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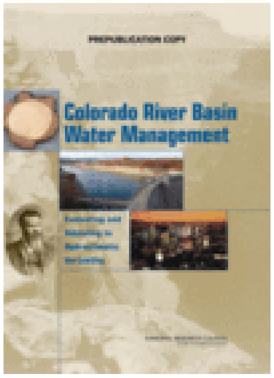

Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability

Committee on the Scientific Bases of Colorado River Basin Water Management, National Research Council

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Summary

Encompassing an area of more than 240,000 square miles, the Colorado River basin covers portions of seven western U.S. states and part of extreme northwestern Mexico. Passing through the heart of what author Wallace Stegner called "the dry core" of the arid western United States, the Colorado's mean annual flow of roughly 15 million acre-feet is not large in comparison to major rivers like the Columbia or the Mississippi. As the largest source of surface water in a large, arid region, however, the Colorado is of great importance to cities, farmers, tribes, anglers, industries, and rafters. In addition to water diversions, Colorado River flows generate hydroelectricity, support recreational opportunities and ecological habitats, and sustain cultural and historical values.

Given the Colorado River's importance, variations in its flow record have long been of keen interest to many parties. Direct streamflow measurements date back to the late 1890s when gaging stations were established at a few sites along the river. As the river's flow was measured over the next century, and as a network of stream gaging stations grew, a more complete understanding of Colorado River flows and variability emerged. For example, it is known today that the Colorado River Compact of 1922—the water allocation compact that divides Colorado River flows between the upper and lower Colorado River basin states—was signed during a period of relatively high annual flows. It is also accepted that the long-term mean annual flow of the river is less than the 16.4 million acre-feet assumed when the Compact was signed—a hydrologic fact of no small importance with regard to water rights agreements and subsequent allocations.

Since the 1970s direct measurements of Colorado River flows have been complemented by studies of past hydroclimate conditions that draw from a body of indirect, or proxy, evidence based on tree-ring data. Because patterns of tree-ring growth of trees at lower elevations can reflect moisture availability, tree-ring data can be used to assemble records, or "reconstructions," of past river flows. Using data from coniferous tree species with long life spans in the Colorado River region, flows dating back several centuries have been reconstructed. The first tree-ring based flow reconstruction for the Colorado River at Lees Ferry, Arizona—the point at which the Colorado River basin is divided legally into its upper and lower basins—was assembled by Charles Stockton and Gordon Jacoby, Jr. in 1976. Additional reconstructions of Colorado River flows that date back to the 15th century, including several undertaken in the past few years, have enhanced scientific understanding of the region's long-term hydrologic and climate patterns.

Tree-ring based reconstructions became increasingly prominent topics of discussion in western water circles in the early 2000s. As this period was exceptionally dry across much of the West, the tree-ring based reconstructions prompted many questions and concerns about the possible extent and severity of future droughts. The water years (as measured from October 1 through the following September 30) 2002 and 2004, for example, were among the 10 driest years of record in the upper basin states of Colorado, New Mexico, Utah, and Wyoming. Significantly, flows into the basin's reservoirs dropped sharply during this period; for example, 2002 water year flows into Lake Powell above Glen Canyon Dam were roughly 25 percent of mean values. These drought conditions stimulated increased interest in tree-ring based flow reconstructions and long-term Colorado River flows and water availability.

Out of interest in these issues and their implications, in 2005 the National Research Council's (NRC) Water Science and Technology Board (WSTB) initiated a study to review hydrologic and climatic sciences of the Colorado River region. The Committee on the Scientific Bases of Colorado River Basin Water Management was appointed to assess the extant body of scientific studies regarding both Colorado River hydrology and hydroclimatic trends that might affect river flows. The committee also was asked to consider related topics including: hydrologic models, data, and methods; organizations for evaluating hydro-climate data; and, systems operations and water management practices (the full statement of task to this committee appears on page 15).

This committee's statement of task called for a report that produced "an improved hydrologic baseline" for Colorado River water management. In discussing this phrase, the committee noted that it might be interpreted in different ways. An improved hydrologic baseline could, for example, entail a new estimate of long-term mean annual Colorado River flows; establishment of new river gaging stations, computer models, or numerical methods; or a recommendation to reorganize existing (or create new) programs and institutions for evaluating hydrologic and climatic data. After discussing the language in its task statement, the committee concluded that the most appropriate way to help improve a hydrologic baseline for the Colorado River would be to evaluate existing scientific information (e.g., temperature and streamflow records, tree-ring based reconstructions, climate model projections) and how it relates to Colorado River water supplies, demands, water management, and drought preparedness.

