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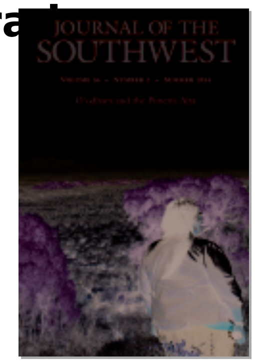

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River of Change: An Environmental History of Climate and Water Management in the Upper Little Colorado Watershed

Thomas Finger and Barbara Morehouse

Perhaps nowhere in the United States has climate and water resource interaction been more closely observed than in the U.S. Southwest (see, e.g., Austin 1988; Worster 1985; Reisner 1993; Sheridan 2001), and with good reason. Overall, semiarid to arid conditions predominate. These conditions, together with wide variability in temperature and precipitation over time and space, challenge even the most earnest human efforts to sustain livelihoods and communities. Scientific studies and popular literature alike reflect recurrent episodes of overexploitation of natural resources due to inadequate recognition or acceptance of environmental limits such as water availability.

Accretion of local knowledge and experience provides a mechanism for anticipating and adapting to the vicissitudes of variability and change. However, factors such as reliance on faulty heuristics (Nicholls 1999), occurrence of events falling outside the range of local memory, policies that restrict decision options, and narrow focus on immediate economic returns can render such knowledge ineffective at best and destructive at worst. Science-based knowledge and predictive capabilities provide avenues for improving decision processes in the face of interacting environmental and societal stresses. To be accepted and used appropriately, such knowledge needs to be framed in ways that mesh well with local values and practices. Environmental histories that create a contextual account of embedded experience, values, and practices provide insights useful to this task.

Recent extended dry conditions in the U.S. Southwest have prompted efforts by researchers and forecasters to develop climate information products useful at local and regional scales for addressing drought

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impacts. This paper provides an environmental history of climate and water resource management for the Upper Little Colorado watershed in northeastern Arizona, with a focus on the hundred years between the mid-nineteenth and mid-twentieth centuries. The study, funded through the NOAA-funded Climate Assessment for the Southwest (CLIMAS) project, provides insight into the experiences, values, knowledge, and practices that have produced conditions existing today. This type of contextual information, if integrated into development of plans, decision processes, and decision tools, holds promise for improving citizens' acceptance of and support for policies aimed at ensuring the sustainability of the watershed's closely coupled human and natural systems.

Based on established historiographic methods, this study aims specifically to uncover how communities and individuals in the watershed have developed and managed water resources in the context of climate variability, especially drought. We present a brief discussion of the precolonial land- and resource-use patterns, and then examine patterns, practices, and events of the past two hundred years. Though we briefly discuss contemporary conditions and trends, we focus on the period between roughly 1850 and 1950. This time period represents early settlement and resource exploitation practices, the more extensive Mormon colonization period of the late nineteenth century, and significant changes that occurred in the ensuing decades. Our analysis considers local experience as well as how local entities have negotiated water shortages in the evolving context of state and national laws and institutions.

As discussed in more detail later, Mormon settlement and agrarian practices are especially important to consider in examining conditions in the watershed today. These first Anglo-American settlements profoundly affected subsequent patterns of population distribution and resource use. The period of population expansion following initial Mormon settlement taxed the water resources available within the basin, and prompted development of local knowledge as well as adoption of successive technologies to address water scarcity problems. Cultural values that emphasized agrarian lifestyles, even while acknowledging that the region was far better suited for animal husbandry and grazing than for farming, strongly influenced the choice of strategies for coping with water resource challenges. Rather than adapting to grazing lifestyles typical of arid areas, residents built dams and introduced groundwater pumping as strategies for supporting crop cultivation. This approach still prevails today.

Post–World War II introduction of mining operations and power-generation facilities into the watershed, combined with rapid growth in tourism and recreation, compounded the stresses on water resources in the basin. By the late twentieth century, water demand throughout the basin combined with recurrent drought led to rising concerns about climate vulnerability. While recognition of local authority over water development and use persists, momentum has grown for introducing institutional mechanisms at the state and federal levels to increase adaptive capacity. Provision of scientific information about climate, hydrology, and resource management and promotion of structured planning processes are among the most prominent contemporary efforts to improve decision making at the watershed and local levels in the U.S. Southwest. In the process, the region's environmental history will be influenced as well.

The Little Colorado River Basin: A Case Study

The evolution of economic, social, and cultural structures and dynamics in the Upper Little Colorado watershed reflects processes unfolding throughout the western United States. Occupied by indigenous peoples when the Spanish explorers first arrived in the early 1600s, southwestern landscapes and livelihoods were significantly transformed by Spanish introduction of livestock grazing and development of towns beginning in the mid-1600s, followed by expansion of farming activities with the arrival of Anglo-American settlers beginning in the mid-1800s and increasing after the end of the U.S. Civil War in 1865. Mormons wrought some of the most influential landscape transformations during this era through their extensive efforts to establish farms across the region, wherever growing seasons were long enough and sufficient water was available. The arrival of railroad lines in the late 1800s produced another round of profound socioeconomic changes across the larger region, prompting rapid expansion of livestock herds, introduction of mining operations, and decimation of forests to provide energy for early mining and industrial needs. Cities such as Denver and Phoenix grew rapidly, especially at the end of World War II when families across the nation began moving westward in search of better lives. The growth of these urban areas, together with increased interest across a broad range of the U.S. population in natural-area tourism and recreation, introduced a new dynamic to rural areas: temporary—and often large—influxes of people during the prime months of summer (for hiking, fishing, etc.) and winter (for skiing and other winter sports), as well as growth in the number of cabins and homes owned by residents of the urban centers and, increasingly, by retirees. Innovations in Internet technologies over the past decade and a half have allowed people to work in remote areas, further swelling the number of permanent residents in some towns. These changes, in turn, have fueled growth of rural towns and the number and variety of services offered in these towns. Meanwhile, across the entire time span from the arrival of the Spaniards to the present day, the native peoples of the western United States have sought to sustain their cultures and livelihoods, often under conditions of considerable adversity. They lost large portions of their previous domains and found themselves largely marginalized from the dynamics of the dominant society, yet their lands, practices, and experiences continue to stand as testaments to pre-European ways of knowing and being. These landscapes also testify to the profound disparities in social and economic well-being that exist among many tribal members. The Upper Little Colorado watershed reflects these conditions and dynamics.

Social Constructions and Biophysical Realities

As historian Elliott West maintains, there is always a dissonance between how humans view the world and how they actually fit within it. Humans have the ability to imagine changes in the world even as they confront it: they visualize new connections and relationships that are not yet present (West 1998). The American West is one of the places where imagination has crucially influenced changes to the natural world, producing a series of imagined landscapes (Cronon 1991; Limerick 1987; Morrissey 1997; Nash 1982; Reisner 1993; White 1991; Worster 1985). Here, broad swathes of arid and semiarid landscapes have been transformed into irrigated agricultural landscapes and urban settlements. The Little Colorado River Basin, whose modern settlement patterns grew out of Mormon visions of Zion and its related agrarian landscapes, is a microcosm of social constructions of the arid/semiarid West. The landscapes we see today, indeed, are the products of what historian Mark Fiege calls "vivid metaphor and compelling myths" (Fiege 1999: 8).

