Atlas of the Upper Gila River Watershed

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The University of Arizona | College of Agriculture & Life Sciences | WRRC | Water RAPIDS Water Research and Planning Innovations for Dryland Systems | Arizona Cooperative Extension | Gila Watershed Partnership of Arizona | Landscape Conservation Cooperatives

The University of Arizona Water Resources Research Center (WRRC) promotes understanding of critical state and regional water management and policy issues through research, community outreach and public education.

The Water Research and Planning Innovations for Dryland Systems (Water RAPIDS) program at the WRRC specializes in assisting Arizona communities with their water and natural resources planning needs. Our goal is to help communities balance securing future water supplies for residential, commercial, industrial, and agricultural demands with water needs of the natural environment.

We would like to acknowledge the irreplaceable assistance of Jan Holder, Bill Brandau, Tahnee Robertson, Mark Apel, Marguerite Rodriguez and Deana Stone. We would also like to thank the members of our Watershed Assessment Steering Committee for their assistance in gathering data and reviewing this document.

Photo on the cover Gila River at Three-Way: Kelly Mott Lacroix, Arizona Water Atlas, Arizona Department of Water Resources

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Photo opposite by David Chan

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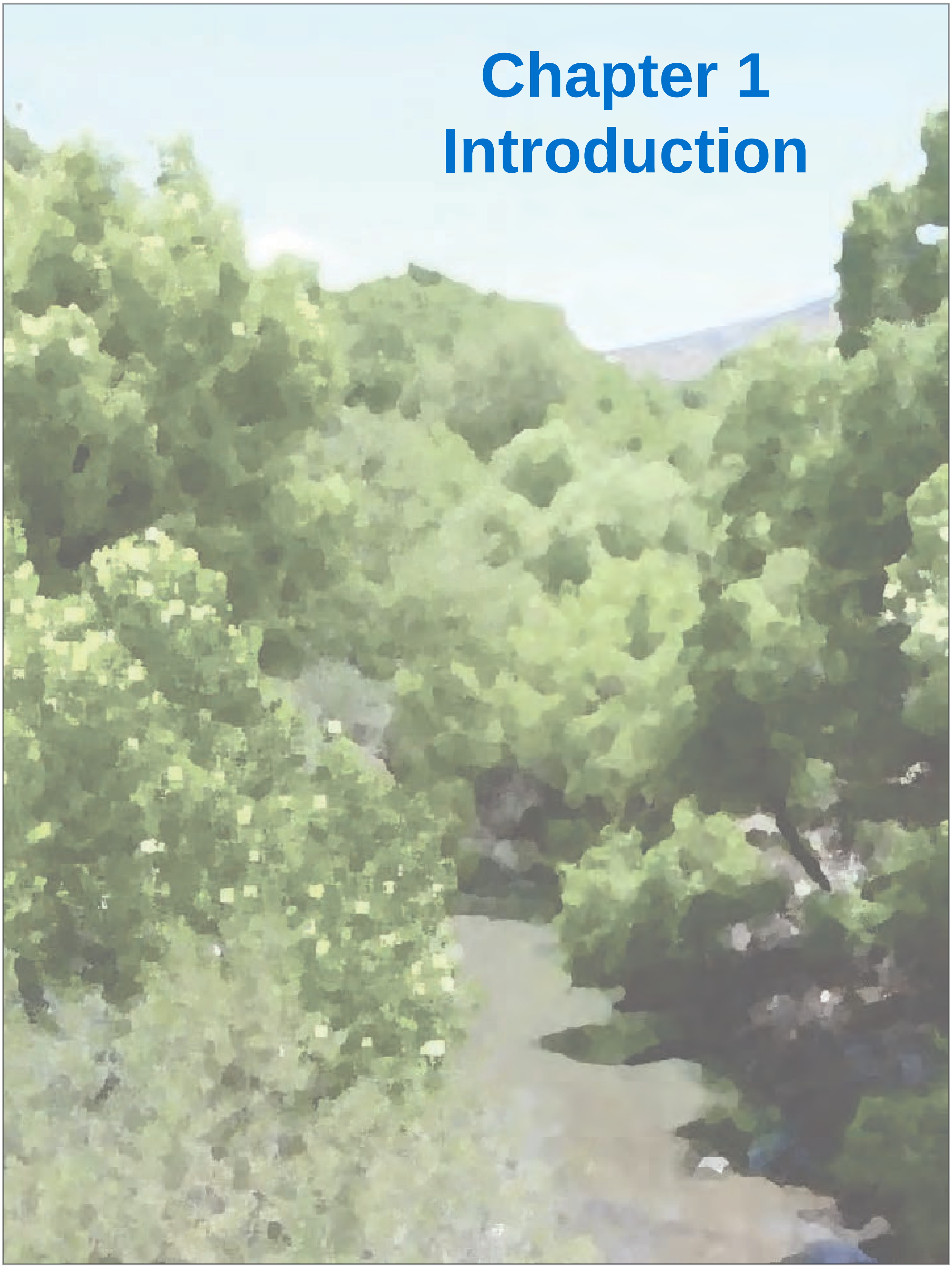


Chapter 1 - Introduction

The Gila River originates in the Mogollon Mountains of New Mexico and flows west across Arizona to join the Colorado River at the California border near Yuma. The river drains the southern half of the state of Arizona. The Upper Gila River Watershed is all the land drained by the portion of the river to the East of Coolidge Dam, which impounds the San Carlos Reservoir.

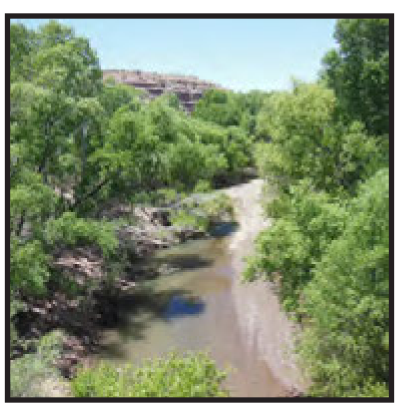
How to Use this Atlas

This atlas (the Atlas) is intended to be a repository of information about the natural, water, and cultural resources of the Upper Gila River Watershed. Here, you can find information about everything from the basic geography of the region – geology, soils, towns, and roads – to maps tracking changes in watershed conditions – land use, forest fires, population, and groundwater levels. The WRRC has also developed a GIS-based watershed model called the Automated Geospatial Watershed Assessment (AGWA) for the Upper Gila River Watershed to determine the impacts of changing land use characteristics on water resources. Maps showing key outputs from this model are included in the last section of the Atlas.

The Atlas can be used as a basic reference to learn about the resources of the Upper Gila River Watershed. It is organized to provide quick access to a wide variety of maps and information. The Atlas can also be used as a starting point for watershed planning. In order to plan for the future, we need a common understanding of where we are today, and how things have changed over time. Each map in the Atlas is selected to address a specific issue that provides information essential for watershed planning. In addition, the Atlas provides a common base of data for all stakeholders, so all participants in a planning process can begin with the same understanding of the status of the watershed's resources.

Project Purpose

This Atlas is the result of a joint effort between the Gila Watershed Partnership of Arizona (GWP), Arizona Cooperative Extension (Extension), and The University of Arizona Water Resources Research Center (WRRC). The Atlas was developed to answer several key questions about the watershed: What are the current conditions of the natural resources? What are the current conditions of the water resources? and How has the status of these resources changed over time?


Photos by David Chan

Through an extensive search, the WRRC compiled a substantial archive of watershed data. This search focused on geospatial data – information that can be mapped using computer software called a Geographic Information System (GIS). While this information is widely available through a number of different public sources, the data are often fragmented, and this disconnection makes it difficult to clearly view the current status of resources at the watershed-scale. Although the emphasis of the Atlas is on the Arizona portion of the watershed, we have included equivalent information for New Mexico when possible.

In addition to geospatial data, the Atlas includes information on the social and natural history of the watershed, which provides important context for the interpretation of other data included in the Atlas. In April 2013, GWP and WRRC hosted a special meeting to develop a “shared history” for the Upper Gila River Watershed. Creating this history was an opportunity for the members of the community to come together to share their memories of significant events in the history of the region, and build on each other’s memories. These memories were used to create a timeline of important events in the history of the watershed to highlight the events and resources that are important to the community. The information generated through the shared history exercise has been supplemented by additional research conducted by the WRRC.

The purpose of the Atlas is to provide a clear, easy-to-access, and broad compilation of information about watershed resources. The Atlas provides a starting point for future watershed planning. It is a resource for learning about the basic history of the Upper Gila River Watershed and the current status of local resources. The Atlas is primarily composed of maps and a short explanation of each map’s content and purpose. Where appropriate and when data are available, we also provide information about how specific resources have changed over time.

Development of the Atlas

The data included in the Atlas is based directly on the interests of regional stakeholders. Feedback from stakeholders was solicited through workshops, monthly GWP meetings, a watershed assessment workgroup, and one-on-one discussions. From these conversations, it was clear stakeholders were interested in seeing a variety of data types mapped – everything from the locations of dams and water diversion structures to areas of critical habitat for threatened and endangered species. Though not every type of data or information could be obtained in a form that can be represented on a map, the WRRC has included as many as possible.



Photos by David Chan, and Kelly Mott Lacroix, Arizona Water Atlas
Arizona Department Water Resources

The Atlas draws on a wide array of available data from a variety of sources. This data was collected, evaluated for accuracy and consistency of format, input to a GIS, and analyzed. Sources of data include but are not limited to:

- Arizona Department of Water Resources (ADWR)
- Arizona Game and Fish Department (AGFD)
- Arizona State Land Department (ASLD)
- Bureau of Land Management (BLM)
- County and local governments
- National Resource Conservation Service (NRCS)
- The University of Arizona
- US Fish and Wildlife Service (USFWS)
- US Forest Service (USFS)
- US Geological Survey (USGS)

The following is the technical description of the process used to create the computer database associated with this Atlas. Understanding this process is not essential for using the Atlas. All datasets used to create the Atlas were checked for accuracy to ensure they were the most accurate and up-to-date sources available. The WRRC used ESRI ® GIS software to compile, map, and analyze the data. To ensure consistent spatial formatting, all data were projected into the same coordinate system to create a spatially-relatable database, to accurately represent these spatial data from different sources. The WRRC then separated data by hydrologic subbasin using 8-digit hydrologic unit codes (HUCs) designated by the USGS. The USGS-defined HUCs provide a standardized, watershed-based unit for analysis. HUCs were used to limit the extent of data analyzed to only the features within the Upper Gila River Watershed. These data were then used to create the geodatabase, which acts as a central repository for all of the information needed to create the maps in the Atlas. A geodatabase is a geo-referenced (all data have a spatial component) computer database (system for storing, querying, and accessing data).

Once all of the data were projected, formatted and added to the geodatabase, maps were assembled. The maps contain carefully chosen data layers and symbols based on various themes (e.g. physical geography, political geography) and changes to the landscape. Each map is accompanied by a narrative written to describe the map's theme and to highlight the watershed features.



Photos by David Chan, and Kelly Mott Lacroix, Arizona Water Atlas
Arizona Department Water Resources

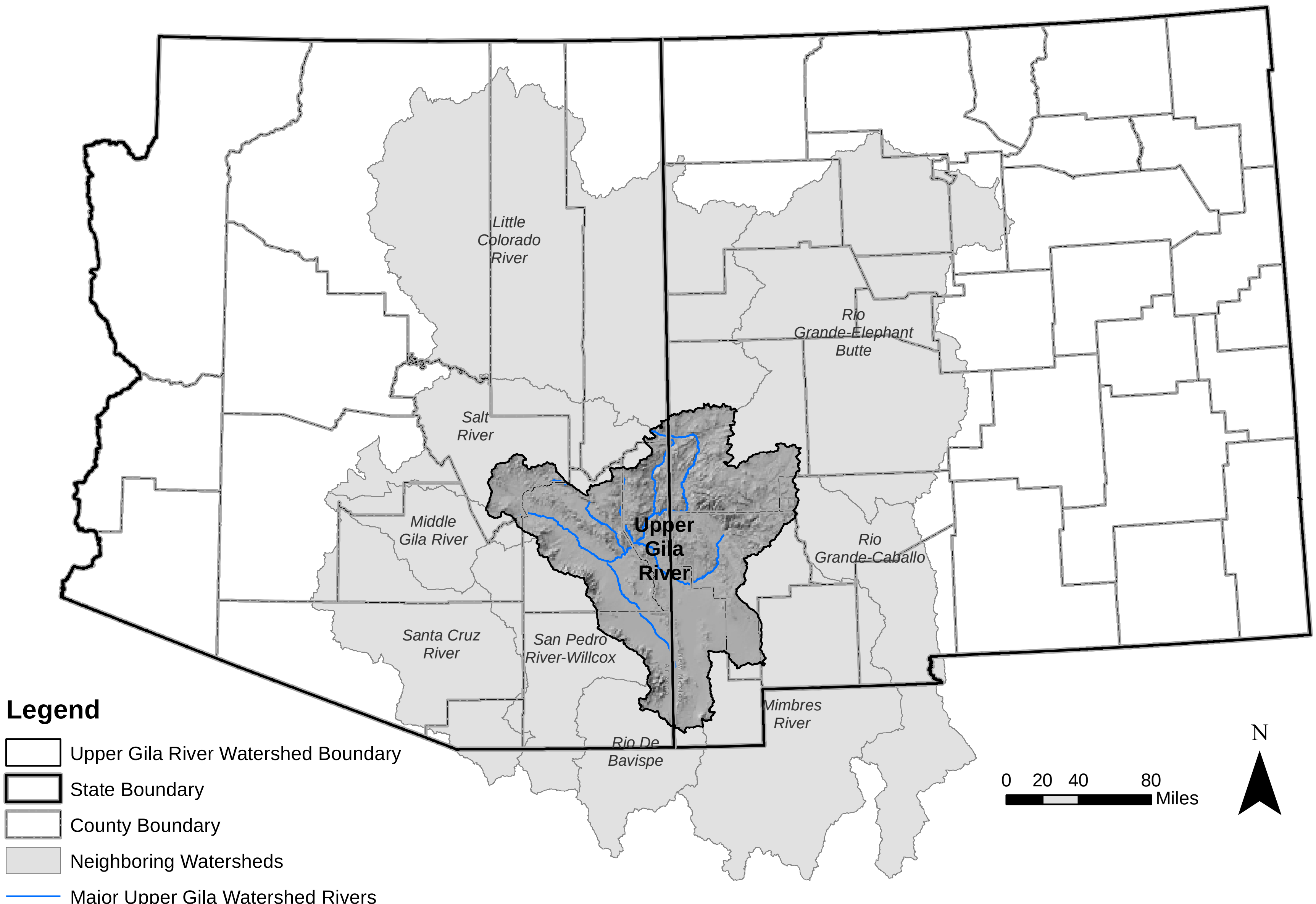


Figure 1-1 Regional Geographic Context

Regional Geographic Context

Watersheds have important physical boundaries that are not always contiguous with political boundaries. The Upper Gila River Watershed has an area of approximately 9.7 million acres (39,350km^2) that straddles the Arizona-New Mexico border, with 48.4% of that total area located Arizona, and the remaining 51.6% in New Mexico.

Spatial data gathered for the Atlas were collected on the basis of physical as well as political boundaries. Some data used was collected and distributed by the states, while agencies of the federal government are responsible for the rest. Each state and federal agency uses a slightly different system to manage their data. State generated information tends to be bounded by state lines. For instance, water rights are administered at the state level; comparable data from both Arizona and New Mexico is not readily available.

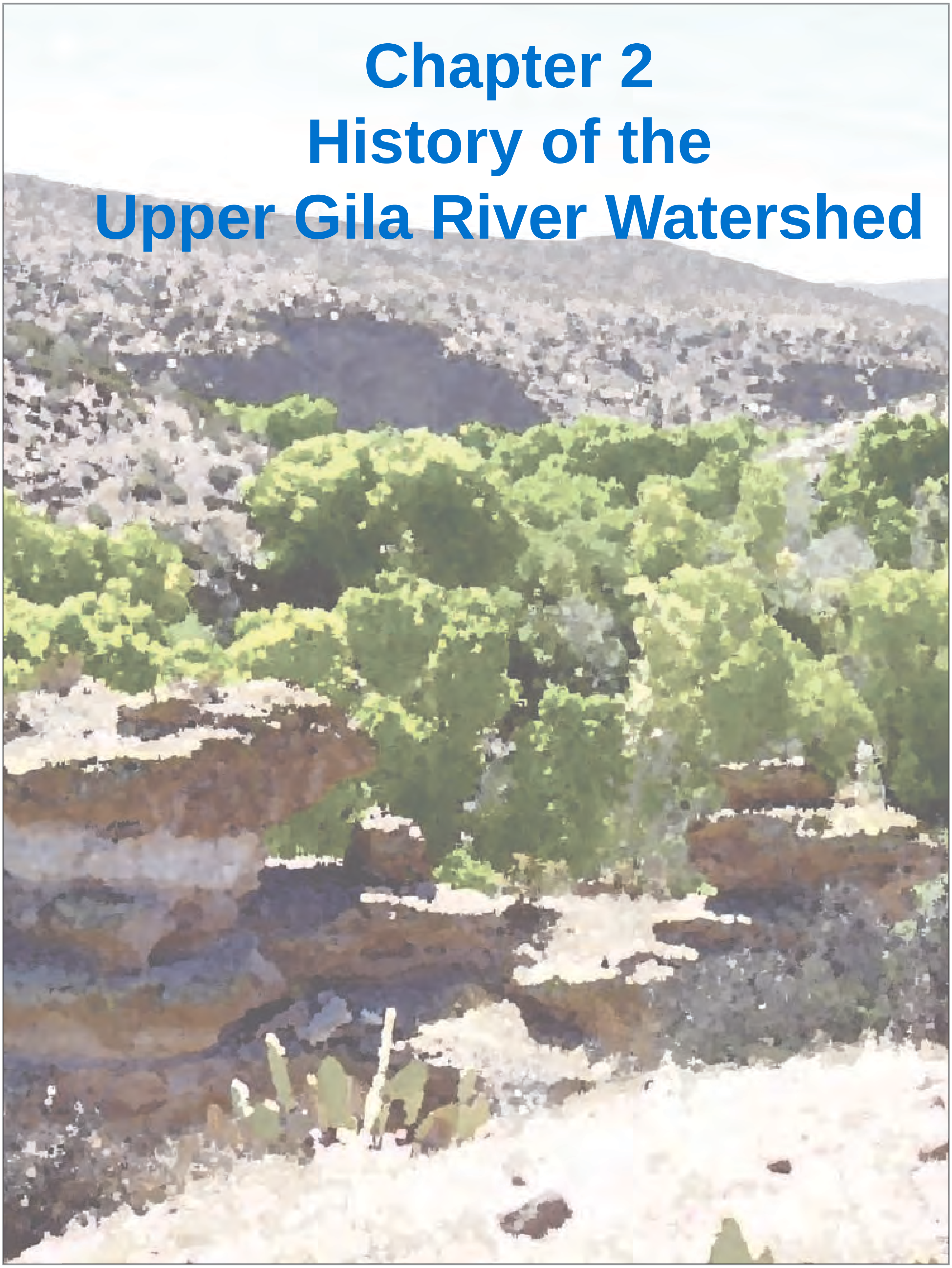
Data for federal agencies is generated for regions or the entire country, but details can be lost at this coarser-scale. Another level of complexity are the inconsistent regional systems used by federal agencies. The Environmental Protection Agency and the Department of the Interior (i.e. USGS, BLM) assign Arizona and New Mexico to separate regions. In contrast, the USFS places the states into the same region.

These discrepancies make consistent representation of the entire watershed challenging. Where possible maps in the Atlas display the entire watershed.



Photos left to right: Cottonwoods on Gila River, Safford Valley Pasture, Gila River by David Chan

Chapter 2
History of the Upper Gila River Watershed



Chapter 2 - History of the Upper Gila River Watershed

This Participatory Assessment seeks to illustrate the state of current conditions in the Upper Gila River Watershed from the perspectives of regional stakeholders. This method also serves as a way of establishing a baseline for planning alternate scenarios for the area's future. A review of the local history with an eye toward trends and changes in the landscape can help inform how current conditions arose and what factors might be important in preparing credible scenarios for the future. Humans have certainly had a notable impact on the shape of the regional landscape going back thousands of years, and patterns of settlement and land use over the last 150 years have led to additional changes in the watershed. The locally unique aspects of geology, geography, and weather patterns have also contributed to an inconstant landscape. A brief exploration of the interaction of several of these elements over time offers insight into the unpredictability and resilience that are hallmarks of the Upper Gila.

Access to reliable and reasonably clean supplies of water has been crucial to sustained human presence in the Upper Gila River Watershed for millennia. Particularly because of the arid climate and the long dry periods between the annual cycle of summer and winter rainfall, water has been a limiting factor on settlement patterns. Modern technology has expanded the availability of water, with improved abilities to drill for water and transport it. As a result, certain areas have been settled and even irrigated when their former uses were more seasonal or transient in nature. Even so, the substantial cost of modern efforts to procure clean and reliable water supplies continues to influence land uses, underscoring the high value of water resources.

The Upper Gila River Watershed has a well-documented and lengthy record of human influence on the landscape. Archaeological studies reveal several periods of extensive settlement. Agriculture has deep roots in the area, and far-reaching canal systems demonstrate a history of carefully-organized irrigated farming. The perennial flows of the Gila River itself, combined with fertile soils in the floodplain, made this region especially suitable for raising crops during the long growing season. Specially-adapted cultivation

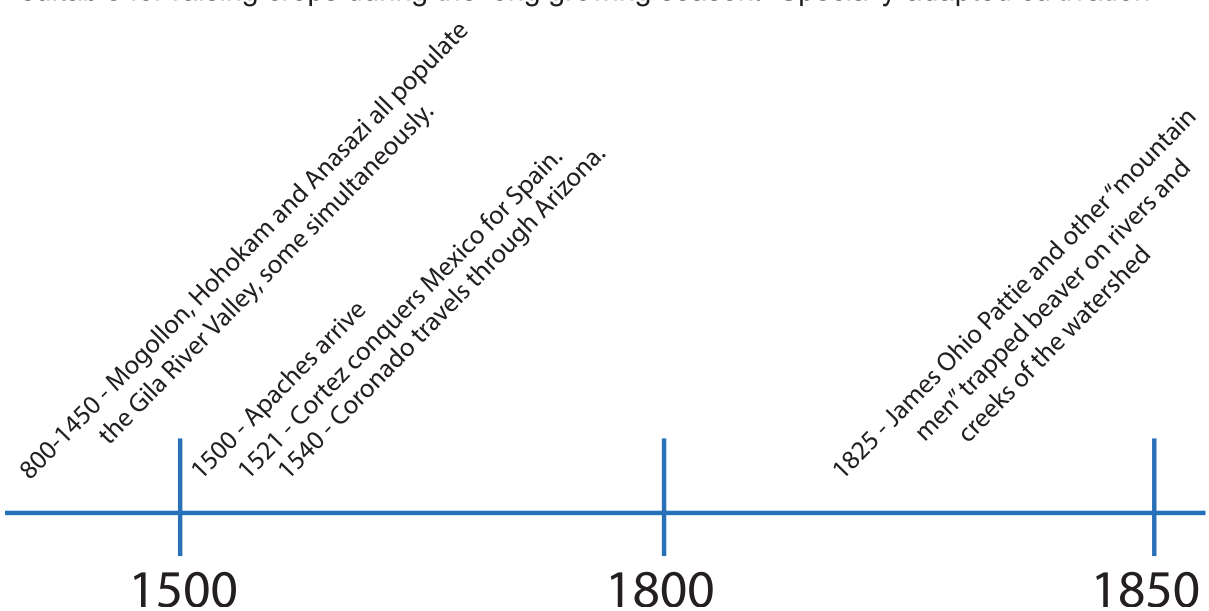


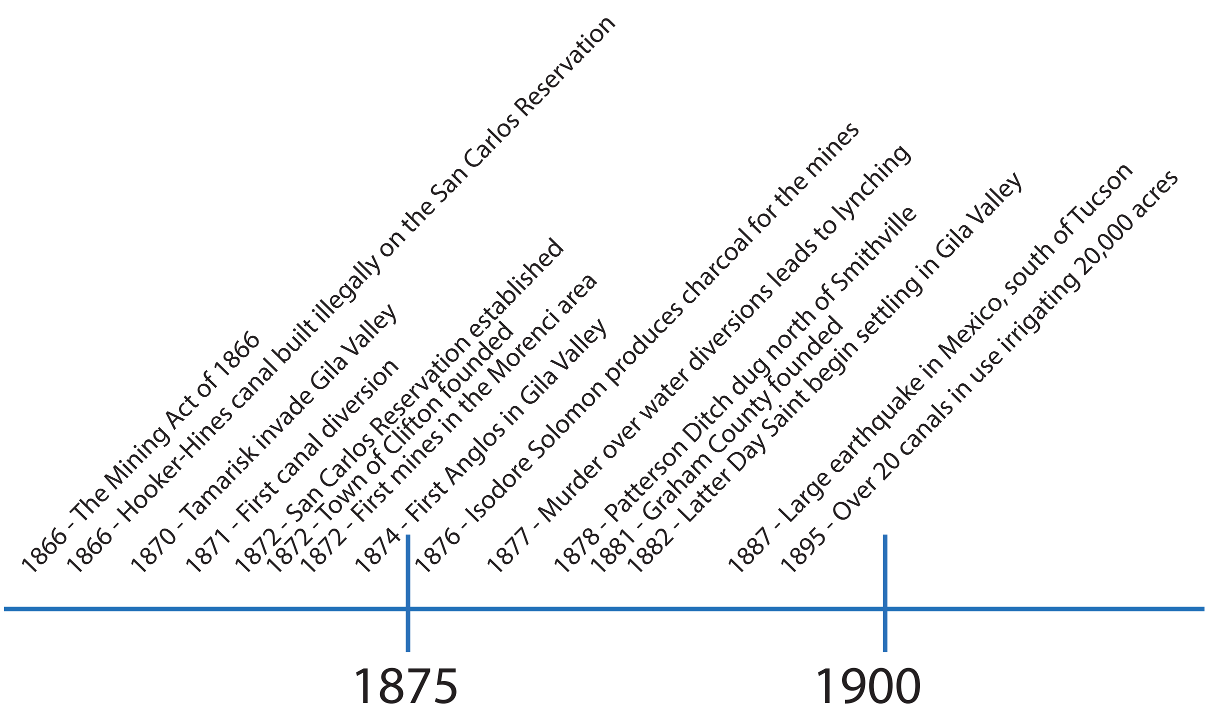
Figure 2-1 Timeline of the Upper Gila River Watershed 800 AD to the Present
Created by Gila Watershed Partnership Members in April, 2013. For an interactive version of this timeline with photos and videos visit http://wrrc.arizona.edu/Upper-Gila-Timeline

practices, as well as the use of native species, allowed desert dwellers to flourish, despite the harsh summer conditions and inter-annual weather variability that are hallmarks of the basin and sky island range region (Tucker & Ezzo, 2006).

Early inhabitants of the watershed were well aware of how elevation, soil type, and rainfall interacted to create different ecosystems in different parts of the watershed. Hanging canals carved into the Mount Graham mountain range collected rainfall that fell in greater amounts at higher elevations and channeled this precious water down to fields at lower levels. Seasonal movements were timed to make use of this variability in order to increase the gathering of food and fiber, such as mesquite beans, saguaro ribs and fruit, nopalitos, and cholla buds from the valley floor, as well as the collection of manzanita fruit and the hunting of animals along the upper slopes of the Pinaleños and other mountain ranges in the area (Lascaux, 2006; Neely & Murphy, 2008).

Remains of pottery, tools, and other artifacts in the watershed indicate not only the long-term presence of human habitation, but also the role of the Upper Gila Valley as a major trade route between regional cultures throughout the Southwest. The topography of parts of the Valley reveals a deeply incised channel within a narrow canyon, rendering travel difficult, but access to a reliable source of water in such a desert region made the route critical for flows of information and trade as well as water. The watershed has thus served as a homeland and weigh station imbedded a regional network of societies for centuries (Hastings & Turner, 1965, pp. 22–46).

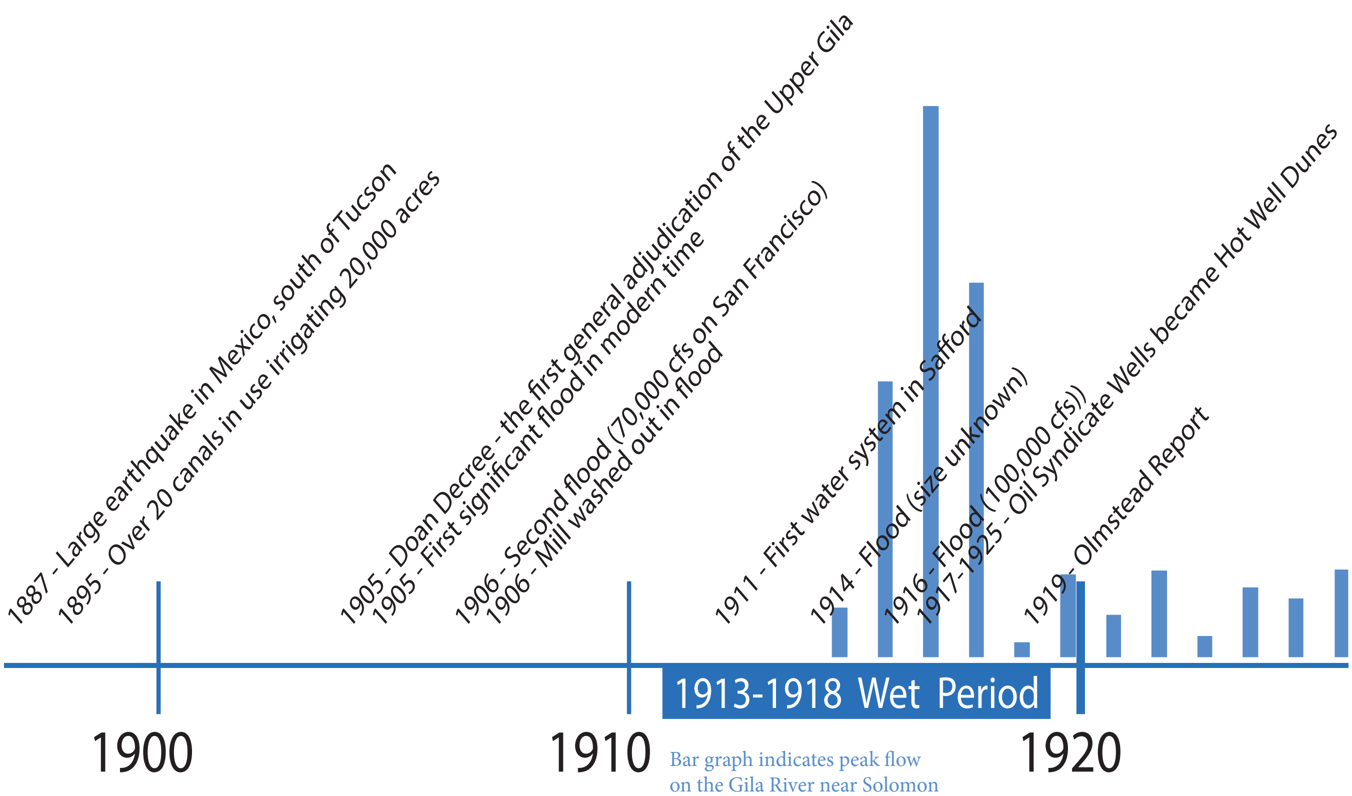
The diaries and other writings of early Hispanic and Anglo visitors to the region confirmed that many of these cultural practices, seasonal harvest migrations, and trade routes continued into recent times. Attempts to maintain ancient traditions among the Apache led many to try to leave the restrictive confines of the San Carlos reservation in the late 1900s. This unfortunately resulted in additional cross-cultural conflict between the Apache, local



Anglo settlers, and the United States Army. Federal policy for decades encouraged less migratory and more sedentary livelihoods for indigenous peoples, which led to increased importance in surface water rights for agriculture and residential use. Water rights for the San Carlos Apache and other Native American cultures along the Gila River have remained a fundamental part of over-all water use in the Valley. The construction of Coolidge Dam and the San Carlos Reservoir in the 1920's was intended by the U.S. Bureau of Indian Affairs to create a more reliable source of water to promote permanent settlement and farming for the Pima and Maricopa communities downstream, whose centuries-old irrigated agricultural practices had suffered from the 1890s onward due to greater diversions upstream (Sheridan, 1995, pp. 207–208). Adjudication of water rights has continued to the present day to play a critical role in shaping the economy of the region.