The following sections of this Summary address the topics of Hydroclimatic Data and Sciences, Realities of Colorado River Water Management, and Improving Drought Preparedness and Planning: Cooperation, Science, and Planning. The report's findings and recommendations are presented in bold faced-print.

HYDROCLIMATIC DATA AND SCIENCES

Temperature Trends and Model Projections

Temperature records across the Colorado River basin and the western United States document a significant warming over the past century. These temperature records, along with climate model projections that forecast further increases, collectively suggest that temperatures across the region will continue to rise for the foreseeable future. Higher regional temperatures are shifting the timing of peak spring snowmelt to earlier in the year and are contributing to increases in water demands, especially during summer. Higher temperatures will result in higher evapotranspiration rates and contribute to increased evaporative losses from snowpack, surface reservoirs, irrigated land, and vegetated surfaces. Projections of future precipitation are more uncertain than are temperature predictions, leading to uncertainty as to possible changes in future streamflow. Recent studies of the hydrologic implications of warming across the region, based on many global climate models, suggest that on average (across models) runoff and streamflow will decrease. There is, however, uncertainty in these predictions, and some models even suggest increases.

The 20th century saw a trend of increasing mean temperatures across the Colorado River basin that has continued into the early 21st century. There is no evidence that this warming trend will dissipate in the coming decades, with many different climate model projections pointing to a warmer future for the Colorado River region.

Modeling results show less consensus regarding future trends in precipitation. Several hydroclimatic studies project that significant decreases in runoff and streamflow will accompany increasing temperatures. Other studies, however, suggest increasing future flows, highlighting the uncertainty attached to future runoff and streamflow projections. Based on analysis of many recent climate model simulations, the preponderance of scientific evidence suggests that warmer future temperatures will reduce future Colorado River streamflow and water supplies. Reduced streamflow would also contribute to increasing severity, frequency, and duration of future droughts.

Estimating Colorado River Flows: Gaging Stations and Tree-Ring Based Reconstructions

The first gaging stations on the Colorado River were established in the late 19th century. The best-known of the river's many gaging stations is at Lees Ferry, Arizona, established there in 1921. For many years the gaged record of Colorado River flows represented the best science-based knowledge about the river's long-term behavior. Imbedded within this gaged record was an implicit assumption that there was a single, mean value of the river's annual flow, and that inter-annual variations occurred around this long-term, fixed average. Under this assumption, the basin may have experienced wet and dry periods, but river flows and weather conditions were nonetheless expected to return to an average state, largely defined by climate and hydrology of the early and middle 20th century.

Questions regarding this long-held paradigm of Colorado River mean discharge arose and have been debated in the latter part of the 20th century. Much of this evolving debate reflected concerns over global climate change that came to prominence beginning in the 1970s. Views of the river's long-term variability continued to evolve with more studies of climate change and hydrology that were conducted beginning in the 1980s. Recent tree-ring based studies demonstrate that Colorado River flows occasionally shift into decadal-long periods in which average flows are lower, or higher, than the 15 million acre-feet/year mean based on the current gaged record. The reconstructions also reinforce the point that the gaged record of Colorado River streamflow covers but a small subset of the range of natural hydroclimatic variability present over several centuries, and that future Colorado River hydrology may not mimic the hydrologic behavior reflected within the Lees Ferry gaged record.

For many years, scientific understanding of Colorado River flows was based primarily on gaged streamflow records that covered several decades. Recent studies based on tree-ring data, covering hundreds of years, have transformed the paradigm governing understanding of the river's long-term behavior and mean flows. These studies affirm year-to-year variations in the gaged records. They also demonstrate that the river's mean annual flow—over multi-decadal and centennial time scales, as shown in multiple and independent reconstructions of Colorado River flows—is itself subject to fluctuations. Given both natural and human-induced climate changes, fluctuations in Colorado River mean flows over long-range time scales are likely to continue into the future. The paleoclimate record reveals several past periods in which Colorado River flows were considerably lower than flows reflected in the Lees Ferry gaged record, and that were assumed in the 1922 Colorado River Compact allocations.

