CLIMATE VARIABILITY AND CHANGE IN THE SOUTHWEST
IMPACTS, INFORMATION NEEDS, AND ISSUES FOR POLICYMAKING

Final Report
of the
Southwest Regional Climate Change Symposium and Workshop

September 3-5, 1997 • Tucson, Arizona

Edited by

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at
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PART I

OVERVIEW

CHAPTER 1
BACKGROUND

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At the request of the U.S. Department of the Interior and the U.S. Global Change Research Program (USGCRP), the Udall Center for Studies in Public Policy and other units at The University of Arizona organized and hosted the Southwest Regional Climate Change Symposium and Workshop in Tucson, Arizona, on September 3-5, 1997.

The intent of the symposium and workshop was to bring together important stakeholders--representatives from the private sector, government agencies, educational institutions, and interested citizens--to determine the state-of-knowledge, information and research needs, and possible policy strategies related to the impacts of and responses to climate variability and change in the Southwest. The event was one in a series of some two dozen such regional climate-change conferences hosted under the auspices of the USGCRP and various federal agencies.

For the purposes of the symposium and workshop, the Southwest was defined as the states of Arizona and New Mexico, as well as adjacent portions of California, Nevada, Utah, Colorado, and Texas. This area corresponds roughly to that encompassed by the lower Colorado River and upper Rio Grande basins, and includes the relevant portions of the U.S.-Mexico border region and Indian Country.

Organization

The organizational and logistical operations for the event were based at the Udall Center for Studies in Public Policy, an applied research and outreach unit of The University of Arizona. ***Robert Merideth***, coordinator of the Center's Global Change and U.S.-Mexico Border Programs supervised the operations. ***Jon Unruh*** served as conference manager and organizer, working with several graduate student assistants, ***David Adams***, ***Emma Olenberger***, and ***Mark Patterson***.

The organizers established a local planning committee that met regularly throughout the summer (1997) to advise and assist with these efforts. These committee members (all from The University of Arizona or the Tucson area) were:

- ***Mark Anderson***, U.S. Geological Survey/Water Resources Division
- ***Roger Bales***, Interim Director, UA Institute for the Study of Planet Earth
- ***David Goodrich***, USDA/Agricultural Research Service
- ***William Halvorson***, UA Cooperative Park Studies Unit/USGS Biological Resources Division
- ***William Harriss*** and ***Michael Molitor***, Columbia University/Biosphere 2
- ***Christopher Helms***, Director, Morris K. Udall Foundation
- ***Malcolm Hughes***, Director, UA Laboratory for Tree-Ring Research
- ***Charles Hutchinson***, Associate Director, UA Office of Arid Lands Research
- ***Diana Liverman***, Director, UA Latin American Area Center and Associate Professor of Geography
- ***Mitchel McClaran***, Associate Professor, UA School of Renewable and Natural Resources

- ***Margaret McGonagill***, Director, UA Federal Relations Program
- ***Steven Mullen***, Associate Professor, UA Dept. of Atmospheric Sciences
- ***Soroosh Sorooshian***, Professor, UA Dept. of Hydrology and Water Resources
- ***Robert Varady***, Interim Director, Udall Center for Studies in Public Policy
- ***Marvin Waterstone***, Associate Professor, UA Department of Geography
- ***Robert Webb***, U.S. Geological Survey/Desert Laboratory

Format

The organizers and planning committee decided upon a three-level format for the program (see Appendix A):

- A one-day ***symposium*** open to the public.
- A one-day ***workshop*** for about 100 invited participants in a series of thematic breakouts to define the research agenda and information needs for each of several sectors and crosscutting issues.
- A half-day ***wrap-up session*** of about 30 persons to begin to fashion a draft outline and text for a conference report based on the previous days' activities.

In addition, the organizers and members of the planning committee for the September program participated in an online ***Web workshop*** (http://geochange.er.usgs.gov/sw/) developed and organized by the U.S. Geological Survey (USGS) and held in July 1997 (see Chapter 2). The Web workshop was intended to initiate a discussion--prior to the September symposium and workshop--on the effects of climate variability, possible natural and human-related long-term climate change, and land-use change in the rapidly growing southwestern United States.

Logistics

Planning and organization for the September event began in May 1997 and continued through the conclusion of the symposium. The first steps involved using the networks of the various planning-committee members to begin contacting potential speakers and panelists for the symposium and developing a list of persons to be invited to the workshop and wrap-up session.

An initial mailing advertisement for the symposium went to the Udall Center's mailing list of some 2,500 names (a broad collection of stakeholders: academics, government-agency persons, elected officials, and private citizens interested in public policy and natural-resources management issues). The Center's list was supplemented by names and mailing lists provided by members of the planning committee. The timing of the first mailing coincided with the start of the USGS's Web workshop.

Additional smaller mailings were done throughout the summer as more names or lists were acquired, and a final-reminder mailing was sent to the entire list again two weeks prior to the symposium.

A similar strategy--with fewer, but more-targeted names--was used to invite participants to the workshop and wrap-up session, in addition to the symposium. Approximately 250 individualized letters of invitation were sent to persons around the region. (For those invited to participate in the workshop, the organizers were able to offer the incentive of a modest stipend to cover travel, lodging, and meals.) Several of the conference staff were assigned to follow up the written invitations with a telephone call until a verbal contact was made with each individual invited.

We believe that the combination of the broad mailing and notification, a stipend to cover travel and related expenses for workshop participants, and persistence in trying to contact each of invited participants contributed to the diversity of stakeholders that attended the series of events (see Chapter 3).

As an attachment to the Udall Center's Web site, (http://udallcenter.arizona.edu) the organizers created a homepage for the symposium and workshop containing: the symposium registration form; the conference and workshop agendas; a listing and online copies of relevant articles in the media; seven commissioned position papers; and a link to the USGS Web workshop.

CHAPTER 2
RELATED USGS WEB WORKSHOP

Robert S. Thompson, Chief Scientist
Global Change & Climate History Program
U.S. Geological Survey
Denver, CO

Format

The U.S. Geological Survey's electronic, or Web, workshop, “Impact of Climate Change and Land Use in the Southwestern United States,” involved academic, governmental, and private sector participants and was organized into four categories: climatic variability, climatic impacts, societal issues, and information resources (Figure 2.1, Plate 1).

- Climatic Variability: provides information and discussion on El Niño climates; on trends in precipitation, droughts, floods, and other aspects of climatic variability in the Southwest during the recent past, or period of instrumentation and records; and on the Intergovernmental Panel on Climate Change (IPCC) 1995 report on potential future climate changes.

- Climatic Impacts: provides information and discussion on the effects of climate change on "Life and Ecosystems," the "Land Surface," and "Water Resources." The first category covers impacts on mammals, birds, reptiles, and cryptobiotic soils, as well as discussions on long-term monitoring of change, land-use history, forest fires, and ephemeral pools. The "Land Surface" section discusses climate-change effects in regard to sand dunes, dust hazards, arroyo cutting, erosion, and landslides, whereas the "Water Resources" section covers past floods, historic trends in water use, changes in wetlands, and ground subsidence.

- Societal Issues: provides discussion of the "Impacts of Climate Change on Society," "Human Impacts on the Landscape," and "Societal Responses to Climate Change." The first category covers U.S.-Mexico border issues, water use and demand, the effects of the endangered species act, and drought and ranching issues. The "Human Impacts" section discusses land-use trends, urban land use, population growth, and other landscape changes. The "Societal Responses" section discusses water management during droughts, transboundary water issues, and rangeland management.

- Information Resources: provides background information, including maps, population-growth figures, and links to other climate-change Web pages.

The USGS obtained and posted some 60 position papers, research articles, and posters for the workshop (Table 2.1). Among these were seven papers provided by the organizers of the September “Southwest Regional Climate Change Symposium and Workshop.”

Response

The online workshop was held from July 7 through July 27, 1997, and had 1,676 distinct users visiting the Web site (with a total of 98,920 page visits). Most users visited the site only once during the workshop period, but nearly 28 percent visited two or more times.

The information from the electronic workshop is still available online and will be available on CD-ROM.

Table 2.1. Online Papers and Posters for USGS Web Workshop: "Impacts of Climate Change and Land Use in the Southwestern United States"

http://geochange.er.usgs.gov/sw/

Climatic Variability

- *Precipitation Trends and Water Consumption in the Southwestern United States* by Henry F. Diaz with Craig A. Anderson
- *Coping with Severe and Sustained Drought in the Southwest* by Michael Dettinger
- *Effects of El Niño on Streamflow, Lake Level, and Landslide Potential* by R. Reynolds with M. Dettinger, D. Cayan, D. Stephens, L. Highland, and R. Wilson
- *Global Climate Change: The 1995 Report by Intergovernmental Panel on Climate Change* by Robert S. Thompson
- *Historic Variations in Moisture Availability* by Katherine H. Anderson with Robert S. Thompson
- *Precipitation Variability at High Spatial Resolution in the Desert Southwest* by Andrew C. Comrie with Bill Broyles
- *Review of Variability in the North American Monsoon* by David K. Adams
- *Some Perspectives on Climate and Floods in the Southwestern U.S*. by the U.S. Geological Survey
- *Evapotransipration and Droughts* by Ronald L. Hanson
- *Climate and Droughts* by Alan L. McNab with Thomas R. Karl

Impacts of Climate Change on Life and Ecosystems

- *Southwest U.S. Change Detection Images: Reno and Lake Tahoe, Nevada* by Kristi Sayler
- *A Method for Deriving Phenological Metrics from Satellite Data, Colorado 1991-1995* by Bradley C. Reed with Kristi Sayler
- *Long-Term Ecological Research (LTER) Program* by Richard L. Reynolds
- *Monitoring Climate and Vegetation Changes at USGS GEOMET Sites* by Paula J. Helm
- *Potential Effects of Global Change on Bats* by Michael A. Bogan
- *Cryptobiotic Soils: Holding the Place in Place* by Jayne Belnap
- *Mesoscale Ecological Responses to Climatic Variability in the American Southwest* by Thomas W. Swetnam with Julio L. Betancourt
- *Global Change Impacts in the Colorado Rockies Biogeographical Area: Research Highlights* by Thomas J. Stohlgren with Jill S. Baron
- *Land Use History of North America - (LUHNA):The Paleobotanical Record* by Craig D. Allen with J.L. Betancourt, Thomas W. Swetnam
- *Land Use History of North America - (LUHNA): Repeat Photography* by Craig D. Allen with Julio L. Betancourt, Thomas W. Swetnam
- *Assessment of Potential Future Vegetation Changes in the Southwestern U.S.* by R. S. Thompson with K.H. Anderson and P.J. Bartlein
- *Desert Tortoise Ecology* by Mojave Desert Tortoise GATF Project
- *Turtles and Global Climate Change* by Jeffrey E. Lovich
- *Potential Impacts of Global Climate Change on Bird Communities of the Southwest* by C. van Riper III with M.K. Sogge and D.W. Willey
- *Past Climate and Vegetation Changes in the Southwestern United States* by Robert S. Thompson with Katherine H. Anderson
- *Forest Fires and Drought in the U.S. Southwest* by Mark W. Patterson
- *Climate Change and Ephemeral Pool Ecosystems: Potholes and Vernal Pools as Potential Indicator Systems* by Tim B. Graham

Impacts of Climate Change on the Land Surface

- *Reactivation of Stabilized Sand Dunes on the Colorado Plateau* by Daniel R. Muhs with Josh M. Been
- *Owens (Dry) Lake, California: A Human-Induced Dust Problem* by Marith C. Reheis
- *The Rio Puerco Arroyo Cycle and the History of Landscape Changes* by Scott Aby with Allen Gellis, Milan Pavich
- *The Arroyo Problem in the Southwestern United States* by Brandon J. Vogt
- *Predicted Dust Emission vs. Measured Dust Deposition in the Southwestern United States* by Marith Reheis with Jonathan Rademaekers
- *Mineral Dusts in the Southwestern U.S.* by Todd K. Hinkley
- *Landslide Incidence and Susceptibility of the Southwestern United States* by R.H. Yuhas with R.L. Reynolds, L.Highland, and J. Godt
- *Wind Erosion Vulnerability and Rainfall Mapping in the Southwestern United States* by Pat S. Chavez, Jr. with Dave MacKinnon, Miguel G. Velasco, Stuart C. Sides, and Deborah L. Soltesz
- *Erosion in the Rio Puerco: Geography and Processes* by Raymond D. Watts with Richard Pelltier, Peter Molnar

Table 2.1 (continued). Online Papers and Posters for USGS Web Workshop

Impacts of Climate Change on Water Resources

- *Paleohydrology and its Value in Analyzing Floods and Droughts* by Robert D. Jarrett
- *Water Use Trends in the Southwestern United States 1950-1990* by Michael O'Donnell with Jonathan Rademaekers
- *Loss of Wetlands in the Southwestern United States* by Roberta H. Yuhas
- *Las Vegas Valley: Land Subsidence and Fissuring Due to Ground-Water Withdrawal* by John W. Bell
- *Summary of Floods and Droughts in the Southwestern States* by U.S Geological Survey

Impacts of Climate Change on Society

- *Climate Variability and Social Vulnerability in the U.S.-Mexico Border Region: An Integrated Assessment of the Water Resources of the San Pedro River and Santa Cruz River Basins* by Diana Liverman with Robert Merideth and Andrew Holdsworth
- *Changing Water Use and Demand in the Southwest* by Jon Unruh with Diana Liverman
- *Earthshots: Great Salt Lake, Utah* by Robb Campbell
- *The Endangered Species Act and Critical Habitat Designation: An Integrated Biological and Economic Approach* by Gary Watts with William Noonan, Henry Maddux, and David S. Brookshire
- *Drought and Ranching in Arizona: A Case of Vulnerability* by Hallie Eakin with Diana Liverman

Human Impacts on the Landscape

- *Land-Use Trends in the Southwestern United States* by Michael O'Donnell
- *Urban Land Use Change in the Albuquerque Metropolitan Area* by Paul Braun with Martin Chourre, Dave Hughes, Jamie Schubert, Heike Striebek and Richard Thorstad
- *Urban Land Use Change in the Las Vegas Valley* by William Acevedo with Leonard Gaydos, Janet Tilley, Carol Mladinich, Janis Buchanan, Steve Blauer, Kelley Kruger, and Jamie Schubert
- *Population Growth of the Southwest United States, 1900-1990* by Martin Chourre with Stewart Wright
- *The Extent of Urbanization in the Southwest As Viewed from Space* by National Oceanic and Atmospheric Association with USAF Defense Meteorological Satellite Program
- *Land Subsidence from Ground-Water Pumping* by S.A. Leake
- *Earthshots: Imperial Valley, California* by Robb Campbell
- *Southwest U.S. Change Detection Images: Las Vegas, Nevada* by Kristi Sayler

Societal Responses to Climate and Landscape Changes

- *Management of Water Resources for Drought Conditions* by William R. Walker with Margaret S. Hrezo and Carol J. Haley
- *Transboundary Water Resources Management in the Upper Rio Grande Basin* by Marvin Waterstone
- *The Malpai Borderlands Project: A Stewardship Approach to Rangeland Management* by R. Randall Schumann

Information Resources

- *Links to Other Climate-Change Related Web sites* by U.S. Geological Survey
- *Population Density Data by County: An Interactive Database* by Peter Schweitzer with Yew Yuan
- *General Map of the Southwestern United States* by the U.S. Geological Survey

CHAPTER 3
PARTICIPANTS

Robert Merideth, Coordinator
Global Change and U.S.-Mexico Border Programs
and
Emma Olenberger, Graduate Research Assistant
Udall Center for Studies in Public Policy
The University of Arizona
Tucson, AZ

The September 3 symposium attracted some 380 participants, representing numerous and diverse stakeholder groups. Table 3.1 provides data on the backgrounds of these participants.

About 100 persons were invited to participate in the workshop breakout sessions held on September 4, while some 20 persons gathered for a wrap-up session on September 5.

The reports and list of participants from the workshop sessions are presented in Chapters 9 through 18, and the recommendations from the wrap-up session appear in Chapter 19.

Table 3.1. Attendance at the Southwest Regional Climate Change Symposium
September 3, 1997 - Tucson, Arizona

Category	Representing	Num.	Pct.
University/education or research institution	▪ 11 universities ▪ 9 other educational and research institutions	148	39%
State/local/tribal government	▪ 30 state, county, or municipal governmental agencies ▪ 9 American Indian tribal governments ▪ 7 elected officials or their representatives (state & local)	78	21%
Other stakeholders	▪ 15 nongovernmental organizations ▪ 14 consulting firms ▪ 11 industries or businesses ▪ 7 media outlets ▪ 7 ranches or farms	78	21%
Federal government	▪ 19 federal agencies ▪ 5 elected officials (representatives for U.S. Senators Kyl and McCain; representatives for U.S. Reps. Hayworth, Pastor, and Shadegg)	73	19%
Total		**377**	

PART II

SYMPOSIUM PRESENTATIONS

SEPTEMBER 3, 1997

CHAPTER 4
PLENARY PRESENTATIONS

Robert Merideth, Coordinator
Global Change and U.S.-Mexico Border Programs
and
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Opening Speakers

Michael Cusanovich, Vice President for Research at The University of Arizona, welcomed the participants and indicated that the symposium reflected the strong interest the University has in global change research, with many faculty serving on key international and federal advisory panels. He also stated that the UA's set of global change activities is but one example of the University's long tradition of and commitment to interdisciplinary environmental research.

John Garamendi, Deputy Secretary of the U.S. Department of the Interior provided the keynote address. Garamendi spoke about the need for scientists to communicate their research findings about climate change to the public and reminded the audience that it doesn't have the luxury of waiting. He quoted President Clinton, indicating that:

> *The science is clear and compelling. We humans are changing the global climate. Concentrations of greenhouse gases levels are at their highest levels in more than 200,000 years and they are climbing sharply. Here in the United States we must do better.*

Garamendi stressed that leadership from the scientific community is critical to move U.S. society—which has four percent of the world's population but is responsible for 20 percent of CO_2 emissions from fossil-fuel burning—to take necessary action.