The Little Colorado River watershed provides a useful focal point for investigating the environmental history of relationships among climate,

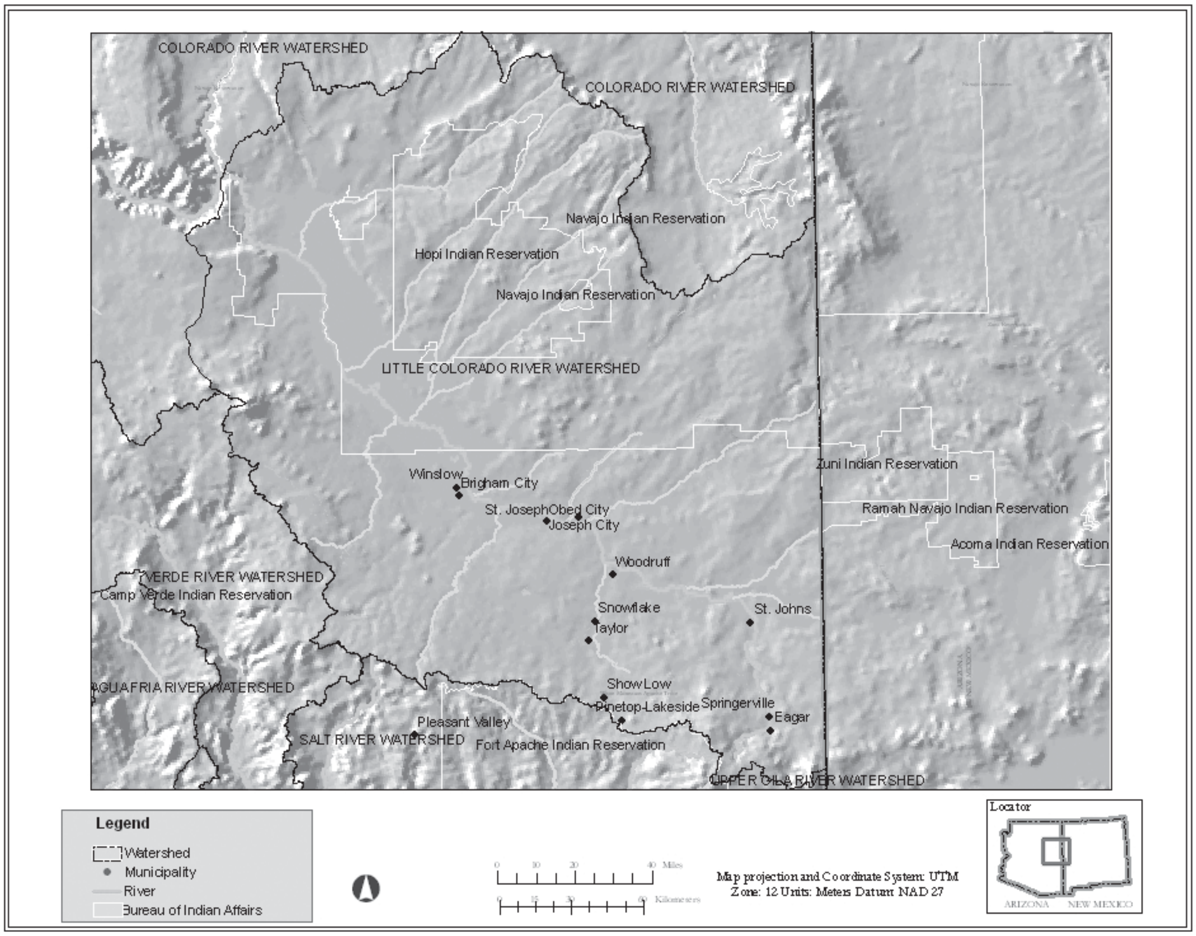

Figure 1. Map of the Little Colorado watershed.

natural systems, and human systems: it is characterized by significant climatic and related environmental fluctuations, and it gathers into an identifiable geographical space a coherent narrative of human-environment relationships over time. The watershed, 26,964 square miles in size and ranging in elevation from some 4,200 feet to more than 7,700 feet above sea level, is located in the northeastern corner of Arizona (figure 1).[1] The area is characterized by topographic complexity, including elevational changes that produce spatial variability in temperature and precipitation and related ecological variability. While the area's climate is characterized by high levels of variability over decadal and longer time spans, climate-division data reveal long-term temperature patterns of cold winters and mild summers and a bimodal precipitation pattern of rather wet winters and summers, with dry spring and relatively dry fall seasons (figure 2). These data show an average annual temperature for the area of 55°F,

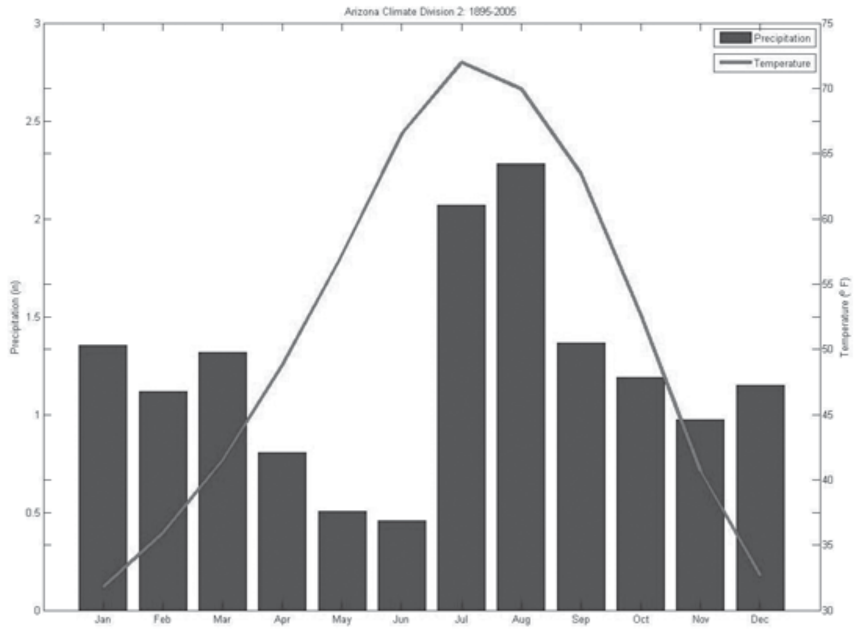

Figure 2. Average annual temperature and precipitation for Arizona Climate Division 2, 1895–2005. (Graph by Ben Crawford, CLIMAS project)

with average lows dropping to 7°F in winter (in the highest elevations) and ascending to highs of around 80°F in the summertime (Sheppard et al. 2002). It is notable, however, that over the past century overall temperatures have risen approximately 2.5 degrees (figure 3). Though highly variable over time, precipitation averages approximately thirty-six inches a year at higher elevations, and about eight inches a year at the lowest elevations (figure 4).[2]

