J. W., and A. A. Balkema. 1987. Consequences of sea level rise– implications from the Mississippi Delta. pp. 146–52. In H. G. Wind (ed.), Impact of Sea Level Rise on Society, Report of a Project-Planning Session, Delft, the Netherlands, August 27–29, 1986. Publisher unknown, City unknown.

DIALOG, F-ABSTRACT, M-HISTORICAL, R-US-MISSISSIPPI, S-MANAGEMENT, T-CASE STUDY

DeAngelis, D. L., and R. M. Cushman. 1990. Potential applications of models in forecasting the effects of climate change on fisheries. Trans. Am. Fish. Soc. 119(2):224–39.

This paper traces and clarifies the general chain of mechanisms that lead from increasing atmospheric concentrations of greenhouse gases to changes in aquatic habitat and ecology. Models that simulate levels along this chain are discussed, as are in some cases uncertainties associated with these models. For instance, models of atmospheric greenhouse gas concentrations can project future trends in concentrations, and sources of uncertainty in these projections can be identified. Climate models can translate greenhouse gas concentration projections into effects on climate. Climate's effect on lake and ocean hydrodynamics can be simulated with mechanistic models, and ecosystem models can simulate the effects of changed physical conditions on productivity and other ecosystem features. The authors suggest that mechanistic models are useful to fishery and water resource managers in understanding possible mechanisms and extents of climate change-induced fishery changes. The paper reviews relevant modeling work, particularly modeling work at the aquatic ecosystem, fish process, and fish population levels, and suggests a research framework and needed research for pursuing a better grasp of the implications of climate change for fisheries.

F-REPRINT, R-NONE, S-USE, T-DISCUSSION, T- REVIEW

Dracup, J. A. 1977. Impact on the Colorado River basin and southwest water supply. pp. 121–32. In Panel on Water and Climate (ed.), Climate, Climatic Change, and Water Supply. National Academy of Sciences, Washington, D.C.

The legal background, hydrology, and geography of water supply in the Colorado River basin are characterized. It is pointed out that energy is the dominant water use variable in the region and water there is already a limited resource with many competing demands. Several scenarios of drought stress on the region are examined. Continued energy development in the area may be unwise in some situations, the report concludes.

F-REPRINT, R-US-COLORADO, S-HYDROLOGY, S-USE, T-DISCUSSION

Dracup, J. A. 1987. Climate change impacts on water resources: Issues and options. pp. 338–47. In M. Meo (ed.), Proceedings of the Symposium on Climate Change in the Southern United States: Future Impacts and Present Policy Issues, May 28–29, 1987, New Orleans, La. Science and Public Policy Program, University of Oklahoma, Norman.

Policy and options of the design and operation of water resource systems in the face of a climate change are discussed. Planning and management for climate change have been limited in the water resource community, where management tends to be short-term. Climate change information is needed at the regional level. Earlier case studies on climate change and hydrology are reviewed, and the report concludes that having a safety margin as a hedge against climate change is a worthwhile practice. Alternatives for water supply, such as increased surface storage, irrigation efficiency, and interbasin transfers are considered, but the author decides these options are impractical. Instead a switch from "supply management" to "demand management" measures is recommended (e.g., pricing water at its marginal value rather than average cost price, increasing reuse of water, increasing use of drip irrigation, employing water conservation, supporting conjunctive use of surface and groundwater, and marketing of water).

F-REPRINT, R-NONE, S-MANAGEMENT, T-DISCUSSION

Dracup, J. A., and D. R. Kendall. 1990. Floods and droughts. pp. 243–68. In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

Definitions of floods and droughts are provided. A site-specific analysis of drought frequency, magnitude, and severity is demonstrated with the use of a synthetic streamflow trace. The effect of a hypothetical shift in mean annual streamflow values on droughts is estimated. For floods, flood frequency analysis is used with and without modifications to the data to show how climate change estimates might be made. Also the report discusses the estimation of reservoir performance with mass curves to predict storage requirements and reservoir yield with and without climate change.

F-REPRINT, R-NONE, S-HYDROLOGY, S-MANAGEMENT, T-DISCUSSION

Dreyfoos, W. W., W. K. Prause, and M. R. Davidson. 1989. Local responses to sea level rise: Charleston, South Carolina. pp. 1395–1406. In Coastal Zone '89: Proceedings of the Sixth Symposium on Coastal and Ocean Management, Charleston, S.C., July 11–14, 1989, Vol. 2. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, R-US-S ATLANTIC/GULF, S-MANAGEMENT, T-DISCUSSION

Eagleson, P. S. 1987. The role of climate in hydrology. p. 12. In B. C. Klein-Helmuth and D. Savold (eds.), Abstracts of Papers, 1987 AAAS Annual Meeting (153rd National Meeting), Chicago, Ill. February 14–18, 1987. American Association for the Advancement of Science.

F-ABSTRACT, R-NONE, S-HYDROLOGY, T-DISCUSSION

Field, R. J., N. A. Neilsen, and R. T. Allen. 1988. The future of freshwater wetlands in the southeast United States. In Proceedings of the American Pollution Control Association 81(6):88/1003.

CLASSIFICATION: DIALOG, F-ABSTRACT, R-US-S ATLANTIC/GULF, S-USE, T-DISCUSSION

Fiering, M. B., and N. C. Matalas. 1990. Decision-making under uncertainty. pp. 75–84. In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

Water management concepts for including uncertainties about a physical system in water management are discussed. This basic framework is proposed: $E = (C - L)$, where E = excess, C = capacity, and L = load; and where S, or safety factor, equals C/L. If capacity and load are uncertain, Monte Carlo or Bayesian techniques can be used. Possible sources of error are identified: errors in density estimation of capacity and load, errors in model, parameterization error, observation error, forecast error, and fabrication error. Most errors, however, can be assessed.

F-REPRINT, R-NONE, S-MANAGEMENT, T-DISCUSSION

Fiering, M. B., and P. Rogers. 1989. Climate change and water resource planning. pp. 91–97. In Y. Y. Haimes and E. Z. Stakhiv (eds.), Risk-Based Decision Making in Water Resources, Proceedings of the Fourth Conference Sponsored by the Engineering Foundation, Santa Barbara, California, October 15–20, 1989. American Society of Civil Engineers, New York.

A general approach is proposed for exploring potential impacts of climate change on water resource systems. This approach can explicitly account for uncertainty in climate change scenarios (but assumes that probabilities of climate change scenarios, specifically, GCM–generated scenarios, can be determined and revised using a Bayesian approach). It is proposed that water systems be modeled and water resource response to alternative climate scenarios be quantified. Analysis of the regret (cost of planning for the wrong climate scenario) can be determined and a system design can be selected with an optimizing solution using a decision criterion that involves the regret.

F-REPRINT, R-NONE, S-MANAGEMENT, T-DISCUSSION

Flaschka, I., C. W. Stockton, and W. R. Boggess. 1987. Climatic variation and surface water resources in the Great Basin region. Water Resour. Bull. 23(1):47–57.

A calibrated and validated water balance model was applied to four watersheds in Nevada and Utah under base and hypothetical climate change scenarios. The four basins were selected on the basis of size, length of climate records, and degree of correlation between streamflow and weather station records. Scarcity of geographically representative, long–term weather station data made calibration and verification of the model problematic. Hypothetical climate change scenarios consisted of ±2°C with ±10% and 25% rainfall values. The $CO_2$ enrichment effect was not simulated because snowmelt is the dominant hydrologic mechanism in the basins. The "most probable change" (+2o C, -10% rainfall) reduced runoff from 17 to 28%. Cooler and wetter scenarios led to greater streamflow. Reduced runoff could cause significant problems in the Great Basin.

DIALOG, F-REPRINT, M-HYPOTHETICAL, R-US-GREAT BASIN, S-HYDROLOGY, T-CASE STUDY

Francis, R. C. 1990. Climate change and marine fisheries. Fisheries 15(6):7–9.

Three priority research areas for understanding linkages between global climate change and marine fisheries production are identified: (1) the effects of climate change on the oceanography of the different ocean zones, (2) an improved understanding of the structure and function of the marine food chain, and (3) an improved understanding of important social aspects of marine fisheries.

S-USE, T-DISCUSSION

Frank, K. T., R. I. Perry, and K. F. Drinkwater. 1990. Predicting responses of northwest Atlantic invertebrate and fish stocks to carbon dioxide–induced climate change. Trans. Am. Fish. Soc. 119(2):353–65.

F-REPRINT, R-US-NEW ENGLAND, R-CANADA, S-USE, T-CASE STUDY, T-REVIEW

Frederick, K. D., and A. Kneese V. 1990. Reallocation by markets and prices. pp. 395–420. In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

F-REPRINT, M-HISTORICAL, R-US-WESTERN, S-USE, T-DISCUSSION, T-CASE STUDY

Geological Society of America. 1990. Hydrogeology and Quaternary Geology and Geomorphology Divisions Symposium: Transient Responses to Global Change – The Geomorphic and Hydrologic Record, Session 90. pp. A208–A253. In Abstracts with Programs, the Geological Society of America 1990 Annual Meeting, Dallas, Texas, October 29 – November 1, 1990. The Geological Society of America.

F-ABSTRACT

Gerwick, B. C. 1990. Effect of global warming on Arctic coastal and offshore engineering. J. Cold Reg. Eng. 4(1):1–5.

DIALOG, F-ABSTRACT, R-ARCTIC, S-MANAGEMENT, T-DISCUSSION

Gissendammer, E. J. 1987. Coastal resource protection policies and a changing climate. pp. 216–22. In M. Meo (ed.), Proceedings of the Symposium on Climate Change in the Southern United States: Future Impacts and Present Policy Issues. May 28–29, 1987, New Orleans, La. Science and Public Policy Program, University of Oklahoma, Norman.

DIALOG, F-REPRINT, R-US-S ATLANTIC/GULF, S-MANAGEMENT, T-DISCUSSION

Glantz, M. H. 1990. Does history have a future? Forecasting climate change effects on fisheries by analogy. Fisheries 15(6):39–44.

Past responses of marine fisheries resource management to a stress on resources analogous to climate change are examined. It is believed that the information gained through this approach ("forecasting by analogy") will help anticipate future responses to climate change effects. Lessons learned from case histories include the importance of perceptions of the resource abundance; the need to determine how to handle a highly variable, highly abundant resource; the need to understand regional distributions of the impacts of environmental change; and the need for national policies to cope with changes in the resource.

F-REPRINT, M-HISTORICAL, R-EUROPE, S-USE, T-CASE STUDY

Glantz, M. H., and T. M. L. Wigley. 1987. Climatic variations and their effects on water resources. pp. 625–42. In D. J. McLaren and B. J. Skinner (eds.), Resources and World Development. John Wiley and Sons, New York.

Past regional hydrologic and social responses to climatic fluctuations for three case study areas are explored: the Colorado River system, the Yakima River basin, and the Ogallalla Aquifer in the Great Plains. The variability and the probabilities of extreme events, including runs of dry or wet years, are revealed to be important in examinations of climatic effects on water resources. A review of methods for assessing the sensitivity of runoff to climate change is also included.

F-REPRINT, M-HISTORICAL, R-US-ARKANSAS/WHITE/RED, R-US-COLORADO, R-US-MISSOURI, R-US-PACIFIC NORTHWEST, S-HYDROLOGY, S-USE, T-CASE STUDY

Gleick, P. 1987. Climate changes, water resources, and institutional responses: A look at the United States, Mexico, and the Colorado River. pp. 450–65. In M. Meo (ed.), Proceedings of the Symposium on Climate Change in the Southern United States: Future Impacts and Present Policy Issues, May 28–29, 1987, New Orleans, La. Science and Public Policy Program, University of Oklahoma, Norman.

The potential vulnerability of current water allocation rules in the Colorado River basin to possible climate change– induced changes in streamflow and potential political complexities in negotiations related to water rights are examined. The following is recommended: review and clarify the U.S.–Mexico treaty to be able to accommodate potential climate change– induced changes; deal with peripheral

political problems now to ease future renegotiations; examine conservation measures; and, in general, revise principles governing international water courses.

F-REPRINT, R-US-COLORADO, S-USE, T-DISCUSSION

Gleick, P. H. 1986. Regional water availability and global climatic change: The hydrologic consequences of increases in atmospheric carbon dioxide and other trace gases. Available from University Microfilms, Ann Arbor, Michigan.

