Climate Change Effects on Central New Mexico's Land Use, Transportation System and Key Natural Resources

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Introduction

This report summarizes potential climate change effects on the availability of water, land use, transportation infrastructure, and key natural resources in central New Mexico (Figure 1). This work is being done as part of the Interagency Transportation, Land Use, and Climate Change Scenario Planning Project in Central New Mexico.

Global and Regional Impacts of Rising GHG Concentrations

In its fifth assessment report on global climate change (GCC) the Intergovernmental Panel on Climate Change (IPCC) finds greenhouse gas (GHG) concentrations at levels unsurpassed in the last 800,000 years (IPCC 2013). The fifth assessment, like prior assessments, forecasts increasing surface and ocean temperatures and rising sea levels and states that "it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century" (IPCC 2013). The IPCC's temperature and sea level rise forecasts are based on a series of computer simulations using the Coupled Model Intercomparison Project (CMIP5) climate prediction tool. The CMIP5 model was used to forecast a range of Representative Concentration Pathways (RCPs) corresponding to different levels of potential GHG mitigation efforts. The simulations show that while there is some uncertainty about how global temperatures will respond to changing levels of GHG emissions, even the scenario with the most aggressive GHG mitigation effort indicates an expected 0.3–1.7° Celsius (C) increase in global temperatures (Figure 2). The simulations also show that a failure to make significant reductions in GHG emissions is expected to cause a dramatic and potentially devastating rise in global temperatures by the end of the 21st Century.

The fifth IPCC assessment report also finds that North America, and more specifically the southwestern United States, is experiencing an increasing number of warm days and nights when compared to cold days and nights (e.g., more than one standard deviation from daily means) annually and has linked GCC to earlier than normal spring snowmelts (Barnett et al. 2008), massive tree mortality events (Allen et al. 2010), extended heat waves (Peng et al 2011), greater frequency of large-scale forest fires (Flannigan et al. 2006), and declining water quality and availability (Milly et al. 2005).

The projected warming is expected to increase drought severity and frequency in arid to semi-arid regions (Stott et al. 2010), increase the frequency of wildland fires (Allen et al. 2010), increase the variability and duration of precipitation events (Zhu et al. 2012), and affect the strength and frequency of the El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO), which is expected to push the North American Monsoon later into the summer (Garfin 2013). The combined impacts of earlier spring snowmelt and later arriving summer monsoons will increase stress on the natural and human systems that depend on streamflow and soil moisture during summer low flows.

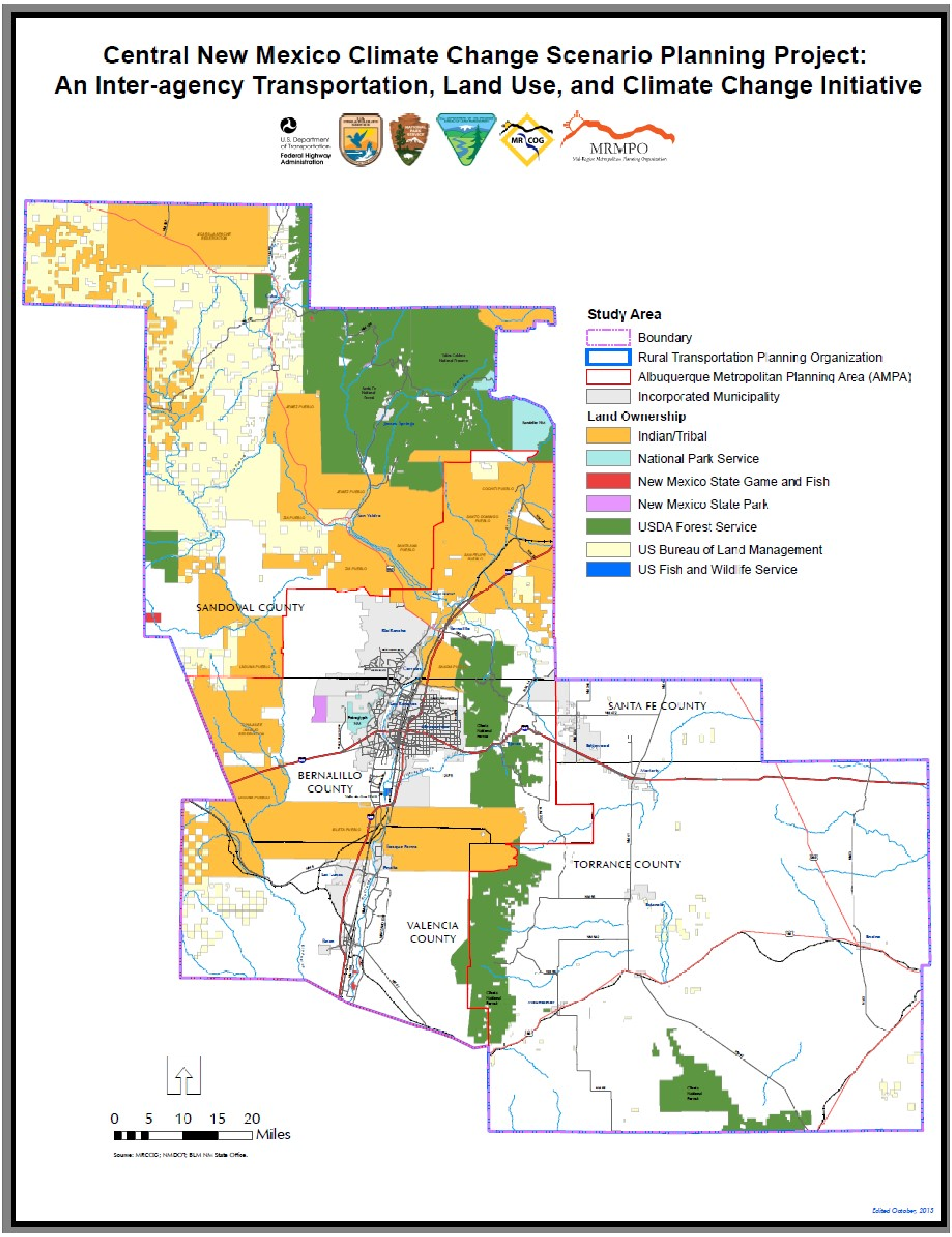

Figure 1. Central New Mexico Study Area (MRCOG 2013).

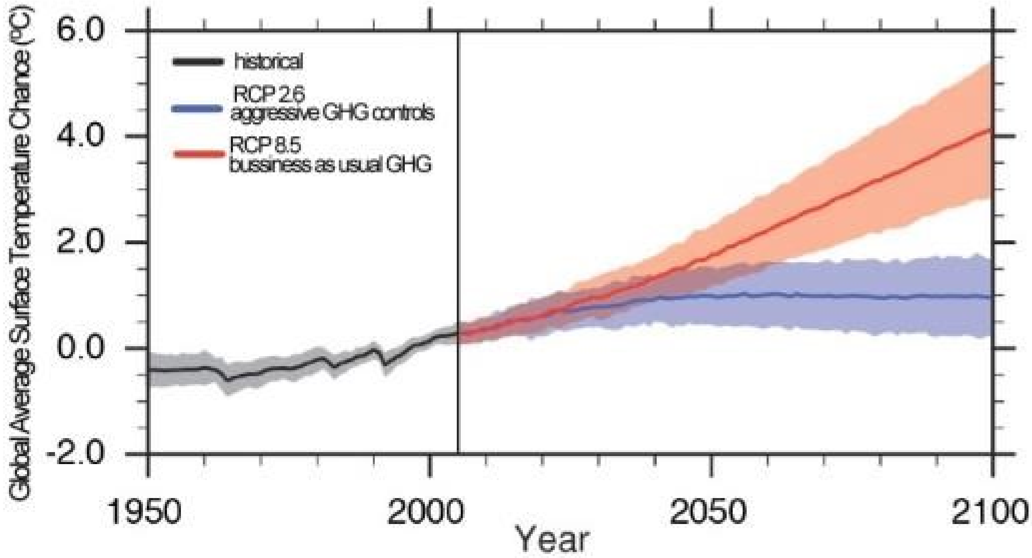

Figure 2. Global warming trends from IPCC 2013 model predictions (modified from IPCC 2013). The two pathways represent the most aggressive (RPC 2.6) and least aggressive (RCP 8.5) GHG mitigation scenarios. The solid lines represent ensemble averages amongst the climate models and the shaded regions represent the full range of model results.

Southwest Regional GCC Implications

Climate change is projected to affect the atmospheric and oceanic processes that influence the location of the climate zone boundary and ocean-driven weather anomalies such as El Niño, La Niña, and the North American Monsoon (Llwellyn and Vaddey 2013). The Bureau of Reclamation, Sandia National Laboratories, and the U.S. Army Corps of Engineers prepared the *West-Wide Climate Risk Assessment: Upper Rio Grande Impact Assessment* report (Reclamation), which discusses future climate change. The projections of future change in temperature and precipitation in this report were based on the National Oceanic and Atmospheric Administration using the Intercomparison Project 3 (CMIP3) models and the North American Regional Climate Change Assessment Program models (Llwellyn and Vaddey 2013).

Both the Reclamation (Llewellyn and Vaddey 2013) and the *Climate Assessment of the Southwest* (CLIMAS; Weiss 2013) reports state there is high confidence that the average temperatures will increase over the 21st century in the Southwest. Summer and fall temperatures will rise more than spring and winter temperatures. The number of cooling degree-days (number of degrees that a day's average temperature is above 65 F (18° C)) and the number of consecutive hot days will increase. Degree days are based on the assumption that the basic temperature where cooling and heating is not needed to be comfortable is 65 degrees Fahrenheit. Degree days is the difference between the daily temperature mean and 65 degrees Fahrenheit. If the temperature is above 65 degrees Fahrenheit, the mean temperature of that day (the high temperature of the day subtracted by the low temperature of the day divided by two) is subtracted by 65 degrees. The difference is cooling degree days (National Weather Service Weather Forecast Office 2014).

The Reclamation report cites model simulations for the Southwestern U.S. used in the most recent National Climate Assessment which projects changes in precipitation that range from -13 percent to +10 percent through the 21st century. The CLIMAS report concludes that annual precipitation in the Southwestern U.S. could change by -10 percent to +7 percent during the 2021–2050 time period. Both the Reclamation and CLIMAS reports conclude that the predictions of precipitation levels have much greater uncertainty than for temperature. Precipitation may become more concentrated in a smaller number of more intense storms. More precipitation may fall as rain and less may fall as snow. The consensus is that temperature-driven increases in evaporation, regardless of whether precipitation increases or decreases, will lead to greater evapotranspiration, a net decrease in soil moisture, and a persistently negative water balance for the region (Llewellyn and Vaddey 2013).

Increased drought is likely in the Southwestern U.S. due to increased evaporation from higher temperatures, according to both the Reclamation and CLIMAS reports. Both reports identify three types of drought. Meteorological drought is a period with below normal precipitation. Agricultural drought is a period of dry soils, which could be caused by high temperatures due to evaporation, changes in land use, vegetative cover, or watershed hydrology. Hydrological drought is declines in water storage and stream flow due to trends in precipitation, temperature, vegetation or land use. A review of 24 IPCC models suggests that temperature increases will be the predominant factor in increasing the likelihood of drought in the Southwestern U.S. even for those models that project precipitation increases in the winter. In a review of 19 models used by the IPCC in its 2007 assessment report, it was found that under the A1B (moderate emissions) scenario, models project a sustained transition to drier climate beginning in the 1990s or early in the 21st century (Seager et al. 2007). This change is driven by declines in precipitation and increases in evaporation. Most of the projected regional drying occurs in winter. The average climate of the Southwest by mid-21st century will resemble that of climate during a multi-year drought today. “The most severe future droughts will still occur during persistent La Niña events, but they will be worse than any since the Medieval period, because the La Niña conditions will be perturbing a base state that is drier than any state experienced recently” (Seager et al. 2007).

Global Climate Change Implications for the Central New Mexico Region

The climate of central New Mexico is highly variable as it located on the boundary between the temperate mid-latitude zone and the subtropical dry zone and elevation ranges from approximately 5,000 feet to 10,600 feet. The Upper Rio Grande basin-average mean-annual temperature is projected to increase by approximately 5° to 6° Fahrenheit (F) (2° to 3° Celsius) during the 21st century (Llewellyn and Vaddey 2013). The CLIMAS report projects temperature to rise 1.3° F to 3.8° F (1.5 to 4.8° C) during the 2021–2050 time period (Weiss 2013). The simulated annual temperature and precipitation averaged over the Rio Grande sub-basins are shown in Figure 3.

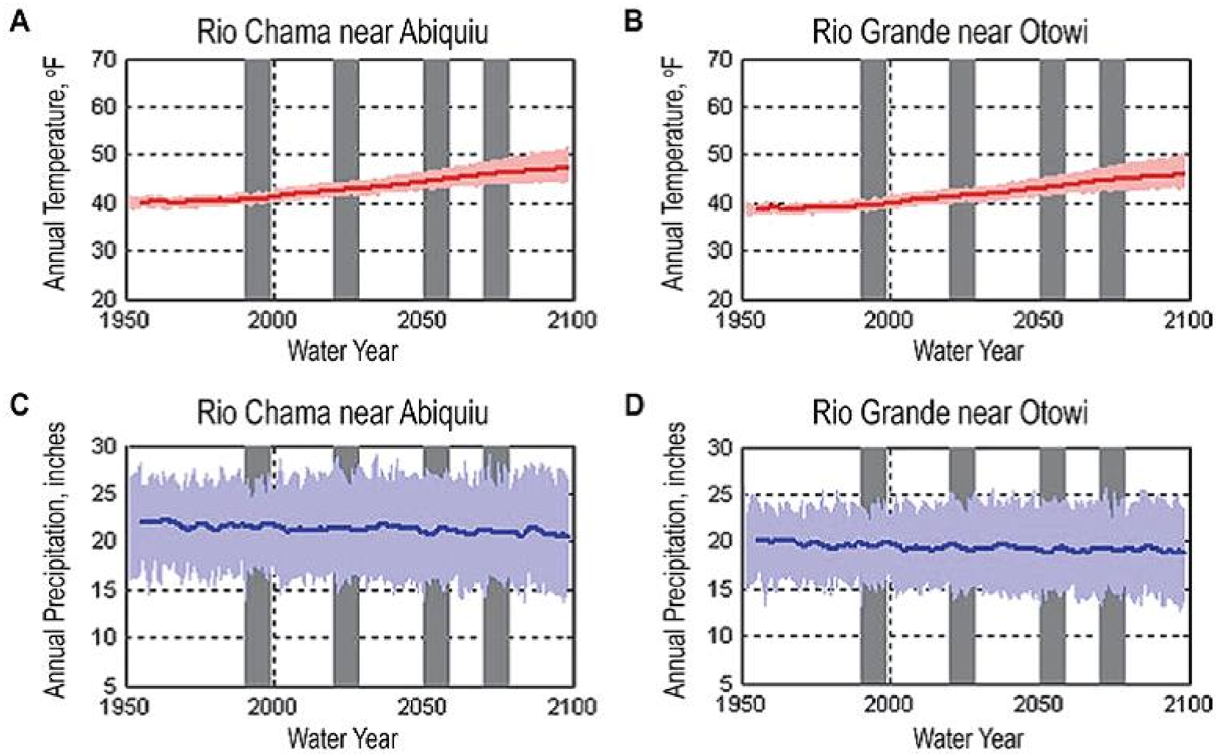

Figure 3. Simulated Annual Climate Averaged over Rio Grande Sub-Basins (Llewellyn and Vaddey 2013).

New Mexico's water security depends on precipitation falling within its borders and water conveyed through the Rio Grande from Colorado and across the continental divide by the San Juan Chama Diversion Project (SJCDP; New Mexico First 2014). The Rio Grande watershed is the fifth largest in the United States and covers an area of approximately 355,000 mi^2. There are three counties within New Mexico that comprise the Middle Rio Grande Basin (MRGB; Figure 4: Valencia, Bernalillo and Sandoval counties). The MRGB, while only encompassing three of the 33 counties in New Mexico, as of 2010 held just over 42 percent of the state's population of 2,059,179 citizens (U.S. Census Bureau). The basin also encompasses two endangered species habitats: the Rio Grande Silvery Minnow (*Hybognathus amarus*) and Southwestern Willow Flycatcher (*Empidonax traillii extimus*). Both of these species rely on the presence of natural flow regimes that episodically inundate the riparian floodplains along the Rio Grande. Climate change is predicted to impact every water district within New Mexico. The MRGB is expected to experience increased temperatures; an overall reduction in annual precipitation amounts, which would result in decreased flows, increase drought, and higher risk of catastrophic fire events (Llewellyn and Vaddey 2013).

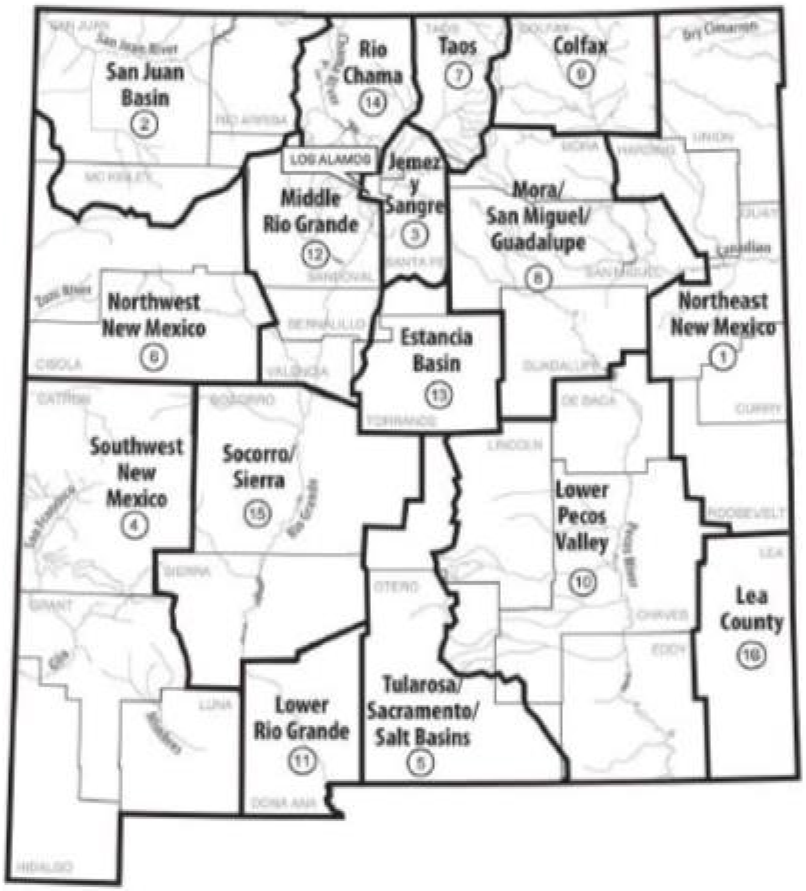

Figure 4. New Mexico Water Planning Regions. Bernalillo, Sandoval and Valencia counties lie in Region #12 (New Mexico First 2014).