Scientific advances in the past several decades have improved understanding and predictive capability with regard to one of the major winter climatic influences on much of the Southwest: the El Niño–Southern Oscillation (ENSO). During El Niño years, the region tends to get wetter than average winters, while during La Niña years, winters are likely to be dry. Current forecasting capabilities allow skillful prediction of possible ENSO conditions as early as the fall preceding the winter rainy season; climatologists update these forecasts monthly based on measurements such as trends in sea surface temperatures in the tropical Pacific Ocean. The climate of the summer months, on the other hand, remains difficult to predict very far in advance. Unlike the broad-scale precipitation associ-

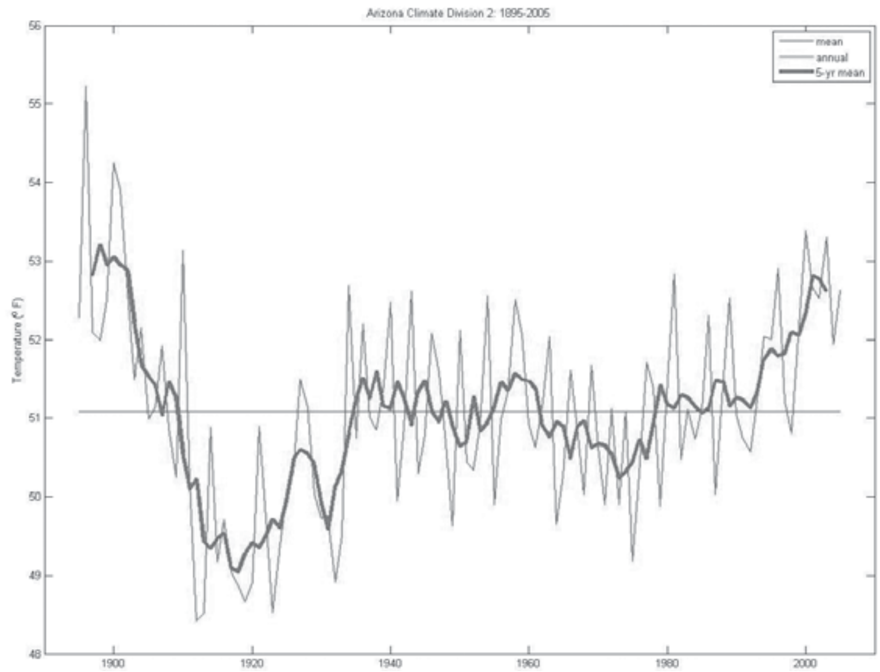

Figure 3. Temperature trends for Arizona Climate Division 2, 1895–2005. (Graph by Ben Crawford, CLIMAS project)

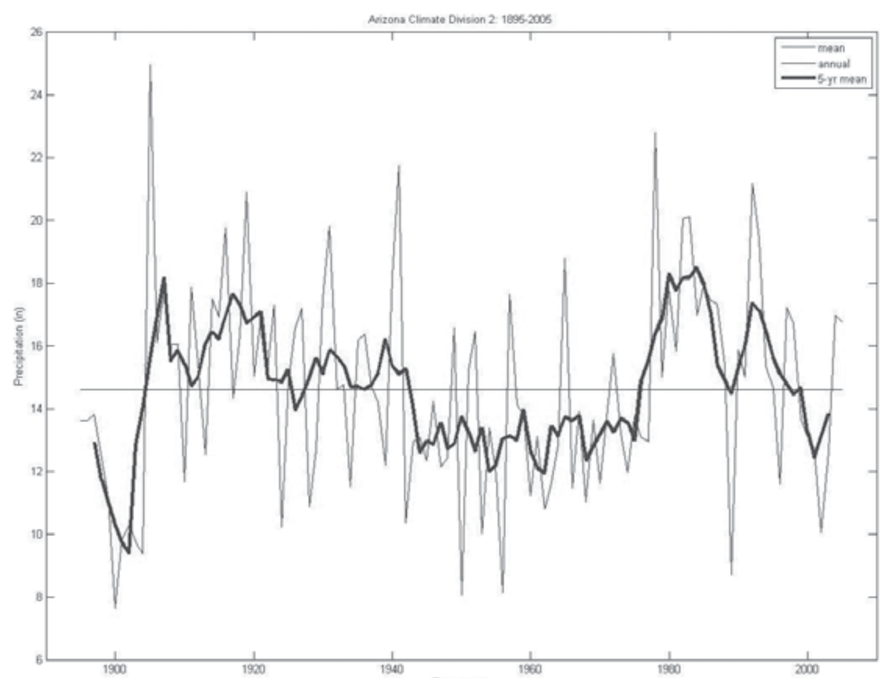

Figure 4. Precipitation trends for Arizona Climate Division 2, 1895–2005. (Graph by Ben Crawford, CLIMAS project)

