PROCEEDINGS

of the

Western Governors' Association
Western States Water Council
California Department of Water Resources

May 2007
Climate Change
Research Needs Workshop

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CALIFORNIA DEPARTMENT OF WATER RESOURCES

WESTERN STATES WATER COUNCIL

WESTERN GOVERNORS' ASSOCIATION

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I. INTRODUCTION

"I say the debate is over. We know the science. We see the threat. And we know the time for action is now." With these words, Governor Arnold Schwarzenegger signed a landmark executive order in June 2005 that established greenhouse gas emission reduction targets and called for preparation of mitigation and adaptation plans to respond to climate change impacts.

In June 2006, the Western Governors' Association (WGA) released a report, prepared with assistance of the Western States Water Council, entitled *Water Needs and Strategies for a Sustainable Future* that, among other things, called for preparations for adapting to climate change impacts.

WGA, the Western States Water Council (WSWC), and the California Department of Water Resources (CDWR) jointly cosponsored a May 2007 workshop on climate change research needs in Irvine, California as part of efforts to follow up and respond to the need for adapting to climate change impacts expressed in these policy directives. The purpose of the workshop was to bring together state and local water managers, academic researchers, and representatives from federal Climate Change Science Program (CCSP) agencies that fund the academic research, to discuss how to better facilitate scientist-end user interactions and develop partnerships with the federal agencies. Given that there are many areas where focused research could help support planning for adapting to climate change impacts, the workshop was intended to help develop a road map for fostering research useful for Western water management.

Early research on climate change was centered around basic science regarding assessment and attribution of atmospheric warming. Progress made in those areas

The polar bear, an icon for the impacts of climate change on sensitive ecosystems, has been proposed for listing as a threatened species, pursuant to the Endangered Species Act, due to the diminishment of its Artic sea ice habitat.

Photo taken by Steve Amstrup on the pack ice in the Beaufort Sea

has been documented by the findings of the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report, which expressed the conclusions of participants from the scientific community that:

- *Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years.*
- *The understanding of anthropogenic warming and cooling influences on climate has improved since the TAR (Third Assessment Report), leading to very high confidence that the global average net effect of human activities since 1750 has been one of warming....*
- *Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures,*

widespread melting of snow and ice, and rising global average sea level.

- *At continental, regional and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones.*
- *Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas emissions… discernable human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns.*
- *Anthropogenic warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized.*

Policymakers at the state and local government levels are increasingly focusing on strategies for mitigating (reducing greenhouse gas [GHG] emissions) and adapting to impacts of climate change. More than 30 states have joined The Climate Registry to track GHG emissions. Governors Schwarzenegger of California, Napolitano of Arizona, Richardson of New Mexico, Kulongoski of Oregon, Gregoire of Washington, Huntsman of Utah, and Premiere Campbell of British Columbia have signed an agreement establishing the Western Regional Action Climate Initiative, an effort to establish a regional target for GHG reductions and to establish a market-based system for meeting the target. Relatedly, WGA has established a Clean and Diversified Energy Initiative to recommend strategies to increase energy efficiency, expand the use of clean energy, meet transmission needs, and better position the Western energy system to respond to new environmental challenges.

Key Climate Change Definitions

The terms mitigation and adaptation are widely used in the climate change community, where they have specific meanings. The IPCC Third Assessment Report defined them as follows:

Mitigation – An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases. (Examples of mitigation measures would include establishing new vehicle standards to reduce GHG emissions, or developing carbon sequestration programs.)

Adaptation – Adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. (Examples of adaptation could include modifying reservoir flood control operations rule curves or constructing seawalls.)

Water managers are especially concerned with adaptation aspects of climate change, a research area that has received lesser attention than has identification of climate change impacts. To date five Western states—California, Alaska, New Mexico, Oregon, and Washington—have expressed policy directives in the form of legislation, executive orders, or formation of high-level advisory bodies to address adaptation. The need for enhanced focus on adaptation was emphasized at WGA's 2007 annual meeting, where incoming chairman Governor Dave Freudenthal of Wyoming announced his plans for the coming year, noting that, "Much of the WGA climate change focus should be centered

on adaptive strategies." Likewise, Governor Janet Napolitano of Arizona said that, "The focus of much of the effort on climate change issues in the last few years has been quite appropriately on reducing greenhouse gases. Today we are looking beyond emission reduction efforts to prepare for a new world under a changing climate."

There is a strong interest in improving the dissemination of climate change research, and its translation into information that can be used by decision-makers to support adaptation. A bill introduced in the 110th Congress to coordinate global change research, H.R. 906, notes that although the United States Global Change Research Program has made significant contributions to understanding Earth's climate and the anthropogenic influences on Earth's climate and its ecosystems, the Program has not produced sufficient information to meet the expressed needs of decision-makers. WGA's May 2007 testimony in support of H.R. 906 before the House Committee on Science and Technology stressed the need to reorient and fully fund the U.S. Global Change Research Program (USGCRP) to make it more user-driven (a copy of the full testimony is provided in the Appendix). The Governors called for refocusing the program to adaptation, with an emphasis on research that helps states, tribes, and local governments understand what adaptation entails. In a similar vein, a resolution adopted by the Western States Water Council (see next page) calls for supporting an information transfer function that bridges the gap between pure research and translation of research outcomes into water management applications.

Excerpt from WGA's *Water Needs and Strategies for a Sustainable Future*

Recommendations:

While recognizing the uncertainties inherent in climate prediction, efforts should be made to focus on vulnerabilities and building increased resiliency to climatic extremes.

5.A. Data Collection

The federal agencies must continue and expand funding for data collection networks and activities necessary for monitoring, assessing, and predicting future water supplies as addressed earlier herein by the Water Needs and Strategies group recommendation (2A).

5.B. Improved Prediction, Modeling, and Impact Assessment

The Western Governors should urge Congress and the Administration through the Climate Change Science Program (CCSP) to fund research for improving the predictive capabilities for climate change, and assessment and mitigation of its impacts. Additionally, given the complex climatology in the West, it is important that climate change modeling be conducted at a much finer resolution, e.g. watersheds and subwatersheds. It is also important that the federal government implement research funding recommendations associated with Goals 4 and 5 of the 2003 CCSP Strategic Plan, including the area of increased partnerships with existing user support institutions, such as state climatologists, regional climate centers, agricultural extension services, resource management agencies, and state and local governments.

Excerpt from WGA's *Water Needs and Strategies for a Sustainable Future (continued)*

5.C. State Planning

1) The Governor of each state should direct their state climatologist, relevant water and environmental agencies, and universities to assess historical, current, and projected climate trends for their particular state and relate these to potential changes in water supply and water quality, in order to prepare for and mitigate the impacts from climate change and climate variability. Such assessments should include an inventory of data sources available for each state, with analysis appropriate to watershed-level management. The Governors should seek necessary funding to support these activities.

2) States should maintain various water-related plans, including state water plans, watershed plans, state drought plans, reservoir management plans, flood plans, etc. These plans should be expanded or enhanced accordingly to include climate change scenarios. Particular emphasis should be placed on climate change within the context of watershed planning. States, similarly, should expand or enhance other state plans that include water-related concerns—such as forest management, energy, and economic development plans—to include the impact of climate-change scenarios.

3) States should coordinate with and include local governments in their climate change planning efforts. Local governments are an everincreasing player in water issues, for example, through land use policies, as the developer of new water supplies, water transfers, and in implementing water restrictions and water use efficiency programs.

4) States should evaluate and revise as necessary the legal framework for water management to the extent allowable to ensure sufficient flexibility exists to anticipate and respond to climate change.

5.D. Ongoing Coordination & Information Sharing Between Scientists, Policy-Makers, and Water Users

The Governors should convene ongoing, broad stakeholder meetings between state water managers, local water supply managers, scientists, federal agencies, universities, and others to make sure water managers understand what the science is saying about climate change and what new tools exist, and, conversely so that scientists understand the data and research needs of water managers and users.

WSWC Resolution

Position No. 285

RESOLUTION of the WESTERN STATES WATER COUNCIL urging the CONGRESS AND ADMINISTRATION TO SUPPORT FUNDING FOR FEDERAL PROGRAMS TO STUDY THE WATER RESOURCES-RELATED IMPACTS OF CLIMATE VARIABILITY AND CHANGE AND OUR ABILITY TO ADAPT

Sioux Falls, South Dakota

May 4, 2007

WHEREAS, climate variability and change have serious potential consequences for water resources planning and management, water rights administration, and future water use; and

WHEREAS, there is growing concern, particularly in the Arid West, over our ability to continue to supply water of adequate quality in quantities needed to sustain current and future uses, including environmental uses; and

WHEREAS, the failure to provide for such needs would have significant regional and national consequences; and

WHEREAS, present water resources planning and sound future decision-making depends on our ability to understand, monitor, anticipate and adapt to changing climatic conditions; and

WHEREAS, climate variability and change present substantial obstacles and uncertainties to present and future water resources planning and management; and

WHEREAS, more frequent and severe droughts, storms, floods and other weather-related events and changes are predicted; and

WHEREAS, changing precipitation, snowmelt, runoff and streamflow patterns are expected, and are already evident, while the magnitude and consequences for society are not well understood; and

WHEREAS, most state, local and tribal water managers and water providers have a limited ability to undertake the necessary research to understand and develop adaptation strategies for future climate variability and change; and

WHEREAS, the federal agencies participating in the Climate Change Science Program (CCSP) have concentrated heavily on basic scientific research, research that needs to be translated into decision support applications for water resources management and needs to be communicated to water managers through technology transfer institutions such as NOAA's RISAs; and

WHEREAS, federal spending for many important programs, such as the National Oceanic and Atmospheric Administration's Regional Integrated Sciences and Assessments (RISA) program, in the Climate Program Office (CPO), support research that addresses complex climate sensitive issues of concern to water managers and administrators at the regional level;

WHEREAS, the Western Governors' Association's June 2006 report, "Water Needs and Strategies for a Sustainable Future," specifically refers to the importance of preparing for climate change impacts;

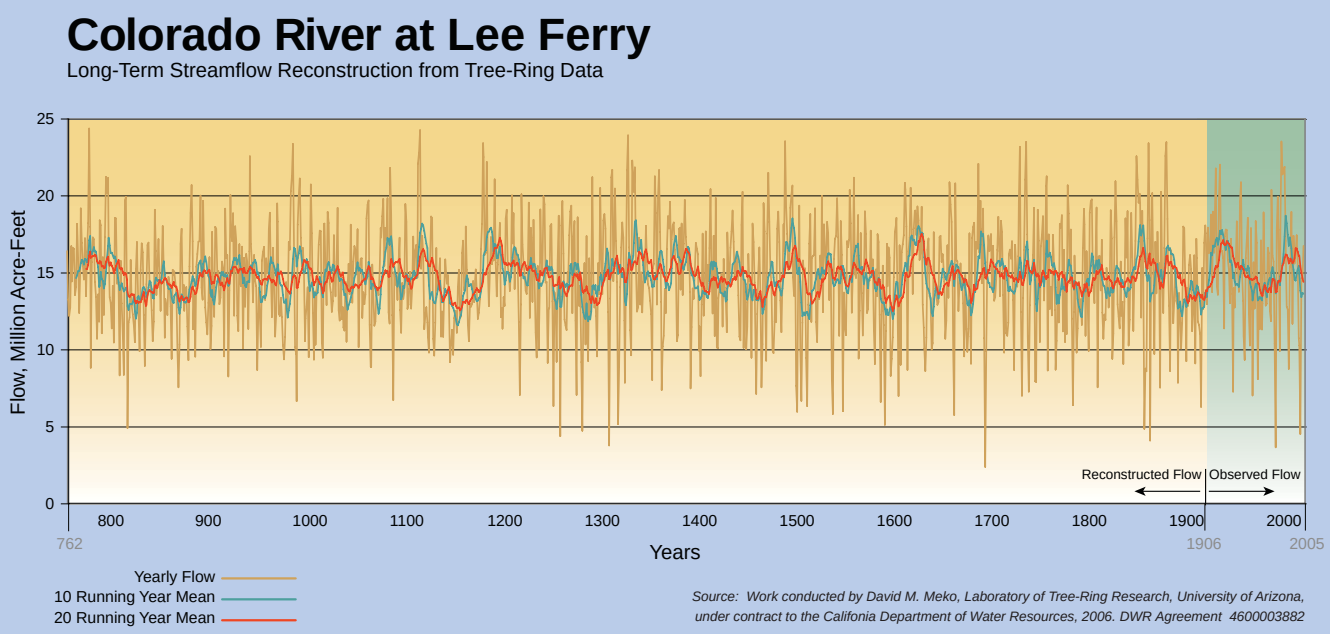
NOW, THEREFORE, BE IT RESOLVED that the Western States Water Council urge the Administration and the Congress to give a high priority to funding for federal programs, such as the RISAs that provide the translation function between basic scientific research on climate variability and change and the application of that research to real-world water management situations at the regional, state, and local levels.