He also highlighted some of the potential impacts in the Southwest from climate change, including shifting sand dunes in the Four Corners region from a decrease in vegetation, an increase in vector-borne diseases, and an increase in severe (extreme) weather events. With regard to the (then upcoming) December 1997 Kyoto Summit, Garamendi asserted that the U.S. has seven general directives to follow:

1. setting binding emission standards for developing countries;
2. achieving flexibility to find cost-effective solutions;
3. ensuring that developing countries participate in emissions reductions;
4. preparing a balanced plan of action between environmental concerns and economic development;
5. notwithstanding the previous directive, preserving the current economic growth;
6. finding the flexibility to use market solutions rather than regulations to solve environmental problems; and
7. using science and technology to provide solutions.

Michael Hall, Director of the Office of Global Programs at the National Oceanic and Atmospheric Administration (NOAA), stressed the need for an ongoing dialogue among scientists, the public, and bureaucrats about climate-change impacts. He suggested that while there should be a national response to global climate change, there also should be a shift from a global to a regional or local focus in terms of research to study the impacts of climate change.

Wilson Orr, Director of Advanced Technology Systems for the City of Scottsdale, AZ (presently

Director of the Global Change and Sustainability Program at Prescott College), echoed the need to think about the occurrence of global change in local places and of the need for communication between scientists and the public.

Topical Presentations

Following these opening remarks, seven plenary speakers were charged with answering several key questions. These presentations are summarized in subsequent chapters.

- ***Diana Liverman***, Director, Latin American Area Center and Associate Professor of Geography, The University of Arizona:

  How does climate affect human activity and the economy of the Southwest?

  Liverman's presentation forms the basis for ***Chapter 5***, "Trends and Issues in the Southwest."

- ***Thomas Swetnam***, Associate Professor, Laboratory for Tree-Ring Research, The University of Arizona:

  How unusual is the Southwest s climate this century compared with that in the past?

- ***Robert Quayle***, Deputy Director, NOAA/National Climatic Data Center, Asheville, NC:

  What is the evidence that climate is changing? What do we know about recent climate trends in the Southwest?

- ***Daniel Cayan***, Director, El Niño Prediction Center, Scripps Institution of Oceanography, La Jolla, CA:

  How does El Niño affect the climate of the Southwest?

- ***Soroosh Sorooshian***, Professor of Hydrology and Water Resources, The University of Arizona:

  How does climate affect surface water and groundwater supply in the Southwest?

  The presentations by Swetnam, Quayle, Cayan, and Sorooshian provide the basis for material in ***Chapter 6***, "Climate Patterns and Trends in the Southwest."

- ***Robert Dickinson***, Regents Professor of Atmospheric Physics, Hydrology and Water Resources, and Tree-Ring Research, The University of Arizona:

  What do we know about the likely climate of the future?

- ***Linda Mearns***, Scientist, Environmental and Social Impacts Group, National Center for Atmospheric Research, Boulder, CO:

  What are the likely future impacts of climate variations and changes on society, the economy, and the environment?

  The presentations by Dickinson and Mearns provide core material for ***Chapter 7***, "Future Climate of the Southwest."

CHAPTER 5
SOUTHWEST REGIONAL OVERVIEW

Diana M. Liverman, Director
Latin American Area Center and
Associate Professor of Geography
The University of Arizona
Tucson, AZ

Environmental Stresses and Social Concerns in the Southwest

Certain social and economic trends and environmental conditions make the Southwest especially vulnerable to climate change:

- The region is experiencing rapid population and economic growth, with tourism, development, retail, and other service sectors now making up much of the regional economy.
- An assured water supply is essential for municipal and industrial users and, to a certain extent, for irrigated agriculture and natural ecosystems (such as riparian vegetation and wildlife).
- The ranching, non-irrigated agriculture, and forestry sectors are dependent on the amount of soil moisture and the timing of rainfall.
- The restructuring of agriculture, due in part to global economic forces, is shifting the types of crops grown. In many cases, the new crop mix is much more water intensive. In other areas, agricultural land is being converted into urban developments.
- Intense differences in values and political conflicts exist over the use of land and water in the region, with disputes arising over local-versus federal-land ownership and control, resource use versus conservation and protection, and urban lifestyles versus rural livelihoods.
- Unresolved water rights for Native American tribes and binational treaty obligations with Mexico pose unique institutional challenges or uncertainties in the region to manage water and other natural resources.
- Differences in income and access to other financial or institutional resources make some segments of the society in region more vulnerable than are others to climate variations and change.

The rest of the chapter provides a socioeconomic profile of the Southwest and shows how each of these activities is affected by or vulnerable to climate change.

Economy

The economies of both Arizona and New Mexico are expanding relatively rapidly and are dominated by the service, retail, and government sectors. At first glance, these activities seem much less vulnerable to climatic variations such as drought than sectors such as agriculture, forestry, or industrial resource extraction.

Yet complex economic linkages both within and outside the region are such that impacts in one sector often affect others.

For example, heatwaves, floods, prolonged droughts, and snowstorms may affect crops, roadways, bridges, and other infrastructure, but also may change energy demand, alter retail sales, or increase insurance claims or hospital admissions in ways that affect service and retail sectors.

Key points

- The economies of Arizona and New Mexico are growing faster than most other states.
- Services and retailing are the largest sectors of the Southwest economy.
- More than 75 percent of employees work in sales, services, or government.

- Severe and prolonged climate events can have a significant direct impact on key economic sectors, as well as an indirect impact on related areas.

Lifestyle

It is important to remember that our climate has made positive contributions to the lifestyle and growth of the Southwest, attracting migrants and tourists, and enabling productive agriculture. Along the way, we have adapted to the stresses of a hot, dry climate through irrigation, air conditioning, and housing design.

The Southwest may provide a model for the rest of the country to adapt to global warming. But we must not forget that our adaptations have come at a cost--in the water transfers, energy demands, and environmental modifications that transformed the desert--and in some cases we may be reaching the limits of our adaptive capabilities.

Many have called for the adoption of more long-term and sustainable strategies, such as increasing reliance on solar energy, increasing energy efficiency, and decreasing per capita water use.

Key points

- The warm climate has attracted people to the Southwest and is an important draw for corporations, retirees, and tourists.
- In some ways the Southwest has already adapted to the warmer, drier, and more extreme climates that could be a result of global warming.
- Adaptations include large-scale water transfers and air conditioning, but these can be costly in terms of federal subsidies, environmental impacts, and individual water and energy bills.
- New, more sustainable strategies are needed to assure a high-quality lifestyle for the current population and future generations.

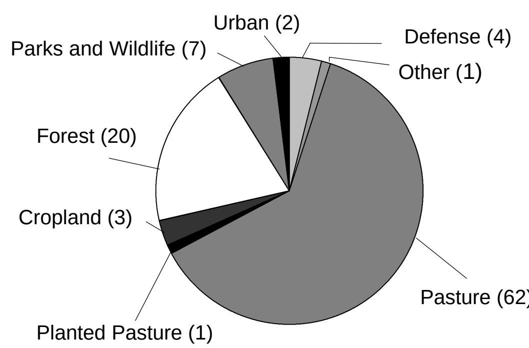
Land Use

Geographical patterns of vulnerability to climatic variation are suggested by the overall pattern and structure of land and water use in the Southwest.

As shown in Figure 5.1, nearly two-thirds of the land in both Arizona and New Mexico is used for ranching, and a quarter is in forests or parks. Both of these sectors depend on the soil moisture provided by rain and snow.

Hence, significant climatic changes (e.g. an extended drought) potentially can have a major impact over a large area of the Southwest. Irrigated cropland and urban settlements, while occupying relatively small areas, are vulnerable due to their heavy reliance on the delivery of

Figure 5.1. Land Use in the Southwest (Percent)



groundwater or surface water supplies.

Key Points

- Pasture, forests, and parks occupy more than 90 percent of the land in Arizona and New Mexico.
- Ecosystems and human activities associated with these areas are particularly vulnerable to extended droughts and may be affected significantly by ecological changes resulting from long-term climate change.

Water Use

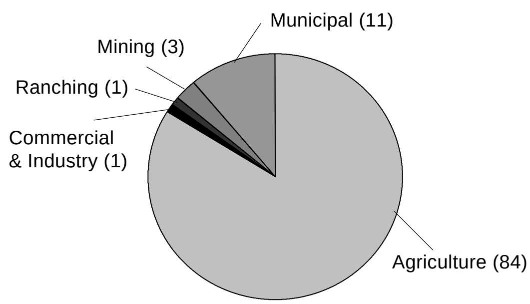
Though relatively small in its land use, irrigated agriculture--as shown in Figure 5.2--is by far the most extensive user of water in the Southwest.

Municipal use is of growing but of secondary importance.

Vulnerability to climate is mediated by the rivers, surface reservoirs, and groundwater aquifers that supply most of the water for the region. But many aquifers are being mined and are only partly replenished by precipitation.

Hot, dry conditions bring on rapid evapotranspiration from crops and surface supplies.

Figure 5.2. Southwest Water Use (Percent)



Key points

- Irrigated agriculture is by far the largest user of water in the Southwest.
- Presently, water supplies in the Southwest are about 50 percent surface water and 50 percent groundwater.
- More groundwater is being pumped than replenished in most regions.
- Municipal water use is increasing with rapidly growing populations and economic development.

Colorado River and Rio Grande

The Colorado River (Figure 5.3, Plate 2) and the Rio Grande (Figure 5.4, Plate 2) have been called the lifeblood of the Southwest. Rights to their water have been fully allocated between nations, states, and different water users. Large fluctuations in year-to-year flows in the rivers or their tributaries (Figure 5.5, Plate 2)--caused mainly by climatic variations--creates stresses for water- management institutions and conflict between users.

Understanding variations and potential changes in the flows of these rivers is critical for water resources, energy and ecosystem management in our region.

Key points

- The Colorado River and the Rio Grande systems are the most important surface water supplies in the Southwest. Rights to the flows are fully allocated.
- Flow in these basins varies from year to year especially in relation to snow conditions in the upper parts of the basins. For example, in 1983, the Colorado River's annual flow was over 22 million acre feet (MAF), while in 1954, it was just slightly more than 10 MAF.
- International treaties divide flows with Mexico and domestic interstate compacts allocate flow between the U.S. states. The allocations stipulated in these agreements, particularly for the Colorado River, were based on periods of unusually high flow. Under present climatic conditions, the flows are inadequate to meet all potential allocations. Climate variability and change may threaten these international and interstate management arrangements if flows become further reduced.

Agriculture and Water

As mentioned earlier, irrigated agriculture uses more water than any other sector, only a portion of which is returned to the system. In hot, dry years, water supplies are limited yet crops require more water to survive.

In Arizona, irrigators are accumulating water credits for water rights they own but do not use because of low crop prices. Institutional changes may mean that farmers can sell these rights to the municipal sector and that as a result, overall water demand may level off or even decline. This could reduce climatic vulnerability.

Key points

- Irrigation is necessary for most crop production in the Southwest, and agriculture is a major water user and holder of water rights.
- Over half the water withdrawn for irrigation is consumed through evapotranspiration or is incorporated into crops, 17 percent is lost by evaporation from lakes and canals or from leaks, and only 29 percent returns to streams or groundwater.
- Climatic variations influence water supplies. High temperatures increase crop water demands.
- Land and water are shifting away from agricultural to urban use.

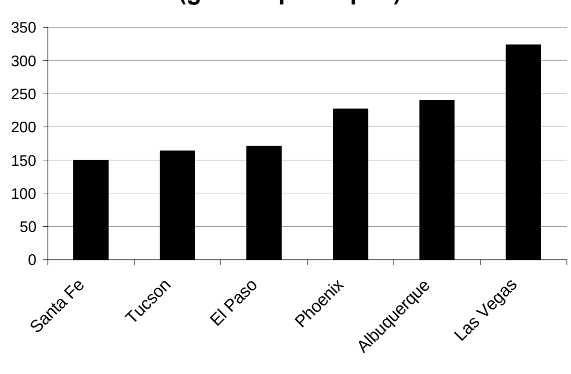
Urban Water Use

In the Southwest--where most of the population dwells in urban areas--populations are growing very rapidly, and municipal water use is expected to grow at least 20 percent by 2040.

Water use varies considerably between cities as a result of urban design and individual behavior. Figure 5.6 shows a dramatic difference in per capita water use between, for example, Santa Fe and Las Vegas.

Urban demands also vary seasonally due to climate and other conditions, with the greatest demand in summer months. Could climate change limit urban development in the Southwest?

Figure 5.6. Daily Municipal Water Use (gallons per capita)



Key points

- Urban populations are growing rapidly in the Southwest, at rates greater than three percent per year.
- Water use per capita varies considerably by community.
- Water use also varies seasonally, with peak demand in the summer months.
- Urban water demand is increasing and is expected to grow at least 20 percent by 2040.

Water Use in Indian Country

Resources on tribal lands have been severely affected by recent droughts. For example, the San Carlos Apache tribe had to deal with the drying up of a major reservoir and the resulting loss of income, such as from reduced fishing and water-recreation fees.

Water use is increasing on many reservations, and if water rights are settled further increases will be possible. Several groups plan to expand irrigated agriculture as illustrated by this data from the Arizona Department of Water Resources.

How vulnerable will these new irrigated areas be to climatic variation ? Will the transfer of rights increase drought impacts for other sectors ?

Key points

- Agriculture, water supplies, and health are vulnerable to climate change on tribal lands in the Southwest.
- Settlement of Indian water right claims (in Arizona, about 3.1 million acre-feet) will increase overall water demand and shift drought vulnerabilities.

Climate Extremes: Floods

Variations in year-to-year precipitation and storm severity can cause serious flooding in the Southwest, particularly during the summer monsoons and spring snowmelt (Table 5.1).

During the summer of 1997, several flood-related deaths and major economic losses occurred in the region. Nationally, floods cost billions of dollars in insurance and personal losses, and in federal, state and private emergency relief. Insurance companies are very concerned about climate change.

Severe floods and droughts have often affected up to 40 percent of the area of the Southwest (see Figure 6.4 in next chapter).

FLOODS IN ARIZONA AND NEW MEXICO

YEAR	STATE	AREA AFFECTED
1862	AZ	Gila and Colorado Rivers
1891	AZ	Central Highlands
1904	NM	N, E, and NE parts of state
1905	AZ	San Francisco - Verde Rivers
1916	AZ	Central Highlands
1921	AZ	Phoenix (Cave Creek)
1926	AZ	San Pedro River
1927	NM	Animas and San Juan Rivers
1941	AZ	Central
1941	NM	Central (S, SW, and SE)
1942	NM	Rio Grande
1942	NM	Canadian and Pecos Rivers
1962	AZ	Brawley/Santa Rosa Washes
1965	NM	N, NE, and SE parts of state
1966	AZ	Verde, Salt, & Gila Rivers
1966	AZ	Grand Canyon - SW Utah
1970	AZ	Tonto Cr. - Hassayampa R.
1972	AZ	Upper Gila River
1974	AZ	Safford/Holyoke Wash
1977	AZ	Central and SE part of state
1978	NM	Gila River
1978	AZ	Central part of state
1979	AZ	SE part of state
1981	AZ	Tucson area
1983	AZ	Colorado River
1983	AZ	Santa Cruz/San Francisco R.
1988	NM	Vermejo River
1993	AZ	Gila River/SW part of state

Table 5.1. Chronology of major and other memorable floods in Arizona and New Mexico (from Paulson et al., 1989)

Climate Extremes: Drought

While several significant droughts have occurred during the past century or so, we only have to look at the summer of 1996 to see some of the impacts of drought in the Southwest. News articles document the losses on ranches, tribal lands, and forests as the soil and wells dried up:

- In 1996, severe drought devastated farms and ranches in Arizona and New Mexico.
- The impact of drought on tribal lands was especially serious. The San Carlos reservoir northeast of Phoenix dropped to 25 percent of its volume.

DROUGHT IN ARIZONA AND NEW MEXICO

YEAR	STATE	AREA AFFECTED
1931-41	NM	Moderate conditions in isolated areas in SW and N mountains; severe conditions elsewhere.
1932-36	AZ	Statewide--effects differed among basins.
1942-79	NM	Moderate conditions in NE and NW; severe conditions elsewhere.
1942-64	AZ	Statewide--second most severe in 350 years.
1973-77	AZ	Statewide, but most severe in eastern part of state.
1995-96	NM/AZ	Statewide

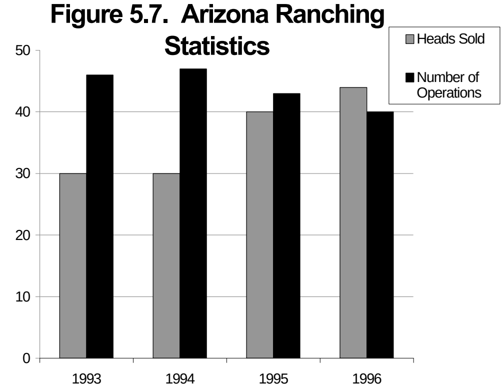
Table 5.2. Chronology of major and other memorable droughts in Arizona and New Mexico (from Paulson et al., 1989)

Ranching

The recent (1995-96) drought also highlighted the vulnerability of ranching to climatic variations. Cattle sales increased (Figure 5.7) and several ranches went out of business as rangelands and wells dried out and feed costs soared.

But factors other than local climate have contributed to the problems of the ranching sector. Global grain reserves were low, contributing to high feed prices, and a multiyear drought in Mexico overwhelmed border markets with low-priced stock.

Figure 5.7. Arizona Ranching Statistics



Key points

- Ranching by nature is particularly vulnerable to drought.

- In 1996, ranchers in Arizona and New Mexico faced drought, dry wells, high feed prices and low stock prices when they tried to sell.

- External factors such as low global grain reserves and drought in Mexico increased the vulnerability of the ranching sector in Arizona, New Mexico, and other U.S. states.

- Some smaller ranches (i.e., with fewer than 50 head) went out of business during this time period.

Energy

Another climate-sensitive sector is energy, with both supply and demand varying with climate. Hydroelectric supplies are clearly the most climate sensitive. Overall electricity demand varies with seasons and from year to year (Figure 5.8).

Extreme events can cut power supplies, and it is important to remember that many people cannot afford to heat or cool their homes properly.