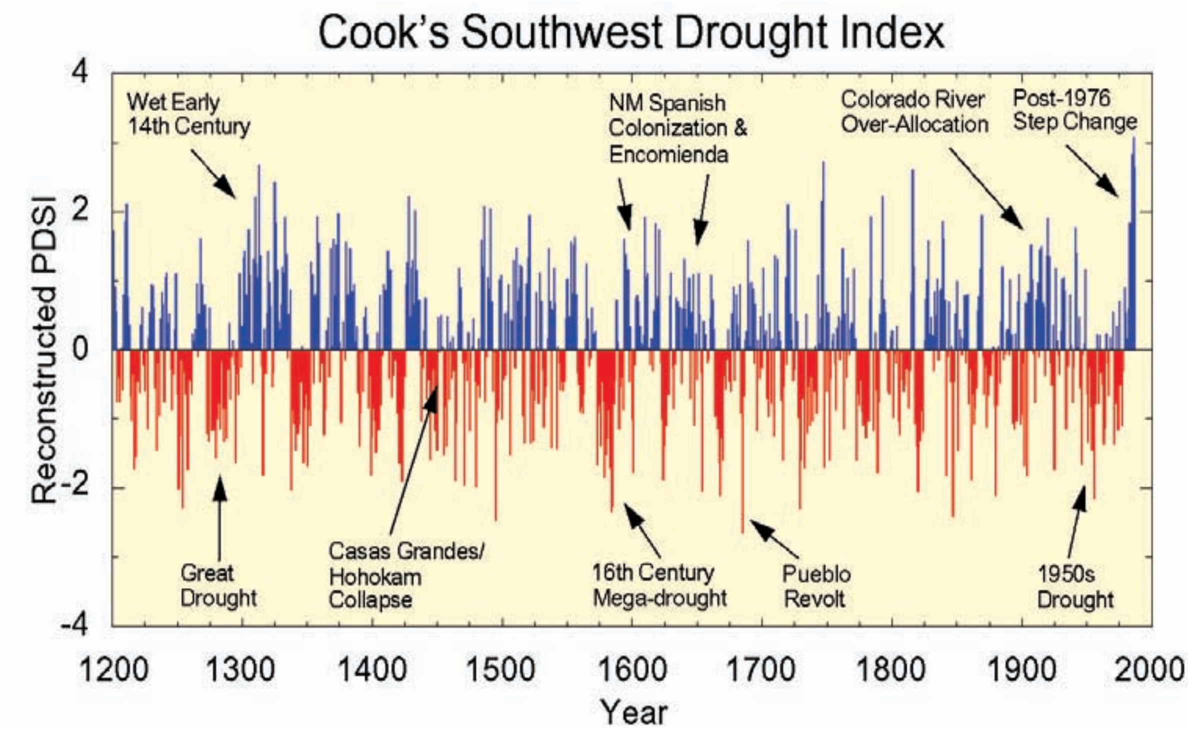

Figure 5. Cook's Southwest drought index, showing long-term moisture trends in the U.S. Southwest. (Graph courtesy of Julio Betancourt, U.S. Geological Survey; based on research by Ed Cook, Lamont-Doherty Earth Observatory)

ated with winter storm fronts, summer climate conditions are characterized by highly localized, often intense thunderstorms associated with the North American Monsoon. As noted previously, the spring season tends to be very dry, but may include significant rain events triggered by synoptic-scale conditions such as tropical cyclones.

Paleoclimatic research highlights longer-term trends in the region's climate, including multi-decadal periods of drought alternating with periods of near-average or above-average precipitation (figure 5; see, e.g., Bannister, Robinson, and Warren 1967; Bannister, Dean, and Robinson 1968; Dean 1988; Ni et al. 2002). As discussed later, such shifts have profoundly affected natural and human systems in the Little Colorado River Basin since the arrival of the first humans in the area.

Most of the land use in the basin is rural. Indian lands encompass almost half the territory, and only about 23 percent of the land is in private ownership (Little Colorado River Partnership, www.water.az.gov/dwr/ content/Find_by_Program/Rural_Programs/ content/map/ UppLitColRivPar.htm, accessed 4/24/06). Forests of blue spruce, Douglas fir, and ponderosa pine dominate the higher elevations, interspersed with grasslands. Drier, lower-elevation areas of the watershed are characterized by sparsely vegetated desert scrub landscapes.

The Little Colorado River, with its tributaries, is the only significant source of surface water in the region. There are, however, many natural seeps and springs. The river, which is generally narrow and shallow and is fed by some thirty smaller tributaries, extends 250 miles between the White Mountains and the Black Mesa Highlands, eventually emptying into the Colorado River. Snowpack from the White Mountains is the primary source of water to the stream; in addition, water from the Coconino Aquifer, also flowing south from the White Mountains, surfaces as a series of springs along the main stem.

The water resources and vegetation coverage of the area are both influenced by climatic conditions, which are marked by high inter-annual to decadal and longer-term variability, as well as by geographical variability across the watershed (see, e.g., Sheppard et al. 2002). Winter precipitation and related snowpack conditions are crucial to sustaining both surface water and groundwater resources in the basin. Rain during the summer season also contributes to surface water availability although, due to the fast-flowing runoff produced by strong storms, summer precipitation is not a major contributor to groundwater aquifer recharge.

Paleo-environmental History of the Watershed

Pre-Columbian Native American land- and water-use practices provide our earliest evidence of interactions between climate changes and corresponding cultural adaptations in the region. The Ancestral Pueblo, Hopi, and Navajo peoples all developed their own water management and shortage-mitigation strategies that, unlike drought adaptations in the nineteenth and twentieth centuries, hinged on mobility and community interconnectivity.[3] Historians and archaeologists have pieced together a complex, evolving narrative of the earliest known habitations in northern Arizona, with most agreeing that humans entered the watershed between 30,000–11,000 BCE and 9500–9000 BCE (Gumerman and Gell-Mann 1994; Jones and Tagg 1994). Archaeological evidence indicates that a mixed strategy of hunting, gathering, and horticulture prevailed by at least 600 BCE, and that in many areas, settlements were seasonal in nature. Responses to drought or flood events revolved around simply moving some distance away from the affected areas. With a shift toward greater agricultural complexity, populations grew (see Gumerman and

Dean 1989), as did the use of available resources. The growth did not occur along a straight line, however. An archaeological study of the Silver Creek watershed revealed significant population increases in the region around AD 900–950 and AD 1000–1050, but found a decline in population between AD 1050 and 1100. At least some of the fluctuation in demographic numbers seems to derive from a change in settlement patterns from small to large: the study found there was a population decline in small sites and an increase in large sites during AD 1100–1150 (Mills, Herr, and Van Keuren 1999). While scholarly disagreement persists regarding the temporal organization of increasing settlement complexity in the Southwest, most agree that by AD 1000 to 1150 human population growth and settlement densities had produced high levels of intercommunity interaction (Gumerman and Dean 1989). Relatedly, increased reliance on agriculture for subsistence increased local vulnerability to climatic variability, since the agrarian groups were less free to leave their crops and move to other areas than were hunter-gatherers. With reduced mobility, the Ancestral Pueblo peoples, for example, changed their practices to emphasize reliance on intercommunity interactions and mixed subsistence patterns (Gumerman and Dean 1989). Communities along the Little Colorado River appear to have adopted a local system of shifting agriculture. For example, groups inhabiting the Homol'ovi area north and east of present-day Winslow, Arizona, shifted their agricultural activities in response to climate-influenced environmental conditions. As local population expanded and individuals were better able to support larger-scale irrigated agriculture, floodplain agriculture came to predominate along the Little Colorado River. During low river flows, however, these farmers were still able to grow crops using runoff and seepage fields, on stabilized sand dunes to the east of the floodplain (Lange 1998).

At the Ancestral Pueblo settlements in nearby Chaco Canyon (located in present-day northwestern New Mexico) agricultural and timber resource demands from a growing population severely taxed the ability of the environment to sustain a large population center. A dry period between AD 1080 and 1100 probably caused many of the inhabitants to seriously consider the efficacy of unchecked demographic growth in the canyon (Lekson 2006). Agricultural choices would have been limited, for as population grew, ever more marginal land was brought under cultivation. With the advent of deep sustained drought in the twelfth and thirteenth centuries (figure 5), the capacity of the land and water resources throughout the Colorado Plateau to support large, sedentary settlements diminished radically (Dean 1988).