II. A CHANGING FUTURE

Western water management has been shaped by a limited period of recorded hydrologic data—typically less than one hundred years for measured streamflows. Major urban and agricultural economies have been developed based upon this climatologically very brief foundation of information about water supply availability. Paleoclimate reconstructions indicate that the West has experienced droughts considerably more severe than those within the historical record. In the Colorado River Basin, for example, an extensive body of work on reconstructing streamflow from tree-ring information has enabled development of a Lee Ferry record dating back to the late 700s, a record that includes the so-called Medieval Megadrought or Medieval Climate Anomaly, characterized in the Upper Colorado River basin by a multi-decadal dry period in the mid-1100s (Figure 1). This period of sustained aridity is also captured in California's Sierra Nevada, where submerged tree stumps rooted in locations such as Mono Lake and the West Walker River were growing in then-dry sites during Medieval times.

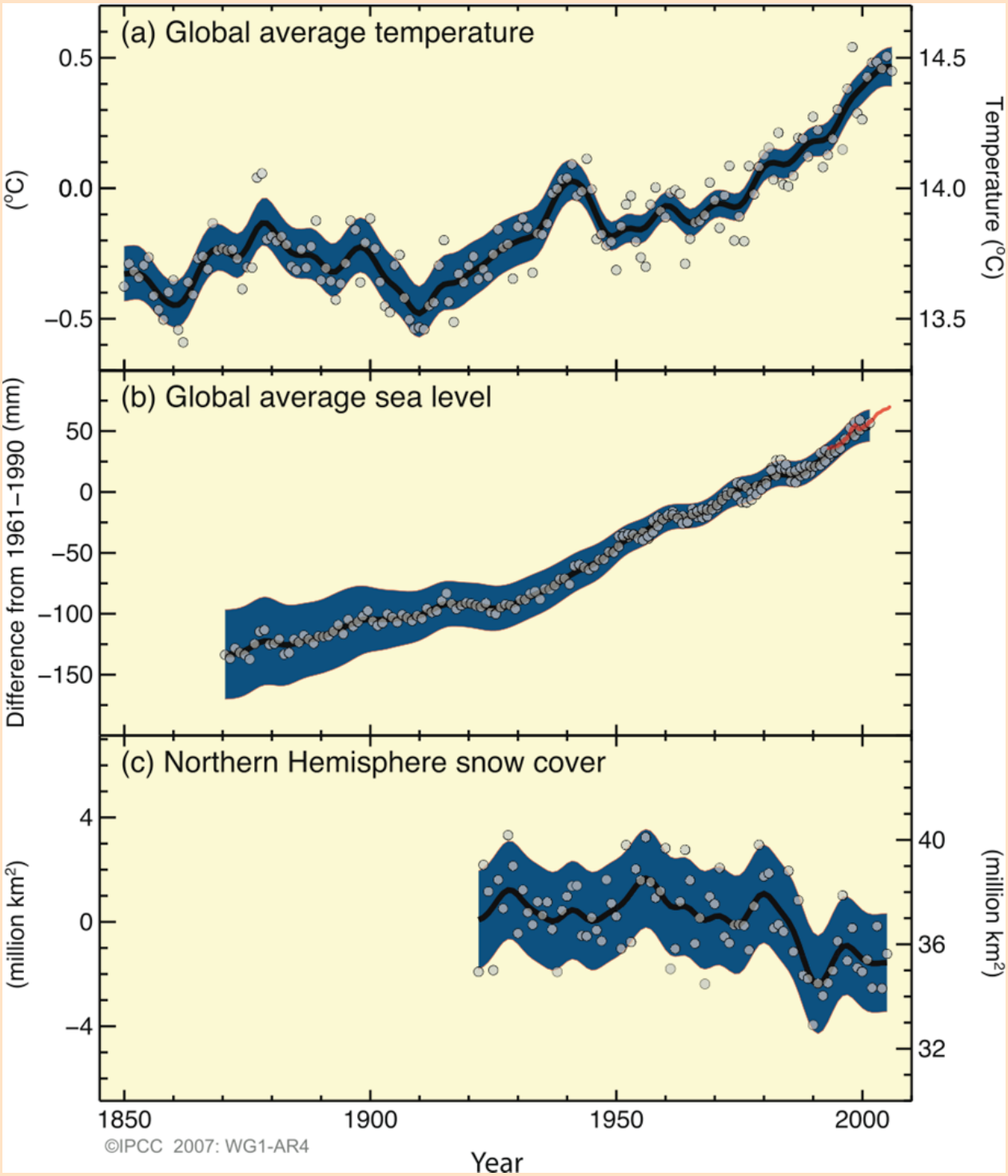
Water mangers must consider not only the large natural variability of climate evidenced by reconstructed records—variability not accounted for in the design of most extant major water projects—but also the additional variability or uncertainty due to anthropogenic climate change (see Figure 2). Climate change impacts have been widely discussed in the popular media—reduction in mountain snowpacks, increased sea levels, increased severity of flood events —but much remains to be done to downscale results of global climate models to a regional or watershed level so that the results can be quantitatively examined with the analytical tools commonly used by water managers. Work also remains to be done to harmonize

Figure 1 – Long-term reconstruction of Colorado River streamflow at Lee Ferry



Source: Work conducted by David M. Meko, Laboratory of Tree-Ring Research, University of Arizona, under contract to the Califonia Department of Water Resources, 2006. DWR Agreement 4600003882

Figure 2 – Changes in Temperature, Sea Level and Northern Hemisphere Snow Cover



Source - IPCC Fourth Assessment

differences among the results of different global climate models; while models show a general consensus on temperature outcomes, their results for projected precipitation outcomes are less congruous. In particular, the ability to forecast precipitation changes in mountain regions—critical sources of Western water supplies —is unreliable in most current models.

Of particular interest to water managers, the IPCC Fourth Assessment notes that the type, frequency and intensity of extreme events are expected to change as Earth's climate changes, and these changes could occur even with relatively small mean climate changes. Changes in some types of extreme events have already been observed, for example, increases in the frequency and intensity of heat waves and heavy precipitation events. The report goes on to say that wet extremes are projected to become more severe in many areas where mean precipitation is expected to increase, and dry extremes are projected to become more severe in areas where mean precipitation is projected to decrease. Some of the report's other findings with respect to projected climate changes include:

- *All of North America is very likely to warm during this century… In northern regions, warming is likely to be largest in the winter, and in the southwest USA largest in the summer.*
- *Annual mean precipitation is very likely to increase in Canada and the northeast USA, and likely to decrease in the southwest USA.*
- *Snow season length and snow depth are very likely to decrease in most of North America.*
- *The uncertainty associated with RCM (Regional Climate Model) projections of climate change over North America remains large despite the investments made in increasing (model) horizontal resolution.*
- *Anthropogenic warming and sea level rise would continue for centuries due to time scales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilised.*

Background — Federal Climate Change Science Research

The Global Change Research Act of 1990 authorized the USGCRP, intended to provide for the development and coordination of a comprehensive and integrated United States research program which will assist the nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change. Under this statutory authority, the Climate Change Research Initiative (CCRI), Climate Change Science Program (CCSP), and Climate Change Technology Program (CCTP) were administratively created in 2001-02. CCSP was intended to integrate federally supported research on climate and global change (USGCRP and CCRI), while CCTP (predominantly a Department of Energy program) was to deal with research and development of technologies associated with reducing, avoiding, or sequestering greenhouse gas emissions. Table 1, taken from the Fiscal Year 2007 edition of the CCSP annual report (*Our Changing Planet*) shows budget information for the federal agencies participating in CCSP. It should be emphasized that the amounts shown in the table reflect only the portions of agency budgets that the agencies classify as supporting CCSP: participating agencies (e.g. the National Oceanic and Atmospheric Administration [NOAA]) may be carrying out additional climate science-related work. It should also be noted that since CCSP is intended to be a research program, operational programs, such as activities of the National Weather Service (NWS), are not included in the budgets shown.

According to CCSP, its participating federal agencies have expended almost $20 billion in climate change-related research since USGCRP inception. As indicated in the table, National Aeronautics and Space Administration (NASA) costs associated with satellite observations and related data management are a dominant feature of CCSP's annual budget. CCSP funding also supports U.S. participation in the IPCC reports cited above. CCSP adopted a strategic plan in 2003 that laid out five major goals for the program:

1. Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change.
2. Improve quantification of the forces bringing about changes in the Earth's climate and related systems.
3. Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future.
4. Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.
5. Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

A major output of CCSP is intended to be a series of 21 "synthesis and assessment" reports scheduled to be completed in 2007-08. Two of the reports have been completed to date, one dealing with temperature trends in the lower atmosphere and the other with GHG emissions scenarios.

Table 1 – Climate Change Science Program FY 2005-2007 Budget by Agency (In Millions)

	FY 2005			FY 2006 Estimate			FY 2007 Request		
Agency	USGCRP	CCRI	CCSP	USGCRP	CCRI	CCSP	USGCRP	CCRI	CCSP
USDA	54	8	62	54	8	62	49	11	60
DOC/NOAA	74	46	120	117	34	151	127	46	173
DOE	102	25	127	105	25	131	102	24	126
HHS/NIH	57	0	57	57	0	57	57	0	57
DOI/USGS	27	0	27	27	0	27	26	0	26
DOT	0	1	1	0	1	1	0	1	1
USAID	0	6	6	0	13	13	0	14	14
EPA	20	0	20	19	0	19	18	0	18
NASA	476	43	519	448	47	495	416	37	453
NSF	173	25	198	172	25	197	180	25	205
SI	6	0	6	6	0	6	6	0	6
Scientific Research Total	989	154	1,143	1,005	153	1,159	981	158	1,139
NASA Space-Based Observations	671	51	722	500	50	550	527	49	576
CCSP Total	1,660	205	1,865	1,505	203	1,709			
President's Request							1,508	207	1,715

Source - CCSP

III. WORKSHOP PRESENTATIONS

The workshop agenda and breakout session questions are provided in the Appendix, together with a participant list.

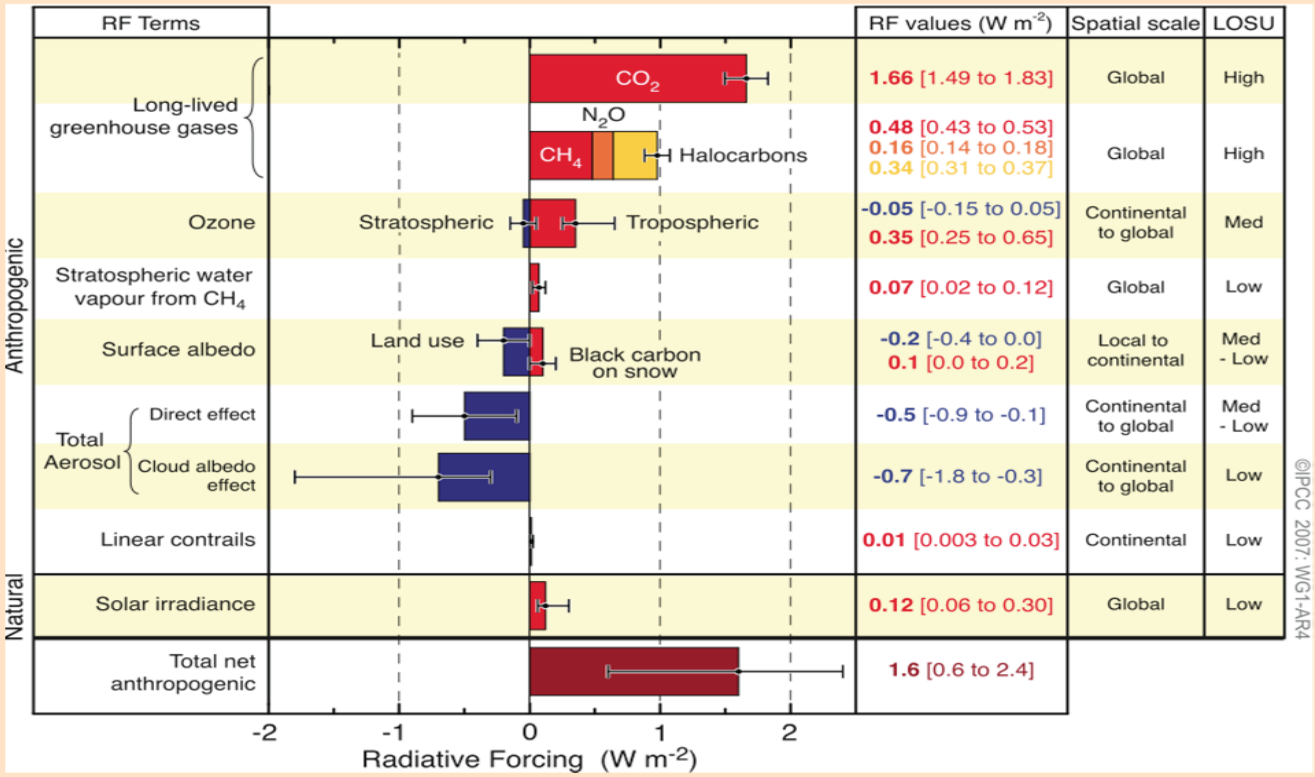
The meeting opened with remarks by Shaun McGrath of WGA and Jeanine Jones of CDWR regarding the purpose of the workshop and its intended outcomes. The workshop was organized to bring together state and local water managers, academic researchers, and representatives from federal CCSP agencies to discuss how to better facilitate scientist-end user interaction and to develop partnerships with the federal agencies. There are areas where focused research could help support planning for water management adaptation to climate change impacts; it was intended that the workshop help the workshop sponsors develop a road map for fostering research useful for western water management.

