Vol. 21: 199–218, 2002 | CLIMATE RESEARCH Clim Res | Published July 16

# Climate and society in the US Southwest: the context for a regional assessment

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ABSTRACT: We examine the general relationships between climate and society in the US Southwest providing a context for the ongoing Climate Assessment for the Southwest (CLIMAS) Project. We review 5 key contextual elements of the region—its demography, economy, land, water, and institutions and values—and indicate how these conditions predispose certain social groups, economic sectors, or geographic areas to be more or less vulnerable, adaptable, or responsive to climate variability, climate information and climate change. Given the rapid influx of people into the region, the significant economic growth, and competing demands for water and other resources, especially in urban areas, vulnerability to climatic variations is already increasing in some areas of the Southwest. Differences in income, access to institutional resources, or employment options make some individuals or groups less able to cope with the adverse effects of climate changes or to use climate information to guide decisions. And the ability to respond to climatic variability and make the best use of climate information often is constrained both by institutional obligations and by the tense politics of some public land management in the region. Yet, improved climate information could assist decision-makers in dealing with these and other climate-related problems within the region, so long as institutional structures, public attitudes, and other internal and external conditions provide the flexibility to use the information in appropriate ways.

KEY WORDS: Climate · Society · Southwest · Regional assessment · CLIMAS · Arizona · New Mexico



## 1. INTRODUCTION

Climate is a salient and defining attribute of the Southwest. The region is noted for its warm and sunny winters that attract new residents, businesses, and visitors. But the area's generally dry climate, prolonged droughts, high summer temperatures, and occasional floods are to be endured or overcome. Societies in the Southwest, both indigenous and contemporary, have learned to take advantage of the more favorable conditions, while adapting or responding to the climatic extremes—viewing climate, as Meyer (2000) has noted, 'as a help and a hindrance, as a resource and a hazard, as an opportunity and a constraint, as a source of gains and a source of losses' (p. 6).

The history of climate and society interactions is a rich one in the Southwest. Early societies, such as the Hohokam in what is now southern Arizona, developed irrigation for agriculture during the period 700 to 1130 AD, and larger communities and towns also began to emerge elsewhere, including the Mogollon in east central Arizona and west central New Mexico, and the Anasazi of the canyonlands and plateau region of northern Arizona and New Mexico and southern Utah and Colorado. Severe droughts have been blamed for early faunal extinctions in the Southwest and for the abandonment of Anasazi and other settlements in the late 1200s, but in both cases there is considerable debate about the role of climate (Martin &

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Klein 1984, Gummerman 1988). Alternative explanations suggest that early hunters were responsible for animal extinctions and that cultural dynamics, demographics, crop diseases, or inter-group conflict explain the disappearance of groups in some regions of the Southwest in the 1200s (Sheridan 1995). By the 1400s, many of the localized native civilizations that remained throughout the region had developed technologies for agricultural water management, including irrigation canals, reservoirs, terraces, check dams, and other water retaining and distribution practices, particularly for the Hohokam and the Pueblos in eastern New Mexico. Many of the Pueblo peoples, living in regions with extremely variable topography, often planted fields at different elevations as a hedge on capturing rainfall or maximizing the growing season on at least some of the parcels of land.

Spanish explorers and settlers in the 1500s and 1600s introduced livestock into the region and new crops, such as wheat. In many parts of the region, agriculture still relies on the acequias, irrigation channels, and water organizations established by the Spanish during their colonial administration (Meyer 1984). Written documents of the Spanish missionaries and administrators record visual observations of weather and climatic events. Direct scientific measurements of weather and climate began in the late 1880s. The record for the region during the 20th century is filled with accounts of climatic extremes, periods of drought and significant floods (Sellers & Hill 1974, Durrenberger & Ingram 1978, Brazel & Evans 1984). The early part of the century was relatively wet, followed by a drier period during the middle of the century and then again by a wetter period near the century's end (Swetnam et al. 1999). In fact, major droughts in Arizona of the 20th century occurred during the periods 1932–36, 1942–56, and 1973–77, the drought during mid-century being the most severe. In southern Arizona, the combination of overgrazing and drought is thought to have had a devastating effect on the area's grasslands and ecosystems during the late 1800s and early 1900s (Bahre & Shelton 1996).

Today's expanding and modern society has adapted to the region's climatic extremes through such technologies as air conditioning, deep-well groundwater pumps, reservoirs and other water-storage structures, flood control, irrigation canals, and water-supply systems (Merideth 2001). Yet, climatic variations and changes continue to have impacts on the society, economy, and environment of the region.

In this article, we examine the general relationships between climate and society in the Southwest, in order to develop a context for the ongoing Climate Assessment for the Southwest (CLIMAS) Project based at The University of Arizona.[1] Several related articles in this CR SPECIAL describe the various research and outreach components of the CLIMAS Project, including discussions on the climate of the Southwest (Sheppard et al. 2002); water resources (Morehouse et al. 2002, Pagano et al. 2002); ranching (Eakin & Connelly 2002); weather, climate, and hydrologic forecasting and the use of forecasting information (Hartmann et al. 2002, Pagano et al. 2002); and a case study on climatic vulnerability (Finan et al. 2002).

As the basis for contextualizing climate assessment in the Southwest, we review several characteristics of the region—its demography, economy, land, water, and institutions and values—and indicate how these conditions predispose certain social groups, economic sectors, or geographic areas to be more or less vulnerable, more or less adaptable, or more or less responsive to climatic variability, climate information and climate change. We conclude by discussing what these outcomes might imply for the use and value of climate information and the long-term sustainability of the region.

## 2. DEFINITIONS AND SCOPE

Inherent in the CLIMAS Project's name are the concepts 'regional assessment' and 'Southwest.' In this section we define the 2 terms and delimit the scale and context for a 'Southwest regional assessment.'

### 2.1. Regional assessment

With regard to climate and its impacts, some scholars define 'assessment' as the entire social process by which expert knowledge related to a policy problem is organized, evaluated, integrated, and presented in documents to inform policy or decision-making (Clark & Dickson 1999). Easterling (1997) uses 'the orderly provision of research knowledge to decision makers charged with managing a problem' (p. 337). Bierbaum (1998) suggests that an assessment helps determine 'what is known, what is not known, what is knowable over what time scales, and what is most important to know' (p. 3). For our purposes, an assessment involves

[1]The CLIMAS Project aims to foster collaboration between climate researchers and the policymakers, resource users, educators, and others who need more and better information about climate and its impacts in the Southwest. With a core project office based at the UA Institute for the Study of Planet Earth, CLIMAS involves an interdisciplinary team of geographers, climatologists, hydrologists, geoscientists, anthropologists, public policy scholars, and others. Information about the CLIMAS Project is available at www.ispe.arizona.edu/climas.

the evaluation and synthesis of current knowledge about climate and its impacts in a given area; integrates the formulation of research questions, methods, and data related to the physical and social sciences; and creates a process that brings together researchers, policymakers, and other stakeholders.

The concept of a 'regional' assessment emerges from several priorities, including the need to translate results of global change research to more local scales and to incorporate local detail in global-scale analyses and models (Easterling 1997, Yarnal 1998). The term regional also recognizes a political reality for federal funding of science: research results that are more relevant to local decision-makers can have a greater likelihood of engendering congressional or administrative support for federal agency budget requests. State universities, especially those with land-grant and extension traditions, see both strategic value and public duty in undertaking research that relates to particular local or regional issues.

The CLIMAS project's approach to regional climate impacts follows similar assessment models presented by others, such as for the middle Atlantic (Fisher et al. 2000) and northwest (Miles et al. 2000) regions of the US, as well as the region-by-region approach adopted by the US Global Change Research Program (2000) for its recent national assessment of climate change.

### 2.2. The Southwest

Given the focus of the CLIMAS Project is on the 'Southwest,' how do we define the term? As Byrkit (1992) has noted, there are many different conceptions for the Southwest depending on the measure of theme of interest. One could broadly delimit the region by the physiographic dimensions of the Colorado River and Rio Grande basins; by the ecological boundaries of the Chihuahuan, Sonoran, and Mojave deserts and the Colorado plateau; by the climatic zones characterized by 2 major precipitation seasons, including the so-called North American, or southwestern, monsoon; or by the cultural influences of Hispanic and Native American traditions. On a map, such definitions likely would include the states of Arizona and New Mexico and parts of California, Colorado, Nevada, Oklahoma, Utah, and Texas. Some scholars also would include the adjacent regions of northern Mexico, especially the states of Sonora and Chihuahua, within a region called the greater Southwest.

Debates over the definition of regions are common, especially when such discussions involve cultural and political significance and contested identities of places, such as in the American West (Riebsame & Robb 1997). Thus, when in 1997, researchers at The University of Arizona and representatives from several federal agencies began to conceive of a regional assessment center for the Southwest, the team faced some classic debates about how to conceptualize the region and the scope of center's interest. The team's physical scientists proposed delimitations based on climatology, hydrology, or ecology given their interest in natural and physical processes. The social scientists, on the other hand, suggested the use of administrative boundaries given that most social and economic data, as well as legal and policy development, is based on such political divisions.

A more pragmatic influence emerged and eventually prevailed: the organizational structure developed by the US Global Change Research Program (USGCRP) and its regional workshops and assessments. By awarding funds in 1997-98 to universities across the country to undertake these efforts, the USGCRP essentially defined the scope of regions. In fact, the USGCRP created 2 Southwests: one focusing on the lower Rio Grande basin (Texas and southern New Mexico), and the other focusing on the lower Colorado River basin, primarily the states of Arizona and New Mexico, and to a lesser extent on the adjacent portions of California, Colorado, Nevada, Utah, and Texas (Merideth et al. 1998, Sprigg & Hinkley 2000, Merideth 2001). Following suit, then, the CLIMAS Project has adopted this latter regional focus and taken as its core region the states of Arizona and New Mexico and parts of adjacent US states and northern Mexico (Fig. 1).