The first records from travelers of European descent into the region reach back to a multi-year quest by Francisco Vázquez de Coronado y Lujánto for the legendary Cibola and the cities of gold. Coronado's large expedition set out from Mexico in 1540, with substantial numbers of horses, cattle, and other livestock to assist in the journey. Their travel generally followed river courses, for access to water for the humans and the livestock was essential as they traveled through the desert landscape. The expedition arrived at the Gila River after following either the Santa Cruz or San Pedro rivers northward. There the party turned eastward and entered the Upper Gila Valley. Their presence was short and did not result in the typical Spanish settlement patterns of missions and presidios in the area. Nonetheless, their journey mirrored the routes of generations of previous travelers seeking their way through the landscape (Faulk, 1970, pp. 3–13).

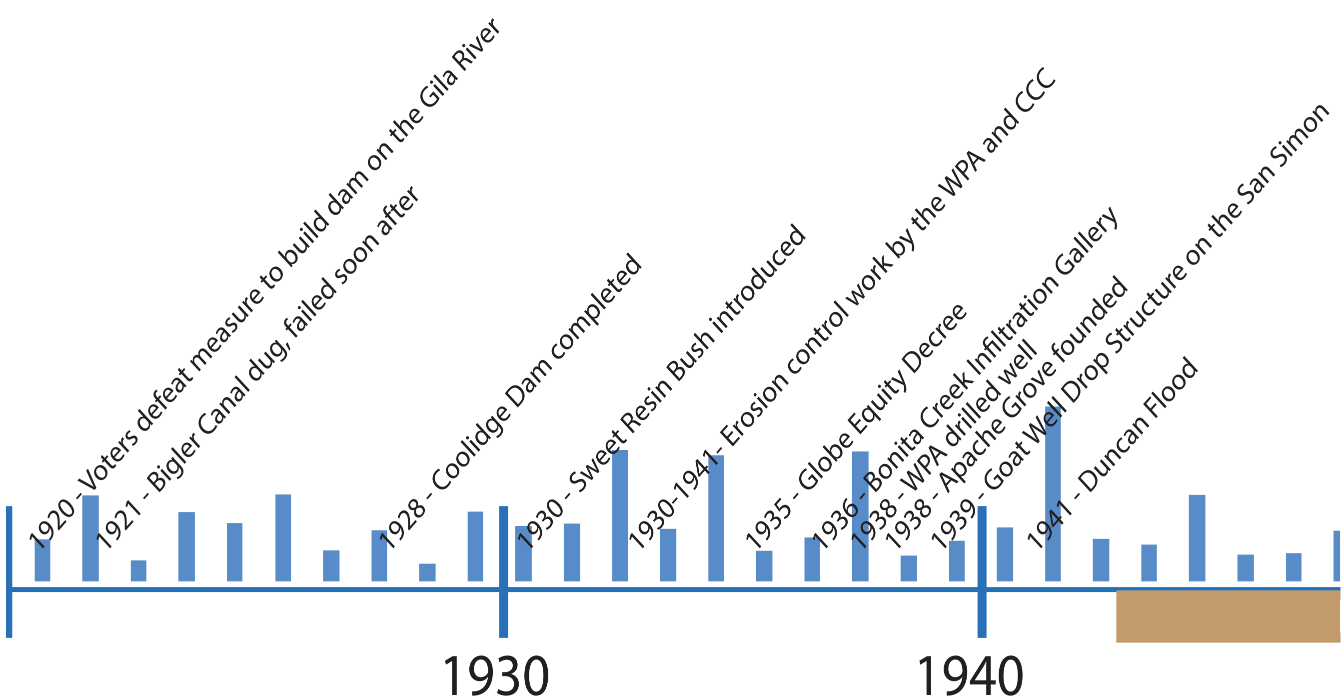
Their trek also played a part in the introduction of new actors on the landscape. Many livestock separated from the expedition and became the core of a remnant feral population of cattle, horses, and donkeys. These new residents of the watershed began to exert a



novel influence on the region through their migration and grazing patterns. The lack of more lasting Spanish settlements likely precluded widespread introduction of other plant and animal species from Europe and beyond into the Valley during this period of history, such as those found further south in what have been referred to as the gardens of New Spain. Even so, because of the region's role as a corridor of travel and trade, introductions of non-native species of flora and fauna have been a regular occurrence. These exotic arrivals sometimes initiated outsized impacts on the existing ecosystems of the watershed (Dunmire, n.d.; Tellman, Finch, Edminster, & Hamre, 1996, pp. 137–157; Webb, Leake, & Turner, 2007, pp. 31–39).

The first presence of Anglo-Americans can be traced to 1826, when a group of trappers ventured into the Valley. James Ohio Pattie chronicled these escapades for readers in the eastern United States, offering enthralling tales of adventures in a far-off land that, at the time, was still part of a newly-independent Mexico. Pattie's group sought to capture animal hides, and particularly beaver pelts, to sell for use in fashionable clothing in the eastern U.S. and Europe. His account thus gives an indication of the types and distribution of wildlife in the region, from javelina and grizzly bears to mountain lions and deer. Pattie may have offered inflated numbers in terms of the total count of pelts his group collected, but his story suggested that there had been healthy populations of beavers, although a rapid reduction in numbers was occurring due to widespread trapping. He noted a lack of beavers on the San Carlos and other tributaries, for instance, which pointed to trapping activities by others in the area and illustrated that there were already noticeable impacts from over-hunting. Though many elements of his stories have been called into question by historians, his book still offers a rare written account of conditions in the Upper Gila before waves of new settlers arrived (Pattie, 1988).

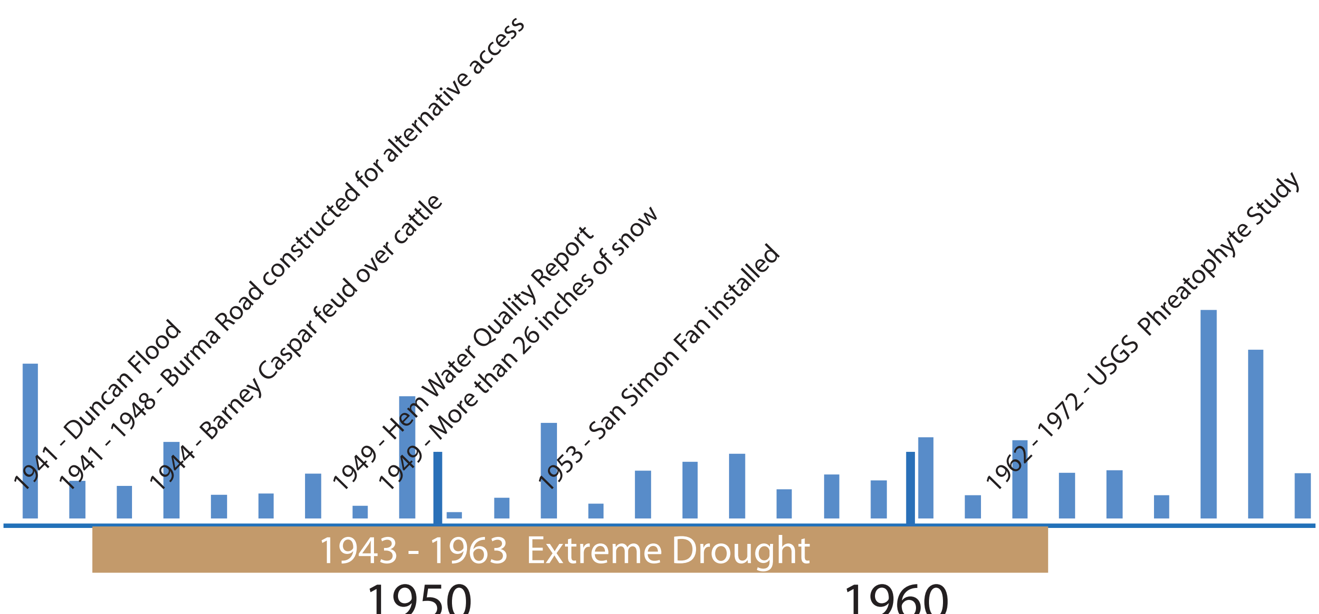
Other travelers also trekked through the Gila Valley on their way westward, including trapper-traders like Kit Carson, military scouts, and miners. The rough terrain proved



challenging for pack animals and nearly impassable for wagons and other wheeled transport. The Kearny military expedition to California marched through the area during the 1846 war with Mexico. One narrow, meandering section of the Gila Valley northwest of the present-day town of Duncan was so challenging to traverse that it earned the moniker of the Devil's Turnpike. These arduous trail conditions encouraged a search for alternate routes westward. By the time of the large-scale westward immigration boom to California, new traces to the south and north had become more popular for use as wagon trails. Until the opening of these other routes, however, the Upper Gila continued to serve as a pathway for explorers, and the region thus figured prominently in accounts of present-day Arizona in the first half of the nineteenth century (Ames & Griffin, 1942; Bieber, 1937; Carson, 1935; Clarke & Perry, 1988; Emory, Abert, Cooke, & Johnston, 1848; Etter, 1998; Turner, 1966).

The river also served as an important political corridor for a time. An extensive length of the Gila marked the border between the United States and Mexico from the signing of the peace treaty ending hostilities in 1846 until the agreement that concluded the Gadsden Purchase in 1854. This shift in the political landscape had implications for the growth of the Gila River Valley. The treaty was spurred on in large part by the push to create a snow-free southern route for a transcontinental railroad, although the completion of the Southern Pacific was still a couple of decades in the making. The opening of alternate transportation corridors by wagon and by rail diverted the future flow of trade and traffic away from the Upper Gila Valley toward towns like Tucson (Griswold del Castillo, 1990; Sheridan, 1995).

Although the region may have lost some development opportunities due to the redirection of regional and national trailways, other events spurred on the influx of new arrivals. In the 1860s, news spread of valuable mineral wealth in parts of the Valley. Prospectors soon followed, and numerous mining operations began in earnest. Much of the early activity was centered near Clifton and Morenci (Patton, 1977; Ramenofsky, 1984; Solomon, 1994). While some gold and silver deposits were uncovered, mining efforts focused on copper as the primary targeted ore for extraction. These large copper deposits led to the construction of a smelter and the first railroad line in Arizona. From early placer mining to more industrially-oriented extraction processes, access to water proved crucial. The communities that developed around mining towns also required water for daily living. Springs and small



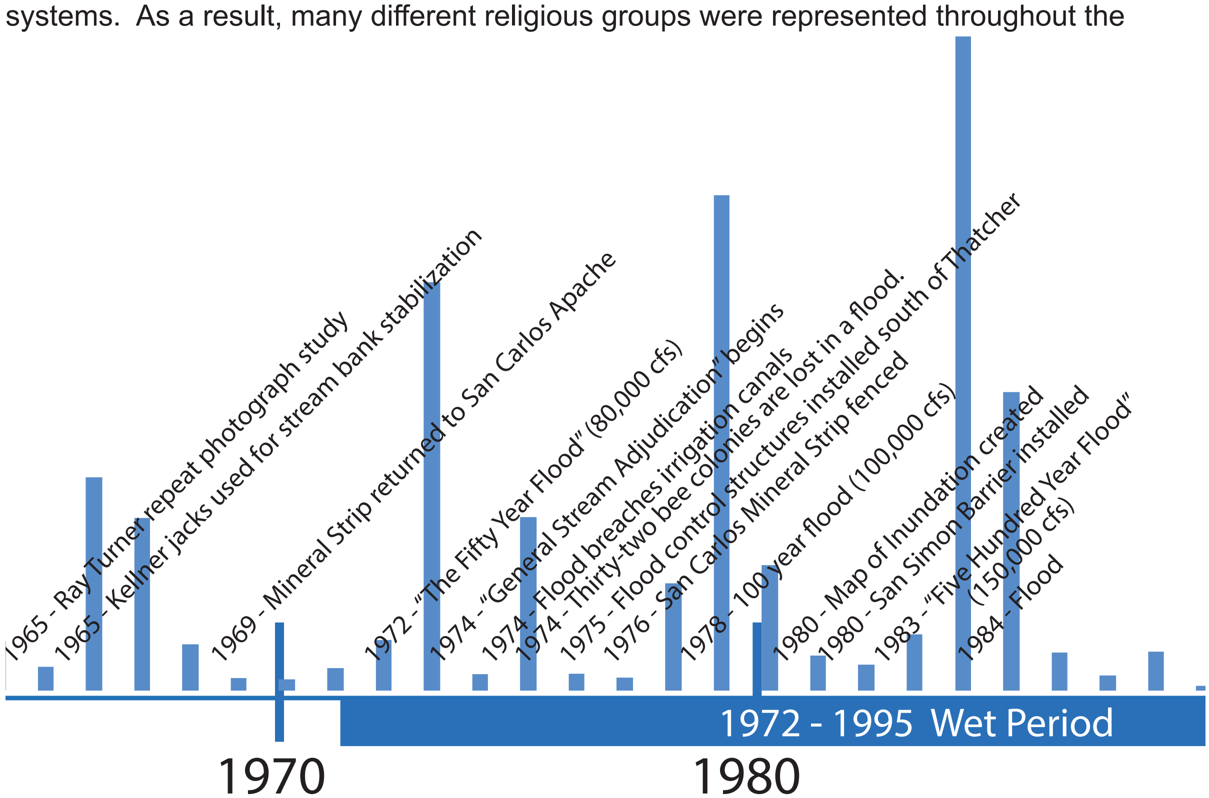
Bar graph indicates peak flow
on the Gila River near Solomon

tributaries were often dammed and piped to meet these varied needs, and the scale of these waterworks grew commensurate with the growing mining and municipal demands (Faulk, 1970, pp. 216–223; Sheridan, 1995, pp. 147–161).

Excitement over new mining sites sometimes led to widespread rumors and the creation of sham corporations. One of the more infamous cases involved the stories of fantastic finds of gold and copper ore associated with the Spenazuma Mining and Milling Company in the northeast foothills of the Santa Teresa mountains. Through the work of an investigative journalist, the sordid details of this grandiose scheme to swindle investors were made public. The company soon went bankrupt, and the townsite was abandoned. Although there were a few notable cases of chicanery and fraud, mining became a major economic pillar in the Valley and has continued to play an important role up to the present-day (Faulk, 1970, pp. 150-151).

Not long after the initial mining boom, waves of settlers arrived looking for arable farmland. Instead of seeking quick riches from mining, these groups sought to build homesteads and plant roots in the region. Early settlements took advantage of water supplies from the Gila River to build irrigation networks – often on top of the remains of the ancient Native American canal systems. Immigrants of many backgrounds soon reached the Valley. Anglo settlers came from the eastern United States. Sizeable numbers of others were immigrants born abroad, including many from Central and Eastern Europe. Many settlers hailed from Mexico. Historical accounts record the prevalence of different languages in various communities, although Spanish and English were used most frequently (Duncan Arizona Centennial Committee, 1983,1984; Eastern Arizona Museum and Historical Society, 1979; Ramenofsky, 1984; Sheridan, 1995; Stout, 1975).

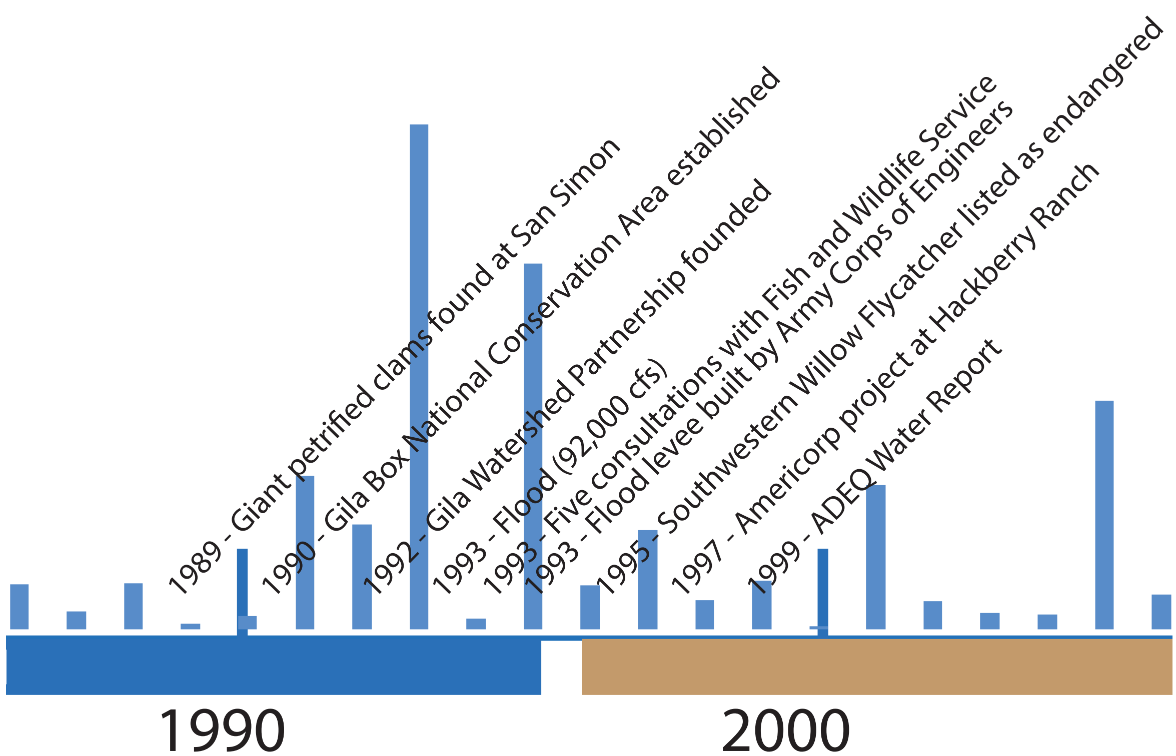
New arrivals brought their cultural traditions and practices with them, including their belief systems. As a result, many different religious groups were represented throughout the



Valley. A Jewish community sprang up early on in this period of growth, with prominent families such as the Solomons of Solomon(ville) among them. Catholic churches soon appeared, as did houses of worship for several different Protestant denominations. From Utah or other points north, Mormons came in large numbers, many as part of a larger plan of settlement throughout the West with the aim of creating a State of Deseret. Religious associations proved important in re-purposing the bottomlands for agriculture. Flood irrigation was required to make the desert bloom during the hot and harsh summer months, and community-oriented irrigation districts were organized to build the canal systems and oversee the heavy demands of maintenance to keep these systems operational (Calvin, 1946, pp. 79–92; "Gila Valley Irrigation District: Safford, Arizona," 1928; Ramenofsky, 1984).

Changes in technology have resulted in modifications to farming and land use patterns throughout the course of the Gila's history of human occupation. From a market-driven perspective, the arrival of the railroad – and later, paved surface roads – led to the integration of the local farm economy into national and international markets. Instead of selling crops to the nearby mining towns or local military installations, new sellers were suddenly available. Choice of crops by local farmers then became influenced by opportunities to participate in distant commodity markets. Cotton became popular among farmers in the Valley, and it remains a staple crop today. Cultivation practices also changed to meet the often water-intensive needs of new crops and make use of the newly available machinery for large scale agriculture (Duncan Centennial Committee, 1984).

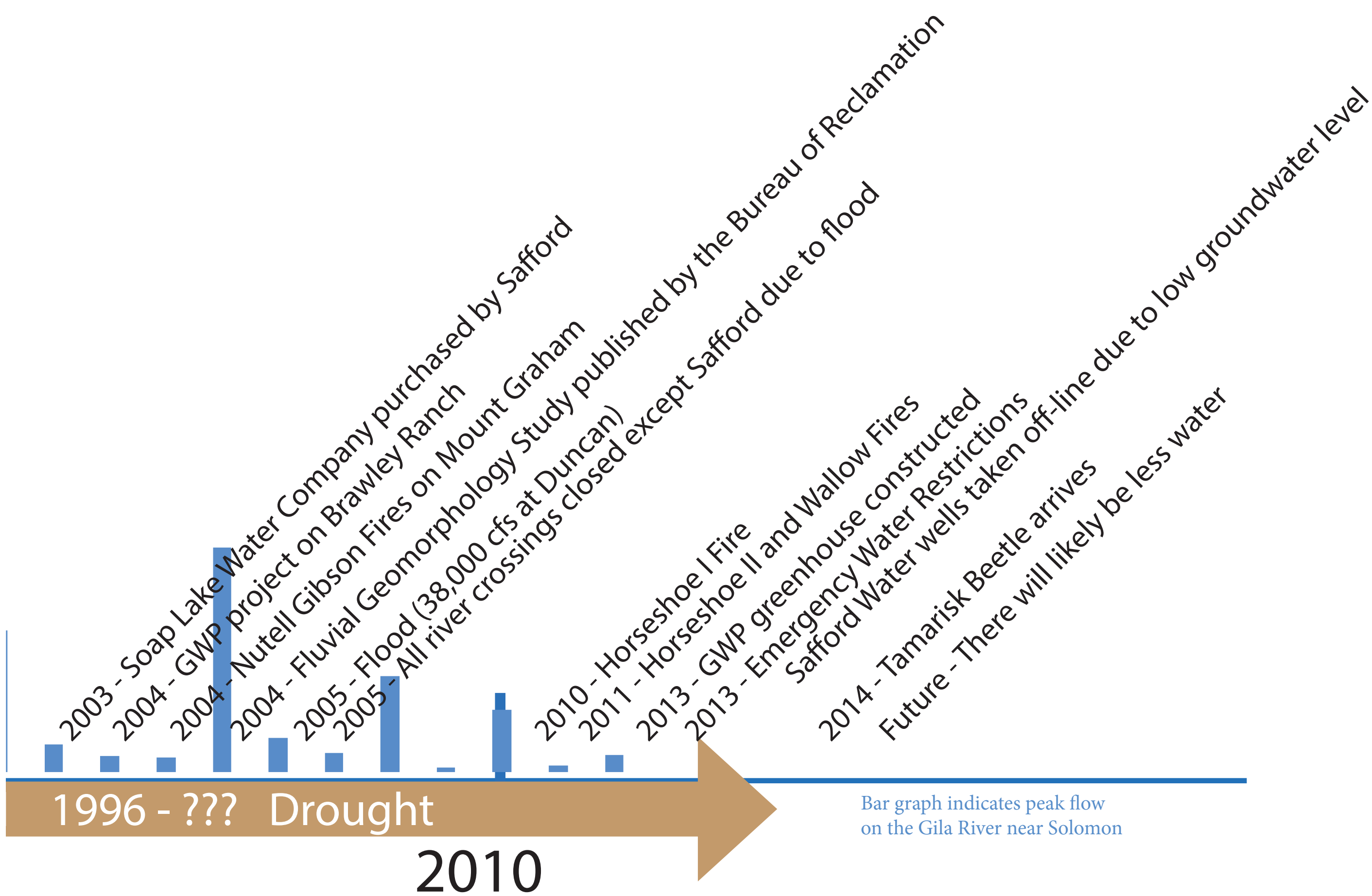
New plant species were introduced into the landscape during these waves of settlement. New crops were planted in the tilled fields, and ornamentals were carefully tended around homesteads. Some plants were reminders of distant childhood homes, while others provided shade in the intense desert sun. Some transplanted species found a suitable habitat in their new locale, and they soon began spreading rapidly into niches throughout the Valley. Certain plants found their way into the riparian areas along the Gila and its tributaries. Often these newcomers had vigorous growth habits and no natural predators,



allowing them to multiply quickly. Major ecological disturbances – whether their causes were settlement activities, like farming and ranching, or were of non-human origin, like droughts or major flood events – would provide opportunities for these new species to crowd out native ones. Some sections of riparian areas along the Gila have been overtaken by these exotic arrivals, such as salt cedar, to the detriment of the earlier cottonwood-willow galleries. The impacts of these shifts on plant and animal communities are currently under intense study by scientists.

The ability to drill deep wells into an aquifer containing agriculturally-suitable water quality has expanded agriculture into some areas far from the Gila and its tributaries. The State of Arizona makes a legal distinction between surface flows and groundwater, which has helped the expansion of agriculture in some areas where surface waters are already completely or even over-appropriated. It also allows for differentiation of water sources for non-agricultural uses. For instance, the municipally-operated water utility in Safford collects groundwater from an infiltration gallery buried in the Bonita Creek subwatershed to provide the majority of the annual demand for drinking water. This designation as groundwater distinguishes the source as legally separate from the already appropriated surface flows along Bonita Creek.

Another long-standing economic driver throughout the watershed is ranching. Feral herds have grazed throughout the region since the appearance of Coronado, but commercial ranching began in earnest in the 1870s and 1880s. Much of the Valley was too far from surface flows to be irrigated economically. Desert-adapted vegetation, however, could subsist on the low and often erratic precipitation. These areas were used by the Apache, as well as later Latino and Anglo settlers, for livestock grazing. Even before the arrival



of the railroad, sizeable herds were driven in from Texas and other distant places to take advantage of areas of luxuriant native grasses. The San Simon bottomlands were considered by early travelers and settlers to be an especially prime area for grazing.

Unfortunately, a combination of heavy over-grazing, the channelization of streambeds by early settlers, and a multi-year drought in the late 1880s and into the 1890s devastated both the herds of cattle and the fragile desert ecosystems. The introduction of non-native grasses during such times of stress and disturbance also made conditions difficult for the return of the native grasses. Loss of vegetative cover over the ensuing decades exposed the bare soils to intense summer monsoon rains and led to heavy erosion and arroyo downcutting in many areas. This contributed to the lowering of the water table and further degradation of vegetation. Enormous efforts have been invested in attempts to slow or stop the erosion process and the restoration of native vegetation cover from the 1930s to the present. Changes in rangeland management on both private and federal lands have been implemented to counteract the negative consequences of earlier grazing practices. The construction of thousands of sediment control structures of a multitude of sizes has prevented the loss of a great deal of additional soil into the Gila River and the San Carlos Reservoir, where soil accumulation decreases the reservoir's total storage capacity. Efforts at vegetation restoration have often been met with at best mixed results (Webb et al., 2007, pp. 185–186).

All these different groups of newcomers were arriving in an already long-settled land. Much of the watershed in the early nineteenth century fell under the influence of the Apache, who were organized into several different bands. In addition to cultivating crops in the floodplain of the Gila and several of its tributaries, they engaged in seasonal harvesting and hunting practices of native plants and animals that involved wide patterns of migration during the course of the typical year. These habits, which might be considered common pool resource management in contemporary terminology, were at odds with prevailing Anglo settler notions of ownership and delineated property rights. Struggles for control and dominance ensued over the coming decades. The Upper Gila River Watershed became nationally known because of these ongoing conflicts and the appearance of charismatic leaders like Geronimo. The federal government in the post-Civil War era began to employ the U.S. Army to quell such conflicts, and the Apache were largely relegated to reservations and government-based support programs by the end of the 1880s. Reservation boundaries and associated rights would contract and expand over the decades, such as with the changing of hands of the San Carlos Mineral Strip, the construction of Coolidge Dam, and the return of the control of grazing rights on parts of the reservation to the Apache in the 1930's. Negotiations continue into the current day, particularly with respect to the seniority of water rights under Arizona's prior appropriation system. Allocation of water rights, along with related efforts at monitoring and enforcement of the exercise of those rights, has widespread effects throughout the watershed, particularly in regard to agriculture (Calvin, 1946, pp. 93–106, Grenville Goodwin).

The communities of the Upper Gila River Watershed have witnessed threshold moments just in the past two hundred years where decision-making at particular points in time resulted in substantial shifts in the future development and land use of the Valley. These threshold moments demonstrate how a collective choice or series of choices can result in long-term effects for residents and the flora and fauna of the region. Land surveys and ownership arrangements established in the late 19th century impacted access to important resources like surface water and mineral rights. Site selections for new roadways and

and railways have had spillover effects for those communities included or excluded from such projects. In other cases, when expensive public projects were constrained by limited budgets, decisions were required to weigh community support. An early 20th century referendum led to the construction of a highway from Safford to Duncan instead of a dam in the area of the Gila Box. A long-term, anti-wildfire policy on federal forest lands has been shown to have counterproductive results, as the reduction in frequent, small-intensity fires is replaced by infrequent, but tremendously destructive high-intensity blazes like the Wallow Fire in 2011. Decisions and policies regarding land use and resource management can have lasting, long-term cumulative impacts on the watershed.

While technology and outside funding sources have increased options regarding access to and availability of water, this resource remains a scarce and therefore valuable resource. Recent droughts and lowered water tables have demonstrated the continuing vital importance of water for a broad variety of uses, from agriculture to mining to ecosystem services to residential/domestic daily activities. The ongoing drought conditions through the year 2013 have resulted in substantial acreage of farmland left fallow and new conservation actions by the City of Safford in response to water supply stresses (Johnson, 2013). From historic examples to the present, the sustainability of water supplies in the face of fluctuating precipitation levels has remained a constant theme in the life of residents of the Upper Gila River Watershed.

Chapter 2 References

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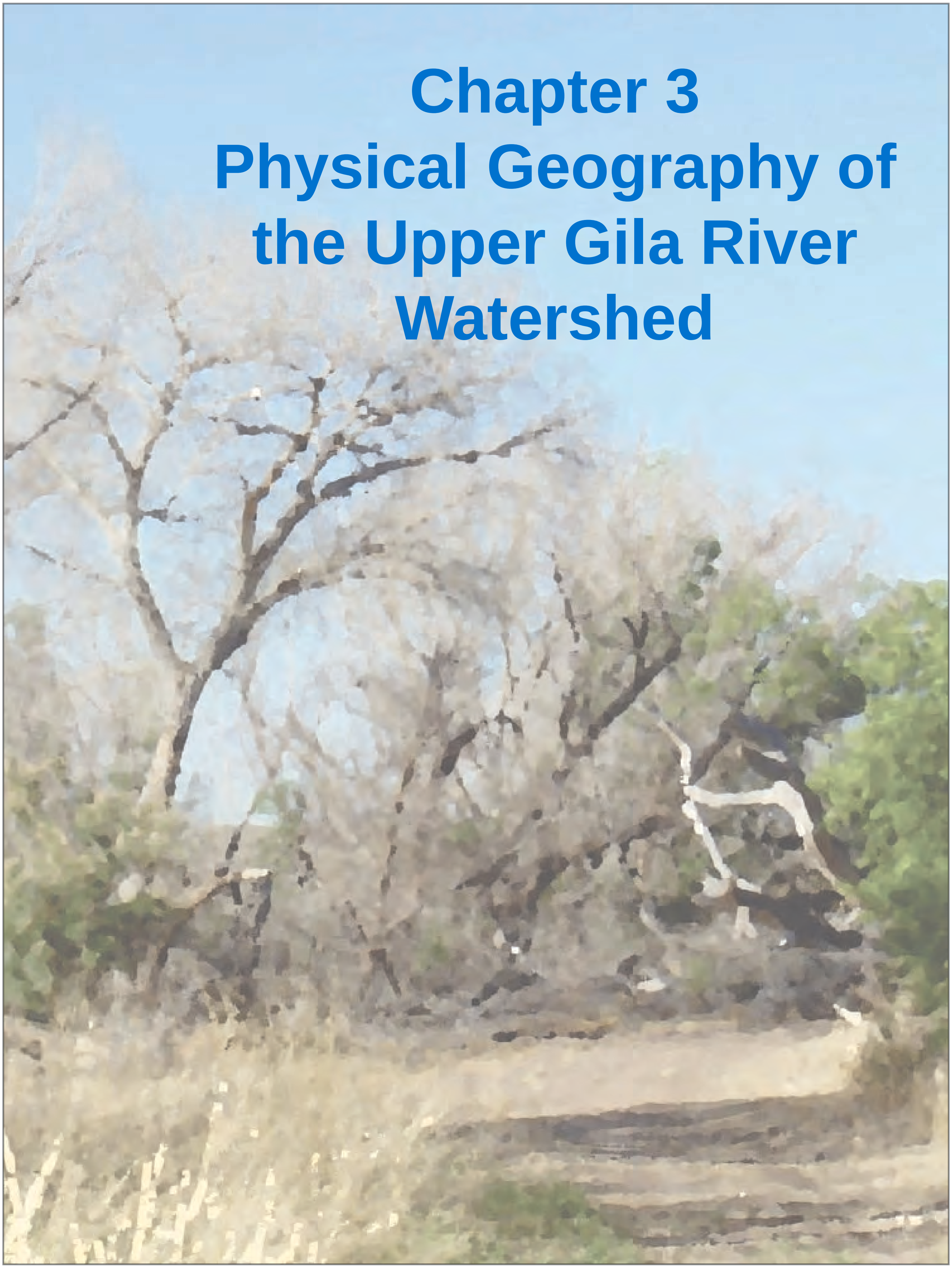
Photo opposite: David Chan

Chapter 3
Physical Geography of the Upper Gila River Watershed



Chapter 3 - Physical Geography of the Upper Gila River Watershed

Section 3-1 Ecology

Biotic Communities

Biotic Communities, or biomes, are "natural communities characterized by a distinctive vegetation" type (Brown, Lowe, & Pase, 1979). Associations are based on biological communities, the limits of moisture and temperature regimes, and the evolutionary origins of the plants and animals present. In the Southwestern United States, elevation often determines both temperature and precipitation: high elevations are generally cooler with greater precipitation than lower elevations. There are 11 biotic communities present in the watershed, ranging from desert to subalpine forest.

