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(Summer Conference, June 11-13)

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Conference Guidebook: Water, Climate and Uncertainty: An Introduction to the Issues, Language, Literature and the Conference Materials

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**WATER, CLIMATE AND UNCERTAINTY:
AN INTRODUCTION TO THE ISSUES, LANGUAGE,
LITERATURE AND THE CONFERENCE MATERIALS**

PART I: WHAT ARE CLIMATE RESEARCHERS SAYING
ABOUT WESTERN WATER? A GUIDE FOR NON-SCIENTISTS

PART II: WHAT SHOULD CLIMATE RESEARCHERS KNOW
ABOUT THE REALM OF WESTERN WATER LAW, POLICY
AND MANAGEMENT?

PART III: WHERE TO FIND ADDITIONAL INFORMATION

Prepared as a Supplement to:

*Water, Climate and Uncertainty:
Implications for Western Water Law, Policy, and Management*

Natural Resources Law Center, University of Colorado School of Law
June 11-13, 2003

by

Doug Kenney, Ph.D.

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This guidebook is a gross distillation of countless sources, and undoubtedly reflects the biases and experiences of the author. In the text, no attempt is made to attribute ideas to specific sources, as the intent is to focus on broad themes emerging from the literature rather than specific projects or individual work. Many of the most salient and accessible of these sources are listed in Part III and, in many cases, are included in pdf form on the Conference CD as part of an electronic library.

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INTRODUCTION TO THE “GUIDEBOOK”

A staggering number of studies, projects, and organizations exist that explore some element crucial to the relationship between potential future climatic conditions and the water resources of the American West. Unfortunately, tying this wealth of information together in a useful way is often beyond the training of any one individual or group of individuals. The purpose of this guidebook, and (in part) the conference it supports, is to build bridges and understanding between two traditionally isolated groups of individuals concerned about water and climate: research scientists interested in climate studies and hydrology, and the community of water resources decision-makers, regulators, planners, and managers trained in disciplines such as law, policy, and economics.

In the case of both communities, finding published information is not difficult—there is a wealth of scholarly work. Rather, the challenge is to find the right information, and in the right order, allowing the reader to quickly build a working knowledge of the most salient issues, findings, and areas of ongoing research. For the newcomer to the scientific literature, this challenge is complicated by the wealth of technical concepts and terms, and by the traditions inherent to the scientific method of inquiry; whereas for the newcomer to the “law and policy” literature, the challenge is often in reading between the lines—i.e., distinguishing between what is described in principle and what occurs in reality.

This document is described as a guidebook since it is designed to lead readers into new subjects and literatures, much as a traditional guidebook can ease a tourist, businessperson, or immigrant into a new territory. Once you have established your bearings, you are encouraged to explore on your own, in this case by using the source materials and conference presentations compiled on the conference CD (following the event).¹

¹ Of course, many readers will find this guide too general and cursory to be of much value, and will recognize the discussions as colored by the opinions and experiences of the author—problems endemic to all guidebooks. For those of you, I suggest you skip it. But for the rest of you, this guidebook should provide the foundation necessary to take full advantage of the conference materials and presentations.

PART I: WHAT ARE CLIMATE RESEARCHERS SAYING ABOUT WESTERN WATER? A GUIDE FOR NON-SCIENTISTS

CLIMATE SCIENCE AND RESEARCH: THE BASICS

AVERAGES AND EXTREMES

A wide variety of scientists and other researchers investigate the relationship between climate and water resources. Some of this science is focused on the possibility of long-term *climate change*, while other investigations focus on *climate variability*—particularly, extreme events such as droughts and floods. In the language of statistics—the foundation of most climate research—the former is the study of fundamental movements in *averages* (means), while the latter is focused on event-specific *deviations from average* (e.g., standard deviations). Both parameters have always been important to water managers. Average climatic conditions establish the basic contours of long-term water availability and system yields, while extreme events shape the design of spillways, reservoir curves, safe yield calculations, and many related facets of water management. Both subjects are independently worthy of study; for example, even in the absence of climate change, increased variability could be highly problematic for water managers. Yet it is the combined impact of changing averages and extremes that is perhaps most relevant to improved resource planning and management.

Historic records of water data are routinely used to estimate both averages and variability, and are the foundation of many current water planning and management decisions. With an adequate history of streamflow monitoring data, for example, it is a simple matter to calculate the average discharge of a river, and to generally describe what a 100-year drought might look like. Often, this history of monitoring data can be greatly extended by paleoclimate reconstructions—i.e., the use of data such as tree-rings to provide estimates of prehistoric climate regimes. However, a detailed knowledge of past climatic conditions is useful for managers only as long as one overriding assumption is valid: that the climate of the future will look like the climate of the past. Unfortunately, that assumption seems increasingly tenuous. In just the past century, the average annual US temperature has risen by almost 1°F (0.6°C), and precipitation has increased by 5 to 10 percent—mostly due to big storms. Changes in the past decade have been the most dramatic, leading some researchers to believe that the 1990s were the hottest decade of the millennium. The trends observed in the 1990s have also sparked interest in the subject of abrupt climate change, as opposed to more gradual (linear) movements in means and variability. Evidence of several large-scale, abrupt climate changes can be found in the geologic record.

CLIMATE CHANGE PROJECTIONS

The research community is increasingly asked to provide projections of future climatic conditions and, more specifically, what this might mean for water availability in specific regions such as the western United States. This is an exceedingly complex task usually involving several linked stages, each aided by different models and, in the latter stages, the involvement of an increasingly diverse

set of professionals and considerations. For our purposes, it is useful to identify six stages, described below.