The Rio Grande is fed primarily by snowpack runoff, receiving upwards of 50 percent of its annual precipitation as snowfall in the winter months (Llewellyn and Vaddey 2013, U.S. Environmental Protection Agency 2013). Baseflow within the river system in early April to June, along with an additional input of 96,200 acre-feet from the SJCDP, serves to replenish reservoir storage throughout the upper watershed and provides water resources to irrigators and municipalities throughout the drier summer and fall months which are accompanied by depleted streamflows (Llewellyn and Vaddey 2013, U.S. Environmental Protection Agency 2013). The annual hydrographs in Figure 5 summarize variations in streamflow for the upper Rio Grande, and for the Rio Chama and Rio Puerco (which are affluents of the Rio Grande) over the course of the year. The solid black lines represent the mean value on each day of the year. The gray region represents the 25 percent and 75 percent quantiles for each day and the dashed blue line indicates the mean annual streamflow. Several important characteristics are evident. First, the upper Rio Grande and Rio Chama are snowmelt-dominated systems with high spring flows and lower summer, fall, and winter baseline flows. The Rio Puerco, on the other hand, is a summer monsoon dominated river. Second, the variability of the data on any given day is exceptionally high. For example, on Day 152 (June 1) the 25 percent and 75 percent quantile values are 1,360 cubic feet per second (cfs) and 5,960 cfs, respectively. In other words, the flow has been at or below 1,360 cfs on June 1 for 25 percent of the years on record and it is been at or above 5,960 cfs for 25 percent of the years. Managing water resources in a system with this degree of variability is remarkably difficult. Climate change is expected to both increase this variability while decreasing the average water availability (Hurd and Coonrod 2012).

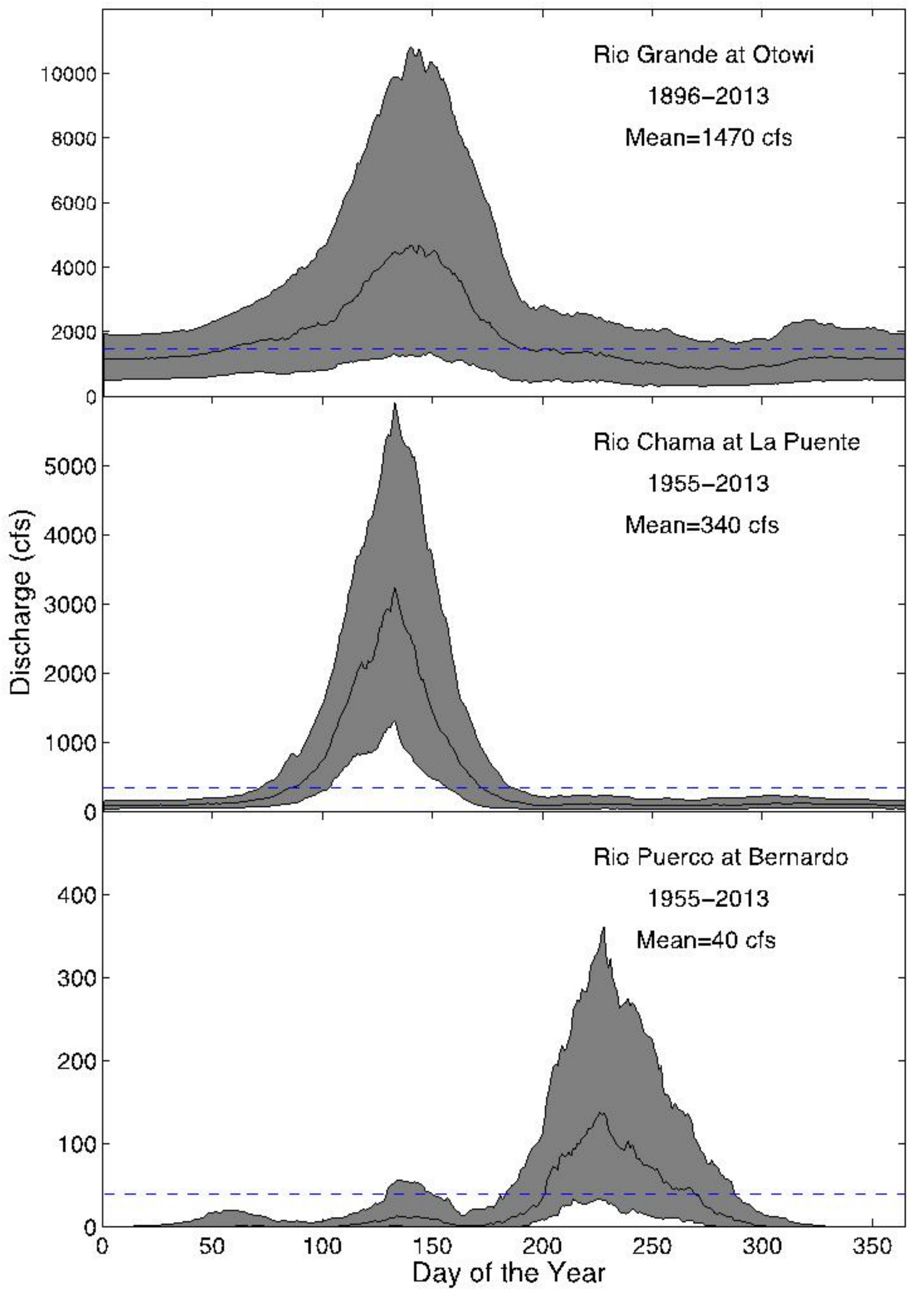

Figure 5. Annual hydrographs (streamflow vs. time) for three major stream gages indicating water availability for the Central New Mexico Region. Solid black lines represent the daily means and the gray areas represent the streamflow between the 25 percent and 75 percent quantile. The blue dashed lines indicate the mean annual streamflow for each gaging station (Llewellyn and Vaddey 2013).

Surface waters within the Rio Grande watershed are allocated to water users within New Mexico or are obligated to be delivered to Texas under the terms of the Rio Grande Compact. The major water users include the Albuquerque Bernalillo County Water Utility Authority (ABCWUA), the Middle Rio Grande Conservation District (MRGCD), the City of Santa Fe, and several other smaller municipalities.

The surface water supply can be segregated into native flows (those that originate in the Rio Grande watershed) and the SJCDP supply. Native flows are subject to compliance under the Rio Grande Compact. Under the terms of the contract and in low-flow conditions, New Mexico must deliver 57 percent of the flow recorded at the Otowi gage (near Los Alamos, NM) to below the Elephant Butte Dam (approximately, equidistant point between Socorro and Las Cruces, NM) for delivery to Texas and can consume the remaining 43 percent of flow. Under high-flow conditions, New Mexico can consume only 13 percent of the Otowi flows and must release 87 percent of the flows below Elephant Butte Dam (Gaume 1999).

SJCDP flows are delivered to the Rio Grande Watershed under the terms of the Upper Colorado Compact and thus are not subject to the Rio Grande Compact. The largest water contractor to the SJCDP is the ABCWUA, which holds rights to 48,200 acre-feet of water each year. The MRGCD holds rights to 20,900 acre-feet of SJCDP water. The City of Santa Fe, other smaller municipalities, and tribes have rights to the remainder of the approximately 96,000 acre-feet of average annual supply.

Effects of Climate Change Impacts on Water Resources within the Albuquerque Metropolitan Area

The Albuquerque metropolitan area (Sandoval, Bernalillo, Valencia, and Torrance counties) had a population of 887,087 residents in 2010 and has historically experienced rapid population growth, exceeding 21 percent in each of the last two decades (U.S. Census Bureau 2014). However, the population growth in New Mexico has slowed dramatically in the last decade (i.e., starting at 0.6% in 2001 and dropping to <0.2% in 2013). Given that the population growth rate for the metropolitan area remained almost perfectly constant during the last decade of a weaker economy, it is expected that the larger population centers in New Mexico will remain the epicenters of continued growth and that a greater demand will be placed on the available water supply as future construction of new homes and businesses continues.

The 2013 U.S. Environmental Protection Agency (EPA) report on climate change suggests that urban development in the Rio Grande Basin is expected to grow 432.4 km^2 by mid-21st century. Newly developed growth in Albuquerque is largely limited to the western side of the Rio Grande because the city is bounded on its northern edge by the Sandia Pueblo, at the east by the Sandia Mountains, and its southern boundary by Kirtland Air Force Base and the Isleta Pueblo. More land is available in Rio Rancho, Belen, and Los Lunas, and these communities tend to exceed the growth rate of Albuquerque during periods when the economy is improved. Regional planners will need to consider how conversions of the available range land to urban use might impact the hydrology of the basin, as well as how to encourage development that minimizes the consumption of the region's water resources and promotes sustainable water use.

From combining GCC projections and land use change within the MRGB, land-use planners and officials can expect to encounter many challenges in meeting water supply demands. In the last few years, the ABCWUA has switched from groundwater pumping to a greater reliance on surface water withdrawals (2010 annual water withdrawals were 54 percent surface water and 46 percent groundwater; New Mexico Office of the State Engineer 2010 Water Withdrawal by Categories) directly from the Rio Grande. The river diversion is located just south of the Alameda Bridge in Albuquerque. ABCWUA is allowed to divert water from the river when surface flows are above 120 cfs, otherwise, the City must rely on groundwater water resources alone. Significant inputs to the river along the Albuquerque reach include the Venada Arroyo, La Baranca Arroyo, Los Montoyas Arroyo, North Diversion Channel, the Calabacillas Arroyo, City of Albuquerque Wastewater Treatment Facility outfall, Tijeras Arroyo, and the South Diversion Channel, all of which usually only flow (with the exception of the treatment facility) during summer monsoon rain events.

ABCWUA's shift towards a greater dependence on surface flows for consumptive use has come about since the realization in the early 1990s that the groundwater aquifer in the region did not contain as large of a volume of drinkable water as once thought. From the time period of 1960 to 2002, the Santa Fe Group aquifer beneath Albuquerque has declined by as much as 130 feet (Hawley and Haase 1992, Thorn et al. 1993, Connell et al. 1998, Cole et al. 2001). Since the start of surface water diversions to supplement water demand, the aquifer has shown signs of rebounding slightly; still, groundwater withdrawal in New Mexico is unsustainable because the volume of water being withdrawn far exceeds the rate at which water is replenished in most areas. Development in the metropolitan area will lead to more impervious cover and less aquifer recharge in the future, and thus a greater importance for the availability of surface water flows for diversion from the Rio Grande.

The shift from entirely groundwater withdrawals for the Albuquerque metropolitan area to a tentative balance with surface water consumption holds additional challenges in regards to the surface component if aquifer recharge is to be improved. Climate change projections in the regions show consistent warming trends across all models and GHG scenarios with high variability in predictions to changes in the magnitude of precipitation (Llewellyn and Vaddey 2013). In spite of the uncertainties regarding precipitation trends, streamflows are expected to decrease dramatically as increased temperatures accelerate the evapotranspiration of the landscape and the evaporation of water bodies. Specifically, the Reclamation report concluded that by the year 2100: (1) native flows in the Rio Grande are expected to drop by approximately one-third and (2) water supply available via the SJCDP is expected to drop by approximately one-quarter (Llewellyn and Vaddey 2013). This realization could further restrict the operation of the water diversion facility in Albuquerque if river flows fall below the 120 cfs limit more frequently; this realization could also influence a shift back to an increased water abstraction of the underground aquifer system and a return to its depletion.

It is not just the availability of the water supply in the greater Albuquerque metropolitan area, but also the quality of the water source that is a matter of concern. A reduction in the river streamflow would result in a greater withdrawal from the groundwater resource by the ABCWUA to meet demand; however, the water condition within the aquifer becomes increasingly saline as water is pumped from greater depths. Processing of highly saline sources for drinking water or irrigation would require expensive technologies such as reverse osmosis filtration along with the associated issues of an additional waste stream (brine water) and large energy demands to drive the filtration units.

Reduced snow pack (see Figure 6) at the onset of the early stream runoff period, which historically begins in April and peaks in May, already heightened drought conditions (Figures 7 to 8), and GCC temperature increases within the region all threaten to lower surface water quality in the Rio Grande. Figures 6 through 8 illustrate the current system response to these climate stresses and provide an indication of the severe limitation in surface water resources that the region is already facing. All of these stressors are expected to worsen under future climate change predictions.

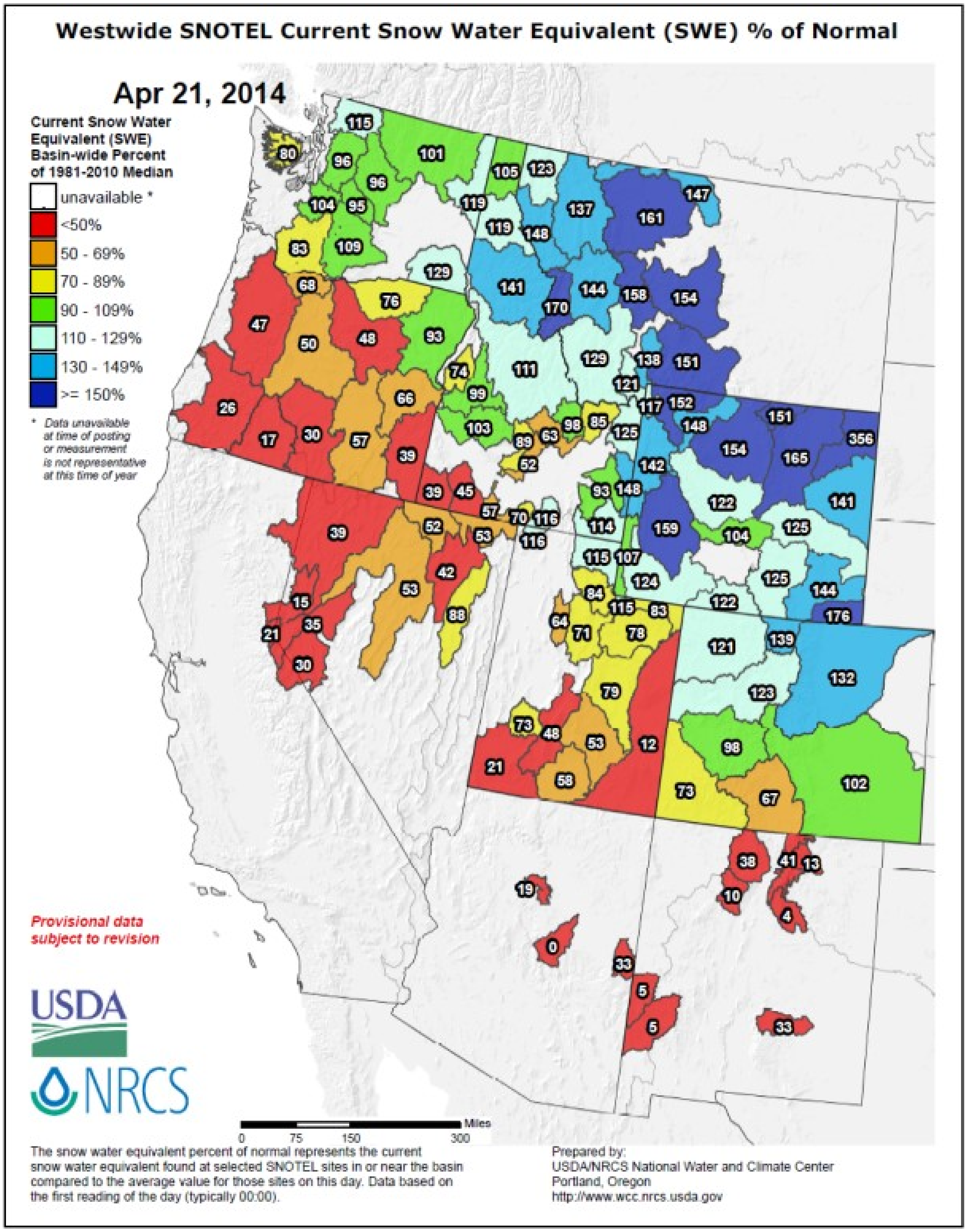

Figure 6. NRCS image of current snowpack conditions for the western U.S. Image from NRCS SNOTEL Snow Water Equivalent.

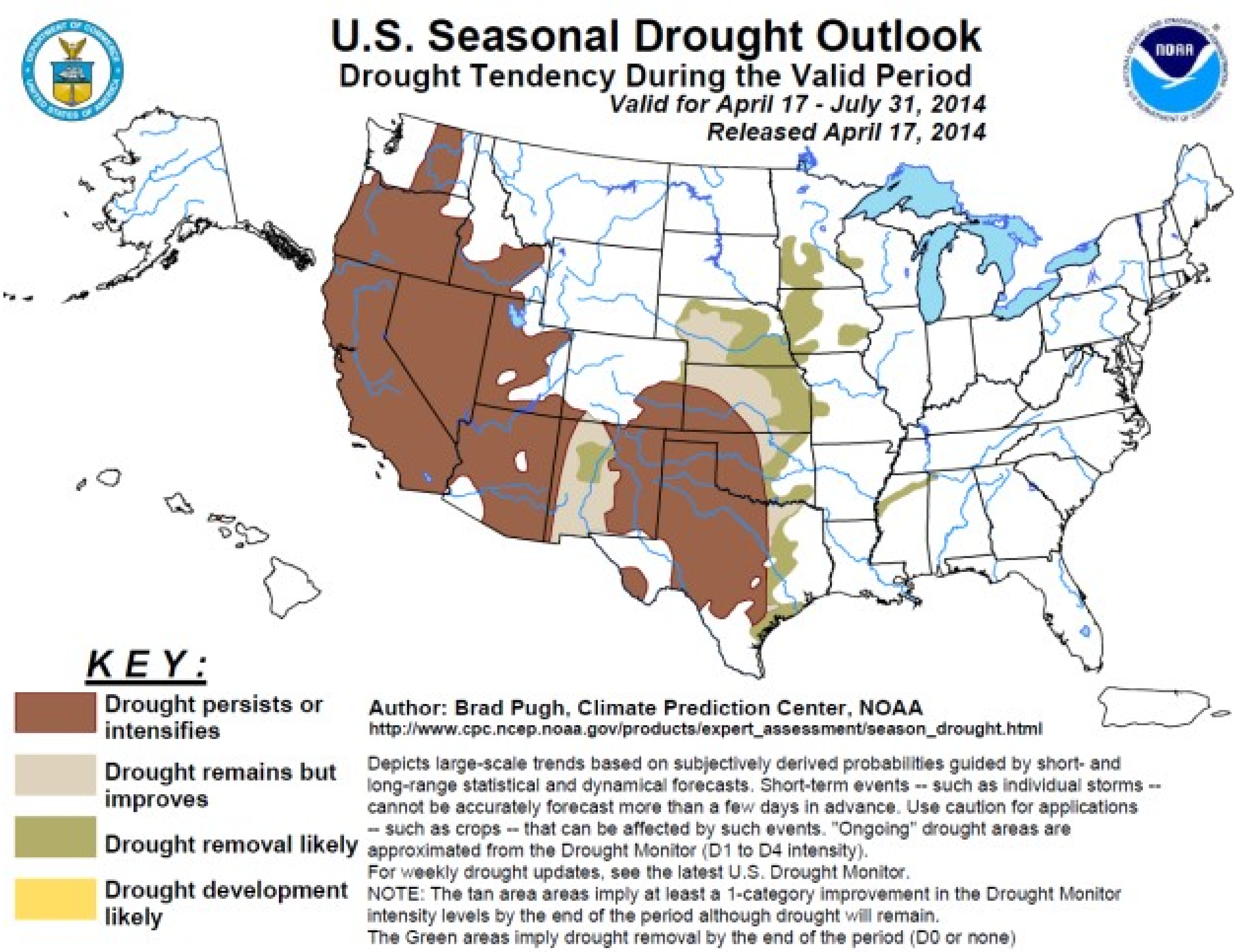

Figure 7. U.S. drought outlook for 2014 spring season. Image from NOAA U.S. Seasonal Drought Outlook.