The biotic communities in the Arizona portion of the watershed can be roughly divided into thirds by generalized plant community type (desertscrub, woodlands and forests, and grasslands). In contrast, the New Mexico portion of the watershed has more than 50 percent tree cover (woodlands and forests) and less desertscrub. (see Table 3-1).

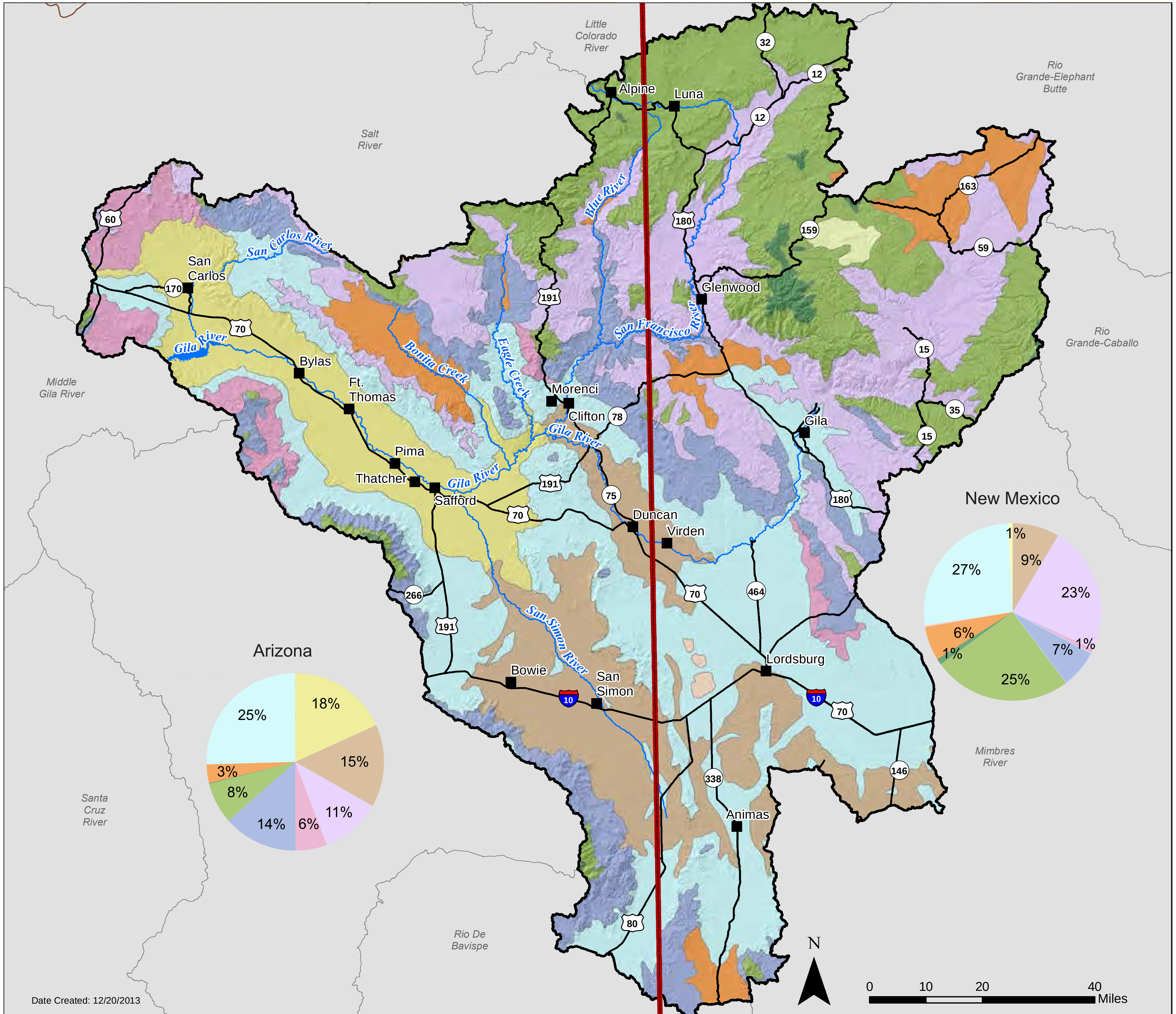
Table 3-1 Biotic Communities in the Upper Gila River Watershed

Biotic Community	Arizona (%)	New Mexico (%)	Entire Watershed (%)
Semidesert Grassland	25.4%	26.6%	26.0%
Great Basin Conifer Woodland	11.0%	23.4%	17.4%
Petran Montane Conifer Forest	7.5%	25.3%	16.7%
Chihuahuan Desert scrub	15.1%	8.5%	11.7%
Madrean Evergreen Woodland	13.5%	7.0%	10.2%
Sonoran Desert scrub	18.2%	0.0%	8.8%
Plains and Great Basin Grassland	3.4%	6.2%	4.8%
Interior Chaparral	5.7%	0.8%	3.2%
Petran Subalpine Conifer Forest	0.1%	1.1%	0.7%
Subalpine Grassland	0%	0.9%	0.4%
Playa	0%	0.3%	0.1%

Challenges

- Long term drought, and variability in temperature and precipitation patterns may cause shifts in the location of biomes. Plant communities at lower elevations may eventually spread into higher elevations.
- The range in elevation in the watershed results in a diverse landscape with many distinct biomes. Managing the watershed as a single landscape is challenging due to its complexity.
- Some biotic communities are more susceptible to fire than others.

Figure 3-1 Biotic Communities

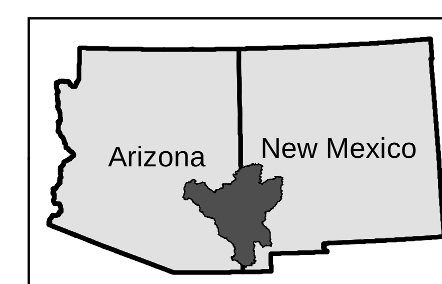


Legend

- City or Town
- Major Rivers
- Major Roads
- Upper Gila River Watershed Boundary
- Arizona-New Mexico Boundary
- Neighboring Watersheds

Biotic Communities (Brown & Lowe 1980)

- AZ UPLAND SUBDIVISION - SONORAN DESERTSCRUB
- CALIFORNIAN CHAPPARAL
- CHIHUAHUAN DESERTSCRUB
- GREAT BASIN CONIFER WOODLAND
- INTERIOR CHAPPARAL
- MADREAN EVERGREEN WOODLAND
- PETRAN MONTANE CONIFER FOREST
- PETRAN SUBALPINE CONIFER FOREST
- PLAINS AND GREAT BASIN GRASSLAND
- PLAYA
- SEMIDESERT GRASSLAND
- SUBALPINE GRASSLAND



Wildlife Features

The Upper Gila River Watershed houses a rich assemblage of wildlife. Only 10% of the Arizona portion of the watershed is privately owned; large areas of the remaining land are managed by the United States Forest Service and Bureau of Land Management. While grazing is a major economic activity in the watershed, in many areas wildlife shares the largely undeveloped land with cattle. The Gila River flows free of large dams above the San Carlos Reservoir, and sustains several perennial stretches that provide habitat for a large number of plants and animals.

The Endangered Species Act protects plants and animals threatened with extinction. Twenty two listed endangered species are found in the Upper Gila River Watershed; nineteen in Graham County and fourteen in Greenlee County (U.S. Fish and Wildlife Service, 2013). The United States Fish and Wildlife Service designates critical habitat (areas considered essential for survival) for each species listed as threatened or endangered. Seven endangered species have designated critical habitat in the watershed, including four fish species: Gila chub, Loach minnow, Razorback sucker, and Spikedace.

<u>Challenges</u>

- The protection of endangered species is often in conflict with human use of natural resources and land development.
- The region may bear a disproportionately large portion of the burden of protecting endangered species, i.e., development in the relatively pristine watershed might be limited because species have previously suffered extirpation in more heavily developed areas.
- Habitat destruction and fragmentation restrict the movement and life cycle habits of wildlife species.
- It is important to connect wildlife corridors before development divides the landscape further. Securing funding for land acquisition or conservation may be a challenge.
- Long term drought and climate change may affect the habitat on which wildlife species depend.
- Invasive species, such as Tamarisk (Salt Cedar) and Russian Knapweed, compete with native species for resources in the watershed.
- The recently introduced Tamarisk leaf beetle is projected to reach the watershed in 2014. It is expected to defoliate Tamarisk trees, but also poses a potential threat to the Southwestern Willow flycatcher, an endangered bird species that uses the non-native trees as habitat.
- Declining groundwater levels will eventually reduce the amount of surface water available for wildlife and their habitat

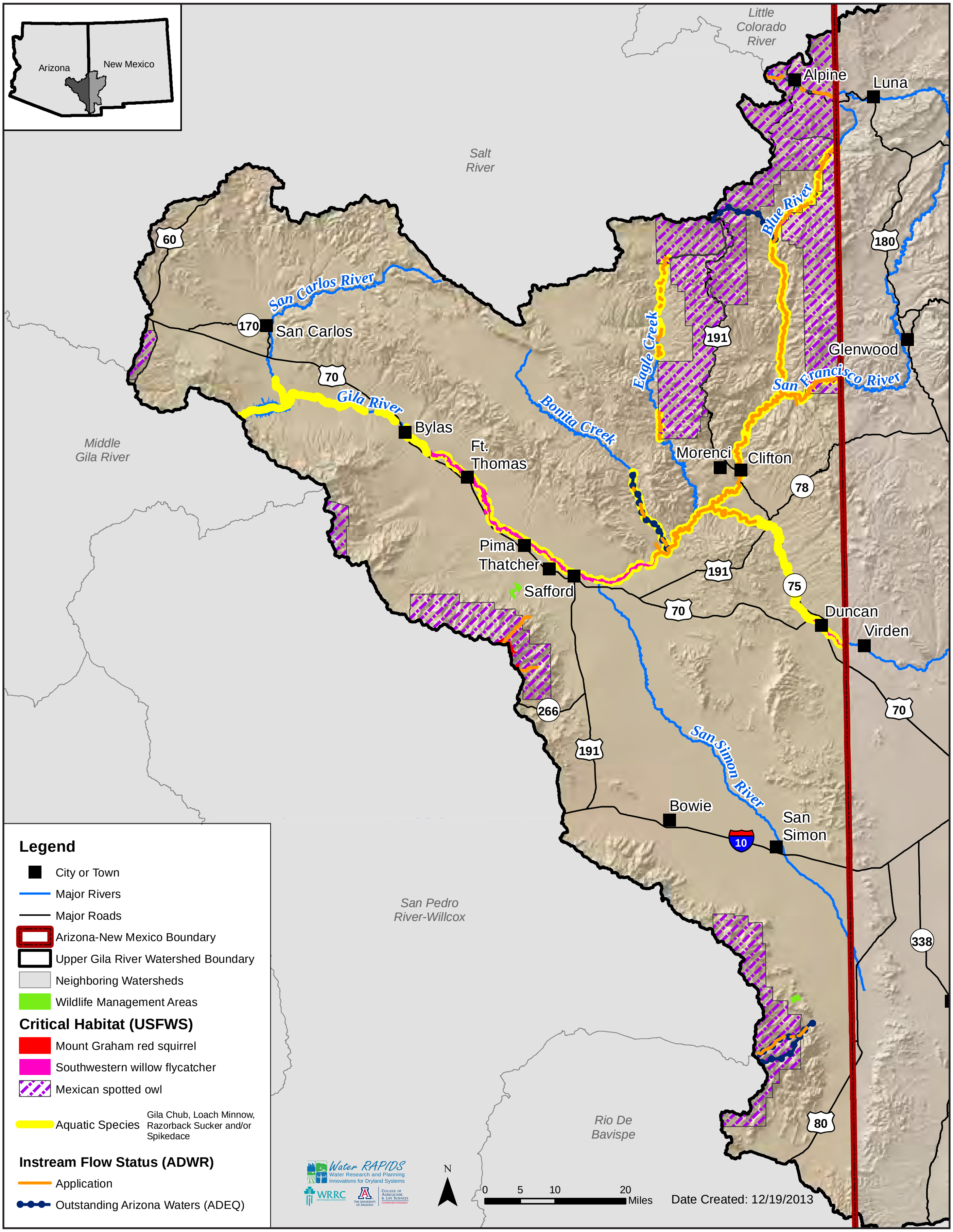


Figure 3-2 Wildlife Features

Section 3-2 Geology and Soils

Geology

The Upper Gila River Watershed is located in the Mexican Highland section of the Basin and Range Province; a geographic region with a unique topography created by a period of tectonic extension (stretching) during the Miocene Epoch (17 million years ago). This region is generally characterized by a series of roughly parallel mountain ranges separated by broad flat valleys with a North-South orientation (Nations & Stump, 1996). The mountains and valleys were created as the continental crust was pulled apart by tectonic forces. As the crust cracked, some pieces dropped lower than others, creating the high and low elevation pattern. Over time, erosion in the mountains collected as fill (primarily sand and gravel) in the valleys, creating what are now aquifers in the watershed.

The mountain ranges bordering the valleys are made of consolidated rocks. The Gila, Peloncillo and Chiricahua Mountains are made of rocks from mostly volcanic origin. The Piňaleno Mountains are formed by metamorphic rocks (rocks altered under great heat and pressure), while the Santa Teresa Mountains are granitic rocks (igneous) formed from cooling magma under the Earth’s surface.

From its headwaters in the Mogollon Mountains of New Mexico to its first major impoundment at Coolidge Dam, the Gila River flows through a relatively narrow channel confined between mountain ranges. The valleys around Safford and Duncan are exceptions with comparatively wide valley floors and made of deep deposits of mostly unconsolidated materials. This is called the Basin Fill Complex and is primarily sand and gravel (Mock, 2008).

Challenges

- Mountainous areas generally have little groundwater storage capacity.
- Surface and groundwater quality is directly affected by the geology of the watershed. Certain formations contribute to salinity as well as patterns of erosion and deposition.

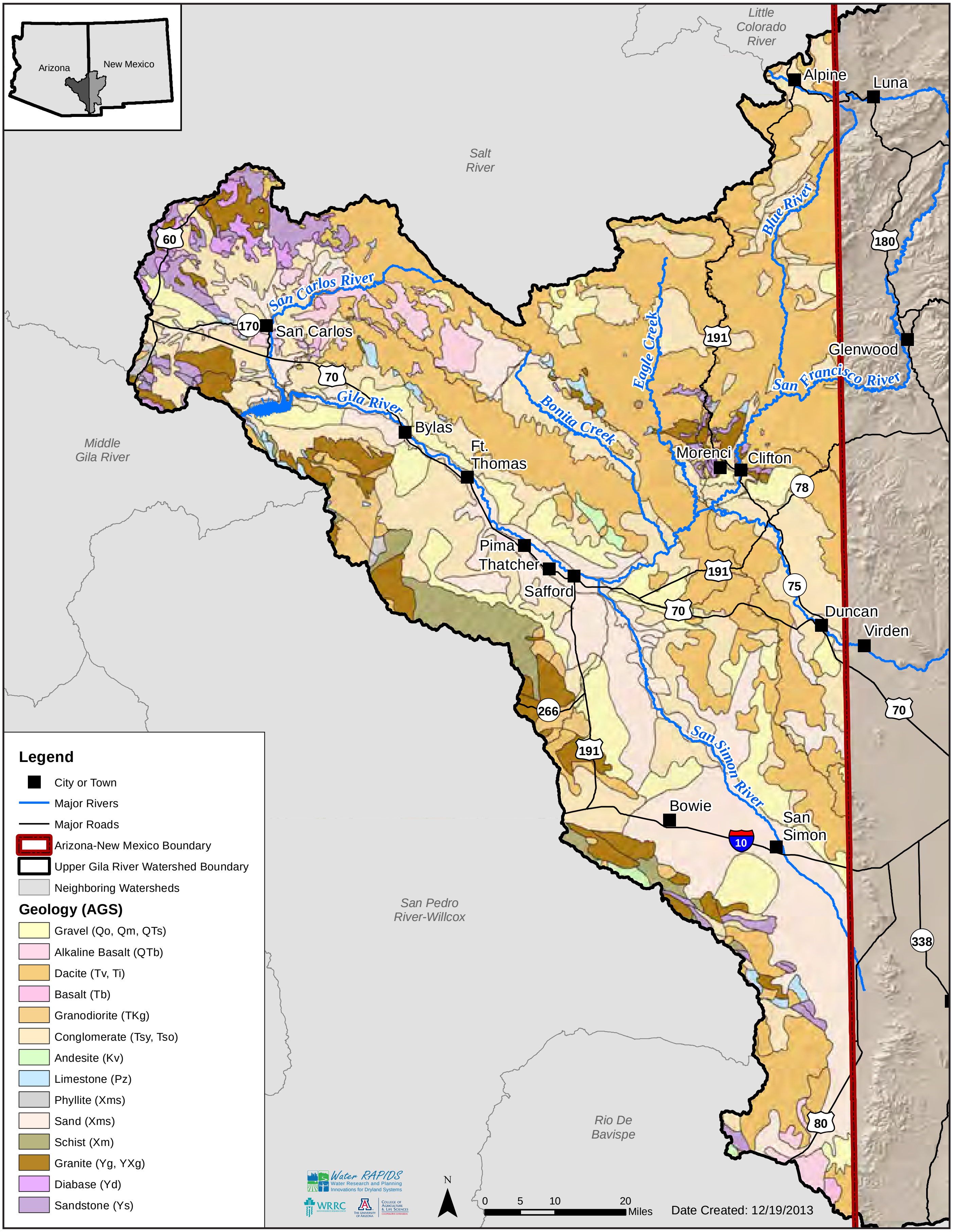


Figure 3-3 Geology

Soil Texture

Soil texture is a measure of the ratio between sand, silt, and clay content in a soil. Depending on the ratio of these three size fractions, a soil can be classified into a textural class such as sandy clay loam or silty clay. This classification can be further modified by the rock content and coarseness of the sand particles such as very cobbly fine sandy loam. Soils within a textural class have similar physical characteristics such as permeability, water holding capacity, plasticity, porosity, and bulk density. Texture largely dictates how quickly precipitation will infiltrate and move within the soil; water generally moves more slowly into and through finer textured soils than coarse textured soils.

In the Upper Gila River Watershed, some of the finest surface textures are in the Gila Mountains, north of the Gila River. These soils are commonly clay loam with high rock fragment content, and are intermixed with areas of rock outcropping. Along the floodplain of the San Simon and Gila Rivers, the texture is also primarily clay loam reflecting the alluvial (unconsolidated sediments deposited by water) nature of these soils. Clay loam textured soil has approximately equal parts of sand, silt and clay. Soils with a clay loam texture generally have good water holding capacity, and when uncultivated often have strong soil structure (aggregation of soil particles), which increases water infiltration.

The terraces and alluvial fans of the San Simon and Safford Valleys are generally loamy in texture with varying degrees of rockiness. Some soils in the San Simon area have higher silt content due to their location on the bed of an ancient lake. Soils with loam texture are considered a moderate soil texture, with less clay than clay loam textured soil. While clay loam has a balance between each soil fraction, the influence of the fractions is equally balanced in loamy soil (i.e. no soil fraction dominates the characteristics of the soil: it is not too sticky nor too loose).

<u>Challenges</u>

- Some soil textures are more susceptible to soil erosion than others. Vegetative cover, organic matter content and strong soil structure can reduce the erodibility of soil.
- Coarse textured soils contain more sand, and water percolates through the soil column rapidly. Finer textured soils have a higher water holding capacity. Moderately textured soil has the highest available water holding capacity (i.e. it can retain the greatest amount of plant available water).
- The surface soil texture largely controls the rate of infiltration of a soil. Poor infiltration causes precipitation to run off the land while coarse textured soils are more porous and therefore more permeable.
- Poor drainage can increase salinity in the soil because water that does not infiltrate readily evaporates leaving the water's mineral content behind. In contrast, minerals are flushed from well drained soils as water moves downward.
- Groundwater contamination can occur more easily through coarse soil. Rapid percolation reduces the time the soil can filter contaminants.
- Some types of clay found in the Safford and Duncan Valleys are expansive. When dry, soils containing this clay retract creating cracks in the soil surface. This characteristic is more pronounced in soils with a higher percentage of clay.

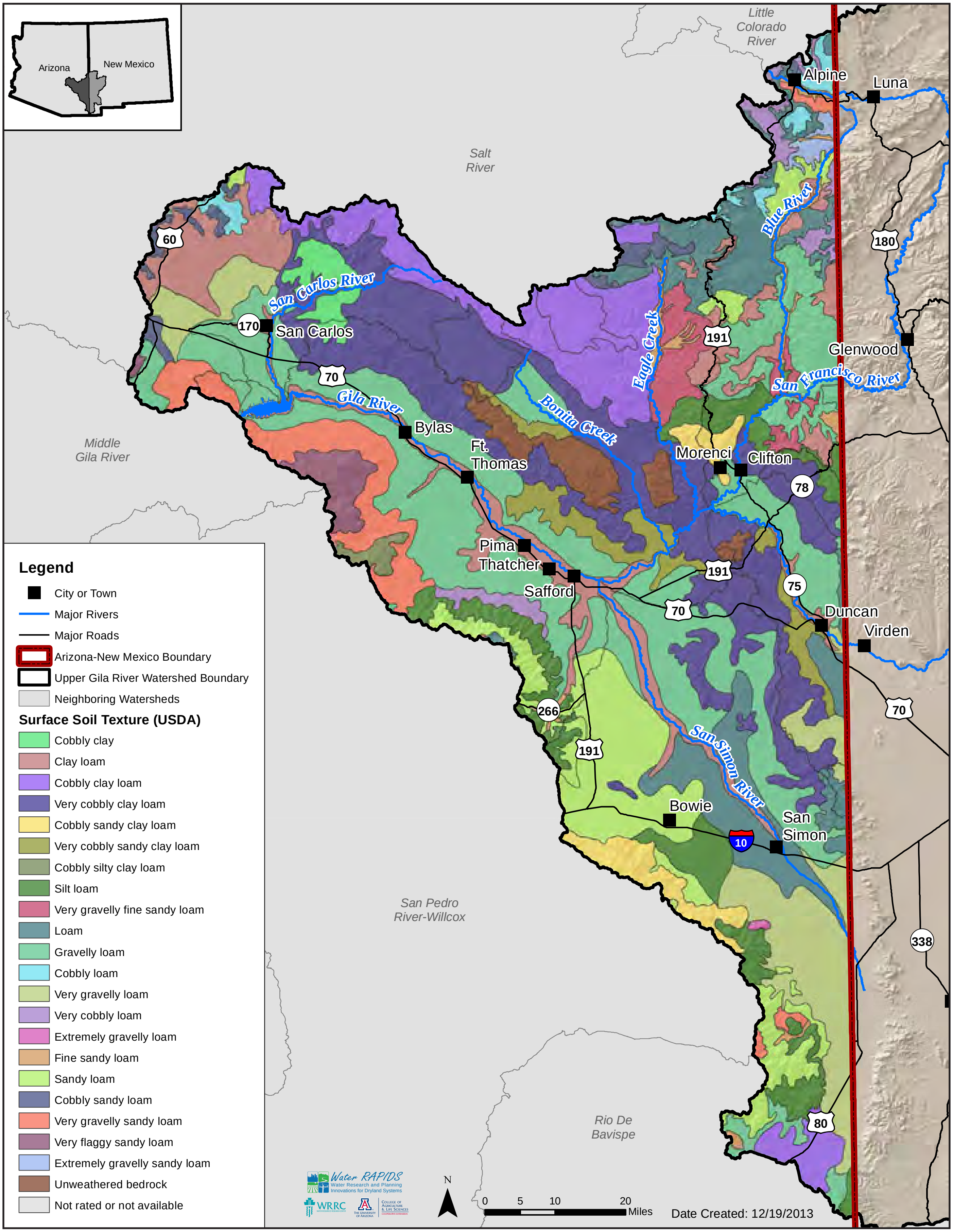


Figure 3-4 Soil Texture

Soil Erodibility

The K-factor is a measure of a soil's susceptibility to erosion. It is related to soil texture (sand, silt, and clay content), organic matter content, soil structure and hydraulic conductivity (permeability). Generally, finely textured soil (high clay content) and coarsely textured soil (high sand content) have the lowest K-factor ratings. Soils with a high percentage of silt are the most likely to erode. The actual amount of erosion expected on any piece of land can be calculated with the Revised Universal Soil Loss Equation, which is a function of the K-factor, the degree and length of slope, the climate (wind and precipitation) and management practices used.

In the Upper Gila River Watershed, the most erodible soils (highest K-factor) are located in the San Simon sub-watershed and the area South of Duncan. These areas have soils with high silt content and low vegetative cover. Parts of the Apache-Sitgreaves National Forest have soils susceptible to gully erosion caused by surface water runoff along a hillside.

Due to its slow regeneration, topsoil is considered a non-renewable resource. When soil erodes, it enters water bodies or the air and pollutes them. In the Upper Gila River Watershed, several river stretches are listed as impaired due to elevated sediment by the Arizona Department of Environmental Quality (ADEQ).

The Upper Gila River Watershed has been the focus of soil conservation efforts since at least the 1930's. Intense grazing in the late 19th century followed by drought in the early 20th century reduced the vegetative cover of the soil. Heavy rains between 1913 and 1918 eroded the exposed soil. To slow the erosion process, sediment control structures were constructed in many parts of the watershed. A recent inventory documented over 4000 remaining structures (Brandau, 2013). Many of these structures are in poor repair and the sediment trapped behind them is now entering streams, contributing to elevated sediment levels.

Challenges

- A large amount of sediment is held behind aging sediment control structures in the watershed. Maintaining or mitigating these structures may be critical to improving water quality in the watershed.
- Drought and overgrazing reduce vegetative cover resulting in greater erosion.
- Several portions of the Gila River have been listed as impaired waters by the ADEQ (see Section 3-5) due to elevated sediment.
- Poor air quality due to wind erosion.
- Loss of topsoil results in lower productivity of the land.
- Climate change is predicted to increase the intensity of individual storms, which may result in greater erosion.
- As the Tamarisk leaf beetle removes Tamarisk from the watershed, erosion may increase due to reduced vegetative cover.

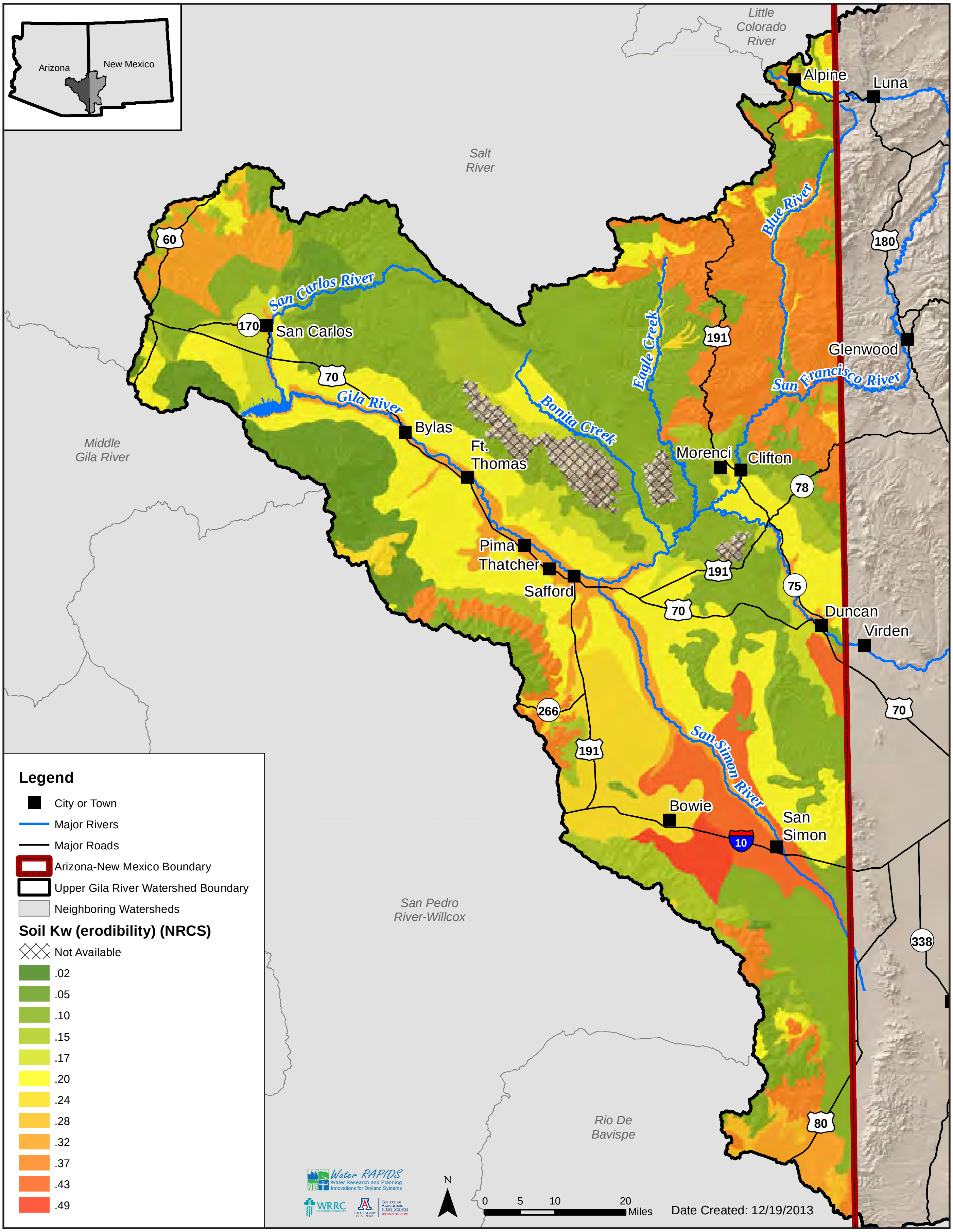


Figure 3-5 Soil Erodibility

Section 3-3 Precipitation

Precipitation

Southeast Arizona receives the majority of its precipitation in the summer and winter. Summer brings large, quick monsoon rainfall events during July and August. These monsoon storms are more intense and spatially heterogeneous; two areas in the watershed might see very different rainfall amounts from the same storm. Winter rainfall events are generally less intense, last longer and are more spatially homogeneous. Precipitation is measured in the watershed by a network of 15 meteorological stations and 5 snow stations.

A 30-year record of annual rainfall measurements from precipitation stations were averaged and spatially-extrapolated by the PRISM Climate Group at Oregon State University to create a precipitation map. More precipitation falls at higher elevation in the 'sky island' region of Southeastern Arizona, creating wetter and more vegetated ecosystems separated by desert 'seas'. The regional topography of these isolated mountain systems, known more generally as the Basin and Range Province, include deep sediment-filled valleys between mountain ranges. The precipitation mountains receive in Southeast Arizona flows via regional flow paths to recharge groundwater in the basin sediment.