(1) Global-Scale Projections. The foundation of most long-term climate projections are massive computer programs called General Circulation Models (GCMs) used to estimate future temperature and precipitation averages at large scales (grid boxes) collectively covering the Earth's surface. A wide variety of GCMs exist producing different projections, fueling intense debate within the scientific and political communities. One major source of differences in projections are the various assumptions about future carbon dioxide (and other greenhouse gas) emissions, which in turn is a function of assumptions about global economic development, population growth, energy policies, and the likely degree (and scheduling) of policy responses to global climate change. Most modelers have much more confidence in temperature projections than in precipitation estimates, something reflected in the much greater diversity seen in the precipitation projections.²

(2) Regional Downscaling. The projections of the GCMs are calculated at the scale of “grid boxes” that differ in size according to the model, but in most cases, are much larger than the scales necessary to evaluate impacts on particular water systems. A variety of models and statistical techniques are used to “downscale” the GCM output to smaller regions of concern, where local topographic and microclimate forces can significantly impact temperature and precipitation.

(3) Streamflow Estimates. Once future temperature and precipitation conditions are projected for a given basin, hydrologists can translate this data into streamflow estimates. This can be particularly difficult in the arid and semi-arid West, where even minor changes in precipitation can have disproportionately large impacts on runoff. Additionally, at this stage, it is a challenge to consider the competing natural processes that influence streamflow. For example, in most US basins, the majority of projections call for increased temperatures and increased precipitation, but whether or not this translates to more runoff is often determined by whether or not rising evapotranspiration (which increases with temperature) will offset additional precipitation. Despite these and many other complications, generating streamflow estimates is generally considered a more precise exercise than either of the two preceding steps. If similar assumptions about future temperature and precipitation regimes are used as input (rather than the diversity of GCM projections), resulting streamflow estimates are generally consistent.

(4) Water System Simulations. Water managers typically employ simulation models to describe the movement of water into, through, and out of the developed water infrastructure of reservoirs and related facilities. These models were generally built and calibrated using historic data, but nonetheless, can often accommodate the analysis of streamflow inputs associated with different future climate scenarios. This is a very useful approach for evaluating how changes in the magnitude and timing of inflows might resonate through a water system, and is the first stage in estimating impacts to water systems.

(5) Vulnerability Assessments. A closely related next step is determining whether or not changes in inflow characteristics have a discernable impact on water yields, reliability, costs, and other key management parameters given the synergistic influence of climate with other variables,

² The challenge in projecting precipitation is evident by comparing the two GCMs used in the National Assessment studies (mentioned later). For the period 1990 to 2030, the Canadian model projects runoff in the Upper Colorado Basin to decrease by 36 percent, while the Hadley (UK) model suggests an increase of 7 percent. Even more divergent are the projections for the Lower Colorado, where the models predict a decrease of 38 percent and an increase of 23 percent, respectively. Some regions—such as California—feature much more consistent projections, but whether consistency equals accuracy is an open question.

such as demographic changes. Ultimately, estimating impacts requires going beyond a purely supply-side investigation of inflows and necessitates a consideration of changing demand patterns.³ Again, this effort usually involves the development of computer models, but also requires the involvement of a much wider variety of experts and disciplines—including the social scientists—than found in the preceding stages. Interdisciplinary assessments are the primary vehicle for determining possible impacts of climate change and variability.

(6) Adaptations. An ideal but frequently missing concluding step is the evaluation of possible adaptation strategies. Both supply-oriented and demand-oriented options normally deserve investigation, implicating tools from the realms of law, economics, engineering, and many other areas.

CLIMATE VARIABILITY & RECURRING PHENOMENA

Some of the most fruitful research in recent years has focused on recurring phenomena that can create or modify extreme events and can alter seasonal precipitation totals. Of particular interest has been the phenomenon of El Niño, or more generally, the El Niño/Southern Oscillation or ENSO. El Niño entails modest (roughly 1°C) increases in sea surface temperatures (SSTs) for several thousand miles along the equator in the eastern Pacific.⁴ A cooling of sea surface temperatures is known as La Niña. While La Niña often follows El Niño, this is not always the case. El Niño and La Niña are associated with different phases of the Southern Oscillation—patterns of surface air pressure changes between north-central Australia and Tahiti. The term ENSO is usually used to refer to this entire suite of related climatic phenomena.⁵

The existence of an El Niño can have dramatic impacts in the “seasonal climate” in a variety of locales throughout the world, although some regions are largely unaffected. In the American West, El Niño generally brings increased precipitation to the Southwest and reduced precipitation to the Northwest.⁶ A generally opposite effect tends to occur during La Niña. ENSO also influences the probability and magnitude of extreme storms (e.g., hurricanes) and can modify other seasonal weather phenomena such as monsoons.

ENSO events are not a new type of phenomenon and are thus not likely a result of more recent increases in atmospheric carbon dioxide concentrations and global temperatures. However, global climate changes may be influencing the frequency, strength, and length of ENSO events. Exploring these connections is an active area of research, but identifying statistically significant linkages is difficult due to the relatively small numbers of ENSO events for which good data exists.