DIALOG, F-ABSTRACT, M-UNKNOWN, R-US- CALIFORNIA, S-HYDROLOGY, T-CASE STUDY

Gleick, P. H. 1986. Methods for evaluating the regional hydrologic impacts of global climatic changes. J. Hydrol. 88(1-2):97–116.

Different hydrologic modeling methods for regional climate change impact studies are evaluated, and issues for determining modeling approach are discussed. These issues include inherent model accuracy, the availability and accuracy of model calibration and validation input data, the validity of the model for climate conditions of interest, and the ability of the model to be used with GCM climate parameter output. This paper demonstrates the suitability of regional water balance models for regional hydrologic climate change studies.

DIALOG, F-REPRINT, R-NONE, S-HYDROLOGY, T-DISCUSSION, T-REVIEW

Gleick, P. H. 1986. Regional water resources and global climate change. pp. 217–249. In Effects of Changes in Stratospheric Ozone and Global Climate. U.S. Environmental Protection Agency, Washington, D.C.

F-REPRINT, M-GCM-BASED, M-HYPOTHETICAL, R-US-CALIFORNIA, S-HYDROLOGY, T-CASE STUDY

Gleick, P. H. 1987. Global climatic changes and regional hydrology, impacts and responses. pp. 389–402. In S. I. Solomon, M. Beran, and W. Hogg (eds.), The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources. International Association of Hydrological Sciences Press, Wallingford, United Kingdom.

DIALOG, F-REPRINT, R-GLOBAL, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-DISCUSSION

Gleick, P. H. 1987. The development and testing of a water balance model for climate impact assessment: Modeling the Sacramento basin. Water Resour. Res. 23(6):1049–61.

A monthly water balance model is developed to perform assessments of potential impacts and sensitivities of water resources in California's Sacramento Basin to greenhouse effect climate change. The model algorithms for computing monthly runoff, assumptions regarding storm runoff fraction, watershed lag, soil moisture for each of two subbasins into which the system is divided, and rationale for dividing the basin into an upper and lower portion are described. The model is verified both with a split sample test in which a 50-year record of precipitation, temperature, and runoff is divided into calibration and verification portions, and with a differential split sample test in which periods of extreme climatic conditions extracted from the 50-year record are used to calibrate and evaluate the model performance under very different climate conditions. Residuals of model predictions are examined for trends. It was concluded that the model performs well under different climate conditions and that there are no discernible biases in the model except for slight overestimation of runoff during the winter and early spring.

DIALOG, F-REPRINT, M-GCM-BASED, M-HYPOTHETICAL, R-US-CALIFORNIA, S-HYDROLOGY, T-CASE STUDY

Gleick, P. H. 1987. Regional hydrologic consequences of increases in atmospheric $CO_2$ and other trace gases. Clim. Change 10(2):137–60.

A water balance model is used to estimate potential hydrologic sensitivities to greenhouse effect climate change in the Sacramento River basin in northern California. The calibration and verification of this model were demonstrated in Gleick (1987). The sensitivity of runoff to hypothetical scenarios of changes in rainfall (monthly rainfall plus or minus 0–20%) and temperature (monthly temperature plus 2–4°C) as well as runoff sensitivity to annual rainfall and temperature regimes taken from GCMs was evaluated. Results indicate that a shift in the seasonality of runoff and soil moisture (increased winter runoff, decreased summer runoff, and decreases in summer soil moisture) is an impact arising from a large range of climate projections. The changes in temperatures had a stronger effect on changes in the seasonal distribution of runoff than the changes in precipitation. This is primarily because of the effects of temperature on the timing and rapidity of spring snowmelt, and on evapotranspiration and soil moisture.

DIALOG, F-REPRINT, M-GCM-BASED, M-HYPOTHETICAL, R-US-CALIFORNIA, S-HYDROLOGY, T-CASE STUDY

Gleick, P. H. 1988. The effects of future climate change on international water resources: The Colorado River, the U.S., and Mexico. Policy Sci. 21:23–39.

This report compiles the results of studies on the effects of climate change on runoff in major semiarid river basins, which are related to possible changes in the lower Colorado River basin. These possible changes in hydrology are discussed in the context of past political conflicts and tensions that have arisen from reductions in water supply in the United States and Mexico. The author recommends that climate change considerations be written into international water resources agreements.

F-REPRINT, R-US-COLORADO, S-HYDROLOGY, S-USE, T-DISCUSSION, T-REVIEW

Gleick, P. H. 1989. Climate change, hydrology, and water resources. Rev. Geophys. 27(3):329–44.

Theory and methods used in research on the potential impacts of climate change on hydrology and water resources are reviewed. A discussion of the basic research scheme (development of estimates of changes in climate, translation of these climate changes into changes in hydrology, and interpretation of hydrologic changes for implications for water resources) is included. Four sources of climate change scenarios are reviewed: GCMs, paleoclimate records, climate analogues, and hypothetical estimates. The applicability of different kinds of hydrologic models– water balance, conceptual, and others—are reviewed. The research literature for work on reservoir, water quality, hydroelectric and other energy production, irrigation, and environmental service impacts of climate change is examined. Research needs, which include the development of appropriate spatial and temporal information from GCMs and a better understanding of ecologic, hydrologic, and regional-scale processes are identified.

DIALOG, F-REPRINT, R-US, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-REVIEW

Gleick, P. H. 1989. Climate change and international politics: Problems facing developing countries. Ambio 18(6):333–39.

DIALOG, F-ABSTRACT, R-GLOBAL, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-DISCUSSION

Gleick, P. H. 1990. Vulnerability of water systems. pp. 223–40. In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

This report defines and discusses three types of water-supply-system vulnerability (meteorologic/climatologic, system and design, and geographic/societal). The paper quantifies, with data from the U.S. Water Resources Council and the U.S. Department of Interior, values for vulnerability for each U.S. water resource region. *Vulnerability* is defined in terms of five measures: storage, demand, hydroelectricity, overdraft, and variability vulnerability. "Risk" maps for each of these vulnerability measures for the United States are presented.

F-REPRINT, R-US, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-CASE STUDY

Gleick, P. H. 1991. The vulnerability of runoff in the Nile Basin to climatic changes. Env. Prof. 13:66–73.

Three analysis approaches are used to examine the sensitivity of runoff in the Nile River to climatic change: climate analogue hydrologic data are reviewed, recent historical climate and hydrologic data are examined, and simple climate-runoff models with GCM-generated climate change scenarios are used to estimate the response of runoff to atmospheric and climatic variations. This review of information about runoff sensitivity to anomalous climates is supplemented by a review of social consequences of prior drought episodes in the basin. The history of water allocation treaties among the several nations that use Nile streamflow, and the current agreement structure, with previously identified weaknesses, are reviewed. The author concludes that although weaknesses in the present international resource management structure should be addressed even if there were no threat of climatic change, the possibility of climate change magnifies the risk associated with the treaty weaknesses.

F-REPRINT, R-AFRICA, S-HYDROLOGY, S-USE

Grubert, J. P. 1989. Greenhouse effect on estuarine saltwater intrusion. pp. 188–93. In M. A. Ports (ed.), Proceedings of the 1989 National Conference on Hydraulic Engineering, New Orleans, La., August 14–18, 1989. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, R-UNKNOWN, S-USE, T-DISCUSSION

Gucinski, H., R. T. Lackey, and B. C. Spence. 1990. Global climate change: Policy implications for fisheries. Fisheries 15(6):33–38.

Fishery management policy options are discussed, including research investment strategies, the option to take no action, and the option to formulate emissions policy. Possible fisheries mitigative actions are presented, such as breeding hardy stocks of fish. The author supports the option to increase research on climate and its effects on fisheries stocks.

F-REPRINT, R-NONE, S-USE, T-DISCUSSION

Hains, D. K., and C. F. Hains. 1989. Impacts of global warming on runoff in the upper Chattahoochee River basin. pp. 8.1–8.26. In J. B. Smith and D. Tirpak (eds.), The Potential Effects of Global Climate Change on the U.S., Appendix A: Water Resources. U.S. Environmental Protection Agency, Washington, D.C.

Two approaches are used to estimate the effects of climate change on the Appalachicola-Chattahoochee-Flint River system in Georgia. A conceptual soil moisture accounting model (the Sacramento model) is applied to estimate runoff from a small headwater basin in the system. An empirical multiple correlation model is applied to historical monthly flow records and monthly rainfall and evaporation data with GCM-based climate change estimates to project potential whole-basin runoff under greenhouse climate conditions.

F-REPRINT, M-GCM-BASED, R-US-S ATLANTIC/GULF, S-HYDROLOGY, T-CASE STUDY

Hains, D. K., and H. R. Henry. 1989. Issues of detectability of climate change impacts on the runoff of a southeastern river basin. pp. 647–52. In M. A. Ports (ed.), Proceedings of the 1989 National Conference on Hydraulic Engineering, New Orleans, La., August 14–18, 1989. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, R-US-S ATLANTIC/GULF, S-HYDROLOGY, T-CRITIQUE, T-DISCUSSION

Hargreaves, G. H. 1981. Water requirements and human-induced climate change. J. Irrig. Drain. 107(IR3):247–55.

The possibility of climate change–induced changes in the needs and management of irrigated and dryland agriculture is discussed, and potential evapotranspiration is the focus of discussion. The implications, uncertainties, and significance of increasing $CO_2$ are examined.

F-REPRINT, R-GLOBAL, S-USE, T-DISCUSSION

Hartmann, H. C. 1990. Climatic change impacts on Laurentian Great Lakes levels. Clim. Change 17:49–67.

This paper discusses simulated lake levels and water supplies in the Great Lakes using inputs from GCMs. GCM outputs were used to modify baseline basin runoff, overlake precipitation, and lake evaporation, which were then used to simulate water supply. Hydraulic routing models and information about operational regulation plans were used to translate water supply into water levels in the Great Lakes under baseline and climate change conditions. It was concluded that wholly new approaches to water management in the Great Lakes may be needed to deal with

possible increased allocation conflicts among Great Lakes water users. Resources that could be affected include environmental (fish, wildlife, and wetlands), power production (hydropower, coal transportation by ship, and economics of peak power demand), navigation (and such transportation-dependent industries as iron, steel, and grain), local economies, agriculture, fishing, and recreation.

F-REPRINT, M-GCM-BASED, R-US-GREAT LAKES, S-MANAGEMENT, T-CASE STUDY

Hawxhurst, P. 1987. Louisiana's responses to irreversible environmental change. pp. 173–86. In M. Meo (ed.), Proceedings of the Symposium on Climate Change in the Southern United States. Science and Public Policy Program, University of Oklahoma, Norman.

DIALOG, F-REPRINT, R-US-S ATLANTIC/GULF, S-MANAGEMENT, T-DISCUSSION

Hay, L. E., G. J. McCabe Jr., D. M. Wolock, and M. A. Ayers. 1991. Simulation of precipitation by weather type analysis. Wat. Resour. Res. 27(4):493–501.

This paper demonstrates a method for translating GCM-based predictions of future changes in synoptic climate variables (wind direction and cloud cover) into daily precipitation sequences. Six classes of weather types are established and related to wind direction and cloud cover. Daily records of these variables are used to create a "weather type calendar" that assigns a weather type to each day in a period. The probability of precipitation on the days of each weather type are calculated on a monthly basis. These probabilities are used to classify each simulated day of the weather type calendar as wet or dry. Wet days are assigned mean monthly precipitation intensities.

F-REPRINT, M-GCM–BASED, R-US-MID-ATLANTIC, S-HYDROLOGY, T-CASE STUDY

Healey, M. C. 1990. Implications of climate change for fish management policy. Trans. Am. Fish. Soc. 119(2):366–73.

F-REPRINT, R-NONE, S-USE, T-DISCUSSION, T-REVIEW

Hekstra, G. P. 1986. Will climatic change flood the Netherlands? Effects on agriculture, land use, and well-being. Ambio 15(6):316–26.

The water resources issues that would be affected by climate change in the Netherlands are defined. A table listing these issues and classifying each issue as critical or of little importance is presented. A discussion of potential impacts includes hydrology and fisheries. Possible effects on the Netherlands' highly regulated river system are also examined. These effects include summer deficits in reservoirs; groundwater intrusion because of lower river, reservoir, and lake levels; and impacts on navigation, sedimentation, harbors, and fisheries. The report suggests that the protection of coasts and better understanding of hydrology are priorities. Research recommendations are provided.