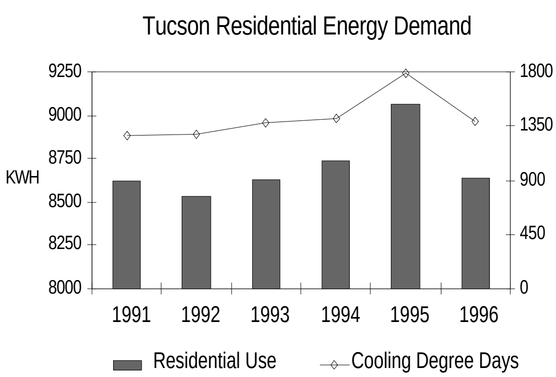


Figure 5.8. Tucson, Arizona, residential energy demand

Key points

- Hydroelectric generation is very dependent on climate.
- Energy consumption also varies seasonally and interannually according to temperatures.

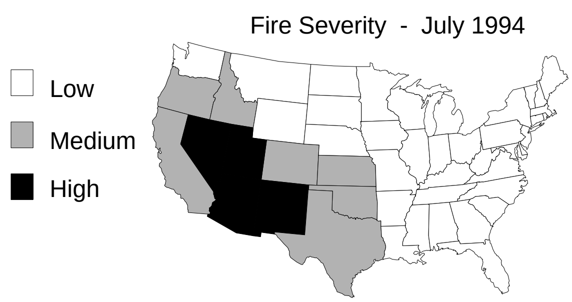
- Heatwaves and severe storms can disrupt power supplies.

- Those who cannot afford to pay for heating and air conditioning may suffer cold and heat stress-related illness and mortality.

Forest Fires

Another highly sensitive sector is forestry, where droughts cause economic and ecological damage. This too has been illustrated by severe fires and high economic costs of losses and fire fighting in recent years.

Fire frequency is influenced by climate variability but also by management decisions such as fire suppression and forest-access policies.



Key points

- Droughts increase fire potential by creating tinder-dry forests.

- Fire potential also depends on how forests are managed.

- Extreme fire danger ratings may close forests to users and force fire crews to suppress fires, countering ecosystem management principles.

- The U.S. Forest Service has allocated $36 million for fire management in 1998 in the Southwest.

Recreation and Tourism

Recreation and tourism are very important to the economy and to the lifestyle of the Southwest. Many climatic factors are important, including snowfall, river flows, irrigated landscape maintenance, and heat stress.

A variety of tourist enterprises is affected by climate variability and could be impacted by climate change. These include skiing, rafting, and bird watching,

Key points

- The warm climate of the Southwest offers many recreation opportunities.
- Climate change could affect many activities by reducing river flow for white-water rafting and water for irrigating golf courses.
- The number of bird species and thus bird watchers could decline if habitats are altered.
- Changing snowfall patterns would affect the ski industry.

These are just some of the ways in which climate affects society and economy in the Southwest. The climate sensitivities and impacts provide an important reason for trying to understand better what is happening to our climate and for finding ways to better use climate information in our planning and decisions.

Sources

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CHAPTER 6
CLIMATE PATTERNS AND TRENDS IN THE SOUTHWEST

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Long-term Historical Patterns

Climate records for the Southwest have been kept since the turn of the century. However, it is possible to reconstruct the region's climatic past back to the late 1500s using dendrochronology studies.

Tree-ring growth is related to climate, with small ring growth indicating stress conditions (e.g., hotter and drier) and larger rings indicating cooler, wetter periods. While tree-ring growth cannot provide an exact reconstruction of rainfall totals, there is a significant correlation between growth and precipitation (r = 0.80).

These studies have revealed the complex and cyclical nature of past climate in the Southwest, including the pattern of the El Niño-Southern Oscillation (ENSO) (Swetnam and Betancourt, 1992). Figure 6.1 illustrates the reconstructed average tree-ring growth in the Southwest dating back to the year 1000.

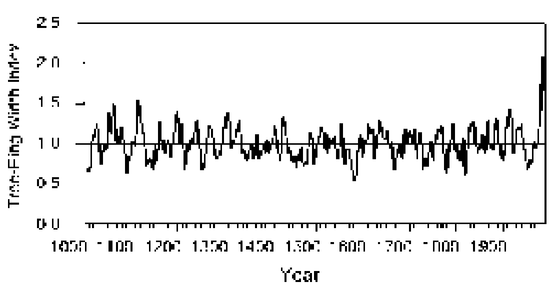

Figure 6.1. Tree-ring width index for the past thousand years in the Southwest (Swetnam and Betancourt, 1992)

The historical pattern of the pattern of the El Niño-Southern Oscillation can be seen in tree-ring growth. The periods from 1740 to 1780 and from 1830 to 1860 were abnormally wet years with large tree-ring growth. The interstitial period (1780 to 1830) was a dry period in the Southwest. Table 6.1 summarizes the extreme historical drought events based on dendrochronology research.

Time Period	Average Annual Precipitation	Duration (in years)
1271-1296	7.88 in.	25
1571-1587	7.60 in.	17
1666-1674	6.95 in.	9

Table 6.1. Extreme historical drought events as reconstructed from tree-ring growths

The first drought period is called the Great Drought by anthropologists and is linked to the disappearance of several indigenous tribes in the Southwest. The third drought is mentioned in the archives of the Spanish explorers in the area. Table 6.2 provides an overview of extreme historical wet events.

Time Period	Average Annual Precipitation	Duration (in years)
1100-1120	10.97 in.	21
1800-1816	12.24 in.	17

Table 6.2. Extreme historical wet periods as reconstructed from tree-ring growths

Current Climatology

Records of the more recent past also show that the Southwest has experienced large seasonal, year-to-year, and decade-to-decade climate fluctuations. For Tucson, the July maximum temperatures and rainfall for the 1961-1990 period show a large year-to-year variation (Figure 6.2, Plate 3).

Although many parts of the Southwest receive the majority of their precipitation from the summer monsoons, wintertime precipitation provides most of the annual runoff for the region.

Winter precipitation is considerably more variable than summertime precipitation, most of the latter being lost to evaporation (Figure 6.3).

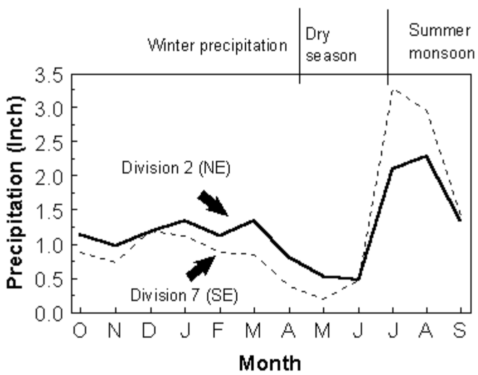

Figure 6.3. Seasonal precipitation patterns in two climate divisions for the Southwest

The impacts of climate variability are also illustrated by Figure 6.4 (Plate 3), which shows that significant areas of the Southwest are affected by moderate to severe drought or wet conditions every year.

The droughts of the 1930s and 1950s are evident. These graphs show no distinct changes in the frequency or extent of severe events.

Are there any systematic patterns or trends in southwestern climate? Figure 6.5 shows annual runoff in the Salt, Tonto, and Verde rivers with high climate variability but no distinct trend.

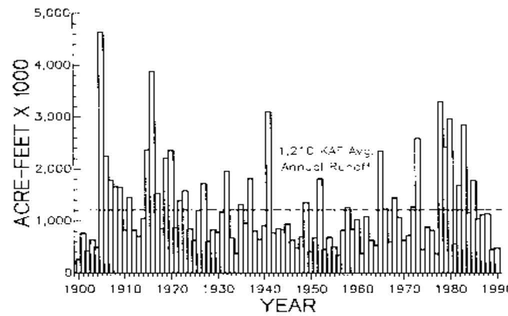

Figure 6.5. Annual flow of the Salt, Tonto, and Verde rivers in Arizona (Keane, 1991)

Longer-term reconstruction of Colorado River flows, based on tree ring records, show decade-long fluctuations associated with sustained wet and dry periods in the Southwest (Figure 6.6, Plate 3). In Arizona, the period since 1960 shows a lower daily temperature range (the difference between the daily maximum and minimum temperatures) for Arizona than for the period prior to 1960. The difference is about 2.5° (F) in the autumn and 1.4° (F) over the year. This annual change is due to a 1.0° (F) increase in daily minimum temperatures and a 0.4° (F) drop in daily maximum temperature, and may be explained mainly by an increase in cloud cover over the same period (W. Sellers, pers. comm.).

Analysis of climate records for the last century for a broader region to include Arizona, New Mexico, Nevada and Utah (Figure 6.7) suggests that there has been a slight increase in both maximum and minimum temperature, but no detectable change in precipitation since the turn of the century.

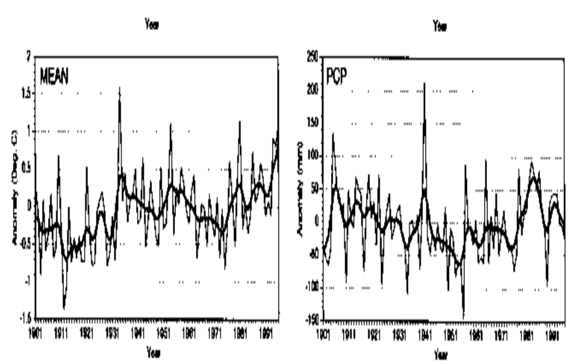

Figure 6.7. Trends in mean annual temperature (MEAN) and annual precipitation (PCP) for the Southwest, 1901-96 (Quayle 1997)

Fluctuations in Pacific sea surface temperatures (SST) and atmospheric conditions known as the El Niño-Southern Oscillation (ENSO) influence climate and its variability in the Southwest. When SSTs are warm (El Niño), the Southwest often experiences relatively wet winters, with higher snow pack and water year stream flows. Cooler events are sometimes associated with droughts (Figure 6.8).

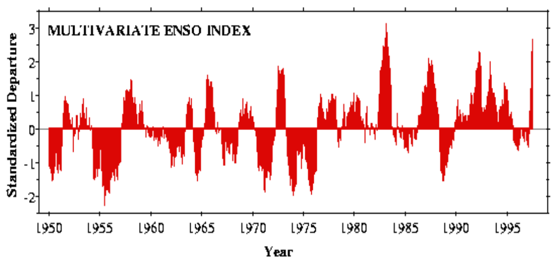

Figure 6.8. The ENSO monthly index since 1950

Values in Figure 6.8 above zero are warm sea surface temperature events, below are cold events (NOAA Web site).

Improved understanding now allows predictions of the climatic effects of El Niño and its influences up to one year in advance in many regions of the world. For example, climate-model simulations of monthly precipitation in the Southwest indicate that El Niño years have about 66 percent more precipitation than other (or control) years (Figure 6.9). Forecasts indicate both the evolution of sea surface temperatures and the probability of seasonal climate conditions. The following page shows some forecasts for the current El Niño.

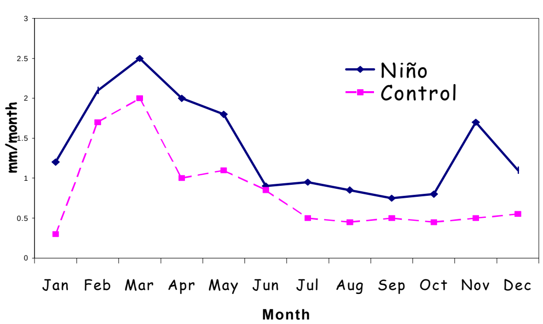

Figure 6.9. Modeling of precipitation (University of Arizona Department of Hydrology and Water Resources, 1997)

The current ENSO event (1997-98) is one of the more intense of recent decades (Figure 6.10, Plate 4). It intensified through the autumn and winter of 1997 and faded out during summer 1998(Figure 6.11, Plate 4).

Using knowledge of El Niño, scientists forecast a wetter 1997-98 winter for the Southwest. Recent ENSO information is available at the NOAA Web site (www.ogp.noaa.gov/enso).

Analysis of Recent Trends

While precipitation in the Southwest continues to fluctuate over a several-year cycle, average daily temperature has increased. In addition, the average daily minimum temperature has increased more than the maximum temperature.

As a result, the diurnal temperature range in decreasing, which could have implications for such sectors as agriculture and rangelands.

The 1980s and 1990s have been climatic anomalies. Concerns about greenhouse gas emissions and global warming have prompted scientists to investigate the link between these concerns and the recent anomalies.

While we cannot claim that global warming has caused any single climate event, we do note that the frequency of extreme events is increasing.

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CHAPTER 7
FUTURE CLIMATE OF THE SOUTHWEST

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How might global warming affect the Southwest? Many scenarios for climate change are based on the results of General Circulation Models (GCMs)--complex computer models of the earth's atmospheric circulation that are used to simulate how climate may change if greenhouse gases continue to rise.

One of the most recent simulations is that conducted by the U.K. Hadley Center, which includes a slow rise in carbon dioxide concentrations (called a transient scenario) and also takes into account the role of sulfur aerosols in cooling some regions.

The maps show the scenarios for the middle of the next century for changes in temperature (TEMP) and precipitation (PRECIP) for winter and summer in the Southwest (Figure 7.1, Plate 4).

The Hadley Center GCM suggests that temperatures in the Southwest will increase by about 5-9° F in both winter and summer as a result of increasing greenhouse-gas concentrations in the atmosphere. The Hadley Center results can be found at the Project LINK Web site (www.cru.uea.ac.uk/link/).

The scenario suggests that winter and summer precipitation will increase in the U.S., but winter precipitation will decrease in much of Mexico. This scenario is consistent with the results of most of the models used by the Intergovernmental Panel on Climate Change (IPCC), which project increases temperatures and changes in precipitation patterns with a doubling or more of greenhouse-gas concentrations in the atmosphere.

There are a number of important limitations in using climate models to create scenarios for regional climate change associated with global warming. For example, the maps in Figure 7.1 (Plate 4) illustrate the coarseness of the grid used to run many of the models.

Regional scenarios have been simulated using "nested" models where a model more sensitive to regional topography and climatology is run in conjunction with a GCM.

For example, the RegCM model, a nested regional climate model, was used in conjunction with the National Center for Atmospheric Research's Community Climate Model (a GCM) to produce scenarios for temperature and precipitation changes under a doubling of CO_2 scenario for midwestern and western United States (Giorgi *et al.* 1998).

Figures 7.2 and 7.3 show the model's simulation of temperature and precipitation changes (compared with the model's simulation of current conditions) for winter and summer conditions.

The model suggests for the Southwest, a decrease in winter monthly and in summer precipitation. Average temperatures are projected to rise up to 4°C (7°F).

Thus, a plausible scenario for how global warming might affect the climate of Arizona and New Mexico would include:

- An increase in annual average temperature of 5-7°F.
- More extremely hot days and fewer cold

days.

- A decrease in winter precipitation.
- A decrease in summer precipitation.
- A decrease in the daily temperature range (due to higher average nighttime temperatures).

However, there are many critical uncertainties and unknowns:

- The magnitude of precipitation change is still very uncertain because current models not accurately simulate the complex topography of the Southwest or the summer monsoons.
- The changes in the frequency and intensity of extreme events such as storms are very uncertain. There are some indications that storms will be more intense in summer.
- We do not know what will happen to El Niño in a warmer world.
- Paleoclimatic studies tell us that the climate and ocean circulation sometimes changes suddenly and this possibility is not included in the models.
- We do not know if trends in human activity and policies will increase or decrease the emissions of greenhouse gases.