A somewhat more embryonic area of research involves a phenomenon known as the Pacific Decadal Oscillation (PDO). The PDO is an ENSO-like phenomenon that operates on a much longer time frame (20-30 years for PDO as opposed to 6 to 18 months for ENSO events) and is centered on the

³ Irrigation demand, for example, is particularly climate sensitive

⁴ El Niño is Spanish for “the Christ Child.” This name derives from the observation that El Niño sea surface temperatures peak around Christmas.

⁵ For more information on ENSO, see: “Frequently (well, at least once)-asked-questions about El Niño.” Billy Kessler, Oceanographer, Pacific Marine Environmental Laboratory, NOAA.

<http://www.pmel.noaa.gov/~kessler/occasionally-asked-questions.html#q17>; and “ENSO Information” from the Climate Diagnostics Center, <http://www.cdc.noaa.gov/ENSO/>.

⁶ The degree to which a region’s weather is influenced is known as its ENSO “signal.” The stronger the signal, the greater the probability that the seasonal climate will be influenced.

North Pacific/North American sector (rather than the tropics for ENSO events). Both “warm” and “cool” PDO cycles can be documented, producing results broadly similar to weak ENSO events.⁷ Understanding the combined impact of ENSO, PDO, and possible global climate change is an important and active area of study.

SCIENCE, UNCERTAINTY AND BEST GUESSES

A better understanding of past and present climate phenomenon is expected, ultimately, to lead to more sophisticated projections of future conditions. The extent to which current research satisfies this need is largely tied to the expectations of the user. For example, if an accurate prediction of year 2100 water availability in a given basin is the goal, then the user is likely to be disappointed by even the most acclaimed studies, as the output is the product of several stages of compounded errors and uncertainties. Models with similar assumptions (and in many cases, identical computer source code) may in fact yield similar results, but this consistency cannot safely be interpreted as accuracy.

In order to make use of this research exploring the long-term relationship between climate change and water management, therefore, it is probably most useful to view the model output as “scenarios”—i.e., plausible alternative futures based on a given set of assumptions—rather than predictions or forecasts. By using a reasonable range of assumptions, a group of scenarios can be generated that, collectively, describe a range of potential futures that are likely to encompass our actual future. In many cases, that range may first appear too broad to help guide actual planning and management decisions, but ultimately, the scenarios can help managers assess the vulnerability of their systems, and can provide useful sidebars within which to explore the utility of adaptation and mitigation mechanisms.⁸

Already, a few consistent findings are emerging from the suite of available scenarios that should merit immediate consideration in the water community. These are discussed in detail in the literature provided (described later) and are the subject of several conference presentations; thus, they are only mentioned briefly here. They include:

- A continued rise in global temperatures, perhaps in the range of 1.4 to 5.8°C (2.5 to 10.4°F) from 1990 to 2100. This range is largely explained by different emissions scenarios; it would likely constitute the most dramatic temperature increase in at least 10,000 years.
- In basins where most of the water supply is associated with snowmelt, the result of warmer temperatures is likely to be a reduced ratio of snow to rain, earlier snowmelt, increased winter stream flows, and lower summer flows. These impacts are likely to be most noticeable in lower mountainous areas, where just a modest temperature increase can noticeably shift the snowline.
- Precipitation trends are highly region-specific and among the most difficult climate variables to forecast, but for most basins in the American West, many researchers believe that the 21st century will continue the late-20th century trend toward wetter conditions. This trend is

⁷ More information about PDO can be found at: “The Pacific Decadal Oscillation: A Brief Overview for Non-Specialists.” Nathan Mantua. <http://tao.atmos.washington.edu/PNWimpacts/Publications/Pub129.htm>

⁸ The distinction between *adaptation* and *mitigation* is important. Members of the water management community are likely confined to seeking *adaptation* measures that attempt to limit vulnerability and impacts associated with a given range of possible climate futures. The term *mitigation* is usually reserved for national or global strategies aimed at reducing human contributions to climate change.

expected to be strongest with increasing latitude. How this influences water availability is a function of several biophysical considerations (such as evapotranspiration rates and surface water/groundwater interactions), water management practices (such as reservoir operations), and potential changes in water demands.

- In addition to water supply concerns, changes to runoff regimes are likely to raise water quality and environmental issues associated with periods of reduced seasonal flows, water temperature increases, storm surges, saltwater intrusion (in coastal areas), and more generally, problems associated with climate changes occurring at rates beyond the natural adaptive capacity of species and ecosystems.

PART II: WHAT SHOULD CLIMATE RESEARCHERS KNOW ABOUT THE REALM OF WESTERN WATER LAW, POLICY AND MANAGEMENT?

Many, if not most, physical scientists have experienced a situation in which new information or scientific understanding was developed with the potential to improve actual resource management, but for a variety of reasons, this promise was never realized. This pattern is certainly well ingrained in the climate research community, in part due the failure of some scientists to understand the decision making context, and partly due to the hesitancy of many decision makers to seek out and use new information. Understanding these factors is a prerequisite to making climate research more relevant to the decision-making community.

CLIMATE ISSUES IN CONTEXT

Part of the challenge of using climate information in the realm of water law, policy, planning and management is that climate change and variability can simultaneously influence every aspect of system design and operation, from the location and sizing of facilities, to the design of reservoir operating rules, to inflow quantities and timing, and perhaps most overlooked, to the magnitude and timing of demands. If these and other parameters are all likely to be affected in complex ways that can only be described in terms of probabilities, it is hard to blame decision makers for hanging onto traditional—and more “manageable”—mechanisms for making water-related decisions. This is especially true given that many of the other threats and stresses on western water systems are much better understood by the law, policy and management community. At the top of this list are the demographic changes occurring in the region, and the heightening competition for limited supplies.