Climate Change Impacts

Following opening remarks from the workshop sponsors, participants heard an overview of recent work on assessing potential impacts of climate change to the water sector. Linda Mearns of the National Center for Atmospheric Research (NCAR) described results from Workgroup I of IPCC's Fourth Assessment, some of which were described in the previous section. Table 2, taken from the Fourth Assessment, describes findings with respect to extreme events. Linda also described initiation of a new activity at NCAR, the North American Regional Climate Change Assessment Program, a planned multi-year analysis of regional (50 kilometer scale) climate model projections. John Andrew of CDWR summarized work performed by CDWR in response to the Governor's Executive Order to analyze climate change impacts – reservoir inflows, salinity in the San Francisco Bay-Sacramento/San Joaquin River Delta Estuary, and Delta levee overtopping – to California's State Water Project (SWP). These analyses are contained in an initial technical report entitled *Progress on Incorporating Climate Change into Management of California's Water Resources*, which is available at http://baydeltaoffice.water.ca.gov/climatechange.cfm. Part of the CDWR analysis included using global climate model results that were statistically downscaled to provide inflows to major Sierra Nevada reservoirs, with the reservoir inflow information then driving the water operations model CDWR uses for simulating SWP and Central Valley Project deliveries. Figure 3 shows impacts of climate change to forecasted 2050 inflows into key Sierran reservoirs. Participants next heard from two speakers representing the Regional Integrated Sciences and Assessments (RISA) program – Dan Cayan of the California Applications Program at the Scripps Institution of Oceanography and Brad Udall of the Western Water Assessment at the University of Colorado. They described expected impacts of climate change in the West, drawing from recent publications in the academic literature. Some highlights of their presentations include:

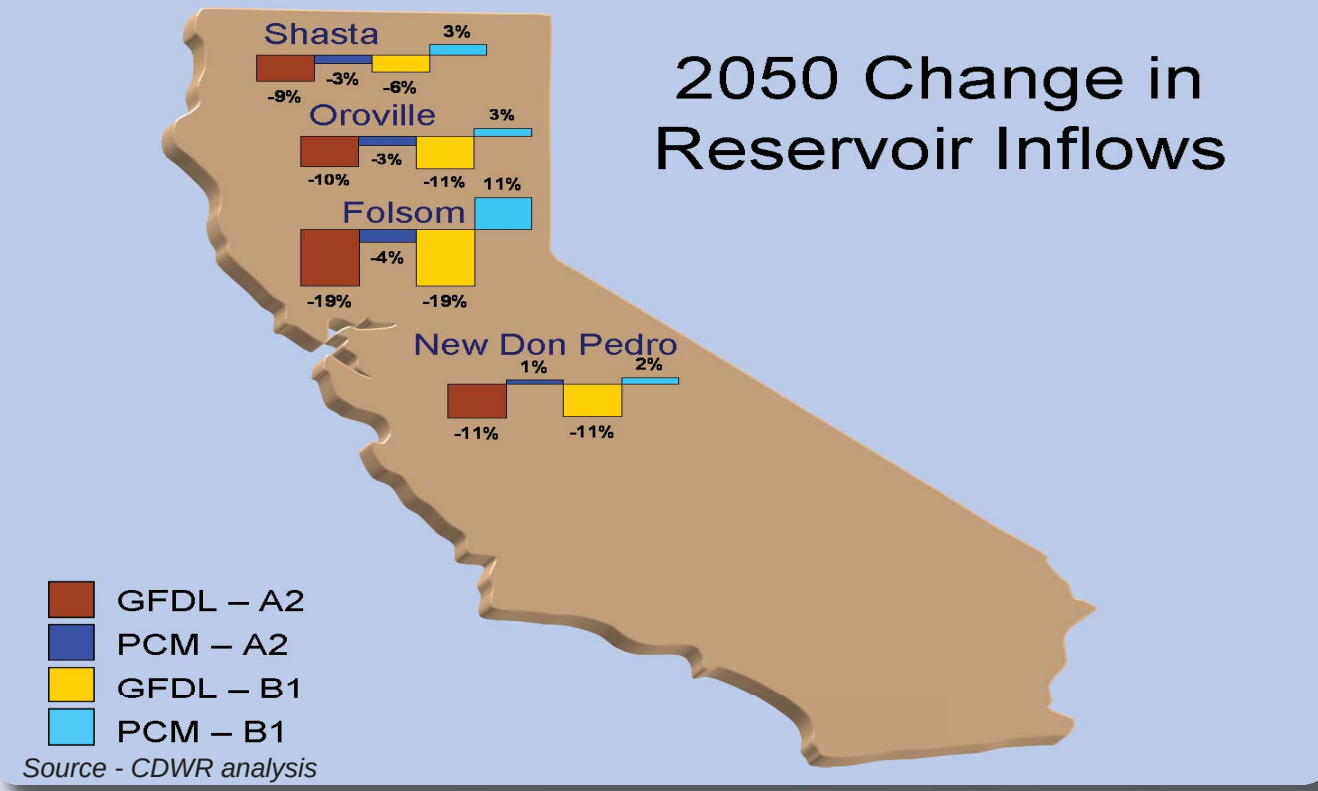
- Western spring snowpack has declined since 1950. By the end of the century, California could lose half of its late spring snowpack due to warming.
- Climate models only provide loose guidance on the amount of sea level rise, but
- It is very likely that rates will increase (Figure 4).
- Since 1985 there was a four-fold increase in the number of large wildfires in the West. Large wildfire threat is aggravated by warmer springs and summers. Wildfires can create

Table 2 – Findings Associated with Extreme Events



Source - IPCC Fourth Assessment

Figure 3 – 2050 Forecasted Change in Reservoir Inflows



Source - CDWR analysis

major maintenance costs for water agencies, e.g. Colorado's Hayman Fire.

- The relative variability of the Sierra stream discharge is the largest of that in the three major watersheds in the western United States. Compared to the Columbia Basin, streamflows in the Sierra combined basins vary greatly, with annual discharge varying from twice to half of historical average.
- Climate models forecast a strong thermal gradient from coastal areas to the interior, with inland areas becoming much warmer, especially in the summer.
- Recent IPCC model projections for California precipitation are scattered, but several show moderate drying as tends to be characteristic of Mediterranean regions globally. Recent modeling also suggests drier conditions in the Colorado River Basin than were indicated in IPCC's prior (third) assessment report.
- The Southwest (including Southern California) is expected to become hotter and drier (Figure 5).

Information Needs from the End User Perspective

Responding to impacts of climate change on water supplies has been one of the most discussed aspects of climate change adaptation. John Andrew of CDWR and Lorna Stickel of the Portland Water Bureau described impacts and information needs from the perspective of California's SWP and Portland's Bull Run River watershed system. Water supplies for both projects are ultimately derived from mountain runoff – the Sierra Nevada range for the SWP and the Cascades for Bull Run. CDWR prepared the report cited above describing potential impacts of climate change on SWP supplies; the City Of Portland contracted with the University of

California's State Water Project

The SWP, operated by CDWR, is California's second-largest water project and largest urban water supply project. Its facilities, mostly constructed in the 1960s and 1970s, include 20 dams, 662 miles of aqueduct, and 26 power and pumping plants. With a storage capacity of 3.5 million acre-feet (MAF), the SWP's Lake Oroville on the Feather River (a Sacramento River tributary) is California's second largest reservoir. Twenty-nine local agencies hold contracts with CDWR for project water; in 2006 CDWR allocated 4.1 MAF of water to its contractors. The SWP, a fully integrated electric utility, is the fourth largest generator of electrical energy in California as well as the state's largest consumer of energy. The SWP diverts water into the California Aqueduct in the Sacramento-San Joaquin River Delta, an estuary demarcated by a network of fragile levees that are highly vulnerable to flood damages.

The SWP's California Aqueduct is the only conveyance facility that moves water from the Central Valley to Southern California.

Figure 4 – Rising Sea Levels

Sea Level has been rising globally and along the West Coast

Increase is about 7 inches over the last 100 years

High sea level events along the California Coast have occurred during large El Ninos

Source - Dan Cayan Presentation

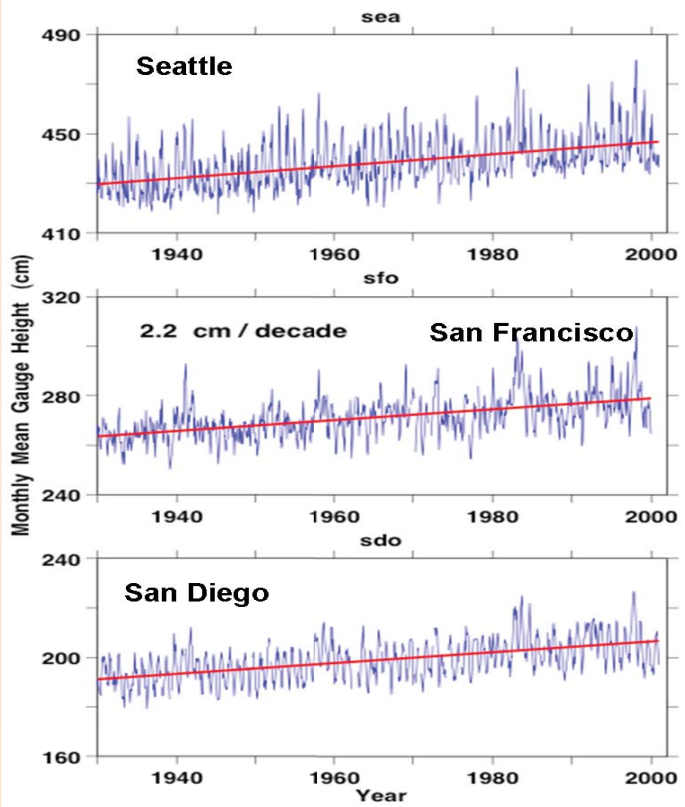
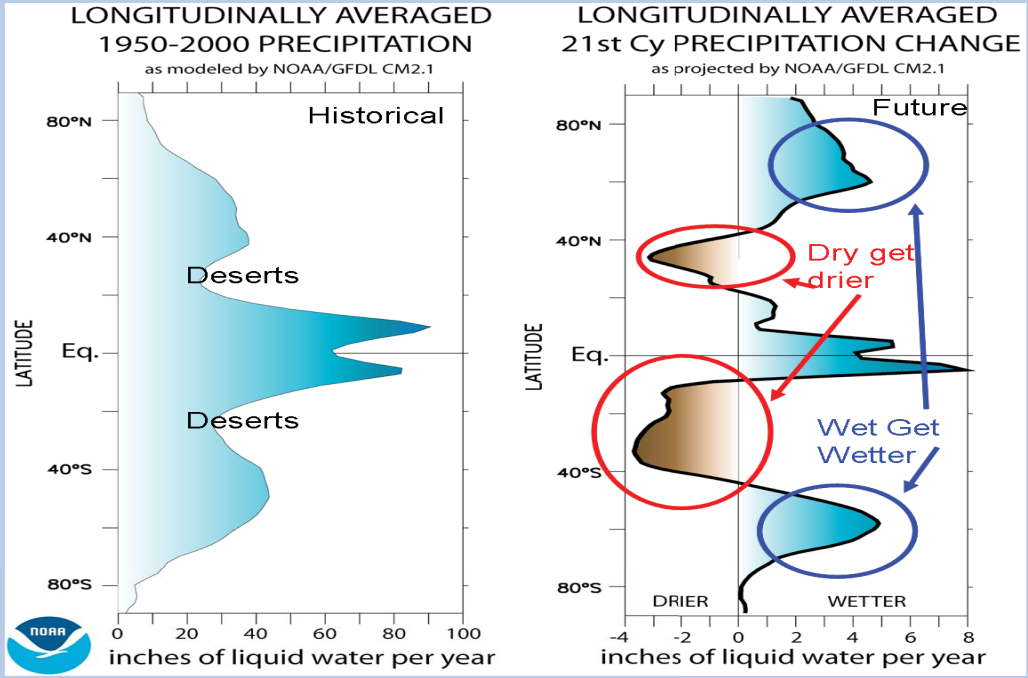


Figure 5 – NOAA Model Results

Wet get wetter and dry get drier?