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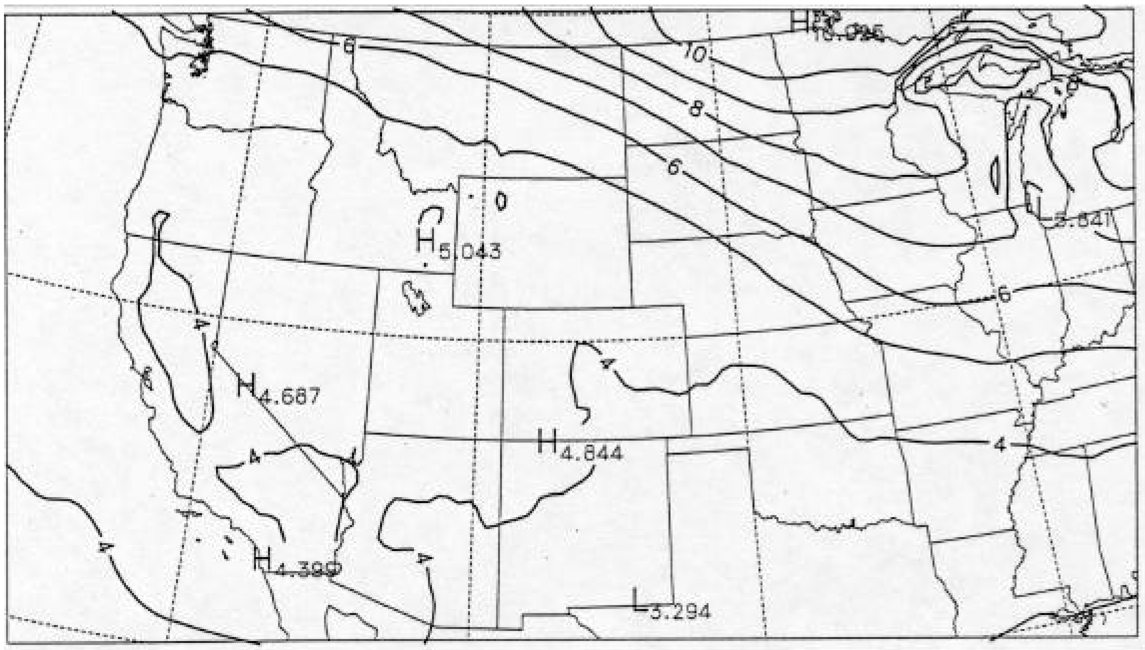
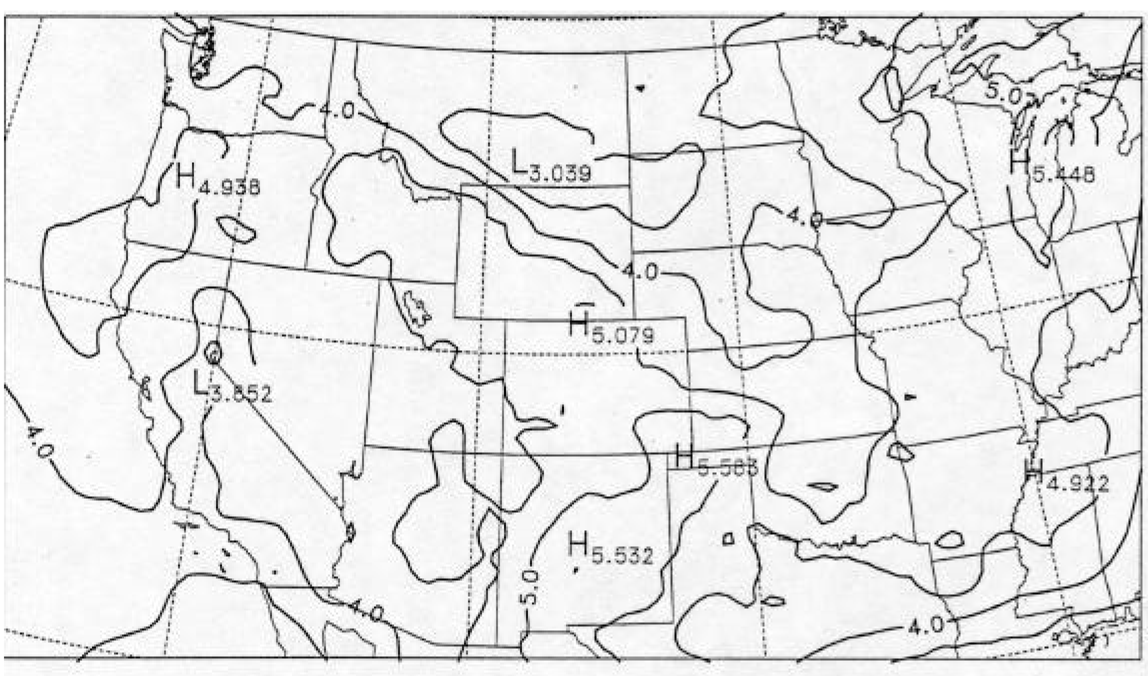


Figure 7.2 Results of the National Center for Atmospheric Research's RegCM nested regional climate model showing simulated changes in temperature ($2xCO_2$ vs. present-day conditions) for winter (*above*) and summer (*below*) in the Southwest (from Giorgi et al. 1998)



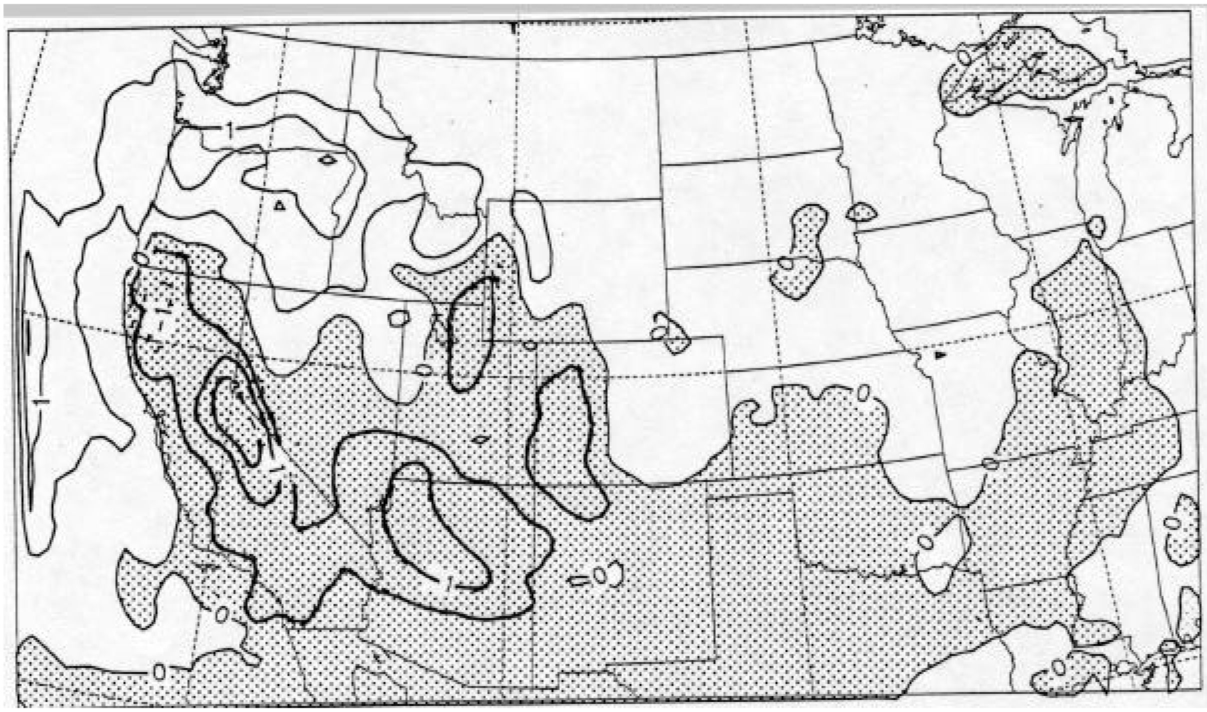
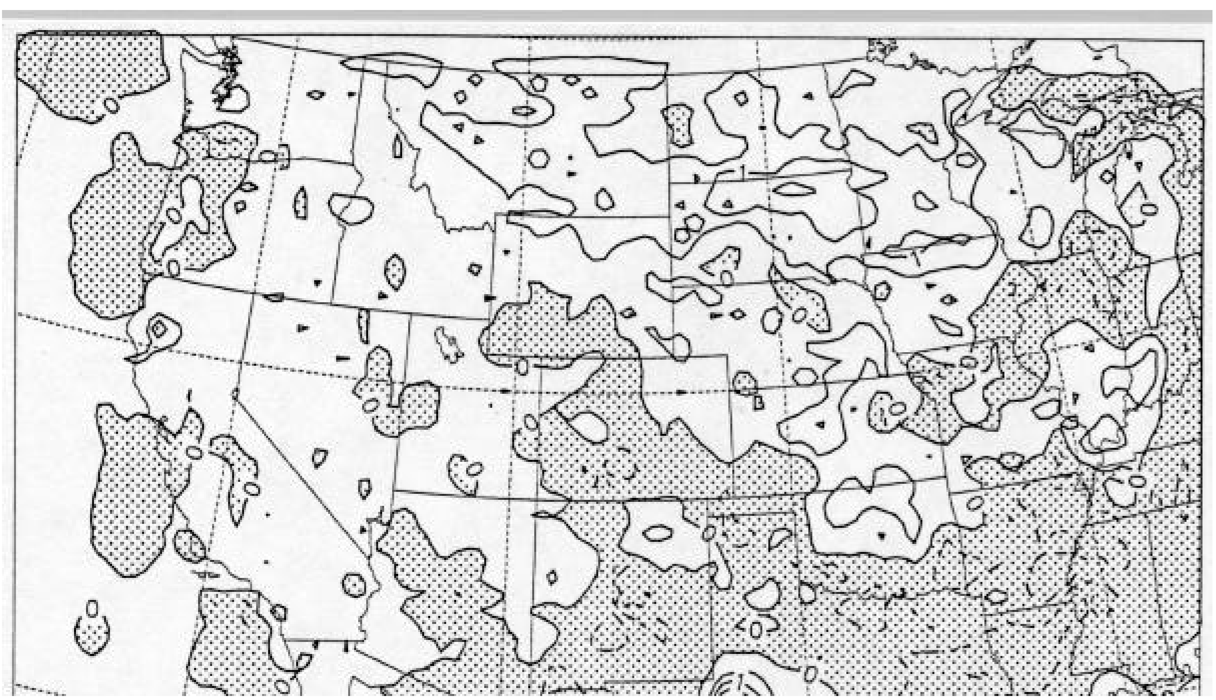


Figure 7.3 Results of the National Center for Atmospheric Research's RegCM nested regional climate model showing simulated changes in precipitation ($2xCO_2$ vs. present-day conditions) for winter (*above*) and summer (*below*) in the Southwest (from Giorgi et al. 1998)



CHAPTER 8
PANEL PRESENTATIONS

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Following the plenary presentations, a series of speakers provided statements and comments related to six sectors: municipal water, natural ecosystems, ranching and agriculture, environmental quality and health, energy production and use, and the U.S.-Mexico border region and Indian Country. Summaries of these panel presentations are provided below.

Panel 1: Municipal Water

Thomas Maddock III, Department of Hydrology & Water Resources, The University of Arizona (Moderator)

Dallas Reigle, Salt River Project, Phoenix, AZ.

Climate variability affects reservoir operations through increases or decreases in supply. Since records have been kept, there have been more years of below-normal flow than of above-normal flow. This affects both delivery of water as well as power production.

The Salt River Project (SRP) experience is that dry periods tend to last about five years. Municipal water supplies need to be augmented during those periods with groundwater. Looking at the period from 1941 to 1966, there was no excess water available for urban demand. More recently, in 1997, water supplies were also below normal.

Katherine Jacobs, Arizona Department of Water Resources, Tucson, AZ.

There is a need in the Tucson area to eliminate groundwater overdraft, but population (demand) is increasing. One of the goals of the Arizona Department of Water Resources is to balance supply and demand. Water from the Central Arizona Project (surface water diverted from the Colorado River) was intended to be a primary water source for Tucson and to meet demand and offset overusage of groundwater resources.

Despite the rejection of this source of surface-water supply by the voters of Tucson, there is still a need to increase use of renewable water supplies and decrease use of non-renewable supplies. California places a much higher priority on Colorado River water than does Arizona. Water shortages are expected to occur 35 percent of the time in the future.

Water banks, for example, can be established to take advantage of periods of abundance. We need to get away from policies that force society to use renewable water.

Scott Chaplin, Rocky Mountain Institute, Snowmass, CO.

Government regulations and economic and population concerns are identified by water managers as key issues, but climate change is not. The old way of dealing with uncertainty was to build dams and canals.

Now decentralized solutions such as recharge, contour plowing, sewer mining, dry wells, rainwater collection, xeriscaping and closed-loop systems are being implemented to reduce water consumption. Water use is decreasing in all sectors except for the urban sector.

Arthur Flagg, Rio Rico Properties, Rio Rico, AZ.

Dependable water supplies are very important to developers, and climate change is a wildcard. Developers face two options: to build or not to build, and this is often determined by the availability of water supplies.

Charles McHugh, Arizona Disaster Management, Phoenix, AZ.

Floods are the most damaging and most costly hazards. In 1993, flooding caused $200 million in damages. What can be done to mitigate this problem? There is a need for non-structural solutions to reduce floods, such as through zoning codes and through providing information about climate trends, population demand for water supplies, and flooding potential.

Panel 2: Natural Ecosystems

David Goodrich, USDA Agricultural Research Service, Tucson, AZ (Moderator).

Julio Betancourt, Desert Research Laboratory, U.S. Geological Survey, Tucson, AZ.

Winter precipitation in Tucson and Las Cruces, NM, is highly variable. The 1940s and 1980s were very wet, but the 1950s saw one of the worst droughts in the recorded history of the region. Large vegetation recruitment events occur in post-drought periods, as do increases in cattle.

Do improved ranges result from management practices or climate variability? The introduction of non-native grass species has led to an increase in fire frequency. If a 1950s-type drought were to occur in the Southwest today, water shortage would halt urban growth, immigration from northern Mexico would increase, and cattle grazing would require public subsidies.

Richard Young, The Nature Conservancy, Tucson, AZ

The primary goal of The Nature Conservancy is to protect and to preserve all plant and animal species. But The Nature Conservancy relies on information from the scientific community to help formulate its policies. Information from scientists is used to develop preservation strategies, adapt management plans, and conduct daily business. But cultural practices such as fire, intervention with the hydrologic cycle, and livestock grazing also alter habitat. Climate variability has important implications for The Nature Conservancy because it is not site specific. Increase in climate variability leads to an increase in habitat loss.

Presently, The Nature Conservancy does not consider climate change a factor. Clearly The Nature Conservancy needs to incorporate climate change into management plans.

Laura Huenneke, Department of Biology, New Mexico State University, Las Cruces, NM.

What are the climatic influences in the desert and semi-deserts of the Southwest? The ecosystem of the Southwest provides many services and assists in such sectors as ranching, tourism, and recreation and the reduction of dust transportation and soil erosion. The few riparian areas in the Southwest are critical for maintaining biodiversity.

Desert organisms represent extremes in adaptation. Organisms that rely on reserves exhibit ephemeral behavior. Growth and productivity of organisms are linked to precipitation and to nutrient availability.

Carbon dioxide increases lead to more efficient water use in plants, but increases in temperature associated with a rise in CO_2 could lead to plant reduction. Other potential climate-change relationships include increases in rainfall that will lead to a decrease in ant and rodent population.

Plant productivity is tracked by animal populations with a 1-2 year time lag. Some climatic effects are hard to predict. Researchers do not fully understand the interactions among these relationships. Sampling in the desert is difficult because of climatic variability. Researchers need long-term data.

Panel 3: Ranching and Agriculture

Kirk Emerson, Udall Center for Studies in Public Policy, The University of Arizona, Tucson, AZ (Moderator).
Jerry Holechek, Department of Animal and Range Sciences, New Mexico State University, Las Cruces, NM.

How can we manage stocking rates to achieve range-resource goals? Survival in the ranching industry relies on managing risk. There are four types of risk faced by ranchers: climatic, financial, political, and biological. By examining climate record in New Mexico it becomes evident that there are distinct patterns concerning climatic risk or climate change.

Drought in the Southwest is somewhat predictable and clustered, and climate alternates between wet and dry periods about every 20 years. Drought and low cattle prices coincide. The last 20 years have been 27 percent wetter than normal.

To facilitate continuing cattle production, plant residue is the key. Ranchers need to leave two-thirds of the plants and grass on their lands to ensure reproduction. Grazing management greatly impacts vegetation cover and soil erosion.

Grazed areas tend to be healthier than ungrazed areas if managed properly in drought conditions.

Diana Hadley, Arizona State Museum, The University of Arizona, Tucson, AZ.

Since the late 1800s, there have been five periods of drought in the US Southwest, 1885-1902, 1918-1922, 1933-34, 1955-60 and 1975-77. During the first three drought periods, public land laws encouraging overstocking of cattle led to negative impacts on the environment.

In the first half of the century there were no guidelines for sustainability and prescribed stocking rates. Moreover, the national cattle market at the time was based on quantity, not quality. The responses to drought since the 1950s have been to feed cattle native vegetation, yet cattle number still continued to rise. By 1990 there was a massive sell-off as ranchers began to recognize the impacts of grazing practices on the land.

Terry Wheeler, Rancher, Globe, AZ.

In the Southwest, proper management of grazing lands can moderate the impacts of climate change. Current policy and technological fixes have resulted in negative impacts on the land such as soil erosion.

We have traded natural processes for technological ones. We need to recognize that technology is not a replacement for nature. In Arizona the use of cattle to reclaim mine tailing has proven successful.

Through seeding of tailings and management of proper grazing levels, ranchers had been able to convert a once ugly tailing pile into a productive pasture for cattle production. Appropriately managed livestock grazing can promote ecosystem health and diversity.

Panel 4: Environmental Quality and Health

Timothy Finan, Bureau of Applied Research in Anthropology, The University of Arizona, Tucson, AZ (Moderator).

Andrew Comrie, Department of Geography and Regional Development, The University of Arizona, Tucson, AZ.

Air-quality trends have improved since the 1980s due to 1970 environmental legislation and the advent of catalytic converters in most vehicles. But the Southwest population is growing fast, which could impact air quality.

Little research has been done on Southwest air quality and the potential impacts of climate change, although we know hotter, drier, and less windy climates are bad for air pollution. Southwestern cities tend to have similar structures and thus, generalizations about air quality can be made.

The major pollutants impacting the air quality of the southwest are carbon monoxide (CO), ozone (O_3), and particulate matter. With respect to CO, cars are the main source for pollution. For example, in the Southwest, we average 1.5 times gas use per capita than New York City.

The impacts of increased CO emissions will be felt at a more localized scale, such as at road intersections, and tend to be winter problems, with inversions being more common. Strategies for abatement include mandating emission checks, using oxygenated fuels, requiring people to drive less and altering traffic patterns to reduce the amount of time that cars spend idling.

Ground-level ozone results from NO_x and hydrocarbons reacting with sunlight. Again, vehicles are the primary source for these chemicals. Ozone, however, is a summer problem and tends to affect the outskirts of town.

In the next 50 years, urbanization, particularly along the Phoenix-Tucson corridor, may lead to serious O_3 problems. Abatement strategies are the same as those for CO. Lastly, particulate matter such as dust and soot tends to be a year-round problem.

Technological fixes for reducing pollution have more or less run their course, so we need to modify behavior. For example, car maintenance is important as older or badly-tuned recent model cars can produce 10 times the amount of CO than new cars.

Several southwestern cities are near non-compliance levels for air quality, which could result in a reduction of federal-highway dollars for the Southwest. While population has grown in the Southwest, air quality has remained relatively constant on a per capita basis. However, climate change may disrupt this relationship.

John Balbus, George Washington University, Washington, DC.

Climate change impacts on human health will not be homogeneous in the Southwest. Rather, human-health impacts are more closely associated with climate variability. Extreme climatic events are more important in regulating the occurrence of climate-related diseases.

For example, the mosquito transmitting dengue fever (*Aedes aegypti*) was found in Tucson in 1994, a particularly hot summer. But climate alone is not the only factor in the spread of such diseases. Other key drivers include breeding sites, population density, and vector-control programs.

Climate change may impact the spread of vector-borne diseases. For example, increase in temperature leads to decrease in mosquito and virus breeding time and an increase in biting frequency. But an increase in temperature in the Southwest may limit mosquitoes. Hanta virus is spread by the inhalation of aerosol rodent fecal material.

In 1993, there was a boom in rodent population and an increase in human contact. Unusually high precipitation levels and more contact with wilderness may lead to an increase in hanta virus outbreak.