The cumulative demands on the West’s water resources are many and growing. In most western states, 80 to 95 percent of water withdrawals are used in agriculture. Although this use has peaked or declined in most areas, these water savings are generally being offset by rapid increases in municipal water demands. Despite the traditional image of the rural westerner, the distribution of the region’s 63 million people is increasingly concentrated in cities—particularly in the “Sunbelt” cities of the Southwest—making the West the most highly urbanized region of the United States (in percentage terms). In just the 1990s, the region’s population grew by almost 20 percent, with the fastest rates of growth found in the most arid states.⁹ This urbanization is expected to continue, with the West adding approximately 1 million new residents per year for the next two decades.

Population growth will further increase the competition for limited supplies, not only between rural and urban users, but also between human uses and environmental values. In both variants, this competition for water is not merely about adequate supply, but about obtaining adequate supplies at desired levels of quality, cost and reliability. Primarily due to population growth, a recent Interior Department study entitled *Water 2025* describes impending water conflict as “highly likely” in several western basins, including Colorado’s Front Range; the middle Rio Grande in New Mexico; the Lower Colorado River between Arizona, California and Nevada; California’s Central Valley; the

⁹ In the 1990s, the nation’s five fastest growing states, in order, were Nevada, Arizona, Utah, Colorado, and Idaho.

Great Basin's Truckee-Carson system, and Utah's Salt Lake valley. Throw the possibility of climatic change and variability into the mix and things could get truly interesting.

THE INSTITUTIONAL SETTING

The risk of future water shortages in the West is distributed unevenly, in part due to geographic and demographic factors, but also due to laws, policies, and other institutional factors. The most important of these considerations is the region's primary legal mechanism for water allocation: prior appropriation. The prior appropriation doctrine is not only the dominant water allocation mechanism in the region, but it is the West's *de facto* water policy, recognized in several state constitutions.

The hallmark of the prior appropriation system is the concept of "first-in-time, first-in-right." This notion allows for the establishment of a priority system to determine the allocation of water amongst users on a stream when supplies are insufficient to satisfy all demands. Priority is based on seniority; "senior" rightsholders are those who first established a pattern of beneficial water use—as recognized in an administrative permit or judicial decree—as compared to more "junior" users. Seniority is important since it determines a water user's vulnerability to climatic events and other possible sources of shortage. In a water short year, senior water rightsholders receive all of their water before any water is made available to junior rightsholders. When necessary, a senior water rightsholder may place a "call on the river" requiring upstream junior rightsholders to cease diversions until more senior users receive their full entitlements.

Water rights acquired through appropriation and officially recognized by permit or decree generally specify the type, timing and place of use, carry a seniority date corresponding to the date of first diversion and use, and are quantified based on the historic level of use calculated in either volumetric amounts (e.g., acre-feet), rate of flow (e.g., cubic-feet-per-second), or described more generally in terms of crop needs. Rights can also be obtained for water storage, with the understanding that water collected during wet periods will be released and consumed in dry seasons. The quantity of water in an appropriation right is the amount of water that is put to a beneficial use in a reasonable time with reasonable diligence. In this respect, diverting more water than reasonably necessary is considered wasteful and inefficient, and is thus not considered part of the water right.

Prior appropriation allows the movement of water within basins and between basins within states, but across state lines, different rules apply. At this larger scale, allocation decisions are typically either determined by litigation before the U.S. Supreme Court, or more commonly, in state-to-state negotiations leading to interstate water allocation compacts. Both approaches generally reject the priority system and instead reserve fixed quantities (or fixed percentages) of water for each state based on a wider variety of considerations. Interstate compacts exist for the Arkansas, Bear, Belle Fourche, Big Blue, Canadian, Colorado, Klamath, La Plata, Pecos, Red, Republican, Rio Grande, Sabine, Snake, South Platte, Upper Colorado, Upper Niobrara, and Yellowstone Rivers, and on Costilla Creek. None of these compacts explicitly address the possibility of climate change, and only one—the Upper Colorado River Compact—even mentions the word drought.

Several different types of governmental and quasi-governmental organizations play important roles in managing western water resources. Prior appropriation is state law devised by state legislators and administered by state agencies, with the overriding management objective simply being to record and enforce the priority system. This role, along with the oversight of interstate agreements, is the extent of major state governmental roles in many western states. The actual planning, development and operation of water systems are typically conducted by other entities, including

municipal water agencies, agricultural water districts, utilities, and the federal government—primarily the Bureau of Reclamation and the Corps of Engineers.¹⁰ The federal government also has major roles in implementing national environmental and water quality laws, overseeing tribal lands and water rights, marketing hydropower, and managing the public lands that cover roughly half of the West. Federal and state water law is often poorly coordinated and somewhat inconsistent, and is a nearly constant source of intergovernmental tension. Water shortages, whether climate-related or not, increasingly highlight these areas of conflict and uncertainty in the law, and draw attention to the politically delicate intergovernmental and jurisdictional arrangements that characterize the institutional environment.

CONNECTING SCIENCE TO POLICY

PULLING THE LEVERS

It can be (and is) argued that the system of allocation and management of the West's water resources is both inflexible and flexible. Much of the inflexibility derives from the fact that many rivers were fully allocated (or "appropriated") well over a century ago, and were apportioned using a strict priority system that has proven highly resistant to fundamental reform, although minor innovations are common.¹¹ Whether prior appropriation is an "antiquated" system is the subject of intense debate, but it is undeniably a fixture in western water institutions. Somewhat analogous is the role of physical structures (dams and reservoirs) on western river systems, generally designed in previous eras to serve purposes, sectors and populations which may or may not best reflect current priorities.