DIALOG, F-REPRINT, R-EUROPE, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-DISCUSSION

Henderson-Sellers, B. 1987. Impact of increasing atmospheric carbon dioxide concentrations upon reservoir water quality. pp. 571–76. In S. I. Solomon, M. Beran, and W. Hogg (eds.), The Influence of Climate Change and Climate Variability on the Hydrologic Regime and Water Resources. International Association of Hydrological Sciences Press, Wallingford, United Kingdom.

This paper examines potential impacts on lake water level resulting from climate change, using a high- resolution (both spatial and temporal) lake thermal stratification model. The model is based on an energy budget equation with a heat transfer component. This study is unusual because estimated change in global mean energy flux as a result of elevated atmospheric greenhouse gas concentrations is used to drive the lake model (as opposed to the frequent use of GCM output to drive limnologic and hydrologic models; see for instance Gleick 1987, Bultot et al. 1988, McCabe et al. 1989, Cooter and Cooter 1990, Chang et al. 1992, among others). Decreases in storage over a 50-year simulation period were projected. Potential greenhouse-induced changes in hydrology are not modeled but are discussed, as are possible changes in lake trophic status. The modeling study location is identified as a site at 54° N lat.

DIALOG, F-REPRINT, M-OTHER, R-UNKNOWN, S-USE, T-CASE STUDY

Hendry, M. D. 1988. Climatic change, future sea-level rise, and implications for Caribbean shorelines. pp. 11–13. In A. Rafi (ed.), Abstracts and Programme, International Conference on Recent Advances in Caribbean Geology, November 18–20, 1988. Geological Society of Jamaica, Kingston.

DIALOG, F-ABSTRACT, R-CARIBBEAN, S-MANAGEMENT, S-USE, T-DISCUSSION

Hengeveld, H. G. 1990. Global climate change: Implications for air temperature and water supply in Canada. Trans. Am. Fish. Soc. 119(2):176–82.

A concise background on the reasons for projections of global climate change is presented, and some estimates of future air temperatures and soil moisture over Canada are summarized. A brief list of aquatic resources that could be affected by changes in climate is also included.

F-REPRINT, R-CANADA, S-OTHER, T-DISCUSSION

Hill, D. K., and J. J. Magnuson. 1990. Potential effects of global climate warming on the growth and prey consumption of Great Lakes fish. Trans. Am. Fish. Soc. 119(2):265–75.

F-REPRINT, M-GCM-BASED, R-US-GREAT LAKES, S-USE, T-CASE STUDY

Holmes, J. A. 1990. Sea lamprey as an early responder to climate change in the Great Lakes basin. Trans. Am. Fish. Soc. 119(2):292–300.

F-REPRINT, M-OTHER, R-US-GREAT LAKES, S-USE, T-CASE STUDY

Idso, S., and A. Brazel. 1984. Rising atmospheric carbon dioxide may increase streamflow. Letter to Nature. Nature 312:51–53.

The authors observe that an earlier modeling study of potential effects of climate change on hydrology in arid basins in Arizona (Revelle and Waggoner 1983) omitted in its model the experimentally-demonstrated "antitranspirant" effects of atmospheric $CO_2$ enrichment on plants. In this paper the modeling study is replicated, but the evapotranspiration term is modified to allow a two-thirds reduction in plant transpiration over the vegetated area of the modeled basins. This modification led to substantially divergent simulated streamflow results; whereas the earlier model produced decreases of 40–74% in streamflow, the modified model produced increases of as much as 40–60%. The results produced by the modified model are compared with those of Aston (1984) in which a deterministic process model was used to simulate the effects of doubled $CO_2$ on stomatal resistance.

F-REPRINT, M-HYPOTHETICAL, R-US-COLORADO, S-HYDROLOGY, T-CRITIQUE, T-CASE STUDY

Jacoby, H. D. 1990. Water quality. pp. 307–28. In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

F-REPRINT, R-US, S-USE, T-DISCUSSION

Johnson, T. B., and D. O. Evans. 1990. Size-dependent winter mortality of young-of-the-year white perch: Climate warming and invasion of the Laurentian Great Lakes. Trans. Am. Fish. Soc. 119(2):301–13.

F-REPRINT, M-GCM-BASED, R-US-GREAT LAKES, S-USE, T-CASE STUDY

Jurak, D. 1989. Effect of climate change on evaporation and water temperature. pp. 138–48. In Conference on Climate and Water, September 11–15, Helsinki, Finland. Valtion Painatuskeskus, Helsinki, Finland.

DIALOG, F-ABSTRACT, M-GCM-BASED, R-EUROPE, S-HYDROLOGY, S-USE, T-CASE STUDY

Karl, T. R., and W. E. Riebsame. 1989. The impact of decadal fluctuations in mean precipitation and temperature on runoff: A sensitivity study over the United States. Clim. Change 15:432–447.

F-REPRINT, M-ANALOG, R-US, S-HYDROLOGY, T-CASE STUDY

Kay, P. A. 1986. Issues in specifying climate forcing of variability. pp. 59–65. In M. Karamouz, G. R. Baumli, and W. J. Brick (eds.), Water Forum '86: World Water Issues in Evolution, Proceedings of the Conference, Long Beach, Calif., August 4–6. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, R-MIDDLE EAST, R-US-GREAT BASIN, S-HYDROLOGY, T-CRITIQUE

Kendall, D. R., and J. A. Dracup. 1988. Hydrologic response of floods and droughts to climatic change. Trans. Am. Geophys. Union 69(44):1221.

Synthetic streamflow records for 10,000 years were generated, then adjusted according to hypothetical climate change scenarios. Then, the 50-, 100-, and 200-year droughts produced with each trace were compared. Small changes in streamflow were observed to have a large effect on drought severity and duration. Because snow storage is likely to decrease, winter streamflow is likely to increase and spring streamflow to decline. These effects would very likely have an impact on western irrigated agriculture. Increased reservoir storage is a suggested mitigation measure. Region is not provided.

DIALOG, F-ABSTRACT, M-HYPOTHETICAL, R-NONE, S-HYDROLOGY, T-DISCUSSION

Kennedy, V. S. 1990. Anticipated effects of climate change on estuarine and coastal fisheries. Fisheries 15(6):16–25.

The resources of estuaries and coastal ecosystems are discussed, along with possible alterations in these resources with climate change (such as sea level rise, changing thermal structure and distribution, changing salinity levels, and changes in wind and water circulation). The paper calls for baseline monitoring.

F-REPRINT, R-NONE, S-USE, T-DISCUSSION

Kite, G. 1989. Use of time series to detect climate change. J. Hydrol. 111(1–4):259–79.

DIALOG, S-OTHER

Klemes, V. 1983. Climate change and the planning of water resource systems. pp. 485–500. In Sixth Annual Hydrotechnical Conference, June 2–3, 1983, Ottawa, Ontario. Canadian Society for Civil Engineering. (As reprinted in Klemes 1985).

The statistical significance of the modeled water resource impacts of climate change produced in an earlier study (Nemec and Schaake 1982) are critically examined. Several points are made, including the observation that the brevity of many hydrologic time series considerably limits the ability to model the hydrologic impacts of climate change as uncertainties in input data and future operating conditions are of the same magnitude as the range of estimates of future climate change. It is suggested that although research and greater understanding of the issue are needed, there is little the water manager can do in anticipation of climate change beyond the traditional tactic of building safety margins in water management devices

F-REPRINT, R-NONE, S-MANAGEMENT, T-CRITIQUE, T-DISCUSSION

Klemes, V. 1985. Sensitivity of Water Resource Systems to Climate Variations. World Meteorological Organization, Geneva. World Climate Applications Programme Publication No. WCP-98. 17 pp. with 5 appendices.

Major technical obstacles to better anticipation of and planning for the possibility of climate change and its impacts on water resources are defined. These obstacles include the following: imperfect understanding of climate dynamics and uncertainty about future climate change; imperfect understanding of mechanisms generating streamflow; lack of long-term streamflow records, which prevents the identification of the underlying structure of the streamflow stochastic process; and limited availability of statistical methods for work with the short hydrologic records that do exist. Research needs are identified.

F-REPRINT, R-NONE, S-HYDROLOGY, S-MANAGEMENT, T-DISCUSSION

Kuo, C. Y. 1986. Sea level rise and coastal stormwater drainage. pp. 35–42. In M. Karamouz, G. R. Baumli, and W. J. Brick (eds.), Water Forum '86: World Water Issues in Evolution, Proceedings of the Conference, Long Beach, Calif., August 4–6, 1986. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, R-UNKNOWN, S-MANAGEMENT, T-DISCUSSION

Kuo, C. Y. 1988. Sea level rise and water resources management. pp. 44–47. In M. Strech (ed.), Proceedings of the 15th Annual Water Resources Conference, June 1–3, 1988, Norfolk, Va. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, R-US-MISSISSIPPI, R-US-S ATLANTIC/GULF, S-MANAGEMENT, S-USE, T-DISCUSSION

Lamb, P. J. 1987. On the development of regional climate scenarios for policy-oriented climate impact assessment. Bull. Am. Meterol. Soc. 68(9):1116–22.

The sources of climate scenarios available for evaluations of impacts of climate variations are reviewed. The two main sources of climate scenarios [use of climate modeling (GCM) results and development of scenarios from past or proxy data] are discussed, and some of their principal strengths and weaknesses are described. Research needed to make climate-change scenarios more useful for impact assessment is suggested.

F-REPRINT, R-NONE, S-OTHER, T-DISCUSSION

Leatherman, S. P. 1988. Implications of sea level rise on the south shore of Long Island, New York. Northeast. Environ. Sci. 7(1):83–90.

DIALOG, F-ABSTRACT, R-US-MID-ATLANTIC, S-MANAGEMENT, S-USE, T-DISCUSSION

Leatherman, S. P., and C. H. Gaunt. 1989. National assessment of beach nourishment requirements associated with accelerated sea level rise. pp. 1978–93. In Coastal Zone '89: Proceedings of the Sixth Symposium on Coastal and Ocean Management, Charleston, S.C., July 11–14, 1989. Vol. 2. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, M-HYPOTHETICAL, R-US, S-MANAGEMENT, T-CASE STUDY

Lettenmaier, D. P. 1989. Hydrologic implications of global warming on water resources in California. pp. 643–46. In M. A. Ports (ed.), Proceedings of the 1989 National Conference on Hydraulic Engineering, New Orleans, La., August 14–18, 1989. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, M-GCM-BASED, R-US-CALIFORNIA, S-HYDROLOGY, S-MANAGEMENT, T-CASE STUDY

Lettenmaier, D. P., K. L. Brettman, and L. Vail. 1989. Robustness of a multiple-use reservoir to seasonal runoff shifts associated with climatic change. pp. 91–97. In Y. Y. Haimes and E. Z. Stakhiv (eds.), Risk-Based Decision Making in Water Resources, Proceedings of the Fourth Conference Sponsored by the Engineering Foundation, Santa Barbara, California, October 15–20, 1989. American Society of Civil Engineers. New York.

The sensitivity of multipurpose reservoir management to increases in annual average air temperature of up to 4°C was examined. The sensitivity to the same temperature changes with the use of two different operational decision making methods (heuristic operating rule or rule curve and optimization algorithm) was also studied. Under both operating methods, water supply reliability would be degraded by roughly the same amount, mostly because of shifts in seasonal runoff distribution induced by increased annual air temperatures. Also, hydroelectricity revenues would increase because of increased power releases made possible by projected winter peak runoff and already existing winter peak demand. The optimization algorithm led to substantially larger hydropower revenues under present climate conditions; under warmer conditions the difference between the two methods decreased.

M-HYPOTHETICAL, R-US-PACIFIC_NORTHWEST, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-CASE STUDY

Lettenmaier, D. P., and S. J. Burges. 1978. Climate change: Detection and its impact on hydrologic design. Water Resour. Res. 14(4):679–87.

Statistical models of streamflow based on different assumptions of stationarity in generic hydrologic process means are discussed and demonstrated. The paper concludes that with short hydrologic records typically available to hydrologists, it will be difficult to determine whether the distribution is generated by a stationary or nonstationary mean. The authors show, on the other hand, that even with nearly indistinguishable differences in generating mechanisms, the impact of the two types of streamflow distributions may have substantial effects on reservoir storage requirements.

R-NONE, S-HYDROLOGY, S-MANAGEMENT, T-DISCUSSION

Lettenmaier, D. P., and T. Y. Gan. 1990. Hydrologic sensitivities of the Sacramento–San Joaquin river basin, California, to global warming. Water Resour. Res. 26(1):69–86.