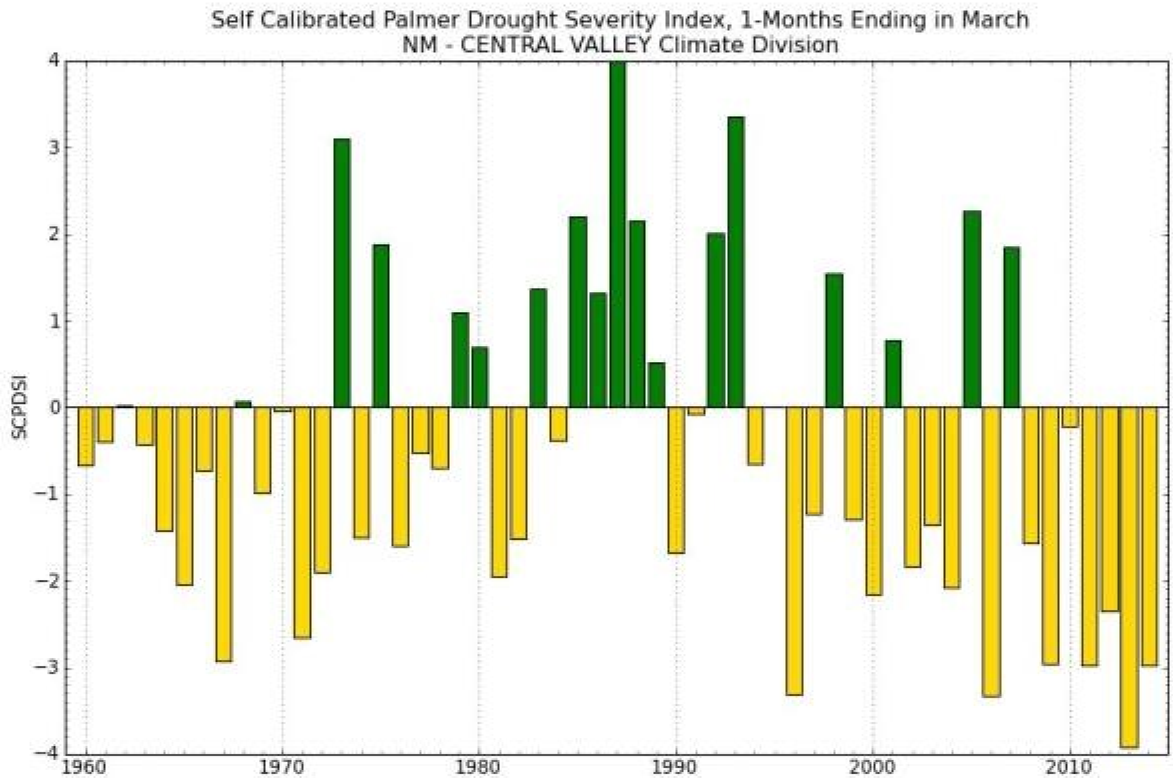

Figure 8. Drought index for the Central Valley of NM (Bernalillo, Sandoval, and Valencia counties) from 1960 to present, image from Western Regional Climate Center west wide drought tracker. It can be seen from the figure that drought within the basin is both occurring frequently and more severely in recent history. The green bars indicate a non-drought year beginning from March of the previous year to March of the selected year, the yellow bars indicate a Palmer Drought Severity Index drought year (built from http://www.drought.gov). The length of the individual bar would indicate either a more severe drought index (yellow) or "better" wet year (green).

Perennial stream systems will flow at shallower depths and will be subjected to intense solar radiation, leading to increased evapotranspiration and in-channel temperature. Higher water temperature will result in lower dissolved oxygen (DO) levels since oxygen solubility is reduced in warmer waters. Also, if less surface water receives the same nutrient inputs from wastewater treatment plants and agricultural runoff, algal blooms and subsequent decomposition would further demand DO consumption. When DO falls below 5 mg/l, fish kills can occur and these are one of the main water quality parameters tested in aquatic systems.

Summary

The water resource challenges faced by government agencies, regulatory bodies, and private water consultants within the Middle Rio Grande Basin are both numerous and daunting. Regional GCC impacts will continue to test resource allocations. Planners can expect both supply and demand challenges due to elevated fire frequency and severity, shifts in the timing of peak and low flows, greater evapotranspiration from elevated surface temperatures, warmer than average stream temperatures, and simultaneous increased demand for available water resources.

Wildfires

Water Supply

Another major concern with respect to the reliability of water supply is the increased frequency, severity, and size of wildland fires in the watershed. GCC predictions show that the frequency of wildfires is likely to increase in the future (IPCC 2013, EPA 2013, Llewellyn and Vaddey 2013). Of the twenty largest wildfires observed in New Mexico's recorded history, nineteen of them have occurred since the year 2000. Three of the most damaging fires include the Cerro Grande fire of 2000, the Las Conchas fire in 2011, and the Whitewater-Baldy fire in 2012 (Figure 9). These three fires together burned over 495,000 acres. Burn scar material from these fires then can be mobilized by monsoon rain events and washed into the stream systems that feed the Rio Grande basin, disrupting both the natural ecology of the system as well as human drinking water supplies.

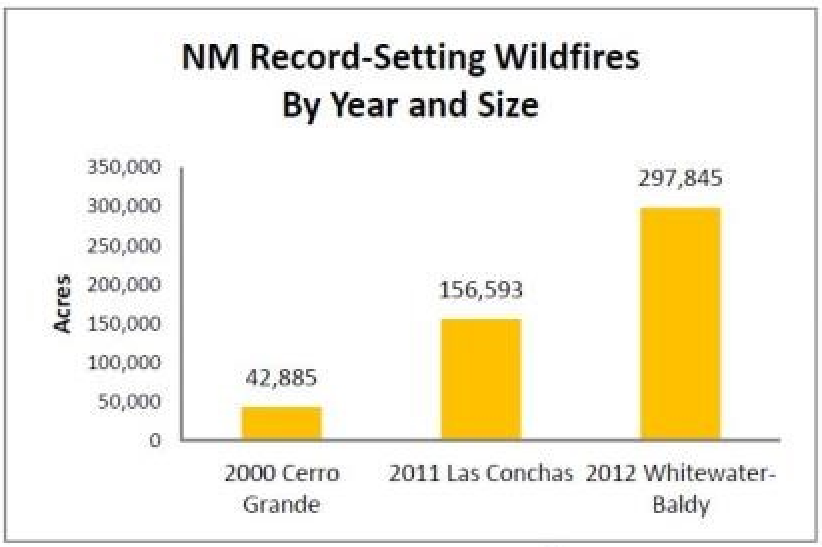

Figure 9. Three of the most damaging fires in NM history have all occurred since 2000 (UNM 2014). The Las Conchas fire burned much of the forested area around Los Alamos, threatening both the security of radioactive material held at the Los Alamos National Laboratory and the drinking water source to the main population centers in the state.

Two dramatic examples of the potential impacts of wildfires on water supply occurred in the wake of the Las Conchas fire. In the summer of 2012, shortly following the fire, the monsoon season mobilized tremendous volumes of ash, sediment, and debris that led to dramatic declines in water quality, which required that the ABCWUA discontinue the use of their Rio Grande diversion for over 40 days. Water quality sensors deployed in the Rio Grande at the US 550 bridge in Bernalillo by the Biology Department within the University of New Mexico measured DO sags down to 0 mg/l for sustained periods of time immediately following the heavy rain events that occurred over the Las Conchas burn scar in 2011 (Dr. Cliff Dahm, personal communication and manuscript in review). The same series of storm events also resulted in the closure of the Cochiti Dam outfall for a few weeks due to the massive amounts of burn material that had accumulated within the reservoir. The Las Conchas fire also threatened to encroach on Los Alamos National Laboratories, a facility that lies upstream of the dam and holds radioactive materials. A loss of containment in this facility caused by the fire and the subsequent leakage of radioactive material into the Rio Grande watershed could have resulted in heightened levels of radioactive isotopes within the region's largest water supply.

In September 2013, five inches of rain fell on the Las Conchas burn scar in Peralta Canyon. The rain event mobilized hundreds of tons of sediment and deposited a sediment plug in the Rio Grande just below Cochiti Dam. The plug filled the river from bank-to-bank and forced the flow onto the floodplain and up against the levee protecting the Village of Peña Blanca. It required several weeks of emergency response by state and federal agencies, along with the Cochiti Pueblo, to excavate a new pilot channel through the sediment plug. Specific events like these are impossible to predict, but the risks of such events are likely to increase under future climate change.

Invasive Species, Forest Pests, and Pathogens

With warmer, drier weather and extended growing seasons, there will be a continuing increase of combustible biomass. Warming temperatures and wildfire will increase the potential for invasive species colonization and native insect outbreaks (U.S. Forest Service 2010). The cumulative basal area loss due to forests pests and pathogens over the 2013–2027 timeframe is shown in Figure 10. As trees become more stressed, they are more susceptible to insects and disease, often resulting in mortality.

The predicted loss of forested lands will result in a change in vegetation patterns, altering the occurrence, severity, and distribution of wildfires. As seen over the past several years, there will continue to be a great increase in the wildfire size, severity and frequency (U.S. Global Change Research Program 2009).

Smoke

Smoke from wildfires will continue to cause a safety problem, especially along travel routes. Indications from the Las Conchas fire emissions analysis is that wildfires contribute more to air pollution and global warming than previously predicted (Department of Energy/Los Alamos National Laboratory 2013). The resulting smoke significantly degrades air quality, damages human and wildlife health, as well as interacting with sunlight to cause substantial warming (Department of Energy/Los Alamos National Laboratory 2013). This large release of carbon can be reduced by thinning woodlands to reduce surface fuels and emissions from wildfires (Restaino et al. 2013).

Landslides

In addition, with drier soils, more sudden precipitation events, and more destructive fires, the risk of land slides in the wildfire area will increase. Storms over areas burned by the Las Conchas fire caused debris and flooding that damaged 79 structures and roads caused erosion on the Santa

Clara Pueblo. The Federal Emergency Management Administration (FEMA) declared two disasters in a month because of flooding (Indian Country 10/25/2013).

Wildland-Urban Interface

The wildland-urban interface (WUI) is an area where community is at risk for wildfire because they are located in close proximity to undeveloped lands and fuels. Central New Mexico has an extensive WUI covering over 350,000 acres (Figure 11). Within the WUI, there are two types of areas: WUI interface and WUI intermix. WUI interface areas are those where developed areas (with densities greater than 1 structure per 40 acres) are located near contiguous undeveloped areas while WUI intermix areas are those where developed and undeveloped areas mix[1].

[1] See details at http://silvis.forest.wisc.edu/old/Library/WUIDefinitions.php.

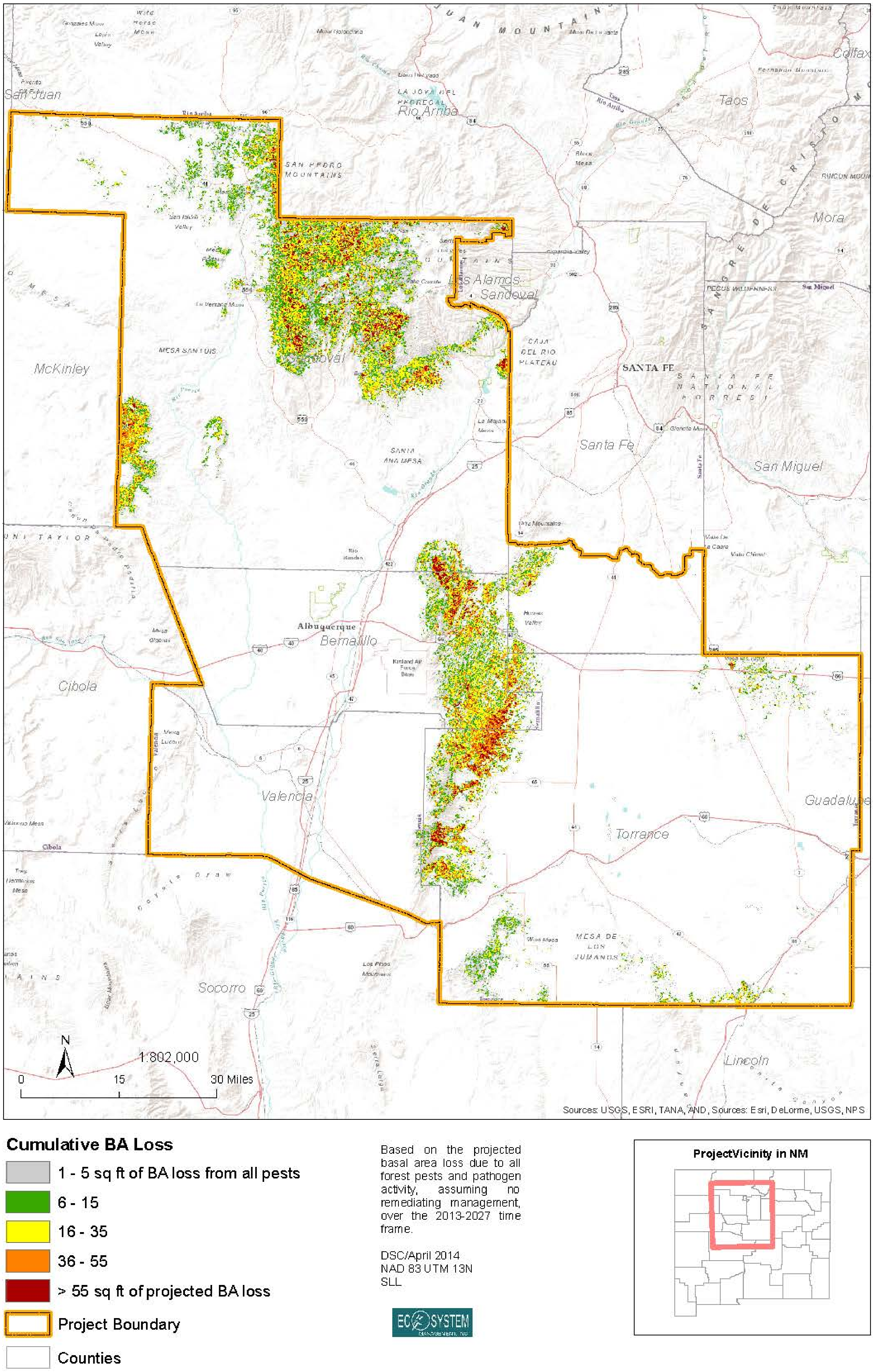

Figure 10. Cumulative Basal Area Loss due to Forest Pests and Pathogens. Projected over the 2013-2027 Time Period.

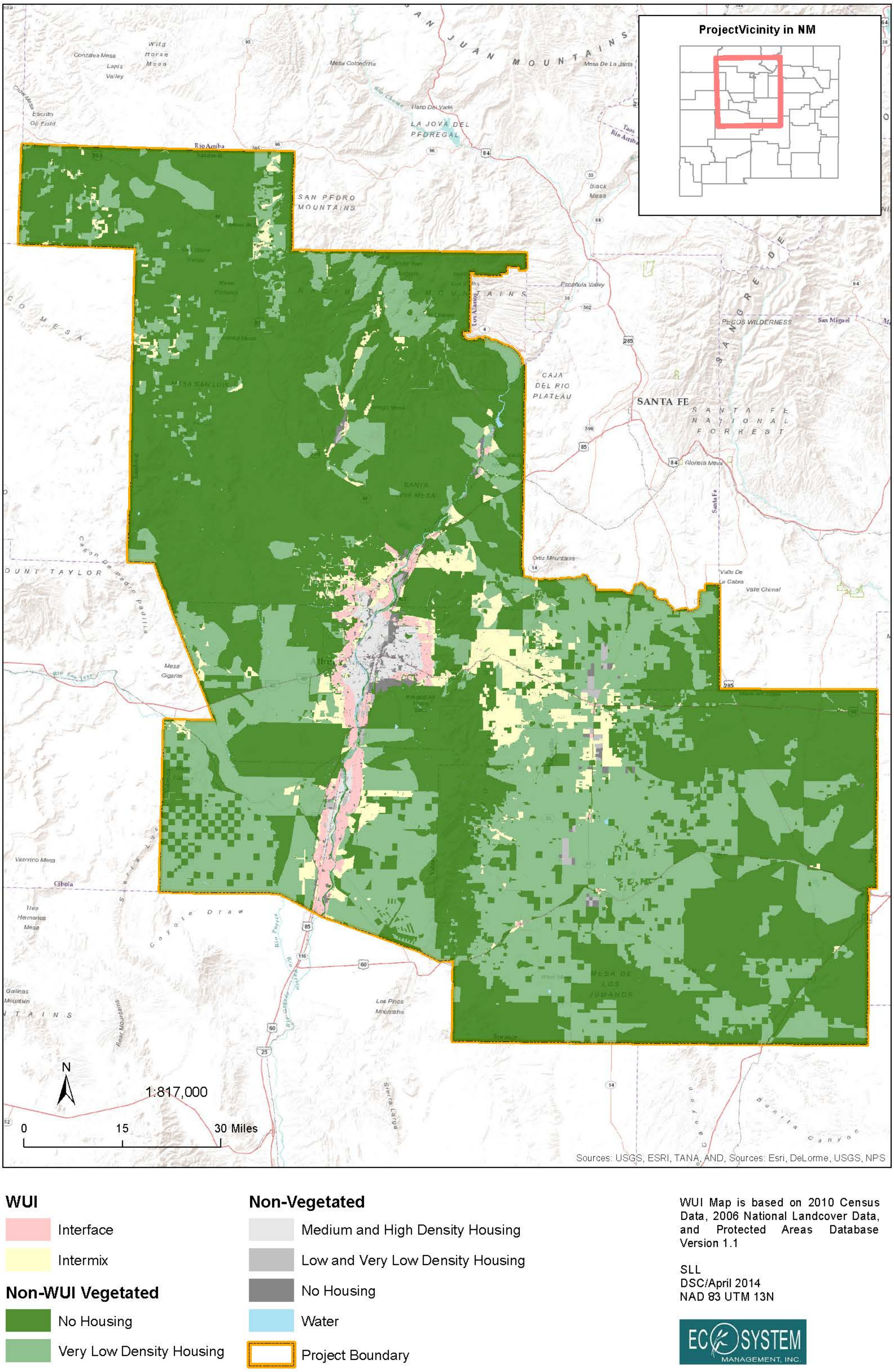

Figure 11. Wildland-Urban Interface.

There are homes, roads, commercial properties, roads, and other infrastructure at risk near the Rio Grande Bosque in Albuquerque. Wildfires are expected to increase in frequency and severity in the region due to hotter temperatures and more droughts that are expected to result from rising carbon dioxide levels in the 21st century (Figure 12, USDOI 2013, Weiss 2013). Fires can threaten both life and property.

Structures and Occupants

Structures and occupants in the WUI are particularly susceptible to wildfires. Fire risks and changes in fire risk vary by location. Table 1 shows the characteristics and area of each land use located in the WUI.[2] Most of the WUI is open space and dry rangeland, although a significant portion is composed of irrigated agriculture, vacant urban land, and single family homes. A substantial number of people and homes are located in the WUI. Note that fire risks in the WUI vary depending on weather and land cover; see additional details about the location of the WUI and fire risks in the key natural resources section of this report.