Ozone also impacts human health. Los Angeles has the highest photochemical smog levels in the nation. Climate change will affect reaction rate between NO_2 and hydrocarbons that produce 0_3. An increase in temperature leads to an increase in reaction rate. Health effects stemming from 0_3 include increase in pulmonary irritants and increase in sensitivity to allergens.

Paulette Middleton, Science and Policy Associates, Boulder, CO.

The primary sources of air pollution in the Southwest are from fossil-fuel activities such as operating cars and burning coal to produce electricity. We have learned from the Grand Canyon Visibility Transport Commission that socioeconomic and environmental factors are highly integrated.

Management plans aimed at improving air quality will require technological fixes and behavior modification. Such plans should be based on a 20 to 30-year critical planning time frame. Communication is the key between the researcher and the public, and must be a two-way discussion.

Converting issues into dollar values will help the public relate to air-quality problems. If we can assign dollar values to problems and issues, they will be more readily entered into a geographic information system (GIS) for analysis.

Panel 5: Energy Production and Use

Roger Bales, Institute for the Study of Planet Earth, The University of Arizona, Tucson, AZ (Moderator).

C.V. Mathai, Arizona Public Service Company, Phoenix, AZ.

What is the connection bewteen international negotiations, climate change, and utilities? The Rio Summit in 1992 provided no indication of what CO_2 level we should aim for. The debate over whether developed and less-developed countries should differentiate responsibilities for reducing carbon emission has been ongoing since 1992.

While the developed countries were to adopt measures aimed at returning greenhouse gases (GHG) to 1990 levels, the final document from the Rio Summit had no teeth. The Berlin mandate (1995) recognized this shortcoming of the Rio Summit and called for a joint implementation for emission reduction.

Put simply, a country can reduce emission from a multinational plant in another country and apply the reduction to home-country figures. However, the Berlin mandate did not include lesser-developed countries.

The Intergovernmental Panel on Climate Change's (IPCC) second assessment (December 1995) recognized that human actions influence climate and called for a legally binding agreement among all countries.

In addition to the IPCC's proposal, there were several other proposal presented including AOSIS--20 percent reduction in greenhouse-gas emission below 1990 levels by 2005; European Union--15 percent reduction by 2010; and Australia--30 to 40 percent reduction.

The U.S. did not support these proposals because due to concerns over less-developed countries' emission reduction. The U.S. wanted maximum flexibility to achieve reduction (i.e. market mechanisms).

Calculations by economists determined pollution permits would cost $100 per ton of greenhouse-gas. Other analyses such as the IAT analysis said reduction in greenhouse-gases to 1990 levels would increase the price of energy accordingly 2¢ per kilowatt hour, $0.26 per gallon of gas, and $1.49 per thousand cubic feet of natural gas.

Prabhu Dayal, Tucson Electric Power Company, Tucson, AZ.

In the U.S. 1.6 billion tons of greenhouse gases are emitted annually, with CO_2 accounting for 80 percent and methane for 11 percent. The sectors contributing the largest amounts of greenhouse-gas emissions were industries (34 percent) and transportation (32 percent).

Policies geared toward reducing emission affect the industrial sector more than the transportation sector. At Tucson Electric Power (TEP), electricity generation is 99 percent coal fired, translating into a release of 15 million tons of CO_2 in 1995.

As demand for energy increases, this rate is growing by two to three percent per year. In an effort to reduce CO_2 emissions, TEP belongs to EPA's Climate Challenge Program. Components of this program include supply-side management, which is looking at the Los Reales landfill to use methane emission to generate electricity (EPA landfill methane program) and the use of solar panels at the old IBM site. TEP is also actively involved in international programs for carbon sequestration.

For example, Nations Energy in Florida (a TEP subsidiary) is involved in a biogas program in Honduras to produce 30 Megawatts/year. This has already resulted in a reduction of 125,000 tons of CO_2 per year.

Other programs TEP is involved with include the Utility Forest Carbon Management Program in Malaysia, Belize, Oregon, and Mississippi.

Michael Stenburg, U.S. Environmental Protection Agency-Region 9, San Francisco, CA.

Too often we become involved with the large picture and fail to focus on small picture or individual scale. Take the examples of the motor vehicle and lightbulbs. Behavior modification is necessary if we are to reduction energy consumption.

As concerned citizens we can reduce energy consumption by using public transportation, bundling trips, not buying sports-utility vehicles, and changing driving habits. As consumers we can purchase “green” lightbulbs, such as fluorescent rather than incandescent, and look for appliances with the EPA energy star recognition. We can also look for homes that are part of the U.S. green builders program.

Panel 6: U.S.-Mexico Border Region and Indian Country

Robert Varady, Udall Center for Studies in Public Policy, The University of Arizona, Tucson, AZ (Moderator).

James Enote, Director, Zuni Conservation Project, Zuni, NM.

Indian people in the Southwest have been dealing with floods and drought for thousands of years. The belief system of the Indian culture is still very important to tribes. Mainstream policies concerning climate change do not account for tribal belief systems. A simple look at differences in fiscal and political structures between the two cultures illustrates this point.

While tribal governments are starting to establish water and air quality standards, non-scientific and empirical observation for hundreds of generations of Indians needs to be tapped to strengthen policies. The adaptability of tribes to changing climate is the key to their successful longevity. Different ways of viewing the world through different knowledge sets is manifested in our landscapes. For example, most tribal lands have a greater biodiversity than public and private lands.

John Bernal, U.S. Commissioner, International Boundary & Water Commission, El Paso, TX.

Policymakers need to increase public awareness of climate-change issues and increase public involvement in decisionmaking. Take for example the allocation of water between the U.S. and Mexico. Policymakers need to be conscious of different political systems and economic potential between the two nations.

The Rio Grande's five-year drought has lead to low reservoir levels. February and March of 1997 were very wet months and people began to relax concern over reservoir levels, thinking the worst was over.

However, we cannot lose sight of the larger, long-term picture. In times of plenty, we tend to expand agriculture land and pay for it in time of scarcity. In Mexico, water use is less efficient than in the U.S. The watershed needs to be the unit of analysis rather than that defined by political boundaries. We need to share information between these two political entities.

Roberto Sánchez, Department of Environmental Studies, University of California, Santa Cruz, CA.

Perspectives on climate change are vastly different on each side of the border. Different social, economic, political, and environmental conditions lead to different vulnerability. For example, flooding in San Diego and Tijuana in 1993 lead to very different responses.

Attention to the impacts of climate change and variability tends to focus on short-term consequences. Dollars are the measure of damage in the U.S., which is not necessarily an appropriate measure in Mexico. There is difficulty in measuring social impacts, especially in Mexico where it is difficult to place a dollar value on everything. Clearly there is a need for cooperation between the U.S. and Mexico, and between scientists and end-users. Forecasts and information need to be such that they can be used by the end user. Decisionmakers need to work toward a long-term perspective of regional impact of climate change.

Victor Magaña, Centro de Estudios de la Atmosfera, Universidad Nacional Autonoma de México, México D.F.

Climate researchers in Mexico and the U.S. face common meteorological problems. Climate models show a lack of disagreement over the impacts of climate change. Current models such as NCAR's CCM3 don't adequately predict changes in temperature and precipitation.

However, we can however examine El Niño/La Niña trends for some answers. El Niño leads to increases in precipitation in the winter and decreases in the summer and warmer temperatures, while La Niña leads to more year-round precipitation and cooler temperatures. Climate variability forecasts impact the management of reservoir levels.

PART III

WORKSHOP: SECTORAL ISSUES

SEPTEMBER 4, 1997

CHAPTER 9
MUNICIPAL AND INDUSTRIAL WATER RESOURCES

Workshop report prepared by:

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The University of Arizona
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Impacts and Vulnerabilities

The water resources in the Southwest are sensitive to:

- a shift in average precipitation
- changes in the year-to-year variance in precipitation
- the magnitude and persistence of seasonal fluctuations in precipitation amount and timing
- the frequency and intensity of extreme storms

Surface-water supplies are particularly vulnerable to climate variability and change, both in timing and amount. Because of relatively short reservoir-storage times for surface water before it is used for municipal and industrial supply, below-average flows of even a few years in length would have an impact. In periods with reduced availability of water, there would be increased competition with other sectors (e.g. in-stream uses, agriculture) for the available flow.

Fluctuations in precipitation have impacts at both seasonal and interannual time scales. Most of the annual runoff is from winter precipitation, and year-to-year fluctuations in seasonal snow accumulation translate directly into water-resource availability for municipal use. The intensity of rain in summer storms has direct impacts through flooding and erosion, while year-to-year fluctuations in the net seasonal input of precipitation as rain impact the well-being of agriculture and ecosystems.

Perhaps the climate fluctuation of greatest concern for the region is when less-than-average seasonal precipitation is sustained over several years.

Spring runoff from snowmelt also provides most of the groundwater recharge for the region. Though most groundwater supplies are less susceptible to climate variability than are surface waters, long-term reductions in groundwater reserves would have several impacts on the region.

Higher temperatures in the Southwest associated with climate change would increase water demand and thus, increase pressure for greater groundwater withdrawals over the long term.

Greater climate variability could have a similar effect, as greater withdrawals in dry years would probably not be offset by greater recharge in wet years, even if facilities were constructed to enhance recharge in wet years.

Some of the direct impacts from greater groundwater overdraft in the Southwest would be land subsidence, higher costs associated with deeper wells, and decreasing water quality in some areas as deeper waters are extracted.

Mitigation of groundwater overdraft could result in water shortages for some users, and secondary impacts.
These impacts could include:

- costs by business, industry, and other urban users to either make a transition to use less water or to pay more for water;
- loss of water by lower-priority users, such as some landscape irrigation or ornamental lakes, or alternatively, costs to switch to reclaimed water use (if available);
- limits on new development in areas that face the most severe shortages.

A shift to greater reliance on groundwater versus surface-water supplies would also mean that some municipal and industrial systems would lose some of their current flexibility and have more constrained and vulnerable systems.

Responses

Many areas of the Southwest already experience groundwater overdraft, competition between sectors for limited supplies, and fluctuations in the availability of surface water supplies. Thus the municipal and industrial water sector is already familiar with a number of possible responses to reduced supplies of and increased demand for water.

In general, there are two categories of responses: increase supplies or reduce demand.

The transfer of water from agricultural use to municipal and industrial use is a current trend in the Southwest that is expected to continue. Urban users are generally willing to pay more for water and land than are agricultural users.

Interregional transport of surface water is an important component of water supply for the Southwest and could increase in the future.

However, water from the Colorado River and Rio Grande is completely allocated, and there are substantial economic and political barriers to transporting water from more distant sources.

Desalination could be used to augment fresh-water supplies, especially if new technology can help lower costs. At present it is not economically feasible in comparison to other means of augmenting municipal and industrial supplies.

Optimal use of existing water supplies of differing quality, e.g. delivery of non-potable supplies such as reclaimed water for some users, should also be examined.

Demand management could relieve some of the pressure on water resources that would occur with a warmer or more variable climate. Voluntary or mandatory conservation, water rationing, limits on new development, and market forces could all be used to reduce demand for water.

Allowing market forces to set water prices and pricing water at least at its full cost could result in a reduction in demand, or could drive further shifts in water from agricultural to municipal and industrial users (water rights and political and local economic considerations notwithstanding).

However, instituting full-cost pricing would have greater economic impacts on some areas and sectors than on others, particularly for low-income domestic users. And for some privately-owned water systems--such as those in Arizona where price increases must be approved by the Corporation Commission--such increases may be difficult to obtain if conservation is not considered a justifiable basis for increasing the water rates.

Research and Information Needs

There is a demand for additional climate information in the municipal and industrial water sector in the Southwest, which generally has scientists and engineers who already use existing information.

First, operators of surface-water supplies would like seasonal (winter) precipitation forecasts 6-18 months in advance in order to manage storage systems, and in some cases to make commitments for water to municipal and industrial rather than to agricultural users.

These forecasts should include both local source areas and source areas for imported supplies, for example, the entire Colorado River basin. The forecasts should also provide estimates of uncertainties.

Second, these same operators need better information on how different components of the hydrologic cycle will respond to interannual and long-term changes in precipitation. That is, given a forecast of seasonal precipitation, what is the expected amount and timing of runoff, evaporation, and recharge during the weeks and months that follow. Better-integrated modeling tools are needed to provide this information.

Planners in the municipal and industrial water sector need estimates of how climate variability and change could stress the capacities of supply systems and influence water demand. This includes:

- multi-year scenarios of increased or decreased precipitation, runoff, recharge, and demand
- possible changes to major supplies that originate outside the region

Estimates of uncertainties are needed to develop appropriate ranges of water supply and demand scenarios. Political factors, e.g., possible changes in water allocations, should be included as well.

Policy Issues

Water policy in the Southwest is becoming increasingly driven by the need to secure reliable long-term water supplies in the face of dwindling groundwater reserves, over-committed surface-water supplies, and rapidly expanding demand due to population growth.

In the face of these pressures, a combination of regulatory control, supply enhancement, and market forces--mentioned above as possible categories of responses--will be needed to maintain the balance between supply and demand. Using market forces to help determine water allocations and pricing would be a major policy shift for the region.

In addition, there is a need for explicit, ongoing support from government and political leaders--within all states of the Southwest and particularly within the Colorado River basin--to gather, analyze, and share information needed to address the policy issues articulated.

For additional discussions on this topic, see the presentations for Panel 1: Municipal Water, in Chapter 8.

CHAPTER 10
URBANIZATION AND ENERGY USE

Workshop report prepared by:

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PART I: URBANIZATION

Impacts and Vulnerabilities

The urban sector with high population densities is significantly at risk to first-order impacts. These are differentiated from second-order impacts as follows:

- First-order impacts: those caused directly and immediately by climate and weather variability. Flood damage to private property and public infrastructure is an example.

- Second-order impacts: those indirectly related, but attributed to, climate variability. For example, a decision to rebuild damaged property at some other location, to move from the area or region, or to replace infrastructure with different facilities would all be second-order impacts.

The highest first-order impact to urban areas is loss of life and property to extreme weather events. These include flooding, wind damage, and power outages. The highest second-order impacts are increased fire danger from succession vegetation (likely more highly flammable grasses), changes to sustained freshwater availability, and the public costs of coping strategies.

More difficult to quantify but extremely important to the sustained vitality of southwestern urban areas would be any long-term changes in climate. Improved models and predictive capabilities for this region would be extremely valuable.

For example, warmer temperatures could render the region a less desirable place to live, resulting in less immigration and thus less development. Intraregional shifts of population from rural to urban areas could exacerbate increasing risks within the urban sector. These could combine as a secondary impact in the demand for urban infrastructure, services, tax and bond structure, and (for better or worse) the problem of rapid growth.

Sustained growth rates have created a dependency--common in many communities in the Southwest--on growth-related income to support current public needs. Thus, urbanization patterns driven by climate change, even across regions of the country, become extremely important to communities in this region.

Tourism is a major income source for many southwestern communities. Shorter cool periods and longer hot periods could diminish the number of winter visitors and the length of their stays. Intraregional shifts in destinations for seasonal visitors would move the benefits and costs of climate change among tourism sectors.

Any increase in snowfall, for instance, would benefit the ski industry that is particularly vulnerable to snow-season precipitation. However, monsoon-season (late summer) precipitation with increased storm severity would make the water-sports sector more hazardous.

With regard to the potential change in hazards in general, the insurance industry would have a unique interest in shifting climatic patterns.

The Southwest is particularly vulnerable to energy costs with high summer usage for the lower elevations and higher elevations experiencing higher demand in the winter. Much of this energy is imported or fossil-derived and therefore subject to carbon taxes or other national and international mitigative strategies.

Water is precious in the Southwest. The increasing demands of urbanization for water outpace declining agricultural uses and have engendered a significant demand on the Colorado River watershed in addition to local groundwater resources. As groundwater resources are depleted, the strong hydrogeologic coupling of the Southwest has led to extraordinary surface subsidence for some areas. Long-term climatic effects on the timing, rate, duration, and total amount of precipitation could bring significant impacts.

The Southwest is a net importer of food. Although some specialty crops are produced for within-state markets, most of the agricultural production is exported. A distinct (second-order and interregional-impact) vulnerability exists to changes in agricultural productivity elsewhere. This climatic-driven factor couples with an increasing global population and demand for food to amplify the risk.

Responses and Opportunities

Higher energy and water costs could spur more resource-efficient construction of both public infrastructure and private development. For example, the fledgling solar industry and other resource-concerned sectors of the Southwest could find significant opportunity in a changing climatic era. The solar resources of the Southwest are enormous and, if not diminished by increased cloud cover from climate changes, would become a distinct and pronounced asset. Water- conservation systems, devices, practices, and policies could provide a major response to change and rapidly expand this emergent industry.

The ability of the technologically rich Southwest to provide assistance and products to other arid lands--as well as to other areas that might experience greater variability in climate-- should not be underestimated.

Research and Information Needs

The risks to extreme weather events and long-term (decadal) regional climatic change are two distinct research categories. Both are critical for intelligent responses to global change.

- A frequency, magnitude, and location envelope for storm events would better facilitate local preparedness.

- The economic readjustments necessary to accommodate long-term change would benefit from improved long-term climatic predictability.

- A third research need is for better communication tools with which to inform concerned citizens, city councils, county commissioners, regional, and state officials. The science community communicates poorly with those who will bear the impacts of a changing climate and at present knows more about climate change than how to communicate this knowledge.

Policy Issues

The entire policy structure affecting resource allocation, usage, pricing, and research needs serious scrutiny. Collaborations between the academic and local government sectors are essential to the region's integrated policy response. This would have to fit with new national policies--indeed, in some cases, become a driving force.
Policies regarding disaster-response activities, authority, and financing require thorough investigation. Water policy, already a confusing

and contested area, also requires serious attention. Improved long-term precipitation models could even become a driving force for unity with regard to water policy.

Cross-sectoral and interregional relationships and impacts will raise many unexpected policy shortfalls. An appropriate policy response, sufficiently broad to address all resources and stakeholders, will be essential to the sustainability of the Southwest.