### 2.3. Scale and context

Despite the interest and need for a focus on regions, one obviously sees that even the most localized interactions between humans and climate are influenced by conditions, trends, and institutions outside any particular region. Contemporary communities and economies are rarely closed systems. People, goods, capital, information, and ideas continuously flow across space and boundaries, however defined. Whether viewed through the theoretical framework of new institutionalism in political science and economics, or political ecology in geography and anthropology, many social scientists are focusing on the interactions between structures and human agency, scales, or institutions and individual decisions when analyzing human environment relations (Liverman 1999a, National Research Council 1999).

Vulnerability to climatic variations, as well as the value of climate information in decisions, is heavily influenced by a wide socioeconomic and institutional context (Stern & Easterling 1999). Such contextual information is important in selecting and justifying


Fig. 1. Map of the Southwest: Arizona and New Mexico

case studies, designing social surveys, building models, drawing more general lessons from local results, making links between economies or assessment in one region to those of another, and integrating across scale to national and global assessment efforts.

Many factors at several scales need to be included in a comprehensive contextual analysis for regional climate assessments, such as socioeconomic conditions and trends, resource distribution and use, institutions, as well as relevant cultural traditions and values. Context also might include an analysis of the major networks of power that control decision-making and information flow, and of the nature of integration of the region into a national or global economy.

A useful model for looking at context in the Southwest is that provided by the Western Water Policy Review Advisory Commission (1998). In the form of background briefing materials, the commission prepared a series of reports on topics such as land use, demographics, economics, value changes, legal issues, and politics related to western water issues (for example, Case & Alward 1998, McDonald 1998, Olinger 1998, Riebsame et al. 1998, Solley 1998).

For the purposes of the CLIMAS Project, the context is dominated by several trends and conditions: (1) *Demography*—the population is growing rapidly, especially in large urban areas, with significant increases in the number of Hispanics and American Indians, persons 65 and older, persons 5 and younger, and individuals in households with inadequate income and services. (2) *Economy*—the economy is expanding, with retail and wholesale trade, services, government, and related activities now much more important in terms of jobs and earnings than region's traditional, primary activities such as mining, agriculture, and ranching—but with these latter activities retaining significance in other ways. (3) *Land*—land use is largely in rangeland, forest, and open space, and land ownership is primarily under the responsibility of public agencies; agriculture, which occupies a very small proportion of the land, dominates water consumption in the region. (4) *Water*—treaties, compacts, and laws define how the region's most precious resource, water, is allocated, and they impose guidelines and constraints of possible responses to climatic changes; in general, demand for scarce water supplies is growing,

with present allocations going mainly to irrigated agriculture, but with increasing competition from municipal users. (5) *Institutions and values*—differences in values and interests are intense related to the allocation and use of natural resources, generating conflicts over urban lifestyles versus rural livelihoods, resource use and land development versus conservation and preservation, and local control versus the public domain.

In the following sections, we assess status, trends, and implications of these 5 elements for climate-society relationships and climate assessment in the Southwest. The discussion is summarized in Table 1.

## 3. CONTEXTUAL ELEMENTS FOR A SOUTHWEST REGIONAL ASSESSMENT

### 3.1. Demography

#### 3.1.1. Growth and composition

Driven in part by favorable climatic conditions, the Southwest is the fastest growing region in the nation. Arizona, with a 40% population increase during the 1990s, from 3.7 million in 1990 to 5.1 million in 2000, was the second fastest growing state in the nation. New Mexico, ranked twelfth, increased its population by 20%, from 1.5 to 1.8 million (US Census Bureau 2000a). The national growth rate was 13% for the same period. In addition, the neighboring states also have very high growth rates: Nevada (66%), Colorado (31%), Utah (30%), and Texas (23%). And though California's growth rate was barely above the national average (just under 14%), its sheer size (now at 34 million inhabitants) meant that it alone accounted for about one-eighth of the nation's growth during the past decade. Forecasts for the next 25 yr show continued high growth for the region.

As is the case across most of the nation, the Southwest is a highly urbanized region, with 80% of Arizonans residing in the metropolitan areas of Flagstaff, Phoenix, and Tucson, and almost 40% of New Mexicans in the Albuquerque metropolitan area. Phoenix was the largest of the 10 fastest growing metropolitan areas during the 1990s, and urban expansion in the 2 states has paralleled the overall high rates of population growth (US Census Bureau 1998).

Other notable demographic characteristics for the region include higher numbers than the national average of elderly, preschool, nonwhite, and poor residents (US Census Bureau 2000[1]). For example, Arizona's growth includes migration from other parts of the US of more than 12% including many retirees, who are represented among the more than 13% of Arizonans who are age 65 or older (just slightly higher than the present national average). But by 2025 the elderly population is expected to increase to 25%. Both Arizona and New Mexico have numbers slightly higher than the national average for residents under the age of 5 (US Census Bureau 2000[1]).

The Southwest is home to a large nonwhite and Hispanic or Latino population. Some 480 000 Native Americans (almost 12% of the national total) from 40 tribes live in the 2 states (US Census Bureau 2000[1]). There are more than 2.1 million Hispanics or Latinos who comprise 25% of Arizona's overall population and 42% of that of New Mexico (US Census Bureau 2000[1]). The proportion of Hispanics or Latinos to the general population is expected to increase to 32% in Arizona and 48% in New Mexico by 2025. Presently, the percentage of residents who identify themselves as nonwhite or Hispanic/Latino is about 36% in Arizona and 55% in New Mexico, compared with 31% for the US overall.

The Southwest also has high levels of poverty, with both Arizona and New Mexico ranking among the 5 poorest states in the nation. For the period 1997–99, an average of 15.2% of Arizonans lived in poverty, as did 20.8% of New Mexicans, compared to a national average of 12.6% (Delaker & Proctor 2000). Median household incomes and per capita education expenditures are also lower for Arizona and New Mexico than for the US, and high school drop out rates and the proportion of people who are uninsured are higher than the national average (Table 2). A disproportionate number of the poor are Native American or Hispanic/Latino. And in New Mexico, more than 100 000 people, most of them Mexican American or Latino, live in colonias and have limited access to safe drinking water and sanitation (Paterson 1998).

#### 3.1.2. Implications for social vulnerability

What these demographic conditions and projections indicate is that there is the potential for heightened vulnerability to severe climatic conditions for certain individuals or groups within the region. For example, the rapid rates of population growth mean increasing demands for water, energy, and other natural resources—adding stress to the allocation mechanisms for already tightly or over-committed resources such as water. This is likely to create conflicts between sectors (urban users, energy producers, agriculture, industry, natural ecosystems) and social groups. Periods of drought, reduced streamflows, high temperatures, or other climatic extremes could exacerbate these stresses.

[1]Available at www.census.gov

Table 1. Status and trends of contextual elements and some implications for climate impacts, vulnerability, and information use in the Southwest

| Status and trends | Implications |
|---|---|
| **DEMOGRAPHY** | |
| **Population growth**: among the most rapidly growing areas in the nation, with increases in both population and per capita resource consumption | Increased demand for water, energy, land, food and other resources may result in increased prices for water; competition between different sectors, regions and groups; pressure on land and ecosystems that can increase vulnerability to extremes of climate especially droughts. But this may also increase the value of climate information to stakeholders |
| **Urbanization**: most residents live in urban areas which are growing rapidly | The security of municipal water supplies is a high priority, especially during drought periods, and it has become critical in local politics and planning. Cities concentrate people and pollution, with health problems resulting when drought or other climate conditions exacerbate the risks of diseases such as valley fever or dengue, respiratory problems, or heat stress. Urban design can increase already high temperatures as a result of the urban heat island effect |
| **Poverty**: relatively large numbers in this region of persons with less educated, lower income, and without insurance; relatively large proportion of poor are Native American, Hispanic or Latino, or nonwhite | The poor are often more vulnerable to extreme events such as drought because, for example, they have less access to financial or informational resources and lower or limited insurance coverage. Inadequate housing, water supplies and healthcare can also make the poor more vulnerable to vector-borne and water-borne diseases and other climate-related illnesses |
| **Elderly and young**: a large number of elderly residents and visitors and preschool (under age of 5) children | The elderly and the very young tend to be more vulnerable to extreme heat and cold temperatures and to airborne and other illnesses |
| **ECONOMY** | |
| **Structure**: largest sector of economy is services, government, and trade; lesser components in construction, manufacturing, transportation and utilities; small contributions from mining, agriculture, and ranching. Many sectors are linked to each other and to sectors beyond the region | There are a large number of different stakeholders in the Southwest, some with larger or more direct sensitivities to climate than others. But because of linkages within and beyond the region, climate variability within or outside the region can have strong ripple effects through a range of sectors |
| **Dependency in communities**: many small communities or rural areas are mostly or entirely dependent on a single activity such as mining, ranching, agriculture, or manufacturing | Single-resource- or enterprise-dependent communities can be particularly vulnerable to severe but localized climatic events, such as heat waves, droughts, floods, or snowstorms, that might negatively affect these dominant economic activities |
| **LAND** | |
| **Land use**: dominant land use is rangeland, forests and parks | Vegetation and wildlife in these areas are reliant almost entirely on rainfall or snowfall and are vulnerable to prolonged droughts and related impacts, such as wildfires |
| **Land ownership**: most land is under the management of federal and state agencies; large areas of tribal lands | Multiple agency management objectives (e.g., wildlife vs recreation vs fire protection) can lead to gaps or vulnerabilities with regard to responding to climatic variations. Federal agencies and tribal groups are important stakeholders for assessments and climate information, and given multiple jurisdictions and cross-boundary impacts, coordination is needed among federal, state and tribal governments, private landholders, and nongovernmental organizations to plan and manage for wildfire protection, wildlife, recreation, and other uses |