These same factors can also be sources of flexibility. Prior appropriation, for example, allows for the reallocation of water through water markets, a mechanism that is key to much of the urban growth that characterizes the modern West. In recent years, many institutional innovations have been geared at facilitating temporary transfers of water, a valuable approach to drought management and, more generally, risk management that allows cities to protect high-valued water uses while avoiding unnecessary dewatering of agriculture in normal years. Similarly, dams and reservoirs can also be a source of flexibility in water systems, through fundamental re-designation of project purposes to more subtle modifications of reservoir rule curves. The potential for change is vast, as the United States trails only China in the number of dams.¹² Over two-thirds of the national water storage capacity is found in the West, home to the nation's 10 largest dams.

Still additional flexibility is, at least theoretically, available through demand management strategies, including conservation programs at both the municipal and agricultural scales.¹³ Economic policies that influence water pricing, water system financing, subsidy programs, and the strength and availability of crop markets can all be particularly salient in influencing water demand.

¹⁰ They are, of course, important exceptions. In California, for example, the state plays an active role in water resource planning and development, as evidenced by the State Water Project.

¹¹ The agenda of reformers is typically focused on broadening environmental protections, encouraging more economically responsible financing and pricing policies, and addressing equity issues between water allocation winners and losers.

¹² Figures compiled for the World Commission on Dams indicates that the United States is home to approximately 6,575 dams at least 15 meters in size, second globally to China's 22,000, and well more than twice as many as the rest of North America, Central America and South America combined.

¹³ Several western states have per capita use figures nearly 3 times the national average.

DECISION MAKERS AND THEIR DECISION SPACE

Each potential entry point for applying climate information has an associated “decision space” comprised of laws, policies, traditions, and related practices that collectively determine the opportunities, obligations, and constraints faced by the decision maker. An understanding of the decision space allows the researcher to design projects and disseminate results based, at least in part, on the following considerations¹⁴:

- What general types of information and knowledge are most strategically relevant to decision makers?
- At what scales and time periods is this information useful?
- How does the value and significance of this information compare to the other factors and phenomenon that influence decision making?
- Is the information accessible and understandable to potential users?
- Will the information and associated recommendations be viewed as credible and trustworthy by decision makers?
- What are the potential risks and rewards to decision makers associated with using (or not using) the new information?

The most practical way to understand the decision space is for researchers to interact with decision makers, ideally in an ongoing manner that allows a two-way flow of ideas and information. This interaction is a major goal of the conference.

¹⁴ This list is primarily drawn from the summary prepared by Katharine Jacobs entitled: “Connecting Science, Policy and Decision-Making: A Handbook for Researchers and Science Agencies.” A copy of this report is on the conference CD’s electronic library.

PART III: WHERE TO FIND ADDITIONAL INFORMATION

LITERATURE AND LINKS

The preceding pages provide a “bare bones” introduction to the issues most relevant to this conference. Much more in-depth and sophisticated introductions can be found in a variety of primers, summary reports, and more specialized reports already prepared, as well as in materials provided by the conference speakers. The following pages list materials available in the conference CD’s “electronic library” as well as Internet links where additional information is available.

REPORTS ON THE CONFERENCE CD: THE “ELECTRONIC LIBRARY”

CLIMATE CHANGE AND VARIABILITY: INTRODUCTIONS, OVERVIEWS AND SUMMARIES

The Science of Climate Change: Global and U.S. Perspectives. Prepared for the Pew Center on Global Change by Tom M.L. Wigley, National Center for Atmospheric Research, 1999. (Pew, Science of Climate Change.pdf) [51 pages]

A Report of Working Group I of the Intergovernmental Panel on Climate Change (IPCC): Summary for Policymakers, multiple authors, 2001. (IPCC, Summary for Policymakers.pdf) [20 pages]

Climate Change 2001: Synthesis Report, Summary for Policymakers, Intergovernmental Panel on Climate Change (IPCC), 2001. (IPCC Synthesis.pdf) [34 pages]

Emissions Scenarios: Summary for Policymakers. Special Report of the Intergovernmental Panel on Climate Change (IPCC), 2000. (IPCC, Emissions Scenarios.pdf) [27 pages]

Climate Change 2001: Impacts, Adaptation and Vulnerability: Summary for Policymakers. Intergovernmental Panel on Climate Change (IPCC), 2001. (IPCC, Impacts.pdf) [18 pages]

Climate Change 2001: Mitigation: Summary for Policymakers. Intergovernmental Panel on Climate Change (IPCC), 2001. (IPCC, Mitigation.pdf) [14 pages]

CLIMATE CHANGE IMPACTS ON WATER RESOURCES

Water and Global Climate Change: Potential Impacts on U.S. Water Resources. Prepared for the Pew Center on Global Climate Change by Kenneth Frederick, Resources for the Future, and Peter Gleick, Pacific Institute for Studies in Development, Environment and Security, 1999. (Pew, Water and Climate Change.pdf) [55 pages]

Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change: Overview, Water Sector. NAST (National Assessment Synthesis Team), 2000. (National Assessment, Overview, Water.pdf) [6 pages]