Tree-Ring Based Reconstructions, Drought, and Future Water Availability

Tree-ring based streamflow reconstructions allow the gaged record to be placed in the context of longer term hydroclimatic variability. Although such reconstructions are only estimates of past river flows, they collectively point to a past in which severe, extended drought was recurrent. They also reveal that 1905-1920 was an exceptionally wet period.

Multi-century, tree-ring based reconstructions of Colorado River flow indicate that extended drought episodes are a recurrent and integral feature of the basin's climate. Moreover, the range of natural variability present in the streamflow reconstructions reveals greater hydrologic variability than that reflected in the gaged record, particularly with regard to drought. These reconstructions, along with temperature trends and projections for the region, suggest that future droughts will recur and that they may exceed the severity of droughts of historical experience, such as the drought of the late 1990s and early 2000s.

Maintaining the Colorado River Streamflow Gaging Network

The Lees Ferry gage record is an important part of the scientific basis for understanding Colorado River discharge and variability and thus for Colorado River water management. Previous federal-level political and financial support for stream gaging stations has been inconsistent. Over the years, some stations have been discontinued. The loss of stations with long (greater than 30 years) periods of record represents a problem of special concern. The value and importance of reliable and continuous hydrologic records will only grow in the future. It would be imprudent and short-sighted to allow the integrity of the Colorado River gaging station network to be compromised or degraded.

Measured values of streamflow of the Colorado River and its tributaries provide essential information for sound water management decisions. Loss of continuity in this gaged record would greatly diminish the overall value of the existing flow data set, and once such data are lost they cannot be regained. The executive and legislative branches of the U.S. federal government should cooperate to ensure that resources are available for the U.S. Geological Survey to maintain the Colorado River basin gaging system and, where possible, expand it.

REALITIES OF COLORADO RIVER WATER MANAGEMENT

In considering its full statement of task and in speaking with Colorado River scientific, engineering, and management experts during the course of this study, this committee identified several trends and realities that affect applications of scientific information in water management. Some of them may prove politically contentious, but they nonetheless merit careful consideration by decision makers at all levels in Colorado River water planning.

Increasing Water Demands, Limited Water Supplies

The late 20th and early 21st centuries witnessed high rates of population growth across the western United States. Population in Arizona, for instance, jumped from about 3.7 million in 1990 to over 5.1 million in 2000—a roughly 40 percent increase (this rate would double Arizona's population in fewer than 20 years). In Colorado, population grew from slightly fewer than 3.3 million in 1990 to about 4.3 million in 2000—a 30 percent increase. These figures do not necessarily equate directly to increases in water demand, as conservation measures, pricing policies, and consumer habits and preferences all influence per capita water uses. In fact, some innovative urban water use and conservation programs have led to reductions in per capita use. Nevertheless, expanding populations have prompted significant increases in urban water demands. Water consumption in Clark County, Nevada (which includes Las Vegas), for example, approximately doubled in the 1985-2000 period. Population growth rates and future projections are on a sharply increasing trajectory in the western United States and they point to sizable and growing water demands for the foreseeable future. In addition, other demands on water supplies, such as those emanating from tribal settlements or from reallocations to support instream flows, will likely grow in the years ahead.

From a water resources perspective, the traditional means of coping with (and effectively encouraging) growth in the western United States was to develop new water supplies by creating large storage reservoirs. After a period of vigorous dam construction in the 1950s and 1960s, prospects for constructing additional large dams in the Colorado River basin have diminished.

Today, rather than creating new reservoirs, municipalities are focusing on new, often nonstructural, strategies for augmenting water supplies. A significant trend in this quest has been the sale, lease, and transfer of agricultural water rights to municipalities, particularly in southern California and Colorado (in Arizona, settlements of tribal water right, with subsequent transfers to municipalities, have also been important).

Agricultural water rights have been crucial to meeting burgeoning urban water demands in many places. There are other ways for urban areas to obtain additional water supplies, such as through greater use of municipal effluent water (the only growing water supply available in the arid West). Nevertheless, agricultural water appears to constitute the most important, and perhaps final, large reservoir of available water for urban use in the arid U.S. West. In aggregate, the amount of water devoted to agricultural uses is quite large, as about 80 percent of western U.S. water supplies are devoted to crop production. Modest shifts of agricultural water to municipal and industrial uses can do much to meet increasing urban water demands. The direct effects associated with the loss of agricultural water, however, such as reduced food production capability, can be significant. In addition, agricultural-urban transfers often entail other, "third party," effects that include costs for rural communities, ecosystems, and other groups indirectly dependent on water supplies affected by the transfers. In recent years many creative water transfer arrangements, involving legally defined water banks and underground water storage programs designed to help mitigate third party effects, have been developed. The availability of agricultural water is finite, however, and such programs thus are limited in their ability to satisfy increasing, long-term demands. The combination of limited Colorado River water supplies, rapidly increasing populations and water demands, warmer regional temperatures, and the specter of recurrent drought point to a future in which the potential for conflict among existing and prospective new users will prove endemic.