Table 1 (continued)

| Status and trends | Implications |
|---|---|
| **LAND (continued)** | |
| **Agricultural lands and production**: overall agriculture occupies relatively small areas but consumes 80% or more of the water resources (75% of cropland is irrigated); concentration of production in small areas for specific crops or products | Geographic concentration of some production (vegetables, cotton, dairy, and cattle operations) could mean that localized climatic events could have larger than expected impacts. Agricultural restructuring results in changes in crops, area, and intensity that alter water use and climate vulnerability |
| **WATER** | |
| **Dependence on major rivers**: large areas of the Southwest depend on the Colorado and Rio Grande rivers | The Colorado and Rio Grande flows have varied considerably over instrumental and longer time periods with major periods of drought. Return to low flows would cause serious impacts on economy, ecosystems and society. Development along rivers has increased flood vulnerability |
| **Importance of groundwater**: groundwater accounts for almost half of the water supply for both Arizona and New Mexico | Although groundwater provides some buffer against drought, aquifers can be vulnerable to climate variations when annual precipitation does not replenish reserves and because demand far exceeds renewal even in wetter years, resulting in serious declines in groundwater levels |
| **INSTITUTIONS AND VALUES** | |
| **Water compacts**: international treaties and interstate compacts determine the amount and priorities for water allocations in the Colorado River and Rio Grande basins | Arizona is vulnerable to drought on the Colorado because California and Nevada are competing for its allocation and the Central Arizona Project is a lower priority during dry periods |
| **Water rights**: system of water legislation and court rulings define rights to water in the Southwest | Prior appropriation doctrine and requirements for 'beneficial' use mean that early users may use water inefficiently while others become vulnerable to drought because of their junior rights. Legal decisions to grant prior rights to Indian users and to ecosystems may result in less water, and greater vulnerability among other users |
| **Public perceptions**: differences exist in perceptions of the value of ecosystems, government vs state or private land ownership, regulations, and development | Such differences in perceptions make it difficult for government to manage resources and create conflict over water and land. This can constrain the credibility of government and scientists as a source of drought policy and climate information |

The rapid urbanization in the 2 states means encroachment on agricultural and ranching lands, such as around Phoenix or Albuquerque, as well as into natural and protected ecosystems, reducing the flexibility of these systems to adjust to climatic variations. In the fast-growing urban areas of southern Arizona, where extensive construction has been disturbing the soil, incidences of valley fever—a lung infection caused by inhaling the spores of a fungus that resides in the desert soil—have been rising dramatically (McClain 2000). More urbanization and sprawl also means more air pollution from vehicle traffic emissions and to a more pronounced 'urban heat island' effect whereby increased numbers of buildings and paved surfaces trap more heat and drive up the urban temperature relative to that in nearby rural areas. Urban areas may also encroach or split wildlife habitat, hindering seasonal migrations in response to temperature or water availability.

With the increasing number of elderly and the very young in these areas, a compounded result may be increased numbers of persons at higher health risk from respiratory illnesses associated with airborne pathogens or from increased air pollution associated with growing urban areas. Higher temperatures and heat waves also affect persons in these age groups more acutely. Another vulnerable group, whose numbers are difficult to count, are undocumented migrants crossing from Mexico into Arizona and New Mexico. Tighter border controls in Texas and California have significantly increased border crossings in Arizona, and every summer migrants are found dead or dehy-

Table 2. Selected social measures for Arizona and New Mexico. Source: US Census Bureau (2000)

| | Nonwhite population (%) | Hispanic or Latino population (%) | Nonwhite or Hispanic/Latino population (%) | Poverty rate, 1997-99 average | Median household income ($), 1998-99 | Per capita educational expenditures ($), K-12 | High school dropout rate (%) | Persons not covered by health insurance (%) |
|---|---|---|---|---|---|---|---|---|
| Arizona | 22.1 | 25.3 | 36.2 | 15.2 | 34 751 | 970 | 14.4 | 24.5 |
| New Mexico | 30.1 | 42.1 | 55.3 | 20.8 | 30 836 | 940 | 11.7 | 22.6 |
| United States | 22.9 | 12.5 | 30.9 | 12.6 | 37 005 | 1030 | 11.2 | 16.1 |

drated from the desert heat and lack of water (California Rural Legal Assistance Foundation; available at www.stopgatekeeper.org/English/facts.htm).

Residents in the colonias in the lower Rio Grande valley of New Mexico may be particularly vulnerable to vector-borne diseases such as dengue and malaria, which could become more frequent in the Southwest as a result of climatic change. The prevalence of hantavirus in Arizona and New Mexico, and in particular on tribal lands, has been linked to climatic variations (increased winter rains propagate seed-bearing plants that sustain larger populations of rodents whose desiccated droppings can spread the virus) and to dusty conditions.

The relatively large populations of poor residents, many of whom live on tribal lands, in colonias, or other areas with inadequate services, are disproportionately vulnerable to water shortages and temperature extremes (Brown & Ingram 1987, Liverman 1999b). These individuals may be the first laid off from work if their employers are adversely affected; they may be unable to afford increased energy or water costs; they may not have health or property insurance to cope with disasters or losses. The rapidity of population growth in the Southwest means that there are likely to be even more persons exposed to greater risks (Merideth 2001).

These differential vulnerabilities indicate the need for regional assessments to pay attention to the varying impacts of climate on, and value of climate information to, different social groups as well as the traditional investigation of geographical and sectoral impacts. The study by Finan et al. (2002) is one example of this approach.

### 3.2. Economy

#### 3.2.1. Trends and patterns

As the population of the region grows, so too do the economies of Arizona and New Mexico. From 1992 to 1997, the Southwest had the highest rates of growth in non farm jobs, with Arizona employment growing by 30% and New Mexico by 19% compared to an average rate of 12% nationwide (US Census Bureau 1997: www.census.gov). Similar to patterns for the United States as a whole, though, the economies of the 2 states are dominated by the trade, service, and government sectors. But there are some important differences as well. We present 2 indicators from the 1997 federal economic census—numbers of jobs and payroll—to show the composition of the states' economies (Table 3).

The service and government sectors dominated the economy of Arizona, generating nearly 750 000 jobs and about 46% of the overall salaries and wages. The trade sector was next with some 460 000 jobs and about 20% of the payroll. Manufacturing, though with less than half the number of jobs (200 000) as compared to trade, contributed nearly as much in payroll, with about 17%. Next in importance is the construction sector (129 000 jobs and nearly 9% of the payroll), transportation and utilities (93 000 jobs and about 7% of the payroll), followed by a minimal contribution from mining (13 000 jobs and slightly more than 1% of the payroll). Agricultural and ranching employ an estimated 44 000 jobs (Arizona Department of Commerce 1998; available at: www.azcommerce.com/datapages/economy.htm) and provide less than 1% of the state's payroll.

New Mexico's economy shows similar patterns to that of Arizona, but with slightly higher proportions for trade and agriculture, relatively higher for mining, and less in the manufacturing sector. New Mexico's numbers for jobs and payroll are: services and government (223 000 jobs, about 48% of the payroll), trade (162 000 jobs, 21% of the payroll), manufacturing (42 000 jobs, 10% pay), construction (39 000 jobs, about 8% of the payroll), transportation and utilities (27 000 jobs, nearly 7% of the payroll). Mining employs nearly 15 000 persons and contributes almost 5% of the payroll, while agriculture and ranching employ about 25 000 people (New Mexico Economic Development Department 1998) and provide about 2% of the state's wages.

When compared with the economy of the United States, the economic make up of the Southwest is about the same proportionately for services and government, trade, and transportation and utilities. However, the Southwest's economy is much less reliant on

Table 3. Employment and income for various economic sectors in the Southwest. Source (unless otherwise indicated): US Census Bureau (1998)

| Sector | Number of jobs (thousands) | | | Payroll (thousands of $) | | |
|---|---|---|---|---|---|---|
| | Arizona | New Mexico | United States | Arizona | New Mexico | United States |
| Agriculture and ranching | 44.0[a] | 25.0[b] | — | 301.4 | 166.4 | 16903.8 |
| | — | — | — | 0.7% | 1.4% | 0.6% |
| Mining | 12.9 | 14.6 | 512.0 | 510.4 | 574.1 | 20906.9 |
| | 0.8% | 2.9% | 0.5% | 1.2% | 4.8% | 0.7% |
| Construction | 129.3 | 39.0 | 5567.1 | 3551.0 | 1001.8 | 170962.0 |
| | 7.9% | 7.7% | 5.5% | 8.5% | 8.4% | 5.8% |
| Manufacturing | 200.0 | 42.3 | 17 557.0 | 6957.2 | 1203.3 | 595685.8 |
| | 12.2% | 8.3% | 17.3% | 16.6% | 10.1% | 20.3% |
| Transportation and utilities | 92.7 | 26.5 | 5689.1 | 2916.6 | 821.0 | 199706.6 |
| | 5.6% | 5.2% | 5.6% | 6.9% | 6.9% | 6.8% |
| Trade | 457.6 | 161.5 | 27 675.2 | 8248.4 | 2513.4 | 525042.2 |
| | 27.9% | 31.8% | 27.3% | 19.7% | 21.0% | 17.9 |
| Services and government | 748.5 | 223.1 | 44440.0 | 19481.5 | 5683.6 | 1399359.5 |
| | 45.6% | 44.0% | 43.8% | 46.4% | 47.5% | 47.8% |

[a]Source: Arizona Department of Commerce (1998); www.azcommerce.com/datapages/economy.htm
[b]Source: New Mexico Economic Development Department (1998); www.edd.state.nm.us/SERVICES/RESEARCH/research.htm

manufacturing than the nation and has relatively higher contributions from construction, mining, and agriculture and ranching. It should be noted that though in Arizona and New Mexico mining, agriculture, and ranching employ relatively few persons compared with other economic sectors, these areas are of historic and cultural significance to the region and continue to dominate the local economies of many rural areas and small communities (Sheridan 1995). Additionally, for agriculture and ranching, an economic measure such as sales of products (crops, head of livestock) would show more significance to these particular sectors than just using jobs and payroll as indicators (i.e. sales of crops and livestock in 1997 of $1.9 billion for Arizona and $1.6 billion in New Mexico).