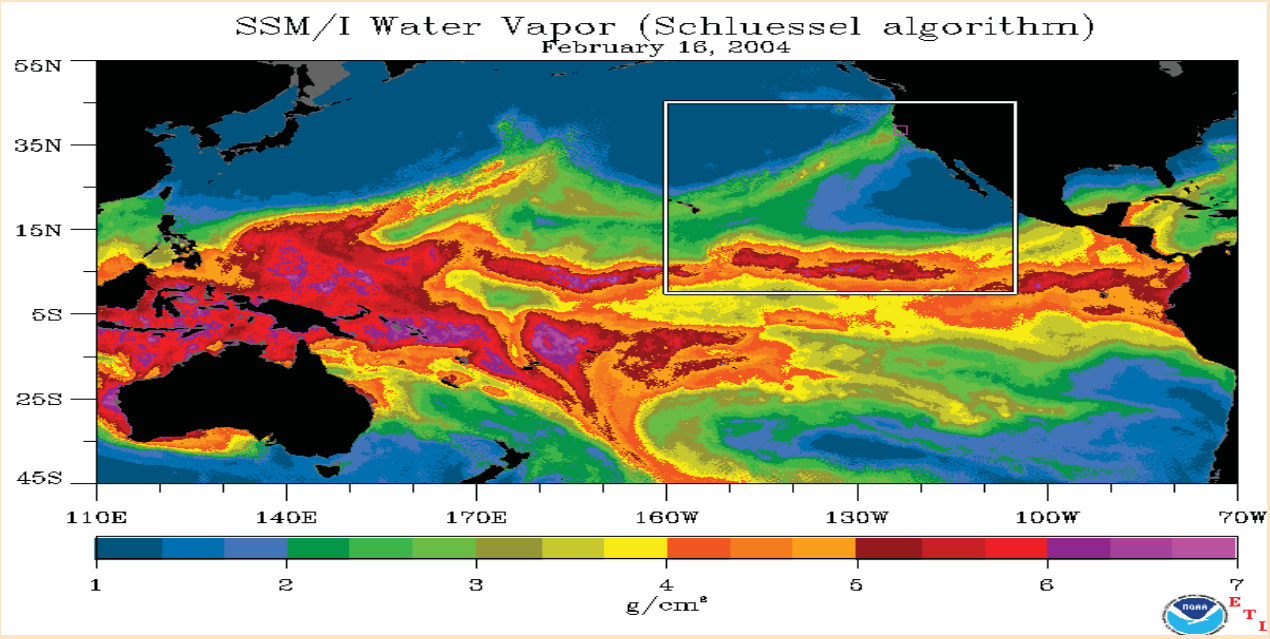
Source - Brad Udall Presentation

Washington to perform a similar study that involved taking outputs of four global climate models and evaluating the outputs through a model developed for Portland's watershed. The Sierra and the Cascades are both expected to experience loss of snowpack and a shift in the balance of runoff between snowmelt and rainfall. With respect to the SWP, Figure 6 shows the results of CDWR's preliminary analysis of climate change impacts on SWP deliveries, at a 2020 level of development using 2050 level hydrology that incorporates climate change. The figure compares expected deliveries using two global climate models and two emissions scenarios against a base case. It should be noted that model capabilities do not permit incorporation of factors such as sea level rise and increased flood risks.

The Portland and CDWR experience to date in assessing climate change impacts on water supplies points out areas where more research or information development is needed. While some of these areas necessarily reflect site-specific considerations, such as flow needs for special status fish species, other subject areas have broad applicability, including:

- Development of regional climate models that can produce high-resolution outputs at a watershed level, and take into account factors such as orographic precipitation;
- Improved understanding of El Niño Southern Oscillation (ENSO) events and storm tracks, in particular as they affect winter precipitation;
- More paleoclimate studies to illuminate past hydroclimate variability;
- Filling in gaps in hydrologic monitoring; and
- Climate change impacts on groundwater, and how they would play into the larger water management picture.

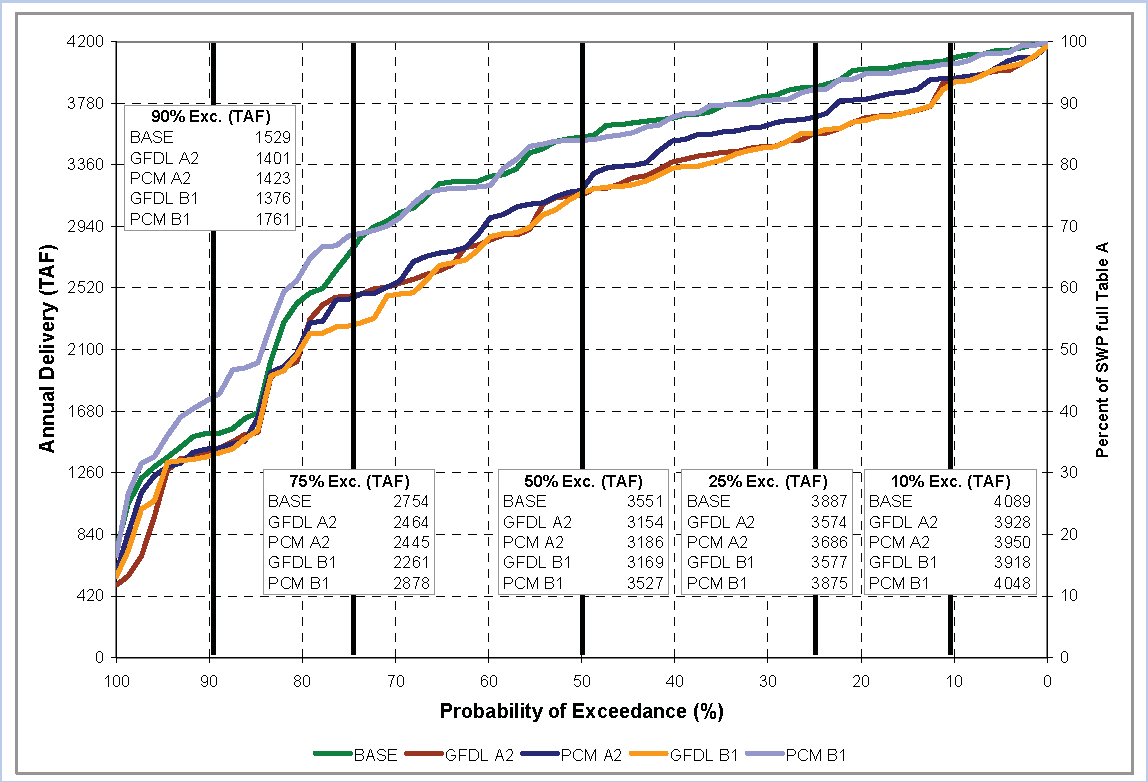
Flood management impacts (too much water) represent the other aspect of



Satellite composite image showing subtropical reservoir of water vapor and an atmospheric river pointing at California's coast.

Image source - NOAA

Figure 6 – Preliminary Analysis of Climate Change Impacts on State Water Project Deliveries