Steadily rising population and urban water demands in the Colorado River region will inevitably result in increasingly costly, controversial, and unavoidable trade-off choices to be made by water managers, politicians, and their constituents. These increasing demands are also impeding the region's ability to cope with droughts and water shortages.

Technologies and Strategies for Augmenting Water Supplies

A wide array of technological and conservation measures can be used to help stretch existing water supplies. These measures include underground storage of water, water reuse, desalination, weather modification, conservation, and changes in water pricing structures and rates. These measures may not necessarily be inexpensive or easy to implement, but many of them show promise and will continue to be pursued and developed as water supplies tighten in future years. Areas experiencing population growth will continue to demand additional water supplies, however, and gains realized through technology, conservation, and other measures will be readily absorbed by increasing population and water demands.

Technological and conservation options for augmenting or extending water supplies—although useful and necessary—in the long run will not constitute a panacea for coping with the reality that water supplies in the Colorado River basin are limited and that demand is inexorably rising.

IMPROVING DROUGHT PREPAREDNESS: COOPERATION, SCIENCE, AND PLANNING

Interstate Cooperation

The drought of the late 1990s and early 2000s prompted the Colorado River states to move toward a new level of interstate cooperation in devising water shortage management criteria. A preliminary proposal presented in a February, 2006 letter from the seven basin states to the U.S. Secretary of the Interior (see Appendix A) responded to the Secretary's request that the states develop shortage guidelines and management strategies under low reservoir conditions. This letter represents a noteworthy effort to avoid potential disruptions of operational criteria that govern flow allocations among the basin states.

The interstate cooperation and initiative exhibited by the Colorado River basin states in their February 2006 letter to the Secretary of the Interior is a welcome development that will prove increasingly valuable—and likely essential—in coping with future droughts and growing water demands.

Scientist-Decision Maker Collaboration

The scientific knowledge base of Colorado River hydrology and climate rivals, and may exceed, comparable knowledge bases for any of the world's river systems. Some of this scientific knowledge has been fundamental to legal and operational decisions, such as the Bureau of Reclamation's Operating Criteria, reservoir operations rule curves, and other aspects of Colorado River basin water resources planning and policy. Some of this scientific information, on the other hand, may not be as well integrated in Colorado River basin water policy as it might be.

Drought conditions in the early 2000s stimulated stronger two-way communication between the scientific community and the water management community. This increased collaboration took the form of workshops, conferences, and other discussions among climate and water experts (especially paleoclimate and tree-ring specialists), hydrologists, civil engineers, and water resources planners and decision makers. Communication between scientists and water managers is important because, for example, it is not always clear what types of scientific information the water management community would find most useful. Scientists can help explain scientific concepts and findings to the water management and user community, while water managers can help scientists frame scientific questions and lines of inquiry that they would find most useful for operational and longer term strategic decisions. These interchanges require sustained, two-way collaboration in order to enhance mutual learning between these groups. It will be important for western water managers to sustain this interest in Colorado River climate, drought, and water planning issues when wetter conditions return, as severe drought conditions will undoubtedly occur again. It will also be important for scientists to sustain their interests in water policy issues related to water supply, demand, and drought management.

A commitment to two-way communication among scientists and water managers is important and necessary in improving overall preparedness and planning for drought and other water shortages. Active communication among people in these communities should become a permanent fixture within the basin, irrespective of water conditions at any given time. Such dialogue should help scientists frame their investigations toward questions and topics of importance to water managers, and should help water managers keep abreast of recent scientific developments and findings.