### 3.2.2. Implications for economic vulnerability

Each of the Southwest's economic sectors has its own degree and type of vulnerability to climatic variations. Depending on the particular climatic conditions and on other external factors, some sectors will be more vulnerable than others to changes. For example, rain-fed agriculture and ranching may be the most directly sensitive to low precipitation and high temperatures. Yet, because these activities occur over vast areas in both states, unless a drought is geographically pervasive or long lasting, local effects could be severe, but regional impacts could be minimal. External factors—crop or feed prices in the Midwest, a drought in Texas or Mexico, or other global market factors—have as significant an impact on agriculture and ranching as local climatic factors.

Mining and certain manufacturing can be vulnerable to climatic variations because of high water demands, cooling needs, or the risk of floods to tailings and waste sites. Yet, as with the agriculture and ranching sectors, other global environmental, economic, or political factors—such as the fluctuating price of copper on the world market—are as important to an industry's viability as the impacts of the regional climate.

The corollary is that other sectors (services, government, trade, transportation, construction) might seem at first glance much less influenced by climatic variations than agriculture, ranching, or mining. However, a closer assessment would reveal that all of these sectors are affected by climatic and other factors both within and outside the region. For example, extreme climatic events—such as droughts, heat waves, floods, snowstorms—affect not only crops, livestock, roadways, reservoirs, and other infrastructure, but also change retail prices, alter energy demands, or increase insurance claims and hospital visits (Merideth 2001). Also, there are more direct effects because many service sector jobs and businesses are dependent on tourism where climate (sun, snow, fire) can be critical to success. For example, many tourist operations are dependent on precipitation for snowfall (skiing), river flows (for rafting, fishing, and water sports), or maintaining the viability of natural areas (for hiking or camping). During periods of drought, many these activities can be affected negatively.

An additional set of factors to consider is the restructuring of some of the Southwest's economy as a result of trade liberalization and the growth of high technology sectors. For example, some businesses are relocating and expanding to Arizona and New Mexico to take advantage of the states' proximity to Mexico or the relatively lower wages and costs-of-living compared to other parts of the country. Some of the new activities have particular climatic sensitivities. For example, secure access to water is needed for some manufacturing activities, and trade with Mexico includes a large volume of fresh produce that is sensitive to climatic impacts in Mexico and to transportation delays and heat waves in the Southwest.

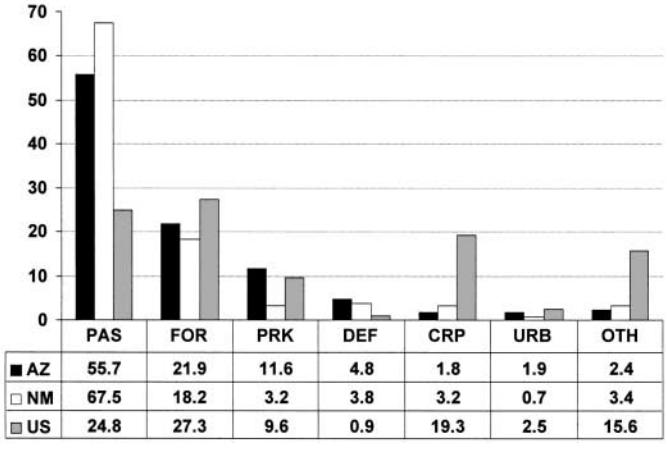
While many of the larger economic enterprises (e.g. utilities, mines, ski resorts) in the Southwest collect and interpret climate information tailored to their needs, many others rely on general regional information provided by the National Weather Service or the media. Preliminary surveys of stakeholders conducted by the CLIMAS project suggest that many small companies would benefit from climate information at more local scales, and with more detail and explanation of past climatic conditions and forecasts of future conditions.

### 3.3. Land

#### 3.3.1. Land use and land cover

The Southwest is a region noted for its wide-open spaces. The dominant land cover in Arizona and New Mexico is grassland and shrubland, with smaller areas covered by forests at higher elevations and localized areas of irrigated cropland along rivers and urban land around major cities (US National Atlas, www.nationalatlas.gov). The US Department of Agriculture reports statewide land uses dominated by pasture (about 56% in Arizona and 68% in New Mexico), forests (about 22% in Arizona and 18% in New Mexico) and parks and wildlife areas (almost 12% in Arizona and 3% in New Mexico) (Daugherty 1995). Urban areas, cropland, and other uses combined occupy about 10% of each state (Fig. 2). The patterns of land use in the Southwest vary considerably with that of the United States as a whole: the Southwest has a much higher proportion of land in pasture than the US, while the nation has a much higher percentage of land in cropland and other land uses (which includes water) than that for the Southwest; the US has a slightly higher proportion of land in forest and urban land, while slightly lower in defense lands.

Over the last few decades, however, changes in land cover have been occurring, rapidly in some areas. For example, an increase in the amount of urban area has paralleled the rapid increase in growth of population and major cities. The amount of forests has declined since 1945, by about 18% in Arizona and 29% in New Mexico. Over the same period, cropland has increased by about 36% in Arizona, mainly through new irrigation districts, and has stayed about the same in New Mexico. The overall area protected by parks and wildlife refuges has increased significantly as new areas have been added to federal, state, and local park systems (US Economic Research Service 1997).




| | PAS | FOR | PRK | DEF | CRP | URB | OTH |
|---|---|---|---|---|---|---|---|
| AZ | 55.7 | 21.9 | 11.6 | 4.8 | 1.8 | 1.9 | 2.4 |
| NM | 67.5 | 18.2 | 3.2 | 3.8 | 3.2 | 0.7 | 3.4 |
| US | 24.8 | 27.3 | 9.6 | 0.9 | 19.3 | 2.5 | 15.6 |

Fig. 2. Land use in the Southwest. Percent of lands in pasture (PAS), forest (FOR), parkland and wildlife areas (PRK), defense lands (DEF), cropland (CRP), urban areas (URB), and other uses (OTH). Land area for Arizona is 72.7 million acres; New Mexico, 77.7 million acres; United States, 2262.5 million acres. Source: Daugherty (1995)

#### 3.3.2. Land ownership

The federal government is the largest landholder in the Southwest (Fig. 3), with about 44% of the land area of Arizona and 36% of New Mexico (National Wilderness Institute 1999). This, in addition to the large amount of land owned by American Indian tribes (about 27% in Arizona and 10% in New Mexico) and state governments (about 13% in Arizona and 11% in New Mexico), is one of the key characteristics of the Southwest. Arizona has a higher proportion of tribal land than any other state and one of the lowest percentages of private land holdings.

The Bureau of Land Management and the US Forest Service are the most important federal landholders in the 2 states (Fig. 4). The Bureau of Land Management is responsible for about 43% of federal lands in Arizona and 46% in New Mexico, and the Forest Service manages about 36% the federal acreage in Arizona and 37% in New Mexico. The National Park Service

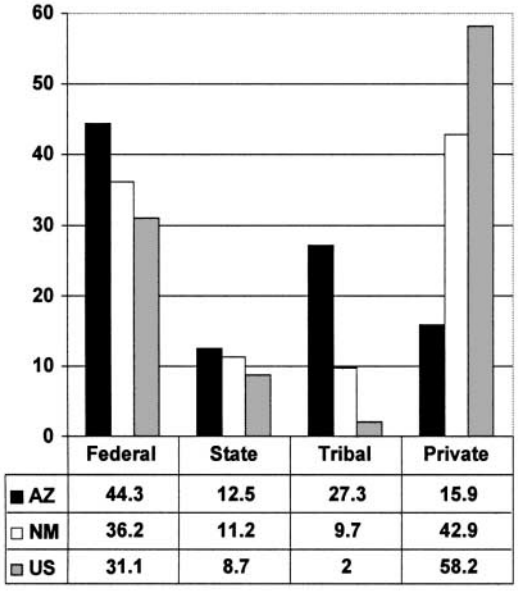



Fig. 3. Land ownership in the Southwest. Percentage of land owned by federal government, state governments, tribal governments, and private individuals or entities. Source: National Wilderness Institute (www.nwi.org/Maps/Land Chart.html)

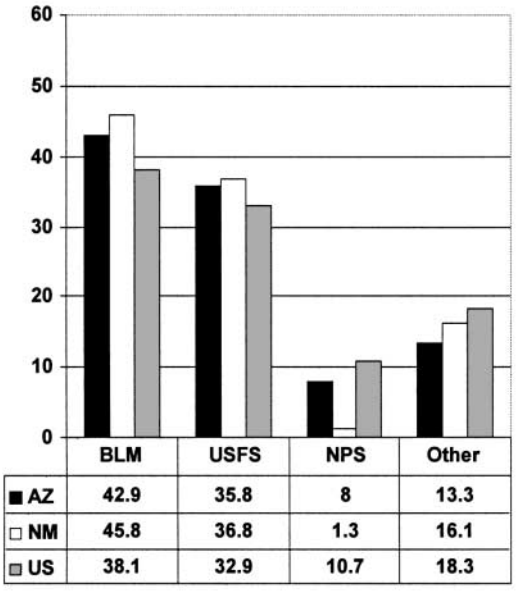



Fig. 4. Management of federal lands in the Southwest. Percentage of federal lands managed by Bureau of Land Management (BLM), US Forest Service (USFS), National Park Service (NPS), and other agencies, including US Fish & Wildlife Service and Department of Defense. Source: National Wilderness Institute (www.nwi.org/Maps/LandChart.html)

and US Fish and Wildlife Service also manage significant portions of the federal lands, including key areas of cultural and ecological significance, such as the Grand Canyon National Park (AZ), the Carlsbad Caverns National Monument (NM), the Bosque del Apache Wildlife Refuge (NM), and the Cabeza Prieta Wildlife Refuge (AZ). Both Arizona and New Mexico have large areas controlled by the Department of Defense, including the White Sands Missile Range (NM), Fort Bliss (NM), the Barry M. Goldwater Air Force Range (AZ) and the Yuma Army Proving Grounds (AZ).