Climate Variability, Climate Change, and Western Water. Report to the Western Water Policy Review Advisory Commission by Kathleen Miller, National Center for Atmospheric Research, 1997. (WWPRAC, Climate Change.pdf) [66 pages]

CLIMATE CHANGE IMPACTS ON LAND AND BIOLOGICAL RESOURCES

Land Use, Land-Use Change, and Forestry: Summary for Policymakers. Special Report of the Intergovernmental Panel on Climate Change (IPCC), 2000. (IPCC, Land Use and Forestry.pdf) [30 pages]

Climate Change and Biodiversity. Intergovernmental Panel on Climate Change (IPCC), 2002. (IPCC, Biodiversity.pdf) [86 pages]

Aquatic Ecosystems and Global Climate Change. Prepared for the Pew Center on Global Change by N. LeRoy Poff, Mark M. Brinson, and John W. Day, Jr., 2002. (Pew, Aquatic Ecosystems.pdf) [56 pages]

REGIONAL IMPACTS OF CLIMATE CHANGE AND VARIABILITY

Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change: Overview, Summary. NAST (National Assessment Synthesis Team), 2000. (National Assessment, Overview, Summary.pdf) [15 pages]

Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change: Overview, West. NAST (National Assessment Synthesis Team), 2000. (National Assessment, Overview, West.pdf) [4 pages]

The Potential Consequences of Climate Variability and Change for California, Robert Wilkinson, September 2002. (California Assessment.pdf) [432 pages]

Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change: Central Great Plains, Dennis S. Ojima and Jill M. Lackett, July 2002. (Central Great Plains Assessment.pdf) [104 pages]

The Regional Impacts of Climate Change: An Assessment of Vulnerability: Summary for Policymakers. Special Report of the Intergovernmental Panel on Climate Change (IPCC), 2001. (1997) [27 pages]

LAW AND POLICY ISSUES IN WESTERN WATER MANAGEMENT

Water in the West: Final Report of the Western Water Policy Review Advisory Commission. 1998. (WWPRAC, Final Report.pdf) [378 pages]

Two Decades of Water Law and Policy Reform: A Retrospective and Agenda for the Future. Douglas S. Kenney, Natural Resources Law Center, 2001. (Water Reforms.pdf) [20 pages]

DEMOGRAPHIC AND WATER USE TRENDS IN THE WEST

Patterns of Demographic, Economic and Value Change in the Western United States: Implications for Water Use and Management. Report to the Western Water Policy Review Advisory Commission by Pamela Case and Gregory Alward, 1997. (WWPRAC, Demographics.pdf) [66 pages]

Estimates of Water Use in the Western United States in 1990 and Water-Use Trends 1960-1990. Wayne B. Solley. Report to the Western Water Policy Review Advisory Commission by Donald Wilhite, 1997. (WWPRAC, Water Use in the West.pdf) [27 pages]

Population Projections: States, 1995 to 2025. U.S. Census Bureau, 1997. (Population Projections, 1995 to 2025.pdf) [6 pages]

Water and Growth in Colorado: A Review of Legal and Policy Issues. Peter D. Nichols, Megan K. Murphy and Douglas S. Kenney, Natural Resources Law Center. (Water and Growth.pdf) [205 pages]

DEALING WITH UNCERTAINTY IN DECISION MAKING AND MANAGEMENT

Devising Resilient Responses to Potential Climate Change Impacts. Discussion by Martyn Clark and Roger Pulwarty; reply by Rob Wilby. Ogmios: Newsletter of the Center for Science and Technology Policy Research, University of Colorado. No. 5, May 2003. (Ogmios, Responding to Climate Change.pdf) [4 pages (pages 2-5)]

Connecting Science, Policy, and Decision-making: A Handbook for Researchers and Science Agencies. Prepared by Katharine Jacobs for the NOAA Office of Global Programs, 2002. (Science and Decision Making, Jacobs.pdf) [30 pages]

Weather Forecasts are for Wimps: Why Water Resource Managers Don't Use Climate Forecasts. Final Report to the NOAA Office of Global Programs by Steve Rayner, Denise Lach, Helen Ingram, and Mark Houck. Undated. (Weather Forecasts are for Wimps.pdf) [80 pages]

DROUGHT MANAGEMENT

Improving Drought Management in the West. Report to the Western Water Policy Review Advisory Commission by Donald Wilhite, 1997. (WWPRAC, Drought Management.pdf) [52 pages]

Managing Water for Drought. Prepared by William Werick and William Whipple, Institute for Water Resources, U.S. Army Corps of Engineers, 1994. (Managing Water for Drought, IWR.pdf) [200 pages]

Drought Response Plan: Denver Water. 2002. (Denver Drought Plan 2002.pdf) [44 pages]

What the Current Drought Means for the Future of Water Management in Colorado. Prepared by Daniel F. Luecke, John Morris, Lee Rozaklis, and Robert Weaver for the Sustainable Water Caucus, 2003. (Drought in Colorado.pdf) [76 pages]