The hydrology of four small catchments in the Sacramento–San Joaquin basin under "current" and greenhouse climate conditions was simulated with calibrated and validated physical/conceptual hydrologic models (coupled National Weather Service snowmelt and soil moisture accounting models). The study used GCM output as well as greenhouse analogue climate records to adjust 100 years of rainfall and temperature records (developed stochastically from 30-year records). Snow accumulation, ablation, and runoff were the primary variables of concern. Analyses of these variables' sensitivity to changes in rainfall and temperature were performed. The response of all four catchments to changed climate conditions was dominated by temperature- related changes in snowmelt and relatively unaffected by GCM-predicted rainfall changes. This study was followed by an examination of the water resource implications of these hydrologic changes (Lettenmaier and Sheer, 1991, also included in this bibiography).

DIALOG, F-REPRINT, M-GCM-BASED, R-US-CALIFORNIA, S-HYDROLOGY, T-CASE STUDY

Lettenmaier, D. P., T. Y. Gan, and D. R. Dawdy. 1989. Interpretation of hydrologic effects of climate change in the Sacramento–San Joaquin river basin, California. pp. 1.1–1.52. In J. B. Smith, and D. Tirpak (eds.), The Potential Effects of Global Climate Change on the United States. U.S. Environmental Protection Agency, Washington, D.C.

Four subbasins of the Sacramento–San Joaquin basin were selected to evaluate the hydrologic sensitivity to climate change. A soil moisture accounting model and the National Weather Service snowmelt model were used to simulate the effects of a set of GCM-based and analogue climate-warming scenarios. Results indicate that in a warmer world, hydrology changes from a snow-dominated to a rainfall-dominated regime. As a consequence, runoff and soil moisture are relatively elevated in the winter, whereas in the summer and spring decreases are simulated. Evapotranspiration peaks earlier in the year. Sensitivity tests indicate that changes in temperature rather than precipitation are more important in influencing the hydrologic regime.

F-REPRINT, M-GCM-BASED, R-US-CALIFORNIA, S-HYDROLOGY, T-CASE STUDY

Lettenmaier, D. P., and D. P. Sheer. 1991. Climatic sensitivity of California water resources. J. Water Resour. Plann. Manage. 117(1):108–25.

A modeling study of reservoir performance in California was conducted using GCM inputs. The results show large differences between base and $2xCO_2$ reservoir

performance, measured by deliveries to clients (thousands of acre-ft). Differences are especially large in early summer through autumn.

F-REPRINT, M-GCM-BASED, R-US-CALIFORNIA, S-MANAGEMENT, T-CASE STUDY

Lewis, J. E. 1989. Climatic change and its effects on water resources for Canada: A review. Can. Water Res. J. 14(1):34–55.

A general review of climate change scenarios for Canada and possible impacts on water supply are provided. Research on this topic, concentrating on hydrology (not water resources) and climate scenarios is reviewed.

DIALOG, F-REPRINT, R-CANADA, S-HYDROLOGY, T-REVIEW

Lins, H. F., E. T. Sundquist, and T. A. Ager. 1988. Information on selected climate and climate-change issues. U.S. Geological Survey Open File Report No. OF88-0718. 26 pp.

DIALOG, F-ABSTRACT, R-US, S-HYDROLOGY, T-REVIEW

Lockwood, J. G. 1989. Hydrometeorological changes due to increasing atmospheric $CO_2$ and associated trace gases. Prog. in Phys. Geogr. 13:115–27.

This paper discusses mechanisms of interaction among atmospheric water vapor, temperature, vegetation, humidity, radiation, and soil moisture. Discusses relationships between sea surface temperature (SST) and rainfall worldwide, with reference to rainfall in sub-Saharan Africa, suggesting that anomalous worldwide SST may indirectly drive rainfall patterns, with feedbacks from surface vegetation response and surface soil moisture.

F-REPRINT, R-NONE, S-HYDROLOGY, T-DISCUSSION

Long, A., and O. K. Davis. 1987. Climate change impacts on urban and rural economics in the Southwest: Focus on Arizona. pp. 466–74. In M. Meo (ed.), Proceedings of the Symposium on Climate Change in the Southern United States: Future Impacts and Present Policy Issues, May 28–29, 1987, New Orleans, La. Science and Public Policy Program, University of Oklahoma, Norman.

F-REPRINT, R-US-COLORADO, S-USE, T-DISCUSSION

Mabbutt, J. A. 1989. Impacts of carbon dioxide warming on climate and man in the semi-arid tropics. Clim. Change 15(1–2):191–222.

DIALOG, F-ABSTRACT, R-TROPICS, S-HYDROLOGY, T-DISCUSSION

MacNeil, J. 1990. Coastal defense plans struggle to tread water. Constr. Weekly 2(17):15–16.

DIALOG, F-ABSTRACT, R-EUROPE, S-MANAGEMENT, T-DISCUSSION

Magnuson, J. J., J. D. Meisner, and D. K. Hill. 1990. Potential changes in the thermal habitat of Great Lakes fish after global warming. Trans. Am. Fish. Soc. 119(2):254–64.

Thermal profiles from two studies of Lakes Michigan and Erie were used to estimate fish habitat volume (measured in meter-months and $km^2$-weeks). Thermal habitat, defined in two ways (broad and narrow), increased under three warming scenarios for three fish species selected to represent cold, cool, and warm thermal niche species. Empirical models of fish yield as a function of thermal habitat volume were used to estimate sustained fish yields for cold- and cool-water species in Lake Michigan. Little change in productivity was simulated for cold-water species, but increased productivity for one cool-water species was simulated. The authors discuss reduction of thermal habitat in terms of a "squeeze" in which a steep vertical thermal gradient in the water column leads to a reduced favorable temperature layer in the lake. The potential of hypolimnetic oxygen depletion for the further reduction of habitat volume was noted. Assumptions, model structure, and quality of data are described.

F-REPRINT, M-GCM-BASED, R-US-GREAT LAKES, S-USE, T-CASE STUDY

Magnuson, J. J., D. K. Hill, H. A. Regier, J. A. Holmes, J. D. Meisner, and B. J. Shuter. 1989. Potential response of Great Lakes fishes and their habitat to global climate warming. pp. 2.1–2.42. In J. B. Smith and D. Tirpak (eds.), The Potential Effects of Global Climate Change on the U.S., Appendix E: Aquatic Resources. U.S. Environmental Protection Agency, Washington, D.C.

The authors modeled potential changes in the Great Lakes thermal structure due to climate change, using GCM-based estimates of changes in climate parameters. Several fish species were selected and bioenergetics modeling of growth under the altered climate was performed. Population modeling was also performed and lake trophic dynamics were examined. It was concluded that climate change may cause changes in lake thermal habitat structure; changes in fish growth, reproductive success, and population size; and changes in prey consumption behavior.

M-GCM-BASED, R-US-GREAT LAKES, S-USE, T-CASE STUDY

Manabe, S., and R. T. Wetherald. 1985. Carbon dioxide and hydrology. Adv. Geophys. 28:131–56.

Discussion of hydrology and GCMs.

F-REPRINT, R-GLOBAL, S-HYDROLOGY, T-DISCUSSION

Mandrak, N. E. 1989. Potential invasion of the Great Lakes by fish species associated with climatic warming. J. Great Lakes Res. 15(2):306–16.

Fifty-eight fish species were identified as either recent invaders of the Canadian Great Lakes basin or as possible invaders. Nine ecological characteristics were used as explanatory variables to predict membership of the 58 species. Species that were reclassified from possible to recent invaders using discriminant analysis were considered to be potential invaders of the Great Lakes under conditions of climate warming. It was suggested that accelerated climatic warming could promote accelerated intrusion of these potential invaders, and such a phenomenon would have significant implications for fisheries managers of the Great Lakes basin.

DIALOG, F-REPRINT, M-GCM-BASED, R-US-GREAT LAKES, S-USE, T-CASE STUDY

Martinec, J., and A. Rango. 1989. Effects of climate changes on snowmelt runoff patterns. Remote Sensing and Large Scale Global Processes. pp. 31. In Proceedings of the International Association of Hydrological Sciences 3rd International Assembly, Baltimore, May 1989.

F-ABSTRACT, M-UNKNOWN, R-UNKNOWN, S-HYDROLOGY, T-UNKNOWN

Matalas, N. C. 1990. What statistics can tell us. pp. 139–50. In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

A discussion of trends in hydrologic records focusing on water quantity (as opposed to water quality) is presented. Testing for trends in means of hydrologic time series is discussed, and attention is given to issues of interpretation of results and significance of statistical tests. Included are results of tests for trends in low, mean, and high flows for regions in the United States which demonstrate, among other things, the considerable effect of the length of the time series on the results of the trend test. The comment is made that inclusion of persistence as an inherent characteristic in stationary hydrologic processes can lead to greater system resilience.

F-REPRINT, R-NONE, S-HYDROLOGY, T-DISCUSSION

Matalas, N. C., and M. B. Fiering. 1977. Water resource system planning. pp. 99–110. In Panel on Water and Climate (ed.), Climate, Climatic Change, and Water Supply. National Academy of Science, Washington, D.C.

This report demonstrates for water managers how uncertainty due to climate can be explicitly included in the development and management of water resource systems.

F-REPRINT, R-NONE, S-MANAGEMENT, T-DISCUSSION

Mather, J. R., and J. Feddema. 1986. Hydrological consequences of increases in trace gases and carbon dioxide in the atmosphere. pp. 251–71. In Effects of Changes in Stratospheric Ozone and Global Climate. U.S. Environmental Protection Agency, Washington, D.C.

F-REPRINT, M-GCM-BASED, R-GLOBAL, S-HYDROLOGY, T-CASE STUDY

Matthews, W. J., and E. G. Zimmerman. 1991. Potential effects of global warming on native fishes of the southern Great Plains and the Southwest. Fisheries 15(6):26–31.

This paper discusses the hypothesis that fish behavioral response to higher than normal temperature, which is to seek lower temperatures, will be limited in the southwestern United States and the southern Great Plains because streams in this region of the country tend to run laterally, not north to south. Furthermore, the authors discuss the assertion that limited existing variation in fish stocks may constrain the adaptability of certain fish species to global climate change. The paper concludes that projected temperature changes may be catastrophic for some species and may require management action.

F-REPRINT, R-US-ARKANSAS/WHITE/RED, R-US-MISSOURI, R-US-RIO GRANDE, R-US-TEXAS/GULF, S-USE, T-DISCUSSION, T-REVIEW

McCabe, G. J., Jr., and M. A. Ayers. 1989. Hydrologic effects of climate change in the Delaware River basin. Water Resour. Bull. 25(6):1231–42.

Potential changes in hydrology in the Delaware River basin, a 13,000 $mi^2$ basin providing water resources for 20 million people in the northeastern United States, were evaluated with a water balance model. Three representative catchments in the southern, middle, and northern (mountainous) regions of the basin were selected, and a Thornthwaite monthly water balance model was applied to simulate GCM-based and hypothetical scenarios of climate change on soil moisture and runoff. Temperature-related changes in evapotranspiration led to 9–25% decreases in average annual runoff in the catchments. Increases in air temperatures as small as 2°C led to significant changes in seasonal runoff distribution as a result of reductions in snow accumulation in the northern catchment. It was observed that increases in air temperatures are associated with increased sensitivity to decreases in rainfall. The GCM-based scenarios produced highly variable runoff results, (e.g., greater than 100% increases in autumn runoff were produced by the Oregon State University GCM, contrasted with nearly 90% decreases in autumn runoff produced by the Goddard Institute for Space Studies GCM). It was observed in general that increased air temperature will cause increased potential evapotranspiration and, if rainfall does not increase concurrently, lower soil moisture. Increased temperature will also decrease snow accumulation, elevating winter surplus but reducing spring runoff.

DIALOG, F-REPRINT, M-GCM-BASED, M-HYPOTHETICAL, R-US-MID-ATLANTIC, S-HYDROLOGY, T-CASE STUDY

McCauley, R. W., and D. M. Kilgour. 1990. Effect of air temperature on growth of largemouth bass in North America. Trans. Am. Fish. Soc. 119(2):276–81.