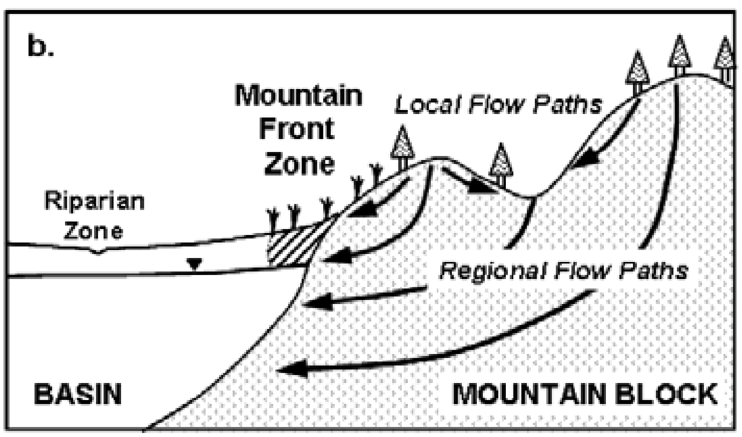


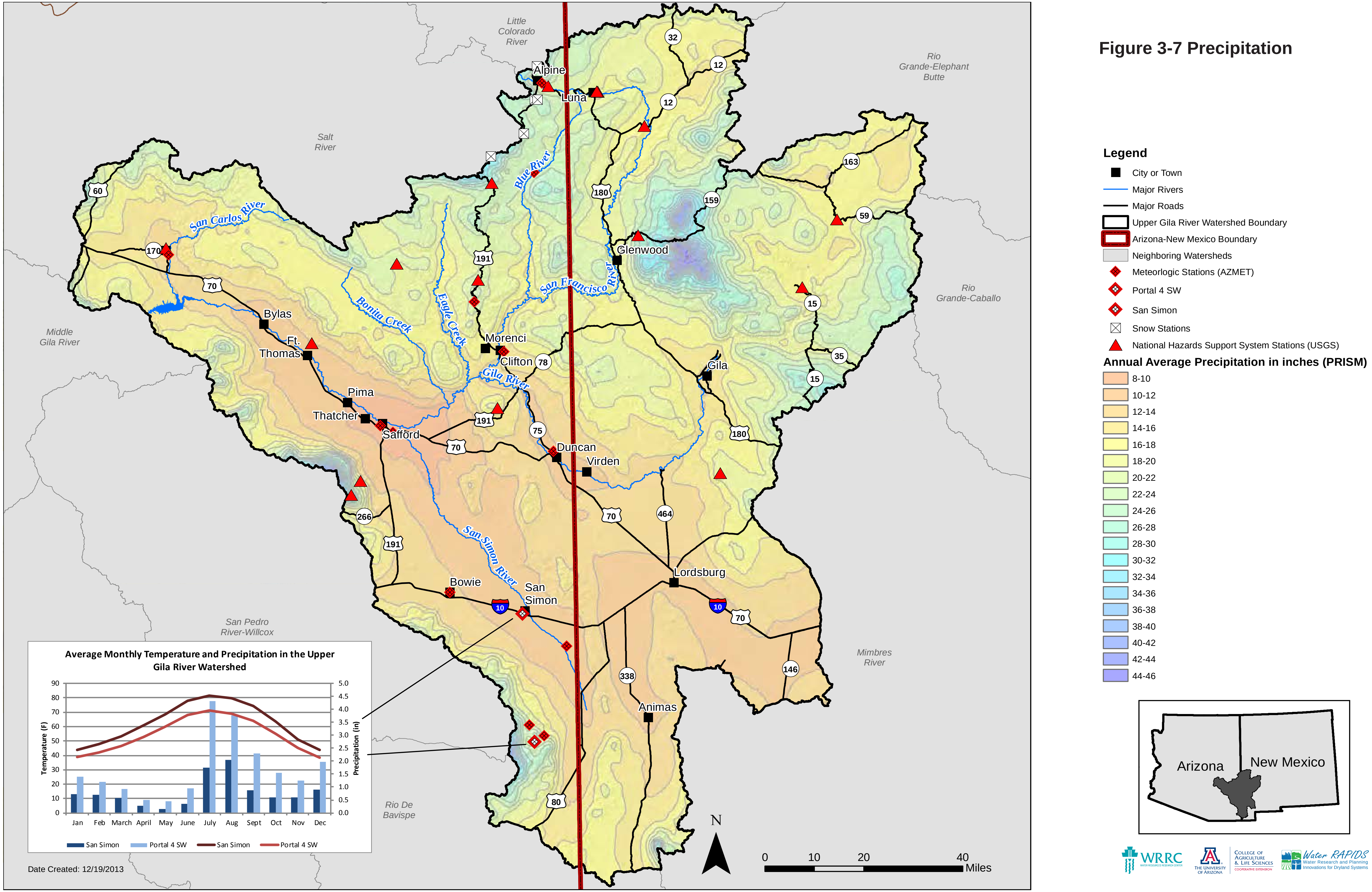
Figure 3-6 Mountain Front Recharge from Wilson and Guan (2004)

Lower elevation areas in the Upper Gila River Watershed, such as the Safford Valley and the San Simon Valley, receive the least rainfall, generally between 8 and 10 inches. The highest peaks in the Pinaleño and Chiricahua mountains receive more than 40 inches. Monthly precipitation totals are shown for the San Simon and Portal 4 SW meteorological stations. In Figure 3-7, both stations have increased precipitation during summer months, but Portal in the Chiricahua Mountains has more than twice the amount of precipitation compared to San Simon for July.

<u>Challenges</u>

- Recent fires (in the Chiricahuas, on Mount Graham, the Wallow, and Whitewater-Baldy Complex Fire), particularly those with high burn severity, will impact soils and may result in less infiltration of precipitation. This would increase surface flow and decrease the amount of mountain front recharge.
- Global climate change models predict the region will receive precipitation in fewer, larger events.

Figure 3-7 Precipitation



Section 3-4 Groundwater Conditions

Depth to Groundwater

Understanding basin-wide groundwater trends requires a general knowledge of the morphology of the basin as well as an understanding of the subsurface geology that comprises the aquifer units. The Upper Gila River Watershed is composed of four smaller-order basins; Bonita Creek, Morenci, Duncan Valley and Safford. The Bonita Creek watershed is entirely contained within the Upper Gila River Watershed and drains to Bonita Creek. The Morenci watershed feeds Eagle Creek and the San Francisco River. The Duncan Valley feeds the Gila River. The Morenci and Duncan Valley watersheds are bounded by the New Mexico border, though the physical boundary contributing to the headwaters of these watersheds extends into New Mexico. The Safford Basin is the main focus of groundwater study.

The Groundwater conditions map shows water levels of 309 shallow groundwater wells. Depth to water and well elevation were measured initially between 1987 and 1992, and then again in 2007 during the winter and early spring (December through March) for all measurements. The initial (1987-1992) water level was subtracted from the newer (2007) water level to calculate the change at each well. Positive change values indicate a rise in groundwater level, and negative values indicated a drop in water level. The overall range of the water level change is -91.2 to +76.8 feet, which indicates localized withdrawal and recharge effects. The greatest decrease in depth to water occurs along the San Simon River, just south of Interstate Highway 10. The well north of the confluence of the Gila and the San Simon Rivers shows the most positive difference in water elevation.

The subsurface geology of the Safford Basin has been described to have four "hydrogeologic units," described further in Table 3-2. While this table provides a general conceptual model of the subsurface structure, it should be noted that geophysical data suggest there is a considerable amount of inconsistency of the depth of these units at the basin-scale, which is why no unit thickness is reported. Cross-sections using geophysical techniques were recently compiled by the Arizona Geological Society for an investigation into the subsurface hydrology of the Safford basin. The report was created to assess the feasibility of carbon sequestration in the basin (Gootee, 2012).

<u>Challenges</u>

- A complicated subsurface creates challenges to understanding regional groundwater hydrology.
- Few wells extend into the Lower Basin Fill or below, and therefore only a few records of geologic material exist below the Upper Basin Fill.
- Water in the Lower Basin Fill is generally of poor quality. If the water level in the Upper Basin Fill Aquifer continues to drop, deepening wells below the Upper Basin Fill Aquifer may not be feasible for most areas.

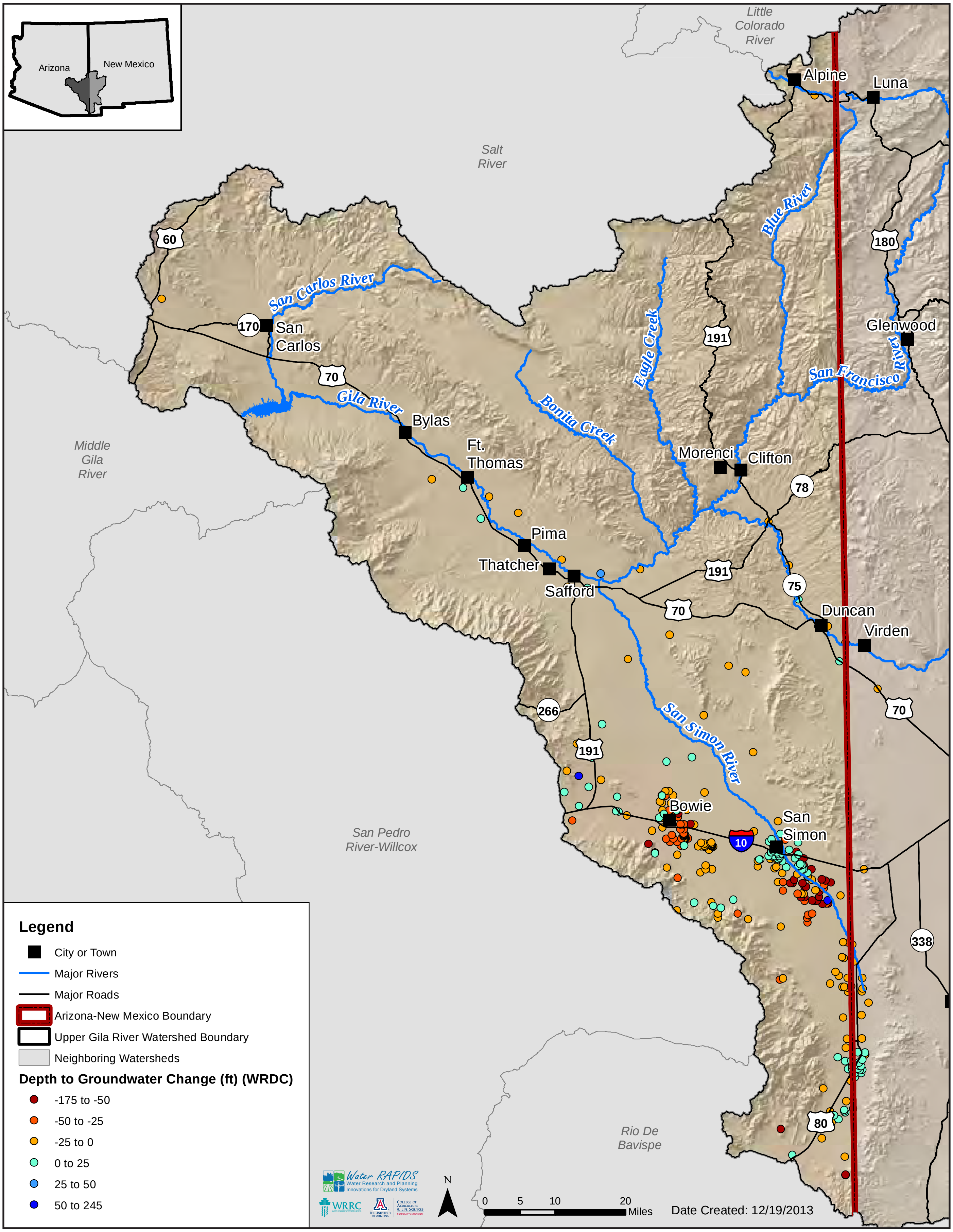


Figure 3-8 Groundwater Level Change

Wells and Aquifers
Regional aquifer data are shown to give a general idea of aquifer variability in the region. The aquifer units are derived from a larger-scale map for the *Ground Water Atlas of the United States* created by the United States Geological Survey. In the watershed, Basin and Range aquifer units are the most common. These are composed of the material eroded from mountain ranges filling the basin areas within the Basin and Range physiographic province, which was created by tectonic activity seventeen million years ago. The basin fill is as thick as 11,200 feet in the Gila Valley and capable of storing significantly more groundwater than the surrounding mountains (Arizona Department of Environmental Quality, 2009).

Arizona well data are from the Arizona Department of Water Resources, New Mexico data are from the Office of the State Engineer. Both sets of well data include all records, and likely overestimate the number of wells in any given area. Wells are most concentrated along the Gila River between Safford and Pima, as well as along the Interstate Highway 10 between Highway 191 and the San Simon River. There is also a cluster of wells near Duncan running north along the Gila River. For information on changes to groundwater in Arizona over time, see section 5-4.

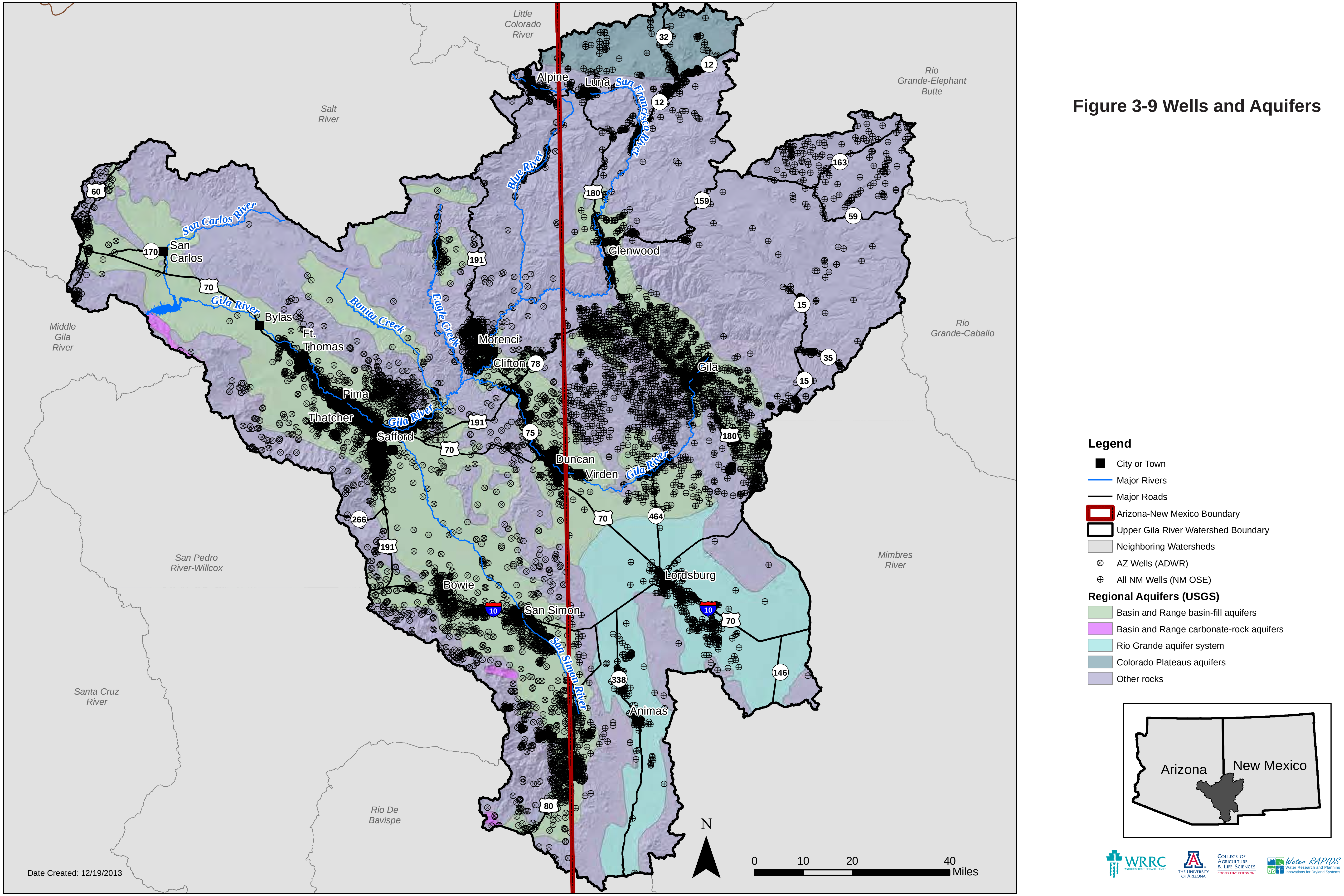
Challenges

- Updated data are needed for a better understanding of current conditions.
- Updated well depth data would also be useful for assessing how groundwater pumping might impact the future availability of groundwater and surface water.

Table 3-2: Geologic description and interpretation of relevance for groundwater, modified from Gootee, 2012.

Basin-Fill Unit	Generalized Geologic Description	Interpretation for Groundwater
Gila River Alluvium	Alluvial and fluvial deposits derived from the modern Gila River network.	Unconfined aquifer, recharged by the Gila River
Upper Basin Fill (UBF)	Unconsolidated coarse and fine siliciclastics, evaporites, and limestone deposited in alluvial, fluvial and lacustrine environments interpreted to have formed from an ancestral Gila River. Regional studies indicate an unconformable relationship with the underlying basin fill unit.	Evaporites in this layer may provide a source of TDS.
Lower Basin Fill (LBF)	Semi-indurated and semi-consolidated coarse and fine silicicalastics, evaporites and limestone deposited in proximal and distal alluvial fans and lacustrine environments. Basalt flows may be interbedded in the lowermost portions of this unit at the downstream and upstream termini of the Safford Basin. Indications of unconformable with underlying volcanic bedrock.	Evaporites in this layer may provide a source of TDS, interbedded less conductive rock may cause changes in local hydraulic head.
Bedrock	Three types of bedrock; oldest units are igneous and metamorphic rocks, middle sedimentary and youngest volcanic (which include andesite and basalt) underlying the LBF.	Discontinuous non-permeable rock may act as a confining unit to water in the bedrock aquifer.

Figure 3-9 Wells and Aquifers



Section 3-5 Surface Water Conditions

Streams, Springs, Runoff, and Riparian Areas

Surface water generally flows from the mountains to join the Gila River, which flows to the San Carlos reservoir at the outlet of the watershed to the West. The main tributaries to the Gila are the Blue River, the San Francisco River, Eagle Creek, Bonita Creek, and the San Carlos River. Surface flows can be divided into three categories: perennial, intermittent and ephemeral. Perennial streams flow year round, intermittent streams flow some part of the year, and ephemeral streams flow only after storm events. Of the 2,343 miles of streams in the watershed, 23% are perennial, see table 3-5.

The locations of springs in the watershed have been gathered from a myriad of sources, including government agencies (United States Geological Survey, Bureau of Land Management, United States Forest Service and National Park Service) and university sources. Of these, only a subset of the most recent and accurately mapped are displayed. The flow rate of springs are often unpredictable; data shown here provide a snapshot in time of the location and flow conditions of springs.

Average annual runoff is variable in the watershed and is typically greater in the mountains, which receive more annual precipitation. The lowest runoff is in the vicinity of Safford and Thatcher along the Gila River and in the southeastern part of the basin - approximately 0.2 inches, or 10.6 acre-feet per square mile. Runoff increases to 5 inches, or 266.6 acre-feet per square mile, in the Chiricahua Mountains along the southwestern boundary.

Table 3-3 Flow Status in the Arizona Upper Gila River Watershed

Flow Status	Length (miles)	Percentage
Ephemeral	1143.2	49%
Intermittent	662.0	28%
Perennial	537.7	23%
Total	**2342.9**	**100%**

<u>Challenges</u>

- Data on spring location and discharge need to be verified and updated.
- Frequency of fires may increase as air temperature increases, which dries out fuel sources. This is more critical in the areas of fire regime class II and IV, which total 13.6% of the Arizona portion of the watershed. Land affected by fire is more likely to have increased runoff and erosion. Associated water courses may experience flooding and impaired water quality.
- The New Mexico portion of the watershed is upstream of the Arizona portion. Changes in New Mexico can impact the watershed in Arizona.
- Climate change is predicted to alter the frequency and severity of storms resulting in fewer, more intense rainfall events. Streams may experience more flooding events and fewer perennial flows as a result.
- Perennial flow is required to sustain healthy aquatic communities and is important for the health of riparian vegetative and animal communities.

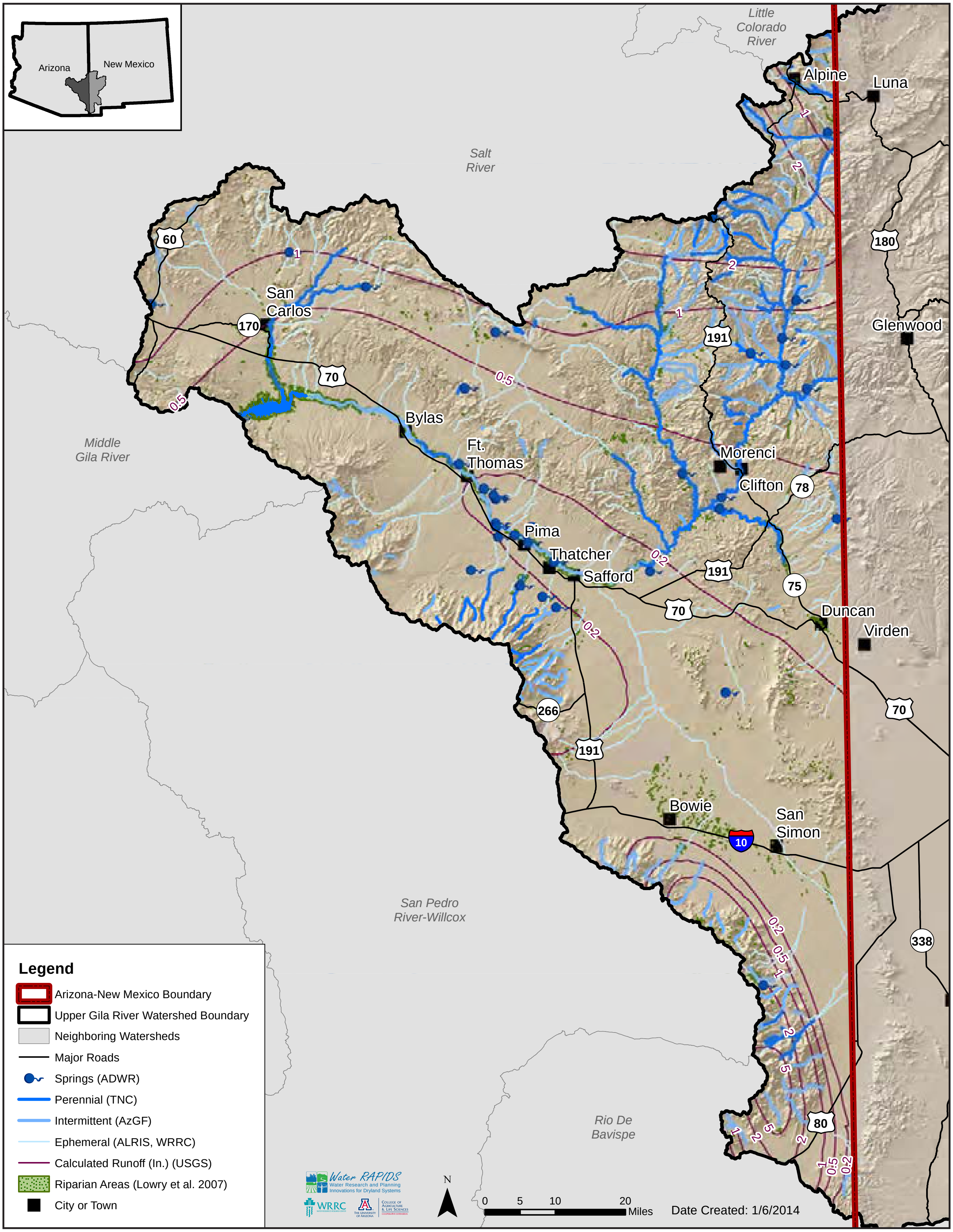


Figure 3-10 Streams, Springs, Runoff, and Riparian Areas

Water Infrastructure

Surface water infrastructure includes dams, irrigation canals, stream gages, and flood alert gages. Due to the high levels of precipitation in the mountains, downstream conditions can change without local weather conditions changing (see Precipitation, Section 3-3). There are 16 Flood Alert Gages in the watershed. Flood Alert Gages include precipitation and river stage monitoring, generally operated by federal agencies (National Weather Service (NWS) and United States Geological Survey (USGS)).

There are 10 operational USGS Stream gages in the watershed. These are predominantly located near the Gila tributary's confluence with the Gila River, on the Blue River, San Francisco, Eagle Creek, Bonita Creek and San Carlos River. There are also gages located just across the border from New Mexico on the Gila River, upstream of the San Carlos Reservoir as well as at the foot of the Reservoir (counted within the 10 though not visible on the map).

Data from the Arizona Department of Water Resources (ADWR) have designated 26 "large" dams in the Upper Gila River Watershed, 6 of which are in New Mexico (2 visible within the range shown on the map).

Flood Management

There are 170,732 acres within the watershed designated as 100-year floodplain areas. The NWS generally evaluates precipitation and stream gage data (often gathered by the USGS) to assess flood danger. There have also been efforts to create statewide flood warnings. The Arizona Flood Warning Office was created in 1980 under ADWR with funding from the state legislature. The office assists Arizona-located USGS offices in maintaining stream gages and the NWS in improving flood prediction.

The Gila Watershed Partnership is currently producing an ecohydrological assessment to identify areas along the Gila River that would be best suited for long-term riparian restoration, which could assist in mitigation of flood impact in the future.

<u>Challenges</u>

- Many stream gages have been discontinued due to insufficient funding. Without historic and current data, it can be difficult to identify long-term trends in streamflow.

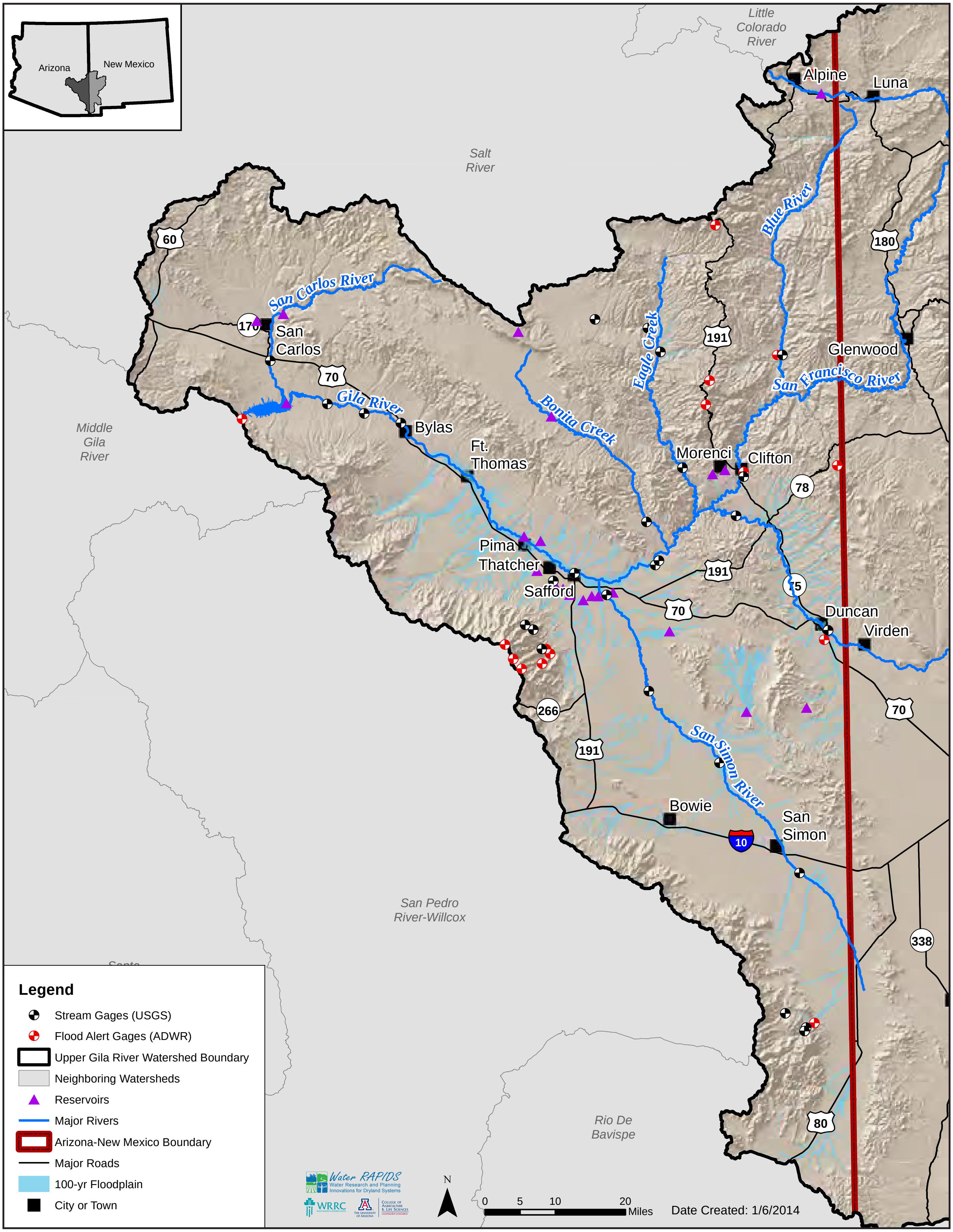


Figure 3-11 Surface Water Infrastructure

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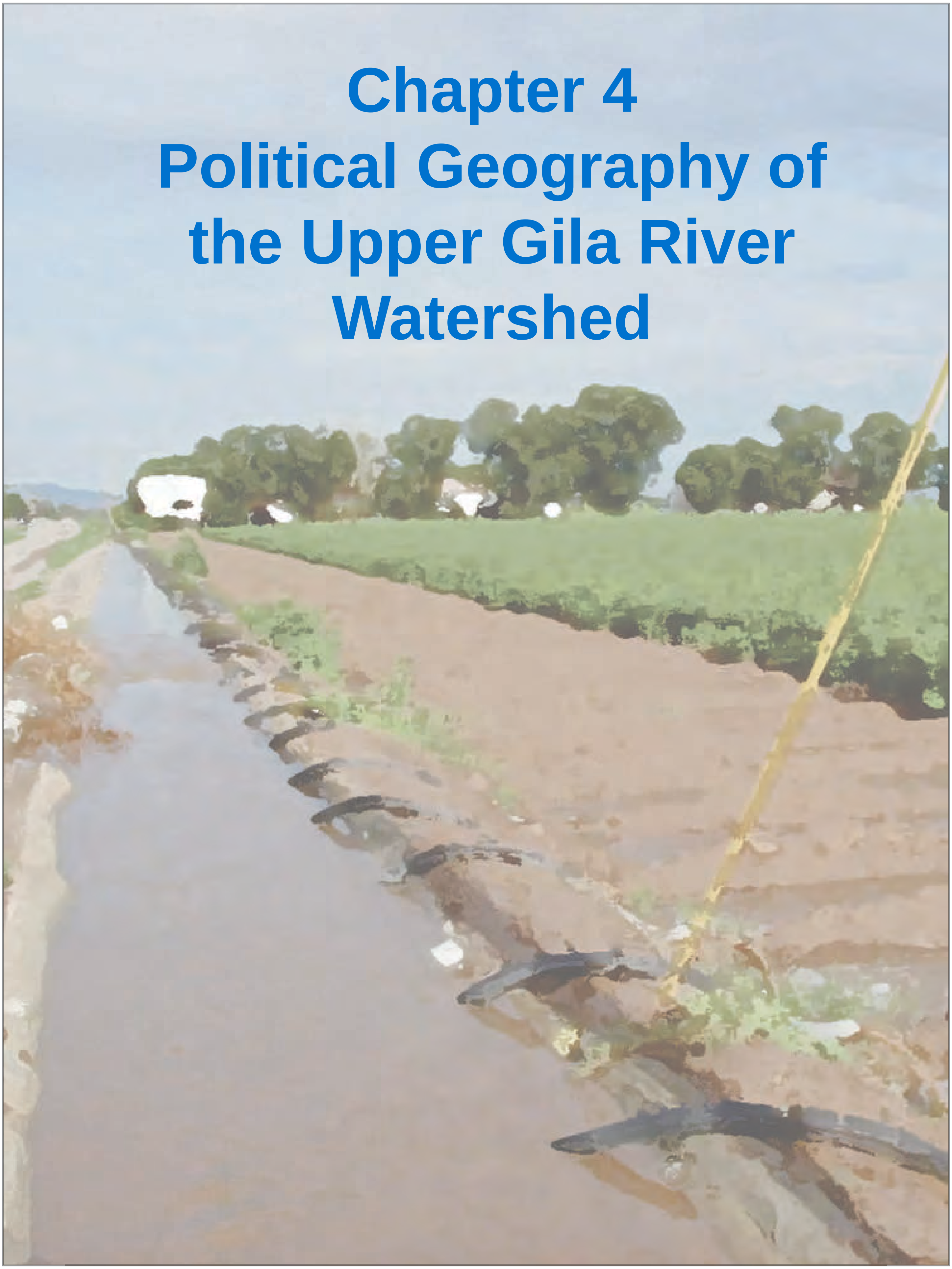
*Map references and additional detail on map data can be found in the Appendix

Photo opposite: Kelly Mott Lacroix, Arizona Water Atlas, Arizona Department of Water Resources

Chapter 4
Political Geography of the Upper Gila River Watershed



Chapter 4 Political Geography of the Upper Gila River Watershed

Section 4-1 Infrastructure

The Upper Gila River Watershed is located in parts of six Arizona counties. The vast majority of the watershed is in Graham and Greenlee counties, with small areas in Apache, Cochise, Gila, and Pinal counties. Population centers are located along the rivers of the watershed, especially the San Francisco and Gila. Approximately 70% of the population lives within 5 miles of one of these 2 rivers.

The infrastructure in the watershed is concentrated along the Gila, San Francisco and San Simon river corridors, in close proximity to water resources. Communities in the area developed around agriculture and mining activities, both of which rely on the availability of a steady water supply. Highways, roads, and railroads connect the communities with public services like airports, schools, and correctional facilities located near the largest population centers: Safford and Clifton. These are also the respective county seats of Graham and Greenlee counties.