The costs of fire protection and fire damage can be significant when high-value structures are at risk or are burned. There can also be costs associated with a loss of property value in areas that are adjacent to fire damage; for example, recently burned areas are less attractive to potential buyers. Residents of Central New Mexico may experience greater rates of injuries and mortality from direct contact with fires. Previous studies evaluating the health impacts of fire in the Southwest have found that wildfire smoke leads to respiratory and eye-related symptoms but not necessarily mortality, while the majority of deaths are related to burns (Brown et al. 2013).

Land

Agricultural areas and dry rangeland are at risk for increased fire damage. Fires can affect crops and livestock, structures and outbuildings, irrigation infrastructure, perennial crops (such as tree crops), and as a result, compromise the economic returns of these lands. Paved areas and vacant urban land may experience damage from fires, but costs are likely to be lower than for occupied structures. Fire ecology is complex and changes are not well understood. Some dry rangeland and unirrigated open space may operate on a natural fire regime. However, changes in the frequency and severity of fires may disrupt ecosystems, altering plant and animal life (see the key natural resources section of this report for additional discussion of habitat impacts).

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[2] Population, housing units, and total acres are calculated from the WUI data in the project area, as shown inTable 1. Land use areas in the WUI in the project area are estimated using a geographic information system and WUI data shown in Figure 11 and the land use data shown in Figure 13.

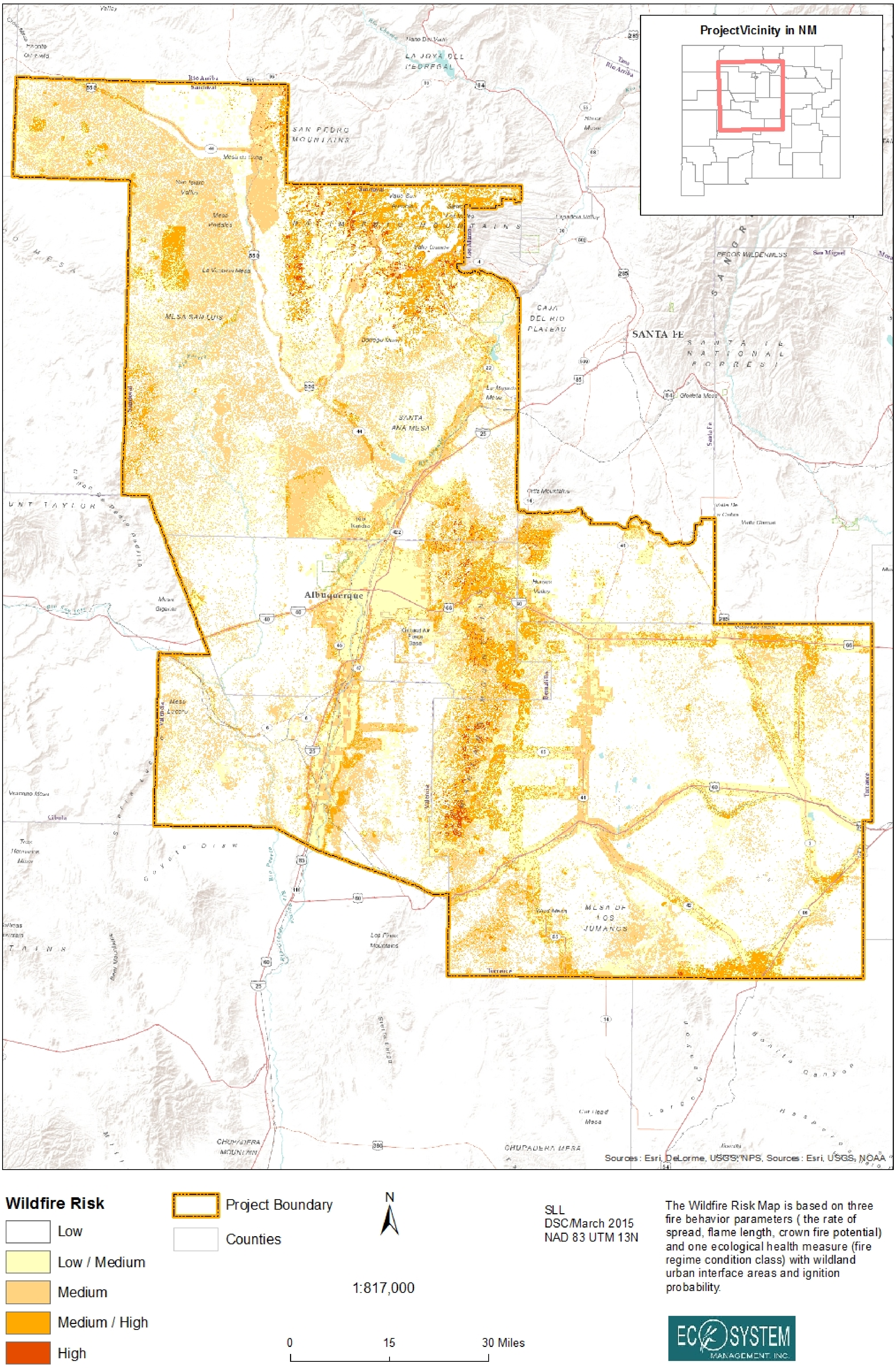

Figure 12. Wildfire Risk.

	Interface	Intermix
General Characteristics		
Population	376,431	131,282
Housing Units	151,478	53,508
Total Area (Acres)	92,418	264,104
Land Use Areas (Acres)		
Structures and Occupants		
Commercial Major	463	98
Commercial Retail	892	681
Commercial Services	457	362
Community	656	1,372
Industrial	1,011	2,151
Medical	115	7
Multi Family	1,326	196
Office	100	18
Office Major	280	46
Schools/Universities	953	474
Single Family	39,007	73,892
Wholesale/Warehouse	326	59
Land (primarily)		
Agriculture-Irrigated	16,191	3,846
Open Space and Recreation	1,975	7,611
Rangeland-dry	6,449	87,527
Urban Vacant	5,565	67,718
Support Infrastructure		
Utilities	337	348
Other structures, occupants, land, and support infrastructure		
Airports	1	21
KAFB	122	134
Prisons	17	12
Transportation and Parking	29	7

Table 1. Land uses in the wildland-urban interface and intermix (2012).

Support Infrastructure

The impacts of increasing wildfire risk on support infrastructure (natural drainage and utilities) are not generally discussed in the climate impacts literature. Speculatively, natural drainage facilities may experience changes in vegetation and increased sediment deposition as a result of wildfires. When floods follow fire damage in drainage facilities or on upstream land, sediment deposition may compromise the functionality of natural drainage areas. Aboveground utilities (e.g., electrical lines, transformers, and distribution stations) could be directly damaged by fires and power lines can experience damage from fire retardants and capacity reductions due to smoke or heat (Tidwell et al. 2013). Power lines may also experience outages due to preventive shutdowns, arcing, or soot buildup caused by smoke (Tidwell et al. 2013).

Land Use

As the global climate changes, both developed and undeveloped areas in central New Mexico will experience various impacts. These impacts will occur in the context of population and land use changes that have been occurring for some time. New Mexico has continued to grow in recent years: the population has increased by 36 percent from 1990 to 2010 and is expected to grow another 37 percent by 2030 (Theobald et al. 2013). To support this increase in population, the area of developed urban land in New Mexico grew nearly 800 percent from 1950 to 2000 (from 24,000 to 191,000 acres) (Theobald et al. 2013). It is expected to grow another 45–80 percent by 2050 (to 277,000–348,000 acres) (Theobald et al. 2013). Similarly, exurban[3] developed land in the state has grown over 550 percent from 1950 to 2000 (from 237,000 to 1,328,000 acres) and is expected to grow another 30–45 percent by 2050 (to 1,730,000–1,925,000 acres; Theobald et al. 2013). While urban and exurban development have exploded, a significant share of the state's land (over 1 percent) has also been converted from cropland to grassland, at least partly as a result of Conservation Reserve Program incentives (Theobald et al. 2013). In central New Mexico, the population has grown by approximately 50 percent from 1990 to 2010 and is expected to grow by another 50 percent from 2010 to 2040[4]. Recent central New Mexico land use trends are similar to statewide trends, exhibiting increasing development of urban and exurban land.

Figure 13 shows land use types by location within the study area. Much of the area is dry rangeland, often used for cattle grazing in the Southwest. Torrance County and southern Santa Fe County are sparsely dotted with single-family residential uses, while the Albuquerque area and parts of the Rio Grande valley are largely made up of single family residential and commercial/industrial uses. Parts of Torrance County, Santa Fe County, and the Rio Grande valley are irrigated agriculture.

This section describes the impacts of climate change (including temperature, fire, drought, and flood impacts) on the range of land uses listed in Figure 14. In many cases, different land use types will experience similar impacts from climate change (e.g., residential and commercial structures will experience impacts similarly); to simplify the discussion, land use types are grouped into broader categories and are discussed at the applicable level of aggregation throughout this section. Although airports and parking are a category of land use, they are discussed in the transportation section of this report.

[3] Exurban development is less dense than urban development but not as sparsely developed as rural or undeveloped areas. The definition used to provide these estimates is a density of one housing unit per 2.5 to 40 acres.

[4] Population growth rates were estimated from 1990, 2010, and 2040 population estimates and projections by county from http://bber.unm.edu. Estimates for four counties (Bernalillo, Valencia, Sandoval, and Torrance) and for five counties (adding Santa Fe, which is only partially included in the project area) were examined to approximate growth rates in the project area; these estimates yielded similar results.

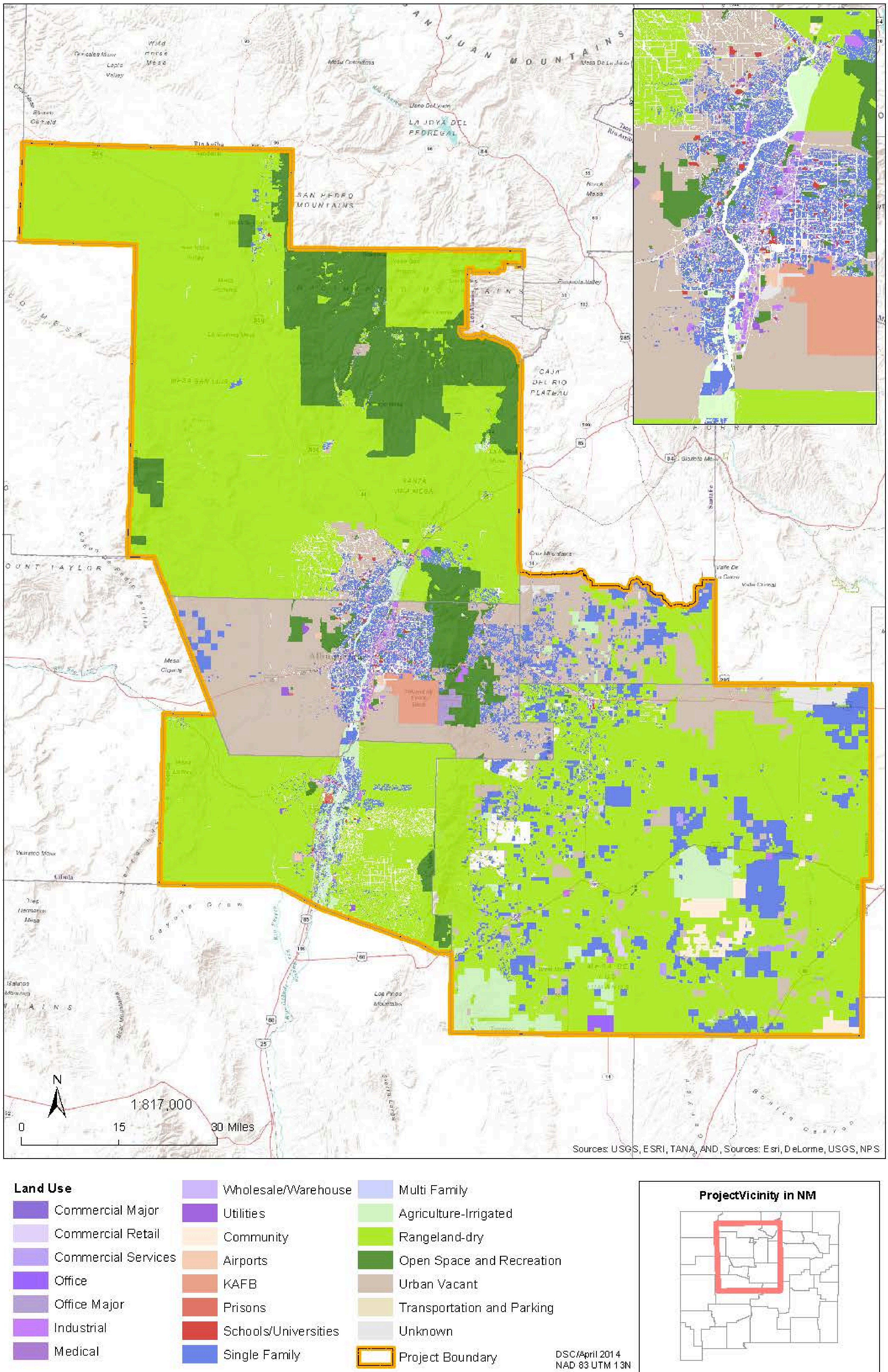

Figure 13. Map of Land Uses in the Study Area. Inset of Albuquerque area shown in upper right.

I. Structures and occupants (primarily)
   a. Residential:
      i. Single-family (density < 8 / acre)
      ii. Multi-family (density > 8 / acre)
   b. Non-residential buildings: Commercial Retail, Commercial Services, Commercial Major, Office, Office Major, Medical, Schools/Universities, Community, Mixed Use
   c. Industrial, Wholesale/Warehouse
II. Land (primarily)
   a. Agriculture–irrigated
   b. Rangeland–dry
   c. Open Space and Recreation (irrigated and dry)
   d. Urban Vacant (includes paved and natural vacant land and abandoned structures)
III. Support Infrastructure
   a. Natural Drainage
   b. Utilities

Figure 14. Major Land Use Categories in Central New Mexico. Modified from land use categories provided by the Mid-Region Council of Governments.

Where available, this section draws from region-specific literature. Where studies of other regions or larger geographies are used, this section adapts the discussion to the specific climate changes that are expected in central New Mexico. Note that the discussion of water supply and natural resource impacts (including rangeland and some open space) in this section is brief and focused on the nature of impacts on particular land uses, as they are each described in more detail in the water supply and key natural resources section of this report.

Temperature Impacts

Central New Mexico is expected to experience temperature increases and increasingly frequent heat waves (particularly at lower elevations) by the middle of the 21st century (USDOI 2013, Weiss 2013). These higher temperatures can affect human health and infrastructure in a variety of ways.

Structures and Occupants

Climate change is likely to affect both structures (including residences, commercial establishments, and retail stores) and their occupants as a result of climate change. Building occupants (rather than buildings themselves) experience the primary impacts of higher temperatures for these land uses so they are the focus of this discussion. Occupants of the Southwest (particularly the elderly and infirm) may be increasingly vulnerable to heat-related morbidity and mortality as temperatures rise due to climate change, especially those without access to cooling systems or cooled shelters (Brown et al. 2013, Pincetl et al 2013). Heat-related morbidity and mortality are worse when heat lasts for several days and is accompanied by higher levels of humidity (Brown et al. 2013). Although central New Mexico has somewhat moderate high temperatures relative to other parts of the Southwest, heat-related health impacts result from unusual conditions relative to what is typical in an area rather than being a function of specific temperatures. Residents and structures in areas that currently experience moderate heat levels may be less adapted to heat and so residents of these areas have greater risks of health impacts of heat events (Brown et al. 2013).

Additionally, higher temperatures may facilitate the formation of ozone and potentially small particles like fine particulate matter ($PM_{2.5}$), depending on other climate changes (wind, humidity, etc.) and likely varying in different areas (Brown et al. 2013). These air pollutants have adverse health impacts, especially for vulnerable populations (the young, the elderly, and those with respiratory illness). Air quality in central New Mexico is currently cleaner than ozone and $PM_{2.5}$ standards, although ozone levels are approaching the standard in some areas.

Disease prevalence is expected to change as a result of temperature changes and effects on insects, although whether disease prevalence will increase or decrease depends on the location and disease. At the same time, pollen releases are expected to be earlier and longer, and in combination with elevated ozone levels (caused by higher temperatures) may lead to more severe allergies (Brown et al. 2013).

Occupied structures are also expected to have greater cooling demands, which will increase electricity demand (in conjunction with air conditioner use) (Tidwell et al. 2013) as well as water demand (in conjunction with swamp cooler use) and consequently electricity and water costs. Climate warming is expected to increase peak period electricity demands for summer cooling. Since electrical energy is a form of energy that cannot be effectively stored in bulk, it must be generated, distributed, and consumed immediately. When the load on a system approaches the maximum generating capacity, network operators must either find additional supplies of energy or find ways to curtail the load, hence load management. If they are unsuccessful, the system will become unstable and blackouts can occur.The average consumption of energy per person in the United States is 302 million British Thermal Units. The British thermal unit (BTU) is the amount of energy needed to cool or heat one pound of water by one degree Fahrenheit (Physical analogue; one four inch, wooden kitchen match consumed completely generates 1 BTU). Studies of climate impacts in California predict increases of 10-20 percent for 90^{th} percentile per capita (per person) electricity loads by the end of the century. While similar studies have not been conducted for the Southwest, the effects are expected to be of the same order of magnitude (Tidwell et al. 2013).

Land

On irrigated agricultural land, milder winters can exacerbate existing pest problems or bring new pests or diseases. Some currently cultivated crops may become economically infeasible, resulting in changes to the crops produced in the region. Changing crops is likely to bring additional costs to farmers, including initial investments (especially high with tree crops), costs of learning about a new crop and its growing practices, and costs of adjusting infrastructure such as irrigation, transport, and processing facilities (Frisvold et al. 2013). These changing costs may also contribute to land use change, e.g., some irrigated agricultural lands may shift to dry rangeland, or in areas near population centers, the irrigated agricultural land may be converted to residential, commercial, or industrial uses.

Warmer temperatures and elevated carbon dioxide levels have some potential to increase productivity of dry rangeland as plants tend to experience greater rates of growth in warm and carbon dioxide rich conditions, although these effects may be offset by drought impacts (Frisvold et al. 2013). Vegetation and wildlife in open space will likely shift as a result of rising temperatures; see the section on key natural resources for more detail. Paved vacant land may experience heat damage, as described for roadways and airport runways in the transportation section of this report.

Support Infrastructure

Climate change will impact support infrastructure. Energy use is expected to increase during heat events (e.g., from greater air conditioning use) (Tidwell et al. 2013), potentially stressing electricity generation and distribution facilities. Power plant efficiencies may also be reduced with higher temperatures (Tidwell et al. 2013). There are two natural gas electricity generation projects in Belen[5]; natural gas electricity generation efficiencies are estimated to decrease by 0.15 to 0.5 percent for every 1°F increase in the ambient temperature (Tidwell et al. 2013). Dry cooled power plants (which are cooled by air rather than water so may be more resilient to drought) are expected to experience greater capacity losses than wet-cooled power plants (Tidwell et al. 2013). Research indicates that the losses to transmission line capacity may also be substantial; for example in some areas an increase of 9°F may result in capacity losses equivalent of 7 to 8 percent of peak loads (Tidwell et al. 2013). In excessively hot and windless weather, transmission lines can experience excessive sagging and permanent damage which can lead wildfires (Tidwell et al. 2013) and higher maintenance costs. Substations and transformers can also experience reduced performance or even fail in high temperatures; transformer capacity losses are estimated at 0.35 percent per 1°F increase, and areas with maximum temperatures that exceed 95°F will have greater risks of failures (Tidwell et al. 2013).