In many cases, there are often multiple uses for these lands (such as for forestry, ranching and recreation) that must share limited water resources and cope with climatic variations in a coordinated way. For example, in a severe drought, recreation uses and grazing allotments in national forests may be curtailed or reduced.

Table 4. Farm, crop, and livestock data for Arizona and New Mexico. 1 acre = 0.405 ha. Source: US Department of Agriculture, www.hass.usda.gov/census

| | Arizona | New Mexico |
|---|---|---|
| Number of farms | 6135 | 14094 |
| Average farm size (acres) | 4379 | 3249 |
| Median farm size (acres) | 80 | 160 |
| Cropland (acres) | 1277169 | 1079953 |
| Irrigated cropland (thousands of acres) | 1013902 | 804616 |
| Cotton (acres) | 331699<br>26.0% | 67996<br>6.3% |
| Hay (acres) | 243946 | |
| Vegetables (acres) | 131204<br>10.3% | 37 687<br>3.5% |
| Wheat (acres) | 103121<br>8.1% | 264190<br>24.5% |
| Sorghum | – | 188615<br>17.5% |

### 3.3.3. Agricultural lands and production

While cropland occupies only relatively small areas of land in both Arizona and New Mexico, agriculture is significant in that it consumes 86% of water in Arizona and 81% in New Mexico (Solley et al. 1998). About 75% of agricultural land is irrigated and with rights to use large proportions of each state's total water withdrawals. The 1997 US Census of Agriculture (US Department of Agriculture 1997; available at: www.nass.usda.gov/census) reports just over 20 000 farms in the Southwest, about 14 000 in New Mexico and 6000 in Arizona (Table 4). Compared with the numbers of farms in 1987, New Mexico is about the same (down by about 1%) but Arizona has seen a significant decrease, about 20%. This compares with a national average

decline of a little more than 8%. Likewise, the amount of land devoted to agriculture has declined from 1987 to 1997, notably in Arizona by about 26%, slightly in New Mexico at about 0.5%, and nationally by just more than 3%. In terms of farm size (including ranches), the average for Arizona in 1997 was 4379 acres (1 acre = 0.405 ha) and in New Mexico 3249 acres, while the national average was 487 acres. (Median farm sizes were 80 acres for Arizona, 160 acres for New Mexico, and 120 acres for the US.) Nonetheless, the figures for Arizona and New Mexico represent a skewed distribution since nearly 73% of the farms in Arizona and 65% in New Mexico were less than 500 acres in size, constituting just 2 and 3% total land area devoted to agriculture in Arizona and New Mexico, respectively.

In terms of crop mix, in Arizona hay and alfalfa occupy the largest areas (19%), followed by cotton (26%), vegetables (10% mainly lettuce) and wheat (8%), and in New Mexico there is wheat (24%), sorghum (17%), corn (7%), cotton (6%) and vegetables (3.5% mainly chile peppers). Orchard crops occupy about 5% of the cropland, with lemons, oranges and pecans important in Arizona and pecans in New Mexico.

Cotton acreage has declined significantly in Arizona from 381 000 acres in 1987 to 263 500 acres in 1998 and now comprises only 12% of state farm receipts (Arizona Agricultural Statistics Service 1998; available at: www.nass.usda.gov/az). The acreage of vegetables has grown from 10% in 1970 to 27% of all agricultural cash receipts (14% just in lettuces). Arizona is capable of producing an increasing variety of vegetables and melons nearly year round because of mild winters in the lower elevations and cooler summer temperatures in the higher elevations. Arizona ranked third nationally in the production of fresh market vegetables (after California and Florida) but is facing some increase in competition from horticultural production in Mexico. Alfalfa acreage in Arizona was 200 000 acres in 1998 (Table 5).

In many cases, production is concentrated in small areas, particularly in Arizona. For example, nearly 68% of the vegetables sold are produced in Yuma County (in southwestern Arizona) on just 5% of the state's cropland. Almost three-fourths of the state's cotton is produced in small areas of the central counties of Maricopa and Pinal on about 18% of the cropland. Vegetable production is the top source of sales (21%) for Arizona, with cotton third in importance (at 16%). The sale of cattle and calves is the second highest area of production, with 19% of sales.

In New Mexico, cattle and calves and dairy products account for 69% of New Mexico's agricultural products. Cotton is much less important than for Arizona (1.9% of farm commodity receipts on only 68 000 acres of cropland), with vegetables at about 8% (just over half from chile pepper production) and hay at 7% of farm receipts (New Mexico Agricultural Statistics Service 1998; available at: www.nass.usda.gov/nm). New Mexico is the nation's top producer of chile peppers and summer onions. Nearly one-third of cattle and calves are sold from 2 counties (Union in the northeast and Curry in the east central part of the state), while 50% of dairy products come from Chaves (southeast) and Doña Ana (south central) counties. Also, more than 40% of the cotton production comes from Doña Ana County.

### 3.3.4. Implications for land management and agricultural vulnerability

Ranching and forestry, the dominant land uses in the Southwest, are very sensitive to changes in climatic conditions. Drought can devastate rangeland resources, and heavy snowfall is a serious risk for livestock, especially in northern New Mexico. Forest productivity is dependent on reliable rainfall, and drought and high temperatures bring high risk of forest fires. Recent droughts and widespread forest fires have

Table 5. Market value of agricultural sales in Arizona and New Mexico. Source: US Department of Agriculture, www.hass.usda.gov/census

| Product | Arizona (total sales = $1.9 billion) | | | New Mexico (total sales = $1.6 billion) | | |
|---|---|---|---|---|---|---|
| | Rank | Sales (millions of $) | Percentage of total | Rank | Sales (millions of $) | Percentage of total |
| Vegetables, sweet corn, and melons | 1 | 398.5 | 20.9 | 4 | 88.8 | 5.5 |
| Cattle and calves | 2 | 356.6 | 18.7 | 1 | 647.4 | 40.0 |
| Cotton and cottonseed | 3 | 298.1 | 15.7 | 7 | 39.0 | 2.4 |
| Dairy products | 4 | 282.2 | 14.8 | 2 | 463.4 | 28.6 |
| Hay, silage, and field seeds | 5 | 174.4 | 9.2 | 3 | 118.8 | 7.3 |
| Nursery and greenhouse crops | 6 | 131.5 | 6.9 | 5 | 48.4 | 3.0 |
| Fruits, nuts, and berries | 7 | 118.5 | 6.2 | 6 | 43.6 | 2.7 |

highlighted these vulnerabilities and increased the interest of ranchers and forest managers in climate information and forecasts. The large areas of land managed by federal agencies and tribal governments indicate the significance of these groups as stakeholders for climate assessment and information in the region.

Because the amount of water used in irrigated agriculture—especially the consumptive losses due to evaporation—depends on the type and location of the crops, small shifts in the use of agricultural land can have significant impacts on water use and vulnerability to climatic changes both for the agricultural sector and for competing water users. The shift that has occurred from cotton to larger areas of vegetables and hay, particularly irrigated alfalfa, with higher consumptive use of water has increased agricultural water demands and sensitivity to any water shortages. Vegetables are also more vulnerable to extreme climate conditions such as frost and heat waves and also to pests and diseases that are often associated with the warm, humid conditions of irrigated agriculture in the Southwest. Chile is particularly vulnerable to heavy rain and hail. Wheat and sorghum on 42% of New Mexico's cropland are mainly dry land crops and are very seriously affected by droughts such as those of 1994–96 and 1998. The vulnerability of the ranching sector is discussed in detail by Eakin & Conley (2002) and is significant because of reliance on rain fed pasture, economic uncertainties and competition from Mexico. Concentrations of agricultural production within sectors or geographically also mean climatic variations can have more of an impact than if production were more dispersed over sectors or space.

## 3.4. Water

### 3.4.1. Background

When humans live in an arid environment such as that of Arizona and New Mexico, supply and demand for water is critical. Water resources have been the basis of human settlements and resource development in the Southwest and are one of the limitations on future population and economic growth. Because irrigated agriculture developed earlier than many other activities in the Southwest, it obtained the right to large amounts of water under the law of prior appropriation, whereby the first users of water retain water rights so long as water is in beneficial use.

Despite rapid growth of other sectors, as mentioned earlier, agriculture continues to be the major user (more than 80%) of water in both Arizona and New Mexico, mostly for irrigation (Table 6; Solley et al. 1998). Remaining water use is divided between municipalities (10% in Arizona, 14% in New Mexico), industry and mining (2% in Arizona, 4% in New Mexico) and power generation (2% in Arizona, 1% in New Mexico). Although the irrigated area is relatively small, and consumptive use is much less than water withdrawals, water use is high as a result of evaporative losses in warm, dry conditions. These water use estimates do not take into account the in-stream and natural ecosystem demands. These demands are difficult to quantify but are entering into institutional frameworks for water allocation through legislation such as the Endangered Species Act (ESA) and priority water rights for federal lands (see below).

Unlike the situation in many other states and for the US as a whole, water supply in the Southwest is split between surface water and groundwater sources, with groundwater supplying 42% of the need in Arizona and 49% of that in New Mexico. The former is more vulnerable, in general and over the shorter term, to climatic variations.

The Colorado River and Rio Grande, the 2 principal river systems for the Southwest, have been deemed the lifeblood of the region. Based on a series of binational treaties between the US and Mexico, interstate compacts involving the various basin states, and treaties between the federal and tribal governments, rights to their waters have been fully allocated (see discussion in Section 3.5).