F-REPRINT, M-HYPOTHETICAL, R-US, S-USE, T-CASE STUDY

McCormick, M. J. 1989. Potential climate changes to the Lake Michigan thermal structure. pp. 6.1–6.26. In J. B. Smith and D. Tirpak (eds.), The Potential Effects of Global Climate Changes on the U.S., Appendix A: Water Resources. U.S. Environmental Protection Agency, Washington, D.C.

A one-dimensional model was used to simulate the vertical thermal structure of Lake Michigan. GCM outputs were used as scenarios of greenhouse climate. Model results suggest that greenhouse climate scenarios may lead to greater heat content of Lake Michigan in all seasons, particularly in the winter, and greater strength and duration of lake stratification. Lake turnover frequency may decrease substantially. These impacts, however, will depend on wind conditions; a reduction in wind speeds could enhance the effects of climate change on lake thermal structure.

F-REPRINT, M-GCM-BASED, R-US-GREAT-LAKES, S-USE, T-CASE STUDY

McCormick, M. J. 1990. Potential changes in thermal structure and cycle of Lake Michigan due to global warming. Trans. Am. Fish. Soc. 119(2):183–94.

F-REPRINT, M-GCM-BASED, R-US-GREAT-LAKES, S-USE, T-CASE STUDY

Mehta, A. J., and R. M. Cushman. 1989. Workshop on sea level rise and coastal processes. DOE/NBB-0086. U.S. Department of Energy, Washington, D.C.

DIALOG, F-ABSTRACT, M-UNKNOWN, S-MANAGEMENT, S-USE, T-DISCUSSION, T-CASE STUDY

Meier, W. L., Jr. 1977. Identification of economic and social impacts of water shortages. p. 85. In Climate, Climate Change and Water Supply. National Academy of Sciences, Washington, D.C.

The concept of water shortage is discussed. The effects of periodic water deficits on utilities and possible management responses, including conservation, restrictions, and shutdowns are reviewed. The author asserts that few utilities have concrete plans for shortages, and cities and utility management tend to delay shortage mitigative actions in order to minimize consumer inconvenience. Two case histories of social, cultural, and economic effects of drought are included: Texas, and York, Pennsylvania.

F-REPRINT, R-US-MID-ATLANTIC, R-US-TEXAS/GULF, S-USE, T-DISCUSSION

Meisner, J. D. 1990. Effect of climatic warming on the southern margins of the native range of brook trout, Salvelinus fontinalis. Can. J. Fish. Aquat. Sci. 47(6):1065–70.

This paper estimates changes in brook trout habitat distribution under a GCM-generated climate scenario. The estimate is based on known altitudinal and latitudinal distribution of trout; the relationship among groundwater temperature, altitude, and latitude; the role of groundwater temperature as a determinant of trout habitat; and an assumption that groundwater temperature can be approximated by adding 1—2°C to mean annual temperatures.

DIALOG, F-REPRINT, M-GCM-BASED, R-US, S-USE, T-CASE STUDY

Meisner, J. D. 1990. Potential loss of thermal habitat for brook trout due to climate warming in two southern Ontario streams. Trans. Am. Fish. Soc. 119(2):282–91.

GCM output is used to project possible changes in thermal habitat for brook trout in streams in southern Ontario.

F-REPRINT, M-GCM-BASED, R-CANADA, S-USE, T-CASE STUDY

Meisner, J. D., J. S. Rosenfeld, and H. A. Regier. 1988. The role of groundwater in the impact of climate warming on stream salmonines. Fisheries 13(3):2–7.

Work on effects of groundwater temperature on salmonine populations is reviewed. The physics of surface energy budget as it relates to groundwater temperature is discussed. A conceptual framework for projecting the effects of climate change on fish is provided.

F-REPRINT, R-NONE, S-USE, T-DISCUSSION, T-REVIEW

Meisner, J. D. et al. 1987. An assessment of the effects of climate warming on Great Lakes basin fishes. J. Great Lakes Res. 13(3):340–52.

Research on climate sensitivities of fish growth, habitat, reproduction/life cycle, population structure, and other biological variables is reviewed. Relationships between shoreline and wetland changes on species habitat requirements and length of growing season are discussed. Research recommendations are included. The paper also discusses and reviews models relating climate parameters to fish yield (a function of trophic state and thermal habitat volume among other variables, which can be gotten from other models) and fish mortality.

F-REPRINT, R-US-GREAT-LAKES, S-USE, T-DISCUSSION, T-REVIEW

Meo, M. 1989. Climate change impacts on coastal environments—implications for strategic planning. pp. 1384–94. In Coastal Zone '89: Proceedings of the Sixth Symposium on Coastal and Ocean Management, Charleston, S.C., July 11–14, 1989, Vol. 2. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, R-US-CALIFORNIA, R-US-MISSISSIPPI, R-US-S-ATLANTIC/GULF, S-MANAGEMENT, T-DISCUSSION

Miller, B. A. 1989. Global climate change implications for large water resource systems. pp. 636–42. In M. A. Ports, (ed.), Proceedings of the 1989 National Conference on Hydraulic Engineering, New Orleans, La., August 14–18, 1989. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, M-GCM-BASED, M-HYPOTHETICAL, R-US-S-ATLANTIC/GULF, S-MANAGEMENT, S-USE, T-DISCUSSION, T-CASE STUDY

Miller, B. A., and W. G. Brock. 1989. Potential impacts of climate change on the TVA reservoir system. pp. 9.1–9.47. In J. B. Smith and D. Tirpak (eds.), The Potential Effects of Global Climate Change on the U.S., Appendix A: Water Resources. U.S. Environmental Protection Agency, Washington, D.C.

GCM-based and hypothetical climate change runoff estimates are used as inputs to a reservoir system operation model (weekly scheduling model). Possible changes in flood frequency; safety issues at dams and nuclear power plants; hydroelectricity production; water supply, storage, and quality; and instream flows are identified. These changes may prompt changes to operating procedures, structures, and nonpoint source and recreational programs.

F-REPRINT, M-GCM-BASED, M-HYPOTHETICAL, R-US-TENNESSEE, S-MANAGEMENT, S-USE, T-CASE STUDY

Miller, B. A., W. G. Brock, and W. R. Waldrop. 1988. Potential effects of global climatic change on the Tennessee Valley Authority reservoir system. pp. 819–25. In Hydraulic Engineering, Proceedings of the 1988 National Conference on Hydraulic Engineering, Colorado Springs, Colo., August 8–12, 1988. American Society of Civil Engineers, New York.

The authors used GCM output to adjust precipitation inputs to a reservoir system model (weekly scheduling model), which simulates long-term, week-to-week variations in water level, discharge, and power production through 42 reservoirs.

DIALOG, F-ABSTRACT, M-GCM-BASED, M-HYPOTHETICAL, R-US-S-ATLANTIC/GULF, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-CASE STUDY

Miller, K. A. 1990. Water, electricity, and institutional innovation. pp. 367–94. In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

This paper explores the adaptability of the hydroelectric power industry in Idaho in recent decades to a water supply stress that may be considered analogous to potential climate change–induced water supply stresses. The development of a water market in the region due to increased competition for resources is discussed. Also, technological, as opposed to economic, options for energy management under changing water supply conditions are outlined.

F-REPRINT, M-HISTORICAL, R-US-PACIFIC-NORTHWEST, S-USE, T-CASE STUDY

Mimikou, M., Y. Kouvopoulos, G. Cavadias, and N. Vayianos. 1991. Regional hydrological effects of climate change. J. Hydrol. 123(1991):119–146.

M–HYPOTHETICAL, R–MEDITERRANEAN, F–REPRINT, S–HYDROLOGY, T–CASE STUDY

Moss, M. E., and H. F. Lins. 1989. Water resources in the 21st century—a study of the implications of climate uncertainty. USGS Circular No. 1030. 25 pp.

F-REPRINT, R-US, S-HYDROLOGY, S-USE, T-DISCUSSION

Moss, M. E., and G. D. Tasker. 1987. Role of stochastic hydrology in dealing with climatic variability. pp. 201–7. In S. I. Solomon, M. Beran, and W. Hogg (eds.), The Influence of Climate Change and Climate Variability on the Hydrologic Regime and

Water Resources. International Association of Hydrological Sciences, Wallingford, United Kingdom.

Stochastic hydrology is described as an extension of statistical hydrology, in which statistical hydrology involves the development of particular statistical descriptors of hydrologic records (such as mean annual flood, 7Q10 flow, and mean annual sediment load), and stochastic hydrology examines the temporal dependence, or persistence, in hydrologic phenomena. It is suggested that stochastic and physical/ process interpretations of hydrologic records combined can provide important and improved insight into hydrologic phenomena.

DIALOG, F-REPRINT, R-NONE, S-HYDROLOGY, S-MANAGEMENT, T-DISCUSSION

Moss, M. E. E. 1988. Climate change and climate variability, hydrologic regime and water resources. Trans. Am. Geophys. Union 69(25):677–78.

DIALOG, F-ABSTRACT, R-UNKNOWN, S-HYDROLOGY, S-MANAGEMENT, T-UNKNOWN

Nemec, J. 1988. Role of hydrological forecasts and river flow modeling in rational agricultural water management in the perspective of a climate change—a case study of the rivers Upper Nile and Niger. Agric. Water Manage. 13(2–4):383–92.

This paper asserts that slowly moving hydrologic means will not be nearly as critical to agriculture as changes in year-to-year variability, but small changes in the mean can translate into large changes in interannual variability. The author uses a model to quantify critical hydrologic conditions that may be expected in basins. Modeling research that should be done to examine the hydrologic implications of nonstationary hydrologic means is discussed.

DIALOG, R-AFRICA, R-MIDDLE-EAST, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-DISCUSSION

Nemec, J., and J. Schaake. 1982. Sensitivity of water resource systems to climate variation. J. Sci. Hydro. 27(3):327–43.

The sensitivity of water resource systems is evaluated in three different regions (a humid basin in Mississippi, an arid basin in Texas, and the Lake Victoria basin in Africa) to hypothetical climate changes. The deterministic Sacramento soil moisture accounting model was used to estimate streamflow under different climate scenarios. A reservoir model and storage-yield relationship was used to examine whether representative current system designs are robust enough to accommodate changes in mean and extreme hydrologic conditions. Changes in precipitation appear to be more influential than changes in evaporation on regional storage. Arid systems seem to be especially sensitive to climate change. Results suggest that a considerable amplification of the effect of climate change on runoff and storage can occur and emphasize that studies of the sensitivities of water resource systems are important.

F-REPRINT, M-HYPOTHETICAL, R-AFRICA, R-US-MISSISSIPPI, R-US-TEXAS/GULF, S-HYDROLOGY, S-MANAGEMENT, T-CASE STUDY

Newman, W. S., and R. W. Fairbridge. 1986. The management of sea-level rise. Nature 320(6060):319–21.

DIALOG, F-REPRINT, R-GLOBAL, S-HYDROLOGY, S-MANAGEMENT, T-DISCUSSION

Newman, W. S., and R. W. Fairbridge. 1987. Project Noah: Managing the rise of modern sea level. In Congr. Int. Union Quaternary Res. 12:232.

DIALOG, F-ABSTRACT, R-AFRICA, R-ASIA, R-EUROPE, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-DISCUSSION, T-REVIEW

Nielsen, N. A., R. D. Urban, and W. M. Seawell. 1987. Climate change and TVA programs: The need for contingency plan development. pp. 364–440. In M. Meo (ed.), Proceedings of the Symposium on Climate Change in the Southern United States.: Future Impacts and Present Policy Issues, May 28–29, 1987, New Orleans, La. Science and Public Policy Program, University of Oklahoma, Norman.

Potential impacts of climate change in the Tennessee Valley and on the Tennessee Valley Authority mission are discussed. Output from three GCMs was used as guidelines to possible climate change, and the response in the Tennessee Valley to drought conditions in 1986 was presented as a case study. The impacts, the report concludes, may be substantial. Topics include electricity, water for navigation, industrial siting, and recreation. The climate sensitivity for each topic is shown. It is recommended that climate scenarios be refined (new upper and lower bounds for climate variability) and changes in operating policy and socioeconomic impacts be considered. The authors conclude that increased flexibility may be needed in the future.

F-REPRINT, M-GCM-BASED, M-HISTORICAL, R-US-TENNESSEE, S-MANAGEMENT, S-USE, T-CASE STUDY

Niemczynowicz, J. 1989. Impact of the greenhouse effect on sewerage systems: Lund case study. Hydrol. Sci. J. 34(6):651–66.