Temperature impacts on natural drainage are not well characterized in the climate impacts literature. Speculatively, these facilities may experience changes in vegetation as a result of higher temperatures.

Drought and Water Supply Impacts

Changes in precipitation levels that will result from climate change in central New Mexico are less certain than other climate impacts. Expected annual changes range from slight increases to moderate decreases. More precipitation is expected to fall as rain and less will fall as snow as a result of warmer temperatures, resulting in earlier peak surface water flows and less water storage in snowpack. At best, these precipitation impacts will not counteract higher temperatures' effect on drought and at worst may exacerbate them. In either case, the region can expect to experience more severe drought conditions (USDOI 2013, Weiss 2013).

Structures and Occupants

The demand for water in landscaped areas around structures will increase as a result of drought. Impacts on landscape plantings that are not well adapted to desert conditions may be more severe (Pincetl 2013). Single family units on large lots may require more water to maintain landscaping

[5] List of power generation projects in New Mexico based on data provided by: http://www.nmenv.state.nm.us/aqb/permit/power.html.

Additionally, acequia[6] communities with historic water rights may be pressured to transfer water to other jurisdictions (water transfers are discussed in more detail below). Residents and businesses that experience severe shortages will likely also experience social and economic impacts (Hurd and Coonrod 2012). Larger irrigated lots and industries and businesses that rely on significant water use may experience higher costs. Some types of businesses may experience greater costs than others, for example, semi-conductor manufacturing, mineral extraction, and agriculture (discussed in more detail below) are relatively water intensive industries that are active in central New Mexico.

Land

Central New Mexico has an active agricultural industry. Major products include dairy, forage, cattle, corn, nursery, greenhouse, floriculture, and sod[7]. While agricultural preservation is a priority for the region, it is expected that the most economically viable way to adapt to stressed water supplies in the Upper Rio Grande Basin (including central New Mexico) will be to transfer water use from irrigated agricultural areas to urban (municipal and industrial) water uses (Firsvold et al. 2013, Hurd and Coonrod 2012). Such water transfers could reduce the economic impacts of drought by 20 to 33 percent (Firsvold et al. 2013). Due to these strong economic forces, if transfers are implemented, agricultural water use would likely decline the most in the face of regional water shortages while use in urban areas would be relatively unaffected (Firsvold et al. 2013, Hurd and Coonrod 2012). These water transfers are not inevitable however; there are currently institutional and legal barriers to such transactions and water transfers would likely involve transaction costs including the costs of additional water storage and conveyance infrastructure (Firsvold et al. 2013). Flows required for the protection of aquatic species are also likely to divert water from agricultural uses under drought conditions (Firsvold et al. 2013, Hurd and Coonrod 2012). If these shifts occur, the agricultural sector would likely experience losses (which could be partially compensated through payments for a transfer) and would likely use fallowing, changes in crops, and other changes in growing practices to conserve water and continue to maintain a strong presence in the region (Firsvold et al. 2013). Note that farmland irrigation reductions would also reduce the amount of green space enjoyed by people and utilized by wildlife (Hurd and Coonrod 2012).

Drought and variable rainfall have the potential to reduce the habitat quality and productivity of dry rangeland and forests (Hurd and Coonrod 2012, Frisvold et al. 2013). Note that these impacts may be partially offset by potential increases in dryland productivity due to elevated carbon dioxide levels and warmer temperatures (Frisvold et al. 2013). To the extent that climate change results in changes to dry rangeland farming practices or feed costs, ranching costs may increase. For example, selling stock at lower weights when feed costs are high or engaging in cycles of herd reduction in dry years followed by herd growth in wetter years is likely to increase costs (Frisvold et al. 2013).

Unirrigated open spaces in Central New Mexico are largely well adapted to drought conditions, although extreme drought and unusually dry conditions along drainages may result in changes to vegetation and wildlife (see key the natural resources section of this report for additional

[6] An acequia is a communally managed irrigation systems. Many acequias in New Mexico date back hundreds of years.

[7] Based on 2007 data provided at 2007 census agricultural profiles for New Mexico counties.

discussion of habitat impacts). Drought impacts on paved areas (which may occur on vacant urban land) have not been evaluated in the climate impacts literature; speculatively, substantial impacts are not expected.

Support Infrastructure

The climate impacts of support infrastructure (natural drainage and utilities) are not well characterized in the research literature. Speculatively, natural drainage facilities may experience loss of vegetation and increased sediment deposition as a result of drought. When floods follow vegetative losses, sediment deposition may compromise the functionality of natural drainage areas.

Utilities such as electricity transmission lines and pipelines are not expected to be substantially affected by drought. Groundwater pumps may use more electricity as water levels drop. Electricity generation that requires water for cooling may be threatened if water shortages occur (Tidwell et al. 2013). In central New Mexico there are two natural gas electricity generation projects (in Belen); these facilities likely require water for cooling, so may experience higher water costs or water shortages that result in reduced electricity production.

Heavy Precipitation Events and Flood Impacts

Even as streamflows decline and expected total precipitation changes little or decreases, central New Mexico is expected to experience more intense precipitation events and increased flooding by the mid-21st century (USDOI 2013, Weiss 2013). Additionally, wildfire damage can increase the risk of mudflows. Floods and mudflows can have direct impacts on life and property.

Figure 15 shows areas that are currently known to be at risk of flooding in central New Mexico. The areas shown could be flooded in a storm that might occur once every 100 years (in red), once every 500 years (in purple), or if a levee fails or is overtopped (in green). Note that these classifications are based on topography, hydrologic characteristics, and historic rainfall information; to the extent that climate change causes more frequent or severe flood events, these areas may flood more frequently than once every 100 or 500 years. Similarly, levees may fail more frequently than currently expected. If storms are very severe or if topography and hydrologic conditions change, other areas (not highlighted) may be at risk for flooding in very severe rainfall events.

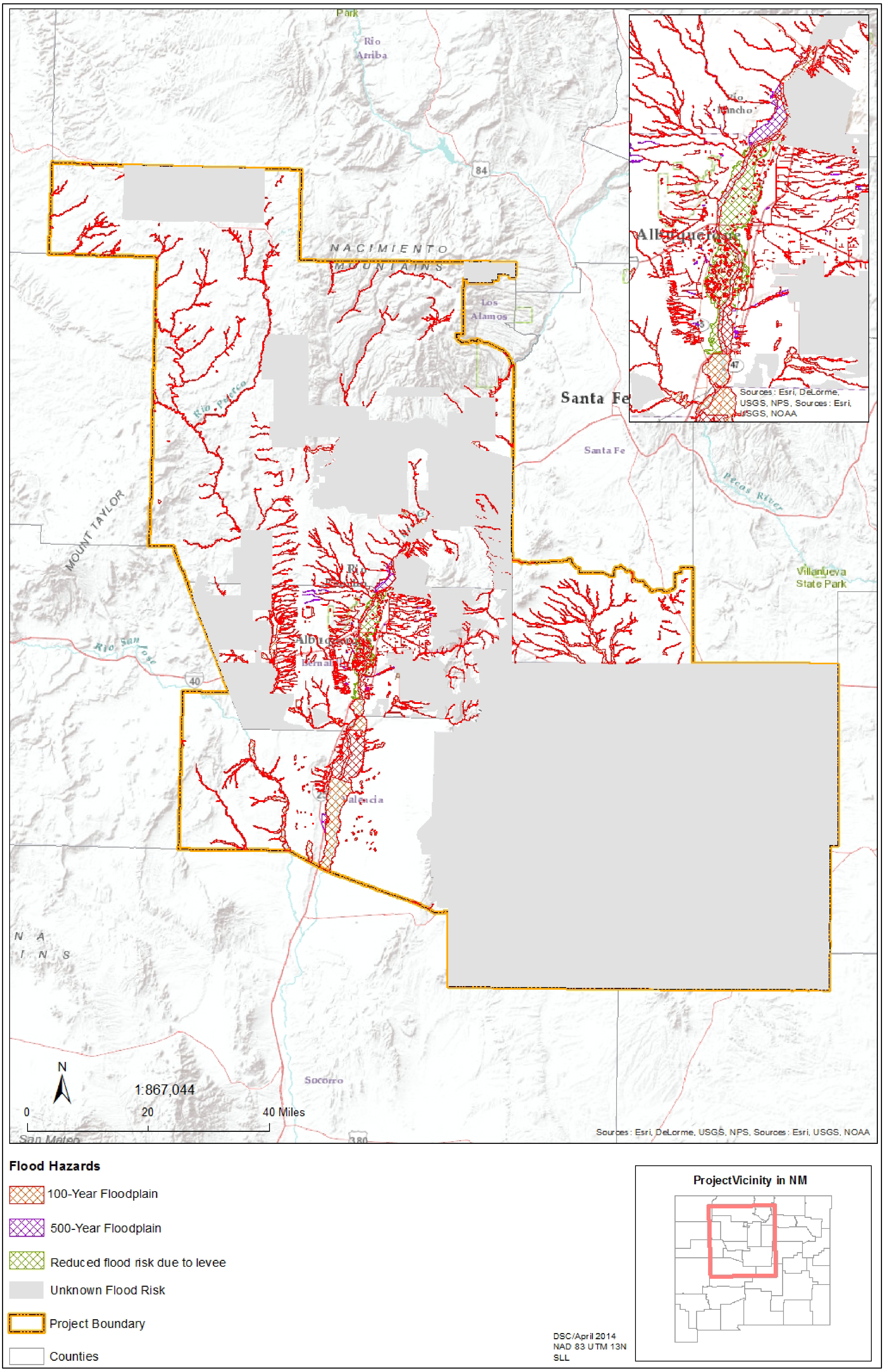

Figure 15. Flood Risks in Central New Mexico. Data from FEMA.

Structures and Occupants

Increasing flood severity and frequency can be expected to cause injuries and mortality (Brown et al. 2013) and structural damage. Given that the area at risk of flood will likely expand with climate change, some areas that are currently not known to be at risk may be at risk in the future; this may include areas that are already developed or are planned for development. Additionally, water quality may suffer as a result of floods (Pincetl 2013).

Agricultural crops, perennial crops (such as tree crops), topsoil, and livestock may be lost or damaged in floods. Outbuildings and irrigation infrastructure may also be damaged. At the same time, deposition of flood sediments may improve fertility of agricultural and dry rangelands. Unirrigated open spaces in Central New Mexico have been subject to flood conditions in the past. Floods may alter vegetation and affect wildlife movements (see key the natural resources section of this report for additional discussion of habitat impacts). Flood impacts on vacant urban land will be similar to impacts on structures, dry land, or paved areas (described in the transportation section below) as applicable to the conditions on the vacant land.

Support Infrastructure

When high-flow events occur, the shape and location of natural drainages may shift (Waters et al. 2001) and sedimentation may compromise their ability to move water out of an area. Where natural drainage systems exist in developed areas, these drainages may require maintenance and repair, and where they fail, existing structures proximate to those systems are at risk of flood or erosion damage (as discussed above). The imagery in Figure 16 shows examples of undeveloped and at-risk properties adjacent to natural drainages in central New Mexico.

Utilities (such as pipelines) may also be damaged from flood events due to erosion and subsidence (National Research Council 2008). If precipitation events bring high winds, aboveground electrical lines may also be damaged.

Summary and Discussion

Climate impacts on various land uses (resulting from floods, fires, heat, and drought) have the potential to cause damages, threaten human health and safety, and disrupt economic activities. Overall, many of the costs of climate change are likely to be borne by those directly affected by its impacts. The region as a whole will also be affected as public funds are allocated to repair damages and respond to extreme events, and the region's economy suffers from losses in productivity, e.g., due to disruptions caused by extreme events, higher electricity and water costs, and shifts in business practices that may be necessary. Mitigating the severity of and adapting to these effects can also bring substantial costs.

Note that some communities will be more heavily impacted than others. In general, health-related impacts of climate change are expected to affect disadvantaged residents (e.g., those without health care) to a greater extent (Brown et al. 2013). Impacts on tribal lands may also be unique and severe, given the location of many tribal areas and the nature of each community's ties to the natural environment (Redsteer et al. 2013).

Arroyo de Los Montoyas, Sandoval County

Arroyo de La Barranca, Sandoval County

Arroyo de Las Calabacillas, Bernalillo County

Figure 16. Examples of Undeveloped and At-Risk Properties Adjacent to Natural Drainages (UNM 2014).

Transportation

Regional transportation networks facilitate both economic and social interactions. Climate change will affect the safety and efficiency of the transport network with likely consequences for the movement of people, goods, and runoff. In many cases, maintenance and operations costs will increase due to increasingly frequent damages associated with extreme weather events.

The costs of building and maintaining transportation infrastructure are substantial. The current Metropolitan Transportation Plan for the Mid-Region Metropolitan Planning Organization allocates nearly $7 billion for transportation infrastructure from 2008 to 2035, largely for roadways (MRMPO 2012). In 2008, roads in central New Mexico accommodated about 18 million vehicle-miles traveled (MRMPO 2012). While most commuters in the Albuquerque Metropolitan Planning Area (AMPA) travel by passenger car, from 2005 to 2009 about 2 percent of commute trips occurred on transit and about 2 percent and 1 percent were walk and bike trips respectively (MRMPO 2012). Transportation infrastructure also moves goods: trucks, planes, and over 1,800 miles of freight rail lines carry over $30 billion worth of freight shipments originating from New Mexico (RITA 2013). The transportation system also brings safety risks. Figure 17 shows the location of major roads, rail lines, and airports in the study area. The major roads shown are defined in data provided by NM DOT.

The State of New Mexico has nearly 4,000 bridges, over 16 percent of which are either structurally deficient or functionally obsolete (RITA 2013). Figure 18 shows the location of water conveyance and control infrastructure in the study area, most of which is located in the Albuquerque area.

Climate change is likely to result in some changes to travel patterns as tourists react to increasing temperatures (e.g., by avoiding extreme heat or wildfires and decreasing winter snow visitation) and agricultural producers shift crop types and timing (Koetse and Rietveld 2009). It will also have direct effects on travelers and transportation infrastructure. This section focuses on the direct effects on travelers and infrastructure, describing the impacts of climate change (including temperature, fire, drought, and flood impacts) on travelers and the transportation features listed in Figure 20. Where available, this section draws from region-specific literature and where studies of other regions or larger geographies are used, this section adapts the discussion to the specific climate changes that are expected in central New Mexico.

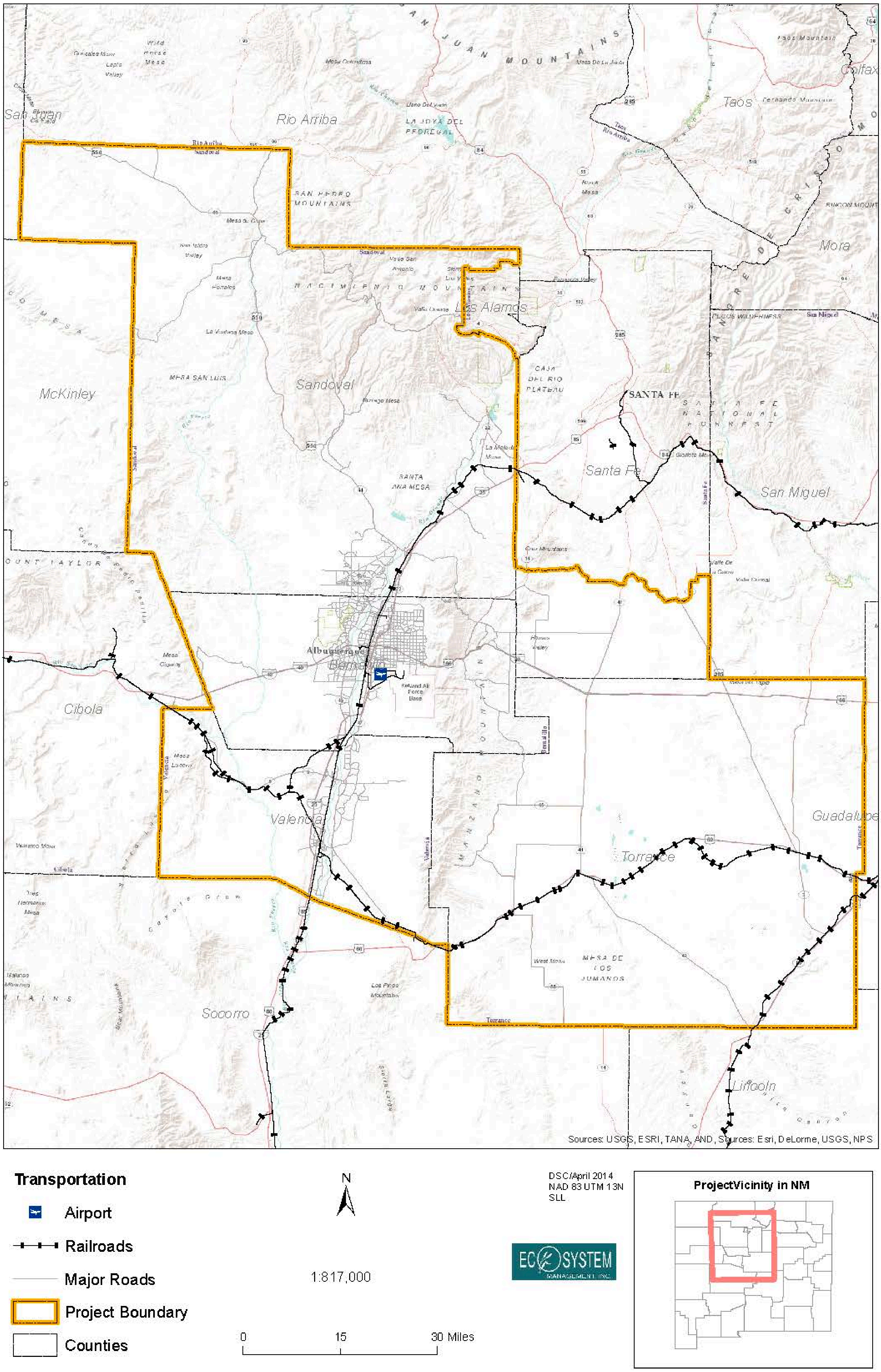

Figure 17. Transportation Infrastructure of Central New Mexico.