Table 4-1 Population

City/Town	County	Population at 2010 Census
	Graham	***37,220***
Safford	Graham	9,566
Thatcher	Graham	4,865
Pima	Graham	2,387
Central	Graham	645
Solomon	Graham	426
Bryce	Graham	175
	Greenlee	***8,437***
Clifton	Greenlee	3,311
Morenci	Greenlee	1,489
Duncan	Greenlee	696

<u>Challenges</u>

- Projected population growth centers may not match the scale and location of existing infrastructure, which could put a strain on municipal services.
- Federal and state funding for infrastructure projects has been reduced nationwide, shifting the cost to local government.
- Statewide, infrastructure construction has not kept pace with the expanding population. Existing infrastructure for sectors such as transportation, water delivery, education, energy, health care and telecommunication are aging as a result. One report estimated the state will need an additional $11 billion per year to provide infrastructure for the 10 million people expected by 2030 (W.P. Carey School of Business, 2008).
- Rural populations are generally under served by state and federal services when compared to more urbanized areas.

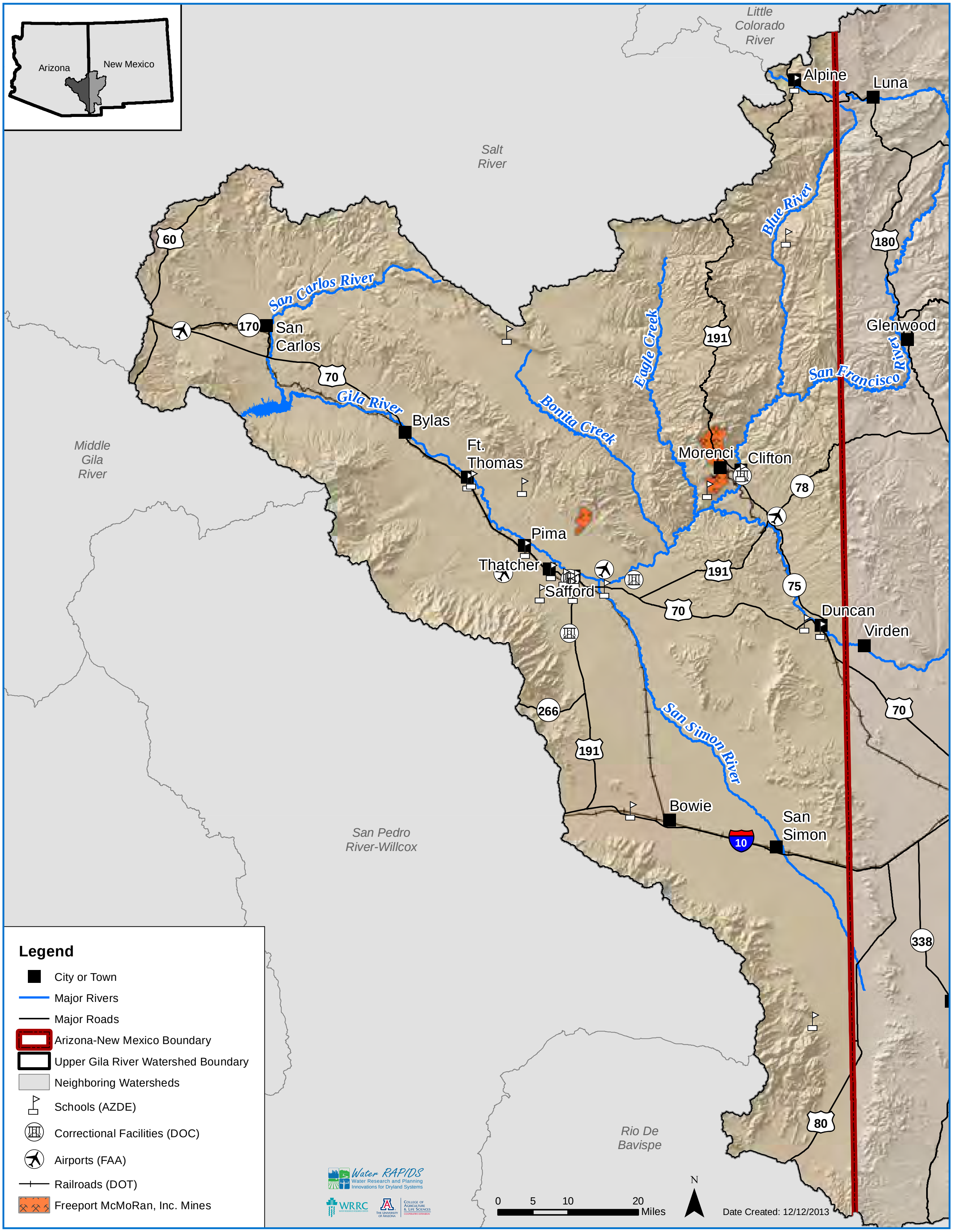


Figure 4-1 Infrastructure

Section 4-2 Water Use

Adequate Water Supply

The Arizona Groundwater Management Act of 1980 governs the use of groundwater in Active Management Areas (AMAs) located in central Arizona. Regions outside the AMAs, like the Upper Gila River Watershed, are subject to the Water Adequacy Program, which is intended to protect consumers from purchasing property without adequate water. This program does not manage groundwater nor limit the amount that can be pumped from the aquifer. Under the Water Adequacy Program, new subdivisions must either obtain water from a water provider with an Adequate Water Supply Designation or apply for an Adequate Water Report from the Arizona Department of Water Resources (ADWR). An adequate water supply must be physically, legally and continuously available for 100 years. An Inadequate Water Supply Designation does not prevent the marketing of real estate; however the first buyer of the property must be informed of its water supply status.

ADWR has processed 35 water adequacy applications in the Upper Gila River Watershed: 2 for Adequate Water Designations and 33 for Adequate Water Reports. The City of Safford holds the single largest designation, almost 4,000 acre feet per year; the second designation was issued in 2010 for more than 3,000 acre feet per year for the Sierra del Sol subdivision, 8 miles south of Safford (Arizona Department of Water Resources, 2013). Of the 33 reports issued, 16 were issued as adequate. It is difficult to determine if the 17 inadequate determinations in the watershed are due to a documented lack of water or incomplete study. The Arizona Water Atlas states the majority of inadequacy determinations in most regions of the state were due to insufficient data or a request for inadequacy in lieu of conducting a detailed study of hydrologic conditions (Arizona Department of Water Resources, 2010).

Challenges

- Adequacy rules apply only to new subdivisions of at least 6 lots where the size of 1 lot is less than 36 acres. In Arizona, land may be subdivided into five or fewer lots without much oversight; these “wildcat” lot splits are not subject to the adequacy rules.
- Adequacy rules allow groundwater pumping to lower the aquifer to 400 feet for lots with their own well, and 1,200 feet for water companies during the first 100 years. In the Upper Gila River Watershed, this is generally deeper than the total depth of the shallow aquifer.
- Incomplete applications hamper water planning efforts as the impact of these developments on the local aquifer is often unknown.
- Calculating the quantity of groundwater in an aquifer is complicated and imprecise. ADWR has been criticized for their methodology issuing Adequate Water Supply certificates, as they might double count groundwater.
- Inadequate Water Supply designations do not allow the county to deny subdivision of land.
- The population of the watershed is predicted to grow while the water supply is not.

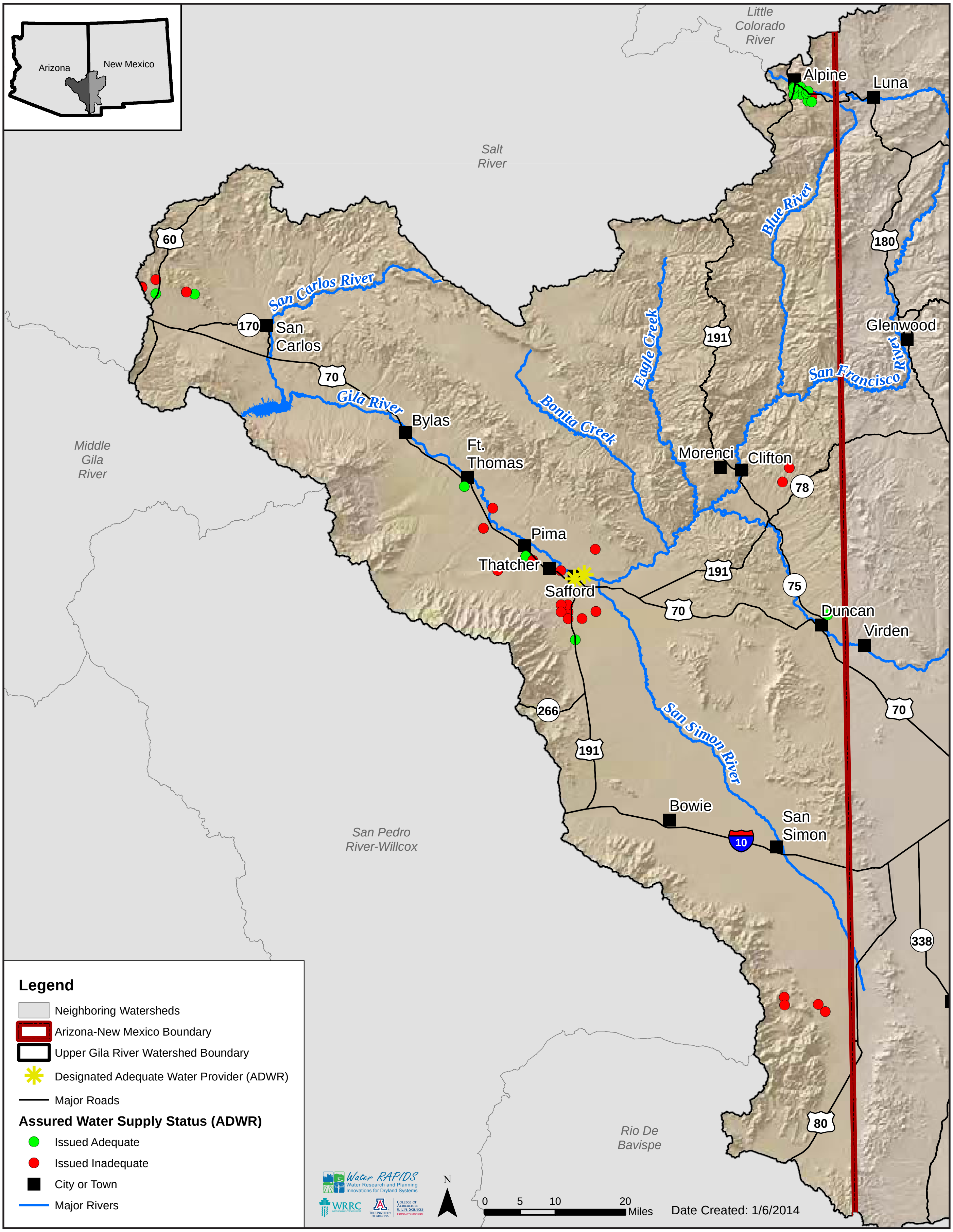


Figure 4-2 Adequate Water Supply

Section 4-3 Surface Water Rights

In Arizona, surface water rights are established by application to the Arizona Department of Water Resources (ADWR). Priority is given to rights depending on the date the water was first put to beneficial use, so that in times of drought the oldest, or senior, water rights are satisfied before the younger, or more junior, rights. Shown on the map at right is the point of diversion (POD) for each surface water right in the watershed.

There are more than 4,800 surface water rights established with ADWR in the Upper Gila River Watershed. Surface rights are not limited to the rivers and streams, but also include springs, stock ponds, and groundwater in some parts of the watershed. These rights are each affected by the Globe Equity Decree, the San Carlos Apache Tribe Water Rights Settlement Act of 1992, the Arizona Water Rights Settlement Act of 2004, and the Gila River General Stream Adjudication in progress in Maricopa County Superior Court. The Arizona Water Rights Settlement Act of 2004 limits agricultural use of both surface and groundwater in the watershed. Water settlements have had a significant impact on water rights in the watershed.

Challenges

- Uncertainty of the effects of the General Stream Adjudication for the Gila River on water rights.
- The Arizona Water Settlements Act of 2004 granted New Mexico the right to an average of 14,000 acre feet per year from the Gila and San Francisco Rivers. New Mexico must declare their intention regarding this water by the end of 2014.
- As some surface water rights are reduced in the watershed, users switch to pumping groundwater. However, groundwater is not managed in the watershed (with the exception of that in the subflow zone) and is vulnerable to overdraft.
- Increased groundwater pumping may impact surface water flows.
- Drought and changes in climate may alter surface water supply. For instance, the watershed may receive less precipitation overall, or fewer more intense storm events may become normal, changing the timing of supply.

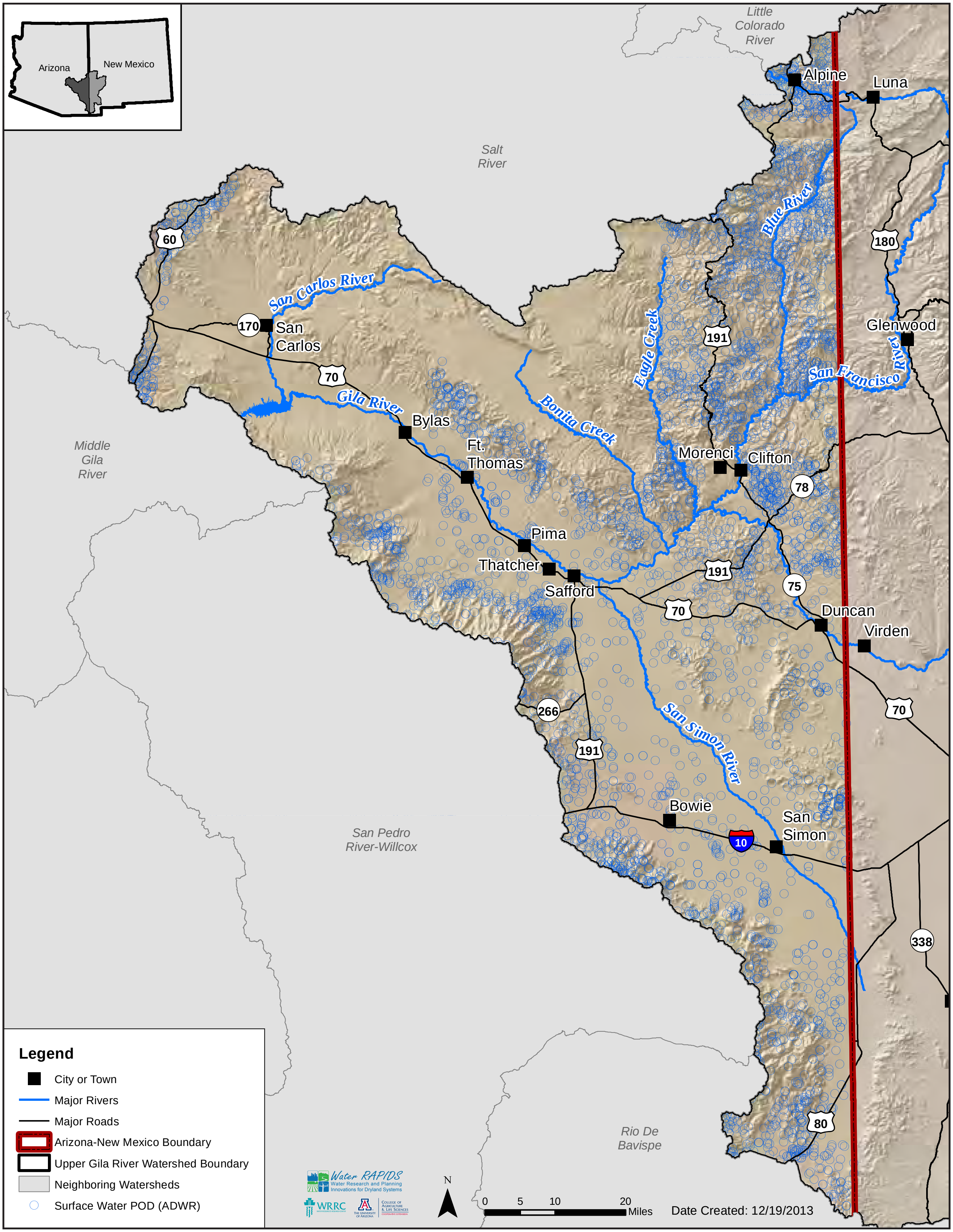


Figure 4-3 Surface Water Right Points of Diversion

Section 4-4 Water Quality

Surface Water

The Arizona Department of Environmental Quality (ADEQ) uses five categories to evaluate the status of a given water source, four of which have been observed in the Upper Gila River Watershed. These categories depend on the suite of parameters tested and the frequency of testing. Attaining all uses (category 1) indicates that a full suite of parameters were tested a sufficient number of times with no exceedances reported at any time. Attaining some uses (category 2) is given for a water that recorded at least one exceedance, but in repeated sampling the exceedance was not consistent. Inconclusive (category 3) is given for a water which was not tested for enough parameters or frequently enough to determine water quality status. Impaired (category 5) is given for a waters that exceed criteria repeatedly. There were no waters with a Not Attaining Waters (category 4) status in the watershed.

Surface water quality is designated impaired on the Gila in two places: just upstream of the confluence with the San Francisco and just downstream of the confluence with Bonita Creek. A smaller surface water drainage from the burned Chiricahua Mountains in the southern portion of the watershed is also designated impaired.

Groundwater

Water quality of groundwater has been studied in the Upper Gila River Watershed by the Arizona Department of Water Resources and ADEQ. These reports are inconsistent regarding the source of high levels of total dissolved solids (TDS), which is the main threat to water quality in the basin. The sources of TDS in the Safford Basin could be weathered dissolved geologic materials (particularly evaporites present in the Lower Basin Fill and Upper Basin Fill) or water where the TDS has been concentrated via evaporation (reducing the volume of water while leaving behind the dissolved materials). Additional theories include a lower artesian aquifer has high TDS which flows upward through faults to concentrate TDS in the Lower Basin Fill and Upper Basin Fill as well as downward migration of high TDS waters from irrigation runoff (data, summarized by Gootee (2012), do not show any correlation between depth of well and TDS).

Chemical parameters that have exceeded minimum quality criteria for groundwater in the basin are: TDS, arsenic, fluoride, lead and nitrite. Many of these exceedances are located near the Safford-Pima corridor, upstream along the Gila as well as south along Highway 191. Many wells have more than one parameter with an exceedance value.

<u>Challenges</u>

- A complicated subsurface creates challenges to understanding regional groundwater hydrology.
- There are few wells extending into the Lower Basin Fill, resulting in very little data on geologic material below the Upper Basin Fill.
- More frequent and consistent testing of surface water chemical data is necessary to better characterize waters, particularly those designated ‘inconclusive’ by ADEQ in their 2012 report.

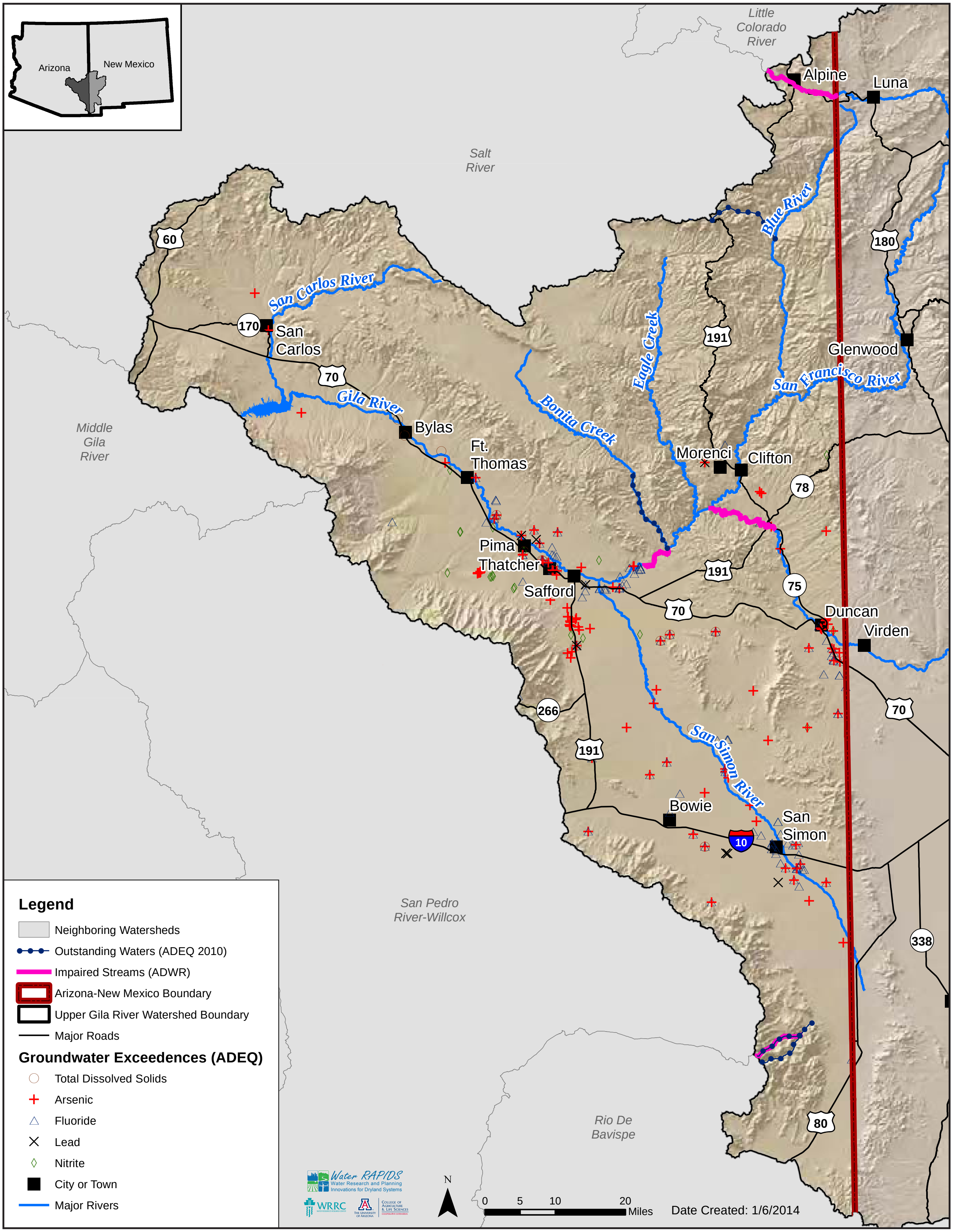


Figure 4-4 Water Quality

Section 4-5 Land Ownership

Land under different ownership is managed in different ways. The San Carlos Apache are a sovereign nation with an independent system of land management and water rights reserved prior to most others in the watershed. The United States Forest Service (USFS), Bureau of Land Management (BLM) and Arizona State Land Department lease lands to private citizens for uses such as grazing, mining, recreation, and rights of way for transportation and utilities. The harvest and collection of forest products is also permitted on USFS land. The State Trust Lands are often interspersed with federally managed land and privately owned land, and may be sold into private ownership in the future. Several small areas in the watershed are managed for wildlife and recreation by the Bureau of Reclamation, the Salt River Project, the National Park Service and the states' Departments of Game and Fish. Private ownership on the remaining parts of the watershed is primarily used for farming, ranching, and housing.

The entire Upper Gila River Watershed is divided at the state line into two pieces of almost equal size, so that comparing the distribution of land ownership in each state is relatively simple as a percentage of land represents the same acreage on either side the border. More than half of the land in the greater watershed is publicly owned and managed by the federal government (USFS, BLM, NPS, and the military). The San Carlos Apache Indian Reservation accounts for another 14% (29% in Arizona, but 0% in New Mexico). Other dissimilarities include a greater degree of private ownership, and more checkerboard ownership of the land in the New Mexico portion of the watershed.

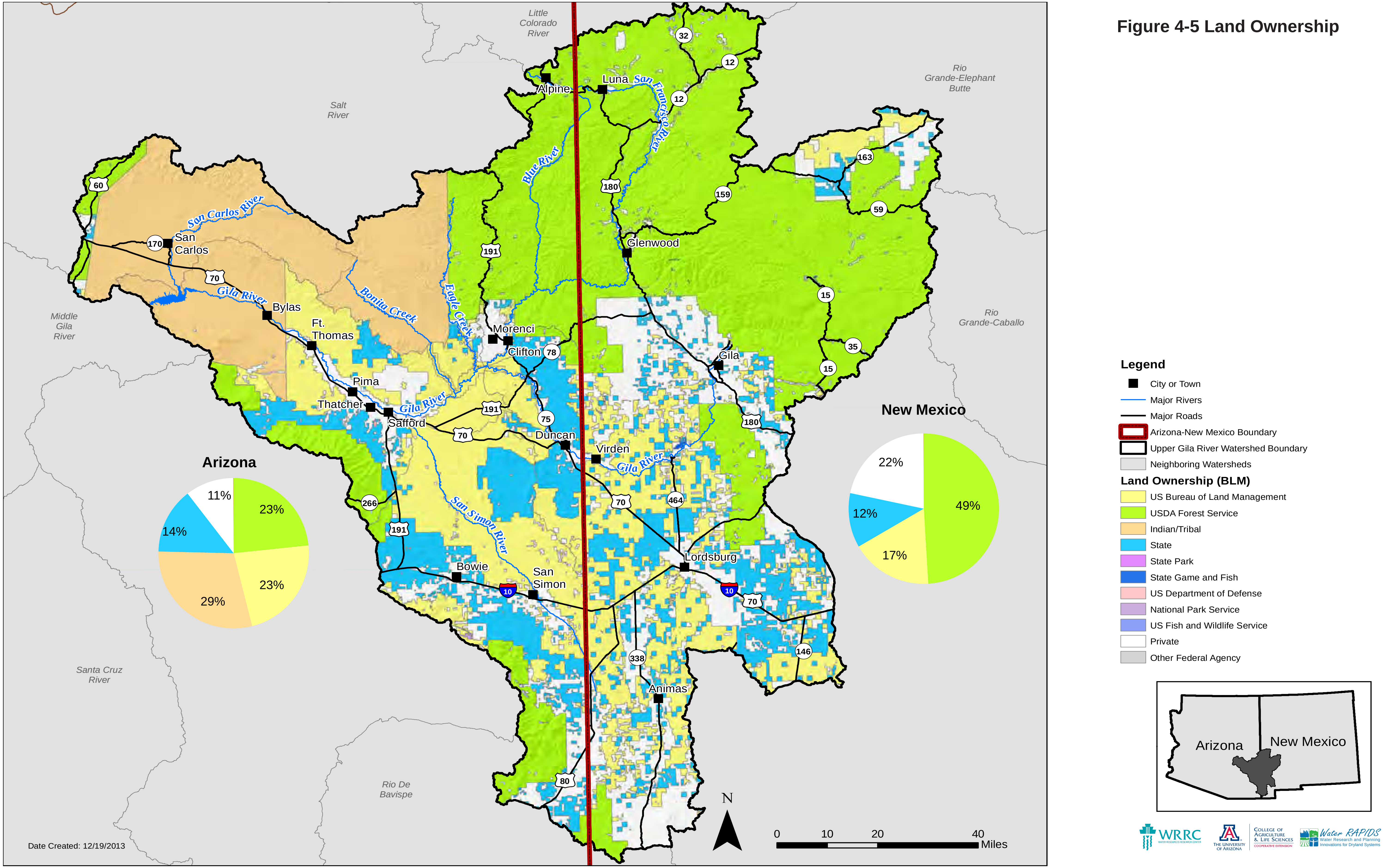
Table 4-3 Land Ownership

Land Owner	Arizona (%)	New Mexico (%)	Entire Watershed (%)
United States Forest Service	23%	49%	37%
Bureau of Land Management	23%	18%	20%
Indian Lands	29%	none	14%
State	14%	12%	13%
Private	10%	22%	16%
State or Local Parks	none	0.1%	0.1%
National Park Service	<0.1%	<0.1%	<0.1%
Military	<0.1%	none	<0.1%

Challenges

- Successful watershed scale planning requires the support of a large proportion of all affected stakeholders.
- The Arizona Water Settlements Act of 2004 and the Adjudication of the Gila River have resulted in the redistribution of water rights in the watershed to the detriment of some community relationships among different land owners/managers.
- Only ten percent of the region is privately owned, however these tracts are concentrated along the rivers of the watershed. Riparian restoration work often necessitates work on private land.
- Different land ownership has different goals, laws and regulations, which are often in conflict with each other.

Figure 4-5 Land Ownership



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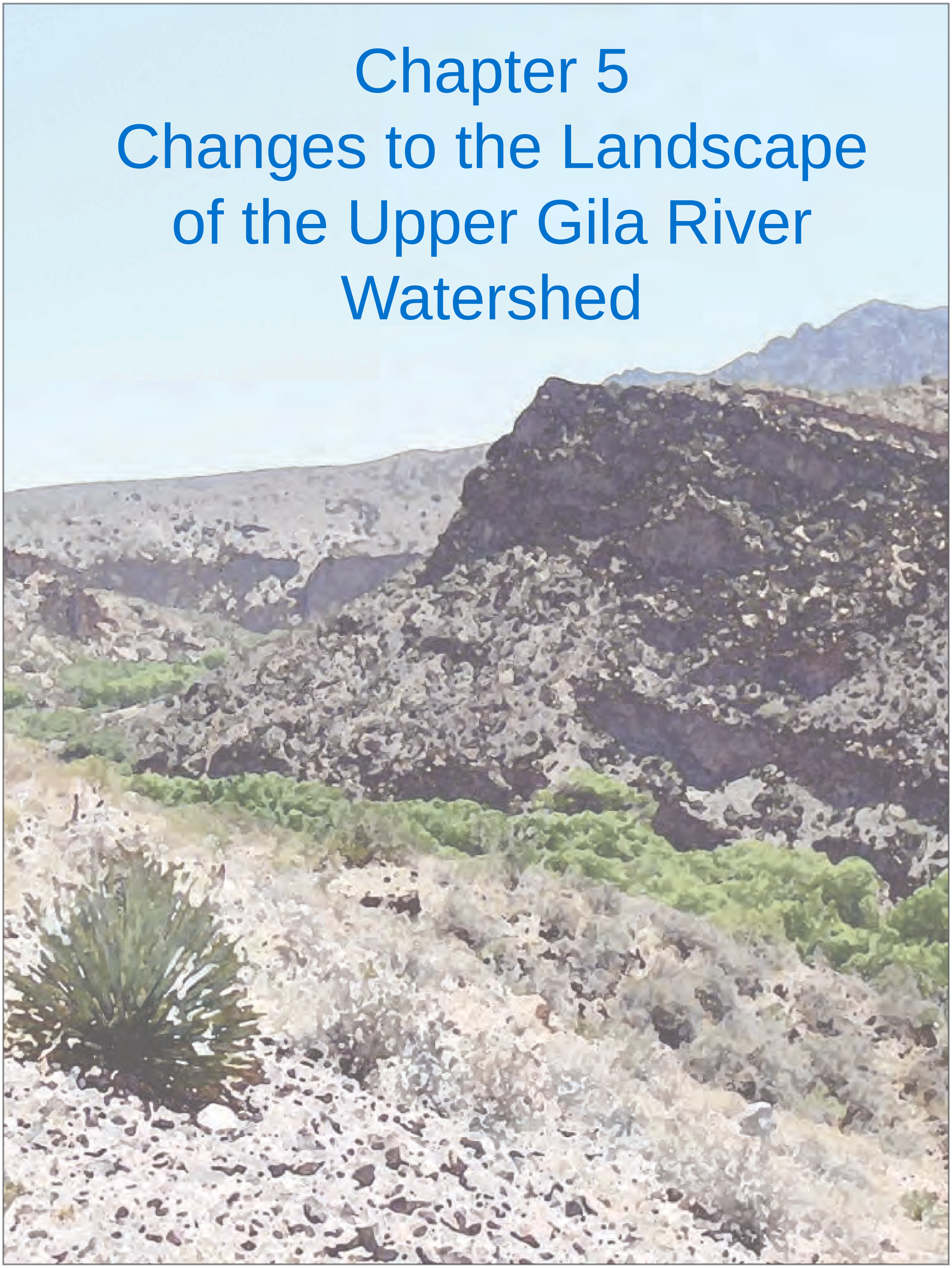
*Map references and additional detail on map data can be found in the Appendix

Chapter 5
Changes to the Landscape of the Upper Gila River Watershed



Chapter 5 - Changes to the Landscape

Section 5-1 Automated Geospatial Watershed Assessment (AGWA)

Introduction to AGWA

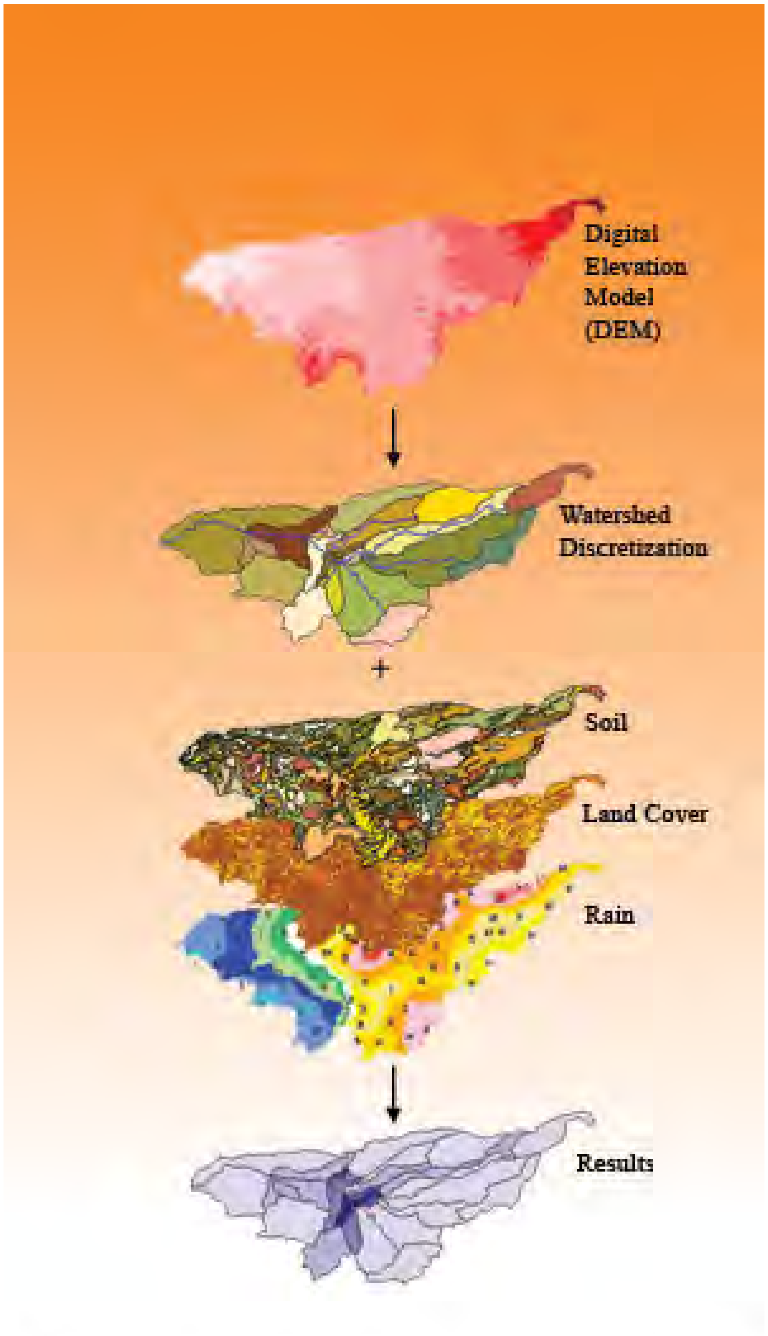
As part of the Atlas, the WRRC built an Automated Geospatial Watershed Assessment (AGWA) model for the region. The AGWA tool is a Geographic Information Systems (GIS) interface jointly developed by the U.S. Environmental Protection Agency, the U.S. Department of Agriculture (USDA) Agricultural Research Service, and the University of Arizona to automate the parameterization and execution of the Soil Water Assessment Tool (SWAT) as well as KINematic Runoff and EROSion (KINEROS2) hydrologic models. The AGWA model shows how Upper Gila River Watershed runoff and sediment yield vary by sub-watershed, over time, and under different conditions.