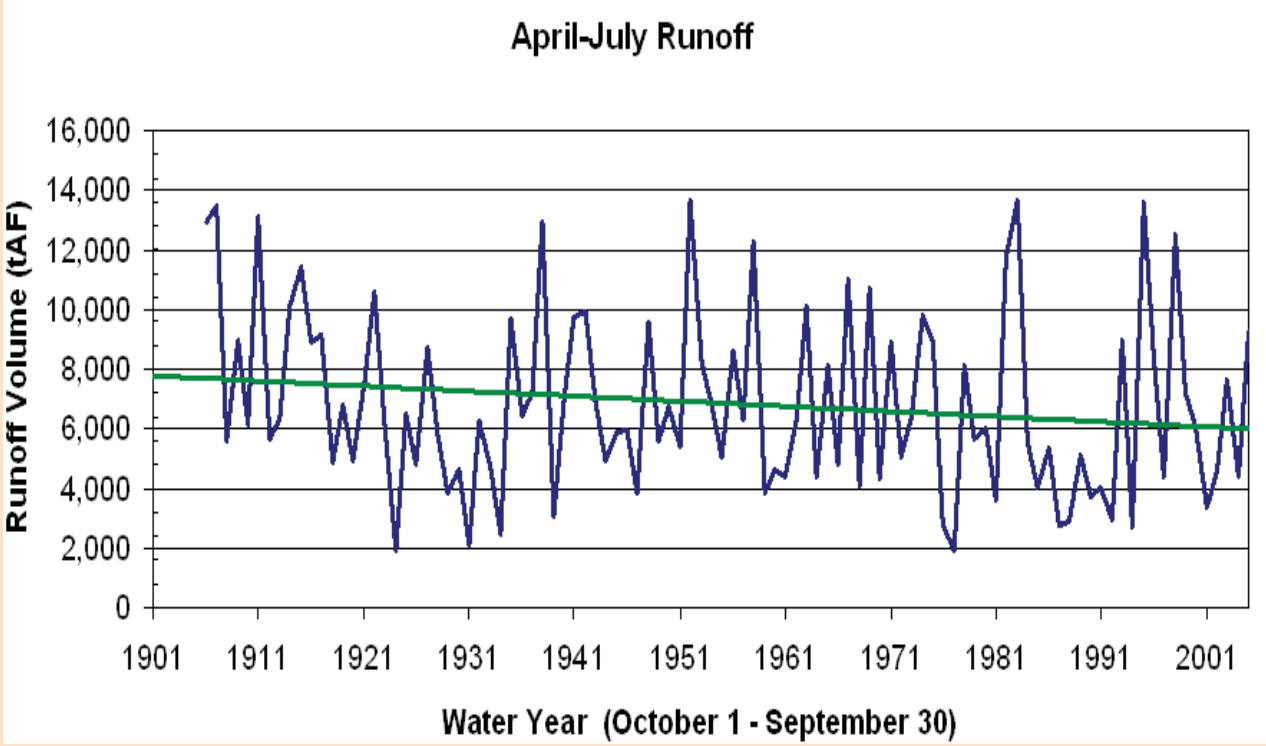


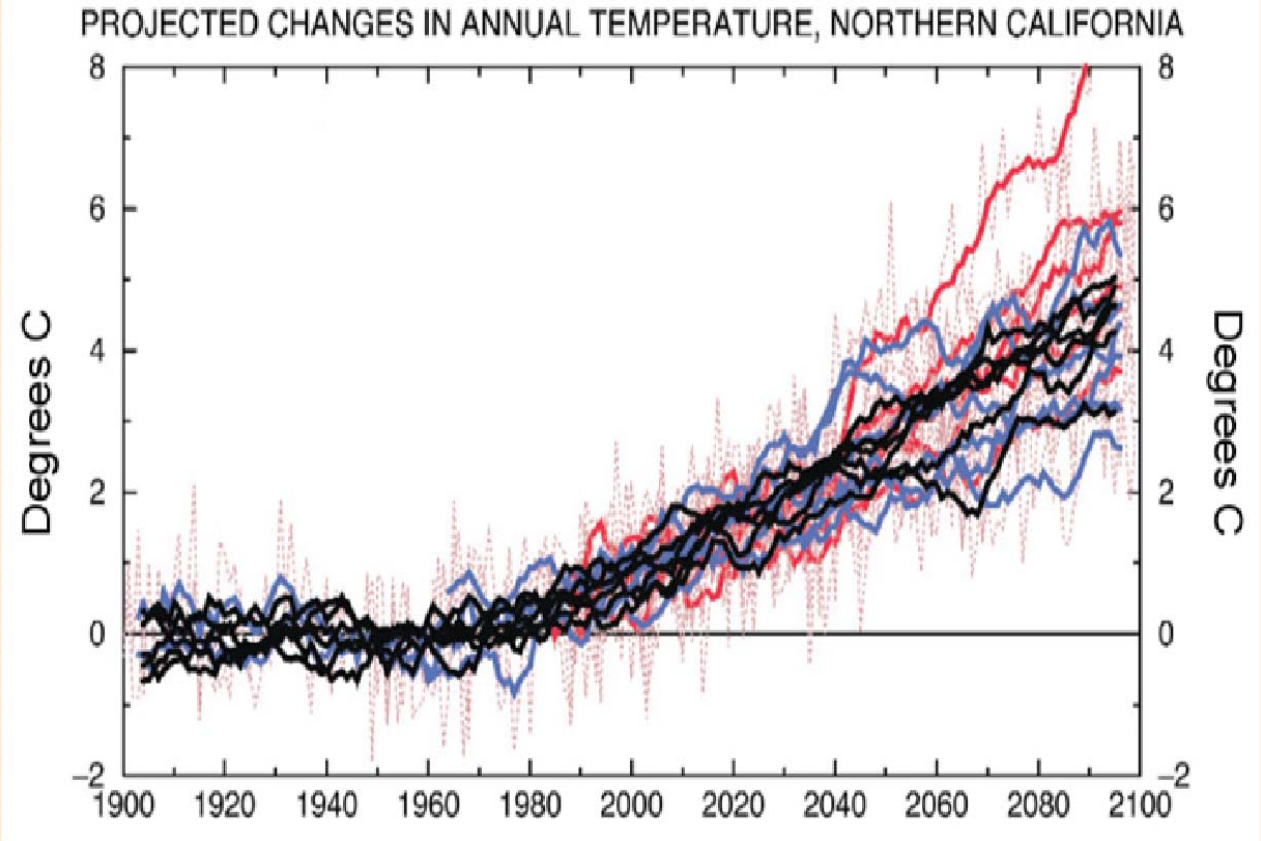
Source - CDWR

the water management spectrum. Mike Anderson of CDWR described research needs associated with flood management, focusing on California's Sierra Nevada. With the trend in reduced snowpack/late spring runoff mentioned by previous speakers, also comes the possibility of larger flood events (Figure 7), a trend already shown in historical observations. Factors contributing to future potential impacts include the possibility of a larger number of warm storms and a greater contributing area for storm runoff. Atmospheric rivers (moisture channels emanating from a subtropical atmospheric moisture source that produce heavy precipitation when they impact the West Coast) are often linked to major floods in California. Better understanding of these atmospheric rivers has been a focus of a NOAA hydrometeorological testbed: the information is important for present flood operations as well as for understanding potential climate change impacts. Other important research subjects include storm structure and warm storm frequency, the rate of seasonal snowpack migration upslope, and snowpack changes at high elevations (where instrumentation is limited). Monitoring is an important component of flood forecasting and management: present networks are being evaluated, and remote sensing techniques are being investigated as a means to improve data coverage. The use of MODIS (a sensor on NASA's Aqua and Terra satellites) data to estimate snow covered area is a current area of research.

The Portland analysis mentioned above considered impacts of climate change on service area water demands, and concluded that demands were less sensitive to climate change than was supply, and that future projected growth would have a greater

Figure 7 – Decline in Late Spring Runoff and Projected Temperature Increases in Northern California





Source - CDWR

impact on the city's water supplies than would climate change alone. Estimating future water demands relies heavily on population forecasts. As Mary Heim of the California Department of Finance described, the standard demographic approach is to forecast a continuation of present trends influencing population growth (e.g. birth rate and migration), unless there are known reasons to deviate from present trends. Standard governmental population forecasts are based on a limited number of factors, and do not include climate-related considerations. Comparing California's historical population growth against historical projections shows time periods when the approach of forecasting present conditions was not a good predictor of the future.

Patricia Gober of Arizona State University's (ASU) Decision Center for a Desert City described efforts to understand drivers of urban water demand and the role played by climate in the Phoenix metropolitan area. The ability to analyze the effects of population growth and climate change simultaneously is important, as is development of methods (e.g. scenario and sensitivity analyses) to present uncertainties associated with climate change. Downscaling regional results to the local level is also important: one study found that a temperature rise of 1°F in the Phoenix area is associated with an average monthly increase of more than 600 gallons of water for a typical single-family dwelling. ASU has developed a computer visualization tool (decision theater) reminiscent of the SimCity video games that would allow water managers to play out scenarios with population growth, climate change, or land development, to see how changing one variable affects others. Ernie Niemi of ECONorthwest described recent preliminary assessments of economic impacts of climate change performed for Oregon and Washington, noting that water-related impacts were key in both assessments. Wildfire risks/forest resources management is another important sector, and one where information is lacking on economic impacts of climate change.

More climate monitoring stations are needed at high-elevation mountain locations.

Information Needs from the Academic Perspective

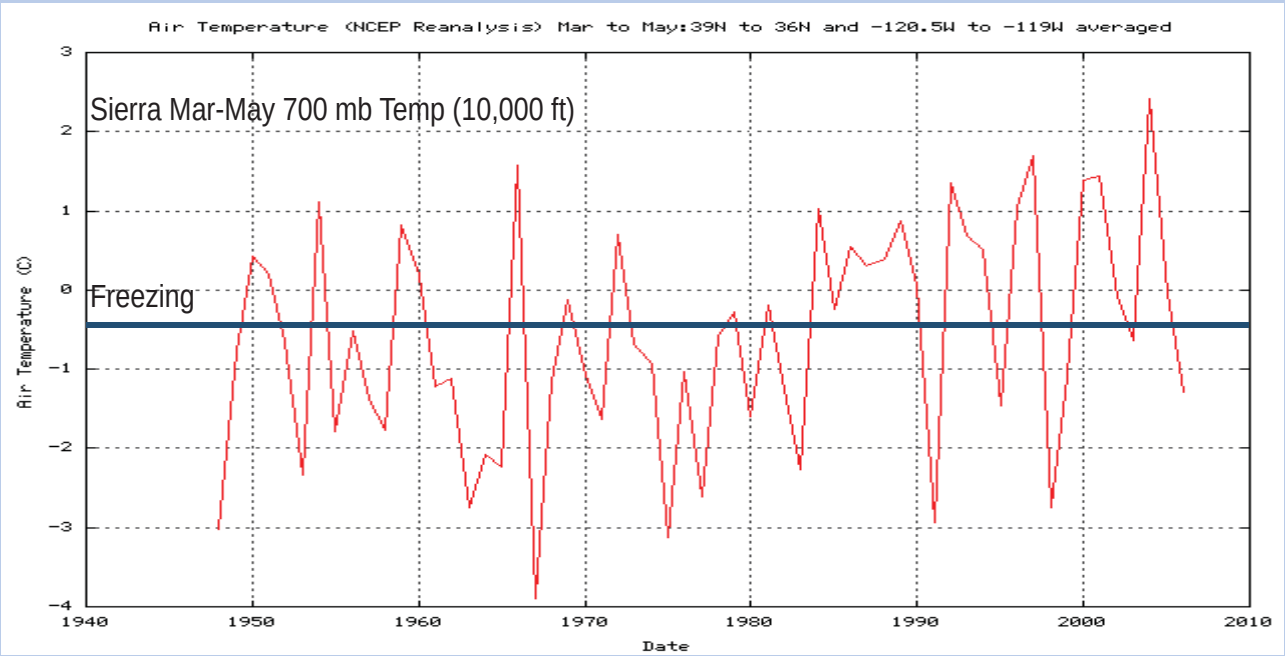
Gregg Garfin of Climate Assessment for the Southwest, the RISA center located at the University of Arizona, discussed climate services and what the Arizona RISA has learned to date in engaging with decision-makers. He stressed the foundational need for adequate physical data collection programs, and reviewed steps need to transform raw data into a meaningful product for information users, emphasizing the need for developing applications in partnership with end users (which may require capacity-building with end users). The Internet offers tremendous opportunities in terms of being able to disseminate data-based climate products, but products must be tailored to the specific needs of a target audience and presented in terminology useful to the audience (avoid "climatese"). Products must be focused on needs of discrete sectors (e.g. water managers, forestry managers) and be location-specific (i.e. provide information the watershed-level or similar scale). Understanding how climate products fit within the context of existing resource management structures (laws, jurisdictional

boundaries) must be part of product development.

Kelly Redmond of the Western Regional Climate Center at the University of Nevada's Desert Research Institute followed up on the need for hydroclimate data and information. It is not possible to measure point data (e.g. soil moisture) at enough sites to fully characterize hydroclimate properties, thus direct measurement points must be combined with modeling that can fill in the gaps. There is an increasing need for gridded data sets to facilitate climate modeling efforts. Special geographic settings require attention – mountains (major water supply source, large climate gradients), urban areas (heat island effects), coasts (large climate gradients). The Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT) is an effort that began in the early 2000s to focus attention on mountain climate data collection and research. The Colorado River Basin provides instructive examples of information needs – do present drought conditions represent an infrequent drought similar to those seen in the past 500 years, are they a harbinger of things to come, or a fundamentally different type of drought driven by anthropogenic warming? Similarly, a series of recent academic papers on forecasted climate change impacts to Colorado River streamflow presented a wide range of forecasted decreases in flow – differences that need to be resolved if the forecasts are to be meaningful to end users.

Having long-term consistent data records is extremely important (Figure 8). Climate data collection programs are typically part of established observation systems or networks, examples of which include the USGS stream gaging network, USDA's SNOTEL network, the federal Remote Automatic Weather Station (RAWS) network, and NOAA's cooperative network. These observational systems are as much social networks as they are hardware, and developing effective

Figure 8 – Historical Data Showing a Shift to Warmer Temperatures in the Sierra Nevada Snowpack Zone



Source- Kelly Redmond Presentation

methods to promote interagency coordination is an ongoing effort. Some priorities for data and observations include:

- Preserving existing networks and preventing further network deterioration (e.g. USGS stream gaging network and NOAA cooperative network)
- Better understanding of regional total water budgets (clouds to groundwater)
- System of benchmark high elevation sites
- Coordinated (modeling and observations) soil moisture monitoring
- Improved ability to convey what is happening with Western climate
- Measurements to facilitate attribution of observed phenomena (e.g. climate change impacts)
- Improved systems for synthesizing and distributing data

Charles Kolstad of the University of California at Santa Barbara discussed risk (probabilities can be estimated) and uncertainties (probabilities not at all understood) in the context of climate change economics. Mitigation and adaptation are needed to reduce impacts of climate change, but tools such as insurance (for risk management) or derivative markets (better for uncertainties) can be used to hedge risks. Research needs associated with climate change economics include long-term basic research to improve/develop analytical tools and development of applied tools to help decision-makers address climate issues. Examples of applications include:

- Developing methods for damage estimation (e.g. losses from drought in California)
- Measuring costs/extent of adaptation
- Developing regulatory tools (e.g. emissions reduction or water use reduction)
- Developing policy assessment models to evaluate impacts of proposed regulatory actions
- Seeking institutional methods for dealing with uncertainties (e.g. derivative markets).

Estimates of snow water content obtained from telemetered snow sensors (snow pillows) and from manual measurement of snow courses provide the foundation for forecasting snowmelt runoff.

Genevieve Maricle of the University of Colorado spoke on the obstacles of knowledge transfer from academia to decision-makers and difficulties associated with directing research priorities to create usable science. The traditional approach of focusing research on impacts may not be as effective as an ongoing dialog between academics and end users to define needed products. In the agricultural sector, USDA's agricultural extension service has historically been a good model for involving academics with practitioners. There has not been a similar level of investment in programs geared toward hydroclimate information users, and the academic climate does not encourage such interactions. There is little financial support for academics to engage in sustained interaction with practitioners.