INTERNET RESOURCES

CLIMATE-RELATED INFORMATION

- Intergovernmental Panel on Climate Change (IPCC): <http://www.ipcc.ch/>
- U.S. Global Change Research Program <http://www.usgcrp.gov/> (including the National Assessment of the Potential Consequences of Climate Variability and Change <http://www.usgcrp.gov/usgcrp/nacc/default.htm>)
- NCAR (National Center for Atmospheric Research) <http://www.ncar.ucar.edu/ncar/>
- UCAR (University Corporation for Atmospheric Research) <http://www.ucar.edu/ucar/>
- A Consortium for the Application of Climate Impact Assessments (ACACIA) <http://www.cgd.ucar.edu/cas/ACACIA/index.html>
- Pew Center on Global Climate Change <http://www.pewclimate.org/>
- Scripps Institution of Oceanography, Climate Research Division <http://meteora.ucsd.edu/>
- National Oceanographic and Atmospheric Administration (NOAA) <http://www.noaa.gov/>
- NOAA's Regional Integrated Sciences and Assessments (RISA) <http://www.ogp.noaa.gov/mpe/csi/risa/>. There are 4 western RISA's:
 - California Applications Program <http://meteora.ucsd.edu/cap/>
 - Climate Assessment for the Southwest (CLIMAS) <http://www.ispe.arizona.edu/climas/>
 - Climate Impacts Group <http://tao.atmos.washington.edu/PNWimpacts/>
 - Western Water Assessment <http://sciencepolicy.colorado.edu/wwa/>
- Cooperative Institute for Research in Environmental Sciences (CIRES) <http://cires.colorado.edu/>
- Climate Diagnostics Center <http://www.cdc.noaa.gov/>
- National Climate Data Center (NCDC) <http://www.ncdc.noaa.gov/oa/ncdc.html>
- The Weather and Climate Impact Assessment Science Initiative – NCAR <http://www.esig.ucar.edu/assessment/index.html>
- NCAR Climate and Global Dynamics Division <http://www.cgd.ucar.edu/>
- Western Regional Climate Center <http://www.wrcc.dri.edu/>

WESTERN WATER LAW, POLICY AND MANAGEMENT

- American Water Works Association <http://www.awwa.org/>
- American Water Resources Association <http://www.awra.org>
- American Society of Civil Engineers <http://www.asce.org/>
- Western States Water Council <http://www.westgov.org/wswc/>
- National Water Resources Association <http://www.nwra.org/index.cfm>
- National Institutes for Water Resources <http://wrri.nmsu.edu/niwr/>
 - The Powell Consortium (of southwestern state water research centers) <http://wrri.nmsu.edu/powell/index.html>
- National Drought Mitigation Center <http://www.drought.unl.edu/index.htm>
- U.S. Bureau of Reclamation <http://www.usbr.gov/>
- EPA Office of Wetlands, Oceans and Watersheds <http://www.epa.gov/owow/>
- U.S. Geological Survey <http://info.er.usgs.gov/>
- American Rivers <http://www.amrivers.org/>
- Water Strategist Community <http://www.waterchat.com/>

GLOSSARY AND LIST OF ACRONYMS

A tremendous variety of specialized terms and acronyms are part of the subject matters covered in this conference. Many of the more salient or confusing terms and acronyms likely to be utilized by speakers are listed below.

Acre-foot = A volume of water equal to 325,900 gallons (or 1.233 million liters).

Adjudication = A legal process, or outcome/judgment of that process, by which the exact qualities of a water right (size, seniority, type of use, point of diversion, etc.) are determined and recorded by the State, based on the presentation of evidence and expert analysis. Adjudications are often required before water rights can be bought, sold, or otherwise transferred.

Anthropogenic = Human-induced.

Appropriation = The withdrawal of water from a watercourse or aquifer for the purposes of establishing a recognized water use and water right.

Assessments = In the world of climate research, “assessments” are detailed studies of possible outcomes and impacts associated with climate change/variability in particular regions.

CAP = California Applications Program. A RISA program dedicated to providing improved climate information and forecasts to decision makers in California. (Internet link provided earlier.) [Can also stand for Central Arizona Project, a massive system of aqueducts, pumping stations, and siphons that moves Colorado River water across the Sonoran desert to users in Phoenix, Tucson, and surrounding agricultural areas.]

CIG = Climate Impacts Group. A RISA program focused on the impact of climate change and variability on the U.S. Pacific Northwest. (Internet link provided earlier.)

CLIMAS = Climate Assessment for the Southwest. A RISA program concerned with the impact of climate change/variability on human and natural systems in the Southwest. (Internet link provided earlier.)

Climate Diagnostics = The attempt to understand the earth’s climate based on atmospheric and geological observations.

Compact = In the context of western water resources, compacts are legally-binding agreements among states typically providing for an allocation of shared rivers.

Composite = Used to describe statistics based on a sub-set of a larger data set.

Conjunctive Use = A term used broadly to define any strategic combined use of surface water and groundwater, usually emphasizing the use of surface water during wet periods and groundwater reserves during dry periods.

Corps (or COE) = U.S. Army Corps of Engineers. A federal agency that builds and operates many water-related facilities, particularly those for flood control, navigation and power generation.

Decision-space = The range of realistic options available to a given manager to address a particular problem.

Downscaling = Procedures for translating data from General Circulation Models (GCMs) (and other tools generating output at large geographic scales) to small geographic scales, such as individual watersheds.

El Niño = A large scale warming of the tropical Pacific Ocean. In the American West, El Niño generally brings increased precipitation to the Southwest and reduced precipitation to the Northwest.

El Niño/Southern Oscillation (ENSO) = A general term used to describe both warm (El Niño) and cool (La Niña) ocean-atmosphere events in the tropical Pacific as well as the Southern Oscillation, the atmospheric component of these phenomena.

Ensemble Technique = The production of findings or projections by using a collection of model runs, rather than relying exclusively on the output of any one run (or ensemble member).

ENSO = See: *El Niño/Southern Oscillation*.