PART II: ENERGY USE

Impacts and Vulnerabilities

The energy sector in the Southwest is vulnerable to changes in temperature from climate change and increased climate variability. An increase in temperature clearly would increase electricity and fuel demands in summer. However, there could be some associated decrease in winter.

The sector is also vulnerable to changes in energy prices resulting from climate variability and change. For example, reduced river flows in some areas would result in less hydropower generation and shifts to higher-priced options.

Increased fossil-fuel use could have direct impacts on atmospheric acidity, and hence on the acid content of precipitation, which would impact vulnerable ecosystems. There would also be a direct impact on urban air quality, and consequently on public health.

International actions to curb fossil-fuel use that resulted in higher fuel costs would also impact the region.

Responses

Market pricing of electricity and pricing energy at its full cost, including externalities, is expected to result in more efficient energy use and help offset increased demand. Higher prices could then help drive innovation and creative responses in the industry, including conservation measures.

Research and Information Needs

There is a demand for more and better climate information in the energy sector, which generally has scientists and engineers who already use existing information. Temperature scenarios are of interest to planners, especially in estimating peak demands for electricity. Better estimates of how demand will respond to climate change are needed as well.

Policy Issues

Full-cost market pricing is an important policy issue that should be addressed by the energy sector. The impact of deregulation in the electricity sector should also be considered.

For additional discussions on this topic, see the presentations for Panel 5: Energy Production and Use, in Chapter 8.

CHAPTER 11
NATURAL ENVIRONMENT

Workshop report prepared by:

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Denver, CO

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Ecosystems, hydrological systems, and the land surface respond directly to many aspects of climatic variations and climate change and thus may provide "early warnings" of the consequences of such fluctuations.

Historical records and geologic studies indicate that the landscapes and ecosystems of the Southwest have continually changed in response to climatic variations over time-spans from decades to tens-of-thousands of years.

Large changes in the landscape may be expected in the future as ongoing climate change interacts with human use of the land and natural resources. Society in the Southwest will have to adapt to changes in the availability of water and other resources, and to transformations of the appearance and composition of ecosystems.

The native vegetation and wildlife of the Southwest are central to the "sense of place" that people feel in regard to this region, and ecosystem changes may alter this perception.

Impacts and Vulnerability

The assessment of the impacts and vulnerabilities of the southwestern environment is based on the perceptions, beliefs, and values of those undertaking the task.

A consensus must be developed on the processes and features that must be maintained in the environment and ecosystems of the Southwest.

Should the lands, the natural processes, or the species and features of the region be preserved? What is more highly valued when preservation of one aspect of the environment conflicts with another or with a societal need?

Although change is a natural part of the southwestern environment, have human activities accelerated the rate of change to an unacceptable degree?

For ecosystems in particular, society must decide how "natural" an ecosystem needs to be. Should ecosystems be maintained in a fashion that maximizes diversity and biomass? Should they be self-maintaining and adaptable? How valued are the roles of natural ecosystems in fire and watershed management, in the maintenance and regeneration of soil, and in the sequestration of carbon?

The rapid population growth of the Southwest will increasingly affect the natural environment of the region and may increase its vulnerability to climatic variations.

In other words, even disregarding the possibility of global warming, climatic fluctuations such as those seen over the past century will have large impacts in the Southwest as the increasing human population demands more water and other resources.

The impacts of climate change in other regions could affect the rate of migration into the Southwest and thus accentuate these impacts.

The environment of the Southwest has changed during the historic period due to agriculture, ranching, other human activities, and due to the invasion of alien species.

Given this backdrop of human-induced change, it is difficult to assess whether on-going ecosystem response to climatic variations exceeds those in the historical record. Human activities, perhaps in concert with historical climatic fluctuations, have caused the regional extinction of wolves, grizzly bears, and other animals.

Land-use and urbanization are closing many of the natural corridors for the movement and migration of wildlife, avenues that may be important for the dispersion of plants and animals in reaction to future climatic variations.

Riparian habitats are of great importance in this regard, both as migration corridors and as habitats for a large number of species. The "sky island" habitats of the Southwest mountain ranges are particularly vulnerable to climatic change, and presently endangered species may face extinction. The reproductive cycles of animal species may be disrupted throughout the Southwest, and changes in selective pressures will impact both plants and animals.

The changes in abundance and geography of species, coupled with regional or total extinction, will change the ecosystems of the Southwest. A measure of the biodiversity of the Southwest has already been lost, and much more may be lost in the future with increasing pressure from human-population growth, habitat loss, and climatic variations.

Desert ecosystems are often dominated by a few plant species, and environmental changes that impact those key species may have wide-ranging impacts on the ecosystems.

Climatic change may accentuate the rate of loss, and alien species may gain competitive edges over native species due to climatic variations.

Climatic fluctuations and changes may also impact agricultural productivity, as variations in the severity of winter freezes and other climatic factors may lead to increases in insect populations and other agricultural "pests."

Human- and climate-induced changes in fire regimes may alter the balance of species and may have impacts on watersheds as well. Water quantity and quality issues will continue to be central to societal concerns about climatic change and land use.

Flooding may increase as soil loss is accentuated by human activities and climatic change, and the withdrawal--and non-replenishment under the current climate--of groundwater for human use not only will affect directly the land surface through subsidence but also will impact water quality.

Soil loss, arroyo-cutting, and other forms of increased erosion will lead to increased sediment loads in the rivers and, consequently, to increased infilling of reservoirs.

The loss of cryptobiotic soils will impact many aspects of the ecosystems, and enhanced surface instability in general may increase dust and visibility problems. The potential loss of the Southwestern "sense of place" may impact recreational opportunities and the associated industries.

The environment of the Southwest will be affected by changes in both the mean climate of the region and by changes in extreme weather events. Small changes may be important for some issues, particularly in ecosystems and erosion processes.

The abruptness of climatic change may also be important, with the same degree of change having a larger effect if it occurs over a short period of time.

Minor changes in climate variability may affect crop yields, both directly and through their effects on pest outbreaks.

Future changes in atmospheric carbon dioxide concentrations will directly affect plant growth and may alter the competitive balance of species within the ecosystems and affect overall primary productivity.

Responses

Responses to climate-induced changes on ecosystems in the Southwest have varied. Many recognize that cattle ranching as currently practiced across most of the Southwest is not sustainable and with recent droughts, ranchers have had to decrease herd size by 80,000 head.

The U.S. Forest Service has acknowledged the importance of fire in maintaining forest health, and has implemented selective anti-fire suppression measures.

Utility companies understand the role that vegetation, such as the saguaro cactus, play in carbon sequestration. Programs such as GLOBE have been designed to educate today's youth on climate change are have been implemented in schools around the Southwest.

Research and Information Needs

Research is required to close gaps in the current understanding of interconnected landscape and ecosystem processes, in how such processes respond to climatic variations, in what the natural ranges and rates of changes that occurred under natural conditions in the Southwest and in how human activities have altered these processes and rates of change.

Models should be developed not necessarily to predict the future, but rather to organize research activities, identify information gaps, and to investigate the interconnections among processes.

Such models can be used in uncertainty analyses and sensitivity tests, and to look for non-linear reactions to climatic changes. These efforts should provide the basis to formulate and test hypotheses about how the Southwest environment will respond to future climatic changes and changes in land use.

Efforts should be made to understand the patterning and rates of change of the Southwest's climate over various time scales, from annual to millennial in length. Does the current range of climatic variability fit into the natural patterning of change, or can we detect a human-induced element of change?
In the area of primary data collection in the natural world, long-term studies should be conducted to understand the connections among biological, climatic, surficial process, and hydrological systems in different environments in the Southwest. Some environments and processes may be sensitive to changes in the mean climate, whereas others may respond to changes in extremes or in variability.

Ecosystem and landscape changes should be closely monitored at a series of long-term protected sites and in a variety of environments. Such plots might be placed on National Park Service or other protected lands.

Special efforts should be devoted to monitoring and understanding the behavior of invasive alien species. These species are currently having large effects on the Southwest's ecosystems. Will they thrive under future climatic conditions and increasingly outcompete native species?

Scientists should develop scenarios of the potential future environmental impacts of climatic change on the Southwest and use these to communicate the issues to the public. Scenario development will also identify gaps in data and in the understanding of processes.

Given the public awareness of El Niño/Southern Oscillation (ENSO) effects on the climate of the region, it could be used as the center of one scenario of possible future climate variation and its consequences.

Regional climate models may provide sufficient structure to permit investigation of potential future climates of the Southwest based on numerical climate models. Such models can be used to explore the potential regional consequences of changing levels of carbon dioxide and other aspects of the global climate system.

Climate models and scenarios should feed into new ecosystem and land-surface models that allow the investigation of the broad-scale impacts of climate change. Sensitivity analysis can then be used to investigate how short-term land-use or political decisions can impact the environment and how small changes in one aspect of the environment influence the rest of the system.

Uncertainty analysis can also be employed to determine if other factors may have caused the observed changes. These studies could then form the basis for communicating the issues and concerns about vulnerabilities to policymakers and to the public.

Improved methods and channels of communication are necessary to direct relevant climatic and environmental data to potential users. Federal, state, and other governmental agencies must improve their intercommunication and foster policies that work across boundaries and borders.

These agencies should seek to build partnerships among themselves, with the private sector, and with the public to increase the regional scope, rationality, and effectiveness of ecosystem and landscape management.

Scientists should participate in this process and should also seek to reach out to the public through increased participation in GLOBE and other programs.

Policy Issues

Political leaders should be involved in the effort to develop a consensus view of what should be preserved in the Southwest's landscapes and ecosystems.

Current regulations place constraints on land managers and often result in conflicting and overlapping mandates. Land-management agencies require policies that give them more flexibility to respond to climate change.

Land-management agencies should utilize scientific data for decisionmaking and should seek to develop common goals and strategies across institutional and geographic boundaries.

Zoning laws, taxes, and other governmental tools should be used to channel growth to preserve corridors for migration and important habitats. A regulatory environment needs to be developed that is aimed at a healthy environment overall, rather than at the maintenance of single species.

The endangered species act mode of a regulation forces agencies to focus on individual species. We need policies that will shift regulatory mandates to a broader scale of species management while including single species as a part of it. Policies should reflect the prioritization of issues and objectives identified by new research.

For additional discussions on this topic, see the presentations for Panel 2: Natural Ecosystems, in Chapter 8.

CHAPTER 12
AGRICULTURE

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Impacts and Vulnerabilities

Of all the uses of water in the Southwest, agriculture is by far the largest user, consuming almost 80 percent of the annual available water. Given this large dependence on water, the agricultural sector in the arid Southwest is particularly vulnerable to climate variability.

Agriculture is heavily dependent on irrigation, as "rainfed" agriculture is limited given the precipitation regimes of the Southwest. Specific crops that are most vulnerable to climate change include cotton, wheat, alfalfa, vegetables, and orchard crops.

Cotton production in the Southwest is the largest agricultural user of water, and while cotton appears to be more tolerant to higher temperatures, the most productive varieties require the most water. Cotton production is declining in the Southwest, in part owing to decreases in national and international prices.

Wheat production on the other hand is gaining momentum, but recent climate-related pest infestations have caused some setbacks and threaten farmers' confidence.

Vegetables such as tomatoes and lettuce are of high value, but require high inputs.

Each crop type requires different irrigation schedules, and deviance from established schedules can be potentially disastrous.

Smaller farms in the Southwest are not flexible in terms of capital, but are able to adapt more readily in the face of increased vulnerability. Organic farmers, however, are more susceptible to the consequences of climate change.

Manifestations of climate change such as mild winters and hot humid summers often impact crops in terms of pest and mold problems. Another indirect impact from climate change is increase soil salinity caused by an increase in evaporation. In general climate-change vulnerability is geographically and problematically diverse.

Responses

The agricultural sector's response to climate variability has been slow and varied. Extensive capital investment in crop-specific farm machinery has many farmers reluctant to change crop types. The flexibility to change crop type is an important factor in decisionmaking. Several farmers for example, have switched from corn to sorghum.

Another response to climate variability by the agricultural sector has been to sell farms and their accompanying water rights to growing cities. (Water rights in the Southwest are tied to land ownership.) In Arizona, the city of Tucson has purchased farmland in nearby Avra Valley while Phoenix has acquired farms as far away as Yuma, several-hundred miles away.

These climate variability-induced water transfers have an indirect impact on the local tax base for governments, as cities are exempt from paying taxes to these local governments. While some farmers believe that too much agricultural land is being lost to residential development, others feel that the trend is passing as the costs of distribution systems are being spread over fewer people.

Research and Information Needs

Increased climate variability is the most difficult aspect of climate change for farmers as it introduces more uncertainty into a farmer's decisionmaking. The planning range for farmers in the Southwest may be a long as ten years.

Adaptation to change is slow and expensive. Farmers require both long term (decadal) and short term (seasonal) forecasts.

Timing and intensity of precipitation, temperature (minimum and maximum), and cloud cover and radiation intensity are critical factors in seasonal planting decisions, while longer-term climatological information is important for selecting crop types.

Stakeholders have identified the following areas in which research and information is required to adapt more effectively to climate variability

- the availability of water for controlled irrigation
- the foreknowledge of pest infestation
- the diurnal temperature range and
- more assistance from Cooperative Extension and outreach services

Scientists, on the other hand, view research on the relationships among CO_2, temperature and water budgets as more urgent.

Policy Issues

The most pressing policy issue identified by stakeholders is that of water management and rights. Stakeholder views vary on whether the existing policies are flexible enough to accommodate climate changes and subsequent impacts.

All agreed however, that urban development on previously agricultural land and the purchase of "water farms" are serious matters. Water policies need to be broadened to consider indirect impacts of climate change such as the erosion of the tax base in rural areas and the economic diversity of the Southwest.

For additional discussions on this topic, see the presentations for Panel 3: Ranching and Agriculture, in Chapter 8.

Chapter 13
Ranching

Workshop report prepared by:

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Impacts and Vulnerabilities

Climate variability impacts the ranching sector primarily through its influence on the amount, seasonal availability, and quality of the forage base. The timing and amount of rainfall are the most important climate factors that impact the ranching sector in the Southwest, with wetter conditions being more beneficial. In most years there is typically a one-to-two-year reserve of forage in the Southwest.

Alternative feeds are usually too expensive for most farmers to use to support all their livestock during drought periods, and when reserve forage is used, most ranchers are forced to reduce the size of their herds.

The recovery, or refilling, of the forage reservoir after a climate-induced decline, will take at least three years under the best of conditions and much longer under worse management conditions.

When ranchers are forced to cull their herds, recovery time--depending on the extent of herd reduction--can take at least five years in the better situations.

In addition to regional climatic conditions, climate variability in the Midwest and Mexico impacts the national and global grain and cattle markets, which in turn affects the ranching sector in the Southwest.

For example, ranchers in Sonora do not have the luxury of reserve forage and during the 1995-96 drought, Mexican ranchers flooded the market with cattle to limit financial losses. This in turn lowered cattle prices in the Southwest.

Responses

The ranching sector in the Southwest typically responds to climate variability in one of two ways. The first way is either a reduction or increase in herd size. For example, Arizona experienced a drought from 1994 to 1996 and the ranching industry responded by reducing herd size from 870,000 to 790,000 head. As the number of cattle sold increased, the number of ranches in business decreased (Figure 9.1).

In addition to reducing herd size, profits fell 15 percent during the same time period. Responses to the drought varied according to ranch size, as larger ranches did not reduce herd size more than usual, while smaller ranches culled herds by 40 to 80 percent. Conversely, climate variability in New Mexico has brought an average of 25 percent more precipitation, which allowed ranchers to increase herd size by more than 100,000 cattle (Figure 9.2).

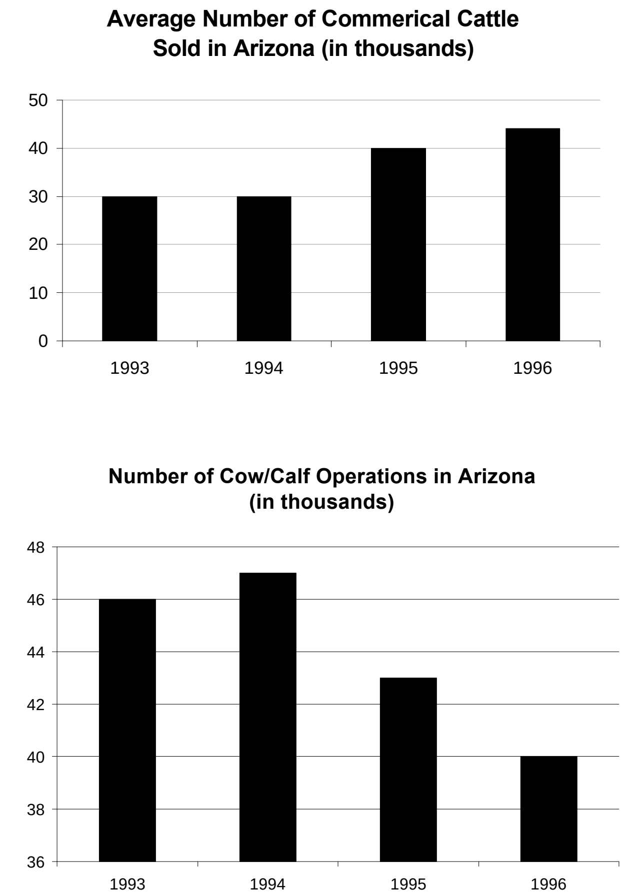

Figure 9.1. Number of Cattle Sold and the Number of Cow/Calf Operations in Arizona 1993-1996 (Eakin and Liverman, 1997)

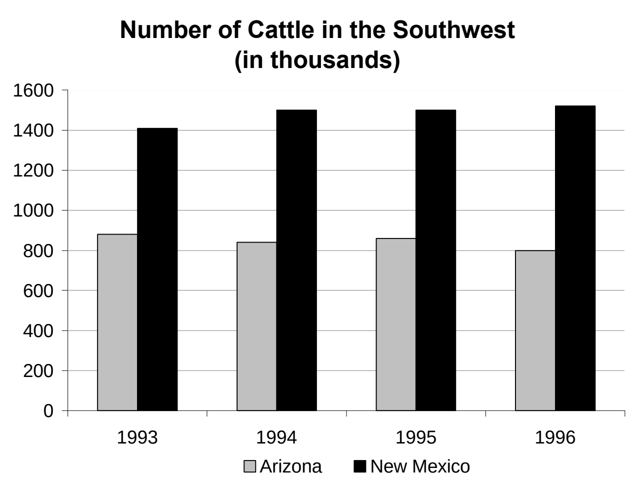

Figure 9.2. Cattle Numbers for Arizona and New Mexico (USDA, 1997)

The second response to climate variability is to change the timing or increase/decease calving and breeding. By offsetting the calving season, ranchers hope to "weather the storm" and wait until more favorable climatic conditions for breeding return.