Applied Research Examples

Mike Dettinger of Scripps/U.S. Geological Survey reported on work being done to assess possible impacts of climate change on skill in making seasonal streamflow forecasts in the West. Water mangers and water users rely heavily on spring snowmelt forecasts for a variety of operational purposes. Traditional snowmelt forecasting provides the primary source of skill in April – July runoff forecasts, with the runoff forecasts typically beginning around January and increasing in reliability as the snow season progresses. The forecasts rely upon empirical relationships derived from long-term data collection programs, and achieve relatively good skill by the time of peak snowpack accumulation (considered to be April 1st in the Sierra Nevada). Consideration of ENSO conditions is an additional tool that can help provide a few months longer lead times for seasonal forecasting, although with less skill. Climate change impacts are expected to reduce the snowpack contribution to forecast skill in many Western basins.

Richard Seager of the Lamont-Doherty Earth Observatory at Columbia University discussed results of recent climate modeling on potential imminent drying of the Southwestern U.S. The historical U.S. Dust Bowl drought of the 1930s was widespread and persistent; observed sea surface temperatures in the tropical Pacific Ocean at the time were characterized by cold, La Niña-like conditions. Use of ensemble runs of global climate models forced by observed sea surface temperatures demonstrates that the models were able to reproduce precipitation deficits experienced during Dust Bowl years. The so-called Medieval Megadroughts (Medieval Climate Anomaly) were characterized by similar widespread geographic extent, but they persisted much longer than droughts in the historical record, lasting for multiple decades. Paleoclimate reconstructions of sea surface temperature anomalies from corals suggest that a persistent La Niña was present during at least part of the Medieval Megadrought period. Looking forward, climate modeling performed for the IPCC Fourth Assessment shows substantial agreement among the models on prospects of drying in the Southwest. However the present models do not well represent the tropical Pacific Ocean, and may not capture how it responds to rising GHG emissions, potentially missing signals of persistent droughts like those that have occurred in the past.

The Dust Bowl drought of the late 1920s/early 1930s stands out in the historical period of record for its widespread impacts and disruptive effects on Midwestern agriculture.
Photo from U.S. National Archives.

Terry Fulp of USBR's Lower Colorado Regional Office described how USBR is incorporating Colorado River streamflows reconstructed from tree-ring records into hydrologic modeling for development of interim guidelines for Lower Basin shortages and coordinated reservoir operation for Lakes Mead and Powell. The Colorado River mainstem has experienced below average flows in seven of the past eight years, and there are no extant operating criteria for managing the river system under drought conditions. USBR is presently preparing an Environmental Impact Statement (EIS) pursuant to the National Environmental Policy Act to establish shortage and related operations guidelines. The Law of the River is founded upon a 1922 interstate compact

that apportions mainstem water. The compact was negotiated using the relatively short historical streamflow record available, which subsequently turned out to represent the wettest period in the historical hydrology. Knowing that the river is hydrologically over-allocated makes consideration of water supply uncertainties a key aspect of EIS preparation. To analyze comparative performance of EIS alternatives, USBR ran its existing river system operations simulation model with four sets of input hydrologic data: sampled from the calculated natural flow record, sampled from the reconstructed paleostreamflow record (dating back to 1490), combined natural flow/paleoflow record, and calculated parametric stochastic. The basic purpose of this assessment was to better quantify uncertainties and improve understanding of risk.

Mike Hayes of the National Drought Mitigation Center at the University of Nebraska covered lessons learned about estimating economic impacts of drought. Policy-makers seek large-scale economic estimates, but many complexities are involved in producing them. Economic impacts of drought are more severe at regional and local scales. [In California, for example, agricultural revenue impacts during 1991, the single driest year of the 1987-92 drought, were about $350 million in 2007 dollars, in comparison to a 2006 California Gross State product of more than $1.7 trillion.] Recent (2006) examples of impacts include $1.71 billion in USDA crop insurance indemnities, $4.1 billion in Texas impacts, and $342 million in Nebraska. Drought losses and costs in 1988, a dry year across much of the West, were estimated at $39 billion, largely related to agricultural and food sectors. Standardized methodologies need to be developed for economic data collection and analysis. Challenges include assessing qualitative versus quantitative and direct versus indirect impacts, temporal and spatial scale issues, and the role of agricultural relief payments/

NIDIS Authorization, a State-Federal Partnership

The National Integrated Drought Information System program was developed by WGA in partnership with NOAA, as described in WGA's 2004 report calling for creation of a drought early warning system. That report described the goals of the NIDIS program as:

- Develop the leadership and partnerships to ensure successful implementation of an integrated national drought monitoring and forecasting system;
- Foster, and support, a research environment that focuses on impact mitigation and improved predictive capabilities;
- Create a drought "early warning system" capable of providing accurate, timely and integrated information on drought conditions at the relevant spatial scale to facilitate proactive decisions aimed at minimizing the economic, social and ecosystem losses associated with drought;
- Provide interactive delivery systems, including an Internet portal, of easily comprehensible and standardized products (databases, forecast, GIS-based products, maps, etc.); and
- Provide a framework for interacting with and educating those affected by drought on how and why droughts occur, and how they impact human and natural systems.

Subsequently, legislation sponsored by WGA to authorize the NIDIS program was enacted in 2006. NOAA is the lead federal agency for administering the program.

insurance. As the 2004 WGA report calling for creation of a drought early warning system noted, no systematic collection and analysis of social, environmental, and economic data focused on the impacts of drought within the United States exists today.

Relationships with Federal Science Programs/Agencies

Kathy Jacobs of the Arizona Water Institute (AWI)/University of Arizona spoke on facilitating interaction between scientists and end users, particularly in the context of adaptation. The AWI is a partnership among three Arizona universities with three state agencies – the Departments of Water Resources, Environmental Quality, and Commerce. Subject areas AWI is focusing on include energy and water sustainability and climate change/drought adaptation. Keys to successful interaction among scientists and end users are well known (although not necessarily practiced):

- Problem definition that is collaborative, but framed by users
- Appropriate funding to sustain long-term partnerships
- Long-term investment in capacity building
- Use of innovators (early adopters) to establish connections
- Tailoring products to specific sectors/ decision-support needs
- Use of boundary organizations or technology transfer functions to bridge between researchers and end users

Examples of adaptation topics that could be examined through scientist/end user partnerships include:

- Strategic design of monitoring programs focused on decision-making needs, including appropriate communication of monitoring results/ outcomes
- Re-evaluation of engineering assumptions used to design key infrastructure (e.g. vis-à-vis the potential for more extreme drought or flood events)
- Exploration/better quantification of the energy-water nexus
- Definition of practical limits of water conservation (taking into account third-party impacts, demand hardening)
- Improvement of regional hydroclimate modeling capability
- Improvement of understanding of interactions between land use changes and sensitive ecosystems

Representatives from two of the federal agencies participating in the CCSP -- Robert Webb of NOAA and Bob O'Connor of the National Science Foundation (NSF) discussed the program and their agencies' involvement in it. CCSP Fiscal Year 09 interagency implementation priorities include:

- Ecological forecasting
- Enhanced carbon cycle research on high latitude systems
- Development of an end-to-end hydrologic projection and application capability
- Assessing abrupt changes in a warming climate
- Development of an integrated earth system analysis capability
- Quantification of climate forcing and feedbacks by aerosols, non-CO2 GHGs, water vapor, and clouds

NOAA and NSF both support research programs (i.e. grant programs) intended to help advance CCSP goals. NOAA water management-related programs/activities

administered through its Climate Program Office include:

1. The RISA program conducts interdisciplinary investigations of complex climate sensitive issues relevant to decision and policy making at a regional level.
2. The Sector Applications Research Program (SARP) identifies/promotes research and application priorities that foster improved decision support for climate-related issues in key socio-economic sectors.
3. The Transition of Research Applications to Climate Services (TRACS) supports transition of climate information tools into user-relevant products.
4. NOAA is the lead federal agency for NIDIS implementation.
5. NOAA contributes to the North American Seasonal Assessment Workshop (NASAW) development of fire forecast potential synthesis products.

NSF grant programs are focused on basic (not applied) scientific research, work that contributes to advancing theoretical understanding or to improving methods. NSF seeks work likely to produce important theoretical knowledge and to have significant broader impacts, such as enhancing infrastructure for research and education (facilities, networks, partnerships) or promoting teaching and training. NSF's Decision Making Under Uncertainty program (social science research) was a special (one-time) appropriation to support climate change science, not a part of NSF normal grants programs.

Aside from the grant programs, there are also opportunities for state/federal partnerships in climate programs, including:

- Addition of new sites to USDA's SNOTEL (snowpack telemetry) program
- Development of mesonets, such as the Oklahoma mesonet (A mesonet is a weather station network designed to measure events at what meteorologists call a mesoscale – events that range in size from about one mile to 150 miles and are of relatively short duration, such as thunderstorms. A densely spaced network of observation sites is required for capturing mesoscale events.)
- Development of derived climate data sets for hydrologic applications
- Expansion of USDA's SCAN (soil climate analysis network) telemetered data collection system for soil moisture/temperature and other parameters
- Reconciliation of the range of global climate model projections in key areas (e.g. precipitation changes in the Colorado River Basin)
- Evaluation of climate uncertainties relative to role played by climate information in policy development

Techniques for working with the academic community and for securing grants for research useful to water managers include:

- Work through boundary organizations such as RISAs
- Work with academic community to find ways to reward academics for engaging with practitioners
- Encourage capacity building, among both academics and practitioners

IV. WORKSHOP RECOMMENDATIONS

As indicated in the Appendix materials, workshop participants broke out into small groups to discuss assigned questions dealing with water management-related climate information and policy needs, and with development of relationships with the federal climate science agencies and with academia. Key themes that arose in those discussions are summarized below.

Information and Policy Needs

Probably the most frequently expressed comment at the workshop was water managers' need to have outputs of climate models available at scales useful for resource management activities – regional and watershed scales – and in a format amenable for incorporation into resource management models. The need for a "one-stop shopping" modeling supermarket was seen -- a place (i.e. web site) where available regional/ watershed-level climate model outputs could be obtained – California's Climate Change Portal was suggested as a possible prototype. It was suggested that the federal government or state governments should take the lead to put together such a site for the water management community. It was also felt that there was a need for saving and archiving full outputs of global climate models (e.g. timesteps more frequent than annual), even if it would require dedication of substantial storage media capacity. The global models generate outputs at daily/hourly timesteps, information that could be used by entities wishing to analyze extreme events (e.g. floods), if that information were readily available in a public forum. Perhaps there could be a condition accompanying federal grant funds for global climate modeling that daily/hourly data sets must be archived and made accessible.

It was also frequently expressed that there needed to be an information broker/translator function to act as the intermediary between climate modelers and practitioners, and to facilitate discussions on practitioners' needs/involve practitioners in development of the research questions. An institutional structure or, to use a term borrowed from the climate scientists, a forcing function, is needed to ensure that these two-way communications occur between modelers and the user community occur. The U.S. lacks a focused resource that translates the IPCC global assessments into downscaled information that can be used by decision-makers. The RISAs could provide that kind of translation service, but they currently lack the necessary funding support.

Both practitioners and academics expressed a strong desire that the federal climate science program perform national and regional assessments. The IPCC assessment reports cover a global/international scale, and by their very nature cannot address the level of detail needed for adaptation. The U.S. Global Change Research Program published a national assessment (*Climate Change Impacts on the United States, The Potential Consequences of Climate Variability and Change*) in 2000 (prior to the creation of CCSP). The 2000 assessment examined both regional and sectoral (e.g. water, agriculture) impacts. It was felt, however, that the substantial improvements in climate modeling and related basic science work since then call for a new assessment at the national level, with even more emphasis being given to quantify impacts at a regional level.

Data collection programs are important for change detection (e.g. high elevation snowpack) and for developing adaptation strategies. Key existing data collection programs have been struggling to maintain

levels of service with flat or declining budgets. Securing adequate funding for the USGS stream gaging network and continuing support for sites with long-term records has been a priority for many users of that information, as has also been the case with USDA's SNOTEL network. Likewise, the potential loss of the Landsat thermal band sensor (see sidebar) threatens continuity of that data record. Maintaining continuity in key historical data collection programs such as these – and taking steps to improve data quality – are critical to climate change adaptation. Challenges to maintaining existing networks include not only funding constraints, but also institutional factors such as adverse impacts of wilderness area designations on pre-existing sites.