One of the advantages of AGWA is its ability to run multiple simulations to examine and compare changes predicted under alternative input scenarios (e.g., climate/storm change, land-cover change, present conditions, and alternative futures). AGWA can also examine pre- and post-fire watershed conditions, watershed group simulations, implementation of stream buffer zones, and installation of retention and detention structures. A land-cover modification tool is provided for the development of prescribed land-cover change scenarios, with a number of options for uniform, spatially random, and patchy change to single or multiple land-cover classes. In 2014, the WRRC will help the Upper Gila River Watershed community use this AGWA model to evaluate how changes to the landscape impact the watershed.

AGWA Results

The AGWA model was used to calculate sediment yield and runoff for the entire Upper Gila River Watershed in 1992, 2001, and 2006 due to the availability of land use data in those years. The initial results show there was significant change between 1992 and 2001 for some sub-watersheds. In contrast, there was little or no change in either runoff or sediment yield between 2001 and 2006. When comparing the results between the two time periods, it is important to note that the first is a 10 year period while the second is only 5.

The most significant increases in sediment yield were in the western portions of the watershed. The most significant increases in runoff were in the southeastern and northwestern portions of the watershed. Differences between areas where sediment yield has increased more significantly than runoff is likely due to the differences in soils and soil erodibility in those areas.



KINEROS	SWAT
Infiltration (mm, m3/km)	Precipitation (mm)
Infiltration (in, ac-ft/mi)	ET (mm)
Runoff (mm, m3)	Percolation (mm)
Peak flow (m3/s, mm/hr)	Surface runoff (mm)
Sediment yield (kg/ha)	Transmission loss (mm)
Channel scour (mm/m2)	Water yield (mm)
Sediment discharge (kg/s)	Sediment yield (t/ha)

Figure 5-1 Schematic for the Elements Used in the Development of an Automated Geospatial Watershed Assessment Model

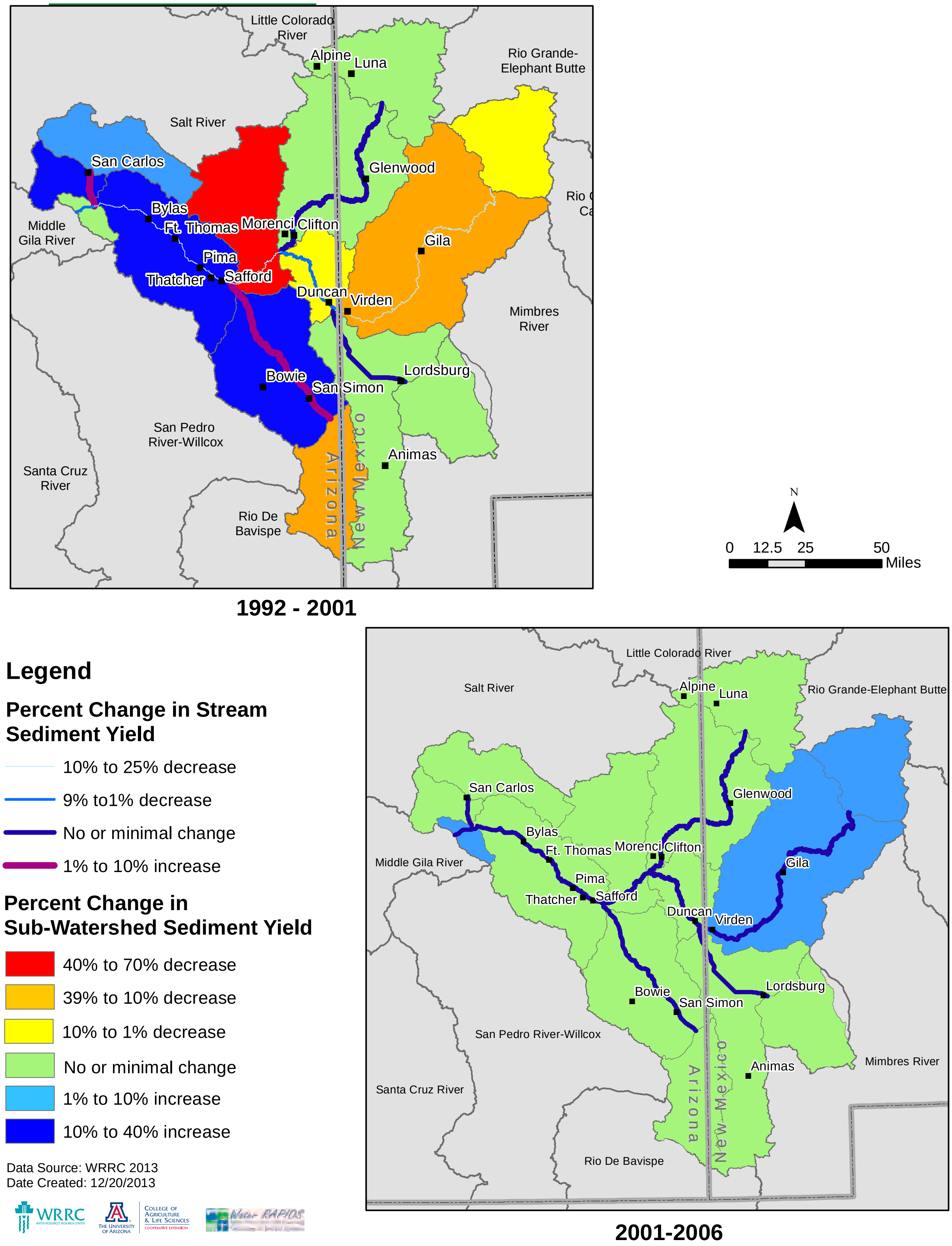


Figure 5-2 Automated Geospatial Watershed Assessment (AGWA) Modeled Changes in Sediment Yield

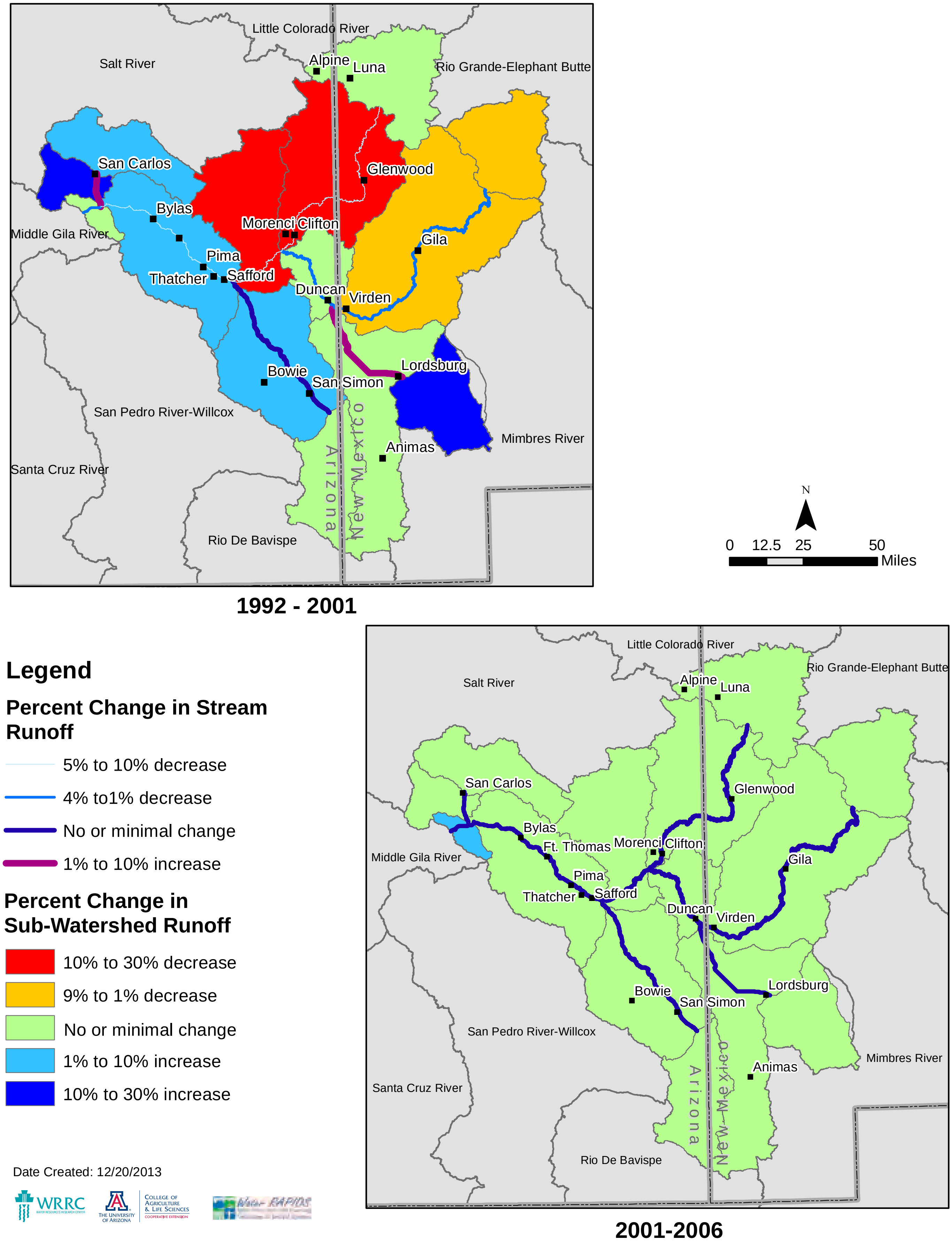


Figure 5-3 Automated Geospatial Watershed Assessment (AGWA) Modeled Changes in Runoff

Section 5-2 Fire

Fire reduces vegetative coverage and can change soil properties, both of which alter the way the landscape retains water. This is particularly acute within the sky islands where the relationship between rain, vegetation, and fire is complex. The greatest amount of precipitation in the watershed falls in the same areas where large fires are the most prevalent (precipitation promotes plant growth, which in turn provides fuel for fires). Areas of potential concern for high intensity fire can be assessed using fire regime classifications, which are determined by vegetation and ecosystem characteristics that have been paired with the severity of past burns.

After a fire, retention of precipitation within the watershed may be increased as less precipitation is intercepted by the vegetation canopy and transpiration losses (water uptake by vegetation) is reduced. However, the impact of fire on watershed hydrology is mostly to decrease its ability to retain water. Canopy reduction increases evaporation loss and soil can develop hydrophobic (water repellent) properties under high severity burns. Hydrophobicity reduces water infiltration, which causes an increase in overland flow (runoff), and greater runoff leads to flooding and accelerated rates of erosion. This soil erosion can result in poor water quality in surface waters due to high sediment loads.

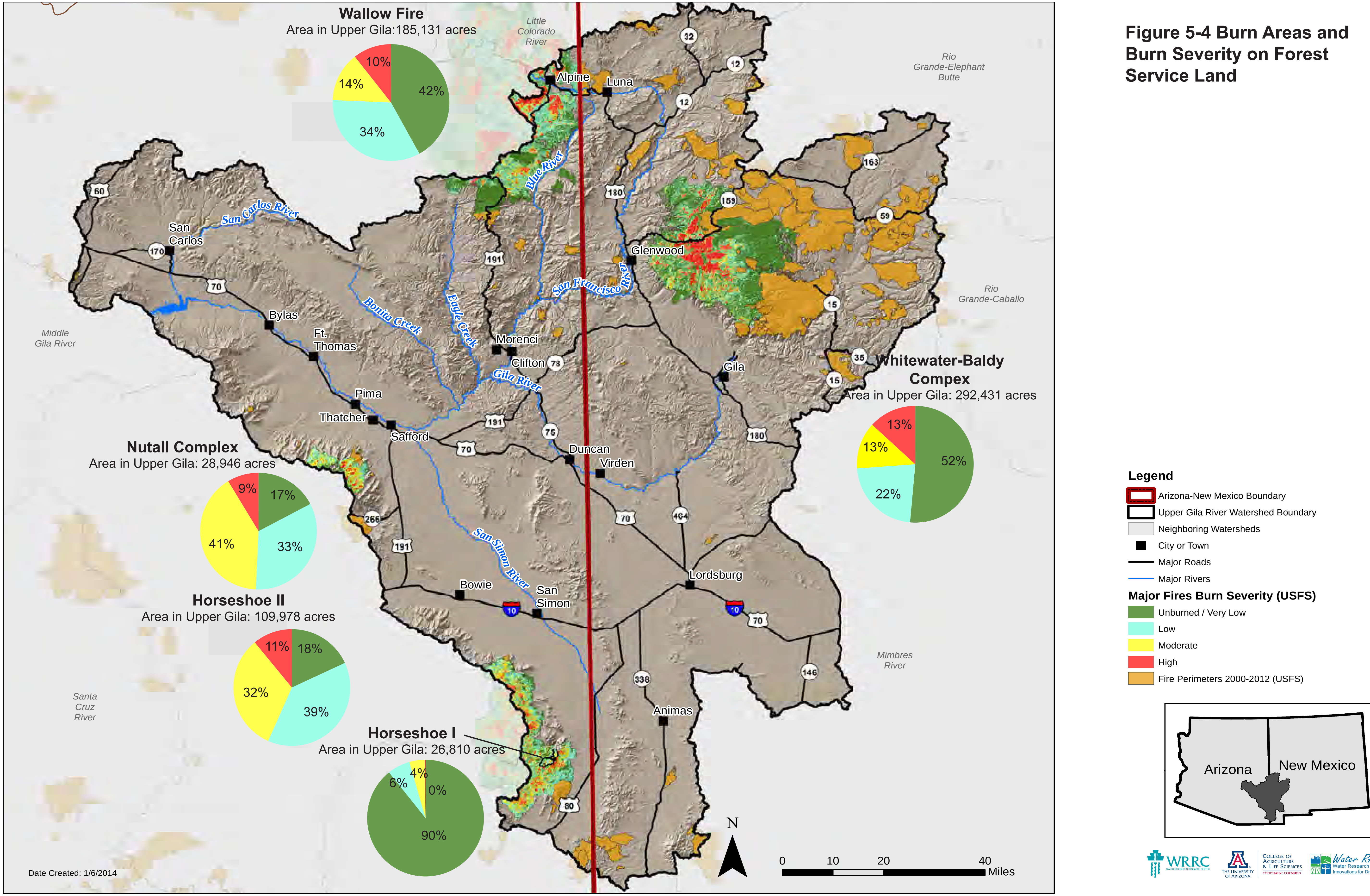
Burn Areas

There have been five significant fires within the watershed since 2001: the Nuttall Complex, Horseshoe I, Horseshoe II, Wallow, and the Whitewater-Baldy Complex. These fires occurred where fuel was available at higher elevations within the watershed, and therefore near the watershed boundary. Of these, only the smaller Horseshoe I and the Whitewater-Baldy Complex were entirely contained within the Upper Gila River Watershed. Figures on the map are statistics for the parts of each fire that occurred within the boundary of the Upper Gila River Watershed.

The majority of the Horseshoe I and the Whitewater-Baldy complex fires was very low severity, and the majority of the Wallow Fire in the watershed was very low or low severity. The Horseshoe II and Nuttall were mostly low to moderate severity. The Whitewater-Baldy complex fire had the highest percent of high severity area, followed by the Horseshoe II and Wallow fires. The Whitewater-Baldy complex fire burned the greatest number of acres within the watershed.

There have been 53 additional fires of less significance on Forest Service lands in the watershed since 2001. Of the total 58 fires since 2001, the distribution of sizes is 1 class C (10-99.9 Acres), 17 class D (100-299.9 Acres), 14 class E (300-999.9 Acres), 13 class F (1000-4999.9 Acres), and the remaining 13 class G (5000+ Acres).

Figure 5-4 Burn Areas and Burn Severity on Forest Service Land



Fire Regime

Fire regime classification provides an integrated scheme to show landscape-level impact through analysis of vegetation/ecosystem type, weather, and climate patterns. There are five fire regime condition classes, defined by the average number of years between fires (frequency) in conjunction with the fire severity (replacement) on the dominant vegetation. Fire regime data were gathered using the landfire tool, from the United States Geological Survey.

Table 5-1 Fire Regime Classifications and Descriptions

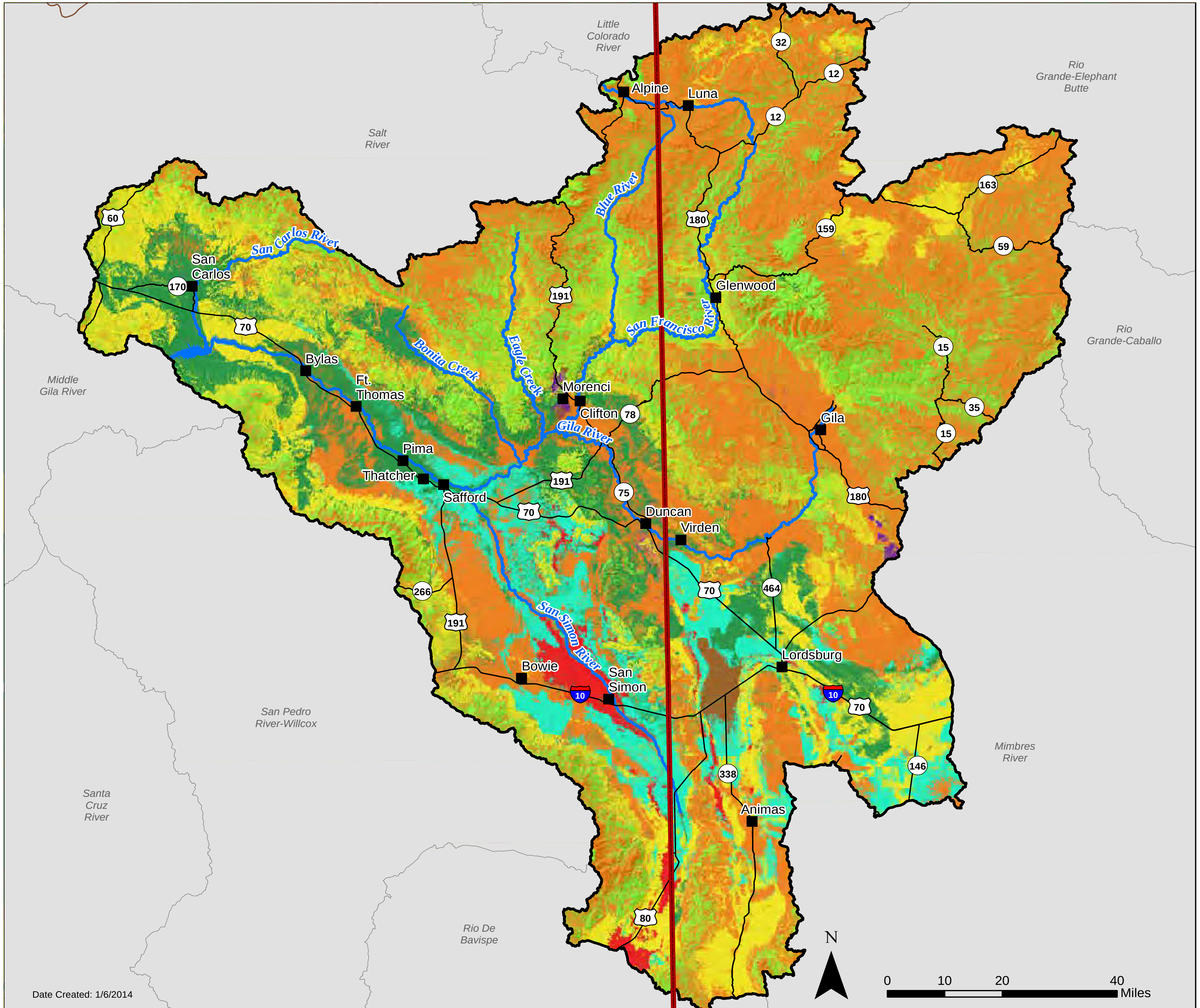
Classification Group	Frequency (years)	Severity	Description	% Arizona
I	0-35	Low/mixed	Generally low-severity fires replacing less than 25% of dominant overstory vegetation, up to mixed-severity fires that replace up to 75% of the overstory.	22.7%
II	0-35	Replacement	High-severity fires replacing greater than 75% of the dominant overstory and stand replacement	1.8%
III	35-200	Mixed/Low	Generally mixed-severity, but also includes low-severity fires	42.7%
IV	35-200	Replacement	High severity fires with stand replacement	12.6%
V	200+	Replacement/ Any severity	Generally replacement severity, including any severity type in this frequency range	17.9%

The remaining 2.3% are designated water (0.2%), barren (0.3%), sparsely vegetated (0.3%), and indeterminate (1.4%).

Challenges

- Frequency of fires may increase as air temperature trends continue to increase, drying out fuel sources.
- The regime class II and IV are the most critical in terms of water resources (total of 13.6% area within the Arizona portion of the watershed)
- The New Mexico portion of the watershed is upstream of the Arizona portion. Fires in New Mexico will have an impact on Arizona.

Figure 5-5 Fire Regime

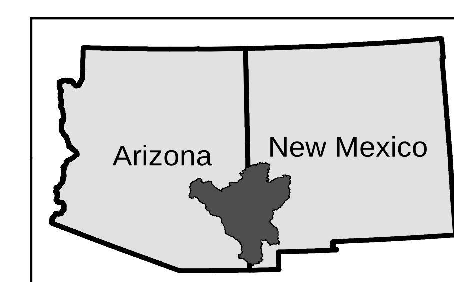


Legend

- City or Town
- Major Rivers
- Major Roads
- Arizona-New Mexico Boundary
- Upper Gila River Watershed Boundary
- Neighboring Watersheds

Fire Regime (USFS)

- 0-35 year frequency, replacement severity
- 0-35 year frequency, low to mixed severity
- 35-200 year frequency, replacement severity
- 35-200 year frequency, low to mixed severity
- 200+ year frequency, any severity
- Barren
- Extremely Low Ignition
- Not defined
- Snow/Ice
- Sparsely Vegetated
- Water



Section 5-3 Land Cover Change

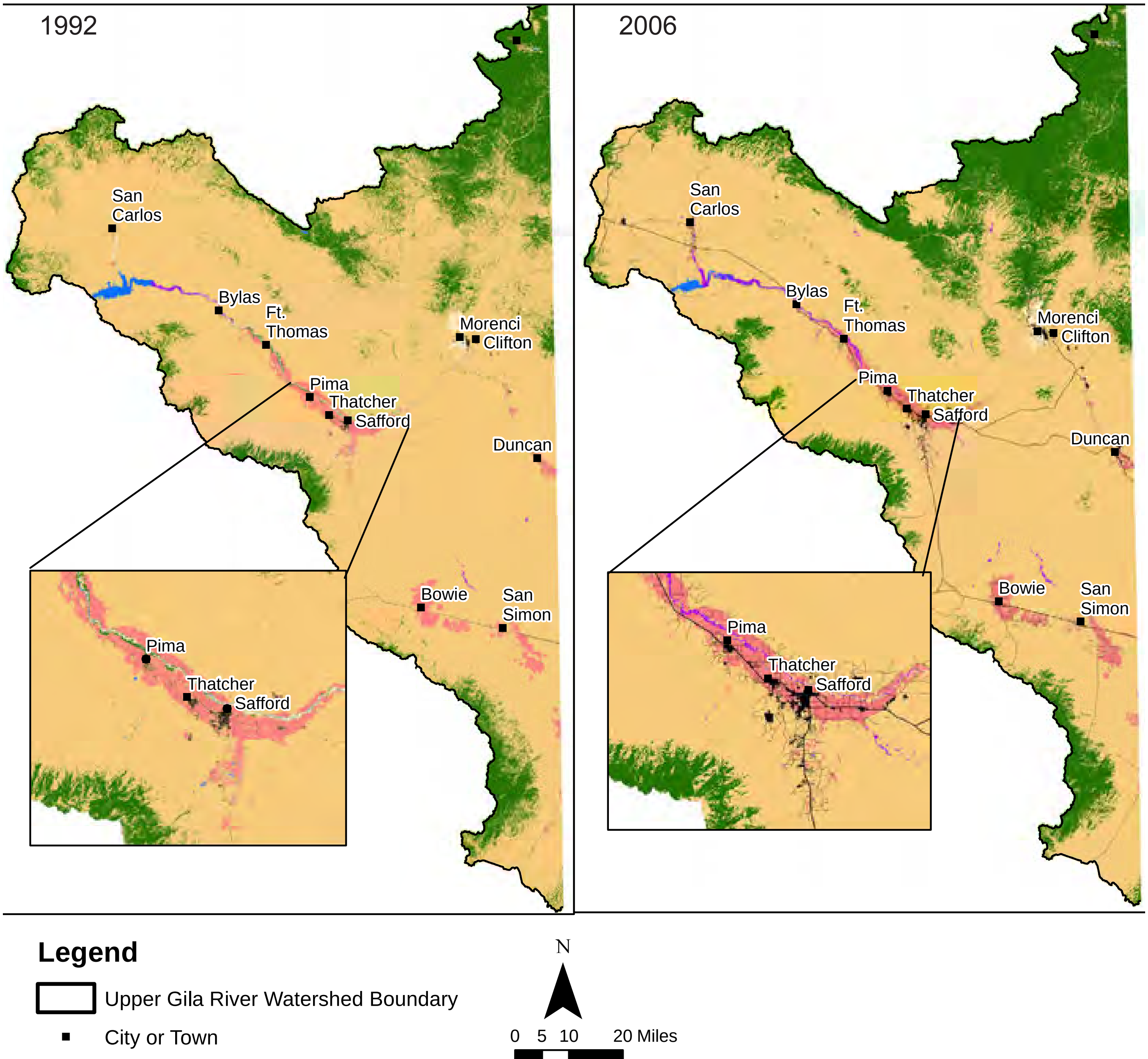
Changes in land cover, such as the conversion of agricultural lands to houses and businesses, can impact the water quantity and quality. For this Atlas the WRRC preformed a simplified land cover change analysis using information from the National Land Cover Database (NLCD). The NLCD was developed by the Multi-Resolution Land Characteristics Consortium (MRLC), a group of ten federal agencies. Datasets were developed for 1992, 2001, and 2006 using satellite imagery (Landsat TM/ETM+) with a spatial resolution of 30 meters. Though all three datasets were produced as part of the same program, changes in methodologies and input between the 1992 NLCD and the 2001 and 2006 NLCD makes it so that these datasets cannot all be directly compared to one another, though products developed by the MRLC for 1992/2001 and 2001/2006 allow for limited comparisons. Overall accuracy of the 1992 NLCD varied by region, but was 70% for the Southwest (Wickham et al. 2004). Overall accuracies for the entire 2001 and 2006 NLCD were 79% and 78%, respectively (Wickham et al. 2013).

To analyze land cover change for the Atlas, the WRRC compared 1992 and 2006. The two original maps had different land classifications, so it was necessary to change both to more general categories that matched. The differences in the original datasets make it difficult to examine change in specific areas, however it is possible to look at the landscape as a whole, and the relative proportion of each land cover class reveals interesting trends of land cover change in the watershed. For example, the percentage of land used for agriculture (2%) remained constant between 1992 and 2006 whereas the land for "urban" or houses, commercial use, and roads increased from 0.1% of the land area to 1%. While it is still a very small fraction of the total area this represents a 580% increase in land used for roads, homes, or businesses.[1] Similarly the area covered by "riparian" plants, which includes both native cottonwoods and willows as well as Tamarisk, increased from 0.1% of the land to 0.5%. While riparian area remains only a tiny fraction of the land cover in the watershed, it increased 330% between 1992 and 2006. Finally, although it is notable that the area of forest land increased from 14% to 20%, the date of these data are prior to several major forest fires noted in Section 5-2 and may not reflect current conditions. It is also possible that the increase in forest land in particular is due, at least in part, to the different classification schemes from the original data.

Challenges:

- Increasing the area covered by homes, businesses and roads increases stormwater runoff, which can lead to flooding and/or water quality concerns.
- Increased area covered by riparian plants is likely due to the spread of non-native Tamarisk. More detailed data would be necessary, however, to determine how much of the growth in the riparian area is due to Tamarisk.
- Detailed and precise information on land cover change is not available for this watershed due to differences in data collection between 1992 and 2006. Furthermore, there is a need for more recent land cover data for the watershed, especially given the recent changes to the landscape due to large fires.

[1] The increase shown here for urban areas is likely over estimated due to differences in the classification of roads between 1992 and 2006. In 2006, the classification included many more road areas in the urban classification than the 1992 classification.



Land Cover	Area 1992	Area 2006
Agriculture	2%	2%
Barren	0.5%	0.3%
Forest	14%	20%
Open Water	0.3%	0.2%
Riparian	0.1%	0.5%
Shrubland and Grassland	83%	76%
Urban	0.1%	1%

WRRC
College of Agriculture & Life Sciences
Water RAPIDS
Water Research and Planning Innovations for Dryland Systems

Figure 5-6 Land Cover Change 1992 - 2006

Section 5-4 Water Demand

Water use in the Upper Gila River Watershed is dominated by agricultural activities. Between 2001 and 2006, an average of 91% of the surface water diversions and groundwater pumping were to meet agricultural water needs (ADWR, 2010). Depending on the irrigation method, much of this water can return to the river or infiltrate through the soil into the aquifer. The more efficient the irrigation method, the less water will return to the river or aquifer.

Water demand for industrial purposes, predominantly mining, makes up 5% of the demand in the watershed, the remaining 4% is used for municipal demand. In contrast to agriculture, industrial and municipal water uses are generally considered consumptive, as they return less water to the river or aquifer. An acre-foot of water for mining uses may, however, be used many times over. The amount of demand from domestic wells are not reported and therefore their contribution to overall water demand in the watershed is not well understood. The number of wells in the watershed have increased significantly over the last 60 years.