Comprehensive, Action-Oriented Study of Pressing Colorado River Water Issues

The Colorado River Compact and much of the Law of the River—the federal and state statutes, interstate compacts, court decisions, and other operating criteria and administrative decisions that define the river's overall governance—were framed during an era in which water for irrigation (and municipal uses in Southern California) was of paramount concern. Today, population growth and increasing water demands have moved urban water issues to the fore of the western water landscape. Increasing urban population and water demands have prompted municipal water managers to think creatively about more efficient water management and ways to increase water supplies and/or limit water use. States and municipalities have sponsored many conservation, landscaping, education, and other related programs. There have been few initiatives, however, to systematically document or synthesize these efforts, which may be hindering progress toward more efficient and better coordinated urban water management across the region. Moreover, knowledge of important topics and issues, such as water demand forecasting and the environmental implications of large-scale agriculture-urban water transfers, lag behind advances in hydrologic and climate sciences.

A more systematic and coordinated approach to urban water conservation and drought preparedness could be promoted through a collaborative investigation across the Colorado River basin. The basin states and municipalities generally establish water practices and policies tailored to their unique circumstances. A comprehensive, accessible report of basin-wide urban water practices, comparing the many lessons learned from diverse experiences across the basin in coping with water shortages and limited supplies, could serve as a more systematic and action-oriented basis for water planning. The collaboration involved in preparing such a report could also promote better communication among federal agencies, the basin states, and municipalities on urban water management strategies and alternatives. It could also encourage a sustained commitment toward a more proactive approach to managing urban water during periods of drought and in the face of growing population.

A comprehensive, action-oriented study of Colorado River region urban water practices and changing patterns of demand should be conducted, as such a study could provide a more systematic basis for water resources planning across the region. At a minimum, the study should address and analyze the following issues:

- **historical adjustments to droughts and water shortages,**
- **demographic projections,**
- **local and regional water demand forecasting,**
- **experiences in drought and contingency planning,**
- **impacts of increasing urban demands on riparian ecology,**
- **long-term impacts associated with agriculture-urban transfers, and**
- **contemporary urban water polices and practices (e.g., conservation, landscaping, water use efficiency technologies).**

The study could be conducted by the Colorado River basin states, a U.S. federal agency or agencies, a group of universities from across the region, or some combination thereof. The basin states and the U.S. Congress should collaborate on a strategy for commissioning and funding this study. These groups should be prepared to take action based on this study's findings in order to improve the region's preparedness for future inevitable droughts and water shortages.

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Colorado River Basin Water Management

Evaluating and Adjusting to Hydroclimatic Variability

Committee on the Scientific Bases of Colorado River Basin Water Management

Water Science and Technology Board

Division on Earth and Life Studies

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* The activities of this committee were overseen and supported by the NRC's Water Science and Technology Board (see Appendix C for listing). Biographical information on committee members is contained in Appendix D.

Preface

The Colorado River has long been uniquely important in the exploration, development, and culture of the western United States. The Colorado is a desert river, stretching from high in the Rockies, through great canyons and arid regions in Utah and Arizona, and finally ending in the Gulf of California in Mexico. For millions of years it has shaped landforms and in the Grand Canyon has exposed geologic formations that are half as old as the Earth itself. The great American scientist John Wesley Powell explored this region widely. He had extensive knowledge of many Native American tribes and his 1869 boating expedition down the Colorado River through the Grand Canyon is legendary. Powell's 1878 publication *Lands of the Arid Region of the United States, with a More Detailed Account of the Lands of Utah* offered many new ideas regarding the roles of the U.S. federal government in developing western water supplies. Although Powell may have foreseen some aspects of western development, one thing he probably did not foresee was the future extent of population growth in the Colorado River region. Nor was Powell likely to have imagined that changes in regional climate might some day affect hydrologic conditions.

Our committee was asked to review the hydrologic and climatic bases of Colorado River water management. In considering this existing body of scientific information, we were struck by the warming across the region in the past century and by the fact that nearly all global climate models forecast increasing temperatures for the Colorado River region. We also noted the exceptionally hot and dry conditions across much of the nation in the summer of 2006, and that the 2006 average annual temperature for the contiguous U.S. was the warmest on record and nearly identical to the record set in 1998. These conditions are consistent with warming trends in the region.

As we proceeded it became clear that a broad understanding of Colorado River water management issues is not possible unless both water supply and demand issues are adequately considered. Terms such as "population growth" and "water demand" do not appear in our statement of task. As we spoke with water experts from across the region at our meetings, however, they identified important linkages among hydrology and climate and issues such as population growth and water demands, urban water management and conservation, riparian ecology, and water transfers. Clearly, interest in hydroclimatic issues in the region is being driven in large part by increasing water demands and a limited ability to augment water supplies through traditional means. Furthermore, our statement of task called for us to consider the broad topics of systems operations and water management practices. We thus felt it incumbent upon us to comment on topics of water demand, technologies and practices for augmenting water supplies, and programs for coping with drought.