Relationships with Academia and the Federal Climate Science Agencies

The federal CCSP has a statutory mandate to produce information that supports decision-making, which must necessarily encompass two-way information transfer and communication between academics and practitioners. However, CCSP has not implemented a strategic communications plan for the program or conducted targeted outreach to stakeholders -- the absence of which is a setback for programmatic relationship building. Institutional obstacles to productive partnerships between academics and practitioners are well known, and are not unique to the climate sciences. The difficulties summarized below are examples of circumstances that should be addressed as part of CCSP administration.

- Generally, members of the academic community are not rewarded professionally for interacting with practitioners – in fact, they are more likely to be indirectly punished for being useful. The academic world rewards research, publishing in scientific journals, and teaching – not partnering with practitioners.
- The science culture in academia and in the allied federal agencies is traditionally relatively "stovepiped", and does not encourage interdisciplinary work.
- The increased focus on adaptation, which tends to be more place-driven

Importance of Landsat Thermal Sensor

The WSWC has strongly supported continuity of Landsat program data, as expressed in this excerpt from WSWC's July 2006 letter to the Director of the Office of Science and Technology Policy:

On behalf of the Western States Water Council, representing the governors of eighteen western states, I am writing to reiterate our strong support for maintaining a thermal band as part of the Landsat Data Continuity Program…The Landsat data archive holds thermal data going back to the launch of Landsat 4 in 1982. We understand that current plans call for a new Landsat satellite to back up and replace the aging and failing Landsat 5 and Landsat 7, and that a request for proposals includes a thermal band option. Given the statutory directives authorizing the data continuity mission, we strongly believe the inclusion of appropriate thermal sensors is not a discretionary option, but rather a mandatory requirement…As the cost of obtaining thermal imaging data has dropped, the uses to which this information has been put have increased dramatically. Currently, demonstrated water resources planning and management applications include quantifying and monitoring consumptive water use by irrigated agriculture, urban and suburban landscapes, and natural vegetation, as well as calibrating ground water models, monitoring aquifer depletion, and computing water budgets for surface water models....This is clearly a successful story where research has evolved into development of valuable practical applications.

and applied than is basic science research, is perceived as a threat to funding for existing basic research programs.

- Science research is typically funded by grants that are specific to an individual project and are of relatively short duration – there is not funding for sustaining the long-term interaction between scientists and practitioners that is important to moving forward with adaptation.
- With little interaction between the research and practitioner communities, it is difficult for academics to find practitioners to partner with on grant applications, or for practitioners to identify potential sources of expertise.
- The CCSP federal agencies evaluate funded research based on outputs (was a paper published), not on outcomes (did the project support policy-making). There are no metrics for determining if a research project is actually effective.

On the positive side, there are many potential techniques that can be explored in the interest of building productive relationships between academics and practitioners. One of the most frequently stressed points was the need to establish sustained, ongoing relationships – while an action such as having an advisory committee for a specific project can be a useful step, it does not replace the need to cultivate multiple, long-term collaborative activities. It was also stressed that practitioners need to take the lead in initiating outreach to the academic community and in spreading the word about specific research topics that would be useful. If research is to be user-driven, users must take the responsibility for communicating research needs and for helping to secure necessary funding. Workshop participants suggested a variety of tools that could be employed to build and strengthen relationships between practitioners and academics:

- Supporting development of a federal climate services grant program that would fund academics for sustained interaction with practitioners and help inform research priorities.
- Supporting capacity building for both academics (to encourage development of faculty interested in pursing adaptation research and service) and practitioners (to provide a climate/atmospheric science background for water managers). The American Meteorological Society's (AMS) environmental science seminar series for policy-makers (unfortunately held only in Washington D.C.) is a good example of something that would be useful for water managers.
- Supporting expansion of the RISA centers' role in bringing together academics and practitioners. The RISA program has been a successful step to a bridging effort between the research community and practitioners. As discussed above, the RISA centers are valuable for water managers, but the

NOAA's RISA Program

The RISA program, established in the mid-1990s, supports research that addresses climate-sensitive issues of concern to decision-makers and policy planners at a regional level. The RISA research team members are primarily based at universities. There are five RISA centers in the West, located at the University of California San Diego, University of Arizona, University of Colorado, University of Washington, and University of Alaska. The research has focused on the fisheries, water, wildfire, and agriculture sectors. The program also supports research into climate-sensitive public health issues. Recently, coastal restoration has also become an important research focus for some of the centers.

small amount of federal funding that they receive limits their ability to take on new workload.

- Seeking federal funding for developing formal university/agency partnerships. The University of Arizona's recently created AWI is an example of such an approach.
- Sponsoring an ongoing series of workshops or colloquia to foster dialog between academics and practitioners, to daylight and receive feedback on research concepts, and to develop joint grant proposals. To be effective the workshops must be held more frequently than annually, and must be continued as a long-term effort.
- Supporting development of a database of academic expertise in the climate change science field, to allow practitioners interested in a particular subject area to identify individuals conducting research in that area. The database would be a good project for CCSP, which is charged with providing centralized integration of climate science work. Researchers' names and information could be generated via the grant proposals submitted to federal funding agencies.
- Encouraging CCSP to establish a web-based master database of grants funded under the program, to allow practitioners to determine what research is being funded and who potential partners for applied research projects might be.
- Encouraging CCSP to develop a database of program stakeholder organizations, organized by sector, to assist researchers in identifying potential supporters of applied research or grant applications.
- Strengthening and expanding criteria for federal research grants to require that research proposals have a decision support/technology transfer function and include demonstrated involvement/participation by practitioners. Some NOAA grant programs now encourage practitioner involvement – this provision should be elevated to a requirement; NSF grant programs should go beyond "outreach" (publicizing results) to require meaningful interaction with end users.
- Seeking opportunities for practitioners to publish in scientific journals, including submitting joint papers with academics. Publishing journal articles is generally a high priority for academics and a low one (due to other workload) for practitioners. Nevertheless, the process of collaboration on publications is an educational one for both sides, and the appearance of more applied research/adaptation examples in the scientific literature would encourage other academics to pursue those lines of endeavor. Similarly, states or other interested agencies could sponsor themed issues (e.g. climate change adaptation) of scientific journals as a way to focus attention of the research community.
- Offering internships for graduate students in state or local resource management agencies is a good way to interest future researchers in work useful to decision-makers. Many state and local agencies do have student employment programs – the challenge is probably in better communicating potential opportunities to the academic community.
- Finding ways to show support for academic research that is useful for resource management is important. In addition to the obvious step of funding research themselves, states

and local agencies should actively seek out opportunities to submit letters of support for helpful academic grant applications and should consider establishing award programs for service and partnership activities. It is important that university management hear that such activities are valued.

- Making an effort to attend each others' events. For practitioners, events such as AMS conferences and the American Geophysical Union annual conference should be a priority. For academics, industry conferences such as the Association of California Water Agencies or Colorado River Water Users conferences would be useful.
- Evaluating the possibility of interagency personnel assignments (IPAs) or similar arrangements between universities and state or local agencies. An academic might use a sabbatical to work on a project at a resource agency, or a practitioner might take on a short-term project at a university.
- Establishing a CCSP pilot program for decision support, in which researchers/practitioners collaborate on specific real world water management research problems identified by practitioners. As well as fostering relationships, this approach would give the climate change social science community a laboratory for examining social science research issues.

Building relationships between water managers and the federal climate science program agencies, which are closely allied with the academic community, is also important. Historically the federal climate science programs and state or local water agencies have had relatively little interaction, especially in contrast to the close working relationships between the water agencies and USBR or U.S. Army Corps of Engineers (USACE). The absence of a process for decision-maker involvement in CCSP at the programmatic level places the burden of initiating contacts and seeking involvement on stakeholders such as water agencies. As with relationships with the academics, there should be a goal of developing structured activities that contribute to sustaining long-term working relationships. Participants suggested a variety of tools that could be employed to develop and strengthen relationships between water managers and the federal climate science programs:

- Establishing structured, long-term processes for interchanging information and setting research priorities/evaluating research outcomes. As with relationships with the academic community, sustained ongoing relationships need to be developed, and the odds of maintaining such relationships are improved if there is an institutional structure – such as a memorandum of agreement for planning joint climate-related projects – that fosters continuity.
- Investing in IPAs or other types of planned work assignments that involve water managers working at a federal organization or federal science agency personnel working at a water agency was a frequently suggested approach. It was recognized that there are often logistical difficulties with establishing IPAs, but that they can be very beneficial under the right circumstances. It might be possible to use tools less administratively complex than an IPA, such as some form of planned work experience, to accomplish the same end of achieving cross-pollination between the federal climate science agencies and water management agencies (including the federal water management agencies).
- Seeking examples of successful

partnerships to copy. The NWS River Forecast Centers might provide a good model for integration of federal agency personnel with water management agencies. The California-Nevada River Forecast Center has had a long history of close cooperation with CDWR, and is co-located with CDWR's flood forecasting center.

- Actively supporting federal funding for climate-related programs (e.g. the RISA program) valued by states and organizations interested in water management. (WSWC does this now for the USGS streamgaging program and for SNOTEL.) Stakeholders need to work with closely with the federal agencies to understand timetables and mechanisms for input to the federal budget process. It was stressed that entities requesting funding for new projects should be aware of the risks of cannibalizing existing programs to support the new activity.
- Establishing advisory committees composed of water management agencies for the major federal agencies funding climate research, such as NASA, NOAA, and NSF.
- Using multi-state partnerships or umbrella organizations such as WGA to focus attention on priorities for applied science that supports water adaptation. Multi-state partnerships on mitigation (e.g. GHG emission reduction) have been effective in focusing congressional attention on needed federal programs. An example of a potential approach (although in a different subject area) is the memorandum of agreement that USACE and the WSWC have entered into for implementing selected recommendations of WGA's water sustainability report.
- Using a pilot program, such as a review of the adequacy of federal agency hydroclimate data collection programs and interagency coordination on data, as a tool to begin a dialog. Such a pilot program could inform development of an eventual climate services program.
- Informing state and local water agencies of federal science program grant opportunities and deadlines, so that they can be aware of opportunities to work with academics to develop grant proposals that would support resource management decision-making. State and local agencies need to proactively seek these opportunities to partner with academics; however, since the agencies have not historically been involved in the academic grant program milieu they have a high learning curve with respect to grant program operations.

V. NEXT STEPS

Workshop sponsors believe that the event provided for valuable exchange of information and ideas regarding needed water-related adaptation research, and ways for water management agencies to effectively partner with the academic community and with the federal climate science agencies. While techniques for adaptation to climate change impacts – such as infrastructure development, diversifying water portfolios, increasing water systems operational flexibility – are in common use now and are well-understood water management approaches, potential climate change impacts bring in new uncertainties with respect to accurate quantification of forecasted impacts. Much of the science associated with delivering high-resolution assessment of hydroclimate impacts is still relatively young and in the process of development. There needs to be an ongoing relationship with the research community to ensure that appropriate user-driven applied science is carried out to clarify uncertainties, improve impact quantification, provide forecasting tools, and transfer research to decision support.

Water managers must take the initiative to clearly communicate their needs for applied science to the research community, and must seek opportunities to guide hydroclimate research in directions that will support real-world problem solving. Workshop participants identified a variety of possible methodologies for engaging with academics and with the federal agencies funding research, together with research topics or information that would support adaptation. Similarly, strategic opportunities were identified for reorienting aspects of the federal climate change science program so that it would support decision-makers. Legislative efforts now underway to reauthorize CCSP could additionally provide a mechanism to accomplish redirection of the program to a more user-focused framework.

Timing of adaptation efforts is key. Long lead times are required to implement both structural (e.g. building new infrastructure) and non-structural (e.g. adopting new USACE flood control rule curves through an administrative or legislative process) options. It is necessary to begin laying the groundwork and making investments to support improved water management reliability – whether to respond to natural climate variability, forecasted climate change impacts, or population growth – well in advance of the time when the reliability is needed. Analytical uncertainties associated with assessing climate change impacts need to be addressed sooner rather than later, since results of those analyses are necessary early in the planning process. It thus makes sense to move expeditiously in developing the collaborative relationships with the climate research community that are important to procuring directed research outcomes.