Overall, in the Upper Gila River Watershed water demand did not change significantly between 1991 and 2009. Figure 5-7 shows that there is, however, year to year variability in the water demand by agricultural and mining users in particular. The proportion of groundwater versus surface water used in the watershed has fluctuated over time, with increased surface water use when it is more available and increased groundwater use when surface water is scarce (Figure 5-9).

Much of the watershed is subject to the provisions of the Arizona Water Right's Settlement Act. The full implications of this act of water supply availablity are too complex for this report, however, it is notable that most of the municipal, industrial and agricultural wells in the watershed are metered and the use of water from those wells is capped, e.g., no more than six acre-feet of water per acre for agriclutral lands within the Act's decreed area.

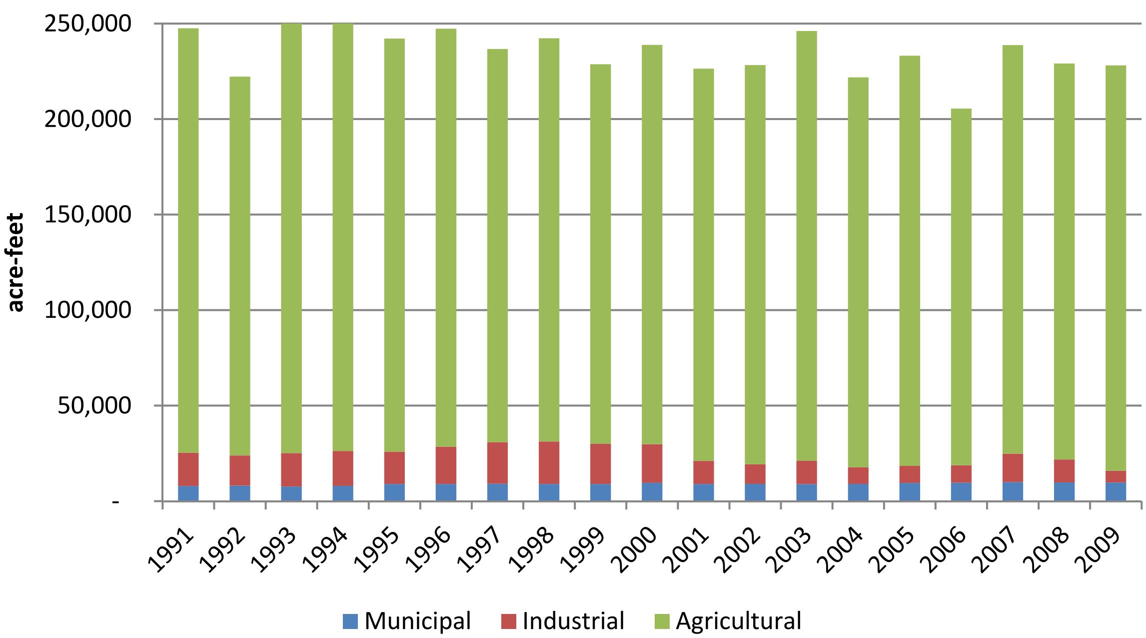


Figure 5-7 Water Demand in the Upper Gila River Watershed 1991-2009

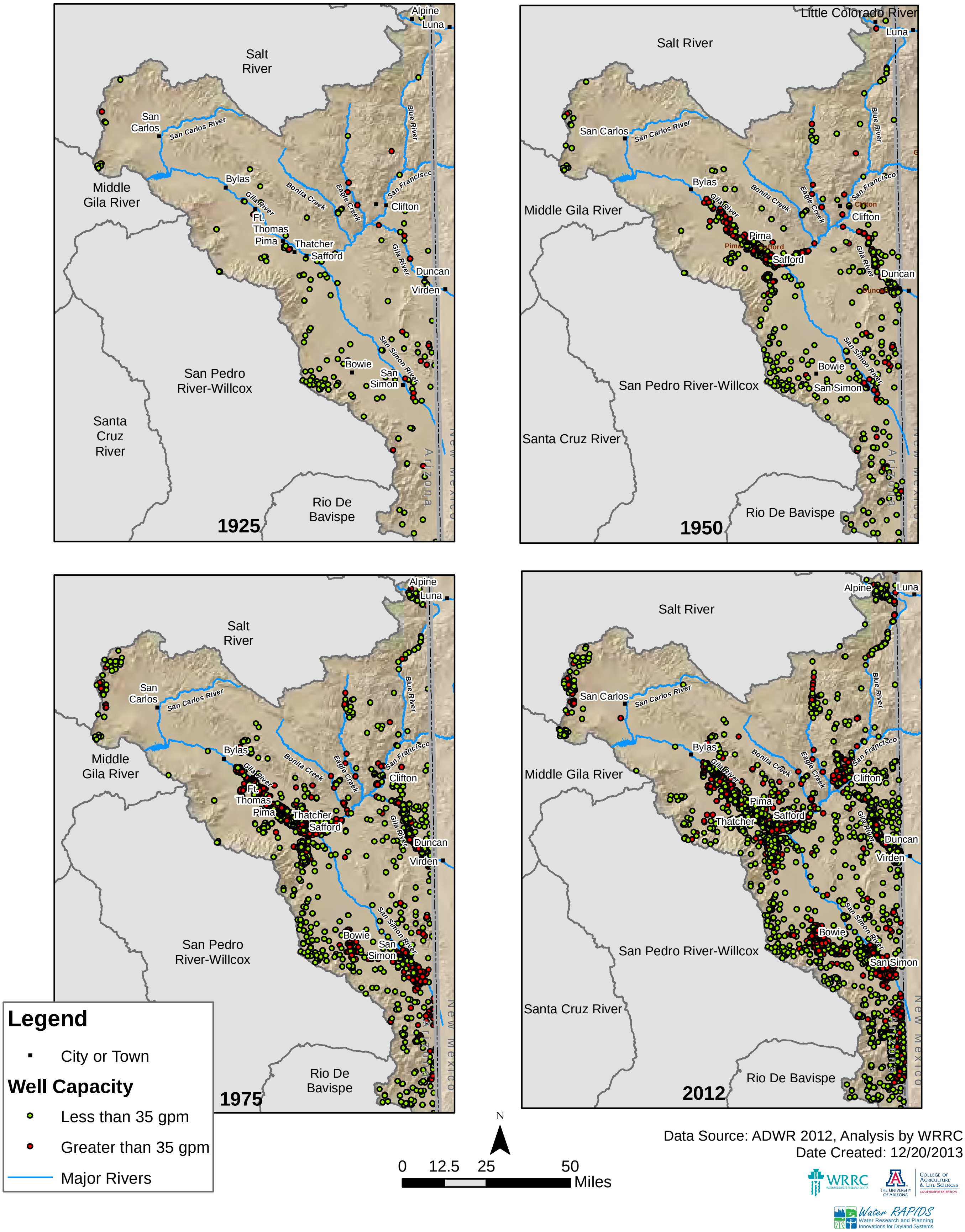


Figure 5-8 Wells Over Time

In 2010 the Arizona legislature created the Water Resources Development Commission (WRDC) for the purpose of assessing the current and future water needs of Arizona. The WRDC was tasked to:

- Compile and consider the projected water needs of each Arizona county in the next 25, 50 and 100 years;
- Identify and quantify the water supplies currently available in each county;
- Identify potential water supplies to meet additional demands in the next 25, 50 and 100 years, and the legal and technical issues associated with using those supplies;
- Identify potential mechanisms for financing the acquisition, treatment and delivery of water supplies; and
- Make recommendations regarding further studies and evaluations.

The WRDC completed its work in October 2011. For the Upper Gila River Watershed, the WRDC determined that in 2035, 2050 and 2100 there would be a gap between water supply and demand in almost all groundwater basins. These estimates were based on known supplies and projected demands. In their analysis, the WRDC assumed municipal and industrial demand for water would grow and that agricultural demand would remain constant.

Challenges

- Water use for many municipal, industrial and irrigation wells in the watershed is capped based on the Arizona Water Rights Settlement Act. This limits the area's legally available water.
- Water use by domestic wells could be significant and is underreported.
- While water use by one does not necessarily mean the water is unavailable to another, water at the price we are used to paying for it and the quality we are accustomed to is increasingly scarce.
- If water use in the watershed continues to grow, there will be significant gaps between the amount of water demanded versus the water supply available.
- Closing the gap between water supplies and demands can be accomplished in many ways. Determining a path forward for the watershed will require cooperation.

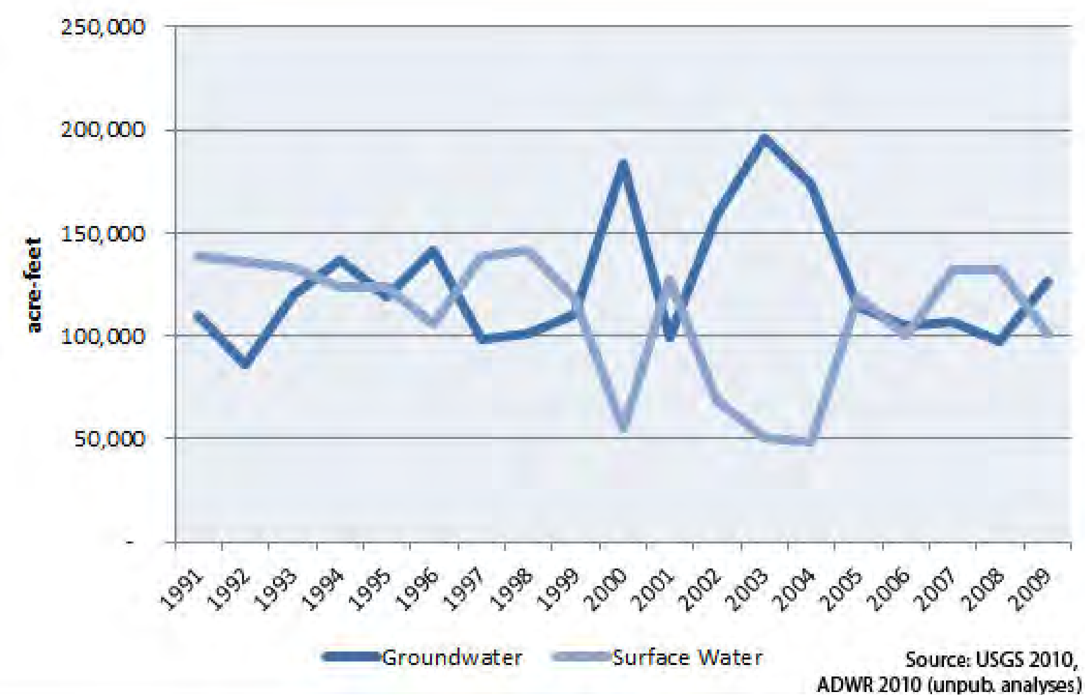
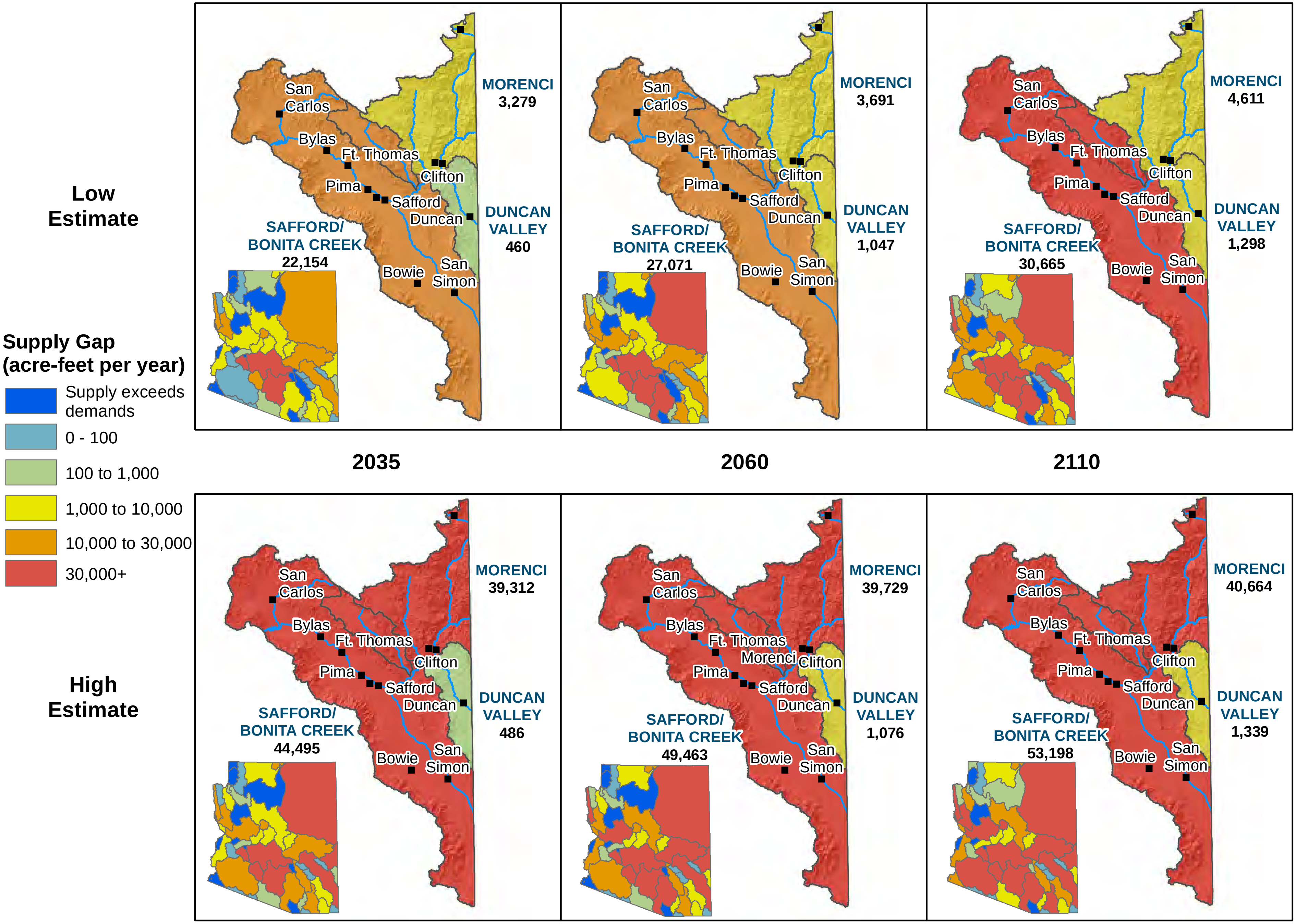


Figure 5-9 Groundwater and Surface Water Demand in the Upper Gila River Watershed 1991-2009



Source: WRDC Water Supply and Demand Working Group Report 2011.
Water supply gap calculated as: Supply Gap = (Projected Future Demand - Currently Available and Adjusted Supply)

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Figure 5-10 Water Supply Gap per year in 2035, 2060 and 2110

*Chapter 5 References**

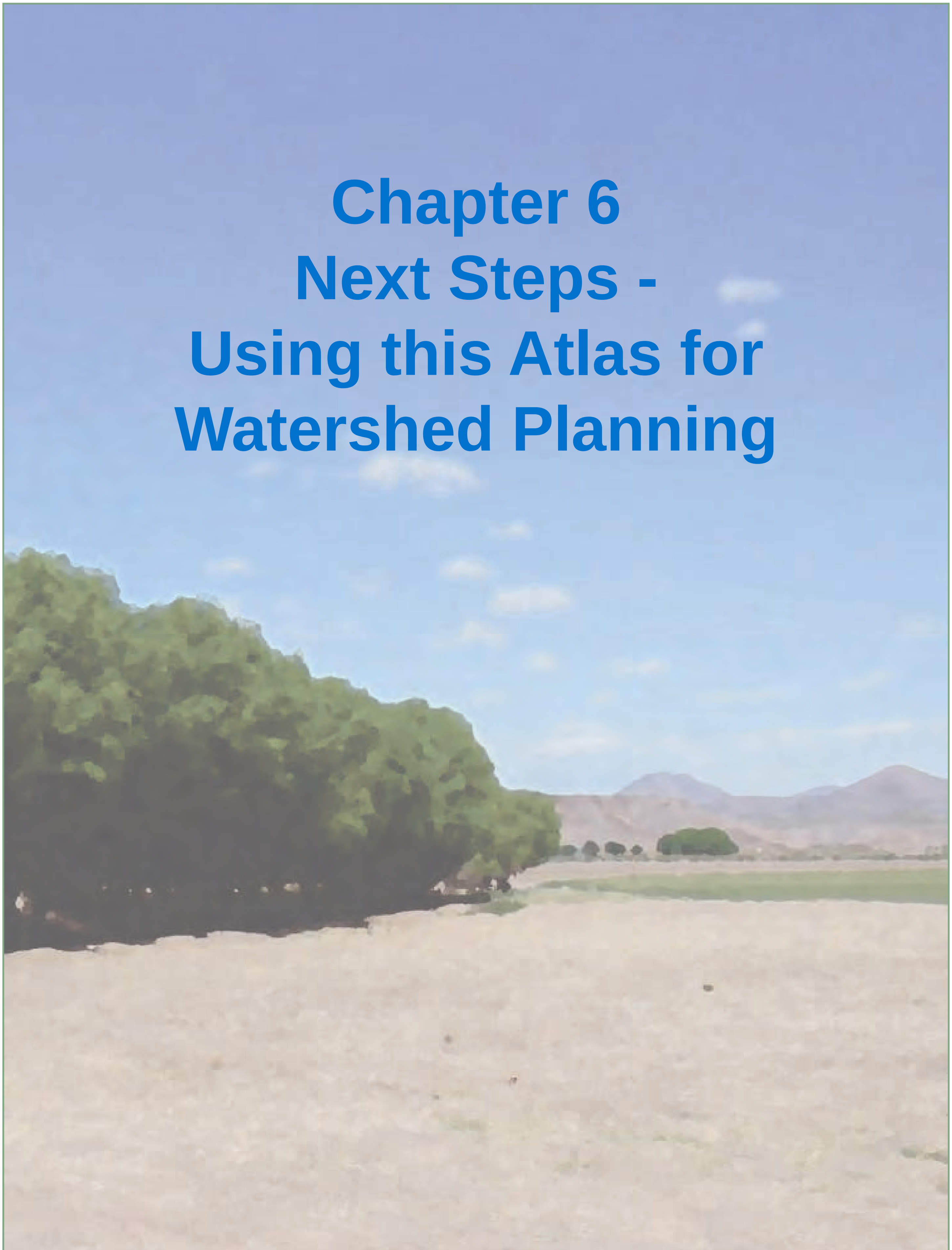
Wickham, J. D., S. V. Stehman, L. Gass, J. Dewitz, J. A. Fry, and T. G. Wade. 2013. Accuracy assessment of NLCD 2006 land cover and impervious surface. Remote Sensing of Environment 130:294-304.

Wickham, J. D., S. V. Stehman, J. H. Smith, and L. Yang. 2004. Thematic accuracy of the 1992 National Land-Cover Data for the western United States. Remote Sensing of Environment 91:452-468.

*Map references and additional detail on map data can be found in the Appendix

Photo Opposite: David Chan

Chapter 6
Next Steps - Using this Atlas for Watershed Planning



Chapter 6 - Next Steps: Using this Atlas for Watershed Planning

This Atlas is a baseline watershed assessment, or an accounting of the existing conditions, in the Upper Gila River Watershed. This Atlas is not intended to be a watershed plan. Rather, it is a starting point for a planning effort and provides a foundation for common understanding of the current status of the Upper Gila River Watershed so all stakeholders interested in pursuing a watershed plan are able to participate.

Management and planning for water resources is a difficult task. The unpredictable weather patterns of southeastern Arizona make this task especially challenging. One day it is hot and dry and the next day fields are flooded and roads are washed away. The uses for our water are almost endless, and each drop in some way fuels our economy. Without water there are no fields, no copper, no cattle, no restaurants, no fishing, and no trees. While use by one does not necessarily mean the water is unavailable to another, water at the price we are used to paying for it and the quality we are accustomed to is increasingly scarce. In the face of increasing scarcity and overlapping demands, how does a community decide how they will use their water? Can they rely on their existing water sources or how much of it they will have in the future?

Planning for the future of your watershed requires many things. Important issues include: what resources you have now; how water law and policy impact your use of these resources; how those resources have changed over time; what those resources might look like in the future; and how you want to use those resources to shape your community.

This Atlas documents the importance of the area's rich cultural history; the abundance of natural resources including timber, ore and grasslands; and the variety of environments ranging from riparian areas in the valleys to montane forests in the mountains. Major issues identified in this Atlas include:

- The increase in areas impacted by fire
- A need for planning to secure water supplies to meet future demands
- The impacts from changing precipitation regimes and ongoing drought
- The growth of urban areas and increase in groundwater wells
- A paucity of data for many key resources including groundwater and springs

Next Steps

In addition to the many smaller projects that the Gila Watershed Partnership (GWP) is currently implementing, there are three projects that will help the GWP both understand and plan for the future of the watershed. These projects include the Participatory Watershed Assessment project led by the WRRC that created this Atlas, the Upper Gila Watershed Riparian Restoration project, and an Appraisal Level study of the area's water resources being conducted by the U.S. Bureau of Reclamation. In 2014 and beyond, the GWP will coordinate work on these projects through the Watershed Planning and Restoration Steering Committee.

In 2014 the Participatory Watershed Assessment project will use discussion of the current conditions shown on these Atlas maps, and the challenges associated with them, to develop a set of scenarios describing the potential future condition of the Upper Gila River Watershed. Key to this next phase is building a shared understanding of what drives change in the watershed. The WRRC will work with the GWP and the Watershed Planning and Restoration Steering Committee through workshops and the committee's monthly meeting to guide the group through the scenario building process.

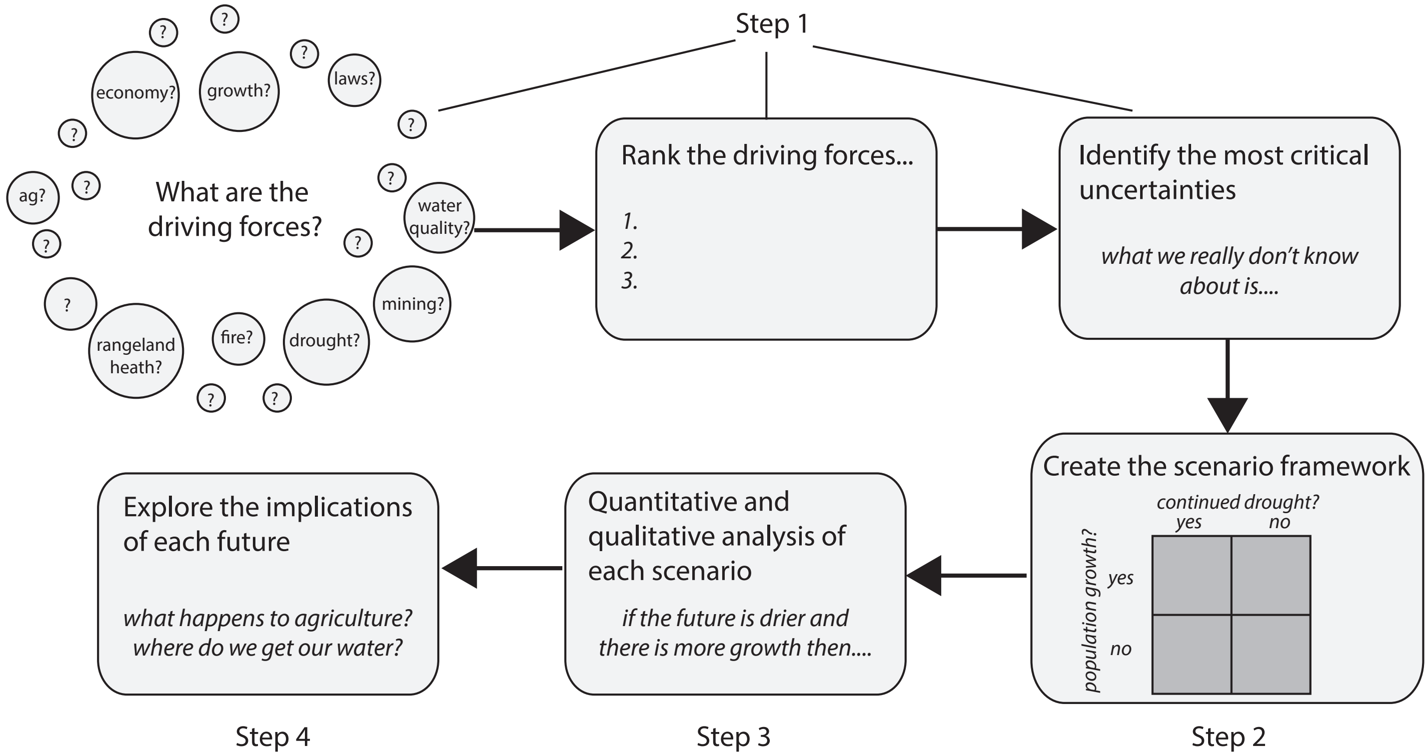


Figure 6-1 Scenario Planning Process

A general outline of the process for building scenarios is as follows:

Step 1. Identify and rank the most important scenario elements, or determinants of change. These include:

- Elements that will occur in all scenarios
- Forces that steer long range changes, or driving forces
- Major actors or agents that have the power to shape the future of the system, or prime movers
- Unknowns that could determine which futures are realized, or major uncertainties

Step 2. Develop scenario framework using major uncertainties.

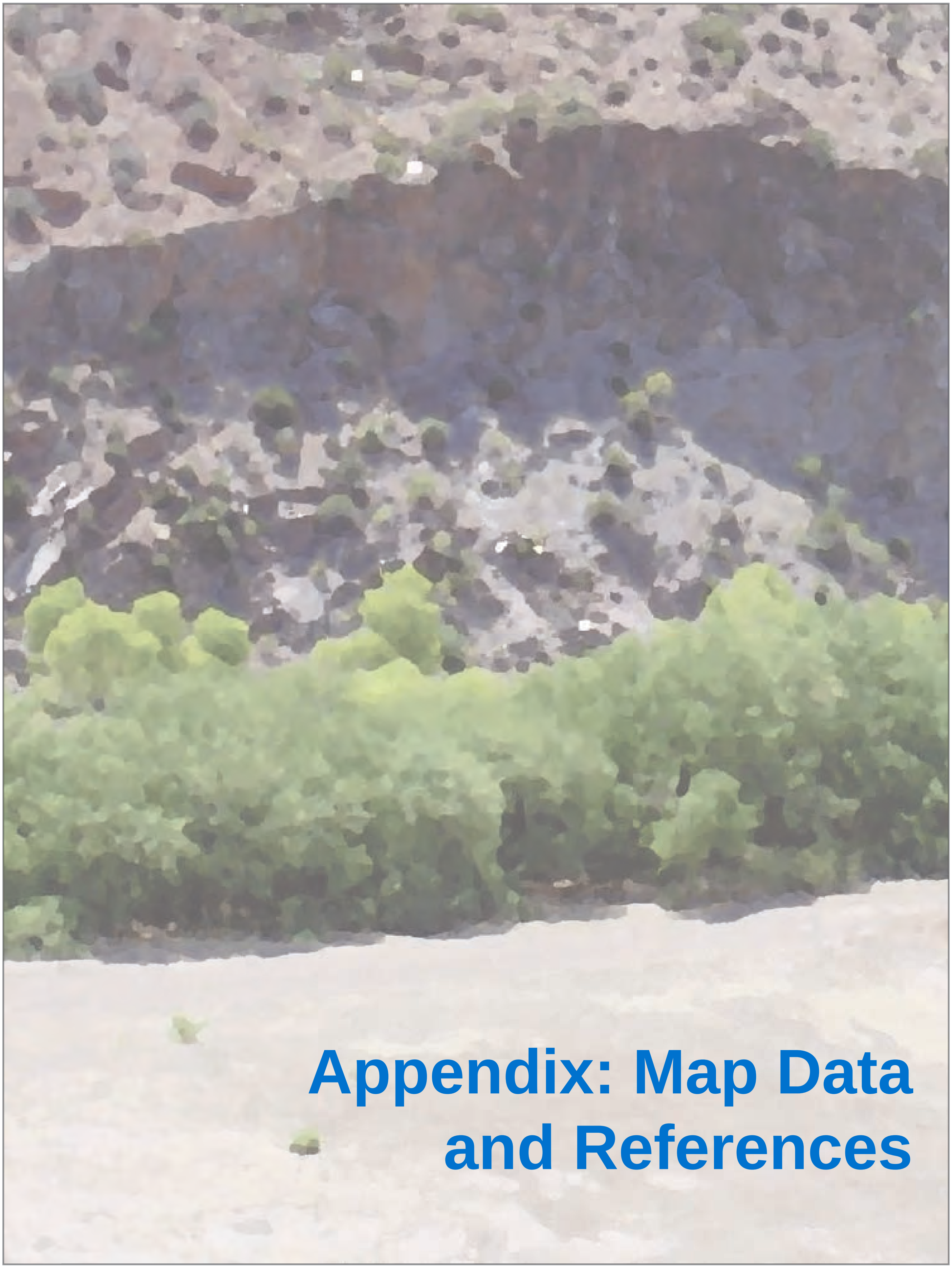
Step 3. Quantitative analysis, where possible, of the scenarios and their impact to the watershed.

Step 4. Explore the implications of each scenario

Taken together with the other ongoing projects in the watershed, these scenarios will be an important tool to help the GWP develop a watershed plan that fully considers the potential impacts of continuing drought, changes in water uses, priorities for natural resources, and other community concerns and desires for the watershed.

Watershed planning offers the opportunity to consider a wide range of resources and issues in a comprehensive way. One limitation of traditional approaches to land use planning and natural resources planning is that these approaches are often limited to political boundaries and a limited set of issues. For example, traditional land use planning typically will address growth, economic development, land use, and natural resources within a give town, city, or county. A land use plan will not typically consider issues beyond the political boundaries of the planning area even though management of these peripheral lands can impact the town or county.

Water resources, including supply and demand balances riparian resources and habitats are impacted by varying land uses, and the long-term impacts of drought and changes in climate may alter natural and water resources. Despite these connections land use plans generally do not take these elements into consideration. When the focus broadens from political boundaries alone to a watershed system, water resources and the broader impacts of land use are considered, enabling more meaningful conversation and informed decisions across political boundaries.



Appendix: Map Data and References

Appendix References and Metadata for Maps

The following section describes in greater detail the extent and limitations of map data, summarized from the original metadata. Metadata are listed in the order they appear in the Atlas with the layer title and author in italics.

General Data

Watershed Boundary: Environmental Protection Agency

This dataset links HUC8 names and ID numbers with their associated HUC6 names and ID numbers. Shapefile boundaries are for HUC8 watersheds. Data downloaded from the Watershed Boundary Dataset (http://water.epa.gov/scitech/datait/tools/waters/data/wbd.cfm) on 1/17/2013

Roads: US Census Bureau

The TIGER/Line Files are shapefiles and related database files (.dbf) that are an extract of selected geographic and cartographic information from the U.S. Census Bureau's Master Address File / Topologically Integrated Geographic Encoding and Referencing (MAF/TIGER) Database (MTDB). The MTDB represents a seamless national file with no overlaps or gaps between parts, however, each TIGER/Line File is designed to stand alone as an independent data set, or they can be combined to cover the entire nation. Primary roads are generally divided, limited-access highways within the interstate highway system or under State management, and are distinguished by the presence of interchanges. These highways are accessible by ramps and may include some toll highways. The MAF/TIGER Feature Classification Code (MTFCC) is S1100 for primary roads. Secondary roads are main arteries, usually in the U.S. Highway, State Highway, and/or County Highway system. These roads have one or more lanes of traffic in each direction, may or may not be divided, and usually have at-grade intersections with many other roads and driveways. They usually have both a local name and a route number. The MAF/TIGER Feature Classification Code (MTFCC) is S1200 for secondary roads.

The TIGER/Line Shapefile products are not copyrighted however TIGER/Line and Census TIGER are registered trademarks of the U.S. Census Bureau. These products are free to use in a product or publication, however acknowledgment must be given to the U.S. Census Bureau as the source.

The horizontal spatial accuracy information present in these files is provided for the purposes of statistical analysis and census operations only. No warranty, expressed or implied is made with regard to the accuracy of the spatial accuracy, and no liability is assumed by the U.S. Government in general or the U.S. Census Bureau, specifically as to the spatial or attribute accuracy of the data. The TIGER/Line Shapefiles may not be suitable for high-precision measurement applications such as engineering problems, property transfers, or other uses that might require highly accurate measurements of the earth's surface. Coordinates in the TIGER/Line shapefiles have six implied decimal places, but the positional accuracy of these coordinates is not as great as the six decimal places suggest.