ESA = Endangered Species Act. Federal legislation (1973 as amended) prohibiting actions that kill, harm or otherwise harass members of species recognized as endangered.

Federal Reserved Rights = The principle that public lands retained by the federal government are guaranteed water rights sufficient to fulfill the purposes for which the land was reserved, generally with a priority date corresponding to the date of land reservation.

GCM = See: *General Circulation Models*. [Also occasionally defined as “Global Climate Model.”]

General Circulation Models (GCM) = Sophisticated mathematical computer-models of the atmosphere and its phenomena over the entire Earth, based on equations of motion and considering radiation, photochemistry, and the transfer of heat, water vapor, and momentum.

Greenhouse Effect = Process whereby energy from the sun is trapped by certain (greenhouse) gases in the atmosphere (i.e., water vapor, carbon dioxide, nitrous oxide, and methane). Human-induced increases in greenhouse gas emissions are thought to be enhancing this natural phenomenon.

Instream Flow Rights = A type of water right administered within the prior appropriation system that calls for water to be left in the stream channel for use, including for environmental purposes.

International Panel on Climate Change (IPCC) = Established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988, the role of the IPCC is to assess scientific, technical and socio-economic information relevant to global climate change.

IPCC = See: *International Panel on Climate Change*.

Julian Day = As used in most applications, this is a numbering of days in a calendar year with January 1st as day 1 and December 31st as day 365.

La Niña = A large scale cooling of the tropical Pacific Ocean occurring at irregular intervals of between about two and seven years and lasting for one to three years. In the American West, La Niña generally brings increased precipitation to the Northwest and reduced precipitation to the Southwest.

Least Regrets Approach = A way of designing future coping strategies such that, even if a projected change does not occur, the adopted strategies will still be beneficial.

Model Skill = A measure of how accurate a model, tool or technique makes predictions.

National Oceanic and Atmospheric Administration (NOAA) = Housed within the U.S. Department of Commerce, NOAA conducts research and gathers data about the global oceans, atmosphere, space, and sun, and applies this knowledge to science and service.

NGO's = Non-governmental organizations (such as interest groups).

NOAA = See: *National Oceanic and Atmospheric Administration*.

Orographic Effects = Climatic phenomena associated with mountains and mountain ranges.

Pacific Decadal Oscillation (PDO) = A long-term ocean temperature fluctuation of the Pacific Ocean. The PDO waxes and wanes approximately every 20 to 30 years.

Palmer Drought Severity Index (PDSI) = A numerical scale for describing abnormal wetness or dryness in a particular region, based on rainfall and temperature. Positive numbers indicate unusual wetness, negative numbers indicate drought; zero indicates normal conditions.

PDO = See: *Pacific Decadal Oscillation*.

PDSI = See: *Palmer Drought Severity Index*.

Prior Appropriation Doctrine = The primary mechanism for allocating surface waters and some groundwater reserves within the western states, based on a "first-come, first-served" concept known as seniority.

Priority = See: *Seniority*.

Recharge = The movement of water from the Earth's surface into aquifers, either through natural processes or active management.

Regional Integrated Sciences and Assessments (RISA) = A NOAA program featuring regionally-focused assessments of climate change/variability and the application of this knowledge to decision-making activities.

Return Flows = The amount of a water diversion that is not consumed as part of a given water use (i.e., diversions minus consumption), and is thus available for other uses.

RISA = See: *Regionally Integrated Sciences and Assessments*.

Rule Curves = A set of policies guiding reservoir operation and management, often presented in diagrams and/or mathematical equations, defined in terms of actual and desired storage levels, expected inflows and outflows, and operational objectives and priorities.

Sea Surface Temperatures (SST) = An important gauge for predicting La Niña or El Niño trends. SSTs are monitored from ship reports, buoys and satellite imagery.

Seniority = In the context of the prior appropriation system of water allocation, seniority refers to the date at which a water use was first established, and the provision that the oldest (i.e., most senior) rights are superior to younger (more junior) rights during periods in which supplies are insufficient to satisfy all rights.

SNOWTEL (Snowpack Telemetry) = An extensive, automated system that collects snowpack and related climatic data in the western United States.

SST = See: *Sea Surface Temperatures*.

Stakeholders = Agencies, groups, or individuals with a vested interest in the outcome of particular decisions or policies.

State Engineer = The chief state water official in most western states charged with the administration of water and water rights.

SWE (or SWC) = Snow Water Equivalent (or Content). A measure of how much water is contained within a given snowpack.

Time Series Data = Values of a given variable recorded successively in time (e.g., annual precipitation totals), and often plotted on a graph with time as the x-axis and the variable as the y-axis.

USBR (or “Reclamation”) = United States Bureau of Reclamation, Department of the Interior. The primary federal agency established to build and operate water projects in the western United States.

Water Right = A legally recognized and protected privilege conferred upon individuals and organizations to use water under given terms. Water rights in the West are generally based on the prior appropriation doctrine, and are defined in terms of the quantity, location, timing, purpose, and seniority of the water use.

Water Transfers = The voluntary movement of water and water rights between sectors and regions through the use of markets. In the West, most transfers move water from agricultural to municipal uses.

WWA = Western Water Assessment. A RISA program focused primarily on water and climate issues along the Rocky Mountain headwaters, particularly the South Platte River Basin. (Internet link provided earlier.)

WWPRAC = Western Water Policy Review Advisory Commission. A congressionally established body charged with reviewing federal laws and policies associated with water resources in the American West. (Completed its work in 1998.)