By reducing calving number, ranchers increase the survival change for the herd. Ranchers in Arizona have steadily reduced the number of calves born since 1993 due to drought conditions, while ranchers in New Mexico have consistently increased calving as precipitation has increased Figure 9. 3).

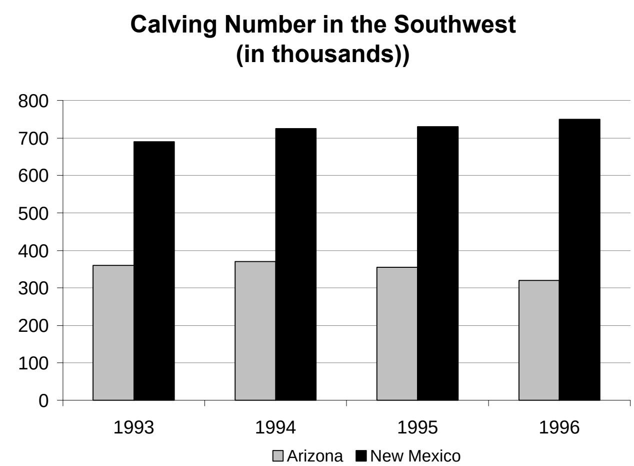

Figure 9.3. Calving Number for Arizona and New Mexico (USDA, 1997)

Research and Information Needs

Ranchers could respond to climatic variability more effectively if longer term (6, 12, and 24 month), more reliable forecasts were available for the Southwest and other regions of relevance, such as the Midwest. With this information ranchers could adopt mitigative strategies to respond to changing forage-reserve levels and market prices.

Research is needed in several areas to:

- describe the sensitivity of forage production and non-forage species to changes in the season and amount of precipitation

- to investigate the role of livestock-management practices before and during drought periods to determine the rate of cattle and the ranching-industry recovery

- create a long-term climate data record from field stations

- undertake a study of the effect of climate variability on pests and disease

- assess diversification as a drought coping strategy

Ranchers also indicate that extension services need to be improved, as there is little or no connection with individuals working at universities. As a result, forecasts are treated with suspicion. Communications between ranchers and scientists and the credibility and reliability of forecasts are key areas influencing individual rancher responses to climate forecasts.

Policy Issues

Constraints on coping with climate variability and change in the ranching sector include:

- livestock prices are determined by factors outside the Southwest

- public land-management agencies and lending institutions can be resistant to providing flexibility in the management of herd sizes in response to climate variability

There exists some concern about the role of government policies in mitigating the potential impacts of climate change. Some argue that government subsidies for feed and water during drought periods have led to an oversupply of cattle, which leaves ranchers even more vulnerable during the next drought period.

While these policies are intended to act as a safety net for the ranching sector, there is growing concern that subsidies and tax incentives reduce the perceived vulnerability associated with climate change and therefore, ranchers do not respond as they might otherwise (i.e., reducing herd sizes).

For additional discussions on this topic, see the presentations for Panel 3: Ranching and Agriculture, in Chapter 8.

PART IV

WORKSHOP: CROSS-CUTTING ISSUES

SEPTEMBER 4, 1997

CHAPTER 14
ENVIRONMENTAL QUALITY AND HEALTH

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Impacts and Vulnerability

Throughout the world, the relationship between water and environmental health has been well-known for centuries.

The harmful effects of water shortages, extreme flooding, contaminated drinking water, and inadequate sewerage are most palpable in developing countries, where both infrastructure and health care are least available. In such environments, water-related ailments include dehydration, water-borne microbial infection, and vector-borne disease.

The consequences of temperature extremes, often in combination with drought or flooding, also seriously affect public health in poor societies.

Chronic gastrointestinitis, cholera, typhoid, malaria, dengue fever, valley fever (coccidiomycosis) and other respiratory diseases, and heat stress are among the most common illnesses attributed to water, sanitation, heat, and wind-borne dust.

What is the likelihood of occurrence and possible severity of certain health problems as a result of climate changes, specifically increases in temperature? Ozone levels, at least transiently, are very likely to increase as a result of higher temperatures. Water-borne diarrheal diseases, specifically hepatitis A, shigella, and salmonella, are current problems of the border area that might exhibit non-linear responses to warmer temperatures if a critical winter killing phase is eliminated by higher temperatures. Cholera is not currently a major concern in the border area, but the proximity to southern Central America makes it worth mentioning.

Not only in developing countries but in economically disadvantaged, resource-poor, or overcrowded areas of relatively wealthy nations, similar conditions can prevail. These areas, already the least stable and most vulnerable to a variety of disruptions, are particularly at risk from changes in the availability and quality of water.

Of course, numerous sociodemographic factors determine water quantity and quality: population change, land-use characteristics, rate of economic development, planning policies, and prevailing politics.

Among physical influences on the stability of water-delivery and water-treatment systems, climate is perhaps the most pervasive. In the short-term, natural disasters, most of them climatic, pose the greatest hazards.

In the long-run, even small changes in temperature and rainfall regimes have the potential to cause serious disruption to these systems, and thus to public health.

Nowhere are the above observations more applicable than in arid and semiarid regions where climatic variability already is high. Social systems in these areas are always stressed because of permanent water shortage.

In the southwestern United States, alternating droughts and floods regularly disrupt communities and affect health. It follows, too, that the Southwest’s most disadvantaged communities are also its most vulnerable to climate variability and change.

Hence, cities, towns, and *colonias* (unplanned urban settlements) on both sides of the U.S.-Mexico border, tribal lands, poor mining communities, and other low-income zones in Arizona and New Mexico are highly prone to climate-induced worsening of health conditions.

And everywhere, especially in inner cities and in distant, outlying rural communities, the elderly and those who cannot afford to pay for heating and cooling are most vulnerable.

Responses

Pressed by the more immediate demands of uneven access to health care, the presence of numerous low-income communities, and the prevalence of other pressing health problems, the public-health community has been slow to acknowledge the potential of climate-change-induced health threats.

Even so, authorities have become increasingly aware of the heightened incidence of certain vector-borne diseases such as dengue fever and hanta virus, and that there may be a connection to increases in these diseases and climate change.

Both of these illnesses are closely associated with temperature and rainfall increase. In response, for example, to limit urban mosquito breeding, authorities in Tucson have mounted a thus-far successful campaign to reduce the presence of stagnant-water pools.

Institutionally, the other notable effort in this domain is the general resolve by the United States and Mexico to improve environmental infrastructure in the at-risk border region (see also the discussion in Chapter 16, "U.S.-Mexico Border").

The Border Environment Cooperation Commission (BECC) and its sibling, the North American Development Bank (NADBank), were established in 1993 primarily to assist border communities in supplying treated drinking water and removing and treating household and industrial waste.

During its three years of operation, BECC, the project-certifying organization, has been mindful of the connection between this type of infrastructure and the status of public health in the communities served. Nonetheless, neither BECC nor NADBank understands or is attuned to the special requirements of responding to climatic variability and change.

Research and Information Needs

Public-health scholars and officials are only slowly beginning to understand the potential impacts of climate change on environmental quality and health.

It is widely accepted that certain socioeconomic groups will be more susceptible to climate-change-related health problems, but it is difficult if not impossible to predict when and where these problems will strike.

Researchers, for their part, need to recognize that temporal and spatial scales are important in defining environmental quality and health. Accordingly, studies should place less emphasis on long-term climatic trends than on short-term forecasts. In regard to health and environmental issues, it is apparent that seasonal and monthly variability are larger factors than decadal or annual variability.

Epidemiologists argue that longitudinal studies are the best way to uncover links between climate change and health problems. These studies could provide information necessary to change human behavior patterns to limit the spread of certain diseases and thereby assure improvements in public health.

Research on environmental quality is needed to make more concrete the linkages between climate change and activities from various economic sectors leading to environmental degradation. For example, it is possible that warmer temperature will lead farmers to increase the application of pesticides.

This increase in pesticides could have detrimental effects on the environment. In turn, increased runoff from extreme precipitation events could lead to more contaminants entering water supplies. Can existing infrastructure cope with increased runoff?
Urban sprawl stemming from increased rural-to-urban migration also is considered a form of environmental degradation. Investigations are needed to understand how climate change, in conjunction with

socioeconomic factors, could lead to increased urbanization.

Policy Issues

In the United States, environmental-health planning, implementation, and enforcement are in the hands of numerous agencies, acting at the federal, state, and local levels.

Additionally, in our society, non-public-sector, sometimes voluntary organizations often play important roles in representing groups and providing care.

Almost always, complex issues are shared by several agencies at all these levels and by nongovernmental organizations.

For example, a southwestern water-related epidemic may involve such organizations as the Centers for Disease Prevention and Control (CDC), the National Institute of Environmental Health Sciences, a state department of health services, a county health department, a city health department, a university research laboratory, a private-sector health-care facility, and a nongovernmental community-support organization.

In view of this convoluted institutional web of research, intervention, monitoring, administration, intervention, and enforcement, better coordination and streamlining surely would improve responsiveness, and eventually, environmental-health conditions per se.

Further, because climate-induced health impacts are perceived as low-priority issues by the professional health-care community, heightened awareness is desirable. Campaigns to educate these professionals in the particulars of health impacts of climate change would prove highly beneficial. And priorities need to be made about which diseases to monitor and how.

Finally, it is important to recognize that politicians and other decisionmakers who are not trained as health professionals inadvertently can generate policies that affect environmental-health conditions. Very often, policies resulting from economic and political considerations--that on the surface may have nothing to do with either climate change or public health--can have important effects on both sectors.

Similarly, the close link between social and economic well-being and a high state of public health suggests that one of the best ways to improve public health is to ameliorate social conditions.

Both of these observations imply that policymakers who are more knowledgeable about climate change and health could be influential in preventing and coping with the health-related impacts of climate variability.

For additional discussions on this topic, see the presentations for Panel 4: Environmental Quality and Health, in Chapter 8.

CHAPTER 15
INDIAN COUNTRY

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Impacts and Vulnerability

The Southwest region is home to the greatest diversity of tribes and longest history of continual habitation in this country. Through thousands of years of climate change, native peoples of this region have endured and maintained a way of life that is uniquely their own.

While tribes have been successful in adapting to past climate changes, these changes occurred more slowly. Today's more rapidly changing climate increases the vulnerability of native peoples and threatens to impact freshwater, agriculture, and energy resources of tribes.

Indian reservations in the Southwest are often bounded by lands owned or controlled by federal or state agencies, and in some cases by Mexico. (The Tohono O'odham Nation in southern Arizona, for example, neighbors on land managed by the National Park Service, Bureau of Land Management, U.S. Forest Service, U.S. Air Force, and Mexico.)

Within the areas separated by such administrative boundaries, land-and-water management practices differ markedly--a factor that in turn frequently impacts the adjoining tribal resource base.

If the uncertain effects of climate change are added to this uncoordinated and often contradictory mix of procedures and approaches to resource use, the risk of inappropriate response increases.

Responses

In discussing possible responses to climate change in Indian country, a starting point is to acknowledge the preeminence of the issue of sovereignty.

For each of the dozens of tribal governments in the Southwest, self-governance and autonomy in all form of decisionmaking--especially regarding decisions that affect the use of water and natural resources--provide the driving rationale for collective action.

Viewed in this light, the seeming cacophony of management practices surrounding Indian lands only reaffirms the resolve of individual tribal units to define their own strategies.

Almost always, these strategies are designed to be consistent with cultural and religious values and with long-held beliefs of proper ways to farm, irrigate, build, and develop communities.

Among the most salient cultural values are those relating to rain and water, the most precious commodities in the dry southwestern region.

Traditional understanding of rain, drought, flooding, and climatic variation are among the most important values in Indian country. Many if not all indigenous agriculturalists and resource managers believe that their cultures already possess sufficient knowledge to respond to climate variation and change.

Additionally, residents of Indian lands expect the policies of tribal authorities to meet the needs of the stakeholders--that is, the growers, holders of water rights, and other producers. Any response to climate change must necessarily account for and respect these interests.

Research and Information Needs

Native peoples are the primary carriers of indigenous languages and cultural expression, and have been architects of sustainable living in the fragile, arid high altitudes and deserts of the Southwest.

Their cultures are rooted in intimate connections between people and nature, and represent storehouses of knowledge and resources. If appropriately used, these repositories can be critical to safeguarding biodiversity, natural resources, production systems, health, and spiritual sustenance of society.

Some would argue that indigenous coping strategies have had a better track record than mainstream approaches in reducing risks. Accordingly, it seems reasonable that more emphasis should be placed on documenting indigenous knowledge and fostering local implementation of traditional strategies--particularly in Indian country, but potentially elsewhere as well.

For this to happen, non-native researchers will need to acknowledge to a greater degree the value of these information sources. At the same time, it is important for non-Indian researchers, resource managers, and policymakers to recognize that certain approaches to reducing vulnerability, such as climate manipulation, are considered taboo by native people.

Researchers and others also need to gain a better understanding of the social structure of tribes before offering suggestions on coping with climate change.

The decisionmaking processes of tribal governments and native peoples vary from one group to another and are often based on different rationales than among non-native people.

The native community has identified specific needs designed to increase awareness and understanding of tribal social structure, and to articulate joint native and non-native research directions:

- Convene tribal staff together with the academic community, funders, practitioners, federal and state governments, and other stakeholders when discussing climate change.
- Review the experiences of key actors in climate change and climate variability in southwestern tribal societies.
- Communicate the most advanced methods for understanding the interaction of human and natural systems.
- Produce a set of durable products for future use by the climate-information agencies and researchers.

Tribes also have indicated the need for more investment per-capita to provide information and resources for Indian communities, and in particular, to rural tribes. Technology to gather data on tribal resource bases is seen as a key element for tribal participation in climate-change discussions, as some federal agencies do not appear to be readily forthcoming with data (according some Navajos, for example).

In addition to the items listed above, a number of other information and research needs can be identified:

- Protocols for improved communications, better inter-institutional relations, and more efficient modes of sharing data and information.
- Enhanced access to forecasts.
- Wider and less-expensive availability of rainfall- and temperature-measurement equipment and instrumentation.

- Easier and more compatible access to information from Mexico.
- Better-adapted and more regionally sensitive climate models.
- A comprehensive, regional, easy-to-access climate-information clearinghouse.

Policy Issues

As noted, tribal sovereignty is a key issue with respect to climate-change policies. While sovereignty may be perceived as a restrictive element in communications, it allows tribes to develop and implement strategies on their own terms and within scales of individual tribal capacity.

To be responsive to tribal needs--and therefore to be acceptable--national climate-change policies will need to represent more completely the interests of tribal communities. These policies will require protocols that recognize and empower most local forms of representation, as well.

Next, policies should recognize that tribal communities are not always homogeneous. On the contrary, they include groups with differing and sometimes conflicting roles, needs, and values.

These differences are vulnerable to the impacts of inappropriate modernization that may be brought about as a result of adaptation to climate change. In short, policies ought to be flexible enough to accommodate widely disparate cultural and political exigencies.

Finally, although the southwestern landscape hosts scores of land-management, water-management, and resource-management regimes, it remains unclear whether the existing quilt of institutions is in fact suitable or adequate.

Certainly, as seen from the point of view of Indian country, non-native institutional coherence and consistency are in need of reform.

For additional discussions on this topic, see the presentations for Panel 6: U.S.-Mexico Border Region and Indian Country, in Chapter 8.

CHAPTER 16
U.S.-MEXICO BORDER

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Impacts and Vulnerability

Culturally, politically, economically, and geographically, the southwest of the United States is one of the nation's most complex regions. Within this large area, no zone diverges more from national norms than the narrow strip of land abutting the border with Mexico.

Here, communities exhibit cultural variety, richness, and complexity that reflect their proximity and ties to Mexico.

The population centers of the southwestern United States and northern Mexico also exist in a physical setting that is exceptionally precarious--chronically water-short, financially resource-poor, and subject to highly variable precipitation.

Adding to their overall vulnerability is a rapidly changing demography characterized by intensive urban economic development, growing transnational trade, heavy in-migration, and seriously strained infrastructure.

On the Mexican side of the border, the 20-year-old maquiladora (foreign-owned industrial plants) phenomenon has spurred multifold growth of the major cities, generally raised per-capita income, and brought greater prosperity--albeit with the usual accompaniments: overcrowding, poor sanitation, reduced air and water quality, greater social instability, inadequate tax revenue, and consequent inability of local governments to finance and implement needed improvements.

North of the border, population growth has remained much more modest--though still large by U.S. standards. The two largest cities (San Diego and El Paso) have grown substantially; the other dozen or so urban centers also have enlarged, but remain relatively small.

More significantly, the U.S. part of the border region remains appreciably poorer than the nation as a whole. Increased investment from the maquiladora program and from the North American Free Trade Agreement (NAFTA) has yet to raise per-capita income levels to those of the core areas of the country.

Similarly, infrastructure--particularly water-management infrastructure--continues to be inadequate. Since early 1995, two post-NAFTA institutions, the Border Environment Cooperation Commission (BECC) and the North American Development Bank (NADBank), have been attempting to reverse a decades-old trend of minimal investment in environmental infrastructure.

Adding to the complexity of problem-solving is the binational nature of environmental issues. Throughout the present century, relations between the United States and Mexico have fluctuated in response to national moods. Sovereignty considerations have dominated relations and complicated attempts at cooperative, local-based efforts.
As a consequence, until very recently, inflexibility prevailed--just when flexibility was most needed. The advent of BECC and NADBank as

progressive, responsive organizations, and the new openness of the venerable International Boundary and Water Commission, offer a promise of greater transnational cooperation and greater capacity to respond to climate-induced environmental threats.