Not much is known about activities in the region between the era of Ancestral Pueblo decline and the arrival of the Spaniards, though it is clear that the Spaniards changed the ecology of the region considerably through the introduction of livestock. Research suggests that the Navajo people entered the area in the fifteenth and sixteenth centuries, perhaps reflecting a strategy of migration from the Rocky Mountains of Colorado and New Mexico to escape the drought that occurred in that area during the late 1500s (Bailey 1980). Navajo subsistence practices revolved around hunting (by men) and agriculture (by women). Though some evidence of granaries suggests the existence of surpluses, trading between settlements was likely to occur only when climatic conditions favored sufficient surplus production (Brooks 2002). The introduction of Spanish livestock from Spanish settlements on the upper Rio Grande in the seventeenth century resulted in adoption by the Navajo of sheepherding; the demands of pastoralism, in turn, led to a dramatic expansion in the people's use of the land and its resources, as well as to social stratification and military aggressiveness (Bonte and Galaty 1991). At the same time, pastoralism also concentrated people and animals into the areas where water and forage were in greatest abundance (West 1998). As resources were depleted, Navajo residents migrated west and south to new lands, leading to pressures on the neighboring Hopi and Apache populations (Mauss 2003). The drought of 1736–48 prompted yet another southwesterly migration (Brooks 2002).

Euro-American Arrival, Mormon Settlement, and New Environmental Stresses

Although Spanish expeditions entered the area in the late 1500s, the Upper Little Colorado watershed saw little non-native settlement until the arrival of the first Mormon settlers in 1876.[4] These individuals brought with them an ethos of sedentary agriculture based on irrigation technologies and corresponding religious institutions that, among other things, determined settlement distribution, influenced land- and water-use practices, and provided a framework for dealing with drought.

The arrival of Mormon settlers was preceded by exploratory trips undertaken by Mormon Church members between the 1850s and the early 1870s. Church leaders, including Brigham Young himself, found the area to be acceptable for Mormon expansion and redemption of desert lands and, equally importantly, believed that the move would facilitate religious conversion of the area's Hopi and Navajo inhabitants. Young commanded specific groups, chosen for their devotion to the faith and their loyalty, to move from Utah to the Little Colorado watershed and establish self-sufficient communal orders (including communal ownership of water) that would be based on irrigated agriculture.

The settlers arrived at an auspicious time, preceded as it was by two five-year periods of wetter than average conditions: the period from 1833 to 1842, with a total of eighty-four inches of precipitation, was the second wettest decade on record in the region; the years from 1865 to 1869, with almost forty-four inches of total precipitation, constituted the third wettest five-year period (figure 5; Ni et al. 2002).[5] It was during the latter period that the Mormon Church sent the series of exploration parties to the watershed. Given precipitation conditions in the years before their arrival, it is perhaps not surprising that their reports depicted the area in favorable terms. It is interesting, however, that the settlers viewed the many Indian ruins in the area not as a warning about the dangers of overtaxing the environment with excessive human occupation, but as a sign that through their religious work the land could be resettled: "to our settling this new land, we had evidence that this land has been densly [*sic*] populated, this choice land will be blessed according to our faithfulness" (J. Smith 1881).

The reports encouraged Mormons to migrate to the area but also generated unrealistic expectations with regard to the region's agricultural capacity (see, e.g., Jackson 1970).[6] Ironically, in their efforts to protect their religious beliefs and practices and avert competition over land and ideology (*Journal of Discourses* 1862), Mormons often sought out lands deemed undesirable by other people. In the Little Colorado watershed, as discussed in more detail later, realization of the full extent of the limits of the land and its resources emerged all too soon with the return of deep and long-lasting drought conditions in the 1890s (figure 5).

Throughout the colony, in local church and community meetings, the settlers talked of trials from God and the need to improve the land through communal endeavor and thus spread Mormonism to as many lands as possible (Leone 1974, 1979). Limiting the colony's success, however, was their philosophy, which focused not on how much rain fell or how much water was in the river, but on how hard they worked at improving the land. The Mormons in this way were like many other western settlers who believed that a religious work ethic would transform arid land into agricultural paradise (H. Smith 1950). This logic dictated that through producing and sustaining a thriving agricultural community, they would achieve victory over natural forces. The settlements in Utah had proven that victory was possible: in 1879 Wilford Woodruff, future president of the Church, "spoke of the first settlement of Utah, that it was a desert, the country is now full, and we have not got room. Zion has to lengthen its cords, it matters not where we are. . . . It is our calling to build up the Kingdom of God" (Eastern Arizona Stake 1979–1886).

The topography of the region, which includes steep slopes and elevational changes that influence local ecological forms and processes, makes agriculture challenging at the best of times and under the best of circumstances. At the time of Mormon settlement, the best agricultural areas lay in the southern portion of the watershed; here water was most abundant and flooding was less intense. However, although many joined Jacob Hamblin in recognizing that the ecology of the watershed was, overall, best suited for grazing—sheep grazing was the primary land use in the area when the Mormons arrived—most Mormons acted on their desire to plant grains and thus improve the land to a "higher" form of land use. As one settler put it, "our people are an agricultural people and wish to beautify and adorn their homes and to improve and cultivate the land. I believe that the Lord has selected this new land for his Saints to gather to, as in thickly populated places wickedness is more prevalent. . . . In these new places there is a feeling of grandeur, a feeling that brings God nearer to us, and brings us nearer to Him" (Snow, quoted in J. Smith 1881). Creating this Kingdom of God required building dams and water-diversion projects, which would eventually render much of the river channel near the settlements devoid of riparian vegetation.

Upon their arrival in the basin, Mormon settlers identified two main areas for community development (see Peterson 1973 for a history of early Mormon colonization in the area). One was in the middle of the river's length, in an area stretching from modern-day Winslow to the town of St. Johns, where a few Mexican settlers had already established homes near a post built by Solomon Barth to supply soldiers stationed at Fort Apache. These early settlers, who herded sheep and grew a little grain (Fish 1895[?]), were most likely immigrants from New Mexico who were attracted to the supply post. A small settlement also existed on Silver Creek, near present-day Snowflake, when Henry Stinson arrived and began building irrigation ditches there in the early 1870s (Fish 1895[?]).

The first Mormon settlers had little knowledge about the Little Colorado River or its flow regime, or about the ecological and climatic processes of the region. However, over the last quarter of the nineteenth century and first decades of the twentieth century, they built, in their church meetings, a body of local knowledge and series of strategies for responding to climatic stress. Their approach, which blended observations of local conditions with religious doctrine, fostered community cohesiveness at the same time that it sought to reduce vulnerability to environmental stresses. As settler Fredrick Christensen observed, "It [is] nescessary [*sic*] to learn by experience hence we should school ourselves and be prepared to return back to the presence of our Father. Let us stick to this work, for this is a preparation to go back and redeem the Center Stake of Zion" (St. Joseph Stake Minutes, 1878).

The irrigation-based agricultural livelihood practices of the Mormons, especially during the early years before the introduction of water pumps and sources of energy to run them, dictated a settlement distribution pattern that was largely based on proximity to the river and the ability to take advantage of gravity to direct flows into the fields. Settlers' decisions about where and how to plant were also influenced by ecological conditions that had been produced by the previous series of wet years. Yet, with the onset of deep drought in the 1890s, much of the knowledge that had informed planting decisions had to be rethought. Lack of sufficient reservoir storage limited the range of options available to some farmers, while sporadic flood conditions forced others to deal with damage to farmlands and structures created by dam failures.