Workshop sponsors intend to evaluate the recommendations summarized in these proceedings, with a goal of identifying actions or combinations of actions that they may wish to implement or support. It is expected that CDWR, WSWC, and WGA will work through their internal decision-making processes to select which actions to adopt and the process for moving forward with them. Clearly, actions could be pursued individually on an ad hoc basis or be combined into a systematic plan. CDWR and WSWC/WGA each have events scheduled for October 2007 (a California climate change water adaptation summit and a Western water policy conference) that will provide a forum for further dialog on planning for adaptation.

APPENDIX A

WGA testimony on H.R. 906

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June 5, 2007

The Honorable Mark Udall
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The Honorable Bob Inglis
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Dear Representative Udall and Representative Inglis,

On behalf of the Western Governors' Association, we are writing to commend you for introducing H.R. 906, "The Global Climate Change Research Data and Management Act of 2007."

The Western Governors believe it is not only appropriate, but also is necessary to reorient and fully fund the U.S. Global Change Research Program to make it more user-driven. The U.S. has spent considerable dollars on understanding the science of climate change, and we must now look to addressing and adequately funding the issue of adaptation. The focus of the USGCRP research must now move with greater focus to help states, tribes and local governments understand what that means: How will climate change manifest itself in different areas of the country? What impacts can we expect at the state and local levels? How can we prepare for the change in an effort to avoid or mitigate the impacts? How can we most effectively implement adaptation measures given that many of them will require a long lead-time?

One recommendation that we would make for the bill is to amend it to address the need for a National Climate Information Service in the context of USGCRP. Such a service could be the focal point for coordination of climate activities across the federal government. The National Integrated Drought Information System (NIDIS) that you authorized the last year would thus become an important component of this larger climate information system.

The Honorable Mark Udall
The Honorable Bob Inglis
June 5, 2007
Page 2

Decision-makers at all levels of government and in the private sector need reliable and timely information to understand the possible impacts and corresponding vulnerabilities that are posed by climate change so they can plan and respond accordingly. The Western Governors' Association supports H.R. 906 as an effort to move the nation's climate change research program in this direction.

Sincerely,

M. Michael Rounds
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Chairman

Dave Freudenthal
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APPENDIX B

WGA/WSWC/CDWR Climate Change Research Needs Workshop Agenda

May 16-18, 2007

Wednesday May 16

9:30 Registration

10:30 Welcome, opening remarks
Shaun McGrath, Western Governors' Association (WGA)
Jeanine Jones, California Department of Water Resources (CDWR)

10:50 Overview of recent climate change activities
IPCC – Linda Mearns, National Center for Atmospheric Research
California's Climate Action Team – John Andrew, CDWR

11:30 Overview of impacts in Western U.S.
Dan Cayan, Scripps Institution of Oceanography
Brad Udall, Western Water Assessment

12:15 Lunch

1:15 Information needs – end user perspective #1
California State Water Project supplies – John Andrew, CDWR
Flood management – Mike Anderson, CDWR
Local agency water supply -- Lorna Stickel, Portland Water Bureau

2:15 Information needs – end user perspective #2
Demography – Mary Heim, California Department of Finance
Decision Center for a Desert City experience – Patricia Gober, Arizona State University
Economic impacts – Ernie Niemi, ECONorthwest

3:15 Small group break-out discussion #1
1. Data collection/monitoring needs
2. Needs for analytical tools, models, data analysis
3. Institutional/public policy issues

4:30 Discussion of breakout #1

5:30 Adjourn

Thursday May 17

7:30 Continental breakfast

8:30 Applied research examples
Hydrologic forecasting – Mike Dettinger, Scripps/U.S. Geological Survey (USGS)
Drought – Richard Seager, Columbia University
Application of paleohydrology – Terry Fulp, U.S. Bureau of Reclamation
Drought economic impacts – Mike Hayes, National Drought Mitigation Center

10:15 Break

10:30 Information needs – academic perspective
Climate services/social sciences interface -- Gregg Garfin, University of Arizona
Hydroclimatic data -- Kelly Redmond, Desert Research Institute
Risk & uncertainty – Charles Kolstad, University of California, Santa Barbara
Knowledge transfer from academia – Genevieve Maricle, Colorado State University

12:00 Lunch

1:00 Getting in the loop
Facilitating scientist-end user interaction -- Kathy Jacobs, University of Arizona
Engaging the federal CCSP agencies:
Robert Webb, National Oceanographic and Atmospheric Administration
Bob O'Connor, National Science Foundation
NIDIS, paradigm for a national climate service? – Shaun McGrath, WGA

2:30 Small group break-out discussion #2
1. Strategies for improving practitioner/academic communication
2. Strategies for partnerships with federal agencies

4:00 Discussion of break-out #2

5:00 Adjourn

Friday May 18

7:30 Continental breakfast

8:30 Overview, federal role in climate research – Jeanine Jones, CDWR

9:00 Proposed USGCRP reauthorization

9:30 Small group drafting of proposed action plan
Group #1 – relationships with academia
Group #2 – relationships with federal program agencies

10:45 Discuss action plan

11:30 Adjourn

APPENDIX C

Questions for Breakout Sessions

Climate Change Workshop

Monday May 16

Data Collection and Monitoring Needs

Given what is known about likely impacts, where are there significant gaps in existing hydroclimate data collection programs (e.g. mid-elevation snowpack)? What would it take to fill the gaps? What are the priorities?

Is the quality (precision, accuracy) of key historical hydroclimate data sets or ongoing data collection programs adequate for present needs? What unresolved issues with existing information (e.g. snow pillow data) need to be addressed?

Are there opportunities to make more/better use of remote sensing data (e.g. satellite observations)? Do resource management agencies have adequate access to this information/in-house capabilities to employ it?

Are there new technologies for hydroclimate data collection that we should be either developing through applied research or transitioning from research to application? What are the priorities?

In addition to traditional hydroclimate data collection, are there other data sets that we should be routinely collecting or systematically compiling (e.g. land use mapping, high-resolution floodplain mapping, evapotranspiration)?

Needs for Analytical Tools, Models, Data Analysis

How do we institutionalize a process for getting results of global-scale climate models expeditiously down-scaled to regional and local levels throughout the Western states? Is there an opportunity for the federal agencies or the researchers they fund to develop analytical tools (e.g. regional models) with the goal of transferring them to state and local entities? How can state and local entities participate in the development process?

What priority research would yield the most bang for the buck in terms of improving mid- and long-range climate forecasting capabilities? What level of investment (time and money) is involved)?

What needs to be done to improve the ability to simulate extreme events (e.g. for flood events)?

What needs to be done to improve existing demographic and water use forecasting methodologies? How do we factor in externalities (e.g. impacts of international trade on agricultural markets and hence water use)?

How difficult would it be to develop a planning-level tool to analyze the carbon footprint of

different water supply or water conservation alternatives, to allow water suppliers to compare the effects of, for example, constructing a well field versus developing a water recycling project?

Institutional/Public Policy Issues

How can two-way communication between the federal climate science program and practitioners be improved, to carry out the existing statutory mandate that the program produce useful information that supports real-world decision-making? Is new legislation needed?

Resource managers must deal with impacts and adaptation to climate change and variability at local, regional, and state levels. How do we get the federal climate science programs to think globally/act locally? Are states aware of the support available through NOAA's limited number of RISAs? Is the RISA model working for those states that do work with RISAs?

Over the long-term, developing adaptation strategies for climate change will necessitate that state water agencies work with interest groups such as the insurance industry (floodplain management) and local land use agencies (water availability for new growth). How do state water agencies go about building relationships with these non-traditional partners? Could WGA play a role in bringing together climate-related stakeholder groups?

Many states are now adopting green house gas (GHG) emission reduction goals, and calling for state agencies to contribute to meeting these goals through the programs they manage. At the federal level, enactment of the Energy Policy Act of 2005 (EPA 2005) called attention to the energy-water nexus and has focused some attention on the relationship between energy conservation (and potential GHG reduction) and water conservation. How can state water agencies get better engaged in DOE's implementation of EPA 2005, and get timely information they can use in administering water conservation and GHG reduction programs?

Should analyses of alternatives performed for regulatory purposes (e.g. National Environmental Policy Act disclosure or state permitting programs) require disclosure or consideration of the carbon footprint of alternatives? Is the technical capacity for routinely making such determinations now available? If not, what resources would be needed to achieve that capacity?

Thursday May 17

Strategies for Improving Practitioner/Academic Communication

Academics are generally "rewarded" professionally for teaching, research, and publishing papers in academic journals, not for outreach/interaction with practitioners. In addition to the obvious alternative of funding academic research, what other actions could practitioners take that would generate "rewards" from the academic perspective?

Conversely, staff workload in most state and local water agencies is such that publishing papers in academic or professional journals is a low priority. However, publishing would be a means of informing academics about issues of concern to resource management agencies, and could help increase agencies' credibility with their stakeholders. Should WGA/WSWC recommend that the priority of this activity be elevated? Could academics help by seeking out

practitioners as co-authors?

There is often a substantial translation gap between the specifics of the information that decision-makers need and the scientific research that would be necessary to provide those answers. How can decision-makers identify key researchers in unfamiliar disciplines and educate them as to information needs? Periodic workshops targeted to academics? Outreach through academic consortia such as RISAs or NCAR? Active participation in key conferences such as AGU?

Should entities such as WGA explore the possibility of working with federal climate science funding agencies to condition their grants to researchers to require that some portion of the grants include involvement/participation of actual stakeholders (e.g. state and local agencies)? Should this be legislatively mandated?

Strategies for Partnerships with Federal Agencies

The federal climate science agencies, either collectively or individually, do not have a structured process for working systematically with state and local agencies on applied research needs relating to climate variability/change. Possible mechanisms for creating a process with one or more federal agencies could include advisory committees or memoranda of agreement. A process could also be established through enactment of legislation, such as the proposed HR 905. Would it be useful to have an entity such as WGA or WSWC attempt to develop a process with one or more federal agencies, or to seek one through legislation (or do both)?

State and federal agencies have historically used the Interagency Personnel Assignment (IPA) approach as one for tool for technology transfer or development of specialized programs. Is there interest in using this tool for capacity building in state agencies and for focusing attention on decision support in federal agencies?

Are there examples or case studies of successful federal agency climate change science partnerships that should be shared among the Western states? Are there common themes that can be discerned from the examples? Should WGA/WSWC hold a conference or workshop to solicit and present case histories?

Federal agencies with operational climate programs (e.g. National Weather Service, USDA Snotel program) have developed good working relationships with end user communities. Are there examples from these programs that could be used as models for the federal climate change science program (e.g. river forecast center/climate change forecast center)?

APPENDIX D

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APPENDIX E

Acronym List

ACIS	Applied Climate Information System
AGRIMET	AGRIcultural METeorology
AGU	American Geophysical Union
AMS	American Meteorological Society
ASU	Arizona State University
AWI	Arizona Water Institute
CDWR	California Department of Water Resources
CCRI	Climate Change Research Initiative
CCSP	Climate Change Science Program
CCTP	Climate Change Technology Program
CIRMOUNT	Consortium for Integrated Climate Research in Western Mountains
CPO	Climate Program Office (NOAA)
DOC	Department of Commerce
DOE	Department of Energy
DOI	Department of the Interior
DOT	Department of Transportation
EIS	Environmental Impact Statement
ENSO	El Niño Southern Oscillation
EPA 2005	Energy Policy Act of 2005
EPA	Environmental Protection Agency
GHG	Greenhouse Gas
HHS	(Department of) Health and Human Services
IPA	Interagency Personnel Assignment
IPCC	Intergovernmental Panel on Climate Change
MAF	Million Acre Feet
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NASAW	North American Seasonal Assessment Workshop
NCDC	National Climatic Data Center
NCAR	National Center for Atmospheric Research
NIDIS	National Integrated Drought Information System
NIH	National Institutes of Health
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation

Acronym List (continued)

NWS	National Weather Service
RAWS	Remote Automatic Weather Station
RCM	Regional Climate Model
RISA	Regional Integrated Sciences and Assessments
SARP	Sector Applications Research Program
SCAN	Soil Climate Analysis Network
SI	Smithsonian Institution
SNOTEL	SNOwpack TELemetry
SWP	State Water Project
TAR	Third Assessment Report (of IPCC)
TRACS	Transition of Research Applications to Climate Services
USACE	U.S. Army Corps of Engineers
USAID	U.S. Agency for International Development
USBR	U.S. Bureau of Reclamation
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Society
USDA	U.S. Department of Agriculture
WIMS	Weather Information Management System
WGA	Western Governors' Association
WSWC	Western States Water Council