Climate model scenarios of changes in rainfall and other climate variables and patterns over Europe are discussed, then an estimate of 10–30% increases in annual precipitation levels over Lund, Sweden, in a greenhouse-warmed world is developed. Annual precipitation is modified according to this estimate and the assumption that the characteristics of rainfall (e.g., cloud velocity, proportion of rainfall events that are convective as opposed to cyclonic events) will be preserved. The Storm Water Management Model, an urban runoff model developed by the EPA, is used to estimate possible impacts for the city's sewerage system. When the intensities of convective storm events are increased by 10 to 30%, combined sewer overflow rates increase, and total costs of necessary construction to accommodate such increases are estimated.

DIALOG, F-REPRINT, M-HYPOTHETICAL, R-EUROPE, S-MANAGEMENT, T-CASE STUDY

Osterkamp, T. E., and A. H. Lachenbruch. 1990. Thermal regime of permafrost in Alaska and predicted global warming. J. Cold Reg. Eng. 4(1):38–42.

Recent data recording permafrost temperature profiles in Alaska are discussed. Current greenhouse effect climate estimates for the Arctic are presented, as well as previous experience with climate warming and permafrost. The probable effects of future potential climate change on both continuous and discontinuous permafrost zones are examined.

F-REPRINT, M-HYPOTHETICAL, R-US-ALASKA, S-HYDROLOGY, T-DISCUSSION, T-CASE STUDY

Palutikof, J. P. 1987. Some possible impacts of greenhouse gas–induced climatic change on water resources in England and Wales. pp. 585–96. In S. I. Solomon (ed.), The Influence of Climate Change and Climate Variability on the Hydrologic Regime and Water Resources. International Association of Hydrological Sciences Press, Wallingford, United Kingdom.

This study uses an empirical streamflow model to estimate climate change impacts under two different assumptions: One, plant transpiration will be affected by increased $CO_2$ levels, and two, transpiration will not be affected by atmospheric $CO_2$ enrichment. Rainfall and temperature records from past anomalous climates (climate "analogues") are used as inputs to model. Runoff appears to decrease when the $CO_2$ enrichment effect is included; runoff increases when the effect is not included. This paper also examines water use trends.

DIALOG, F-REPRINT, M-ANALOGUE, R-EUROPE, S-HYDROLOGY, T-CASE STUDY

Peck, A. J., and G. B. Allison. 1988. Groundwater and salinity response to climate change. pp. 238–51. In G. I. Pearman (ed.), Proceedings of Greenhouse '87: Planning for climate change, Melbourne, Victoria, Australia, November 30–December 4, 1987. CSIRO, Division of Atmospheric Research, the Netherlands.

DIALOG, F-ABSTRACT, R-AUSTRALIA, S-HYDROLOGY, T-DISCUSSION

Peterson, D. F., and A. A. Keller. 1990. Irrigation. pp. 269–306. In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

This chapter covers several issues. First, a brief history of irrigation in the United States is provided. Two case studies of historical responses of irrigation and socio-economic conditions to changing water availability are conducted, one for south-western Utah and another for Great Plains regions dependent on the Ogallala aquifer for irrigation water. Insights and lessons from these case studies are discussed. Modeling studies are used to demonstrate the effects of hypothetical climate changes on irrigation requirements across the United States. A discussion of mitigative measures such as increased efficiency of irrigation practices and of crop water use is also included.

F-REPRINT, M-HISTORICAL, M-HYPOTHETICAL, R-US, R-US-ARKANSAS/WHITE/RED, R-US-GREAT-BASIN, R-US-RIO-GRANDE, R-US-TEXAS/GULF, S-WATER-USE, T-CASE-STUDY, T-DISCUSSION

Peterson, D. H., et al. 1987. Some effects of climate variability on hydrology in western North America. pp. 45–62. In S. I. Solomon, M. Beran, and W. Hogg (eds.), The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources. International Association of Hydrological Sciences Press, Wallingford, United Kingdom.

This paper discusses relationships between anomalous atmospheric circulations and regional weather anomalies and the influence of runoff and climate variations on riverine chemistry.

F-REPRINT, R-US-WESTERN, S-HYDROLOGY, S-USE, T-DISCUSSION

Quinones, F., and A. B. Hoos. 1990. A simplified Thornthwaite climatic index model to study potential changes in runoff in Tennessee induced by the greenhouse effect. p. 72. In M. J. Sale and P. M. Presley (eds.), Extended Abstracts from the Third Tennessee Water Resources Symposium, August 7–9, 1990. Tennessee Section, American Water Resources Association, Nashville, Tennessee.

F-ABSTRACT, M-HYPOTHETICAL, R-US-TENNESSEE, S-HYDROLOGY, T-CASE STUDY

Ramirez, J. A. 1991. The role of atmosphere/surface interactions in global and regional hydrologic cycles. pp. 47–58. In H. J. Morel-Seytoux (ed.), Proceedings of the Eleventh Annual American Geophysical Union Hydrology Days, April 2–4, 1991, Colorado State University, Fort Collins, Colo. Hydrology Days Publications, Fort Collins.

A one-dimensional land surface–atmosphere column model is developed and tested and preliminary results of sensitivity experiments are presented. Sensitivity of hydrologic and atmospheric boundary fluxes to inclusion of subgrid-scale variability in both land surface and soil type specified in the model is examined.

F-REPRINT, M-HYPOTHETICAL, R-NONE, S-HYDROLOGY, T-CASE STUDY

Rango, A. 1988. Evaluating effects of climate change on the snowmelt hydrology of mountain basins. Trans. Am. Geophys. Union 69(44):1203.

A snowmelt-runoff model is used to estimate possible changes in snowmelt runoff and snow cover in mountainous watersheds in western North America and Europe. The paper concludes that under climate scen-arios believed likely for the next century, runoff may be redistributed and snow cover reduced earlier in the year.

DIALOG, F-ABSTRACT, M-UNKNOWN, R-EUROPE, R-US-WESTERN, S-HYDROLOGY, T-CASE STUDY

Regier, H. A., J. A. Holmes, and D. Pauly. 1990. Influence of temperature changes on aquatic ecosystems: An interpretation of empirical data. Trans. Am. Fish. Soc. 119(2):374–89.

A "combined exponential model," a biological process rate model with temperature terms, is evaluated for its suitability to aquatic ectothermic popula-tions and ecosystems. Mathematical expressions of the model are examined, and criteria for applications are discussed. The authors conclude that the model may be a useful tool for illustrating some possible aquatic ecological effects of climate change.

F-REPRINT, R-NONE, S-USE, T-DISCUSSION, T-REVIEW

Regier, H. A., and J. D. Meisner. 1990. Anticipated effects of climate change on freshwater fishes and their habitat. Fisheries 15(6):10–15.

Linkages among climate parameters, fish habitat, and fish biology are sketched. The authors propose a monitoring program (i.e., a wild salmonid watch) because the subject may be a good indicator of changing climate conditions.

F-REPRINT, R-NONE, S-USE, T-DISCUSSION

Revelle, R. R., and P. E. Waggoner. 1983. Effects of a carbon dioxide-induced climatic change on water supply in the western U.S. pp. 419–31. In Changing Climate, Report of the Carbon Dioxide Assessment Committee. National Academy Press, Washington, D.C.

An empirical (regression) model is used to relate basin discharge to precipitation and temperature in the Colorado River basin. A model from a 46-year record is developed. The results of the effects of hypothetical climate changes produced by the model agree with an earlier study (Stockton and Boggess 1979). The results suggest that moderate increases in temperature and decreases in precipitation could severely reduce quantity and quality of water in the western United States. The paper concludes that water resource planners should consider climate change in the planning of water resource systems and there is a need for higher spatial resolution in climate models.

F-REPRINT, M-HYPOTHETICAL, R-US-COLORADO, S-HYDROLOGY, T-CASE STUDY

Rhoads, P. B., C. C. Shih, and R. L. Hamrick. 1987. Water resource planning concerns and changing climate—a South Florida perspective. pp. 348–63. In M. Meo (ed.), Proceedings of the Symposium on Climate Change in the Southern United States: Future Impacts and Present Policy Issues. May 28–29, 1987, New Orleans, La. Science and Public Policy Program, University of Oklahoma, Norman.

Current practices and options in South Florida related to coastal wetlands, water supply, and flood protection management are reviewed. The paper suggests that more freshwater inputs are needed in coastal areas because of sea level rise and points out that wells are starting to be located inland to avoid saltwater intrusion from a possible sea level rise. The authors believe that greater reservoir storage and reuse of water are potential mitigative actions. Technological fixes seem to be appropriate to some climate change-related problems.

F-REPRINT, R-US-S-ATLANTIC/GULF, S-MANAGEMENT, T-DISCUSSION

Riebsame, W. E. 1988. Adjusting water resources management to climate change. Climatic Change 13(1):69–97.

The sensitivity of water resource systems to climate change is discussed, and criteria for evaluating system sensitivity (system reliability, resiliency, vulnerability, and adjustability) are specified and clarified. The response processes and mechan-isms used by water managers in their reaction to supply stresses in the Sacramento River basin in California are examined. Methods of improving the decision-making position of water resource managers are discussed.

DIALOG, F-REPRINT, M-HISTORICAL, R-US-CALIFORNIA, S-MANAGEMENT, T-DISCUSSION, T-CASE STUDY

Rind, D. 1988. The doubled carbon dioxide climate and the sensitivity of the modeled hydrologic cycle. J. Geophys. Res. 93(D5):5385–5412.

DIALOG, F-ABSTRACT, R-US, S-HYDROLOGY, T-DISCUSSION, T-REVIEW

Rind, D., et al. 1990. Potential evapotranspiration and the likelihood of future drought. J. Geophys. Res. 95(7):9983–10004.

DIALOG, F-ABSTRACT, M-GCM-BASED, R-US, S-HYDROLOGY, T-CASE STUDY

Rogers, P. P., and M. B. Fiering. 1990. From flow to storage. pp. 207–22. In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

A modeling methodology that integrates a basin hydrologic model and a reservoir model is presented and it is shown that it can be extended to include economic parameters. The integrated model includes climate-sensitive parameters and allows climate change to be dealt with probabilistically. Regional coordination and operation of water resource systems are also encouraged.

F-REPRINT, R-NONE, S-HYDROLOGY, S-MANAGEMENT, T-DISCUSSION

Rosenberg, N. J., M. S. McKenney, and P. Martin. 1989. Evapotranspiration in a greenhouse-warmed world: A review and simulation. Agric. For. Meteorol. 47(2–4):303–20.

DIALOG, F-ABSTRACT, M-UNKNOWN, R-US-MISSOURI, R-US-TENNESSEE, S-HYDROLOGY, T-CASE STUDY, T-REVIEW

Rosenberg, N. J., et al. 1990. From climate and carbon dioxide enrichment to evapotranspiration. pp. 151–76. In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

Effects of global warming and atmospheric $CO_2$ enrichment on evapotranspiration are discussed. Three simulations of evapotranspiration sensitivity to hypothetical single and multifactor climate changes, and to GCM-based climate scenarios, are conducted using the Penman-Monteith equation for evapotranspiration. Three types of eco-

systems are simulated: wheat field in Nebraska, mixed forest in Tennessee, and tall grass prairie in Kansas.

M-GCM-BASED, M-HYPOTHETICAL, R-US-MISSOURI, R-US-TENNESSEE, S-HYDROLOGY, T-DISCUSSION, T-CASE STUDY

Russell, G. L., and J. R. Miller. 1990. Global river runoff calculated from a global atmospheric general circulation model. J. Hydrol. 117(1990):241–54.

F-REPRINT, M-GCM-BASED, R-GLOBAL, S-HYDROLOGY, T-DISCUSSION

Rymarczyk, W. J., et al. 1989. Power plant availability and cooling impoundment restrictions during severe weather conditions. pp. 433–38. In Proceedings of the 51st American Power Conference, Chicago, Ill., April 24–26, 1989. Illinois Institute of Technology, Chicago.

DIALOG, F-ABSTRACT, R-US, S-USE, T-DISCUSSION

Salinas, L. M., R. D. DeLaune, and W. H. Patrick, Jr. 1986. Changes occurring along a rapidly submerging coastal area: Louisiana, U.S.A. J. Coastal Res. 2(3):269–84.

DIALOG, F-ABSTRACT, M-HISTORICAL, R-US-MISSISSIPPI, S-MANAGEMENT, S-USE, T-CASE STUDY

Sanderson, M. 1989. Effects of climate change on the Great Lakes. Trans. R. Soc. Can. 5(3):33–46.