### 3.4.2. Water use in Arizona

In Arizona water use has grown from 6.6 million acre-feet (maf) $yr^{-1}$ in 1963 to 7.4 maf in 1995 due to increases in both agricultural and municipal uses

Table 6. Water use data for Arizona and New Mexico, 1995. 1 gallon = 3.7875 l. Source: Solley et al. (1998)

| | Arizona | New Mexico |
|---|---|---|
| Total water withdrawals (million gallons $d^{-1}$) | 6830 | 3505 |
| Total water withdrawals (million acre-feet $yr^{-1}$) | 7.4 | 3.9 |
| Total water withdrawals, 1960 (million acre-feet $yr^{-1}$) | 6.6 | 2.7 |
| Percent water supply from groundwater | 42 | 49 |
| Per capita use (gallons $d^{-1}$) | 1620 | 2080 |
| Agriculture use (%) | 86 | 81 |
| Municipal use (%) | 10 | 14 |
| Industry use (%) | 2 | 4 |
| Power use (%) | 2 | 1 |

(1 acre-foot = 1230 $m^3$). About 56% of the water supply is consumptive use—not returned as groundwater recharge or stream flow—while about 15% of water consumed is lost in conveyance. Most of the population is served by public and municipal water systems, and domestic water use is about 8% of all withdrawals. Industry, power generation, and mining collectively use less than 5% of water withdrawals. By far the most important water user is irrigated agriculture, using 83% of total withdrawals and consumptive use on about 1 million acres.

Trends and patterns of water use are carefully assessed in Arizona's 5 Active Management Areas (AMA) established under the Groundwater Management Act, with goals of achieving safe yield (groundwater pumping not to exceed recharge) in the Phoenix, Prescott and Tucson urban areas, while sustaining agriculture and economic growth in Pinal and Santa Cruz counties.

For the Phoenix AMA, with the largest population in the state (2.5 million people in 1995 projected to reach 4.5 million by 2025), the Arizona Department of Water Resources estimates that municipal demand will increase from about 0.9 maf in 1995 to 1.4 maf $yr^{-1}$ by 2025 with about half of this demand met by supplies from surface water and just under 20% each from groundwater and the Central Arizona Project (Arizona Department of Water Resources 1997; available at http://water.az.gov). Agricultural demand will stay stable at about 1.3 maf, with decreases in non-Indian agricultural demand as a result of urban conversion and purchase of cropland, and a doubling for Indian demand to 0.47 maf by 2025. Industrial demand is projected to increase from 0.08 to 0.14 maf by 2025, with a small and stable riparian demand of 0.05 maf over the period.

In the Tucson AMA (population 768 000 in 1995 projected to reach 1.3 million by 2025), municipal demand is projected to increase from about 0.13 maf to 0.27 maf by 2025 and agricultural demand is projected to decrease from 0.9 to 0.7 maf as irrigated acres are retired from non-Indian uses and Indian use increases slightly. Industrial demand is projected to double to about 0.08 maf. The supply is estimated to be met by a decreasing proportion of groundwater (from 0.27 to 0.19 maf) as the use of Central Arizona Project water increases to 0.18 maf and the use of effluent increase slightly.

### 3.4.3. Water use in New Mexico

New Mexico water withdrawals have also increased over the last 30 yr from 2.7 maf in 1960 to 3.9 maf in 1995—an increase of 47% (Solley et al. 1998). Just over half of these withdrawals are consumptive uses that reached 2.24 maf in 1995 after a decline in the 1980s with economic problems in the agriculture and mining sectors. In 1995, about half of all water withdrawals were from groundwater with the remainder from surface supplies, especially the Rio Grande. Conveyance losses were higher than in Arizona at 18%. As in Arizona, the dominant water withdrawal and consumptive use is agricultural (86%) on just under a million acres of irrigated cropland. About 67% of municipal and public withdrawals are for domestic use, and home use is about 6% of all water withdrawals. As in Arizona, mining, power and industry use less than 5% of total water withdrawals in New Mexico.

The greatest growth in municipal water use is around Albuquerque, where groundwater withdrawal doubled from 1970 to 1990, resulting in significant declines in the aquifer level. Albuquerque has a higher per capita consumption of water (205 gallons $d^{-1}$ [gpd]) than either Phoenix (175 gpd) or Tucson (170 gpd).[2] One of the trends in many southwestern cities has been an increase in potential per capita demand with new housing developments with pools and more bathrooms, compensated by attempts to promote conservation through education and pricing programs.

### 3.4.4. Implications for water resource vulnerability

These trends, discussed in much greater detail for Arizona by Morehouse et al. (2002), reflect important shifts in water use, supply and vulnerability in the region, with urban demands placing stress on groundwater resources, and future urban expansion requiring shifts from agricultural to municipal sectors in order to meet demand without overdrafting groundwater supplies. They also reflect the allocation and development of Indian water rights and some industrial expansion projected with new economic activity in the states. Because many agricultural irrigators do not use their full allocation in normal years, they are buffered against shorter-term climatic variations. Domestic users are more vulnerable because most providers are only just meeting demand under average climate and must introduce water restrictions in dry years. Perhaps the most vulnerable sector are riparian areas and ecosystems, where without adjudication of in-stream rights, rivers and lakes may run dry in drought periods.

[2]Albuquerque Water Conservation Office (www.cabq.gov/waterconservation/index.html); Phoenix Water Department (www.ci.phoenix.az.us/WATER/wtrfacts.html); Water Resources Research Center, University of Arizona (http://ag.arizona.edu/AZWATER/publications/sustainability)

### 3.5. Institutions and values

These sectoral vulnerabilities are strongly influenced by institutions and values that result in a set of laws, structures and beliefs that control the use of water and the management of the environment more broadly in the region. Some of the key institutional structures, in terms of climate assessment, include the major river compacts, the systems of water and property rights, and federal regulations relating to water quality and ecosystem protection. Critical values include actual monetary values for economic activities such as crop revenues and a range of non-market values that people hold regarding the environment, culture and recreation.

#### 3.5.1. Compacts and treaties

For instance, Arizona has the right to 2.8 maf $yr^{-1}$ of Colorado River flow, but historically has not utilized its entire allocation. California, on the other hand has an annual allocation 4.5 maf, but has been using up to 6.6 maf—the extra allocation coming from the 'unused' water by Arizona and other states. Recently, however, Arizona (as well as Nevada and other claimants, such as several American Indian tribes) has begun to use more of its assigned allocation. This has come about through a water 'banking' project, whereby Colorado River water is extracted and stored in aquifers for later use and also as a result of the Central Arizona Project, which transfers Colorado River water to Phoenix and Tucson and which provides a surface water alternative that responds to state laws aimed at reducing groundwater depletion. In 1994-95 Arizona obtained about 28% of its overall water supply from the Colorado River (Morrison & Gleick 1997). The Bureau of Reclamation indicates that Arizona's usage went up from 2.15 maf in 1994 to 2.73 maf in 1999 but dropped slightly to 2.54 maf in 2000 (US Bureau of Reclamation, www.lc.usbr.gov/~g4000/rivops.html).

In the case of New Mexico, under the 1938 Rio Grande Compact with Colorado and Texas, the state has rights to the use and diversion of a specified percentage of the Rio Grande flows. On average about 325 000 af $yr^{-1}$ reaches New Mexico from Colorado, 650 000 af $yr^{-1}$ flows in from tributaries within New Mexico, and 100 000 af $yr^{-1}$ is transferred from the Colorado Basin from the San Juan River. Of the 700 000 af $yr^{-1}$ that flows near Alburquerque, about two-thirds of that flows into the Elephant Butte reservoir, located just north of the city of Las Cruces (Niemi & McGuckin 1997). Allocations under the compact are based on a percentage of actual flows and thus fluctuate considerably due to year-to-year climatic variations. In a dry year, for instance, the compact states that New Mexico would get about 20% of the flow from Colorado and provide about 57% of the flow to Texas and Mexico, as monitored at the Elephant Butte reservoir. The Mexico allocation is fixed at 60 000 af $yr^{-1}$ except in extremely dry years. In wet years about 80% of the flow must cross from Colorado to New Mexico, and 90% from New Mexico to the Elephant Butte reservoir (Niemi & McGuckin 1997).

Research focused on these 2 critical river basins has shown considerable vulnerability to climatic variations and possible climatic change. Historical and ecological records of the flow of the Colorado indicate annual flows as low as 9.6 maf (over the past 500 yr) and 13.4 maf (during the past 100 yr), below the 20th century annual average of 15.2 maf (calculated by the Bureau of Reclamation) and well below the allocated quotas from the Colorado River treaty that total 16.5 maf (Powell Consortium 1995). Studies of the possible impacts of global warming suggest possible flow reductions of up to 56% in the lower Colorado River basin (Meko et al. 1995) and that the reservoir levels on the Rio Grande might fall by 50% (Schmandt & Ward 1991). The regional impacts of reduced flows are determined by institutional arrangements that allocate water between states. Arizona is legally given a lower priority than California and Nevada for Colorado River water and might therefore be more vulnerable to a sustained drought if reliance on Central Arizona Project water increases.

In some ways, the Colorado River compact has a more rigid structure than the Rio Grande, because the former is based on absolute rather than proportional flows except in extreme drought conditions. But in both cases the compacts can mean that more junior water rights holders may not receive water in low flow conditions and that the flexibility to manage resources in the face of climate variability and change is limited. As many have noted, the allocation of Colorado River water was made during a period of unusually high flows, and the 16.5 maf $yr^{-1}$ currently allocated is more than the current average flows of about 15 maf $yr^{-1}$ (Gleick 1988, Powell Consortium 1995, Miller 1997). Recent dry periods have caused competition among states and users, and several researchers have suggested that the institutional arrangements for the Colorado may need restructuring to cope with climate change.