The spatial and temporal variability of stresses on the communities in the watershed reflected to a large extent, then as today, spatial and temporal variability in climatic and hydrologic conditions. This variability helps account for the fact that some of the Mormon settlements established with high expectations did not survive past the nineteenth century. The settlements of old Taylor, Obed City, and Brigham City were among the earliest communities established, having been built by the first group of migrants arriving in 1876, yet all were virtually abandoned before the beginning of the twentieth century. Obed, located amid wetlands, dissolved in the wake of a malaria outbreak in 1877 (Jensen n.d.). At old Taylor and Brigham City, repeated dam failures and resulting crop failures led to the communities' demise. Woodruff often borrowed food supplies and manpower from other settlements, due to its exposure to spring and late-summer floods: the settlement was located below the confluence of a seasonal tributary with the Little Colorado River. Between 1876 and 1890, the settlement experienced ten dam failures. Thirteen dam failures occurred near the settlement of St. Joseph over the same period.

Archival information indicates that these downstream communities (figure 1) have always been more susceptible to flooding and water shortages than their upstream neighbors. People living in the downstream stretches of the river had to depend on surface water that was infamous for its unpredictability and its heavy silt load. These communities were eventually forced to resort to groundwater to overcome problems caused by irrigation activities on the main channel of the Little Colorado River. Dissatisfaction with communal institutions arose during the later decades of the nineteenth century, eventually resulting in their abandonment. The demise of the communal culture occurred in no small part because of the difficulties in sustaining lives and livelihoods in the region (Peterson 1986).

More broadly, though some settlements were successful and remain thriving communities today, the early Mormon experiences reveal the types of problems that arise when significant disparities exist between values and livelihood practices on one hand and inescapable environmental limits on the other. Many settlers, upon abandoning communities in the lower basin, moved upstream to establish new towns such as Snowflake and St. Johns. Here they found greater success, for they faced much less difficulty in developing surface water and groundwater resources. The settlement of Snowflake, for example, purchased from Henry Stinson in 1878, quickly became the most productive agricultural settlement in the region because of its relatively rich water resources. Silver Spring and Silver Creek were—and still are—the most consistent water sources in the basin (Eastern Arizona Stake 1879–1886; Flake and Clayton 2000; Abruzzi 1985, 1993; ADWR 1989). Rather than fluctuations in water availability, the primary challenge for the upper-basin settlements such as Springerville, Eager, Alpine, and Pleasant Valley was the short growing season due to higher elevations.

Yet even in these communities, concerns about water shortage persisted. In 1886, for example, the Joseph City Irrigation Company mandated a fee of $7 per acre for water used by its members. The revenues were to be used for building and maintaining water infrastructure (Allen

City Minutes 1876–1886). These fees continued to rise as St. Joseph's water problems persisted: there was insufficient water when they needed it in the spring, and too much water when they did not need it in the late summer. By 1894, water fees had risen to $20 per acre, forcing individuals to plant more acreage (McLaws 1894).

With the arrival of the railroad in 1881, communities had access to more sophisticated irrigation and water-diversion technologies. At the same time, however, the railroad brought large-scale cattle grazing into the watershed (*Arizona Gazette,* Feb. 26, 1915). The relocation from Texas of the Aztec Land and Cattle Company (also known as the Hashknife Outfit), with herds of as many as 40,000 cattle, was particularly instrumental in driving environmental change. Mormon settlers strongly objected to the cattle operators' encroachment on and claiming of vast tracts of land, noting a lack of respect for the rights of others (LeRoy and Wilhelm 1982). The issue of encroachment was especially critical to the Mormons, for legal practices at that time persistently failed to officially recognize Mormon settlement claims.

A series of wet years in the late 1880s (figure 5), coinciding with the arrival of the Hashknife outfit, prompted the group to ship in even more livestock and eventually to run 150,000 head of cattle and 120,000 head of sheep in the area. These animals shared the range with Mormon herds and with greatly increasing numbers of Navajo sheep, thus placing enormous stress on the area's rangelands.[7] Conditions changed, however, due to deep drought beginning in the mid-1890s and extending to 1904. During this time period, the area received less than half the precipitation that had fallen during the previous wettest five-year periods. During the five-year period in the depth of the drought, 1900–1904, total precipitation amounted to a little less than twenty inches (Ni et al. 2002). The environmental and social impacts were huge. Mormon residents commented that this drought had "no parallel in recorded history" (LeRoy and Wilhelm 1982); water was scarce, and the grass disappeared. One settler observed, "It is stated that three fourths of all the stock along the river will die. The stock men feel about ruined and the outlook looks dark for all classes of business" (Fish 1895[?]). Widespread erosion and siltation of waterways were among the environmental effects of the interactions between drought and overgrazing. The comparison with conditions when the Mormons first arrived was stark:

> When we came to Arizona in 1876, the hills and plains were covered with high grasses and the country was not cut up with ravines and

> gullies as it is now. This has been brought about by overstocking the ranges. On the Little Colorado we could cut hay for miles and miles in every direction. . . . Water followed the cattle trails and cut the country up. Later tens of thousands of cattle died because of drouth and lack of feed and disease." (quoted in Tellman, Yarde, and Wallace 1997).

A study of arroyo-cutting in the Southwest in the late nineteenth and early twentieth centuries (correlating roughly with the years of Mormon settlement) found widespread erosion throughout the region. During this time, the Southwest was characterized by rapid and pronounced erosion as well as by the desiccation of river valleys. Social factors limited locally to the watershed, such as Mormon irrigation practices and cattle grazing by the Hashknife, constituted one but not the only driver of erosion (Cooke and Reeves, 1976). Indeed, erosion and arroyo cutting, especially on the Little Colorado, is best explained as the outcome of human activity combined with climatic variability and changes in vegetation cover. Maitland Bradfield (1971), in his study of Hopi agriculture, found that climatic variability and loss of vegetation contributed heavily to erosion in the Little Colorado River watershed between 1880 and 1900, 1971). He notes, however, that late-nineteenth-century arroyo cutting along the Little Colorado River and elsewhere can only be explained by combining the impacts of social factors with the impacts of climatic variability. Clearly, though, the 1890s drought contributed substantially to erosion processes as well as to corresponding water-resource problems throughout the Mormon settlements.

Twentieth-Century Institutional and Technological Responses to Climate Variability

The impacts of the turn-of-the century drought on water resources prompted significant institutional change, including the first systematic effort within the basin to record the water rights of each holder. This effort foreshadowed modern water-rights institutions that organize rights to water chronologically, with the claimant having the longest history being accorded first priority, and so on. The information produced by the recording process prompted a change in water allocation practices in times of shortage: rather than relying on community decision making, water was henceforth allocated based on individual recorded rights.

For instance, in Joseph City, on April 15, 1907, a committee of three was appointed to "record the dams and water according to their judgement" (Porter n.d.) The Joseph City Irrigation Company, previously responsible only for construction and maintenance of dams and irrigation ditches, was now charged with managing water allocations in response to drought-induced shortages.