These political, economic, and demographic conditions, combined with the exigencies of the region's aridity and semiaridity, induce a state of perpetual and serious vulnerability to climatic variability.

Historically, drought and flooding have frequently alternated, disrupting livelihoods, and causing economic hardship and social displacement. In such an environment, urban water supplies are particularly susceptible to changes in precipitation.

At the other extreme, seasonal flooding, especially during the summer monsoon season, often overtaxes the capacity of local sewage systems, resulting in health-endangering surface flows of untreated waste.

Responses

On both sides of the border, existing sanitation infrastructure is often inadequate or not fully functional. On the Mexican side, many neighborhoods are unserved and even under non-extreme circumstances, systems--which are old, leaky, too small, and poorly maintained--are not able to cope with increasing demands. Sewage chronically contaminates groundwater and surface-water supplies, and during extreme events, overflows its bounds and is directly exposed.

Comparably, in times of drought or excessive heat, water supply can be inadequate. In Mexican communities, directly-piped drinking water is not universally supplied, so many residents store water in rooftop tanks.

When water is scarce, prices rise, delivery is more infrequent, and water is less available. On such occasions, public health is seriously impacted. In U.S. border towns, the situation is less critical, but nonetheless of concern, most particularly in colonias (unplanned settlements) in New Mexico and Texas.

In an area whose climate is characterized by uncertainty and high variability, it would be reasonable to assume that populations have developed adaptations and coping mechanisms to counteract or mitigate the effects of extreme heat on the one hand and extensive flooding on the other.

Indeed, the region's indigenous populations had such mechanisms: maintaining the modest size of their communities, selecting the most habitable and least vulnerable sites, tailoring their agricultural production systems to rainfall availability, and constraining their uses of water.

With development and migration, however, adaptive features have been lost, and towns and cities have been modeled after others elsewhere. The results have been the conditions described above.

As noted, the Free Trade Agreement has brought with it some promise of investment in water/wastewater infrastructural improvements. BECC in particular has stressed sustainable development, insisting on sustainability in the design of projects it approves.

Most notably, this requirement refers to wise and efficient use and reuse of water. Whether BECC's criteria result in better water management in the long-run has yet to be tested. Nor has BECC or any other binational border institution confronted the additional consequences of possibly increased climate variability.

Research and Information Needs

Perhaps even more than in other sectors, lack of information and data constrains responses to environmental problems in general and to climate-induced problems in particular.

Partly, the complicating factor here is the set of burdens imposed by the transboundary nature of issues and institutions. Thus availability of reliable and timely information, limited in any event, is even more restricted in the binational setting.

The disparity in financial resources combined with varying, often disparate, political and cultural approaches to planning and management in the two countries result in many differences in:

- languages
- economic development priorities
- availability of trained personnel
- measurement systems and scales of analysis
- precision and accuracy of scientific data
- levels of access to technology, especially computer-information technology
- general availability of relevant raw and processed information

Paradoxically, just when technological and analytical tools are becoming more sophisticated and better adapted, the complications of transboundary information management and application are often seen as impediments to easy, low-cost solutions.

The post-NAFTA institutions are beginning to address some of these information problems through direct community technical assistance programs, greater responsiveness to public needs, and dissemination of documents. But the mandate of BECC and NADBank addresses only environmental-infrastructure projects--that is, new constructions.

It is evident that the regions' broader environmental problems, including climate change, will require additional attention. Accordingly, these problems will entail greater cross-border cooperation, development of tailored protocols, and substantial investment in improving information access.

In particular, an information and public-outreach clearinghouse for the region would meet a number of the immediate needs of managers of the sectors most vulnerable to climate change.

Policy Issues

As seen, all environmental problems in the border region, including those associated with climate-change impacts and responses, are confounded by binationalism.

Responsive decisionmaking holds the key to developing successful strategies, but the nature of policy varies greatly in the two neighboring countries. In the United States, much decisionmaking and most management is localized, while in Mexico both remain highly centralized.

The resulting imbalance frequently manifests itself at the national level in apparent contradiction, greater inflexibility, or the appearance of lack of political will.

To serve as the most effective units of analysis, sectors of the border region need to be viewed as ecological zones, airsheds, watersheds, and communities--not as political entities. Policies formulated to address climate-change impacts should recognize this, even if the policies themselves are national in scope.

In this regard, the border region offers some promise since some communities already have begun to put in place formal and informal cooperative arrangements to deal with environmental issues.

The challenge for climate-change planners and managers is to harness the palpable diversity, rich indigenous knowledge base, and nascent local-level cooperation of local communities to frame responsive policies.

For additional discussions on this topic, see the presentations for Panel 6: U.S.-Mexico Border Region and Indian Country, in Chapter 8.

CHAPTER 17
DISASTER MANAGEMENT

Workshop report prepared by:

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Only when phenomena and processes in the other sectors (e.g., water, energy, health, etc.) become disasters (as defined momentarily) do they become of concern. Otherwise they are simply the events of everyday life.

Impacts and Vulnerability

Defining Disasters

To begin our discussion, the group tried to define disasters and came up with this formulation: A disaster is an extreme event with adverse consequences that are beyond the scope of typical coping mechanisms. These adverse consequences may be loss of life, loss of property, loss of resources.

The extreme events may be biophysical, economic, and/or social. However, given our definition, in most cases the effects will transcend the biophysical realm and begin to be felt in economic and social terms.

A second implication that flows from this definition is that disasters can arise from a change in the initiating events themselves, a change in the coping mechanisms available, or through some combination.

However, it is important to keep in mind that it is the interaction between coping capabilities and the characteristics of the initiating events that leads to conditions beyond coping capacity, and hence disaster vulnerability. As an example, two communities may be exposed to exactly the same weather/climate conditions, but depending on their abilities to access emergency-water supplies, may be more or less vulnerable to drought.

Impacts in the Southwest

Given the previous, it is important to be able to identify the kinds of phenomena that may be affected by climatic change in this region and therefore lead to disasters.

In many ways, these phenomena are those covered in several of the other sectoral topics of this report. It is possible that disasters could occur in water resources (flooding or droughts), natural ecosystems, agriculture, ranching, energy, or health and air quality.

It is critical to understand the characteristics of these phenomena in so far as these characteristics might produce effects beyond the typical coping capacities of responsible entities. Such characteristics might include the magnitude of the event, its duration, its areal extent, and its speed of onset.

It is also useful to keep in mind that in many sectors, the typical pattern in the Southwest is one of extremes. This has engendered a particular set of coping strategies for many climate-related phenomena that might make the area more resilient in the face of climate alterations.

On the other hand, in some sectors (e.g., water resources, if current use patterns are to remain the same) the region might be at the limit of its flexibility, and small changes in climate could put typical events beyond coping capacity.

Responses

Determining Coping Capability

The coping capability of any specific management entity (including individuals, communities, regions, states, nations, and international bodies) is dependent on a variety of factors. These might include such components as knowledge, experience, resources, networks, and jurisdictional and other legal/institutional characteristics.

However, the coping capability is again dependent upon the combination of these (and possibly other) characteristics of the management entity as they intersect with particular hazardous phenomena. The same phenomenon will produce very different events depending on the coping capacity, and vice versa.

Mitigation Strategies

Strategies to mitigate disasters, therefore, can focus on the initiating events themselves (e.g., reduction of air pollution, or elimination of disease vectors), on increasing coping capabilities, or on some combination. Particular strategies are highly context-dependent.

Research and Information Needs

Data

The group discussed a number of informational and data needs pertinent to managing climate-related disasters. There was significant concern that timely and spatially appropriate data are not always available.

This problem is being exacerbated by:

- increasing moves toward privatization of data collection and storage;
- reduced budgets for governmental agencies for monitoring, data collection, and storage;
- a heavy and increasing reliance on remotely sensed data, and a lag in ground truthing;
- gaps between more recent, digitized data and historical data in analog form, making time-series construction difficult and/or expensive; and
- difficulties in translating the necessary knowledge into forms usable by decisionmakers and policy-implementation entities.

Decisionmaking

The group also attempted to characterize a number of informational and other problems regarding decisionmaking for disaster management. One of the key issues identified was the significant mismatch between events and decisions.

This mismatch is captured by two acronyms:

- NIMBY, meaning “not in my backyard,” a spatial mismatch between the scale of events and the jurisdictional reach of particular entities; and
- NIMTOO, meaning “not in my term of office,” a temporal mismatch between the duration or timing of events, and the time-sensitive concerns of policymakers.

Another issue, in this regard, is the dynamic nature of these processes. The Southwest is characterized by rapid population growth, which tends to be areally-extensive (i.e., sprawl).

One implication of this is that populations may be moving into highly sensitive regions, areas that are increasingly vulnerable to slight alterations of environmental and climatic conditions, and/or areas that are at the margins of existing jurisdictional domains.

In this last regard, governmental or private coping mechanisms (emergency services, for example) may be increasingly difficult or expensive to deliver.

Communication

Related to the matters of decisionmaking are essential communication improvements. These include improving communication to the public as part of any mitigation strategy, and this involves walking the fine line between apathy and panic.

It is important for communicators to provide not only accurate and timely information, but also to be able to convey a sense of efficacy.

It is also important to communicate information to particular sectors that is relevant to those managers' specific needs. This may mean tailoring information, which will involve close interaction between information providers (researchers and governmental agencies) and those who need the information for decisionmaking.

Policy Issues and Research Questions

Finally the group turned to the policy issues and research needs emerging out of the previously described examination. The following were considered important areas for future investigation:

Vulnerabilities and Populations

- Are some populations more vulnerable than others to changes in climate?
- Does scale matter and in what ways?
- How can we deal with the issue of ecosystem vulnerability?
- Are social, economic, and political changes more important than plausible climate changes?
- Can we conduct vulnerability analyses of differing populations at differing scales?
- In what ways, if any, does climate change affect coping mechanisms and vulnerability?
- What impacts are most important, and what sectors are most sensitive to climate change?

Identify Policymakers Needs for Making Decisions in Each Sector

- Will better information improve decisionmaking?
- What constitutes better information; i.e., what information do decisionmakers actually need?
- How do we avoid NIMBY and NIMTOO problems?
- How do we avoid “Chicken Little” and “crying wolf” problems?
- What kinds of decisionmaking processes are needed?
- Are different/improved models required to address decisionmakers needs?
- How are information and policymaking linked?

Translating Data into Useful Information

- How do data become useful for decisionmaking by policymakers and the public?
- How does such information get communicated?
- In addition to information about phenomena and processes, what can be communicated about response?

Developing Contingency Plans

- What is the content of an effective contingency plan?
- In formulating contingency plans, should entities focus on comprehensiveness or concentrate on specific events and “hot spots”?

CHAPTER 18
EDUCATION AND OUTREACH

Workshop report prepared by:

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Public Information and Participation

Many aspects of climate variability are poorly understood and appear to be unrelated to many people's daily lives. There are few aspects of our lives, however, that are not affected by climate. Climate impacts agriculture, recreation, energy consumption, and ranching, to name a few.

Educators need to increase the public's awareness of climate variability and related issues, including:

- fundamentals of earth-system science with an emphasis on the integration of biological, physical, and social sciences;
- a renewed stress on our role as stewards of the environment;
- an appreciation for the long-term costs and benefits of everyday action;
- the nature of uncertainty in our search for new and improved understandings of our role on planet earth.

Before politicians and industry are able to enact significant institutional change, many basic public attitudes and conceptions need to be updated to ensure meaningful public participation.

Many environmental issues such as climate change defy all-encompassing solutions. The public must be as active in defining these issues as they are in learning from them. Educators cannot be effective without the support and collaboration of many regional and local groups such as neighborhood associations and environmental groups. Clearly public involvement and participation is critical. Among the groups that need to be drawn together are scientists, educators, parents, consumers, and industry.

K-12 Education

Outreach endeavors need to target the K-12 segment of the population to create and increase its understanding of the impacts of climate variability and the potential to affect it. Educators are a critical link between today's youths and society-at-large.

Teachers play an important role in educating youth by structuring information, publicizing alternative choices, explaining risk assessment and uncertainty, dispelling misconceptions, avoiding sensationalism, and putting fads into perspective.

With respect to climate variability, teachers can make a difference by focusing on primary issues such as earth-system science, environmental stewardship, a holistic understanding of nature and society, conservation and recycling, exploring the limits of growth, and case studies of human impacts.

Schools are not the only medium where students can learn about climate variability. The climate-change community needs to target other communication sources such as the Internet, news media, and popular media (e.g., MTV, PBS).

These sources may not be the best in terms of scientific content, but they are certainly the major information source for this age group.

Educators, particularly in the Southwest, also need to be mindful of language and cultural differences. The reality is that presentations and literature must be in Spanish (and in some cases, in other languages) as well as in English.

They must present climate variability as a non-discriminating phenomenon that affects all cultures in the Southwest, and that mitigation requires the cooperation of both developed and developing countries. Schools and teachers also need to take advantage of resources located in their communities.

Such resources include field trips to industries and businesses that are aware of their impacts on the environment and are doing something to curb those impacts. Guest speakers from government, industry, and academia can also visit schools to give talks to increase student awareness of climate variability.

Adult Education and Professional Training

Education is a continuing process that does not stop once we have completed high school. The education of adults cannot be overlooked, for they too play a significant role in the lives of today's youths by setting examples.

Adults need to be able to translate technical issues into more understandable and common elements, and to live according to sound environmental principles.

The ways in which adults view the environment and climate variability is reflected explicitly and implicitly by lifestyle choices. They need to be informed of the environmental consequences of these choices.

Informing this segment of the population can serve as a moderating influence to the effects of climate change and variability by preparing us to accept the consequences of climate change, describing alternative lifestyles and coping strategies, and realigning public expectations with environmental realities.

Educating the public on these issues will require training on the part of the climate-change community. Educators are critical stakeholders in assessing and defining the impact of regional climate variability. Their task is to help the public understand the importance of our investment in science.

Educators influence basic social and environmental behavior, assimilate and translate complex issues, develop focused science exhibits and are respected leaders of their community.

There is a need for more professional-training seminars and workshops to train educators on climate-change issues.

These seminars and workshops must be a two-way discussion, as scientists can learn from educators as well. Viewpoints from industry and stakeholders are also vital components that need to be included. Success and failures need to be examined so that we can learn from our mistakes and improve upon our achievements.

PART V

WRAP-UP SESSION
SEPTEMBER 5, 1997

CHAPTER 19
FINAL RECOMMENDATIONS

Wrap-up session report prepared by:

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Recommendations from 18 attendees were submitted to the conference's organizing committee on the final day of discussion. While most attendees contributed more than one recommendation, there was significant overlap among the various submissions.

After reviewing the submissions, the final recommendations are presented here in seven broad categories. These categories are not mutually exclusive, as there are some crosscutting themes found in several categories. The following is a summary of the seven categories listed in order of perceived (by the attendees) importance.

The list of recommendations is presented on the pages that follow.

Recommendations: Information/Data

1. Create a clearinghouse for data.

- Archive historical and current climate data.
- Provide public access to these data.
- Identify users and their information and data needs.

2. Assess decisionmaking processes

3. Identify what data are required for making decisions and who the users are.

4. Provide policymakers with information on who is affected by climate changes, what geographic areas are affected, how these people and areas are affected, and potential mitigation strategies.

- Identify how stakeholders use information in making decisions.
- Researchers/scientists should frame the issues of climate change in a form understandable to stakeholders.
- Stakeholders need to assume a more active role in guiding research directions and providing feedback to researchers and scientists.
- Use *in situ* data with remotely-sensed imagery as a data source.
- Incorporate data with GIS to produce maps showing spatial extent of climate change.

Recommendations: Climate Forecasting and Hydrological Modeling

5. Provide better climate forecasting.

- Improve seasonal to intra-annual forecasts of precipitation frequency and intensity.

- Downscale long-term forecasts to usable formats.

- Predict the regional and local impacts of El Niño.

- Use data from the Coop Observation Network to predict climate.

- Develop model for reproducing large scale atmospheric features of the summer monsoon.

6. Provide better hydrological modeling.

- Improve hydrologic models to predict/estimate overall water budget.

- Use water budget as foundation for defining climate variables.

Recommendations: Market Responses to Climate Change

7. Develop improved understanding of pricing of resources.

- Will water and energy stresses in the Southwest lead to full-cost pricing?

- Will externalities (e.g. pollution) be incorporated into allocation mechanisms?

- What are the costs for mitigating pollution, and who will pay them?

- What is the net present value of a future gallon of fresh water?

8. Develop improved understanding of consumer behavior

- Can consumer behavior (fossil-fuel consumption) be modified via the market?

Recommendations: Indigenous Knowledge & Southwest Perspective

9. Learn from indigenous knowledge.

- There is a need to incorporate indigenous knowledge about climate in the Southwest into existing databases.

- Indian tribes need to be considered as stakeholders, as they have much "non-scientific" knowledge to contribute in the forms of songs, verse, and drawing.

10. Learn from the southwestern experience.

- If the rest of the U.S. becomes drier and hotter, those areas can learn from adaptations in the Southwest.

- Highlight the Southwest's unique position of being able to adapt to climate extremes.

Recommendations: Health Issues

11. Develop better understanding of how climate change might affect public health.

- What are the effects of climate change on water quality and sanitation?

- Is a lower socioeconomic status related to an increased vulnerability of health problems?

- How will climate change affect the incidence of vector-borne diseases from water, mosquitoes, and rodents?

Recommendations: Sensitivity Analyses by Sector

12. Utilize sensitivity analyses to better understand vulnerability and responses.

- What are regional/local variations in vulnerability?
- How are uncertainty and vulnerability measured?
- What is the robustness and resiliency for each of various sectors?

Recommendations: Ecosystem Monitoring

14. Use ecosystems as natural benchmarks to measure change and resiliency to climate change.

15. Develop appropriate management strategies.

- Land-management agencies must develop common standard or protocol for managing ecosystems.
- Long-term management approaches are required.
- Ecosystem health can be used as a baseline to examine impacts of climate change.

PART VI

APPENDICES

A. SYMPOSIUM & WORKSHOP PROGRAMS