DIALOG, F-ABSTRACT, M-UNKNOWN, R-US-GREAT-LAKES, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-CASE STUDY

Sanderson, M., and L. Wong. 1987. Climatic change and Great Lakes water levels. pp. 477–87. In S. I. Solomon, M. Beran, and W. Hogg (eds.), The Influence of Climate Change and Climate Variability on the Hydrologic Regime and Water Resources. International Association of Hydrological Sciences Press, Wallingford, United Kingdom.

GCM output is used to estimate water supply ("net basin supply") in the Great Lakes. Results show that lake levels may drop on all the Great Lakes, and some decreases may require alterations to current regulatory procedures. Issues of consumptive use and current operating procedures are considered.

DIALOG, F-REPRINT, M-GCM-BASED, R-US-GREAT-LAKES, S-HYDROLOGY, T-CASE STUDY

Schaake, J. C. 1987. Statistical methods for climatic and hydrologic variability. p. 12. In B. C. Klein-Helmuth and D. Savold (eds.), Abstracts, 1987 AAAS Annual Meeting—153rd National Meeting, Chicago, Ill., February 14–18, 1987. American Association for the Advancement of Science.

DIALOG, F-ABSTRACT, R-AFRICA, S-HYDROLOGY, T-DISCUSSION

Schaake, J. C. 1990. From climate to flow. pp. 177–206. In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

A general water balance equation is developed and used to show the sensitivity of runoff to changes in precipitation and potential evapotranspiration. Then the use of a more complex monthly water balance model for the evaluation of the sensitivity of runoff and other water resource variables in basins in the Southeast to hypothetical changes in monthly rainfall and potential evapotranspiration is demonstrated. Finally, a group of hydrologic models, including snow accumulation and ablation models and the Sacramento soil moisture accounting model, are used to evaluate the sensitivity of runoff in the Animas River basin in Colorado. A brief discussion of streamflow forecasting is included.

F-REPRINT, M-HYPOTHETICAL, R-US, R-US-MISSISSIPPI, R-US-S-ATLANTIC/GULF, R-US-TENNESSEE, S-HYDROLOGY, T-CASE STUDY

Schaake, J. C., and Z. Kaczmarek. 1979. Climate variability and the design and operation of water resource systems. pp. 165–82. In World Climate Conference—A Conference of Experts on Climate and Mankind. World Meteorological Organization, Geneva.

This is a discussion of the ways in which hydro-climatic data are currently used in the design and operation of water resource systems such as water supply and multi-purpose reservoirs and reservoir systems. Principles and uses of hydrologic statistics (e.g., frequency distributions of peak streamflow) and stochastic hydrologic models are reviewed. Climate regime and basin and project characteristics can influence which kinds of hydro-climatic data are most important. Major types of models used to translate hydro-climatic data into hydrologic data (statistical, analytical, and numerical) and their limitations are briefly discussed; this discussion is similar in scope to Beran (1986). Suggestions for needed improvements in climatic data used by water resource management are presented.

F-REPRINT, R-NONE, S-HYDROLOGY, S-MANAGEMENT, T-DISCUSSION

Schaake, J. C., Jr. 1989. Climate change and U.S. water resources, results from a study by the American Association for the Advancement of Science. pp. 667–72. In M. A. Ports (ed.), Proceedings of the 1989 National Conference on Hydraulic Engineering, New Orleans, La., August 14–18, 1989. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, R-US, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-REVIEW

Schertzer, W. M., and A. M. Sawchuk. 1990. Thermal structure of the lower Great Lakes in a warm year: Implications for the occurrence of hypolimnetic anoxia. Trans. Am. Fish. Soc. 119(2):195–209.

F-REPRINT, M-ANALOGUE, R-US-GREAT-LAKES, S-USE, T-CASE STUDY

Schindler, D. W. et al. 1990. Effects of climatic warming on lakes of the central boreal forest. Science 250:967–70.

Water quality and other limnologic features of a highly instrumented lake in arid, boreal northwest Ontario (ca. 55° N lat) during a recent (1969–1978), clearly defined, anomalously warm, dry, and windy period, are reported. The anomalous nature of the recent climate— with a roughly 2° rise above long-term mean air temperature, more frequent occurrence of years with lower-than-average rainfall, and increased wind speed resulting from reduced vegetative cover in the region because of increased incidence of forest fire— is established. It is suggested that the anomalous period is analogous (but not necessarily related) to some scenarios of greenhouse-effect climate change. Water temperature, runoff into the lake, heat content of the lake during the ice-free season, duration of ice-free season, concentrations of major ions, and of total dissolved nitrogen, secchi-disk depth, depth of thermoclime, and phytoplankton biomass and diversity are among the variables whose levels are recorded and presented. Increased water temperature, residence time, total dissolved nitrogen, N:P ratio, $SO_4$, Ca, clarity, and standing crop of phytoplankton are observed. Authors speculate that increases in water temperature, depth of thermocline, and chemical concentrations could change the geographic distribution of cold-water fish species and other inhabitants of boreal freshwater ecosystems.

F-REPRINT, M-HISTORICAL, R-CANADA, S-USE, T-CASE STUDY

Schlesinger, M. E. 1985. Carbon dioxide–induced changes in seasonal snow cover simulation by the OSU-coupled atmospheric-ocean general circulation model. pp. 249–70. In Snow Watch '85: Glaciological Data Report GD-18, March 1986, NTIS No. DE86-011983.

DIALOG, F-ABSTRACT, M-GCM-BASED, R-UNKNOWN, S-HYDROLOGY, T-CASE STUDY

Schneider, S. H., and R. L. Temkin. 1977. Water supply and the future climate. p. 25. In Panel on Geophysics (ed.), Climate, Climatic Change, and Water Supply. National Academy of Sciences, Washington, D.C.

F-REPRINT, R-GLOBAL, S-OTHER, T-DISCUSSION

Schwabacher, R. A., and S. H. Bolton. 1989. Coastal policy implications of global warming. pp. 231–35. In Oceans '89, Part I: Fisheries, Global Ocean Studies, Marine Policy and Education, Oceanographic Studies; September 18–21, 1989; Seattle, Wash. IEEE Service Center, Piscataway, New Jersey.

DIALOG, F-ABSTRACT, R-US, S-MANAGEMENT, T-DISCUSSION

Schwarz, H. E. 1977. Climatic change and water supply: How sensitive is the Northeast? pp. 111–20. In Panel on Water and Climate (eds.), Climate, Climatic Change, and Water Supply. National Academy of Sciences, Washington, D.C.

This report discusses how water managers may evaluate water resource system sensitivites to potential changes in climate, while commenting on the difficulties in implementing climate change expectations into the water management process (e.g., uncertainties in estimates of future climate conditions). The single conclusive fact is that changes in climate are likely, and several points for consideration are presented. These include evaluation of the sensitivities of streamflow, reservoir, and groundwater yield; raw water quality; systems reliability; and regional intercommission supply management to changes in climate and hydrologic distributions.

F-REPRINT, R-US-NEW-ENGLAND, S-MANAGEMENT, T-DISCUSSION

Schwarz, H. E., and L. A. Dillard. 1989. Impact on water supplies. Oceanus 32(2):44–45.

The potential effects of climate change on urban water supply systems are discussed. Interviews with senior management and technicians from New York City; Salt Lake City; Washington, D.C.; and Worcester, Massachusetts are presented. The prevalent attitude is "wait and see" with respect to the potential impact of climate change on urban water systems.

DIALOG, F-REPRINT, R-US, S-MANAGEMENT, T-DISCUSSION

Schwarz, H. E., and L. A. Dillard. 1990. Urban water. pp. 341–66. In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

F-REPRINT, M-OTHER, R-US, S-MANAGEMENT, T-DISCUSSION, T-CASE STUDY

Sharma, M. L. 1989. Impact of climate change on groundwater recharge. pp. 511–20. In Conference on Climate and Water, September 11–15, Helsinki, Finland. Valtion Painatuskeskus, Helsinki.

DIALOG, F-ABSTRACT, M-HYPOTHETICAL, R-AUSTRALIA, S-HYDROLOGY, T-CASE STUDY

Sheer, D. P., and D. Randall. 1989. Methods for evaluating the potential impacts of global climate changes: Case studies of the state of California and Atlanta, Georgia. pp. 2.1–2.28. In J. B. Smith and D. Tirpak (eds.), The Potential Effects of Global Climate Change on the U.S. Appendix A: Water Resources. U.S. Environmental Protection Agency, Washington, D.C.

Performance of two water resource systems—the Central Valley system in California and the system serving the Atlanta metropolitan area—was simulated under GCM-based greenhouse climate conditions. In both cases operating models of the water systems were used. The mass balance model used for the Lake Lanier (Atlanta) system simulation was developed with input from several water management agencies. In California the simulation produced increased system streamflows but changed the seasonal distribution of these streamflows. Wetter winters, drier summers, increased probability of spring flooding, and decreases in water deliveries to consumers were simulated. In Georgia a shift in seasonal distribution of streamflow was also observed, and changes in lake elevation and power generation are possible consequences.

F-REPRINT, M-GCM-BASED, R-US-CALIFORNIA, R-US-S-ATLANTIC/GULF, S-MANAGEMENT, S-USE, T-CASE STUDY

Shiklomanov, I. A. 1989. Climate and water resources. Hydrol. Sci. J. 34(5):495–529.

The hydrologic cycle; global interrelations between climate and water resources; relationships between water consumption and climate; and relationships among human activity, water resources, and climate are discussed. Water resources in the Soviet Union and the Caspian and Aral seas are also discussed.

DIALOG, F-REPRINT, R-GLOBAL, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-DISCUSSION

Short, A. D. 1988. Areas of Australia's coast prone to sea level inundation. pp. 93–104. In G. I. Pearman (ed.), Proceedings of Greenhouse '87: Planning for climate change, Melbourne, Victoria, Australia, November 30–December 4, 1987. CSIRO Division of Atmospheric Research.

DIALOG, F-ABSTRACT, R-AUSTRALIA, S-MANAGEMENT, T-DISCUSSION

Shuter, B. J., and J. R. Post. 1990. Climate population viability and the zoogeography of temperate fishes. Trans. Am. Fish. Soc. 119(2):314–36.

CLASSIFICATION: F-REPRINT, M-HYPOTHETICAL, R-CANADA, R-EUROPE, R-SOVIET-UNION, R-US, S-USE, T-CASE STUDY

Sibley, T. H., and R. M. Strickland. 1985. Fisheries: Some relationships to climate change and marine environmental factors. pp. 99–143. In M. R. White (ed.), Characterization of Information Requirements for Studies of $CO_2$ Effects: Water Resources, Agriculture, Fisheries, Forests and Human Health. U.S. Department of Energy, Washington, D.C.

This chapter covers possible effects of climate change on marine fisheries and discusses case study marine fisheries in the northeastern Pacific Ocean. Some sections—those related to oceanic thermohaline circulcation, for example—are not relevant to freshwater resources, but much of the chapter is helpful for study of climate change and freshwater fish and fisheries. The authors identify some theoretical effects of climate change on physical marine environments and discuss likely associated chemical and biological effects. Research on potential climate change effects on marine fisheries is reviewed, gaps and weaknesses in the research base are identified, and research needs are presented. Programs already performing research on effects of climate change on marine fisheries are identified.

F-REPRINT, M-HYPOTHETICAL, R-GLOBAL, R-US-ALASKA, R-US-PACIFIC NORTHWEST, S-USE, T-DISCUSSION, T-CASE STUDY

Singh, B. 1987. Impacts of $CO_2$-induced climate change on hydroelectric generation potential in the James Bay Territory of Quebec. pp. 403–18. In S. I. Solomon, M. Beran, and W. Hogg (eds.), The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources. International Association of Hydrological Sciences Press, Wallingford, United Kingdom.

GCM-based climate scenarios were used to estimate "net basin supply," or streamflow, in the James Bay Territory, with a water balance equation that included terms for overland runoff, net precipitation, evaporative loss from reservoir surfaces, and consumptive use of water. Literature values for the relationship between net basin supply and average energy generation were used to estimate energy potential for the region. Some issues related to regional energy economics are briefly discussed.

DIALOG, F-REPRINT, M-GCM-BASED, R-CANADA, S-USE, T-CASE STUDY

Smith, J. G., and D. Tirpak (eds.). 1989. The Potential Effects of Global Climate Change on the United States. EPA-230-05-89-050. U.S. Environmental Protection Agency. Washington, D.C.