These sorts of institutional changes also afforded opportunities for coping with variability within long-term droughts. For example, while 1904 stands as one of the driest years on record (with a mere 1.6 inches of precipitation), 1905 (at 13.7 inches) was the third wettest year since the late 1890s (figure 5; Ni et al. 2002). Such wide swings in inter-annual variability made it virtually impossible to sustain consistent agricultural output by relying solely on surface flows. The first strategy adopted by the settlers for coping with variability in water availability was impoundment of water in reservoirs. The St. Johns Stake, for example, built seventeen dams between 1883 and 1921 on the main stem of the Little Colorado River and its tributaries (LeRoy and Wilhelm 1982). Dams and reservoirs posed their own challenges, however: violent summer storms could produce large volumes of water that led to breaches in the dams and consequent loss of life and property, while extended drought conditions diminished the amount of water entering the reservoirs.

Around the same period, the Joseph City Irrigation Company made the first serious attempt to systematically explore for and exploit groundwater resources (Porter n.d.).[8] This effort notwithstanding, groundwater development in much of the basin remained minimal until the mid-1900s. As late as 1946, only 600 acre-feet of groundwater were being pumped in the Joseph City–Holbrook area (Babcock and Snyder 1947). By contrast, groundwater pumping in Navajo County was much more intensive, producing an estimated 11,000 acre-feet around 1950 and more than 38,000 acre-feet by 1972. The growth in groundwater development coincided with three of the driest ten-year periods in the instrumental record for the area: 1942–1951, 1955–1964, and 1968–1977 (figures 3 and 5). During these decadal periods, precipitation amounted to only 73, 82, and 83 percent of average (www.ispe.arizona.edu/climas/research/paleoclimate/ product/AZ2/instrumental.html).

Groundwater provided distinct advantages over surface water: it was available year-round and was less sensitive to climate variability (Abruzzi 1985). It also facilitated economic growth and development in the basin, including construction of three coal-powered generating stations (near

St Johns, Springerville, and Joseph City), a paper mill, and a mining operation. These industrial activities increased demand pressures on available water resources and generated tensions—which still persist—among local residents. Increased appropriation of water combined with drought conditions prompted the state of Arizona to declare a "critical groundwater area" near Joseph City in 1948. The designation, formalized as the Joseph City Irrigation Non-Expansion Area in the state's 1980 Groundwater Management Act, was introduced as an effort to curtail declines in groundwater supplies through prohibiting expansion of irrigated acreage. The groundwater basin underlying the Joseph City portion of the watershed came under particularly intense pressure beginning in 1960 due to substantial growth in water demand emanating from construction and expansion of the Cholla power generating plant. The Arizona Public Service (APS) utility, which serves the greater Phoenix area, had bought land or water rights within a 16.5-mile radius of the plant; its purchases included all of the wells except two that were owned by the Joseph City Irrigation Company. These purchases plus designation of the groundwater basin as the Joseph City INA served to preclude further competition between irrigation and power plant water uses (Abruzzi 1985: 256; Dames and Moore Inc. 1973). Today, use of water for irrigation continues to be restricted to acreage that had been irrigated during the years from 1975 through 1979 (ADWR 2006). The amount of water pumped by industry is not insignificant: the Cholla generating station used around 7,425 acre-feet of water in 1980; the paper and pulp mill constructed near Snowflake was using 16,469 acre-feet in the same year. At the same time, however, the amount of water extracted for agricultural uses declined in tandem with reduction in the amount of farmland being actively irrigated. Today, although irrigated agriculture continues to use the greatest amount of water in the region, irrigated acreage has decreased. For example, in Navajo County, irrigated farmland decreased from 11,390 acres in 1978 to 6,351 acres in 1992. Nevertheless, agriculture today accounts for less than 2 percent of the region's total employment, a sharp contrast to the 40 percent thus employed in 1940. The fastest growing water use, by contrast, is in industrial and export activities (U.S. Census Bureau 2000).

Whereas the drought of 1955–1964 and dry conditions between 1968 and 1977 (Ni et al. 2002) placed pressures on the growing and sometimes conflicting water demands within the Little Colorado River watershed, the wettest conditions in the instrumental record occurred on the heels of the latter drought period (figures 3 and 5). It was during this period, beginning in 1978, that adjudication of water rights began within the watershed (ADWR 1989). It is notable that the 1980 Groundwater Management Act was enacted during this period. The act emerged in response to federal demands that the state get its groundwater overdraft problems under control before approval would be granted for construction of the Central Arizona Project (CAP), which would deliver Colorado River water to the state's main cities and the heavily agricultural area in Pinal County (located between Phoenix and Tucson). While strong regulation of groundwater applied only to the central corridor of the state, the act did address rural issues to a minor degree with establishment of state-level administration, through the Arizona Department of Water Resources (ADWR), of surface-water rights as well as responsibility for collecting and archiving data about water resources in the state and regulating the spacing of groundwater wells.[10]

A proposed interbasin transfer to support mining-related operations outside the Little Colorado watershed illustrates one hotly contested aspect of contemporary water politics in Arizona. In a 1992 decision, the special master of the Arizona General Stream Adjudication[11] addressed a dispute over a proposal by Phelps Dodge to divert water to which it had rights in Show Low Lake to its operations in the Salt River and Gila River watersheds. The special master mandated that "when water is diverted into another watershed or river system as part of an exchange agreement, DWR shall report information on all aspects of the exchange sufficient to allow potential objectors in the watershed of origin to make an informed decision about whether or not to object to the claimed water rights" (Office of the Special Master 2003). The decision illustrates the limitations of state authority over local water resource management: DWR is required to supply information, but the actual decision on whether a water transfer can occur is left to the parties involved. In this case, the dispute became moot when, in 2005, Phelps Dodge Corporation relinquished its rights to Show Low Lake.

A Contemporary Environmental History of the Watershed

Access to—and wise use of—water resources is key to sustainable habitation in the Upper Little Colorado watershed. Climatic variability and change, combined with significant changes in population dynamics and related resource use over the past several decades, underlie water resource vulnerability in the area. Significant growth in tourism and recreation activities, for example, draws large numbers of people to the area. Though the area is experiencing greater winter tourism and recreation such as skiing, the area continues to host considerable numbers of visitors during spring, summer, and fall, when water resources may be most stressed. Also significant have been negotiations involving settlement of Indian water rights claims. Climate factors, including a marked warming trend over the past several decades, wet conditions between the 1980s and mid-1990s, and reemergence of drought in the late 1990s and early 2000s, continue to pose challenges to efficient and equitable management of the region's limited water resources. Population growth remained high in the most recent census, showing increases of 4 percent in Winslow, 12 percent in Pinetop-Lakeside, and 22 percent in Show Low between 2000 and 2004. During roughly the same period, between 1999 and 2003, only twenty-three inches of precipitation fell in northeastern Arizona (Morrill 2005). A comparison of this drought with the extended drought period from 1947 to 1956 indicates that, while both periods exhibited significantly below-average precipitation, the latest drought resulted in a consistently lower snowpack. In addition, warmer temperatures combined with the timing of snowfall affected runoff and recharge patterns (figures 3 and 4) (Morrill 2005). Research into these conditions suggests that global warming might be implicated in producing more intense drought conditions, in which case greater problems are likely in the future.