The senior priority under the Colorado River legislation is the delivery of water to Mexico of 1.5 maf $yr^{-1}$. The 1944 Treaty allows for 'extraordinary drought' to reduce the allocation to Mexico in proportion to reductions in consumptive uses in the US. However, there is no definition of 'extraordinary drought' or of 'consumptive uses' (Powell Consortium 1995). The Lower

Basin currently has a higher priority than the Upper Basin under the 1922 Compact because 75 maf must be guaranteed below Lee Ferry in any 10 yr period. The operating rules for Lake Powell require the delivery of 8.25 maf to meet the 7.5 maf lower basin commitments plus the 0.75 maf share of the US commitment to Mexico. In the 1964 Arizona vs California Supreme Court decision, the US Supreme Court ruled that when flow drops below 7.5 maf to the lower basin the Secretary of Interior should allocate water first to those holding rights under prior appropriation. This includes 3 maf in California, 1 maf in Arizona and Nevada, and almost 1 maf to Indian tribes. The latter are not yet using their allocation, but there are plans to greatly expand water use on Indian lands. The Central Arizona Project allocations are subservient to the California allocations and then to Nevada. Within California a 1931 agreement sets priorities for the 4.4 maf Colorado River allocation with agricultural users in the Imperial, Coachella, and Palo Verde valleys first in line, and only then the Metropolitan Water District which serves Los Angeles and San Diego. Thus, sustained drought in the basin would first affect the Upper Basin, then Arizona, then Nevada and metropolitan California, then Californian agriculture and finally Mexico (Powell Consortium 1995).

### 3.5.2. Water rights law

Water rights in the Southwest are complex but provide a critical context for understanding the impacts of climate on water resources, irrigated agriculture, urban areas and ecosystems. The overarching legal doctrine regarding water in the western United States is that of prior appropriation, usually described simply as 'first in time, first in right' on a 'use it or lose it' basis. Taking the case of Arizona as an example, if you developed or diverted a water resource in Arizona prior to 1919, you have senior rights to that water so long as you use it. After 1919, a user could obtain water rights by applying for a permit for offstream beneficial use. The State Water Code of 1919 states that 'the water of all sources, flowing in streams, canyons, ravines or other natural channels, or in definite underground channels belong to the public and are subject to appropriation and beneficial use.' Beneficial uses include domestic, municipal, irrigation, stock watering, hydropower, recreation, wildlife, including fish, artificial groundwater recharge, and mining. This philosophy of beneficial use and prior rights, whilst assuring that some water users have assured water in time of drought, encourages the inefficient use of water and makes later users extremely vulnerable to climatic variability and change. For example, early irrigation diversions can obtain water in dry periods even if urban drinking water is scarce.

For many years it was not clear if the prior appropriation doctrine applied just to surface water or to groundwater as well. In 1953, the Arizona Supreme Court decided that the prior appropriation doctrine did not apply to groundwater, so that senior surface water rights could be negatively affected by more recent groundwater pumping with no legal recourse. Drought can increase groundwater extractions that then reduce in-stream flows (Glennon & Maddock 1994).

Water rights on American Indian lands are another important issue in the Southwest. Although for many years Native Americans had great difficulty in gaining rights to water and were extremely drought vulnerable, there is precedent to suggest that US federal lands, including Indian reservations, have senior water rights over others to take water for a 'reserved' use. In Winters vs United States (1908)—now known as the Winters Doctrine—it was found that an Indian reservation may reserve enough water to irrigate all of the 'practicably irrigable acreage' on the reservation with a priority dating from the treaty, act of Congress, or executive order that established the reservation. These 'reserved rights' are based on water held, or 'reserved,' by the federal government. In New Mexico, the rights of the Indian Pueblos predate even Winters because their sovereignty was recognized by the Spanish and in the transfer of lands from Mexico to the US in the 19th century. The Pueblos currently divert about 6% of the flow in the Middle Rio Grande valley (Niemi & McGuckin 1997).

In Arizona, a court case involving the Gila River in 1935 recognized that Indian lands might hold prior appropriation rights, later defined as the right to use water for all practicable irrigable acreage (PIA) of land on a reservation. In 1974, the Salt River Valley Water Users Association requested the adjudication of water rights on the Gila River, and in 1981 this was consolidated into a General Adjudication of water rights for that basin. The purpose of the Gila River Adjudication was to consolidate all diversely created and administered water rights into a single comprehensive determination of all rights. The adjudication resulted from the over-appropriation of surface water in the Gila River system, groundwater overdraft, and growing municipal water use. The Gila River Adjudication involves several thousand claimants (more than 8000 just in the San Pedro River basin) and 12 Indian Reservations and could result in almost 1230 thousand cubic meters ($Mm^3$) of water being assigned to Indian rights (Arizona Department of Water Resources 1997). This would affect the water rights along the San Pedro River, which flows into the Gila River, as well as along

the Santa Cruz River, if water transfers from the Colorado River are used in the Gila River settlement. This shift in rights and demand could reduce the vulnerability of Indian agriculture and communities to drought whilst dramatically increasing competition for water amongst non-Indian users.

The case Cappaert vs United States (1976) determined that federal lands can also have priority for water (reserved rights) on lands other than Indian reservations set aside for specific federal purposes such as National Parks and Forests. The Cappaert case also established that when a dispute exists between state and federal interests, federal rights take precedence. On the other hand, the ruling implied that the federal right reserves only 'that amount of water necessary to fulfill the purpose of the reservation, no more' (Arizona Department of Water Resources 1997; available at http://water.az.gov). The Court also held that federal reserved rights could protect water from subsequent diversion, whether the diversion is of surface or groundwater. In Arizona, the Cappaert ruling is important with regard to the San Pedro River, in that the establishment of the federal San Pedro National Riparian Conservation Area may establish reserved rights and may also be used to protect the habitat of other endangered species.

The US Endangered Species Act (ESA), which requires habitat protection for those species listed under threat of extinction, has brought a new set of issues and conflicts to the Southwest, because it necessitates the maintenance of in-stream flows for many species. In New Mexico the listing of the Rio Grande silvery minnow may limit diversions for other uses in drought years, and in the San Pedro, ESA protection of several animal and plant species may give in-stream flows priority in addition to the Cappaert decision.

### 3.5.3. Values

Changes in environmental values and perceptions can alter vulnerability to climatic variability and change. For example, the increasing value placed by some groups on in-stream water rights and recreation is shifting water allocations in ways that can increase overall demand and vulnerability of other sectors whilst reducing the vulnerability of ecosystems to drought and climate change. In New Mexico, studies demonstrate that natural ecosystem and recreation amenities are given considerable value by the state's residents and that this places a non-market value on water that would shift uses if water rights were more flexible or as water markets develop (Niemi & McGuckin 1997). Public opinion polls show that residents of the Southwest place considerable value on environmental protection, especially drinking water, and are willing to pay for secure and high-quality water resources (Case & Alward 1997). These values, reflected in water prices, mean that urban areas such as Phoenix, Tucson and Albuquerque have purchased agricultural land and water rights to ensure supplies to domestic users. The agricultural value of water is biased/subsidized by the considerable capital and maintenance costs borne by government agencies such as the Bureau of Reclamation, and some studies suggest that full cost pricing of irrigation water would result in land going out of production or to higher value crops such as chile rather than pasture in New Mexico (Niemi & McGuckin 1997).

As (or if) these values are reflected in institutional, legal, and market changes, the structure of water use and the response to fluctuations in supply may transform to conditions that better mirror the values of the contemporary Southwest. However, since institutional change is often a response to political power rather than public opinion, some fear that access to water, and the ability to cope with climate-related supply fluctuations will depend on money and influence, rather than need or vulnerability (National Research Council 1992, Office of Technology Assessment 1993).

There are institutional factors that mediate the human relationship to climate in sectors other than water in the Southwest. For example, on public lands the multiple responsibilities of Federal Agencies and the politics of public land management can make flexible responses to climate variability difficult. For example, the National Parks Service and the National Forest Service are both tasked with protecting resources while providing public access and recreation—even when a dry season means a high fire risk. The Bureau of Land Management leases to ranchers at relatively low cost and finds it politically difficult to raise grazing fees, fence off riparian areas, or control herd size in order to fund range recovery, protect ecosystems, or reduce overgrazing, especially during droughts (Nelson 1995, Bryner 1998).

Some groups in the Southwest are arguing for the privatization of government lands and for the absolute protection of private property rights and are strongly against regulations such as the ESA (Switzer 1997). There are also some strong feelings against land-use planning that permeate debates about development, ecosystem protection, and water (Baden & Snow 1997, Hess & Baden 1998). Such conflicts over the future of public land and land and water development in the American West are another set of frameworks and contested values that will affect future human-environment interactions in the region, including the ability to manage responses to climate variability.

## 4. CONCLUSIONS

Humans have occupied the Southwest for nearly 10 000 yr and have adapted and responded to climatic variations and changes throughout that time. Early inhabitants responded to climate in order to maximize hunting and gathering yields, developed irrigation canals and diversion structures to maintain agriculture in periods of rainfall deficit, and built homes to accommodate seasonal temperature changes. In the 20th and 21st centuries, the occupants of the Southwest have adapted with large-scale irrigation channels, water conveyance pipelines, groundwater pumps, flood-control structures, and air conditioning. Yet, these adaptations have significant financial, social, and environmental price tags attached. And some observers suggest that the society in the region has already overextended its adaptive resources and instead has mortgaged reserves that might be needed for future generations and created even greater vulnerabilities.

Given the rapid influx of people into the region, the significant economic growth, and competing demands for water and other resources, especially in urban areas, vulnerability to climatic variations is already increasing in some areas of the Southwest. The restructuring of agriculture, due in part to global economic forces, is shifting the types of crops grown in the region, in many cases to crops that require more water. In other areas productive agricultural and pasture land is rapidly being converted into urban developments. Given the large quantities of water tied to agricultural lands, municipal and other sectors needing more water are seeking to purchase water rights from these lands, diverting water from one sector to another. Interstate and intergovernmental compacts in the United States, and binational treaty obligations with Mexico, as well as unresolved water rights for American Indian tribes and riparian or in-stream uses, pose unique challenges and uncertainties for the region in managing water resources and developing adaptive strategies for droughts or climate changes.