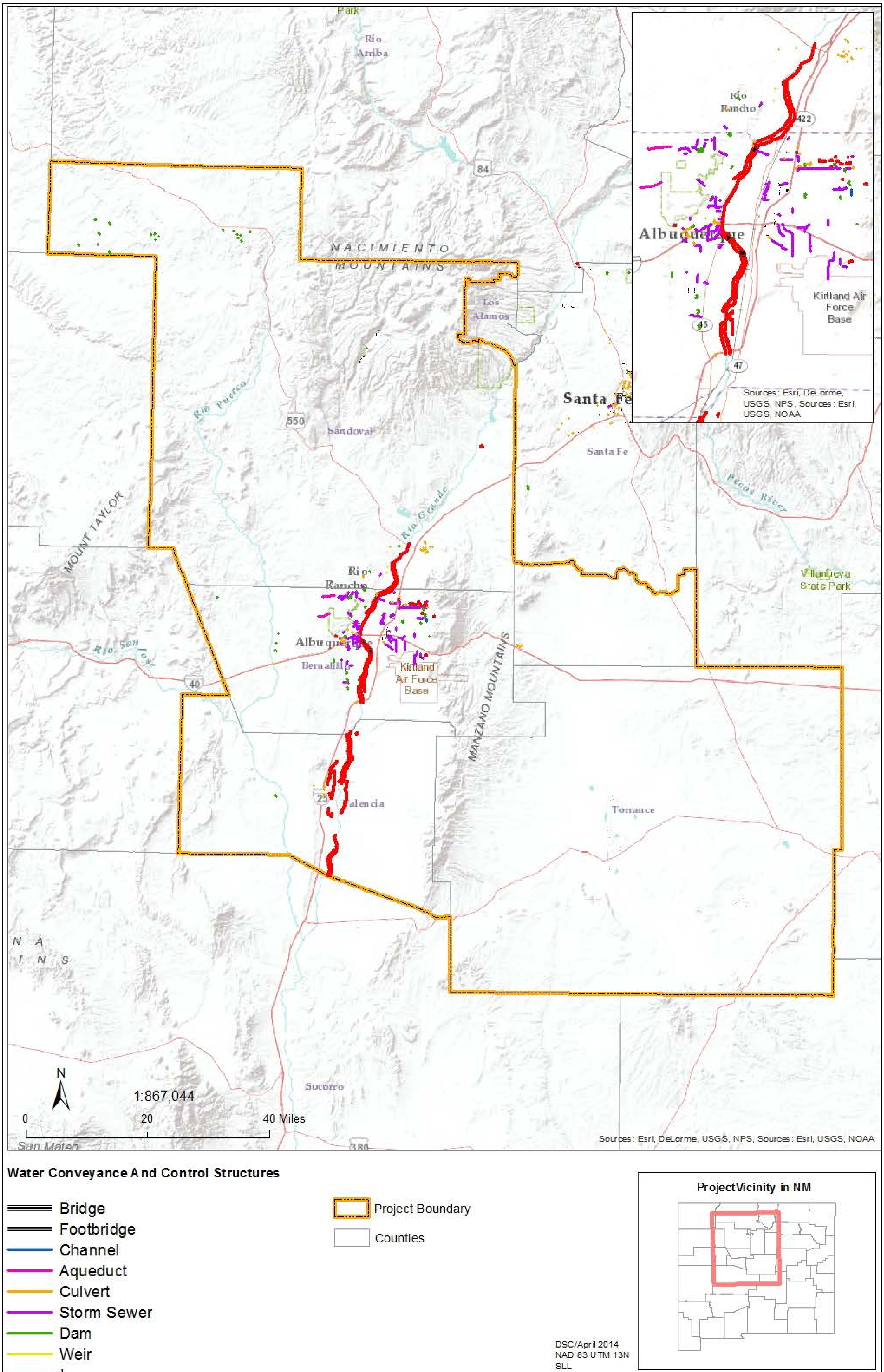

Figure 18. Central New Mexico Water Conveyance and Control Infrastructure. Data from FEMA.

I. Vehicle transport (trucks, bus transit, and personal vehicles)
    a. Vehicles and Drivers
    b. Road pavement and parking lots
    c. Roadway elements (signage, signals, lighting, guard rail, barriers, etc.)
    d. Landscaping and roadside vegetation
II. Bike/Pedestrian transport
    a. Cyclists and pedestrians
    b. Bike/Pedestrian facilities
III. Rail travel
    a. Rail lines and related infrastructure
IV. Air travel
    a. Airports and airplanes
V. Bridges, drainage and flood control
    a. Bridges, Major Structures, Culverts
    b. Storm Drain systems and flood control infrastructure

Figure 19. Transportation Infrastructure Categories.

Temperature Impacts

Central New Mexico is expected to experience temperature increases and increasingly frequent heat waves (particularly at lower elevations) by the middle of the 21st century (USDOI 2013, Weiss 2013). These temperature changes can impact transportation infrastructure and travelers in a variety of ways.

Vehicle Transport

Higher temperatures will likely increase the use of vehicle air conditioners, potentially increasing vehicle emissions (vehicles using air conditioners emit 37 percent more pollutants) and reducing fuel economy (vehicles using air conditioners use 13–43 percent more fuel) (Niemeier et al. 2013). Hotter conditions can also contribute to accident risks due to heat-stress (Koetse and Rietveld 2011), truck and tire wear, and vehicle overheating (Camp et al. 2013, FTA 2011, National Research Council 2008). In particular, transit bus air conditioning systems may fail or require more maintenance, as doors open and close repeatedly and may not be able to handle very hot temperatures (FTA 2011). Transit riders may also be susceptible to heat-related illness or mortality when waiting for a bus or riding a bus with inadequate cooling (FTA 2011).

Roadway and parking lot pavement will have a shorter lifetime as a result of higher temperatures and resulting expansion, softening, and rutting of pavements and migration of liquid asphalt, especially at temperatures exceeding 90°F (Camp et al. 2013, National Research Council 2008, Neiemeir et al. 2013, Schwartz 2010). Highways may also experience heat-related damage due to expansion of concrete joints, steel, protective cladding, and coats and sealants (Camp et al. 2013). Hot weather may reduce the available work hours of construction and maintenance crews to address safety concerns (Federal Transit Administration 2011, ICF International 2013, Schwartz 2010). Road damage will affect the use of roads (Niemeier 2013) and likely increase vehicle maintenance costs (Camp et al. 2013) and accident risks. At the same time, warmer winter temperatures may reduce ice damage to roads and snow removal costs, as well as reduce the impacts of road salt and improve the safety of winter travel (National Research Council 2008, Camp et al. 2013).

Traffic signals may also be affected by heat waves when high temperatures increase air conditioning demand, leading to blackouts (FTA 2011); compromised traffic signals can increase traffic, travel delays, and accident risks. Roadside vegetation and landscaping can also be adversely impacted by higher temperatures (National Research Council 2008).

Bike/Pedestrian Facilities

Very high and very low temperatures can discourage bike trips and result in shifts to vehicle travel (Koetse and Rietveld 2009); the net effect of temperature changes in central New Mexico (which will be warmer in winter, which could result in more bicycle trips and warmer in summer which could result in fewer bicycle trips) is unknown. Higher temperatures can deteriorate pavements used on bicycle and pedestrian facilities (Niemeier et al. 2013), increasing maintenance costs and potentially decreasing safety.

Rail Travel

Elevated temperatures can cause rail lines to buckle (FTA 2011, National Research Council 2008, Niemeier et al. 2013, Schwartz 2010), which may result in delays, derailments and a loss of life or spills of hazardous materials. These "sun kinks" or "heat kinks" can also hinder rail travel (due to derailments or reduced travel speeds to avoid derailments; FTA 2011; Niemeier et al. 2013), potentially increasing the costs of shipping and travel by rail. Heat kinks are expected to increase as the number of days with heat over 90^{o}F increases (FTA 2011); failure risk is increased at 110^{o}F (National Research Council 2008). Electrical locomotive and rail equipment can also fail when temperatures climb (FTA 2011). At the same time, warmer winter temperatures may cause decreases in ice-related damages and safety impacts (Koetse and Rietveld 2011; National Research Council 2008).

Air Travel

Airport and runway pavements can experience the same damage as road pavements. Concrete facilities can also experience damage from heat (National Research Council 2008, Niemeier et al. 2013). Airplanes may also experience weathering and declining engine performance due to heat (Camp et al. 2013, Niemeier et al. 2013). Hotter temperatures can also reduce airplane lift (particularly at high elevation airports such as the Albuquerque International Sunport), necessitating lighter planes, canceled or delayed flights, or longer runways (National Research Council 2008). At the same time, warmer winter temperatures will reduce costs of ice and snow removal and their impacts on runoff (National Research Council 2008).

Bridges, Drainage and Flood Control

Greater temperatures can result in bridge damage due to expansion of bridge expansion joints in excessively hot conditions (National Research Council 2008, Niemeier et al. 2013, Schwartz 2010).

Wildfire Impacts

Hotter and drier conditions and fire-prone vegetation that has been damaged by drought, pests, and rising temperatures will in turn lead to more frequent, more severe, and larger wildfires

(USDOI 2013, Weiss 2013). Fires can threaten the safety of travelers and the integrity of transportation infrastructure as described in more detail below. Fires can also increase the risk of mudflows when fire damaged areas experience rainfall events, resulting in flood impacts.

Vehicle Transport

Increasing frequency and severity of wildfires can cause damage to roads, road closures, and reduced visibility (Camp et al. 2013, National Research Council 2008, Niemeier et al. 2013). Freight traffic may be delayed by fires (Camp et al. 2013) and travelers may experience increased safety risks from fires. Bus service may be suspended or rerouted to avoid road closures (FTA 2011); where alternate routes are not available, compromised transit service can have significant impacts for transit dependent populations. Mudflows can cause damage similar to that of floods, with additional risks and cleanup associated with debris carried by mudflows.

Bike/Pedestrian Facilities

Bike and pedestrian facilities and travelers will experience similar impacts as road infrastructure and travelers including greater damages from fire, mudflows, facility closures, reduced visibility, and increased safety risks.

Rail Travel

Rail infrastructure will also experience greater damages, closures, and delays due to fires, mudflows, and reduced visibility. Wooden rail bridges are at particularly high risk of damage from wildfires (Camp et al. 2013).

Air Travel

Wildfires can reduce airplane visibility (National Research Council 2008, Niemeier et al. 2013), which can lead to delays and cancellations at some airports (Koetse and Rietveld 2009). Wildfires can also directly damage airport facilities (Niemeier et al. 2013), especially those that are adjacent to fire-prone undeveloped land at Kirtland Air Force Base and the adjacent Albuquerque International Sunport, increasing costs and safety risks.

Bridges, Drainage and Flood Control

Sediment and debris from upstream areas that have been damaged by fire can damage and settle in drainage facilities, increasing maintenance costs and reducing their functionality.

Drought and Water Supply Impacts

The nature of future precipitation change in central New Mexico is difficult to predict. Expected impacts range from small increases in annual rainfall to moderate decreases. More precipitation is expected to fall as rain and with less falling as snow, resulting in earlier peak surface water flows and less water storage in snowpack. In either event, the region can expect to experience more severe droughts (USDOI 2013, Weiss 2013).

Vehicle Transport

Droughts can increase the costs of keeping buses clean, as they increase dust levels (FTA 2011). However, given the low frequency of rainfall and high dust levels in central New Mexico, the difference in this region is likely to be minor.

Other Facilities

Drought impacts on bike/pedestrian facilities, rail travel, air travel, drainage, and flood control are not discussed in the climate impacts literature reviewed for this report. Impacts to these facilities are unknown at this time and are speculatively expected to be minor.

Heavy Precipitation Events and Flood Impacts

Central New Mexico is expected to experience a greater number of heavy precipitation events, which is likely to lead to increased flooding (USDOI 2013; Weiss 2013). Additionally, an increase in wildfires may lead to greater mudslide risks in some areas. These events threaten the safety of travelers and the integrity of transportation infrastructure as described in more detail below. Figure 15 (shown and discussed in the land use section) shows the location of flood risks in New Mexico.

Vehicle Transport

In general, heavy rainfall events reduce travel demand and travel speeds, increase car and bus accident risks (particularly after dry weather), and reduce the efficiency of vehicle travel (FTA 2011, Koetse and Rietveld 2011, Niemeier et al. 2013). Given that total precipitation may be neutral or decrease in central New Mexico while severe events are expected to increase, the net effect of precipitation changes on vehicle travel demand, speeds, accidents, and travel efficiency in this region is difficult to predict. However, the presence of more extreme weather events has the potential to lead to freight trucking delays (Camp et al. 2013).

Potential safety impacts are also complex, as snowfall also increases accident risk (though to a lesser extent than rainfall; Koetse and Rietveld 2011) and will be decreasing (as snow shifts to rainfall). Furthermore, while rain and snow increase the frequency of accidents, they may also decrease the severity of accidents due to reductions in travel speeds (Koetse and Rietveld 2011).

Some flooding impacts on vehicle transport are clear: an increase in flood events will likely cause more vehicle travel disruptions, damage the structural integrity of inundated roads, strand travelers, and impact evacuation routes (Camp et al. 2013, National Research Council 2008). These flood events can increase accident risks and road maintenance costs. If heavy precipitation events are accompanied by high winds, downed trees and power lines can block roads (FTA 2011) and road signage may be damaged. Flooding of bus routes and bus storage lots can compromise transit reliability, which has important impacts on transit dependent populations, especially when transit is needed to evacuate residents from flooded areas (FTA 2011).

Bike/Pedestrian Facilities

As with vehicle travel, heavy precipitation events can negatively impact bike and pedestrian travel (Koetse and Rietveld 2009), safety, and efficiency. Flood events can disrupt travel, damage facilities, and strand travelers, increasing safety risks and maintenance costs.

Rail Travel

Passenger and freight rail lines are vulnerable to floods and mudflows as they are often located near steep slopes and waterways (Camp et al. 2013). Flooding of rail lines could compromise their stability, potentially leading to damage and delays (FTA 2011, National Research Council

2008). If heavy precipitation events are accompanied by high winds, trains may reduce their speed and downed trees and power lines can block rail lines (FTA 2011).

Air Travel

Heavy precipitation events can result in air travel delays, accidents, and airport floods and closings (Camp et al. 2013, Koetse and Rietveld 2011, National Research Council 2008, Niemeier et al. 2013). Floods can also damage airport structures, runways, drainage systems and navigational aids (Camp et al. 2013, National Research Council 2008, Niemeier et al. 2013). If storm events also bring high wind speeds, delays and accident risks may further increase (Camp et al. 2013, Koetse and Rietveld 2011).

Bridges, Drainage, and Flood Control

Drainage and flood control systems can be overloaded in flood conditions (National Research Council 2008, Niemeier et al. 2013), which may result in deposition of debris and sediment in drainage systems and may scour or damage culverts and drainage channels (Willems 2012). These impacts can decrease drainage effectiveness and increase maintenance costs. Bridge damage can also result from floods through bridge scour, which can erode foundations and weaken bridge structures (Camp et al 2013, FTA 2011). Impacts to bridges and culverts may be a significant concern because they are more costly to replace and have longer design lifetimes (changes to their design generally occur more slowly than climate changes) than, for example, pavement (Meyer and Weigel 2011). Additionally, bridge failures can have significant safety and travel delay impacts.

Summary

Most disruptions to transportation infrastructure (from floods, fires, heat damage, etc.) have the potential to disrupt travel itself, which can lead to delays, higher travel or shipping costs, and inefficiencies in the movement of people and goods (Camp et al. 2013, Niemeier et al. 2013). Delays, inefficiencies, damages, infrastructure failures, and safety impacts that may result from climate change impacts on all travel modes all have associated costs. These costs can affect travelers, public funds, and the region's economy.

Key Natural Resources

Key natural resources evaluated for this study area are vegetation, crucial habitat, riparian habitat, and threatened and endangered species. All resources are anticipated to be adversely affected by climate change. The relatively dry region will become increasingly arid and desert-like. Precipitation and temperature strongly influence the distribution and abundance of species. In this region and globally, the effects of climate change on species, ecosystems, and ecosystem services include declines in species populations (Pounds et al. 2006), shifts in species distributions (Root et al. 2005), disruption of the synchronization of seasonal plant and animal life history events (Brown et al. 1997), increased invasion by exotics (Walther et al. 2002), spread of pathogens and pests (Brooks and Hoberg 2007), appearance of vegetation dieback (Breshears et al. 2005), and community-ecosystem reorganization (Brown et al. 1997). Growth of the human population results in water use conflicts with natural resources as well as habitat fragmentation (Finch 2012).

Vegetation

Like other regions of the Southwest, central New Mexico is expected to experience large temperature increases, increased severity and duration of drought periods, increased wildfire activity (both in size and severity), insect outbreaks, and overall reduction in river and stream flows. The current vegetation communities are shown in Figure 20. Projected changes in the plant communities in the central Rio Grande Valley are shown in Figure 21 (Friggens et al. 2013). The future community compositions are based in the IPCC IS92a scenario (1 percent increase in greenhouse gases per year after 1990) and two general circulation models (GCMs): the Hadley Center and the Canadian Center for Climate modeling and Analysis. Chihuahuan desert scrub is predicted to expand considerably. Creosote bush (*Larrea tridentata*) is the dominant plant species in the Chihuahuan desert scrub. This species is currently predominantly found in the desert regions to the south of central New Mexico.

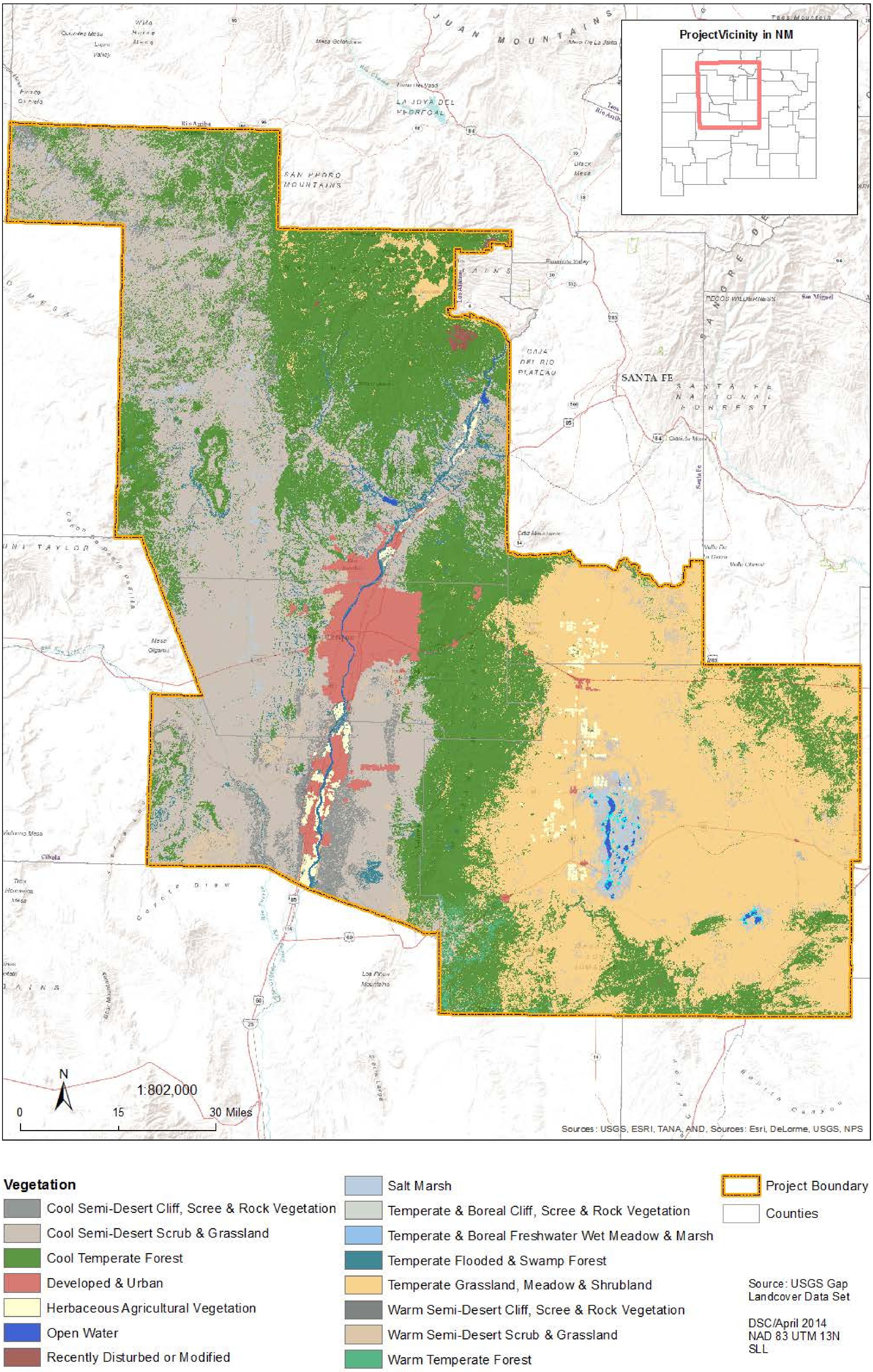

Figure 20. Current Vegetation Communities in Central New Mexico.