Towns: US Geological Survey

The Geographic Names Information System contains information about physical and cultural geographic features of all types in the United States, associated areas, and Antarctica, current and historical, but not including roads and highways. The database holds the Federally recognized name of each feature and defines the feature location by state, county, USGS topographic map, and geographic coordinates. Other attributes include names or spellings other than the official name, feature designations, feature classification, historical and descriptive information, and for some categories the geometric boundaries. The database assigns a unique, permanent feature identifier, the Feature ID, as a standard Federal key for accessing, integrating, or reconciling feature data from multiple data sets. The GNIS collects data from a broad program of partnerships with Federal, State, and local government agencies and other authorized contributors. The GNIS provides data to all levels of government and to the public, as well as to numerous applications through a web query site, web map and feature services, file download services, and customized files upon request.

The Geographic Names Information System (GNIS) is the Federal standard for geographic nomenclature. The U.S. Geological Survey developed the GNIS for the U.S. Board on Geographic Names, a Federal inter-agency body chartered by public law to maintain uniform feature name usage throughout the Government and to promulgate standard names to the public. The GNIS is the official repository of domestic geographic names data; the official vehicle for geographic names use by all departments of the Federal Government; and the source for applying geographic names to Federal electronic and printed products of all types. See http://geonames.usgs.gov for additional information.

Digital Elevation Model: US Geological Survey

Data are 1/3 arc-second (10m) resolution, downloaded from The National Elevation Dataset (NED) (http://ned.usgs.gov), the primary elevation data product of the USGS. The NED is a seamless dataset with the best available raster elevation data of the conterminous United States, Alaska, Hawaii, and territorial islands. The NED is updated on a nominal two month cycle to integrate newly available, improved elevation source data. All NED data are public domain. The NED is derived from diverse source data that are processed to a common coordinate system and unit of vertical measure. NED data are distributed in geographic coordinates in units of decimal degrees, and in conformance with the North American Datum of 1983 (NAD 83). All elevation values are in meters and, over the conterminous United States, are referenced to the North American Vertical Datum of 1988 (NAVD 88). The vertical reference will vary in other areas. NED data are available nationally (except for Alaska) at resolutions of 1 arc-second (about 30 meters) and 1/3 arc-second (about 10 meters), and in limited areas at 1/9 arc-second (about 3 meters).

Major Streams: Arizona Land Resources Information System (ALRIS)

The original ALRIS streams layer was queried for just the larged streams in the watershed, indiated as 1,2, or 3 order streams in this dataset. The original dataset was converted in the fall of 1988 from USGS 1:100,000 scale DLG data to ARC format. Since then, multiple and extensive corrections have taken place. Early on, several Arizona agencies were part of rectification including: attributes, features, edgematching and the re-tiling of the data into the USGS Hydrologic Unit Code (HUC) library tiling format. The Environmental Protection Agency (EPA) has since added critical attributes to the Arizona database, including: A nationally recognized management link code (the Reach Id), names, and hydrologic information. Arizona has enhanced the theme further by adding Descriptive Attribute Codes, Cartographic Order, more Names, and intense Quality Assurance Controls.

Physical Geography

Biotic Communities

David Brown and Charles Lowe (1979); The Nature Conservancy in Arizona (2004); Arizona Land Resource Information System (1993); Instituto del Medio Ambiente y el Desarollo Sustenable del Esatado de Sonora (1998); New Mexico Cooperative Fish and Wildlife Research Unit (1996)

This map is intended for broad, regional, landscape-scale analysis. The source scale of these data is 1:1,000,000.

At the time of printing data were available at: www.azconservation.org

Instream Flow Status: Arizona Department of Water Resources

Original data by ADWR of applications, permits and certificates for instream flow. Up to date as of June 2012.

Critical Habitat: US Fish and Wildlife Service

Critical habitats are areas considered essential for the conservation of a listed species. These areas provide notice to the public and land managers the importance of these areas to the conservation of this species. Special protections and/or restrictions are possible in areas where federal funding, permits, licenses, authorizations, or actions occur or are required.

To provide the user with a general idea of areas where proposed critical habitat for various threatened and endangered species occur. The geographic extent has been clipped to include only the state of Arizona. Data for each species were downloaded from http://criticalhabitat.fws.gov/crithab/ on January 25, 2013 and aggregated together to form this single coverage. For data that were only available as line files, a 30ft buffer polygon was created in lieu of the line feature.

The GIS files and their associated coordinates are not the legal source for determining the critical habitat boundaries of species described within this dataset. Inherent in any data set used to develop graphical representations, are limitations of accuracy as determined by, among others, the source, scale and resolution of the data. While the Service makes every effort to represent the critical habitat shown with this data as completely and accurately as possible (given existing time and resource constraints), the USFWS gives no warranty, expressed or implied, as to the accuracy, reliability, or completeness of these data. In addition, the USFWS shall not be held liable for improper or incorrect use of the data described and/or contained herein. Graphical representations provided by the use of this data do not represent a legal description of the critical habitat boundary. The user is referred to the critical habitat textual description in the appropriate final rule for this species as published in the Federal Register. These data are to be used only in the context of the definition and purpose of critical habitat. This primarily relates to Section 7 consultation under the Endangered Species Act. These data may be used for planning and land management purposes. They are not to be used for legal survey use.

Geology: Arizona Geological Survey, US Geological Survey

These digital maps are a reformulation of previously published maps, primarily maps of states. The reformulation gives all the maps the same structure and format, allowing them to be combined into regional maps. The associated data tables have information about age and lithology of the map units, also in a standard format. Data downloaded from http://mrdata.usgs.gov/geology/state/state.php?state=AZ

This database is not meant to be used at scales appreciably larger or smaller than the original scale. Any printed material utilizing these databases shall clearly indicate their source. If modifications to the data are made, this should be clearly indicated and described in print. Users specifically agree not to misrepresent these data, nor to imply that any changes they have made were approved by the U.S. Geological Survey. This database has been approved for release and publication by the Director of the U.S. Geological Survey. Although the database has been subjected to review and is substantially complete, the U.S. Geological Survey reserves the right to revise the data pursuant to further analysis and review. The database is released on the condition that neither the U.S. Geological Survey or the United States Government may be held liable for any damages resulting from its authorized or unauthorized use. Original source of this data was the Arizona Geological Survey.

Soil Kw (Erodibility): National Resources Conservation Service

Indicate the susceptibility of a soil to erosion via water. These values (Kw) indicate the erodibility of the whole soil.

Erosion factor K indicates the susceptibility of a soil to sheet and rill erosion by water. Factor K is one of six factors used in the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) to predict the average annual rate of soil loss by sheet and rill erosion in tons per acre per year. The estimates are based primarily on percentage of silt, sand, and organic matter and on soil structure and saturated hydraulic conductivity (Ksat). Values of K range from 0.02 to 0.69. Other factors being equal, the higher the value, the more susceptible the soil is to sheet and rill erosion by water. Data are derived from SSURGO and were mapped using the Soil Data Viewer http://soils.usda.gov/sdv/ . Soil polygons are further divided by subwatershed.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database for Arizona. Available online at http://soildatamart.nrcs.usda.gov. Accessed 12/13/2012.

Soil Texture: National Resources Conservation Service

Soil texture data for the Upper Gila Watershed. Based on STATSGO data. Texture is given in the standard terms used by the U.S. Department of Agriculture. These terms are defined according to percentages of sand, silt, and clay in the fraction of the soil that is less than 2 millimeters in diameter. “Loam,” for example, is soil that is 7 to 27 percent clay, 28 to 50 percent silt, and less than 52 percent sand. If the content of particles coarser than sand is 15 percent or more, an appropriate modifier is added, for example, “gravelly.”

National Hazard Support System stations: US Geological Survey
These data present the locations of stream gages and weather stations located in the United States, as well as the locations of Federal Lands. This map was developed as part of the United States Geological Survey's (USGS) Natural Hazards Support System (NHSS) which is available at http://nhss.cr.usgs.gov. But although this application was developed by the USGS, it contains data and information from a variety of public data sources, including non-USGS data. Therefore detailed information about each of these data providers, including specific data source, data currency and disclaimers, is provided at http://nhss.cr.usgs.gov/data.shtml.

Met Stations: Western Regional Climate Center
The weather stations presented are part of a cooperative network maintained by the National Oceanic and Atmospheric Administration (NOAA) and the National Weather Service (NWS). Data from these stations has been compiled by the WRCC and posted on its website. Station locations were pulled from http://www.wrcc.dri.edu/inventory/sodaz.html and were last updated in August 2010. The station attribute data was appended with HUC8 subwatershed name

Precipitation Average: Oregon State Univeristy
Monthly 30-year "normal" dataset covering the conterminous U.S., averaged over the climatological period 1981-2010. Contains spatially gridded average annual precipitation at 800m grid cell resolution. Distribution of the point measurements to the spatial grid was accomplished using the PRISM model, developed and applied by Dr. Christopher Daly of the PRISM Climate Group at Oregon State University. This dataset was heavily peer reviewed, and is available free-of-charge on the PRISM website. http://www.prism.oregonstate.edu/

Groundwater Level Change: Arizona Department of Water Resources
Original groundwater level change data were created for the Arizona Water Atlas project of the Arizona Department of Water Resources. These data were updated by the Department in 2011 for the Water Resources Development Commission. It is that data that are shown here.

Arizona Well Data: Arizona Deparment of Water Resources
The Wells 55 Registry database contains different well types - Notices of Intent to Drill (NOI) (55-500000 and 55-200000, series), Electronic NOI (eNOI) (55-900000 series), registrations of existing wells (55-600000 and 55-800000 series), discovered unregistered wells (55-700000 series),and existing wells that are registered to be abandoned (55-400000 series). In other words, the database contains NOIs to drill, modify, abandon, or deepen, registrations, driller reports, completion reports, change of well information, change of ownership, notice of well capping, and abandonment completion reports.
This feature class is provided to the general public as a single DVD obtained from the Arizona Department of Water Resources (ADWR) Bookstore. Background: ADWR has three groundwater well data sets for the state of Arizona. The first is the entire database, the 'Wells 55 Registry', which contains all wells registered in the state. The database was created in 1980 to store registration information submitted by well owners and drillers. It contains 193599 well records. The second data set is the Groundwater

Well Site Inventory (GWSI), which is a statewide database that contains well locations, construction, and water level measurements for wells that have actually been located and sampled in the field originally by the USGS and since 1990 by ADWR. The GWSI database contains 44035 well records. Of those, 22950 have a 'Wells 55 Registry ID'. The third data set is the 'Wells 35 Registry', which has not been maintained since 1980, when the Wells 55 Registry was created. The data on this DVD is only of the Wells 55 Registry Database, up to November 5, 2010. The data for GWSI and Wells 35 are available on other CD/DVD datasets from the ADWR Bookstore.

New Mexico Well Data: Office of the State Engineer

The exported ESRI point shapefile 'allwells' was made using Arc Map 8.2 on a Win2000 pc The points were created from a download of the informix data base in June, 2002. Source of the location of the points varies. All State Plane Coordinates were entered by the applicant as the location of his well, usually from looking at a 1:24k USGS topographical map. A UTM coordinate is calculated to the center of the third quarter, or the smallest quarter of a section of land within the Public Land Survey System (PLSS). These quarters were also identified by the applicant as the location of the well. If no quarter was given, the UTM coordinate is calculated to the center of the section. The Bureau of Land Management's GCDB *.lx files were used to plot the wells in the database that are entered by section, quarter, quarter, quarter description. Points that were originally located in the State Plane Coordinate system were projected using ArcInfo to UTM Zone 13, NAD83. The final data set is projected in UTM Zone 13, NAD83. Attributes found with this coverage are downloaded from the OSE WATERS database with the exception of X-coord, y-coord which were calculated.

Data were downloaded for the Upper Gila Watershed Atlas on November 4, 2013 from the New Mexico Resource Geographic Information System Program (http://rgis.unm.edu/)

Aquifers: US Geological Survey

These data are intended for use in publications, at a scale of 1:2,500,000 or smaller. Due to the small scale, the primary intended use is for regional and national data display and analysis, rather than specific local data analysis.

This map layer contains the shallowest principal aquifers of the conterminous United States, Hawaii, Puerto Rico, and the U.S. Virgin Islands, portrayed as polygons. The map layer was developed as part of the effort to produce the maps published at 1:2,500,000 in the printed series "Ground Water Atlas of the United States". The published maps contain base and cultural features not included in these data. This is a replacement for the July 1998 map layer called Principal Aquifers of the 48 Conterminous United States.

The Ground Water Atlas of the United States (GWA) chapters include additional information that may be relevant to the use of this map layer, such as maps of alluvial and glacial aquifers that overlie the aquifers in this map layer, as well as other information described below.

The areal extent of the aquifers, as shown in this map layer, represents the area in which a named aquifer is the shallowest of the principal aquifers. These aquifer areas are not necessarily the only areas in which ground water can be withdrawn, for two reasons: 1) The aquifers shown may have a larger areal extent than is represented here. The boundaries in this map layer generally represent an interpretation of the surface location (outcrop), or near-surface location (shallow subcrop) of the uppermost principal aquifer for the area. An aquifer may extend beyond the area shown, but be overlain by one or more other aquifers, and (or) low-permeability material. 2) There may be areas of water-bearing surficial material not shown in this map layer. Major alluvial aquifers that occur along main watercourses are not shown. Significant unconsolidated sand and gravel aquifers, that are not indicated in this map layer but are important sources of water, may occur locally in glaciated regions. The user of this map layer is advised that to get complete information regarding areas that serve as sources of water, more information about surficial aquifers needs to be obtained, particularly in glaciated areas.

This map layer was constructed by combining data created for or from the regional GWA chapters. Minor aquifers that are important local sources of water were mapped in some regions, so the regional maps in the GWA may show more detail than this map layer.
The data were reviewed, adjusted, and published based on new information provided by national, State, and local scientists. The juxtaposition of regionally mapped aquifers has led to some instances where an aquifer outcrop or shallow subcrop is bounded by a State line. This is a result of the regional mapping and national categorization methods used and is not meant to imply a hydrogeologic change coincident with a State boundary.
The aquifer outcrop and shallow subcrop boundaries represent broad, regional categories and should not be interpreted as site-specific. Comments regarding the names of aquifers or the hydrogeologic interpretation of the aquifers can be directed to the U.S. Geological Survey, Water Resources Division, Office of Ground Water, ogw_webmaster@usgs.gov.

Riparian Areas: Arizona Game and Fish Department
Riparian areas shown are based both on recent modeled data. Data for the modeling effort was derived from the Southwest Regional Gap Analysis Project in 2007.Lowry, J.H, Jr., Ramsey, R.D., Thomas, K.A, Schrupp, D., Kepner, W., Sajwaj, T., Thompson, B. (2007) "Land cover classification and mapping." In J.S. Prior-Magee, et al., (Eds.) Southwest Regional Gap Analysis Final Report(Chapter 2). Moscow, ID: U.S. Geological Survey, Gap Analysis Program.

Springs: Arizona Department of Water Resources
The original database was created for the Arizona Water Atlas project. Spring data to create the Department database were obtained from a variety of sources, most notably the USGS (2006a), which maintains a database of spring discharge records. Reports compiled from universities and public land agencies such as the U.S. Forest Service, National Park Service, and BLM were also useful (ADWR, 2008b). Many of the springs with discharge data were listed in more than one data source. To avoid over-counting, the Department compared spring names, locations, discharge rates, and dates of measurement and removed obvious duplicates. Topographic maps were also checked to verify that the springs had been mapped. Those springs not verified on topographic maps were included in the Atlas but noted accordingly.

Perennial Streams: The Nature Conservancy (TNC)
Data on perennial streams is taken from TNC's 2010 Freshwater Assessment (http://azconservation.org/downloads/arizona_statewide_freshwater_assessment_gis_data_package) Streams displayed here are those designated by TNC as either perennial or regulated.

Intermittent Streams: Arizona Game and Fish Department
Information taken from 1997 AZGF reported preared during the last phase of the Statewide

Riparian Inventory and Mapping Project. For this project intermittent stream reaches were idenfictied on topographic maps by staff of AZGF, BLM, NPS and USFS. Original report citation is: AZGF, 1997, Remote sensing mapping of Arizona intemrittent stream riparian areas: GIS cover and Tehcnical Report 112 by Wahl and others.

Ephemeral Streams: Arizona Land Resources Information System with WRRC analysis

Layer of likely ephemeral streams based on mapping of intermittent and perennial streams. This layer originated as the ALRIS streams layer by the Arizona State Land Department. It was queried for all but the smallest (1-4 CO, the ALRIS method of describing stream size where 1 = largest rivers) streams. It was also queried for only those waterways indicated as a stream or wash. Finally it was joined with the TNC Flow Needs Assessment layer of perennial, regulated or effluent dominated reaches (2010) and the Az Game and Fish Intermittent Streams layer (1997). Any stream reaches that were included in either of these datasets were removed from the layer.

Runoff Contours: US Geological Survey

Average annual or 'unit' runoff contours are plotted and show the magnitude and spatial variation in runoff, in inches per year, based on streamflow data collected by the USGS during 1951 through 1980. The data reflects the runoff in tributary streams, rather than in major rivers, as an indication of how runoff varies regionally with precipitation and other geographic features. The streamflow data were compiled by the USGS in 1985 and, in 1987, a 1:2,000,000-scale unit-runoff contour map of the conterminous United States was published. The map has since been digitized and posted on the USGS website.

Flood ALERT Gages: Arizona Department of Water Resources

This information was originally collected for the Arizona Water Atlas and was obtained from the Department's Surface Water Division, which maintains a database of flood warning equipment across Arizona. The Department's database was queried in fall 2005 and the information presented in the Atlas was accurate at that time. According to staff in the Surface Water Division, new flood warning gages are routinely added to the ALERT (Automated Local Evaluation in Real Time) network so the current number of stations may be greater than presented.

Stream Flow Gages: US Geological Survey

Stream flow gages as of 2010, note some gages may have been discontinued and no longer recording data.

Reservoirs: ADWR

Data from ADWR Arizona Water Atlas, up to date as of 2010. Large reservoirs are defined as water bodies with a maximum storage capacity of 500 acre-feet or greater, or where capacity information was not avaiavlity a surface area of 50 acres or greater. ADWR used 5 primary data sources to build their reservoirs layer:

- National Inventory of Dams maintained by the U.S. Army Corps of Engineers;
- ADWR's database of jurisdictional and non-jurisdictional dams in Arizona;
- Arizona Game & Fish Department's waterways file and lake classification study;
- Digital versions of 1:100,000 scale USGS topographic maps; and
- ADWR's registry of surface water right filings (see further discussion in this section under 'Stockponds') and adjudication reports.

Political Geography

Schools: Arizona Departnent of Education

Displays all public and charter schools in Arizona. Data are from the Arizona Department of Education (http://www.azed.gov/) and are accurate as of March 28, 2013.

Bridges: Federal Highway Administration

One of the layers requested from the meetings was something that shows bridge locations. The source for Bridges is the National Bridge Inventory conducted by the Federal Highway Administration. You can go to http://www.fhwa.dot.gov/bridge/nbi/ascii.cfm to choose which year of data you want. On the next page, scroll down to the delimited files section and choose state of interest. Data will be downloaded in a comma-separated text file. In the text file, there are 116 different columns. Go here http://www.fhwa.dot.gov/bridge/mtguide.pdf for official descriptions.

One challenge with this data is the Lat/long data (columns 16 and 17) are in the format DDMMSS.SS, which can be difficult to separate out into a useable decimal degree format. Do the following in Excel:

Adequate Water Supply Determinations: Arizona Department of Water Resources

Designations of Adequate Water Supply and Water Reports determining adequate or inadequate subdivision water supply in areas located outside of active management areas in the state, pursuant to A.R.S. § 45-108.

Adequacy is driven by the definition of a subdivision from the Arizona Department of Real Estate (ADRE) as six or more parcels with at least one parcel having an area less than 36 acres. This includes residential or commercial subdivisions, stock cooperatives, condominiums, and all lands subdivided as part of a common promotional plan (including golf courses, parks, schools, and other amenities). Short-term leases (12 months or less) and subdivisions where all parcels are greater than 36 acres in size do not fall under this definition. If the proposed development does not meet the definition of a subdivision, then the program does not apply.

The Adequate Water Supply program, first created in 1973, operates outside of the Active Management Areas as a consumer protection program. Developers are required to obtain a determination from the Department concerning the quantity and quality of water available before the ADRE will allow any lot sales. If the application for a Water Adequacy Report successfully demonstrates that water of sufficient quality will be physically, legally, and continuously available for the next 100 years, then the Department will determine the water supply to be adequate. If the water supply is determined to be inadequate, the developer may still sell lots, but the inadequate determination must be disclosed to potential buyers in the public report approved by ADRE and in all promotional materials. If a provider with a Designation of Adequate Water Supply will serve the proposed subdivision, then the developer only has to provide a written commitment of service from the designated provider.

This data set contains statewide data for the Water Atlas. Sources for this information come from the Arizona Department of Water Resources (ADWR) and include electronic databases maintained by the Office of Assured and Adequate Water Supply and paper files stored in the Hydrology Division.

Database queries were reviewed and some information was excluded from the Atlas based on subdivision location, duplicate applications, etc. Paper files were also reviewed to complete information that had not been entered into the databases such as number of lots and reasons for inadequate determinations.

Sources for adequate water supply determinations come from the Department and include electronic databases maintained by the Office of Assured and Adequate Water Supply and paper files stored in the Hydrology Division. Each determination of the adequacy of water supplies available to a subdivision is based on the information available to the Department and the standards of review and policies in effect at the time the determination is made.

Surface Water Rights Points of Diverion: Arizona Department of Water Resources
This SWR feature class was created at the request of the Water Atlas group in order to make the final maps of Points of Diversions (PODs) for the Water Atlas publication. Data downloaded from http://www.azwater.gov/azdwr/gis/ on April 23. 2013. Data only current up to 2/05/09

Water Quality: Arizona Department of Environmental Quality/Arizona Department of Water Resources
Dataset originally from ADEQ, version here was edited by/used for the Arizona Water Atlas by ADWR. The maps show the location of wells, springs, and mines that have equaled or exceeded drinking water quality standards and lakes and streams that are impaired for designated uses. Tables for the wells, springs, and mines list the type of sampling site, its location (township, range and section), and relevant water quality parameters.

Water quality data for the wells, springs, and mines were obtained from the following primary sources:

- ADWR's Groundwater Site Inventory (GWSI) database;
- USGS's National Water Inventory System (NWIS) database;
- ADEQ's Safe Drinking Water (SDW), Rural Watershed Study, and Arsenic databases; and
- Various technical reports prepared by the Department, ADEQ and USGS.

Data on impaired lakes and streams comes from ADEQ's 2005 report The Status of Water Quality in Arizona – 2004, Arizona's Integrated 305(b) Assessment and 303(d) Listing Report.

Several of the well, spring, and mine sites have been sampled more than once and/or results from the same sampling date are listed in more than one data source. An effort was made to remove duplicate data using available information on site location. The water quality data presented in the ADWR's Atlas indicate areas where water quality exceedences have previously occurred. Additional areas of concern may currently exist where water quality samples have not been collected or sample results were not reviewed by the Department. For example, as part of ADEQ's Underground Storage Tank (UST) and Aquifer Protection Permit (APP) programs, thousands of water quality samples have been collected and analyzed. Results from these analyses were not included in the Atlas. What is included for these and other environmental programs is a 2006 map from ADEQ that shows the location of contaminated sites across the state (See Contamination Sites).

Finally, note that the water quality data presented in the Atlas may not reflect the quality of water being supplied by public water systems. The latter are required by federal and state law to supply water that meets drinking water standards. ADWR's Atlas data indicates areas where private well owners and surface water users may want to test the quality of their water or restrict its use. The distribution of common ground water quality exceedences in Arizona ground waters (arsenic, fluoride, nitrate and total dissolved solids) is shown in Figure 1-26 of this volume.

Outstanding Arizona Waters: Arizona Deparment of Environmental Quality
This data set is a general reference for the Outstanding Arizona Waters (formerly unique waters). The term "outstanding Arizona water" (OAW), replaces the term "unique waters". The terms "outstanding water" or "outstanding Arizona water" and "unique water" are to be considered synonymous. Last updated with the 2010 assessments.
http://www.azdeq.gov/environ/water/assessment/assess.html

Land Ownership: Bureau of Land Management
These data was collected by the U.S. Bureau of Land Management (BLM) in New Mexico at both the New Mexico State Office and at the various field offices. This dataset is meant to depict the surface owner or manager of the land parcels. In the vast majority of land parcels, they will be one and the same. However, there are instances where the owner and manager of the land surface are not the same. When this occurs, the manager of the land is usually indicated. BLM's Master Title Plats are the official land records of the federal government and serve as the primary data source for depiction of all federal lands. Information from State of New Mexico is the primary source for the depiction of all state lands. Auxilliary source are referenced, as well, for the depiction of all lands. Collection of this dataset began in the 1980's using the BLM's ADS software to digitize information at the 1:24,000 scale. In the mid to late 1990's the data was converted from ADS to ArcInfo software and merged into tiles of one degree of longitude by one half degree of latitude. These tiles were regularly updated. The tiles were merged into a statewide coverage. The source geodatabase for this shapefile was created by loading the merged ArcInfo coverage into a personal geodatabase. The geodatabase data were snapped to a more accurate GCDB derived land network, where available. In areas where GCDB was not available the data were snapped to digitized PLSS. In 2006, the personal geodatabase was loaded into an enterprise geodatabase (SDE). This shapefile has been created by exporting the feature class from SDE.

No warranty is made by the Bureau of Land Management as to the accuracy, reliability, or completeness of these data for individual use or aggregate use with other data, or for purposes not intended by BLM. Spatial information may not meet National Map Accuracy Standards.

Changes to the Landscape

Fire Perimeters: US Forest Service
Large fires in Arizona and New Mexico, within Region 3 of the USFS. Data are preliminary burn severity data from the Burned Area Emergency Response (BAER) Imagery (http://www.fs.fed.us/eng/rsac/baer/) downloaded on April 16, 2013. Fire boundaries are clipped to fire perimeter data (http://www.fs.usda.gov/detail/r3/landmanagement/gis/?cid=stelprdb5201889) and only includes fires in the Upper Gila Watershed

Fire Regime: US Forest Service, US Geological Survey

Broad-scale alterations of historical fire regimes and vegetation dynamics have occurred in many landscapes in the U.S. through the combined influence of land management practices, fire exclusion, ungulate herbivory, insect and disease outbreaks, climate change, and invasion of non-native plant species. The LANDFIRE Project produces maps of historical fire regimes and vegetation conditions using the disturbance dynamics model VDDT. The LANDFIRE Project also produces maps of current vegetation and measurements of current vegetation departure from simulated historical reference conditions. These maps support fire and landscape management planning outlined in the goals of the National Fire Plan, Federal Wildland Fire Management Policy, and the Healthy Forests Restoration Act.Data Summary: The Fire Regime Groups layer characterizes the presumed historical fire regimes within landscapes based on interactions between vegetation dynamics, fire spread, fire effects, and spatial context (Hann and others 2004). Fire regime group definitions have been altered from previous applications (Hann & Bunnell 2001; Schmidt and others 2002; Wildland Fire Communicator's Guide) to best approximate the definitions outlined in the Interagency FRCC Guidebook (Hann and others 2004). These definitions were refined to create discrete, mutually exclusive criteria. This layer is created by linking the BpS Group attribute in the BpS layer with the Refresh Model Tracker (RMT) data and assigning the Fire Regime Group attribute. This geospatial product should display a reasonable approximation of Fire Regime Group, as documented in the Refresh Model Tracker. The Historical Fire Regime Groups data layer categorizes simulated mean fire return intervals and fire severities into five fire regimes defined in the Interagency Fire Regime Condition Class Guidebook (Hann et al. 2004). The classes are defined as follows: Fire Regime I: 0 to 35 year frequency, low to mixed severity Fire Regime II: 0 to 35 year frequency, replacement severity Fire Regime III: 35 to 200 year frequency, low to mixed severity Fire Regime IV: 35 to 200 year frequency, replacement severity Fire Regime V: 200+ year frequency, any severity Additional data layer values were included to represent Water (111), Snow / Ice (112), Barren (131), and Sparsely Vegetated (132). Vegetated areas that never burned during the simulations were included in the category "Indeterminate Fire Regime Characteristics" (133); these vegetation types either had no defined fire behavior or had extremely low probabilities of fire ignition.
Data Sources

Hann, W.. A. Shlisky, D. Havlina, K. Schon, S. Barrett, T. DeMeo, K. Pohl, J. Menakis, D. Hamilton, J. Jones, and M. Levesque. 2004. Interagency Fire Regime Condition Class Guidebook. Interagency and The Nature Conservancy fire regime condition class website. USDA Forest Service, US Department of the Interior, The Nature Conservancy, and Systems for Environmental Management. www.frcc.gov.

Data have been collected and analyzed by teams at both USGS EROS, Sioux Falls, SD and at the USFS, Rocky Mountain Research Station, Missoula, MT. Depending on the data set described primary responsibility may reside with USGS EROS or with USFS. Contact information will be listed in the Contact Section and in the Metadata Reference section with regards to the primary responsibility.

Fire Burn Severity: US Forest Service

These data were created by the USDA Forest Service Remote Sensing Applications Center to support Burned Area Emergency Response (BAER) teams. FTP data sets are available to any user with access to the USFS FSWEB. There are no restrictions on use, except for reasonable and proper acknowledgment of information sources.

These data products are derived from Landsat Thematic Mapper data. The pre-fire and post-fire subsets included were used to create a differenced Normalized Burn Ratio (dNBR) image. The dNBR image attempts to portray the variation of burn severity within a fire. The severity ratings are influenced by the effects to the canopy. The severity rating is based upon a composite of the severity to the understory (grass, shrub layers), midstory trees and overstory trees. Because there is often a strong correlation between canopy consumption and soil effects, this algorithm works in many cases for BAER teams whose objective is a soil burn severity assessment. It is not, however, appropriate in all ecosystems or fires. These data products are derived from Landsat Thematic Mapper data. Pre-fire and post-fire scenes are analyzed to create a differenced Normalized Burn Ratio (dNBR) image. The dNBR image portrays the variation of burn severity within the fire. The pre- and post-fire Landsat images are terrain corrected and further processed to convert bands 1-5 and 7 to at-sensor-reflectance. The Normalized Burn Ratio (NBR) is computed for each date of imagery using the following formula:

(Band 4 - Band 7) / (Band 4 + Band 7) = NBR

The Differenced NBR is computed to determine severity by subtracting the post-fire NBR from the pre-fire NBR:

(PreNBR - PostNBR) = dNBR

The BARC products are a generalization of the raw dNBR dataset. Both BARC products have been resampled to unsigned 8-bit images and are easily viewed and edited within ArcGIS.

The classes represented on the BARC products are created with thresholds chosen by an analyst at RSAC. These thresholds can be roughly related back to original dNBR values by multiplying by 5 and then subtracting 275 (for example, a BARC256 value of 100 would relate to a dNBR value of 225). The BARC thresholds used on this particular fire are:

Unchanged: All values less than 65.
Low: All values greater than 65 and less than 99.
Moderate: All values greater than 99 and less than 177.
High: All values greater than 177.

General descriptions of the severity classes are as follows:

Unchanged: This means the area after the fire was indistinguishable from pre-fire conditions. This does not always indicate the area did not burn.
Low: This severity class represents areas of surface fire with little change in cover and little mortality of the dominant vegetation.
Moderate: This severity class is between low and high and means there is a mixture of effects on the dominant vegetation.
High: This severity class represents areas where the canopy has high to complete consumption.

Land Cover Change: WRRC
For this Atlas the WRRC preformed a simplified land cover change analysis using

information from the National Land Cover Database (NLCD). The NLCD was developed by the Multi-Resolution Land Characteristics Consortium (MRLC), a group of ten federal agencies. Datasets were developed for 1992, 2001, and 2006 using satellite imagery (Landsat TM/ETM+) with a spatial resolution of 30 meters. Though all three datasets were produced as part of the same program, changes in methodologies and input between the 1992 NLCD and the 2001 and 2006 NLCD makes it so that these datasets cannot all be directly compared to one another, though products developed by the MRLC for 1992/2001 and 2001/2006 allow for limited comparisons. Overall accuracy of the 1992 NLCD varied by region, but was 70% for the Southwest (Wickham et al. 2004). Overall accuracies for the entire 2001 and 2006 NLCD were 79% and 78%, respectively (Wickham et al. 2013).

Water Supply Gap: Water Resources Development Commission (WRDC)

Data for the water supply gap map come from the analysis by the WRDC of existing water supplies and projected (high and low) water demands. For more information on the data and methods for this analysis see the WRDC Final Report and Appendicies available at: http://www.azwater.gov/AzDWR/WaterManagement/WRDC_HB2661/Meetings_Schedule.htm