Our report presents population growth data for much of the western United States that is served by Colorado River water. The cities in the region are collectively the fastest-growing in the nation. Of further concern is that this growth seems to be occurring with little regard to long-term availability of future water supplies. Ideally, these issues will be openly discussed and squarely addressed before the water supply-demand balance across the region becomes more critical. This is important because, for example, the drought of the early 2000s turned out to be even worse than many assumptions regarding a worst case scenario drought. This ongoing drought has contained a sequence of exceptionally dry years. Inflows into the basin's storage reservoirs have been well below normal and it may take fifteen years of average future hydrologic conditions to refill the basin's largest water storage reservoirs, Lakes Mead and Powell. These hydroclimatic trends are especially troubling in light of rapidly increasing water demands.

I thank our committee members for their hard work and intellect they devoted to producing this consensus report. Each of them brought unique expertise to our deliberations and report preparation and they all devoted many hours of personal time to our study. Their views were fully considered in our study process and I thank them for their contributions, good will, and spirit of collaboration. I also thank the many water scientists, engineers, administrators, and other experts from across the region that spoke with our committee. They provided a comprehensive and fascinating update of key water and science issues across the region and presented important topics and questions for our committee's consideration, all of which was essential to our deliberations and report (a full list of these speakers is in Appendix B).

I also thank the National Research Council (NRC) staff members for their dedication and diligent work in our study process. Jeff Jacobs, senior staff officer with the Water Science and Technology Board (WSTB), ensured that our committee stayed on task and that the varying opinions and written contributions from our committee members were blended to create a single, coherent report. Jeff and the committee were ably assisted by WSTB research associate Dorothy Weir, who handled administrative details of the meetings and ably assisted in all phases of report preparation.

We are grateful to the sponsors who provided support for this study. These sponsors included federal, state, and municipal water organizations across the West, which reflects the broad interest and importance in these issues. These sponsors were the California Department of Water Resources, the Metropolitan Water District of Southern California, the Southern Nevada Water Authority, and the U.S. Bureau of Reclamation. We also thank the National Academies for providing a substantial portion of funding and for exercising leadership in initiating this study.

This report was reviewed in draft form by individuals chosen for their breadth of perspectives and technical expertise in accordance with the procedures approved by the National Academies' Report Review Committee. The purpose of this independent review was to provide candid and critical comments to assist the institution in ensuring that its published report is scientifically credible and that it meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The reviewer comments and draft manuscript remain confidential to protect the deliberative process. We thank the following reviewers for their helpful suggestions, all of which were considered and many of which were wholly or partly incorporated in the final report: John A. Dracup, University of California; Jerome B. Gilbert, Orinda, California; W.R. Gomes, University of California; Martin P. Hoerling, National Oceanic and Atmospheric Administration; Malcolm K. Hughes, University of Arizona; Katharine L. Jacobs, University of Arizona; John W. Keys, III, Moab, Utah; Upmanu Lall, Columbia University; John E. Thorson, California Public Utilities Commission; and James L. Wescoat, Jr., University of Illinois.

Although these reviewers provided constructive comments and suggestions, they were not asked to endorse the report's conclusions and recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Daniel P. Loucks, Cornell University, who was appointed by the NRC's Report Review Committee, and by A. Daniel Tarlock, Chicago Kent College of Law, who was appointed by the NRC's Division on Earth and Life Studies. Drs. Loucks and Tarlock were responsible for ensuring that an independent examination of this report was conducted in accordance with NRC institutional procedures and that all review comments received full consideration. Responsibility for this report's final contents rests entirely with the authoring committee and the NRC.

The seven Colorado River basin states and cooperating agencies, particularly the Bureau of Reclamation, face great challenges in addressing the complex issues of Colorado River water supply management. The pressures of meeting the needs of the burgeoning population in the face of future severe droughts and uncertain impacts of global change are indeed great. Political pressures will abound but there are signs of increasing cooperation on a variety of water use issues. We hope this report represents a contribution to the knowledge base of Colorado River hydroclimate and water management and that it helps promote common understanding and cooperation on these matters.

Ernest T. Smerdon
Chair

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