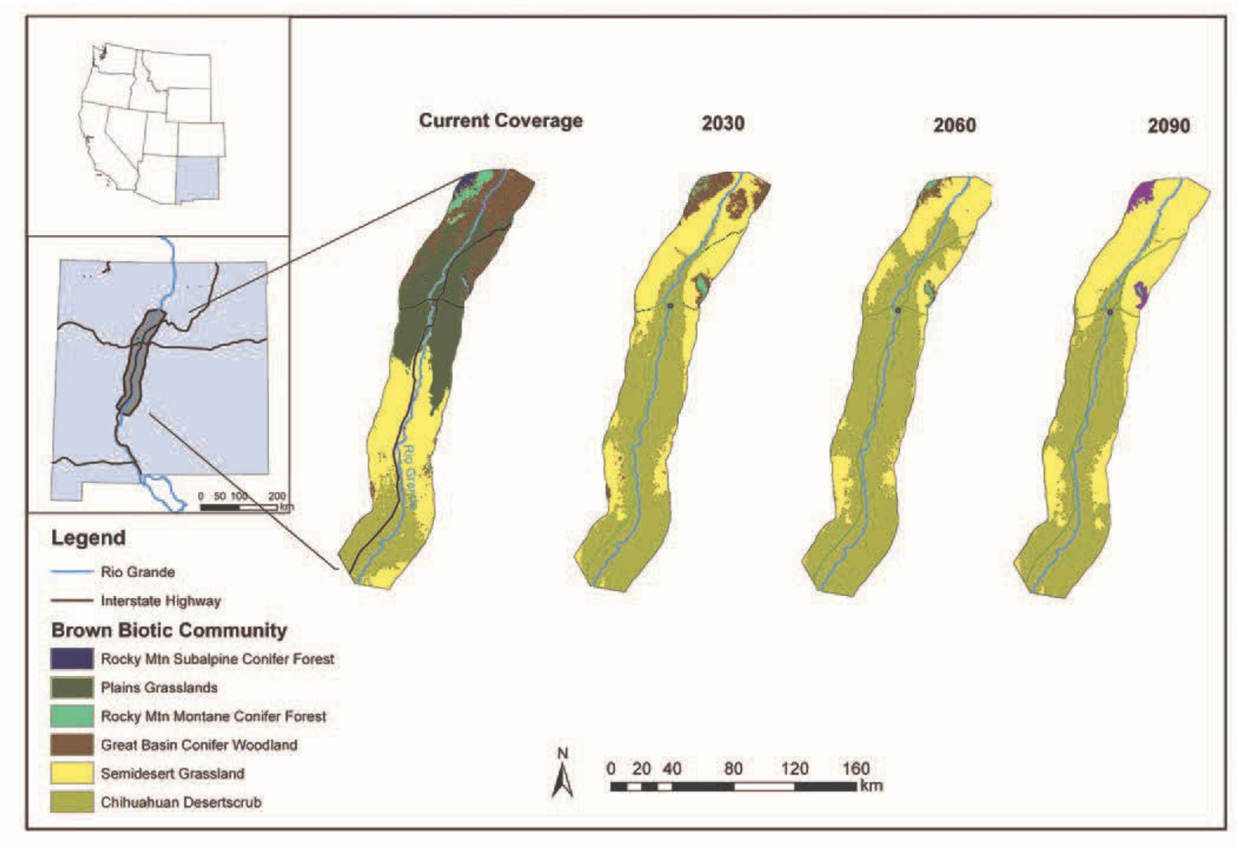

Figure 21. Projected Changes in Vegetation in Central Rio Grande Valley.

Crucial Habitat

Crucial habitats are places containing food, water, cover, shelter, and corridors for wildlife. The Western Governors' Crucial Habitat Assessment Tool (CHAT) was used to map these areas in Central New Mexico (Figure 22). Wildlife corridors are shown in Figure 23 (Middle Rio Grande Council of Government). Climate change will further fragment habitat and wildlife corridors. The risk of large animals being killed crossing roadways is likely to increase as their habitat and connectivity between the lands they use declines. Of the large animals, the black bear is at greatest risk as there is a risk of mismatch between critical resources and breeding (Glick et al. 2011). In New Mexico, bears usually enter their dens between mid-October and early December. Bears emerge from their dens between mid-March and early May. The timing of den entry and emergence are influenced by body condition, sex, reproductive state, food availability, and weather. In spring and early summer they are lower down the mountains, feeding on roots and manzanita berries; later they move up the mountains where they feed on berries, grapes, and other items. As climate change shifts the distribution of their food sources, conflicts are likely to increase as they seek out new, suitable habitat.

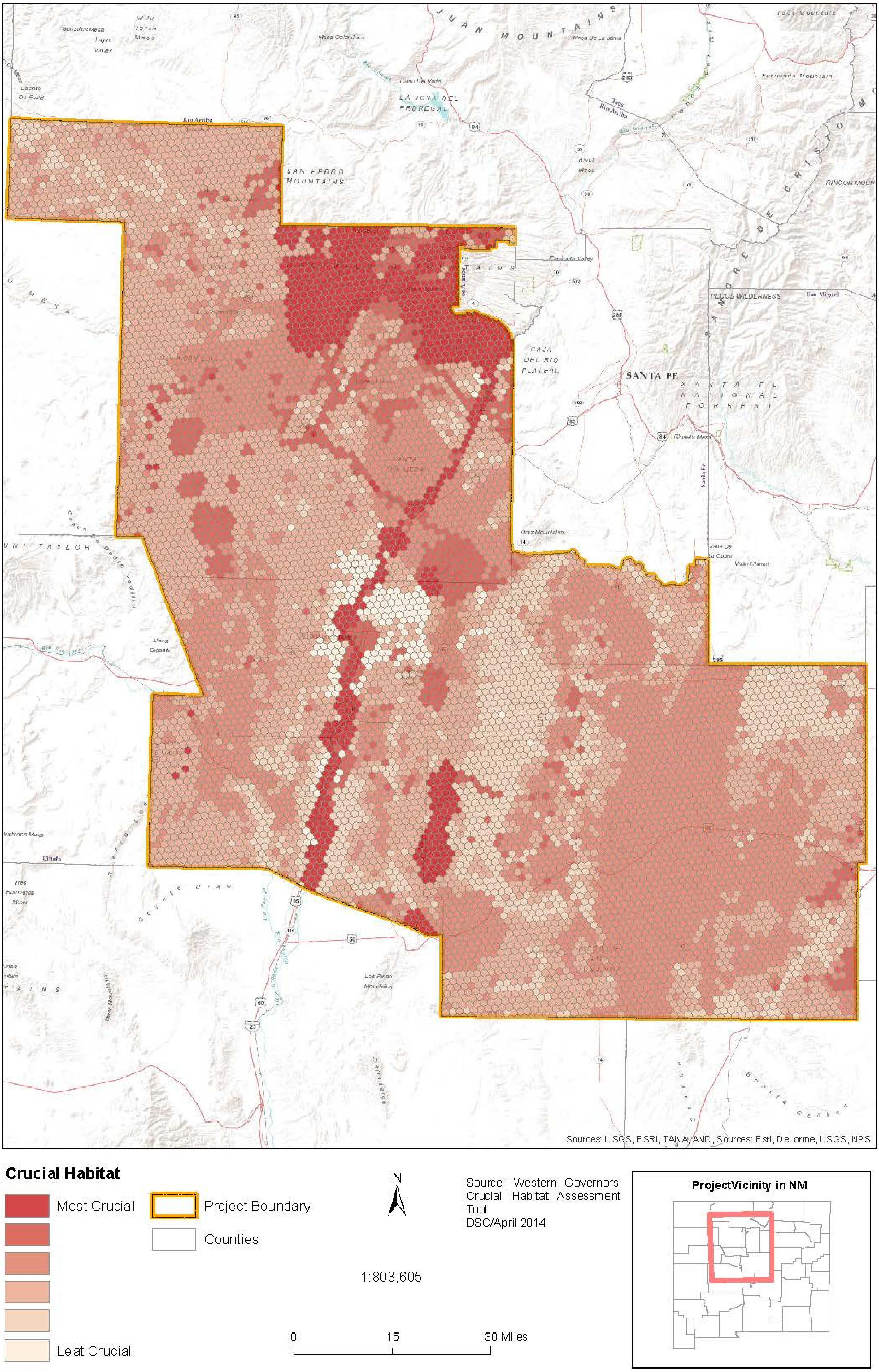

Figure 22. Crucial Habitat Areas in Central New Mexico.

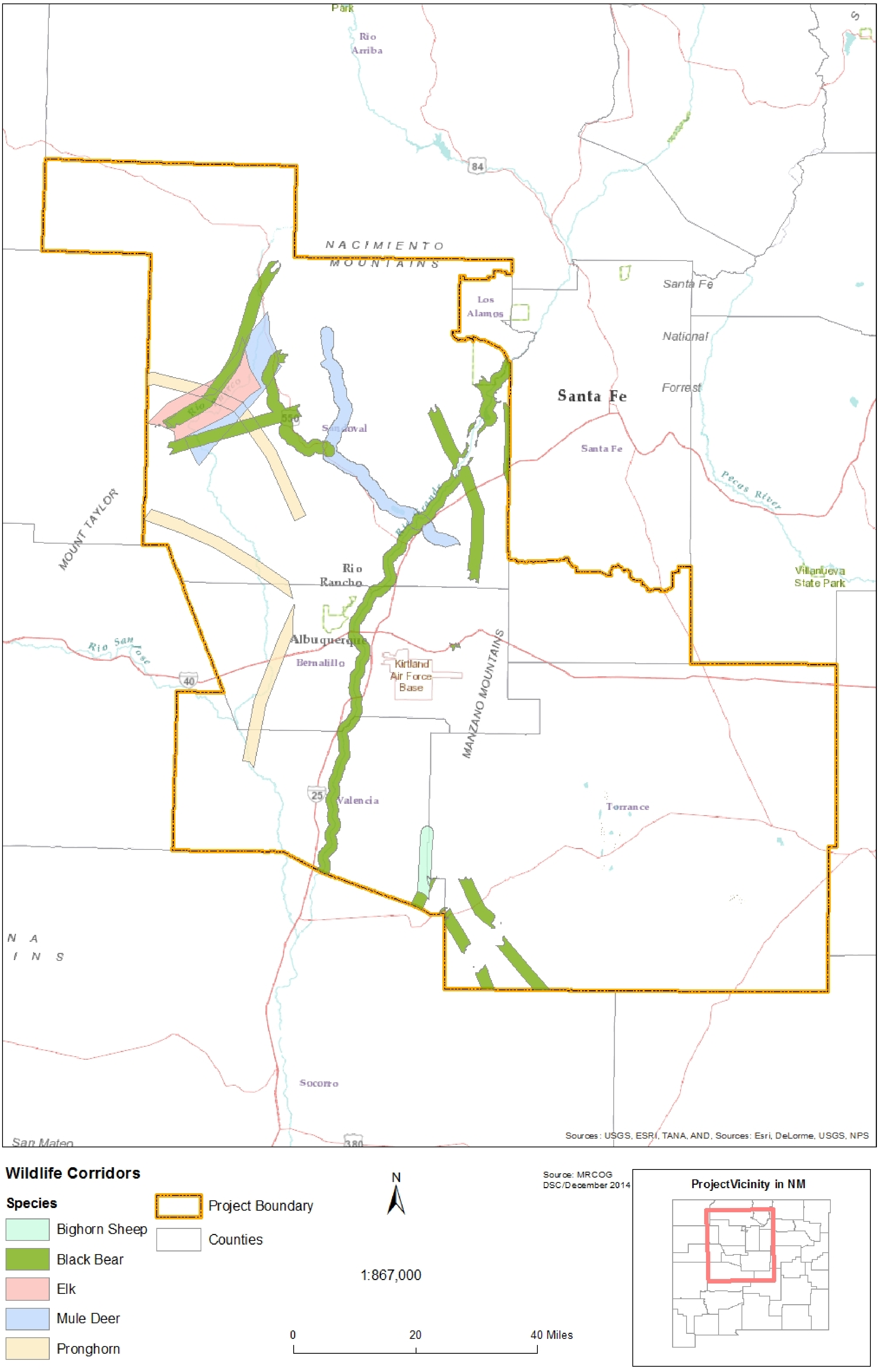

Figure 23. Wildlife Corridors in Central New Mexico.

Riparian Habitat

Riparian habitat is by far the most critical habitat in the project area. Cottonwoods (*Populus fremontii* and *Populus deltoids*) and willows (*Salix exigua*) are the predominant native riparian species in the study area. Human development of wetlands has resulted in 80 percent of the wetlands being drained (Water Assembly and Mid-Region Council of Governments 2005). Climate change will result in increasing demand for water and decreased supplies. Experts predict decreasing availability of riparian habitat, including the loss of mature trees due to fire and insect and disease, which would directly and indirectly affect many species of birds and mammals (Llewellyn and Vaddey 2013).

The predicted increase in extreme events could increase floodplain connection to the river, but also have other consequences. The floodplain is broader in its activities and functions than just the area of land that may be covered in water during a possible 100-year flood event. Areas that are periodically inundated by the lateral overflow of rivers or lakes, and/or by direct precipitation or groundwater, provide many vital functions to the river by providing nutrients, improving water quality, and also serving as a habitat that is high in biodiversity (Tockner, Lorang and Stanford, 2010). Long periods of lower flows will increase channel narrowing, which often results in a reduction of riparian habitat. These activities would both directly and indirectly negatively affect most of the species that depend upon this habitat (Llewellyn and Vaddey 2013). However, the conversion of the bosque to a more sparsely vegetated and drier habitat would positively affect more adaptive species, such as roadrunners and coyotes (Llewellyn and Vaddey 2013).

Invasive species may well be the greatest challenge in managing riparian habitat. They often outcompete native vegetation, become quickly established, and are difficult to remove (more salt, fire, and drought tolerant and resistant to water stress). Climate change may lower the water table and increase the risk of fire, which favors invasive species over native riparian species. Invasive species are generalists that are able to thrive in a greater range of environmental conditions.

Salt cedar or tamarisk (*Tamarix spp.*) is an invasive species that has been a major focus of management and restoration in the Middle Rio Grande basin. The species is associated with water draw down, floodplain loss, and increased fire risk. The species has the capacity to establish in sites that are less suitable for native flora due to alteration of flows and grazing (Stromberg et al. 2009). As the climate changes, tamarisk is likely to spread and outcompete cottonwood species (Glick et al. 2011 and Friggens et al. 2013). Stress due to water limitations and increased fire will continue to favor the establishment of tamarisk. Tamarisk also shades areas, which reduces cottonwood recruitment (Obedzinski et al.2001).

Listed and Proposed Threatened and Endangered Species

Historic development of the Upper Rio Grande has had impacts on the listed species and their habitats. Climate change promises to exacerbate those impacts, primarily through decreases in stream flows and available water to support riparian habitat (Llewellyn and Vaddey 2013). There are three endangered species, two threatened species, one proposed endangered species, and one proposed threatened species in the counties in the study area. Areas designated as critical habitat by the U.S. Fish and Wildlife Service (FWS) for the threatened and endangered species are shown in Figure 24. Based on the predicted temperature change and number of freshwater species of concern, the Rio Grande-Elephant Butte watershed is classified as one of the most vulnerable in the states of New Mexico, Arizona, Colorado, and Utah (Robles and Enquist 2010).

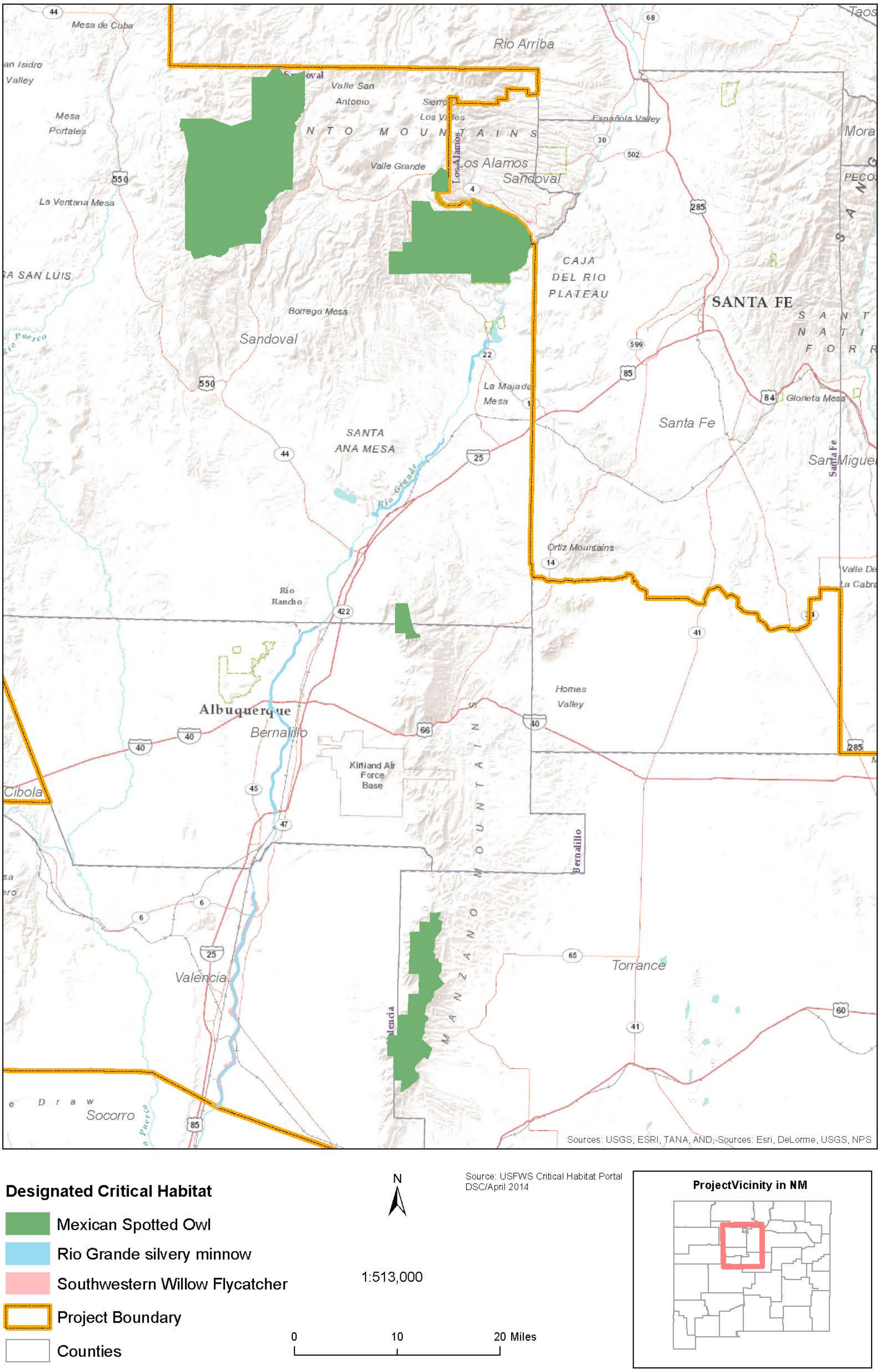

Figure 24. U.S. FWS Designated Critical Habitat for Threatened and Endangered Species.