This report is a collection and assimilation of the reports prepared for a research program initiated by EPA at the request of Congress to assess potential effects of climate change on the United States. The objectives and methodologies in the research program are described. Findings from participating researchers in the areas of forests, agriculture (including irrigation demand), sea level rise, water resources, electricity demand, and other sectors are synthesized in Chapters 5–13. The chapter on water resources includes discussion of potential changes in hydrologic conditions and water resources, regional impacts, management practices, and policy implications. Findings for major resource sectors are also summarized by geographic region (California, Great Lakes, Southeast, and Great Plains). Appendices are compilations of individual researchers' research reports. Appendix subjects include water resources, sea level rise, aquatic resources, agriculture, and variability.

F-REPRINT, M-GCM-BASED, R-US, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-CASE STUDY

Snedaker, S. C., and D. P. deSylva. 1987. Impact of climate change on coastal resources; implications for property values, commerce, estuarine environments, and fisheries, with special reference to South Florida. pp. 187–215. In Proceedings of the Symposium on Climate Change in the Southern United States. U.S. Environmental Protection Agency, Washington, D.C.

DIALOG, F-REPRINT, R-US-S-ATLANTIC/ GULF, S-MANAGEMENT, S-USE, T-DISCUSSION,

Stockton, C. W., and W. R. Boggess. 1979. Geohydrological implications of climate change on water resource development. U.S. Army Coastal Engineering Center, Ft. Belvoir, Virginia.

This report presents a comprehensive introduction to climate change, implications for water resources, and the hydrologic science tools available for investigating the issues. Projected global circulation changes and the implications these circulation changes may have on regional weather and climate patterns are discussed. Work in deterministic and hydrologic approaches for estimating hydrologic sensitivity to climate is reviewed. The Langbein empirical model for relating runoff to precipitation and temperature is applied to each water resource region of the United States, using hypothetical rainfall and temperature changes. An appendix includes model-estimated statistics for each water resource region under each climate change scenario—such as mean, variance, skewness, persistence for the variables yield, reservoir storage, groundwater, water quality, and demand. These results are presented as a matrix (after Schwarz 1977).

F-REPRINT, M-HYPOTHETICAL, R-US, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-DISCUSSION, T-CASE STUDY

Thomsen, R. 1990. Effect of climate variability and change in groundwater in Europe. Nordic Hydrol. 21(1990):185–94.

F-REPRINT, R-EUROPE, S-HYDROLOGY, S-MANAGEMENT, T-DISCUSSION

Titus, J. G. 1985. Sea level rise and wetland loss. pp. 1979–90. In Coastal Zone '85: Proceedings of the Fourth Symposium on Coastal and Ocean Management, Baltimore, Md., July 30–August 2, 1985, Vol. 2. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, R-NONE, S-HYDROLOGY, S-MANAGEMENT, T-DISCUSSION

Titus, J. G. 1986. The causes and effects of sea level rise. pp. 104–25. In H. G. Wind (ed.), Conference on Impact of Sea Level on Society, Delft, the Netherlands, August 27–29, 1986. A. A. Balkema, Rotterdam.

DIALOG, F-ABSTRACT, R-US-MID-ATLANTIC, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-DISCUSSION

Titus, J. G. 1988. Can coastal communities adapt to a rise in sea level? pp. 241–60. In D. Abrahamson and P. Ciborowski (eds.), The Greenhouse Effect: Policy Implications of a Global Warming. Center for Urban and Regional Affairs, University of Minnesota, Minneapolis.

DIALOG, F-ABSTRACT, M-UNKNOWN, R-US-S-ATLANTIC/GULF, S-MANAGEMENT, T-CASE STUDY

Titus, J. G., et al. 1987. Greenhouse effect, sea level rise, and coastal drainage systems. J. Water Resour. Plann. Manage. 113(2):216–27.

Recent estimates of rates of sea level rise were used to compare the costs of designing and building two southeastern U.S. coastal drainage systems with and without accommodations for a rise in sea level. The effects of changing precipitation patterns and rising sea levels on the loading and efficiency of drainage systems were evaluated. Options were examined for accommodating hypothetical sea level rise and rainfall scenarios in the systems' design. It was demonstrated that in some cases, it can be cost-effective to design for sea level rise, even if there is some uncertainty about the nature and extent of the changing sea level.

DIALOG, F-REPRINT, M-HYPOTHETICAL, R-US-S-ATLANTIC/GULF, S-MANAGEMENT, T-CASE STUDY

Tonn, W. M. 1990. Climate change and fish communities: A conceptual framework. Trans. Am. Fish. Soc. 119(2):337-52.

F-REPRINT, R-GLOBAL, S-USE, T-DISCUSSION

Urban, R. D. 1987. Intergovernmental response to extreme events: The case of drought in the Southeast. pp. 444-49. In M. Meo (ed.), Proceedings of the Symposium on Climate Change in the Southern United States: Future Impacts and Present Policy Issues, May 28-29, 1987, New Orleans, La. Science and Public Policy Program, University of Oklahoma, Norman.

An anecdotal, firsthand account of TVA experience with the drought of 1986 is presented. This drought took managers by surprise, since it was not a part of their operating con-cerns. The psychological hurdles the report concludes, can be significant, demon-strated by the fact that managers did not perceive the drought, even though it began in the early 1980s.

F-REPRINT, M-HISTORICAL, R-US-TENNESSEE, S-MANAGEMENT, T-CASE STUDY

U.S. Geological Survey. 1991. Compendium of Abstracts Presented at U.S. Geological Survey Global Change Research Forum, March 18-20, 1991.

Numerous abstracts collected from U.S. Geological Survey bureaus throughout the United States are presented. Many report on baseline data collection activities, plans, and proposals, using such techniques as remote-sensing by satellite. Abstracts of comprehensive hydrology, water requirements, and current and planned water management studies in specific selected water regions or basins are also included.

F-ABSTRACT

van der Kley, W., and A. A. Balkema. 1987. Sea level rise: Evaluation of the impacts of three scenarios of sea level rise on flood protection and water management of the Netherlands. pp. 159-66. In H. G. Wind (ed.), Impact of Sea Level Rise on Society: Report of a Project-Planning Session, Delft, the Netherlands, August 27-29, 1986.

DIALOG, F-ABSTRACT, M-HYPOTHETICAL, R-EUROPE, S-MANAGEMENT, T-CASE STUDY

Volker, A., and A. A. Balkema. 1987. Impacts of a rapid rise of the sea level on flood protection and water management of low-lying coastal areas. pp. 167-76. In H. G. Wind (ed.), Impact of Sea Level Rise on Society: Report of a Project-

Planning Session, Delft, the Netherlands, August 27–29, 1986. A. A. Balkema, Rotterdam.

DIALOG, F-ABSTRACT, R-UNKNOWN, S-HYDROLOGY, S-MANAGEMENT, T-DISCUSSION

Waggoner, P. E. 1990. The issues. pp. 9–18. In P. E. Waggoner (ed.), Climate Change and U.S. Water Resources. John Wiley and Sons, New York.

A list is introduced of issues important to a discussion of climate change and water resources produced by a multidisciplinary team of engineers, agronomists, ecologists, historians, economists, and managers. These issues, presented as individual chapter topics, include future water use; the likelihood of climate change; the relationship between climate and atmospheric change and vegetation response; the relationship between climate conditions and hydrologic response; vulnerabilities of water resources by U.S. geographic region; potential impacts of climate change on water quality, recreation, wildlife, urban water systems, energy production, water economics and markets; and the political agenda.

R-US, S-HYDROLOGY, S-MANAGEMENT, S-USE, T-DISCUSSION

Waggoner, P. E. (ed.). 1990. Climate Change and U.S. Water Resources. John Wiley and Sons. New York.

This is a comprehensive examination of issues related to potential climate change and water resources in the United States. Each chapter is contributed by different members of an interdisciplinary set of contributors. Key concerns are identifed and described in the first section, and a projection of future U.S. water use and prospects for the occurrence of climate change are presented. The second section contains chapters devoted to the key concerns identified in the first section. These include detection of trends in hydrologic time series, how climate change may effect evapotranspiration by plants, the sensitivity of runoff and other water resource variables to changes in rainfall and temperature, and an assessment of vulnerability to changing water resource availability, by geographic region and by water resource issue (e.g., demand, supply, groundwater, hydroelectricity). Chapters are also devoted to floods and droughts, irrigation, water quality, recreation and wildlife, urban water, electric utility responses, and economic and political issues. Recommendations for scientists, government, and individuals and organizations are provided.

Waggoner, P. E. 1991. U.S. water resources vs. an announced but uncertain climate change. Science 251:1002.

F-REPRINT, R-US, S-MANAGEMENT, S-USE, T-DISCUSSION

Waldrop, W. R. 1990. Effects of climate changes on TVA activities. p. 73. In M. J. Sale and P. M. Presley (eds.), Extended Abstracts from Third Tennessee Water Resources Symposium, August 7–9, 1990. Tennessee Section, American Water Resources Association, Nashville.

F-REPRINT, R-US-TENNESSEE, S-MANAGEMENT, T-DISCUSSION

Walters, R. A. 1989. Effects of runoff changes and sea level rise on salinity in the Delaware River estuary. pp. 685–86. In M. A. Ports (ed.), Proceedings of the 1989 National Conference on Hydraulic Engineering, New Orleans, La., August 14–18, 1989. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, M-UNKNOWN, R-US-MID-ATLANTIC, S-USE, T-CASE STUDY

Wigley, T. M. L., and P. D. Jones. 1985. Influences of precipitation changes and direct carbon dioxide effects on streamflow. Nature 314:149–52.

F-REPRINT, R-NONE, S-HYDROLOGY, T-CRITIQUE, T-DISCUSSION

Williams, P. 1989. Adapting water resources management to global climate change. Clim. Change 15:83–93.

F-REPRINT, R-NONE, R-US-CALIFORNIA, S-MANAGEMENT, S-USE, T-DISCUSSION

Wolock, D. M., et al. 1989. Effects of climate change on watershed runoff. pp. 673–78. In M. A. Ports (ed.), Hydraulic Engineering '89 Proceedings, National Conference on Hydraulic Engineering, New Orleans, La., August 14–18, 1989. American Society of Civil Engineers, New York.

DIALOG, F-ABSTRACT, M-HYPOTHETICAL, R-US-MID-ATLANTIC, S-HYDROLOGY, T-CASE STUDY

Wolock, D. M., M. A. Ayers, and G. M. Hornberger. 1988. Forecasting global warming effects on regional catchment hydrology. Trans. Am. Geophys. Union 69(44):1221.

DIALOG, F-ABSTRACT, M-HYPOTHETICAL, R-US-NEW-ENGLAND, S-HYDROLOGY, T-CASE STUDY

Wolock, D. M., and G. M. Hornberger. 1991. Hydrological effects of changes in levels of atmospheric carbon dioxide. J. Forecasting 10:105–16.

The sensitivity of catchment runoff to assumptions about (1) stomatal resistance changes due to the $CO_2$ enrichment effect, (2) degree of change in average storm intensity, and (3) degree of change in average annual air temperature was examined in a hydrologic modeling study. A variable source area hydrologic model and stochastically derived precipitation and air temperature time series were used. Lack of information about long-term hydrometeorologic and vegetative response to increased atmospheric $CO_2$ leads to gross variability in projections of runoff response. The detectability of trends in runoff statistics produced with different degrees or durations of changes in the precipitation and temperature time series was also examined. Significant changes in the time series did not necessarily induce detectable trends in runoff output time series because of underlying natural variability in the climate input variables.

F-REPRINT, M-HYPOTHETICAL, R-US-MID-ATLANTIC, S-HYDROLOGY, T-CASE STUDY

Woo, M. K. 1990. Consequences of climate change for hydrology in permafrost zones. J. Cold Reg. Eng. 4(1):15–20.

F-ABSTRACT, M-UNKNOWN, R-ARCTIC, S-HYDROLOGY, T-UNKNOWN

Wynne, A. A. 1989. Sea level rise and coastal planning in South Australia. pp. 302–7. In Proceedings of the 9th Australian Conference on Control and Ocean Engineering, preprints of papers, Adelaide, Australia, December 4–8, 1985. Institution of Engineers, Barton, Australia.

DIALOG, F-ABSTRACT, R-AUSTRALIA, S-MANAGEMENT, T-DISCUSSION

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