The dominance of public lands in the Southwest means that government agencies are important stakeholders and land managers in the region. The ability to respond to climate variability and make the best use of climate information is constrained both by institutional obligations and by the tense politics of some public land management in the West.

The Southwest is also a region where significant segments of the population are disproportionately vulnerable to extreme climate conditions because they are poor, elderly, or otherwise marginalized. For example, differences in income, access to institutional resources, or employment options make some sectors of society less able to cope with the adverse effects of climate changes or to use climate information to guide decisions.

Overall, the Southwest United States is a region with considerable historical and contemporary sensitivity to climatic variations and where any future climate change could have a significant impact on human activities. This suggests that improved climate information could be of benefit to decision-makers within the region, so long as institutional structures and public attitudes provide the flexibility to use the information in appropriate ways.

*Acknowledgements*. Funding to support this research has come from the National Oceanic and Atmospheric Administration's Office of Global Programs, the Department of the Interior, National Park Service Intermountain Region, and the Morris K. Udall Foundation.

LITERATURE CITED

Baden JA, Snow D (eds) (1997) The next West: public lands, community, and economy in the American West. Island, Washington, DC

Bahre CJ, Shelton ML (1996) Rangeland destruction: cattle and drought in southeastern Arizona at the turn of the century. J Southwest 38:1–22

Bierbaum RM (1998) Preface: Regional assessments of climate change and policy implications. Clim Res 11:1–3

Brazel AJ, Evans KE (1984) Major storms and floods in Arizona, 1862–1983: compiled from the records of the National Weather Service. Laboratory of Climatology, Arizona State University, Tempe

Brown FL, Ingram H (1987) Water and poverty in the Southwest. Arizona, Tucson

Bryner GC (1998) US land and natural resources policy: a public issues handbook. Greenwood, Westport, CT

Byrkit JW (1992) Land, sky, and people: the Southwest defined. J Southwest 34:257–387

Case P, Alward G (1997) Patterns of demographic, economic and value change in the western United States: implications for water use and management. Western Water Policy Review Advisory Commission, Denver

Clark W, Dickson N (1999) The global environmental assessment project: learning from efforts to link science and policy in an interdependent world. Acclimations, September/October, US Global Change Research Program, Washington, DC

Delaker J, Proctor BD (2000) Poverty in the United States: 1999. US Census Bureau current population reports series P60-210. Government Printing Office, Washington, DC. Available at: www.census.gov/hhes/www/povty99.html

Daugherty AB (995) Major uses of land in the United States: 1992. Agicultural economic report 723. USDA Economic Research Service, Washington, DC

Durrenberger RW, Ingram RS (1978) Major storms and floods in Arizona, 1862–1967. Office of Arizona State Climatologist, Tempe

Eakin H, Conley J (2002) Climate variability and the vulnerability of ranching in southeastern Arizona: a pilot study. In: Yarnal B (ed) CLIMAS: Climate Assessment for the Southwest. CR SPECIAL 12. Clim Res 21:271–281

Easterling WE (1997) Why regional studies are needed in the

development of full. Global Environ Change Human Policy Dim 7:337
Finan TJ, West C, Austin D, McGuire T (2002) Climate vulnerability in the Southwest U.S.: an integrated assessment of the middle San Pedro river valley. In: Yarnal B (ed) CLIMAS: Climate Assessment for the Southwest. CR SPECIAL 12. Clim Res 21:299–310
Fisher A, Neff R, Barron EJ (2000) The mid-Atlantic regional assessment: motivation and approach. Clim Res 14:153–9
Gleick P (1988) The effects of future climate changes on international water resources: the Colorado River, the United States and Mexico. Policy Sci 21:23–39
Glennon RJ, Maddock TJ III (1994) In search of subflow: Arizona's futile effort to separate groundwater from surface water. Ariz Law Rev 36:567–610
Gummerman GJ (ed) (1988) The Anasazi in a changing environment. Cambridge, New York
Hartmann HC, Bales R, Sorooshian S (2002) Weather, climate, and hydrologic forecasting for the U.S. Southwest: a review. In: Yarnal B (ed) CLIMAS: Climate Assessment for the Southwest. CR SPECIAL 12. Clim Res 21:239–258
Hess K, Baden J (eds) (1998) Writers on the range. University of Colorado, Niwot, CO
Liverman D (1999a) Vulnerability and adaptation to drought in Mexico. Nat Resour J 39:99–115
Liverman D (1999b) Climate change and the borderlands: an introduction and assessment. Borderlines 7:23–39
Martin PS, Klein RG (eds) (1984) Quaternary extinctions: prehistoric revolution. University of Arizona Press, Tucson, AZ
McClain C (2000) Valley fever cases jump 50 percent in Pima County. Arizona Daily Star, May 2, p 1B
McDonald JW (1998) The upper basins' political conundrum: a deal is not a deal. Western Water Policy Review Advisory Commission, Denver, CO
Meko D, Stockton CW, Boggess WR (1995) The tree-ring record of severe sustained drought. Water Resour Bull 31: 791–801
Merideth R (2001) A primer on climatic variability and change in the Southwest. Udall Center for Studies in Public Policy and Institute for the Study of Planet Earth, University of Arizona, Tucson, AZ
Merideth R, Liverman D, Bales R, Patterson M (eds) (1998) Climate variability and change in the Southwest: impacts, information needs, and issues for policymaking. Udall Center for Studies in Public Policy, University of Arizona, Tucson, AZ
Meyer MC (1984) Water in the Hispanic Southwest: a social and legal history, 1550–1850. University of Arizona Press, Tucson, AZ
Meyer W (2000) Americans and their weather. Oxford University Press, New York
Miles EL, Snover AK, Hamlet AF, Callahan B, Fluharty D (2000) Pacific northwest regional assessment: the impacts of climate variability and climate change on the water resources of the Columbia river basin. J Am Water Resour Assoc 36:399–420
Miller K (1997) Climate variability, climate change, and western water. Western Water Policy Review Advisory Commission, Denver, CO
Morehouse BJ, Carter RH, Tschakert P (2002) Climate sensistivity of urban water systems in Phoenix, Tucson, and Sierra Vista, Arizona. In: Yarnal B (ed) CLIMAS: Climate Assessment for the Southwest. CR SPECIAL 12. Clim Res 21:283–297
Morrison J, Gleick P (1997). Water resources supply and use in the Colorado River basin. Commission on Environmental Cooperation, Montreal
National Research Council (1992) Water transfers in the West: efficiency, equity and the environment. National Academy, Washington, DC
National Research Council (1999) Human dimensions of global environmental change: research pathways for the next decade. National Academy, Washington, DC
Nelson RH (1995) Public lands and private rights: the failure of scientific management. Rowman & Littlefield, Lanham, MD
Niemi E, McGuckin T (1997) Water management study: upper Rio Grande basin. Western Water Policy Review Advisory Commission, Denver, CO
Office of Technology Assessment (1993) Preparing for an uncertain climate. Government Printing Office, Washington, DC
Olinger T (1998) Indian water 1997: trends and directions in federal water policy, a summary of the conference proceedings. Western Water Policy Review Advisory Commission, Denver, CO
Pagano TC, Hartmann HC, Sorooshian S (2002) Factors affecting seasonal forecast use use in Arizona water management: a case study of the 1997–98 El Niño. In: Yarnal B (ed) CLIMAS: Climate Assessment for the Southwest. CR SPECIAL 12. Clim Res 21:259–269
Paterson K (1998) New Mexico border colonias. BorderLines 6:42
Powell Consortium (1995) Severe sustained drought : managing the Colorado River System in times of shortage. Water Resources Research Center, University of Arizona, Tucson, AZ
Riebsame W (1998) Atlas of the new West. Norton, New York
Riebsame WE, Wescoat J, Morrisette P (1998) Western land use trends and policy: implications for water resources. Western Water Policy Review Advisory Commission, Denver, CO
Schmandt J, Ward G (1991) Texas and global warming: water supply and demand in four hydrological regions. LBJ School of Public Affairs, University of Texas, Austin, TX
Sellers WD, Hill RH (eds) (1974) Arizona climate, 1931–1972. University of Arizona Press, Tucson, AZ
Sheppard PR, Comrie AC, Packin GD, Angersbach K, Hughes MK (2002) The climate of the US Southwest. In: Yarnal B (ed) CLIMAS: Climate Assessment for the Southwest. CR SPECIAL 12. Clim Res 21:219–238
Sheridan T (1995) Arizona: a history. University of Arizona Press, Tucson, AZ
Solley WB (1998) Estimates of water use in the western United States in 1990 and water-use trends, 1960–90. Western Water Policy Review Advisory Commission, Denver, CO
Solley WB, Pierce R, Perlman H (1998) Estimated use of water in the United States in 1995. US Geological Survey Circular 1200. Government Printing Office, Washington, DC
Sprigg WA, Hinkley T (eds) (2000) Preparing for a changing climate: the potential consequences of climate variability and change: Southwest. Institute for the Study of Planet Earth, University of Arizona, Tucson, AZ
Stern PC, Easterling WG (eds) (1999) Making climate forecasts matter. National Academy, Washington, DC
Swetnam TW, Allen CD, Betancourt JL (1999) Applied historical ecology: using the past to manage for the future. Ecol Appl 9:1189–1206
Switzer JV (1997) Green backlash: the history and politics of environmental opposition in the United States. Lynne Rienner, Boulder, CO
US Census Bureau (1998) 1997–98 state and metropolitan area data book. Government Printing Office, Washington, DC

US Economic Research Service (1997) Agricultural resources and environmental indicators, 1996–97. Agricultural Handbook Number 712. US Department of Agriculture, Washington, DC

US Global Change Research Program (2000) Climate change impacts on the United States: the potential consequences of climate variability and change: overview. Cambridge University Press, New York

Yarnal B (1998) Integrated regional assessment and climate change impacts in river basins. Clim Res 11:65–74

*Submitted: May 15, 2000; Accepted: June 21, 2001*

*Proofs received from author(s): October 18, 2001*