Rio Grande silvery minnow (Hybognathus amarus)

Currently, the Rio Grande silvery minnow is endangered and believed to only occur in one reach of the Rio Grande in New Mexico, a stretch of river that runs the entire length of the planning area (Figure 25). The U.S. FWS identified four primary constituent elements in the critical habitat designation for this species:

1) a hydrologic regime that provides sufficient flowing water capable of providing a diversity of aquatic habitats including backwaters, shallow side channels, and pools;
2) low velocity-habitat;
3) substrates of predominantly sand or silt; and
4) water of sufficient quality to maintain natural, daily, and seasonally variable water temperatures in the approximate range of greater than 1 degree Celsius (°C; 35 degrees Fahrenheit[°F]) and less than 30 °C (85°F) and reduced degraded water quality conditions (decreased dissolved oxygen, increased pH, etc.).

Successful recruitment or survival of young fish is strongly linked to the magnitude and duration of spring runoff. Population increases coincide with inundation of overbank habitats that support larval development. In the summer and fall, the drying river causes mortality to the silvery minnow. The decline in populations is mainly due to modification of its habitat, competition and predation by non-native species, and water quality degradation.

Climate change is projected to reduce available water in the Upper Rio Grande system, making environmental flows in the river more difficult to maintain and reducing the shallow groundwater available to riparian vegetation. Overbank flow events are projected to become less common in future years, although an increase in extreme events is also forecast, which could increase floodplain connection but also have other consequences. Long periods of lower flows may also increase the process of channel narrowing, which decreases available riverine and riparian habitat (Llewellyn and Vaddey 2013). Soil erosion caused by wildfire contributes to altered flow regimes that depart significantly from natural conditions and reduce or modify habitat by preventing overbank flooding, trapping nutrients, and altering sediment transport regimes. These changes affect the Rio Grande silvery minnow by reducing its food supply, modifying its preferred habitat, preventing dispersal, and providing a continual supply of non-native fish that may compete with or prey upon the species. Young silvery minnows occupy shallow, low-velocity areas associated with backwaters and secondary channels. Soil erosion changes the fluvial geomorphology of the habitat. Large non-native fish prey upon the minnows in deeper water.

Cohen et al. (2013) modeled the direction and magnitude of the climatic shift this species would incur under three future scenarios: the low (B1), intermediate (A1B), and high (A2) projected temperature and atmospheric concentrations of carbon dioxide and methane (Figure 26). The authors utilized climate variables from the IPCC. The models were built using a limited set of predictor variables (notably, various topographic, precipitation, and temperature variables). Topographic variables do not change, thus projection shifts should be interpreted as shifts in climate-based niche suitability only, not projected population trends. Conclusions drawn from these projection results should be limited only to direction and magnitude of climatic pressure (personal communication, Dean Hendrickson). Suitable habitat for this species is projected to shift to the south of central New Mexico.

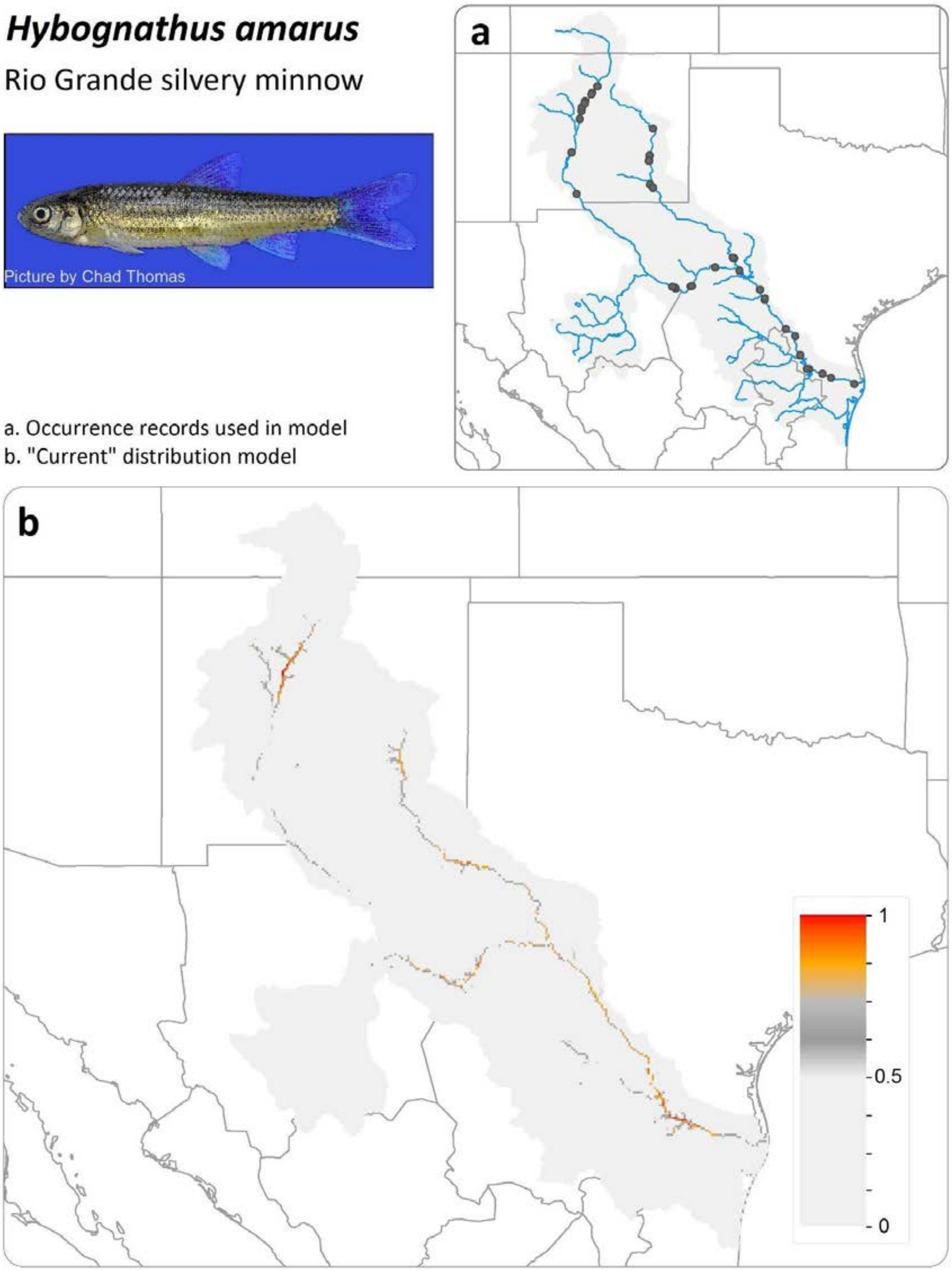

Figure 25. Current Distribution of the Rio Grande Silvery Minnow (1-0 is the probability of occurrence; the higher the value, the more probable the occurrence).

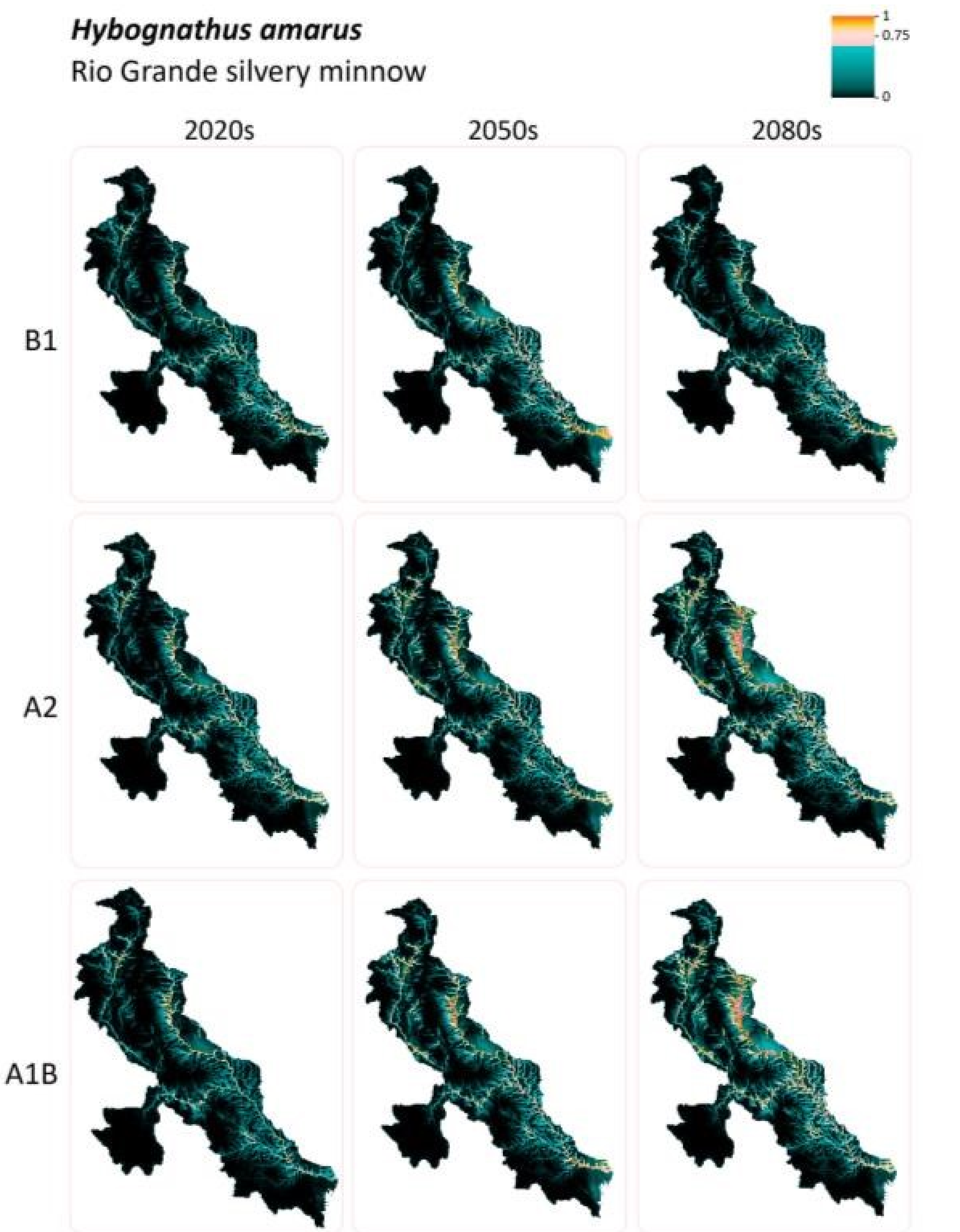

Figure 26. Projected Distribution and Magnitude of Rio Grande Silvery Minnow (1-0 is the probability of occurrence; the higher the value, the more probable the occurrence).

Southwestern Willow Flycatcher (Empidonax traillii extimus)

The Southwestern Willow Flycatcher is listed as an endangered species. Nearly half (43 percent) of the endangered Southwestern Willow Flycatcher territories are found in riparian patches consisting primarily (greater than 90 percent) of native trees such as willow (*Salix* spp.) (New Mexico Biota Information System 2014). This species is known to nest in tamarisk as well. The greatest threats to the species is modification of habitat, changes in flood and fire regimes, changes in water and soil chemistry, as well as establishment of invasive non-native plants (U.S. FWS 2002). This species is also vulnerable due to thermal tolerances and brood parasitism by brown-headed cowbirds.

A vulnerability assessment of 117 vertebrate species that occur in the Middle Rio Grande Bosque identified the Southwestern Willow Flycatcher as the most vulnerable to climate change as it is restricted to a local food source during nesting season and the primary food source, insects, depends on water for some phase of their lifecycle. This species received the highest vulnerability rating for phenology (Friggens et al. 2013). The flycatcher is a migrant at risk of a timing mismatch between initiation of migration and availability of critical resources at the destination site. The species also has a short nesting season that is thought to be limited by resource availability. Lower than average precipitation reduced flycatcher seasonal productivity at both Roosevelt Lake and the San Pedro River in Arizona in 2002. Reduced precipitation could lead to more frequent incidents of extremely low reproductive success, such as occurred at Roosevelt Lake during the 2002 drought. Successive years of low productivity could lead to unsustainable local populations (Paxton et al. 2007).

Jemez Mountain Salamander (Plethodon neomexicanus)

The Jemez Mountain salamander is listed as an endangered species. The Jemez Mountain salamander is endemic to north-central New Mexico in areas of tree canopy cover greater than 50 percent, elevation between approximately 7,000 and 11, 250 feet, and coniferous logs. The underground habitat is comprised of deep, fractured, subterranean igneous rock in areas of high moisture (Federal Register 2013). Climate change will cause changes in fire regime and forest structure that will constrict the distribution of the species and genetically isolate populations (Parmenter 2009). After a stand-replacement wildfire burned a fire-suppressed landscape in New Mexico that historically burned with low- or mixed-severity fires, microhabitat temperatures in severely burned habitats consistently exceeded preferred temperatures (and occasionally the critical thermal maximum) of the Jemez Mountains salamander. The mean size of salamanders in the burned area decreased during the four years after the fire (Cummer and Painter 2007).

New Mexico Jumping Meadow Mouse (Zapus hudsonius luteus)

The New Mexico jumping meadow mouse is a proposed endangered species. The New Mexico jumping meadow mouse is associated with tall, dense, herbaceous riparian vegetation, especially areas dominated by sedges. The species distribution has declined due to loss of this habitat, primarily as a result of livestock grazing. However, drought, development, recreation, forest fire, and loss of the American beaver (*Castor canadensis*) also contributed (Frey and Malaney 2009). Of 37 mammals assessed for vulnerability to climate change in the middle Rio Grande valley, the New Mexico jumping meadow mouse was the most vulnerable based on habitat, physiology, and biotic interactions (Friggens et al. 2013). Biotic interactions are food, predators, symbionts, disease, and competitors. Wet meadow habitat could constrict due to loss of riparian habitat.

Mexican Spotted Owl (Strix occidentalis lucida)

The Mexican Spotted Owl is listed as a threatened species. The Mexican spotted owl's preferred habitat is high canopy closure, high stand density, a multi-layered canopy, uneven-aged stands, numerous snags, and downed woody matter. This species is vulnerable to increased temperatures because it has a narrow and low thermal neutral zone. Population projections for this species in New Mexico, modeled under three IPPC scenarios, predict a substantial decline (Figure 27; Peery et al. 2012). A vulnerability assessment was conducted by the U.S. FWS (2012) using three tools: 1) Nature Serve *Climate Change Vulnerability Index* (Young et al. 2010); 2) Environmental Protection Agency *Framework for Categorizing the Relative Vulnerability of Threatened and Endangered Species to Climate Change* (Galbraith and Price 2009); and 3) Rocky Mountain Research Station's *Species Vulnerability Assessment Method* (Bagne and Finch 2008). All three tools indicated at least moderate vulnerability to climate change for the Mexican spotted owl, however, along with fairly high uncertainty in the ratings (U.S. FWS 2012).

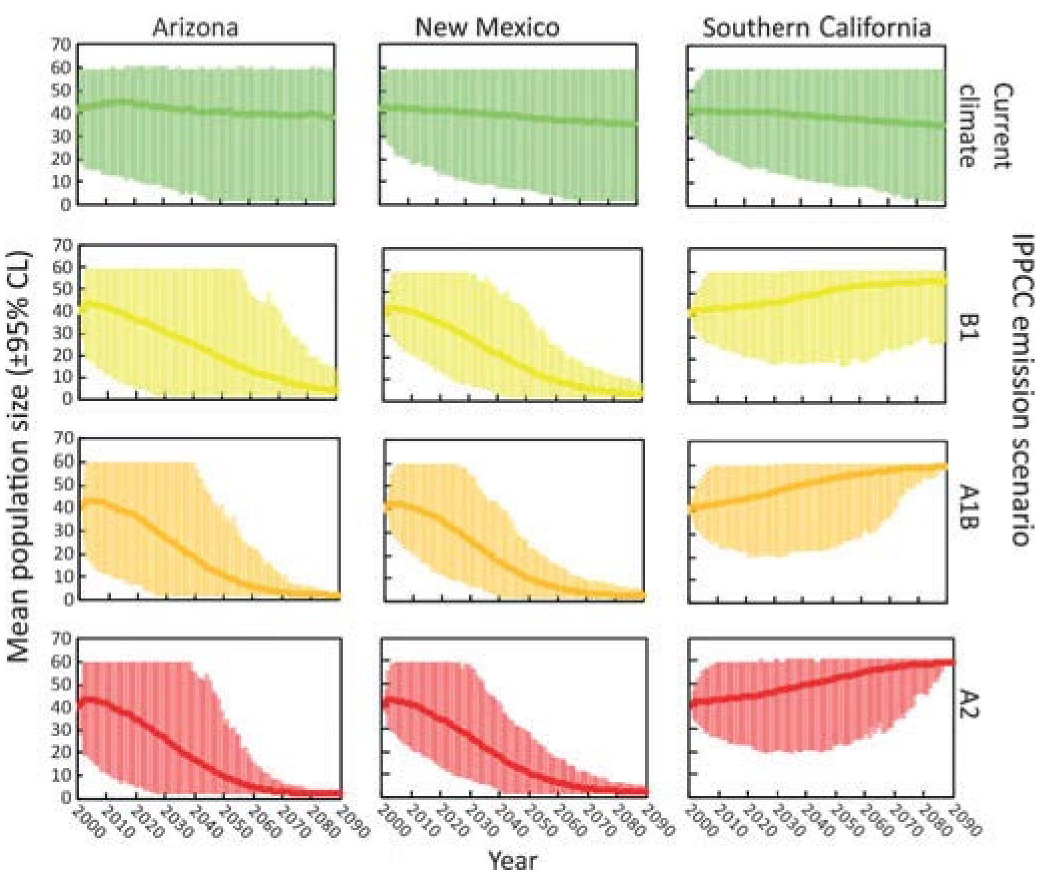

Figure 27. Projected Changes in Mexican Spotted Owl Populations (Peery et al. 2012).

Pecos Sunflower (Helianthus paradoxus)

The Pecos sunflower is listed as a threatened species. Pecos sunflower is a wetland plant that grows on wet, alkaline soils at spring seeps, wet meadows, stream courses, and pond margins. Populations are all dependent upon wetlands from natural groundwater deposits. Incompatible land uses, habitat degradation and loss, and groundwater withdrawals are current and historic threats to this species (U.S. FWS 2005). Decreased groundwater and increased groundwater pumping as periods of drought increase could jeopardize populations of these species as climate changes.

Yellow-billed Cuckoo (Coccyzus americanus occidentalis)

The western population of the yellow-billed cuckoo is a proposed threatened species. This species generally prefers mature riparian habitats and are most commonly associated with cottonwood or other native forests. Of 42 avian species assessed for vulnerability to climate change in the Middle Rio Grande area, the western yellow-billed cuckoo was ranked as the fourth most vulnerable. The species is vulnerable in all categories assessed: habitat, physiology, phenology, and biotic interactions (Friggens et al. 2013).

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