Deep, sustained drought exacerbated by climate change may well constitute the gravest threat yet to the sustainability of the human and natural systems in the watershed and beyond. This threat raises serious questions about the future of the area's water resources and demands ongoing adaptation, including identification and enactment of measures to avert or mitigate the impacts of climate variability and change.

Native peoples within the basin have the longest history of interaction with the biophysical environment; however, it is only in the past few decades that they have begun to recapture control over certain important portions of their resource base. Native peoples, in contrast to the other cultural groups in the watershed, place a high spiritual value on water bodies and water resources, a value that embodies the unique environmental histories of the different groups. In the case of the Zuni people, recent developments have led to successful reappropriation of an important water source. The Zuni people had for centuries inhabited land along the Little Colorado and Zuni Rivers, but by 1877, they had lost all but 3 percent of their traditional lands. Most serious was a federal executive order that forced tribal members onto a 408,000-acre reservation in western New Mexico. This forced migration deprived the Zunis of the right to live near the Colorado River, thus disrupting their spiritual practices. Since at least the sixteenth century, the Zuni people have traveled to a sacred location known as Zuni Heaven, a lake located near the confluence of the Little Colorado and Zuni Rivers that has now dried up due to upstream water diversions and groundwater extractions (Committee on Indian Affairs 2003). Years of effort to reacquire the lake finally culminated, in 1984, in establishment of the Zuni Heaven Reservation for the primary purpose of furthering "the religious and cultural needs of the Tribe" (Committee on Indian Affairs 2002). Once again in possession of their spiritual lands, the tribe began restoring the riparian areas around the lake; in 1990, Congress contributed to their efforts through establishment of the Zuni Heaven Resource Development Trust Fund, which provided $25 million to help restore the area's wetlands. Further assistance materialized in the Water Rights Settlement Agreement of 2003, which empowered the tribe, for purposes of restoring the wetlands, to purchase up to 3,600 acre-feet of surface water rights from upstream sellers and to pump up to 1,500 acre-feet per year of groundwater (Committee on Indian Affairs 2003).

Mormon settlers relied on a different set of spiritual values to link their communities with the land and its resources. For example, frequent dam failures and fluctuations in the length of growing seasons, along with the resulting variability in crop output, prompted reliance on religious tenets that viewed natural events such as flooding as trials or tests sent by God and adherence to notions of communal work as religious ritual to improve upon nature. The Mormons' religion-based decision making in the face of environmental stress often involved negotiations between communities that were competing for the same resources. For example, residents of Joseph City (then called St. Joseph) invoked notions of religious community to compel upstream residents of Woodruff to breach their dam. Even though this act could have compromised their ability to grow their crops, Woodruff complied, though they observed that "after working so hard and under such adverse circumstances this was pretty severe medicine" (Dean n.d.). The early reliance on religious rhetoric has since faded, and Mormons no longer make up the dominant Euro-American presence in the watershed. They do, however, continue to represent a locally strong presence in communities such as Snowflake and Joseph City; in locations such as these, religion continues to influence resource management decisions.

Conclusions

The history of the Little Colorado River Basin is one of oscillating periods of plenty and scarcity, with climate constituting a significant but far from determinant influence over the distribution of vulnerabilities to floods and drought. Climate-society interactions in the watershed have strongly influenced the area's biophysical and human environments and have prompted successive innovation and revision of institutional mechanisms aimed at sustaining lives and livelihoods. For the early Mormon settlers, decision making resided at the community level where the main concerns were sustaining the settlements through agricultural production. Organization of the settlements into stakes, while primarily serving religious and community-building functions, also served as venues for addressing problems generated by environmental variability and change, including variability in hydrologic processes and water availability. Successive droughts, however, eventually resulted in a transfer of decision making from the community at large to irrigation companies, which focused more on rational water management practices than on religious ideals. Throughout the first half of the twentieth century, these companies increasingly turned to groundwater to buffer drought-induced variability in surface-water availability and to meet the considerable growth in water demand. Increases in groundwater use, however, produced overdraft conditions in the area's aquifers, most notably those in the Joseph City area. Here, water table decline induced conflict between power-generation and agricultural uses, eventually leading—for the first time—to substantive state-level intervention and regulation through creation of the Joseph City Irrigation Non-Expansion Area.

The Little Colorado watershed faces an uncertain future characterized by growth in the number of groups vying for access to water and the possibility of greater climatic variability, long-term warming trends, and deeper and longer-lasting droughts. Under such conditions, state-level regulation is likely to increase. A report summarizing an evaluation of the

ADWR by the Arizona auditor general has already called for state-level regulation of water throughout the state (Norton 1999).

Knowledge of the environmental history of the watershed provides valuable insight into the experiences, values, knowledge, and practices that have produced the conditions existing today. These "thick" narratives (Geertz 1973), if integrated into development of plans, decision processes, and decision tools, hold promise for improving citizens' acceptance of and support for policies aimed at ensuring the sustainability of the watershed's closely coupled human and natural systems. Scientific research aimed at understanding the nature, intensity, and potential impacts of climate variability and change, and at developing products designed to support policy and decision processes, can also benefit from understanding the contexts in which the products and knowledge will be used. ✣

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Notes

1.. The Little Colorado River watershed is the largest in the state of Arizona.

2. Temperature and precipitation data used in this report are based on data from the stations in the watershed; these data were obtained from the Western Regional Climate Center, www.wrcc.dri.edu.

3. Most anthropologists have discarded the term *Anasazi* in favor of Ancestral Pueblo.

4. James H. McClintock's 1921 book (reprint, 1985) was among the first to chronicle colonization in the Little Colorado watershed.

5. All descriptions of climatic conditions prior to the instrumental record—i.e., before the early 1900s—are based on data for the larger Colorado Plateau.

6. Historian Charles Peterson (1973: 154) sees the Mormons' ideology as "modified Jeffersonian agrarianism."

7. Sheep numbers grew from 30,000 head in 1870 to 1,297,589 head in 1930 (Tellman, Yarde, and Wallace 1997; Bailey 1980).

8. While the document describing this attempt does not have a date, in it Porter states that the drilling took place on February 23, "of this year." Porter states eleven wells were drilled around Joseph City between 1935 and 1940.

9. While the Arizona Department of Water Resources (ADWR) does not require institution of specific water-conservation practices and generally does not regulate the quantity of water used within the boundaries of the INA, the agency does require owners of non-exempt wells to submit annual reports of their groundwater pumping (ADWR 2006).

10. A report by the Arizona auditor general recommended that ADWR's mandate be expanded to regulate water development and use outside the Active Management Areas in the central corridor of the state (Norton 1999); to date however the Arizona legislature has not taken significant steps to address his recommendations. Considerable local opposition to state-level regulation continues to exist throughout rural Arizona.

11. The Arizona General Stream Adjudication is a process intended to adjudicate rights to all surface waters in the state.

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